



Room 14-0551
77 Massachusetts Avenue
Cambridge, MA 02139
Ph: 617.253.5668 Fax: 617.253.1690
Email: docs@mit.edu
<http://libraries.mit.edu/docs>

DISCLAIMER OF QUALITY

Due to the condition of the original material, there are unavoidable flaws in this reproduction. We have made every effort possible to provide you with the best copy available. If you are dissatisfied with this product and find it unusable, please contact Document Services as soon as possible.

Thank you.

Some pages in the original document contain color pictures or graphics that will not scan or reproduce well.

PAGES 390-391, 393-394, 396-397, 413 AND 419
ARE MISSING,

SOME PAGES ARE ILLEGIBLE AND ASKEWED.

**The Expertise of Germs: Practice, Language and
Authority in American Bacteriology, 1899-1924**

by
Eric D. Kupferberg

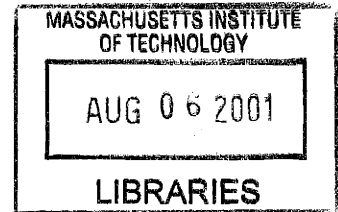
B.A. Political Science, University of Kentucky, 1987
M.A. History, University of Maryland, 1989

Submitted to the Doctoral Program in the History and Social Study of Science and
Technology in Partial Fulfillment of the Requirements for the Degree of

Doctor of Philosophy at the
Massachusetts Institute of Technology

February 2001

© Eric D. Kupferberg, All Rights Reserved



The author hereby grants to MIT permission to reproduce and to distribute publicly paper
and electronic copies of this thesis document in whole or in part.

ARCHIVES

V. 1

Signature of Author:

Program in the History and Social Study of Science and Technology
February 8, 2001

Certified by:

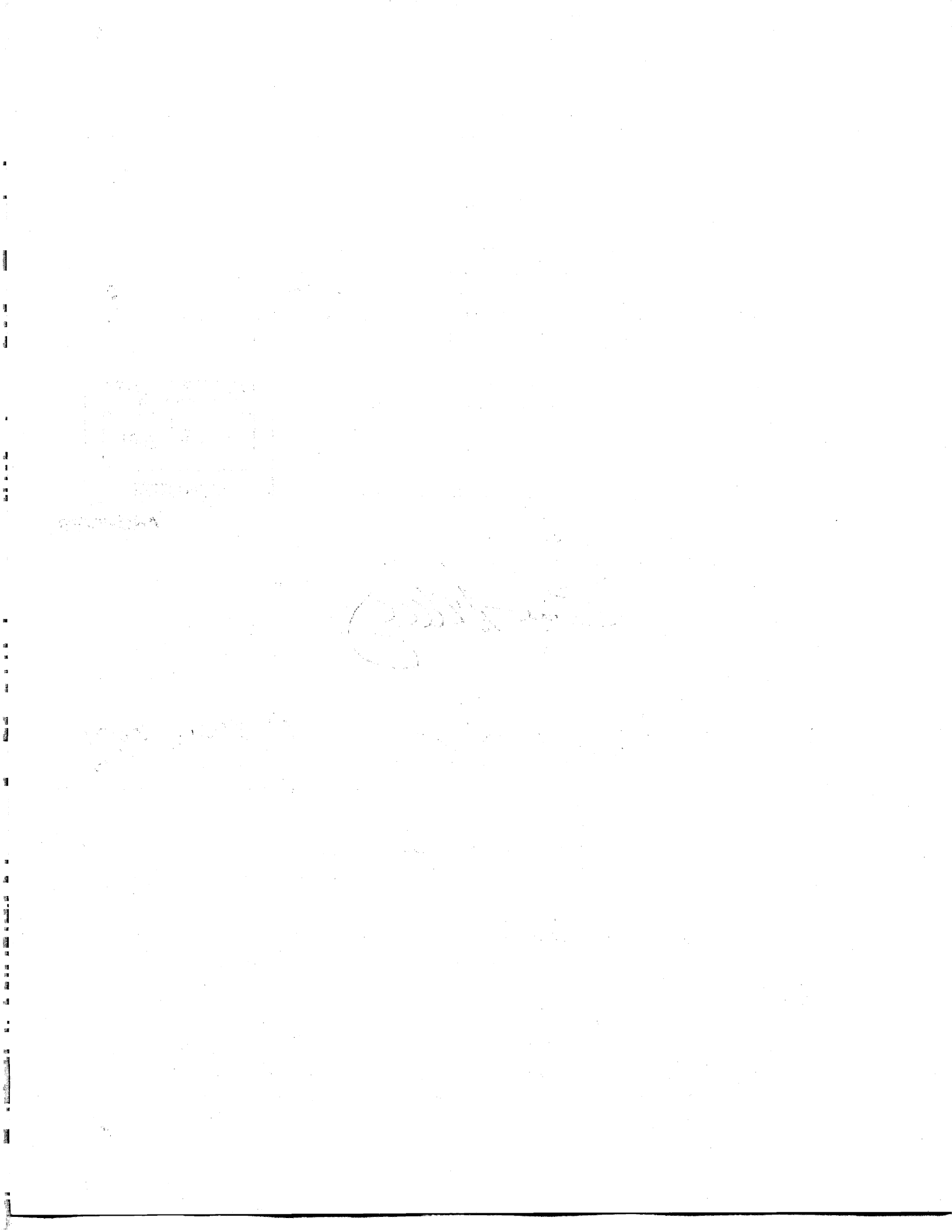
Deborah Fitzgerald, Associate Professor of the History of Technology and
Director of Graduate Studies, Thesis Supervisor
1 May 2001

Hugh Gusterson, Associate Professor of Anthropology and Science Studies

Everett Mendelsohn, Professor of the History of Science, Harvard University

Accepted by:

Merritt Roe Smith, Professor of the History of Technology
Director, Program in the History and Social Study of Science and Technology
May 1, 2001



To my family

A lucky line here and there should not make us think any higher of ourselves, for such lines are the gift of Chance or the Spirit; only the errors are our own. I hope the reader may find in my pages something that merits being remembered; in this world, beauty is so common.

-- Jorge Luis Borges, *In Praise of Darkness*

CONTENTS

ACKNOWLEDGMENTS	9
ABSTRACT	13
LIST OF TABLES, GRAPHS AND FIGURES	15
LIST OF ABBREVIATIONS	19
INTRODUCTION: GROWTH AND UNEASE	21
Chapter	
1. "KILL THE GERM": MEDICAL, PUBLIC HEALTH, AND SANITARY BACTERIOLOGY	48
Pathology, and the "Golden Age of Bacteriology"	
Bacteriology and Public Health	
Public Health and Sanitary Bacteriology	
Killing the Germ, Limiting the Science	
2. "KILL THE GERM" ONCE AGAIN: VETERINARY BACTERIOLOGY	106
Service and Science in the Agricultural Context	
Incorporating Bacteriology within Veterinary Science	
Veterinary Bacteriology and the Hygienic Vision	
Five Examples of Hygienic Success	
The Service Role of Hygienic Exclusion	
3. FROM PATHOGENIC GERMS TO PRODUCTIVE MICROBES	157
Scientific Agriculture and the Productive Microbe	
Milk Sanitation and the Hygienic Vision	

The Bacteriologic Vision of Dairy Microbes

Exploiting the Productive Microbe

Late Blooming – Soil Bacteriology

Promises, Promises

An Uncertain Home

Control and Self-Doubt

Benefits of Struggle

Between Routine and Productive

4. THE SOCIETY OF AMERICAN BACTERIOLOGISTS AND THE
SEARCH FOR IDENTITY

251

Founding Societies, Building Disciplines

Building a Society of American Bacteriologists

Who Were Bacteriologists? Or, Reading the SAB Rosters

What is Bacteriology? Or, Visiting the SAB Meetings

Finding the Fundamental in “General and Technical”

Moving from the Medical

Addressing and Redressing the Society

SAB’s Biological Steps

Anxiety as a Productive Force?

5. CHARTING THAT BACTERIA – THE SOCIETY’S CARD AND
STANDARD METHODS

326

On Methods and Materials

Charting the Chart

The Utility of Loose Methods

6. FINDING A NAME: THE SAB AND THE *BERGEY'S MANUAL OF DETERMINATIVE BACTERIOLOGY* 387

The Reign of Chaos

An Unwelcome Inheritance

An Institutional Response

Resistance and Revision

The Bergey's Committee and a New Determinative Manual

The Strength of the Routine

CONCLUSION 532

Appendix

1. TABLES FOR CHAPTERS 1-3 543

2. GRAPHS FOR CHAPTER 4 581

3. FIGURES FOR CHAPTERS 5 AND 6 603

Bibliographies

1. PRIMARY PUBLISHED SOURCES 631

2. BACTERIOLOGY TEXTBOOKS AND MANUALS 695

3. SECONDARY SOURCES 1899-1964 715

4. SECONDARY SOURCES 1965-2000 737

ACKNOWLEDGMENTS

This doctoral dissertation grew out of research for my Master's thesis, completed at the University of Maryland in 1989, and entitled "The International Society for Microbiology and the Promotion of Interfield Connections." In summer of 1988, my advisor, Lindley Darden, indicated that the International Union of Microbiological Societies (IUMS) offered a fellowship for archival research. The Center for the History of Microbiology, housed at the Albin O. Kuhn Library of the University of Maryland, Baltimore County, contained the Union's records. In completing that thesis it became clear to me that both scientific societies and disciplinary taxonomies play a far more active role in the development of a science than has been previously ascribed. The following chapters are, in many respects, a continued exploration of these areas. Professor Rita R. Colwell, and other directors of the IUMS, sponsored the project, and over the course of the next decade offered support and encouragement, reassuring me that practicing microbiologists were indeed interested in their discipline's history.

The American Society for Microbiology (ASM) has actively encouraged research in the history of microbiology. In addition to sponsoring the Center for the History of Microbiology, its annual meeting periodically features a symposium on the development of the discipline. I have been fortunate to participate in two sessions, including the Centenary Celebration held in Chicago, May 1999. The ASM's Archives Committee has managed a burgeoning collection.

My own effort owes much to the arduous labor of Toby A. Appel, Donald Shay, and, in particular, Jeff Karr. The Center for the History of Microbiology has welcomed me to their archives on several occasions, placing their vast collections and resources at my disposal. I cannot begin to express sufficient gratitude to the Archives Committee.

I have benefitted greatly from a nascent community studying the development of bacteriology. At several meetings of the History of Science Society, and the International Society for the History, Philosophy and Social Study of Science, Technology and Medicine, several other historians have graciously offered guidance and suggestions, including: Olga Amsterdamska, Jill Cooper, Marcel C. LaFollette, John Andrew Mendelsohn, Philip J. Pauly, Susan Spath, James Strick, William C. Summers, and Nancy J. Tomes. Moreover, this thesis bears the imprint of discussions held at the seminars and short-courses in history of biology, sponsored by the Dibner Institute for the History of Science and Technology and the Marine Biological Laboratory at Woods Hole. The collegial atmosphere, fostered by the likes of Jane Maienschein, John Beatty, and Garland Allen, afforded a wonderful opportunity to explore possible directions for my thesis. I am fortunate to have met Elihu Gerson and Jan Sapp at those workshops. Both introduced me to methodological and theoretical frameworks that became the foundations of my investigations. During the summer of 1990, I was privileged to receive a fellowship from the American Museum of American History. While in residence, Patricia Peck Gossel graciously guided me through many aspects of American bacteriology, correcting my mistaken assumptions and pointing me to fruitful areas of examination. My efforts owe much to her own research, as well her occasional counsel.

At MIT, the Program in Science, Technology and Society cultivated a supportive

community of scholars, where faculty and visiting postdoctoral fellows regularly assisted struggling graduate students. When the scope of my project swelled to unmanageable proportions, Sherry Turkle and Jean-Paul Gaudilliere offered suggestions for winnowing. Several of my fellow graduate students vetted early drafts of chapters, including David Guston, Jessica Wang, and David Mindell. David Kaiser carefully examined chapter five, pointing to ways in which the history of bacteriology seemed to parallel the development of twentieth century physics. I hope one day to explore that provocative remark. Much of the thesis research was supported by a pre-doctoral fellowship from the Dibner Institute for the History of Science and Technology. I feel deeply honored to have spent two years among the other fellows in an environment conducive to both scholarly debate and quiet study.

For the past five years, I have found an academic home in Harvard University's Department of the History of Science. In addition to providing ample teaching opportunities, office space, and library privileges, the department has welcomed me as one of their own. Among the faculty, I am indebted to Allan Brandt, Barbara Rosenkrantz, Bridie Andrews, Bob Brain, and Stephanie Kenen, each of whom supported my efforts. Likewise, many of the graduate students examined unpolished chapters. Michael Gordin, Denise Phillips, and Theresa Levitt offered changes to chapter five. During the final year of writing, Grace Y. Shen provided a wellspring of encouragement and criticism. She reminded me again and again that careful scholarship demands exacting standards. Nearly every paragraph of this dissertation bears the imprint of her comments, as well as her proofreading. I could not have asked for a more insightful reader, one who worked by questioning and coaxing, rather than merely criticizing. I also owe considerable gratitude for the efforts of Judith Lajoie. As chief administrative officer,

she ensured that I never felt like an outsider to the department.

I have had the unique blessing of an active and obliging dissertation committee. For the first five years, Lily E. Kay served as my major advisor. During that time, we deliberated nearly every aspect of the nascent project. Lily was always willing to engage, and to challenge. Her own work served as an inspiration. I hope someday to meet Lily's expectations of me. Her passing was a loss to many of us; I miss her dearly. Evelyn M. Hammonds guided the writing of chapters one and two, and David S. Barnes provided advice to chapters three and four. I learned a great deal as David's teaching assistant in his course on the "History of Germs." During the times when I struggled and anguished, my current committee managed to come to my rescue. Everett Mendelsohn, Hugh Gusterson, and Deborah Fitzgerald scoured each line of the thesis, recommending changes, proposing additions, and (fortunately) offering ways to focus my analytic ambitions. No matter the difficulties or delays, they located a way for me to get each chapter done, and done well.

Lastly, my family provided encouragement, advice, and comfort, more than I could ever express in words. They periodically welcomed my 'thinking out loud,' finding ways to support a project that threatened to continue without end. I feel an unending gratitude to my wife, Susan, whose patience seemed largely inexhaustible. When I found the words to share my excitement or frustration, she responded with an unmatched understanding. When I shared the written pages, she provided pivotal editorial guidance. When the words failed me, as they frequently did, I found healing distraction in the basketball victories of my beloved University of Kentucky Wildcats, the songs of Declan Patrick Aloysius MacManus (a.k.a. Elvis Costello), the rhythms of my band Sam Hill, and the kindness of the Sunday night Calvary Group (especially Jack & J.P.).

ABSTRACT

This thesis traces the development of American bacteriology during the first quarter of the twentieth century. While bacteriology experienced a period of rapid growth, an enduring disciplinary anxiety equally characterized the field. In particular, bacteriologists feared increasing specialization and conceptual fragmentation. Leading practitioners repeatedly worried that their science constituted a collection of unrelated techniques, carried out in the service to other practical endeavors without the benefit of an underlying theory or unifying language. I suggest that the sources of bacteriology's rapid professional growth equally accounted for this sense of conceptual impoverishment and disciplinary privation. Typically, bacteriologists focused on what bacteria *did* rather than what they *were* in any biological sense. The first three chapters provide a comprehensive survey of the institutional contexts bacteriology (*e.g.*, medical schools, public health laboratories, water sanitation works, dairies, land-grant colleges, and agricultural experiment stations). For the most part, bacteriologists studied bacteria only so far as to isolate, identify and eliminate pathogens. Dairy and soil bacteriologists, however, sought to distinguish productive types of bacteria, and render those forms more active, a direction that led them to consider a range of phenomena and organisms normally occluded by the practices of medical, public health, and sanitary bacteriology.

The final three chapters of the dissertation trace the attempts of American bacteriologists to render their science less fragmented and more biological, focusing in particular on the actions of the Society of American Bacteriologists (SAB). Established in 1899, the SAB endeavored to bridge the divergent interests and practices of American bacteriologists. Through its inclusive membership, ecumenical leadership, diverse meeting programs, and society journal, the SAB served as an organizational exploration of those shared aspects of the discipline. Furthermore, the SAB issued a comprehensive chart for the identification of unknown cultures. While never endorsed as its official methods, the chart soon formed the basis of undergraduate and graduate training, while it guided research programs and published papers. In addition, the serial revisions of the chart led bacteriologists to consider many fundamental aspects of bacteria. Lastly, the SAB struggled to reform bacterial systematics. At the time of the SAB's founding, bacteriology languished under a state of taxonomic chaos, with each specialty offering its own system of naming and grouping bacteria. Believing that this linguistic fragmentation precluded the emergence of a unified discipline, the SAB overhauled bacterial systematics, arranging bacteria according to their detailed morphology, physiology, and likely evolutionary histories. While the SAB's taxonomy did not find immediate adherents, it did become authoritative by way of the classroom and laboratory. The SAB issued a new comprehensive determinative guide, the *Bergey's Manual of Determinative Bacteriology*, which incorporated the SAB's scheme. As the *Bergey's Manual* became ubiquitous to laboratory practice and course instruction, American bacteriologists unwittingly adopted a broader range of considerations. If bacteriology comprised a more unified and fundamental science by 1924, it was the descriptive chart and determinative manual that most enabled that end.

TABLES, GRAPHS AND FIGURES

Table

1.1	Instruction in Medical Bacteriology Begun Prior to 1900	543
1.2	Instruction in Medical Bacteriology, Begun 1900-1919	545
1.3	Research Institutions in Medical Bacteriology Prior to 1920	546
1.4	Public Health Bacteriology Laboratories Prior to 1920	550
1.5	Instruction in Public Health Bacteriology Prior to 1920	552
1.6	Institutions Performing Bacteriological Examinations of Water, Milk or Food	553
1.7	Instruction in Water, Milk, Food or Sanitary Bacteriology Prior to 1920	555
1.8	Research in Water, Milk, Food or Sanitary Bacteriology Prior to 1920	557
2.1	Instruction in Veterinary Bacteriology Prior to 1920	561
2.2	Research in Veterinary Bacteriology Prior to 1920	563
2.3	Some Producers of Veterinary Biologics	566
2.4	Research in Poultry Pathology Prior to 1925	567
2.5	Instruction in Poultry Pathology Prior to 1925	568
3.1	Instruction in Dairy Bacteriology Prior to 1925	569
3.2	Research in Dairy Bacteriology Prior to 1920	570
3.3	Commercial Producers of Legume Inoculation Cultures	572
3.4	Stations Distributing Legume Inoculation Cultures	572
3.5	Research in Soil Bacteriology	573

TABLES, GRAPHS AND FIGURES – *Continued*

Table

3.6	Research in Plant Pathology Prior to 1915	576
3.7	Instruction in Plant Pathology Prior to 1915	578
3.8	Instruction in Soil Bacteriology Prior to 1925	579

Graph

4.1	SAB Membership, 1899-1909	581
4.2	SAB Membership, 1909-1914	581
4.3	SAB Executive Council, 1899-1909	583
4.4	SAB Executive Council, 1910-1916	583
4.5	SAB Executive Council, 1917-1924	585
4.6	SAB Elections, 1900-1909	585
4.7	SAB Membership Nominations, 1910-1916	587
4.8	SAB Membership Nominations, 1917-1924	587
4.9	Nominated, Not Elected	589
4.10	SAB Annual Meeting Participants, 1899-1909	589
4.11	SAB Annual Meeting Participants, 1910-1916	591
4.12	SAB Annual Meeting Participants, 1917-1924	591
4.13	SAB Meeting Participants, 1899-1909: By Category	593
4.14	SAB Meeting Participants, 1910-1916: By Category	593
4.15	SAB Meeting Participants, 1917-1924: By Category	595

TABLES, GRAPHS AND FIGURES – *Continued*

Graph

4.16	SAB Meeting Papers, 1899-1909	595
4.17	SAB Meeting Papers, 1910-1916	597
4.18	SAB Meeting Papers, 1917-1924	597
4.19	General & Technical Papers, 1899-1909	599
4.20	General & Technical Papers, 1910-1916	599
4.21	General & Technical Papers, 1917-1924	601

Figure

5.1	SAB Descriptive Chart Group Number, 1907	603
5.2	Kendall's 1903 Chart	604
5.3	Gage and Phelps' 1903 Chart	605
5.4	Herbert W. Conn's Second Chart, 1901	606
5.5	Salient Features and Detailed Features, SAB Chart, 1905	607
5.6	Group Number, SAB Chart, 1905	608
5.7	Manwaring's Instructional Chart, 1905	609
5.8	SAB Descriptive Chart, 1907	610
5.9	Gorham's Descriptive Chart, 1913	611
5.10	SAB Descriptive Chart, 1914	612
5.11	SAB Instructional Chart, 1917	613
5.12	SAB Descriptive Chart, 1920	614

TABLES, GRAPHS AND FIGURES cont.

Figure

5.13	SAB Descriptive Chart, Reverse Side, 1920	615
5.14	SAB Descriptive Chart, 1924	616
6.1	Migula's Classification of Bacteria	617
6.2	Chester's Classification of Bacteria, 1901	618
6.3	Winslow and Roger's Classification of the <i>Coccaceae</i> , 1908	619
6.4	The CCCBT's Artificial Key to the Families of the <i>Eubacteriales</i> , 1917	620
6.5	The CCCBT's Orders, Families and Genera of the <i>Eubacteriales</i> , 1917	621
6.6	Kligler's Outline of the Relationships of Bacterial Groups, 1917	622
6.7	Buchanan's Outline of Phylogenetic Relationship among Bacteria, 1918	623
6.8	Buchanan's Key to the Orders of the Class <i>Schizomycetes</i> , 1917	624
6.9	The CCCBT's Final Key to the Class <i>Schizomycetes</i> , 1920	625
6.10	Macy's Key to the <i>Schizomycetes</i> , 1921	626
6.11	<i>Bergey's Manual's</i> Key to the Orders, Families, Tribes, and Genera of the Class <i>Schizomycetes</i> , 1923	627
6.12	Phillips' List of Pathogenic Organisms and their New Designations, 1925	628
6.13	<i>Bergey's Manual's</i> Revised Key to the Orders, Families, Tribes and Genera of the Class <i>Schizomycetes</i> , 1925	629

LIST OF ABBREVIATIONS

AAAS	American Association for the Advancement of Science
ADSA	American Dairy Science Association
AMNH	American Museum of Natural History
APHA	American Public Health Association
APS	American Physiological Society
ASM	American Society of Microbiologists
ASN	American Society of Naturalists
ATCC	American Type Culture Collection
AVMA	American Veterinary Medical Association
BAI	Bureau of Animal Industry, United States Department of Agriculture
BOS	Bureau of Soils, United States Department of Agriculture
BPI	Bureau of Plant Industries, United States Department of Agriculture
BSA	Botanical Society of America
CCCBT	Committee on the Characterization and Classification of Bacterial Types
NRC	National Research Council
OES	Office of Experiment Stations
SAB	Society of American Bacteriologists

INTRODUCTION: GROWTH AND UNEASE

During the first quarter of the twentieth century, American bacteriology experienced a period of rapid growth. Measured in institutional locations, faculty appointments, publications, and numbers of practitioners, bacteriology comprised a flourishing scientific enterprise. These laboratory experts rightfully claimed to have contributed to the fields of pathology, public health, sanitation engineering, veterinary medicine, dairying, and soil science. Yet, American bacteriologists frequently bemoaned the deficient condition of their discipline. In the eyes of several notable leaders, bacteriology remained an incomplete science. They accused many practitioners of serving the role of “handmaiden” to other applied fields, employing a simple collection of laboratory techniques unsupported by theoretical or fundamental groundings. These critical commentators called for bacteriology to adopt a more “biological” orientation, but usually without specifying what that would entail. To some bacteriologists, their science remained hopelessly fragmented. The field lacked a common set of concerns, a shared language, and a unifying theory. As a result, each area of applied bacteriology threatened to become so specialized as to appear irrelevant, if not foreign, to other domains of the discipline.

This thesis examines both the growth and unease of American bacteriology. The following chapters explore a lingering anxiety, suggesting that the rapid institutional expansion may have contributed to this perception of disciplinary fragmentation and conceptual deficiency. These pages recount a discipline in search of itself, and the manifold attempts among

bacteriologists to determine what should constitute bacteriology. At first glance, the repeated appeals for a more biological bacteriology might be dismissed as mere rhetorical flourishes, a collective lament to inspire bacteriologists in their various studies. Even so, these calls conveyed a sense of worry. That worry may have sprung from a sense that American researchers arrived after the "Golden Age" of bacteriology had already passed. During that exalted epoch (1870's-1890's), the laboratories of Robert Koch and Louis Pasteur identified the etiological agents of many infectious diseases. The discoverers of these microbial malefactors earned worldwide acclaim, and the lasting register of eponymous designations (e.g., *Bacillus Koch-Weeks*, *Bacterium Kochii*, *Clostridium Pasteurianum*, *Bacillus Zopfii*, Frankel's gas bacillus, Friedlander's pneumobacillus, *Neisseria*, *Oospora Metschnikovii*, etc.). American bacteriology emerged with a slight sense of privation, a suspicion that domestic scientists might not match the achievements of their European predecessors. In investigating the dual status of growth and unease, this thesis shuns singular attention to the "cutting edge" moments of bacteriology. The ensuing six chapters narrate very few great discoveries. Instead, these pages detail a daily science at the bench, in the dairy barn, within the experiment station, and at the water treatment plant. The achievements of American bacteriology may have resided in the routine features of the science, the administrative arrangements that allowed bacteriologists to perform innumerable diphtheria throat cultures, sputum examinations, tests for fecal contaminations of water, desiccations of legume inoculants, and the like.

In describing the disciplinary development of American bacteriology, this thesis points to the principal importance of institutional settings, routine techniques, and shared language. The institutional contours of bacteriology sculpted bacteriology to particular applied needs. For

example, Chapters One and Two of this thesis argue that the contexts of pathology, public health, sanitary engineering, and veterinary medicine fostered a “hygienic vision” of bacteriology. This vision emphasized the isolation, identification, and elimination of germs from humans and animals, and their environments. Researchers sought to remove their objects of study (*e.g.*, *B. typhosus*, *B. tuberculosis*, *B. abortus*), not to understand them. While this approach directed scant attention to the microbe itself, it did manufacture several bacteriological procedures that could be routinized and reproduced in several locations. In contrast, Chapter Three contends that dairy and soil bacteriologists failed to develop similar routine practices. In their efforts to manage, and not eliminate bacteria, these agricultural scientists sought to render microbes more efficient in the production of cheese, butter, and legume nodules. Consequently, these researchers viewed to problems and phenomena normally occluded by the “hygienic vision” (*e.g.*, bacterial nutrition and metabolism, associative behavior, variation, taxonomy, phylogenetic relationships). Paradoxically, the more institutionally successful branches of bacteriology suffered from conceptual constriction, while the methodologically capacious specialties never witnessed comparable institutional growth.

Chapters Four, Five and Six investigate the actions of the Society of American Bacteriology (SAB). Established in 1899, the SAB featured a diverse membership, incorporating representatives from every sphere of microbiology. Unlike many other scientific associations who delineated their disciplines by exclusion, the SAB cultivated a wide and varied membership. However, the Society during the first twenty-five years of its existence struggled to identify the shared elements of bacteriology. Its founders dedicated the association to advancement of bacteriology as “a biological science.” This objective remained elusive, as Society members

rarely agreed on what would constitute the biological elements of bacteriology. Chapter Four examines the SAB's annual meetings, officers, committees, and its *Journal of Bacteriology*, documenting the Society's collective search for the unifying elements of the discipline. In curious fashion, this communal uneasiness proved productive, prodding bacteriologists to look beyond the methodological safety of their routine procedures.

Their common techniques may have been the lone unifying thread among American bacteriologists. At the most basic level, bacteriology encompassed the manipulation of bacteria, and bacteriologists were those who practiced those procedures. Chapter Five details the development of the SAB's Descriptive Chart. The Descriptive Chart aided in the identification of unknown bacterial forms, providing a list of technical interventions to describe an indeterminate culture. Its serial editions represented the SAB's estimation of the most useful bacteriological methods. Moreover, as the Society and its committees debated revisions to the chart, they contemplated those fundamental aspects that underlay the most basic manipulations (e.g., Gram's stain, gas production, nitrate reduction). By 1920, most bacteriology textbooks and manuals embraced the Descriptive Chart, and students mastered the science through rehearsing the procedures it contained. As the chart itself grew more expansive in its list of technical explorations, the discipline broadened its range of conceptual considerations. Nonetheless, the Society steadfastly refused to adopt the Descriptive Chart as in any sense "official" or "standard." Other bodies (e.g., American Public Health Association) concerned with routine examinations of milk and water supplies demanded standardized methods. SAB leaders believed that fixed methods jeopardized conceptual explorations. If the Society were to advance bacteriology as a biological science, it had to offer a collection of adjustable techniques, rather

than rigid formulae. While the SAB never adopted the Descriptive Chart as standard or official, it did become authoritative.

Chapter Six moves from examining determinative techniques to looking at disciplinary language. American bacteriology, during the first quarter of the twentieth century, suffered from a state of taxonomic chaos. A single bacterium could bear multiple names. Likewise, the same name could represent several distinct species. Bacteriologists, particularly medical bacteriologists, rarely followed accepted rules of biological nomenclature, shunning the principle of binomial Latin designations in favor of tri- or even quadrinomials. In practice and in print, the language of bacteriology resembled neither botany nor zoology. More importantly, each bacteriological specialty developed its own system of nomenclature and classification. The taxonomic chaos reflected and perpetuated the disunity of bacteriology. The SAB, through its Committee on the Characterization and Classification of Bacterial Types and its Committee on Taxonomy, endeavored to establish a unified bacterial systematics. In particular, these committees believed that a taxonomic scheme should reflect the phylogenetic relationships among bacteria, a consideration largely ignored by earlier systems of classification. Genera and families, they contended, ought to represent physiologically similar organisms. In this effort, the SAB's program of taxonomic reform focused attention directly on the bacteria themselves, rather than their usefulness to humans, as Society officials grappled with the problem of bacterial variation, explored the minutiae of nutrition and metabolism, and pondered possible evolutionary scenarios.

In 1920, the SAB published a radically new taxonomy, one featuring several new families and genera fashioned from phylogenetic accounts. While many bacteriologists resisted the

SAB's efforts, unwilling to surrender their familiar designations and *ad hoc* groupings, and while the ensuing debate never found formal resolution, the new systematics became authoritative through a process of education. The SAB organized a committee to author a new manual of determinative bacteriology. The Committee on the Determinative Manual embraced the SAB's taxonomy, embedding the new scheme in its myriad keys for identifying unknown bacterial forms. As a result, the next generation of bacteriologists trained by using the *Bergey's Manual of Determinative Bacteriology*. In instructional laboratories, public health departments, and agricultural experiment stations, each time a practitioner employed the *Bergey's Manual* he (or more commonly she) unwittingly absorbed the SAB's taxonomy.

Despite the SAB's concerted efforts, the disciplinary unease never completely dissipated. There were no declarations that bacteriology emerged triumphantly unified, a fundamental science featuring a shared set of uncomplicated methods, theoretical moorings, stable taxonomy, and common problems. Instead, the lingering anxiety merely revealed what bacteriology lacked. In some measure, the search for a more biological bacteriology defined the discipline, supplying the Society of American Bacteriologists with rallying cry and compelling purpose. This disciplinary unease, in fact, proved to be productive.

Historiographical Leanings and Methodological Eclecticism

This thesis borrows from a wide body of historical and sociological literature. Historians have maintained a keen interest in the origins of bacteriology, returning time and again to reconsider the founders of the science,¹ and the development of the germ theory of disease.²

¹ See, for example, Gerald Geison, *The Private Side of Louis Pasteur* (Princeton: Princeton University Press, 1994); Thomas D. Brock, *Robert Koch: A Life in Medicine and Bacteriology* (Madison: Science Tech

While recent scholarship has shed new light on the careers of Louis Pasteur, Robert Koch, Joseph Lister, and their disciples,³ much of the writing continues to grapple with the traditional narrative of the scientific conquest of disease.⁴ For those historians studying the development of American bacteriology, most seek to illuminate bacteriology's impact on other fields. Historians of medicine, for example, have documented the changes wrought by the introduction of bacteriological methods and an increasing reliance on laboratory experts. Illness, in many

Publishers, 1988); and, M. Penn, and M. Dworkin, "Robert Koch and Two Visions of Microbiology," Bacteriological Reviews 40 (1976): 276-283.

² Phyllis A. Richmond, "American Attitudes Toward the Germ Theory of Disease (1860-1880)," Journal of the History of Medicine 9 (1954): 428-454; Richmond, "Some Variant Theories in Opposition to the Germ Theory of Disease," Journal of the History of Medicine and Allied Sciences 9 (1954): 290-303; John K. Crellin, "The Dawn of the Germ Theory: Particles, Infection and Biology," in Medicine and Science in the 1860's, edited by F.N.L. Poynter (London: Wellcome Institute for the History of Medicine, 1968), 57-66; Richard Harrison Shryock, "Germ Theories in Medicine Prior to 1870," Clio Medica 7 (1972): 81-109; Oswei Temkin, "A Historical Analysis of the Concept of Infection," in The Double Face of Janus (Baltimore: Johns Hopkins University Press, 1977); K. Codell Carter, "Ignaz Semmelweis, Carl Mayrhofer, and the Rise of Germ Theory," Medical History 29 (1985): 33-53; Carter, "Koch's Postulates in Relation to the Work of Jacob Henle and Edwin Klebs," Medical History 29 (1985): 353-374; John Farley, "Parasites and the Germ Theory of Disease," in Framing Disease: Studies in Cultural History, eds. Charles E. Rosenberg, and Janet Golden (New Brunswick: Rutgers University Press, 1992), 33-49; Thomas J. Garipey, "The Introduction and Acceptance of Listerian Antisepsis in the United States," Journal of the History of Medicine and Allied Sciences 49 (1994): 167-206; Nancy J. Tomes and John Harley Warner, "Introduction to the Special Issue on Rethinking the Reception of the Germ Theory of Disease: Comparative Perspectives," Journal of the History of Medicine and Allied Science 52 (1997): 7-16; Tomes, "American Attitudes Toward the Germ Theory of Disease: The Richmond Thesis Revisited," Journal of the History of Medicine and Allied Sciences 17 (1997): 17-50; and, Anna Greenwood, "Lawson Tait and Opposition to Germ Theory: Defining Science in Surgical Practice," Journal of the History of Medicine and Allied Sciences 53 (1998): 99-131.

³ See, Nils Roll-Hansen, "Pasteur: An Underestimated Hero of Science: An Essay Review," Centaurus 40 (1998): 81-93; Richard K. Aspin, "Pasteur, a Hundred Years on," Friends of the Wellcome Institute, Newsletter, no. 8 (Sept. 1995); K. Codell Carter, "The Development of Pasteur's Concept of Disease Causation and the Emergence of Specific Causes in Nineteenth-century Medicine," Bulletin of the History of Medicine 65 (1991): 528-548; and, Christopher J. Lawrence and Richard Dixey, "Practising on Principle: Joseph Lister and the Germ Theories of Disease," in Medical Theory, Surgical Practice: Studies in the History of Surgery (London: Wellcome Institute in the History of Medicine, 1992), 153-215.

⁴ For examples of this traditional narrative, see, Hubert A. Lechevalier and Morris Solotorovsky, Three Centuries of Microbiology (New York: McGraw-Hill Book Co., 1965); Harry F. Dowling, Fighting Infection: Conquests of the Twentieth Century (Cambridge: Harvard University Press, 1977); and, Wesley W. Spink, Infectious Diseases: Prevention and Treatment in the Nineteenth and Twentieth Centuries (Minneapolis: University of Minnesota Press, 1978). In recent decades, scholars expanded the canonized list of "first" microbiologists. See, Jose Lopez Sanchez, "Carlos J. Finlay and the Conception of Contagion," Indian Journal of History of Science 16 (1981): 156-168; and, Harold M. Malkin, "The Trails and Tribulations of George Miller Sternberg (1835-1915) -- America's First Bacteriologist," Perspectives in Biology and Medicine 36 (1992-1993): 666-678.

quarters, became equated with contagious germs, and the eradication of infectious diseases became synonymous with the identification of microbial agents.⁵ In other instances, doctors resisted the reduction of disease to microbial invasion, accepting the encroachment of bacteriologists and pathologists only on negotiated terms.⁶ Scholars have similarly investigated the assimilation of bacteriological techniques within public health; whereby trained specialists were enlisted to identify the cases of tuberculosis, typhoid fever, diphtheria, syphilis, gonorrhea, meningitis, and scarlet fever.⁷ Nineteenth-century sanitary science fostered healthy environments through broad-based clean-up campaigns and civic reforms. In contrast, the new

⁵ George Rosen, "The Bacteriological, Immunologic, and Chemiotherapeutic [sic] Period, 1875-1950," Bulletin of the New York Academy of Medicine 90 (1964): 491; Esmond R. Long, A History of Pathology (New York: Dover Publications Inc., 1965); W.D. Foster, History of Medical Bacteriology and Immunology (London: Heinemann, 1970); Elizabeth Fee, Disease and Discovery: A History of the Johns Hopkins School of Hygiene and Public Health, 1916-1939 (Baltimore: Johns Hopkins University Press, 1987); Victoria A. Harden, Rocky Mountain Spotted Fever: History of a Twentieth-Century Disease (Baltimore: Johns Hopkins University Press, 1990); Andrew Cunningham and Perry Williams, eds., The Laboratory Revolution in Medicine (Cambridge: Cambridge University Press, 1992); and, George F. Haddad, "Germ Theories, Scientific Medicine, and the Buffalo Medical Community," in Medical History in Buffalo, 1846-1996: Collected Essays, eds. Lilli Sentz and Ronald E. Batt (Buffalo: SUNY Buffalo, 1996), 115-162.

⁶ Russel C. Maulitz, "Physician vs. Bacteriologist: The Ideology of Science in Clinical Medicine," in The Therapeutic Revolution, eds. M.J. Vogel and C.E. Rosen (Philadelphia: University of Pennsylvania Press, 1979), 91-107; Maulitz, "Robert Koch and American Medicine," Annals of Internal Medicine 97 (1982): 761-766; and, Evelyn M. Hammonds, "Science, Politics, and the Art of Persuasion: Promoting the New Scientific Medicine in New York City," in Hives of Sickness: Public Health and Epidemics in New York City, ed. David Rosner (New Brunswick, NJ: Rutgers University Press, 1995).

⁷ Barbara G. Rosenkrantz, "Cart Before Horse: Theory, Practice, and Professional Image in American Public Health, 1870-1922," Journal of the History of Medicine and Allied Sciences 29 (January 1974): 55-74; Rosenkrantz, "The Trouble with Bovine Tuberculosis," Bulletin of the History of Medicine 59 (1985): 155-175; Judith Walzer Leavitt, The Healthiest City: Milwaukee and the Politics of Health Reform (Princeton: Princeton University Press, 1982); Jonathan Liebenau, Medical Science and Medical Industry: The Formation of the American Pharmaceutical Industry (Baltimore: Johns Hopkins University Press, 1987); Michael P. McCarthy, Typhoid and the Politics of Public Health in Nineteenth-Century Philadelphia (Philadelphia: American Philosophical Society, 1987); Alan M. Kraut, "Silent Travelers: Germs, Genes, and American Efficiency, 1890-1924," Social Science History 12 (Winter 1988): 377-394; Naomi Rogers, "Germs with Legs: Flies, Disease and the New Public Health," Bulletin for the History of Medicine 63 (1989): 599-617; Rogers, Dirt and Disease: Polio in America Before FDR (New Brunswick, NJ: Rutgers University Press, 1992); Evelyn M. Hammonds, Childhood's Deadly Scourge: The Campaign to Control Diphtheria in New York, 1880-1930 (Baltimore: Johns Hopkins University Press, 1999); and, Leavitt, Typhoid Mary: Captive to the Public's Health (Boston: Beacon Press, 1996).

public health of the twentieth-century focused efforts on the sources of bacterial contamination.⁸

Notions of personal hygiene incorporated bacteriological maxims, as dirt and foul airs were gradually seen as vehicles for germ transit, rather than as sources of illness in and of themselves.⁹

Historians of agricultural sciences have likewise begun to elucidate the consequences of bacteriological discoveries for veterinary medicine, plant pathology, and the dairy industry.¹⁰

Despite this burgeoning scholarship, the history of bacteriology itself remains largely unwritten. Initially, attention has centered primarily on the birth of the science, both in Europe and America (circa 1860-1900), leaving later decades relatively unexamined.¹¹ Secondly,

⁸ Barbara G. Rosenkrantz, Public Health and the State: Changing Views in Massachusetts, 1842-1936 (Cambridge: Harvard University Press, 1972); John Duffy, "Bacteriology Revolutionizes Public Health," in The Sanitarians: A History of American Public Health (Urbana: University of Illinois Press, 1990); Judith Walzer Leavitt, "'Typhoid Mary' Strikes Back: Bacteriological Theory and Practice in Early Twentieth-Century Public Health," Isis 83 (1992): 608-629; Christopher Hamlin, A Science of Impurity: Water Analysis of Nineteenth Century Britain (Berkeley: University of California Press, 1990); Julie Miller, "To Stop the Slaughter of Babies: Nathan Straus and the Drive for Pasteurized Milk, 1893-1920," New York History 74 (1993): 158-184; and, Edward F. Keuchel, "Science, Technology and Food Preservation: The Introduction of Bacteriology to the American Canning Industry," in Essays in American History in Honor of James C. Malin, ed. Burton J. Williams (Lawrence, KS: Corondo Press, 1973).

⁹ See, Nancy Tomes, "The Private Side of Public Health: Sanitary Science, Domestic Hygiene, and the Germ Theory, 1870-1900," Bulletin of the History of Medicine 64 (1990): 509-539; Tomes, The Gospel of Germs: Men, Women, and the Microbe in American Life (Cambridge: Harvard University Press, 1998); and, Suellen Hoy, Chasing Dirt: The American Pursuit of Cleanliness (Oxford: Oxford University Press, 1995).

¹⁰ Richard A. Overfield, "Hog Cholera, Texas Fever and Frank S. Billings," Nebraska History 57 (1976): 99-128; Ho Yin Tang, "The Enigma of Hog Cholera: Controversies, Cause, and Control, 1833-1917," (Ph.D. diss., University of Minnesota, 1986); Ole H.V. Stalheim, "The Hog Cholera Battle and Veterinary Professionalism," Agricultural History 62, no. 2 (1988): 116-121; Jeanne Logue, Beyond the Germ Theory: The Story of Dr. Cooper Curtice (College Station: Texas A&M University Press, 1995); John D. Blaisdell, "With Certain Reservations: The American Veterinary Community's Reception of Pasteur's Work on Rabies," Agricultural History 70 (1996): 503; C. Lee Campbell, Paul D. Peterson, and Clay S. Griffith, The Formative Years of Plant Pathology in the United States (St. Paul: APS Press, 1999); and, Edward H. Beardsley, Harry L. Russell and Agricultural Science in Wisconsin (Madison: University of Wisconsin Press, 1969).

¹¹ Those scholars examining events after the turn of the century have done so with an eye toward the later development of antibiotics and bacterial genetics. See, for example, Carol L. Moberg and Zanvil A. Cohn, eds., Launching the Antibiotic Era: Personal Accounts of the Discovery and Use of the First Antibiotics (New York: Rockefeller University Press, 1990); Allen I. Marcus, "From Ehrlich to Waksman: Chemotherapy and the Seamed Web of the Past," in Beyond the History of Science: Essays in Honor of Robert E. Schofield (Bethlehem, PA: Lehigh University Press, 1990); Thomas D. Brock, "The Bacterial Nucleus: A History," Microbiological Reviews 52 (1988): 397-411; Brock, The Emergence of Bacterial Genetics (Cold Spring Harbor, NY: Cold Spring Harbor Laboratory Press, 1990); and, William C. Summers, "From Culture as Organism to Organism as Cell: Historical Origins of Bacterial Genetics," Journal of the History Biology 24 (1991): 171-190.

historians have focused on the pivotal discoveries, technical innovations, and conceptual breakthroughs of bacteriology. The routines of the science, practiced by the vast majority of bacteriologists, have elicited scant historical interest.¹² Thirdly, and most importantly, we have detailed descriptions of bacteriology's influence on medicine, public health, sanitary science, veterinary medicine, and plant pathology, but only a meager comprehension of how these several fields shaped bacteriology. The development of bacteriology, while studied by many historians, abides as a poorly understood domain.

This thesis seeks to correct, in part, this historical lacuna. My own analysis begins with Charles Rosenberg's notion of "ecologies of knowledge." Rosenberg contends that scientific knowledge is "structured by diverse institutional contexts," such as universities, professional schools or applied research laboratories. Disciplines and departments guide "the scholar or scientist's relationship to a particular institutional context." Given that many researchers participate in multiple disciplinary and institutional circumstances, "professional life becomes then a compromise defined by the sometimes consistent and sometimes conflicting demands of discipline or subdiscipline and the particular conditions of an individual's employment."¹³

¹² Notable exceptions to this characterization are, Keith Vernon, "Pus, Sewage, Beer and Milk: Microbiology in Britain, 1870-1940," History of Science 28 (1990): 289-325; Anne-Marie Moulin, "Bacteriological Research and Medical Practice in and Out of the Pasteurian School," Clio Medica (Amsterdam) 25 (1994): 327-349; and, Annemarie de Knecht-van Eekelen, "The Rise of the Science of Bacteriology in the Netherlands," in Proc. of the XXXIInd International Congress on the History of Medicine, Antwerp, 3-7 Sept. 1900 (Bruxells: Societas Belgica Historiae Medicinae, 1991), 351-360.

¹³ Rosenberg, "Toward an Ecology of Knowledge: On Discipline, Context and History," in, No Other Gods: On Science and American Social Thought, rev. and exp. ed. (Baltimore: Johns Hopkins University Press, 1997), 228 & 230. See also the chapters on, "Science and Social Values in 19th Century America: A Case Study in the Growth of Scientific Institutions," "Science, Technology and Economic Growth: The Case of the Agricultural Experiment Station Scientists, 1875-1914," "The Adams Act: Politics and the Cause of Scientific Research," and, "Unintended Consequences: The Ideological Shaping of American Agricultural Research, 1875-1914." A similar argument is found in Margaret W. Rossiter, "The Agricultural Sciences in the United States, 1860-1920," in The Organization of Knowledge in Modern America, 1860-1920, eds. Alexandra Oleson and John Voss (Baltimore: Johns Hopkins University Press, 1979).

Rosenberg points to the relationship of American genetics and biochemistry to medicine.

Genetics, in the late nineteenth- and early twentieth-centuries, “grew as a discipline largely out of the work of biologists employed either by university departments of zoology or botany or in agricultural colleges and experiment stations (supported by an atypical federal commitment to the funding of farm-related research).” Medicine, however, had little incentive to promote genetics, “which seemed only potentially related to everyday clinical realities.” Biochemistry, in contrast, found ample support from medical institutions, owing to its promise of efficient diagnostic techniques.¹⁴

Rosenberg warns against positing disciplines as homogenous entities. While a researcher might identify himself as a geneticist or biochemist, particular institutional environments produce specific research agendas and characteristic forms of knowledge. He identified bacteriology as potentially illustrative case study:

A bacteriologist working at an agricultural experiment station or pharmaceutical firm deals with very different questions and in a very different work environment from a medical school bacteriologist or one attached to a research team at, let us say, Rockefeller University. At the end of the nineteenth century, indeed, bacteriology was not a field at all; it could be defined only in terms of botanists and mycologists, alert and ambitious pathologists, and employees of state and municipal departments of public health. To write a history of the origins of bacteriology would imply an evaluation of all these contexts and the specific influence they had in shaping the work and aspirations of would-be bacteriologists.¹⁵

Indeed, this thesis demonstrates that American bacteriologists tailored their work to their institutional settings, often mediating the difficult compromise between science and service. At medical colleges, public health departments, agricultural experiment stations, pharmaceutical

¹⁴ Rosenberg, “Toward an Ecology of Knowledge,” 230-231.

¹⁵ Rosenberg, “Toward an Ecology of Knowledge,” 230.

companies, and dairies, bacteriologists performed innumerable routine examinations, leaving little time for original investigations into matters not promising immediate practical benefit. Yet, many of these same bacteriologists did find occasion (and resources) to conduct research, often in pursuit of more efficient or accurate routine procedures. For example, bacteriologists gained favor from agricultural experiment station directors by supplying improved dairy starter cultures, legume inoculations, and diagnostic tests for pullorum. But it was these improvements that led researchers to refine culture techniques and probe bacterial physiology. While Rosenberg stressed the importance of institutional factors in shaping research schools and disciplinary styles, he did allow for a dialectical influence, where the conceptual and methodological developments of science might alter the institutional setting.¹⁶

According to Rosenberg, disciplines usually encompass a heterogeneous membership. He points to the American Society of Biological Chemists (1906), which drew researchers from a variety of social contexts: "industry, agricultural colleges and experiment stations, university departments of physiology and physiological chemistry, as well as medical schools and hospitals." Similarly, the American Chemical Society included "a host of individuals occupying very different social locations and making use of very different bodies of knowledge and agenda-committing systems of experimental practice."¹⁷ The Society of American Bacteriologists mirrored, in this regard, these chemical societies. The SAB comprised an eclectic

¹⁶ For other historians adopting an "ecology of knowledge" perspective, see, Barbara A. Kimmelman, "The American Breeders' Association: Genetics and Eugenics in the Agricultural Context, 1903-1913," Social Studies of Science 13 (1983): 163-204; Kimmelman, "A Progressive Era Discipline: Genetics at American Agricultural Colleges and Experiment Stations, 1890-1920," (Ph.D. diss., University of Pennsylvania, 1987); and, Alan I. Marcus, Agricultural Science and the Quest for Legitimacy: Farmers, Agricultural Colleges, and Experiment Stations, 1870-1890 (Ames: Iowa State University Press, 1985).

¹⁷ Rosenberg, "Toward an Ecology of Knowledge," 231.

aggregate of physicians, public health officials, veterinarians, plant pathologists, soil scientists, fermentation specialists, canning representatives, and dairymen. As result, SAB members did not share a common set of characteristics or research interests. Nonetheless, membership in SAB constituted an act of disciplinary affiliation. As Rosenberg reasons, "scholars and scientists who identify themselves with a particular discipline, no matter how diverse their workplaces or marginal their commitment to the larger discipline, still feel some residual sense of common identity . . ." ¹⁸ The following chapters examine the possible sources for that common identity among bacteriologists, documenting its fragile basis, and the struggle to fortify its foundations.

Other historians have followed Rosenberg's call to study the relationship between scientific disciplines and their varied institutional contexts. For example, Robert Kohler, in *From Medical Chemistry to Biochemistry*, maintained that disciplines encompass "diverse segments, often identified with competing styles or programs. These different programs are adapted to different institutional contexts, and, most important, they prescribed favored relationships with other disciplines . . ." Kohler identified three distinct styles of biochemistry prior to 1940 (biological, bioorganic and biophysical, and clinical), each suited to the conditions of particular university departments and institutions (e.g., biology, chemistry, physiology, medical schools, hospitals). Biochemists, in Kohler's narrative, struggled to cope with a scarcity of resources. As such, Kohler appraised the particular styles of biochemistry for "their utility in discipline building." ¹⁹ For example, "general biochemistry" embodied a "broadly biological

¹⁸ Rosenberg, "Toward an Ecology of Knowledge," 231 & 234.

¹⁹ Kohler, *From Medical Chemistry to Biochemistry: The Making of a Biomedical Discipline* (Cambridge: Cambridge University Press, 1982), 6-7. Kohler argues that especially during the "vulnerable formative years of a new discipline, intellectual priorities are shaped by the mode of production of scientific knowledge. As institutions provide a stable basis of support, disciplines may lose their distinctive style, becoming more varied and receptive to various research programs," 252. See also, John Servos, "Physical Chemistry in America, 1890-1933: Origins,

program, taking as its domain all forms of life: microbes, plants, invertebrates, and higher animals. It was concerned ultimately with fundamental processes -- growth, development, energy transformation, and biochemical control -- rather than special problems of human physiology and pathology." Similar to bacteriologists advocating a more biological approach to their discipline, general biochemists "looked to more varied constituencies: zoologists, botanists, microbiologists, as well as physiologists and pathologists . . ." ²⁰ In the case of biochemistry, however, this gesture represented a strategy for disciplinary independence, if not survival. Bacteriology, in contrast, did not experience a comparable lack of institutional support. Even so, biochemistry's disciplinary fragmentation paralleled that of bacteriology, and Kohler's account of the American Society of Biological Chemists and the *Journal of Biological Chemistry* echoes the following depiction of the Society of American Bacteriologists and the *Journal of Bacteriology*.²¹ This thesis differs from Kohler's work, however, in at least one key respect. Kohler deliberately ignored the conceptual dimensions of biochemistry, arguing that the growth of the discipline derived more from a set of institution-building strategies than from the construction of accurate theories. While my exploration of American bacteriology attends to strategies of institution-building, this thesis also seeks to integrate these factors with the conceptual, linguistic, and methodological developments of bacteriology.

In some measure, this thesis hearkens to Daniel Kevles' analysis in *The Physicists*.

Growth and Definition," (Ph.D. diss., Johns Hopkins University, 1979); N. Aronson, "Nutrition as a Social Problem: A Case Study of Entrepreneurial Strategy in Science," *Social Problems* 29 (1982): 474-487; Hamilton Cravens, "Establishing the Science of Nutrition at the USDA: Ellen Swallow Richards and Her Allies," *Agricultural History* 64 (1990): 122-133; and, Alberto Cambrosio and Peter Keating, "The Disciplinary Stake: The Case of Chronobiology," *Social Studies of Science* 13 (1983): 323-353.

²⁰ Kohler, *From Medical Chemistry to Biochemistry*, 73.

²¹ Kohler, "Chapter 8 – Unity in Diversity: The American Society of Biological Chemists," *From Medical Chemistry to Biochemistry*, esp. 195-205.

Kevles portrayed the American physics community as struggling to match the achievements of their European counterparts. At the dawn of the twentieth century, domestic physicists sought increased support from university departments and government agencies. In their attempt to cull adequate resources, American researchers pledged untold practical benefits. This strategy, while garnering unprecedented institutional favor, heightened the conflict between the demands of service and their desire for investigative autonomy. Kevles maintained a keen focus on the empire-building efforts of a few elite scientists.²² My own analysis shifts attention to the lesser known researchers, those that managed to fashion the character of American bacteriology without ever publishing a revolutionary finding. The Secretary of the SAB, I argue, can exert the same influence on a science as the Director of the National Research Council. Additionally, this thesis addresses many of the more prosaic aspects of a science. Unlike Kevles, who attended to the luminaries of American physics, the following pages profile the development of bacteriology after most of its revered founders had passed on, asking an array related questions: What were the activities, methods, and techniques of bacteriology? What kinds of institutions employed bacteriologists and why? How were novices trained? How did bacteriologists select among pressing research problems, and what counted as adequate resolutions? How did bacteriologists construct the object of their study? In what ways did the microbe shape the microbiologist? How did the particular institutional contexts determine the “work” of bacteriologists? How distinct were the several “styles” of bacteriology? In evaluating the state of their own discipline, what did bacteriologists find lacking? What remedies did they consider? What remedies did

²² Kevles, The Physicists: The History of a Scientific Community in Modern America (Cambridge: Harvard University Press, 1977).

they reject? For those measures that they enacted, what were the intended and unintended consequences?

In addition to borrowing from Rosenberg's "Ecology of Knowledge," this thesis speaks more generally to the abundant literature in the history and sociology of professions and disciplines.²³ Even though bacteriology differed from many sciences in that it did not suffer from a continued lack of institutional support, this scholarship remains useful in examining the rapid disciplinary growth of bacteriology.²⁴ Moreover, these accounts point to the mechanisms by which institutional settings shaped both individual scientist's research ambitions and also the development of their disciplines.²⁵ The following chapters detail bacteriology's attempt to

²³ Magali Sarfatti Larson, The Rise of Professionalism: A Sociological Analysis (Berkeley: University of California Press, 1977); Gerald L. Geison, ed., Professions and Professional Ideologies in America (Chapel Hill, NC: University of North Carolina Press, 1983); Whitley, The Intellectual and Social Organization of the Sciences (New York: Oxford University Press, 1984); Jan Goldstein, "Foucault Among the Sociologists: The 'Disciplines' and the History of the Professions," History and Theory 23 (1984): 170-192; Thomas F. Gieryn, G.F. Bevens, and S.G. Zehr, "The Professionalization of American Scientists," American Sociological Review 50 (1985): 392-409; Eliot Freidson, Profession of Medicine: A Study of the Sociology of Applied Knowledge (Chicago: University of Chicago Press, 1988); Andrew Abbott, The System of Professions: An Essay on the Division of Expert Labor (Chicago: University of Chicago Press, 1988); JoAnne Brown, The Definition of a Profession: The Authority of Metaphor in the History of Intelligence Testing, 1890-1930 (Princeton: Princeton University Press, 1992); and, Rudolf Stichweh, "The Sociology of Scientific Disciplines: On the Genesis and Stability of the Disciplinary Structure of Modern Science," Science in Context 5 (1992): 3-15.

²⁴ See, especially, Michael Worboys, "The Emergency of Tropical Medicine: A Study in the Establishment of a Scientific Speciality," in Perspectives on the Emergence of Scientific Disciplines, eds. Gerard Lemaine, Roy Macleod, Michael Mulkay, and Peter Weingart (Chicago: Aldine, 1976); Richard Whitley, "Umbrella and Polytheistic Scientific Disciplines and Their Elites," Social Studies of Science 6 (1976): 471-497; Eugene Cittandino, "Ecology and the Professionalization of Botany in America, 1890-1905," Studies in the History of Biology 4 (1980): 171-198; William Bechtel, "Integrating Sciences by Creating New Disciplines: The Case of Cell Biology," Biology and Philosophy 8 (1993): 277-299; Michael Chayut, "The Hybridisation of Scientific Roles and Ideas in the Context of Centres and Peripheries," Minerva: Review of Science, Learning and Policy 32 (1994): 297-308; Paolo Palladino, "The Professionalisation of Plant Breeding in the United States: The Technology of Hybridisation and Its Consequences," Minerva 29 (1991): 507-515; and, Palladino, Entomology, Ecology and Agriculture: The Making of Scientific Careers in North America, 1885-1985 (Amsterdam: Harwood Academic Publishers, 1996).

²⁵ See, Richard A. Overfield, "Charles E. Bessey: The Impact of the 'New' Botany on American Agriculture, 1880-1910," Technology and Culture 16 (1975): 162-181; R.G.A. Dolby, "The Transmission of Two New Scientific Disciplines from Europe to North America in the Late 19th Century," Annals of Science 34 (1977): 387-410; William Coleman, "The Cognitive Basis of a Discipline: Claude Bernard on Physiology," Isis 76 (1985): 49-70; Deborah Fitzgerald, The Business of Breeding: Hybrid Corn in Illinois, 1890-1940 (Ithaca: Cornell University Press, 1990); Fitzgerald, "Mastering Nature and Yeoman: Agricultural Science in the Twentieth

become more biological. As such, I provide an account of disciplinary desire – and not disciplinary competition – as I pose a few guiding questions: What were the components of biology that bacteriologists found absent their own science? How did these perceived deficiencies manifest themselves? What steps did they take to remedy the content and conduct of bacteriology? In what measure did they succeed or fail, and why?²⁶

Following other historians, I regard scientific societies and their official journals as active agents, and not mere reflections, of disciplinary change.²⁷ American bacteriologists have repeatedly pointed to the central role served by the SAB and the *Journal of Bacteriology* in the

Century,” in Science in the Twentieth Century, eds. John Krige, and Dominique Pestre (The Netherlands: Harwood Academic, 1997), 701-714; Lily E. Kay, The Molecular Vision of Life: Caltech, the Rockefeller Foundation, and the Rise of the New Biology (New York: Oxford University Press, 1993); J. Davison, “The Role of Experimentation and Experimental Evidence in the Development of Bacteriology in Britain,” (Ph.D. diss., University of Northumbria at Newcastle, 1993); and, Daniel J. Kevles and Gerald J. Geison, “The Experimental Life Science in the Twentieth Century,” Osiris 10 (1995): 97-121.

²⁶ American bacteriologists found it difficult to identify the biological aspects of their science, in part because biology itself was changing during the early twentieth-century. See, Garland E. Allen, “The Transformation of a Science: T.H. Morgan and the Emergence of a New American Biology,” in The Organization of Knowledge in Modern America, 1860-1920: Jane Maienschein, Ronald Rainger, and Keith R. Bensen, “Introduction: Were American Morphologists in Revolt?,” Journal of the History of Biology 14 (1981): 83-87; Allen, “Morphology and Twentieth-Century of Biology: A Response,” Journal of the History of Biology 14 (1981): 159-176; Frederick B. Churchill, “In Search of the New Biology: An Epilogue,” Journal of the History of Biology 14 (1981): 177-191; Joel B. Hagen, “Experimentalists and Naturalists in Twentieth-century Botany: Experimental Taxonomy, 1920-1950,” Journal of the History of Biology 17 (1984): 249-270; and, Bensen, “From Museum Research to Laboratory Research: The Transformation of Natural History in Academic Biology,” in The American Development of Biology, eds. Rainger, Bensen, and Maienschein (Philadelphia: University of Pennsylvania Press, 1988).

²⁷ Richard S. Cowan, “The Origins and Early History of I.A.P.T.,” Taxon 31 (1982): 415-420; Brother C. Edward Quinn, “Ancestry and Beginnings: The Early History of the American Society of Zoologists,” American Zoologist 22 (1982): 735-748; and, Keith R. Bensen and Quinn, “The American Society of Zoologists, 1889-1989: A Century of Integrating the Biological Sciences,” American Zoologist 30 (1990): 353-396. The history of American societies for chemistry is particularly rich. See, Herman Skolnick and Kenneth E. Reese, eds., A Century of Chemistry: The Role of Chemists and the American Chemical Society (Washington, D.C.: American Chemical Society, 1976); James J. Bohning, “The Continental Chemical Society,” Bulletin for the History of Chemistry 6 (1990): 15-21; George B. Kaufmann, Coordination Chemistry: A Century of Progress, 1893-1993 (Washington, D.C.: American Chemical Society, 1994); and, Mary Ellen Bowden and John K. Smith, American Chemical Enterprise: A Perspective on 100 Years of Innovation to Commemorate the Centennial of the Society of Chemical Industry (Philadelphia: Chemical Heritage Foundation, 1994).

discipline's development.²⁸ Chapters Four, Five and Six examine the means by which the SAB influenced the character of American bacteriology. My analysis begins by inquiring how the SAB positioned itself as an instrument of disciplinary development. In what regard were its goals congruent with the aspirations of most bacteriologists? In which instances did SAB leaders advance a minority position? What rhetorical or administrative measures did SAB officials take to persuade bacteriologists to become more "biological"? In what ways did SAB members resist?²⁹

In an attempt to narrate a discipline in search of itself, my analysis is informed by the methods of symbolic interactionism, and its notion of "a social worlds perspective." A social world, according to Anselm Strauss, comprises a "universe of regularized mutual response" and an "arena in which there is a kind of organization." A social world might circumscribe a "cultural area," but is defined "neither by territory or formal membership, but by limits of effective communication." There exist countless numbers of social worlds, of various sizes, and

²⁸ J.R. Porter, "History of the *Journal of Bacteriology*," *ASM News* 40 (1974): 585-594; L.S. McClung, "The American Society for Microbiology/Society of American Bacteriologists: A Brief History," *ASM News* 44 (1978): 446-451; Stuart B. Levy, "The First Centennial and On to the Next," Barbara Hyde, "Society Founded by 'Lost Souls' among the Naturalists," Michael Goldberg and Jeffrey L. Fox, "Leaders Share Views on ASM Past and Future," Moselio Schaechter and John L. Ingraham, "A Glimpse at Selected ASM Journals through the Years," Bernard Dixon, "A Century of Society Meetings," Patricia Peck Gossel, "When Bacteriologists Wore Black," Arnold L. Demain, "Stunning Achievements of Industrial Microbiology," Anne K. Vidaver, "Plant Microbiology: Century of Discovery, with Golden Years Ahead," and, Clifford W. Houston, Martin Dworkin, and W. Robert Fleischmann, "20th-Century Evolution of Microbiological Education," *ASM News* 65 (1999): 258-259, 266-296, 311-316, 358-370.

²⁹ Mark S. Granovetter, "The Strength of Weak Ties," *American Journal of Sociology* 78 (1973): 1360-1380; Mark Granovetter, "The Strength of Weak Ties: A Network Theory Revisited," *Sociological Theory* 1 (1983): 201-233; Ilana Lowy, "The Strength of Loose Concepts -- Boundary Concepts, Federative Experimental Strategies and Disciplinary Growth: The Case of Immunology," *History of Science* 30 (1992): 371-396; Fulton Lutz, "History of the Soil Science of America," *Journal of the Soil Science Society of America* 41 (1977): 152-173; Toby A. Appel, "Biological and Medical Societies and the Founding the American Physiological Society," in *Physiology in the American Context, 1850-1940*, eds. Gerald Geison (Bethesda: American Physiological Society, 1987); and, Appel, "Organizing Biology: The American Society of Naturalists and Its 'Affiliated Societies,' 1883-1923," in *American Development of Biology*, 87-120.

degrees of formality. For the most part, each social world is associated with at least "one primary activity," located in specific sites and employing particular practices. Social worlds often intersect each other, and frequently segment into specifiable subworlds.³⁰ One might speak of reproductive endocrinology, economic entomology, British neurophysiology, sanitary bacteriology, dairying, and soil science as social worlds. Bacterial taxonomy, however, did not constitute its own social world until the second decade of the twentieth century. Among the handful of bacteriologists interested in systems, there was no "universe of recognized mutual response," no agreed upon concerns, no means of effective communication, no institutional locations, or settled conceptual tools. Instead, the SAB created a "social world" of bacteriology taxonomy, establishing a dialogue and avenues for discussion and meaningful change.

Within each social world, "various issues are debated, negotiated, fought out, forced and manipulated by representatives of implicated subworlds." Strauss suggests that a social worlds perspective "tells us that some organizations are relatively embedded within a social world, while others stand at intersections, indeed may have been intentionally constructed" to that end. Most formal associations "can be viewed as arenas wherein members of various subworlds or social worlds stake differential claims, seek differential ends, engage in contests, and make or break alliances in order to do the things they wish to do."³¹ Chapters Four, Five and Six depict the Society of American Bacteriologists in a similar light. The SAB struggled to define bacteriology as a fundamental, or biological science, while at the same time negotiating the interests and

³⁰ Anselm L. Strauss, "A Social Worlds Perspective," Studies in Symbolic Action 1 (1978): 119-123, quoting from Tomastu Shibutani, "Reference Groups as Perspectives," American Journal of Sociology 60 (1955): 522-529.

³¹ Strauss, "Social Worlds Perspective," 124-125; and, Strauss, "Social Worlds and Legitimation Processes," Studies in Symbolic Interaction 4 (1982): 171-190.

desires of bacteriology's sundry specialities.

For the sociology of science, symbolic interactionism suggests that scientific knowledge "represents and embodies work," an activity not fundamentally different from other forms of work. Scientific work involves the "processes of making commitments and negotiating constraints and opportunities. In science, framing and solving the research problems immediately at hand shape and organize the work commitments and conventions or 'standard operating procedures' of actors." Scientists, like other workers, attempt to solve particular problems, which serve as the "touchstone against which all decisions are ultimately made and around which essentially all conflicts are fought."³² Scientists may interact across social worlds, coming together to address difficult problems while still maintaining "different perspectives on the work at hand." In this light, the diversity and disunity of bacteriology is neither surprising, nor does it represent a serious disciplinary failure. Rather, the SAB, the Descriptive Chart, and the Bergey's Manual comprised mechanisms for practitioners of dissimilar interests and training to "do things together."³³

³² Adele E. Clarke and Elihu Gerson, "Symbolic Interactionism in the Social Studies of Science," in Symbolic Interaction and Cultural Studies, eds. Howard S. Becker and Michal M. McCall (Chicago: University of Chicago Press, 1988), 179-214, esp. 181-183. See also, Elihu Gerson, "Scientific Work and Social Worlds," Knowledge 4 (1983): 357-377; Susan Leigh Star, "The Sociology of the Invisible: The Primacy of Work in the Writings of Anselm Strauss," in Social Organization and Social Process: Essays in Honor of Anselm Strauss, eds. David Maines (Hawthorn, NY: Aldine de Gruyter, 1991), 265-283; Star, "Work and Practice in Social Studies of Science, Medicine, and Technology," Science, Technology and Human Values 20 (1995): 501-507; and, Star, ed., Ecologies of Knowledge: Work and Politics in Science and Technology (Albany, NY: SUNY Press, 1995).

³³ See, Herbert Blumer, Symbolic Interactionism: Perspectives and Method (Englewood, NJ: Prentice Hall, 1969); Howard S. Becker, Doing Things Together: Selected Papers (Evanston, IL: Northwestern University Press, 1986); Adele Clarke, "A Social Worlds Research Adventure: The Case of Reproductive Science," in Theories of Science in Society, eds. Thomas Gieryn, and Susan Cozzen (Bloomington: University of Indiana Press, 1990); Clarke, "Social Worlds/Arenas Theory as Organizational Theory," in Social Organization and Social Process: Essays in Honor of Anselm Strauss, ed. David Maines (Hawthorn, NY: Aldine de Gruyter, 1991), 119-158; and, Clarke, Disciplining Reproduction: Modernity, American Life Sciences, and the Problem of Sex (Berkeley: University of California Press, 1998).

Regarding science as another form of organized work, sociologists (and some historians) have pointed to the fundamental importance of tools and techniques in defining a scientific community.³⁴ Like university departments, professional societies, or academic journals, a discipline's methods and materials (both mundane and cutting edge) help select appropriate research problems, define likely results, and mediate the resolution of disputes.³⁵ Tools and techniques negotiate exchanges between scientific fields, providing common ground for dissimilar researchers to address shared problems.³⁶ Novices and outsiders become acquainted with a science by learning these techniques. They become members of that community by gaining proficiency.³⁷ In most instances, bacteriologists selected and modified their methods in

³⁴ Michael Lynch, Art and Artifact in Laboratory Science: A Study of Shop Work and Shop Talk in a Research Laboratory (London: Routledge and Kegan Paul, 1985); Joan Fujimura, "Constructing Doable Problems in Cancer Research: Articulation and Alignment," Social Studies of Science 17 (1987): 257-293; and, Susan L. Star, and James R. Griesemer, "Institutional Ecology, 'Translation,' and Boundary Objects: Amateurs and Professionals in Berkeley's Museum of Vertebrate Zoology, 1907-1939," Social Studies of Science 19 (1989): 387-420.

³⁵ According to actor-network theory, disciplinary tools and techniques can serve as "obligatory points of passage," codifying uneven alliances among actors while stabilizing the production of scientific facts. While my own analysis is informed by the work of Bruno Latour and Michel Callon, and while their notion of "translation" could be helpful in examining the the SAB's Descriptive Chart and the Bergey's Manual of Determinative Bacteriology, they assume a nearly Machiavellian competition among actors and groups. See, Bruno Latour, Science in Action: How to Follow Scientists and Engineers Through Society (Cambridge: Harvard University Press, 1987); Latour, The Pasteurization of France (Cambridge: Harvard University Press, 1988); Michel Callon, "Struggles and Negotiations to Decide What is Problematic and What is Not: The Sociology of Translation," in The Social Processes of Scientific Investigation, eds. Karin Knorr, Roger Krohn, and Richard Whitley (Dordrecht: Reidel, 1980), 197-220; Callon, and John Law, "On Interests and Their Transformation: Enrollment and Counter-Enrollment," Social Studies of Science 12 (1982): 615-625; and, Callon, "Some Elements of a Sociology of Translation," in Power, Action, and Belief: A New Sociology of Knowledge?, ed. John Law (London: Routledge and Kegan Paul, 1986), 191-233. For a critical assessment of Latour and Callon, see, Olga Amsterdamska, "Surely You Are Joking, Monsieur Latour!," Science, Technology, and Human Values 14 (1990): 495-504; and, Fujimura, "Crafting Science," 169-171.

³⁶ The importance of tools and techniques has also been a theme for those studies of scientific "practice." See, for example, Andrew Pickering, "From Science as Knowledge to Science as Practice," Ian Hacking, "The Self-Vindication of the Laboratory Sciences," Karin Knorr-Cetina, "The Couch, the Cathedral, and the Laboratory: On the Relationship between Experiment and Laboratory in Science," and, Joan H. Fujimura, "Crafting Science: Standardized Packages, Boundary Objects, and 'Translation'," in Science as Practice and Culture, ed. Pickering (Chicago: University of Chicago Press, 1992), 1-26, 29-64, 113-138, 168-211.

³⁷ See, Mary Douglas, How Institutions Think (Syracuse: Syracuse University Press, 1986); Jean Lave, and Etienne Wenger, Situated Learning: Legitimate Peripheral Participation (Cambridge: Cambridge University Press, 1991); and, Howard S. Becker, Tricks of the Trade (Chicago: University of Chicago Press, 1998).

response to institutional demands, developing techniques congruent with both routine work and research endeavors.³⁸ Unlike other scientific associations, the Society of American Bacteriologists never sanctioned the Descriptive Chart as its "official" or "standard" methods. Given this decision, there remains the question of how an "unofficial" or "non-standard" set of techniques guided the disciplinary and conceptual development of American bacteriology. In what ways can a set of techniques become "canonized" without being officially mandated? How did the Descriptive Chart facilitate the construction of "do-able" problems, or "bandwagons" toward particular styles of bacteriological research?³⁹

This thesis addresses a similar set of questions concerning the development of bacterial systematics. Classification schemes, I argue, can organize a discipline, supplying not only a

³⁸ Paul Weindling, "Scientific Elites and Laboratory Organization in Fin de Siecle Paris and Berlin. The Pasteur Institute and Robert Koch's Institute for Infectious Diseases Compared," in The Laboratory Revolution in Medicine, 170-188; and Weindling, "Between Bacteriology and Virology: The Development of Typhus Vaccines Between the First and Second World Wars," History and Philosophy of the Life Sciences 17 (1995): 81-90. For discussions on the role of instruments and methods in other life sciences, see the collected essays in Adele E. Clarke and Joan H. Fujimura, eds., The Right Tools for the Job: At Work in Twentieth-Century Life Science (Princeton: Princeton University Press, 1992); Merriley Borell, "Instrumentation and the Rise of Modern Physiology," Science and Technology Studies 5 (1987): 53-62; Timothy Lenoir, "Models and Instruments in the Development of Electrophysiology, 1845-1912," Historical Studies in the Physical and Biological Sciences 17 (1986): 365-417; Alberto Cambrosio, and Peter Keating, "Going Monoclonal: Art, Science and Magic in the Day-to-day Use of Hybridoma Technology," Social Problems 35 (1988): 244-260; Jean-Paul Gaudilliere, "Biologists at Work: Experimental Practices in the Twentieth-Century Life Sciences," in Sciences in the Twentieth Century, 683-700; Ilana Lowy and Gaudilliere, eds. The Invisible Industrialists: Manufactures and the Production of Scientific Knowledge (London: Macmillan, 1997); and, Robert E. Kohler, Lords of the Fly: Drosophila Genetics and the Experimental Life (Chicago: University of Chicago Press, 1994).

³⁹ Joseph O'Connell, "Metrology: The Creation of Universality by the Circulation of Particulars," Social Studies of Science 23 (1993): 129-173; Eric Monteiro, Ole Hanseth, and Morten Hatling, "Developing Information Infrastructure: The Tension Between Standardization and Flexibility," Science, Technology and Human Values 21 (1996): 407-426; Stefan Timmermans, and Marc Berg, "Standardization in Action: Achieving Local Universality Through Medical Protocols," Social Studies of Science 27 (1997): 273-305; Joan Fujimura, "The Molecular Biology Bandwagon in Cancer Research: Where Social Worlds Meet," Social Problems 35 (1988): 261-283; Richard Sawyer, "Monopolizing the Insect Trade: Biological Control in the USDA, 1888-1951," Agricultural History 64 (1990); and, Karen A. Rader, "Making Mice: C.C. Little, the Jackson Laboratory, and the Standardization of *Mus Musculus* for Research," (Ph.D. diss., Indiana University, 1995).

common language, but also a body of shared concepts and assumptions.⁴⁰ Disciplinary taxonomies negotiate the intersections of social worlds, just as they manage the segmentation or specialization within a field.⁴¹ As such, they often become objects of conscious discussion and debate. The SAB's attempts to develop a stable classification and nomenclature constituted acts of discipline building, rather mere matters of semantics.⁴² The disputes over bacterial systematics reflected schisms within the discipline. In what ways, I inquire in Chapter Six, did the SAB's new taxonomy promise to redefine, if not unify, bacteriology? What changes, both in practice and in theory, did the new systematics necessitate? What role did the training of novices play in the acceptance of the Society's classification and nomenclature?

Admittedly, this thesis can not adequately answer all of questions I have listed. Yet, it does begin to situate American bacteriology within its varied institutional and disciplinary contexts. I draw upon a small but informative body of scholarship on American bacteriology,

⁴⁰ See, Geoffrey C. Bowker and Susan Leigh Star, Sorting Things Out: Classification and its Consequences (Cambridge: MIT Press, 2000); David Bloor, "Durkheim and Mauss Revisited: Classification and the Sociology of Knowledge," Studies in the History and Philosophy of Science 13 (1982): 267-292; Mary Douglas, and David L. Hull, How Classification Works: Nelson Goodman Among the Social Sciences (Edinburgh: Edinburgh University Press, 1992); Harriet Ritvo, "Zoological Taxonomy and Real Life," in Realism and Representation: Essays on the Problem of Realism in Relation to Science, Literature, and Culture, ed. George Levine (Madison: University of Wisconsin, 1993), 235-254; and, Ritvo, The Platypus and the Mermaid, and Other Figments of the Classifying Imagination (Cambridge: Harvard University Press, 1997).

⁴¹ Joel B. Hagen, "Experimental Taxonomy, 1930-1950: The Impact of Cytology, Ecology, and Genetics on Ideas of Biological Classification," (Ph.D. diss., Oregon State University, 1982); Erwin N. Hiebert, "Discipline Identification in Chemistry and Physics," Science in Context 9 (1996): 93-119; and, Anselm L. Strauss, "Social Worlds and Their Segmentation Processes," Studies in Symbolic Interaction 5 (1984): 123-179.

⁴² For discussion of taxonomic disputes in other scientific fields, see, John Dean, "Controversy Over Classification: A Case Study from the History of Botany," in Natural Order: Historical Studies of Scientific Culture, eds. Barry Barnes, and Steve Shapin (Beverly Hills: Sage, 1979), 211-230; Dean, "A Naturalistic Model of Classification and Its Relevance to Some Controversies in Botanical Systematics, 1900-1950," (Ph.D. diss., Edinburgh University, 1995); Gordon R. McQuat, "Species, Names and Things: From Darwin to the Experimentalists," (Ph.D. diss., University of Toronto, 1993); McQuat, "Species, Rules and Meaning: The Politics of Language and the Ends of Definitions in 19th Century Natural History," Studies in the History and Philosophy of Science 27 (1996): 473-519; and, Geoffrey C. Bowker, "The Game of the Name: Nomenclatural Instability in Botany," in History of Information Science, ed. Robert V. Williams (forthcoming).

extending and refining conclusions of other historians. Patricia Peck Gossel, in her unpublished dissertation, surveyed the discipline of bacteriology as it gained it a foothold in municipal health departments, medical colleges, agricultural experiment stations, and federal agencies.⁴³ Her account ends in 1900, just after the founding of the Society of American Bacteriologists. My own thesis begins where Gossel's ends, describing the substantial developments of the discipline during the next quarter century. Where Gossel documents the introduction of bacteriology to various institutions, this thesis explores how bacteriologists tailored their science to fit changing institutional environments. Moreover, I argue that the rapid institutional growth of the 1880's and 1890's failed to produce a sense of disciplinary coherence. My focus differs in many regards from Gossel's. Gossel suggested that American bacteriologists developed standard methods in the late 1890's to legitimize their science in the eyes of public health departments.⁴⁴ I maintain that American bacteriologists reexamined their methods and techniques to make sense of their own enterprise. Gossel noted that the SAB took form in 1899 to advance bacteriology as a biological science. This thesis explores the sundry attempts during the next quarter century to achieve that elusive aim.⁴⁵ Whereas Gossel's narrative ends on a note of disciplinary confidence, the following chapters are a narrative of collective anxiety, an account of bacteriologists struggling to fashion a sense of collective self.

A few historians have documented the tension between pure and applied research in

⁴³ Patricia P. Gossel, "The Emergence of American Bacteriology, 1875-1900," (PhD diss., Johns Hopkins University, 1988).

⁴⁴ Patricia Peck Gossel, "A Need for Standard Methods: The Case of American Bacteriology," in The Right Tools for the Job, pp. 287-311.

⁴⁵ Bacteriologists themselves have documented these efforts at individual institutions. See, for example, Walter L. Mallmann, Recollections of Early Microbiology at Michigan State University (East Lansing: Department of Microbiology and Public Health, Michigan State University, 1974); and, L.S. McClung, and K.F. Meyer, "Beginnings of Bacteriology in California," Bacteriological Reviews 38 (1974): 251-271.

bacteriology. Olga Amsterdamska and Robert Kohler have each noted that medicine and pathology constrained the conceptual scope of bacteriology, discouraging researchers from probing microbial physiology and variation.⁴⁶ The institutional demands of rapidly performed diagnostic examinations forced bacteriologists to bracket most considerations not immediately relevant to the performance of routine cultures. While I agree with Amsterdamska's and Kohler's assessment of medical bacteriology, Chapter Three demonstrates that dairy and soil bacteriologists escaped those conceptual constrictions. In their pursuit of the productive microbe, these non-medical practitioners attended carefully to the vicissitudes of bacterial physiology. In fact, Robert Bud and Keith Vernon have suggested that industrial and agricultural bacteriologists differed greatly from their medical counterparts.⁴⁷ This thesis details how great that difference became, arguing that bacteriology endured a widening gulf between medical and agricultural researchers.⁴⁸

In the ensuing chapters, I refer to divergent "visions" in bacteriology. This is not to

⁴⁶ Olga Amsterdamska, "Medical and Biological Constraints: Early Research on Variation in Bacteriology," Social Studies of Science 17 (1987): 657-687; Amsterdamska, "Stabilizing Instability: The Controversy Over Cyclogenetic Theories of Bacterial Variation During the Interwar Period," Journal of the History of Biology 24 (1991): 191-222; Robert E. Kohler, "Innovation in Normal Science: Bacterial Physiology," Isis 76 (1985): 162-181; and, Kohler, "Bacterial Physiology: The Medical Context," Bulletin of the History of Medicine and Allied Sciences 59 (1985): 54-74. See also, Neil Morgan, "Pure Science and Applied Medicine: The Relationship Between Bacteriology and Biochemistry in England After 1880," Society for the Social History of Medicine Bulletin 37 (1985): 46-49.

⁴⁷ Robert Bud, The Uses of Life: A History of Biotechnology (Cambridge: Cambridge University Press, 1993); Keith Vernon, "Microbes at Work: Microorganisms, the D.S.I.R. and Industry in Britain, 1900-1936," Annals of Science 51 (November 1994): 593-613. John Andrew Mendelsohn pointed to a similar divide in late nineteenth-century French and German bacteriology. Mendelsohn, "Cultures of Bacteriology: Formation and Transformation of a Science in France and Germany, 1870-1914," (PhD. diss., Princeton University, 1996).

⁴⁸ For other historical treatments of disciplinary fragmentation and disunity, see, Rachel A. Volberg, "Constraints and Commitments in the Development of American Botany, 1880-1020," (Ph.D., University of California, San Francisco, 1983); William Bechtel, ed., Integrating Scientific Disciplines (Dordrecht: Nijhoff, 1986); Ian Hacking, "The Disunified Sciences," in The End of Science?, ed. Richard Q. Elvee (Lanham, MD: University Press of America, 1991); and, Ilana Lowy, "On Hybridizations, Networks and New Disciplines: The Pasteur Institute and the Development of Microbiology in France," Studies in History and Philosophy of Science 25 (Oct. 1994): 655-688.

suggest that medical practitioners embracing the “hygienic vision” of microbial exclusion shared nothing in common with soil bacteriologists intent on maximizing bacterial efficiency. Rather, I maintain that these communities exhibited a dissimilar set of dispositions and tendencies, what Pierre Bourdieu has deemed as “habitus.”⁴⁹ Medical, public health, sanitary and veterinary bacteriologists sought to isolate, identify, and eliminate infectious germs. Most bacteriologists operating within the “hygienic vision” demonstrated little propensity or inclination to investigate organisms or phenomena not immediately relevant to the conception of microbes as agents of infectious disease. Dairy and soil bacteriologists, in contrast, shared a “feel” for the productive aspects of living organisms. Within the context of scientific agriculture, these researchers expected laboratory investigations to assist in the control and exploitation of this natural resource.⁵⁰ The divide among various fields of bacteriology was less a product of differing estimations of the relative merit of pure or applied research than it was a consequence of separate trajectories. The actions of the Society of American Bacteriologists, in turn, constituted an effort to manage a discipline that appeared strangely undisciplined, a gesture to accommodate a community of practitioners with little in common. Bacteriology’s self-conscious disciplinary anxiety might not be singularly unique. Other disciplines certainly experienced periods of

⁴⁹ Pierre Bourdieu, “The Social Space and the Genesis of Groups,” Social Science Information 24 (1985): 195-220; Bourdieu, “The Genesis of the Concepts of ‘Habitus’ and ‘Field’,” Sociocriticism 2 (1985): 11-24; Bourdieu, “The Social Space and the Genesis of Groups,” Social Science Information 24 (1985): 195-220; Bourdieu, “From Rules to Strategies,” Cultural Anthropology 1 (1986): 110-120; Bourdieu, “The Peculiar History of Scientific Reason,” Sociological Forum 6 (March 1991): 3-26.

⁵⁰ For discussions of analogous “styles” or “trajectories” in scientific practice, see, Jane Maienschein, “Whitman at Chicago: Establishing a Chicago Style of Biology?,” in The American Development of Biology (Philadelphia: University of Pennsylvania Press, 1988); Jonathan Harwood, Styles of Scientific Thought: The German Genetics Community, 1900-1933, in Science and Its Conceptual Foundation Series (Chicago: University of Chicago Press, 1993); Paolo Palladino, “Between Craft and Science: Plant Breeding, Mendelian Genetics, and British Universities, 1900-1920,” Technology and Culture 34 (1993): 300-323; and, Lily E. Kay, Who Wrote the Book of Life? A History of the Genetic Code (Stanford: Stanford University Press, 2000).

disquiet. What renders American bacteriology so historically illuminating is its continued discussions of the sources for that anxiety, its proclivity to debate laboratory methods, and its understanding of the relationship between taxonomic and conceptual development.

CHAPTER ONE

“KILL THE GERM”: MEDICAL, PUBLIC HEALTH, AND SANITARY BACTERIOLOGY

Bacteriology is a child of many adoptions, ever precocious but not yet fully mature. Born with a definite mission to serve and to save, it has recreated pathology, given inspiration and new life to botany and zoology, contributed generously of its substance to agriculture and home economics, and lent itself as the framework around which modern hygiene and preventative medicine have been built. Yet all the while it has conducted itself in competent hands as a pure science.

Leo F. Rettger¹

Leo Rettger delivered this portrayal of the adolescent science before the 19th annual meeting of the Society of American Bacteriologists, held at Washington D.C. in December of 1917. The presidential address simultaneously disclosed a celebration of the diversity of service roles for bacteriology as well as an anxious desire that the field be designated as a “pure science.” While the introductory remarks of his oration asserted that the exalted status had already been bestowed, the remainder of Rettger’s address belied this initial confidence. There were indeed many reasons to concede that “bacteriology was still in its infancy.” In the late 1910’s, bacteriology remained a disorganized, disunified, but remarkably successful endeavor,

¹ Leo F. Rettger, “The Science of Bacteriology and Its Relations to Other Sciences,” Journal of Bacteriology 3 (1918): 103.

practiced by a disconnected collection of trained laboratory specialists residing in disparate institutional settings.²

There are number of features often define a 20th century science. One might find some of the following: 1) a central problem, 2) a domain of recognized “facts” relating to the central problem, 3) general explanatory factors and goals that shape expectations as to how the problem is to be solved, 4) shared techniques and methods, 5) a central set of concepts, laws and theories that facilitate research and understanding of the problem, and 6) a special vocabulary.³ These interrelated and overlapping elements are usually reproduced and modified through specialized journals and societies, university departments, commercial laboratories, governmental agencies, research technologies and instruments, textbooks, and public statements. This list should not be used to demarcate “legitimate,” or established sciences, but it can help recognize those social worlds in which bacteriologists worked. Moreover, the above elements help characterize an awkward stage in the growth of American bacteriology, during which time the adolescent science experienced remarkable growth and precious little coordination.

At a cursory glance, bacteriology between 1900 and 1919 exhibited by many of the above characteristics. Its central problem was to determine the relationship between the microscopic and macroscopic worlds. The domain of recognized facts, while far from formalized, included: the ubiquity of microbial life, their necessity for human survival, their disproportionate potential

² Rettger, “The Science of Bacteriology,” 113.

³ Lindley Darden and Nancy Maull, “Interfield Theories,” *Philosophy of Science* 44 (1977): 43-48; Maull, “Unifying Science without Reduction,” *Studies in the History and Philosophy of Science* 8 (1977): 147-149; Dudley Shapere, “Scientific Theories and Their Domains,” in *The Structure of Scientific Theories*, ed. F. Suppe (Urbana: Univ. Illinois Press, 1974), 518-565; and Stephen Toulmin, *Human Understanding*, vol. 1 (Princeton: Princeton University Press, 1972), chaps. 2 & 3.

for harm or beneficence, and their suitability to laboratory manipulations.⁴ The general explanatory factors enabled a principal program of isolating, identifying, and manipulating bacteria, with an eye toward controlling those microbes most immediately relevant to various "service roles." The goal of bacteriology embodied a broader engineering ideal in biology, a conviction that laboratory explorations of nature could transform the natural world for human betterment.⁵ Pure culture methods comprised the set of shared techniques, providing workers with descriptions of morphology, colony characteristics, nutritive requirements, fermentation products, and pathogenicity.⁶ In the estimation of William T. Sedgwick of the Massachusetts Institute of Technology, the distinguishing marks of bacteriology remained "not so much the peculiar organisms with which it deals -- interesting and important as these are -- as the peculiar means it has devised and employed for studying these organisms."⁷

Nonetheless, unlike more seasoned biological fields (*e.g.*, botany, zoology, embryology), bacteriology lacked a set of unifying theories, laws, or fundamental concepts, save the assumption that nature could be reproduced in the laboratory. Bacteriologists, as a whole,

⁴ The domain of subjects was poorly defined, as bacteriologists often studied organisms other than bacteria. For example, Charles Bolduan and Marie Grund's textbook mentions, without irony, that: "The study of germs is called bacteriology, this usually includes not merely bacteria, but also protozoa and fungi." Applied Bacteriology for Nurses (Philadelphia: W.B. Saunders Co., 1913), 13.

⁵ Philip J. Pauly, Controlling Life: Jacques Loeb and the Engineering Ideal in Biology (New York: Oxford University Press, 1987); and Garland Allen, Life Sciences in the Twentieth Century (London: Cambridge University Press, 1978).

⁶ For Rettger, the specialized methods of bacteriology constituted its defining features. While bacteriologists worked within institutional contexts of other pursuits (*e.g.*, pathology, fermentation industries), "its technique and methods of experimentation and control are its own." Rettger, "The Science of Bacteriology," 105. See, Frank F. Westbrook, "Laboratory Methods and Devices," Journal of Infectious Diseases supp. 1 (1905): 304-324; and Stephen M. de Gage, "Apparatus and Expedients in the Bacteriological Laboratory." Technology Quarterly 21 (December 1908): 508-21.

⁷ William T. Sedgwick, "The Origin, Scope and Significance of Bacteriology," Science 13 (1901): 126. This claim is a central thesis of Patricia P. Gossel's "The Emergence of American Bacteriology, 1875-1900" (Ph.D. diss., Johns Hopkins University, 1988).

attended more to what bacteria did than what they were in any biological sense. This is not to suggest a complete absence of fundamental or theoretical interests. The following pages illustrate, in part, the ways in which fundamental concerns emerged from applied pursuits. There were, however, few shared theoretical assumptions or concerns underlying the field.⁸

Bacteriology, for many of its practitioners, reduced to a collection of techniques appertaining to other scientific undertakings. As Charles E. Marshall explained in a textbook that he intended to "biologize" his discipline: "... from the organization of microbiology by Pasteur, the technic, the subject together with, in large part as well, its economic bearing, seems to be the applied determining factor in bounding the field."⁹ As a consequence (and as later chapters will demonstrate) this theoretical impoverishment hindered the establishment of a sense of disciplinary unity or coherence.

By the second decade of this century, the diverse service roles of bacteriology -- in pathology, public health, sanitary science, veterinary medicine, agriculture, dairying, canning and fermentation industries -- circumscribed its conceptual development. Rettger was not alone in acknowledging that the field had "been the victim of gross paternalism by those sciences which it has come to redeem." If bacteriology was to "emerge from its servile state," bacteriologists had

⁸ Rettger, who was trained at Indiana and Yale in physiological chemistry, advocated reducing bacteriology to biochemistry. George Valley, "Leo Frederick Rettger, 1874-1954," Journal of Bacteriology 69 (1955): 1-3.

⁹ Marshall, ed., Microbiology: A Textbook of Microorganisms, General and Applied, 3rd ed. (Philadelphia: P. Blakiston's Son & Co., 1921), 12. Barnett Cohen, the late archivist for the SAB, recalled that at the turn of the century, "there were few, if any, adequate centers in which the science was cultivated for its own sake. Let it be remembered that bacteriology had been developing as an applied science, without much of a prior store of purely scientific knowledge . . . since the methods of the young science were rather primitive and not especially difficult, and an apt student could master them sufficiently in a short time and turn to one of the many problems awaiting investigation." Cohen, "Comments on the Relation of Dr. Welch to the Rise of Microbiology in America," Bulletin of the History of Medicine 24 (July-August 1950): 323.

to “be able to do more than pour gelatin and agar plates and to count colonies.”¹⁰ Yet, these service roles, served by such mundane enumerations, fueled the discipline’s growth in America. Rettger himself taught pathology to students of Yale’s medical school and functioned as bacteriologist to the Storrs Agricultural Experiment Station. He directed his research principally to the economically ruinous diseases of cattle (*e.g.*, contagious abortion) and poultry (*e.g.*, pullorum, blackhead and keel). At some level, Rettger’s plea for pure science belied his own professional experience.

The initial chapters of this thesis profile bacteriology’s myriad service roles in order to advance two interrelated claims. First, that the field of bacteriology experienced a period of rapid growth during the first decades of this century. The tools of this young laboratory science were ensconced within the institutional contexts of pathology, public health, sanitation engineering, veterinary medicine, dairying, soil science, and fermentation industries. Bacteriologists could rightfully claim that their expertise contributed immeasurably to each of these spheres.¹¹ More importantly for their professional advancement, bacteriologists routinized their microbial manipulations, enabling them to do “work” in a variety of contexts. While the cutting edge of bacteriological research followed uncertain lines of investigation, the vast majority of workers tread upon established, standardized, and well-supported paths. In each of its applied spheres, a steadfast adherence to service roles fostered the field’s increasing support.¹²

¹⁰ Rettger, “The Science of Bacteriology,” 103-104.

¹¹ In an address before the 1904 Universal Exposition at St. Louis, Edwin O. Jordan proclaimed that, within bacteriology, “discovery has trod upon the heels of discovery in bewildering succession . . . At present, the science touches nearly many human interests, and sustains manifold and far-reaching relations to the whole body of natural knowledge.” Jordan, “The Sphere of Bacteriology,” *American Medicine* 8 (1904): 875.

¹² See, Frederick G. Novy, “Practical Benefits of Bacteriology,” *Report of the Michigan Academy of Sciences* 1 (1894): 14-8.

Secondly, the proliferation of applied bacteriology was paralleled by a disciplinary and conceptual disunity. At a mundane level, the varied institutional contexts of bacteriology promoted an abiding disunity. Young practitioners received their advanced training outside of formal classes. They published in narrowly focused journals (*e.g.*, *Soil Science*, *Journal of Dairy Science*, *Journal of Infectious Diseases*) and joined singular societies. While the most rudimentary methods of isolating, identifying, and manipulating bacteria were widely shared, few textbooks or manuals provided adequate instruction in all areas of bacteriology.¹³ Moreover, the movement of investigators among the medical, sanitary and agricultural spheres decreased during the twentieth century. The research careers of leading bacteriologists Herbert W. Conn, Edwin O. Jordan, Mayzick P. Ravenel, David H. Bergey, Theobald Smith, and H. Meade Bolton each traverse multiple applied fields. But, these individuals represented a generation from the previous century. Their students were less likely, or less able, to move about the expanse of bacteriology.¹⁴

Institutional factors aside, the routines of microbial manipulations reproduced this disunity of service roles. At the core, bacteriologists cultivated bacteria in pure cultures. In some respects, bacteriology resembled “breeding, gardening, or agriculture.” Sedgwick frequently likened his science to a “kind of microscopic horticulture or apiculture (bee-keeping).”

¹³ Of the dozens of textbooks and manuals published before 1919, very few declared an intention to be truly “general.” See, Frederick G. Novy, Directions for Laboratory Work in Bacteriology (Ann Arbor: George Wahr, 1894); William D. Frost, A Laboratory Guide in Elementary Bacteriology (Madison, WI: Tracy, Gibbs & Co., 1901); Frost and Eugene F. McCampbell, A Text-book of General Bacteriology (New York: Macmillan Co., 1910); and Ward Giltner, Laboratory Manual in General Bacteriology (New York: John Wiley & Sons, 1916).

¹⁴ Paul F. Clark viewed the movement between sub-fields as pre-disciplinary characteristic: “It was a major crusade with men joining in the march from widely different fields. There were no bacteriologists, so physicians, zoologists, botanists, physicists, engineers, and old fashioned naturalists enthusiastically took over the new tools and the new thinking. The promise of hope was not remission of sins, but better crops, better living, and freedom from the great plagues.” Clark, Pioneer Microbiologists in America (Madison: University of Wisconsin Press, 1961), 7.

Bacteriologists grew bacteria.¹⁵ This formula, while magnificently successful in daily practice, discouraged the exploration of traditionally biological problems. Bacteriologists could find little interest in the conceptual infrastructures of other life sciences. Only rarely, and when practical considerations demanded, did bacteriologists concern themselves with issues of variation, response to environmental stimuli, cytology, antagonistic or symbiotic relationships, and systematics.¹⁶ They worked on the margins of twentieth century biochemistry (*i.e.*, a catholic interest in enzymes), and were distanced far from the cutting edge of genetics.

The program of isolation, identification, and manipulation constituted the core of instruction in bacteriology. The 1904 course catalogue's description of the University of Tennessee's "General Bacteriology," offered within the Department of Botany, explained:

Form, structure, reproduction, requirements for growth and chemical products of bacteria are studied. Special attention is given to the preparation of culture media, separation and making of pure cultures, sterilization and disinfection. The knowledge obtained in the course prepares the student for the practical application of its methods in the study of agriculture, dairying, household economics, sanitation, and medicine.¹⁷

The textbooks and manuals accompanying these courses resembled cookbooks, listing recipe after recipe under the assumption that bacteriology comprised a collection of culture and staining techniques. The inventories could be comprehensive, with fifteen methods for culturing anaerobes, multiple formulae for preparing each media, and hundreds of procedures for differential stains. There is little doubt that bacteriological technique was difficult to master. Yet, the courses endeavored to display the panoply of microbial manipulations, not a conceptual

¹⁵ Sedgwick, "The Origin, Scope and Significance of Bacteriology," 127.

¹⁶ See, Thomas D. Brock, "The Bacterial Nucleus: A History," Microbiological Reviews 52 (1988): 397-411.

¹⁷ D. Frank Holtman, "A History of Microbiology at the University of Tennessee," ca. 1969, American Society for Microbiology Archives [ASM], Regional History Collections, Folder 29-A, p. 3.

unity. One former University of Wisconsin student portrayed the pith of his own preparation at the turn of the century: "The thing we acquired, which was of permanent value, was an appreciation of the many points at which germ life touch our ordinary activities and a burning desire to add to the scanty stock of information in this field."¹⁸

Despite the remarkable professional growth of bacteriology during the first decades of the 20th century, the conceptual disunity supplied a fountainhead of lingering anxiety. More than a few commentators weighed the field as a "biological" endeavor, alternating between assertions that bacteriology constituted more than cookbook formulae, and impassioned pleas for further studies in "pure" areas. T. Mitchell Prudden, who, along with William H. Welch, was chiefly responsible for introducing bacteriology to American medical schools, warned that a bacteriologist or pathologist must "must think in cells." Medicine was, "after all, only one phase of the great science of life which we call biology" whose "varied themes must be pursued by the same methods" as other fundamental sciences. Yet, in Prudden's own department at Columbia's College of Physicians and Surgeons, students were rarely given the opportunity to study bacteria outside of their role as agents of disease.¹⁹

Other observers denied the inherent contradiction between service and basic research, believing that bacteriology should be judged on its own terms. Charles-Edward Amory

¹⁸ H.A. Harding, "Early Bacteriology at the University of Wisconsin," 1938, [ASM] box 7-IIA, folder 10.16, p. 17.

¹⁹ T. Mitchell Prudden, "New Outlooks in the Science and Art of Medicine," Popular Science Monthly 48 (1896): 362-363. Similarly, Jordan noted that bacteriology had "contributed relatively little to the enrichment of the parent science (of biology). Morphologically, the bacterial cell is so small and so simple as to offer many problems of surpassing interest but of great difficulty." Bacteriology had much to offer to the study of physiology and biochemistry, although the achievements in this area have been "far from commensurate with its potentiality. This may be partly because of its temporary engrossment in other seductive lines of research, partly because of the lack of workers adequately trained in bacteriologic methods and at the same time possessed of an appreciation of purely biologic data." Jordan, "The Sphere of Bacteriology," 877.

Winslow, an active investigator in many fields (e.g., water sanitation, public health, natural history), remonstrated: "microbiology is not a technical tool for the doctor, the agriculturalist or the engineer. It is a basic biological science and it may well be claimed it has rendered greater service to mankind than any other science of this class." For Winslow, "this service has been made possible because it is a basic science."²⁰ Winslow shared Rettger's opinion that practical or applied bacteriology "need not be any less scientific."²¹

In each of the following spheres of applied bacteriology, we shall see the same coincident growth and disunity, the concurrent optimism and uncertainty, and coextensive praise and denunciation of the laboratory "routine." The disciplinary program of isolate, identify and manipulate, was not, however, monolithic across all pursuits. The organisms isolated, the conditions of identification, and the goals of manipulation varied from applied context to applied context. This chapter examines the remarkable professional growth and coincident conceptual limitation of pathogenic bacteriology. Within medicine, public health, and sanitary science, bacteriology comprised a set of technical manipulations, geared toward isolating suspected pathogens from individuals, populations, and environments. These manipulations were enacted with the goal of exclusion, collectively articulating a "hygienic" vision, that sought to eliminate germs, not probe the biological, biochemical, or ecological dimensions of microbial populations.

²⁰ Quoted in Ira V. Hiscock, "Charles-Edward Amory Winslow," *Journal of Bacteriology* 73 (1957): 295-296. See also, Frederick P. Gay, "The Contribution of Medical Science to Medical Art as Shown in the Study of Typhoid Fever," *Science* 44 (1916): 110.

²¹ Rettger, "The Science of Bacteriology," 105. The conflation of service and science explains how Sedgwick could maintain that "bacteriology must henceforward be recognized as a broad and fundamental branch of science, coordinate with, rather than subordinate to, the other grand divisions of biology such as medicine, agriculture, zoology and botany," yet admit in the same page that "the time has forever gone by when bacteriology can be regarded merely, or even chiefly, as the handmaid of medicine or pathology. It is no less the servant of agriculture, of industry, of sanitation and of household life." Sedgwick, "Forward: The Genesis of a New Science," *Journal of Bacteriology* 1 (1916): 4.

Bacteriology in service to the “hygienic” vision was inherently restricted. While medical, public health, and sanitary bacteriology never fully routinized the “routine” manipulations, research within these contexts was sporadic, restricted, and ultimately unable to found a fundamental science of bacteria. By comparing the practice of bacteriology in each of these realms, we can also examine the institutional, conceptual, and technical determinants of the science’s simultaneous growth and limitation.

Pathology, and the “Golden Age” of Bacteriology

We are left in the hands of the generations which, having heard of microbes much as St. Thomas Aquinas heard of angels, suddenly concluded that the whole art of healing could be summed up in the formula: Find the microbe and kill it. -- Bernard Shaw²²

During the first decades of the twentieth century, American bacteriologists labored under the thralling legacy of a “golden age,” that “heroic period” of the 1880's and 1890's when the etiological agents of “some two score diseases” were revealed in the laboratories of Robert Koch and Louis Pasteur.²³ Among many medical bacteriologists, they felt both nostalgia and a sense of loss. America arrived late to the revolution in pathology. The microbial malefactors of anthrax, tuberculosis, cholera, diphtheria, typhoid, and septicemia were sequestered to the pages of French and German journals. At the turn of the century, domestic bacteriologists could point

²² “Preface on Doctors,” in Doctor’s Dilemma, quoted in Illana Lowy, “Immunology and Literature in the Early Twentieth Century: Arrowsmith and The Doctor’s Dilemma,” Medical History 32 (1988): 319.

²³ Frederick G. Novy, “Some Results of Microscopical Research Which Have Been Significant for Human Welfare,” Science 84 (1936): 125-6; “Fifty Years of Applied Bacteriology,” American Journal of Public Health 11 (1931): 176; Philip P. Mortimer, “The Bacteria Craze of the 1880s,” Lancet 353 (1999): 581-584; and, Claire Salomon-Bayet, “Bacteriology and Nobel Prize Selections, 1901-1920,” in Science, Technology and Society in the Time of Alfred Nobel, edited by C.G. Berenhard, E. Crawford, and P. Sorbom (Oxford: Pergamon, 1982), 377-400.

to few comparable achievements.²⁴ Instead, they studied in foreign laboratories, translated foreign textbooks, and patterned their curricula on models from abroad.²⁵ The importation of European research programs in the 1880's and 1890's fashioned the conceptual and institutional traits of American medical bacteriology in the next century, where the model of isolation, identification, and manipulation was narrowly construed.

In large measure, T. Mitchell Prudden and William H. Welch introduced bacteriology to American medical schools. At the College of Physicians and Surgeons at Columbia University, and at Johns Hopkins University Medical School, the next generation of American-trained bacteriologists rehearsed the techniques of morbid anatomy and pathology; staining tissue, blood, urine, and sputa samples for suspected pathogens. Welch himself regarded bacteria predominately as agents of disease, and his students (both medical students and post-graduates) practiced bacteriological manipulations as part of routine autopsies. While the laboratories of Prudden and Welch assembled notable research findings in the 1880's and 1890's (*e.g.*, the discovery of the gas-gangrene bacillus), their prominent bequest was the promotion of bacteriology through pathology.²⁶ Their students, remarkable in number and influence, rooted

²⁴ W.D. Foster, History of Medical Bacteriology and Immunology (London: Heinemann, 1970); Paul B. Beeson, "Infectious Diseases (Microbiology)," in Advances in American Medicine: Essays at the Bicentennial, vol 1., eds. J.Z. Bowers, and E.F. Purcell (New York: Josiah Macy Jr. Foundation, 1976), 100-156; Esmond R. Long, A History of Pathology (New York: Dover Publications Inc., 1965); and Fielding H. Garrison, An Introduction to the History of Medicine, 4th ed (Philadelphia: W.B. Saunders Co., 1929).

²⁵ Phyllis A. Richmond, "American Attitudes toward the Germ Theory of Disease, 1860-1880," Journal of the History of Medicine 9 (1954): 428-454; Thomas Bonner, American Doctors and German Universities (Lincoln: University of Nebraska Press, 1963); and Charles F. Thwing, The American and the German University (New York: The Macmillan Company, 1928). For a list of translated textbooks used in early American bacteriology courses, see, L.S. McClung, "Early American Publications Relating to Bacteriology," Bacteriological Reviews 8 (1944): 119-160.

²⁶ Clark, Pioneer Microbiologists in America, 95; Simon Flexner and James T. Flexner, William Welch and the Heroic Age of American Medicine (New York: Viking Press, 1941); Alan M. Chesney, The Johns Hopkins Hospital and the Johns Hopkins University School of Medicine: A Chronicle, 3 vols. (Baltimore: Johns Hopkins Press, 1943); and Ludvig Hektoen, "Biographical Memoirs of Theophil Mitchell Prudden," Biographical Memoirs

bacteriology in the service of pathology at medical schools across the nation.²⁷

During the last decades of the nineteenth century, bacteriology comprised a small, but increasingly common, component of medical instruction. In 1888, Herbert W. Conn reported the results of his survey of twenty-eight prominent American medical schools, finding that 75% of the respondents held a favorable view of bacteriology, and a majority offered both instruction and “opportunities” for original research.²⁸ Nevertheless, aside from didactic lectures and demonstrations relating to diagnosis and etiology, these institutions provided but scant bacteriological training. At the University of Pennsylvania, for example, William Osler reported in 1888 that: “In the second and third years a good deal of time is spent by the students in the pathological laboratory. Bacteriology forms part of the regular course of instruction.” However, the University of Pennsylvania did not offer its first formal course, with limited laboratory instruction, until 1891. When the Hygienic Laboratory opened in 1895, medical students encountered more demanding tutelage, but consigned most of their hours to preparing culture media.²⁹

Pennsylvania was hardly unique. Prestigious institutions such as Chicago Medical

of the National Academy of Science 12 (1928): 73-97.

²⁷ Prudden and Welch’s students and associates found academic residence in: University of Pennsylvania (A.C. Abbott, Simon Flexner, Frederick P. Gay); Albany Medical College (George Blumer; Herbert D. Pease); University of Rochester (Stanhope Bayne-Jones); Harvard Medical School (William T. Councilman, F.P. Gay, Hans Zinsser); Western Reserve University (William T. Howard, Roger G. Perkins); Stanford Medical School (A.L. Bloomfield, Ernest C. Dickson; Wilfred H. Manwaring, Hans Zinsser); University of Missouri (David H. Dolley); University of California (F.P. Gay); Long Island Medical College (Ostwald T. Avery; George T. Kemp); University of Virginia (Harry T. Marshall); Washington University (Eugene L. Opie); Women’s Medical College (Adelaide W. Peckham); New York University & Bellevue Medical College (Herman M. Biggs, William H. Park); Cornell Medical College (James Ewing); and Cornell University (Veranus A. Moore).

²⁸ Herbert W. Conn, “Bacteriology in Our Medical Schools,” Science 11 (1888): 124; and Conn, “The Germ Theory as a Subject of Education,” Science 11 (1888): 5-6.

²⁹ Conn, “Bacteriology in Our Medical Schools,” 124; and Joseph McFarland, “The Beginning of Bacteriology in Philadelphia,” Bulletin of the History of Medicine 5 (1935): 149-172.

College equated thorough instruction with a six-credit lecture course, and the presence of a laboratory containing "all the apparatus necessary for making pure cultures of the more important varieties of bacteria." Among the second tier schools, a bacteriological laboratory conferred a sign of status and scientific prestige. St. Louis' Marion Sims College of Medicine announced a "complete accouterment of appliances and apparatuses" for the study and teaching of bacteriology in 1891, and even denoted a separate department in 1893. Beaumont Medical College, which introduced bacteriology to its students in 1888, boasted in 1898 that their laboratory was "equipped with the a full set of apparatus of the latest and most approved construction, including four large incubators."³⁰

Medical bacteriology was frequently taught in a post-graduate setting. At Bellevue Hospital and the College of Physicians and Surgeons, private doctors enrolled in special classes, often of modest duration. Similarly, between 1895 and 1901, Walter L. Bierring presented a one-month laboratory course for practitioners, and in 1899, Harvard announced a comparable six-week course for interns at Massachusetts General Hospital. These cursory surveys constituted critical forums for introducing bacteriology to physicians. The Long Island College Hospital, for example, enrolled more than 115 post-graduates between 1888 and 1904.³¹

In 1899, Harold C. Ernst reported that thirty American schools offered instruction in

³⁰ George H. Weaver, "The Introduction of Bacteriology into the Medical Curriculum in Chicago," Bulletin of the Society of Medical History of Chicago (1937): 1-2; Guy P. Youmans, "History of Bacteriology at Northwestern University," 1959, [ASM] box 2-IXC, folder 73; and Moyer S. Fleisher, "The History of Microbiology in the Eastern Missouri Branch," 1959 [ASM], Regional History, folder 20-A1, p. 4.

³¹ Walter L. Beirring, "The Story of Bacteriology at the University of Iowa," Journal of the Iowa State Medical Society 27 (1937): 656-658; Samuel C. Prescott, "The Development of Bacteriology in Boston," [ASM], box 2-IXC, folder 77; John H. Hanks, "Department of Bacteriology, Harvard Medical School, 1885-1952," 1952 [ASM], box 2-IXC, folder 77; and Arnold H. Eggerth, The History of the Hoagland Laboratory (Brooklyn: s.n., 1960).

bacteriology, with fifteen listing "Bacteriology" separately in their course catalogues, and twenty-three requiring an examination in bacteriology for a medical degree. Table 1.1 (in appendix), assembled from my own research in the American Society for Microbiology (ASM) archives, enumerates more than forty schools furnishing bacteriological training before the turn of the century. Ernst calculated that the average curricula stood at sixty lecture hours and one-hundred-and-twenty laboratory hours given over the period of one academic quarter.³² From this training, the typical medical matriculant was expected to be versed in the bacterial etiology of nearly a dozen diseases (*e.g.*, tuberculosis, typhoid, cholera, diphtheria, anthrax, etc.); be familiar with methods for staining suspected pathogens and growing them in pure culture form; and to understand the fundamentals of immune reactions and serum therapies. However, as Paul G. Heinemann recognized of his own pupils at the University of Chicago, students arrived at medical schools inadequately prepared for bacteriological instruction, as they "often have had too little previous training in methods of precision. . . . Many of the pieces of apparatus employed in a bacteriological laboratory are novel, even for the student trained in chemistry and biology."³³ A medical degree conferred an introduction to bacteriology, not an exhaustive understanding of the field.

A handful of medical schools exceeded Ernst's mean. At the University of Michigan, Victor C. Vaughan and Frederick G. Novy returned in 1889 from their own training in Berlin and Paris to introduce a two-semester lecture and laboratory course of 288 hours.³⁴ The University of

³² Harold C. Ernst, "Instruction in Bacteriology in the Medical Schools of America and Europe," Journal of the Boston Society of Medical Sciences 4 (1900): 67-71.

³³ Paul G. Heinemann, A Laboratory Guide in Bacteriology, for the Use of Students, Teachers and Practitioners, 1st ed. (Chicago: University of Chicago Press, 1905), v-vi.

³⁴ Malcom Soule, "Bacteriology at the University of Michigan," SAB Round-Table, 1946, [ASM], box 2-IXC, folder 53; "Department of Microbiology," University of Michigan Alumni Letter 8 (April 1966); Novy, "The

Michigan was, however, the exception that proved the rule. More commonly, training provided by such institutions as the Southern Branch of the California Medical School (later University of Southern California), Utah Medical College, Tufts Medical College, and the University of Dallas Medical Department (later Baylor Medical College), consisted of a short, two to three month course where students practiced "the preparation of culture media and how to isolate, study and make pure cultures of various forms of bacteria, especially those forms associated with diseases most frequently found in general practice."³⁵ The proliferation of schools teaching bacteriology continued throughout the first decades of this century, but with little change in the scope of instruction. (See table 1.2) Even Harvard Medical School confined its bacteriology requirement to a skeletal component of the pathology curriculum until 1906.³⁶

Moreover, bacteriology was customarily confined to other academic departments. At Hopkins, William H. Welch deemed it "better to place bacteriology with pathology or hygiene than to make of it a separate department."³⁷ Charles B. Morrey, of Ohio State University, struggled for nearly three years before he extracted bacteriology from the clutches of the physiology department. Other institutions, such as Columbia University and the University of

Hygienic Laboratory," Michigan Alumnus 6 (1900): 242-244; Novy, "Victor C. Vaughan: An Appreciation," Michigan Alumnus 36 (1929): 171-173; and, Ruth Good, "Frederick G. Novy: Biographic Sketch," University of Michigan Medical Bulletin 16 (1950): 257-68.

³⁵ O.B. Williams and W.B. Sharp, "The History of Bacteriology in Texas," 56th Annual Meeting of the SAB, 1956, [ASM], Regional History, 9B-15; Robert A. Green, "The History of Microbiology in the Southern California Branch," 66th Annual Meeting of the ASM, 1966, [ASM], box 11-IIAG, folder 5; Paul S. Nichols, "The History of the Intermountain Branch of the ASM," 1978, [ASM], Regional History, 30-A1; and, R. Wheeler, "Bacteriology at Tufts College Medical School," 1952, [ASM], box 2-IXC, folder 77.

³⁶ Hanks, "Department of Bacteriology, Harvard Medical School," op cit; The Boston Medical and Surgical Journal 187 (1922): 424-425; and, J.W. Farlow, "Harold Clarence Ernst," Boston Massachusetts Historical Society (1922). McFarland bitterly complained that the two primary textbooks in use between 1890 and 1910, by George Sternberg and A.C. Abbott, were never revised in light of new developments. Abbott, "Bacteriology in Philadelphia," 191-197.

³⁷ Cohen, "Relation of Dr. Welch to the Rise of Microbiology," 320; and Simon Flexner, "Biographical Sketch of Dr. William H. Welch," Science (5 Nov. 1920).

California, countenanced the tethering of bacteriology to pathology, creating independent departments for bacteriology only in 1909 and 1921 respectively.³⁸

By the turn of the century, bacteriology was firmly established within the curricula of many medical colleges. The occasions for original research were, however, uncommon. In 1906, the eminent New York pediatrician, L. Emmett Holt, remarked that American medical laboratories were, “for the instruction of students and possessed but little equipment beyond what was necessary for this end.”³⁹ Before 1900, only a smattering of institutions supported novel investigations in bacteriological topics, and even fewer conferred PhD’s in bacteriology. By 1910, that modest sum more than doubled, aided by the beneficence of philanthropic foundations. (Table 1.3) The Rockefeller Institute in New York, the John McCormick Institute in Chicago, and the Henry Phipps Institute in Philadelphia, employing many of the recent doctoral graduates, quickly established themselves as the vanguard of medical research.⁴⁰ Additionally, the Hygienic Laboratory of the U.S. Public Health Service expanded the scope of its activities to found a Division of Scientific Research in 1901, as well as several field laboratories to study specific transmissible diseases (*e.g.*, plague, leprosy, Rocky Mountain

³⁸ William A. Starin, “History of Bacteriology, The Ohio State University,” 1949, [ASM], box 2-IXC, folder 64; Charles B. Morrey, South Miami, to Barnett Cohen, Baltimore, 29 May 1937, [ASM], box 7-IIA, folder 10.13; Frederick P. Gay, “A Method of Correlated Teaching of Pathology and Bacteriology in the Second Year of Medical Instruction,” Johns Hopkins Hospital Bulletin 23 (1912): 170-3; Gay, Karl F. Meyer, and Glanville Y. Rusk, Outline of Combined Courses in Pathology, Including Bacteriology and Protozoology, etc. (Berkeley: Univ. of Calif. Press, 1915); T. Mitchell Prudden, “Pathology and the Department of Pathology,” Columbia University Bulletin 19 (1898): 103. Alphones R. Dochez surmised that: “Up to this time, 1910, bacteriology had not yet achieved administrative and teaching independence as a scientific discipline. . .” Dochez, “Frederick Parker Gay, 1874-1939,” National Academy of Sciences (U.S.) Biographical Memoirs 28 (1954): 101.

³⁹ Quoted in George Rosen, “Patterns of Health Research in the United States, 1900-1960,” Bulletin of the History of Medicine 39 (1965): 201.

⁴⁰ George W. Corner, A History of the Rockefeller Institute, 1901-1953: Origins and Growth (New York: Rockefeller Institute Press, 1965); Ludvig Hekteon, The John McCormick Institute for Infectious Diseases: Brief History and Description (Chicago: n.p., 1915); E. Leifson, “History of Bacteriology in Chicago,” 1951, [ASM], box 2-IXC, folder 73; and, McFarland, “Bacteriology in Philadelphia,” 180-190.

Spotted Fever).⁴¹ Even so, most medical schools abnegated the stead of science for the priority of instruction.⁴²

Research, practice, and instruction in medical bacteriology militated against a broad understanding in microbiology in three ways. First, medical bacteriologists were concerned with a finite number of organisms. Frederick D. Chester, at the University of Delaware, catalogued some 800 species of bacteria in his 1901 determinative manual. Pathogenic forms, however, comprised a small portion of the then known microbial population, and only a fraction of that group was deemed immediately relevant to medicine.⁴³ Among the textbooks and courses, the short list of putative pathogens included the bacteria for tuberculosis, typhoid fever, diphtheria, dysentery, cholera, pneumonia, streptococcal and staphylococcal (pyogenic) infections, meningitis, gonorrhea, plague and malignant edema.⁴⁴ For university faculty and institutions

⁴¹ A.M. Stimson, "The Hygienic Laboratory of the U.S. Public Health Service," International Clinics 4 (1925): 199-208; J.W. Kerr, "Scientific Research by the Public Health Service," Annals of the American Academy of Policy and Social Science 37 (1911): 27-41; Victoria A. Harden, Inventing the NIH: Federal Biomedical Research Policy, 1887-1937 (Baltimore: Johns Hopkins University Press, 1986); and, Harden, Rocky Mountain Spotted Fever: A History of a Twentieth-Century Disease (Baltimore: Johns Hopkins University Press, 1990). While the activities of the Hygienic Laboratories were broad, they were macerated by insufficient funds and personnel.

⁴² Exceptions to this claim would include the Hoagland Laboratory of the Long Island Medical College and the Hygienic Laboratory at University of Pennsylvania. However, the balance between instruction and investigation in these institutions was pertinaciously unstable. See, Eggerth, The History of the Hoagland Laboratory, 126; A. McGehee Harvey, "John Billings: Forgotten Hero of American Medicine," Perspectives on Biology and Medicine 21 (1978): 353-7; and, Theobald Smith, "Medical Research: Its Place in the University Medical School," Popular Science Monthly 66 (1905): 515-30.

⁴³ Frederick D. Chester, A Manual of Determinative Bacteriology, reprint ed. (New York: MacMillan & Co., 1909). Chester himself considered his tally an underestimation. Walter E. King estimated that more than 1,400 bacterial forms had been identified and described by 1909. See, Synopsis of Lectures for Bacteriology I: For Students in the General Fundamental Course (Manhattan, KS: Kansas State Agricultural College, 1909), 10-13.

⁴⁴ The list remained constant in most textbooks. See, William Carter, ed., Notes on the Lectures of Prof. John Guiteras on General and Special Pathology (Philadelphia: Avil Printing Co., 1895); John McFarland, A Text-book Upon the Pathogenic Bacteria, for Students of Medicine and Physicians, 1st ed. (Philadelphia: W.B. Saunders Company, 1896); William H. Park and Arthur Guerard, Bacteriology in Medicine and Surgery: A Practical Manual for Physicians, Health Officers, and Students (New York: Lea Brothers & Co., 1899); Edwin O. Jordan, A Text-book of General Bacteriology, 1st ed. (Philadelphia: W.B. Saunders Co., 1908); and, William T. Councilman, Disease and its Causes (New York: H. Holt & Co., 1913).

afforded the indulgence of original research, they divided their efforts between the study of known pathogens and those afflictions whose etiological agents remained unidentified (*e.g.*, smallpox, scarlet fever, measles, poliomyelitis, whooping cough, mumps, typhus, Rocky Mountain spotted fever, and yellow fever).⁴⁵ Nonetheless, the register of microbial subjects never exceeded two score.

Second, medical bacteriologists were less attentive to pathogens themselves than to the immune responses they provoked. During the first decade of the twentieth century, many researchers shifted their focus away from the search for etiological agents to the elucidation of the principle mechanisms of immunity.⁴⁶ In departments at Stanford, Columbia, Berkeley and Chicago, leading bacteriologists (*e.g.*, Hans Zinsser, Philip His, Karl Meyer, Ludvig Hektoen, and H. Gideon Wells) probed the specificity of opsonins, the mechanism of phagocytosis, the distribution of antibodies, the nature of complement fixation reactions, and the phenomena of anaphylaxis. Within these studies, haptens and protein fractions constituted the primary objects of scrutiny, supplanting the spotlight previously reserved for bacterial pathogens.⁴⁷

⁴⁵ See, William T. Councilman, "Recent Progress in Pathology and Bacteriology," Boston Medical & Surgical Journal 128 (1893): 188-192; E.O. Shakespeare, Walter Reed and Victor C. Vaughan, Abstract of Report on the Origin and Spread of Typhoid Fever in U.S. Military Camps during the Spanish War of 1898 (Washington: GPO, 1900); J.K. Olistsky, "Hans Zinsser and His Studies on Typhus Fever," JAMA 116 (1941): 907-912; and, John F. Anderson, "The Differentiation of Outbreaks of Typhoid Fever Due to Water, Milk, Flies, and Contact," American Journal of Public Hygiene 19 (1909): 251-259.

⁴⁶ See, George Rosen, "The Bacteriological, Immunologic, and Chemiotherapeutic [sic] Period, 1875-1950," Bulletin of the New York Academy of Medicine 90 (1964): 491; and, Simon Flexner, "A Half Century of American Medicine," Science 85 (1937): 509.

⁴⁷ Frederick P. Gay, "A Half Century of Bacteriology at Columbia," Columbia University Quarterly (1939): 124-129, 203-217; Harry M. Rose, "Microbiology at Columbia University," Microbiology in New York City, ed. Merrill W. Chase (Wash. D.C.: ASM, 1975); A.W. Meyer, "Hans Zinsser," Stanford Medical Alumni Bulletin 6 (1942): 7; S.B. Wolbach, "Hans Zinsser, 1878-1940," Biographical Memoirs, National Academy of Sciences 24 (1947): 323-360; J.H. Mueller, "Hans Zinsser, 1878-1940," Journal of Bacteriology 40 (1940): 747-753; James P. Simonds, "Ludvig Hektoen: A Study in Changing Scientific Interests," Proceedings of the Institute of Medicine, Chicago 14 (1942): 284-287; Paul R. Cannon, "Ludvig Hektown, Pathologist," Archives of Pathology 52 (1951): 390-394; and, E.R. Long, "Harry Gideon Wells, 1875-1942," Biographical Memoirs, National Academy of Sciences 26 (1950): 233-263.

In the pursuit of novel serum therapies and chemotherapeutic agents, bacteria did remain central research components. For example, E.L. Trudeau's evaluation of antitoxic immunizations and Paul A. Lewis's exploration of arsenic compounds revealed much about the chemical and cellular composition of the tubercle bacilli.⁴⁸ Still, by the late 1910's, the emerging field of immunology -- with its emphasis on host responses to parasitic invasion -- began to resemble physical or biological chemistry more than bacteriology.⁴⁹ Bacteria were viewed less as organisms than as carriers of chemical constituents responsible for specific immune responses.

Thirdly, and most importantly, the principal program of medical bacteriology (*i.e.*, the isolation, identification, and elimination of microbial pathogens) forestalled the field's development as a fundamental biological science. On an institutional level, microbiology found sustenance in its service to medicine; proffering reliable diagnostic techniques, rather than the promise of original research. For medical bacteriologists, the hospital setting furnished professional rewards and institutional support. However, as Robert Kohler and Olga Amsterdamska have suggested, the medical context was an equivalent source of limitation. Medical bacteriologists consigned a large measure of their time to the tedious preparation of mundane stains and cultures. At Columbia University's Department of Bacteriology, for example, most bacteriologists also worked as residents or pathologists for St. Luke's Hospital

⁴⁸ Long, "American Association of Pathologists and Bacteriologists,"; Edward L. Trudeau, "Recent Work on the Chemistry of the Tubercle Bacillus," Trans. Assoc. Am. Physicians (1901); and Trudeau, "Antibacterial or Antitoxic Immunization in Tuberculin Treatment," J.A.M.A. (23 Jan. 1909): 261-263.

⁴⁹ William W. Ford, Bacteriology, Clio Medica Series (New York: Paul B. Hoeber Inc., 1939), 145. The Rockefeller Institute for Medical Research was partly responsible for the increasing reduction of medical bacteriology to methods of immunochemistry in the 1910's. See, Corner, History of the Rockefeller Institute, 108-187; Lowy, "Immunology and Literature," 323-327; anon., "Chemistry in the Field of Microbiology," Science 60 supp. 10 (1925); and, Olga Amsterdamska, "Between Medicine and Science: The Research Career of Oswald T. Avery," in Medicine and Change: Historical and Sociological Studies of Medical Innovation, ed. Illana Lowy (London: John Libby, 1993).

(e.g., T. Mitchell Prudden, Augustus B. Wadsworth, Hans Zinsser, J. Gardner Hopkins, Leumuel W. Famulener).⁵⁰ Among research-minded practitioners, progress was defined by the pursuit of diagnostic procedures, and most channeled their limited resources to problems of immediate medical relevance.⁵¹ Bacteriology maintained a symbiotic but ultimately confining relationship with medicine. The routine of diagnostic work provided bacteriologists with financial remuneration and access to clinically interesting material. In return, metropolitan hospitals gradually “recognized the need of including research possibilities in order to secure a really competent personnel.”⁵²

Celebrity within bacteriology was reserved for “discoverers” of previously unidentified etiological agents. The legacy of the “Golden Age” enshrined the eponymous register of pathogenic bacteria (e.g., *B. typhosus* Eberth, *B. pfeiffer*, etc.), and American bacteriologists wistfully recalled an era when “it became a kind of parlor game to demonstrate the ‘cause of disease’ in pure culture.” The “Golden Age,” however, slowly evanesced.⁵³ In order to “discover” or unambiguously demonstrate new etiological agents, a bacteriologist struggled to

⁵⁰ Other institutions found alternative means of negotiating the conflict between service and science. At the Hoagland Laboratory, Ezra Wilson, Benjamin White and Oswald Avery were free to investigate the chemistry of the toxins, because Archibald Murray performed the innumerable bacteriological, serological and hematological tests for the affiliated Long Island Hospital. Most research-minded bacteriologists, however, were rarely emancipated from the manacles of hospital pathology. H. Gideon Wells, “Education in Hospital and Laboratory,” Bulletin of the American Academy of Medicine 5 (1901): 540.

⁵¹ Olga Amsterdamska, “Medical and Biological Constraints: Early Research on Variation in Bacteriology,” Social Studies of Science 17 (1987): 661; Robert Kohler, “Bacterial Physiology: The Medical Context,” Bulletin of the History of Medicine 59 (1985): 57-74; and Kohler, “Innovation in Normal Science: Bacterial Physiology,” Isis 76 (1985): 162-181. Amstardamska and Kohler each concentrate on exceptions to the norms of medical bacteriology, with particular emphasis on developments in the 1920's and 1930's.

⁵² Frederick P. Gay, “Research in the Medical Sciences,” Science 57 (1923): 366-368.

⁵³ In Edwin Jordan's estimation: “The phase of relatively easy demonstration of the relation of specific bacteria to disease came to a natural conclusion after ten to fifteen years, with the exhaustion of the problems susceptible of solution by the use of the first simple methods. Only the tough nuts remained to be cracked.” Jordan, “The Relations of Bacteriology to the Public Health Movement Since 1872,” American Journal of Public Health 12 (1922): 1044-1045.

fulfill each of Henle's and Koch's four "postulates":

- 1) the organism must be present in disease tissues, 2) the organism must be isolated and cultured free from other microorganisms, 3) that the disease must be reproduced from pure cultures, and 4) that the microorganisms must be recovered from experimental animals and cultured again in pure form.

In most instances, these postulates presented an insuperable barrier. Even among acknowledged etiological agents, only a few could be "subjected to this complete regimen."⁵⁴ In numerous diseases, bacteriologists recovered microbes from pathogenic lesions, but could not cultivate them in pure culture. In other infectious states (e.g., typhoid fever, Asiatic cholera, leprosy, syphilis, malaria, etc.) definite bacterial species could be isolated and cultivated, but upon inoculation failed to reproduce the exact disease symptoms in experimental animals. More problematic were the instances where a single species produced a variety of disease conditions (e.g., *Streptococcus pyogenes*, *Micrococcus lanceolatus*) or when a normally saprophytic organism displayed pathogenic properties (e.g., *Bacillus coli communis*, *Bacillus subtilis*).⁵⁵

Nonetheless, the pertinacious quest for new disease germs comprised the core of research in medical bacteriology. As Theobald Smith recalled: "To have isolated, recognized, and cultivated a bacterium and produced some sort of pathological changes in an inoculated animal was considered equivalent to half or more of the battle won over the depredations of such organism."⁵⁶ American bacteriologists yearned to reproduce the heroic victories of the "Golden

⁵⁴ Theobald Smith, "Koch's Views on the Stability of Species Among Bacteria," Annals of Medical History (1932): 529.

⁵⁵ A.C. Abbott, The Hygiene of Transmissible Diseases: Their Causation, Modes of Dissemination, and Methods of Prevention, 2nd ed. (Philadelphia: W.B. Saunders & Co., 1901), 61-64. Nevertheless, Jordan and others regarded the pure culture methods, or the "rigid and undeviating adherence to definite rules and principles," as the defining characteristic of bacteriology. Quoted in Heinemann, A Laboratory Guide in Bacteriology, ix.

⁵⁶ Smith, "Parasitism as a Factor in Disease," Science 54 (1921): 101. William H. Welch suggested that fame was still reserved for those who studied previously "discovered" bacteria, particularly if they illustrated the special characters, portals of invasion, behavior in the human body, channels of discard, and survival or distribution

Age," adding to the list of microbes subject to the control of laboratory isolation and identification. Scanning the realm of unconquered pathogens, many American researchers held a keen interest in spirochetes. Hideyo Noguchi, an associate at the Rockefeller Institute, gained international notoriety for successfully cultivating *Treponema pallidum* (*Spirochaeta pallida*), the etiological agent of syphilis originally isolated by Schaudinn and Hoffmann. Noguchi's methods were soon integrated into routine diagnostic procedures, as Noguchi himself directed his attention to related microbes. Between 1908 and 1914, Noguchi developed elaborate techniques for obtaining pure cultures for a variety of spiral organisms, both harmless and pathogenic.⁵⁷ Elsewhere, investigators conducted analogous studies on sundry trypanosomes, spirochetes and leptospira.⁵⁸

In the pursuit of other agents, American bacteriologists met with occasional success during the first decades of the century. While European laboratories isolated the organisms responsible for whooping cough, Malta fever, and contagious abortion, domestic investigators could, by 1919, point to paramount findings pertaining to tularemia, Rocky Mountain spotted fever, and typhus fever,⁵⁹ as well as significant contributions to the etiological understanding of

in the outer world. Welch, Public Health in Theory and Practice: An Historical Review (New Haven: Yale University Press, 1925), 36-37.

⁵⁷ Hideyo Noguchi, Laboratory Diagnosis of Syphilis: A Manual for Students and Physicians (New York: P.B. Hoeber, 1923); Noguchi, "Spirochaetes," Harvey Lectures 11 (1917): 174-270. See also, Gustav Eckstein, Noguchi (New York: Harper and Brothers, 1931); Paul F. Clark, "Hideyo Noguchi, 1876-1928," Bulletin for History of Medicine 33 (1959); and, Theobald Smith, "Memorial Addresses," Bulletin of the New York Academy of Medicine 5 (1929): 877-886.

⁵⁸ At the University of Michigan, for example, Frederick Novy and his associates devoted more than a decade to generating standard culture methods for the organisms responsible for the assorted varieties of relapsing fever. See, Novy and Ward J. MacNeal, On the Cultivation of *Trypanosoma Lewisi*, Contributions to Medical Research (Ann Arbor: Univ. of Michigan, 1903); and, Novy, "On Trypanosomes," Harvey Society Lectures 1 (1906): 33-72.

⁵⁹ George W. McCoy, "Tularemia," U.S. Public Health Bulletin 43 (1911): 1-71; McCoy and C.W. Chapin, "Further Observations on a Plague-like Disease of Rodents with a Preliminary Note on the Causative Agent, *Bacterium tularensis*," Journal of Infectious Diseases 10 (1912): 61-72; Howard T. Ricketts, "A

mumps, measles and scarlet fever.⁶⁰ Nevertheless, the bulk of American bacteriologists engaged in the research equivalent of "mopping-up," the less prestigious but equally imperative task of formulating reliable procedures for the routine of isolation and identification. At Columbia's College of Physicians and Surgeons, Philip Hanson Hiss' most celebrated accomplishment was the improvement of differential criteria to discriminate streptococci from pneumococci, and the development of media differentiating enteric organisms of the colon-typhoid group. For American bacteriologists, their eponymous register listed techniques (e.g., Novy's method of anaerobic cultures), instruments (e.g., Smith fermentation tube, Barber pipette) and media (e.g., Dorset's egg medium), rather than revealed pathogens.⁶¹

In medical schools, courses in bacteriology rehearsed the techniques of isolation and identification. Students emulated, in an elementary fashion, the original "discoveries" of microbial pathogens as they followed a near universal drill of training in routine diagnostics. Initially, students practiced the rudiments of pure culture methods. They cooked media and repeated the techniques for growing, plating, isolating, and staining the bacteria using incubators, sterilizers, autoclaves, and animals.⁶² Thus armed, they moved from exemplar to exemplar,

Microorganism which Apparently has a Specific Relationship to Rocky Mountain Spotted Fever," JAMA 52 (1909): 379-380; and, Ricketts and Russell M. Wilder, "The Relation of Typhus Fever to Rocky Mountain Spotted Fever," Archives Internal Medicine 5 (1910): 361-370.

⁶⁰ See, Martha Wollstein, "An Experimental Study of Parotitis (Mumps)," Journal of Experimental Medicine 23 (1916): 353-375; William J. Elser and Frank M. Huntoon, "Studies on Meningitis," Journal of Medical Research 20 (1909): 371-541; Henry Heiman and Samuel Feldstein, Meningococcus Meningitis (Philadelphia: J.B. Lippincott Co., 1913); Alphonse R. Dochez, "Etiology of Scarlet Fever," Harvey Lectures 20 (1900); and, Ludwig Hektoen, "Is Scarlet Fever a *Streptococcus* Disease?" JAMA 48 (1907): 1158-1160. The list of conspicuous American failures would include David J. Davis' description of whooping cough, Simon Flexner's transmission experiments for poliomyelitis, and H.D. Gedding's professed isolation of the causative agent for yellow fever.

⁶¹ Gay, "Half Century of Bacteriology at Columbia," 205; and, Philip H. Hiss and F.F. Russell, "A Study of a *Bacillus* Resembling the *Bacillus* of Shiga from a Case of Fatal Diarrhea in a Child, with Remarks on the Recognition of Dysentery, Typhoid, and Allied Bacilli," Medical News 82 (1903): 289-295.

⁶² Incidentally, they were to master the principles of disinfection and sterilization. Milton J. Rosenau, "Laboratory Course in Pathology and Bacteriology," Hygienic Laboratory Bulletin 8 (August 1902): 5-48.

accumulating the technical tricks that defined the practice of bacteriology and pathology.

Students might begin the semester with a *Bacillus subtilis* (a harmless soil microbe), comparing it weeks later to another spore former, such as *Bacillus anthracis*, noting the differences in optimal temperature growth, pigment production, and ability to liquify gelatin. They cultivated each of the exemplar organisms (e.g., *Micrococcus tetragenus*, *Bacillus pycyanus*, *Bacillus melitensis*) under a variety of conditions (e.g., gelatin plates, agar plates, agar streak cultures, growth in bouillon, on potatoes, and litmus whey) in order to gain a level of determinative proficiency (e.g., the ability to distinguish meningococci from other diplococci).⁶³ At the Detroit Medical College, instruction in bacteriology reenacted the fulfillment of Henle-Koch postulates:

The saprophytes are studied first until the student has mastered the technique necessary for studying pathogenic bacteria. Each bacterium is studied separately, inoculation being made into animals, autopsies performed on the animals, the post-mortem appearance of the pathological process studied, and the germ recovered. Especial study is given to the pyogenic, diphtheria, pneumonia, typhoid, colon and tubercular organisms. The student, to receive credit for the course, must pass a practical examination which consists in the identification and cultivation in pure culture of bacteria obtained from a mixed or unknown culture.⁶⁴

Similarly, examinations at Boston University, according to the 1901 catalogue, presented the students with the “opportunity to diagnose typhoid fever, diphtheria, and tuberculosis in the bacteriological laboratory.”⁶⁵ The daunting challenge was lessened only by the limited range of

⁶³ The catalogue for the University of Illinois College of Medicine explained: “When the students’ techniques are sufficiently developed, a series of ten non-pathogenic bacteria is subjected to systematic study of various media, including the necessary microscopic examinations. After completing these studies pathogenic bacteria are examined in much the same way, and the special characters of each are shown.” Milan V. Novak, “The History of Bacteriology at the University of Illinois, Colleges of Medicine, Dentistry and Pharmacy,” 1951, [ASM], box 2-IXC, folder 73, p. 14. See also, John M. Slack, “A Brief History of Bacteriology at the School of Medicine, West Virginia University,” 1954, [ASM], box 2-IXC, folder 88.

⁶⁴ Quoted from 1914 edition of “The Erythrocyte.” Harry L. Clark, “Bacteriology at Wayne University,” 1946, [ASM], box 2-IXC, folder 56.

⁶⁵ David L. Belding, “Microbiology at Boston University School of Medicine,” 1952, [ASM], box 2-IXC, folder 77.

bacteria studied. At the Long Island College Hospital, for example, the list of pathogenic organisms encompassed only those "directly applicable to clinical diagnosis," including staphylococci, streptococci, gonococci, pneumococci, and the bacilli of anthrax, tuberculosis, typhoid fever, glanders and mouse septicemia.⁶⁶

Determinative proficiency did not entail an understanding of the underlying principles of the microbial world, only the ability to isolate and identify unknown organisms from tissue, blood, urine and sputum samples. Bacteriological instruction, like bacteriological research in medicine, was restricted by design.⁶⁷ Textbooks, likewise, imposed a narrow and technical approach to bacterial determination. They preached the necessity of pure cultures, a state of extracting organisms under artificial conditions which necessarily excluded the possibility of bacterial associations or mixed infections.⁶⁸ The determinative manuals posited invariable traits demarcating a pathogen from its related forms. Neither variation, nor the mechanisms underlying the morphological or cultural characteristics, was figured. Students needed only to know that *Staph. pyogenes aureaus* is "not motile . . . stains by Gram's method; is a facultative anaerobe; grows rapidly, best at 30 to 37 degrees C. It liquefies gelatin . . . does not lead to fermentation with the production of gas, but produces various acids," and differs from the *albus*

⁶⁶ The catalogue for 1899 mentioned: "Students are taught to make differential stains for tubercle, gonorrhoea and other pathogenic organisms susceptible to such differentiation and are further familiarized with the commoner pyogenic germs." Eggerth, The History of the Hoagland Laboratory, 100.

⁶⁷ At Brown University, the course announcement for 1911 pledged a broad study of microbiology, with "a general discussion of bacteria in all their relations." Yet, both the "General" and "Advanced" offerings focused almost exclusively on the isolation and determination of unknown species. C.A. Stuart, "Summary of History of Bacteriology at Brown," 1952, [ASM], box 2-IXC, folder 77.

⁶⁸ "In order to properly study bacteria," Bolduan and Grund insisted, "it is absolutely essential that they be grown by themselves, i.e., not mixed with a lot of other bacteria." Applied Bacteriology for Nurses, 27. Gay, Meyer, and Rusk's text similarly maintained: "If we intend to study one special kind it is necessary to separate it from all others . . ." Outline of Combined Courses in Pathology, 38.

variety in that it is more pathogenic and produced pigments.⁶⁹

The preeminence of developing reliable diagnostic techniques did, in some circumstances, lead researchers and instructors to break from the rigid cookbook approach to medical bacteriology. As biochemical activities, such as the capacity to ferment specific sugars, yield acids and gas, or produce indol, became increasingly valuable in differentiating species, a few bacteriologists sought a deeper understanding of bacterial physiology.⁷⁰ Likewise, as bacteriologists isolated species resembling, but not identical with, pathogenic forms, they focused a portion of their attention to bacterial systematics.⁷¹ Even the phenomena of bacterial associations drew occasional interest, particularly as it related difficulties in obtaining pure cultures or possibility of therapeutic measures.⁷²

⁶⁹ Herbert U. Williams, A Manual of Bacteriology, 2nd ed, rev. and enl. by B. Meade Bolton (Philadelphia: Blakiston, 1901), 94. The recipe and checklist approach to determination can also be seen in, Veranus A. Moore, Laboratory Directions for Beginners in Bacteriology: An Introduction to Practical Bacteriology for Students and Practitioners of Comparative and of Human Medicine, 2nd ed. (New York: Ginn & Company, 1900); William D. Stovall, Outline of Laboratory Work in Clinical Laboratory Diagnosis (Madison: n.p., 1900); Allen J. Smith, Lessons and Laboratory Exercises in Bacteriology: An Outline of Technical Methods Introductory to the Systematic Study and Identification of Bacteria. Arranged, for the Use of Students (Philadelphia: P. Blakiston's Son & Co., 1902); and, Robert L. Pitfield, A Compend on Bacteriology Including Animal Parasites (Philadelphia: P. Blakiston's, 1907).

⁷⁰ O.W.H. Mitchell acknowledged that, "To know bacteria, one must have an understanding of these various substances resulting from bacterial activity." Mitchell, "Bacteria and Disease," The University of Missouri Bulletin: Medical Series 1 (1913): 13. For the most part, isolation and identification required a knowledge of the food requirements, preferences of reaction, concentrations, moisture, temperature, and response to light and the presence of foreign substances. See, King, "Factors Necessary for the Development of Bacteriology," Synopsis of Lectures, 24-28.

⁷¹ See, Alexander C. Abbott and Nathaniel Gildersleeve, "The Etiological Significance of the Acid-Resisting Group of Bacteria, and the Evidence in Favor of Their Botanical Relation to *Bacillus Tuberculosis*," University of Pennsylvania Medical Bulletin (June 1902); William W. Ford, "Classification of Intestinal Bacteria," Journal of Medical Research 6 (1901): 211-219; W.L. Holman, "The Classification of *Streptococci*," Journal of Medical Research 29 (1916): 377-443; and, Alphonse R. Dochez and Rebecca Lancefield, "Studies on the Biology of *Streptococcus*," Journal of Experimental Medicine 30 (1919): 179-213.

⁷² See, Leo Rettger, "The Antagonism of Bacteria and their Products to other Bacteria," paper presented before the 6th meeting of the Society of American Bacteriologists (1904); William D. Frost "The Antagonism Exhibited by Certain Saprophytic Bacteria Against the *Bacillus Typhosus Gaffky*," Journal of Infectious Diseases 5 (1904): 599-640; and, Jules Brunel, "Antibiosis from Pasteur to Fleming," Journal of the History of Medicine and Allied Sciences 6 (1951): 287-301.

Bacterial variation, however, supplied a well-spring of refractory phenomena, the aspect of routine bacteriology that resisted routinization. Most bacteriologists acknowledged that morphological and pathological traits varied greatly, particularly among cultures grown under artificial conditions for any length of time. Yet, variation, as biological phenomena, rarely comprised a subject of investigation, as aberrant cultures were simply deemed "degenerate" or "involution" forms.⁷³ With the exception of Theobald Smith, no American bacteriologist before 1915 held a sustained interest in the nature of variation.⁷⁴ In 1916 Felix Lohnis proposed a cyclogenic theory of bacterial life cycles, but among medical bacteriologists the publication piqued more indifference than controversy.⁷⁵ In fact, many commentators concluded that the problem of variation derived from inadequate culture methods, not an inherent characteristic of microbial life. As Edwin Jordan entreated:

To-day we need, in much the same way as did the bacteriologists of the seventies, methods that will enable us to preserve and study the types of microorganism isolated from the animal body without changing essentially the characteristics these types possess

⁷³ The label of "involution" required no further theoretical elaboration. For example, in Gay, Meyer and Rusk's text, they merely mention that, "under certain conditions" bacteria would not grow to form, but to "peculiarly swollen, aberrant, degenerated forms." Outline of Combined Courses in Pathology, 152. Amsterdamska has documented the methodological and institutional sources for a strict adherence to monomorphism in the nineteenth century, noting that variation only became a legitimate topic when the practical necessities of differentiating enteric organisms demanded. See, Amsterdamska, "Medical and Biological Constraints," 671-675.

⁷⁴ Theobald Smith, "Observations on the Variability of Disease Germs," New York Medical Journal 52 (1890): 485-487; Smith, "Modification, Temporary and Permanent, of the Physiological Characters of Bacteria in Mixed Cultures," Transactions of the Association of American Physicians 9 (1894): 85-106; Smith, "Variation Among Pathogenic Bacteria," Journal of the Boston Society of Medical Sciences 4 (1899): 95-100; Smith, "Adaptation of Pathogenic Bacteria to Different Species of Animals," Boston Medical and Surgical Journal 142 (1900): 473; and, Smith, "Some Problems in the Life History of Pathogenic Microorganisms," Science 20 (1904): 807.

⁷⁵ Felix Lohnis and Nathan R. Smith, "Life Cycles of the Bacteria: Preliminary Communication," Journal of Agriculture 6 (1916): 675-702. For studies exploring Lohnis' model of life cycles, see, Nobel Pierce Sherwood, "A Study of Several Strains of Pleomorphic *Streptococci*," University of Kansas Science Bulletin 10 (1917): 245-257; and, Ralph R. Mellon, "Life Cycles of the Bacteria and Their Possible Role in Pathology," American Journal of Medical Science 159 (1920): 874-882.

when freshly obtained.⁷⁶

The medical context necessitated a bacteriology of reliable techniques for isolation and identification, not a domain of absorbing biological questions. When the demands of routine diagnosis entailed fundamental research, investigators could rationalize that "the discovery of new principles" would lead "very rapidly to practical results."⁷⁷ Studies of nutritive requirements, physiological processes, biochemical products, associative behavior, and variation were occasionally sanctioned, but only in so far as they aided in the mission of medical diagnosis. Theobald Smith once lamented that there were two lines of bacteriology, one "trying to dig beneath the observations toward more fundamental concepts embodied in physics and chemistry, and the medical or practical striving towards the surface to bring research into use." While institutionally medical bacteriology experienced an explosive growth during the first decades of this century, "the knowledge of the function of microorganisms has had to fight its way to recognition step by step."⁷⁸

Bacteriology and Public Health

As with the medical context, the growth of public health laboratories facilitated a remarkable expansion of bacteriology. While the activities of these bureaus closely resembled medical microbiology, with a primary task of aiding in the diagnosis of tuberculosis, diphtheria, typhoid fever, gonorrhoea, etc., public health laboratories ostensibly attended to populations not

⁷⁶ Jordan, "Relations of Bacteriology to the Public Health Movement," 1045.

⁷⁷ Gay, "Contribution of Medical Science to Medical Art," 116; See also, Hans Zinsser, "The Transformation of Medicine by Public Health Development," Transactions of College of Physicians, Philadelphia 4 Supplement (1937): 65.

⁷⁸ Theobald Smith, quoted in Microbiology in New Jersey: Origins and Developments, ed. Selman A. Waksman, Robert L. Starkey, and Richard Donovan (Washington D.C.: American Society for Microbiology, 1965), 31.

individuals. Initially, health commissioners supported bacteriological efforts in order to accurately ascertain the presence and prevalence of infectious diseases. With the development of antitoxins, therapeutic sera and vaccines, the perceived utility of bacteriology skyrocketed. Public health officials pointed to diphtheria antitoxin, in particular, as a harbinger of a revolution to come, a laboratory promise to protect not only innocents from a childhood scourge but a model to combat other diseases. By the 1910's, bacteriological manipulations represented an integral component of public health in twentieth century America,⁷⁹ adding the luster of scientific prestige to the institutional scions of Progressive era municipal reform.⁸⁰ As a parallel to the previous section, the ensuing paragraphs argue that public health laboratories promoted an expanding bacteriology, one narrowly focused on the entrenched routine of microbial isolation, identification and elimination. In the service of preventive medicine, bacteriology found its greatest success, as well as its most limited expression.⁸¹

The history of American public health institutions has been well-documented. By 1890

⁷⁹ See, James H. Cassedy, Charles V. Chapin and the Public Health Movement (Cambridge: Harvard University Press, 1962); Harry Wain, A History of Preventive Medicine (Springfield, Ill.: Charles C. Thomas, 1970); and, John Duffy, "Bacteriology Revolutionizes Public Health," in The Sanitarians: A History of American Public Health (Urbana: University of Illinois Press, 1990). Even before the introduction of antitoxin treatments, the implications of bacteriology for public health were widely recognized. Herbert Conn predicted in 1888, "In short, knowledge collected concerning the parasitic nature of disease and the habits of the specific microbes is giving us hundreds of ways of fighting the diseases outside of the body, even though it has yet not been very fruitful in directing our physicians how to treat the disease when it has once vigorously attacked the body." Conn, "The Germ Theory as a Subject of Education." Science 11 (1888): 5-6.

⁸⁰ Barbara Rosenkrantz has argued that bacteriological laboratory techniques were largely responsible for shifting the "center of action and the criteria for professional identity" within the public health movement. Rosenkrantz, "Cart Before Horse: Theory, Practice, and Professional Image in American Public Health, 1870-1922," Journal of the History of Medicine and Allied Sciences 29 (1974): 68. See also, Frederick P. Gorham, "The History of Bacteriology and Its Contribution to Public Health Work," in A Half Century of Public Health: Jubilee Historical Volume of the American Public Health Association, ed. by M.P. Ravenel (New York: American Public Health Association, 1921), 76.

⁸¹ Frederick G. Novy, "Bacteriology in Its Relation to Public Health." Proceedings of the 4th Annual Conference of Health Officers (n.p., 1899), 14-24; and, William H. Park, "Contribution of Bacteriology to Therapeutics," Pediatrics 4 (1897): 385-398, 442-449.

several states and municipalities maintained already established health departments, albeit on an inconsistent basis. A portion of these bureaus sponsored laboratory investigations, usually of chemical nature, and most public health departments attended to contagious diseases (*e.g.*, smallpox and cholera). The introduction of bacteriological methods contributed greatly to proliferation and growth of these institutions during the last decade of the nineteenth century.⁸² Between 1890 and 1910, the bacteriological component of laboratory work comprised an increasingly large segment of public health activities, particularly as it related to the diagnosis of contagious diseases and the preparation of sera, antitoxins, and vaccines.⁸³ As a result, bacteriologists in the employ of public health departments found themselves highly valued, but greatly overworked.

Although, strictly speaking, the Rhode Island Department of Health created the first bacteriological laboratory in 1888, the New York City Health Department truly defined public health bacteriology for a half century. The Health Department's Division of Pathology, Bacteriology and Disinfection originated in 1892, primarily in response to the specter of another epidemic of Asiatic cholera. Herman Biggs, a former pupil of Welch at Bellevue, directed the Division in its initial assignment, the bacteriological confirmation of cholera in enigmatic cases. In 1893, Biggs added the functions of terminal disinfection and fumigation.⁸⁴ Shortly thereafter,

⁸² See, Alexander C. Abbott, "The Development of Public Health Work in Philadelphia: An Historic Sketch," University of Pennsylvania Medical Bulletin (Sept. & Oct. 1909): 14-36; George C. Whipple, State Sanitation: A Review of the Work of the Massachusetts State Board of Health (Cambridge: Harvard University Press, 1917); and, Barbara G. Rosenkrantz, Public Health and the State: Changing Views in Massachusetts, 1842-1936 (Cambridge: Harvard University Press, 1972).

⁸³ C.-E.A. Winslow, "The Laboratory in the Service of the State," American Journal of Public Health 6 (1916): 225. Public health bacteriology also included examinations of water, milk and food, topics that will be discussed in a later section.

⁸⁴ Hermann M. Biggs, "The Organization, Equipment, and Method of Work of the Division of Pathology, Bacteriology, and Disinfection of the New York City Health Department," Transactions of the New York Academy of Medicine 10 (1893): 303-320.

William H. Park, a protégé of T. Mitchell Prudden at the College of Physicians and Surgeons, joined the Health Department as an Inspector and Bacteriological Diagnostician of Diphtheria. Park proposed the widespread employment of throat cultures in order to separate true from false cases of diphtheria, thereby preventing unnecessary hospitalization of sick children. In 1894, the Health Department offered free "culture outfits" to area physicians, and established forty convenient delivery depots with a promise of a twenty-four hour diagnostic reply. Almost overnight, Park created a bacteriological empire within the Division, with thirty-four full time workers performing some 5,000 examinations in 1896.⁸⁵

The empire expanded almost without limits in the 1890's. In 1895, the Health Department commenced the manufacture and distribution of diphtheria antitoxin, supplying it without charge to area physicians. While the decision drew suspicion and criticism from some practitioners and pharmacists, the production of antitoxin offered an administrative and public relations windfall for the Health Department. Beginning in 1897, the network of production (relying on the skills of bacteriologists, chemists, pharmacists, and veterinarians), outstripped the metropolitan market, and the Department sold its excess to public health agencies nationwide.⁸⁶ Profits from antitoxin sales subsidized the burgeoning activities of the Division of Pathology, Bacteriology and Disinfection, as the lucre from one bacteriological enterprise funded the siring

⁸⁵ David A. Blancher, "Workshops of the Bacteriological Revolution: A History of the Laboratories of the New York City Department of Health, 1892-1912," (Ph.D. diss., City University of New York, 1979); and, William H. Park, "The History of Diphtheria in New York City," American Journal of Diseases of Children 92 (1931): 1439-1445. Evelyn M. Hammonds has provided a thorough and provocative account of the New York City Health Department's efforts to combat diphtheria, and its resultant expansion of laboratory operations. See, Hammonds, Childhood's Deadly Scourge: The Campaign to Control Diphtheria in New York City, 1880-1930 (Baltimore: Johns Hopkins University Press, 1999); and, Hammonds, "The Search for Perfect Control: A Social history of Diphtheria, 1880-1930" (Ph.D. diss., Harvard University, 1993).

⁸⁶ Wade W. Oliver, The Man Who Lived for Tomorrow: A Biography of William Hallock Park, M.D. (New York: E.P. Dutton & Co, 1941); and, C.-E.A. Winslow, The Life of Herman M. Biggs, M.D., D.Sc., LL.C.: Physician and Statesman of Public Health (Philadelphia: Lea & Febiger, 1929).

of others (*e.g.*, examinations for tubercle bacilli, gonococci, typhoid bacilli and malarial trypanosomes).⁸⁷

Other public health departments emulated the New York City model. In Brooklyn, the Commissioner of Health established a Bureau of Pathology, Bacteriology and Disinfection in 1894, under the supervision of Ezra Wilson at the Hoagland Laboratory. From the third floor of the Long Island College Hospital building, the Bureau purveyed diphtheria culture kits and antitoxin. Wilson, like his cross-borough counterparts, operated a disinfection station, performed routine examinations for typhoid, gonorrhoea, and tuberculosis, and in 1897, began production of tetanus antitoxin.⁸⁸ The City of Boston and the Massachusetts Department of Public Health stood as New York City's poor relations. In the 1890's, both instituted diphtheria diagnostic services, produced antitoxin, and performed examinations for tubercle bacilli, typhoid fever, malaria, glanders and gonococci. Yet, Boston and the Massachusetts State Board granted paltry support for bacteriological services, relying instead on the beneficent labors of Harold C. Ernst and Theobald Smith. Indeed, among the several public health bacteriological laboratories founded before 1910 (table 1.4), the experience of Boston and Massachusetts was typical.⁸⁹

The practice of public health bacteriology principally involved the isolation and

⁸⁷ Charles F. Bolduan, "A Guide to Some of the Hygienic Features of New York City." New York Department of Health Monograph Series, no. 6 (1912): 1-66; Bolduan, "Typhoid Fever in New York City, Together with a Discussion of the Methods Found Serviceable in Studying Its Occurrence," New York Department of Health Monograph Series no. 3 (1912): 1-52; and Bolduan, "Over a Century of Health Administration in New York City," New York Department of Health Monograph Series no. 13 (1916): 1-39.

⁸⁸ Eggerth, The History of the Hoagland Laboratory, chpts. 3-5.

⁸⁹ Catherine Atwood, "Report on the Historical Development of Bacteriological Work in the Health Department, City of Boston"; Helen H. Gillette, "History of the Diagnostic Laboratory, Massachusetts Department of Health"; and Edgar J. Staff, "Rhode Island Department of Health," 1952 (?), [ASM], box 2-IXC, folder 77. The establishment of municipal bacteriological laboratories proceeded slowly. Charles Chapin recorded that "in 1900 there were nine of the forty largest cities of the countries without laboratories and included among these was one of nearly half a million inhabitants." Chapin, "History of State and Municipal Control of Disease," in A Half Century of Public Health, 143.

identification of the three microbes responsible for diphtheria, typhoid, and tuberculosis. In each instance, the diagnostic task lent itself to both routinization and directed research. Despite continued efforts to exclude intractable phenomena from diagnostic procedures, the routine of bacteriology was never unproblematic. Diphtheria cultures, for example, presumed that the diphtheria bacillus could be reliably identified, and that its presence unambiguously implied an infection of diphtheria.⁹⁰ The bacillus, however, was never so accommodating, varying greatly in morphological, cultural and staining characteristics. In many cultures, bacteriologists found it difficult to distinguish true diphtheria bacilli from the pseudo-diphtheria or Hofmann's bacillus. In addition, diphtheria bacilli occasionally resided in healthy throats, and some diphtheria forms appeared non-virulent upon animal inoculation.⁹¹ As a consequence, a few public health bacteriologists, such as Henry Albert at Iowa and Frank Wesbrook at Minnesota, broke from the monotony of Löffler's serum cultures to examine the relationship between morphological characters and pathogenicity, while others pursued the enigmatic presence of diphtheria bacilli in healthy throats.⁹²

Isolating and identifying *B. typhosus* from blood, urine, or feces relied on slightly more

⁹⁰ For early statements promising the reliability of diphtheria cultures, see, Henry W. Bettman, "Diphtheria: Its Bacterial Diagnosis and Treatment with the Antitoxin," Medical News 67 (July 6 1895): 1-5; and, William H. Welch, "Bacteriological Investigations of Diphtheria in the United States," American Journal of Medical Science 57 (1894): 427-61.

⁹¹ See, G.H.F. Nuttall and G.S. Graham-Smith, eds., The Bacteriology of Diphtheria (Cambridge: Cambridge University Press, 1908), chpts. 4-7; and Bolton, A Manual of Bacteriology, 343.

⁹² Frank F. Wesbrook, Orianna McDaniel and L.B. Wilson, "Varieties of *Bacillus Diphtheriae*," Transactions of the Association of American Physicians 15 (1900): 198-223; and Morris Schaeffer, "William H. Park (1863-1939): His Laboratory and His Legacy" American Journal of Public Health 75 (1985): 1296-1302. The problem of healthy carriers occupied the attention of public health researchers throughout the period between 1900 and 1920, leading to a variety of novel diagnostic procedures, such as the Schick test and later the Dick test. See, Wilber A. Sawyer, "Ninety Three Persons Infected by a Typhoid Carrier at a Public Dinner," JAMA 63 (1914): 1537-1542; Sawyer, "Late History of a Typhoid Carrier," JAMA 64 (1915): 205-253; and, Frederick Gay and John N. Force, "Preliminary Note on a Skin Reaction Indicating Protection against Typhoid Fever," University of California Publications in Pathology 2 (1913): 127-130.

reliable procedures, partly due to methods developed by Alfred Hess and Charles Krumweide at the New York City Health Department. But in the interests of convenience, most public health bureaus still employed the intractable Widal test for typhoid fever diagnosis.⁹³ Similarly, examinations for tubercle bacilli in sputa posed occasional difficulties. In cultures, extraneous bacteria frequently outgrew the suspected pathogen, and normal staining procedures could not distinguish tubercle bacilli from other acid-fast organisms.⁹⁴

Despite these complications, diagnostic services, not research, continued to comprise the preponderance of bacteriological activities in public health agencies. In a 1915, C.-E.A. Winslow, then Chairman of the Laboratory Section of the American Public Health Association (APHA), conducted a survey among forty-seven state departments of public health. Winslow related that forty-five respondents performed laboratory tests for diphtheria and typhoid (excepting New Mexico and Wyoming) and forty-four for tuberculosis. In addition, forty-one states reported examinations for malaria, thirty-seven for rabies, and thirty for glanders. "Most surprising" for Winslow, were bacteriological diagnostic services for venereal diseases, with thirty-six states examining pus for gonococci and twenty-seven conducting Wassermann tests for syphilis.⁹⁵

In addition to isolating and identifying suspected pathogens, public health bacteriologists manipulated microbes in order to produce antitoxins, sera, and vaccines. In the first years of the century, a handful of states and municipalities manufactured diphtheria antitoxin, while others

⁹³ George C. Whipple, Typhoid Fever: Its Causation, Transmission and Prevention (New York: John Wiley & Sons, 1908), 8-20.

⁹⁴ Herman Biggs discouraged his staff from studying diagnostic techniques for tuberculosis, choosing instead to combat the disease in other ways. C.-E.A. Winslow, The Contributions of Herman Biggs to Public Health (New York: New York Tuberculosis and Health Association, 1928).

⁹⁵ Winslow, "Laboratory in the Service of the State," 226.

prepared typhoid, rabies, and smallpox vaccines.⁹⁶ New York City's extensive experience with diphtheria antitoxin encouraged Park to establish an experimental program with tetanus antitoxin, which met with slight success.⁹⁷ The Health Department realized considerable success with other biologics, installing a Meningitis Division in 1906, and a "Laboratory for Special Therapy" in 1911 to develop anti-streptococcal and anti-pneumococcal sera.⁹⁸

These investigations were typical of research properly classed serology, not bacteriology. Yet, they did elucidate some fundamental features of bacterial pathogens. For example, at the University of Minnesota, Winford P. Larson studied the effect of surface tension on the growth and physiology of bacteria in effort to efficiently produce toxoids for diphtheria and scarlet fever immunizations.⁹⁹ In the same light, Charles Krumweide studied the chemical composition of pneumococci as part of a cooperative project between the New York City Health Department and the U.S. Army to develop quick strain typing for serum treatment. Frederick Gay, at University of California, explored mixed strains of typhoid cultures in order to extend the

⁹⁶ Winslow, "Laboratory in the Service of the State," 226. Anti-rabies vaccines and sera were produced and administered in sundry "Pasteur Institutes" across the country. These centers held a complex administrative relationship with public health departments, operating often independently while being staffed by municipal bacteriologists. For example, Charles N. Hewitt, the executive officer of the State Board of Health, established a Pasteur Institute in Minnesota. Between 1892 and 1921, Hewitt's institute treated some 2,000 patients, before being closed by the state.

⁹⁷ Herman Biggs, "Preventive Medicine in the City of New York," British Medical Journal 2 (11 Sept. 11 1897): 629-38; and Biggs, "The Serum-treatment and Its Results," Medical News 85 (22 July 1899): 97-105, 137-143. Tetanus antitoxin was most effective when administered prophylactically, and in 1903 the American Medical Association sponsored an educational campaign to encourage doctors to administer the antitoxin at every summer puncture wound. See, Mazyck P. Ravenel, "Preventive Medicine: Its Accomplishments and Its Aims," University of Missouri Bulletin 16, med. ser. 8 (1915): 14.

⁹⁸ Herman Biggs, "Preventive Medicine: Its Achievements, Scope, and Possibilities," American Medicine 7 (1904): 946-950; and Biggs, "The Development of the Research Laboratories," Monthly Bulletin of the Department of Health, New York City 1 (1911): 54-56. Blancher argues that budgetary constraints resulting from the end of antitoxin sales, and political pressures led to abandonment of meaningful research. Blancher, "Workshops of the Bacteriological Revolution," 214-235.

⁹⁹ Larson also studied the physiology of pneumococci in an effort to produce a high titre serum. H.O. Halvorson, "A History of Microbiology in the North Central United States," History Roundtable, 71st Annual Meeting, 1971, [ASM], box 11-IIW, folder 5.

duration of typhoid immunizations and reduce the frequency of serum sickness.¹⁰⁰

These achievements aside, public health departments did not act as a primary locus of bacteriological investigations. The laboratories typically hired young physicians on a part-time basis, most of whom lacked adequate training for experimental work. Among designated public health "bacteriologists," the common background consisted of a short eight or ten week course received in medical school.¹⁰¹ The majority of laboratory employees were, in fact, minimally prepared technicians. For example, at the Massachusetts Department of Public Health and at the California State Hygienic Laboratory, a legion of poorly paid female assistants performed the myriad routine diagnostic services.¹⁰²

Between 1900 and 1920, several universities introduced undergraduate courses in "municipal laboratory methods," often as compliments to the existing classes in "public" or "community hygiene." Even so, only Simmons College and Kansas University provided more than a half semester of laboratory instruction, offering the first A.B. degrees for university

¹⁰⁰ Paul S. May, "The Development of Bacteriology in the New York City Public Health Laboratories," 1967, [ASM], regional history collections, box 24, folder B; Frederick P. Gay, Typhoid Fever Considered as a Problem of Scientific Medicine, Semicentennial Publications of the University of California, 1868-1818 (New York: Macmillan, 1918); and Mazyck P. Ravenel, "The Control of Typhoid Fever by Vaccination," American Philosophical Society Proceedings 52 (1913): 226-233. Researchers at the Rockefeller Institute reproduced and then extended Krumweide's studies. See, Alphonse R. Dochez and L.J.A. Gillespie, "A Biological Classification by Means of Immunity Reactions," JAMA 61 (1913): 727-30; and O.T. Avery, *et. al.*, "Acute Lobar Pneumonia; Prevention and Serum Therapy," Rockefeller Institute, Monograph no. 7 (1917).

¹⁰¹ Winslow's 1915 survey reported 20 states conducting "research," with the remaining 27 respondents confining themselves "solely to routine." Winslow, "Laboratory in the Service of the State," 230. Of these, only a handful employed a bacteriologist who contributed regularly to scholarly journals (*e.g.*, New York, Illinois, Ohio, Michigan, Minnesota, and California). See also, Blancher, "Workshops of the Bacteriological Revolution," 218; Rettger, "The Science of Bacteriology," 104; and, Paul Nichols, "The Development of Bacteriology in Utah and the Intermountain Area," 1978 (?), [ASM], regional history, box 30, folder A-1.

¹⁰² At the Massachusetts Department, diphtheria cultures were examined by the likes of Edith A. Beckler, Ruth Bryant, A.P. Hale, Kathleen Marden, and Helen Gillette, of which, only the last received formal advanced training. Gillette, "History of the Diagnostic Laboratory," 4. At the California Hygienic Laboratory, the female assistants (Margaret Henderson, Elsi Cole, Dorothea Van Orden, Eleanor C. Symour, Esther Skolfield, Grace A. Macmillan, Violet Bathgate) varied widely in educational background. L.S. McClung and K.F. Meyer, "Beginnings of Bacteriology in California," Bacteriological Reviews 38 (1974): 263-264.

women seeking careers as laboratory technicians.¹⁰³ (Table 1.5) At the graduate level, advanced degrees in public health methods remain equally uncommon. Harvard University, University of Pennsylvania, Johns Hopkins University, and the University of Chicago each conferred Doctors of Public Health, as well as fostered research.¹⁰⁴ Nonetheless, throughout the 1910's, only a small number of institutions trained public health laboratory workers.

The lack of adequate funds placed an additional limitation on research. In Winslow's 1914 survey, a majority of states reported disbursing between \$5,000 and \$10,000 in annual laboratory expenditures. Over twenty states devoted less than one cent per inhabitant per year.¹⁰⁵ Indeed, the histories of municipal and state departments of health repeatedly tell of unfunded or privately operated laboratories. The Missouri State Board of Health, for example, featured the most financially starved public health laboratory, with a miserly 1914 budget of \$2,700 or 0.07 cents per capita. George C. Jones, the bacteriologist for the State Board of Health complained so bitterly, and persistently, of the deficient resources that in 1919, the state refused to authorize any subventionary monies. Jones subsequently moved the lab to the University of Missouri's

¹⁰³ Catherine Witton and Curtis M. Hilliard, "Bacteriology at Simmons College," Symposium on the History of Bacteriology in the Northeast Area, 1952, [ASM], box 2-IXC, folder 77. Noble P. Sherwood recalled that the laboratory technician major included course work "in Pathogenic Bacteriology, Diagnostic Bacteriology, Immunology, Chemistry, including the same chemistry offered to pre-meds such as inorganic, quantitative and qualitative analysis, organic and also bio-chemistry, Parasitology, Mycology and Hematology." After graduation, "these young women...spend a year at our teaching hospital," to receive their state certification. Sherwood, "The History of Bacteriology at the University of Kansas," 1951, regional history collection, [ASM], box 12, folder B2, p.8

¹⁰⁴ Within these graduate programs, bacteriology was taught along with vital statistics and epidemiology, public health administration, industrial hygiene, sanitary engineering, parasitology, etc. John S. Billings, "The Objectives, Plans and Needs of the Laboratory of Hygiene. An Address Delivered at the Opening of the Laboratory of Hygiene at the University of Pennsylvania, February 22, 1896," Medical News (Philadelphia) 60 (1892): 232-235; A.C. Abbott. "The Organization and Experiences of the School of Hygiene at University of Pennsylvania," Proceedings of the Association of American Medical Colleges 34 (1924): 174-80; J.A. Curran, editorial, Harvard School of Public Health Alumni Bulletin 23 (Jan. 1966): 2-4; Stewart A. Koser, "Bacteriology at the University of Chicago," Bios 23 (1952): 175-191; and, William Burrows, "Edwin Oakes Jordan, 1866-1936," Biographical Memoirs of the National Academy of Sciences 20 (1939): 197-225.

¹⁰⁵ Winslow, "The Laboratory in the Service of the State," 231.

Department of Preventive Medicine. Even Rhode Island, which allotted the highest per capita expenditure (2.0 cents) in 1914, survived the first decade of its existence without public facilities, relying instead on the private laboratories of two local physicians.¹⁰⁶

Confronted by a deluge of diagnostic tests, these paltry budgets stretched increasingly thin. In the great municipalities such as New York City, Chicago and Boston, public health laboratories performed more than 10,000 examinations per year. During the late 1890's and early 1900's, the laboratories devoted themselves mostly to diphtheria cultures, but by the mid-1910's public health bacteriologists assumed responsibility for a variety of new diagnostic services (*e.g.*, Schick and Wassermann tests).¹⁰⁷ Overburdened and understaffed, most agencies simply could not afford research. The few exceptions to this maxim only prove the rule. The Minnesota State Board of Health, for example, sponsored research ventures in numerous spheres (*e.g.*, water purification, food poisoning, milk standards, disinfectants, embalming fluids). However, the Board performed a relatively low number of diagnostic cultures, did not provide free antitoxin or sera, and required that each of its research staff conduct one kind of routine test. The Minnesota State Board augmented its above average annual budget of \$19,000 (0.9 cents per capita) with the uniquely profitable sale of anti-typhoid vaccine.¹⁰⁸ Even the Commissioner of the New York City Health Department, that shining beacon of scientific pursuits, felt obliged to justify the

¹⁰⁶ Staff, "Rhode Island Department of Health." For similar accounts in other states and cities, see, Waksman, Starkey and Donovan, Microbiology in New Jersey, 35-36; Leo Rettger, New Haven, to Barnett Cohen, Baltimore, 3 March, 1937, [ASM], regional history, box 7-II, folder A6; and, Williams and Sharp, "The History of Bacteriology in Texas," no page number.

¹⁰⁷ Atwood, "Historical Development of Bacteriological Work in the Health Department, City of Boston," 7-8; Fred O. Tooney, "The Introduction of Bacteriology into the Service of Public Health in Chicago," Bulletin of the Society of Medical History of Chicago 5 (1937): 26; and, John L. White, "History of Public Health Bacteriology in Chicago," Symposium on the History of Bacteriology, 1951, box 2-IXC, folder 73.

¹⁰⁸ Orianna McDaniel, "Reminiscences," Roundtable on the History of Bacteriology in Minnesota, 1940, [ASM], box 2-IXC, folder 60; and, Winslow, "Laboratory in the Service of the State," 231.

research budget solely on the promise of a "rapid" yield in "the coinage of practical utility."¹⁰⁹

In contrast to the penurious research allowance afforded to public health departments, private pharmaceutical firms devoted considerable resources to bacteriological and serological studies. In fact, commercial laboratories employed a contingent of bacteriologists in the decades surrounding the turn of the century.¹¹⁰ University faculty and public health officials regularly staffed the research divisions of H.K. Mulford Company, Cutter Analytic, E.R. Squibb and Sons, Lederle, Eli Lilly, and Parke Davis and Company. A few bacteriologists held joint appointments in academic and commercial laboratories (*e.g.*, Joseph McFarland).¹¹¹ Others worked exclusively for private enterprises, drawn by the prospects of higher salaries and greater autonomy.¹¹² Still more common were the bacteriologists who moved periodically, and seamlessly, between

¹⁰⁹ Ernst J. Lederle, "The Function of Research in Municipal Health Administration," Monthly Bulletin of the Department of Health of the City of New York 1 (March 1911): 51-53. See also, Samuel C. Prescott, "Laboratory in Public Health Work," American Journal of Public Health 16 (February 1926): 130; William T. Sedgwick, "The Relations of the Public Health Science to Other Sciences," Science 15 (1905): 905; and, Sedgwick, "American Achievements and American Failures in Public Health Work: Address of the President, American Public Health Association," Science 42 (1915): 361.

¹¹⁰ Jonathan Liebenau, Medical Science and Medical Industry: The Formation of the American Pharmaceutical Industry (Baltimore: Johns Hopkins University Press, 1987), chpts. 4-7; and, Louis Galambos, with Jane Eliot Sewell, Networks of Innovation: Vaccine Development at Merck, Sharp & Dohme, and Mulford 1895-1995 (Cambridge: Cambridge University Press, 1996), chpts. 2-4.

¹¹¹ McFarland held joint appointments at the University of Pennsylvania and the Medico-Chirurgical College while directing the laboratories at Mulford, and then Parke Davis. Joseph McFarland, "The Beginning of Bacteriology in Philadelphia," Bulletin of the History of Medicine 5 (1935): 148-172; David H. Bergey, "Early Instructors in Bacteriology in the United States," Journal of Bacteriology 2 (1917): 595-601. Similarly, G.L. Leonard lectured on bacteriology to students at Rutgers in the 1910's while directing E.R. Squibb's laboratories. And, Oswald Avery devoted the summer of 1912 to teaching at Mulford, during which he developed techniques in preparing antitoxins, tuberculin and vaccines. Eggerth, The History of the Hoagland Laboratory, chpts. 3-5.

¹¹² In 1907, Kansas State College hired Walter E. King to head its newly created Department of Bacteriology, only to lose his services to Parke Davis, which doubled his \$2,000 yearly salary. Similarly, the University of California surrendered John G. Fitzgerald to the directorship of Connaught Laboratories in Toronto. For A.P. Hitchens and Claude P. Brown, H.K. Mulford offered as many opportunities for challenging research as any university. Mulford gradually became an informal center for bacteriology in Philadelphia, hosting meetings of the "Microbiology Club," sponsoring the Mulford "School of Bacteriology and Immunology," and eventually luring F.M. Huntoon from Cornell's Medical College to head its Glenolden plant. Harry E. Morton, "A History of the Eastern Pennsylvania Branch of the American Society for Microbiology, a Personal Review," 1984, [ASM], box 11-IIG, folder 8; and C.J. Bucher, "Introductory Remarks," Round Table on Bacteriological History, 1947, [ASM], box 2-IXC, folder 56.

pharmaceutical, municipal and university stations.¹¹³

These companies endeavored to develop a catalogue of profitable biologicals (*i.e.*, toxins, antitoxins, sera, vaccines) patterned on the model of diphtheria antitoxin. Parke Davis, for example, manufactured anti-tetanic serum; anti-streptococcic serum for puerperal fever, erysipelas and scarlatina; anti-tubercle serum; erysipelas and prodigiousus toxins for the treatment of malignant tumors; culture media and microscopic slides of ten different pathogenic organisms.¹¹⁴ Despite the questionable therapeutic value of many of these products, they received both continued bacteriological investigation and considerable commercial backing. For example, following Simon Flexner's studies in 1908, Mulford promoted an anti-meningitis serum in 1910. Mixed reviews did not preclude Mulford's proceeds, and the company opened a San Francisco branch in 1915. E.R. Squibb & Sons, eyeing comparable profits, recruited John F. Anderson from the Hygienic Lab and G.F. Leonard of Rutgers to develop their anti-meningitis product.¹¹⁵

Commercial ventures aside, research in public health bacteriology remained

¹¹³ George H. Smith, a PhD in Bacteriology from Brown, worked at Mulford for five years before assuming full professorship at Yale. Ivan C. Hall and Selman Waksman each worked at Cutter Analytical prior to academic appointments at Berkeley and Rutgers, and Severance Burrage, a protégé of Sedgwick and Prescott at MIT, directed research at Eli Lilly in between years at Perdue and Colorado State University. The boundaries between public and commercial sectors were as permeable. J.J. Kinyoun, left his directorship of the Hygienic Laboratory for the Mulford Company. E.J. Lederle, the former health commissioner of New York, exploited his past connections and Park's reputation to found the highly successful Lederle Laboratories. See, Leibenau, Medical Science and Medical Industry; Kerr, "Scientific Research by the Public Health Service," 35-40; and A.M. Stimson's, "A Brief History of Bacteriological Investigations of the USPHS," Public Health Reports suppl. no. 141 (1938).

¹¹⁴ A.S. Schlingman, "Parke, Davis and Company," History Roundtable, 1946, [ASM], box 2-IXC, folder 53, pp. 34-40.

¹¹⁵ Simon Flexner, "Mode of Infection, Means of Prevention, and Specific Treatment of Epidemic Meningitis," Rockefeller Institute for Medical Research, Monographs (1917), 45; and, Selman A. Waksman and Robert L. Starkey, "Bacteriology in New Jersey," 1937, Regional History, [ASM], box 7-IIA, folder 10.11, p. 14. Some commercial products carried minimal scientific support. Parke Davis, for example, distributed a "polyvalent vaccine," derived from common pyogenic organisms and the colon bacillus. Developed by Joshua Van Cott of the Hoagland Laboratory, there was little evidence of its effectiveness. Still, for a few years, surgeons employed the vaccine extensively in cases of severe injuries.

circumscribed. Municipal departments afforded original investigations only in so far as they aided in the routine diagnosis and treatment of the prescribed list of infectious diseases. Research focused on a small number of pathogens and aimed toward developing and standardizing therapeutic sera.¹¹⁶ Moreover, most public agencies lacked the funding, personnel, or time for experimental programs. In comparison, commercial laboratories were more likely to possess the resources for research, but concern for secure capital investments led many directors to shy away from fundamental investigations.¹¹⁷ Public health bacteriologists, like their counterparts in medical schools and hospitals, staked their professional advancement on the ability to isolate, identify, and exclude potential pathogens. In that endeavor, they achieved considerable success. Yet, the fulfillment of the service role precluded the advancement of the science. Pressed for reliable and cost efficient diagnostic and therapeutic measures, public health departments neither accommodated nor encouraged explorations of lingering questions.

Public Hygiene and Sanitary Bacteriology

The increasing complexity of modern society gives rise continually to new sanitary problems which must be solved and the results applied if we would escape race deterioration and the loss of industrial property. -- J.W. Kerr¹¹⁸

In the first decades of this century, medical and public health bacteriology encompassed techniques to isolate, identify and eliminate putative pathogens from individuals or groups of

¹¹⁶ A 1902 federal statute authorized the Hygienic Laboratory to monitor and issue licenses for the production of biologicals. As a consequence, the laboratory became the focus of ongoing research to standardize viruses, serums, and toxins. See, Kerr, "Scientific Research by the Public Health Service," 35-40; and Stimson, "Hygienic Laboratory," 199-208.

¹¹⁷ Difco committed only limited research monies to sera, hiring instead Herbert D. Pease (New York State Department of Health), J.W.M. Bunker, Anna Williams, Edward Banzaf, and Benjamin White (New York City Health Department) to help develop the highly profitable culture media proteose peptone. H.G. Dunham, "Bacteriology at Difco," History Roundtable, 1946, [ASM], box 2-IXC, folder 53, pp. 29-33.

¹¹⁸ J.W. Kerr, "Scientific Research by the Public Health Service," 270.

individuals. In contrast, sanitary bacteriology targeted germs in environments rather than bodies, particularly as those found in water, milk, and food. Moreover, the defining characteristic of sanitary bacteriology was its near exclusive emphasis on eliminating germs, and relative neglect of the tasks of isolating and identifying them. For the medical and public health bacteriologists, differentiating pathogenic from nonpathogenic species comprised a core element of their expertise. In the context of sanitary science, all bacteria portended a source of danger. As a consequence, sanitary bacteriology served as the embodiment of the "hygienic" vision of bacteriology, a technical task with little incentive to understand the very organisms it vowed to eliminate. As with the previous sections, the following paragraphs argued that the development of sanitary science facilitated a remarkable professional growth of bacteriology, as well as its conceptual limitation.

Sanitary science in the United States emerged as an outgrowth of urbanization. Aligned with a loose collective of trained professionals and reformers, sanitary scientists championed the study of environmental influences as they affected the well-being of communities and individuals, with the intent of eliminating the unfavorable environmental contacts and strengthening the favorable. Its advocates viewed the undertaking as an essential corrective to the unintended consequences of modernization, a scientific approach to the task of municipal reform.¹¹⁹ Bacteriology represented one ingredient in the pursuit of a salubrious and efficient

¹¹⁹ Earle B. Phelps, a Professor of Sanitary Science at University of Florida, explained that the goal of his field was the "the protection of the individual from the sanitary hazards which result from his associations in society." Phelps and John E. Kiker, "Rediscovering Our Heritage in Sanitation," American Journal of Public Health 43 (1953): 7 & 10. For historical interpretations of the link between sanitary science and modernization, see, Jon A. Peterson, "The Impact of Sanitary Reform Upon American Urban Planning, 1840-1890," Journal of Social History 13 (1979): 83-104; Stanley K. Schultz and Clay McShane, "To Engineer the Metropolis: Sewers, Sanitation and City Planning in the Late Nineteenth-century America," Journal of American History 65 (1978): 389-411; and, Sam Alewitz, Filthy Dirty: A Social History of Unsanitary Philadelphia in the Late 19th Century

environment, and sanitary bacteriologists viewed themselves as stalwarts of science in the solution of social problems.¹²⁰

Although institutionally related to public health departments, sanitary science, in the opinion of its practitioners, was distinct from medicine. C.-E.A. Winslow, while still an Assistant Professor at MIT, defined the field in 1906. Winslow acknowledged that sanitary science owed its origins to medicine; the municipal and state concern for health and healthy environments undoubtedly derived from the progress of medical science. Nonetheless, sanitary biologists, sanitary chemists and sanitary engineers employed specialized methods and techniques in their management of water supplies, sewerage, heating and ventilation, garbage collection and disposal, and gas lighting. Sanitary bacteriologists, according to Winslow, were best trained outside of medical colleges, in educational environments that taught chemistry and civil engineering rather than histology or anatomy.¹²¹

On the occasions when sanitary bacteriologists delved into topics properly within the domain of medicine, they turned their attention to matters of "personal" hygiene. This dimension of sanitary science paralleled instruction in public hygiene, the portion of undergraduate courses and recondite writings where "experts" conveyed the laws of healthy living. Between 1900 and 1920, a remarkable number of bacteriologists expatiated on topics of

(New York: Garland, 1989).

¹²⁰ See, Edwin O. Jordan, "The Field of Municipal Hygiene," Popular Science Monthly (1903): 132-40; Jordan, "The Problems of Sanitation," JAMA 50 (1908): 493-8; David H. Bergey, Handbook of Practical Hygiene (Easton, PA: The Chemical Publishing Co., 1899); William T. Sedgwick, "The Experimental Method in Sanitary Science and Sanitary Administration. Address of the Vice-President and Chairman for 1905 of Section K, A.A.A.S. Meeting, 1906," Science 23 (1906): 362; George C. Whipple, The Value of Pure Water 1st ed. (New York: J. Wiley and Sons, 1907); and M.N. Baker, The Quest for Pure Water (New York: American Water Works Association, 1949).

¹²¹ Winslow, "The Teaching of Biology and Sanitary Science in the Massachusetts Institute of Technology," Technology Quarterly 19 (Dec. 1906): 419-423. See also, Prescott, "Laboratory in Public Health Work," 130.

muscular exercise, sleep, foods and feeding, bathing, clothing, and mental work.¹²² Even so, sanitary bacteriology primarily offered means of protecting the individual from unhealthy environments, not strengthening the powers of resistance among individuals.

Bacteriology, in the service of sanitary science, sought to eliminate germs in four environments: the home, water supply, milk, and food. Among these, water and milk bacteriology constituted the principal foci of attention. As for the home environment, bacteriologists developed and tested disinfectants and fumigants. Employed on a widespread basis by health departments and individuals alike, terminal disinfection involved the elimination of disease germs from sick rooms and hospitals. Historians of public health have made much of the "New Public Health" and its consequent abandonment of disinfection practices in the twentieth century. Citing the 1885 report of the APHA Committee on Disinfection, Herman Biggs' support for "bacteriological" over "hygienic" approaches to public health in 1890's, and Charles V. Chapin's stentorian pronouncements in the following decade, these historians have implied that the rise of bacteriological diagnoses directly led to the decline of disinfection. Infected individuals, and not contaminated environments, represented the principal sources of contamination.¹²³ The causal connection is, however, not so clear. The New York City Health

¹²² Winslow, "Teaching of Biology and Sanitary Science," 420. For examples, see, David H. Bergey, Handbook of Practical Hygiene (Easton, PA: The Chemical Publishing Co., 1899); Joseph F. McFarland, Prophylaxis, Personal Hygiene, Civic Hygiene, Care of the Sick (Philadelphia: P. Blakiston's Sons, 1902); William T. Sedgwick and Theodore Hough, The Human Mechanism: Its Physiology and Hygiene and the Sanitation of Its Surroundings, 1st ed. (Boston: Ginn & Company, 1906); and, Jean Broadhurst, Home and Community Hygiene: A Textbook of Personal and Public Health (Philadelphia: Lippincott, 1918).

¹²³ John Duffy, The Sanitarians: A History of American Public Health (Urbana: University of Illinois Press, 1990), esp. chpt. 13, "Bacteriology Revolutionizes Public Health"; Naomi Rogers, "Germs with Legs: Flies, Disease and the New Public Health," Bulletin of the History of Medicine 63 (1989): 599-617; Rosenkrantz, Public Health and the State; and, Rosenkrantz, "Cart before Horse: Theory, Practice and Professional Image in American Public Health, 1870-1920," Journal of the History of Medicine and Allied Science 29 (1974): 57. The sources of this interpretation are found in C.-E.A Winslow's, Conquest of Epidemic Disease: A Chapter in the History of Ideas (Princeton: Princeton University Press, 1943) and a reliance on the writings of Charles Chapin. See, "The

Department continued to operate a disinfection station throughout the 1890's, as did the Brooklyn Bureau of Pathology, Bacteriology and Disinfection. Ezra Wilson of the Hoagland laboratory devoted a substantial portion of his laboratory resources to studying methods of disinfection, as did members of Columbia's College of Physicians and Surgeons and the Hygienic Laboratory of the U.S. Public Health Service. Nationwide, public health departments regularly directed their bacteriological staff to evaluate commercial germicides. While university departments gradually abandoned studies of bromine, sulfur dioxide, and formaldehyde fumigants, research on "fomites" (*i.e.*, the presence, survivability, and distribution of germs through inanimate objects) continued.¹²⁴

Sanitary bacteriology found its greatest application and public success in the management of municipal water supply and sewage. As the threat of great cholera epidemics receded in the waning years of the nineteenth century, public health authorities turned their attention to the perennial problem of typhoid fever. While the disease was endemic to many urban centers, the steady (and largely unnoticed) rates of incidence were punctuated by sporadic and dramatic outbreaks. In 1913, the U.S. Public Health Service reported 17,000 deaths from typhoid fever,

Fetich of Disinfection." Journal of the American Medical Association 47 (1906): 574-80; Chapin, "The Evolution of Preventive Medicine," Journal of the American Medical Association 86 (1921): 215-22; Chapin, Municipal Sanitation in the United States (Providence: Snow & Farnham, 1901); and, Chapin, The Sources and Modes of Infection, 2nd ed. (New York: John Wiley & Sons, Inc, 1912).

¹²⁴ Murray P. Horwood, of MIT, devoted almost his entire career to the study of fomites. See, M.P. Horwood, "History of Bacteriology at the Massachusetts Institute of Technology," Symposium on History of Bacteriology in Northeast Area, 1952, [ASM], box 2-IXC, folder 72. See also, Charles E. Marshall, "Combatting Disease-producing Germs," Bulletin of the Michigan State Agricultural College Experiment Station 172 (1899): 293-310; Mazyck P. Ravenel, "Disinfection and Commercial Disinfectants," Bulletin of the University of Wisconsin Agricultural Experiment Station no. 166 (1909): 1-19; and, William D. Frost, "Our Short Course for Janitors, and Bacteriological Tests of Methods of Cleaning," National Education Association of the United States. Journal of Proceedings and Addresses (1911): 985-992.

resulting from some 150,000 cases, a rate second only to tuberculosis.¹²⁵ The problem of typhoid infected waters periodically held the public's attention. At the World's Columbian Exposition, for example, the Chicago Fair's planners blanched at the highest typhoid fever mortality rate of any American or European city. Rather than conceal the threat of foul waters, the sponsors organized, and publicized the remediations of sanitary engineering. Fair goers took comfort in discovering that their drinking water arrived from new intakes miles from shore, was purified at a plant located on fair grounds, and examined using the most scientific laboratory methods.¹²⁶

The myriad water and sewage systems implemented between 1890 and 1920 demonstrated the utility of sanitary engineering. By 1921, 8,000 filtration plants were in operation in the United States and Canada, serving more than twenty million people, or roughly a third of the residents of cities and towns.¹²⁷ For sanitary bacteriology, these successes sustained a remarkable professional growth. Each filtration plant required a bacteriologist, both during construction and in operation. At MIT, Sedgwick and his pupils proffered bacteriology as the measure of sanitary engineering, the technical means of evaluating a water's purity and a plant's effectiveness. MIT's President Walker noted in an annual report that the Lawrence Station "created a demand from the outside for skilled bacteriologists which up to this time the Institute

¹²⁵ William T. Howard, Public Health Administration and the Natural History of Disease in Baltimore, Maryland, 1797-1920 (Washington: Carnegie Institute of Washington, 1924); Whipple, Typhoid Fever; and, Clayton R. Koppes, and William P. Norris, "Ethnicity, Class, and Mortality in the Industrial City: A Case Study of Typhoid Fever in Pittsburgh, 1890-1910," Journal of Urban History 11 (1985): 259-279.

¹²⁶ William Sedgwick and Allen Hazen, of MIT's Lawrence Experiment Station, designed the water and sewage system. See, Michael P. McCarthy, "Should We Drink the Water? Typhoid Fever Worries at the Columbian Exposition," Illinois Historical Journal 86 (1993): 2-14; and, Karen M. Keefer, "Dirty Water and Clean Toilets: Medical Aspects of the 1904 Louisiana Purchase Exposition," Gateway Heritage 9 (1988): 32-37.

¹²⁷ George W. Fuller, "The Influence of Sanitary Engineering on Public Health," American Journal of Public Health 12 (1922): 17. As a result, typhoid fever incidence rates drooped from 50 to 10 per 100,000.

has not been able fully to meet.”¹²⁸

In departments of public health, bacteriological analyses of water comprised the mainstay of laboratory work. In Winslow’s 1914 survey, two-thirds state departments reported performing regular and routine examinations.¹²⁹ (Table 1.6) There remained, however, a profound irony to these investigations. The pathogenic germ responsible for typhoid fever, *Bacillus typhosus* (Eberth), was nearly impossible to isolate and identify from water samples. Initially, its distribution, even among heavily polluted waters, was minimal. Water presented an unfavorable medium for the multiplication of *B. typhosus*, although only small numbers were needed to incite an outbreak. Secondly, *B. typhosus* closely resembled other intestinal (and non-pathogenic) bacteria. In most respects it was indistinguishable from *B. coli communis*, a nearly ubiquitous inhabitant of mammal intestines. Thirdly, hardier saprophytic organisms almost always out-grew and “swamped” *B. typhosus* on plate cultures. And, finally, the incubation period of typhoid fever (usually ten to fourteen days) and the normal delays of initiating and completing bacteriological cultures (minimum of three days) meant that the suspected water was no longer available for examination. In George Whipple’s singularly authoritative monograph on typhoid fever, he admitted that the “isolation of the typhoid fever bacillus from infected water is a matter of such difficulty that less than a dozen authentic cases of its finding are on record.”¹³⁰

¹²⁸ Quoted in E.O. Jordan, G.C. Whipple, and C.-E.A. Winslow, A Pioneer of Public Health, William Thompson Sedgwick (New Haven: Yale University Press, 1924), 38. In addition to the Lawrence Station, MIT operated another experimental facility in Chestnut Hill and a “Sanitary Research Laboratory” in South Boston. Sedgwick’s students included: H.E. Babbitt (Instructor in Municipal and Sanitary Engineering, University of Illinois); G.C. Bunker (Sanitary Expert, Panama Canal); Theodore Horton (Chief Sanitary Engineer, New York State Board of Health); Charles Gilman Hyde (Prof. Sanitary Engineering, University of California); Earle B. Phelps (Consulting Sanitary Engineer, Washington Health Department and New York City); George W. Fuller (Commissioner of Water Wokds, Cincinnati); and Allen Hazen (Dir. Lawrence Experiment Station).

¹²⁹ Winslow, “Laboratory in the Service of the State,” 227.

¹³⁰ Whipple, Typhoid Fever, 332. B. Meade Bolton remarked: “There is probably no other organism associated with an infectious disease which present so much difficulty in its identification in given cases as the

Faced with such insuperable obstacles, sanitary bacteriologists employed presumptive tests, reasoning that the discovery of *B. coli*, *B. vulgaris*, or *B. sporogenes* indicated a likely contamination of water with human wastes.¹³¹ These presumptive tests, however, neither isolated nor identified specific bacteria. Rather, after plating of water samples on lactose-litmus agar and incubating in lactose-bile medium in fermentation tubes, the formation of acid and gas presumably indicated the presence of intestinal bacteria.¹³² Such methodological uncertainties spurred continued bacteriological investigations, as many sanitary biologists refused to give up hope of isolating the real culprit, or at least of fixing the proper relationship between *B. coli* contamination and the assured presence of *B. typhosus*.¹³³

For sanitary bacteriologists employed by departments of public health, the immediate task remained one of developing standardized methods of water analysis. In 1894, the American Public Health Association (APHA) created a Subcommittee of the Committee of Pollution of Water Supplies in order to bring "order out of the chaotic state of the literature of water bacteria." Wyatt G. Johnston, Director of the Montreal Municipal Laboratory, chaired the subcommittee, and William Welch supervised a set of meetings in New York. In 1897, the

typhoid fever bacillus, and yet there is none which so frequently demands early and prompt identification." Bolton, quoted in editor's revision of Williams, A Manual of Bacteriology, 2nd ed., 372.

¹³¹ It was inferred that a "water rich in bacteria contains the necessary food-supply for the growth and development of bacteria, and hence would support the life of any pathogenic species that might gain access to it." Bergey, Principles of Hygiene, 99. See also, William T. Sedgwick, Principles of Sanitary Science and the Public Health (New York: Macmillan Co., 1902); and, Samuel C. Prescott and C.-E.A. Winslow, Elements of Water Bacteriology, with Special Reference to Sanitary Water Analysis (New York: J. Wiley & Sons, 1904).

¹³² Endorsement of bacteriological examinations of water continued, despite the reliance on questionable methods. Bolton provided a rare moment of critical self-examination in his textbook, relating that "many of those who have made disinterested study of the subject are inclined to question the value of chemical and bacteriological analysis *in toto*, and in view of the arbitrary and mechanical manner in which the results of these analyses are sometimes interpreted, this attitude is justified." Bolton, A Textbook of Bacteriology, 148.

¹³³ See, for example, Steve De Gage, "Bacteriological Studies at the Lawrence Experiment Station with Special Reference to the Determination of *B. Coli*," 33rd Annual Report of the Massachusetts Board of Health, 1901 (1902): 397-420.

“Committee of Bacteriologists,” as it was known, issued a preliminary report stressing the need “for a full and accurate description of species of bacteria in which the items have been determined by methods common to the main body of workers, and as a consequence are capable of verification and control.”¹³⁴ The Laboratory Section of the APHA emerged in 1899 as an outgrowth of these meetings and reports. Theobald Smith served as the Section’s first president, and Sedgwick its secretary.¹³⁵ The Section devoted its exclusive efforts to standardizing techniques, and issuing periodically revised reports on methods. While these activities solidified bacteriology’s preeminent position within the APHA in the early twentieth century, they shed precious little light beyond the routine of water analysis.¹³⁶

The rubric of sanitary engineering largely subsumed the study of water bacteriology. At M.I.T., the Sanitary Engineering Department was isolated from the Biology Department, both physically and methodologically. Students received their primary training in civil and hydraulic engineering, with the goal of designing, operating, and monitoring cost-effective sand and mechanical filter systems tailored to individual communities. Bacteriology did comprise a component of the curriculum, as students performed regular examinations for *B. coli communis*.

¹³⁴ Committee of American Bacteriologists to the Committee on the Pollution of Water Supplies of the American Public Health Association, “Procedures Recommended for the Study of Bacteria, with Especial Reference to Uniformity in the Description and Definition of Species,” in American Public Health Association, Proceedings 23 (Concord N.H.: Rumford Co., 1897). See, Mazyck P. Ravenel, “The American Public Health Association, Past, Present, Future,” in A Half Century of Public Health, 7-21; C.-E.A. Winslow, “Some Leaders and Landmarks in the History of Microbiology,” Bacteriological Reviews 14 (1950): 99-114; and, Anna M. Sexton, “Wyatt Galt Johnston and the Founding of the Laboratory Section,” American Journal of Public Health -- Year Book 40 (1950).

¹³⁵ Howard Bodily, “The First Section: Laboratory,” American Journal of Public Health 63 (August 1973): 668-669; Anna M. Sexton, “Theobald Smith: The First Chairman of the Laboratory Section,” American Journal of Public Health -- Yearbook 41 (1951); and, Edwin O. Jordan, “William Thompson Sedgwick,” Journal of Infectious Diseases 28 (1921): i-ii.

¹³⁶ See, “Report of the Committee on Standard Methods of Water Analysis to the Laboratory Section of the American Public Health Association,” Journal of Infectious Diseases, Suppl. 1 (May 1905): 1-141; and, “Report of the Committee on Standard Methods of Water Analysis,” American Journal of Public Hygiene 17 (1907): 367.

Nonetheless, bacteriological examinations were never considered to be as vital or as definitive as chemical tests.¹³⁷ Other university programs conveyed a corresponding view of water bacteriology. (Table 1.7) Bacteria may have comprised the object of action for sanitary engineering (*i.e.*, the organisms to be eliminated) but not the primary object of study.¹³⁸ (Table 1.8)

Sanitary bacteriologists themselves held marginal interest for bacteria. As George Whipple admitted in 1908:

A mere list of the titles of the papers which have been written about typhoid fever would fill a volume of considerable size. Yet with all this study we know but little about the inner structure of the organism, little about its physiology, and little about the conditions which affects its behavior inside, or its longevity outside the human body.¹³⁹

On a few occasions, the germ did assume center stage. One such instance arose from a suit before the U.S. Supreme court, filed by the City of St. Louis and the State of Missouri to enjoin the Chicago Sanitary District's opening of the Chicago Drainage Canal. The Drainage Canal represented a monumental public works project, designed in the mid-1890's by the former director of the Lawrence Experiment Station Allen Hazen, that effectively reversed the flow of the Chicago River in an effort to separate the city's sewage from its water supply. Rather than depositing sewage into Lake Michigan, Chicago thereafter directed its wastes to the Illinois

¹³⁷ Samuel C. Prescott, "Professor Sedgwick - His Life and His Work," Journal of the Boston Society of Civil Engineers (Jan. 1948): 79-82; Prescott, "Opening Remarks, Symposium on History of Bacteriology in the Northeast, 1952," [ASM], box 2-IXC, folder 77; George Whipple, "Fifty Years of Water Purification," in A Half Century of Public Health, 179; and, Whipple, "There were Giants in Those Days," American Journal of Public Health 34 (1953): 17.

¹³⁸ At the University of Pittsburgh, for example, instruction in water bacteriology was provided by a professor of chemistry. Charles Gainor, "Report on the History of Bacteriology in Pittsburgh," Symposium on the History of Bacteriology, 1954, [ASM], box 2-IXC, folder 88. See also, George C. Whipple, "Sanitary Engineering at Harvard University," Bulletin of the Society for the Promotion of Engineering Education (1912): 242-247; Whipple, "The Element of Chance in Sanitation," Journal of the Franklin Institute (July/August 1916): 37-59, 206-228; and, Mansfield Merriman, Elements of Sanitary Engineering (New York: Wiley, 1918).

¹³⁹ Whipple, Typhoid Fever, 8.

River, which in turn fed the Mississippi thirty-three miles north of St. Louis.¹⁴⁰

Fearing that sewage poured into the Illinois River and carried down the Mississippi would contaminate its drinking water, the St. Louis Health Department directed its bacteriological staff to evaluate the potential danger. This investigation, headed by Amand Ravold of the Bacteriology Department at Washington University, employed a novel experimental design. In order to calculate survivability in natural environments, Ravold deposited enormous quantities of *Bacillus prodigiosus*, a saprophytic organism not normally found in river waters, at the canal's origin, isolating them again from the St. Louis intake.¹⁴¹

In response, Chicago's health commissioner requested its own bacteriological investigations, performed by acknowledged experts from the University of Illinois (Arthur W. Palmer, T.J. Burrill), Northwestern University (J.H. Long, F.R. Zeit) and the University of Chicago (E.O. Jordan, Adolph Gerhmann). To contest Ravold's claims, Jordan developed an equally novel experimental design, employing actual *B. typhosus* enclosed in celloidin sacs that allowed exchange of fluids, but not the escape of the microbes. From their three years of study, Jordan and his associates argued before the court that the pathogens were no longer viable after their 357 mile journey.¹⁴²

¹⁴⁰ James C. O'Connell, Chicago's Quest for Pure Water, Essays in Public Works History Series, no. 1 (Chicago: Public Works Hist. Society, 1976); Louis P. Cain "Unfouling the Public's Nest: Chicago's Sanitary Diversion of Lake Michigan Water," Technology and Culture 15 (1974): 594-613; Cain, Sanitation Strategy for a Lakefront Metropolis: The Case of Chicago (DeKalb: Northern Illinois University Press, 1978); and, Cain, "The Search for an Optimum Sanitation Jurisdiction: The Metropolitan Sanitary District of Greater Chicago -- A Case Study," Essays in Public Works History 10 (1980): 1-35.

¹⁴¹ Fleisher, "The History of Microbiology in the Eastern Missouri Branch," op cit. The demonstrative utility of *B. prodigiosus* is notable because when cultured on solid media, its colonies appear as bright red specks, plainly visible to untrained, and unaided, eyes.

¹⁴² Edwin O. Jordan, The Self Purification of Streams, Decennial Publications of the University of Chicago, First Series, 10 (Chicago: University of Chicago Press, 1903), 81-89; and, Jordan, Harry L. Russell, and F.R. Zeit, "The Longevity of the Typhoid Bacillus in Water," Journal of Infectious Diseases 5 (1904): 641-689.

The suit itself featured testimony from hundreds of experts, including such luminaries as Theobald Smith and William Sedgwick, reported in some 8,000 printed pages. The case attracted considerable public attention and press coverage. While the court dismissed the complaint without prejudice in 1906, Jordan became something of a celebrity among public health officials and bacteriologists. More importantly, his efforts drew attention, at least obliquely, to the study of bacteria within sanitary science.¹⁴³ Sanitary bacteriologists slowly turned their attention to such fundamental issues as systematics, and the biochemistry of activated sludge in Emscher tanks. By the late 1910's, such research lines progressed considerably, probing the environmental and associational conditions (*i.e.*, mixed and changing bacterial flora) that oxidized and reduced sewage.¹⁴⁴ Even so, the goal of water bacteriology stood as the elimination, not comprehension, of bacterial specimens.

A similar hygienic vision sustained bacteriological examinations of milk. Beginning in the 1890's, health reformers and pediatricians suspected that "impure" milk defined more than simple adulteration and skimming. Early reports indicating that market milk harbored innumerable germs heightened their concerns.¹⁴⁵ During the first years of this century,

¹⁴³ Burrows, "Edwin Oakes Jordan," 207; and White, "History of Public Health Bacteriology in Chicago," 3. A similar attention to the viability of bacteria resulted from the controversies surrounding the use of chlorination in cases of infective filtration. See, Colleen K. O'Toole, The Search for Purity: A Retrospective Policy Analysis of the Decision to Chlorinate Cincinnati's Public Water Supply, 1890-1920 (New York: Garland, 1990); and, Frank F. Westbrook, H.A. Whittaker, and B.M. Mohler, "The Resistance of Certain Bacteria to Calcium Hypochlorite," Journal of the American Public Health Association 1 (Feb. 1911).

¹⁴⁴ See, for example, Edwin O. Jordan, "The Kinds of Bacteria Found in River Water," Journal of Hygiene 3 (Jan. 1903): 1-27; Steven De Gage with Earle B. Phelps, "On the Classification and Identification of Bacteria with Description of the Card System in Use at the Lawrence Experiment Station for Records of Species"; Arthur I. Kendall, "A Proposed Classification and Method of Graphical Tabulation of the Characters of Bacteria," both in American Public Health Association, Proceedings 1902 28 (1903): 481-492, 493-505; and, Edward G. Birge, "The Action of Certain Bacteria on the Nitrogenous Material of Sewage," in Papers on Bacteriology and Allied Subjects, by Former Students of Harry Luman Russell (Madison: University of Wisconsin, 1921), 420.

¹⁴⁵ See, William T. Sedgwick and John L. Batchelder, "A Bacteriological Examination of the Boston Milk Supply," Boston Medical and Surgical Journal 126 (1892): 25; and, Theobald Smith, "Channels of Infection, with

bacteriologists joined controversies over the transmission of tuberculosis, septic sore throat, scarlet fever, and infant diarrhea, through dairy products. The central questions regarded the identity of bacteria, that is, whether the bovine type of tubercle bacilli was akin to the human type, or whether the streptococci recovered from milk were related to those responsible for septic sore throat.¹⁴⁶ In this regard, milk bacteriology paralleled medical or public health investigations, which relied heavily on techniques for differentiating pathogenic from nonpathogenic microbes.

The hygienic goal of exclusion soon superseded questions of identity. In Chicago, for example, the Department of Health publicly reported bacterial counts from local milk dealers. A 1904 study by Edwin Jordan and Paul G. Heinemann of the University of Chicago found that over 50% of market samples contained between 1 and 20 million bacteria per cubic centimeter, while 16% harbored more than 20 million. Likewise, studies of Baltimore milk revealed an average count of 5 million per c.c. These startling numbers evidenced an "impurity" of dairy products, and clean milk campaigns became a mainstay of muckraking journalists and civic reformers. Little effort was expended in determining the pathogenic and saprophytic portions of these high bacterial counts. Instead, reformers reiterated the ambiguous claim that city milk contained more germs than an equivalent quantity of sewage.¹⁴⁷

Special Reference to Water and Milk," Popular Health Magazine 1 (1893): 279-287.

¹⁴⁶ Theobald Smith argued in 1896 that the two types of tubercle bacilli constituted distinct species. Smith, "Comparative Study of Bovine Tubercle Bacilli and Of Human Bacilli from Sputum," Journal of Experimental Medicine 3 (1898): 451-511; Hans Zinsser, "Theobald Smith," National Academy of Sciences Biographical Memoirs 17 (1936): 261-303; and, Barbara G. Rosenkrantz, "The Trouble with Bovine Tuberculosis," Bulletin of the History of Medicine 59 (1985): 155-175. Mazyck P. Ravenel challenged this assumption, isolating the bovine type of bacilli from human lesions in 1901. See, Ravenel, "The Intercommunicability of Human and Bovine Tuberculosis," Proceedings of Pathological Society of Philadelphia (May 1902); and, Ravenel, "The Comparative Virulence of the Tubercle Bacillus from Human and Bovine Sources," Lancet 2 (1901): 349-356, 443-448.

¹⁴⁷ Charles E. North, "Milk and Its Relation to Public Health," in A Half Century of Public Health, 239; Ravenel, "Preventive Medicine," 16; Judith Walzer Leavitt, The Healthiest City: Milwaukee and the Politics of Health Reform (Princeton: Princeton University Press, 1982), 156-189; William H. Park, "The Great Bacterial Contamination of the Milk of the Cities. Can It Be Lessened by the Action of Health Authorities?" Journal of

In response to public concerns, reformers and physicians founded medical milk commissions nationwide, enlisting bacteriologists to develop standards, set limits, and perform bacterial counts. The development of standard methods followed the precedent set by water bacteriology. In 1899, the APHA appointed a Committee on the Bacteriological Analysis of Milk, and in 1905 the Laboratory Section agreed to issue a manual of methods to standardize such procedural details as the optimal time and temperature for incubation, methods of dilution, and formulae for stains.¹⁴⁸ Setting numerical limits for “safe” milk proved a more problematic task. Among sanitary bacteriologists, there was an unstated agreement that 10,000 bacteria per c.c. was ideal, 500,000 per c.c. was tolerable, and over 5 million dangerous, but no one could offer experimental evidence in support of these limits.¹⁴⁹ Nonetheless, medical milk commissions sponsored routine examinations, often as part of standard health department operations. In Winslow’s 1914 survey, 30 of 47 respondents reported conducting bacteriological counts. While the issue of milk hygiene will be examined at length in the next chapter, these developments illustrate how sanitary bacteriology embraced the hygienic vision to validate a reform campaign that equated all germs with disease.¹⁵⁰ In this manner, milk bacteriology represents another example of sanitary science’s goal of eliminating, rather than investigating,

Hygiene 1 (1901): 391; and, Julie Miller, “To Stop the Slaughter of Babies: Nathan Straus and the Drive for Pasteurized Milk, 1893-1920,” New York History 74 (1993): 158-184.

¹⁴⁸ See, Francis H. Slack, “Methods of Bacteriological Examination of Milk,” and Samuel C. Prescott, “The Need for Uniform Methods in the Sanitary Examination of Milk,” both in Papers and reports of the American Public Health Association 31, no. 2 (1905): 214-222, 246-248; “Preliminary Statement by the Committee on Standard Methods of Bacterial Milk Analysis,” American Journal of Public Hygiene 17 (1907); “Standard Methods of Bacteriological Analysis of Milk: Provisional Report of the Laboratory Section of the American Public Health Association,” American Journal of Public Health 6, no. 12 (1916); and, APHA, Standard Methods for the Examination of Dairy Products, Microbiological and Chemical (New York: American Public Health Association, 1910, revised in 1916).

¹⁴⁹ Gay, Meyer and Rusk, Outline of Combined Courses in Pathology, 133.

¹⁵⁰ Winslow, “The Laboratory in Service to the State,” 228.

bacteria in the human environment.

Killing the Germ, Limiting the Science

The development of medical, public health, and sanitary bacteriology traditionally proffers a narrative of success, a process where laboratory experts revealed the true etiological agents of disease, and developed mechanisms for their prevention or cure. There is little doubt as to the validity of this account. To varying degrees, bacteriology did provide the doctor, health commissioner, and hygienist with tools to accurately diagnose and therapeutically address numerous infectious diseases. There is also little doubt that the puissance of bacteriological manipulations promoted the rapid professional growth of the discipline. By 1920, medical colleges, hospitals, and public health departments increasingly integrated bacteriologists and their laboratory manipulations. Bacteriology was increasingly called upon to provide and legitimate ventures of municipal and civic reforms.

This chapter illustrates the ways in which bacteriology's professional growth, aided by its attentive service to other enterprises, arrived at the expense of disciplinary and conceptual development. Leo Rettger's 1918 address before the Society of American Bacteriologists voiced a concern that bacteriology was little more than a collection of techniques and methods. In Rettger's opinion, and he was not alone, bacteriology lacked a theoretical grounding and a fundamental knowledge of bacteria as biological organisms.

The sources of this conceptual impoverishment were manifold. Within medical bacteriology, most practitioners remained ill-trained in the field, receiving a meager semester in laboratory instruction paired with a series of didactic lectures. Medical bacteriologists concerned

themselves with a limited number of organisms, those directly responsible for pathological processes. For the most part, research in medical bacteriology addressed issues of immune response, rather than the cytological, physiological, or biochemical properties of the pathogens. Most importantly, the programmatic methods of isolation, identification, and elimination narrowed the range of phenomena available for investigation. The near universal methods for pure culture precluded extended examinations of variation, heredity, microbial associations, and the like.

The public health context similarly limited the scope of bacteriological investigations. The number of organisms addressed was smaller, the training more scant, and the institutional environment even more restrictive. Public health laboratories remained underfunded, understaffed and overworked. As a whole they were ill-inclined to stray from the immediate task of efficiently and reliably performing the overwhelming quantity of examinations. In some institutional environments, particularly within commercial pharmaceutical laboratories, bacteriologists performed a modicum of original research pursuant to the development of antitoxins, sera and vaccines. Still these efforts addressed few organisms, focused on immune responses, and sought to fix microbial behavior in invariable states.

Within sanitary science, bacteriology jettisoned its concern for isolating and identifying. The hygienic vision of exclusion placed a preeminent priority on eliminating (or at least reducing) all germs from the human environment. Sanitary bacteriologists contributed greatly to attainment of clean water and clean milk, offering their services to city planners, civil engineers and health reformers. Nonetheless, the chief tasks of sanitary bacteriology centered on problems of standardization, the effort to routinize methods for the discrimination of safe environments.

On occasion, bacteriologists recognized the confines of their disciplinary success. In an address before the 1904 St. Louis International Congress of Arts and Sciences, Theobald Smith reasoned that bacteriology differed from “the older sections of biology” in several regards. Initially, “it has been developed under the stress of practical demands. The enormous economic and sanitary significance of bacterial life has pushed forward this study very rapidly, and the problems undertaken” were those most prominent in medical practice. In its hurried maturation, “there was no ulterior interest in the study of bacteria as such, which is a strong impulse in many other departments of biologic science. It is what bacteria do rather than what they are, that commanded attention.” Most importantly, bacteriology pursued the elimination of its object of study, *qua* parasite. As soon as the bacteria “could be handled in pure culture, the study prosecuted most actively was how most quickly to destroy them. . . .The first impulse of the youthful branch of bacteriology was thus to destroy, rather than to study and analyze.” Smith concluded: “As a result of this rather unique state of affairs, bacteriology is not a self-contained, well-defined field of work, but one greatly subdivided by aims and methods of study.”¹⁵¹

Nonetheless, this chapter demonstrates that medical, public health, and sanitary bacteriology did not always remain entirely consumed with routine examinations. Each of these contexts sustained original research, adding in an unintentional fashion to the store of knowledge of bacteria themselves. These investigations, while frequent and often probing, were disjointed and pursued with single minded intent to solve specific problems. Moreover, medical, public health, and sanitary bacteriologists conducted research with the goal of eliminating bacteria from

¹⁵¹ Theobald Smith, “Some Problems in the Life History of Pathogenic Microorganisms,” Science 20 (1904): 818.

individuals and human environments, not with the aim understanding their underlying behavior or unity of composition.

CHAPTER TWO

“KILL THE GERM” ONCE AGAIN: VETERINARY BACTERIOLOGY

The preceding chapter delineated bacteriology's service role to medicine, public health, and sanitation, suggesting that the discipline experienced a period of rapid growth as it tendered tools for the isolation, identification, and elimination of pathogens. This “hygienic program” favored the development of routine bacteriological manipulations, while it discouraged research in the fundamental, or biological, aspects of bacteria. Pure culture methods comprised the unifying techniques of the field, and although they enabled bacteriologists do “work” in a variety of settings, their cookbook and recipe formulations limited the range of phenomena that bacteriologists considered relevant. Underlying this critique of medical bacteriology is the assumption that eliminating a discipline's object of study is a poor path toward understanding that object. The “hygienic vision” -- nurtured within the contexts of medicine, public health, and municipal sanitation -- probed the nature of microorganisms only as far as necessary to identify pathogens and facilitate their removal.

These next two chapters examine the development of American bacteriology outside spheres of medicine, public health, and municipal sanitation. They provide a description of bacteriology in the agricultural context. Curiously, veterinary, dairy, and soil bacteriology have largely escaped historical scrutiny. Unlike developments in the medical or public health spheres,

agricultural bacteriology remains without a critical historiography. The scholarly lacuna might be explained by the limited attention devoted to agricultural science in general. Charles Rosenberg and Alan Marcus stand as the two principle contemporary historians of American scientific agriculture, and while their inquiries have led to a clearer understanding of the development of experiment stations and land grant colleges, the full dimensions of agricultural research remain to be explored. The following few chapters aspire, in small some measure, to encourage further investigation into the history of American agricultural science.¹

Chapters 2 and 3 situate bacteriology outside the medical realm, and argue that the agricultural context nurtured the development of divergent visions of bacteriology. On the one hand, veterinary bacteriologists reenacted the hygienic program of medical bacteriology, seeking to isolate, identify and eliminate pathogenic germs from animals and their environment rather than explore the diverse nature of microorganisms. The tools they developed to these ends proved highly successful, facilitating a professional growth that rendered bacteriologists

¹ While the historiography of agricultural science might be slight, it does feature notable attempts to integrate agricultural research within the broader development of American natural sciences. See, for example, Alan I. Marcus, Agricultural Science and the Quest for Legitimacy: Farmers, Agricultural Colleges, and Experiment Stations, 1870-1890 (Ames: Iowa State University Press, 1985); Hamilton Cravens, Marcus, and David M. Katzman, eds. Technical Knowledge in American Culture: Science, Technology, and Medicine Since the Early 1800's (Tuscaloosa: University of Alabama Press, 1995); Charles Rosenberg, No Other Gods: On Science and American Social Thought (Baltimore: Johns Hopkins University Press, 1976); Rosenberg, "Rationalization and Reality in the Shaping of American Agricultural Research," Social Studies of Science 7 (1977): 401-422; Margaret W. Rossiter, The Emergence of Agricultural Science: Justus Leibig and the Americans, 1840-1880 (New Haven; Yale University Press, 1975); Deborah Fitzgerald, The Business of Breeding: Hybrid Corn in Illinois (Ithaca: Cornell University Press, 1990); Barabar Kimmelman, "The American Breeders' Association: Genetics and Eugenics in the Agricultural Context," Social Studies of Science 13 (1983): 163-204; Paolo Palladino, "The Professionalisation of Plant Breeding in the United States: The Technology of Hybridisation and its Consequences," Minerva (1991): 507-515; Palladino, Entomology, Ecology and Agriculture: The Making of Scientific Careers in North America, 1885-1985 (Amsterdam: Harwood Academic Publishers, 1996); Richard C. Sawyer, To Make a Spotless Orange: Biological Control in California (Ames: Iowa State University Press, 1996). For a sample listing of this historiography, see, Rossiter, A List of References for the History of Agricultural Science in America (Davis: Agricultural History Center, 1980); and, Glenn L. McMullen, Sources for the History of Agriculture and Rural Life in the Iowa State University Library (Ames, Iowa: Iowa State University Library, 1996).

indispensable to veterinary science. However, as in medical, public health, or sanitary bacteriology, this professional flowering arrived at the expense of conceptual development. Like their medical counterparts, veterinary bacteriologists attended to a limited number of organisms and a narrow range of phenomena. This re-enactment is notable given the dissimilarity between the institutional and social contexts of agricultural and medical science. Chapter Two thus offers another illustration of how the success of the routine in bacteriology restricted the study of the fundamental.

On the other hand, dairy science and soil science fostered the development of a contrasting view of the microbial world. Comprising what became the core of "agricultural bacteriology," these two areas nourished practices and technical interventions for the exploitation, rather than elimination, of bacteria. Within these two research sectors, the productive microbe gradually displaced the pathogenic germ, and the ideal of microbial management supplanted that of hygienic exclusion. Yet, the cleavage between the hygienic aims of veterinary bacteriology and the "bacteriologic" vision of agricultural bacteriology was never absolute. Dairy bacteriologists, for example, devoted considerable effort to reducing bacterial counts of market milk. Nonetheless, for the production of cheese and butter, and for the maintenance of soil fertility, these technical experts offered more than simply a catalogue of harmful microscopic agents and techniques for their elimination. Chapter Three contends that the productive microbe enjoined bacteriologists to ascertain its nutritive requirements, biochemical properties, taxonomic relations, and associative behaviors. In pursuit of this knowledge, restrictive pure culture manipulations gradually gave ground to a more fundamental approach to dynamic bacterial populations.

This chapter proceeds in five parts. The initial section delineates the contours of agricultural science, suggesting that bacteriology presented an ideal compromise between pure and applied research, a biological science in the service of state farmers. In the decades bracketing the turn of the 20th century, agricultural experiment stations flourished, evolving from small, understaffed sites of routine examinations into centers for expansive research. This first section draws on the admittedly sparse secondary historical literature of American agricultural science, offering bacteriology as one example of how stations negotiated the conflicting goals of service and basic science. I will suggest that this tension was, in part, productive for agricultural bacteriology, whose proponents could present the science as simultaneously pure and applied.

As this chapter focuses on the hygienic vision of veterinary bacteriology, the second section outlines the general development of veterinary science in America, arguing that bacteriology, in the first decades of this century, gradually came to constitute a core component of instruction and research. Bacteriologists stood within the profession as progenitors of research progress and providers of a new scientific approach to veterinary practice. Their service role to livestock interests facilitated an impressive disciplinary growth, as veterinary bacteriologists offered an array of new diagnostic and therapeutic aids to the local practitioner. Veterinary medicine embraced the laboratory and field techniques of bacteriology at a later date than medicine, but with greater ease.

The third section argues that veterinary bacteriology closely paralleled the content and methods of medical, public health, and sanitary bacteriology. Veterinary bacteriologists, like their medical counterparts, investigated the etiological agents of infectious diseases, offering prophylactic measures of sanitation, vaccinations, and therapeutic sera. In large measure, they

produced simply another instantiation of the hygienic program of isolation, identification, and elimination. During instruction, veterinary bacteriologists focused attention to a limited number of organisms and a narrow range of biological behavior. Researchers adhered to the tenets of pure culture methods, neglecting associational or populational features, while practitioners rehearsed techniques for the routine diagnoses of infectious disease.

The ensuing chapter segment depicts five examples of American research in veterinary bacteriology in order to illustrate how the agricultural science assimilated the hygienic vision of microbial exclusion. The parallel between medical and veterinary bacteriology stems from a number similar of characteristics, from shared pathogens, to a mutual interest in biologics. More importantly, this chapter will contend that the achievements of veterinary bacteriology relied heavily upon the program of isolation, identification, and elimination. The early twentieth century triumphs over bovine tuberculosis, blackleg, hog cholera, contagious abortion, and pullorum wed veterinarians to bacteriological manipulations, but all within the pursuit of hygienic exclusion.

The final section offers, in concluding remarks, a series of potential explanations for the durability of the hygienic vision in veterinary bacteriology. More importantly, this chapter draws a parallel to experiences in the medical sphere, where the "successes" of veterinary bacteriology arrived at the expense of conceptual growth. Once bacteriologists developed techniques for diagnosis and controlling infectious diseases, there remained little incentive within the institutional environment of veterinary medicine to support further research on bacteria themselves.

Service and Science in the Agricultural Context

American research in agricultural science dates to the early nineteenth century. Initially conducted by individual farmers and chemists, and reported in various local societies, agricultural science found institutional support through the mid-century establishment of land grant colleges and an expansion of the United States Department of Agriculture. The passage of the Hatch Act in 1887 created a national system of federally supported experiment stations, each receiving \$15,000 per annum and charged with the legal obligation to conduct original research.² The Act specified several fields of investigation, including topics potentially subject to bacteriological methods. The statute provided for research in "the diseases" to which animals and plants "are severally subject" and "remedies for the same," and authorized the study of "the scientific and economic questions in the production of butter and cheese." In 1890, Congress approved a second Morrill Act, prompting further development of agricultural colleges. At many universities, the increased resources fueled a rapid expansion and specialization among the agricultural sciences, affording the creation of separate departments for such fields as horticulture, veterinary science, animal husbandry, dairy industry, and agronomy.³

Linked by personnel and administration, experiment stations developed in conjunction with the agricultural colleges. In 1890, the forty-six stations employed 429 persons. By 1905,

² Seven states actually established stations before the 1887. The Hatch Act, however, has been credited with having launched scientific research of any kind in most American universities. See, Alfred C. True, "A History of Agricultural Education in the United States," United States Department of Agriculture, Miscellaneous Publication, no. 36 (1929): 1-420; James Gordon Horsfall, The Pioneer Experiment Station, 1875-1975 (Lexington, KY: Antiocha Press, 1992); and, James Gray, The University of Minnesota, 1851-1951 (Minneapolis: University of Minnesota, 1951), 95.

³ At the University of Maryland, for example, the annual operating budget grew 500% between 1887 and 1892, from approximately \$10,000 to \$50,000. George H. Calcott, History of the University of Maryland (Baltimore: Maryland Historical Society, 1966); and, Madison Kuhn, Michigan State: The First Hundred Years, 1855-1955 (East Lansing: Michigan State University Press, 1955), 125, 231 & 238.

the fifty-six stations retained a staff of 850. Among the special branches, the number of research personnel increased steadily. For example, in 1895, the Office of Experiment Stations (OES) listed eleven dairymen and twenty-four veterinarians. A decade later, the OES identified thirty-nine dairymen and thirty-four veterinarians. The OES staff records did not list bacteriologists in 1895 or 1900, but in 1905, the OES identified twenty-five researchers with "bacteriology" as part of their title.⁴

Funding for agricultural experiment stations varied widely. Some states chose to augment the annual federal subvention. In 1905, Indiana appropriated \$85,000, and New York offered \$110,000. By 1909, these amounts increased to \$93,194 and \$122,328, and several other legislatures provided similarly generous support.⁵ In 1916, average funding for experiment stations stood at \$98,985, and in 1920 it reached \$129,840.⁶ In contrast, many other stations endured relative impoverishment. In 1905, fourteen stations operated without state aid, and another five relied on meager revenues collected from inspection duties. At the Virginia station, for example, the scarcity in funding produced a research institution that was understaffed, ill-

⁴ Alfred C. True, "Agricultural Experiment Stations in the United States," Yearbook of the United States Department of Agriculture, 1899 (Washington D.C.: Government Printing Office, 1900), 522; True, "A History of Agricultural Experimentation in the United States, 1607-1925," USDA Miscellaneous Publications, no. 251 (1937): 137; and, Harry L. Russell, "The Development of American Bacteriology," in, Papers and Reports of the American Public Health Association, Presented at the 31st Annual Meeting, October 1903, vol. 29 (Columbus: Press of Fred. J. Heer, 1904), 333.

⁵ In 1909, North Carolina allotted \$120,000, Ohio \$118,9990, Illinois \$102,500, California \$99,067, Minnesota \$59,194; and New Jersey \$38,806. Other states, such as Missouri and Maryland, offered increased budgets only in the 1910's. See, Frederick B. Mumford, "History of the Missouri College of Agriculture," Missouri Agricultural Experiment Station Bulletin 483 (1944) 73-74; M.F. Miller, "The Missouri College of Agriculture Through Half a Century -- in Retrospect," Bulletin of the University of Missouri Agricultural Experiment Station 769 (July 1969); and, anon., A Harvest of Progress: 100 Years of Agricultural Research in Maryland: The University of Maryland, Agricultural Experiment Station (College Park: University of Maryland, 1988).

⁶ These station appropriations were often twice the annual budgets allotted to their affiliated land grant colleges. See, for example, Richard G. Moores, Fields of Rich Toil: The Development of the University of Illinois, College of Agriculture (Urbana: University of Illinois Press, 1970); and, Fitzgerald, Business of Breeding, esp. chapter 4.

equipped, and over-crowded, and whose few notable investigators quickly departed for more remunerative positions.⁷

Nonetheless, the scope and reach of agricultural science expanded considerably in the late nineteenth and early twentieth century, as stations widely disseminated their reports and circulars. At Cornell University, the station in the 1890's distributed bulletins to some 14,000 addressees. Historian Margaret Rossiter characterizes the decades surrounding the turn of the century as one of "the golden ages of agricultural science," due to the remarkable funding and organizational structures supporting the conduct and dissemination of research.⁸ To legislators and granges at the turn of the century, the phrase "scientific agriculture" no longer presented a contradiction in terms. In Alan Marcus' opinion, the Hatch Act and OES "granted a national imprimatur to agricultural science and scientists."⁹

Within the burgeoning enterprise of agricultural science, bacteriology followed the disciplinary path blazed by proponents of the "New Botany." Organized in the Society for the Promotion of Agricultural Science during the 1880's, an agglomeration of agricultural botanists endeavored to transform botany from the "pleasurable pastime of identifying the plants of the neighborhood" into an experimental science devoted to the solution of pressing practical demands. These advocates of the "New Botany" exhorted researchers to re-examine the lower

⁷ Harold N. Young, The Virginia Agricultural Experiment Station, 1886-1966 (Charlottesville: University Press of Virginia, 1975), 54-57.

⁸ Gould P. Colman, Education and Agriculture: A History of the New York State College of Agriculture at Cornell University (Ithaca: Cornell University, 1963), 135; and, Margaret Rossiter, "The Agricultural Sciences in the United States, 1860-1920," in The Organization of Knowledge in Modern America, 1860-1920, eds. Alexandra Oleson and John Voss (Baltimore: Johns Hopkins University Press, 1979), 213.

⁹ Marcus maintains that there was always a strong leaning toward science among certain agricultural sectors. In particular, against the background of grave economic conditions, supporters of science viewed new expertise as a "viable alternative to both direct political action and farmer based reforms." Marcus, Agricultural Science and the Quest for Legitimacy, 6, 32 & 217; and, Harold W. Cary, The University of Massachusetts: A History of One Hundred Years (Amherst: University of Massachusetts, 1962), 116.

plants, and in particular those relevant to plant pathology.¹⁰ As such, during the late 1880's and early 1890's, land grant institutions in Wisconsin, Iowa, and Minnesota included bacteriology within their advanced botany courses. Many forerunners of agricultural bacteriology, such as Erwin F. Smith, L.H. Pammel, Harry L. Russell, William D. Frost, began their careers as botanists.¹¹ At state colleges in such dissimilar regions as Texas and New Hampshire, bacteriology prospered within departments of botany or horticulture. The microbial world, according to some of these bacteriologically inclined botanists, represented yet another class of organisms, with particular implications for the phenomena of decomposition, fermentation, and disease.¹²

As independent spheres of research and instruction, the assorted fields of agricultural bacteriology emerged on their own terms in the years surrounding the turn of the century, a full decade after medical bacteriology. For example, the Wisconsin Agricultural Experiment Station named a Department of Agricultural Bacteriology in 1894, built bacteriological laboratories

¹⁰ As a discipline, botany flourished under this new direction, comprising some 700 staff scientists of the USDA in 1916, or 12% of the total staff of 5,500. The Bureau of Plant Industry employed 400 botanists, and another 600 were "engaged in advanced botanic work" at sundry colleges and stations. Richard Overfield, "Charles E. Bessey: The Impact of the 'New' Botany on American Agriculture, 1880-1910," Technology and Culture 16 (1975): 165; Byran D. Halsted, "Botany as it May be Taught," Popular Science Monthly 33 (1888): 369-376; Charles E. Bessey, "Some of the Next Steps in Botanical Science," Science 37 (1913): 2; George T. Moore, "Applied Botany and its Dependence on Scientific Research," Science 21 (1905): 321-332; and, G.P. Clinton, "Botany in Relation to Agriculture," Science 43 (1916): 1-13.

¹¹ E.W. Allen, "The Society for the Promotion of Agricultural Science: Its Present and Its Future," Science 57 (1923): 216; Edward A. Birge, Synopsis of a Course of University Extension Lectures on Bacteriology (Madison: State Journal Printing Company, 1892); and, E.G. Hastings, "Bacteriology at the University of Wisconsin," 1937, American Society for Microbiology Archives [ASM], box 7-IIA, folder 10.16, p. 6.

¹² O.B. Williams, "History of the Department of Bacteriology at the University of Texas, Taken from Material Prepared for the Cornerstone of the Experimental Science Building," 1950, [ASM], Regional History Collection, folder 31-B1, p. 2; L.W. Slanetz, "History of Bacteriology at the University of New Hampshire," 1952, [ASM], box 2-IXC, folder 77; anon., "A History of the New Hampshire Agricultural Experiment Station, 1887-1987," Bulletin of the New Hampshire Agricultural Experiment Station, no. 512 (Dec. 1990); and, Donald C. Babcock, History of the University of New Hampshire, 1866-1941 (Durham: University of New Hampshire, 1941).

within the new Agricultural Hall in 1904, and established a department within the college of agriculture in 1910.¹³ At other universities, agricultural bacteriology developed in concert with medical bacteriology. For example, William Trelease, a Professor at Washington University's Shaw School of Botany offered bacteriology to medical students in the early 1890's, and to sanitary engineering majors in the late 1890's. Herbert Waite, at the University of Nebraska, demonstrated bacteriological methods to both veterinary and medical students, until the medical school was moved to Omaha in the early 1900's. Similarly, John L. Sheldon, a plant pathologist for the West Virginia Agricultural Experiment Station, taught both medical and agricultural bacteriology from 1903 to 1913, when the former course finally transferred to the medical school.¹⁴

Instruction in agricultural bacteriology grew steadily in the first decades of this century, encompassing a wide range of topics and perspectives. In his review of agricultural bacteriology in American colleges and experiment stations, Charles Barthel defined the field as the pursuit of "knowledge of the part played by microorganisms in the bio-chemical processes in soil which stand in connection with absorption of nutriment by cultivated plants, the changes undergone by

¹³ H.A. Harding, "Early Bacteriology at the University of Wisconsin," [ASM], box 7-IIA, folder 10.16; and, Harry L. Russell, "Description of the Laboratories of Agricultural Bacteriology," Annual Report of the Wisconsin Agricultural Experiment Station 21 (1905): 368. For mention of the later development of agricultural bacteriology, see, Felix Lohnis, William Stevenson, and J. Hunter-Smith, Laboratory Methods in Agricultural Bacteriology (London: Charles Griffin and Co., 1913), v; Charles E. Marshall, "Technical Application of Microorganisms to Agriculture," Science 42 (1915): 257-264; and, Robert S. Breed, "Agricultural Bacteriology in Italy, France and England as Seen by a Tourist," Journal of Dairy Science 7 (1924): 205-206.

¹⁴ Moyer S. Fleisher, "The History of Microbiology in the Eastern Missouri Branch of the Society of American Bacteriologists," 1959, [ASM] Regional History Collections, folder 20-A1, p. 11; anon., "The History of Microbiology in the Missouri Valley Branch of the American Society for Microbiology," 1962, [ASM] Regional History Collection, folder 20-A2, pp. 19-20; H.A. Wilson, "A Brief History of General and Agricultural Bacteriology at West Virginia University and the West Virginia Agricultural Experiment Station," 1954, [ASM] box 2-IXC, folder 88; and, Ernest J. Nesius, The First 100 Years: A History of the West Virginia Agricultural and Forestry Experiment Station (Morgantown: West Virginia University, 1988).

natural manure” and “also the changes undergone by milk and dairy products.” These potential applications to veterinary, dairy, and soil sciences enticed many universities to include bacteriological topics within general agricultural curricula, home economics, vocational classes, or farmer’s (winter) short courses.¹⁵ The Michigan Agricultural College, for example, listed fifteen separate courses within the Department of Bacteriology and Farm Hygiene in 1902 (e.g., “Applied,” “Physiological,” “Dairy,” “Soil,” “Household,” “Fermentation,” etc.). In 1905, the college enrolled approximately 1,000 students, 600 of which registered for some form of bacteriological instruction before graduation. The same department registered 1,219 of the college’s 1,993 students in 1916, partly as a response to the College’s new degree in “applied science.” At the University of Illinois, T.J. Burrill perennially complained of insufficient staff and space, as enrollments in bacteriology exceeded classroom limits by more than 30%. At the University of Wisconsin, enthusiasm for bacteriology grew so large that William D. Frost initiated a correspondence course in 1912, featuring a boxed bacteriology kit, mimeographed instructions, outlined lessons, and even tests. At these colleges, bacteriology embodied an ideal compromise between scientific and practical farming, garnering the succor of university officials and state granges.¹⁶

¹⁵ Charles Barthel, A Review of the Present Problems and Methods of Agricultural Bacteriology (Stockholm: Knut and Alice Wallenberg Foundation, 1923), 1. Short courses in agriculture and dairying included bacteriology at Wisconsin and Rutgers. At Brigham Young University, agricultural bacteriology was taught to students enrolled in a preparatory year preceding college matriculation. And, at Kansas Agricultural College and bacteriology comprised a core component of the general agricultural curriculum and household economics. See, J.D. Walters, History of the Kansas State Agricultural College (Manhattan: Kansas State Agricultural College, 1909). At most agricultural colleges, bacteriology remained an elective and technical subject, comparable with chemistry, economic entomology, or plant pathology. True, “A History of Agricultural Education,” 267-284.

¹⁶ Walter L. Mallmann, Recollections of Early Microbiology at Michigan State University (East Lansing: Dept. of Microbiology and Public Health, Michigan State University, 1974), 12-15; Kuhn, Michigan State, 238; T.J. Burrill, Urbana, to E.J. Townsend, Urbana, 23 February 1907, [ASM] Presidential Biography Collection, folder 13-114, pp. 1-2; and, Russell E. Frost, Beloved Professor: Life and Times of William Dodge Frost (New York: Vantage Press, 1961). In a review of a textbook in agricultural bacteriology, Paul G. Heinemann explained that the

The steady growth is also explained by the administrative ascendance of certain bacteriologists at their respective institutions. In the 1910's, the Utah Agricultural College offered the most complete curriculum in bacteriology west of the Mississippi, and sponsored an extensive research program in soil microbiology. Elmer G. Peterson, who had served as a Professor of Physiology and Bacteriology, became Director of the Extension Service in 1912, and then President of the College in 1916. Peterson transformed what was once a fledgling independent program into a burgeoning department with several graduate students, instructors, and research staff. The similarly expansive departments at Rutgers University and the University of Wisconsin developed along similar lines, where Jacob G. Lipman and Harry L. Russell each served as director of the experiment station and dean of the college of agriculture.¹⁷

As a research endeavor, agricultural bacteriology held the promise of unending applications, and occasionally garnered sizable budgets.¹⁸ The field's diversity, however,

field "is gaining prominence in scientific and practical circles. The agriculturalist realizes more and more that scientific investigations are of help to him and the demand on colleges for courses in agricultural topics is constantly increasing." Science 39 (27 February 1914): 327. Barthel suggested that, within agricultural bacteriology, American researchers had quickly surpassed their European counterparts. Barthel, A Review of the Present Problems and Methods of Agricultural Bacteriology, 3.

¹⁷ Anon., "Development of Bacteriology in Utah and the Intermountain Area," 1954, [ASM] Regional History Files, 30-A1; O.W. Israelson, ed., "Pioneering in Western Agriculture: A Résumé of the First Half-Century of Research, 1888-1938," Bulletin Utah Agricultural Experiment Station, no. 282 (1938); Joel E. Ricks, The Utah State Agricultural College: A History of Fifty Years, 1888-1938 (Logan: The Deseret News Press, 1938); A.S. Alexander, A History of the Wisconsin Experiment Station (Madison: Wisconsin Agricultural Experiment Station, 1935); and, William H.S. Demarest, A History of Rutgers College, 1766-1924 (New Brunswick: Rutgers University Press, 1924). Likewise, Charles E. Marshall, after assuming directorship of the Massachusetts station in 1912, greatly expanded the bacteriology department at the Agricultural College. See, Frank P. Rand, Yesterdays at Massachusetts State College: 1863-1933 (Amherst: Mass. State College, 1933).

¹⁸ Former Wisconsin vice president Ira Baldwin recalled that support for bacteriology was greater in the agricultural college than it was at the medical school. "Agriculture had funds appropriated for research. You had the Agricultural Experiment Station with both state and federal funds. And there were very few research funds appropriated directly for any other aspect of work in the University. Occasionally someone would make a grant or a bequest or something, and occasionally there would be a little foundation money coming in. But until the end of World War II there was very little research in areas other than agriculture. Agriculture was almost the research arm of the University." Donna Taylor Hartshorne, My Half Century at the University of Wisconsin, Ira L. Baldwin (Madison: Omnipress, 1995), 59-60, emphasis added. Baldwin's portrayal is corroborated in Kuhn, Michigan State: The First Hundred Years, 213.

frequently presented an institutional disadvantage. At both Iowa State College and the University of Illinois, the newly created departments of bacteriology did not include its applied fields. As a result, the Department of Dairy Husbandry encompassed dairy bacteriology, Agronomy housed soil bacteriology, and the Department of Animal Pathology and Hygiene incorporated veterinary bacteriology.¹⁹ Rather than foster a unified discipline by legitimating bacteriology's standing as a fundamental science, these divisions served to isolate bacteriologists in their various departmental applications.

Moreover, the service role of bacteriology reduced opportunities for non-applied research. At the Michigan Agricultural College, Charles E. Marshall explained in his 1897 annual report that "we have begun no new field of research but one over which the plow has left little to upturn. Our object is not so much to reveal new things as it is to render available and practical what is already known in theory." Marshall reiterated this theme yearly, feeling obliged to carefully justify research expenditures on topics without immediate applications. In his 1911 report to the College President, Marshall defended Otto Rahn's studies on the fermentation capacity of single lactic acid bacteria: "while the subject does not deal with any immediate and direct application to agriculture, it is, however, of fundamental interest and use to workers in the field of microbiology and will doubtless prove essential to the proper development of applied problems."²⁰

The experiences of the Michigan Agricultural College and Experiment Station were, in

¹⁹ G.I. Wallace, "Early Bacteriology at the University of Illinois, Urbana," 1951, [ASM] box 2-IXC, folder 73, p. 4; and, R. Allen Packer, "Bacteriology at Iowa State College," 1958, [ASM] Regional History Collection, no folder number.

²⁰ Mallmann, Recollections of Early Microbiology, 5 & 12. See the entry on Marshall in William J. Beal, History of the Michigan Agricultural College and Biographical Sketches of Trustees and Professors (East Lansing: Michigan Agricultural College, 1915).

many respects, illustrative. Ward Giltner, who assumed directorship of the department following Marshall's departure in 1912, introduced several courses and research projects at the request of other departments. The station bacteriologists produced hog cholera serum and virus, distributed cultures for legume inoculations and vinegar production, and tested samples of water and milk. Not a single staff member, however, held a graduate degree in bacteriology, nor did the department offer an advanced course until 1924. Instead, the department restricted its activities to those fulfilling what Giltner termed the "Land Grant College philosophy" of service and extension.²¹

The conflict between service and science pervaded all aspects of agricultural research in the early twentieth century, and not simply bacteriology. On the one hand, most station directors sought to recruit competent scientific personnel and to conduct original investigations. On the other, these stations were beholden to their client agricultural constituents. The demands of service and extension constrained the choice of research problems and the methods of investigation.²² In 1899, at least twenty-eight state legislatures instructed their stations to inspect commercial seeds, fertilizers and foods. These mundane examinations comprised "practical investigations" that generated immediate payoffs for local farmers and station directors, but they demanded an increasing portion of the staffs' effort. Station personnel "diagnosed samples of

²¹ In his annual report for 1924, Giltner tentatively suggested the need for advanced training: "Very recently we have undertaken to give all dairy students a special course in dairy bacteriology following a lecture and laboratory course in general bacteriology. The results are promising. It might be very well for all crops and soils students to take a similar course soil bacteriology. Students in engineering would profit by more instruction in sanitary bacteriology and home economic students might advantageously pursue their studies in the laboratory beyond what is now required." Quoted in Mallmann, Recollections of Early Microbiology, 25.

²² The body of historical scholarship on agricultural science focuses on this tension between research and service. See, Rosenberg, "Rationalization and Reality," 401-422; Rosenberg, "Science, Technology, and Economic Growth: The Case of the Agricultural Experiment Station Scientist, 1875-1914," Agricultural History 44 (Jan. 1971): 1-20; and, Reynold M. Wik, "Science and American Agriculture," in Science and Society in the United States, D.D. Van Tassel and M.G. Hall, eds. (Homewood, Ill.: The Dorsey Press, 1966), 81-106.

sick soils, made tests for lime requirements, counseled on questions of drainage, fertilization and the use of green manures, analyzed samples of fertilizers and lime, and answered a host of questions on individual problems."²³ Additionally, at least fourteen colleges required their station staff to teach agricultural courses, thus serving double duty.²⁴ Many station members and extension workers held positions on the college faculty, filling two roles for the price of one. In the first years of this century, these exigencies left little time for other ventures. As a consequence, station directors experienced difficulty retaining preeminent investigators who had become increasingly dissatisfied with low salaries, the "causal standards for original investigation," and the "unceasing pressure" from "an aggressive farm constituency for immediate results."²⁵

The passage of the Adams Act in 1906 represented a turning point for agricultural science. The Act doubled the annual federal allotment for each station, from \$15,000 to \$30,000, and specified that the new monies exclusively fund research. In fact, the Adams Act demanded

²³ Norwood A. Kerr, The Legacy: A Centennial History of the State Agricultural Experiment Stations, 1887-1987 (Columbia, MO: Missouri Agricultural Experiment Station, 1987), 31; and, Carl R. Woodward and Ingrid N. Waller, New Jersey's Agricultural Experiment Station, 1880-1930 (New Brunswick: New Jersey Agricultural Experiment Station, 1932), 53. See also, Robert L. Haney, Milestones: Marking Ten Decades of Research (College Station: Texas Agricultural Experiment Station, 1989).

²⁴ Fortunately, enrollments in most agricultural colleges were extremely small until the second decade of the century, at which time they grew rapidly. True, "A History of Agricultural Education in the United States," 300; Wilson Smith, "'Cow College' Mythology and Social History: A View of Centennial Literature," Agricultural History 44 (1970): 299-310; Frank F. Stephens, A History of the University of Missouri (Columbia: University of Missouri Press, 1962); anon., A Historical Sketch of the Iowa State College of Agriculture and Mechanic Arts: Published for the Semi-centennial Celebration, June 6-9, 1920 (Ames: Iowa State College, 1920), 10; Wayland F. Dunaway, History of the Pennsylvania State College (Lancaster: Lancaster Pres, Inc., 1946), 268; Morris Bishop, A History of Cornell (Ithaca: Cornell University Press, 1962); and, H.J. Webber, Some Facts Concerning the New York State College of Agriculture at Cornell University, (Ithaca: Ithaca Journal Print, 1910), 3.

²⁵ Rosenberg, No Other Gods, 149-150. Bacteriology departments equally suffered from high attrition rates. At Kansas Agricultural College, for example, Walter E. King was appointed the first head of the newly created Bacteriology Department in 1907, only to leave two years later for Parke, Davis and Company due to "superior financial considerations and research opportunities." His replacement, Francis Slack, similarly stayed only a year. Anon., "History of Microbiology in the Missouri Valley Branch," 4-5.

that the Office of Experiment Stations approve a station's proposal for "original research" before releasing federal funds.²⁶ No longer could station directors be content to perform routine examinations. Charles Rosenberg, among other historians, has argued that the Adams Act solidified the priority of original research within stations and land grant colleges. Julius T. Willard, in describing his own experiences at Kansas Agricultural College, recalled that prior to 1906, "those wishing to pursue investigations the immediate application of which in practical farming was not apparent were at a great disadvantage. The so-called practical held a whip hand over the scientific. The Adams Act provided funds especially for the relief of this type of experiment station workers." Thus, in 1909, the newly appointed president of the College, H.J. Waters, could confidently reaffirm the "larger responsibility" of stations to make "an exact science of agriculture."²⁷

As for the station scientists themselves, by the second decade of the twentieth century, a greater percentage held advanced degrees from the newly created graduate programs of agricultural colleges, and carried them with a "heightened sense of themselves as professionals

²⁶ Organized in 1894 under the direction of Alfred C. True as an oversight agency, the OES labored to reorient station work away from local problems and toward improving the scientific foundations of agriculture. True openly criticized routine work, and threatened to withhold federal funds from those stations not pursuing original investigations. Lou Ferleger, "Uplifting American Agriculture: Experiment Station Scientists and the Office of Experiment Stations in the Early Years After the Hatch Act," Agricultural History 64 (1991), 5 & 14. True's efforts were strongly opposed by some station directors and college administrators. For examples of administrators' commitment to the 'practical bent', see, Frank P. Rand, Yesterdays at Massachusetts State College: 1863-1933 (Amherst: Massachusetts State College, 1933); John Viles, The University of Missouri: A Centennial History (Columbia: University of Missouri, 1939), 331; and, Stephen F. Strausberg, A Century of Research: Centennial History of the Arkansas Agricultural Experiment Station (Fayetteville: University of Arkansas, 1989), 8.

²⁷ Rosenberg, No Other Gods, 179-183. Julius Willard, History of Kansas State College of Agriculture and Applied Science (Manhattan: Kansas State College Press, 1940), 164; and, H.J. Waters, "The Duty of the Agricultural College," Science 30 (1909): 781. See also, Earle E. Ross, A History of the Iowa State College of Agriculture and Mechanic Arts (Ames: Iowa State College Press, 1942), 242; and, Ross, The Land-grant Idea at Iowa State College: A Centennial Trial Balance, 1858-1958 (Ames: Iowa State College Press, 1958).

deserving of the same respect as their fellow scientists and academicians."²⁸ The research ethos produced a new category of agricultural publications, the 'technical bulletin.' Previously, bulletins chiefly sought to interpret agricultural science to the farmer needs, providing such mundane details as spraying calendars, seed tests, fertilizer reviews, rotation suggestions, etc. Technical bulletins, in contrast, announced research findings to fellow agricultural scientists, not farmers, and therefore provided an interdisciplinary outlet for original investigations.²⁹

The Adams Act offered a panoply of benefits for agricultural bacteriologists. In fact, Rosenberg has suggested that the fund was particularly critical to the development of new agricultural sciences, such as of genetics, biochemistry and bacteriology.³⁰ However, the transformation of bacteriology in the post Adams Act era was not always smooth, and the additional funding occasionally heightened the tension between pure and applied goals of agricultural science. At Wisconsin, the continuing conflict spawned a rather unusual institutional controversy. Upon his promotion from Professor of Bacteriology to Dean of the College of Agriculture in 1907, Harry L. Russell introduced a greater emphasis on fundamental

²⁸ Kerr, The Legacy, 48; Rosenberg, "Rationalization and Reality," 413; and, David B. Danbom, "The Agricultural Experiment Station and Professionalism: Scientists Goals for Agriculture, 1887-1910," Agricultural History 60 (1986): 246-255. The aggregate numbers of station scientists increased in the decade following the passage of the Adams Act. In 1915, the agricultural staff of the University of California rose to 145, Iowa State College 213, Michigan Agricultural College 109, Cornell 189, and Massachusetts Agricultural College 82. Clinton, "Botany in Relation to Agriculture," 3.

²⁹ There is good reason to believe that the average addressee could not comprehend these new technical bulletins, and undoubtedly many more "bulletins were used to start fires in kitchen stoves than were read and used by farmers." Still, the Adams Act and the publication of technical bulletins were fundamental to the advancement of agricultural science. See, Joseph C. Fitzharris, "Science for the Farmer: The Development of the Minnesota Agricultural Experiment Station, 1868-1910," Agricultural History 48 (1974), 219; Roy V. Scott, The Reluctant Farmer: The Rise of Agriculture Extension to 1914 (Urbana. University of Illinois Press, 1970); Colman, Education and Agriculture, 135-136; and, Rosenberg, "Rationalization and Reality," 401. Station "Circulars" emerged as the chosen forum for interpreting "scientific agriculture" to the average farmer

³⁰ Madison Kuhn, in his Michigan State: The First Hundred Years, listed several examples of original research facilitated by the technical bulletins, including C.E. Marshall's studies of bacterial associations, Otto Rahn's "The Usefulness of Curves in the Interpretation of Microbial and Biochemical Processes," and Ward Giltner's research on infectious abortion, p. 244.

investigations at the college and experiment station. Convinced that pressing agricultural problems demanded basic research, Russell bolstered his departments of plant pathology, genetics, entomology, veterinary science, and bacteriology. Edward A. Birge, Professor of Zoology and Dean of the College of Letters and Sciences, was displeased. Basic science, Birge believed, did not reside in the province of a "vocational" institution such as the College of Agriculture. Research in plant pathology properly belonged in botany, experimental breeding and entomology in zoology. Birge insisted, "If general bacteriology is to be taken over, in whole or in part by the College of Agriculture" there was no reason "why general chemistry, botany, or any other science would not equally be taken over."³¹ The regents of the university offered a compromise of duplication, creating two departments of bacteriology, one devoted to medical and public health applications, and the other to all other facets (e.g., dairying, soil science, poultry pathology, veterinary medicine). While the administrative solution was ultimately short-lived, it did allow Russell to sustain a department of agricultural bacteriology bent on both pure and applied investigations.³²

The above paragraphs suggest that bacteriology found ample, if conflicted, institutional support in agricultural colleges and experiment stations during the early twentieth century. Station directors could simultaneously underscore its service role and scientific import, and a

³¹ Edward H. Beardsley, Harry L. Russell and Agricultural Science in Wisconsin (Madison: University of Wisconsin Press, 1969), 68-77; and, Wilber H. Glover, Farm and College: The College of Agriculture of the University of Wisconsin, a History. Madison: University of Wisconsin Press, 1952).

³² Russell is, in fact, best remembered for fostering the practical side of bacteriology, a trait evidenced by his solicitation of some twenty-five industrial grants and fellowships from such companies as Meade Johnson, Quaker Oats, and Commercial Solvents. See, Vernon Carstensen, ed. The Growth of Agricultural Research in Wisconsin (Madison: Wisconsin Agricultural Experiment Station, 1958); and, Merle E. Curti, Vernon R. Carstensen, Edmund D. Cronon, and John W. Jenkins. The University of Wisconsin: A History. Vol. 3 (Madison: University of Wisconsin Press, 1949).

significant number of bacteriologists found employment in state stations and land grant colleges. The remaining sections of this chapter illustrate how this institutional setting influenced the development of veterinary bacteriology, where the success of the service role tended to lessen interest in further study of the microorganism..

Incorporating Bacteriology within Veterinary Science

As a discipline and profession, American veterinary science grew tentatively during the second half of the nineteenth century. Among livestock owners, infectious diseases exacted economically devastating costs, and veterinary bacteriology developed partly in response. Afflictions such as pleuropneumonia, Texas fever, tuberculosis, hog cholera, anthrax, dourine, chicken cholera, equine encephalitis, and equine influenza were prevalent, accounting for annual livestock mortality rates as high as 50% in some southern and mid-western counties.³³ The contagions of black leg, hemorrhagic septicemia, infectious abortion, and Johne's disease ravaged other regions, leading many farmers to believe that the increased traffic in purebreds would only further raise the incidence of animal infections.³⁴

Economic concerns spawned the creation of the first institutional site for veterinary

³³ J.F. Smithcors, The American Veterinary Profession, Its Background and Development (Ames, Iowa: Iowa State University Press, 1963), 419-152; and, Smithcors, The Veterinarian in America, 1625-1975 (Santa Barbara: American Veterinary Publications, 1975).

³⁴ Veranus A. Moore, "The Relation of the Veterinary College to the State," and "The Veterinarian and Conservation: Confidence and Cooperation," in The Report of the Conference at the New York State Veterinary College During the Semi-Centennial Celebration of the Cornell University, June, 1919 (Ithaca: Cornell University Press, 1919), 35-43; and, Ole H.V. Stalheim, The Winning of Animal Health: 100 Years of Veterinary Medicine (Ames, Iowa: Iowa State University Press, 1994), 5 & 23. Secretary of Agriculture, D.F. Houston, estimated the total losses from animal diseases between 1875 and 1915 at \$212 million. Hog cholera headed the list at \$75 million, followed by Texas fever at \$40 million, tuberculosis at \$25 million, contagious abortion at \$20 million, blackleg at \$6 million, glanders at \$5 million, and anthrax at \$1.5 million. See, Bert Bierer, History of Animal Plagues of North America, with an Occasional Reference to Other Diseases and Diseased Conditions (Washington: U.S. Dept. of Agriculture, 1939), 10-17.

research in America, the USDA's Bureau of Animal Industry (BAI). In 1869, Congress appropriated \$15,000 for the study of livestock diseases and, in 1878, allocated another \$10,000 to investigate methods for controlling pleuropneumonia (lung plague in cattle). The next year, the Commissioner of Agriculture established a Veterinary Division, with Daniel E. Salmon as its director. Equipped with a budget of \$150,000, the Cornell University trained Salmon concentrated the Bureau's efforts on the control of contagious diseases. Although a staffing shortage hampered the BAI during its decade of operation, and while it initially shunned research in favor of quarantine and slaughter (*e.g.*, "stamping out"), the Bureau did draw focused attention to the etiological component of animal plagues.³⁵

Concerns for animal health also spurred the development of veterinary colleges. The majority were two-year, proprietary institutions located in urban centers with livestock interests (*e.g.*, St. Louis, Chicago, Kansas City, Cincinnati, Baltimore, Detroit, etc.). Most 19th century veterinary colleges experienced a remarkably short life span; thirty schools open their doors in the 1800's, but only sixteen survived to the turn of the century.³⁶ Among the land grant colleges, veterinary medicine occupied a particularly tenuous existence. For example, the Kansas Agricultural College organized a veterinary department in 1872, only to discontinue it in 1874 for "want of means and room." The Massachusetts Agricultural College offered lectures in veterinary science began in 1869, but did not establish a professorship of veterinary science until

³⁵ T.S. Harding, Two Blades of Grass: A History of Scientific Development in the U.S. Department of Agriculture (Norman, OK: University of Oklahoma Press, 1947); True, "A History of Agricultural Experimentation in the United States," 59; and, Timothy P. White, Retrospection: Depicting in Words the Story of the Bureau of Animal Industry, United States Department of Agriculture (Washington: Bureau of Animal Industry, 1920).

³⁶ Bert Bierer, A Short History of Veterinary Medicine in America (East Lansing: Michigan State University Press, 1955); Bierer, History of Animal Plagues; and, True, "A History of Agricultural Education," 264.

1890. Even institutions that would later flourish struggled mightily in the 19th century. Iowa State founded a school of veterinary medicine in 1879, but only enrolled 3% of the student body throughout the 1880's. At Washington State, the board of trustees authorized a veterinary college in 1890, but offered no classes until 1899.³⁷

In contrast to the institutional struggles of the nineteenth century, veterinary instruction blossomed in the twentieth century, particularly at land grant colleges. By 1927, all but one state offered courses in veterinary medicine, and eleven institutions conferred full veterinary degrees.³⁸ Consequently, the number of American veterinarians rose steadily, from 2,130 in 1890, to 8,163 in 1900, and 11,652 in 1910. Only in the 1920's did veterinary medicine experience a professional crisis, when poor salaries and a decreased reliance on horse power promoted veterinary college enrollments to drop by more than 40%.³⁹

Most veterinary colleges did not sponsor or sustain original research. Instead, several

³⁷ Lilley B. Caswell, Brief History of the Massachusetts Agricultural College: Semi-Centennial, 1917 (Amherst, Mass.: F.A. Bassette Co., 1917); Charles H. Stange, History of Veterinary Medicine at Iowa State College (Ames: Iowa State College, 1929); and, Robert W. Hadlow, "A History of the Development of Scientific Research at the Washington Agricultural Experiment Station in Pullman, 1890-1940" (MA thesis, Washington State University, 1987). An exception to this pattern was the Kansas City Veterinary College, whose dean and president held close affiliations with the BAI. Some 40% of BAI veterinarians in 1905 were Kansas City veterinarians, and the school could afford handsome salaries for its instructors.

³⁸ These thirty-two colleges employed more than 1,000 veterinarians, under such faculty titles as "Professor of Animal Diseases," "Professor of Veterinary Pathology," and "Professor of Bacteriology and Veterinary Science." While a majority offered only limited instruction, a few colleges listed multiple courses in veterinary medicine. See, J.F. Shigley, "The Teaching of Veterinary Medicine to Agricultural Students," 67 Journal of the Veterinary Medical Association (1925): 16-23; and, David S. White, "Teaching Veterinary Medicine to Agricultural Students," Journal of the American Veterinary Medical Association 23 (1926): 189.

³⁹ Bert Bierer, American Veterinary History (Fort Dodge, Iowa: American Veterinary Historical Society, 1940), 113; Ward Giltner, "Some Suggestions for Financing and Promoting Veterinary Education in America," Journal of the American Veterinary Medical Association 67 (1925): 8-15; Veranus A. Moore, "The Significance of the Crises in the Veterinary Profession," Cornell Veterinarian (Oct. 1925): 392-397; and, Moore, "Some Problems for the Veterinarian," Journal of the American Veterinary Medical Association 58 (1925): 1-9. Many veterinarians blamed encroachment from extension agents, and their bacteriological tools, for the cause of their troubles. See, Moore, "American Veterinary Education and Its Problems," Science 34 (1911): 457-464; and, E.T. Hallmann, "Veterinary Education and Research," Journal of the American Veterinary Medical Association 70 (1926): 11.

agricultural experiment stations conducted the bulk of research in veterinary medicine. In his 1899 annual report, Office of Experiment Stations Director Alfred True listed twenty-four stations (with thirty-two veterinarians) investigating animal diseases and methods for their prevention or cure. These researches were not always, however, rigorous or original. More than 50% of the veterinary bulletins reported only routine diagnostic activities, with "no research as a basis" for their findings.⁴⁰ Among the station veterinarians, most "were so overloaded with teaching in the agricultural college, lecturing at farmer's institutes, (and) performing the duties of state veterinarian," that there "could have been little time for research."⁴¹ Nonetheless, the severe limits on time and resources did not diminish the appeal of research for station veterinarians, and many found it possible to conduct meaningful studies despite the burden of routine diagnoses and teaching obligations.⁴²

Within the curricula of late nineteenth- and early twentieth-century veterinary colleges, bacteriology represented an essential, but not sizable, component. (Table 2.1) Throughout the 1870's and 1880's, the *American Veterinary Review* defended the germ theory of animal diseases,

⁴⁰ George C. Christensen, "Veterinary Medical Education," in Smithcors, The American Veterinary Profession, 536; and, True, "Agricultural Experiment Stations in the United States," 524. For examples of non-research bulletins, see, Lowery L. Lewis, "Glanders, Texas Fever, Symptomatic Anthrax," Bulletin of the Oklahoma Agricultural Experiment Station, no. 27 (1897); and, Nelson S. Mayo, "Some Diseases of Cattle: Texas Itch, Blackleg, Tuberculosis, Texas Fever," Bulletin of the Kansas State College Agricultural Experiment Station, no. 69 (1897): 103-134.

⁴¹ Louis A. Merrillat and Delwin M. Campbell, Veterinary Military History of the United States, with a Brief Record of the Development of Veterinary Education, Practice, Organization and Legislation in Two Volumes (Chicago: Veterinary Magazine Corp., 1935), 377. In a review of the 325 station bulletins published on veterinary topics between 1887 and 1900, John J. Repp reported that a "a considerable proportion of these are largely popular bulletins representing little if any investigation." Repp, "The Work of the Veterinary Section of the Experiment Stations," Proceedings of the 37th Annual Meeting, American Veterinary Medical Association, quoted in Merrillat, Veterinary Military History, 377.

⁴² Veranus A. Moore, for example, insisted that "application can never run ahead of the knowledge to be applied and that the only road to higher achievement in practical professional things is by the further development of pure science." Moore asserted that the "greatest amount of so-called practical work of a higher order has been attained in those localities that were characterized by their large number of purely scientific investigators and those doing research." Moore, "Veterinary Science and its Problems," American Veterinary Review (June 1910), 2-3.

translating many of Pasteur's and Koch's studies for a curious domestic readership. And, in contrast to physicians, very few veterinarians objected to bacteriological intrusions into their barnside practice. As a consequence by 1905, Veranus Moore could confidently remark that "bacteriology has become one of the recognized branches in the curriculum of all medical and veterinary colleges."⁴³ A select number of schools featured even extensive instruction in bacteriology. At Iowa State, Louis H. Pammel offered in 1889 a full semester's class in bacteriology. Within two years, the course included an intensive laboratory component, and was required of all senior veterinary students. Similarly, the New York State Veterinary College at Cornell constructed a spacious and well-equipped bacteriology building in the late 1890's to accommodate the increasing enrollments in its several laboratory courses.⁴⁴

The Bureau of Animal Industry and the American Veterinary Medical Association (AVMA) also acted to strengthen the place of bacteriology in veterinary training. In 1908 the BAI employed more than 800 veterinarians, and contemplated the implementation of civil service requirements. That year, the BAI and AVMA appointed a committee to evaluate all veterinary colleges, and make recommendations for their betterment. The final document, which resembled the Flexner report for medical colleges, established standards for admission to veterinary schools, fixed a course of 3 years, and mandated a minimum of 3,200 hours of

⁴³ Smithcors, The American Veterinary Profession, 393; William A. Hagan, "Veterinary Medical Education -- Its Evolution and Present Status," Journal of the American Veterinary Medical Association (1951): 287-292; and, Veranus A. Moore, Laboratory Directions for Beginners in Bacteriology: An Introduction to Practical Bacteriology for Students and Practitioners of Comparative and of Human Medicine, 3rd ed., enl. & rev. (New York & Boston: Ginn & Company, 1905), xxi.

⁴⁴ Packer, "Bacteriology at Iowa State," 3; Packer, "Early History of the Teaching of Veterinary Bacteriology at Iowa State University," Presented at the Annual Meeting of the American Veterinary History Society, NYC, July 19, 1983; William H. Hagan, "History of Bacteriology at Cornell," 1958, [ASM], box 7-IIA, folder 10.12; and, Hoobler, "A Modern Bacteriological Laboratory," Journal of Applied Microscopy and Laboratory Methods 5 (1902): 1909-1916.

instruction. Included among its "recommendations" were 420 hours for pathology, of which 110 were to be devoted to bacteriology (20 lecture and 90 laboratory). The BAI report critical judged most schools, finding that private colleges lacked facilities, while public institutions lacked faculties. As no veterinarian was eligible for BAI employment without meeting these minimum standards, the report effectively eliminated many of the proprietary veterinary schools that were unable to afford new laboratory equipment.⁴⁵

With the failure of most private veterinary schools, the burden of instruction fell to the land grant colleges. Despite federal and state support, these public institutions struggled to afford the costs of additional laboratory instructors, and the BAI requirements did nothing to aid enrollments.⁴⁶ Those that managed survive into the 1920's retained a significant bacteriology component in their curricula, often exceeding the BAI's minimum. A 1929 AVMA survey indicated that many veterinary schools still subsumed bacteriology within their units in pathology or hygiene. Of the eleven colleges listing bacteriology separately, the average hours of laboratory instruction approached 148, and lecture hours 61, far surpassing the BAI's minimum requirements.⁴⁷

⁴⁵ In 1915, fourteen strictly private veterinary schools operated in America, but by 1921 only 3 remained. In 1927 the last private college closed its doors. True, "A History of Agricultural Education," 264-266; Ole H.V. Stalheim, "Contributions of the Bureau of Animal Industry to the Veterinary Profession," Journal of the American Veterinary Medical Association 184 (1984): 1222-1224; A.D. Melvin, "Regulations Governing Entrance to the Veterinary Inspector Examination, and List of Accredited Veterinary Colleges," Circular of the Bureau of Animal Industry, no. 150 (1909); and, J.F. Smithcors, Evolution of the Veterinary Art (Kansas City, Missouri: Veterinary Medicine Publishing Co., 1957).

⁴⁶ At the University of West Virginia, a 3 year veterinary science degree was offered in the college of agriculture beginning in 1905. However, the school and its graduates were never recognized by the BAI, and it closed in 1912. Nesius, A History of the West Virginia Agricultural and Forestry Experiment Station, 57. See also, Veranus A. Moore, "Veterinary Education," Journal of the American Veterinary Medical Association (March 1923): 1-3.

⁴⁷ Veranus A. Moore, "The Veterinary Curriculum," Journal of the American Veterinary Association, (Dec. 1922): 1-14; and, Nelson S. Mayo et. al., "Report of the Committee on Education," Journal of the American Veterinary Medical Association (1931): 669-702.

Research in veterinary bacteriology paralleled developments in its instruction. For example, Nelson S. Mayo represented the only staff member of the Kansas station skilled in veterinary bacteriology in the early 1890's, and published mostly perfunctory bulletins on actinomycosis (1892), mastitis (1894), blackleg, tuberculosis, and Texas fever (1897). At the Agricultural College, Mayo's replacement, Paul Fischer, introduced a course in bacteriology in 1897. The following year, the college incorporated this course into the general agricultural curriculum, and the station established a laboratory to investigate swine plague and blackleg. During the next six years, the college and station employed several veterinarians keenly focused on bacteriological issues. Upon the creation of an independent college of veterinary science, both research and teaching in veterinary bacteriology increased exponentially.⁴⁸

At other stations, bacteriology's service role to state livestock interests produced broad research and extension programs. (Table 2.2) The Utah Station veterinarians served as inspectors for the state, evaluating cases and publishing on tuberculosis, glanders, anthrax, blackleg, sheep scab, and lumpy jaw. At the Arkansas Agricultural Experiment Station, Robert R. Dinwiddie issued bulletins between 1890 and 1912 on hog cholera, Texas fever, bovine tuberculosis, glanders, rabies and blackleg.⁴⁹ The range of bacteriological activities occasionally proved detrimental to ongoing investigations. At both the Virginia and Iowa stations, the veterinarian staff was so over-burdened with enforcing the states' quarantine laws, publishing instructional

⁴⁸ Jean D. Folse, "A Short History of Veterinary Medicine at Kansas State College," typed manuscript (1953), [ASM] Regional History Collection, no folder number.

⁴⁹ Kenneth W. Hill, "History of the Experiment Station: Science Serves the Citizens," Bulletin of the Utah Agricultural Experiment Station, no. 507 (1982); M.C. Merrill and Byron Alder, "A Day at the Utah Agricultural Experiment Station," Circular of the Utah Agricultural Experiment Station, no. 39 (1918); Marie L. Lavallard, "Arkansas Agricultural Experiment Station: The First Forty Years," in Agricultural Progress in Arkansas (Fayetteville: Arkansas Agricultural Experiment Station, 1976); and, Harrison Hale, University of Arkansas, 1871-1948 (Fayetteville: Univ. of Arkansas Alumni Association, 1948).

bulletins, and teaching in college that the directors temporarily terminated all original research.⁵⁰

In addition to the efforts of the experiment stations, the BAI also sponsored significant research in veterinary bacteriology. Equipped with its own animal experiment station, and a half million dollar annual appropriation, the Bureau established eradication or control programs for Texas fever, hog cholera, bovine tuberculosis, fowl cholera, glanders and foot-and-mouth disease. With the creation of the Pathology and Biochemic Divisions in the mid-1890's, Congress increased the operating budget to nearly \$1 million. The Bureau's staff grew steadily, from 777 members in 1897, to 3,311 in 1912, and 4,171 in 1927. While most of the personnel engaged in inspection and regulatory activities, the central office of the Pathology Division employed twenty-four members with the title "research pathologist" or "bacteriologist." Likewise, the budget line for "research" in the Division increased from \$77,360 in 1915 to \$124,560 in 1919, affording generous salaries for bacteriologists.⁵¹

Veterinary Bacteriology and the Hygienic Vision

Conceptually and methodologically, veterinary bacteriology reproduced the hygienic program of isolation, identification, and elimination. This parallel to medical, public health, and sanitary bacteriology can be explained on two levels. First, the fields were linked by training.

⁵⁰ Young, The Virginia Agricultural Experiment Station, 19; Stange, History of Veterinary Medicine at Iowa State College, 18 & 88; and, R.A. Packer, The First 100 Years of the College of Veterinary Medicine, Iowa State University: A Pictorial History (Ames: Iowa State University Press, 1980). A similar dilemma of increasing service demands and decreasing budgets vexed veterinary departments of Cornell and the Maine State Agricultural Station. See, E.P. Leonard, A Cornell Heritage: Veterinary Medicine, 1868-1908 (Ithaca: NY State College of Veterinary Medicine, 1979); Elmer R. Hitchner, "History of Bacteriology at the University of Maine," 1952, [ASM], box 2-IXC, folder 77; and David C. Smith, The Maine Agricultural Experiment Station: A Bountiful Alliance of Science and Husbandry (Orono: University of Maine at Orono, 1980).

⁵¹ U.G. Houck, "History and Activities of the Bureau of Animal Industry," Veterinary Medicine 18 (1923): 82-88; Fred W. Powell, The Bureau of Animal Industry: Its History, Activities, and Organization (Baltimore: Johns Hopkins Press, 1927), 42; and, Daniel E. Salmon, The United States Bureau of Animal Industry, at the Close of the Nineteenth Century, 1884-1900 (Washington: George E. Howard & Co. Printers, 1901).

Early leaders in veterinary bacteriology (e.g., Leonard Pearson, H.J. Detmers, Daniel E. Salmon, Paul Paquin, Harry L. Russell, Charles E. Marshall, Charles B. Morrey) received their bacteriological instruction in the same European laboratories as their medical counterparts. In addition, many of the forerunners held both veterinary and medical degrees.⁵²

In the United States, bacteriological instruction in the late nineteenth century was often combined for medical and veterinary students. At Ohio State, H.J. Detmers taught in the school of veterinary medicine and in the department of physiology until 1890, when separate courses were created. The separation remained only for a short while, as these two listings recombined in 1895 under the instruction of Charles B. Morrey. The bacteriology department of the Pennsylvania School of Veterinary Medicine likewise featured faculty from the Medical School and Hygienic Laboratory (e.g., Mazyck P. Ravenel, Henry Formad, A.C. Abbott, and David Bergey).⁵³ At Cornell, Veranus A. Moore held joint appointments at the New York Veterinary College and at the newly opened Ithaca campus of the medical school. Similarly, Thomas Bowhill and Henry B. Kugeler held concurrent positions on the faculties of the University of California, Berkeley, and the California Veterinary College in the 1890's.⁵⁴ Bacteriologists

⁵² Francis S. Schoenleber, who held a V.M.D and M.D., actually practiced medicine in Chicago while serving as Dean of McKillip Veterinary College.

⁵³ William A. Starin, "History of Bacteriology: The Ohio State University," 1949, [ASM], box 2-IXC, folder 64; Letter from Charles B. Morrey, South Miami to Barnett Cohen, Baltimore, 29 May 1937, [ASM], box 7-IIA, folder 10B; anon., "Some Notes on the History of Microbiology in Ohio, 1833-1963," 1963, [ASM], regional history collection, folder 25-A1; Alexis Cope, Thomas C. Mendenhall, Osman C. Hopper, and Wilbur H. Siebert, History of Ohio State University (Columbus: Ohio State University Press, 1920); Evan L. Stubbs, "The History of Veterinary Bacteriology in Philadelphia," 1947, [ASM], box 2-IXC, folder 56; and, Stubbs, A History of Veterinary Medicine in Pennsylvania (Philadelphia: University of Pennsylvania Press, 1960).

⁵⁴ Simon Gage, "V.A. Moore," Journal of Bacteriology 22 (1931): 1-5; Elizabeth A. Fontana, Centennial Celebration: 100 Years of Creating a Healthier Future for Animals and People (Ithaca: College of Veterinary Medicine, 1994); James Law, "Half Century of Veterinary Medicine in Cornell University," in, New York State Veterinary College During the Semi-Centennial Celebration, 15-20; McClung and Meyer, "Beginnings of Bacteriology in California," 5; and, Donald E. Jasper, A Short History of the School of Veterinary Medicine, University of California (Davis: Simmons Publishing Co., 1964). In fact, until the mid-1910's, the Veterinary Science Building at Berkeley housed the Department of (Human) Pathology, the State Hygienic Laboratory, and the

frequently moved among medical, public health, and veterinary spheres. Between 1890 and 1930, the career paths of B. Meade Bolton, Herbert U. Williams, Coutland Y. White, and Karl F. Meyer included positions at veterinary colleges, medical schools, livestock sanitation boards, and public health departments.⁵⁵

Instruction in veterinary bacteriology inculcated the values of isolation, identification, and elimination. In fact, many bacteriology textbooks covered both human and animal pathogens.⁵⁶ These texts arranged bacteria along pathological lines, defining microorganisms primarily by the diseases they elicited (*e.g.*, the “fowl diphtheria group”). A student might review five or six genera, but with an eye to distinguishing the thirty plus species of animal pathogens from harmless saprophytes.⁵⁷ As Veranus Moore explained in his 1912 manual, “in practical bacteriological analysis, usually no attempt is made to identify all the species present” but to simply detect the “presence of bacteria belonging to groups known to contain species” that were of pathologic significance. This aim encouraged the student to consider the biology of bacteria as relevant to pure culture methods, and the goals of identification and elimination. It was necessary to “learn the life history of each species” merely to determine “its means of

Division of Sanitary Science, with shared equipment, classrooms, and personnel.

⁵⁵ See, James H. Steele, “Karl Friedrich Meyer,” Journal of Infectious Diseases 129 suppl. (May 1974): S3; J.F. Smithcors, “The Medical Men and Veterinary Medicine in America,” Bulletin of the History of Medicine 33 (1959): 330-341; and, W.M. Rosser, “Corollary Development of the Professions of Veterinary and Human Medicine in the United States,” Veterinary Heritage (March 1991): 3-29.

⁵⁶ See, for example, Thomas Bowhill, Manual of Bacteriological Technique and Special Bacteriology (New York: W. Wood & Co., 1899); Frederic P. Gorham, A Laboratory Course in Bacteriology, for the Use of Medical, Agricultural, and Industrial Students (Philadelphia: W.B. Saunders, 1901); Allen J. Smith, Lessons and Laboratory Exercises in Bacteriology: An Outline of Technical Methods Introductory to the Systematic Study and Identification of Bacteria (Philadelphia: P. Blakiston's Son & Co., 1902); and, Ward Giltner, Laboratory Manual in General Microbiology (New York: John Wiley & Sons, 1916). Almost all textbooks included glanders and anthrax as exemplary bacterial diseases.

⁵⁷ Moore, for example, intended his manual to provide merely a “technical and working knowledge of certain of the more essential methods,” and he included descriptions of only four animal, four human, and two shared pathogens. Moore, Laboratory Directions for Beginners in Bacteriology, iii; and Moore, The Pathology and Differential Diagnosis of Infectious Diseases of Animals (Ithaca: Taylor & Carpenter, 1902).

dissemination, the method of its invasion and its resistance to destructive agents, such as sunlight, drying and disinfectants.”⁵⁸ At the University of Tennessee, for example, the course in “Veterinary Bacteriology” stressed “methods of cultivation, isolating and staining of different microorganisms,” with the principal goal of furthering “veterinary hygiene.”⁵⁹

There is some evidence that this confining view of veterinary bacteriology only narrowed with time. In the first edition of his textbook of veterinary bacteriology, Robert Buchanan deduced that since bacteria were plants, “this science may be considered as a subdivision of the great mother of botany.” The second edition curiously omitted this proclamation. Additionally, Buchanan, who was increasingly attuned in his other work to the “complex interrelationships existing between microorganisms and their environment,” limited the chapter on “Bacterial Physiology” in his veterinary text to the particular media requirements of certain pathogens.⁶⁰

Secondly, leading veterinarians desired closer professional affiliations with medicine, while disparaging their institutional location within agriculture.⁶¹ In his 1935 history of

⁵⁸ Veranus A. Moore, Principles of Microbiology: A Treatise on Bacteria, Fungi and Protozoa Pathogenic for Domesticated Animals (Ithaca: Carpenter & Company, 1912), 40 & 159.

⁵⁹ D.F. Holtman, “A History of Microbiology at the University of Tennessee,” 1969, [ASM], Regional History Collection 29-A, p. 2. Other universities reproduced this same approach. See, Veranus A. Moore, Synopsis of Lectures in Bacteriology (Ithaca: Cornell University, Dept. of Comparative Pathology and Bacteriology, 1905); and, Moore and Clifford P. Fitch, Exercises in Bacteriology and Diagnosis for Veterinary Students and Practitioners (New York: Ginn & Company, 1914). At Oklahoma A & M, the laboratory course in bacteriology stressed “the identification of bacteria, the action of disinfectants, the growing of colonies, the examination of substances, etc.” Annual Report of the Oklahoma Agricultural Experiment Station, 1903, p. 13.

⁶⁰ Buchanan, Veterinary Bacteriology: A Treatise on the Bacteria, Yeasts, Molds, and Protozoa Pathogenic for Domestic Animals, 1st. & 2nd eds. (Philadelphia: W.B. Saunders Company, 1911 & 1916), 17 & 45.

⁶¹ See, F.M. Hayes, “Education and Research in Veterinary Medicine,” Journal of the American Veterinary Medical Association 67 (1925): 773-779; Veranus A. Moore, “The Address of the President,” Journal of the American Veterinary Medical Association 56 (1919): 238-250; Henry C. Dethoff and Donald H. Dyal, A Special Kind of Doctor (College Station: Texas A&M University Press, 1991), and Michael S. Dettelbach, “The Harvard University School of Veterinary Medicine, 1882-1901: Veterinarians and the Professional Vision of Charles W. Eliot,” (A.B. honor thesis, Harvard University, 1986). In 1908, there was a proposal to incorporate the veterinary school within the agriculture college. James Law, Dean of the Veterinary School, vociferously objected, arguing that “Veterinary medicine is closely allied to medicine of man, not agriculture. . . . A direction which does not keep

veterinary science, Louis A. Merillat maintained that the Adams and Hatch Acts “divorced veterinary science from the science of medicine and consummated for it a sort of morganatic marriage with agriculture.” Merillat reasoned that “the effort to provide veterinary instruction on the agricultural instruction cost level deprived state veterinary schools of necessary laboratory and clinical facilities,” as well as competent instructors and researchers.⁶² Charles Stange, former Dean of the Iowa State Veterinary College, insisted that “agriculture, from an education and scientific standpoint, has little or nothing to offer veterinary medicine.” In its stead, Stange advocated an alliance with the medical sciences, as research “problems in the entire field of medicine are fundamentally the same and must be solved by the application of the same fundamental sciences.”⁶³

Investigations in veterinary bacteriology, as in medical bacteriology, centered on resolving etiological uncertainties of infectious diseases. In the first decades of the twentieth century, there remained many contagious conditions without identified causal agents (*e.g.*, rinderpest, foot-and-mouth, rabies, fowl diphtheria, equine influenza, canine distemper, infectious abortion, fowl pest, etc.). Moreover, certain diseases (*e.g.*, hemorrhagic septicemia) afflicted diverse animal species, and bacteriologists debated whether they were due to a single bacterial type. In some research programs, veterinary bacteriologists strove to understand the mechanisms by which the same class of microbes could exhibit both saprophytic and parasitic

the essential object preeminent must inevitably neglect, ruin, or dwarf that object.” Quoted in Fontana, Centennial Celebration, 17

⁶² Merillat, Veterinary Military History, 374.

⁶³ “Medical colleges are not training dietitians per se, neither are home economics colleges attempting to train physicians. By the same token why should there be any different relationship between colleges teaching the breeding and feeding animals and those concerned with veterinary medicine.” Stange, “Progress in Veterinary Education,” Journal of the American Veterinary Medical Association 76 (1930): 822-823.

behavior, or to develop diagnostic tests for rapid diagnosis of bacterial infections.⁶⁴

The emerging science of comparative pathology further aligned medicine and veterinary science. Theobald Smith acted, in the United States, as the principal proponent of the field, and offered bacteriology as the unifying investigative tool.⁶⁵ With the creation of the Rockefeller Foundation's Department of Animal Pathology in 1914, and its million dollar endowment, Smith and his associates (*e.g.*, Harry W. Graybill, Ralph B. Little, Ernest W. Smillie, and Richard E. Shope) reoriented comparative pathology along the lines of immunology, incorporating the animal pathogen within the general domain of host-parasite reactions.⁶⁶

Five Examples of Hygienic Success

The hygienic program of isolating, identifying, and eliminating pathogenic germs pervaded most aspects of veterinary bacteriology. This section depicts five cases -- bovine tuberculosis, blackleg, hog cholera, contagious abortion, and pullorum -- in which American investigators rendered significant contributions to the achievement of these aims, as they

⁶⁴ Buchanan and Murray, Veterinary Bacteriology, 2nd. ed., 279; L. Van Es. and Harry M. Martin, "The Nebraska Hemorrhagic Septicemia Experiments and the Critics," Journal of the American Veterinary Medical Association 11 (1921): 572-589; Veranus A. Moore, Observations on the Morphology, Biology and Pathogenic Properties of Twenty-eight Streptococci Found in the Investigation of Animal Diseases (Washington, D.C.: G.P.O., 1893); Moore and Floyd R. Wright, "Observations on Bacillus Coli Communis from Certain Species of Domestic Animals," American Medicine 3 (1902): 504-507; John S. Buckley, "Activities of the Bureau of Animal Industry Laboratories in Washington," Journal of American Veterinary Medical Association 59 (1921): 234; and, Moore, "Growth of Veterinary Science and the Application of New Knowledge," Cornell Veterinarian (April 1926): 1-9.

⁶⁵ See, Theobald Smith, "Comparative Pathology: Its Relation to Biology and Medicine," Philadelphia Medical Journal 6 (1900): 409; William Bulloch, "Obituary Notice of Deceased Member: Theobald Smith, 1859-1934," Journal of Pathology and Bacteriology 40 (1935): 621-635; and, Paul F. Clark, "Theobald Smith, Student of Disease (1859-1934)," Journal of the History of Medicine 14 (1959): 490-514.

⁶⁶ Lise Wilkinson, Animals and Disease: An Introduction to the History of Comparative Medicine (Cambridge: Cambridge University Press, 1992), chapter 12; G.W. Corner, A History of the Rockefeller Institute. 1901-1953: Origins and Growth (New York: Rockefeller Institute Press, 1963), 135-135; Christopher H. Andrews, "Richard Edwin Shope," Yearbook of the American Philosophical Society (1971): 179-183; and, T. Mitchell Prudden, "Professor Theobald Smith and a New Outlook in Animal Pathology," Science 39 (1914): 751-754.

reenacted the experiences of medical bacteriology in an agricultural context. In each of these instances veterinary bacteriology conferred diagnostic or therapeutic tools, thereby amassing disciplinary prestige and scientific authority within veterinary medicine. While these achievements undoubtedly facilitated the control or eradication of economically devastating animal diseases, they also reinforced the dominance of the hygienic vision among veterinary bacteriologists. For most investigators and practitioners, bacteria were worthy only of elimination, and not careful or prolonged scrutiny.

Initially, bovine tuberculosis presented the “the greatest problem to confront the American veterinary profession” in the late 19th century, and due to its relation to human infection drew “more attention . . . than most of the other problems combined.”⁶⁷ Among cattle herds, infection rates ranged from 4% in Vermont to 50% of all cattle in Massachusetts. Table 2.2 shows that, in the 1890's, many station veterinarians studied tuberculin reactions and most published bulletins recommending hygienic practices to protect local herds. In Merrillat's estimation, concern among veterinarians was “probably overdone in view of what was actually known about the prophylaxis of the disease at that time.” Merrillat, in fact, suggested that the prominence given to the subject had been due to its “importance as a means of bringing public recognition to the profession and the opportunity to fulfill the mission for which a profession is maintained.”⁶⁸ Veterinary bacteriology derived many professional benefits from public anxiety over bovine tuberculosis. For years, bacteriologists such as Leonard Pearson and Mazyck

⁶⁷ Bierer, American Veterinary History, 193; and, George T. Howland, Bovine Tuberculosis: Its Cause, Symptoms, and Treatment (Norwich, Conn.: The Waters Press, 1911).

⁶⁸ “The profession was truly excited over tuberculosis.” Merrillat, Veterinary Military History, 303-304. Veranus Moore believed that the dominant public health concerns “have caused many of the phases of the disease to be neglected with attended financial losses to the live stock industry.” Moore, A Report on Bovine Tuberculosis (Albany: Argus Co., 1903), 6.

Ravenel, of the University of Pennsylvania and the State Livestock Sanitation Board, received funds from both agricultural interests and the Henry Phipps Institute for the Study and Prevention of Tuberculosis.⁶⁹ Other bacteriologists, such as Henry L. Russell, conducted public demonstrations of tuberculin tests, mostly to warn livestock owners of the dangers of reactors, but also to parade the utility of bacteriological tools.⁷⁰

American bacteriologists investigated two principal aspects of bovine tuberculosis. By the mid-1890's, most of the rudimentary facts remained largely unquestioned. Robert Koch, among other European investigators, had isolated the tubercle bacillus, demonstrated its causative relationship, described staining techniques, and developed tuberculin as a diagnostic test. The lingering questions involved the reliability of the tuberculin test, and the transmissibility of bovine and human tuberculosis. In these areas, domestic investigators published extensively.⁷¹

Regarding the tuberculin test, it was introduced to American livestock owners in the early 1890's, and was employed in several state eradication campaigns by the end of the decade. Typically, legislative authorities provided for testing of susceptible herds, and ordered the mandatory slaughter or isolation of all positive reactors. In most cases, the states passed indemnity laws, but failed to furnish adequate compensation for condemned animals. In

⁶⁹ Leonard Pearson, "Tuberculosis of Cattle," Bulletin of the Pennsylvania State College Agricultural Experiment Station, no. 29 (1894); anon. "Leonard Pearson, B.S., V.M.D.," American Veterinary Review 36 (1909): 4; Clarence J. Marshall, ed. In Memoria: Leonard Pearson, (Philadelphia: s.n., 1910); and, Faculty Veterinary Alumni, comp., History of the School of Veterinary Medicine of the University of Pennsylvania, 1884-1934 (Philadelphia: Veterinary Alumni Society, 1935).

⁷⁰ For some, the tuberculin test represented a bacteriological challenge to veterinary authority, as "even the most experienced and careful veterinarian cannot be certain by a physical examination whether an animal is tubercular or not." Harry L. Russell and Edwin G. Hastings, "A Catechism on Bovine Tuberculosis," Circular of Information of the University of Wisconsin Agricultural Experiment Station, no. 23 (1911): 9.

⁷¹ Veranus A. Moore, Bovine Tuberculosis and Its Control (Ithaca: Carpenter & Company, 1913), iv.

response, dairymen in New York, Illinois, and Massachusetts publicly challenged the validity of the test, insisting that it commonly produced errors, and that all results were subject to interpretation.⁷² Their concerns were, for the most part, justified. The test involved reading the temperature of the animal after a subcutaneous injection of a glycerated tubercle extract. Typically, infected animals would show a noticeably elevated body temperature. Subjects were labeled “reactors” if their temperature increased by more than 3 degrees F. However, the temperatures of cows varied from 99 to 103 degrees F., not only among animals, but from time to time. Exercise, excitement, and hot weather could raise body temperature. Moreover, an elevation of 2 degrees was classed “doubtful,” unless other animals in the herd “reacted,” in which case the borderline animals were also condemned.⁷³

Experiment station bacteriologists struggled to account for the frequent false negatives, and to develop a test that would distinguish the presence of “true” tubercle bacilli from those infections due to other, non-tubercular, acid-fast organisms. The endeavor led some researchers to explore the chemical constituents of the tubercle bacilli, and others to the immunological aspects of the tuberculin reaction. For the most part, however, bacteriological “studies” of the tuberculin test merely reported the percentage of reactors that harbored tubercle bacilli in their bodily fluids and tissues, leaving lingering doubts until the introduction of the intradermal test in the early 1910's.⁷⁴

⁷² Other farmers feared ill-effects from Koch's lymph (*e.g.*, sterility, abortion, etc.), and some even implicated the legislative movement as a conspiracy of oleomargarine interests. See, Harry L. Russell and Agricultural Science, 28; and, Simon Baatz, “Venerate the Plough”: A History of the Philadelphia Society for Promoting Agriculture, 1785-1985 (Philadelphia: Philadelphia Society for Promoting Agriculture, 1985), 94-97.

⁷³ Harry L. Russell and Edwin G. Hastings, Agricultural Bacteriology (Madison: State Journal Printing, 1909), 120-125; and, Moore, “Veterinary Science and its Problems,” 7.

⁷⁴ See, for example, Julius Nelson, “Experimental Studies of the Koch Test for Tuberculosis,” Bulletin of the New Jersey Agricultural Experiment Station (1895); Paul Fischer, “Bovine Tuberculosis,” Bulletin of the

American investigators devoted a larger portion of their efforts to the question of transmissibility of bovine tuberculosis to humans. In the 1890's, European and American bacteriologists documented well-defined morphological, cultural, and pathogenic difference between the bovine and human tubercle bacilli. In this country, Theobald Smith posited two distinct types, or species, of tubercle germs, and when Koch denied the possibility of human infection from bovine sources in 1900, livestock owners found added incentive to resist eradication efforts.⁷⁵ In the ensuing decade, American bacteriologists disagreed regarding the potential public health risks posed by reactor cows. Herbert Conn, for example, confidently asserted that many reactors actually recovered to "live several years of useful life," showing no signs of infection upon post-mortem examination. He distinguished between "clinical tuberculosis," which resulted in the death of the animal, and "tuberculin tuberculosis," which merely indicated the "temporary and insignificant" presence of tubercle bacilli.⁷⁶ Likewise, Veranus Moore documented that only a small percentage of tuberculous cows had infected udders, and therefore milk from most reactors was unharmed. Instead of matching control

Kansas Agricultural Experiment Station 79 (1898); Edwin G. Hastings and Harry L. Russell, "Distribution of Tuberculosis in Suspected and Non-Suspected Herds in Wisconsin," Bulletin of the University of Wisconsin Agricultural Experiment Station 133 (1907); John R. Mohler, "Recent Studies Regarding Causation and Character of Animal Tuberculosis," American Veterinary Review 34 (Dec. 1908): 323; and, E.T. Hallman, "The Tuberculin Tests for Tuberculous Cows," Special Bulletin of the Michigan Agricultural Experiment Station 62 (1913).

⁷⁵ Theobald Smith, "The Relation Between Human and Animal Tuberculosis, with Special Reference to the Question of Transformation of Human Other Types of the Tubercle Bacillus," Boston Medical and Surgical Journal 159 (1908): 708-709; Simon H. Gage, "Theobald Smith, 1859-1934," Cornell Veterinarian 25 (1935): 207-228; and Gage, "Theobald Smith: Investigator and Man," Science 84 (1936): 117-122. This aspect is extensively discussed by Barbara G. Rosenkrantz, in "The Trouble with Bovine Tuberculosis," Bulletin of the History of Medicine 59 (1985): 155-175.

⁷⁶ Conn objected to the mandatory slaughter of reactor cows, maintaining that the threat of transmission to humans "has probably been exaggerated." Conn, Agricultural Bacteriology: A Study of the Relation of Germ Life to the Farm with Laboratory Experiments for Students: Microorganisms of Soil, Fertilizers, Sewage, Water, Dairy Products, Miscellaneous Farm Products and of Diseases of Animals and Plants, 1st ed. (Philadelphia: P. Blackiston's Son & Co., 1901), 370; and, Conn, "The Relation of Bovine Tuberculosis to That of Man and Its Significance in the Dairy Herd," Bulletin of the Storrs Agricultural Experiment Station 23 (April 1902), 6-7.

efforts with tuberculin tests and mandatory slaughter, Moore advocated removing reactors only when they began to manifest physical "evidence of disease."⁷⁷

In contradistinction, Ravenel and Pearson declared that reactors, even those showing no physical signs of illness, disbursed enough infectious material to propagate human tuberculosis. Ravenel marshaled an arsenal of bacteriological and pathological arguments to indicate transmissibility, including evidence that: infected children often harbored the bovine type in intestinal lesions; that their lesions resembled those found in cows; that the bovine type was more pathogenic than the human type for experimental animals; and, that a number of butchers had been accidentally infected with bovine tuberculosis from contaminated carcasses.⁷⁸ Pearson directed attention on the tubercle bacillus, arguing for an essential unity between the human and bovine types. He noted that many bacterial species displayed morphological, cultural, and pathogenic variance, and no bacteriologist had documented differences in tubercle types "even as great as those observed between the germs of many diseases that are confined to but one species of animals." Between the dissimilar bovine and human types lay "an intermediate series of transition forms." Veranus Moore, who downplayed the threat of transmission, conceded:

... there seems to be no reason for doubting that the bovine and human forms are races or varieties of the same species. The difference in the conditions of life under which they exist in the body of men and of cattle seems to be quite enough to explain resulting

⁷⁷ Veranus A. Moore, "Bovine Tuberculosis," Bulletin of the New York Agricultural Experiment Station, no. 225 (1905); Moore, "The Elimination of Tubercle Bacilli from Infected Cattle," Journal of Medical Research 24 (1911): 525; and, Moore, "The Elimination of Tubercle Bacilli from Infected Cattle, and the Control of Bovine Tuberculosis and Infected Milk," Bulletin of the Cornell University Agricultural Experiment Station, no. 299 (1911): 697-711.

⁷⁸ Mazyck P. Ravenel, "The Comparative Virulence of the Tubercle Bacillus from Human and Bovine Sources," Lancet 2 (1901): 349-356, 443-448; and, Ravenel, "The Intercommunicability of Human and Bovine Tuberculosis," Proceedings of the Pathological Society of Philadelphia (May 1902). See also, Robert R. Dinwiddie, "The Relative Virulence for the Domestic Animals of Human and Bovine Tubercle," Bulletin of the Arkansas Agricultural Experiment Station, no. 57 (1899).

differences in the properties of the bacteria.⁷⁹

If the two types comprised, in biological terms, members of the same species, ingestion of the bovine type risked transmutation and consequent human infection.

The phenomena of host-induced variation represented one facet of bovine tuberculosis that was subject to bacteriological expertise alone. Neither veterinarians nor public health officials could resolve this issue, and American bacteriologists offered diametrically opposed assessments.⁸⁰ In the processes of this debate, they focused attention on issues normally excluded by the hygienic program of isolation, identification, and elimination. Ravenel, for example, proffered a phylogenetic, or evolutionary, account of the tubercle bacillus:

It is certain that the various types of tubercle bacillus known to us have sprung from a stock common to them all, and that they have acquired their racial peculiarities by residence in different animals, through which they are subjected to a difference in food, temperature, and resistance. In other words, the struggle for life is carried on in the various species of animals under varying conditions, the result being that in each animal the tubercle bacillus acquires properties which best enable it to carry on life in that particular host.⁸¹

Theobald Smith, who acknowledged a common ancestry for the two types, rejected the possibility of transmutation, arguing instead that each type developed "a specific machinery of transmission" suited to a particular host. Smith himself had documented a "certain plasticity" of

⁷⁹ Pearson, "The Pennsylvania Plan for Controlling Tuberculosis of Cattle and a Summary Review of Reasons Upon Which It is Based," Proceedings of the American Veterinary Medical Association 36 (1899): 175 & 166; Moore, A Report on Bovine Tuberculosis, 8; and, Moore, "Bovine Tuberculosis," Bulletin of the Cornell University Agricultural Experiment Station, no. 250 (1908).

⁸⁰ In Pearson and Ravenel's opinion, there was "scarcely a subject related to agriculture or public health that has occasioned as much or as bitter discussion, or has led to the expression of so many divergent views as this one of tuberculosis in cattle." Leonard Pearson and M.P. Ravenel, "Tuberculosis of Cattle and the Pennsylvania Plan for Its Repression," Bulletin of the Commonwealth of Pennsylvania, Department of Agriculture 75 (1901), 11.

⁸¹ Ravenel believed in a rapid rate of adaptation: ". . . I do not think we are forcing a point in believing that it is at least possible for the bovine bacillus to become rapidly so changed in the body of man that it will show the cultural and pathogenic properties which we find usually in cultures of human origin." Ravenel, "The Intercommunicability of Human and Bovine Tuberculosis," 31.

tubercle bacilli, and demonstrated that variation could be induced by “degeneration from unhealthy environments.” But Smith concluded that “any regular or wholesale conversion of bovine into human bacilli in the human body is out of the question . . .”⁸² With regards to bovine tuberculosis, veterinary bacteriologists traversed a path already worn by their medical analogues, where the narrow paths of hygienic exclusion occasioned important, but infrequent, deliberations of the biology of the bacteria.

The parallel between medical and veterinary bacteriology can also be explained by the shared interest in biologics (*i.e.*, vaccines, diagnostic tests, therapeutic sera). Bacteriology’s service role to livestock interests placed a high premium on therapeutic sera and preventative vaccines. As table 2.3 suggests, many station veterinarians and bacteriologists distributed tuberculin and mallein for diagnoses of tuberculosis and glanders, produced vaccines for immunization against chicken cholera, smallpox, and blackleg, and developed sera for treatment of hemorrhagic septicemia. Pharmaceutical companies, such as Parke, Davis and Co. and H.K. Mulford, sold products to both medical and veterinary practitioners. Even proprietary veterinary colleges, such as McKillip in Chicago, produced tetanus antitoxin to treat infected horses. At the Bureau of Animal Industry, biologics represented a core area of research activity. With the formation of a Biochemic Division in 1897, the BAI more than doubled these efforts, as it increased its production and distribution of tuberculin from 57,000 doses in 1897 to 329,000 in 1921. The BAI also increased its production and distribution of mallein from 1,400 to 135,000 doses over the same period. In 1913, Congress passed the Virus-Serum-Toxin Act, and the

⁸² Smith, “The Relation between Human and Animal Tuberculosis,” 711; and, Smith, “The Channels of Infection in Tuberculosis, Together with Some Remarks on the Outlook Concerning a Specific Therapy,” Transactions of the Massachusetts Medical Society (1907): 15-16.

Bureau hired a legion of bacteriologists to monitor the preparation, sale, and shipment of veterinary biologics.⁸³

For the most part, research in veterinary biologics centered on elucidating host-immune reactions, and not on exploring the bacterial pathogen itself. On occasion, progress in the former area necessitated work in the latter. Blackleg, for example, comprised a common and invariably fatal scourge among cattle and sheep in the 19th century. At the time, livestock owners had access to a preventive vaccine, manufactured from the heated and ground tissues of infected animals. The vaccine, developed earlier in the century in Lyon, France, proved problematic. It was laborious to administer (requiring two inoculations at an eight-day interval), risky (actually producing the disease in some instances), and unpredictably weak. Victor A. Norgaard, a veterinarian, bacteriologist, and chief of the BAI's Pathology Division, modified the Lyons vaccine in 1897, such that a single dose conferred adequate protection, and during the next twenty-five years the BAI distributed 47 million doses.⁸⁴

While Norgaard's vaccine reduced blackleg mortality rates from 10% to 1% per year, it still failed to produce a reliable lifetime immunity. At Kansas State College and Experiment Station, Francis Schoenleber, O.M. Franklin and Thomas P. Haslam believed that the solution lay in the abandonment of infected tissue in favor of employing pure cultures of the causative agent, *Bacillus chauvoei*. Unfortunately, owing to the difficulties in cultivating this anaerobe, no American bacteriologists had obtained a pure culture. Franklin acquired the organism from abroad and developed techniques for culturing the agent. Franklin's investigations demanded

⁸³ Harding, Two Blades of Grass, 159; and, Powell, The Bureau of Animal Industry, 41.

⁸⁴ Daniel E. Salmon, "Some Examples of the Development of Knowledge Concerning Animal Diseases," in Yearbook of the United States Department of Agriculture, 1899 (Washington: Government Printing Office, 1900), 123; and, Stalheim, The Winning of Animal Health, 23-27.

that he study not only the nutritive requirements of *B. chauvoei*, but also its metabolic by-products, and associations with other anaerobes. Using germ-free filtrates and bacterial fragments, Franklin produced a new vaccine. Haslam employed the pure cultures to manufacture an anti-serum, using procedures analogous to the production of diphtheria antitoxin.⁸⁵ The combined application of a vaccine and antisera effectively eliminated blackleg in this country, and Franklin and Haslam soon stood as emblematic figures in veterinary bacteriology. In this instance, the hygienic goal of elimination required at least a short-term regard for the pathogen.⁸⁶

The principal triumphs of American veterinary bacteriologists resided not in their research on bovine tuberculosis or even blackleg, but rather in their control of hog cholera, contagious abortion, and poultry diseases. Hog cholera offers an ironic historical episode, as the disease is now known to be due to a viral, and not bacterial, agent. Yet, during the late nineteenth century it constituted the primary focus of veterinary bacteriology, with several microorganisms identified as the causative germ. Hog cholera, in the 1870's and 1880's, devastated swine herds in the mid-west, resulting in an annual mortality rate of up to 60%, and a financial loss of \$60 million.⁸⁷ Even before the creation of the BAI, the USDA commissioned Henry J. Detmers, Daniel E. Salmon, and James Law to examine the disease. After 1884,

⁸⁵ O.M. Franklin and Thomas P. Haslam, "The Strength and Composition of Blackleg Vaccines," Journal Infectious Diseases 19 (1916): 408-415; and, Francis Schoenleber, Haslam, and Franklin, "A Preliminary Report on Two Methods of Preventing Blackleg by Means of an Anti-Blackleg Serum and Aggressin," Kansas State Agricultural Experiment Station Circular, no. 59 (Jan 1917): 1-4.

⁸⁶ Stalheim, The Winning of Animal Health, 29-31; Charles W. Wood, "Science and Politics in the War on Cattle Diseases: The Kansas Experience, 1900-1940," Agricultural History 54 (1980): 261-303; and, Charles R. Koch, "The Man Who Whipped Blackleg," The Farm Quarterly (Winter 1964-65): 12-15.

⁸⁷ Smithcors, The American Veterinary Profession, 452; and, O.H.E. Stalheim, "The Hog Cholera Battle and Veterinary Professionalism," Agricultural History 62 (1988): 116-121.

Salmon, Theobald Smith, and a young Veranus A. Moore, intensified the Bureau's bacteriological explorations of hog cholera. In 1887, Salmon posited two discrete, but often co-existent, diseases, hog cholera and swine plague. Each resulted in unique pathological conditions, and Salmon offered distinct bacterial pathogens, *Bacterium suis* and *Bacterium suipestifer*.⁸⁸

Salmon's etiological claims, however, provoked a major controversy in American veterinary bacteriology. Frank S. Billings, a Professor of Animal Pathology at the University of Nebraska who trained under Koch and Virchow, publicly challenged Salmon's reports. Billings professed a singled cause for the complex of swine maladies and personal priority for the discovery of its etiological agent. The ensuing dispute, conducted in the pages of *The American Veterinary Review* and at meetings of the AVMA, was protracted and acrimonious. Between charges of plagiarism and fraud, Billings and Salmon each demanded that an independent commission settle the issue. In 1888, the USDA appointed a panel comprised of Edward O. Shakespeare from the Bacteriological Laboratory of the Philadelphia Bureau of Health, University of Illinois T.J. Burrill, and B. Meade Belton, the Director of the Hoagland Laboratory in Brooklyn. The panel featured members with ample bacteriological training, but not a single veterinary degree. Although the commission sided with Salmon, the dispute endured, with the

⁸⁸ Daniel E. Salmon, "Two Distinct Swine Plagues," American Veterinary Review (March 1887): 573; C.G. Cole, "History of Hog Cholera Research in the U.S. Department of the Agriculture." Supplement to Agricultural Information Bulletin, no. 241 (1962); and, anon., "D.E. Salmon," American Veterinary Review 46 (1914): 93. Hog cholera was, in practice, very difficult to distinguish between swine plague. Additionally, there was considerable variation in the pathogenicity of both pathogens. Robert R. Dinwiddie and J.F. Stanford, "Studies on the Bacteriology of Infectious Swine Diseases," Technical Bulletin of the Arkansas Agricultural Experiment Station, no. 105 (1910); and, Bierer, History of Animal Plagues, 37.

editors of the *American Veterinary Review* and Billings's colleagues rejecting the panel's report.⁸⁹

The wrangling between Billings and Salmon might have represented the nadir of veterinary professionalism in the late nineteenth century. Historian Ole Stalheim has suggested, however, that the episode defined the place of research in veterinary medicine. Most stations and veterinary colleges lacked the resources or incentive for original research. The hog cholera dispute placed a priority on bacteriological studies, and during the 1890's the BAI and some stations intensively pursued this investigative line.⁹⁰

Doubts over the etiological relationship between *Bact. cholera suis* and the disease lingered, particularly since the organism could not be recovered in several cases, nor did a subcutaneous injection of the organism unfailingly produce the illness in uninfected hogs. In the late 1890's, Marion Dorset, Emile de Schweinitz and John McBirney developed a bacterial-sera, and conducted extensive field trials in Page County, Iowa.⁹¹ During the production of this sera, de Schweinitz noticed that pure cultures of *Bact. cholera suis* failed to infect experimental animals. Shortly, he began to suspect a filterable germ. In 1903, Dorset and de Schweinitz suggested, tentatively at first, that hog cholera might be viral.⁹² Within four years of the

⁸⁹ Richard A. Overfield, "Hog Cholera, Texas Fever and Frank S. Billings," *Nebraska History* 57 (1976): 99-128; Norman R. Underdahl, "A Pioneer Microbiologist, Frank S. Billings (1845-1912)," *ASM News* 40 (1974): 265-268; Robert P. Crawford, "These Fifty Years: A History of the College of Agriculture of the University of Nebraska," *Circular of the University of Nebraska, College of Agriculture, Experiment Station*, no. 26 (1925); and, R.P. Crawford, "These 50 Years: History of the College of Agriculture of the University of Nebraska," (Lincoln, 1925).

⁹⁰ Stalheim, *The Winning of Animal Health*, 75.

⁹¹ Cole, "History of Hog Cholera Research," 8; and, Emile A. de Schweinitz and Marion Dorset, *The Serum Treatment of Swine Plague and Hog Cholera* (Washington: Government Printing Office, 1899). Hog cholera was an elusive illness in that it almost always involves mixed infections. See, J.F. Smithcors, "The History of Some Current Problems in Animal Diseases, VI. Hog Cholera," *Veterinary Medicine* (1957): 383-386.

⁹² Bierer, *A Short History of Veterinary Medicine*, 60-70; de Schweinitz and Dorset, "A Form of Hog Cholera Not Caused by the Hog Cholera Bacillus," *Circular of the Bureau of Animal Industry*, no. 41 (1903); and, de Schweinitz and Dorset, "New Facts Concerning the Etiology of Hog Cholera," *Annual Report for the Bureau Animal Industry, 1903* (1904), 235-268. The BAI chemists initially exercised "restraint in making their announcement because the leading bacteriologists of the time had, for many years, accepted the hog cholera bacillus

announcement, investigators at the Biochemic Division developed a serum and vaccine from recovered pigs, and busied themselves with vast field trials. The new hog cholera vaccine and serum spurred an explosive growth in veterinary bacteriology. In 1908, the BAI held a series of conferences in Iowa to demonstrate the methods of production to station veterinarians from across the nation. As this disease "touched the farmer's pocketbook," several state legislatures responded by appropriating funds for the manufacture of vaccine and sera.⁹³ By 1913, over 400 private firms produced the biologics, with thirty states collectively allotting more \$100,000 to purchase and administer the vaccine and sera. In 1914, Congress added to the BAI's budget another \$450,000 for this effort. Stalheim contends that "the triumph over the scourge of the swine producer was more than a great achievement -- it was a major transforming event in veterinary professionalization," one that resulted in the public accordng "them due respect and the status of health professionals." As a subset of the veterinary professional community, bacteriologists reaped comparable benefits, and station directors in New York, Minnesota, Iowa and Kansas parleyed their new-found stature to solicit additional research funds for bacteriology.⁹⁴

The fourth illustration of American veterinary bacteriologists' research achievement

as the cause of hog cholera." Cole, "History of Hog Cholera Research," 10.

⁹³ Stephens, A History of the University of Missouri, 414.

⁹⁴ Stalheim, The Winning of Animal Health, 73, 86, & 178. See also, Andrew Boss, "Agricultural Research Through Fifty Years, 1885-1935," Bulletin University of Minnesota Agricultural Experiment Station, no. 328 (1936), 67; Stange, History of Veterinary Medicine at Iowa State College, 31; and, Veranus A. Moore, "Veterinary Education and Service at Cornell University, 1896-1929," Cornell Veterinarian (1929): 199-242. On the other hand, the attention to biologics demanded resources that might otherwise be allocated to research. At the Oklahoma Station, Lowery L. Lewis justified the elimination of his research budget in the annual report for 1909: "The prevention of disease . . . is of vastly more importance than any other experimental work that is open to this department, and it is our purpose to use every effort to supply such product as will best serve this department." Lewis, Annual Report of the Oklahoma Agricultural Experiment Station, 1909 (Stillwater: Oklahoma Agricultural and Mechanical College, 1910), 25.

involved contagious abortion. As early as the 1880's, the malady drew the attention of station veterinarians and BAI officials, for it claimed not only the lives of unborn calves and foals, but induced sterility in dams for several seasons. Olaf Bang, working in Scandinavia, identified the causative agent in 1897, but no American investigator could culture the bacillus until 1910. At the BAI, bacteriologists attempted to isolate the *Bacterium abortus* (Bang) from the placenta of aborting cows in 1900, but owing to the difficulties of cultivating the fragile organism, the bacillus remained beyond American technical capacities for another decade.⁹⁵

In the early 1910's, Copenhagen bacteriologists C.O. Jensen and Sven Wall developed an agglutination test for the bacillus, and American researchers once again took heed.⁹⁶ With bovine tuberculosis slowly coming under hygienic control, contagious abortion assumed the leading cause of financial loss among livestock owners. The AVMA's Committee on Diseases warned in 1911 that "contagious abortion in cows is assuming dangerous proportions." The BAI estimated that the affliction calculated a loss of \$20 million in 1915, and the next year Secretary of Agriculture D.F. Houston acknowledged that "contagious abortion . . . has reached such proportions as seriously to threaten the cattle raising industry."⁹⁷

⁹⁵ Bierer, The History of Animal Plagues, 36; Edwin P. Niles, "Infectious Abortion in Cows," Bulletin of the Virginia Agricultural Experiment Station, no. 13 (1892); Charles E. Marshall, "Review of Professor Bang's Work with Contagious Abortion," Special Bulletin of the Michigan Agricultural Experiment Station, no. 13 (1899); Ward J. MacNeal and J.E. Kerr, "Bacillus Abortus Bang, the Cause of Contagious Abortion in Cattle," Journal of Infectious Diseases 7 (1910): 469; and, MacNeal, "Contagious Abortion of Cows," Bulletin of the Illinois Agricultural Experiment Station, no. 152 (1911).

⁹⁶ Bierer, American Veterinary History, 209; W.D. Pouden, "Infectious and Metabolic Diseases of Dairy Cattle," Journal of Dairy Science 39 (1956): 769-772; and, Donald C. Beaver, "Bacteriology and Pathology of Sterility in Cattle," Technical Bulletin of the University of Minnesota Agricultural Experiment Station, no. 5 (May 1922), 5-7.

⁹⁷ In 1928, John R. Mohler surmised: "About ten years ago, infectious abortion and tuberculosis rivaled each other for the distinction of being the greatest plague of the livestock in the United States. Since that time, tuberculosis has declined materially as the result of systematic eradication, but the abortion disease is a more conspicuous cause than ever of livestock losses. The malady threatens the source of the Native cattle supply and effects the very organ, the udder, on which the entire dairy industry depends." Mohler estimated annual losses at \$50 million, from calf mortality, reduced milk flow, and sterility. Quoted in, Bierer, American Veterinary History.

In response, veterinary bacteriologists followed the familiar program of isolation, identification, and elimination. At the University of Minnesota, Winford P. Larson initiated a series of studies on contagious abortion in 1911. Larson, who held an M.D., and who trained in agricultural bacteriology under Harry L. Russell and in medical bacteriology in various European laboratories, developed a complement fixation test and new agglutination test for *Bact. abortus*. Armed with these determinative tools, Larson set his sights on uncovering the etiological paths of the disease, suggesting an important role for chronic carriers. Similarly, at Wisconsin, Burr A. Beach and Frederick B. Hadley fashioned a new complement-fixation test in 1912. In their examination of 500 cows, they determined that more than 35% harbored the germ. More importantly, they showed that their test was not only as accurate as other methods, but could be administered with greater ease. As a consequence, bacteriologists at Storrs, Cornell and other stations focused their research efforts on devising efficient eradication programs.⁹⁸

Veterinary bacteriologists studying contagious abortion found an uncanny resemblance, in certain respects, to bovine tuberculosis. In 1911, BAI veterinarians isolated *Bact. abortus* from the milk of healthy cows, and from the removed tonsils of children. During the next two years, Leslie H. Cooledge of the Michigan Agricultural Experiment Station, and Alice C. Evans of the U.S. Public Health Service Hygienic Laboratory, recovered a variant of *Bact. abortus* in

209.

⁹⁸ H.O. Halvorson, "Dr. W.P. Larson --1880-1947," 1940, [ASM], box 2-IXC, folder 60; Larson, "The Complement Fixation Reaction in the Diagnosis of Contagious Abortion of Cattle," Journal of Infectious Diseases 10 (1912): 178-185; Elwin Bird Johnson, Forty Years of the University of Minnesota (Minneapolis: General Alumni Association, 1910); Burr A. Beach and Frederick B. Hadley, "The Diagnosis of Contagious Abortion in Cattle by Means of the Complement Fixation Test," Bulletin of the University of Wisconsin Agricultural Experiment Station, no. 24 (1912): 217-218; Leo Rettger and George C. White, "Infectious Abortion in Cattle," Bulletin Storrs Agricultural Experiment Station, no. 93 (1918); and, White and Rettger, "Specific Measures of Control and Ultimate Eradication," Bulletin of the Storrs Agricultural Experiment Station, no. 103 (1919).

healthy udders, and the two suggested that animal could harbor the organism without infection, until a time when the animal's resistance was lowered. A few bacteriologists considered the possibility of pathogenic effects for humans. In 1912, Frank Surface of the Kentucky Experiment Station considered:

The fact that a large portion of dairy milk contains the abortion bacilli and the further fact that in cattle the most common means of infection is through the alimentary canal make it at least suggestive that this organism may be an etiological factor in certain human infections.⁹⁹

Surface, however, did not implicate a specific malady. The suggestion was left for Cooledge, who in 1915 initiated a series of studies on the transmissibility of *Bact. abortus* to man, only to conclude that the bovine affliction posed no danger to humans.¹⁰⁰

The possible relevance for human illness remained. In the early 1920's, Henrick J. Stafseth and I. Forest Huddleson at the Michigan Experiment Station, and Veranus Moore and C.M. Moore at Cornell, continued to study the bacterium's pathogenicity. Alice C. Evans, during that period, documented the relation between milk containing *Bact. abortus*, and undulant fever, a common but frequently misdiagnosed illness of Midwesterners.¹⁰¹ As a consequence both veterinarians and public health officials enlisted bacteriologists to diagnose and control contagious abortion. The BAI adopted ambitious eradication efforts modeled after the ongoing program against bovine tuberculosis, and bacteriologists at Michigan and other stations

⁹⁹ Frank M. Surface, "Notes on Infectious Abortion in Cattle," *Science* 36 (1912): 412.

¹⁰⁰ Leslie H. Cooledge, "Is *Bacterium abortus* (Bang) Pathogenic for the Human?" *Journal of Medical Research* (1916); and, Cooledge, "A Study of the Presence of *Bacterium Abortus* (Bang) in Milk," *Technical Bulletin of the Michigan Agricultural Experiment Station*, no. 33 (1916).

¹⁰¹ Henrick Stafseth and I. Forest Huddleson, "Studies in Infectious Abortion," *Technical Bulletin of the Michigan Agricultural Experiment Station*, no. 49 (1920); Huddleson, "A Comparative Pathogenicity of Several Strains of *Bacterium Abortus*," *Technical Bulletin of the Michigan Agricultural Experiment Station*, no. 55 (1923); Huddleson, "Is *Bacterium Abortus* Pathogenic for Man?" *JAMA* 86 (1926): 943; and, E. O'Hern, "Alice Evans, Pioneer Microbiologist," *ASM News* 39 (1973): 573-578.

undertook the development of a *Bact. abortus* vaccine.¹⁰² The hygienic program of isolation, identification, and elimination produced yet another instance of bacteriological mastery.

Veterinary bacteriologists also contributed to the emerging field of poultry pathology. Pasteur, of course, had investigated chicken cholera in the 1860's, and a few American veterinary bacteriologists (e.g., Daniel E. Salmon) maintained a prolonged interest in *B. cholerae gallinarum*, a cause of epidemic illness among pigeons, turkeys, chickens, ducks, and geese. At the turn of the century, the nosology of poultry illnesses remained poor understood. However, as table 2.4 shows, a hand full of bacteriologists initiated investigations to uncover the complex etiologies of such diseases as fowl cholera, contagious eitheliosis (e.g., roup, chicken pox, and canker), goose septicemia, fowl typhoid, and blackhead in turkeys.¹⁰³ During the 1910's and 1920's, several land grant colleges established departments of poultry pathology, with bacteriology comprising a core component of instruction at these institutions.¹⁰⁴

As for research in poultry pathology, bacteriologists contributed a series of celebrated techniques for the isolation, identification, and elimination of fowl pathogens. In 1903, Leo F. Rettger initiated a cooperative arrangement with Yale University and the Storrs Agricultural

¹⁰² See, for example, Ward Giltner, "The A.V.M.A. and Infectious Abortion of Cattle," Journal of American Veterinary Medicine 64 (1924): 469-474; and, Huddleson, "Studies on a Non-Virulent Living Culture of *Bacterium Abortus* towards Protective Vaccination of Cattle against Bovine Infectious Abortion," Technical Bulletin of the Michigan Agricultural Experiment Station, no. 65 (1924).

¹⁰³ See, for example, Cooper Curtice, "Goose Septicaemia," and "Fowl Typhoid," Bulletin of the Rhode Island Agricultural Experiment Station, nos. 86 & 87 (1902); Archibald Ward, "Fowl Cholera," Bulletin of the California Agricultural Experiment Station, no. 156 (1904); Philip B. Hadley, "Fowl Cholera and Methods of Combatting It," Bulletin of the Rhode Island Agricultural Experiment Station, no. 144 (1910); Kenneth L. Bullis, "The History of Avian Medicine in the U.S.: II. Pullorum Disease and Fowl Typhoid," Avian Diseases 21 (1977): 422-429; and, O.G. Hanke, J.L. Skinner, and J.H. Florea, eds. American Poultry History (Madison: American Poultry Historical Society, 1974).

¹⁰⁴ See, Philip L. Carpenter, "Bacteriology at the University of New Hampshire," 1952, [ASM], box 2-IXC, folder 77; and, Herman F. Eschenbacher, The University of Rhode Island: A History of Land-Grant Education in Rhode Island (New York: Appleton-Century-Crofts, 1967). At Cornell, James Rice's Department of Poultry Pathology attracted a large number of students, with 185 registrants in the full academic class in 1907, and dozens more in the winter short course. Colman, Education and Agriculture, 189.

Experiment Station to study “bacillary white diarrhea” of barnyard birds. Pullorum, as the disease later came to be known, represented the most economically devastating disease in the poultry industry. Pullorum produced an annual mortality among young chicks of 40-90% in some hatcheries. During the next twenty years, Rettger and his associates isolated and described the causative agent, defined the carrier state, identified the seat of infection in the ovaries of hens, and suggested a diagnostic means of identifying infected birds.¹⁰⁵

Along with the development of improved incubation technologies and brooding devices, Rettger’s research made possible an intensive system of poultry production. By 1924, an estimated 300 million birds were valued at \$1 billion, and this enlarged commercial enterprise produced two consequences. Initially, the intensified poultry production increased the incidence and variety of pathogenic conditions. Veterinarians encountered an expanding array of diseases and parasites, including gastritis, enteritis, apoplexy, bronchitis, chicken pox, avian tuberculosis, “Keel,” fowl plague, etc.¹⁰⁶ Furthermore, bacteriologists discovered a new institutional home for their research and training. Poultry departments developed independently of veterinary medicine, and often later. The triumphs of Rettger and others, however, spawned new poultry programs at the Minnesota, Wisconsin, Maine, New Jersey, and Kansas experiment stations.¹⁰⁷ (Table 2.5) In turn, bacteriologists lent their expertise to the discovery of new pathogens, the

¹⁰⁵ See, George Valley, “Leo Frederick Rettger,” Journal of Bacteriology 69 (1955): 1-3; Leo Rettger, “The History of Bacteriology in Connecticut,” 1937, [ASM], Regional History College, folder 4.A, pp. 1-3; and, Rettger and S.C. Harvey, “Pullorum Disease,” Journal of Medical Research 18 (1908): 277-290.

¹⁰⁶ Stalheim, The Winning of Animal Health, 35-37; and, Burr A. Beach, “A Discussion of Poultry Disease Control,” U.S. Egg and Poultry Magazine (Jan. 1936): 40-62.

¹⁰⁷ In the Annual Report of the New Jersey Agricultural Experiment Station for 1920, W.C. Thompson estimated that infectious diseases cost state poultrymen in excess of \$1 million per year. “Many poultrymen have said...that if the problem of disease prevention could be completely solved, the poultry industry of the state would grow by leaps and bounds....” p. 122.

development of novel diagnostic tests, and the implementation of extensive eradication procedures. As a result, the number of bacteriologists engaged in poultry pathology began to rival, in the 1920's, the collective total in all other aspects of veterinary science.¹⁰⁸

The Service Role of Hygienic Exclusion

Within the context of late nineteenth- and early twentieth-century agricultural science, bacteriology tilled a fertile field for disciplinary growth. As experiment stations and land grant colleges struggled to define the compromise between their service roles and scientific aspirations, proponents of agricultural bacteriology offered their enterprise as an example of both applied and fundamental research. As a result, bacteriology flourished at several institutions, with newly founded departments employing staff members and training students in significant numbers. Historians of medicine and public health have offered detailed accounts of bacteriology's role in the development of those fields. The preceding pages have contended that veterinary bacteriology wrought similar changes in the agricultural sphere.

Veterinary medicine defined one service role for agricultural bacteriology, replicating a hygienic program of isolation, identification, and elimination. Similar to their professional experiences within human medicine, bacteriologists garnered disciplinary stature by offering techniques for the diagnosis and control of infectious diseases. Moreover, their contributions arrived at a critical juncture in the development of American veterinary science. In the second half of the nineteenth century, veterinary colleges, experiment stations, and the Bureau of Animal

¹⁰⁸ Boss, "Agricultural Research Through Fifty Years," 67; Merritt C. Fernald, History of the Maine State College and the University of Maine (Orono: University of Maine, 1916); J. Frank Witter, "The History of Avian Medicine in the United States: I. Before the Big Changes," Avian Medicine 20 (1976): 622-630; and, Kay Wheeler, "Avian Influenza," in 100 Years of Animal Health, 1884-1984, eds. Vivian D. Wiser, Larry Mark and H. Graham Purchase (Beltsville, Md.: Associates of the Nation: Agricultural Library, Inc., 1986)

Industry responded to the economic losses caused by infectious animal diseases. In the first decades of the twentieth century, these institutions incorporated bacteriology within their curriculum and research. Bacteriology largely defined the efforts to control such diseases as bovine tuberculosis, hog cholera, blackleg, contagious abortion, and pullorum.

Within this service role, the conceptual and methodological characteristics of veterinary bacteriology paralleled those of medical bacteriology. Instruction in both fields stressed familiarity with a limited number of pathogenic forms, and students memorized techniques for their isolation and determination in pure cultures. Research focused on the search for the etiological agents of undetermined diseases. The reproduction of the hygienic program guaranteed that veterinary bacteriology would conform, in a disciplinary sense, to the institutional contours of veterinary science. Nonetheless, the disciplinary success arrived at the expense of conceptual breadth. Bacteria represented objects of elimination, not extensive study. Associational aspects of bacterial populations, their metabolism and physiology, bacterial cytology, and taxonomic questions did not constitute the center of investigative efforts. Rather, as the five achievements depicted in this chapter illustrate, research targeted the isolation, identification, and elimination of animal pathogens.

In a few instances, bacteriologists turned to investigate a wider range of biological phenomena. For example, the question of transmissibility between bovine and human forms of tuberculosis required a detailed consideration of the nature of bacterial variation and speciation. However, in most instances, veterinary bacteriology simply aided eradication efforts. Other aspects of the microbial world did not warrant attention, and veterinary bacteriology did little beyond mirroring the developments in medical bacteriology. The next chapter offers a contrast

to this hygienic program, detailing two areas of agricultural bacteriology that escaped the narrow confines of isolate, identify, and eliminate.

CHAPTER THREE

FROM PATHOGENIC GERMS TO PRODUCTIVE MICROBES

Too long has agriculture been considered simply an art -- a vocation which one had to learn wholly in the school of experience, but the serious student of farm life finds it necessary to understand the phenomena of the plant and animal world and to combat or utilize successfully the activities of various microscopic organisms. -- Harry L. Russell and Edwin G. Hastings¹

The task of the medical bacteriologist usually centers upon the problem of becoming acquainted with the disease-producing germ, and to find out how it can successfully be fought and eliminated. The farmer, however, should know under what conditions he will be able to secure the most favorable results from the cooperation of the useful bacteria, and how to avoid the detrimental effects of the activities of harmful microorganisms. -- Felix Lohnis and Edwin B. Fred²

Agricultural bacteriology, as it was integrated into dairying and soil science, facilitated the emergence of an alternative to the "hygienic vision" detailed in the previous two chapters. No longer was the goal of bacteriological manipulations equated with the isolation, identification, and elimination of germ life. Microbes, as envisioned by many dairy and soil bacteriologists, were to be controlled, rationalized, and exploited. The "productive microbe," so

¹ Harry L. Russell and Edwin G. Hastings, Agricultural Bacteriology (Madison: State Journal Printing, 1909), iii.

² Felix Lohnis and Edwin B. Fred, Textbook of Agricultural Bacteriology (New York: McGraw-Hill Book Co., 1923), 4.

essential to the manufacture of dairy products and the maintenance of soil fertility, replaced the pathogen as the central object of study. This chapter narrates the formulation of the “bacteriologic vision” of dairy and soil bacteriology in order to advance two interrelated arguments. First, the service roles of dairying and soil science necessitated the abandonment of the “hygienic vision” of microbial exclusion. If bacteriologists, as a group, attended to what bacteria “did,” dairy and soil bacteriologists sought ways of making them do more. Secondly, this alternative vision encouraged the development of methodological and conceptual innovations. Together, these two claims seek to situate the development of bacteriology within two forgotten institutional realms, where the productive aspects of microbial action took precedence over issues of infectious disease.

The previous chapters have argued that the hygienic vision engendered both professional growth and disciplinary restriction. Medical, public health, sanitary, and veterinary bacteriologists studied a limited number of organisms, considered a narrow range of phenomena, and encouraged investigations only as they aided in the elimination of infectious disease. This chapter contends that dairy and soil bacteriologists eluded the conceptual constrictions of the “hygienic vision” by examining a greater number of organisms and a wider range of phenomena. Rationalizing the microbial world directed attention to nutritional requirements and growth by-products; focused interest on bacterial cytology; encouraged the replacement of pure cultures with enrichment techniques that demonstrated a full range of variations; demanded a consideration of microbial populations; and facilitated a careful regard of taxonomic issues. Managing microbes yielded an understanding not procured by the effort to eliminate germs. Furthermore, dairy and soil bacteriologists greatly influenced the discipline in the 1920's and

1930's, serving as officers of the Society of American Bacteriologists (SAB), editors of the *Journal of Bacteriology*, and heads of university departments.

This present chapter follows in three sections. The first reassesses the context of agricultural science in an attempt to identify those institutional features that fostered the emergence of the "bacteriologic vision." Dairy and soil bacteriologists tended to be trained in botany, not medicine, and their professional desire to be more "scientific" was expressed in attempts to be more "biological." Moreover, a portion of bacteriologists working at experiment stations and land grant colleges considered microbes as an agricultural resource -- much like soils, seeds, and livestock -- rather than a pest. "Scientific farming," within this analogy, required that students and station staff adopt techniques for the management and exploitation of the microbial world. Textbooks, manuals, and survey courses preached efficiency over elimination. The overarching goal of microbial management, on an institutional level, promoted the development of novel methodologies, and invited a conceptual confederation with other biological sciences.

The second section examines dairy bacteriology, and serves as an illustration of how a research community could simultaneously seek to eliminate germs and manage microbes. In service to public health officials and municipal reformers, bacteriologists identified sources of contamination and recommended hygienic practices to reduce bacterial counts in market milk. They characterized germs as an inherent and undifferentiated source of danger, and cultivated means for their elimination. In service to dairy industries, however, many of the same bacteriologists identified the productive microbes that ripened cheese and butter and provided the texture, flavor, and aroma that consumers demanded. This managerial aim required knowledge

of how microbes could be acquired, controlled, and exploited, leading dairy bacteriologists to facets ignored by the hygienic program of milk sanitation. While the "hygienic" and "bacteriologic" visions coexisted for two decades among dairy bacteriologists, there is good evidence to suggest that, by the mid 1910's, the latter came to supplant the former.

The third section examines developments in soil bacteriology, a field that survived on the disciplinary margins by promising to uncover the relationship of microbes to plant food and soil fertility. Unlike veterinary and dairy bacteriology, soil scientists rarely examined pathogens. Moreover, soil microbes constituted a dynamic population, a protean mix of bacteria, fungi and protozoa, that posed refractory difficulties for the standard pure culture methods of isolation and identification. Managing productive soil microbes necessitated a nearly complete abjuration of the techniques of medical bacteriology, and by the early 1920's soil bacteriologists had generated a host of novel manipulations and research problems. Consequently, soil scientists addressed many of the fundamental, or biological, characters excluded by the routines of isolation, identification and elimination. Indeed, they were among the first to pursue studies of bacterial "physiology," to delineate the metabolic growth requirements of microbes and their relation to a changing environment of available energy sources. While comprising only a small fraction of professional bacteriologists, soil scientists constituted the most innovative, and challenging branch of the discipline. This chapter concludes with a few speculations as to the self-conscious, and often self-critical, reflections of bacteriologists in the late 1910's and early 1920's. Bacteriology was a discipline cognizant of both its professional growth and conceptual limitations.

Scientific Agriculture and the Productive Microbe

At first glance, dairy and soil bacteriology diverged in four respects from the conceptual and methodological precedents set by medical and veterinary bacteriology. Firstly, the botanical background of many instructors encouraged a more "biological" approach to studying bacteria. At Berkeley, for example, bacteriology was offered in the late 1890's by Frederic T. Bioletti, a graduate student in systematic botany with a keen interest in oenology. Bioletti's lecture notes outlined three principle approaches to the bacterial world:

The botanist studies them from the biological point of view investigating their forms, life history and affinities, the chemist and manufacturer are particularly interested in their action on the media in which they live and the industrial uses to which they can be put, while the physician gives most of his attention to their relations to disease and the various functions of the animal organism.³

Bioletti's curriculum, however, provided scant instruction in the medical phases of the new science. Rather, he devoted his first two lectures to morphology and the next two to reproduction, followed by lessons on classification, distribution, and characterization of new species. Pathogenesis and human diseases represented only two of the sixteen sections. Bioletti acknowledged the importance of medical bacteriology, but his own interests and the interests of the college led him to emphasize the "biological" and "industrial" aspects.⁴

At Wisconsin, Harry L. Russell and William D. Frost were both trained in biology, and deliberately fashioned a bacteriology program more general in its nature than at most of the other universities. Frost's laboratory section in general bacteriology, for example, provided detailed

³ F.T. Bioletti, "Lecture Notes -- Agriculture 9A," 1900, [ASM] Miscellaneous Manuscript Collections, folder 2, p.1.

⁴ Bioletti, "Lecture Notes," 1; and, L.S. McClung and K.F. Meyer, "Beginnings of Bacteriology in California," *Bacteriological Reviews* 38 (1974): 258. The graduate courses at the University of Illinois shared similar emphasis on bacterial taxonomy, variation, and physiology. G.I. Wallace, "Early Bacteriology at the University of Illinois, Urbana," 1951, [ASM], box 2-IXC, folder 73, p. 3.

consideration of topics normally slighted in medical courses (*e.g.*, morphology, physiology, taxonomy, and the “biology of special groups of bacteria” as determined by biochemical activity).⁵ Frost patterned his own 1910 manual on a standard text for physiological botany, and in the preface he declared an intention to escape the exclusive emphasis on pathogenic forms.⁶ Similarly, the biological training of Herbert W. Conn and L.H. Pammel might explain the long standing interest in bacterial physiology and taxonomy at Wesleyan and Iowa State College.

At other universities, the conceptual and methodological disengagement of “agricultural” from medical aspects of bacteriology was often prolonged or partial. Samuel M. Bain and Samuel H. Essary taught “General Bacteriology” within Tennessee’s Department of Botany in 1904, covering, “Form, structure, reproduction, requirements for growth and chemical products of bacteria.” While the course prepared the student for “practical applications” in “agriculture, dairying, household economics, sanitation, and medicine,” it devoted “special attention” to pure culture methods, and hygienic techniques of “sterilization and disinfection.” Four years later, Bain and Essary added “Agricultural Bacteriology,” designed “primarily for agricultural students,” which offered “a consideration of the relation of bacteria to the general question of good farming, especially, in connection with soil fertility, decomposition, humus formation,

⁵ E.G. Hastings, “Bacteriology at the University of Wisconsin,” 1937, [ASM], box 7-IIA, folder 10.16, p. 10; Frost, Beloved Professor, 252; and W.D. Frost, A Text-Book of General Bacteriology (New York: The Macmillan Co., 1914), 1. Russell trained in Robert Koch’s lab, earned a PhD in biology at Johns Hopkins, studied plant physiology, spent a year at the Naples Zoological station, and a summer at the Marine Biological Laboratory in Woods Hole. Russell viewed biology as the productive exploitation of nature, and reasoned that “bacteriology ought not be considered solely as an adjunct of medicine but as a field that merited independent development. . .” Edward H. Beardsly, “Making of a Scientist: Harry L. Russell in Europe,” Wisconsin Magazine of History 49 (1965): 3-15.

⁶ Textbooks in agricultural bacteriology were, in general, more “biological” than their medical counterparts. Joseph E. Greaves, for instance, included full chapters on the “place of bacteria in nature,” morphology, classification, composition, food requirements, enzymes, and metabolic products. Greaves, Agricultural Bacteriology (Philadelphia: Lea & Febiger, 1922).

nitrogen processes in the soil and bacteria in the dairy.”⁷ The new course provided a streamlined focus on the productive, rather than pathogenic, aspects of bacterial life.⁸

Secondly, promoters of agricultural bacteriology, like Wesleyan’s Herbert W. Conn, likened bacteria to soils, seeds, and livestock; microbes were resources and not simply pests. “Farming without the aid of bacteria is an impossibility,” Conn reasoned. The “advanced farmer” seeking the best use of the “means at his disposal” and “to profit by discoveries” made in science, “must have at least a general knowledge of the fundamental factors of bacteriology.” Bacteriology represented, in Conn’s assessment, the apotheosis of scientific farming, as the “successful farmer of to-morrow will be the one who most skillfully regulates the growth of microorganisms.”⁹ These bacteriologists pursued the goal of exploiting the productive microbe. Agricultural bacteriology, in the estimation of Conn, had “become a topic of importance equal to, if not greater than, medical bacteriology,” and while the physician only gained “a certain advantage from his knowledge of bacteria,” the farmer was “obliged to make use of these agents

⁷ D.F. Holtman, “A History of Microbiology at the University of Tennessee,” 1969, [ASM], Regional History Collection 29-A, pp. 3-4.

⁸ Among most courses in “agricultural bacteriology,” the curriculum was eclectic, providing instruction in both the hygienic exclusion of pathogens and the management of productive forms. Cornell University listed Course 14, within the college of agriculture, with the following description for 1912: “The characteristics of bacteria, the place of bacteria in nature; fermentations; bacteria in air, water and sewage; the manure heap; soil bacteria; nitrogen fixation; relation of bacteria to the dairy and its products; the preservation of farm products, including fruits, vegetables, silage, etc.” W.A. Stocking, “Report of the Department of Dairying,” Annual Report of Cornell University, College of Agriculture (1912): clxxiii. See also, the exercise outlines in, Edwin G. Hastings and William A. Wright, A Laboratory Manual of General Agricultural Bacteriology, 1st ed. (Madison: Grimm Book Bindery, 1913).

⁹ Herbert W. Conn, Agricultural Bacteriology: A Study of the Relation of Germ Life to the Farm with Laboratory Experiments for Students: Microorganisms of Soil, Fertilizers, Sewage, Water, Dairy Products, Miscellaneous Farm Products and of Diseases of Animals and Plants (Philadelphia: P. Blackiston’s Son & Co., 1901), 21; and Conn, Agricultural Bacteriology, 2nd ed., rev. and enl., (1909), 1. The translator’s preface to Lohnis’ textbook asserted that “the curriculum of an Agricultural or Dairy College is incomplete without a course in Bacteriology. . . . It is one of the present day requirements that each student of Agriculture or Dairying should work through a systematic course of Practical Bacteriology in the laboratory.” Lohnis, William Stevenson, and J. Hunter-Smith, Laboratory Methods in Agricultural Bacteriology (London: Charles Griffin and Co., 1913), vii.

in a large number of his farming processes,” and was hence required to thoroughly grasp the more detailed phases of bacterial life.¹⁰

Fundamentally, agricultural bacteriology, like other facets of scientific farming, comprised a discipline of control, and not elimination. Conn maintained, “from beginning to end, the occupations of the agriculturalist are concerned with the attempt to obtain the aid of these microorganisms where they may be of advantage, and in preventing their action in places where they would be a detriment.”¹¹ Additionally, the management of microbes could not be affected through simple horticultural techniques. It demanded experimental foundation. Felix Lohnis explained:

The excellent results obtained by careful selection and breeding of the cultivated plants and domesticated animals led many to believe that it should be the foremost task of the agricultural bacteriologist to select and to cultivate the most efficient strains of useful bacteria in order to make them available for the practical agriculturalist. However, only in a few cases can such direct results be expected. . . .In all cases the conditions under which these useful microorganisms live and work must first be investigated very thoroughly.¹²

Exploiting productive bacteria necessitated a breadth of understanding not required for the elimination of pathogens, and because application required original investigations, “agricultural

¹⁰ The initial research phase of agricultural bacteriology was, however, one of identification, and not detailed biological investigation. As A.C. True indicated in the Yearbook of the United States Department of Agriculture, 1899 (Washington D.C.: Government Printing Office, 1900): “The bacteriological work of the stations has included the isolation, culture, and description of many of species of useful and pathogenic bacteria in air, soil, fertilizers, plants, foods, feeding stuffs, and other agricultural products. . . .Methods and apparatus for bacteriological investigations have been devised and means for repression of pathogenic bacteria have been worked out,” p. 535. The vision of microbial exploitation, was not clearly articulated by USDA officials until nearly a decade later.

¹¹ In the preface to Conn’s textbook, he explains that “some agricultural processes are so closely bound with other industrial phenomena that they cannot be separated. Agriculture grades by imperceptible degrees into numerous secondary industries.” Conn, Agricultural Bacteriology, 1st ed., 20-21, & v. Viewed in this light, the inclusion of Iowa State’s Department of Bacteriology within the Division of Industrial Science is not incongruous. See, Robert E. Buchanan’s text, Agricultural and Industrial Bacteriology (New York: D. Appleton and Co., 1921).

¹² Lohnis and Fred, Textbook of Agricultural Bacteriology, 4.

bacteriology is to-day the advance ground of research."¹³

Thirdly, agricultural bacteriologists introduced methodological alternatives to pure culture isolations. As the following sections will illustrate, soil and dairy bacteriologists employed enrichment cultures and solution methods, developed tests for symbiosis and antagonisms, and broadened their analytic scope to include non-bacterial microbes. At the core of these methodological innovations lay a conviction that bacteria should be studied as dynamic populations.¹⁴ Many agricultural bacteriologists recognized that "in nature the different species of bacteria are found associated in all sorts of indefinite mixtures," and only under exceptional conditions did pure cultures exist. While they were easily produced in the bacteriologist's laboratory by technical manipulations, "they always represent artificial preparations, and therefore, are usually unlike any natural conditions of bacterial life."¹⁵ For soil and dairy bacteriologists seeking to exploit the activities of certain productive microbes, these artificial conditions did not render serviceable data. The abandonment of exclusive pure culture methods, while never fully reproducing the natural conditions, allowed agricultural bacteriologists to escape the conceptual confines of the hygienic vision.

¹³ Conn, Agricultural Bacteriology, 1st. ed., 20. Lohnis was equally convinced that the agricultural bacteriology required both fundamental and practical studies. See, Lohnis & Fred, Textbook of Agricultural Bacteriology, 2, 66 & 77. The goal of efficiency supplied the continued rationale for pure research in agricultural science. The Director of the Texas Station, in 1921, reasoned that: "Money expended for agricultural research is an investment in the nature of cold-blooded business enterprise. No good business man would think of engaging in any business without some knowledge or facts upon which to base his business policies, and every good business man who has had any immediate contact with agriculture is well aware of the fact that here is a field that is more circumscribed by a lack of definite knowledge than perhaps any other business." B. Youngblood, "Directors Report," 34th Annual Report of the Texas Agricultural Experiment Station (1921), 4.

¹⁴ For a lucid defense of these new methods, see Lohnis et al., Laboratory Methods, 55-59. Not all agricultural texts abandoned the tenants of pure culture techniques. See, Howard Reed, A Manual of Bacteriology for Agricultural and General Science Students (Boston: Ginn and Co., 1914), 5-6, & 38-41; and, John Percival, Agricultural Bacteriology, Theoretical and Practical (London: Duckworth, 1910), 55.

¹⁵ Conn, Agricultural Bacteriology, 1st ed., 33-34.

The fourth distinguishing feature of agricultural bacteriology lay its attempt to ally the discipline with agricultural chemistry. The endeavor was not entirely new, as nineteenth century European investigators attempted to subsume bacterial behavior within the categories of oxidation, reduction, and fermentation. Among American bacteriologists, some believed that chemistry offered the clearest paths toward productivity. Charles E. Marshall, for example, insisted that fermentation reactions accounted for the bacterial component to soil fertility, dairying, plant and animal diseases, canning, sewage disposal, and vaccines. The combined pursuit of agricultural chemistry and bacteriology might, in Marshall's opinion, render "the profession of agriculture more definite and more scientific." At Indiana University, Robert E. Lyons included bacteriology in the 1890's within the department of chemistry, and termed the courses as "zymochemistry." In 1902, Lyons added "Bacteriological Chemistry," a course devoted to studying the nutritive requirements and metabolic products of microorganisms. It would be a mistake to claim that Lyons and Marshall founded a fully developed field of bacterial physiology in the early years of the century. Yet, their regard for agricultural chemistry did draw attention to normally overlooked aspects of bacterial growth (*e.g.*, nutritive requirements, metabolic by-products).¹⁶

Milk Sanitation and the Hygienic Vision

The "bacteriologic vision" and its abiding interest in the productive microbe did not characterize all bacteriological work within the agricultural context. The previous chapter portrayed veterinary bacteriology, often situated in experiment stations and land grant colleges,

¹⁶ L.S. McClung, "History of Bacteriology at Indiana University," Proceedings of the Indiana Academy of Science 53 (1944): 59-61.

as a close parallel to medical bacteriology. In addition, agricultural bacteriologists, in service to the production and distribution of milk, similarly reproduced a hygienic program of exclusion. Station staff and USDA scientists investigated the sources of milk contamination, vetted the reliability of bacterial counts, and examined the effectiveness of pasteurization techniques. On the whole, these efforts regarded germs as an inherent source of danger, and dairy bacteriologists offered their technical expertise to the campaign of hygienic exclusion. There is ample evidence, however, to indicate that these scientific workers, by the second decade of the century, became increasingly dissatisfied with milk sanitation efforts.

American interest in milk bacteria dates, for the most part, to the early 1890's. As Chapter One demonstrated, public health bacteriologists viewed market milk as an analogue to municipal water. Health officers and civic reformers feared that contamination might pose significant risks, and bacteriologists, in response, sought to quantify that contamination. After examining market milk in Boston, New York City, Chicago, Baltimore, and Philadelphia, bacteriologists in the 1890's and early 1900's reported appallingly high numbers of germs, often millions per cubic centimeter.¹⁷ The numbers were appalling in that they exceeded counts taken from polluted water. As Mazyck P. Ravenel reasoned in 1898, "It is not a pleasant thought, yet it is nevertheless true, that milk as it reaches the consumer is usually richer in bacteria than the sewage of our great cities."¹⁸ This oft-repeated comparison generated a climate of public concern

¹⁷ See, for example, William T. Sedgwick, and John L. Batchelder, "A Bacteriological Examination of the Boston Milk Supply," Boston Medical and Surgical Journal 126 (1892): 25-28; and, David H. Bergey, "Sanitary Supervision of the Collection and Marketing of Milk," University of Pennsylvania Medical Bulletin 17 (1904): 187-192.

¹⁸ Ravenel, "Milk-supply from the Bacteriological Standpoint," Journal of Comparative Medicine and Veterinary Archives 19 (April 1898): 217; and, Herbert W. Hill and "Bacterial Counts of Boston's Milk Supply," American Journal of Public Hygiene 14 (1904): 236-248. George Lloyd Magruder, an emeritus professor at Georgetown Medical College, commented, "Everybody knows that a water supply contaminated with sewage is a

that the most wholesome of products, milk, posed the most insidious of germ threats.

Concurrent with these routine quantitative examinations was a venture among medical bacteriologists to isolate and identify specific pathogens in market milk. Bovine tubercle bacilli, as the previous chapter mentioned, comprised a principally feared pathogen, and while the luminaries of the field weighed the likelihood of transmissibility, many remained convinced of the etiological danger. In the first decade of the century, municipal bacteriologists estimated that active tubercle bacilli could be found in 6 to 10% of city milk and concluded that among consumers of raw milk, no one could "reasonably hope to escape introducing many tubercle bacilli into his body."¹⁹ Other researchers studied the relationship between contaminated milk and outbreaks of typhoid fever, diphtheria and scarlet fever.²⁰

The task of isolating and identifying specific germs in market milk proved, however, difficult. Contaminated milk never contained more than a small number of pathogenic forms, which were regularly outgrown by other organisms in plate cultures. Bacteriologists rarely isolated the actual typhoid, diphtheria, or tubercle bacilli in milk samples.²¹ Moreover, bacteriologists found it difficult to demonstrate that a particular organism reliably produced a

danger to Public Health. Much market milk is more contaminated with germs than the sewage of many large cities." Magruder, The Solution of the Milk Problem (Washington, D.C.: R. Beresford, 1913), 3.

¹⁹ E.C. Schroeder, "Milk and Its Products as Carriers of Tuberculosis Infection," Circular of Bureau of Animal Industry no. 143 (1909): 186. See also, Alfred F. Hess, "Cultures of Tubercle Bacilli Isolated from Milk," Journal of Infectious Diseases 6 (1909): 329-331; Hess, "The Incidence of Tubercle Bacilli in New York City Milk, with a Study on the Effects on a Series of Children," Journal of the American Medical Association (1909): 1011-1016; and, Fred O. Tonney, "Tuberculosis in Market Milk of Chicago," Journal of the American Medical Association 55 (1910): 1252.

²⁰ See, Rowland G. Freeman, "Milk as an Agency in the Conveyance of Disease," Medical Record no. 13 (1896); J.W. Trask, "Milk and Its Relation to the Infectious Diseases," Journal of the American Medical Association (1908): 1491; and, Trask, "Milk as a Cause of Epidemics of Typhoid Fever, Scarlet Fever, and Diphtheria," Hygienic Bulletin of the Public Health and Marine Hospital Service no. 56 (1909): 23-149.

²¹ C.O. Jensen, and Leonard Pearson, Essentials of Milk Hygiene: A Practical Treatise on Dairy and Milk Inspection and On the Hygienic Production and Handling of Milk, for Students of Dairying and Sanitarians (Philadelphia: J.B. Lippincott Co., 1907), 234

specific disease. For example, in the first years of this century, William H. Park and L. Emmett Holt posited a relationship between contaminated milk and infant cholera. After examining a host of bacterial types, they found that none of 139 varieties were pathogenic for young experimental animals. Nonetheless, they maintained that germ-laden milk posed a risk to infants and invalids, and that it remained a “safe conclusion that no more bacteria should be allowed than it is practicable to avoid.” This assertion epitomized the hygienic view of milk bacteria, a belief that all forms represented an undifferentiated source of infection, and that the higher the bacterial counts, the greater the danger.²²

As isolation and identification proved to be elusive goals, bacteriologists and dairymen placed a high priority on elimination. The dominance of this approach was largely sustained by the urban context of milk bacteriology. Throughout the nineteenth century, clean milk campaigns constituted a mainstay of muckracking journalists and civic reformers. “Child saving” was equated, in part, with the improvement of market milk. As early as 1850, the *New York Tribune* blamed impure milk for the deaths of 9,847 children under the age of two. By the end of the century, germs rivaled adulteration as the principal menace, and milk bacteriology was enlisted within this particular branch of Progressive Era reform. George L. Magruder, an emeritus professor at Georgetown Medical College, proclaimed in a 1909 USDA circular: “Safe milk saves babies and diminishes the prevalence of tuberculosis, typhoid fever, diphtheria, septic

²² Park and Holt, “Report Upon the Results with Different Kinds of Pure and Impure Milk in Infant Feeding in Tenement Houses and Institutions in New York City,” Annual Report of the Department of Health, City of New York, 1902 (1903): 275-299; and, Park, “The Bacterial Condition of City Milk and the Need of Health Authorities to Prevent the Sale of Milk Containing Excessive Numbers of Bacteria,” Science 13 (1901): 322. George L. Magruder distilled this view, asserting that “it is dangerous for any person to expose his health to disease germs at any time.” All “milk must be clean. Germs are few in clean milk. . . . Dirt and germs in milk are danger signals and warnings. . . .” The Solution of the Milk Problem (Washington, D.C.: R. Beresford, 1913), frontace page and 3.

sore throat and other diseases.” This booklet, which offered bacterial counts as a measure of milk purity, concluded: “Mothers, arise, and demand with one voice that your physicians and law-makers secure SAFE MILK TO SAVE YOUR BABIES.”²³ Bacteriologists, in this context, were *de facto* participants in the effort to educate citizens, pressure governments, and police commercial interests, and many accepted, at least tacitly, this role.²⁴

Dairy bacteriologists, employed at experiment stations and within the Bureau of Animal Industry (BAI), contributed to this “hygienic vision” of milk sanitation. Initially, they reiterated and sanctioned the popular equation of dirt with disease. Edward Webster, the chief of the BAI’s Dairy Division, explained that, “Bacteriology teaches that every particle of dirt, whether it seems to the eye a source of contamination or not, carries with it great numbers of bacteria” Lucius L. van Slyke, of the Geneva station, posited a very simple linear relation: “the more dirt there is in milk, the more bacteria there will be. Bacteria and dirt always go together in dairy matters.”²⁵

²³ Magruder, The Solution of the Milk Problem, 3 & 32. Similarly, E.C. Schroeder, the Superintendent of the BAI’s experiment station, concluded, “It is for the sake of children especially, the little beings whose welfare is a sacred obligation that stands second to nothing, that the fight for pure milk should be made so strong that it will overwhelm every opposition.” Schroeder, “The Relation of the Tuberculous Cow to Public Health,” Circular of the Bureau of Animal Industry no. 153 (1910): 45. See also, Julie Miller, “To Stop the Slaughter of Babies: Nathan Straus and the Drive for Pasteurized Milk, 1893-1920,” New York History 74 (1993): 158-184; Thomas R. Pegram, “Public Health and Progressive Dairying in Illinois,” Agricultural History 65 (1991): 36-50; and, Eric Brunger, “Dairying and Urban Development in New York State, 1850-1900,” Agricultural History 29 (1955): 169-174.

²⁴ See, for example, Theobald Smith, “Channels of Infection, with Special Reference to Water and Milk,” Popular Health Magazine 1 (1893): 279-287; William H. Park, “The Great Bacterial Contamination of the Milk of the Cities. Can It Be Lessened by the Action of Health Authorities?” Journal of Hygiene 1 (July 1901): 391-406; William M. Esten and Christie J. Mason, “Sources of Bacteria in Milk,” Bulletin Storrs Agricultural Experiment Station no. 51 (1908): 65; John R. Mohler, “The Importance of a Wholesome Milk Supply,” Circular of the Bureau of Animal Industry no. 153 (1910): 28-37; and, Harry A. Harding and James D. Brew, “The Financial Stimulus in City Milk Production,” Bulletin of New York Agricultural Experiment Station no. 363 (April 1913): 165-178.

²⁵ Edward Webster, “Some Important Factors in the Production of Sanitary Milk,” Circular of Bureau of Animal Industry no. 142 (1909): 100; and, Lucius L. van Slyke, and Charles A. Pablow, Science and the Practice of Cheese Making: A Treatise on the Manufacture of American Cheddar Cheese and Other Varieties, Intended as a Text-book for the Use of Dairy Teachers and Students in Classroom and Workroom (New York: O. Judd Company, 1909), 4-5. There was an explicit condemnation that accompanied high counts, as they documented “slovenly and careless methods of handling” that admitted dust and “animal excreta” to milk. Harry L. Russell and Edwin G. Hastings, Outlines of Dairy Bacteriology: A Concise Manual for the Use of Students in Dairying, 3rd ed. (Madison, Wisc.: H.L. Russell, 1902), 55.

As a research program, dairy bacteriologists, particularly those employed at the Cornell, Geneva, Wisconsin, and Illinois stations, labored to uncover the sundry sources of contamination.

Beginning with a demonstration that milk, as it leaves the udder, is comparatively free of germs, these investigators documented the nearly endless routes of infestation, including barnyard dust, hay, feed, unwashed milk bottles and utensils, milking machines, flies, and milkers' hands.²⁶

Researchers at the Dairy Division sustained a particular interest in quantifying the relative importance of each source. For example, one investigator estimated the typical "untrained" milker would produce milk with average bacterial count of 17,105 per c.c., while a "trained" handler rendered milk with an average of 2,455 per c.c. Mostly, these hygienic studies reaffirmed common sense. There were, however, some noteworthy findings, such as the determination that the primary route of tubercle contamination of milk arrived not through infected udders, but via fecal particles from cows showing no signs of illness.²⁷

This line of research regarded all bacteria as equally undesirable, and the connection between dirt and germs implicated milk as an intrinsic source of contagion. Dairy bacteriologists recognized the disciplinary implications of the hygienic vision. James D. Brew and William D. Dotterer of the Geneva station expressed little surprise that the "general public has come to have the feeling that the average glass of milk is to be looked upon with suspicion." Other

²⁶ For examples, see, Archibald R. Ward, "The Invasion of the Udder by Bacteria," Bulletin of the New York (Cornell) Agricultural Experiment Station no. 178 (1900); William Stocking, Christie J. Mason, and Charles L. Beach, "Milking Machines," Bulletin of the Storrs Agricultural Experiment Station no. 47 (1907); H.A. Harding, Godfrey L.A. Ruehle, J.K. Wilson, and George A. Smith, "The Effect of Certain Dairy Operations Upon the Germ Content of Milk," Bulletin of the New York Agricultural Experiment Station no. 365 (1913): 197-233; and, Ruehle, and W.L. Kulp, "Germ Content of Stable Air and Its Effect Upon the Germ Content of Milk," Bulletin of the New York (Geneva) Agricultural Experiment Station no. 409 (1915): 418-474.

²⁷ Schroeder, "Milk and its Products as Carriers of Tuberculosis," 187-189; Webster, "Some Important Factors in the Production of Sanitary Milk," 164; and, Jenks Cameron, The Bureau of Dairy Industry: Its History, Activities, and Organization (Baltimore: Johns Hopkins Press, 1929), 12.

bacteriologists conceded that their studies may have contributed to the belief that "every particle of dust in the barn air" should be looked "upon as an omnibus overloaded" with dangerous germs. Acknowledging that their own hygienic approach brought financial consequences, a SAB roundtable of dairy bacteriologists agreed that "any procedure which will remove this suspicion and stimulate the increased consumption of milk will be of great economic benefit to the dairy industry as well as to the consumer."²⁸

In consenting to this service aim, dairy bacteriologists sought methods for improving milk sanitation. By determining the relative importance of each route of contamination, dairy bacteriologists constructed a compendium of cost-effective, if mundane, suggestions for milking, handling, and transportation.²⁹ The bacteriologically sanctioned recommendations included: clipping and combing of flanks and rears; washing teats; employing small-mouthed pails with seamless joints; moistening walls to reduce dust; cooling the milk immediately after milking; and, not mucking the barn or feeding the cows near milking times. With regard to the milkers themselves, the station scientists insisted that they be clean shaven, clothed in white uniforms, and "equipped with the most modern tools and stools."³⁰ As milk sanitation became a matter of

²⁸ James D. Brew and William D. Dotterrer, "The Number of Bacteria in Milk," Bulletin New York State Agricultural Experiment Station no. 439 (1917): 477; H.A. Harding, Robert S. Breed, E.S. Hastings, and W.A. Stocking, "What is Meant by 'Quality' in Milk?" Journal of Dairy Science 1 (1917): 208-209, & 203; and, John T. Schlebecker and Andrew W. Hopkins, A History of Dairy Journalism in the United States, 1810-1950 (Madison: University of Wisconsin Press, 1957), 119.

²⁹ Charles E. Marshall, "Bacteria and the Dairy," Bulletin of the Michigan State Agricultural Experiment Station no. 146 (1896); Charles F. Doane, "Economical Methods for Improving the Keeping Quality of Milk," Bulletin of the Maryland Agricultural Experiment Station no. 88 (1903): 117-164; Walton K. Brainerd, and Walter Mallory, "The Production of Clean and Sanitary Milk: Results of Experiments to Determine the Number of Bacteria in Milk Produced under Different Conditions," Bulletin of the Virginia Agricultural Experiment Station no. 185 (1909): 1-24; Herbert W. Conn, Practical Dairy Bacteriology: Prepared for the Use of Students, Dairymen, and All Interested in the Problems of the Relation to Milk to Public Health (New York: O. Judd Company, 1907); and, Wilhelm Ernst and John Mohler, Text-book of Milk Hygiene (Chicago: A. Eger, 1915).

³⁰ Kenelm Winslow and Hibbert W. Hill, The Production and Handling of Clean Milk, Including Practical Milk Inspection, 2nd ed. (New York: W.R. Jenkins Co., 1909), 145; William A. Stocking, "The Covered Pail, a Factor in Sanitary Milk Production," Bulletin of the Storrs Agricultural Experiment Station no. 25 (1903); C.F.

public cleanliness, bacteriologists prided themselves in knowing that they had contributed to the dramatic reduction of bacterial counts. Harry L. Russell confidently reported that, when his register of hygienic practices were dutifully implemented, atmospheric contamination rates could be lowered from 5,250 to 114 germs per c.c..³¹

In addition to aiding in the initial production of clean milk, bacteriologists developed methods for performing uniform and rapid bacterial counts of market samples. As Chapter One indicated, the American Public Health Association (APHA) contemplated standard methods for milk analysis in 1905. Its Laboratory Section issued a final report in 1910 (and a revision in 1916) which specified incubation times and temperatures, ingredients for culture media, and detailed instructions for acidity testing, dilution techniques, and quantitative determinations. The Laboratory Section intended to produce uniformity, as truly standard methods would allow health officials to compare bacteria counts from sample to sample, and from city to city. The APHA's plate culture method itself, however, was problematic. Culture counts could only be performed by trained workers in well-equipped laboratories, and required 24 to 48 hours to complete. The estimates did not account for "clumping" among bacteria, nor did the media provide suitable nutrients for all forms. The standard methods failed to specify uniform oxygen

Doane, "Economical Methods for Improving the Keeping Qualities of Milk," Bulletin of the Maryland Agricultural Experiment Station no. 88 (1903); Wilbur J. Fraser, "Preventing Contamination of Milk," Bulletin of the Illinois Agricultural Experiment Station no. 91 (1903); Stocking, "Quality of Milk Affected by Common Dairy Practices," Bulletin of the Storrs Agricultural Experiment Station no. 42 (1906): 66-90; and, Martin J. Prucha, and H.M. Weeter, "Germ Content of Milk: I. As Influenced by Factors at the Barn," Bulletin of the Illinois Agricultural Experiment Station no. 199 (1917).

³¹ Russell, "Tainted or Defective Milks: Their Causes and Methods of Prevention," Bulletin of the Wisconsin Agricultural Experiment Station no. 62 (1897). For examples of bacteriologists echoing the gospel of cleanliness, see, Winslow, The Production and Handling of Clean Milk, 3; Esten and Mason, "Sources of Bacteria in Milk," 68-77; and Ravenel, "Milk Supply from the Bacteriological Standpoint," 221.

requirements, and were plagued by both bacterial antagonisms and colony "spreaders."³² Moreover, the standard methods failed to produce real uniformity. As one reviewer of the revised standards explained, "Bacteriologists, have, from the beginning, been aware of the difficulties involved in making accurate bacterial counts and of the wide fluctuations possible in duplicate counts." While the APHA methods standardized many of the procedures, "it is well known that there still exists great difficulty in getting uniform plate counts from the same sample of milk when the analyses are made in two different laboratories, or even when the analyses are made by two different workers in the same laboratory."³³ In response to these recognized difficulties, a few agricultural bacteriologists proposed alternatives to the conventional culture methods. At the Geneva station, Robert S. Breed and James D. Brew developed a direct microscopical technique. The procedure, as proposed in 1915, involved pouring a known quantity of milk onto a slide, which was then dried, stained, and counted. The method required no culturing, little time, and only minimal skills. The direct method did not, however, distinguish between living and dead bacteria (and was thus useless in testing pasteurized milk). Additionally, it produced higher counts than plate methods, a phenomenon that Breed never fully explained.³⁴ While the direct microscopic method never found widespread acceptance, it did

³² Mazyck P. Ravenel, William H. Park, Robert S. Breed, and J.A. Anderson, "Standard Methods of Bacteriological Analysis in Milk," American Journal of Public Health 7 (1916): 4-11; and, Herbert W. Conn, "Standards for Determining the Purity of Milk," U.S. Public Health Service, Public Health Reports 30 (1915): 2349-2395.

³³ Brew and Dotterrer, "The Number of Bacteria in Milk," 480-481. See also, Robert S. Breed, "Report of Committee of American Dairy Science Association on Bacteriological Methods for Market Milk Analysis," Journal of Dairy Science 1 (1918): 380-382; Breed and William A. Stocking, "The Accuracy of Bacterial Counts from Milk Samples," Technical Bulletin of the New York Agricultural Experiment Station no. 74 (1920); and, Edwin G. Hastings, "Review of the Fourth Edition of the Standard Methods of Milk Analysis," Journal of Dairy Science 7 (1924): 210-211.

³⁴ James D. Brew, "A Comparison of the Microscopical Method and the Plate Method of Counting Bacteria in Milk," Bulletin of New York Agricultural Experiment Station no. 373 (1914); Breed and Brew, "Counting Bacteria by Means of the Microscope," Technical Bulletin of New York Agricultural Experiment Station

establish dairy bacteriologists, and agricultural experiment stations, as authoritative participants in the development of standard methods for milk examinations.³⁵

Dairy bacteriologists also contributed to the development of milk pasteurization. The involvement of public health officials and reformers, particularly those in New York City and Chicago, in the adoption of mandatory pasteurization ordinances has been well-documented. Historians have rightfully identified Ernest Lederle, Charles North, Rowland Freeman, and Nathan Strauss as principal public advocates for pasteurized milk. North, in particular, played a prominent role, in developing an improved apparatus for commercial pasteurization. The new technique helped convince the National Commission on Milk Standards that pasteurized milk and certified milk need not be mutually exclusive goals.³⁶ Other medically oriented researchers, such as Milton J. Rosenau of the U.S. Public Health Service, contributed to the pasteurization movement by demonstrating that heated milk was just as digestible, and just as nutritious, as unheated milk.³⁷

no. 49 (1916); Breed and Brew, "The Control of Bacteria in Market Milk by Direct Microscopic Examination," Bulletin of the New York Agricultural Experiment Station 443 (1917): 717-746; and, Breed, "Questions Concerning the Control of a City Milk Supply Answered," Bulletin of the New York Agricultural Experiment Station no. 456 (1918): 1-10.

³⁵ J.J. Jezeski, "Progress in Basic Bacteriology of Milk," Journal of Dairy Science 39 (1956), 659; Robert S. Breed, "Forty Years of Progressive Dairy Sanitation," Journal Dairy Science 32 (1948): A16; J. Lloyd Henderson, "Market Milk Operations, 1906 Versus 1956," Journal of Dairy Science 39 (1956): 812-818; and, H.A. Harding, "The Development of City Milk Supply Problems," in University of Wisconsin Studies, Science No. 2, Papers on Bacteriology and Allied Subjects (Madison: University of Wisconsin, 1921), 29-54.

³⁶ See, for example, Julie Miller, "To Stop the Slaughter of Babies," 165-182; Shirley Wynne, "The History of Milk in New York City" Cornell Veterinarian 24 (1934): 299-309; Susan Turnbull Shoemaker, "The Philadelphia Pediatric Society and Its Milk Commission, 1896-1917: An Aspect of Urban Progressive Reform," Pennsylvania History 53 (1986): 275; Judith Walzer Leavitt, The Healthiest City: Milwaukee and the Politics of Health Reform (Princeton: Princeton University Press, 1982), 156-189; and, Charles E. North, "Milk and Its Relation to Public Health," in, A Half Century of Public Health: Jubilee Historical Volume of the American Public Health Association, Mazyck P. Ravenel, ed. (New York: American Public Health Association, 1921), 236-289.

³⁷ Milton J. Rosenau, "Milk and Its Relation to the Public Health: Pasteurization," Bulletin of the Hygienic Lab, U.S. Public Health and Marine Hospital Service no. 41 (1908): 589-624; Rosenau, "Pasteurization, Its Advantages and Disadvantages," Circular of the Bureau of Animal Industry no. 153 (1910); and, G. Lloyd Magruder, "Milk as a Carrier of Contagious Diseases, and the Desirability of Pasteurization," Circular of the

Dairy bacteriologists, working in experiment stations and at the BAI's Dairy Division, have been curiously excluded from these histories. Harry L. Russell's interest in pasteurization actually preceded the turn of the century. In the mid-1890's, Russell examined heated milk, but not from a hygienic or medical perspective. Instead, he considered an aesthetic obstacle. Consumers of bottled milk had long associated a column of cream with milk quality. Heating milk to 155 degrees F. destroyed that cream line, and rendered the milk watery. In order to alleviate anticipated consumer objections, Russell and Stephen Babcock, the chemist for the Wisconsin station, studied the chemical and physical changes wrought by pasteurization. They found that a mixture of lime and sugar-water, when added to milk, reintroduced clotting. In 1897, they marketed this product commercially as "Viscogen." Similarly, Charles F. Doane, the dairy specialist for the Maryland station, predated Rosenau's investigations on the digestibility of pasteurized milk. His own studies, conducted on newborn farm animals instead of infants, revealed that moderate heating did not substantially alter the healthfulness of milk.³⁸ Even after pasteurization became a standard nation-wide practice, dairy bacteriologists maintained an active research interest. At the Dairy Division, Lore A. Rogers, S. Henry Ayers, and William T. Johnson devoted more than a decade to bacteriological investigations of pasteurized milk,

Bureau of Animal Industry no. 153 (1910): 7-26. By 1912, 40% of the milk sold in New York City and 75% of the Boston supply was pasteurized. Bacteriologists were regularly enlisted to perform counts of pasteurized milk. See, E.O. Jordan, "The Case for Pasteurization," Journal of the American Medical Association 59 (1912): 1450-1457.

³⁸ Both the aesthetic and medical objections rested on the assumption that the thermal death point of tubercle bacilli in milk was 155 degrees F., over twenty minutes. Theobald Smith, however, demonstrated that the pathogen could be rendered harmless by heating to only 140 degrees. Edward H. Beardsley, Harry L. Russell and Agricultural Science in Wisconsin (Madison: University of Wisconsin Press, 1969), chpts. 2-4; Harry L. Russell, "The Pasteurization of Milk," Pharmaceutical Review 14 (May 1896): 12; Charles F. Doane, "The Comparative Digestibility of Raw, Pasteurized and Cooked Milk," Bulletin of the Maryland Agricultural Experiment Station no. 77 (1901): 1-38; Doane, "The Character of Milk During the Period of Heat," Bulletin of the Maryland Agricultural Experiment Station no. 95 (1904): 25-30; and, Theobald Smith, "The Thermal Death-point of Tubercle Bacilli in Milk and Other Fluids," Journal of Experimental Medicine 4 (1899): 217-233.

convincingly demonstrating that pasteurization reproduced the characteristics of clean, freshly drawn milk.³⁹

With regard to the certified milk movement, agricultural bacteriologists assisted in no small measure. Most Medical Milk Commissions originated in the decades surrounding the turn of the century. Usually, these volunteer reform organizations affiliated with municipal public health departments, and enlisted bacteriologists to enforce numerical limits for germs in “certified milk.” By 1906, certification involved periodic or unannounced on-site inspection of dairy farms and creameries. Raymond A. Pearson, a professor of dairy industry at Cornell, developed a dairy “score card” for these inspections. Borrowing an idea employed in judging animals, plants, and seeds at country fairs, Pearson fashioned a numerical checklist for sanitary evaluations, allowing inspectors to record and compare their inspection reports, and affording a seemingly objective basis for assigning “certification” permits. Pearson’s card was soon modified by the Committee of the Official Dairy Instructors Association, and then again by officials of the USDA. By 1908, some 140 cities adopted some version of this card. The card weighted heavily the “sanitary methods” specified in the previous pages. As for bacterial counts, the Pearson instructed inspectors to award a perfect score, or 20 points, for a count less than 10,000 per c.c., 16 points for 100,000 or less, and so on.⁴⁰

³⁹ Lore A. Rogers, “Bacteria of Pasteurized and Unpasteurized Milk Under Laboratory Conditions,” Bulletin of Bureau of Animal Industry no. 73 (1905), 27-28; S. Henry Ayers, William T. Johnson, “The Bacteriology of Commercially Pasteurized and Raw Market Milk,” Bulletin of the Bureau of Animal Industry no. 126 (1910): 1-98; Ayers, “The Pasteurization of Milk,” Circular of the Bureau of Animal Industry no. 184 (1912); and Ayers, “The Present Status of the Pasteurization of Milk,” Bulletin of the United States Department of Agriculture no. 342 (1916): 1-16.

⁴⁰ Clarence B. Lane, and George M. Whitaker, “The Score-Card System of Dairy Inspection,” Circular of the Bureau of Animal Industry no. 139 (16 April 1909): 5-18; C.A. Abele, “Fifty Years of Progress in Dairy Farm Sanitation,” Journal of Dairy Science 39 (1956): 783-788; and, Walton Brainerd and Walter L. Mallory, “Milk Standards: A Study of the Bacterial Count and Dairy Score Card in the City Milk Inspection,” Bulletin Virginia Agricultural Experiment Station no. 194 (1911): 1-20.

These efforts, from the identification of the sources of contamination, to the participation in pasteurization and certified milk campaigns, subsumed dairy bacteriology under the “hygienic vision.” Milk contaminated by germs was both “impure” and unhealthy. Dirt served as the proximate cause of contamination, and the final outcome inevitably produced infant mortality. As some milk organisms elicited infectious disease, all germs were implicated. Dairy bacteriologists sustained the “hygienic vision” by offering an expertise of elimination. They served the interests of dairymen, health officials, and consumers by providing measures to reduce bacterial counts in market milk. Yet, most dairy bacteriologists never fully endorsed the “hygienic vision.” They questioned the validity of numerical limits for bacterial counts. Certainly, the wide discrepancy in municipal standards, from 30,000 bacteria per c.c. in Rochester to 2,000,000 in St. Louis, implied a measure of arbitrariness. Moreover, as Lore A. Rogers and S. Henry Ayers noted, a sample containing millions of germs need not harbor any dangerous forms. And, in Harry Russell’s opinion, the great inaccuracies of all methods for quantitative determinations rendered any standard based on numerical limits “extremely problematical.” James D. Brew, of the Geneva station, even disputed the relationship between dirt and bacterial contamination. In a 1915 review of 34 dairy environments, Brew failed to find a relationship between the dairy score card results and the quality of milk produced.⁴¹

⁴¹ Rogers and Ayers, “Interpretation of Results of Bacteriological Examination of Milk,” 46; Russell, *Outlines of Dairy Bacteriology*, 3rd ed., 49 & 51; and, James D. Brew, “Milk Quality as Determined by Present Dairy Score Cards,” *Bulletin of New York Agricultural Experiment Station* no. 398 (1915): 190, 107. Harry A. Harding repeatedly disparaged the use of bacterial counts, noting that: 1) they lacked educational value “because dairymen are unable to translate quantitative results into terms of dairy processes,” 2) the numerical limits “had little value” because “they fluctuate so widely,” and, 3) they were “not necessary, since the best results in improvement of city milk supply can be obtained without the aid of quantitative determinations.” Harding, “What is the Value of Quantitative Bacteriological Determinations in the Control of City Milk Supply?” *Science* 33 (1911): 542.

Dairy bacteriologists raised two additional, and more fundamental, objections to the “hygienic vision.” First, their participation in the quest for milk sanitation added little to their own understanding of either milk or its bacterial inhabitants. Bacterial counts were used primarily to “reveal whether the milk has been properly handled or not.” High counts documented a “telltale or automatic register of the treatment the sample has received,” as neglect of any sanitary methods was “written down by these faithful ‘recording angels’ for the bacteriologist to read.” The repeated employment of score cards and milk counts served to coax dairymen to adopt “a regime as shall make contamination by pathogenic organisms improbable.” The actual number of bacteria in milk was “of no special significance, except as an indication of the cleanliness of the dairyman in handling his cows and in caring for his dairy.” Within this sanitary scheme, the bacteriologist acted as little more than an inspector of cow sheds, albeit *in absentia*.⁴²

Secondly, dairy bacteriologists resisted the adoption of APHA methods as the “standard.” In 1916, the American Dairy Science Association (ADSA) appointed a Committee on Bacteriological Methods, and selected Robert S. Breed as its chair. Breed, a dairy and soil bacteriologist at the Geneva Station, also served as a member of the APHA Committee on Standard Methods, and his ADSA Committee was charged with evaluating the newly revised “standard methods.” Breed delicately noted that the APHA report, “drawn up as it is with the primary purpose of standardizing” methods for “inspection work, would not meet the needs of the members of this association” who were most “interested in research work” and the “analytic

⁴² Winslow, The Production and Handling of Clean Milk, 219 & 244; Rowland Freeman, as quoted in Jenson, Essentials of Milk Hygiene, 168-169; Conn, Agricultural Bacteriology, 177-183; and Hibbert Hill, quoted in Winslow, The Production and Handling of Clean Milk, 247.

methods suitable for commercial purposes.” The APHA fashioned its methods, according to Breed, with the aim of judging the healthfulness of milk. Bacteriologists of the ADSA were, however, interested in the “control” and not elimination of microbial life, and they required methods that could predict the variables important to commercial dairy production.⁴³

Other members of the ASDA’s Committee on Bacteriological Methods shared Breed’s apprehensions. Harry A. Harding objected “strenuously” to “having that policeman, or those police methods taken as official methods.” Harding, who directed Illinois’ Department of Dairy Husbandry, speculated that dairying students might “be misled by the application of this so-called police method,” and “get the idea that this is the way” of studying milk bacteria. William Stocking concluded that there was “a vast difference between the real work that this Association is trying to do” and the inspection duties of health officers. For Stocking, the Head of Cornell’s Department of Dairy Industry and President of the ADSA, it was “not very advisable” for the two associations to adopt identical methods. While the program of milk sanitation represented the bread and butter of dairy bacteriology in the first decades of the century, the consternation of Breed, Harding, and Stocking reflected a recognition that their field promised something more than the elimination of germs.⁴⁴

The Bacteriologic Vision of Dairy Microbes

Dairy bacteriologists elaborated an alternative to the “hygienic vision” of milk sanitation.

⁴³ Robert S. Breed, “Bacteriological Methods for Market Milk Analysis,” *Journal of Dairy Science* 1 (1917): 380-381. See also, Breed, “Comments Upon the Present Standard Methods of Milk Examination,” *Abstracts of Bacteriology* 6 (1922): 33.

⁴⁴ Harding and Stocking quoted in Breed, “Bacteriological Methods for Market Milk Analysis,” 382. See also, O.W. Kaufman, “Fifty Years of Progress in Dairy Plant Sanitation Methods,” *Journal of Dairy Science* 39 (1956): 865; and, Jezeski, “Progress in Basic Bacteriology of Milk,” 659.

In contradistinction to the efforts to eliminate germs from milk samples, dairy bacteriologists also sought to control, manage, and exploit bacterial life. The “bacteriologic vision” did not regard all germs as an inherent source of danger. Milk bacteria could be both beneficial and detrimental, and dairy bacteriologists placed great emphasis on distinguishing between the various types of microorganisms. More importantly, the desire to control bacterial life led researchers to consider a host of issues normally neglected by the “hygienic vision,” such as bacterial physiology, systematics, and associative behavior.

Like the “hygienic vision,” the “bacteriologic” approach emerged within a specific institutional context. Its origins can be traced to the appearance of dairy husbandry, or dairy industry, as an academic subject in the late nineteenth century. Historians of American agriculture have characterized the 1880's and 1890's as an era of rapid specialization and industrialization in dairy manufacturing. Farmers in New York and the Midwest increasingly looked to butter and cheese production for a steady source of agricultural income. As historian Eric Lampard explained, “the whole process” was “caught up in an industrial revolution” which demanded that all involved “in its exacting routine” had to “meet industrial standards and adapt to industrial norms.” Dairying magazines, such as *Hoards Dairyman*, regularly counseled farmers to study and employ the principles of “scientific dairying,” while the various farmer’s institutes and cheese makers’ associations endorsed this “happy blending of science and practical knowledge.”⁴⁵ Between 1890 and 1910, more than twenty land grant colleges and state

⁴⁵ Lampard, *The Rise of the Dairy Industry in Wisconsin: A Study in Agricultural Change, 1820-1920* (Madison: State Historical Society of Wisconsin, 1963), 109, 145, & 219; Charles F. Doane, “The Relative Profits of Selling Milk, Cream and Butter,” *Bulletin of the Maryland Agricultural Experiment Station* no. 97 (1904): 45-46; John J. Dillon, *Seven Decades of Milk: A History of New York’s Dairy Industry* (New York: Orange Judd Publishing Co., 1941); and, John T. Schlebecker, *A History of American Dairying* (Chicago: Rand McNally & Co., 1967).

experiment stations established dairy departments.⁴⁶ Instruction, often provided in short winter courses, remained practically oriented, included bacteriology in so far as it directly aided in the control of cheese and butter production. (Table 3.1) At a handful of state agricultural experiment stations, however, research in dairy bacteriology flourished, often in concert with chemistry faculty (e.g., Minnesota, Wisconsin, Iowa State, Illinois, Cornell, and Geneva).⁴⁷ (Table 3.2)

In 1906, these agricultural scientists formed the National Association of Dairy Instructors and Investigators. This organization, which later changed its name to the American Dairy Science Association (ADSA), fortified the disciplinary alliance between dairying and bacteriology. For example, Penn State's James M. Sherman served in executive capacities for both the ADSA and the SAB during the late 1910's. Within the Dairy Division of the BAI, bacteriologists regularly teamed with dairy experts, as the Division increasingly explored issues of dairy production, and not simply milk hygiene.⁴⁸ As a consequence of these institutional developments, leading dairymen viewed bacteriology as a remarkable source of rationalized efficiency. If dairy production stood as an emblem of scientific farming, then bacteriology could

⁴⁶ H.P. Davis, "Fifty Years of Progress in Dairy Production Teaching," Journal of Dairy Science 39 (1956): 795-797; Alfred C. True, "A History of Agricultural Education in the United States," U.S. Department of Agriculture, Miscellaneous Publication no. 36 (1929): 250-251; and, Arbuckle, "Teaching of Dairy Manufacturing," Journal of Dairy Science 39 (1956): 876.

⁴⁷ Harry L. Russell, "Summary of Experimental Work in Bacteriology for the Years 1893-1903," University of Wisconsin, Agricultural Experiment Station, Annual Report 20 (1904); Anne G. Lewis, "Agricultural Experiment Station, University of Minnesota, 1885-1985," Minnesota Science 39 (1984); J.L. Robinson, "One Hundred Years of Dairy Science," Illinois Research 17 (1976): 14-15; H.W. Mumford, "A Half-Century of Achievement by the Illinois Agricultural Experiment Station," Science 87 (1938): 539-545; and, R.E. Krauss, "About the Experiment Station -- A Centennial Celebration," Special Report of the New York Agricultural Experiment Station, Geneva 48 (May 1983).

⁴⁸ Wilber J. Fraser, "The Formation of the American Dairy Science Association," Journal of Dairy Science 6 (1933): 583-586; Malcolm G. Trout, "Fifty Years of the American Dairy Science Association," Journal of Dairy Science 39 (1956): 625; R.E. Hodgson, "Dairy Production Research in the United States Department of Agriculture," Journal of Dairy Science 39 (1956): 766; A.M. Loomis, "Research Work of the Dairy Division," Hoard's Dairyman 60 (6 Aug. 1920): 3; and, S.R. Winters, "Who's Who in the U.S. Dairy Division," Hoard's Dairyman 63 (1922): 108-109.

comprise the engine of change.⁴⁹ It was this service role to dairy interests, with its attendant appreciation for laboratory and field research, that encouraged dairy bacteriologists to develop an alternative to the “hygienic vision.”

There are a few distinguishing features to the “bacteriologic vision.” Initially, most dairy bacteriologists considered knowledge of the *kinds* of bacteria in a milk sample to be more informative than an indication of the *numbers*. For sanitary examinations, high plate counts implied danger, as all germs were viewed with suspicion. In contrast, “the bacteriologic vision” posited a normal flora of milk, which, under most circumstances posed no risk to the consumer. As William Esten and Christie Mason of the Storrs station insisted, “the numbers of bacteria in milk are no criterion of its healthfulness.” Ten typhoid bacilli in a quart of milk could kill, while ten million lactic acid bacteria per c.c. in buttermilk not only rendered the product harmless, but quite delectable.⁵⁰ This precept carried significant methodological implications. Dairy bacteriologists required techniques for differentiating milk bacteria; information not tendered by the quantitative examinations of the hygienic program.

At Wisconsin, Geneva, Illinois, and Connecticut state stations, dairy specialists endeavored to survey the normal flora of milk. In turn, they instructed their dairy students to master the rudimentary methods for isolating and identifying bacterial types.⁵¹ The task of

⁴⁹ Otto F. Hunziker, The Butter Industry: Prepared for the Use of Creameries, Dairy Students and Pure Food Departments, 1st ed. (La Grange, Ill.: by author, 1920), 24; Henry E. Alvord, “Dairy Development in the United States,” in Yearbook of the United States Department of Agriculture, 1899 (1900): 381-402; and, Conn, Agricultural Bacteriology, 2nd ed., 137.

⁵⁰ Esten and Mason, “*Bacterium Lactis Acidi* and its Sources,” Bulletin of the Storrs Agricultural Experiment Station no. 59 (1909): 65 & 71; Buchanan, Outlines of Dairy Bacteriology, 3rd ed., 53; and Conn, Agricultural Bacteriology, 1st ed., 186. As Veranus A. Moore estimated, “it is the exception when the bacteria in milk” will “produce any harm to the consumer.” Moore, Bacteria in Milk: A Summary of the Present Knowledge Concerning their Source and Significance (Albany: J.B. Lyon Company State Printers, 1902), 17.

⁵¹ See, for example, Herbert W. Conn, “The Bacteria of Milk,” Report of the Conn. Board of Agriculture (1890), 28-43; and, Conn, “The Fermentations of Milk,” Experimental Station Bulletin no. 9 (1892). At the Storrs

determination, however, proved a difficult one. The majority of milk bacteria were indistinguishable on simple morphological or cultural criteria, and liquefiers ruined most plate cultures. Nonetheless, dairy bacteriologists developed methods for discriminating between various kinds. Herbert Conn and William Esten, for example, separated some thirty "types" based on colony formation and growth on litmus-lactose-gelatin.⁵² Similarly, S. Henry Ayers and William T. Johnson at the Dairy Division, and James Sherman of Penn State, generated several determinative techniques for milk organisms in the 1910's.⁵³

Despite these efforts, the goals of isolation and identification remained unfulfilled in the early twentieth century, as most dairy bacteriologists grouped milk organisms into loosely defined clusters (e.g., "true" lactic acid bacteria, casein-digesting or peptonizing bacteria, non-liquefiers, etc.) rather than precise taxonomic units. Moreover, these groupings served many of the purposes of the "hygienic vision." For example, the Rockefeller Foundation financed Conn and Esten's 1903 investigations of the effect of temperature on various types of milk bacteria. They found that 20 degrees C. tended to favor growth of normal (and harmless) lactic acid

station and Connecticut Agricultural College, this program for isolating and identifying milk bacteria comprised a significant segment of the "research" performed at these sites between 1890 and 1910. See, James G. Horsfall, The Pioneer Experiment Station, 1875-1975 (Lexington: Union College Press, 1992); anon., Semi-Centennial of the Connecticut Agricultural Experiment Station (New Haven: Tuttle, Morehouse & Taylor Co., 1925); anon., "Storrs Agricultural Experiment Station, Fiftieth Anniversary, 1888-1938," (1938); and, Walter Stemmons and Andre Schenker, Connecticut Agricultural College: A History (New Haven: Tuttle, Morehouse & Taylor, 1931).

⁵² For example, two common milk organisms, *B. acidi lactici* and *B. lactici aerogenes*, could be distinguished by noting that the former grew beneath the surface of the gelatin and showed irregularities around its edges, while the latter grew on the surface and produced an intensely acid reaction in the litmus medium. Conn and Esten, "The Comparative Growth of Different Species of Bacteria in Normal Milk," 14th Annual Report of the Storrs Agricultural Experiment Station (1901), 16.

⁵³ Ayers and Johnson, "Ability of Streptococci to Survive Pasteurization," Journal of Agricultural Research 2 (1914): 321-330; Ayers and Johnson, "Ability of the Colon Bacilli to Survive Pasteurization," Journal of Agricultural Research 3 (1915): 401-411; M.A. Farrell, "A Brief of History of Bacteriology at Penn State, 1904-1905," 1945, [ASM] SAB annual meeting, box 2-IXC, folder 88; and, Keith E. Roe, "History and Checklist of the Pennsylvania Agricultural Experiment Station Journal Series, 1926-1937," Progress Report: Pennsylvania State University, Agricultural Experiment Station no. 376 (1981).

bacteria, while higher temperatures tended to favor "more dangerous" kinds. Conn and Esten's report legitimized municipal ordinances which prohibited the sale of milk above 30 degrees C.⁵⁴ Other researchers employed these groupings to identify the sources of contamination. For example, most gas-producing liquefiers originated from animal excreta and produced a host of undesirable effects in milk, while non-liquefiers, derived from udders, did not adversely effect either the milk or its consumers.⁵⁵ These efforts combined the hygienic aim of exclusion with the bacteriologic method of differentiation and management.

In another instantiation of the "bacteriologic vision" in service to hygienic aims, dairy bacteriologists strove to uncover the origins of abnormal fermentations and milk faults, including: gassy milk (caused by the colon bacillus and *B. lactis aerogenes*); "sweet curdling" (caused by spore-forming liquefiers from filth and manure); ropy or slimy milk (caused by *Strep. Hollandicus*, *Bact. lactis viscosum*, and *M. pituitoparus*); "bitter milk" (caused by *M. casei amari* and *B. aerogenes capsulatus*); and discolored milk (caused by *B. prodigiosus*, *B. lactis erythrogenes*, *B. cyanogenes*).⁵⁶ These undesirable contaminations extracted considerable costs

⁵⁴ Herbert W. Conn and William M. Esten, "The Effect of Different Temperatures in Determining the Species of Bacteria Which Grow in Milk," Storrs Agricultural Experiment Station, 16th Annual Report (1904): 28-34. See also, Esten and Mason, "Sources of Bacteria in Milk," 75-78; and, Lowery L. Lewis, "Bacteriology of Milk," Bulletin of the Oklahoma Agricultural Experiment Station no. 40 (1899): 3-16.

⁵⁵ William Esten and Christie Mason, "*Bacterium Lactis Acidi* and its Sources," 67; H.A. Harding and J.K. Wilson, "A Study of the Udder Flora of Cows," Technical Bulletin of the New York (Geneva) Agricultural Experiment Station no. 27 (1913); and, Alice C. Evans, "The Bacteria of Milk Freshly Drawn from Normal Udders," Journal of Infectious Diseases 18 (1916): 437-476.

⁵⁶ Russell, Outlines of Dairy Bacteriology, 3rd ed., chpt. 4. See also, Archibald R. Ward, "Ropiness in Milk and Cream," Bulletin of the Cornell Agricultural Experiment Station no. 165 (1899); Bernard W. Hammer, "A Bacteriological Study of Blue Milk," Research Bulletin of the Iowa Agricultural Experiment Station no. 15 (1914); Hammer and Robert E. Buchanan, "Slimy and Ropy Milk," Research Bulletin of the Iowa Agricultural Experiment Station no. 22 (1915): 212-295; and, Hammer, "Bacteriological Studies on Two Yellow Milk Organisms," Research Bulletin of the Iowa Agricultural Experiment Station no. 20 (1915): 136-150. The search for agents of milk diseases shared many characteristics of medical bacteriology. In 1901, Harry Harding, George A. Smith, and Lore Rogers studied "rusty spot in cheddar cheese," isolating a certain *B. rudensis*. In order to demonstrate its etiological relationship they followed Koch's postulates: they grew the microbe in pure culture, inoculated a sterile vat of milk, reproduced the "diseased condition," and then recovered the same organism. Harding, Smith, and Rogers,

among dairymen, and bacteriologists confidently maintained that “almost all dairy problems have a bacteriological background, with solutions largely turning upon the matter of control of bacterial content and growth.”⁵⁷ Milk taints yielded an unsellable product, and bacteriologists offered technical interventions to control losses.

True, these efforts at differentiation appear to have been motivated by a desire to eliminate, rather than manage, bacterial life. They could be classified as examples of the “hygienic” rather than “bacteriologic” vision. Yet, the methodological move to studying kinds, rather than numbers, of milk organisms led researchers to consider phenomena normally neglected by the hygienic goal of milk sanitation. The second distinguishing feature of the “bacteriologic vision” was that dairy bacteriologists remained interested not only in determining *which* microorganisms were responsible for the various changes in milk, but were also intent on understanding *how* these bacteria produced those changes. In pursuit of this aim, dairy bacteriologists increasingly contemplated the role of bacterial associations, the realm of bacterial physiology, and the quandary of bacterial systematics.

Associative action among dairy organisms, both symbiotic and antagonistic, had been acknowledged by bacteriologists before the turn of the century. Freshly drawn milk, they noted, contained a wide of range of types. After 24 hours, however, the lactic acid forms tended to predominate, and by 48 hours, nearly excluded all other kinds. The explanation for this antagonistic phenomena remained elusive, as some researchers believed that lactic acid bacteria

“Notes on Some Dairy Troubles,” Bulletin of the New York Agricultural Experiment Station no. 183 (1900): 175-193; and, Harding and Smith, “Control of Rusty Spot in Cheese Factories,” Bulletin of the New York Agricultural Experiment Station no. 225 (1902): 303-329.

⁵⁷ Cameron, The Bureau of Dairy Industry, 18. See also, Moore, Bacteria in Milk, 13; and, Winslow, The Production and Handling of Clean Milk, 3.

merely outgrew concomitant organisms, while others held that the lactic acid forms produced substances injurious to their rivals. Regardless of its fundamental explanation, the notion of antagonisms carried practical import. For example, it encouraged the employment of culture starters. If lactic acid bacteria, which produced no ill effects in milk beyond normal souring, reproduced at the expense of other forms, they could be "inoculated" into milk to protect it from undesirable bacteria.⁵⁸ Moreover, for dairymen intent on shipping milk over great distances, knowledge of the conditions (*e.g.*, temperature) conducive to lactic acid bacteria might help ensure that their milk would arrive in a "wholesome" state.⁵⁹

As for symbiotic associative actions, they became the focus of Charles E. Marshall's investigations at the Michigan experiment station. In the first decade of the century, Marshall determined that an eclectic group of organisms, when grown in the presence of *Bact. lactis acidi*, encouraged the rapid multiplication of the latter form, thereby increasing the level of acidity in milk. For Marshall, these associative actions explained many of the variations occurring in the production of sour milk by lactic bacteria, including the variable flavor and aroma of sour milks. Bacteriologists had "been aware of discrepancies occurring" in any milk culture, and for years had remained "somewhat at a loss to discover the cause for this." Marshall held that 57% of the

⁵⁸ Despite their repeated employment of the term "inoculation" and the belief in its protective value, I have not recovered an instance where a dairy bacteriologist explicitly connected culture starters with immunization practices in medical or public health bacteriology. For examples of this conceptual schism, see, Van Slyke, Science and the Practice of Cheese Making, 296; and, Hunziker, The Butter Industry, 183 & 231.

⁵⁹ Conn and Esten's studies of the "Effect of Different Temperatures in Determining the Species of Bacteria which Grow in Milk" produced a few paradoxical findings. While they confirmed that high temperatures (*i.e.*, above 37 degrees C.) favored pathogenic and taint producing forms, Conn and Esten also demonstrated that cold temperatures (*i.e.*, below 10 degrees C.) sustained a manifold variety of species. They concluded that well-chilled milk might remain sweet, yet still not be as "wholesome" as milk delivered at 20 degrees C. Conn and Esten, "The Effect of Different Temperatures," 88.

organisms in day-old milk either aided or hindered lactic acid fermentation.⁶⁰ To probe the more intractable questions of sour milk, dairy bacteriologists were compelled to view dairy bacteria as dynamic population. Pure culture methods, according to Marshall, would hardly suffice.⁶¹

In addition to Marshall's studies of associative actions, other dairy bacteriologists explored aspects of bacterial physiology in order to comprehend the complexities of sour milk. In 1901, Conn and Esten reported that the number of bacteria present in freshly drawn milk gave no indication of the number, or kinds, that might be present in later hours. In their research, they could not correlate multiplication with any set of predictive factors. William A. Stocking, an assistant in Esten's laboratory at Storrs, examined the possibility of a "germicidal property" of milk, which could account for both an initial lag in bacterial growth, and the indefinite composition of its later flora. Lactic acid forms, Stocking hypothesized, might alter their metabolic activities in order to adjust to the changing character of ripening milk. Likewise, Otto Rahn of the Michigan station, compared the fermentative capacities of young and old lactic acid bacterial cultures, positing alterations in their enzymatic production in order to explain the differences. At the Dairy Division, researchers pointed to the unexpected presence of alkali producing forms in sour milk, and hypothesized an ebb and flow between the opposing alkali and

⁶⁰ Marshall, "A Study of Associative Action of Bacteria in the Souring of Milk," American Public Health Association Report no. 31 (1905): 312 & 317. See also, Marshall, "A Preliminary Note on the Associative Action on Bacteria in the Souring of Milk and in Other Milk Fermentations," Special Bulletin of the Michigan Agricultural Experiment Station no. 23 (1904); Marshall, "Additional Work Upon the Associative Action of Bacteria in the Souring of Milk and in Other Milk Fermentations," Special Bulletin of the Michigan Agricultural Experiment Station no. 29 (1904); Marshall, "Extended Studies of the Associative Action of Bacteria in the Souring of Milk," Centr. Bakt. Parasiten. 2 (1905): 688-704; and, Marshall and Belle Farrand, "Bacterial Associations in the Souring of Milk," Michigan State Agricultural College Special Bulletin 42 (1908) : 63.

⁶¹ For examples of how Marshall's dicta were incorporated into textbooks and research programs, see, Lohnis and Fred, Textbook of Agricultural Bacteriology. 179; and, Robert E. Buchanan and B.W. Hammer, "Slimy and Ropy Milk," Science 42 (Sept. 3 1915): 320.

acid types.⁶²

Their interest in lactic acid fermentation also led dairy bacteriologists to contemplate the limits of bacterial variation and the nature of bacterial systematics. Paul G. Heinemann, of the University of Chicago, demonstrated that the fermentative capacity of *Strep. lacticus* (a.k.a., *Bact. lactis acidi*) could be altered by animal passage, artificial cultures, or availability of free-oxygen. According to Heinemann, changes in lactic acid fermentation resulted from enzymatic responses to alterations in the bacterial environment.⁶³ Conn and Esten speculated that these responses might even have adaptive significance. In this regard, bacteria might be incorporated into the evolutionary compass of general biology.⁶⁴

On a more concrete level, the study of lactic acid milk bacteria directed bacteriologists to the most immediate questions of taxonomy. Conn and Esten identified some 200 "kinds" of microorganisms in milk, of which 100 could render lactic acid from lactose. Conn and Esten's "classifications" of these forms were not widely endorsed. However, their 1899 and 1907

⁶² Conn and Esten, "The Comparative Growth of Different Species of Bacteria in Normal Milk," 76; William A. Stocking, "The So-called 'Germicidal Property' of Milk," Bulletin of the Storrs Agricultural Experiment Station no. 37 (1905): 1-20; Otto Rahn, "The Fermenting Capacity of the Average Single Cell of *Bacterium Lactis Acidi*," 24th Annual Report of the Michigan Agricultural Experiment Station (1911): 443-480; S. Henry Ayers, William T. Johnson, and Philip Rupp, "A Study of the Alkali-forming Bacteria Found in Milk," Bulletin of the United States Department of Agriculture no. 782 (1919): 1-39; and, Robert S. Breed, J.C. Baker, and H.J. Conn, "The Relation between Lactic Acid Production and Bacterial Growth in the Souring of Milk," Bulletin of the New York Agricultural Experiment Station no. 74 (1919). In a similar manner, bacteriologists determined that the undesirable butyric acid fermentations were usually the product of a "long series of fermentative changes." Moore, Bacteria in Milk, 15.

⁶³ Heinemann, "Relation of the Number of *Streptococcus Lacticus* to the Amount of Acid Formed in Milk and Cream," Journal of Infectious Diseases 15 (1915): 285-291; and, Heinemann, "The Variability of Two Strains of *Streptococcus Lacticus*," Journal of Infectious Diseases 16 (1915): 221-239. See also, Harry A. Harding, "The Constancy of Certain Physiological Characters in the Classification of Bacteria," Technical Bulletin of the New York Agricultural Experiment Station no. 13 (1910): 1-41.

⁶⁴ "The general biological laws which control living things are materially concerned in such a problem. . . . The different species of bacteria are endeavoring to adapt themselves to the conditions, and there is a 'struggle for existence' among them, the conclusion of which is a matter of much importance in its bearing upon general biological laws." Conn and Esten, "Comparative Growth of Different Species of Bacteria," 14.

bulletins did focus attention to the problematic concepts of “species” and “variety” among bacteria. Even the nomenclature of milk bacteria demanded critical investigation, as the most common dairy type bore twelve different names (e.g., *Streptococcus lactis*, *Bacterium lactis*, *Bacteria lactis acidi*).⁶⁵ Chapter 6 will argue that dairy bacteriologists played a vital part in the reformation of bacterial systematics. In fact, they were over-represented within the editorial board of the *Bergey's Manual of Determinative Bacteriology* and on the SAB's Committee for the Characterization and Classification of Bacterial Types. At this point, it will suffice to state that an interest in the phenomena of milk souring encouraged bacteriologists to uncover the “natural” relations among these microbes.⁶⁶

The influence of the “bacteriologic vision” among dairy scientists in the first decades of the century was profound. The dual emphasis on determining the kinds of organisms responsible for changes in milk, and the processes by which these changes affected, led bacteriologists to consider a range of phenomena normally occluded by the hygienic goal of eliminating germs. In their 1902 dairying textbook, Russell and Hastings insisted that: “Before one can gain any intelligent conception of the manner in which bacteria affect dairying, it is first necessary to know something of the life history of these organisms in general, how they live, move and react toward their environment.” At first glance, this appeal to the biology of bacteria might appear gratuitous. Yet, for dairy bacteriologists, practical advances remained inexorably linked to

⁶⁵ Conn and Esten, “Classification of Dairy Bacteria,” Storrs Agricultural Experiment Station, Annual Report (1899), 13-68; Conn, Esten, and William A. Stocking, “Classification of Dairy Bacteria,” Annual Report, Storrs Agricultural Experiment Station (1907): 91-203; Russell and Hastings, Outlines of Dairy Bacteriology, 3rd ed., 55; and, Lohnis et al., Laboratory Methods, 72.

⁶⁶ See, for example, Lore A. Rogers, and Brook J. Davis, “Methods of Classification the Lactic-Acid Bacteria,” Bulletin of the Bureau of Animal Industry no. 154 (1912): 7-8; and, E.G. Hastings, “A Preliminary Note on a Group of Lactic Acid Bacteria not Previously Described in America,” Science 28 (1908): 656.

progress in "general" bacteriology.⁶⁷

Exploiting the Productive Microbe

In service to dairying interests, bacteriologists offered their technical skills to the rationalized production of cheese and butter. It was this manufacturing endeavor that facilitated the emergence of the most salient feature of the "bacteriologic vision," the productive microbe. As the previous section intimated, dairy bacteriologists recognized that "Not more than one per cent of all bacteria are harmful to man." Their methodological predilection toward examining *types*, rather than numbers, lent credence to this tenet. Dairy bacteriologists also articulated a corollary to the claim that most microbes were harmless. As William Esten and Christie Mason professed, the remaining "ninety-nine per cent are beneficial and are absolutely necessary to the existence of life on the earth."⁶⁸ Their declaration was undoubtedly hyperbolic; most bacteria could not be directly connected to either beneficial or essential processes, particularly as they existed in milk products. Nonetheless, the assertion demonstrates that many dairy bacteriologists regarded their enterprise as diametrically opposed to the hygienic goal of exclusion.

In order to rationalize the productive microbe (and the manufacture of cheese and butter), dairy bacteriologists pursued three related lines of research: they isolated and identified the organisms responsible for desirable qualities of cheese and butter; they investigated the processes by which these bacteria produced such changes; and they sought mechanisms through which

⁶⁷ Russell and Hastings, *Outlines of Dairy Bacteriology*, 3rd ed., 1; and, Jezeski, "Progress in Basic Bacteriology of Milk," 657. For many years, bacteriologists recognized that their dairy-minded members were the most attuned to "fundamental" issues. For example, in William Hagan's history of bacteriology at Cornell, he depicted the extensive courses in veterinary bacteriology as simply "applied subjects. . . . What may be called pure bacteriology is given only in the Dairy Department." Hagan, "History of Bacteriology at Cornell," 18 March 1958, [ASM], box 7-IIA, folder 10.12.

⁶⁸ Esten and Mason, "*Bacterium Lactis Acidi* and its Sources," 70.

dairymen could control and exploit those processes. The three-tiered program yielded a wealth of unexpected knowledge. For example, as J.J. Jezeski recalled at the 50th anniversary of the ADSA, the initial search for the most productive forms supplied detailed studies on the morphological and cultural characteristics of the normal milk flora, which in turn permitted many of the same to be classified in an orderly fashion. In examining the more fastidious types, dairy bacteriologists developed techniques and media that revealed the nutritional requirements of both the normal and productive forms. Additionally, since dairymen focused on the changes in milk wrought by microorganisms, bacteriologists examined the biochemical precursors and by-products of bacterial growth. The aim of rationalized control spawned an emphasis "in the area of bacterial physiology and nutrition, with detailed experiments being designed to determine the mechanisms by which flavor and odor, and the appearance of defects, were produced."⁶⁹ These studies closely paralleled changing demands within the cheese and butter industries.

American interest in the bacteriology of cheese can be traced to three research sites: the agricultural experiment stations at Wisconsin and Geneva, and the Dairy Division of USDA. This interest should also be viewed in light of the peculiar history of American cheese production. In the 1870's and early 1880's, hard cheeses comprised a sizable percentage of the agricultural market, particularly in states such as New York, where dairymen not only sold to local consumers but shipped out of state, and even over-seas. However, product quality remained suspect, and as producers sought to maximize profits they stocked grocery shelves with foul-tasting and rancid cheese. As a consequence, consumer demand for cheese diminished rapidly, and a few foreign nations contemplated prohibiting the importation of American

⁶⁹ Jezeski, "Progress in Basic Bacteriology of Milk," 657.

cheeses.⁷⁰

In Wisconsin these developments carried particular significance. Dean Henry, director of the state agricultural experiment station, maintained that dairying could provide the financial solution for those farmers plagued by fluctuating grain prices. In the late 1880's and early 1890's, Henry established departments of chemistry and bacteriology within the station and college, and recruited Stephen Babcock, from the Geneva Station, and Harry L. Russell as their respective heads. Henry believed that chemical and bacteriological research could revitalize the ailing dairy industry, particularly if it could control the costs of production and predict the quality of product. Furthermore, he regarded both chemistry and bacteriology as essential tools for uncovering the mechanism of cheese curing, that process by which the insoluble and tasteless casein in curd decomposed into water-soluble, digestible, and delectable proteides.⁷¹ Since the early 1880's, dairy scientists had suspected bacterial and enzymatic mechanisms, a belief supported by the fact that disinfectants, when added to milk, halted curing, and by reports of an increase in lactic acid forms during the initial period of transformation. Babcock and Russell sought to delineate the range of bacterial and enzymatic action.⁷²

In the late 1890's, Babcock and Russell's work yielded two important findings. First, they reported that enzymatic, rather than bacterial, causes accounted for the fundamental

⁷⁰ See, Sally A. McMurry, Transforming Rural Life: Dairy Families and Agricultural Change, 1820-1885 (Baltimore: Johns Hopkins University Press, 1995); Lampard, The Rise of the Dairy Industry in Wisconsin, chpts. 2-4; Schlebecker, A History of American Dairying, chpts. 3-5; Schlebecker and Hopkins, A History of Dairy Journalism, chpt. 2; and, Thomas R. Pirtle, History of the Dairy Industry (Chicago: Mojonner Bros. Co., 1926).

⁷¹ Glenn S. Pound, 100 Years of Research: Wisconsin Agricultural Experiment Station, Centennial Celebration, March 24 1983 (Madison: University of Wisconsin, 1983); Harry L. Russell, Stephen Moulton Babcock: Man of Science (Madison: Wisconsin Alumni Res. Foundation, 1943); and, A.S. Alexander, A History of the Wisconsin Experiment Station, (Madison: Wisconsin Agricultural Experiment Station, 1935).

⁷² Beardsley, Harry L. Russell, 53; and, Babcock and Russell, "The Cheese Industry: Its Development and Possibilities in Wisconsin," Bulletin of the Wisconsin Agricultural Experiment Station no. 62 (1897).

transformation in casein. By employing chloroform to halt bacterial activity, they demonstrated that living organisms were not essential to the digestion of milk proteins. Moreover, Babcock and Russell found that galactase, as they deemed it, was present in milk itself, and not a product of bacterial growth. Secondly, they showed that cheese curing could be achieved at lower temperatures than normally employed (*i.e.*, 50 instead of 70 degrees F.). "Cold-curing" yielded milder tasting and longer lasting hard cheeses, qualities that enabled dairymen to limit costs and increase profits.⁷³

These findings might have truncated bacteriological interest in cheese production, as Russell and Babcock seemed to exclude bacteria from the process of curing. Yet, interest did not wane. Russell himself presumed a role for bacterial action in the production of hard cheese, maintaining that "it may be safely predicted that future progress in dairying will, to a large extent, depend upon bacteriological research." At the turn of the century, bacteriologists recognized that lactic acid types proliferated during the first three weeks of curing, and then rapidly declined. However, as Herbert Conn explained, "The difficulty lies chiefly in the fact that the process is such a long one and that so many different species of bacteria are found in the cheese at different times. This makes it impossible to say which are essential and which are incidental." The flora of cheddar cheese, to take one example, varied considerably, with lactic acid micrococci predominating in the outer part, while streptococci and lactobacilli occupied the center. At the border regions, there were undoubtedly symbiotic or antagonistic relations. It remained for dairy bacteriologists to determine the range of conditions which favored "certain

⁷³ Edward H. Beardsley, "An Industry Revitalized: Harry Russell, Stephen Babcock and the Cold Curing of Cheese," Wisconsin Magazine of History 49 (1965): 122-137.

associations of microorganisms whose activities produce the characteristic quality, taste, and flavor” of each variety of cheese.⁷⁴

During the first two decades of this century, dairy bacteriologists inspected possible functions of bacterial growth in the curing of cheddar cheese. William Esten and Harry Harding pointed to the exclusionary development of lactic acid bacilli, submitting that their presence was “absolutely essential in the first stages” in order to prevent “the growth of certain bacteria which would change the cheese.” C.F. Doane, of the Dairy Division, argued that bacteria supplied an active ingredient to rennet, while his colleague Lore A. Rogers, maintained that their primary significance lay in the production of flavor.⁷⁵ Interestingly, these studies failed to identify a singular role for cheese bacteria. In a comprehensive and lengthy review of bacteriological research on cheddar cheese, Edwin G. Hastings, E.B. Hart, and Alice C. Evans, of the Wisconsin Station, indicated that various forms aided in the flavoring of rennet curdling, the mechanical shrinking of the curd, and the expulsion of whey. They also hypothesized that the high acid-producing bacteria, *B. bulgaricus*, might determine the keeping qualities of commercially packaged cheddar.⁷⁶ Dairy bacteriologists predicted “a great future for the cheese industry along the lines of the practical application of bacteriological discoveries,” even if their understanding

⁷⁴ Russell and Hastings, Outlines of Dairy Bacteriology, 3rd ed., preface; Conn, Agricultural Bacteriology, 1st. ed., 263-264; and, Lohnis and Fred, Textbook of Agricultural Bacteriology, 197 & 200.

⁷⁵ Esten, “*Bacterium Lactis Acidi* and Its Sources,” 7; Harry A. Harding, “The Role of Lactic-Acid Bacteria in the Manufacture and in the Early Stages of Ripening of Cheddar Cheese,” Bulletin of the New York Agricultural Experiment Station no. 237 (1903): 165-180; Doane, “The Cold-Curing of American Cheese,” Bulletin of the Bureau of Animal Industry no. 85 (May 1906); Doane, “Development of Lactic Acid in Cheddar Cheese-Making,” Bulletin of the Bureau of Animal Industry no. 110 (Nov. 1908); Lore A. Rogers, “The Relation of Bacteria to the Flavors of Cheddar Cheese,” Bulletin of the Bureau of Animal Industry no. 62 (1904): 1-38; and, Harry A. Harding and M.J. Prucha, “The Bacterial Flora of Cheddar Cheese,” Technical Bulletin of the New York Agricultural Experiment Station no. 8 (1908).

⁷⁶ Edwin G. Hastings, Alice Evans and E.B. Hart, “The Bacteriology of Cheddar Cheese,” Bulletin of the Bureau of Animal Industry no. 150 (2 Oct. 1912).

of curing remained partial. As Herbert Conn explained, "the great financial interests connected with the cheese industry have attracted quite a number of bacteriologists to the study of the problems, and most dairy bacteriologists at the present time are working upon various phases of the problem of the ripening of cheese."⁷⁷

In the 1910's, the Dairy Division sponsored bacteriological studies of cheeses not normally manufactured in the United States, such as Swiss and Emmenthaler varieties. The research program led bacteriologists to organisms and relationships not immediately relevant to the production of cheddar. For example, Division bacteriologists identified *Streptococcus Hollandicus* as an aid in the making of Edam. *Strep. Hollandicus* had already been implicated as a cause of stringy or ropy whey, an undesirable "milk taint." In the manufacture of Edam, however, it produced no ill effects, and prevented the growth of detrimental gas-producing organisms. At the Storrs station, bacteriologists William M. Esten and Christie J. Mason collaborated with the USDA mycologist, Charles Thom, to explore the domestic possibilities for camembert, roquefort, and neufchatel cheese. This research required investigators to consider the dynamic interaction between bacteria and molds, and Thom concluded that the latter were the decisive factors in the curious rise, fall, and return of lactic acid bacteria in these cheeses. The relationships among microbial forms, particularly non-bacterial types, represented a novel research endeavor in the 1910's, one that would not draw wide interest until the advent of

⁷⁷ Conn, Agricultural Bacteriology, 1st ed., 270 & 272. The concern with cheese flavors led dairy bacteriologists to focus their attention to biochemical activities of microorganisms. As Harry Russell outlined in the 1912 Annual Report of the Wisconsin Agricultural Experiment Station, "... since there are differences in these constituents of cheese which can have been produced only by bacterial activity, a study is being made of the by-products produced by pure cultures of the various groups of organism normally present in cheese. It is hoped that it may be demonstrated that certain bacterial types are responsible for the production of definite compounds which cause flavor," p. 29.

penicillin and streptomycin two decades later. It would be a mistake to offer Thom's studies as a direct precursor to the antibiotic era. Even so, his investigations served to broaden the scope of dairy bacteriology.⁷⁸

Research results in dairy bacteriology induced changes in instruction, as even the most cursorily trained dairyman appreciated the complexity and importance of bacterial life to cheese production.⁷⁹ In the decades after the turn of the century, dairymen increasingly employed starter cultures to "insure a more complete and more uniform souring of the curd." As a consequence, dairy schools imparted the exacting techniques for the "handling and management" of bacterial cultures. In the "better" factories, the starter commanded the "best possible facilities, and the most skillful technicians." Commercial laboratories marketed culture kits, and experiment stations performed comparative and control tests. The Dairy Division, in the 1910's, launched an expansive research program dedicated to starter cultures. The directors reasoned that effective control over ripening would prevent millions in financial losses, and enable the dairy industry to extend its market.⁸⁰ These investigations elicited a fund of information on the biochemical and

⁷⁸ Esten and Mason, "Bacteriological Studies," Bulletin of the Storrs Agricultural Experiment Station no. 83 (1915): 104-135; Doane and Carl W. Larson, "Varieties of Cheese: Descriptions and Analysis," Bulletin of the Dairy Division of the Bureau of Animal Industry no. 105 (Jan. 1908); Charles Thom, James N. Currie, and K.J. Matheson, "Studies Relating to Roquefort and Camembert Type of Cheese," Bulletin of the Storrs Agricultural Experiment Station no. 79 (1914): 336-410; and, Kenneth B. Raper, "Charles Thom, 1872-1956," National Academy of Sciences Biographic Memoirs 38 (1965): 335-344.

⁷⁹ See, for example, Harry L. Russell and Edwin G. Hastings Experimental Dairy Bacteriology (Boston: Ginn and Co., 1909); William A. Stocking, Manual of Milk Products (New York: Macmillan Co., 1917); and, Charles Thom and Walter W. Fisk, The Book of Cheese, 1st ed. (New York: Macmillan, 1918). Lohnis and Fred acknowledged that, while many bacteriological investigations merely elucidated "the inherent reasons" for commonly employed dairy practices, they might also allow "technical modifications" to be "chosen and applied much more intelligently and successfully than at the time when all depended on experience and practical skill." Lohnis and Fred, Textbook of Agricultural Bacteriology, 210.

⁸⁰ Conn, Agricultural Bacteriology, 2nd ed., 185; Walter V. Price, "Cheese Manufacture," Journal of Dairy Science 39 (1956): 827-828; Christie J. Mason, "Tests and Comparisons of Commercial Lactic Starters," Bulletin of the Storrs Agricultural Experiment Station no. 83 (1915): 104-135; E.O. Whittier, "Research by Federal Agencies on Dairy Manufacturing," Journal of Dairy Science 39 (1956): 800-803; and, Lore A. Rogers, "The Science and Art of Cheesmaking," Scientific Monthly 42 (1936): 437-443.

associational properties of dairy bacteria. In 1908, Charles F. Doane determined that three distinct cultures were essential in the production of Swiss cheese. In the ensuing decade, James M. Sherman demonstrated that the “eyes” and flavor of Swiss cheese were the result of a sequential growth of propionic-acid-producing forms. There could be no single starter culture for Swiss cheese.⁸¹

In their effort to control the proper growth-rate and sequence of Swiss cheese organisms, the Dairy Division conducted fundamental investigations into the biochemical and associational characteristics of cheese microbes. Lore A. Rogers remained particularly interested in the factors limiting bacterial populations. As part of this research, Rogers directed William M. Clark to determine the role of acid and alkaline reactions in bacterial growth. Clark arrived at the Dairy Division in 1912, and was already engaged in efforts to differentiate gas producing bacteria of the colon group when Rogers asked him to study pH. At that time, bacteriologists employed methods developed by Alfred Jorgensen in Denmark to determine the quantity of acidity in given medium. However, Clark’s experience with gas production led him to believe that it was the intensity, and not quantity, of acidity that limited bacterial populations. In the late 1910's, Clark and H.A. Lubs elaborated a graduated series of indicators to accurately measure hydrogen-ion concentrations. Clark’s technical innovations earned him a place in the history of biochemistry, but the dairying context of his achievements has been overlooked. For the development of

⁸¹ Charles F. Doane, “Varieties of Cheese: Descriptions and Analyses,” Bulletin of the Bureau of Animal Industry no. 105 (1908): 1-72; John W. Decker and Fritz W. Woll, Cheese Making: Cheddar, Swiss, Brick, Limburger, Edam, Cottage, etc., 5th rev. ed. (Madison: Mendota Book Co., 1913); Johan D. Frederiksen, The Story of Cheese, 2nd ed. (New York: Macmillan, 1923); and, anon., The Ten Master Minds of Dairying (Des Moines, IA: Meredith Publishing, 1930). The failure of pure culture starters did not prevent experiment stations, such as Wisconsin, from producing and distributing the mixed starters thought to be essential for Swiss cheese production in the early 1920's.

bacteriology, Clark represents an important moment in biochemical studies of bacterial metabolism, and a methodological advance brought about by the demands of Swiss cheese production.⁸²

American research efforts in the bacteriology of butter developed along similar lines. Before churning, the germ content of ripened cream exceeds 500 million bacteria per c.c., and in freshly made butter, counts average around 120,000 per gram. Herbert W. Conn was the first domestic bacteriologist to consider the significance of these staggering numbers. In Conn's early estimation, the numbers of butter bacteria remained "inconceivably great, far surpassing the numbers found in sewage, or indeed, in any other natural material where bacterial analyses have been made." For the production of butter, Conn remarked that "instead of being the dairyman's foes" the bacteria were "his allies."⁸³ However, for more than two decades, Conn proved unable to identify the exact nature of this microbial alliance.

Danish dairymen first proposed the idea of a starter culture for butter in 1890. Heeding this suggestion, Conn believed that the superior organisms could be isolated, identified, and commercially marketed, and in 1891 launched a program to survey the bacteria from creameries near in the Storrs station. The next year, at the request of the Secretary of Agriculture, Conn prepared an exhibit for the Columbian Exposition at Chicago to illustrate the relation of germ life to dairying. The exhibit consisted of thirty-five kinds of bacteria isolated from butter cultures,

⁸² William M. Clark, "A Study of the Gases of Emmental Cheese," Bulletin of the Bureau of Animal Industry no. 151 (1912): 1-32; Clark, "The Final Hydrogen Ion Concentrations of Cultures of *Bacillus Coli*," Journal of Biological Chemistry 22 (1915): 87-98; Clark and H.A. Lubs, "The Differentiation of Bacteria of the Colon-Aerogenes Family by the Use of Indicators," Journal of Infectious Diseases 17 (1915): 160-173; and, Clark and Lubs, "The Colorimetric Determination of Hydrogen Ion Concentration and its Application in Bacteriology," Journal of Bacteriology 2 (1917): 191-236.

⁸³ Conn, Agricultural Bacteriology, 223 & 226.

and each was given a number. At the fair's opening in 1893, No. 2 produced the best flavor, while No. 15 rated the worst. These two contrasting organisms were employed for the daily production of the fair's butter, and visitors were encouraged to note the difference in taste as they perused the glass case of all thirty-five cultures. Conn's exhibit generated lively discussions and lengthy accounts in the local papers, and during the summer Conn added nine new varieties. One of the new types, B41, did not resemble the typical lactic acid bacterium. It produced only small quantities of acid, and appeared to act more vigorously on the casein than on the milk sugar. Conn left the Exposition convinced of the culture's commercial potential, and within a year a well-known butter judge of the day capitalized on Conn's scientific standing by manufacturing the butter starter.⁸⁴

B41 never attained commercial success. In fact, in a series of curiously public trials, Wisconsin's Harry L. Russell demonstrated that the starter yielded only tolerable flavor. Nevertheless, Conn's efforts directed bacteriologists' continued attention to butter production, and led American creamerymen to believe that efficient starters were soon forthcoming. In the late 1890's, dairy specialists identified the several physical changes affected by bacteria in ripening cream. While butter could be produced without "ripening," that is, from "sweet" cream with low bacterial counts, bacteria removed the albuminous envelope from fat globules, thus allowing them to cohere easily when churned. During the next two decades, dairy bacteriologists worked in concert with chemists to determine the relationship between these physical changes in

⁸⁴ William M. Esten, "Profession Herbert W. Conn," *Journal of Bacteriology* 2 (1917): 501-503; and, Harold J. Conn, "Professor Herbert William Conn and the Founding the Society," *Bacteriological Reviews* 12 (1948): 276-296.

butter fat, and the production of flavor.⁸⁵

After the turn of the century, the Dairy Division developed an interest in the keeping qualities of butter. In 1902, Congress authorized the USDA to regulate the interstate sale of butter, and in that same year, the Dairy Division offered to manufacture butter for the Navy. As a result, Lore A. Rogers and Charles E. Gray initiated a series of cooperative investigations with station staff at Iowa, Madison, and Storrs to explore the possibility of butter made from pasteurized cream. They demonstrated that not only could butter be made from low acid cream, but that it would keep longer. In addition, they isolated bacterial causes of common butter taints, including fishy, oily, and metallic flavors.⁸⁶ However, butter made from the pasteurized cream and pure culture starters lacked the "high" and "quick" flavor desired by domestic consumers. Moreover, Conn demonstrated that the production of acid, flavor, and aroma were not related. In particular, different organisms produced good aroma and good flavor, and Conn suggested that most flavor producers were actually alkaline and not acid forms. For the next two decades dairy bacteriologists, such as Bernard W. Hammer at Iowa State, directed their studies to controlling the complex and symbiotic growth of mixed butter flora.⁸⁷

In pursuit of the "productive microbe," dairy bacteriologists explored conceptual and

⁸⁵ Russell and Hastings, Outlines in Dairy Bacteriology, 3rd. ed., chpt. 7; Hunziker, The Butter Industry, 1st ed., 277; and, L.C. Thomson, "Butter Manufacture," Journal of Dairy Science 39 (1956): 819-821.

⁸⁶ Cameron, The Bureau of Dairy Industry, 13; Lore A. Rogers, "Studies upon the Keeping Quality of Butter," Bulletin of the Bureau of Animal Industry no. 57 (1904); Rogers and Charles E. Gray, "Investigations in the Manufacture and Storage of Butter," Bulletin of the Bureau of Animal Industry no. 84 (1906): 1-24; and, John A. Alford, "Lore A. Rogers, A Rare Species," ASM News 41 (1975): 85-91.

⁸⁷ Clarence H. Eckles, "The Relation of Acid Fermentation to Butter Flavor and Aroma," Bulletin of the Iowa Agricultural Experiment Station no. 40 (1899); B.W. Hammer, "Volatile Acid Production of *S. Lacticus* and the Organisms Associated with it in Starters," Research Bulletin of the Iowa Agricultural Experiment Station, no. 63 (1920): 60-96; Hammer, "The Type of Lactic Acid Produced by Starters and by the Organisms Isolated from Them," Research Bulletin of the Iowa Agricultural Experiment Station no. 65 (1920): 116-128; and, Iowa State College of Agriculture and Mechanic Arts, B.W. Hammer: Panegyric (Ames, Iowa: Collegiate Press, Inc., 1937).

methodological concerns not immediately relevant to hygienic elimination of germs. Bacteria proved essential to the production of cheese and butter; their manifold presence was not only harmless, but entirely desirable. In order to rationalize the manufacture of dairy goods, bacteriologists surveyed the normal flora of cream in search of the most efficient organisms, examined the mechanisms by which they produced chemical and physical changes, and sought means by which their activities could be amplified or controlled.⁸⁸ Unlike their medical or veterinary counterparts, dairy bacteriologists focused their technical expertise on the physiological and associational aspects of bacteria, regarding microbes as dynamic populations. There is little indication that dairy bacteriologists, in the first decades of this century, consciously sought to broaden the conceptual expanse of bacteriology. Rather, it was the flavor and aroma of cheese and butter that led them there.⁸⁹

Late Blooming -- Soil Bacteriology

Soil bacteriology, during the first decades of this century, most clearly embodied the "bacteriologic vision." For those interested in soil organisms, attention to pathogenic forms elicited only marginal interest, and although they may have sought techniques to eliminate certain forms from crop soils, the goal was never hygienic exclusion. Rather, for soil bacteriologists struggling to define a professional role in experiment stations and agricultural

⁸⁸ Most courses in dairy bacteriology were, however, a combination of the hygienic and bacteriological approaches. At Cornell, for example, the 1912 catalogue described an eclectic offering. "This course deals with the sources of milk bacteria and methods of controlling their growth, bacteriological studies of market milk and other dairy products, different species of dairy bacteria, making of starters, effect of straining separation, pasteurization and temperature, bacteriological methods of city milk inspection." Annual Report of the Cornell University, College of Agriculture and Agricultural Experiment Station (1912): clxxxiii.

⁸⁹ Lore A. Rogers believed that the transformation in the goals of dairy research, from the "perfection of the art" to the "development of a scientific basis" of dairy good, was mostly accidental. Rogers, "Research Work at the Bureau of Dairying," Journal of Dairy Science 8 (1925): 4-14.

colleges, the aim remained one of microbial control, management, or exploitation, in the interests of soil fertility. Like their dairy counterparts (and some bacteriologists were both), soil scientists cultivated methods that transcended the rigid cookbook formulae for pure cultures, exploring characteristics not normally revealed by the tasks of isolation and identification. Soil bacteriologists attended to associational behavior, regarding soil microbes as a dynamic population capable of adapting to subtle environmental changes. They readily adopted the methods of soil chemistry, scrutinizing the nutritional requirements and by-products of bacterial growth. Additionally, soil bacteriologists sought to comprehend the metabolic activities of microorganisms, forging a nascent conception of bacterial physiology.

The conceptual blossoming of soil bacteriology paradoxically accompanied a state of disciplinary uncertainty. During the first quarter of this century, soil bacteriologists survived on the margin of agricultural science, never fully able to convince station directors of their immediate value, nor able to persuade college presidents of the promise of their fundamental research. There lingered a pervasive unease among many members, and a recurrent need for critical self-examination. Unlike other fields of bacteriology, soil scientists lacked "routine" procedures, and as long as the goal of controlling soil fertility remained elusive, they labored to locate secure sources of disciplinary growth. As a corollary to the arguments outlined in the previous chapters, this section suggests that disciplinary uncertainty spawned conceptual advancement; soil bacteriologists were attuned to any methodological innovations that might secure an efficient exploitation of soil microbes.

American interest in soil bacteria arrived nearly a decade after that in dairy bacteriology. In the waning years of the nineteenth century, researchers such as Herbert Conn and Frederick D.

Chester surveyed the micro-flora of cultivated soils. While standardizing sampling methods, culture media, and enumeration techniques, these few investigators assumed the "pioneer's job of census-taking." Other notable American bacteriologists simply took heed of developments across the Atlantic.⁹⁰ Rutgers University and the New Jersey Agricultural Experiment Station established the first comprehensive research department for soil bacteriology in 1901, under the direction of chemists and bacteriologists E.B. Voorhees and Jacob G. Lipmann. Joined by a string of assistants and graduate students, the two devoted the first decade of the twentieth century to examining the influence of bacteria on the transformation of nitrogen and nitrogenous compounds in soils. They authored a thorough literature review in 1907, and issued a laboratory manual four years later.⁹¹

In the first years of the new century, few researchers sustained an interest in soil bacteria. Textbooks and manuals of "general bacteriology" neglected soil organisms, and introductory agricultural courses provided only the briefest mention of bacteria in their relation to soil fertility. At many experiment stations, soil bacteriology represented an afterthought or research curiosity, allowable only when demands in veterinary and dairying departments lessened.⁹² Even

⁹⁰ Charles Thom, "Soil Bacteriology in America," in Lipman Hall: Being an Account of the Proceedings at the Dedication on June 12th, 1951, of a Building Named in Honor of Jacob Goodale Lipman (New Brunswick: New Jersey Agricultural Experiment Station, 1952), 37 & 41, Harry L. Russell, "The Fixation of Free Nitrogen by Plants," Botanical Gazette 19 (1894): 284-293; Russell, "Investigations on Bacteria," Botanical Gazette 20 (1895): 419-422; and, Jacob Lipman, "Nitrogen-fixing Bacteria," Popular Science Monthly 62 (Dec. 1902): 141. Frederick D. Chester quipped that the subject was "marked by the char.m of youth." Chester, "Bacteria of the Soil in Their Relation to Agriculture," Bulletin of the Delaware College Agricultural Experiment Station no. 98 (1902): 7.

⁹¹ Their inclusive aim was to discern the "general laws controlling the main factors in the direction and intensity of the agriculturally important transformations in the soil. . ." Lipman and Voorhees, A Review of Investigations in Soil Bacteriology (Washington, D.C.: GPO, 1907), 14. See also, Lipman and Percy E. Brown, A Laboratory Guide in Soil Bacteriology (n.p., 1911); Robert V. Allison, "Lipman, the Soil Scientist," in Lipman Hall, 23-35; and, William H.S. Demarest, A History of Rutgers College, 1766-1924 (New Brunswick: Rutgers University Press, 1924).

⁹² For example, at Kansas Agricultural College, Walter E. King offered a two semester course in bacteriology. He devoted only one lecture to soil bacteria, and included little mention of the special methods and techniques of the field. King, Synopsis of Lectures, Bacteriology I: For Students in the General Fundamental

those agricultural colleges with expansive departments in bacteriology (e.g., University of Wisconsin) slighted soil studies until the 1910's.⁹³ Within the U.S. Department of Agriculture, the Bureau of Soils and the Bureau of Plant Industry sponsored soil bacteriology as early as 1901, but at funding levels significantly lower than those that allocated for veterinary and dairy work within the Bureau of Animal Industry and the Dairy Division.⁹⁴

The more general field of soil science, in contrast, developed steadily. Chemical analyses of soils comprised a core activity of state experiment stations in the late nineteenth century. Guided by the legacy of Justus Liebig's theories of soil fertility, agricultural chemists confidently held if they analyzed the constituents of certain plants, and then surveyed the constituents of specific soils, they could determine which elements needed to be added to increase crop productivity. This ledger approach, however, revealed only the total amount of plant food in a given soil, but not its availability to plants. Many regions contained enough of the essential elements, but they remained in insoluble forms. In practice, the station chemists could recommend additions to render a singular sample "complete," but they remained incapable of prescribing long-term practices to maintain soil fertility.⁹⁵ Nonetheless, such "accounting"

Course (Manhattan KS: Kansas State Agricultural College, 1909), 66-69. As for research, King himself published only a single bulletin on soil microorganisms, as did his predecessor, Nelson Mayo.

⁹³ At Wisconsin, it was not until 1909 that Harry L. Russell assigned Conrad Hoffmann and B.W. Hammer to initiate studies on soil bacteria. Curiously, Russell soon returned Hammer to dairy research projects, believing his chemical expertise was too valuable to expend on soil studies. Russell, "Summary of Experimental Work in Bacteriology for the Years 1893-1903," 20-37; and, Perry W. Wilson, "Biological Nitrogen Fixation -- Early American Style," Bacteriological Reviews 27 (1963): 412-414.

⁹⁴ T. Swann Harding, Two Blades of Grass: A History of Scientific Development in the U.S. Department of Agriculture (Norman, OK: University of Oklahoma Press, 1947), 160-194; Gustavus A. Weber, The Bureau of Chemistry and Soils: Its History, Activities and Organization (Baltimore: Johns Hopkins Press, 1928), 1-3; and, Herbert P. Holman, et al., Index of Publications of the Bureau of Chemistry and Soils, Originally the Bureau of Chemistry and the Bureau of Soils: 75 Years -- 1862-1937 (Washington: Government Printing Office, 1939).

⁹⁵ Charles W. Burkett, Soils: Their Properties, Improvement, Management, and the Problems of Crop Growing and Crop Feeding (New York: Orange Judd Company, 1908), 74; Margaret W. Rossiter, The Emergence of Agricultural Science: Justus Liebig and the Americans, 1840-1880 (New Haven: Yale University Press, 1975); Hans Jenny, E.W. Hilgard and the Birth of Modern Soil Science (Pisa, Italy: Collan della Rivista, 1961); J. Fulton

procedures remained commonplace, and by the first years of the twentieth century, chemists and agronomists warned of a deficit in soil fertility. Cyril G. Hopkins of the Illinois station posited that it was "an almost universal rule that old land is less productive than new land." Given the disappearance of virgin, or uncultivated, American soil, "this simple and well-recognized fact points inevitably toward future poverty . . . for the commonwealth of the nation."⁹⁶ According to Hopkins and others, soils could naturally replace all but two of their essential plant food elements, nitrogen and phosphorus. Nitrogen, in particular, constituted "the most expensive, the most evasive, and the most difficult to replace." Cultivating crops rapidly removed nitrogen, and what remained might be leached away by rainwater. A farmer could return a portion of the nitrogen to his soil by applying manures, artificial fertilizers, or turning over stubble and other plant tissues as green manure. Yet, manures and artificial fertilizers were prohibitively expensive, and the world's reserve of nitrate of soda was limited. Hopkins might have articulated an unduly apocalyptic vision, but other agronomists echoed his portent. A few agricultural doomsayers predicted a state of nitrogen starvation within fifty years.⁹⁷

Given such concerns, the rationale for research in soil bacteriology became nearly self-evident. As bacteria assisted in the acquisition and transformation of nitrogen compounds, a

Lutz, "History of the Soil Science of America." Journal of the Soil Science Society of America 41 (1977): 152-173; Alexis A.J. de Sigmond, "Development of Soil Science," Soil Science 40 (1935): 77-86; and, Milton Whitney, "Soil Investigations in the United States," Yearbook of the United States Department of Agriculture, 1899 (Washington D.C.: GPO, 1900), 342.

⁹⁶ Hopkins alluded to recurrent famines in Russian and China when declaring that "among all the nations of the earth, the United States stands first in rapidity of soil exhaustion." Hopkins, Soil Fertility and Permanent Agriculture (Boston: Ginn and Company, 1910) xviii; and, Hopkins, "The Duty of Chemistry to Agriculture," Bulletin of the University of Illinois Agricultural Experiment Station no. 105 (1906): 25. See also, Charles W. Burkett, Frank L. Stevens, and Daniel H. Hill, Agriculture for Beginners (Boston: Ginn & Co., 1903), 19.

⁹⁷ Lipman, "Nitrogen-fixing Bacteria," 139; Conn, Agricultural Bacteriology, 1st ed., 66; Meade Ferguson, "Soil Inoculation with Artificial Cultures," Bulletin of the Virginia Agricultural Experiment Station no. 159 (1906): 83; and, William A. Withers, "The Formation of Nitrates in the Soil," Bulletin of the North Carolina Agricultural Experiment Station no. 190 (1905): 3-8.

thorough understanding of their activities might allow farmers to “properly regulate” soil fertility “so that the needed supply of plant food may be available for crop production.” Director Voorhees reasoned in the 1904 Annual Report of the New Jersey Agricultural Experiment Station, that through bacteriological investigations, “the most important question in the maintenance and increase of soil fertility could be solved perhaps, and the energy and money expended in the attempt to supply to the growing crop a sufficient quantity of combined nitrogen could be largely saved.”⁹⁸ Like-minded soil scientists believed that “any information giving a clearer understanding” of the bacterial process of nitrogen fixation and nitrification “may be justified as contributing” to the amelioration of “one of the fundamental problems in any state or nation.”⁹⁹ Voorhees believed it “safe” to “assert that systematic investigation in this field will reward us richly in a broader knowledge of plant-food and plant food assimilation,” allowing farmers “to make better provision for the economic utilization of the plant food derived from soil sources or from the manures and fertilizers applied.” By equating soil fertility with soil bacteriology, soil scientists found a warrant to ground their requests for greater shares of station resources.¹⁰⁰

⁹⁸ Percy E. Brown, “Bacteria and Soil Fertility,” Circular of the Iowa Agricultural Experiment Station no. 7 (1913): 3; and, E.B. Voorhees, “Director’s Report,” Annual Report of the New Jersey Agricultural Experiment Stations (1904): 30.

⁹⁹ William A. Albrecht, “Symbiotic Nitrogen Fixation as Influenced by the Nitrogen in the Soil,” Soil Science 4 (1920): 275; Firman E. Bear, “Report of the Department of Soils,” Annual Report for the West Virginia Station (1915): 19; and, Albrecht, “Soil Inoculation for Legumes,” Circular of the Missouri Agricultural Experiment Station no. 86 (1919): 1.

¹⁰⁰ Voorhees and Lipman, A Review of Investigations in Soil Bacteriology, 7; Herbert W. Conn, “Is There a Solution to the Nitrogen Problem?” Annual Report of the Pennsylvania Board of Agriculture (1898); and, Voorhees, “A Popular Review of the Work of the Experiment Station,” Bulletin of the New Jersey Agricultural Experiment Stations no. 182 (1905): 30-31. Percy Brown insisted that “the relation between bacteria and soil fertility is very close and very vital and systems of permanent agriculture must rest firmly on a bacteriological basis to be of any value.” Brown, “Bacteria and Soil Fertility,” 16. The assertion proved, for some audiences, persuasive. Albert F. Woods, the Assistant Chief of the Bureau of Plant Industry, reasoned that “it is now pretty well agreed that” soil fertility was “a problem of bacteriology, with the soil as the culture medium.” Woods, “The Present Status of the Nitrogen Problem,” in, United States Department of Agriculture, Yearbook, 1906

Within the broader field of soil science, support for bacteriological investigations was not universal.¹⁰¹ In fact, soil bacteriologists entered into a protracted and acrimonious dispute regarding the nature of soil fertility. At the Bureau of Soils, senior staff chemists Curtis F. Marbut, Milton Whitney and Frank K. Cameron doubted the prophecy of decreasing soil fertility. In USDA bulletins, agricultural periodicals, and congressional hearings, these officials maintained that most soils contained sufficient plant food, and that the supply was nearly inexhaustible. Declining soil fertility, they argued, represented a merely temporary phase. The capillary action of soil moisture would inevitably return minerals to the surface to be used again as plant food. A farmer commonly inflicted lasting injury to his soil by mono-cropping (*i.e.*, the continuous cultivation of one type of plant). It was in this scenario that the Bureau of Soils scientists found a role for bacteria. Borrowing notions from sanitary science, Milton Whitney explained:

Plants must have a healthful home to life in. Plants, like animals, throw off excreta, which must be disposed of -- we must clean out the soils as we do the stalls in our stable. If we do not, the substances given off by the plants, or the substances which are formed from these substances by the action of bacteria, will produce acid substances, will produce what we call toxic or poisonous matters, that will serious affect if not kill the crop . . .

Infertile ground represented another example of auto-intoxication. Fortunately, since these toxins were plant specific, crop rotations and fallowing allowed the soil "time to recover its tone and cleanse itself."¹⁰²

(Washington: USDA, 1906), 125.

¹⁰¹ For example, Cyril G. Hopkins' text, Soil Fertility Laboratory Manual (Boston: Ginn & Co., 1910) and G.S. Fraps' Principles of Agricultural Chemistry (Easton, PA: The Chemical Publishing Co., 1913) provided course outlines in soil fertility, without any meaningful mention of bacteria.

¹⁰² Whitney, "Soil Fertility," USDA Farmers' Bulletin no. 257 (1903): 15-16; Whitney, "Factors in Soil Fertility," Bulletin of the Bureau of Soils no. 22 (1903); and, Frank K. Cameron, "The Soil as an Economic Factor," Popular Science Monthly 60 (1902): 539; Oswald Schreiner and Howard S. Reed, "Some Factors Influencing Soil

Many soil scientists found the Bureau of Soil's "official, orthodox doctrine" factious in three respects. Firstly, Bureau officials denied that fertilizers added plant food. If their application was advantageous, it was only due to their ability to "neutralize the action of certain toxic organic compounds." This claim undermined the legitimacy of the research and control work of most agricultural chemists, who evaluated soil samples and commercial fertilizers in order to recommend proper applications. Secondly, according to Bureau chemists, soil bacteria multiplied without benefit to soil fertility, except in those instances in which they contributed to or removed the "excrement of plants." The upkeep of plant food remained a product of physics, not biology. Thirdly, the Bureau proffered a missive of carefree optimism. Farmers need not heed the dire warnings of soil scientists, nor require their continuing expert advice. They had only to maintain their normal pattern of crop-rotations.

Within experiment stations, soil scientists decried the Bureau's sanguine assessment. Led by Cyril Hopkins, a committee of seven leading soil chemists publicly challenged the scientific basis for the doctrine of undepletable soils.¹⁰³ By the early 1910's, the consensus of opinion weighed against the Bureau's claims. Few investigators doubted the benefit of fertilizers or the likelihood of declining soil productivity. Soil bacteriologists, however, situated themselves as unlikely mediators in the conflict, offering biological support for both the Bureau's doctrine and its critics. Frederick D. Chester, of the Delaware Station, agreed that most soils contained

Fertility," Bulletin of the U.S. Bureau of Soils no. 40 (1907): 1-40; and, Schreiner, Reed, and Joshua J. Skinner, "Certain Organic Constituents of Soils in Relation to Soil Fertility," Bulletin of the U.S. Bureau of Soils no. 47 (1907): 1-52.

¹⁰³ Cyril G. Hopkins, Soil Fertility and Permanent Agriculture, 312-316; Hopkins, "The Present Status of Soil Investigation," Science 19 (1904): 629; Hopkins, "Chemical Principles of Soil Fertility," Circular, University of Illinois Agricultural Experiment Station no. 124 (1908): 1-16; and, A.W. Blair, "Jacob G. Lipman: Philosopher and Scientist," in Lipman Hall, 35-55.

sufficient plant food, but argued that bacteria were necessary for their conversion to available forms. Percy E. Brown, of the Iowa Station, suggested that the ill-effects of one-cropping were due to the disturbance of a soil's normal bacterial flora. Walter G. Sackett, in Colorado, accepted that plants excreted toxic by-products, and hypothesized that they hindered fertility by inhibiting bacterial growth.¹⁰⁴ These bacteriological forays did not vindicate Whitney's prognostication of unceasing abundance. However, the decade-long controversy did bring attention to the biological processes underlying soil fertility, and thus granting increasing authority to bacteriological explanations.¹⁰⁵

With the outbreak of World War I, soil bacteriology garnered even greater notice. Sodium nitrates, ammonium sulfates, and cyanamide comprised essential ingredients in both explosives and artificial fertilizers. The demands of the military took priority, and station directors sought means of conserving the meager "nitrogen supply set aside for agricultural uses." The war effort also diminished available farm labor, and soil scientists assumed the task of increasing per acre production without lessening agricultural profits. During the interwar years, that aim was recast in terms of soil preservation and permanence. As the perceived

¹⁰⁴ Chester, "The Bacteriological Analysis of Soils," Bulletin of the Delaware College Agricultural Experiment Station no. 65 (1904): 52; Brown, "Bacteriological Studies of Field Soils: Effects of Continuous Cropping and Various Rotations," Research Bulletin of the Iowa Agricultural Experiment Station no. 6 (1912): 216-246; and, Sackett, "Some Soil Changes Produced by Micro-organisms," Bulletin of the Colorado Agricultural Experiment Station no. 196 (1914): 19. During his brief tenure at the University of Kansas, Conrad Hoffmann investigated the Bureau's theory of soil movement. Hoffmann found that bacteria produced dramatic changes in the amount and form of soil components, thus influencing water tension which resulted in the circulation of mineral elements. Hoffmann, "A Contribution to the Subject of the Factors Concerned in Soil Productivity," Kansas University Science Bulletin 9 (1914): 81-99.

¹⁰⁵ See, Weber, The Bureau of Chemistry and Soils, 90-100; William J. Robbins, "The Cause of the Disappearance of Cumarin, Vanillin, Pyridine and Quinoline in the Soil," Bulletin of the Alabama Agricultural Experiment Station (1917): 50-64; Robbins and E.A. Elizando, "The Destruction of Vanillin in the Soil by the Action of Soil Bacteria," Bulletin of the Alabama Agricultural Experiment Station no. 204 (1918): 126-131; A.W. Blair and A.L. Prince, "Studies on the Toxic Properties of Soils," Soil Science (1923); and, Howard Reed and Bruce Williams, "The Effect of Some Organic Soil Constituents Upon Nitrogen Fixation by *Azotobacter*," Technical Bulletin of the Virginia Agricultural Experiment Station no. 4 (1915): 81-91.

decline in crop productivity became apparent to some observers, bacteriology was seen as one analytic tool in the fashioning of “sound” soil practices.¹⁰⁶

Promises, Promises

Between 1900 and 1930, soil bacteriologists labored to convey to experiment station directors and USDA officials the import of their efforts. The value of soil science was mostly acknowledged, and within experiment stations bacteriologists continually adjusted their priorities to fit changing research and institutional contexts. Nonetheless, soil bacteriologists did find it difficult to deliver their promise of improved soil fertility. From the late nineteenth century onward, the field focused on four primary processes and one central goal. The processes consisted of nitrification, nitrogen fixation, the destruction of plant tissues, and mineralization. The goal was one of supplying nitrogen for future crops, through the dissolution of plant residues and manures, and through the fixation of atmospheric nitrogen. While American soil bacteriologists furthered the understanding of the four processes, they fell short of realizing the shared goal.

The history of nitrification studies predates American involvement. In the early 1890's, European researchers outlined the bacterial breakdown of complex proteins into ammonia, nitrites, and nitrates. Sergei Winogradsky, among others, identified the three-step

¹⁰⁶ Jacob Lipman, “Director’s Report,” Annual Report of New Jersey’s Agricultural Experiment Stations (1917): 7; A.B. Conner, “Director’s Report,” 41st Annual Report of the Texas Agricultural Experiment Station (1928): 6; Conner, “Director’s Report,” 42nd Annual Report of the Texas Agricultural Experiment Station (1929): 5; Margaret Rossiter, “The Agricultural Sciences in the United States, 1860-1920,” in The Organization of Knowledge in Modern America, 1860-1920, eds. Alexandra Oleson and John Voss (Baltimore: Johns Hopkins University Press, 1979), 236; and, F.J. Bergerson and J.R. Postgate, eds., A Century of Nitrogen Fixation Research (London: Royal Society of London, 1987).

transformation, and the causative organisms.¹⁰⁷ American researchers, in contrast, arrived at this phenomena through a related research problem. In the mid-1890's, German investigators warned that applications of nitrate of soda fertilizers, in combination with animal manures or straw, invited rapid bacterial reduction of nitrates, and the liberation of nitrogen gas. Such "denitrification" would be detrimental to soil fertility, and brought into question prevailing fertilizing practices. At the New Jersey Station, Voorhees and Lipman scrutinized the role of denitrification in practical farming. Their undertaking isolated two new denitrifying bacteria, but it also demonstrated that denitrification carried a negligible effect on crops grown under normal conditions. More importantly, their work established methods by which later soil chemists and bacteriologists could ascertain the factors influencing protein decomposition.¹⁰⁸ During the next three decades, experiment station bacteriologists explored the dynamics of ammonification and nitrification. Although they demonstrated many complex relationships among the physical, chemical, and bacteriological factors, they could not recommend practical measures for substantially increasing the store of soil nitrates.

The biological dimensions of nitrogen fixation, like nitrification, had been elucidated by European bacteriologists in the 1880's and 1890's. Martinus Willem Beijerinck identified the causative bacteria in legume nodules in 1888, terming it *B. radicicola*. It was often deemed a

¹⁰⁷ Winogradsky identified two forms capable of oxidizing ammonia into nitrites, *Nitrosobacter* and *Nitrosococcus*, and one form which oxidized nitrites into nitrates, *Nitrobacter*. See, Selman Waksman, Sergei N. Winogradsky: His Life and Work, The Story of a Great Bacteriologist (New Brunswick: Rutgers University Press, 1953); and, Lohnis et al., Laboratory Methods, 100-110.

¹⁰⁸ Selman A. Waksman, Jacob G. Lipman: Agricultural Scientist, Humanitarian (New Brunswick: Rutgers University Press, 1966); anon., "Necrology, Dr. Ooska Keller, Dr. Edward Burnett Voorhees, Prof. Franklin Hiram King," Proc., Society for the Promotion of Agricultural Science (1911): 77-84; Voorhees and Lipman, "Investigations Relative to the Use of Nitrogenous Materials, 1898-1907," Bulletin of the New Jersey Agricultural Experiment Station no. 221 (1909): 1-52; and, Allison, "Lipman, the Soil Scientist," 25-28.

“symbiotic” organism, for it seemingly supplied nitrogen within legume nodules for the benefit of the host plant. In the 1890's, Beijerinck and Winogradsky isolated “non-symbiotic” forms capable of fixing atmospheric nitrogen in absence of legume hosts, or indeed any plant (*e.g.*, *Clostridium pasteurianum*, *Azotobacter chroococcum*, and *Az. agilis*).¹⁰⁹ Within a decade, German commercial firms manufactured and marketed bacterial cultures to inoculate soils. The pharmaceutical firm Friedrich Bayer, of Elberfeld, promoted “Alinit” as an acceptable substitute for costly fertilizers. Spending just a few dollars, a farmer could augment the nitrifying and nitrogen fixing powers of his soils, while maintaining his normal crop rotations.

These claims elicited enthusiasm and suspicion on both sides of the Atlantic. At experiment stations and at the Bureau of Plant Industry (BPI), investigators conducted field trials, finding “Alinit” to be worthless. By 1904, the brand disappeared from American markets, although the alluring prospect of a bacterial fertilizer lingered. Bacteriologists, in the employ of commercial interests, isolated and cultivated other active strains of beneficial soil organisms. Field inoculations, however, provided only negative results. The failures proved enlightening, for they demonstrated that each strain was adapted to a specific set of conditions, and cultures survived poorly when introduced to new soil environments.¹¹⁰ Undaunted, many held steady in their pursuit of a microbial philosopher’s stone. In a review of commercial non-symbiotic soil inoculants, BPI plant physiologist George T. Moore acknowledged that some investigators harbored “great hopes” for any means to increase “nitrogenous salts without the aid of any

¹⁰⁹ G.L. van Iterson, L.E. den Dooren de Jong, and A.J. Kluyver, Willem Beijerinck: His Life and Work (The Hague: Nijhoff, 1940), chap. 18. As Chapter 6 will document, the name of the symbiotic nitrogen fixer was never set, with alternative genus designations as *Pseudomonas* and *Rhizobia*.

¹¹⁰ Greaves, Agricultural Bacteriology, 151 & 287; and, Chester, “Bacteria in their Relation to Agriculture,” 83.

manure or mineral fertilizer." Unfortunately, the experimental evidence was discouraging, and "from a practical standpoint the use of such cultures is now considered worthless." Moore, however, believed that as soil scientists became "better acquainted with the habits of these bacteria and learn the conditions which are most favorable to fixing nitrogen" they should "able to discover some means of using the nitrogen gatherers in practical farming." While all present cultures remained ineffective, "the possibility of eventually securing the proper organism and method for distributing it is not unlikely."¹¹¹

Inoculations with symbiotic nitrogen fixing bacteria fared noticeably better, albeit with an equally dubious introduction. In the second half of the nineteenth century, chemists and farmers understood that legume crops (*e.g.*, clover, alfalfa, soybeans, vetch, etc.) returned more nitrogen to the soil than they consumed. Crop rotations, often in three or four year cycles, typically included one season of legumes, which were used as livestock feed, sold as greens, or plowed under (*i.e.*, "green manuring"). Soil scientists further noted that the amount of nitrogen returned correlated closely with the number and size of nodules present on the roots of the legumes. Absent root-nodules, the crop continued to grow, but without contributing to the soil's nitrogen reserve. Upon Beijerinck's isolation of the causative organism, *B. radicicola*, and the discovery of its variable power to form nodules and fix atmospheric nitrogen, a German firm manufactured and marketed "Nitrigin," a supposedly vigorous culture that promised to maximize the yield of fixed nitrogen. In 1900, the BPI sent Walter T. Swingle, another plant physiologist, to Germany to study the feasibility of inoculating legumes with "Nitrigin." Swingle returned convinced that

¹¹¹ Moore, "Bacteria and the Nitrogen Problem," in Yearbook of the Department of Agriculture, 1902 (Washington: GPO, 1903), 336 & 388; and, Moore, "Soil Inoculation for Legumes, with Reports Upon the Successful Use of Artificial Cultures by Practical Farmers," Bulletin of the Bureau of Plant Industry no. 71 (1905): 12. See also, Karl F. Kellerman, "The Present Status of Soil Inoculation," Centl. f. Bakt. ii abt. 34 (1912): 42-46.

the German product was valueless. The BPI directors, however, believed that inoculations still held promise, and that year solicited a congressional appropriation for bacteriological research along those lines. George T. Moore directed the study, and determined that the organism in “Nitrigin” was weakened by the culture media employed in its manufacture. Specifically, he demonstrated that *Ps. radiculicola*, when cultured in normal media, lost its ability to infect legume roots and fix nitrogen. Unlike common bacteria, *Ps. radiculicola* retained its primary characteristics (*i.e.*, the ability to fix atmospheric nitrogen) only when grown in a nitrogen-free environment.¹¹²

During the next two years, Moore, and his colleagues Karl F. Kellerman and Thomas R. Robinson, elucidated many of the unusual physiological traits of the legume bacteria, and developed a novel method for producing pure cultures on dried cotton. The cultures were to be shipped to local farmers, who would then re-hydrate and apply them to legume seed before sowing.¹¹³ In 1903, the BPI patented the process, and began distribution. The initial demand was enormous, and the BPI mailed more than 12,000 doses in two years. Commercial firms could employ the BPI method, without licensing fees, and some companies even adopted the Bureau’s product name, “Nitro-bacterine.” Seed and fertilizer interests produced their own inoculants, and advertised widely in farmer’s journals.¹¹⁴ (Table 3.3) Print ads ballyhooed the

¹¹² Albert F. Woods, “Inoculation of Soil with Nitrogen-fixing Bacteria,” Bulletin of the Bureau of Plant Industry, no. 72 (1905): 3-10; Moore, “Soil Inoculation for Legumes,” 17-37; J.C. Temple, “Studies of *Bacillus Radiculicola*,” Bulletin of the Georgia Agricultural Experiment Station, no. 120 (1916): 67-80; and, F.O. Ockerblad, “Viability of *Pseudomonas Radiculicola* under Anaerobic Conditions,” Michigan Board of Agricultural, Annual Report (1918): 255-264.

¹¹³ Moore and Thomas R. Robinson, “Beneficial Bacteria for Leguminous Crops,” USDA Farmers’ Bulletin, no. 214 (1905): 1-48; and, Karl F. Kellerman, “Methods of Legume Inoculation,” Circular of the Bureau of Plant Industry no. 63 (1910).

¹¹⁴ In addition to the usual agricultural product firms, H.K. Mulford produced legume inoculants. Their promotions relied heavily on their reputation from medical and veterinary biologics: “No one can be better prepared than we are for making inoculating legume cultures . . . and few, if any, can have better facilities equal to

“wonderful discovery” of a “vest pocket fertilizer” that, for only \$2 per acre, “doubles the yield” of legume crops. In response to these “immoderate and exaggerated claims,” station bacteriologists found themselves performing the familiar function of product control.¹¹⁵ With authorization from state legislatures, they evaluated the purity and performance of inoculants, just as they tested the vitality of commercial seeds or the composition of artificial fertilizers. Their assessments were often unfavorable, and even the BPI cultures did not escape criticism.¹¹⁶ In the process of conducting these routine examinations, many experiment stations inaugurated work in soil bacteriology, and a few dedicated resources to determining the conditions of successful inoculations. By the mid-1910's, the production of legume cultures had improved greatly, and several stations distributed their own inoculants.¹¹⁷ (Table 3.4) Although

ours [sic]. For many years, physicians, veterinarians and druggists everywhere have known and used the Mulford Antitoxins, Serums, Vaccines, Assays and Tested drugs, etc., to treat your family and your live stock when they were sick and you may respond with the same confidence in their legume cultures.” H.K. Mulford Co., The Evidence: In Picture and in Prose (Philadelphia: H.K. Mulford Company, 1915), 8, 22, & 23.

¹¹⁵ Andrew M. Soule and Meade Ferguson, “The Inoculation and Cultivation of Alfalfa,” Bulletin of the Virginia Agricultural Experiment Station no. 154 (1904): 109; and, Martin J. Prucha and H.A. Harding, “Quality of Commercial Cultures for Legumes in 1906,” Bulletin of the N.Y. Agricultural Experiment Station no. 282 (1906): 274-279. See also, Jacob Lipman, “Tests of Commercial Cultures for Soil Inoculation” Bulletin of the N.J. Agricultural Experiment Station no. 227 (1910): 1-23; Karl F. Kellerman, “Testing Cultures of Nodule-Forming Bacteria,” Circular of the Bureau of Plant Industry no. 120 (1913); and, Carl R. Fellers, “Report on the Examination of Commercial Cultures of Legume Infecting Bacteria,” Soil Science 6 (July 1918).

¹¹⁶ Cyril Hopkins reasoned: “Like many other things that have merit, the necessity for inoculation and the benefits to be derived from it are being greatly exaggerated . . . For each grain of truth in this advertisement, there are at least ten grains of error or deception.” Hopkins was particularly rankled by those who “strengthen their claims by erroneous or misleading references to the work of experiment stations and departments of agriculture.” Hopkins, “Science and Sense in the Inoculation of Legumes,” Circular of the University of Illinois Agricultural Experiment Station no. 86 (1906): 1-2; Stevens, 17th Annual Report of the North Carolina Agricultural Experiment Station (1907): 50; and, Stevens and J.C. Temple, “The Efficiency of Pure Culture Inoculations for Legumes,” 13th Annual Report of the North Carolina Agricultural Experiment Station (1907): 48-57.

¹¹⁷ No longer did station bacteriologists depict legume inoculants as fraudulent. Instead, they afforded the farmer a “rapid, easy, and cheap method to supply the bacteria essential for getting a successful stand of any legumes. Failure to secure a benefit from this method of inoculation may usually be attributed to unsuitable soil conditions rather than any inherent failing in the culture used.” S.F. Edwards, “Soil Bacteriology,” in, Microbiology for Agricultural and Domestic Science Students, 3rd ed., ed. Charles E. Marshall (Philadelphia: P. Blakiston's Son & Co., 1921), 415. See also, Samuel A. Buchan, “Bacteria of the Soil and Their Bearing on Soil Fertility,” (B.S. thesis, Virginia Polytechnic Institute, 1919) 18; Percy E. Brown, “The Inoculation of Legumes” Circular of the Iowa Agricultural Experiment Station no. 8 (1913): 1-14; Augusto Bonazzi, “Inoculation of

these cultures sold at a fraction of commercial costs, some station directors used profits from sales to fund other bacteriological endeavors.¹¹⁸ What began as routine control work, in these instances, fortuitously developed into research programs.

In contrast to the continued attention devoted to the processes of nitrification and nitrogen fixation, the bacterial role in the complex destruction of plant tissues attracted only intermittent interest among American researchers. In the first years of the century, the Russian bacteriologist Sergei Winogradsky, and his assistant V.L. Omeliansky, isolated and described a few microorganisms capable of dissolving plant cellulose. Nearly a decade later, bacteriologists at the BPI, and at Wisconsin Experiment Station, returned to the Russians' findings. Investigations of nitrogen fixing bacteria revealed that these forms required substantial quantities of soluble carbon compounds. In fact, the amount of nitrogen fixed appeared directly proportional to the amount of available carbon. Plant cellulose offered the greatest source of carbonaceous material, but it was also the most resistant to decomposition by normal putrefactive bacteria. If soil scientists were to increase nitrogen fixation, they needed to determine the conditions facilitating cellulose decomposition.¹¹⁹ In the early 1910's, BPI investigators isolated thirteen new types of

Legumes," Monthly Bulletin of the Ohio Agricultural Experiment Station (1918); and, Alonzo F. Vass, "Legume Inoculation," Circular, University of Wyoming Agricultural Station no. 15 (1920).

¹¹⁸ The bacteriological departments at the Michigan, Wisconsin, Missouri, Oregon, and Wyoming stations reported substantial revenue from legume inoculants. At the Washington station, the director requested, in 1918, the appointment of a full time assistant to perform the "practical and investigational legume work," as the production of inoculants precluded the execution of any other bacteriological projects. C.M. Woodruff, "A History of the Department of Soils and Soil Science at the University of Missouri," Special Report, College of Agriculture no. 413 (1990), 28; anon., "The First Fifty Years of the Oregon Agricultural Experiment Station, 1887-1937," Circular of the Oregon Agricultural Experiment Station no. 125 (Aug. 1937); anon., 100 Years of Progress: The Oregon Agricultural Experiment Station, Oregon State University, 1888-1988 (Corvallis: Oregon State University, 1990), 41; C.A. Magoon and Bliss F. Dana, "Preparation and Use of Pure Cultures for Legume Inoculation," Bulletin of the Washington Agricultural Experiment Station no. 149 (1918): 5-16; and, Magoon, Annual Report of the Washington State Agricultural Experiment Station 1918): 11.

¹¹⁹ Karl F. Kellerman and Ira G. McBeth, "The Fermentation of Cellulose," Centl. f. Bakt. ii abt. 34 (1912): 485-494; and, McBeth, "Cellulose as a Source of Energy for Nitrogen Fixation," Circular of the Bureau of Plant Industry no. 131 (1913): 25-34.

cellulose-fermenting bacteria. Despite the increasing understanding of these organisms, however, soil bacteriologists never realized their the hope of intensifying cellulose decomposition.¹²⁰

Soil bacteriology also encompassed the study of mineralization – the process of rendering of mineral rock elements into soluble forms. Plant physiologists, in the 19th century, had determined that plants required several elements for their growth, including potassium, phosphorus, sulfur, and iron. In the first years of the 20th century, Beijerinck and Winogradsky identified biological sources for two of those elements, sulfur and iron, which were oxidized by specific bacteria. Their discoveries elicited little notice at the time, particularly as most soils contained sufficient quantities of those mineral elements. American investigators re-examined the sulfur bacteria in 1910's, but not with the intent of increasing sulfur. Rather, it was phosphorus and potassium that resided in forms unavailable to plants.¹²¹ Fertilizer manufacturers had developed means of rendering rock phosphate into “superphosphate” -- which was easily assimilated by plant roots -- but only at an exorbitant cost. At the New Jersey, Iowa, Wisconsin,

¹²⁰ Karl F. Kellerman, Ira G. McBeth, Freeman M. Scales, and Nathan R. Smith, “Identification and Classification of Cellulose-dissolving Bacteria,” Centl. f. Bakt., i abt. 39 (1913): 502-525; McBeth and Scales, “The Destruction of Cellulose by Bacteria and Filamentous Fungi,” Bulletin of the Bureau of Plant Industry no. 266 (1913): 3-50; and, McBeth, “Studies on the Decomposition of Cellulose in Soils,” Soil Science 1 (1916): 437-487.

¹²¹ Cyril Hopkins, in particular, argued that phosphorus was crucial to maintaining permanent systems of soil fertility. Not only did plants require phosphorus for their own growth, but the element was equally vital to activities of nitrogen fixing bacteria. Hopkins warned that “the total known supply of high-grade phosphate in the United States is limited and probably will be exhausted during the next forty or fifty years.” Hopkins, Soil Fertility and Permanent Agriculture, 183; Hopkins, “A Phosphate Problem for Illinois Landowners,” Circular of the University of Illinois Agricultural Experiment Station no. 130 (1909): 1-11; Hopkins, “European Practice and American Theory Concerning Soil Fertility,” Circular of the University of Illinois Agricultural Experiment Station no. 142 (1910): 1-31; Conrad Hoffman and B.W. Hammer, “Some Factors Concerned in the Fixation of Nitrogen by Azotobacter,” Research Bulletin of the Wisconsin Agricultural Experiment Station no. 12 (1910): 155-172; William E. Tottingham and Hoffmann, “Nature of the Changes in the Solubility and Availability of Phosphorus in Fermenting Mixtures,” Research Bulletin of the University of Wisconsin Agricultural Experiment Station no. 29 (1913): 273-321; and, Joseph E. Greaves, Bacteria in Relation to Soil Fertility (New York: D. Van Nostrand Co., 1925), 85-88.

and Illinois stations, bacteriologists explored the biological oxidation of sulfur compounds, and its role in transforming phosphates into soluble states. They sought methods of working rock phosphate, sulfur, and sulfur bacteria (e.g., *Thiobacillus thiooxidans*) into composts and soils, such that the resultant sulfuric acid would yield available phosphorus.¹²² Selman Waksman and his associates at the New Jersey station imagined that it might even be possible to inoculate soils with sulfur and their oxidizing bacteria, but their efforts fell short of that goal.¹²³

American soil bacteriologists, during the first decades of this century, never fulfilled their promise of supplanting artificial fertilizers with microbial forms. Only legume inoculations added substantially to soil fertility. Even so, these same bacteriologists made more mundane contributions to scientific agriculture. As part and parcel of the service role of many experiment stations, farmers regularly sent soil samples to the state station for evaluation. Soil bacteriologists suggested that bacteriological examinations could supplement the usual chemical analyses. Soil microorganisms, they posited, might provide an accurate index of soil fertility. Stations would determine the numbers and kinds of bacteria, and measure the soil's facility for nitrification and nitrogen fixation. Equipped with this information, the client farmer could rationally select the amounts and types of fertilizers. More specifically, he might alter his tillage

¹²² Percy E. Brown and Edward H. Kellogg, "Sulfofication in Soils," Research Bulletin of the Iowa Agricultural Experiment Station no. 18 (1914): 50-111; Brown and Harlan W. Johnson, "Studies in Sulfofication," Research Bulletin of the Iowa Agricultural Experiment Station no. 34 (1916): 1-24; Brown and A.R. Gwinn, "Effect of Sulfur and Manure on Availability of Rock Phosphate in Soil," Research Bulletin of the Iowa Agricultural Experiment Station no. 43 (1917): 370-389; Cyril G. Hopkins and Albert L. Whiting, "Soil Bacteria and Phosphates," Science 44 (1916): 246; and, Walter P. Kelley, "The Effect of Nitrifying Bacteria on the Solubility of Tricalcium Phosphate," Journal of Agricultural Research 12 (1918): 671-683.

¹²³ Jacob Lipman, Harry C. McLean, and Harry C. Lint, "The Oxidation of Sulfur in Soils as a Means of Increasing the Availability of Mineral Phosphates," Soil Science 1 (June 1916); Waksman and Joffe, "The Chemistry of the Oxidation of Sulfur by Microorganisms to Sulfuric Acid and Transformation of Insoluble Phosphates into Soluble Forms," Journal of Biological Chemistry 50 (1922): 35-45; and, Charles Barthel, A Review of the Present Problems and Methods of Agricultural Bacteriology (Stockholm: Knut and Alice Wallenberg Foundation, 1923), 77.

or liming practices in order to enlarge the numbers and activities of desirable bacteria. For example, in light sandy soils, excessive tillage increased the nitrifying activities among the resident bacteria, producing nitrogen in quantities too large for crops to use, and risking loss through leaching. This particular farmer would be encouraged to compact his soil, reducing nitrification to the crop's optimal level.¹²⁴ Regarding other considerations, bacteriologists at the Ohio, Iowa, and Wisconsin stations attempted to determine the effect of different crop rotations on the soil flora. If, for example, corn favored the development of bacteria which aided in the growth of oats, then they could recommend that oats follow, and not precede, corn in the rotation.¹²⁵ Other bacteriologists examined animal manure, in order to determine new methods of "fermenting" or "rotting" to increase the manure's benefit to plant growth.¹²⁶

None of these investigative efforts held the grand promise of research in nitrification and nitrogen fixation. No one expected them to uncover a microbial fountain of ceaseless fertility.

¹²⁴ Frederick D. Chester, "Soil Bacteria in Their Relation to Agriculture, Part I," Bulletin of the Delaware College Agriculture Experiment Station no. 40 (1898): 9, 18, 44 & 45; Andrew M. Soule and Edna H.L. Turpin, Agriculture, Its Fundamental Principles (Atlanta: B.F. Johnson Publishing Company, 1907), 83; F.L. Stevens, W.A. Withers, J.C. Temple, and W.A. Syme, "Nitrification in Soils and in Solutions," in, 31st Annual Report of the North Carolina Agricultural Experiment Station, (Raleigh: Edwards & Broughton Printing Co., 1908), 41; Percy E. Brown, "Some Bacteriological Effects of Liming," Research Bulletin of the N.J. Agricultural Experiment Station no. 2 (1911): 52-107; Howard S. Reed and Bruce Williams, "Four Papers on Nitrogen Fixation and Nitrification in Various Soil Types," Technical Bulletin of the Virginia Agricultural Experiment Station no. 3 (1915): 59-80; and, Brown and William V. Halversen, "Effect of Seasonal Conditions and Soil Treatment on Bacteria and Molds in Soil," Research Bulletin of the Iowa Agricultural Experiment Station no. 56 (1919): 252-278.

¹²⁵ Percy E. Brown, "Relation between Certain Bacterial Activities in Soils and Their Crop Producing Power," Journal of Agricultural Research 5 (1916): 855-869; and, E.R. Allen and A. Bonazzi, "On Nitrification: Preliminary Observations," Technical Series, Bulletin of the Ohio Agricultural Experiment Station no. 7 (1915): 1-42.

¹²⁶ Meade Ferguson and E.B. Fred, "Denitrification: The Effect of Fresh and Well-Rotted Manure on Plant Growth," Annual Report of the Virginia Agricultural Experiment Station (1908): 134-149; James C. Temple, "The Influence of Stall Manure Upon the Bacterial Flora of the Soil," Bulletin of the Georgia Experiment Station no. 95 (1911): 5-35; Percy E. Brown, "The Effects of Barnyard Manure," Centl. f. Bakt. i, abt. 39 (1913): 532-542; J.E. Greaves and E.G. Carter, "Influence of Barnyard Manure and Water Upon Bacterial Activities of the Soil," Journal of Agricultural Research 6 (1916): 889-926; and, Harry L. Fulmer and E.B. Fred, "Nitrogen Assimilating Organisms in Manure," Journal of Bacteriology 2 (1917): 423-434.

Instead, they were conducted in an effort to integrate soil bacteriology within the complex of common farming practices. Soil bacteriology, like soil chemistry, might simply be one of the essential components of scientific agriculture, a means for understanding the nature of soil fertility and a tool for increasing crop production. At a handful of institutions, this approach legitimated the professional standing of soil bacteriology.¹²⁷

An Uncertain Home

Between 1893 and 1925, fifty-one separate institutions supported some research in soil bacteriology, including forty-six state experiment stations, and two distinct USDA bureaus. (Table 3.5) At first glance, this number might indicate a vigorous professional growth for soil bacteriology, on par with or even surpassing the development of veterinary and dairy bacteriology. This tabulation is misleading. Nearly half of the experiment stations devoted only limited funds to issues of soil bacteriology, and many lacked adequate facilities or trained personnel.¹²⁸ Of the remainder, only a handful maintained expansive research programs for more than a few years. The fate of soil bacteriology, it seems, was often tethered to other domains of

¹²⁷ Percy E. Brown, "Bacterial Activities and Crop Production," Research Bulletin of the Iowa Agricultural Experiment Station no. 25 (1915): 360 & 384. Paul Burgess rationalized the disciplinary status in these terms: "Soil bacteriology as a handmaiden in the service of soil fertility is no longer to be regarded as the penchant of the agricultural botanist or as the illusory dream of impractical soil scientists. On every hand practical as well as scientific men are beginning to note the aid that his infant science has already rendered to the art of soil management, and its rapidly growing literature is replete with promise of invaluable benefits which it is still to bestow . . ." Burgess, Soil Bacteriology Laboratory Manual (Easton, PA: The Chemical Publishing Co., 1914), ix.

¹²⁸ In the Department of Biology at Texas A&M, O.M. Ball studied legume bacteria. However, his laboratories were not "provided with adequate facilities" to isolate *B. radicicola* from the soils, and Ball was forced to detect their presence by the growth of nodules on legumes. At the Ohio Agricultural Experiment Station in Wooster, the chemistry staff discontinued its studies of nitrogen fixing bacteria and their relation to the phosphorus cycle on "account of not being able to maintain properly controlled conditions . . ." See, William E. Krauss, "History: 1882-1982," Ohio Report on Research and Development in Agriculture, Home Economics, and Natural Resources 67 (May-June 1982); and, Bonnazzi & Allen, Annual Report of the Ohio Agricultural Experiment Station (1916): 29.

agricultural research.

At the USDA, both the Bureau of Soils (BOS) and the Bureau of Plant Industry (BPI) sponsored original research on soil bacteria. The Bureau of Soils, following the passage of the Adams Act in 1906, listed investigations on the effects of tillage and irrigation on soil flora, the nitrifying properties of different soil types, and bacterial fermentation of barnyard manure. The open hostility among the directors of the Bureau toward bacterial accounts of soil fertility, however, effectively macerated the pursuit of these studies until 1914. With the appointment of new leadership, and with assistance from Charles Thom of the Bureau of Chemistry, the BOS took up, in earnest, the most pressing issues in soil bacteriology during the mid-1910's, including a lengthy study on the complex interrelationships among the several soil transformations (e.g., sulfification, nitrification, and nitrogen fixation). Paradoxically, when the Bureaus of Chemistry and Soils amalgamated in the mid-1920's, interest in bacteriology waned once more, superseded by the Bureau's growing concern over food spoilage and irrigation schemes.¹²⁹ At the BPI, bacteriology occupied a more secure position, approbated by congressional statute specifying the study of legume inoculation. To this directed budget line item, the BPI subjoined further studies on the effects of crop rotations, irrigation, and tillage on soil bacteria. The Bureau incorporated bacteriology within its division of plant physiology, and retained a half dozen staff members proficient in both research fields.¹³⁰ Along with the experiment stations in New Jersey, Iowa, and

¹²⁹ True, "A History of Agricultural Experiment Stations," 208 & 239; and, Weber, The Bureau of Chemistry and Soils, 2-5.

¹³⁰ B.T. Galloway, in Karl F. Kellerman, "Conditions Affecting Legume Inoculation," Bulletin of the Bureau of Plant Industry, no. 100, pt. 8 (1906): 73; Kellerman and Thomas R. Robinson, "Progress in Legume Inoculation," USDA Farmers' Bulletin no. 315 (1908): 1-20; Kellerman, "The Functions and Value of Soil Bacteriology," USDA Yearbook, 1909 (1910): 219-226; and, Fred W. Powell, The Bureau of Plant Industry: Its History, Activities and Organization, Service Monographs of the United States Government, no. 47 (Baltimore: The Johns Hopkins Press, 1927; reprint, New York: AMS Press, 1974), 4-15.

Utah, the BPI sustained the bulk of American research efforts in soil bacteriology.

For the majority of other experiment stations, soil bacteriology did not comprise its own department, but rather was subsumed within chemistry or plant pathology. On an institutional level, the integration with soil chemistry was understandable. As early as 1899, the USDA appropriated funds for stations to survey all state soils, including the "nature of the nitrifying organisms which they contain." Ten years later, the Department of Agriculture provided more than \$130,000 per annum for such surveys. While many state stations limited themselves to detailing the physical and chemical characteristics of soils, others included the microbes responsible for generating those characteristics.¹³¹ At the Geneva, Delaware, Utah, and North Carolina stations, surveyors closely examined the microbial flora, correlating its activities with the particular soil conditions, seasons, and regional crops.¹³² For example, at the Utah station, investigators found that their arid soils were rich in non-symbiotic nitrogen fixers (*i.e.*, *Azotobacter*). They also determined that the ground was so saturated with alkali salts as to prohibit normal nitrifying activities. The underlying aim of their survey efforts endeavored to develop irrigation practices that would maximize the former while minimizing the later.¹³³

¹³¹ Weber, The Bureau of Chemistry and Soils 23; and, E.W. Hilgard, "Methods of Physical and Chemical Soil Analysis," Circular of the California Agricultural Experiment Station no. 6 (1903): 1-23.

¹³² See, for example, F.L. Stevens, "Report of the Biologist," 32nd Annual Report of the North Carolina Agricultural Experiment Station (1909): 10; Harold J. Conn, "Bacteria in Frozen Soil," Centl. f. Bakt. ii abt. 28 (1910): 422-434; Conn "Distribution of Bacteria in Various Soil Types," Journal of the American Society of Agronomy 5 (1913): 218-221; T.D. Beckwith, A.F. Vass, and R.H. Robinson, "Ammonification and Nitrification Studies of Certain Types of Oregon Soils," Oregon Agricultural College Experiment Station Bulletin no. 118 (1914) 1-40; and, Conn, "The General Soil Flora," Bulletin of the N.Y. Agricultural Experiment Station no. 429 (1927): 3-10.

¹³³ The Utah staff included bacteriological diversions as part of a strategy to increase crop harvests in a region not known for fertile soil. Robert Stewart and Joseph E. Greaves, "A Study of the Production and Movement of Nitric Nitrogen in an Irrigated Soil," Bulletin of the Utah Agricultural Experiment Station no. 106 (1909): 67-96; Stewart and Greaves, "The Movement of Nitric Nitrogen in Soil and its Relation to Nitrogen Fixation," Bulletin of the Utah Agricultural Experiment Station no. 114 (1911): 181-194; anon., "Development of Bacteriology in Utah," 1954, [ASM] Regional Histories, folder 30-A1, p. 3; and, O.W. Isrealeson, ed., "Pioneering in Western Agriculture: A Résumé of the First Half-Century of Research, 1888-1938," Bulletin of the Utah

The affiliation between soil bacteriology and plant pathology was no less plausible. In fact, in the 1880's and 1890's, plant pathologists such as T.J. Burrill and Byron D. Halsted were among the first Americans to examine bacterial forms of any kind. At the BPI, Erwin F. Smith served as Chief of the Laboratory of Plant Pathology for more than three decades. During that period, he and his staff identified over one hundred types of bacterial plant pathogens. Smith maintained an interest in the paths of microbic invasion and the mechanism of plant tissue destruction, and it was this perspective that led BPI pathologists and physiologists to study the formation of legume root nodules.¹³⁴ The majority of crop rusts, smuts, and wilts, however, were due to fungal, and not bacterial, causes. As a consequence, most plant pathologists trained in mycology. They acquired bacteriological skills only as necessary to remedy particular regional ailments.¹³⁵ On occasion, this demand forged a lasting alliance between mycology and bacteriology. At the Delaware station, for example, Frederick D. Chester held the various titles of botanist, mycologist, bacteriologist, and plant pathologist. During his first decade at the station, Chester investigated diseases of fruit trees, legumes, and sweet potatoes. Only in his eleventh year did he turn his attention to the bacteriology of nitrification and nitrogen fixation.

Agricultural Experiment Station no. 282 (1938): 3-129.

¹³⁴ H.H. Thornberry, "The History of Plant Pathology in Illinois," 1958, [ASM], box 2-IXC, folder 73, pp. 4-15; Erwin F. Smith, "In Memorium," Thomas J. Burrill," Journal of Bacteriology 1 (1916): 269; J.T. Barrett, "Thomas Jonathan Burrill, 1839-1916," Phytopathology 8 (1918): 1-4 Melville T. Cook, "Byron David Halsted," Botanical Gazette 67 (Feb. 1919): 169-170; Louis H. Pammel, "Dr. Byron D. Halsted," Proc. Iowa Academy of Science 26 (1919): 31-33; Charlotte Elliott, Manual of Plant Pathology (Baltimore: Williams & Wilkins Co., 1930; Smith, "Destruction of Cell Walls by Bacteria," Science 15 (1902): 405; and, Albert F. Woods, "Inoculation of Soil with Nitrogen-fixing Bacteria," 3-10.

¹³⁵ The principal bacterial plant diseases numbered less than two dozen, including: fire blight of pears; bacteriolysis of walnuts; alfalfa blight; bean blight; yellows of hyacinths; black rot of cabbage and turnips; onion rot; cucumber wilt; potato wilt; tobacco wilt; and olive knot. See, F.L. Stevens and John G. Hall, Diseases of Economic Plants (New York: Macmillan Co., 1910); Stevens, Plant Pathology: Laboratory Outline (Champaign, Ill.: Loyde's University Store, 1917); King, Synopsis of Lectures, 72-75; and, Frederick D. Heald, Manual of Plant Diseases, 1st. ed. (New York: McGraw-Hill, 1926).

For the next twenty years the station nurtured the bonds between soil bacteriology and plant pathology. Similar to arrangements fashioned at other stations, staff trained in plant pathology were expected to conduct occasional forays in bacteriology.¹³⁶ (Table 3.6)

The relationship between plant pathology and soil bacteriology was, for the most part, asymmetrical. Plant pathology constituted a growth field in the early twentieth century, with agricultural colleges offering an increasing number of courses, and industry-sponsored graduate fellowships.¹³⁷ (Table 3.7) Bacteriology represented an accepted, but less-prestigious, sub-field of plant pathology. Researchers such as Bliss F. Dana at Washington and Henry W. Barre at South Carolina each began their experiment station careers with the joint title of "Assistant in Plant Pathology and Bacteriology." As they were promoted, they acquired the title of "Plant Pathologist," ceding the study of bacterial plant diseases and legume inoculations to more junior staff. Other phytopathologists, such as Colorado's Walter G. Sackett, continued to investigate problems in soil bacteriology throughout their careers. Yet, their research interests lay decidedly with non-bacterial plant diseases. By the late 1910's, plant pathology gradually dissolved its disciplinary entente with bacteriology, leaving soil bacteriology to subsist on its own terms.¹³⁸

¹³⁶ B.T. Galloway, "Twenty Years Progress in Plant Pathology," Society for the Promotion of Agricultural Science (1900): 90-102; John L. Sheldon, "Tubercles on Legumes with and without Cultures," Bulletin of the West Virginia Agricultural Experiment Station no. 105 (1906); and, Thomas F. Manns and Joseph M. Goheen, "A Preliminary Report on Muck Humus as a Fertilizer and Carrier of Beneficial Soil," Bulletin of the Delaware College Agricultural Experiment Station no. 115 (1916): 1-40.

¹³⁷ Rutgers, for example, offered seven fellowships in Plant Pathology in 1910, but the department could only supply seven graduate students. Interestingly, the same department devoted a 1913 Union Sulfur Company fellowship to Harry C. Lint, who studied both potato scab and the bacteriology of sulfur oxidation.

¹³⁸ At the Michigan and Wisconsin stations, the partition yielded two vigorous departments. At Vermont, only plant pathology flourished. See, L.R. Jones, "The Relation of Plant Pathology to Other Branches of Botanical Science," Phytopathology 1 (1911); Jones, "Problems and Progress in Plant Pathology," American Journal of Botany 1 (1913): 97-111; G.P. Clinton, "Botany in Relation to Agriculture," Science 43 (1916): 11; Donald B. Johnstone, "Historical Information on the Development of Bacteriology at Vermont," 1952, [ASM] box 2-IXC, folder 77, pp. 3-5; and, Donna Taylor Hartshorn, My Half Century at the University of Wisconsin, Ira L. Baldwin (Madison: Omnipress, 1995), 31.

Instruction in soil bacteriology shared a similarly tenuous institutional status. With the exception of Rutgers and Iowa State, there existed no departments of soil bacteriology between 1900 and 1925. Instead, courses in soil bacteriology were offered within departments of agronomy, soil fertility or general agricultural chemistry. Infrequently, departments given to veterinary, dairy, or water bacteriology would offer a singular class in soil bacteriology, or a winter short course (e.g., Oregon State University, Michigan Agricultural College).¹³⁹ (Table 3.8) Graduate level courses were even more uncommon. As late as 1925, one could obtain a masters and doctorate in soil bacteriology at only a handful of institutions (e.g., Utah Agricultural College, Rutgers, Iowa State, University of Wisconsin and Oregon Agricultural College). In his 1920 review of soil bacteriology, Percy Brown admitted that it remained a incipient instructional field, one without adequate textbooks or an agreed-upon curriculum. Yet, he found solace in noting that many colleges devoted increasing attention to bacteria within courses on soil fertility. For Brown and others, soil bacteriology could be integrated with normal instruction on tillage, drainage, manuring, green manuring, and liming. The new laboratory science merely facilitated a greater "comprehension of agricultural facts."¹⁴⁰ Even without separate courses, departments, or graduate programs, soil bacteriology developed, albeit incrementally, during the first quarter

¹³⁹ At Oregon State, for example, Emil Pernot combined lectures in water and soil bacteriology during 1899 and 1900. No additional instruction was offered, however, until 1909. At the University of Illinois, the Botany Department taught agricultural bacteriology, except for soil bacteriology, which was part of Agronomy. Even when the University granted bacteriology its own departmental status in 1921, soil bacteriology remained separate. Similarly, soil bacteriology was sequestered to Agronomy at the University of West Virginia. See, W.B. Bollen, "History of the Department of Microbiology at Oregon State University," [ASM], Regional History Collection; H.A. Wilson, "A Brief History of General and Agricultural Bacteriology at West Virginia University and the West Virginia Agricultural Experiment Station," 1954, [ASM] box 2-IXC, folder 88; and, Wallace, "Early Bacteriology at the University of Illinois," 3.

¹⁴⁰ Brown, "The Teaching of Soil Bacteriology," Journal of the American Society of Agronomy 13 (1921): 323-328. For a similar approach to the teaching soil bacteriology, see, Lipman and Brown, Laboratory Guide in Soil Bacteriology; Paul S. Burgess, Soil Bacteriology Laboratory Manual (Easton PA: The Chemical Publishing Co., 1914); and E.B. Fred, Laboratory Manual of Soil Bacteriology (Philadelphia: Saunders Co., 1916).

of twentieth century.

Control and Self-Doubt

Three characteristics distinguished American soil bacteriology from the hygienic program of isolation, identification, and elimination. Initially, soil bacteriologists, like their dairy counterparts aimed to control, rather than eradicate, the microbial population. For the most part, they focused on identifying beneficial bacteria and the conditions which would allow their maximum exploitation. Secondly, soil bacteriologists were given to persistent self-examination. The principal investigators remained highly critical of their own methods and aims, and as a consequence, soil bacteriology lacked the "routine" procedures that marked other branches of the science. Their public displays of self doubt did not herald the imminent professional collapse. Rather, the dissatisfaction expressed a frustration among those strapped with ambitious goals and an intractable subject matter. The third defining feature is a natural product of the first two. Given the objective of control, and the recurring critical self-examination, soil bacteriology quickly and resolutely abandoned the pure culture methods of the hygienic program. As the following section demonstrates, this branch of the discipline encouraged conceptual innovations in an effort to secure professional growth.

The dream of control dominated American soil bacteriology. Unlike medical and public health bacteriology, soil scientists (like dairy bacteriologists) confronted the "practical question" of how to "stimulate the development of soil organisms." As Joseph Greaves explained: "It is the problem of the worker in soil bacteriology to learn how to speed up the work of the beneficial

and to suppress or weed out the injurious."¹⁴¹ This vision of microbial management furthered three lines of research. The first entailed adjusting common farming practices in order to favor helpful microbes. If a soil scientist could "ascertain the conditions under which" the beneficial forms "operate most energetically, thus establishing control" the farmer could "utilize soil organisms in an economic way for better production" of crops by changing aspects of the soil environment, whether they be "moisture, aeration, temperature, reaction, or amount of organic matter." Jacob Lipman, in particular, believed that at given stages in the nitrogen cycle, a soil's flora stood particularly "susceptible" to "decided modifications," including the well-timed application of fertilizers or "so-called stimulants, like manganese, cooper, zinc, etc."¹⁴² He posited a theoretical condition of "highest bacterial efficiency," or a maximum ammonification, nitrification, and nitrogen fixation, accompanied by a minimum loss of nitrogen through leaching, evolution of free nitrogen gas, or conversion into insoluble forms. Each soil exacted a distinctive set of optimal conditions, and by adjusting the soil reaction through liming, or altering the proportion and composition of organic matter through selective application of manures, the scientifically inclined farmer could maintain the "maximum rate" of favorable bacterial activity.¹⁴³

¹⁴¹ Chester, "Soil Bacteria and Nitrogen Assimilation," 13; and, Greaves, Bacteria in Relation to Soil Fertility, 11 & 92.

¹⁴² Marshall, "Technical Application of Microorganisms," 259; Waksman, Jacob G. Lipman: Agricultural Scientist, Humanitarian, 38; Lipman, "Soil Bacteriological Studies. Further Contributions to the Physiology and Morphology of Members of the *Azotobacter* Group," in 25th Annual Report of the N.J. Station (Patterson, N.J.: News Printing Co., 1905), 237; Lipman, "Problems in Soil Bacteriology," Science 42 (1915): 316; Herbert W. Conn, "Nitrogen-gathering Plants," United States Department of Agriculture, Yearbook (1911): 213-218; and, T.L. Lyon and J.A. Bizzell, "Some Conditions Favoring Nitrification in Soils," Science 30 (1910): 773.

¹⁴³ Paul D. Heuser, "Soil Fertility and Microorganisms," (B.S. thesis, Virginia Polytechnic Institute, 1916), 16, 25 & 26; Greaves, Agricultural Bacteriology, 28; R. Nagan Gowda, "Oxidation of Ammonia and Nitrates by Microorganisms under Different Conditions," Soil Science 17 (1924): 57-64; Selman A. Waksman and Robert L. Starkey, The Soil and the Microbe: An Introduction to the Study of the Microscopic Population of the Soil and its Role in the soil Processes and Plant Growth (New York: John Wiley & Sons, 1931), 49-50; and, E.J. Russell, ed.

The second path toward microbial management lay in the discrimination and selection of specific bacterial types. Bacteriologists proposed to survey the microbial population of the soil, and then introduce those kinds that were "needed to raise the bacterial activity to the highest state of efficiency." One might imagine that a farmer could "regularly inoculate his fields before planting a crop."¹⁴⁴ Albert F. Woods, the Acting Chief of the BPI, drew a familiar analogy:

A man who wants to make a success of growing sugar beets plants seeds of high sugar-producing strains. The importance of using selected seed for all crops has been so amply demonstrated that no argument in favor of the practice is needed. It is the very foundation of progress in plant culture. Soil bacteria are no exceptions to the rule, and pure-bred bacteria for specific work are as clearly an economic necessity as pure-bred cattle or pure-bred sugar beets.¹⁴⁵

The research goal resonated with accepted agricultural precepts. The soil bacteriologist and his client farmer understood that bacteria were neither entirely helpful or harmful. Rather, the introduction of certain forms could be advantageous given particular soil conditions and crop demands.

The third course to bacterial mastery resided in the effort to alter the microorganisms themselves. The legume bacteria had, after all, been modified to increase their "zymotic efficiency." Much as public health bacteriologists selected and enhanced the diphtheria organism to amplify the production of antitoxin, station and BPI researchers developed culture techniques to augment the power of *B. radicum* to invade root hairs and fix atmospheric nitrogen.¹⁴⁶

The Microorganisms of the Soil (London: Longmans, Green, & Co., 1923), v.

¹⁴⁴ Woods, "The Present Status of the Nitrogen Problem," 127 & 132; Frederick D. Chester, as quoted in Charles E. Bessey, "The Bacteriological Analysis of Soils," Science 19 (1904): 769; and, E.J. Russell, A Student's Book on Soils and Manures, 2nd ed. (Cambridge: Cambridge University Press, 1919), 46.

¹⁴⁵ Woods, "The Present Status of the Nitrogen Problem," 134. Paul Emerson reasoned that "just as one may infect his soil with good seed, bad seed, or weed seed, so may he inoculate it with good, indifferent, or injurious bacteria." In addition, "many forms may be classified as bacterial weeds." Emerson, "Tests of an 'All Crops' Soil Inoculum," Emerson, Bulletin of the Maryland Agricultural Experiment Station no. 214 (1918): 127.

¹⁴⁶ The BPI and most commercial firms prepared their inoculants by alternatively culturing them on nitrogen free media and on the roots the particular host legume, "thus breeding the bacteria up to a high state of

Moreover, bacteriologists eyed the prospect of modifying the organism to fix nitrogen after the death of the legume, or even fix nitrogen within non-leguminous plants.¹⁴⁷ They knew that through environmental manipulations, they could train one strain of *B. radicum* to live upon many different legumes. If, "by any such process of breeding, or evolution, a species of nitrogen-fixing bacterial could be developed which could live on a non-leguminous plant, as corn, for example, it would be of incalculable value." The legume component of crop rotations was not always profitable, and in a "period of extreme nitrogen shortage" an all-crops inoculum would constitute a "veritable panacea for all of the farmer's troubles."¹⁴⁸ Similarly, if the power of cellulose decomposing bacteria could be harnessed, the farmer could apply them directly to fresh straw, fermenting it down to "a mixture of humus compounds," and thus reducing his expenditures on purchase of animal manures.¹⁴⁹

The notion of microbial control was not singularly unique to soil bacteriology. In the

efficiency." Percy E. Brown, "Soil Inoculation," Circular, Iowa Agricultural Experiment Station no. 43 (1918): 5; Ferguson, "Soil Inoculation with Artificial Cultures," 88; Kellerman and Robinson, "Conditions Affecting Legume Inoculation," 78-82; and, George T. Moore, "Bacteria and the Nitrogen Problem," 333-342. Paul Emerson attempted the same with non-symbiotic forms, but his results were mostly negative. Emerson, "Soil Inoculation with *Azotobacter*," Research Bulletin of the Iowa Agricultural Experiment Station no. 4-5 (1918): 27-64.

¹⁴⁷ Cyril G. Hopkins, "Nitrogen Bacteria and Legumes," Bulletin of the Illinois Agricultural Experiment Station no. 94 (1904); Jacob Lipman, "The Associative Growth of Legumes and Non-Legumes," Bulletin of the N.J. Agricultural Experiment Station no. 253 (1912): 1-48; T.J. Burrill and Roy Hansen, "Is Symbiosis Possible between Legume Bacteria and Non-Legume Plants?" Bulletin of the Illinois Agricultural Experiment Station no. 202 (1917); and, L.W. Erdman and Percy E. Brown, "The Inoculation of Non-legumes," Bulletin of the Iowa Agricultural Experiment Station no. 262 (1929): 319-339.

¹⁴⁸ Hopkins, Soil Fertility and Permanent Agriculture, 209; and, Emerson, "Tests of an 'All Crops' Soil Inoculum," 128, 129 & 143. Burrill asserted that this prospect was within reach. See, "Micro-organisms of Soil and Human Welfare," Science 20 (1904), 432. Most attempts, however, produced negative results. See, Felix Lohnis and Lewis T. Leonard, "Inoculation of Legumes and Non-Legumes with Nitrogen-Fixing and Other Bacteria," USDA Farmer's Bulletin no. 1496 (1926): 1-28; and, Brown and Erdman, "Inoculation of Legumes," Circular of the Iowa Agricultural Experiment Station no. 102 (1927): 1-7.

¹⁴⁹ E.J. Russell, The Microorganisms of the Soil, 29. See also, Harold J. Conn and R.C. Collison, "Fermentation and Preservation of Manure: A Study of Certain Bacteria Involved in the Ammonification of Manure," Bulletin of the N.Y. Agricultural Experiment Station no. 494 (1922): 1-74; and, Collison and H.J. Conn, "Artificial Manure from Straw," Bulletin of the N.Y. Agricultural Experiment Station no. 573 (1929): 1-17.

production of antitoxins, dairy products, and industrial alcohols, bacteriologists had already endeavored to govern, rather than halt, bacterial activities. Nonetheless, soil bacteriologists were particularly driven by the goal of microbial exploitation. Historian Philip Pauly has detailed the influence of Jacques Loeb among certain American biologists during the early twentieth century, arguing that Loeb's engineering idea guided many research programs. In particular, Pauly has described how Loeb regarded organisms and their constituent cells as "chemical factories," subject to modification by environmentally induced changes.¹⁵⁰ In a parallel fashion, soil bacteriologists, such as E.B. Fred, Joseph E. Greaves and Charles B. Lipman held that bacteria were "enzyme factories," whose output could be accelerated or reduced by exposure to alkali salts, sodium carbonates, or toxic metals. The task remained one of determining which compound succeeded for each particular soil, crop, and condition.¹⁵¹ Selman Waksman and Charles Lipman even trained under one of Loeb's protégés, and Waksman eagerly acknowledged the Loebian influence in his textbooks.¹⁵² While these researchers never fully realized the goal of controlling life, the engineering ideal pervaded much of their work, and demarcated soil bacteriology from other areas of the discipline.

¹⁵⁰ Pauly, Controlling Life: Jacques Loeb and the Engineering Ideal in Biology (New York: Oxford University Press, 1987); and, Pauly, "General Physiology and the Discipline of Physiology, 1890-1940," in Physiology in the American Context, 1850-1940, ed. Gerald L. Geison (Bethesda: American Physiological Society, 1987), 195-207.

¹⁵¹ Diane Johnson, Edwin Broun Fred: Scientist, Administrator, Gentleman (Madison: University of Wisconsin Press, 1974), 25; Fred and E.B. Hart, "The Comparative Effect of Phosphates and Sulphates on Soil Bacteria," Research Bulletin of the University of Wisconsin Agricultural Experiment Station no. 35 (1915): 35-66; Greaves, "Stimulating Influence of Arsenic upon the Nitrogen Fixing Organisms of the Soil," Journal of Agricultural Research 6 (1916): 389-416; C.B. Lipman, "Toxic Effects of 'Alkali Salts' in Soils on Soil Bacteria," Centl. f. Bakt. ii abt. 32 (1911): 58; and, Lipman and Paul S. Burgess, "The Protective Action Against Magnesium Carbonate of Calcium Carbonate for *Azobacter Chroococcum*," Journal of Agricultural Research 6 (1916): 484-494.

¹⁵² Waksman, Principles of Soil Microbiology, 1st ed. (Baltimore: William and Wilkins, 1927), ix; and, Waksman, My Life with the Microbes (New York: Simon & Schuster, 1954), 50-91.

Beyond the aspiration to control the microscopic realm, their recurrent self-doubt defined soil bacteriologists. In journal articles, textbook introductions, and public addresses, leading researchers measured their own inadequacies. To a large extent, this was a case of unrealistic expectations. With the discovery of symbiotic and non-symbiotic fixing bacteria, American investigators entertained the "high hope" that "the nitrogen problem in agriculture had been solved." In the first years of the century, commercial inoculants "fired the imagination" of those seeking to increase the earth's fertility. To those familiar with the "amazing efficiency of bacterial action," the enthusiasm seemed justified.¹⁵³ Between 1893 and 1928, more than one thousand papers appeared on nitrogen fixation, but no one convincingly demonstrated that inoculations could replace fertilizers. In addition, since 1904, no new soil processes had been discovered. Thirty years of study had only elaborated the findings of Beijerinck and Winogradsky.

Interest in soil bacteriology wavered in the second and third decades of the 20th century. As Percy Brown reasoned, "the important results of the studies in medical bacteriology had led many to expect similar radical and far-reaching effects of soil bacteriological research upon practical agriculture." When the revolutionary results did not appear, "many scientists and practical agriculturalists were vastly disappointed and lost interest in the subject."¹⁵⁴ In fact, Selman Waksman declared the field moribund in 1924, with all but the most committed

¹⁵³ Greaves, Bacteria in Relation to Soil Fertility, 148 & 150; Thom, "Soil Microbiology in America," 40; Gordon D. Knox, The Spirit of the Soil; Or, An Account of Nitrogen Fixation in the Soil by Bacteria and of the Production of Auximones in BacterIALIZED Peat (New York: Frederick A. Stokes Co., 1915), 53; and Brown, "Bacteria and Soil Fertility," 10.

¹⁵⁴ Brown, "The Beginnings and Development of Soil Microbiology," Soil Science 40 (1935): 57. See also, Waksman, Principles of Soil Microbiology, 1st ed., 839.

researchers turning their attention to other problems.¹⁵⁵ Waksman's assessment, delivered before a meeting of the Society of American Bacteriologists, proved, in part, accurate. Of those experiment station bacteriologists who published on soil bacteria, a majority penned only once or twice on the topic. Other researchers took graduate degrees in soil bacteriology, only to abandon the field upon graduation. Among those who continued, most pursued other, unrelated, research lines (e.g., the physiology of tomatoes, the influence of storage on flour).¹⁵⁶ Nonetheless, some observers remained more sanguine. The number of original research articles increased incrementally in the 1910's and 1920's, as did the number of graduate students. At colleges such as Rutgers, departments even secured a supply of industrial fellowships and grants for soil bacteriology.¹⁵⁷

These professional achievements aside, Waksman thoroughly criticized the methodological and theoretical foundations of soil bacteriology. Waksman asserted that, while soil bacteriology had received "considerable attention from various points of view," and had an "extensive literature," the "present knowledge of the soil microflora and microfauna and of the numerous transformations that they bring about" had not "advanced beyond a mere beginning" of isolating responsible forms. The processes by which those organisms effected changes

¹⁵⁵ Waksman, "Soil Microbiology in 1924: An Attempt at an Analysis and Synthesis," *Soil Science* 19 (1925): 20-46. Among the committed soil bacteriologists, there was a lingering optimism. Charles E. Marshall suggested that "projected applications can not be measured by a score of years, but by centuries, not by present attainment, but by future progress." Marshall, "Technical Applications of Microorganisms," 259. Brown hoped that "in the future" the field may "have some extremely significant effects upon practice." The detractors simply expected the "startling discoveries of the early studies of a new science to be continued indefinitely." Brown, "The Beginnings and Development of Soil Bacteriology," 54.

¹⁵⁶ Rossiter, "The Agricultural Sciences in the United States," 236. The long list of bacteriologists with only one or two articles in soil topics includes many with distinguished careers in dairy or veterinary bacteriology, or even general biology (e.g., Lowery L. Lewis, Herbert Waite, Edward C. Mohr, William L. Owen, Robert Stewart, Reginald H. Robinson, Ralph McBurney, James M. Sherman, Percy L. Gainey, and William J. Robbins).

¹⁵⁷ Brown, "The Beginnings and Development of Soil Microbiology in the United States," 49-50; and, A.G. McCall, "The Development of Soil Science," *Agricultural History* 5 (1931): 49.

remained poorly understood. In Waksman's opinion, there was "still lacking the science of soil microbiology proper, or the applied science."¹⁵⁸ Winogradsky, in a review of a celebrated textbook, likewise complained that soil bacteriology represented, by the 1920's, a compilation of facts without theoretical grounding.¹⁵⁹

The conceptual deficit was largely a consequence of inadequate methods. Like dairy bacteriology, the standard gelatin plate techniques of medical bacteriology failed to provide relevant information for soil scientists. Numerical counts remained wildly inaccurate, and provided a poor indication of a soil's fertility. Soil bacteriologists were not interested in the number of microbes, but rather their functions, and American researchers sought to determine the "physiological efficiency" of a certain flora.¹⁶⁰ Additionally, some important soil organisms (e.g., nitrifiers, cellulose decomposers) failed to grow on common peptone-based media, or presented only in inactive spores.¹⁶¹ Obtaining pure cultures of nitrifiers proved nearly impossible, and soil bacteriologists decried their own inability to study these forms in

¹⁵⁸ Waksman, "Soil Microbiology in 1924," 22-29; and, Waksman, Principles of Soil Microbiology, 1st ed., vii-viii & 837.

¹⁵⁹ Waksman, Sergei N. Winogradsky, 42. See also, Barthel, A Review of the Present Problems and Methods of Agricultural Bacteriology, 71; and, Thom, "Soil Microbiology in America," 39. Waksman's judgment might be self-serving, as he reiterated for decades the contention that it was his guidance at Rutgers that salvaged the field of soil bacteriology. See, Waksman, "Fifty Years of Soil Microbiology at Rutgers," in Lipman Hall, 7; Waksman, "The Background of Soil Science," Soil Science 101 (1966): 6-10; and, H. Boyd Wooldruff, "A Soil Microbiologist's Odyssey," Annual Reviews of Microbiology 35 (1981): 1-28.

¹⁶⁰ Herbert W. Conn, Agricultural Bacteriology, 1st ed., 56; Greaves, Agricultural Bacteriology, 161 & 197; Lohnis & Fred, Textbook of Agricultural Bacteriology, 240; and, Charles B. Lipman, "The Distribution and Activities of Bacteria in Soils of the Arid Region," University of California Publications in Agricultural Science 1 (1912): 1-20.

¹⁶¹ Voorhees and Lipman, A Review of Investigations in Soil Bacteriology, 8-9; Percy E. Brown, "Media for Quantitative Determination of Bacteria in Soils," Research Bulletin of the Iowa Agricultural Experiment Station no. 11 (1913): 382-407; William L. Owen, "Effect of Carbonates upon Nitrification," Bulletin of the Georgia Agricultural Experiment Station no. 81 (1908): 1-42; and, E.B. Fred and Audrey Davenport, "The Effect of Organic Nitrogenous Compounds on the Nitrate Forming Organism," Soil Science 11 (1921): 389-407.

isolation.¹⁶² Determining the causative role of soil organisms was no less simple. Several forms could produce an identical transformation. For example, *B. mycoides*, *Sarcina lutea*, *B. subtilis*, and *Proteus vulgaris* all oxidized ammonia, and investigators struggled to detect which form, or combination of forms, was active in a given soil.¹⁶³

As a consequence, many soil investigators rejected the dominant solid culture techniques in favor of Beijerinck's "enrichment culture method" or Remy's solution method.¹⁶⁴ The former procedure involved infusing media with the ideal nutrient for the desired organism, thus encouraging it to outgrow other forms. This selected culture would then be employed to reveal the morphological, cultural, and physiological characteristics of the bacterial type. The latter method directed the bacteriologist to place a measured soil sample into a solution of a known composition. By examining the chemical changes, one could gauge the ammonifying, nitrifying, or nitrogen fixing power of a given sample. Both methods were unique to soil bacteriology in the first decades of this century, but neither were adequate. Solutions comprised, by their nature, unnatural and uncontrolled conditions. The media could not be sterilized without altering its condition, and did not resemble the physical characteristics of soil. Furthermore, the nutrient solutions removed interactions between forms, allowing some organisms to multiply more

¹⁶² William M. Gibbs admitted that "very often difficulties arise which make the undertaken work absolutely useless, or if one believes that he is at his goal, a new difficulty suddenly appears . . . And we may comfort ourselves with the thought that up to this time no other investigator has been successful" in isolating the *Nitrosomonas*. Gibbs, "The Isolation and Study of Nitrifying Bacteria," Soil Science 8 (1919): 435-446; Lohnis et al., Laboratory Methods in Agricultural Bacteriology, 110; and, R. Nagan Gowda, "Nitrification and the Nitrifying Organism," Journal of Bacteriology 9 (1924): 251-272.

¹⁶³ Greaves, Bacteria in Relation to Soil Fertility, 113; and, Lohnis & Fred, Textbook of Agricultural Bacteriology, 135. There was also the real possibility that the "same organism may also produce different end products from different initial compounds, or from the same compound under different conditions." Waksman and Starkey, The Soil and the Microbe, 31.

¹⁶⁴ Thom, "Soil Microbiology in America," 46; and, Moore, "Soil Inoculation for Legumes," 27-28. For those preferring solid media, they employed silica jelly or synthetic media. See, Harold J. Conn, "Future Methods of Soil Bacteriological Investigations," Centl. f. Bakt. ii abt. 25 (1909): 454.

rapidly than they would in soils, even to the point of suppressing of activities of other integral species.¹⁶⁵ By the mid-1910's, American bacteriologists increasingly shunned both plate and solution techniques, opting instead to study bacteria in soil extracts or in cylinders. This decision effectively "black boxed" the specific bacteria. Unlike other realms of bacteriological procedures, no organisms were isolated or scrutinized. Rather, the cylinders comprised a closed environmental system, where the influence of moisture, soil constituents, and the like, was correlated with changes in plant food and the presumed activities of microorganisms.¹⁶⁶

The abjuration of traditional bacteriological methods elicited considerable unease. As Selman Waksman noted, "the pathologist can study the action of his organism *in vivo*" and "the microbiologist working on the fermentation process can sterilize his medium, without altering its composition greatly, and inoculate it with a pure culture of the organism concerned." The soil bacteriologist lacked a comparably reliable experimental system, and statements of frustration grew increasingly common.¹⁶⁷ At the Ohio Station, Edward R. Allen and Augusto Bonazzi terminated their experiments on the nitrifying organisms in 1914 in order to direct their attention "toward devising more accurate methods." In a report to the station director the two offered that "the reason that there are so many incomplete experiments and so many loose ends . . . is that the

¹⁶⁵ Voorhees & Lipman, A Review of Investigations in Soil Bacteriology, 11-12; and, Brown, "The Solution Versus the Soil Method for the Bacteriological Examination of Soils," Science 42 (1915): 316.

¹⁶⁶ Waksman, Principles of Soil Microbiology, 1st ed., 840; Stevens et al., "Nitrification in Soils and in Solutions," 41; Stevens et al., "Ammonification in Soils and in Solutions," Centl. f. Bakt. ii abt. 23 (1909): 776-787; Stevens and Withers, "The Inhibition of Nitrification by Organic Matter Compared in Soils and in Solutions," Centl. f. Bakt. ii abt. 27 (1910): 169; Percy E. Brown, "Bacteriological Studies of Field Soils," Research Bulletin of the Iowa Agricultural Experiment Station no. 13 (1913): 426-448; and, R. Stevenson and Brown, "Testing Soils in the Laboratory and Field," Circular of the Iowa Agricultural Experiment Station no. 15 (1913): 1-16.

¹⁶⁷ Waksman, Principles of Soil Microbiology, 1st ed., 840. See also, H.C. Lint and David A. Coleman, "Sources of Error in Soil Bacteriological Analysis," Soil Science 2 (Aug. 1916); Barthel, Present Problems and Methods of Agricultural Bacteriology, 50; Waksman, Sergei Winogradsky, 43; and, Winogradsky, "The Method in Soil Microbiology as Illustrated by Studies on *Azotobacter* and the Nitrifying Organisms," Soil Science 40 (1935): 59-76.

methods used (which are the customary ones) are so fraught with errors that we can never hope to solve” the most pressing questions by them. Similarly, in his summary of research on the bacteria of animal manures, Percy Brown lamented that the methods were “so unsatisfactory and so constantly changing that the results obtained by their use can hardly be regarded as showing the actual extent and importance of bacterial processes in the soil, nor as bringing out the difference in soils due to the effects of different treatment.”¹⁶⁸ Even George T. Moore, who had previously trumpeted the impending revolution in soil bacteriology, branded the field with methodological tomfoolery. In an address before the AAAS, Moore remarked that there existed no bacteriological method of examining soils that was “of the least practical value.”

Rhetorically, he inquired how one might “hope to gain much definite information either as to the needs or the activities of these bacteria, when conclusions regarding them are drawn exclusively from such an inconsistent and uncertain source.”¹⁶⁹ In 1917, Harold J. Conn reexamined the technical standards for soil bacteriology. He admitted that “it was practically impossible to obtain direct evidence as to what actually goes on within the soil” through laboratory experiments. The constant presence of certain organisms in manure soil, for example, did not prove their role in decomposing manure. Conn pessimistically conceded that “a little thought will show that no rules as strict as Koch’s postulates have ever been followed in establishing the

¹⁶⁸ Allen & Bonazzi, “On Nitrification,” 35; and, Brown, “Effects of Barnyard Manure,” 523. Referring to non-symbiotic nitrogen fixation, Joseph Greaves insisted that a methodological overhaul was necessary “before we can state definitely the part which they play in the economy of nature and before we can say which are the very best methods for increasing their usefulness.” Greaves, “Azofication,” *Soil Science* 6 (1918): 205.

¹⁶⁹ Moore, “Microorganisms of the Soil,” *Science* 36 (1912): 614. See also, Stevens and Withers, “Concerning Methods for Determination of Nitrifying and Ammonifying Powers of Soils,” in, *32nd Annual Report of the North Carolina Agricultural Experiment Station* (1909): 129-144.

agency of bacteria in any soil activity . . . ¹⁷⁰

Benefits of Struggle

More than others areas of the science, soil bacteriology suffered from a lack of confidence, both in its institutional status and in its methods. It lacked those “routine” procedures that defined the medical, public health, and veterinary bacteriology, and served to guarantee their professional growth. Soil bacteriologists could not offer techniques comparable to diphtheria cultures, water and milk examinations, or hog cholera antisera. Ironically, this enduring uncertainty fostered an exploration of conceptual issues normally ignored by other bacteriologists. Like their station counterparts in dairy science, soil bacteriologists borrowed methods from agricultural chemistry, viewed bacteria as dynamic populations, and seriously deliberated the problematic nature of bacterial systematics. Moreover, they nurtured a nascent study of bacterial physiology, one dedicated to uncovering not only what bacteria did, but how they did it. As Chapter 4 will show, this conceptual development incited some bacteriologists to appraise their subjects as biological organisms.

The appropriation of methods from agricultural chemistry was natural, given that the core research problems of soil bacteriology centered on the transformation of nitrogen, sulfur, and phosphorus compounds. Biochemical methods allowed bacteriologists to measure the effect of aeration, reaction, or moisture on these transformations, and led them to investigate the sensitivities of soil bacteria to different protein and carbonaceous substances. They regarded soil bacteria as chemical factories, which manufactured useful by-products during their growth from

¹⁷⁰ Conn, “The Proof of the Microbial Agency in the Chemical Transformation of Soil.” Science 46 (1917): 252-253.

surrounding materials.¹⁷¹ For some researchers, this biochemical perspective required only a determination of the input and output of the factory, and not an examination of its interior activities (*i.e.*, the bacteria's metabolic processes). One need not appreciate the full nutritional requirements of the organism, only those cultural elements necessary to produce the desired by-product. Other bacteriologists, however, sought to relate those products to the functions of the microbial cell itself.¹⁷² They found a group of organisms with a peculiar set of characteristics. The bacteria of nitrification and sulfification, for example, differed from most living forms in that they did not require organic substances, but rather acquired energy from the oxidation of inorganic minerals. Both Winogradsky and Beijerinck called attention to these autotrophic organisms, but few American researchers held an interest in contrasting their physiology with heterotrophs. Rather, most sought to understand their metabolic processes in order to harness their beneficial activities.¹⁷³ Similarly, *B. radicola* displayed a remarkable tolerance to desiccation and high susceptibility to light. Soil bacteriologists were drawn to study its atypical features in order to produce more effective legume inoculants.¹⁷⁴

¹⁷¹ H.W. Wiley, "Historical Sketch of the Association of Official Agricultural Chemists," Chemical Bulletin 57 (1899): 16; Greaves, Bacteria in Relation to Soil Fertility, 55, 143 & 115; C.B. Lipman and Paul S. Burgess, "The Effect of Copper, Zinc, Iron and Lead Salts on Ammonification in Soils," University of California Publications in Agricultural Science 1 (1914): 127-139; and, Percy L. Gainey, "Influence of the Absolute Reaction of a Soil upon its *Azotobacter* Flora and Nitrogen Fixing Ability," Journal of Agricultural Research 24 (1923): 907-938.

¹⁷² Emerson, Principles of Soil Technology, 280; James C. Temple, "Why Do Some Soils Nitrify Organic Nitrogenous Substances and the Ammonium Salts of Organic Acids Faster than they do Ammonium Sulphate or Ammonium Chloride?" Science 35 (1912): 227-228; and, Waksman, "Microbiology -- Yesterday and Today," in Microbiology, Yesterday and Today: A Symposium Held in Honor of the Seventieth Birthday of Selman A. Waksman, ed. Vernon Bryson (New Brunswick: Rutgers University Press, 1959), 111.

¹⁷³ Waksman, Sergei Winogradsky, 17; Lipman, Annual Report of the New Jersey Experiment Station (1906): 121; T.J. Murray, "The Oxygen Requirements of Biological Soil Processes," Journal of Bacteriology 1 (1916): 597-614; and, J.K. Plummer, "Some Effects of Oxygen and Carbon Dioxide on Nitrification and Ammonification in Soils," Bulletin of the Cornell University Agricultural Experiment Station no. 384 (1916): 305-330.

¹⁷⁴ Brown, "The Beginnings and Development of Soil Microbiology," 52; F.D. Chester, "The Effect of Desiccation on Root Tubercle Bacteria," Bulletin of the Delaware College Agricultural Experiment Station no. 78

By the late-1910's, American soil bacteriologists specifically referred to the "physiology" and "metabolism" of bacteria, and many believed that they could increase a microbe's "efficiency" through detailing its intermediate growth products and metabolic pathways.¹⁷⁵

Textbooks and manuals featured chapters on "Bacterial Metabolism" and on the various products of incomplete oxidations. Increasingly, these investigators examined the "energetics" of these organisms, or their ability to derive energy from specific carbon compounds to perform specific functions.¹⁷⁶ They spoke of a "cell's biochemical economy," and bacteriology's relation to the "fundamental laws of thermodynamics." Nitrogen fixation, for example, might be dependent on the "energy value of a particular compound as well as the nature of its decomposition."¹⁷⁷

During the 1920's, bacterial physiology, as envisioned by American soil bacteriologists, pursued a set of interrelated questions about the microbe itself: How does the organism live? What are the stages or phases of growth for the individual microbe and the culture? How does it gain the energy for its life and multiplication? What changes does it make within the cell as it

(1907): 1-15; and, Ward Giltner and Hannah V. Langworthy, "Some Factors Influencing the Longevity of Soil Microorganisms Subject to Desiccation with Special Reference to the Soil Solution," Journal of Agricultural Research 5 (1916): 927-942.

¹⁷⁵ Brown, "The Beginnings and Development of Soil Microbiology," 53; Jacob Lipman, "Further Contributions to the Physiology and Morphology of Members of the *Azotobacter* Group," Annual Report of the New Jersey Station 25 (1905): 268; Karl F. Kellerman and Nathan R. Smith, "The Absence of Nitrate Formation in Cultures of *Azotobacter*," Centl. f. Bakt. ii abt. 40 (1914): 479-482; and, Bruce Williams, "Some Factors Influencing Nitrogen-Fixation and Nitrification," Botanical Gazette 62 (1916): 311.

¹⁷⁶ Lipman and Brown, Laboratory Guide in Soil Bacteriology, 25-50; Greaves, Agricultural Bacteriology, 82; Waksman and Fred, Laboratory Manual of General Microbiology, with Special Reference to Microorganisms of the Soil (New York: Macmillan, 1928), v; Charles T. Doryland, "The Influence of Energy Material upon the Relation of Soil Microorganisms to Soluble Plant Food," Bulletin of the North Dakota Agricultural Experiment Station no. 116 (1916): 319-410; Otto Rahn, "Physiology of Microorganisms," in Microbiology, 2nd. ed., 158; and, Heylar, "Director's Report," Annual Report of the New Jersey Agricultural Experiment Station (1919): 20.

¹⁷⁷ Waksman, Principles of Soil Microbiology, 563; Waksman and Robert L. Starkey, "Carbon Assimilation and Respiration of Autotrophic Bacteria," Proceedings of the Society of Experimental Biology and Medicine (1922); and, J.H. Quastel, "Microbial Biochemistry and its Development," in Microbiology, Yesterday and Today, 3. See also, Waksman and Starkey, "On the Growth and Respiration of Sulfur-Oxidizing Bacteria," Journal of General Physiology (Jan. 1923); and, Starkey, "Concerning the Physiology of *T. Thioxidans*, and Autotrophic Bacterium Oxidizing Sulfur under Acid Conditions," Journal of Bacteriology (March 1925).

consumes food? How do changes in the source of nutrition affect the growth and activities of the cell and culture? What modifications does the organism produce in its surrounding medium during each stage of growth?¹⁷⁸ The field still focused on nitrification, nitrogen fixation, cellulose decomposition, and mineralization, but with a notable change in perspective. If investigators studied ammonification, they did so not simply to delineate efficient cultivation practices, but also to understand the role of protein decomposition in relation to the metabolic activities of the microbes growth. Soil bacteriologists found the exploration of fundamental or biological questions a prerequisite for attaining practical goals.¹⁷⁹ For example, soil scientists recognized that the combination of elemental nitrogen constituted an endothermal process, one requiring a considerable amount of energy. In this light, bacteriologists could understand why *Azotobacter* demanded readily available carbohydrates, why it failed to fix atmospheric nitrogen in the presence of soil nitrates, and why it fixed nitrogen most efficiently when cultures were young and multiplying rapidly. The practical task therefore remained one of determining which plant tissues provided the best source of carbon when turned under as green manure.¹⁸⁰

The attention to physiological efficiency led to other conceptual explorations. In a

¹⁷⁸ William V. Halversen, "The Nitrogen Metabolism of Nitrogen-Fixing Bacteria," (Ph.D. diss., Iowa State College, 1924); Lipman, "Soil Bacteriology," Microbiology, 3rd ed., 387; Hartshorn, My Half Century at the University of Wisconsin, Ira L. Baldwin, 42; and, Elizabeth McCoy, William M. Higby, and E.B. Fred, "The Assimilation of Nitrogen by Pure Cultures of *Clostridium Pasteurianum* and Related Organisms," Centl. f. Bakt. ii abt. 76 (1928): 314-320.

¹⁷⁹ Wilson, "Biological Nitrogen Fixation," 409-413. As Waksman reasoned, "The organism themselves must be studied, so as to learn by what biochemical processes the work is accomplished and what ends are attained, and only thus shall we be able to learn how to utilize the microorganisms for our needs in the economy of the soil and in other lines of human endeavor." Waksman, "Studies on Proteolytic Activities of Soil Microorganisms, with Special Reference to Fungi," Journal of Bacteriology 3 (1918): 476 & 490.

¹⁸⁰ Percy Brown and F.E. Allison, "Influence of Humus Forming Materials of Different Nitrogen-Carbon Ratios on Bacterial Activities," Research Bulletin of the Iowa Agricultural Experiment Station no. 36 (1916): 1-16; Greaves, "Azofication," 182; Harry L. Fulmer, "The Relation of Green Manures to Nitrogen Fixation," Soil Science 4 (1917): 1-17; T.J. Murray, "The Effect of Different Plant Tissues on Fixation of Atmospheric Nitrogen," Technical Bulletin of the Virginia Agricultural Experiment Station, no. 15 (1917): 93-117; and, E.J. Russell, A Student's Book on Soils and Manures, 2nd ed. (Cambridge: Cambridge University Press, 1919), 45.

parallel to their dairy counterparts, soil bacteriologists examined the symbiotic and antagonistic relationships among the mixed soil flora. In their efforts to increase the efficiency of nitrogen fixation, bacteriologists found that *Azotobacter* fixed a larger amount of atmospheric nitrogen when grown in the presence of *B. radiobacter* or *B. levaniformus*. These symbiots either rendered the carbonaceous material more available to *Azotobacter* or removed deleterious waste products. Likewise, the anaerobic nitrogen-fixing *Clostridium pasteurianum* seemed to require the concurrent growth of an aerobe to keep its immediate surroundings free of oxygen.¹⁸¹ Between 1900 and 1925, American soil scientists revealed that "crude" or mixed cultures acted more vigorously than pure cultures during nitrification, denitrification, nitrogen fixation, and cellulose decomposition. Moreover, they demonstrated a legion of associational relationships between bacterial and non-bacterial microbes. Waksman, in particular, underscored the importance of actinomyces and fungi in transformation of organic soil compounds.¹⁸²

On a methodological level, their enrichment and solution culture techniques assumed a competition among bacterial types for available nutrients. The soil bacteriologist selected a particular organism for rapid growth in his solutions through modifying the sources of energy in a medium. By the late-1910's, American researchers posited a delicate or unstable equilibrium among soil microbes, and explicitly referred to the "ecology" of soil strata. This theoretical framework presumed that any alterations in the physical, chemical, or biological conditions

¹⁸¹ Woods, "The Present Status of the Nitrogen Problem," 129; Lipman and Brown, A Laboratory Guide in Soil Bacteriology, chpt. 4; Fred, Manual of Soil Bacteriology, 62; Greaves, Agricultural Bacteriology, 198; and, Chester, "Soil Bacteria and Nitrogen Assimilation," 7-13.

¹⁸² Waksman, Principles of Soil Microbiology, 1st ed., 641; Allen and Bonazzi, "On Nitrification," 6; H.J. Conn, "Relative Importance of Fungi and Bacteria in Soil," Science 44 (1916): 857-858; Conn, "Studies on the General Soil Flora," Journal of Bacteriology 13 (1926): 51-52; Waksman and R.E. Curtis, "The Actinomycetes of the Soil," Soil Science 1 (Feb. 1916); and, Woodwood & Waller, New Jersey's Agricultural Experiment Station, 173-174.

would disturb the established equilibrium, bringing new species and new reactions to the foreground, and eventually producing a new equilibrium.¹⁸³ Unlike the carefully controlled conditions of pure cultures employed in pathogenic and sanitary bacteriology, soil bacteriology necessitated consideration of complex natural environments. The total sum of physical, chemical, and biological factors, at any given moment, governed the kinds of organisms and their activities.¹⁸⁴ Nitrification, for example, presented a two-step sequential process, effected in rapid succession by coexisting species. Depending on the proportion of ammonia compounds to nitrites, either form could predominate, only to become nearly inactive once the surrounding environment changed.¹⁸⁵ Furthermore, soil bacteriologists believed that a population "adjusted" or even "adapted" itself to local conditions. A few referred to the "struggle for existence" among mixed flora, the "natural selection" of fit organisms, and the "evolution" of specialized types.¹⁸⁶

American soil bacteriologists also maintained a persistent interest in taxonomic issues. Partly due to their participation in soil surveys, and partly due to their recognition of a diverse soil flora, they were among the earliest investigators to contemplate the intrinsic difficulties in

¹⁸³ Waksman, "The Soil Population," Proceedings of the National Academy of Science 11 (1925): 476-481; Waksman, Principles of Soil Microbiology, 1st ed., 642; Waksman, Jacob G. Lipman, 183; and, Peter Baldry, The Battle Against Bacteria: A Fresh Look. A History of Man's Fight Against Bacterial Disease with Special Reference to the Development of Antibacterial Drugs (Cambridge: Cambridge University Press, 1976), 131.

¹⁸⁴ Emerson, Principles of Soil Technology, 299; Waksman and Starkey, The Soil and the Microbe, 73; Percy Brown and Roy Smith, "Bacterial Activities in Frozen Soils," Research Bulletin of the Iowa Agricultural Experiment Station no. 4 (1912): 160-184; and, Frans H. van Suchtelen, "The Environment of Soil Organisms," paper delivered before the 15th Annual SAB Meeting, 1913.

¹⁸⁵ Emerson, Principles of Soil Technology, 313; Lohnis et al., Laboratory Methods in Agricultural Bacteriology, 97; and, Iterson et al., Willem Beijerinck, 105. These bacteriologists hypothesized that the majority of soil organisms, at any given moment, lived in a dormant state. Individual groups performed particular and temporary processes, which were followed by other activities performed by different groups. Waksman, Sergei Winogradsky, 45 & 53.

¹⁸⁶ Herbert Conn, Agricultural Bacteriology, 1st. ed., 110; Voorhees and Lipman, A Review of Investigations in Soil Bacteriology, 6-7; Greaves, "Azofication," 205; and, Waksman, Principles of Soil Microbiology, 1st ed., 6.

bacterial systematics.¹⁸⁷ For example, bacteriologists understood that legume bacteria were mostly host specific, that is, certain forms could invade roots and fix nitrogen only in certain legumes. As early as 1898, investigators created divisions among the *B. radiculicola*, with some workers positing as many as ten types, and others proposing only two. These same researchers pondered the demarcation of "species" among bacteria, and during the next two decades they engaged in an unresolved debate over the variable physiological characteristics that seemed to distinguish one legume microbe from others. Even the nomenclature of these organisms elicited confusion. European bacteriologists had initially proposed a single genus and species, *Schnitzia cellulicola*, and then *Phytomyxa*, with two species, *Ph. leguminosarum* and *Ph. lupini*. Beijerinck submitted *B. radiculicola* with seven recognized varieties. American bacteriologists adopted Beijerinck's designation, only to gradually employ the generic term *Rhizobium* by the 1920's.¹⁸⁸

The taxonomic mire arose as a product of inadequate methods, which thwarted the ability to distinguish between closely related forms. It also derived from the unusual morphology of symbiotic nitrogen-fixers. Similar to the causative agent of diphtheria, *B. radiculicola* revealed

¹⁸⁷ See, Frederick D. Chester, "Organisms Related to *Bacillus Subtilis*," 15th Ann. Rept. of the Delaware College Agricultural Experiment Station (1903): 42-89; Lipman, "Suggestions Concerning the Terminology of Soil Bacteria," Botanical Gazette 51 (1911): 454-460; Kellerman et al., "Identification and Classification of Cellulose-dissolving Bacteria," 502-525; Lohnis and J. Hansawa, "The Classification of *Azotobacter*," Centl. f. Bakt. 42 (1914); Maurice Mulvania, "Observations on *Azotobacter*," Science 42 (1915): 463; H.J. Conn and Robert S. Breed, "The Nomenclature of the *Actinomycetaeaceae*," Journal of Bacteriology 4 (1919): 585-602; and, Paul Emerson, "A Chemical Classification of the Activities of Soil Micro-organisms," Proc., Iowa Academy of Science 29 (1922): 355-359.

¹⁸⁸ Herbert W. Conn, Agricultural Bacteriology, 1st ed., 150-151; Johnson, Edwin Broun Fred, 60-61; Fred and Jesse W. Stevens, "Grouping Legume Nodule Bacteria," Bulletin of the Wisconsin Agricultural Experiment Station no. 352 (1923): 76-77; Stevens, "A Study of Various Strains of *Bacillus Radiculicola* from Nodules of Alfalfa and Sweet Clover," Soil Science 20 (1925): 45-65; and, Rudger H. Walker, "Physiological Studies on the Nitrogen Fixing Bacterial of the Genus *Rhizobium*," Research Bulletin of the Iowa Agricultural Experiment Station no. 113 (1928): 373-406.

branched forms, occasionally resembling a "T" or "Y". Some soil scientists regarded them as fungi, higher bacteria, or simply misshapen rods produced by environmental factors (e.g., available nutrition, resistance from the host legume). A few researchers likened these organisms to protozoa, and posited a "life-cycle" for *B. radicum*. The non-symbiotic nitrogen fixers, *Azotobacter*, displayed an equally curious morphology, appearing in unusually large egg-shaped forms, and often in close proximity to a poorly identified short rod.¹⁸⁹ At the BPI, Felix Lohnis argued that every microorganism underwent a similarly complex cycle of development, and that all of bacterial systematics needed a radical overhaul.¹⁹⁰ While Lohnis' theory found few adherents, the notion of life-cycles did focus attention on the nature of bacterial variation, and its role in the process of nitrogen fixation.¹⁹¹

Soil bacteriologists found one final incentive to consider the biological dimensions of objects of study. The Laboratory of Plant Physiology at the BPI conducted most of the studies on legume inoculations, and many of the Bureau's key investigators held the title, at one time or another, of "physiologist." When the BPI established an Office of Soil Bacteriology in the early 1910's, the Bureau combined it with Plant-Nutrition Investigations. As a result, several soil

¹⁸⁹ O.M. Ball, "A Contribution to the Life History of *Bacillus (Ps.) Radicum Beij.*," Centl. f. Bakt. ii abt. 23 (1909): 47-59; Robert E. Buchanan, "The Bacteroides of *Bacillus Radicum*," Centl. f. Bakt. ii abt. 23 (1909): 59-69; Emerson, Principles of Soil Technology, 285; Heuser, "Soil Fertility and Microorganisms," 2; Greaves, Bacteria in Relation to Soil Fertility, 148; and, Augusto Bonazzi, "Cytological Studies of *Azotobacter Chroococcum*," Journal Agricultural Research 4 (1915): 225-241.

¹⁹⁰ Barthel, Present Problems and Methods of Agricultural Bacteriology, 65-66; Jacob Lipman, "Review of *Soil Bacteria and Soil Fertility*, by Felix Lohnis," Journal of the American Chemical Society (April 1916); Felix Lohnis and Nathan R. Smith, "Life Cycles of the Bacteria," Journal of Agricultural Research 6 (1916): 675-702; and, Lohnis, "Studies upon the Life Cycles of the Bacteria," Memoirs of the National Academy of Science 16 (1922): 213-246.

¹⁹¹ George T. Moore, "Soil Inoculation for Legumes," 33; E.B. Fred, "A Physiological Study of the Legume Bacteria," Annual Report of the Virginia Polytechnic Institute Agricultural Experiment Station (1912-1913), 145-173; and, Ward D. Cutler and M. Crump Lettice, Problems in Soil Microbiology (London: Longmans, Green & Co., 1935), 19-20.

bacteriologists retained a decidedly "botanical" outlook, seeking to understand the conditions that allowed bacteria to supply the nitrogen for its host legume.¹⁹² At many agricultural colleges and experiment stations, plant pathology linked soil bacteriology to plant physiology. Nitrogen-fixing bacteria produced legume nodules resembling the galls and tumors caused by pathogens, and station scientists studied, on a general level, the host responses to bacterial invasion.¹⁹³ It was this line of investigation that encouraged soil bacteriologists to occasionally appropriate the methods and perspectives of pathogenic bacteriology, as they contemplated the fundamental aspects of symbiosis and parasitism. For some bacteriologists, such as Virginia's E.B. Fred, the formation of legume nodules represented a clear example of parasitism. His scrutiny of nodule cross-sections revealed that "mitosis goes on in the nodule much the same as it does in the disease tissues of animals." In other words, "the mitotic figures are larger, very irregular, and not very well marked, with an uneven number of chromosomes." Employing histological and cytological methods common to both experimental botany and human pathology, Fred argued that the formation of nodules was a result of mutual parasitism between germ and legume, as each struggled for survival.¹⁹⁴ Fred and fellow adherents of this view of parasitism even

¹⁹² Albert F. Woods, "Relation of Plant Physiology to the Development of Agriculture," USDA Yearbook, 1904 (1905): 119-132; Albrecht, "Symbiotic Nitrogen Fixation," 283-307; E.B. Fred and Edward J. Gaul, "The Effect of Soluble Nitrogenous Salts on Nodule Formation," Journal of the American Society of Agronomy 8 (1916): 316-328; T.L. Hills, "Influence of Nitrates on Nitrogen Assimilating Bacteria," Journal of Agricultural Research 12 (1918): 183-230; and, Burrill and Hansen, "Is Symbiosis Possible between Legume Bacteria and Non-Legume Plants?" Bulletin of the Illinois Agricultural Experiment Station no. 202 (1917).

¹⁹³ Erwin F. Smith et al., "The Relation of Crown-gall to Legume Inoculation," Circular, Bureau of Plant Industry no. 76 (1911): 3-6; Thomas F. Manns, "Some New Bacterial Diseases of Legumes and the Relationship of the Organisms Causing the Same," Bulletin of the Delaware College Agricultural Experiment Station no. 108 (1915): 1-44; Martin J. Prucha, "Physiological Studies of *Bacillus Radicicola* of Canada Field Pea," Memoir, Cornell University Agricultural Experiment Station no. 5 (1915): 1-83; and, J.K. Wilson, "Physiological Studies of *Bacillus Radicicola* of Soybean (*Soja Max Piper*) and of Factors Influencing Nodules Production," Bulletin of the Cornell University Agricultural Experiment Station no. 386 (1917): 369-412.

¹⁹⁴ Fred, "The Infection of Root-hairs by Means of *Bacillus Radicicola*," Annual Report of the Virginia Polytechnic Institute Agricultural Experiment Station for 1909 and 1910 (Lynchburg, V.A.: J.P. Bell Company, 1911), 123; Moore, "Soil Inoculation for Legumes," 35; Prucha, "Physiological Studies of *Bacillus Radicicola*," 75-

borrowed the language and techniques of “immune responses,” “host specificity,” and “virulence” to describe nitrogen fixation.¹⁹⁵

For other investigators, the relationship between legumes and their attendant bacteria remained an indisputable illustration of symbiosis, despite evidence of a mutual struggle. They noted that both plant and bacteria flourished after the formation of nodules. The host legume likely furnished a suitable carbohydrate to the nodule bacteria in exchange for the production of nitrogen. If a bacterium appeared “specific” to a particular legume, it was because both microbe and plant had become “adapted” to each other. Regarding the language of pathogens, Jacob Lipman repeatedly insisted that the term “virulence” was misleading. The ability of bacteria to enter plant roots, and fix atmospheric nitrogen, according to Lipman, comprised an element of “physiological efficiency.”¹⁹⁶ On a broader level, a few soil microbiologists and plant physiologists envisioned an ecological relationship between plants and soil microorganisms, where members of each group supplied the conditions necessary for the other’s growth. Rather than viewing crops as unfortunate victims of bacterial invasion, these researchers studied the means by which plants influenced the surrounding flora for their mutual benefit.¹⁹⁷ It would be

76; and, Emerson, Principles of Soil Technology, 318.

¹⁹⁵ See, A.L. Whiting and Roy Hansen, “Cross Inoculation Studies with the Nodule Bacteria of Lima Beans, Navy Beans, Cowpeas and others of the Cowpea Group,” Soil Science 10 (1920): 291-300; Jesse W. Stevens, “Can All Strains of a Specific Organism be Recognized by Agglutination?” Journal of Infectious Diseases 33 (1923): 557-566; and, G.E. Helz, I.L. Baldwin and E.B. Fred, “Strain Variation and Host Specificity of the Root Nodule Bacteria of the Pea Group,” Journal of Agricultural Research 35 (1927): 1039-1055.

¹⁹⁶ See, A.T. Perkins, “Regarding Possible Adaptation of Soybean Radicicola for a Specific Host Variety,” Journal of Agricultural Research (Feb. 1925); E.B. Fred, A.L. Whiting, and Hastings, “Root Nodule Bacteria of *Leguminosae*,” Research Bulletin of the University of Wisconsin Agricultural Experiment Station no 72 (1926): 1-43; Lipman, “Nitrogen Fixing Bacteria,” 143; Voorhees and Lipman, Review of Investigations in Soil Bacteriology, 92; and, Lipman, “Soil Bacteriology,” 410.

¹⁹⁷ Emerson, Principles of Soil Technology, 286-292; Thomas L. Lyon, “Some Relations of Certain Higher Plants to the Formation of Nitrates in Soils,” Memoir, Cornell Agricultural Experiment Station no. 1 (1913); Karl F. Kellerman and R. Claude Wright, “Mutual Influence of Certain Crops in Relation to Nitrogen,” Journal American Society of Agronomy 6 (1914): 204-210; William C. Frazier and E.B. Fred, “Movement of Legume Bacteria in Soil,” Soil Science 14 (1922): 29-35; and, James K. Wilson and Lyon, “The Growth of Certain Microorganisms in

an exaggeration to claim that these reflections fully incorporated soil bacteriology within early twentieth century evolutionary biology. Still, they showed an inclination toward theoretical realms (*e.g.*, ecology, evolution) normally absent in other areas of bacteriology.

Between Routine and Productive

The “bacteriologic” vision emerged predominantly within the institutional context of agricultural science. As an alternative to the “hygienic” vision, its adherents were more likely to regard bacteria as a source of both potential danger and potential benefit. The search for productive forms, and the conditions by which they could exploit that productivity, encouraged dairy and soil bacteriologists to escape the methodological confines of isolation, identification, and elimination. As a group, these researchers considered a greater number of microbial forms and explored a wider range of behavior than their medical, public health, or veterinary counterparts. In their attempts to manufacture quality dairy products and enhance soil fertility, they paid close attention to the associational aspects of bacterial populations, a conceptual framework that demanded lengthy reflection on the nature of bacterial variations and on the enigmatic task of bacterial systematics. Moreover, as dairy and soil bacteriologists sought to exploit productive forms, they were not content simply to identify what these microbes “did.” Rather, in their attempt to make them “do” more (or less, in some circumstances) these investigators ventured into bacterial physiology. Many agricultural bacteriologists endeavored to understand *how* bacteria “did” what they did.

The institutional basis for the “bacteriologic” vision is relatively easy to understand. In

Planted and in Unplanted Soil,” Memoir, Cornell Agricultural Experiment Station no. 103 (1926): 1-25.

general, dairy and soil bacteriologists trained in botany or plant physiology, and not medicine. When they exhorted bacteriology to become more "scientific," they implied that it should become more "biological." As the next three chapters will discuss, there was little agreement over what would constitute a "biological" bacteriology. Still, there remained a consensus that efficiency, and not elimination, should be the predominant goal, and that microbes should be valued as an agricultural resource, rather than as a pest. Agricultural bacteriologists claimed their share of experiment station resources with the promise of increased profits for dairymen and farmers. On occasion, they explicitly cited the revolutionary changes in medicine and public health, reasoning that a similar bacteriological revolution could be reproduced on the farm. In other instances, they merely offered to aid in the founding of a more "scientific" agriculture, where practical farming experience could blend with biological principles.

There is an ironic tinge to the eschewal of the "hygienic vision." Bacteriologists in the medical, public health, sanitary, and veterinary spheres found secure sources of institutional support from the constrictions of their science. The tasks of isolation, identification, and elimination were simple in comparison to the comprehension of bacterial physiology. By the second decade of this century, these medical, public health, sanitary, and veterinary bacteriologists rendered the principal techniques of these fields "routine." They could learn them quickly, and they could present them as reliable and necessary measures to combat an omnipresent threat to social welfare. Dairy and soil bacteriologists lacked a comparable set of routine procedures. True, those inspecting municipal milk supplies could rely on the standard methods of the American Public Health Association. In fact, many bacteriologists performed such counts for health departments and certified milk commissions. Dairy bacteriologists,

however, regarded the quantitative examinations as inadequate. Not only did these inspections fail to accurately measure the number of microorganisms in milk, but they shed no light on the kinds of bacteria present or their activities. In the 1910's, dairy bacteriologists embraced a service role to dairy manufacturing, submitting their expertise to the aim of better quality butter and cheese. Given this professional ambition, quantitative examinations offered no basis for disciplinary growth. Instead, it was their search for butter and cheese starters that led dairy bacteriologists toward the complexities of bacterial populations.

Soil bacteriology occupied a marginal position in agricultural science. Among soil scientists, bacteria stood as vital factors in soil fertility, and soil chemistry often incorporated bacteriological techniques. Likewise, plant pathology adopted components of soil bacteriology. Nonetheless, soil bacteriologists were never fully able to convince station directors and college deans of their fundamental worth. They failed to find a biological replacement for costly fertilizers, and soil inoculations proffered only marginal returns. As a consequence, there lingered a persistent unease among members of the field. Many regarded their methods as woefully flawed, and bewailed their own theoretical shortcomings. In no small measure, this lingering self-doubt contributed to the conceptual advances in soil bacteriology. They critically examined those techniques that other bacteriologists regarded as "routine." In their employment of enrichment cultures and solution methods, coupled with a preoccupation with bacterial efficiency, soil bacteriologists forged nascent notions of bacterial physiology and bacterial ecology. As late as the 1930's, soil bacteriology could still not claim to have incited a revolution in soil fertility, nor a conceptual overhaul in general bacteriology. Yet, their professional uncertainty demonstrates the advantages of operating beyond the "routine."

CHAPTER FOUR

THE SOCIETY OF AMERICAN BACTERIOLOGISTS AND THE SEARCH FOR IDENTITY

My Dear Sir:

An attempt is being made to organize a society of American Bacteriologists . . . It is thought that such an association will conduce to unification of methods and aims, will emphasize the position of bacteriology as one of the biological sciences, and will bring together workers interested in the various branches into which bacteriology is now ramifying.

Article 2 — The object of this society shall be the promotion of the science of bacteriology; the bringing together of American Bacteriologists; the demonstration and discussion of bacteriological methods; and the consideration of subjects of common interest.¹

Both the circular letter and the constitution of the Society of American Bacteriologists (SAB) date from 1899, and announce the same three founding intentions. The SAB would bring together a diverse assembly of researchers; allow them to exchange technical details and methodological innovations; and promote bacteriology as a biological discipline. Among these three objectives, the first two were not unique to the SAB. During the last decades of the nineteenth century, more than a dozen societies in the biological and medical sciences organized to facilitate communication and cooperation among like-minded workers.² Through their annual

¹ A.C. Abbott, H.W. Conn, and E.O. Jordan, "Circular Letter," sent to prospective members of the Society of American Bacteriologists, October 1889, reprinted in H.J. Conn, "Professor Herbert William Conn and the Founding of the Society," *Bacteriological Reviews* 4 (1948): 287; and "Constitution — SAB Book of Minutes, 1899-1909," [ASM] box 1-IVA, folder 1, p. 1.

² Ralph H. Bates, *Scientific Societies in the United States*, 3rd ed. (Cambridge: MIT Press, 1965), 85-136.

meetings, sponsored journals, and honorific awards, these societies shaped the conceptual, institutional, and methodological development of fledgling disciplines. In this light, the SAB, in its first twenty-five years of existence (1899-1924), mirrored other associations. Its meetings attracted scientists of dissimilar training, occupation, and concerns, with attendance rising from a mere thirty in 1900 to almost three hundred in 1924. The "Technical Sessions" and demonstrations comprised a significant portion of the scientific programs, and the annual meetings did much to introduce and disseminate the more inventive methods amongst participants. Nevertheless, while SAB leaders could confidently assure themselves that they had met two of their founding objectives, few would assert that they had accomplished the third. In their presidential addresses, committee reports, and personal communications, SAB leaders chafed at the prospect that bacteriology might still be a "handmaiden" to other scientific endeavors (*e.g.*, pathology, public health, water sanitation, etc.), a mere collection of technical manipulations rather than a "biological" science.

This chapter is, in large measure, a narrative of disciplinary anxiety. The SAB struggled during its first quarter century to answer three related questions of identity: 1) Who were bacteriologists? 2) What was bacteriology? 3) What was *that* bacteria? Answers to these queries rarely proved satisfying, and as a result, the SAB confronted them again and again. As the next chapter argues, it was the attention devoted to the third question that helped resolve the first two. By focusing on the first two questions, this chapter weighs an enduring uneasiness among American practitioners. Bacteriologists, for many SAB officials, were those who practiced the techniques of handling microbes. Yet, these same SAB spokesmen struggled to define their field as something more than a collection of related techniques. They repeatedly

refused a disciplinary demarcation founded on the "tools of the trade." Instead, Society interlocutors beseeched their fellow bacteriologists to examine the fundamental aspects of their practice, to uncover those areas that could render their science more biological. While most participants in this dialogue concurred with the aim, they never agreed upon its execution. Even so, this chapter does not detail a disciplinary failure. Instead, the following pages contend that organizational anxiety was productive. The collective consternation fostered a protracted process of self-examination, one that facilitated conceptual, technical, and organizational advances.

The body of this chapter follows in three parts. The initial section reexamines the secondary literature describing scientific societies as discipline-building agencies. While this historiography is interpretively rich, the record of the SAB's initial decades contradicts at least one key theme in recent scholarship. Unlike the American Medical Association, the American Physiological Society, the American Society of Plant Morphologists and Physiologists, or even the American Society of Naturalists, the SAB did not define the discipline by exclusion. True, membership in the SAB required demonstration of published research work, and indeed, total membership was limited to a certain number. However, SAB officials maintained intentionally lax standards for evaluating worthy nominees, and regularly raised the numerical ceiling on membership. In 1899, the SAB constitution specified that membership should not exceed sixty. The next year, it was amended to seventy-five, and the following year to one-hundred. In 1913, the SAB removed the numerical limit outright, and opened its rolls to anyone conducting original research. By 1916, even that restriction was eliminated, and membership required only an interest in the field, and a willingness to pay a \$4 annual fee. SAB leaders forged an association of catholic interests, and many of its members maintained affiliations with other disciplinary

societies. For these SAB officials, strength derived from numbers, and not selectivity. If the core of bacteriology remained elusive, it was to be fashioned from the combined approaches of an assorted set of participants, and not winnowed down to the inclinations of a chosen elite.

The second section addresses the question, Who were bacteriologists? At first glance, the preceding three chapters might seem to have already addressed that question. The list of members and officers of the SAB, however, provides a more accurate answer. Applying for membership betokened an act of self-identification. Not every person employing bacteriological methods in the early twentieth century joined the Society. Many did not desire to become members. By examining the composition of the SAB rolls, we can determine which kinds of researchers chose to align themselves with a bacteriological association, and possibly infer why they did so. Similarly, by electing society officers, SAB members implicitly announced who they believed should represent their field. The list of executive council members can cautiously be read as a communal act of self-declaration. Taken together, the membership and executive council rosters demonstrate a decreasing interest among SAB members in aspects of medical bacteriology. In turn, many medical bacteriologists emigrated to other societies (e.g., the American Association of Pathologists and Bacteriologists or the American Society of Immunology). Nonetheless, by the early 1920's, the SAB membership remained eclectic, and included several who worked in hospitals or medical colleges. It was the increasing dominance of non-medically oriented researchers in the SAB's hierarchy, however, that fueled the continued exploration of bacteriology's fundamental aspects.

Section three examines the scientific content of the SAB's annual meetings, its committees on research and education, and the society-sponsored publication, the *Journal of*

Bacteriology. The printed programs and published papers reflect the diverse interests among SAB members. At any given meeting, attendants could witness demonstrations on the presence of halophilic (*i.e.*, salt-loving) bacteria in cured fish as well as hear explications on the nitrogen metabolism of sulfur-oxidizing bacteria in soils. The heterogeneous presentations were the product of a concerted effort among SAB leaders to garner greater attention for its activities, and to heighten the profile of bacteriology. An expansive program offered something for everyone, while it demonstrated the manifold social utility of the science. When the rising number of accepted papers forced meeting organizers to adopt simultaneous and divided sessions after 1915, the SAB's annual meetings still featured two or three plenary sessions presented before the entire membership. These sessions most clearly embodied the SAB's effort to define the fundamental features of bacteriology. Predictably, these sessions were deemed "General and Technical" bacteriology, an ironic pairing given that most of the technical papers were written for a specialized subset of bacteriologists. Nonetheless, these sections announced the rarely articulated conviction that bacteriologists were bound by their techniques alone. The plenary sessions further demonstrated that technical dilemmas frequently led to fundamental questions. Those papers on the physical chemistry of bacterial cultures, bacterial nutrition, cytology, pH, and physiological variations arose from technical concerns. If SAB leaders struggled to raise fundamental biological questions in bacteriology, technical quandaries were "good to think with," leading participants to continually seek what "bacteria are" rather than simply settle for what bacteria did.

Beyond the "General and Technical" sessions, the SAB found other means to express its intention to further the biological component of bacteriology. In the 1910's and 1920's, the

Society sought to fashion the discipline directly through its committees on research and education. While neither committee successfully persuaded the Society to adopt its recommendations, both provided forums for collectively contemplating the discipline. As such, the committees' reports reveal where bacteriologists found fault with their field. The records document a lingering professional anxiety, as well as an ongoing struggle to define measures for addressing the perceived deficiencies.

The *Journal of Bacteriology* functioned in a similar manner. Established in 1916, it too accentuated the "fundamental" or "general" aspects of bacteriology. The *Journal's* editorial policy explicitly excluded those papers more suited to publications of medicine, dairying, veterinary science, or plant physiology. Moreover, it shunned technical papers relevant to only a specialized branch of bacteriology. The mission of forging a field of "general bacteriology," however, was not easily accomplished. The meeting programs and journal contents reveal that the SAB leaders never settled on a cohesive set of fundamental questions. Those authors who reported on the supposed life cycles in *Azotobacter*, for example, shared few interests with those who studied its nitrogen metabolism. Almost yearly, the presidential address included an impassioned plea for bacteriologists to become more "biological." These inwardly directed critiques represented more than mere window dressings or casual calls to arms. They announced a lingering unease that bacteriology remained theoretically impoverished. At minimum, they illustrate the difficulty of fashioning a biological bacteriology during a period in which biology itself was in flux.

This chapter concludes with a few historiographical remarks. Too frequently, historians of science have characterized discipline-building as an intentional activity, whereby scientists

consciously exercise their will upon university departments, society programs, and peer-reviewed journals in order to transform a science along particular lines. Indeed, the following account is cobbled from reading the conscious intentions of historical actors (*e.g.*, SAB officers, committee members, journal editors). This chapter differs from this traditional account in at least one respect. The actor's disciplinary goals need not be met for their activities to be productive. Uneasiness, frustration, and even disappointment have their uses. In this light, the following pages broach the fecundity of bacteriology's disquiet.

Founding Societies, Building Disciplines

The role of scientific societies in shaping the development of disciplines is well-documented. In particular, scientists themselves have been keen to identify the importance of these associations in the formation of university departments and independent journals.³ A few commentators have even outlined the general characteristics of these associations. Karen Levitan, for example, argues that scientific societies advance a particular field by encouraging contact and cooperation among members from disparate research locations. The annual meetings, she explains, offer a regular re-affirmation of shared goals.⁴ Society sessions shape a discipline by highlighting certain topics and problems, introducing new methods and techniques,

³ See, K.K. Chen, ed., The Pharmacology and Experimental Therapeutics: The First Sixty-years, 1908-1969 (Bethesda: American Society for Pharmacology and Experimental Therapeutics, 1969); Brother C. Edward Quinn, "Ancestry and Beginnings: The Early History of the American Society of Zoologists," American Zoologist 22 (1982): 735-748; R. Chittenden, The First Twenty-five Years of the American Society of Biological Chemists (New Haven: American Society of Biological Chemists, 1945); Nicholas A. Michels, "The American Association of Anatomists: A Sketch of Its Origin, Aims and Meetings," Anatomical Record 122 (1955): 685-671; William C. Steere, ed., Botanical Society of America: Fifty Years of Botany (New York: McGraw-Hill, 1958); and, H.W. Wiley, "Historical Sketch of the Association of Official Agricultural Chemists," Chemical Bulletin 57 (1899): 16.

⁴ Karen B. Levitan, "Functions of Scientific Societies: Views of Biomedical Scientists," (Ph.D. diss., University of Maryland, 1976), 4.

and offering an informal means of contact among researchers.⁵ In America, the significance of scientific societies increased in the late 19th century. As disciplines grew more specialized, and research sites more geographically distant, the society meetings offered a unique opportunity to disseminate information, resolve scientific controversy, and evaluate the worth of new discoveries.⁶ The presentations paved an avenue for scientists to learn of the most recent discoveries, to gain an overview of the field, and to put their own work in a broader scientific perspective. These gatherings supplied one of the few forums available to forge and modify a scientific consensus.⁷

Scientific societies also sponsored journals, which served as an indispensable tool for building a discipline. Peer-reviewed publications passed judgement on the scientific validity of an article, and as such, the referees and editors established the criteria for admission into the community of scholars. The journal demarcated the range of problems considered important, and limited the approaches deemed appropriate.⁸ As Richard Whitley explains:

By structuring cognitive space and functioning as guardians of procedural norms, scientific journals organise commitments and skills developed in educational systems and employed in research organisations. Research that is unpublished is, on the whole, research that has not been done with respect to the public system of science and hence cannot form part of the corpus of public knowledge. Consequently, the existing set of

⁵ See, William Bechtel, Integrating Scientific Disciplines (Dordrecht: Martinus Nijhoff Publishers, 1986), 3-48; and, Lindley Darden and Nancy Maull, "Interfield Theories," Philosophy of Science 44 (1977): 43-64.

⁶ Paraphrase of Margaret Rossiter, "The Organization of the Agricultural Sciences," in The Organization of Knowledge in Modern America, 1860-1920, eds. Alexandra Oleson and John Voss (Baltimore: Johns Hopkins University Press, 1979), 219; and, Levitan, "Functions of Scientific Societies," 6-7. See also, Oleson and Voss' introduction to Organization of Knowledge, xiii-xiv; and, Harland G. Bloland and Sue M. Bloland, American Learned Societies in Transition: The Impact of Dissent and Recession (New York: McGraw-Hill, 1974), 5.

⁷ Donald C. Pelz and Frank M. Andrews, Scientists in Organizations: Productive Climates for Research and Development, rev. ed. (Ann Arbor: University of Michigan Press, 1976), 53; Levitan, "Functions of Scientific Societies," 11; and, Bates, Scientific Societies in the United States, 173.

⁸ Derek L. Price, "Development and Structure," manuscript reported by M.G. Russell, "Peer Review in Interdisciplinary Research: Flexibility and Responsiveness," in Managing Interdisciplinary Research, eds. S.R. Epton, R.L. Payne and A.W. Pearson (New York: Wiley & Sons, 1983), 185.

journals in a science constrain and direct research topics and ways of working on them.⁹ In many cases, the society journal surpassed the annual meeting in importance. Traditionally, the journal stood as a symbol or banner for the field, defining in its periodic pages the discipline's subject matter and methodology.¹⁰

In the estimation of many historians of science, disciplinary societies function by exclusion. Through membership limitations, professional associations have functioned to map "out boundaries with respect to other disciplines, or more colloquially, to stake out intellectual turf."¹¹ The Society of American Bacteriologists did demarcate its domain from other disciplines, primarily by drawing attention to those aspects of bacteria occluded by the hygienic vision of pathology and public health. In this regard, the SAB instrumentally defined the "intellectual context of research," or "that abstracted set of norms and procedures which both govern and constitute what is done to what phenomena, in which cognitive setting, and how it is understood."¹² Societies also award honorific tributes, through the election of officerships. Rather than shaping the conceptual standards of a field by such direct means as ostracism and exclusion, the honorific reward system encourages researchers, both new and old, to conform to the society's selection of important topics, accepted theories, and proper research methods.¹³

⁹ Richard Whitley, "The Context of Scientific Investigation," in The Social Process of Scientific Investigation, eds. K.D. Knorr, R. Krohn, and R. Whitley (Dordrecht: Reidel, 1980), 315.

¹⁰ Rossiter, "Organization of Agricultural Sciences," 219; and, Bates, Scientific Societies, 175.

¹¹ Toby A. Appel, "Biological and Medical Societies and the Founding the American Physiological Society," in Physiology in the American Context, 1850-1940, ed. Gerald Geison (Bethesda: American Physiological Society, 1987), 156.

¹² Whitley, "Context of Scientific Investigation," 302. See also, Dudley Shapere, "Scientific Theories and their Domains," in The Structure of Scientific Theories, ed. Frederick Suppe (Urbana: University of Illinois Press, 1974), 521-522.

¹³ Bloland and Bloland, American Learned Societies, 7, 9 & 13; W.O. Hagstrom, The Scientific Community (New York: Basic Books, 1965), chpts. 2-4; and, Ronald L. Geiger, To Advance Knowledge: The Growth of American Research Universities, 1900-1940 (New York: Oxford University Press, 1986).

Even if a society accomplishes very little in concrete terms, its actions in this regard may carry substantial symbolic value.¹⁴

The disciplinary development of biochemistry and physiology, offering case studies, as both owed much to the efforts of their respective societies. The American Physiological Society (APS), for example, employed membership restrictions to distinguish the conceptual domain of physiology from other sciences. Prospective members were nominated on the condition that they perform and publish original research. Moreover, as Toby Appel suggests, only those “experimental” physiologists – neither too zoological nor too clinical – were ultimately elected. In this manner, the APS circumscribed physiology along particular lines.¹⁵

The American Society of Naturalists (ASN) paralleled some, but not all, of the characteristics of the APS. Founded in 1883 as an offshoot of the American Association for the Advancement of Sciences (AAAS), the ASN also restricted its membership. In fact, its founders expressly sought to mitigate what they viewed as the “over-dilution” of the AAAS’s Natural History Section with non-professional members.¹⁶ Like the APS, its confederation was capped by a numerical limit, and prospective members required nomination and final election by a majority of current members. These restraints, however, remained comparatively lax. According to Toby Appel, the ASN promoted disciplinary growth by way of another mechanism, by bridging the disparate fields of biology. Unlike chemistry and physics, biology appeared to

¹⁴ See, A. Hunter Dupree, “The National Academy of Sciences and the American Definition of Science,” in Organization of Knowledge in Modern America, 344-345.

¹⁵ Appel, “Founding of the American Physiological Society,” 156, 165-166. See also, Robert E. Kohler, From Medical Chemistry to Biochemistry: The Making of a Biomedical Discipline (Cambridge: Cambridge University Press, 1982).

¹⁶ Sally Gregory Kohlstedt, The Formation of the American Scientific Community: The American Association for the Advancement of Science, 1848-1860 (Urbana: University of Illinois Press, 1976).

many observers to be disunified. Graduate training in biology encouraged early specialization, and the sundry professional associations accepted only those researchers from specific fields. By the first decade of this century, the ASN offered one of the few means to bridge the varied domains of biology, holding its winter gatherings in concert with the annual meetings of the American Physiological Society, the American Association of Anatomists, the American Morphological Society (later the American Society of Zoologists), the Botanical Society of America, and the Society for Plant Morphology and Physiology. The ASN convocation excluded only those predominantly applied associations (*e.g.*, forestry and agriculture).¹⁷ In contrast to its affiliated societies, the ASN operated by incorporation, not exclusion.

The Society of American Bacteriologists emerged under the aegis of the American Society of Naturalists. The SAB's initial meetings were well-attended, and its published proceedings presumably read by many. The congresses themselves afforded ample time for formal and informal discussions on a wide range of topics, and the sessions fostered contact between researchers from different institutions and specialties. Its discipline-building efforts resided not in its exclusionary practices, but in the SAB's ability to span the several applied areas of bacteriology. As previous chapters have demonstrated, bacteriology already obtained secure institutional standing by 1900. Its social worth remained well-established. The SAB viewed its mission as one of defining the conceptual core of bacteriology, or delineating the fundamental

¹⁷ Appel, "Founding of the American Physiological Society," 164-165; and, Appel, "Organizing Biology: The American Society of Naturalists and its 'Affiliated Societies,' 1883-1923," in The Development of American Biology, eds. Ronald Rainger, Keith R. Benson, and Jane Maienschein (Philadelphia: University of Pennsylvania Press, 1988), 87-88. See also, Frank R. Lillie, "The American Society of Naturalists: Cooperation in Biological Research," Science 27 (1908): 369-372; Charles S. Minot, "The Relations of the American Society of Naturalists to Other Scientific Societies," Science 15 (1902): 241-244; and, E.G. Conklin, "Fifty Years of the American Society of Naturalists," American Naturalist 68 (1934): 385-401.

(e.g., biological) aspects of the science, rather than promoting its potential utility. The SAB did restrict its membership, but these limits were generous. When membership totals approached the maximum number, the SAB consistently voted to raise the society limit.¹⁸ This chapter is, in many respects, devoted to the SAB's 'umbrella' character. The Society stood as an organization both proud of its welcoming nature, and uncomfortable with its apparent disunity.

The following discussion of the Society of American Bacteriologists and the disciplinary development of bacteriology is not entirely novel. Patricia Gossel, in her 1988 dissertation, tenders an entire chapter to the founding of three American scientific societies devoted to bacteriology. The scope of her thesis ends with the year 1900, or right after the birth of the SAB. Gossel argues that the SAB, along with the American Association of Pathologists and Bacteriologists, and the Laboratory Section of the American Public Health Association, signaled a new era in bacteriology. According to Gossel, "improvements in methodology would come only with greater understanding of the bacteria themselves," and those pressing public health concerns would "require communication and cooperation."¹⁹ While this chapter concurs with both points, it argues that the necessities of public health "routine" did not provide the only incentives to explore the "biology" of bacteria. Rather, it was the search for the unifying elements among medical, public health, industrial, and agricultural bacteriology that prompted the key initiatives of the SAB.

Regarding the search for the "biology" of bacteria, Gossel states that the SAB "provided

¹⁸ In his presidential address, Robert L. Starkey assessed: "Possibly the principal contribution of the Society has been that of fostering communication, through meeting for consideration of scientific results and ideas, and through journal publication for more widespread dispersal of information." Starkey, "Microbiology and the Microbiologist," *Microbiological Reviews* 27 (1963): 244.

¹⁹ Patricia Peck Gossel, "The Emergence of American Bacteriology, 1875-1900," (Ph.D. diss., Johns Hopkins University, 1988), 361-362.

a forum for the presentation of papers on the biology of bacteriology.” In the SAB’s first decade, she notes, “about a quarter of the papers presented dealt with bacterial varieties, morphological patterns in culture, physiological responses of bacteria to altered growing conditions, and descriptions of naturally occurring organisms.”²⁰ This assessment remains entirely accurate. However, this chapter contends that the choice of these topics emerged from a process of ongoing negotiation. While many SAB leaders sought to render bacteriology more “biological,” they were never able to reach a clear consensus as to what that goal implied. The following pages begin where Gossel’s concludes. The SAB’s first quarter century can be read as a continuing effort to identify the “biological” or “physiological” aspects of bacteriology.

Building a Society of American Bacteriologists

In the waning years of the nineteenth century, the Society of American Bacteriologists emanated from the American Association for the Advancement of Science (AAAS), and the American Society of Naturalists (ASN). According to extant Society archives and secondary recollections, a handful of preeminent bacteriologists “felt that the rapid development of this subject along biological, agricultural, industrial, as well as hygienic and pathological lines” created a “special brand of science,” one which could benefit from “an association of investigators.”²¹ The idea for a society of bacteriologists has actually been traced to a particular moment, in a conversation between two pathologists, Franklin P. Mall of Johns Hopkins and Alexander C. Abbott of the University of Pennsylvania. At the 1898 meeting of the AAAS, Mall

²⁰ Gossel, “The Emergence of American Bacteriology,” 366-367.

²¹ Quoting E.O. Jordan, and Herbert W. Conn, reprinted in “The History of Microbiology in the North-East Branch of the American Society for Microbiologists, 70th Annual Meeting,” April 26-May1, 1970, [ASM], box 2-IXC, folder 77, p.1. See also, L.S. McClung, “The American Society for Microbiology/Society of American Bacteriologists: A Brief History,” *ASM News* 44 (1978): 446-451.

pointed to Edwin O. Jordan, remarking to Abbott that he resembled a "lost soul," for Jordan and other bacteriologists did not possess a meeting or association of their own. When Abbott and Jordan reassembled at the winter 1898 meeting of the American Society of Naturalists, they voiced their shared disciplinary anxiety with Herbert W. Conn, a dairy bacteriologist from Wesleyan University and the Storrs Agricultural Experiment Station.²² Together, these three elected to circulate a letter inquiring about the possibility of creating a bacteriological association after the 1899 New Haven meeting of the ASN.

Among the forty or so who received the letter, thirty-seven responded. All the answers were positive, but to varying degrees. The letter itself specified that the new federation would resemble the Society of American Physiologists or the Society of American Morphologists, and would meet as an affiliated society of the ASN. The circular outlined an awareness among "certain members of the American Society of Naturalists that, with the multiplication of scientific societies, there was none whose nature was such as to bring together the large and growing number of investigators who were studying bacteriological topics."²³ This appeal succeeded, and within four months Abbott and Conn began preparations for the first meeting.²⁴

²² H.J. Conn, "Founding of the Society," 275-296. See also, Barnett Cohen, "The History Program of the Society of American Bacteriologists," Bulletin of the History of Medicine 8 (1940): 312-321; Cohen, Chronicles of the Society of American Bacteriologists, 1899-1950 (Baltimore: Williams and Wilkins, 1950); and, McClung, "Oral History for Archives of the American Society for Microbiology," ASM News 35 (1969): 24-26.

²³ "SAB Book of Minutes, 1899-1909," 17. For a description of this record of minutes, see, C.C. Roos, "The Original Minutes of the Society of American Bacteriologists," Journal of Bacteriology 37 (1939): 103.

²⁴ The letter drew upon the anxiety, felt among some bacteriologists, that their science was held in low regard by members of other disciplines. Harry Russell recalled, in 1904, that "A decade ago there was hardly any scientific meeting for the bacteriological student who was not closely in touch with the medical aspect of the work. I remember some few of us used to attend the meetings of the American Association for the Advancement of Science. This was long before the days of the Section on Preventative Medicine. The botanists were our sponsors, but there was little time or opportunity for any discussion on things strictly bacteriological." Russell, "The Development of American Bacteriology," in Papers and Reports of the American Public Health Association, Presented at the 31st Annual Meeting, October 1903 (Columbus: Press of Fred. J. Heer, 1904), 330. See also, Floyd B. Jensen, "Illinois Society for Microbiology," ASM News 40 (1974): 685-687; and, anon., "Fifty Years of

In the months before the December 1899 inaugural meeting, Conn, Abbott, Jordan, Theobald Smith, and Wyatt G. Johnston drafted the Society's constitution. The SAB, they announced, will "conduce to unification of methods and aims, will emphasize the position of bacteriology as one of the biological sciences, and will bring together workers interested in the various branches into which bacteriology is now ramifying (*sic*)." Given the composition of that informal committee – Smith was a comparative pathologist, and Johnston a sanitary scientist – it is remarkable to discover such a broad mandate. This society, dedicated to the "promotion of the science of bacteriology," was explicitly inclusive and welcoming in its disciplinary vision.²⁵

The inaugural meeting of the SAB opened at the Medical School Building of Yale University, New Haven, on December 28th, 1899, with more than thirty investigators in attendance from across the nation. The participants represented most existing branches of bacteriology. Employing the taxonomy outlined in previous chapters, there were twelve delegates from medical or public health bacteriology, twelve from sanitary fields, four veterinary bacteriologists, and two from spheres of productive bacteriology (*i.e.*, dairy, soil, or industrial bacteriology).²⁶ The scientific program was equally eclectic, featuring several general and technical papers. For example, Erwin F. Smith and Frederick Chester delivered separate presentations on bacterial taxonomy, while Conn and Theobald Smith discussed the significance

Applied Bacteriology," American Journal of Public Health 11 (1931): 176.

²⁵ "Book of Minutes," 18; and, Conn, "Founding of the Society," 287.

²⁶ This chapter defines medical or public health bacteriologists as those who predominantly seek to identify and eliminate pathogenic germs from human individuals; sanitary bacteriologists as those who endeavor to isolate and eliminate pathogens from human environments (*e.g.*, supplies of water, milk, and food); veterinary bacteriologists as those who isolate and eliminate animal pathogens; and productive bacteriologists as those who endeavor to have bacteria produce certain useable products (*e.g.*, cheese, fertile soil, alcohol, linen, tobacco). This classification is admittedly problematic for practitioners at the turn of the century. Harold C. Ernst, for example, held an appointment at the Harvard Medical School. At the first meeting, however, he presented a paper on bacterial enzymes and their role in the curing of tobacco. Moreover, many medical bacteriologists also performed sanitary analysis of water and milk supplies.

of induced variations among pathogenic bacteria. The latter contribution exemplified the Society's stated goal of furthering the *fundamental* aspects of bacteriology. Smith outlined his belief that parasitic forms "evolved" from saprophytic types, and that induced variations were limited only by the "specific structure of the organism."²⁷

Other presentations of general interest included Oscar Loew's discussion of bacteria-dissolving enzymes, and Harold C. Ernst's description of his "Methods Employed in the Teaching of Bacteriology." True, the twenty-six paper program also featured submissions on the bacteriology of sewage, milk sanitation, and the demonstration of new pathogens, but the significance of the general entries was noticed by all.²⁸ Afterward, Herbert Conn lauded the success of the nascent Society, recognizing in particular those papers devoted to "purely biological aspects of bacteriology." The program diversity indicated, according to Conn, "the extent to which bacteriology has extended in the short years of its existence as a branch of science, and plainly points out the need of some organization to centralize the work and bring to a common point of mutual interest."²⁹

Following the conclusion of the New Haven meeting, the Society registered fifty-seven members. Of these, twenty-eight, or nearly half, represented medical or public health bacteriology. Among the remaining, twenty came from water, milk, or food sanitation; five from veterinary science; one from plant pathology; and, three from the spheres of productive bacteriology. For the most part, the members held advanced graduate degrees: twenty-five held

²⁷ Smith, "Significance of Varieties among Pathogenic Bacteria," paper presented to the 1st Annual SAB Meeting, 1899, abstracted in *Science* 11 (1900): 456.

²⁸ C.E.A. Winslow, "The First Forty Years of the Society of American Bacteriologists," *Science* 91 (1940): 125-129.

²⁹ Conn, "Society of American Bacteriologists," 158.

an MD alone; nine PhD or ScD; three held MD's and PhD's; one listed a PhB; three held an MD and PhB; one held an MD and DVS; and, six listed relevant masters degree. Only nine members held only a bachelors degree.³⁰

The initial gathering of the SAB established two important precedents. First, the Society announced that it welcomed applicants of varying qualifications and research interests. If membership in the SAB identified one as a "bacteriologist," then many kinds of researchers could adopt such a designation. Pathologists, sanitation engineers, veterinarians, horticulturalists, and dairymen gained admission. Secondly, the Society sought, through the programs of its scientific meetings, to identify the common ground among these diverse practitioners. If its membership appeared disjointed and disunified, the SAB, like the ASN, could provide a productive forum for dissimilar practitioners to uncover that which unified their work. Those who applied for SAB charter membership in 1899 implicitly endorsed the collective aim of rendering bacteriology "one of the biological sciences," rather than a collection of techniques in service to other applied endeavors (*e.g.*, pathology, public health, sanitation, veterinary medicine, dairying, soil science). For subsequent members, and subsequent meetings, the question remained: "Where was the biology in bacteriology?"

Who Were Bacteriologists? Or, Reading the SAB Rosters

In some measure, the preceding three chapters have already answered one facet of this question, detailing the several investigative areas and institutional settings of early 20th century bacteriology. The SAB registers, however, offer a more pointed indication. Not every individual

³⁰ "SAB, Book of Minutes," 3-14; and, Gossel, "Emergence of American Bacteriology," 365.

practicing bacteriological techniques chose to apply for membership. Those that did explicitly accepted disciplinary affiliation. Likewise, the election of Society officers announced the collective choice of who should represent the field. Together, the evolving composition of the general membership and executive council indicate a gradually decreasing interest among SAB members in medical bacteriology. As a result, many preeminent pathologists left the SAB in favor of other societies (*e.g.*, the American Association of Pathologists and Bacteriologists, or the American Association of Immunologists). The emigration, however, was never complete. In fact, SAB membership remained eclectic throughout its first twenty-five years of existence (1899-1925). What endured was a quantitative growth and a willingness to recognize bacteriologists of varying research interests.

Numerically, SAB membership rose from 57 in 1899, to 1,226 in 1924. That number was actually capped for the first fourteen years. In 1899, the SAB limited membership to 60, only to raise that ceiling to 75 in 1900, 100 in 1902, 125 in 1905, 150 in 1909, and 200 in 1911. In December of 1913, the SAB removed the cap entirely, and by 1914 listed 331 members.³¹ During the second decade of the century, SAB Secretary A. Parker Hitchens persistently reiterated his dictum that the Society could have only have a wide influence if it had a larger membership.³²

In 1916, the SAB established the *Journal of Bacteriology* as its official publication. Annual dues climbed from \$2 to \$5, with each member receiving a subscription to the *Journal*.

³¹ This number is slightly deceptive, as many listed members were behind in their dues, and assumed to be "inactive."

³² Letter, Robert S. Breed, Geneva, to I.L. Baldwin, Madison, 8 May, 1944, p. 1, [ASM] box 4-IIB, folder 8.

In order to finance the new publication, the SAB launched a concerted effort to increase membership. The Society eliminated its last restrictive qualification, that a proposed nominee be one who has "conducted and published original work." By 1917, membership approached 500, with SAB leadership seeking to double that number in five years. During the pre-*Journal* era, the SAB turned away some prospective members. After the *Journal's* founding, the Society actively solicited new recruits. In 1920, the Membership Committee mailed 900 letters to "good prospects," attracting 100 applicants. Two years later, the SAB recognized over 1,000 members.³³

The quantitative expansion of the SAB arrived at a cost. The turn-over rate escalated with the acquisition of new members. In 1922, Secretary A.P. Hitchens reported that 250 members, or 28% of the SAB total, had either resigned or let their membership lapse. Hitchens wistfully recalled the years when the association contained "150 active workers" who took the "keenest interest in the Society's affairs." He wondered why many of the older workers, who remained active in bacteriology, chose not to maintain their membership in the SAB. It might be that these former members ended their Society affiliation as they advanced to higher "administrative positions" and away from active research. Or, contrastingly, Hitchens reasoned that the attrition might be due to the SAB's move away from applied aspects that interested older members, and toward the "fundamental" approach appealing to younger practitioners.³⁴ The next year, incoming Secretary James M. Sherman explained that "many new members were obtained whose interests were not primarily in bacteriology and who would later discontinue their

³³ "Summary of Data on Subscriptions to the Society Publications," [ASM], box 4-IIA, folder 9, p. 1.

³⁴ A.P. Hitchens, "Secretary's Report, 22 December 1922," [ASM], box 1-IVA, folder 5, p.1-2.

memberships." Seeing that many of the recent applicants failed to renew after two years, Sherman argued that the SAB should end its membership campaign, and endeavor instead to "solidify our present membership."³⁵

The removal of membership restrictions wrought another troublesome change in the SAB's composition. After the 17th annual meeting (1915), Secretary Hitchens duly noted 118 new members, with the hesitant remark that forty did not hold degrees above a bachelor's, and several more had not graduated college at all. Finding 'strength in numbers' risked a loss in professional prestige. SAB leaders assumed this cost under the belief that increased membership, and increased revenue, could sustain the publication of its *Journal of Bacteriology*.

Regarding the primary research interests among SAB members, the relative proportions remained constant. As graphs 4.1 and 4.2 indicate, roughly 50% of Society members, during the SAB's first fifteen years, could be classified as pathogenic bacteriologists (*i.e.*, directed toward isolating and eliminating pathogenic forms from humans). Of the remaining, another 25-35% practiced in sanitary bacteriology (*i.e.*, targeting the identification and elimination of pathogenic forms from human environments, such as food, water, or milk supplies). The portion of researchers in productive bacteriology (*i.e.*, employing bacteria to produce cheese, fertile soils, industrial alcohols, linen, tobacco, *etc.*) increased from 5 to 15%. Plant pathologists and veterinary bacteriologists comprised the last few percentages.³⁶

³⁵ James M. Sherman, "Minutes of the SAB Annual Meeting, 1923," [ASM], box I-VA, folder 6, p. 2.

³⁶ This categorical accounting is admittedly problematic. Of primary note is that bacteriologists during this decade tended to move between varied research areas. For example, Frederic P. Gorham, between 1902 and 1909, migrated from sanitary to productive bacteriology; and, Norman McL. Harris from medical to sanitary fields. Moreover, bacteriologists often maintained concurrent research projects, and could be classed in several categories. L.H. Pammel, best known for his studies in plant pathology and veterinary bacteriology, presented before the SAB on issues of water sanitation. Harry L. Russell devoted the initial years of century to plant pathology *and* dairy science. Likewise, Theobald Smith bridged medical, sanitary, and veterinary domains. For the purposes of this

The composition of the SAB's executive council remained equally varied. Comprised of a president, vice-president, secretary-treasurer, and four at-large members, the council maintained a balance between representatives of pathogenic bacteriology (*i.e.*, medical or public health) and non-pathogenic bacteriology (*i.e.*, sanitary, veterinary, productive, and plant pathology fields). (Graphs 4.3, 4.4 & 4.5) The original council featured two members from pathogenic bacteriology, three from sanitary, one from productive fields, and one veterinary bacteriologist. With the exception of 1905, each annually-chosen council contained at least one member working in dairy or soil bacteriology. These charts can be read in two ways. Initially, they might demonstrate the SAB's eagerness to be seen as encompassing more than just medical or public health bacteriology. Alternatively, they might reveal that the SAB attracted more active participation from non-pathogenic bacteriologists precisely because it was one of the few associations that recognized the scientific worth of their fields.

A more indefinite measure of the Society's collective identification can be found in the list of successful and unsuccessful membership nominations. At the SAB's founding, membership required that a nominee be "proposed by a member," approved by the executive council, and elected by a majority of members present at an annual meeting. In 1901, the Society amended its constitution to require one nominator, two seconds, and then a general vote. Moreover, the SAB requested that a candidate present, before the entire Society, evidence of published research. Graphs 4.6, 4.7, and 4.8 suggest that the SAB, during its twenty-five years, maintained its proportional representation, with pathological bacteriologists accounting for no

tabulation, these ambiguous cases are classed according to the paper topics they submitted to the annual SAB meeting. As such, Russell, for example, appears in the category of productive bacteriology for all but one year, when he delivered a demonstration in plant pathology.

more than half of the newly elected members. The membership selections for the 6th (1904) and 9th meetings (1907) deserve special note. At the 1904 meeting, the SAB elected ten new members, and not one held an MD. Instead, the successful nominees included three soil bacteriologists, two veterinarians, and a plant pathologist. In 1907, the SAB accepted four new members from medical and public health fields. However, the Society also approved of four plant pathologists, and one soil bacteriologist. In years between 1900 and 1909, the SAB listed failed nominations. In most instances, these candidates were re-nominated, and elected the following year. Unfortunately, the extant archival records fail to document the collective rationale for the nominees' non-election. Still, as graph 4.9 suggests, those not making the cut were as diverse as those who were selected.

Another measure of the SAB's membership profile is found in the resignations of 1915. At the 17th annual meeting, Secretary Hitchens reported that twenty-three members withdrew from the Society. This number exceeded previous departures, and among those resigning, twelve practiced in pathological bacteriology. Furthermore, the list included several notable figures: Alphonse Dochez, Simon Flexner, Peyton Rous and S.J. Meltzer from the Rockefeller Institute for Medical Research; George H. Weaver from the University of Chicago; and, George C. Whipple from Harvard. As the next several paragraphs document, this exodus coincided with the SAB's deliberate attempt to distinguish its program content from that of pathology and immunology. The Society sought to identify the *biological* component of bacteriology. While SAB officials never fully achieved this conceptual aim – the biological dimensions of bacteriology remained elusive – Society leaders acknowledged that their efforts might alienate a number of preeminent pathologists. This represented, in some measure, a strategic disciplinary

choice. If bacteriology were to become an independent field of scientific study, the SAB had to be willing to continue despite the absence of many medically minded practitioners. These society spokesmen wavered between a satisfaction in bacteriology's remarkable eclecticism and a driving faith in a hidden disciplinary core.

What is Bacteriology? Or, Visiting the SAB Meetings

As a disciplinary society, the SAB and its meeting programs served to define the field of bacteriology. From the onset, the number of papers submitted consistently exceeded the available slots for annual meetings. As such, the Society leaders actively selected those papers whose methods and topics matched their collective vision for the discipline. During its first quarter century, the content of the SAB meetings remained decidedly varied. Certain gatherings focused particularly on pathogenic, sanitary, or agricultural bacteriology. Nonetheless, these yearly meetings featured several papers that exceeded the limited aims of applied bacteriology. The programs announced new techniques and methods that cut across the assorted specializations. Moreover, these same meetings addressed issues of bacterial taxonomy, associations, evolution, nutrition, metabolism, and physical chemistry. If the SAB were to achieve its aim of uncovering the "biological aspects of bacteriology," it was these submissions, frequently grouped under the rubric of "General and Technical bacteriology," that served the Society's purpose.³⁷

In the aggregate, attendance at SAB annual meetings rose steadily from 1899 to 1924. As graphs 4.10, 4.11, and 4.12 demonstrate, the number of meeting registrants increased more than

³⁷ Herbert .J. Conn, "Herbert William Conn and the Founding of the Society," 275.

four-fold during that period. Participation at the meetings paralleled the overall Society membership, with pathogenic bacteriologists comprising between 20% and 45% of the total. (Graphs 4.13, 4.14 & 4.15) However, the scientific programs diverged slightly from this distribution. Papers devoted to pathogenic bacteriology represented only 10% to 30% of the total presentations. (Graphs 4.16, 4.17 & 4.18) In this regard, the meeting programs placed a disproportionate emphasis on non-medical topics.

Individually, the character of particular meetings carried the imprint of the association meetings that accompanied SAB gatherings. Traditionally, the SAB organized its sessions immediately following the ASN or AAAS conclaves. The SAB frequently featured joint sessions with another ASN member society, or Section K (Pathology & Medicine) of the AAAS. On occasion, these concurrent programs elicited papers traversing the conceptual domains of the SAB and its related ASN organizations. At the SAB's 2nd annual meeting (1900), for example, Erwin F. Smith delivered an address before a joint session of the Society of Botanists, on "The Morphology and Physiology of Bacterial Diseases of Plants." Similarly, the 1904 meeting featured a session, held in concert with the ASN, on "The Mutation Theory of Organic Evolution." More often, however, these joint ventures starkly evinced the disciplinary isolation of bacteriology. The 1902 SAB/ASN symposium featured a presentation on "Protective and Directive Coloration of Animals," while their 1903 collaboration centered on "Recent Explorations in Patagonia." Not every ASN panel was so impertinent. L.O. Howard's summary on the "International Work with Beneficial Insects" possibly heartened those bacteriologists studying productive germs. Then again, the shared programs may have simply reminded SAB members that their discipline had little in common with other ASN associations.

SAB relations with the AAAS proved equally varied. Beginning with its 1906 meeting, the SAB allocated a portion of its scientific program to joint sessions with the AAAS's Section K (Pathology & Medicine). These bilateral endeavors, of course, highlighted the pathogenic aspects of bacteriology. The 1906 shared sections, for instance, spotlighted reports on "The Protozoa in Relation to Disease," as well as brief demonstrations on tetanus toxins, typhoid fever, opsonic indexes, and oral infections. Similar sessions appeared in the SAB programs for the 1907 and 1908 gatherings. Interestingly, the SAB voted in 1909 to terminate its affiliation with the AAAS. At that time, the American Society of Naturalists considered scheduling its aggregated associations apart from the AAAS. The SAB resolved to meet with the ASN, and not the AAAS, should the former choose to break with the traditional winter calendar. This vote constituted a formal declaration, however tentative, that the SAB stood as a biological, and not medical, association. When the SAB met again with the AAAS in 1914, it was under different circumstances. The Society held 1914 meeting in conjunction with both the ASN *and* the AAAS. Moreover, the program featured two joint SAB/AAAS sessions. The first paired the SAB with Section K of the AAAS, focusing on the problems of ventilation and health. The second coupled bacteriologists with the AAAS's Section C (agricultural sciences), under the heading of "The Lower Organisms in Relation to Man's Welfare," a topic quite familiar to those bacteriologists working with productive microorganisms.

Another ten years passed before the SAB met again with the AAAS. At the 26th annual SAB meeting (1924), Harvard's Richard Strong organized a session on free-living microorganisms and disease. The joint symposium appeared noticeably apart from the SAB program, so much so that the AAAS offered a \$1,000 prize for the best paper presented in

medical bacteriology. The AAAS's appeal failed to solicit widespread interest among SAB officials. The prize was never awarded. Instead, the Society council members directed their attention to the upcoming International Congress of Plant Sciences. These actions intimate an underlying sentiment that the Society of American Bacteriologists deliberately distanced itself from pathological or medical associations. While the SAB welcomed medically-minded practitioners, its leaders purposely decided against subsuming their interests within the medical sciences.

Finding the Fundamental in the "General and Technical"

The organizers of SAB annual meetings believed that the sessions and papers devoted to "General and Technical" bacteriology constituted the most compelling component of the program. As graphs 4.16, 4.17 and 4.18 demonstrate, this category comprised between 20% and 70% of the total presentations. For example, at the 1904 meeting, twenty-seven of thirty-nine papers fell into this category. This organizational predilection might seem to contradict the SAB's founding goal of promoting bacteriology as a *biological* science. The "technical" component of a science represented, in some aspects, the most specialized, and therefore the least fundamental, area. Certainly, a share of the SAB's "General and Technical" papers offered little more than brief announcements of mundane improvements in instruments or methods. The 1904 meeting included among the twenty-seven "General and Technical" entries mostly demonstrations of new pipettes, starch-jellies, steam stills, germ-proof filters, thermostat regulators, and test-tube stands. Other discussions compared manipulations for photomicrographing flagella, performing direct microscopical enumerations, and accommodating

leaking incubators.

Nonetheless, SAB members recognized that it was their shared techniques that bound them together. By the mid-1910's, the "General and Technical" sessions opened each meeting, and drew the largest audience. Graphs 4.19, 4.20 and 4.21 sub-divide this group into eight categories: SAB/Teaching, Associations/Evolution, Physical Chemistry, Metabolism, Nutrition, Variation/Morphology, Taxonomy/Determination, and New Techniques & Apparatuses.³⁸ These graphs suggest that the mundane introductions of instrumental refinements constituted only a fraction of the "General and Technical" entries. In the early 1920's, when the annual meetings featured simultaneous and competing sessions, the SAB maintained a priority for the "General and Technical" program. Secretary A.P. Hitchens explained that these papers concerned the entire membership, and he would not schedule rival sections to the "General and Technical" assemblies.³⁹ For the 1921 and 1924 meetings, the three-day program allocated the first two days to "General and Technical" presentations, while only the third allowed concurrent schedules for "Human & Animal Pathology, and Immunology," and "Agricultural and Industrial Bacteriology."

SAB members most directly canvassed the biological component of bacteriology within these "General and Technical" discussions. Apart from their immediate and applied concerns,

³⁸ "SAB/Teaching" includes addresses devoted to the Society's origins, structure, and direction, as well as discussions of the pedagogics of bacteriology. "Associations/Evolution" covers papers discussing mixed cultures, and interactions among bacterial species producing adaptations. "Physical Chemistry" includes presentations on the effect of pH, surface tension, temperature, light, etc. on bacterial growth. "Metabolism" specifies those investigations on the physiological products of bacterial growth, while "Nutrition" indicates those studies on the requirements of growth. "Variation/Morphology" encompasses researches on induced and natural changes in bacteria, particular those changes in morphology. "Taxonomy/Determination" contains both bacterial classification and determination. "New Techniques" specifies the demonstrations of instruments and methods.

³⁹ Hitchens, "Secretary's Newsletter to SAB Members, 24 January 1921," [ASM] box 2-2IXC, folder 4.

Society members exchanged views concerning unsettled and speculative topics. For example, they repeatedly addressed the perplexities of bacterial variation. Hibbert W. Hill, Director of the Bacteriological Laboratory for the Boston Board of Health, presented a paper at the 1904 meeting outlining the inherent difficulty of determining the "normal morphology" of microorganisms.⁴⁰ The following year, University of Chicago's Edwin O. Jordan delivered his presidential address on bacterial variation, in which he made extended reference to the recent work of Hugo DeVries. Jordan borrowed DeVries' distinction between environmental modifications and true mutations, and beseeched his fellow investigators to evaluate all normal variations as fluctuations oscillating around an average type. While Jordan was unable to perfectly analogize bacteria to primroses, other investigators, presenting at later meetings, heeded his call.⁴¹

SAB meetings tackled another aspect of microbial variation, regarding the suspected life cycles of bacteria. In the mid-1910's, Felix Lohnis and Nathan Smith, of the USDA's Bureau of Plant Industry, argued that bacteria manifest dramatic and predictable morphological transformations. Employing *B. subtilis* as their model organism, Lohnis and Smith declared that

⁴⁰ Hill urged "much more detailed attention to every phase of morphology than has as yet generally been given to it." The solution was direct continuous microscopic examinations, particularly on the processes of fission, spore formation, germination, etc. This was a plea for a "more exact abstract science of morphology." Hibbert W. Hill, "Introductory Remarks on the Morphology of Bacteriology," *Science* 21 (1905): 489.

⁴¹ E.O. Jordan, "Variation in Bacteria, Presidential Address of the Society of American Bacteriologists, Ann Arbor, December 1905," [ASM], Presidential Collections, box 9-B, folder 14. At the 8th meeting (1906), Stephen DeM. Gage examined the variations in biochemical reactions of the colon-typhoid group in order to determine if they followed the "law of biological variation." Similarly, at the 10th meeting (1908), C.E.-A. Winslow and L.T. Walker studied the inheritance of bacterial variability, promising to "throw important light upon some of the fundamental biological problems of heredity and evolution." Winslow & Walker, "Case of Non-Inheritance of Fluctuating Variations among Bacteria," *Science* 29 (1909): 1013. Yale's Leo Rettger, at the 11th and 14th meetings (1909 & 1912), likewise speculated on the possibility of bacterial transmutation. Rettger's colleague at Yale, M.R. Smirnow, submitted four papers to the SAB's 1914 and 1915 meetings on induced and inherited variations. Each of these investigators implicitly adopted DeVries' distinction between variations, which tend to revert to normal types, and true mutations, which breed true in subsequent generations to the new traits.

a single bacterial culture displayed a variety of shapes and sizes. If true, this life-cycle hypothesis demanded a radical revision of bacterial determination and taxonomy. The myriad microbial types might be reduced by half, as the divergent forms would simply represent different growth stages of the same species.⁴² At the 1916 SAB meeting, Lohnis and Smith articulated their hypothesis, while Karl Kellerman and Freeman M. Scales, also from the Bureau of Plant Industry, documented life-cycle transformations in *B. coli*. Curiously, Lohnis' contention elicited few published comments from fellow bacteriologists. The several bacteriological journals were hesitant to print claims regarding such a speculative claim. In contrast, the SAB annual meetings were a welcome forum for collective deliberation. Between 1916 and 1924, the Society programs profiled papers and discussions of natural and induced bacterial variations. These meetings did much to detail a 'lag phase' or 'dormancy' of bacterial growth, correlating various morphological changes with the age of cultures.⁴³ While the life-

⁴² See, Felix Lohnis and Nathan R. Smith, "Life Cycles of the Bacteria: Preliminary Communication," Journal of Agriculture 6 (1916): 675-702; and, Lohnis, "Studies upon the Life Cycles of the Bacteria: Part One, Review of the Literature, 1838-1918," Memoirs of the National Academy of Sciences 16, 2nd memoir (1922): 1-246. For a discussion of the life cycle hypothesis, as it developed in the 1920's and 1930's, see Olga Ansterdamska, "Stabilizing Instability: The Controversy Over Cyclogenic Theories of Bacterial Variation during the Interwar Period," Journal of the History of Biology 24 (1991): 191-222; Ansterdamska, "Medical and Biological Constraints: Early Research on Variation in Bacteriology," Social Studies of Science 17 (1987): 657-687; and, M Penn and M. Dworkin, "Robert Koch and Two Visions of Microbiology," Bacteriological Reviews 40 (1976): 276-283.

⁴³ See, for example, Paul Clark's "Youth, Maturity, and Senility in Bacteriology," from the 18th Annual SAB Meeting (1916). At the 20th Annual SAB Meeting, Clark presented "Morphological Changes During the Growth of Bacteria," while Arao Itano and James M. Neill discussed "The Influence of Temperature and Hydrogen Ion Concentration upon the Spore Cycle of *Bacillus Subtilis*." Dan H. Jones, at the 21st Annual SAB Meeting (1919), reported his partially replication of Lohnis and Smith's observations in a paper entitled "Continued Studies of Some Azotobacter." At the 23rd gathering (1921), Arthur T. Henrici offered a "Statistical Study of the Growth and Life-Cycle of a Spore-Bearing Bacillus" in which he outlined a possible explanation for the varying cell size during the serial phases of culture growth. Ralph M. Mellon, at the 24th and 26th SAB Annual Meetings (1922 & 1924), not only defended the life-cycle hypothesis, but argued that the pleomorphic tendencies were a product of sexual reproduction among bacteria. See, Mellon, "Life Cycles of the Bacteria and their Possible Role in Pathology," American Journal of Medical Science 159 (1920): 874-882; Mellon, "Experiments on the Hereditary Origin of Group and Specific Agglutinins among the Enteric Organisms," Abstracts of Bacteriology 9 (1925): 2-3; and, Mellon, Studies in Microbic Heredity (Washington, D.C.: Society of American Bacteriologists, 1925).

cycle hypothesis remained unsettled during this period, the SAB facilitated a reconsideration of the assumed morphological stability of bacterial types.

The "General and Technical" sessions similarly served as the principal medium for the construction of a unified system of bacteria taxonomy. As the Chapter 6 will demonstrate, the SAB and its committees on "Taxonomy" and the "Determinative Manual" instituted a sweeping revision of microbial nomenclature and classification in the early 1920's. During the first two decades of this century, SAB participants submitted sundry provisional taxonomic schemes. For example, Frederic D. Chester broadly sketched his determinative outline at the 1904 SAB meeting.⁴⁴ Other bacteriologists regularly tendered systematic keys for particular groups (*e.g.*, Winslow's descriptions of the *Coccaceae* in 1906 and 1912; Karl Kellerman's survey of *B. subtilis* in 1912; Charles Krumweide's map of the paratyphoid group; and, the Mulford staff's extended appraisal of *Streptococci* in 1916). Most importantly, SAB gatherings encouraged individual workers to develop classifications that cut across the various applied areas of bacteriology. Winslow's revision of the *Coccaceae*, for instance, targeted not only sanitary scientists analyzing water samples, but also dairy workers, pathologists, and veterinarians.⁴⁵

Furthermore, SAB gatherings promoted the study of bacterial physiology. From its earliest programs, Society members explored the physical and chemical conditions of bacterial cell growth (*e.g.*, temperature, light, acidity, surface tension). In fact, it was at the 1914 annual meeting that William M. Clark, of the USDA's Bureau of Animal Industry, first announced his

⁴⁴ See, Frederick D. Chester, A Manual of Determinative Bacteriology (New York: Macillian & Co., 1901).

⁴⁵ C.-E.A. Winslow and Anne F. Rogers, "A Revision of the *Coccaceae*," Science 21 (1905): 486-487; Winslow and Rogers, The Systematic Relationship of the *Coccaceae*: With a Discussion of the Principles of Bacterial Classification (New York: John Wiley & Sons, 1908); and, Winslow, "The Characterization and Classification of Bacterial Types," Science 39 (1914): 77-90.

series of graduated indicators for determining the hydrogen-ion concentration of liquid material. In addition to offering improved methods for adjusting the reaction of culture media, Clark explored the relationship between oxidation-reduction potentials and microbial cell growth.⁴⁶ In the early 1920's, Winslow and his associates at the Yale Medical School introduced SAB members to rudimentary techniques of electrophoresis. As part of their studies of the effect of mineral salts on microbial viability, Winslow, Isadore Falk, and Dorothy Holland demonstrated the utility of measuring the electrical resistance of bacterial suspensions.⁴⁷

More frequently, SAB presentations in "bacterial physiology" implied the elucidation of bacterial nutrition and metabolism. From the 1880's onward, bacteriologists concerned themselves with the specific requirements for culturing certain microbes. If bacteriology, as a practice, constituted a set of cookbook procedures, these "recipes" for bacterial growth comprised the core of the field. Particular organisms were largely defined by their peculiar nutritive needs (*e.g.*, *B. diphtheriae* and Loeffler's blood serum) and their metabolic by-products (*e.g.*, *B. coli* and the production of gas from sugars). In routine practices, the microbe itself could be black-boxed, and identified merely based on its input and output characteristics. The SAB participants, however, regularly endeavored to uncover the internal activities of cell growth, or those physiological processes that explained the nutritive demands and metabolic yields.

⁴⁶ William M. Clark, "The Influence of Hydrogen-Ion Concentration upon the Physiological Activities of *Bacillus Coli*," paper presented at the 16th Annual SAB meeting (1914); Clark and Barnett Cohen, "The Influence of pH on the Reproduction of Some Common Bacteria," paper presented at the 19th Annual SAB meeting (1917); and, Clark and H.A. Lubs, "The Colorimetric Determination of Hydrogen-Ion Concentration and its Application in Bacteriology," *Journal of Bacteriology* 2 (1917): 191-236.

⁴⁷ Winslow and Holland, "The Effect of Potassium and Magnesium Salts upon Bacterial Viability," and Falk, "Preliminary Studies on the Isoelectric Points of Bacteria," papers presented at the 23rd Annual SAB meeting (1921). See also, Winslow and H.J. Shaughnessy, "The Migration of Bacteria in the Electric Field," paper presented at the 25th Annual SAB meeting (1923); and, Winslow *et al.*, "Further Studies on Cataphoresis," paper presented at the 26th Annual SAB meeting (1924).

Brown University's Michael Sullivan, for example, presented at the 1902 and 1904 annual meetings on the metabolism of pigment producing species. Beginning with a careful analysis of their essential nutritive elements and the chemistry of their pigment products, Sullivan outlined the probable internal transformations.⁴⁸ Sullivan's mentor and colleague at Brown, Frederic P. Gorham, shared a similar interest in the physiology of pigment production among phosphorescent microorganisms. For Gorham, however, this investigation necessitated the novel use of synthetic media. Only by culturing a microbe on media of precisely known constituents could a researcher accurately assess its physiological properties.⁴⁹ Such focus on the activities of individual bacteria is equally evident in papers by Otto Rahn (1910) and Robert Buchanan (1917) on the fermenting capacities of single cells, and Louis J. Gillespie's description of the gas metabolism of *B. coli* (1911).⁵⁰

In the 1910's, SAB sessions ventured to define a general bacterial physiology, or those processes shared by large clusters of species. Leo Rettger and his colleagues at Yale University, Stuart Koser, Nathan Berman, and William Sturges, Jr., serially reported their work on the utilization of protein and non-protein sources of nitrogen among several classes of pathogens and saprophytes. Rather than simply identifying the by-products indicative of individual microbes,

⁴⁸ Sullivan, "The Chemistry of Bacterial Pigments," and "The Pyocyanin and Fluorescent Functions of Bacteria," papers presented at the 4th Annual SAB meeting (1902); and, Sullivan, "The Metabolism of Chromogenic Bacteria," paper presented at the 6th Annual SAB meeting (1904). See also, Hibbert W. Hill, "Preliminary Note on Chromogenic Cultures of *B. Diphtheriae*," paper presented at the 4th Annual SAB meeting (1902).

⁴⁹ Gorham, "Photogenic Bacteria," paper presented at the 5th Annual SAB Meeting (1903); and, Gorham, "Biochemical Problems in Bacteriology," presidential address before the 13th Annual SAB meeting (1911), reprinted in *Science* 35 (1912): 357-362.

⁵⁰ Otto Rahn, "The Fermenting Capacity of the Average Individual Cell (*Bacterium Lactis Acidi*)," and Louis J. Sullivan, "Gas Metabolism of *B. Coli*," papers presented at the 12th Annual SAB meeting (1910); and, Robert E. Buchanan, "Fermentation Capacity of a Single Bacterial Cell," paper presented at the 19th Annual SAB meeting (1917).

Rettger and company sought those intermediate steps common to all types.⁵¹ By the end of the decade, the same "General and Technical" sessions included Charles J.T. Doryland, Selman Waksman, and Robert Starkey's daring explorations of the "energetics" of bacterial growth. For these soil bacteriologists from Rutgers and Yale, the key questions of bacterial physiology centered on the energy extracted from the internal oxidations and reductions of nutritive elements. The events between the "input" and "output," or those inmost cell processes, concerned them.⁵²

Additionally, the search for the biological components of bacteriology looked to issues beyond individual bacteria and internal cell activities. Bacterial associations and the ecology of microorganisms drew increasing recognition from SAB participants. At the 1904 annual meeting, Charles Marshall and Leo Rettger directed attention to the antagonistic and associative behavior of several bacteria.⁵³ In his presidential address before the 1908 annual meeting, Wisconsin's Harry L. Russell sketched the "Ecology of Microorganisms." Russell maintained that while most mixed cultures profiled a single dominant organism, the subordinate forms served equally important functions for the culture and population. Lore Rogers and Arnold Dalhberg, of the USDA, returned to Russell's theme at the 1913 meeting when they described "The Relation of Habitat and Physiological Characters in the Streptococci." For these two dairy

⁵¹ These studies on bacterial nutrition appeared in the SAB programs for the 17th-19th annual meetings (1915-1919), and were published as Berman and Rettger, "Bacterial Nutrition: Further Studies on the Utilization of Protein and Non-Protein Nitrogen," *Journal of Bacteriology* 3 (1918): 367-388; and, Berman and Rettger, "The Influence of Carbohydrate on the Nitrogen Metabolism of Bacteria," *Journal of Bacteriology* 3 (1918): 389-402.

⁵² Charles J.T. Doryland, "Relation of Energy Requirements to Certain Physiological Properties of Bacteria," paper presented at the 21st Annual SAB Meeting (1919); and, Selman Waksman and Robert Starkey, "Energy Transformations by Microorganisms," paper presented at the 24th Annual SAB Meeting (1922).

⁵³ Rettger, "On the Antagonisms of Bacteria and their Products towards Other Bacteria," and Marshall, "The Associative Action of Bacteria in the Souring of Milk," papers presented at the 6th Annual SAB Meeting, (1904), printed in *Science* 21 (1905): 491 & 492.

scientists, "true species of bacteria" would likely correlate with "a definite habitat as it is with the higher plants and animals." The relevant ecological factors included not only the immediate physical and chemical environment, but competing microbes and the presence of more complex life forms. At the next year's gathering, Marshall again spoke on "Microbial Associations" in his presidential address. Marshall intimated that if bacteriology were to address its most refractory quarries, then its practitioners must regard their subjects outside of the unnatural state of pure cultures.⁵⁴

The Society meetings did not restrict the examination of biological facets to the "General and Technical" sessions. Indeed, the same considerations of variation, systematics, and physiology arose, albeit less frequently, in exposition of applied subjects. For example, early assemblies vetted the variable morphologies of diphtheria and tuberculosis bacilli, seeking to correlate their pathogenic powers with tendencies toward branching.⁵⁵ Meanwhile, agriculturally-minded bacteriologists fretted over the inconstant fermentative capacity of *B. lactis acidii* in their starter cultures for cheese and silage.⁵⁶ These questions of variation, when brought to a practical setting, inevitably raised taxonomic dilemmas. As the previous chapter has documented, dairy bacteriologists wrestled with the myriad forms capable of fermenting milk with the production of lactic acid. Moreover, Herbert Conn and William Esten's characterization

⁵⁴ Russell, "Ecology of Microorganisms," presidential address before the 10th Annual SAB Meeting (1908); Rogers and Dahlberg, "The Relation of Habitat and Physiological Characters in the Streptococci," paper presented at the 15th Annual SAB Meeting (1913); and, Marshall, "Microbial Associations," presidential address before the 16th Annual SAB Meeting (1914), printed in *Science* 41 (1915): 306-312.

⁵⁵ See, A.C. Abbott, "Branching Forms of the Diphtheria Bacillus," paper presented at the 2nd SAB Meeting (1900); Frederic P. Gorham, "The Morphology of *Bacillus Diphtheriae*," F. Marion Dorset, "A Note on Branched Forms of Tubercle Bacilli Found in Cultures," A.P. Ohlmacher, "Observations upon the Morphologic Variation of Certain Pathogenic Bacteria," and Hibbert W. Hill, "Branching in Bacteria, with Special Reference to *B. Diphtheriae*," papers presented at the 3rd SAB Meeting (1901).

⁵⁶ See, for example, William Esten's "Variation in the Acidity of Fresh Milk," and "Some Observations on the Fermentation of Silage," papers presented at the 10th and 11th SAB Meetings (1908 & 1909).

of *B. lactis acidii* appeared so general as to include organisms normally classed as *B. coli communis*. At the 1901 gathering, MIT's Samuel Prescott warned that if the dairy bacteriologists' definition held true, then *B. coli* could not be employed as the presumptive test for fecal contamination of water. *B. lactis acidii* stood as an emblem of harmless, if not helpful germs, while *B. coli* signaled imminent danger. In their discussions before the entire Society membership, dairy and water bacteriologists forged differential criteria for distinguishing the microbes of munificence from those of malignity.⁵⁷

The routine tasks of isolating, identifying and eliminating specific types also advanced the study of bacterial physiology. For example, University of Michigan's Frederick Novy presented "On the Germicidal Action of the Organic Peroxides" at the 1901 meeting, where he pondered the exact mechanisms by which disinfectants inhibited cell growth. Three years later, Marion Dorset, of the Bureau Animal Industry, reexamined the chemical composition of the tuberculosis bacillus when comparing the common methods of staining tissues and sputum.⁵⁸ In public health bacteriology, the manufacture of diphtheria antitoxin prompted a number of physiological inquiries. In the 1910's, SAB members correlated toxin production with Clark and Lubs' methods for determining optimal pH. At the 1918 meeting, Newell Ferry and Lewis Davis discussed the "Role of Amino Acids in the Metabolism of *Bacterium Diphtheriae*." In their attempts to detail the requisite amino acids and accessory growth factors, these Parke, Davis &

⁵⁷ Samuel Prescott, "On the Apparent Identity of the Cultural Reactions of *B. Coli Cummunis* and Certain Lactic Acid Bacteria," paper presented at the 3rd Annual SAB Meeting (1901); Esten, "Lactic Acid Bacteria," paper presented at the 7th Annual SAB Meeting (1905); and, W.L. Lewis, "A Source of Error in the Use of Lactose as a Differentiating Medium," paper presented at the 9th Annual SAB Meeting (1907).

⁵⁸ Novy, "On the Germicidal Action of Organic Peroxides," paper presented at the 3rd Annual SAB Meeting (1901); and Dorset, "Notes on the Chemical Constitution of *Bacillus Tuberculosis*," paper presented at the 6th Annual SAB Meeting (1904).

Co. workers also determined that diphtheria toxin was not a synthetic product of bacteria growth, but rather a catabolic substance elaborated only in the presence of vitamin-like substances.⁵⁹

Even the most common considerations of pathogenic bacteriology occasionally elicited a reexamination of fundamental culture precepts. In 1918, Frederick Ebersson of the Rockefeller Institute described a "A Yeast-Agar Medium for the Meningococcus," a seemingly unremarkable technical contribution to the SAB's program. However, Ebersson labored to identify the ideal medium for shipping the pathogen over long distances. Most culture recipes favored optimum growth rates, so much so that "the end-products accumulate and retard further growth." Ebersson probed the predictable pattern of explosive reproduction and subsequent collapse typical of pure cultures, speculating on those internal physiological processes that might allow for slow, lasting, and controlled growth.⁶⁰

Moving from the Medical

Despite the conceptual fecundity of these presentations in pathogenic bacteriology, the SAB gradually reduced its emphasis on medical, public health, or sanitary concerns. More pointedly, the programs avoided instances of the purely hygienic view, where presenters focused

⁵⁹John W.M. Bunker, "Some Effects of Hydrogen-Ion Concentration on the Metabolism of the Diphtheria Bacillus," paper presented at the 18th Annual SAB Meeting (1916); and, Lewis Davis and Newell S. Ferry, "The Role of the Amino Acids in the Metabolism of *Bacterium Diphtheriae*," paper presented at the 20th Annual SAB Meeting (1918).

⁶⁰Ebersson, "A Yeast-Agar Medium for the Meningococcus," paper presented at the 20th Annual SAB Meeting (1918), summarized in Abstracts in Bacteriology 3 (1918): 10. James Sherman and William Albus returned to these issues in "The Function of 'Lag' in Bacterial Cultures," paper presented before the 24th Annual SAB meeting (1922), summarized in Abstracts in Bacteriology 7 (1923): 7. They objected to the accepted view that the latent period was the "expression of an 'injury' received by the organism." Instead, they suggested that "a more satisfactory explanation would be to consider it as a biological rejuvenescence, in a sense, perhaps comparable to the phenomenon of endoxisis in protozoa."

primarily on the isolation, identification and elimination of pathogens.⁶¹ (Graphs 4.16, 4.17 & 4.18) After its initial few gatherings, the SAB rarely included papers discussing disinfectants or germicides. At the 11th annual meeting (1909), E.M. Houghton, from Parke, Davis & Co., wondered "How Shall the Value of Disinfectants be Determined?" Houghton's paper evoked lively, though unfocused discussion, so much so that Theobald Smith, William D. Frost and Frederic P. Gorham proposed a Committee for the Study of Disinfectants. Other members noted, however, that such a body already functioned as part of the American Public Health Association, and Frost and Groahm quickly withdrew their motion. In only one other instance, in its first quarter century of existence, did the SAB devote appreciable attention to the issue of disinfectants.⁶² The Society remained quite willing to cede this hygienic domain to another association.

SAB meetings occasionally welcomed immunological subjects. As early as the 1902 meeting, scientific programs included papers on agglutination, complement fixation reactions, and other serological techniques. Nonetheless, many SAB members also belonged to the American Association of Pathologists and Bacteriologists, and with the founding of the American Association of Immunologists in 1913, SAB officials tacitly relegated medical and immunological matters to these other organizations.⁶³ The SAB, however, never fully abnegated

⁶¹ Even those sessions devoted to "pathogenic" bacteriology featured papers in veterinary science or comparative pathology, topics normally excluded from the domain of medical bacteriology.

⁶² Houghton, "How Shall the Value of Disinfectants be Determined?" paper presented at the 11th Annual SAB Meeting (1909), discussion summarized in "SAB Book of Minutes, 1899-1909," [ASM] Box 1-IVA, folder 1, p. 106. The 24th annual meeting included a subsection on "Disinfection and Growth Inhibition."

⁶³ Esmond R. Long, "History of the American Association of Pathologists and Bacteriologists," American Journal of Pathology 77 (1974) suppl.; "Origins of the FASEB and its Member Societies," Federation Proceedings 46 (1987): 223-250; and, Michael Heidelberger, "Immunology in Perspective: A Symposium Convened at Las Vegas, 3 May 1988, in Commemoration of the 75th Anniversary of the Founding of the American Association of Immunologists," Journal of Immunology 141 (Oct. 1988): suppl.

immunology and pathology. By the late 1910's, meeting programs included sections bearing the title "Human and Animal Pathology," or even "Immunology." Even so, these sessions were decidedly unremarkable. After the 1922 annual meeting, New York City Department of Public Health's Charles Krumwiede Jr. expressed the Pathology Section Committee's disappointment. Upon reviewing a session that featured both Ruben L. Kahn's elaboration of his precipitin test for syphilis as well as four papers on poultry pathology, Krumwiede insisted that a "stronger program" could be obtained only by "soliciting papers from persons known to be *actually engaged in research work*."⁶⁴ The former president's strident appraisal drew notice. SAB Secretary A.P. Hitchens admitted that this "was a matter of greatest importance and that a committee of three should be appointed" to assemble "a group of very strong papers for the next meeting." Curiously, no committee materialized.⁶⁵ Although, the sessions on "Comparative Pathology and Immunology" for the 1923 and 1924 meetings lured many preeminent medically-minded researchers into submitting papers (e.g., Frederick Gay, Hans Zinsser, Edward C. Rosenow, Roscoe R. Hyde), Krumwiede's frustrations betrayed a lingering insouciance, among some SAB members, in the pathological side of bacteriology.

In contrast, the SAB eagerly facilitated the development of agricultural and industrial bacteriology. The preceding chapter argued that workers in dairy and soil science most directly pursued the biological components of the discipline. In the years prior to the formation of the National Association of Dairy Instructors and Investigators (1906) and the Soil Science Society

⁶⁴ The section included such eclectic offerings as: Pearl L. Kendrick and R.L. Kahn, "Quantitative Relation between Complement Fixation, Agglutination and Precipitation," C.H. Werkman, "The Immunological Significance of Vitamines," and L.D. Bushnell, "The Relation between *B. Avisepticus* Types Isolated from Roup and Fowl Cholera."

⁶⁵ Emphasis added. "Minutes of the 24th Annual SAB Meeting, Dec. 28-30, 1922, Detroit," [ASM] box 1-IVA, folder 5, p. 53.

of America (1916), the SAB's actively sought to provide a forum for these like-minded researchers to report their efforts.⁶⁶ Additionally, these December meetings comprised the principal means for medical, public health, and sanitary bacteriologists to witness the methods and findings of these divergent practitioners. For example, Frederick Chester, at the 1902 and 1903 meetings, reported his studies of *B. subtilis* and his review of the symbiotic, anaerobic nitrogen-fixers in soils.⁶⁷ At these early meetings, the smattering of papers in soil bacteriology mostly described the flora of productive or barren soils, and detailed procedures for the inoculation of legumes with *B. radicola*.⁶⁸ Nonetheless, these tentative contributions drew attentive discussion from preeminent bacteriologists holding little direct interest in soil fertility (e.g., William T. Sedgwick, Alexander C. Abbott, William H. Welch, and Joseph Kinyoun).⁶⁹

The 1910 annual meeting was the first to list a separate section on "Soil Bacteriology," suggesting that this speciality had come of age in the SAB's eyes. The session included fourteen papers of remarkable breadth, covering such topics as cellulose decomposition, *Azotobacter* inoculants, microbial associations with higher plant forms, and uncommon culture media. Moreover, that gathering established the Society's lasting predilection toward a self-conscious

⁶⁶ Several SAB leaders articulated the unique function of the Society in promoting soil and dairy bacteriology. See, Harold J. Conn, "What the Society Can Do to Advance Agricultural Bacteriology," paper presented at the 21st Annual SAB Meeting (1919). Outside perceptions seemed to concur. When the National Research Council requested that the SAB designate an official delegate, it was to the section on Agriculture, and not Medicine. See, "Minutes of the 24th Annual SAB Meeting," pp. 42-44.

⁶⁷ Frederick D. Chester, "Oligo-nitrophilic Bacteria of the Soil," paper presented at the 4th Annual SAB meeting (1902); and, Chester, "Notes on the *B. Subtilis* Group," paper presented at the 5th Annual SAB Meeting (1903).

⁶⁸ See, for example, H.A. Harding and M.J. Prucha, "Absorbent Cotton as a Medium for Distributing *Pseudomonas Radicola*," and, Karl Kellerman and T.D. Beckwith, "The Nodule-Forming Bacteriology of the *Leguminosae*," papers presented at the 7th Annual SAB Meeting (1905); Harding and Prucha, "Commercial Cultures of *Pseudomonas Radicola*," and Kellerman and Edna H. Fawcett, "Movements of Certain Bacteria in Soils," papers presented at the 8th Annual SAB Meeting (1906).

⁶⁹ "SAB Book of Minutes, 1899-1909," pp. 44, 55 & 73.

examination of the methods of soil bacteriology.⁷⁰ By the late 1910's and early 1920's, these sessions on soil bacteriology reported research in bacterial nutrition and metabolism, including several describing the "energetics" of microbial physiology.⁷¹ In all likelihood, these later reports did not elicit the same general interest as the presentations during the SAB's infancy. The annual meetings now held concurrent and competing sessions, and the majority of bacteriologists working in non-agricultural spheres undoubtedly attended other talks. Still, these soil programs fostered fundamental explorations among like-minded researchers.

The SAB similarly embraced the field of dairy bacteriology, beginning with Harry L. Russell and Edwin G. Hastings' initial report on the flora of hard cheeses to the 1905 meeting. Subsequent presentations focused attention on such topics as the associative action among dairy microbes, the operative flora of Swiss cheese, and the intermediate metabolic by-products of high-acid forms.⁷² In addition, the SAB played a formative role in the emergence of industrial bacteriology. University of Wisconsin's Harry L. Russell summarized the first American study devoted to the bacteriology of silage at the 1900 meeting.⁷³ Beginning in 1914, the SAB listed

⁷⁰ See, for example, Percy E. Brown, "A New Method for the Bacteriological Examination of Soils," paper presented at the 14th Annual SAB Meeting (1912); Jacob Lipman, "Report of the Committee on Cooperative Study of Microbiology in the Soil," presented at the 17th Annual SAB Meeting (1915); and Selman Waksman, "Methods in Soil Microbiology," paper presented at the 24th Annual SAB Meeting (1922).

⁷¹ See, Percy E. Brown and J. Franklin Morgan, "Interpretation of the Cycle of Carbon, Nitrogen and Sulphur," paper presented at the 19th Annual SAB Meeting (1917); Charles J.T. Doryland, "Relation of Energy Requirements to Certain Physiological Properties of Bacteria," paper presented at the 21st Annual SAB Meeting (1919); Arao Itano, "Influence of Vitamine B and Nucleic Acid on *Azotobacter*," paper presented at the 23rd Annual SAB Meeting (1921); Sebastian Lomanitz, "Decomposition of Proteins and Amino Acids by Various Groups of Soil Microorganisms," paper presented at the 25th Annual SAB Meeting (1923); and, Selman Waksman, "Energy Transformation by Microorganisms and it Application to Soil Processes," paper presented at the 26th Annual SAB Meeting (1924).

⁷² Russell and Hastings, "Abnormal Cheese Troubles due to Lactose Fermenting Yeasts," paper presented at the 7th Annual SAB Meeting (1905); C.F. Doane, "The Action of *Bacillus Bulgaricus* in Suppressing Gassy Fermentations in Cheese Milking," and E.E. Eldridge and Lore A. Rogers, "The Normal Bacteria of Swiss Cheese," papers presented at the 14th Annual SAB Meeting (1912).

⁷³ Harry L. Russell and Stephen M. Babcock, "Concerning the Theories of Silage Formation," paper presented at the 2nd Annual SAB Meeting (1900).

“Industrial Bacteriology” as its own section or sub-section. Aside from periodic reports on silage, the SAB meetings included presentations on the bacterial preparation of pickles, sauerkraut and sardines; the retting of flax; the production of liquid starch using *Aspergillus oryzae* enzymes; and the manufacture of butyric acid for airplane dope and smokeless gunpowder. Like their companion workers in soil and dairy bacteriology, these investigators highlighted aspects of bacterial associations, nutrition, metabolism, and variation in their attempts to harness the productive power of germs.⁷⁴

Addressing and Redressing the Society

Aside from the inclusion of research reports on soil, dairy, and industrial topics, the SAB fostered the search for the biological components of bacteriology by other – more organizational – means. The annual presidential address represented a unique opportunity for a Society officer to appraise the scope, methods, and direction of the discipline. As such, these locutions tended to betray a lingering dissatisfaction, an unease that somehow bacteriology lacked an elemental quality possessed by other sciences. A review of the first twenty-five presidential speeches reveals two related themes: that bacteriology ought to become more “biological,” however loosely defined; and, that bacteriologists ought to look beyond their immediate, applied concerns, and seek the fundamental or “pure” aspects of their discipline. The fact that these exhortations appeared again and again, indicates that while many SAB leaders shared the conviction that

⁷⁴ Lester A. Round, “Normal Fermentation of Sauerkraut,” paper presented at the 17th Annual SAB Meeting (1915); J.S. Horn, “Importance of Pure Culture Work in Industrial Processes,” paper presented at the 19th Annual SAB Meeting (1917); Zae Northrup Wyant, “Experiments in Silage Inoculation,” and Waksman, “Industrial Application of Enzymes of *Aspergillus Oryzae*,” papers presented at the 21st Annual SAB Meeting (1919); and, E.B. Fred and William H. Peterson, “Associative Growth of Butyric and Lactic Acid Bacteria,” paper presented at the 25th Annual SAB Meeting (1923).

bacteriology should be more biological and pure fundamental, their goal remained elusive.

Either they could not agree upon the exact set of remedies for the discipline, or they were unable to convince the practitioners of bacteriology to follow suit.

William T. Sedgwick offered the first such call in his presidential address before the 2nd annual meeting (1900) entitled "The Origin, Scope and Significance of Bacteriology." Sedgwick insisted, before the general assembly, that microbiology was not merely a handmaiden of pathology and medicine but a fundamental science. As a field of study, it emerged as an "offspring of chemistry and biology, enriched by physics" and quickly enlisted to the service of medicine, agriculture and industry.⁷⁵ In order to aid the SAB in fulfilling its stated mission of furthering "the position of bacteriology as one of the biological sciences," Sedgwick proposed a five member committee to make ongoing recommendations as to the scope and function of the Society, and to suggest guidelines for the number and character of papers presented.⁷⁶

Even after the initial ten SAB meetings, doubts persisted as to whether the Society held true to its founding purpose. Before the general assembly of the 1909 meeting, Charles -E.A. Winslow railed that the Society "was getting into a rut by having presented papers largely of a technical nature, and lacking those reflecting the attitude of bacteriology discussed from the lofty heights of pure science." Winslow enjoined his fellow bacteriologists to "solicit papers covering important phases of bacteriology not otherwise represented on the general program." The extant

⁷⁵ Sedgwick, "Origin, Scope and Significance of Bacteriology," Presidential Address before the 2nd Annual SAB Meeting (1900), printed in *Science* 13 (1901): 121-128; and Paul F. Clark, "A Half Century of Presidential Addresses of the Society of American Bacteriologists," *Microbiological Reviews* 17 (1953): 214.

⁷⁶ Membership included Sedgwick, Herbert W. Conn, William Welch, A.C. Abbott and Theobald Smith. In 1902, the SAB renamed the administrative body the "Committee on Working Organization of the Society," with C.-E.A. Winslow, Hibbert W. Hill, and Frederic P. Gorham as members. "SAB Book of Minutes, 1899-1909," pp. 33 & 46.

records do not indicate what topics Winslow felt should be added. A clue might be found in Winslow's next proposed motion: that the SAB hold joint sessions with the Botanical, and not Medical or Physiological, section of the AAAS.⁷⁷

In his presidential address before the 1911 SAB meeting, Brown University's Frederic P. Gorham provided a few concrete steps to render bacteriology more biological. Gorham's speech, entitled "Some Biochemical Problems in Bacteriology," voiced an impassioned plea for the use of synthetic media of precisely known constituents, even in the most routine procedures. He called for the development of exacting quantitative methods, arguing that his kind of data offered central resolutions to questions of bacterial taxonomy, variation, and heredity. Like Sedgwick and Winslow, Gorham emphasized the need for fundamental research, and counseled younger bacteriologists against rapid entry into applied fields.⁷⁸

Yale University's Leo Rettger delivered the most trenchant of presidential appraisals at the 19th annual meeting (1917), issuing an appeal for disciplinary independence. Bacteriology had "been the victim of gross paternalism by those sciences which it has come to redeem." It was to "pathology that it has been holding itself in bondage." If the science were to "emerge from its servile state," Rettger insisted that bacteriologists had to be "able to do more than pour gelatin and agar plates" and "count colonies."⁷⁹ In Rettger's estimation, most public health and sanitary "specialists" were simply physicians equipped with less than ten weeks of bacteriological instruction. A thorough comprehension required more than a familiarity with

⁷⁷ "SAB Book of Minutes, 1899-1909," p. 99.

⁷⁸ Gorham, "Some Biochemical Problems in Bacteriology," Presidential Address before the 13th Annual SAB Meeting (1911), reprinted in *Science* 35 (1912): 357-362; and Clark, "Half Century of Presidential Addresses," 218.

⁷⁹ Rettger, "The Science of Bacteriology and its Relation to Other Sciences," *Journal of Bacteriology* 3 (1918): 103-104.

rudimentary methods, for “at the foundation,” bacteriology’s principles were as “scientific as those of any other branch of knowledge.” Rettger even specified areas for further study: “biological classification, variation, cell growth and metabolism, the response of microorganisms to stimuli, enzyme action, organic synthesis and decay, etc.” More pointedly, Rettger recommended the enlistment of tools from physiological chemistry. “Exhaustive chemical investigations into the composition of bacteria,” their “real food requirements,” and their “multitudinous products” would afford an understanding of how microorganisms assimilated food elements and incorporated them into their living cells.⁸⁰ Without such knowledge, the discipline would be limited to what bacteria do, rather than comprehending what they are in any biological sense.

Edwin G. Hastings, of the University of Wisconsin, returned to these broad themes in his presidential oration before the annual gathering in 1923. Hastings chastised anyone who might believe that “finality has been attained in some fields of study by our present methods of investigation.”⁸¹ Specifically, Hastings decried the predominant method of instruction, whereby a student examined each organism in isolation, scrutinizing its unique chemical or pathological transformations. The process was one of memorizing a “specific name” and its distinct behavior, yielding the impression that bacteriology represented nothing more than a compilation of culture recipes, organismic labels, and disconnected phenomena. Hastings beckoned the development of “general bacteriology,” or the study of processes common to larger groups of microorganisms.

⁸⁰ Rettger, “Science of Bacteriology,” 105-107. Rettger presaged the success of the Delft School of general microbiology, where physiologists outlined universal physiological processes, shared by microbes and higher life forms alike. See, C.B. van Niel, “The ‘Delft School’ and the Rise of General Microbiology,” Microbiological Reviews (1949): 161-174.

⁸¹ Hastings, “Some Questions of Method in Bacteriology,” Journal of Bacteriology 9 (1924): 96.

In order to facilitate this level of understanding, Hastings recommended the study of mixed cultures and associations, or “the complex life” of bacteria. Moreover, he pleaded with his fellow practitioners to be critical of even the most routine techniques. “If all interested in bacteriology are wide awake to the limitations of our tools, it will not be long before they are much improved and we shall feel more certain of the structures built within.” Hastings acknowledged that “research and practice are somewhat incompatible,” but insisted that this need not always be the case.⁸²

Like SAB leaders before him, Hastings considered his presidential address as a bully pulpit. His oration not only marked where the discipline had been, but outlined where it must go. These ceremonial speeches voiced a shared anxiety that bacteriology somehow lacked an adequate biological or fundamental component. The exact nature of that conceptual deficiency eluded the Society executives. Each struggled to provide a list of bacteriology’s shortcomings, and no two presidents agreed on a single set of solutions.

SAB’s Biological Steps

The Society of American Bacteriologists, during its first quarter century, considered several concrete measures to render bacteriology more biological. While they never reached a consensus as to what that would entail, SAB executives created committees for the promotion of pure research, for the reformation of undergraduate and graduate instruction, and for the founding of the *Journal of Bacteriology*. Each of these endeavors begged the question as to what *was the biology* in bacteriology. As such, their archival records lucidly portray the SAB’s

⁸² Hastings, “Some Questions of Method in Bacteriology,” 98-110.

struggle to identify what exactly their science required. In hindsight, the Society's efforts brought mixed results. The Committee on Research accomplished very little, and the Committee on Teaching issued recommendation after recommendation, without ever garnering full Society sanction. Only the *Journal of Bacteriology* realized lasting approbation. Nevertheless, even their self-acknowledged organizational inadequacies are instructive. What the Society desired is as revealing as what it actually accomplished.

The Committee on Research grew out of discussions at the 1919 meeting concerning a proposed affiliation with the National Research Council (NRC). John W.M. Bunker, a former instructor in sanitary analysis at Harvard and current assistant director of Digestive Ferments Company in Detroit (Difco), expressed a common sentiment regarding SAB meetings. Bunker recalled returning home from each SAB gathering "with enthusiasm" to explore the more promising aspects discussed. Then, "the pressure of (the) routine dims the memory and you forget all about it and many important bits of original work are buried when they should be developed." Bunker proposed that the SAB establish a committee charged with keeping "in mind things that come up from time to time; things that seem necessary to follow up." The Society could then serve as an institutional reminder, or clearinghouse, of cutting edge research topics, prodding members to remember what they ought not to forget. Moreover, this list would assist those bacteriologists unable to attend the SAB meetings. "Many institutions," Bunker reasoned, "are so handicapped financially and otherwise that it is not possible to have a representative at the annual gatherings of the Society."⁸³ SAB secretary A.P. Hitchens recalled

⁸³ Bunker, "Minutes of the 21st Annual Meeting, Dec. 29-31, 1919, Boston," [ASM] box 1-IVA, folder 3, pp. 13-14.

that the Society of Phytopathologists organized such an office, entitled the Committee on Research. Hitchens recommended that the SAB do the same, and that the chair of the committee be the Society representative to the NRC. This proposal is noteworthy because it declared that the SAB meetings honed the cutting edge of the science, a process so vital that every bacteriologist should be informed of its proceedings. Additionally, the proposal stood as a proclamation that the Society should not only report the work of its members, but actually encourage research along certain lines.

At the business meeting of the 1920 annual conclave, discussants debated the composition of the fledgling Committee on Research. Hastings originally intended for it to consist of past Society presidents, as they would be able to speak authoritatively to members of the NRC and other scientific societies. MIT's Samuel C. Prescott, the immediate past-president himself, advocated that this body include less senior members. Prescott doubted whether the NRC, or any other body, would ever supply monies. The SAB's stripling, therefore, ought to guide research already in progress, rather than lobby for improbable funds.⁸⁴

At the same SAB meeting, Lore A. Rogers, of the USDA's Dairy Division, spoke on "The Need for Research in Abstract Bacteriology." Rogers noted that "there was no laboratory devoted to the study of basic questions in bacteriology." In this regard, bacteriology differed "from other related sciences." Rogers envisioned a new laboratory, allied with either an existing university or a government site. The lab might equally be independent, similar to the Carnegie Institute's Geophysical Laboratory. In order to function, Rogers recommended four full-time

⁸⁴ "Minutes of the 22nd Annual SAB Meeting, Dec. 28-30, 1920, Chicago," [ASM] box 1-IVA, folder 4, pp. 12-13.

research staff members, and a budget of \$25,000. As for topics of investigation, Rogers named bacterial cytology (including life-cycles); the relation of bacteria to each other and to other organisms; taxonomy (particularly of those groups without economic importance); physiology and nutrition; adaptation to changing environments; and, the processes of anaerobic growth.⁸⁵

Rogers' ambitious proposal drew reserved responses. E.G. Hastings fully endorsed the plan, and speculated that the NRC would likely assist in such a laudable undertaking. Secretary A.P. Hitchens spoke more diffidently. Hitchens counseled that, in addition to sponsoring original research, such a bacteriological institution should serve as the Society's permanent headquarters, and house the American Type Culture Collections. Furthermore, Hitchens presaged the need for "a definite plan to submit to the National Research Council," and moved that the SAB appoint a five-member committee with Rogers as the chair.⁸⁶

There is no further record of Roger's committee. Instead, the next annual meeting (1921) voted to appropriate funds for a research fellowship in "pure bacteriology." In his report to the SAB membership, mailed after the close of the Philadelphia conference, Secretary Hitchens explained that:

... while excellent work is being carried out in many places, nearly all of the problems under investigation have as their aim a practical application and there are, therefore, many gaps in our knowledge of fundamental principles.⁸⁷

The fellowship promised to partly remedy this situation, as applicants were asked to pursue a "purely scientific and fundamental phase of bacteriology, although a certain latitude of choice

⁸⁵Rogers, "The Need of Research in Abstract Bacteriology," paper presented at the 22nd Annual SAB Meeting (1920), reprinted as "Preliminary Status of a Project for a Laboratory for Research in Abstract Bacteriology," *Abstracts in Bacteriology* 5 (1921): 1-2.

⁸⁶"Minutes of the 22nd Annual SAB Meeting," 6-7.

⁸⁷A.P. Hitchens, "Report of the Secretary upon the Philadelphia Meeting (1921) of the Society of American Bacteriologists," 27 March 1922, [ASM] box 1-VB, folder 1, p. 10.

will be permitted.” The only other stipulations were that the applicant hold a bachelor’s degree or higher, and be affiliated with an existing research institution. The stipend provided \$100 per month. In Hitchens’ estimation, the fellowship made manifest the SAB’s lasting commitment to do “more than hold annual meetings and publish journals.” The Society, in some small measure, was “trying to advance the science of bacteriology along the broadest of lines.”⁸⁸

The Fellowship Committee designated Ellen Armstrong, in 1922, for the research award. Unfortunately, in the time it took for the Committee to make its decision, she accepted another position. Afterwards, Hitchens, and the other SAB executives expressed their shared disappointment, and soon dissolved the committee, with the hope that Rogers would reintroduce his proposal for a Bacteriological Institute. By this time, Rogers was equally disillusioned, and made no effort to resurrect his ambitious scheme.⁸⁹ It would be another four decades before the SAB returned to the idea of funding bacteriological research. Nonetheless, this brief consideration demonstrates the Society’s willingness to directly alter the direction of the field.

The SAB sought to sculpt the discipline through another direct means. From its onset, the Society considered various formulas for revamping undergraduate and graduate instruction. Typically, these presentations and committee reports began by deploring the limited focus of bacteriological training. Students characteristically received only the briefest introduction to the rudiments of bacteriological technique and studied a mere smattering of common bacterial types. Those who pursued careers in bacteriology acquired the tools of their trade via an informal apprenticeship from a well-known practitioner. Society commentators repeatedly argued that

⁸⁸ Hitchens, “Report of the Secretary upon the Philadelphia Meeting,” p.10 & 2.

⁸⁹ “Minutes of the 24th Annual Meeting,” p. 4.

bacteriological instruction should provide a thorough understanding of the science.

Recommendations usually called for additional prerequisite courses in elementary sciences (*e.g.*, chemistry, physics, botany, math) and greater time for laboratory instruction (*i.e.*, three to five hours per week). For SAB commentators, these discussions of bacteriological instruction acted as a venue for articulating a vision of a more “biological” bacteriology, one less routinely technical, while more educationally expansive. As such, the several papers on bacteriological education, and the serial reports of the Committee on Teaching, reveal both a critical assessment of the discipline, and a vision for how it should be remedied.

Presentations on bacteriological instruction comprised a regular feature of SAB gatherings. At the 1st annual meeting (1899), Harvard’s Harold C. Ernst described some “Methods in the Teaching of Bacteriology,” in which he outlined his strategies for demonstrating techniques and apparatuses to classes of ten or more students. Francis C. Harrison, of Ontario’s Agricultural College, lead a brief review on “Classroom and Laboratory Instruction” before the 1905 annual meeting.⁹⁰ It was at the 1908 gathering, however, that the Society began to formulate its broader aims for bacteriological education. Hibbert W. Hill, then at the University of Minnesota, discussed “Bacteriology as an Important Non-Technical Study.” Hill lamented that few universities offered bacteriology as its own field of study. Instead, departments tethered instruction in other applied areas (*e.g.*, agriculture, medicine, sanitary engineering, *etc.*). Hill reasoned that since bacteriology presented many of the most important lessons of natural history and experimental science, it was as suitable for the “illustration of biological truths as any other

⁹⁰ Ernst, “Methods in the Teaching of Bacteriology,” paper presented at the 1st Annual SAB Meeting (1899); and, Harrison, “Notes on Classroom and Laboratory Instruction,” paper presented at the 7th Annual SAB Meeting (1905).

biological study now taught; and, from the control of the conditions possible, some phases of biology can be illustrated best by bacteriology.”⁹¹

Veranus A. Moore returned to the import of Hill’s pronouncements in his presidential address before the 1910 annual assembly. Moore, a Professor of Veterinary Pathology and Bacteriology at Cornell, echoed the disquiet of other SAB leaders. Bacteriology, Moore reminded his audience, held the “most sacred duty” to “ascertain the facts in the life history of microorganisms, to describe the laws governing them and to bring this knowledge into bold relief” Yet, the “bacteriological work that is being done at the present time is for the most part aimed directly” at some practical concern. Moore counseled that “this haste to apply new theories” invariably led to the premature application of findings with consequent distortions and misinterpretations. In Moore’s estimation, this harnessing of bacteriology to medicine and agriculture explained why “it has not reached its full development as an independent science.”⁹²

Regarding the Society itself, Moore insisted that “the essential purpose of this organization is to safeguard the purity of the science and to point out the way for its advancement.” Accordingly, the SAB held license to propose changes in curricula. As for specific remedies, Moore painted only broad strokes. In his opinion, instruction ought to be “dominated by a scientific system of presentation,” where the “laws of bacteriology” were clearly developed prior to the presentation of “fragmentary facts such as staining tubercle bacilli, or the examination of water for the colon bacillus.” Given its diversion to “practical lines,” there

⁹¹ Hill, “Bacteriology as an Important Non-Technical Study,” paper presented at the 10th Annual SAB Meeting (1908), abstracted in *Science* 29 (1909): 1013. Hill further contended that bacteriology was an ideal forum for teaching the principles of hygiene and sociology, claims that will be discussed in Chapter 7 of this thesis, “The Expertise of Germs.”

⁹² Moore, “Bacteriology in General Education,” presidential address before the 12th Annual SAB Meeting (1910), reprinted in *Science* 33 (1911): 277-278, & 282.

remained “too much specialization before there is a foundation of basic knowledge sufficient to support the superstructure.”⁹³ Moore did not identify the domain of laws and facts that would constitute a scientific presentation or superstructure. Instead, his address spawned the creation of a Committee on Microbiological Technique and Education.

Initially, the Committee conducted a comprehensive survey of bacteriological education in United States and Canada. MIT’s Samuel C. Prescott chaired the Committee, and delivered its preliminary findings to the annual meeting in 1911. The Committee mailed a questionnaire to some 550 institutions, and received 121 replies. The letter inquired as to the courses offered in bacteriology; the number of hours for lecture and laboratory work; year of instruction; target students; prerequisite courses; applied fields; and, textbooks and manuals used.⁹⁴ The report categorized the replies into five groups. Group I represented thirty-nine smaller colleges where brief instruction was given “from the standpoint of general education” usually connected with “courses in general biology, botany or hygiene given from the cultural rather than the professional standpoint.” These courses, taught by non-bacteriologists, typically included brief laboratory demonstrations concerning a few applied aspects. Courses in this group provided “only an introduction, and the student produced cannot be regarded as a trained bacteriologist.”⁹⁵

Group II included twenty-two institutions with one or two courses organized along “broader lines,” featuring more extensive laboratory work, and taught by a trained instructor. These offerings approximated introductory classes in chemistry, botany, or zoology. While

⁹³ Moore, “Bacteriology in General Education,” 281-282.

⁹⁴ Prescott, “The Teaching of Microbiology in Colleges of the United States and Canada,” *Science* 35 (1912): 362-362. Unfortunately, the actual 121 replies and the committee’s complete report are no longer extant.

⁹⁵ Prescott, “Teaching of Microbiology,” 364.

superior to instruction represented by Group I, these courses subordinated “the biology of bacteria as a group of living things” to the “examination of water for colon bacilli or the microscopical study of a few restricted types, such as the more common of the pathogens.” As such, the Group II colleges failed to “give the student a broad knowledge of the fundamental principles underlying bacteria’s behavior or activity.”⁹⁶

Group III encompassed twenty-eight institutions that, for the most part, met with the committee’s approval. Of these, some twenty-five universities featured a “well-rounded department of bacteriology and microbiology, with a central fundamental course in general bacteriology.” In most cases, these institutions also listed seminars in soil, dairy, sanitary bacteriology, “fermentation work and medical or public health work.” In contrast, Group VI described bacteriological instruction in ten well-known medical schools. The principal criticism centered on the Committee’s belief that in these medical classes, “the student loses sight entirely of the important general relations of the bacteria to human welfare” Medical graduates were likely to regard bacteria simply as pathogens “and never from the standpoint of industrial or economic value, or from the standpoint of general culture.” Curiously, the Committee disparaged instruction in medical colleges not on the grounds that it produced graduates with poor bacteriological technique, but rather that it produced graduates who believed that all bacteria were harmful. Group V consisted of engineering colleges that included a “smattering of bacteriology” as part of sanitary engineering and elicited a similar perfunctory dismissal from the Committee.⁹⁷

⁹⁶ Prescott, “Teaching of Microbiology,” 364.

⁹⁷ Prescott, “Teaching of Microbiology,” 365.

Prescott concluded the Committee's report with a plea for teaching the fundamental aspects of bacteriology, where the science was "placed upon a very broad biological and physiological basis," and where courses correlated with "training in physics, chemistry and mathematics." Like Moore's presidential address from the previous year, Prescott failed to detail specific recommendations, choosing instead to reiterate his conviction that "modern bacteriology includes far more than the microscopical [sic] examination and cultivation of a few pathogenic types."⁹⁸

Prescott and Moore's uneasiness largely hinged on the then-current method of teaching bacteriology, whereby students learned the rudiments of bacteriological technique and theory by culturing representative microbes, studying their particular characteristics, and finally identifying unknown cultures. Unavoidably, this instruction-by-example impeded a general understanding of the unifying principles of bacterial life. In most instances, students finished these courses with an adequate grasp of only those microbial exemplars and the groups that they epitomized. Organisms not included in the instructive inventory (*e.g.*, soil and dairy bacteria, saprophytes in general) escaped the pupils' comprehension. Moreover, laboratory cultures effaced the exploration of microbes in their natural environments (*i.e.*, serial behavior, associative actions, etc.) Prescott and Moore stumbled when faced with the task of posing alternative courses of instruction. What in fact were the alternatives? William T. Sedgwick, himself a long-time educator at MIT, pondered this question in an address at the dedication of the Carnegie Science Hall of Bates College. "Teaching," according to Sedgwick, "must forever recapitulate and epitomize the achievements" of the science. "Consciously or unconsciously it acts along the

⁹⁸ Prescott, "Teaching of Microbiology," 366.

lines of the biogenic law.”⁹⁹ The classroom laboratory reenacts famous experiments in order to inculcate methods, perspectives and problems:

. . . the modern college laboratory is not so much a workshop as a school room, in which selected natural phenomena, facts and processes may be conveniently, rapidly and successively demonstrated and enforced. It should provide at the outset an epitomized, easy and rapid recapitulation of the slow and laborious discoveries of the past, and thus somewhat resemble the museum of art or natural history which likewise affords examples or models of past achievement.¹⁰⁰

The difficulty lay in arranging these representative examinations in an “orderly fashion,” so that the student appreciated the underlying laws that explained the particulars.

University of Pennsylvania’s David H. Bergey returned to this topic for his presidential oration before the 17th meeting of the SAB (1915). Like the other commentators, Bergey was highly critical of bacteriological instruction. Bergey reasoned that the problem was explainable, given that most teachers remained interested “more in the practical application of a knowledge of bacteriology, than in the development of the educational importance of the subject.” In contrast, elementary instruction should “lay greater stress upon the broad fundamental biological principles involved . . .” Before a student enrolled in such a course, Bergey recommended that he or she have a general understanding of botany, zoology, plant and animal physiology, chemistry, and elementary physics. Only then could the pupil be in a “position to understand something of the biological relation of bacteria” to man and nature.¹⁰¹

Bergey urged that general bacteriology courses include at least twelve hours of classroom and laboratory instruction per week, an amount far greater than most colleges specified. Lessons

⁹⁹ Sedgwick, “The Interpretation of Nature and the Teaching Laboratory: An Address at the Dedication of the Carnegie Science Hall of Bates College, January 14, 1913,” *Science* 38 (1913): 172.

¹⁰⁰ Sedgwick, “The Interpretation of Nature,” 173.

¹⁰¹ Bergey, “The Pedagogics of Bacteriology,” presidential address before the 17th Annual SAB Meeting (1915), reprinted in *Journal of Bacteriology* 1 (1916): 5 & 8.

should, according to Bergey, begin with staining techniques, the isolation of bacteria in pure cultures, and the principles of determination. The student would be asked to recognize all ordinary forms, in part to avoid confusion from common contaminations. After mastering the basic methods, the instructor could present special exercises to illustrate "the relation of bacteria to decomposition, putrefaction, fermentation, nitrification, denitrification, and nitrogen fixation," as well as fermentation, water purification, dairy industries and food preservation. Within this idealized course, Bergey intentionally minimized the medical aspects of bacteriology.¹⁰²

Additionally, Bergey disparaged bacteriological instruction in medical schools. He maintained that it was "largely a waste of time to attempt to teach clinical bacteriology to a student who knows nothing about disease in general," and therefore recommended that bacteriology be moved from the second to the third year in the regular medical curriculum. Furthermore, Bergey advocated introducing an earlier "course in elementary bacteriology," taught by biology professors "who would develop the subject on a broad biological basis." Bergey reasoned that "with such a preliminary training in general bacteriology the medical student could then take up clinical bacteriology with much greater profit."¹⁰³

Bergey's proposals before the SAB seemed undoubtedly impractical, if not disingenuous. As a faculty member of the University of Pennsylvania's Medical College, Bergey knew that the medical curriculum had been recently revamped in light of the Flexner Report, and that the course load stood at full capacity. Adding a second course in bacteriology, to be given by

¹⁰² Bergey, "The Pedagogics of Bacteriology," 9-11. Bergey did acknowledge that no course was complete without at "least a brief introduction" to the relation of bacteria to plant and animal disease, as well as the implications for preventative medicine and hygiene, p. 11.

¹⁰³ Bergey, "The Pedagogics of Bacteriology," 12.

outside biology faculty was simply unrealistic. Nevertheless, Bergey intended only to provide the broadest outline for a "more biological" course of instruction. The specifics could be fleshed out, according to the departing SAB president, by a recrudescing Committee on Teaching.

The 1916 annual meeting featured the first full session on "Pedagogics," organized by Bergey, and comprised of fifteen full papers. Seven of these presentations were comparative in scope, offering descriptions of bacteriology as it was taught in agricultural, industrial, or medical colleges.¹⁰⁴ Four papers spoke to the common concern of teaching to increasingly large classes. John Weinzirl, of the University of Washington, described the disadvantage of having students prepare their own media in laboratory exercises. While there was much to be learned by careful assembling, mixing, and cooking of the culture ingredients, Weinzirl maintained that it required too much time, and recommended the use of ready-made culture media. Similarly, Jean Broadhurst, of Columbia University's Teachers' College, argued that demonstrations, given before entire lecture halls, could replace many of the exercises normally required in laboratory courses. Weinzirl and Broadhurst both sought to create greater room for lessons normally excluded from the typical bacteriology syllabus.¹⁰⁵

Of the remaining submissions, three papers argued that bacteriological instruction should become more biological. Iowa State's Robert E. Buchanan described "The Place of Systematic

¹⁰⁴ Leo F. Rettger, "The Teaching of Bacteriology in Scientific and Technical Schools," Ward Giltner and Walter L. Kulp, "The Pedagogics of Bacteriology from the Standpoint of Industrial Education," Charles B. Lipman, "The Pedagogics of Agricultural Bacteriology," T.D. Beckwith, "Bacteriology in an Agricultural College," W.R. Stokes, "The Teaching of Bacteriology in a Medical School," W.H. Manwaring and John T. Connell, "Animal Experiments Supplementary to an Introductory Course in Pathology," and, Hans Zinsser, "The Teaching of Immunity in the Medical Schools," papers presented at the 18th Annual SAB Meeting (1916).

¹⁰⁵ Weinzirl, "The Media Problem in Large Classes," and, Broadhurst, "The Demonstration as a Legitimate Part of Elementary Laboratory Work." See also, Arao Itano, "The Direction of Laboratory Classes in Microbiology," and, William W. Ford, "The Teaching of Bacteriology in a Medical School," papers presented at the 18th Annual SAB Meeting (1916).

Bacteriology and Bacterial Philogeny [*sic*] in the Teaching of Bacteriology.” In Buchanan’s estimation, taxonomic studies constituted the unifying principles of biological pursuits, and their inclusion in bacteriological courses would bring botanical and zoological interests to the fore. Harry A. Harding, of University of Illinois, delineated the “Problem of Teaching Dairy Bacteriology and the Lines of Demarcation between Dairy Bacteriology as Such, and the Subject of City Milk Supplies.” Harding remonstrated that training in milk sanitation was too often confused with instruction in dairy bacteriology. The former taught students methods of preventing milk contamination, while the latter imparted the principles of enlisting microbial life to manufacture dairy products.¹⁰⁶ MIT’s Samuel Prescott and Edward A. Ingham advanced an equally sweeping indictment. The presenters chided the lack of “general courses” in bacteriology, insisting that referring to the typical pathology syllabus as “bacteriology” would be analogous to regarding a class in animal parasites as “zoology.” Prescott and Ingham maintained that in any introductory survey, bacteria “should be considered as a biological group and their distribution, morphology, and physiology studied.”¹⁰⁷

Despite the several calls for a thorough course in “general bacteriology,” the 1916 session did not produce an exemplary syllabus. In fact, when the SAB returned to the topic of pedagogics at the next annual meeting, the only program inclusions were Jean Broadhurst’s short discussion of blue-prints as illustrative material for laboratory classes, and Zae Northrup’s survey

¹⁰⁶ Buchanan, “The Pedagogics of Systematic Bacteriology: The Place of Systematic Bacteriology and Bacterial Philogeny (*sic*) in the Teaching of Bacteriology,” and, Harry A. Harding, “The Problem of Teaching Dairy Bacteriology and the Lines of Demarcation between Dairy Bacteriology as Such, and the Subject of City Milk Supplies,” papers presented at the 18th Annual SAB Meeting (1916).

¹⁰⁷ Prescott and Ingham, “Comments on the Scope of a Course in General Bacteriology,” paper presented at the 18th Annual SAB Meeting (1916).

of ninety-two college catalogues for courses teaching bacteriology.¹⁰⁸ Within the "General and Technical" session of the 21st meeting (1919), Bergey sketched an introductory course in systematic bacteriology, one so rudimentary as to offer very few innovations for others to adopt.¹⁰⁹ If SAB members shared a dissatisfaction with bacteriological instruction in the 1910's, they did little to remedy the problem.

The Society's willingness to refashion bacteriological education found expression in the actions of the 1921 gathering. At this meeting, Charles A. Hunter, of Penn State College, appraised "General Bacteriology in the Curriculum" of agricultural and industrial education. In this deliberation, Hunter posed a few rhetorical queries:

Are not some of the experiments now given practically worthless? Are we giving all the essential experiments we should? Could not laboratory work be better organized so that the experiments would be more thoroughly planned and the desired points thus illustrated to better advantage?¹¹⁰

In his own review of forty-three courses in bacteriology, Hunter reported a hodgepodge of curricular components. Hunter proposed that the SAB "take immediate steps" to reestablish a Committee on Teaching of Bacteriology. Furthermore, Hunter counseled that a "considerable portion of one session of our annual meetings be devoted to papers and discussions pertaining to the teaching of courses in bacteriology."¹¹¹

The meeting concluded with the appointment of the Committee, with University of

¹⁰⁸ Jean Broadhurst, "Blue Prints as Illustrative Material for Classes in Bacteriology," and Zae Northrup, "Comparative Study of Courses in Bacteriology in the United States," papers presented at the 19th Annual SAB Meeting (1917). There is no extant copy of Northrup's report, only a short summary statement that "the correlation of this data present some interesting facts."

¹⁰⁹ Bergey, "The Teaching of Elementary Systematic Bacteriology," paper presented at the 21st Annual SAB Meeting (1919), summarized in Abstracts in Bacteriology 4 (1920): 1.

¹¹⁰ Hunter, "General Bacteriology in the Curriculum," paper presented at the 23rd Annual SAB Meeting (1921), summarized in Abstracts in Bacteriology 6 (1922): 12.

¹¹¹ Hunter, "General Bacteriology in the Curriculum," 12.

Pennsylvania's David H. Bergey chosen as its chair. Other members included Hunter, Fred W. Tanner of the University of Illinois, Brown University's William W. Browne, and Charles E. Marshall of the Massachusetts Agricultural College. The Committee delivered its first report to the 1922 annual meeting, summarizing yet another survey of this country's bacteriological instructors. Among the nearly seventy responses, a majority favored the development of a general bacteriology course suitable for all university students, regardless of their major or college affiliation. The Committee acknowledged that there was no agreed upon curricula for this general course and pointed to a dismaying lack of adequate textbooks. Most instructors employed their own, mimeographed, laboratory manuals, and rarely followed curricular outlines of popular textbooks. Moreover, the respondents agreed that "in general too little attention is given to general bacteriology and too much stress laid upon applied bacteriology." These same instructors recognized that their advanced, and specialized, courses would be more efficient if all students had "taken the same general course in bacteriology which covered the fundamentals of the science."¹¹²

Bergey then described a "Course in General Bacteriology," to be offered to all students "regardless of their subsequent continuation of the subject along more specialized lines." Bergey maintained that in order for this course to "include some reference to the relation of bacteriology to life in general," the student must enroll with a working knowledge of general biology, elementary physics, and organic chemistry. Instruction began with the elemental techniques of handling bacteria, staining, microscopic examinations, and the simpler methods of cultivation, in

¹¹² Bergey, "Investigations on the Teaching of General Bacteriology," reported in the "Minutes of the 1922 Annual Meeting of the SAB," [ASM], box 1-IVA, folder 5, pp. 17-20.

order that the student observe the “various morphologic types of bacteria.”¹¹³ The student would then be asked to “isolate and study, in detail,” organisms obtained from the air, soil, water, milk, and animal bodies, in order to gain “some insight into the distributions and functions of the bacteria,” aside from those traditionally given in lectures and texts. In addition, Bergey suggested that the student be shown “the influences of environment upon the life and activities” (e.g., light, moisture, temperature, oxygen supply, pH, and surface tension).¹¹⁴

Thus far, Bergey’s course was in fact very “general,” providing only marginally novel suggestions. Where Bergey diverged from the common introductory format was in his emphasis on bacterial enzymes. Believing that enzymatic action constituted the bulk of bacterial phenomena, Bergey advised that the student carry out various tests to “demonstrate the presence of enzymes in cultures, the substances attacked, and the metabolic products formed by different bacteria.” In this manner, the student could witness not only the action of pathogens and the practice of immunization, but also the “carbon, nitrogen, sulphur and phosphorus cycles” of soil bacteriology, and the “utilization of enzyme action of bacteria in industry.” In Bergey’s opinion, the fundamental aspects of bacteriology were best imparted through the biochemical investigation of bacterial enzymes.¹¹⁵

At the conclusion of Bergey’s presentation, the Committee Chair proposed a rather audacious motion: that the SAB issue an “outline of subject matter to be covered in lectures and discussions, and experiments to be carried out in the laboratory by each student, this is to be

¹¹³ Bergey, “Course in General Bacteriology,” reported in the “Minutes of the 1922 Annual Meeting of the SAB,” [ASM], box 1-IVA, folder 5, pp. 21-23.

¹¹⁴ Bergey, “Course in General Bacteriology,” 24-25.

¹¹⁵ Bergey, “Course in General Bacteriology,” 25-26.

designated as the 'Standard Course in General Bacteriology'." The motion carried, albeit with an unexplained objection from one of the Committee members.¹¹⁶ The Committee reported again at the 25th annual meeting (1923), indicating that it had begun to develop course outlines. In sweeping terms, they imagined the class to be comprised of three parts: 1) lectures on the "principle phases of general bacteriology," 2) daily laboratory exercises covering the principal techniques and methods, as well as "the general distribution of bacteria in nature, the common bacterial flora of certain environments, and the various activities of bacteria in nature," and, 3) a course of supplemental reading from five textbooks, largely covering "certain special phases" of the field. The Committee offered to make copies of the course outlines available, once completed, and recommended a round-table discussion for the following year. Response from the SAB membership was tepid, with the Executive Council choosing to postpone the round-table until after the courses were finished and widely distributed.

Separately, Elizabeth Genung, of Smith College, discussed "Some Problems in Teaching Bacteriology," particularly within liberal arts colleges. "In these colleges," Genung explained, "bacteriology is somewhat erroneously considered a technical science, whereas it is a truly cultural subject since it gives the student valuable training and information." Nonetheless, bacteriological instruction remained limited in most liberal arts colleges by a lack of laboratory assistants, the expense of materials, and the choice of pre-requisite courses. Genung entreated the Committee members to consider the liberal arts student, and construct a curriculum that would interest both technical and non-technical pupils.¹¹⁷

¹¹⁶ "Minutes of the 1922 Annual Meeting," 27. Charles E. Marshall opposed the motion.

¹¹⁷ Genung, "Some Problems in Teaching Bacteriology," paper presented before the 25th Annual SAB Meeting (1923), summarized in Abstracts in Bacteriology 8 (1924): 1-2.

The Committee adopted a new moniker at the 1924 annual meeting, the "Committee on Bacteriological Education," but did not submit its course outlines, which were still being "tested out" by select Society members. Bergey inquired whether the Society could publish the final report, possibly in its *Journal of Bacteriology*. To his surprise, no motion was proposed. When two SAB members suggested, at the Business Meeting, that the SAB officially sanction a "standard course" in general bacteriology, the reaction confirmed Bergey's increasing worries. In the span of just two years, the SAB Executive Council and membership cooled to the idea of a uniform curriculum, even at the elementary level. For many SAB members, standardization jeopardized one of the Society's great strengths, the diversity of its practitioners. Homogenization risked the loss of innovation, to say nothing of the likely rejection by members whose specialty was not fully represented in the course material. After nearly two decades of intermittent attention, the SAB chose not to legislate bacteriological education. The Committee would continue, but only to "suggest" revisions to render instruction more fundamental and thorough.¹¹⁸

In contrast to the unfulfilled efforts of the Committee on Bacteriological Education, the Society concretely influenced the course of the discipline through its founding and management of the *Journal of Bacteriology*. The notion of a society publication first arose at the inaugural meeting of the SAB (1899). While several members tendered suggestions at that time, the Society took no action, choosing only to consider the issue at the next gathering.¹¹⁹ For the 1900 annual meeting, the program included a scheduled discussion, led by McGill University's Wyatt

¹¹⁸ James M. Sherman, "Minutes of the 27th Annual Meeting, 1927," [ASM], box 1-IVA, folder 7, pp. 13-15.

¹¹⁹ See, J.R. Porter, "History of the Journal of Bacteriology," *ASM News* 40 (1974): 585-595.

Johnston, concerning "An American Bacteriological Journal." In the months preceding this conclave, the Executive Council solicited opinions from the likes of William T. Sedgwick, Frederick D. Chester, Herbert W. Conn and Frederic P. Gorham. Nonetheless, at the conclusion of the meeting, the SAB again failed to take action.

The Society returned to the topic at the 1902 gathering, where Chester submitted a motion to create a Committee on the Publication of a Journal. The subsequent year, William T. Sedgwick delivered the Committee's report to the 1903 meeting. While that report is no longer extant, its contents might be inferred, as the Society voted to terminate the Committee's activities. Despite this organizational abjuration, the idea persisted. Speaking before the 1903 meeting of the American Public Health Association, Wisconsin's Harry L. Russell maintained that "the establishment of a medium of publication that would especially embrace the activity of American work would undoubtedly be of great service in bringing a more complete knowledge of American investigations to all American workers." While the SAB chose not to sponsor such a journal on its own, Russell "hoped that the representative bacteriological societies in this country may agree on some feasible plan which will result in the consummation of this project."¹²⁰ Russell's call went unanswered for another dozen years.

The Society made the decision to publish the *Journal of Bacteriology* at the 17th annual meeting (1915), held in Urbana, Illinois. Unfortunately, there remain few records chronicling the events preceding the formal resolution. The documents that do remain suggest that the plan for a *Journal* emerged from the efforts of secretary A.P. Hitchens, past-presidents Winslow, Bergey,

¹²⁰ Russell, "Development of American Bacteriology," 337.

and Conn, and current president T.J. Burrill, from the University of Illinois.¹²¹ Hitchens, in particular, was “commonly in favor of any expansive practices,” and it was he that presented the proposal to the Urbana meeting.¹²² While the majority of members voted in favor of the plan, “there were a number of people who objected,” mostly on the grounds that there were “more than enough scientific journals and there would be no place for this new journal.” Others feared that the undertaking was “sure to be a financial failure.”¹²³ Regarding the first hesitation, a few members, such as Wisconsin’s Paul Clark, favored some collaboration with the *Journal of Infectious Diseases*. Even the *Journal of Bacteriology*’s preselected editor, C.E.-A. Winslow, indicated that he wished to confer with E.O. Jordan, who edited the *Journal of Infectious Diseases* for the McCormick Institute in Chicago. Winslow was not only concerned about unnecessary duplication, but feared insulting his friend and former SAB president.¹²⁴

Despite these reservations, Hitchens and Burrill persuaded SAB leaders to put the question to a Society-wide, mail-in vote. Publication of the *Journal* required both a change in the SAB’s constitution and an increase in annual membership dues from \$2 to \$5.¹²⁵ Two weeks after the close of the 17th meeting, a tally indicated eighty-six favorable replies to ten against. Of those who opposed the *Journal*, three were members of the Rockefeller Institute, and Hitchens reasoned that they may have voted to protect the Institute’s *Journal of Medical Research*.¹²⁶ Two

¹²¹ Porter, “History of the *Journal of Bacteriology*,” 586.

¹²² James M. Sherman, Ithaca, to J.R. Porter, Iowa City, 28 March 1956, reprinted in Porter, “History of the *Journal of Bacteriology*,” 586.

¹²³ Sherman, to Porter, 28 March 1956, reprinted in Porter, “History of the *Journal of Bacteriology*,” 586.

¹²⁴ Paul F. Clark, Madison, to J.R. Porter, Iowa City, 5 April 1956, and Winslow, New Haven, to A.P. Hitchens, Glenolden, 6 November 1915, both reprinted in Porter, “History of the *Journal of Bacteriology*,” 588 & 586.

¹²⁵ Burrill stressed that *Journal* was instrumental to the growth and influence of the SAB. Porter, “History of the *Journal of Bacteriology*,” 588.

¹²⁶ A.P. Hitchens, Glenolden, to C.E.-A. Winslow, New Haven, 15 January 1916, [ASM], box 4-IIA, folder 11.

days later, the count stood at one hundred and thirty-three in favor, and sixteen opposed. More worrisome, however, was Simon Flexner's resignation from the society, followed by other medically minded bacteriologists (*e.g.*, Alphonse R. Dochez, Peyton Rous, George H. Weaver, and William B. Wheery). The desertions did not deter Hitchens efforts, who quipped, "... I am certain a great many others will come in and the loss will be more theirs than ours." The Secretary estimated that between fifty and one hundred members would leave the Society, but predicted that the publicity of the *Journal* would encourage one hundred and fifty new members to join. Moreover, Hitchens' reasoned that departing likely represented "men interested exclusively in medical bacteriology, or those practically not interested in bacteriology," who were no more than "dead wood in the Society."¹²⁷ Even as mail-in ballots continued to arrive, and the final outcome had not yet been determined, Hitchens entered into negotiations with the Williams and Wilkins Company to publish the new journal.¹²⁸

In private, Hitchens harbored less confidence. The Secretary understood that "from the standpoint of our society, 75% of our active members would be interested in a small section" of the *Journal*.¹²⁹ This, Hitchens understood, was an inherent limitation of a diverse organization. He wrote to all who objected to the *Journal* or tendered their resignation. Hitchens personally visited the Rockefeller Institute, expecting to face a "somewhat chilly" reception from Flexner

¹²⁷ Hitchens, Glenolden, to Winslow, New Haven, 26 March 1916, [ASM], box 4-IIA, folder 11, and Hitchens, to Julius H. Frandsen, Amherst, 12 October 1916, [ASM], box 4-IIA, folder 12.

¹²⁸ In January of 1916, Hitchens conferred with John J. Abel, who helped found both the *Journal of Biological Chemistry* and the *Journal of Pharmacology and Experimental Medicine*. Abel knew Williams & Wilkins well, and the publishing company also issued the *Journal of Immunology* and *Soil Science*. Williams & Wilkins agreed to underwrite the *Journal of Bacteriology*, at 500 pages per year. If there were any profits, 60% would go the SAB and the remainder to the publisher. See, Porter, "History of the *Journal of Bacteriology*," 589; and, William M. Passano, Jr., "A Brief History of the Williams & Wilkins Co. and its Relationship with the American Society of Microbiology," *ASM News* 40 (1974): 5-7.

¹²⁹ Hitchens, Glenolden, to Winslow, New Haven, 13 July 1916, [ASM], box 4-IIA, folder 12, p.2.

and his research staff. Instead, Flexner, Hideyo Noguchi, Rufus Cole, and Harold Amoss, received him warmly, pledging their support to the new journal and offering, curiously, to rejoin the SAB.¹³⁰

During the first weeks of 1916, Hitchens and Winslow endeavored to place their fledgling publication on firm ground, conscripting associate editors from across the many specialties of bacteriology.¹³¹ The first issue of the *Journal of Bacteriology* appeared in April of 1916 (although dated January) and drew heavily from the December 1915 SAB meeting. William T. Sedgwick, by now an elder statesman of the Society, penned the “Forward” to the inaugural number, entitled “The Genesis of a New Science.” In the essay, Sedgwick reasserted his belief that, “Bacteriology must henceforward be recognized as a *broad* and *fundamental* science.” As such, the *Journal* “shall cover the whole field and be devoted to the subject in its broadest sense. The time is forever gone by when [*sic*] bacteriology can be regarded merely, or even chiefly, as the handmaiden of medicine or pathology.”¹³² During this formative period, Hitchens and Winslow took pains to ensure the catholic scope of the *Journal*, actively soliciting abstractors and editors from such reaches as “mycology and protozoology in their relations to the arts and sciences.”¹³³ In an advertising circular dispatched to several colleges and libraries, the publisher and editors announced:

¹³⁰ Hitchens, Glenolden, to Winslow, New Haven, 30 January 1917, [ASM], box 4-IIA, folder 12.

¹³¹ Of the twenty-two associate editors, seven worked in medical or public health fields (e.g., Charles Bass, Paul Clark, Frederick Gay, Hibbert Hill, Milton Rosenau, Anna Williams, and Hans Zinsser), seven from sanitary science (e.g., Herbert W. Conn, Frederic Gorham, E.O. Jordan, A.I. Kendall, Mary Pennington, Earle B. Phelps, and William T. Sedgwick), five from productive bacteriology (e.g., Robert E. Buchanan, Francis C. Harrison, Charles Lipman, Charles Marshall, and Lore A. Rogers), two from veterinary science (Veranus A. Moore and Leo Rettger), and one plant pathologist (Frank L. Stevens).

¹³² Sedgwick, “The Genesis of a New Science – Bacteriology,” *Journal of Bacteriology* 1 (1916): 4, emphasis added.

¹³³ Hitchens, Glenolden, newsletter to SAB Members, 9 February 1917, [ASM], box 1-IVB, folder 1.

The *Journal of Bacteriology* is the only publication in the English language devoted to the broader aspects of this science -- its relation to pathology and clinical medicine; botany; agriculture; industrial processes; sanitation, including water and sewage; immunity; phytopathology; protozoology and pedagogics The broad lines of the *Journal's* development will be of every interest to the practitioner and student, as well as the scientist.¹³⁴

Not every issue of the new *Journal* reached this expansive standard. The third number, for example, featured articles on milk sanitation, biologics, anaerobic pathogens, and culture media for gonococci. Strikingly absent were submissions in soil, dairy or plant bacteriology, to say nothing of papers on microbial classification or ecology.

Nevertheless, the *Journal* blossomed during its first years, both in scientific breadth and circulation. Hitchens and Winslow mailed the premiere issue to editors of other journals, soliciting advice and reviews.¹³⁵ By August of 1916, the *Journal of Bacteriology* boasted more than 500 total subscribers, with 192 pledged from non-SAB members. Three years later, the aggregate circulation exceeded 1,300.¹³⁶ The *Journal's* content similarly fulfilled its promise, at least after its initial volumes. For the year 1918, the *Journal* published forty-nine papers, of which four were in medical or public health bacteriology, fourteen in sanitary science, four from veterinary perspectives, and three in productive bacteriology. In addition, this third volume contained twenty-four papers, or nearly half, in general and technical bacteriology, comprised of

¹³⁴ Advertising copy conveyed in Charles C. Thomas, Circulation Manager, Williams & Wilkins Co., Baltimore, to Winslow, New Haven, 12 October 1916, [ASM] box 4-IIA, folder 14. A later circular, written by Winslow and Hitchens, read, "The fact that it is devoted in particular to the broader phases of the subject -- to problems of classification, of physiology, of laboratory technique and of ecology, which are of fundamental interest to all bacteriologists -- makes it indispensable to workers in every branch of the science." [ASM], box 4-IIA, folder 14.

¹³⁵ For one of the highly favorable reviews, see *Lancet* 2 (1916): 64.

¹³⁶ Hitchens, Glenolden, to Winslow, New Haven, 4 August 1916, [ASM], box 4-11A, folder 12. The Secretary reported five new applications, on average, per week. Hitchens, Glenolden, to Winslow, New Haven, 3 November 1917, [ASM], box 4-IIA, folder 9.

thirteen contributions in taxonomy, three in bacterial nutrition and metabolism, two on Society matters, and six describing new equipment or techniques. Its editors could rightly claim that their periodical advanced bacteriology in its broadest, and most fundamental sense.¹³⁷

Administratively, the *Journal of Bacteriology* presented few intractable problems. During its initial decade, the *Journal* turned a profit, albeit modest. Editor Winslow, for his part, continued to solicit articles and authors, thereby avoiding high rejection rates.¹³⁸ Winslow's chief complaint concerned the *Journal's* limited space. Williams and Wilkins agreed to publish between 600 and 700 pages a year. In light of the high acceptance rate, Winslow noted that each year ended with a large number of "papers on hand." Moreover, by 1921, the *Journal* carried a three year backlog for publication. As a consequence, Winslow was compelled to reject several worthy papers, "many of which really belong in our journal."¹³⁹ At the 1923 annual meeting, Winslow reported that submissions to the *Journal* dropped dramatically, explaining that authors "do not send papers to us if they know they are not going to get early publication."¹⁴⁰

In an effort to alleviate the backlog, Winslow and the Society officers contemplated another journal for "technical" or "applied" bacteriology. Winslow eventually thought better of the idea, believing that it would be "wiser to broaden the scope of the *Journal of Bacteriology* and issue it monthly," as opposed to bimonthly. Winslow's sentiments were echoed by Johns

¹³⁷ Within its first ten volumes, the *Journal* carried "exhaustive studies of the nutritive requirements, the amino-acids, salts, the vitamins [sic], and the various analysis of the organic materials which were synthesized or decomposed by bacteria." Winslow, "First Forty Years of the Society of American Bacteriologists," 127.

¹³⁸ Annual profits ranged from \$463.77 in 1917, to \$1,613.88 in 1924. "Final Summary of the *Journal of Bacteriology* and *Bacteriological Reviews*," no date, [ASM], box 4-IIA, folder 9. For rates of rejected and accepted articles, see, Porter, "History of the *Journal of Bacteriology*," 592.

¹³⁹ Hitchens, "Secretary's Report, Minutes of the 24th Annual SAB Meeting," 28 December 1922, [ASM], box 1-IVA, folder 5, p. 1.

¹⁴⁰ James M. Sherman, "Secretary's Report, Minutes of the Annual Meeting, 1923," [ASM], box 1-IVA, folder 6, p. 5.

Hopkins bacteriologist William Ford, then a member of the SAB's executive council, who "felt that applied bacteriology should be not separated from general bacteriology, and since all phases of bacteriology were so closely allied it was unwise to separate bacteriology into too many phases."¹⁴¹ The editor's plan betokened wishful thinking. Williams and Wilkins refused to add another 450 pages per year to the *Journal*, at least not without a proportionate increase in the subscription cost. The Society, in turn, declined to raise its annual dues to accommodate the expanded *Journal*. Winslow found that his vision of a publication devoted to bacteriology "in its broadest sense" had to bow to the realities of SAB and its publisher. For the time being, Winslow could not publish all the worthy papers "which really belong" in the *Journal*.¹⁴²

The SAB did take one step to alleviate the burgeoning contents of the *Journal of Bacteriology*. In the *Journal's* first volume, 127 pages (out of the nearly 500 total pages) were devoted to abstracted papers presented at the SAB meeting, or to papers published in other journals. In Hitchens and Winslow's opinion, this was a doubly disappointing effort. In the first place, the abstracts occupied pages otherwise consigned to original research. In the second, 127 pages of abstracts, no matter how well-chosen, could only minimally represent the burgeoning domain of bacteriology. In December of 1916, at the 18th annual meeting, Hitchens proposed another publication, *Abstracts of Bacteriology*. Noting comparable journals in other disciplines, the Secretary petitioned the entire Society membership to give unanimous consent to the

¹⁴¹ Reported in "Minutes of the Annual Meeting, 1923," pp. 5-6. For the original inception of the plan for the new journal, see, Sherman, "Circular to SAB Members," 12 November 1923, [ASM], box 2-IXC, folder 5, pp. 4-5.

¹⁴² These realities did not lessen Winslow's persistent appeals. In 1922, for example, Winslow and Hitchens argued that "the society is interesting itself in many enterprises which have for their aim the advancement of bacteriology, but none is more important than that of having a journal of such size that it can contain a large proportion of the important new work being reported." Hitchens, "Secretary's Report, 1922," 1.

undertaking. Unlike the *Journal of Bacteriology*, subscription to *Abstracts* was not obligatory of SAB members, although the SAB offered its affiliates a discounted subscription rate.

The *Abstracts* resembled the *Journal* in one important respect, the breadth of its analytic scope. The “Forward” to *Abstracts of Bacteriology*, written by Hitchens and associated editor George H. Smith, of Yale University, underscored both the growth and importance of bacteriology:

From the study of a few obscure diseases, the subject has expanded until it covers the entire field of human activity. From a pure science it has broadened to include every branch of applied science. All procedures, medical, agricultural, industrial, recognize the value of bacteriological technic or information.¹⁴³

Hitchens and Smith further asserted that bacteriology was increasingly valued as a “pure science.” Conjoined with “the older science, chemistry, bacteriology is approaching more and more closely the solution of the mystery of life.” Still, bacteriology was not “yet an exact science.” Lacking well-grounded methodological “traditions,” the science manifest errors of “youthfulness.”¹⁴⁴ *Abstracts of Bacteriology* offered two remedial measures. It allowed bacteriologists access to research across the entire compass of their science, vetting methods and theories beyond their own sphere of specialized interests. Additionally, *Abstracts* constituted an ideal forum for “preliminary announcements concerning work in progress, especially if it is an important advance to which the investigator has every right to claim priority.” Such immediate publication benefitted not only the innovator, but the entire field which could quickly assimilate novel methods and findings.¹⁴⁵

¹⁴³ Hitchens and Smith, “Forward,” *Abstracts of Bacteriology* 1 (1917): 1.

¹⁴⁴ Hitchens and Smith, “Forward,” 1-2.

¹⁴⁵ Hitchens, “Newsletter to SAB Members,” 24 January 1921, [ASM], box 2-IXC, box 4.

Unfortunately, *Abstracts of Bacteriology* never met Hitchens' aspirations. Financially, the publication proved nearly ruinous, accumulating considerable debts. Subscription rates fell far short of that for the *Journal*. More damning was the *Abstracts'* own form of backlog. Rather than publishing synopses of the latest research and reports, *Abstracts of Bacteriology* printed summaries from articles more than a year old, in some cases three years prior. In 1924, Hitchens admitted that this Society serial did not prove "as useful as an abstract journal ought to be and it comes nowhere near serving its function." At the end of the next year, the SAB ceased publication of *Abstracts of Bacteriology*, offering instead to assist in the task of including bacteriology within the unaffiliated *Biological Abstracts*.¹⁴⁶ It would be another decade before the Society endeavored to found a second periodical (*Bacteriological Reviews*), relying instead on its *Journal* to embody its collective vision of a "broad" and "fundamental" bacteriology.¹⁴⁷

Anxiety as a Productive Force?

The Society of American Bacteriologists originated with three principal aims: first, to bring together a diverse assembly of researchers; second, to promote "the science of bacteriology" through the shared demonstration and discussion of bacteriological methods and subjects of common interest; and third, to "emphasize the position of bacteriology as one of the biological sciences." As SAB leaders soon discovered, fulfillment of the first two did not necessitate the attainment of the third. During its first quarter century of existence, Society

¹⁴⁶ William C. Steere, "Abstracts of Bacteriology, 1917-1925," 18 April 1975, [ASM], box 4-IIA, folder 7, pp. 8-9.

¹⁴⁷ See, R.N. Doetsch and R.G. E. Murray, "Historical Notes on *Bacteriological Reviews*," *ASM News* 40 (1974): 2-3; and Einer Leifson, "A Proposal for the Establishment of a New and Different Type of Journal in Bacteriology," circa 1932, [ASM], box 4-IA, folder 3.

membership swelled, and the annual meetings drew increasingly greater numbers of attendants. By 1924, the SAB could boast of its own journal, official recognition by the AAAS and the National Research Council, and gatherings that routinely featured a hundred presented papers. Yet, its leaders recurrently articulated the same set of anxieties, that bacteriology remained a collection of unrelated techniques and methods, that it lacked those fundamental concepts that would render it *biological*. Neither the sheer size of the Society, nor its organizational accomplishments could soothe this persistent disquiet.

The lingering anxiety might be interpreted in a number of ways. Initially, one could view the SAB efforts as regrettably flawed. Certainly, hindsight allows us to recommend alternative paths for the Committee on Teaching or the Committee on Research. Neither body displayed the tenacity to lobby for directed Society action. Instead, their tentative proposals proved easy to dismiss. It is equally possible to imagine actions not contemplated by the SAB, be they smaller gatherings and workshops, the pre-circulation of general papers, printed discussions, etc. Undeniably, the SAB did not exhaust all alternatives. Its leaders might rightfully be accused of being too timid, or its membership too reticent. Given the estimable goal of transforming bacteriology into a truly biological science, the SAB's actions appear remarkably prosaic.

Alternatively, one could judge the SAB's ambitions as simply unrealistic. Scientific societies, one might argue, rarely perform the kind of disciplinary work required to forge a body of shared fundamental concepts. The core theories of a science, this line of reasoning suggests, emerge organically, through informal deliberations among loose research networks. Moreover, bacteriology suffered from its own unique limitations. It remained, unavoidably, a science defined by technical manipulations of microbes in particular applied contexts. Bacteriology's

diversity comprised both its nature and its strength. The exponential growth of the discipline, measured in numbers of practitioners and institutional locations, testify to the social sanction of bacteriology's utilitarian predilections. The exhortations of SAB presidents and committee chairs inevitably fell on some deaf ears. For the bacteriologist performing routine examinations in public health departments, medical colleges, agricultural experiment stations or fermentation plants, what return could they anticipate from the uncertain explorations of bacterial cytology, biochemistry, systematics, or genetics? If the Society membership ignored the call to fundamental arms, who could blame them? The disciplinary anxiety, one might posit, spread only among those who did not bear the burden of performing daily, mundane, bacteriological examinations. The likes of Frederic P. Gorham, Leo Rettger, and David H. Bergey, as department chairmen and senior researchers, could afford to dwell on the status of bacteriology as a biological science. Freed from the obligation of innumerable throat cultures, tubercle stains, and water samples, these senior researchers alone fretted over the biological status of bacteriology. Their annual ceremonial exhortations sounded as disciplinary whistling in the dark. They spoke of the ideal, and the imagined, not the practical and likely.

This chapter pursued a third tack, one suggesting that disciplinary disquiet, can in some circumstance be productive. The Society leaders endeavored to move the science of bacteriology beyond its eclectic collection of technical procedures. That SAB leaders continued to voice discontent does not imply that organization's efforts produced little effect. In fact, the preceding pages demonstrated that these Societal anxieties cast a collective spotlight in search of bacteriology's missing conceptual or theoretical elements. The shared uneasiness fostered an enduring commitment to discerning the "general" components within the "General and

Technical” meeting sessions. It lent weight to presidential appeals to studying bacterial physiology, cytology, genetics and systematics. It fueled the critical reviews of the Committees on Teaching and Research. And, it explained the curious selectiveness among the editors of the *Journal of Bacteriology*. The process of critical examination may have allowed the SAB to advance conceptual growth in bacteriology. While the discipline never lived up to the lofty standards of Gorham, Rettger, Bergey and others, the Society did manage to highlight those aspects likely to be forgotten in the conduct of routine procedures. In this manner, the SAB fostered the development of a more fundamental, if not biological, bacteriology.

CHAPTER FIVE

CHARTING THAT BACTERIA – THE SOCIETY’S CARD AND STANDARD METHODS

The preceding chapter considered the two enduring questions that faced the Society of American Bacteriologists (SAB) in the first decades of this century: Who are bacteriologists and what is bacteriology? These examinations of identity were addressed directly by the selection of members, the composition of executive councils, the programs of annual meetings, the committees on research and teaching, and the pages of the *Journal of Bacteriology*. A third, and more central, question faced each and every bacteriologist of the period: What is *that* bacteria? The determination of unknown cultures, this chapter maintains, comprised the central shared activity of bacteriology. It might have been the only common practice among all bacteriologists. It constituted *both* the most mundane and most difficult aspects of the discipline, and the Society, from its inception, sought to aid in that pervasive task.

Between 1905 and 1924, SAB committees produced five editions of the “Society’s Card,” a determinative chart which enabled a practicing bacteriologist to identify unknown cultures. Although the SAB declined to formally sanction the card as its “official methods,” nearly every bacteriologist employed the card. By the late 1910’s, the “Society’s Card” was nearly universal to American laboratories, forming the basis for undergraduate and graduate training, and organizing data for published reports in several specialities. While rarely

constituting the cutting edge of the science, the card established a common ground for disparate members of a diverse field. This chapter argues that in their attempts to answer the question, “What is *that* bacteria?” SAB members unwittingly answered the questions “who were bacteriologists and what is bacteriology?” In some measure, bacteriologists were simply those who used the card, and bacteriology was defined by kinds of information requested by the card. Determining *that* bacteria also determined *those* bacteriologists and *their* science.

Furthermore, in its attempts to refine and revise the Society’s Card, the SAB directly confronted the task of pinpointing the biological components of bacteriology. In an unintentional, and largely unrecognized fashion, the Society’s concern for the most mundane activity may have represented its most fundamental undertaking. If the SAB endeavored to render bacteriology more fundamental, those in charge of revising the Society’s Card directly confronted the task of exploring the biology of bacteria.

As for the role of the Society’s Card in building the discipline of bacteriology, its importance cannot be overstated. In fact, it might have constituted the only successful mechanism for unifying an inherently fragmented field. Yet, it did not resemble the “standard methods” discussed by sociologists and historians of other scientific disciplines. In fields such as nineteenth century chemistry or twentieth century genetics, a growing methodological confidence and technical conformity facilitated disciplinary cohesion. Bacteriology, however, was never so fortunate. Its methods remained imprecise and technically problematic. The serial editions of the Society’s Card, and committee correspondence, evince dogged dissatisfaction. The Society’s Card failed to proffer the “right tool for the job.” Instead, the chart demanded that bacteriologists negotiate a common set of imperfect tests. It was this consequent unease which

led them to reflect, time and again, upon the biology of bacteria. This chapter agrees with those sociologists and historians who contend that the "routine" of scientific practice organizes even cutting edge research. Those organizing tools, however, need not be standard. Methodological anxiety can, to continue another theme from the preceding chapter, be productive.

On Methods and Materials

The following pages draw upon a wide body of secondary literature in the history and sociology of science. At the most general level, this chapter contends that the disputes over the routine practices of bacteriology were, on the whole, 'good to think with.' For nearly three decades, historians and sociologists of science have advanced similar arguments. John Law, in 1973, proposed the notion of a "technique- or methods-based" specialty, wherein researchers share a commitment to a particular tool or procedure, rather than an over-arching theoretical program. Similarly, Richard Whitley, in 1976, defined "research areas" as those collectives organized by agreed criteria for specifying investigative problems and for selecting appropriate techniques for addressing them.¹ In the ensuing decade, a number of scholars articulated those characteristics that rendered certain tools "right for the job." Joan Fujimura, exploring the development of cancer research, suggested that techniques often define a research front, identifying certain problems as worthy of investigation, while cloaking others. Adele Clarke contended that laboratory techniques and methods, once mastered, become entrenched, and thereby constrain all future work. Robert Kohler maintained that an instrument, or research

¹ John Law, "The Development of Specialties in Science: The Case of X-ray Protein Crystallography," *Science Studies* 3 (1973): 300; and, Richard Whitley, "Umbrella and Polytheistic Scientific Disciplines and their Elites," *Social Studies of Science* 6 (1976): 472-473.

organism, can create and maintain a lasting laboratory culture, one that adjusts institutional structures and work relations.² Bacteriology appears to have followed suit. The SAB's Descriptive Chart (often termed the "Society's Card") and *Manual of Pure Culture Methods* influenced the choice of legitimate research problems, and strongly circumscribed the methods enlisted. The Chart and *Manual* comprised the shared domain among bacteriologists, offering those "dynamic interfaces" which pervaded overlapping, though institutionally separate, research communities.³

Nonetheless, the techniques and methods of bacteriology were not 'black boxed,' never taken for granted as fixed, resolved, and unproblematic practices. They instantiated Kathleen Jordan and Michael Lynch's notion of a "translucent box," or a "recalcitrant" set of techniques. Similar to molecular biology's plasmid prep, the procedures prescribed for the determination of unknown cultures constituted an evolving "assemblage of tools, ingredients, and actions, which can be used for a variety of purposes and in combination with various instruments, specimen materials, and other techniques." The Chart and *Manual* were not linked to any single experiment. Rather, they provided a wide variety "of disciplinary routines and experimental recipes," both adjustable and re-combinable. Their most rudimentary instructions resembled "the simple and more familiar procedures described in cookbooks . . . like separating egg-whites from yolks and whipping until stiff . . ." ⁴ The SAB methods were only loosely standardized, and

² Joan Fujimura, "Constructing Doable Problems in Cancer Research: Articulation and Alignment," *Social Studies of Science* 17 (1987): 257-293; Kohler, "Drosophila: A Life in the Lab," *Journal of the History of Biology* 26 (1993): 281-310; and, Adele Clarke and Fujimura, "What Tools? Which Jobs? Why Right?" in *The Right Tools for the Job* (Princeton: Princeton University Press, 1992), 3-43.

³ See, Bruno Latour's description of "immutable mobiles," in *Science in Action: How to Follow Scientists and Engineers through Society* (Cambridge: Cambridge University Press, 1987).

⁴ Jordan and Lynch, "The Sociology of a Genetic Engineering Technique: Ritual and Rationality in the Performance of the 'Plasma Prep'," in *The Right Tools for the Job*, 77-114, quote from p. 90. The authors imply

subject to recombination. They called out for constant revision, and remained open to adjustment. The SAB never intended its Descriptive Chart and *Manual of Pure Culture Methods* to be fixed or complete. They existed only as the most broadly useful, and most flexible, techniques available.⁵ These routine prescriptions performed as “boundary objects,” inhabiting “several intersecting social worlds” of bacteriology, while satisfying the “divergent informational requirements of each of them.”⁶

In this regard, the development of bacteriological technique differs from other narratives of biological practice. Robert Kohler has argued that, in the case of drosophila genetics, the construction of a ‘standard’ research organism determined the social, conceptual, and institutional dimensions of the field. In contrast, bacteriology never cultivated a ‘standard organism.’ True, bacteria, like fruit flies, performed “things that humans value that they might not have done in nature.” Moreover, laboratory microorganisms embodied “layers of accumulated craft knowledge and skills” which were subsequently “tinkered into new forms to serve the peculiar purposes of experimental life.”⁷ However, SAB bacteriologists never adopted such constraining experimental organisms or systems. If the Society’s Card and *Manual* served to guide the development of the discipline, they did so only at a rudimentary level. The Card and *Manual* represented the generally agreed upon procedures, and not the discipline’s most

that most procedures operated not as rigorously uniform practices, but as a “multitude of variations on a theme,” p. 81.

⁵ For a slightly different view on the fluidity of experimental techniques and systems, see, Hans-Jorg Rheinberger, *Toward a History of Epistemic Things: Synthesizing Proteins in the Test-Tube* (Stanford: Stanford University Press, 1997), 29-35.

⁶ Clarke and Fujimura, “What Tools?” 12-14. See also, James R. Griesemer, “The Role of Instruments in the Generative Analysis of Science,” in *The Right Tools for the Job*, 47-75.

⁷ Kohler, *Lords of the Fly: Drosophila Genetics and the Experimental Life* (Chicago: University of Chicago Press, 1994), 3, & 6-7. See also, Karen A. Rader, “Making Mice: C.C. Little, the Jackson Laboratory and the Standardization of *Mus Musculus* for Research,” (Ph.D. diss., Indiana University, 1995).

cherished research goals. They constituted, as this chapter will demonstrate, the core of the discipline, and not its cutting edge.⁸ The Card and *Manual* outlined points of departure, rather than tools of conformity.

With specific reference to the development of American bacteriology, Patricia Gossel has underscored the central importance of laboratory techniques. In an article depicting the American Public Health Association's Laboratory Section, and its efforts to standardize bacterial water analysis, Gossel described a technical crisis that, in the early-1890's, "challenged the credibility of the field." Gossel noted that without standard methods and techniques, bacteriologists examining water samples unavoidably produced inconsistent and unconvincing results. They may have been able to identify potential pathogens, but their proclamations of warning carried little authority.⁹ In response, the APHA formed a committee to evaluate the available methods, and issue standard procedures. In Gossel's estimation, these cooperative efforts led directly to the issuance of the SAB's descriptive chart in 1905, and the *Bergey's Manual of Determinative Bacteriology* in 1923.¹⁰ As this chapter will show, the connection between the APHA's standard methods for water analysis and the SAB's Descriptive Chart and Manual of Pure Culture Methods was indeterminate, at best. In stark contradistinction to the methods of the APHA's Laboratory Section, the SAB remained quite clear in its intention *not* to issue a set of absolute uniform procedures. The SAB's Descriptive Chart, and its serial revisions, represented a continuing program of disciplinary self-reflection, whereby SAB members

⁸ Kohler, *Lords of the Fly*, 33, 78, 79 & 88.

⁹ Gossel, "A Need for Standard Methods: The Case of American Bacteriology," in *The Right Tools for the Job*, 287-288.

¹⁰ Gossel, "The Emergence of American Bacteriology, 1875-1900" (Ph.D. diss., Johns Hopkins University, 1988), 367-368; and, Gossel, "A Need for Standard Methods," 302-304.

ventured into the biological borderlands of their science, while they settled upon the accepted methods for the determination of bacterial characteristics. On an interpretive level, this chapter agrees with Gossel in her conclusion that the routine aspects of bacteriology generated fundamental questions. This chapter offers a more detailed, and more thorough, exploration of this provocative contention.

Charting the Chart

From its inception, the SAB's "Society's Card" served two interrelated purposes for bacteriologists working with unknown cultures: description and identification. To describe an organism entailed listing all of its salient characteristics. Employing the "Society's Card," a researcher could detail an organism's morphology (*i.e.*, shape, size, presence of flagella and spores, involution forms, staining reactions, etc.), its cultural features (*i.e.*, growth and changes produced in agar, potato, blood serum, gelatin, milk, etc.), and its biochemical behavior (*i.e.*, production of gas and acid from various sugars, formation of ammonia and indol, reduction of nitrates, temperature and oxygen relations, tolerance to sunlight and drying, etc.). Some editions of the card allowed for the bacteriologist to "sketch" the culture. A completed card, therefore, comprised a "complete" description.

The "Society's Card" also aided in the identification of unknown cultures. Employing information compiled from the description, a bacteriologist would assign the organism a "group number." Figure 5.1 reproduces the "group number" index from the 1907 SAB card. A sanitary bacteriologist might describe a typical water organism in the following manner: a bacillus that did not produce endospores; grew in either the presence or absence of oxygen; did not liquify

gelatin; formed acid and gas from dextrose, lactose, and saccharose; reduced nitrates with the formation of gas; appeared non-chromogenic; and, showed feeble diastatic action on potato starch. That culture bore the group number B. 222.111102, and betokened the organism commonly known as *Bacillus coli*. Ideally, every recognized bacterial type would be assigned a group number. The bacteriologist describing an unknown organism could simply compare its group number to a shared and comprehensive index. In theory, this was determination made simple. As the ensuing paragraphs will demonstrate, however, these laudable aims proved elusive.

The "Society's Card" originated from the American Public Health Association's (APHA) "Standard Methods of Water Analysis." First issued in 1897, the "Standard Methods" were the product of a Committee of Bacteriologists to the Committee on the Pollution of Water Supplies. The APHA, earlier in the decade, had assumed responsibility for guiding public health officials in their interpretation of bacteriological and chemical analyses of water. According to Gossel, this was no simple task. Each municipal laboratory employed its own methods for bacteriological inspection, generating a technical crisis that "challenged the credibility" of the entire practice.¹¹ Recognizing that these inspections should be subject to "verification and control," the APHA's Committee affirmed the need for "a full and accurate description of bacteria in which the items have been determined by methods common to the main body of workers . . ." ¹² If a bacteriologist in one city surveyed public water supplies for potential

¹¹ Gossel, "A Need for Standard Methods," 287-288.

¹² American Public Health Association, "Proceedings of the Bacteriological Convention, New York, June 21 and 22, 1895," Public Health, Papers and Reports 20 (1895): 459-515; and, Committee of American Bacteriologists to the Committee on the Pollution of Water Supplies, "Procedures Recommended for the Study of Bacteria, with Especial Reference to Uniformity in the Description and Definition of Species," American Public Health Association, Proceedings 23 (1897): 5-25.

pathogens, the APHA declared that he (or in many cases she) ought to employ the identical methods used in other municipalities. Uniformity, the Association reasoned, assured reliability and accuracy.

In September of 1897, the Committee offered its provisional report, specifying a regimen of procedures for conducting bacteriological analyses of water. The Committee provided exacting formulae for media constituents, detailing sterilization temperatures and times, as well as media reaction. The report indicated the method for determining each of the morphological, cultural, and physiological characteristics. For example, the Committee stipulated the thickness of film to be used in measuring the dimensions of a bacterial cell, and the phenolphthalein indicator for determining acid production in dextrose broth. Despite their best attempts to control all possible variables, the Committee recognized "considerable" difficulties with each technique. Uniform methods, they acknowledged, did not guarantee uniform results.¹³

A "Standard Chart for Bacterial Diagnosis" accompanied the APHA 1897 report. Compiled by Columbia University's Timothy M. Cheeseman, the chart proffered a convenient summary form for the "Standard Method's" several tests of unknown cultures, including morphological (*e.g.*, plane of division, spore and capsule formation, size of cell, staining reactions, and motility), physiological (*e.g.*, growth on nutrient broth, gelatin plates, and blood serum), and "chemical" characteristics (*e.g.*, temperature reactions, relation to oxygen). While the Committee of Bacteriologists approved the "Standard Chart" one month after sanctioning the

¹³ The elimination of this variance became the central goal of subsequent revisions of the "Standard Methods." See, "Report of the Committee on Standard Analysis of Water to the Laboratory Section of the American Public Health Association," Journal of Infectious Diseases, suppl. no. 1 (May 1905): 1-141; and, "Report of the Committee on Standard Methods of Water Analysis," American Journal of Public Health 17 (1907): 365-367.

“Standard Methods,” the chart never achieved widespread use.¹⁴ Instead, sanitary scientists followed the specifications of the latest edition of the “Standard Methods,” reporting their findings to authorities whenever they detected water contaminated by potential pathogens. It was, after all, the official methods, and not the chart, that lent reliability and authority to their analyses.

Members of the American Public Health Association also fostered the notion of a “group number.” Wyatt G. Johnston, a lecturer in “medico-legal” pathology at McGill University, proposed the idea of assigning culture numbers to the 1895 APHA gathering. Johnston believed that a bacterial description could be recorded “compactly,” forming an index “code” similar to the Dewey decimal system for arranging library books.¹⁵ At the time, Johnston did not provide a comprehensive scheme for group numbers. Instead, his suggestion for a convenient indexing system was taken up by George W. Fuller and George A. Johnson, two bacteriologists from the Cincinnati Water Works. Fuller and Johnson separated forty-two species of water bacteria on the basis of twenty-six cultural reactions, each recorded on the edge of a 4 x 6 card with a “+” or “-“. By completing this graphical tabulation for an unknown culture, a bacteriologist could compare the column of pluses and minuses to that of known forms, thereby identifying the organism in question.¹⁶

¹⁴ Gage and Phelps suggest that Cheeseman’s forms, when completed, were extremely bulky: “. . . a comparison of any considerable number of species recorded on them becomes a laborious task.” Stephen DeM. Gage and Earle B. Phelps, “On the Classification and Identification of Bacteria with a Description of the Card System in Use at the Lawrence Experiment Station for Records of Species,” American Public Health Association, Proceedings 28 (1903): 501.

¹⁵ Johnston, “On Grouping Water Bacteria,” American Public Health Association, Proceedings 20 (1895): 445-449; and, Harry A. Harding, “The Constancy of Certain Physiological Characters in the Classification of Bacteria,” Technical Bulletin of the New York Agricultural Experiment Station no. 13 (1910): 12.

¹⁶ Fuller and Johnson, “On the Differentiation and Classification of Water Bacteria,” Journal of Experimental Medicine 4 (1899): 609-626.

Fuller and Johnson's scheme did not find pervasive use, in part because it excluded from consideration several tests mandated by the APHA's "Standard Methods" (e.g., morphology, growth on gelatine and agar, effect on milk, etc.). Nevertheless, other sanitary bacteriologists saw great promise in the tabular form of bacterial determination. Arthur I. Kendall, a former assistant at the Lawrence Experiment Station, described his particular method for graphically recording bacterial characteristics to the 1903 meeting of the APHA. Rather than relying on a column of pluses and minuses, Kendall formulated a four-digit "type number." The first two places designated the morphological qualities of the organism, followed by a decimal point. The third digit indicated the "cultural or biochemical features" of the organism grown in a carbohydrate solution (i.e., liquefaction of gelatin, formation of gas or acid from dextrose). The final number described the predominate chromogenic properties.¹⁷ For example, a bacillus with peritrichic flagella, that liquified gelatin, produced gas and acid in dextrose, and displayed a noticeable dark red hue earned the "type number" 22.53. The student or investigator, referencing a list of known forms, could quickly identify the organism as *B. prodigiosus*. Likewise, the same list revealed that this culture closely resembled *B. vulgaris*, which carried the number 22.51, and differed from *B. prodigiosus* only in color. Kendall's graphical method encompassed vastly more information than his "type number," including tests not specified by the APHA's standard methods. (Fig. 5.2) In comparison to Fuller and Johnson's design, Kendall's may have been too elaborate for routine employment.¹⁸

¹⁷ Kendall, "A Proposed Classification and Method of Graphical Tabulation of the Characters of Bacteria," American Public Health Association, Proceedings 28 (1903): 481-493.

¹⁸ Harry A. Harding, and Martin J. Prucha maintained that the minute details demanded by Kendall's chart "simply increases confusion in the present state of the science." Quoted in, "The Bacterial Flora of Cheddar Cheese," Technical Bulletin of the New York Agricultural Experiment Station no. 8 (1908): 139. Kendall conceded that "it may be argued that this system is complicated," but he reasoned that "it must be remembered that the facts

Stephen DeM. Gage and Earle B. Phelps, also from the Lawrence Experiment Station, presented their own arrangement to the same 1903 APHA meeting. They too offered a numerical designation, but with greater simplicity than Kendall required. Moreover, they altered the layout of the descriptive card such that the determining details appeared at the top margin of the sheet. By placing several cards such that only the marginal columns were visible, a researcher could simultaneously compare the pluses, minuses and index numbers of many cultures. (Fig. 5.3) The value of this card system, Gage and Phelps claimed, would be apparent to "all who have had occasion to trace out a number of cultures, eliminating duplicates, and trying to establish identity with previously described species."¹⁹ However, they tailored their scheme for work in water bacteriology, and readily acknowledged that other tabular arrangements might be better suited to different bacteriological contexts. For a descriptive chart to be truly useful, Gage and Phelps admitted that it must be uniformly adopted.

In many respects, the SAB's "Descriptive Chart" and "Manual of Methods" derived from the APHA's efforts. The format for the early editions of the SAB's "Society's Card" (1905, 1907, 1913 and 1914) resembled Cheeseman's "Standard Chart," and included many of same instructions. The SAB's venture to issue a "Manual of Methods" in the late 1910's can likewise be compared to the APHA's "Standard Methods," with one notable exception. The SAB never intended its chart or methods to be "official" or "standard." Harold J. Conn, long-term chair of

to be explained are complicated." Kendall, "Method of Graphical Tabulation," 488, emphasis in original.

¹⁹ Stephen DeM. Gage and Earle B. Phelps, "On the Classification and Identification of Bacteria with a Description of the Card System in Use at the Lawrence Experiment Station for Records of Species," American Public Health Association, Proceedings 28 (1903): 494-505. See also, Gage, "Bacteriological Studies at the Lawrence Experiment Station with Special Reference to the Determination of *B. Coli*," Annual Report of the Massachusetts Board of Health, 1901 33 (1902): 397-420; and, B.R. Rickards, "A System of Recording Cultures of Bacteria Genealogically for Laboratory Purposes," Annual Report of the Boston Health Department, 1901 30 (1902): 75-79.

the relevant SAB committees and scion of SAB founder Herbert W. Conn, noted that other organizations longed for the “standardization of technic and establishment of official methods.” In contrast, Conn believed that the SAB might “have a wider usefulness as an agency through which different procedures may be compared and their relative merits for different purposes established without giving official standing to any one technic.”²⁰ For Conn and his fellow committee members this was no small point of distinction. Sanitary and public health workers concerned themselves with “official control work,” and naturally sought “methods that give uniform and reasonably reliable results with as little labor as possible . . .” The SAB, as an organization of *bacteriologists*, “should be interested in the accuracy of technic rather than in simple and inexpensive methods.”²¹ If bacteriology embodied a fundamental science, rather than a set of routine procedures in the stead of other applied sciences, the SAB was obliged to forswear fixed or uniform methods. “*Research* methods,” Conn professed, “ought not to be standardized.”²² One example can illustrate Conn’s concerns. The APHA’s Standard Methods specified that all culture media reactions should be set to a titre of +1.5 acidity. This acidity facilitated the growth of the most relevant water bacteria. Many soil microbes, however, grew only in media of greater alkalinity, and several dairy microbes required substantially more acidity. Rather than fix the exact reaction across all culture media, the SAB sought to define uniform and exact methods of determining media reaction. The research bacteriologist was therefore free to alter the reaction of the media to suit the organisms under investigation.

²⁰ Harold J. Conn, “Report of the Committee on Technic,” Abstracts of Bacteriology 5 (1921): 1.

²¹ Harold J. Conn, “Progress Report for 1920, Committee on Bacteriological Technic,” Journal of Bacteriology 6 (1921): 136.

²² Harold J. Conn, “Report of the Committee on Technic,” Abstracts of Bacteriology 6 (1922): 1, emphasis added. See also, Harold J. Conn, “Report of the Committee on Bacteriological Technique,” Journal of Bacteriology 7 (1922): 519-522.

While the APHA's chart and methods derived from the field of sanitary science, the SAB's card emerged from the efforts of dairy and soil bacteriologists, as well as those engaged in water analysis. Herbert W. Conn, studying dairy forms at the Storrs Agricultural Experiment Station, published his own numerical and tabular method of determining bacterial types in 1899. Conn devised a system for managing the myriad cultures presented in daily investigations, and a format for comparing bacterial descriptions among dairy scientists in disparate locales.²³ Conn based his descriptive chart on Fuller and Johnson's, altering their form to indicate the characteristics relevant to dairy bacteriology. Conn's chart, for example, did not leave room for anaerobiosis, the reduction of nitrates, the production of indol, or pathogenesis, while it did request data on the curdling of milk and the digestion of casein (milk protein). These modifications, of course, rendered it difficult to compare Conn's dairy types with those found in water, a limitation which Conn readily confessed.²⁴ In preparing his revised determinative key of dairy bacteria (1901), Conn formulated a new chart, comprising one side of a single sheet of paper. (Fig. 5.4) Believing that this card included "all of the characteristics usually adopted for general descriptions of bacteria," Conn circulated copies to practitioners outside of the dairy field.²⁵ It was Conn's second chart, along with those of Kendall and Gage & Phelps, which most directly influenced the SAB's decision to investigate determinative practices.

The Society's involvement dates to its third annual meeting (1901), when Kendall

²³ Herbert W. Conn, "Classification of Dairy Bacteria," Report of the Storrs (Connecticut) Agricultural Experiment Station for 1899 (Middletown, Conn.: Pelton & King, 1900): 13-68.

²⁴ Herbert W. Conn, "Classification of Dairy Bacteria," 20.

²⁵ Herbert W. Conn, William M. Esten, and W.A. Stocking, "A Classification of Dairy Bacteriology," 18th Annual Report of the Storrs Agricultural Experiment Station, 1906 (Middletown, Conn.: Pelton & King, 1907), 93. Conn's second chart, with the exception of his omission of Gram's stain and oxygen requirements, formed the basis of the SAB's first two cards. Harding, "Constancy of Certain Physiological Characters," 8-9, & 14.

presented his method of graphically tabulating bacterial characteristics. Employing a series of well-known micrococci, Kendall demonstrated to the assembly the utility of cataloguing cultures with descriptive cards.²⁶ Two years later, Frederick D. Chester, a soil bacteriologist and mycologist from the Delaware Agricultural Experiment Station, proposed that the SAB take the initiative in developing a determinative chart and manual. Chester himself had published *A Manual of Determinative Bacteriology* in 1901, which earned widespread acceptance as an indispensable laboratory guide.²⁷ Some SAB members quietly suggested that the Society endorse his manual, distribute Gage and Phelps' card, and be done with the matter. Others recommended that the SAB only act in concert with the APHA. In reply, Chester noted the lack of continued interest within the APHA's Laboratory Section, and insisted that neither his, nor any other current scheme, was acceptable. As Harry Harding recalled seven years later, "Chester presented the matter so forcibly" at the 1903 meeting, that the Executive Council relented, and appointed a Committee on the Identification of Bacterial Species.²⁸ Chester served as its first chair, joined by Brown University's Frederic P. Gorham, and Erwin F. Smith, the chief plant pathologist for the USDA.

The Committee submitted its initial remarks to the 1904 SAB meeting, where Chester announced his support of a "group number" to indicate the salient characteristic of an organism.

²⁶ Kendall, "A Graphical Tabulation of the Morphological, Cultural and Biochemical Characters of Certain Bacteria, Together with References to Authorities, Synonyms, Literature, etc.," paper presented at the 3rd Annual SAB Meeting (1901), abstracted in *Science* 15 (1902): 377.

²⁷ Chester, *A Manual of Determinative Bacteriology* (New York: Macmillan Co., 1901). Chester provided a brief chart as a guide in the description and determination of bacteria species, pp. 41-42. Kendall noted it was Chester who "published a set of terms covering the possible reactions of bacteria upon the different media, and these terms admit only one interpretation. Furthermore, they are in general use among bacteriologists at this time." Quoted in, "A Proposed Classification," 487-488.

²⁸ Harding, "Constancy of Certain Physiological Characters," 23-24.

In Autumn of 1905, the Committee issued its preliminary report, which was distributed to SAB members for suggestions and criticism. As to the need for a descriptive chart, Chester explained that:

The past literature of bacteriology abounds in such imperfect descriptions of organisms as to make their grouping, according to any system impossible. This fact calls for the adoption of some scheme to which all descriptions shall conform, in order that no essential character shall be overlooked.²⁹

The report featured a provisional card, with the instruction that it was to be completed like "catalogue cards, and arranged in accordance with the group number, thus bringing similar organisms together and rendering comparison easy."³⁰

The card itself was printed stiff paper, 5x8 inches in size, and consisted of three parts. The first section indicated the "Salient Features" with a brief graphical tabulation of the organism's primary characteristics. (Fig. 5.5) In addition to providing spaces for "Genus," "Group Number," and "Source," this section listed thirty-one specific tests, indicated by a "+" or "-" placed at the bottom of a column. In a manner akin to that recommended by Gage and Phelps, and Conn, a researcher could stack several cards upon each other, with only the top margin of each visible. By comparing the row of pluses and minus, one could spot similarities among cultures, and possibly determine the identity of individual organisms.

The list of "Salient Features," when compared to earlier cards, seemed hardly

²⁹ Chester, "Principles of Classification of Bacteria," paper presented before the 6th Annual SAB Meeting (1904), abstracted in Science 21 (1905): 485. Harding maintained that Chester composed nearly all of the provisional report and card, with the "other two members having made only a few suggestions." Harding based this claim on communications with F.P. Gorham and E.F. Smith. "Constancy of Certain Physiological Characters," 27.

³⁰ "Preliminary Report of the Committee on the Identification of Bacterial Species," 1905, reprinted in Harold J. Conn, H.A. Harding, I.J. Kligler, W.D. Frost, M.J. Prucha, and K.N. Atkins, "Progress Report for 1918 of the Committee on the Descriptive Chart of the Society of American Bacteriologists," Journal of Bacteriology 4 (1919): 108.

abbreviated, as it contained sixteen additional columns of required tests. Under the subsection of "Morphology," the SAB's provisional card added inquiries as to the approximate size of the cell (*i.e.*, "diameter over 1 micron"), the formation of chains, and the presence of spores. This card removed fermentation of dextrose, saccharose, and lactose from the cultural subsection, but requested information on growth in nutrient broth, agar, gelatin plates and stabs, and on potato. Under the sub-heading of "biochemical features," the SAB edition specified three separate tests for liquefaction (as compared to only one in earlier cards), three new tests for effect on milk, reaction to hydrogen sulfide, production of ammonia, and Gram's stain. Curiously, the "Salient Features" section did not signify either oxygen relations or pathogenesis, leaving those characters to the blank space for "Additional Salient or Diagnostic Features." In an unspoken, and possibly unintentional fashion, the SAB's provisional card delivered a profound missive – to understand a microorganism, even *briefly*, required extensive and careful study. A researcher or student completing the card's "Salient Features" section was strongly discouraged from conducting a few diagnostic tests (*e.g.*, pathogenesis) to determine an organism's likely identity.

The provisional card's second section specified an extensive list of "Detailed Features." (Fig. 5.5) Some of these encompassed expanded examinations of the "Salient Features" (*e.g.*, spore formation, growth on various media, reduction of nitrates, etc.), while others occupied places in this section only (*e.g.*, presence of flagella and capsules, growth on blood serum, fermentation of various sugars, effect on starch jelly, and pathogenesis). If the card's previous section cautioned bacteriologists against making hasty or cursory determinations, this portion

commanded a nearly exhaustive list of general characteristics.³¹ Chester excluded only those tests he considered particular to individual or limited groups (*e.g.*, anaerobiosis, phosphorescence, etc.).³² Moreover, Chester specified a number of cultural examinations requiring proficient skill in chemistry (*e.g.*, production of ammonia and indol, reduction of nitrates). In Chester's regard, the bacteriologist after the turn of the century "must familiarize himself with chemical methods, since in the future the study of chemical functions of bacteria will form a most important factor" in the determination of species.³³

The final section provided instructions for completion of the card, including a table describing the "Numerical System of Recording the Salient Characters," methods for preparing media and cultures, and a glossary of descriptive terms.³⁴ The group number differed noticeably from that of Gage and Phelps. The first two digits, which previously designated morphology, were eliminated in favor of a written generic label (*i.e.*, *Bacillus*, *Bacterium*, *Pseudomonas*, *Microspira*, etc.) In Chester's system, the group number featured eight digits, with three preceding a decimal point, and five following. (Fig. 5.6) The number marked an organism's production of spores, relation to oxygen, liquefaction of gelatin, production of acid or gas from three sugars (*e.g.*, dextrose, saccharose, and lactose), reduction of nitrates, fluorescence, and chromogenic tendencies. Nearly half of these traits were new to Chester's group number.

³¹ Harding depicted the list of "Detailed Features" as a significant "step toward accommodating a complete record of an organism on a single card." Harding, "Constancy of Certain Physiological Characters," 28.

³² Chester placed only minor importance on chromogenesis, arguing that it was "variable character dependent upon environment." Chester, "Preliminary Report," quoted in Harold J. Conn, "Progress Report for 1918," 108.

³³ Chester, *A Manual of Determinative Bacteriology*, 17.

³⁴ For the most part, Chester specified the 1905 revised culture methods of the APHA, with additional instructions for hanging drop preparations, titrations for acidity, and tests for the production of ammonia and the reduction of nitrates. In addition, the card stipulated that all morphological observations must be extended over four weeks, a length greatly in excess of that indicated by the APHA's methods.

Chester, in order to lessen likely confusion, supplied group numbers for four widely recognized bacterial types: *Bacillus coli* (now B. 212.11110), the common indicator of fecal contamination in water; *Bacillus alcaligenes* (B. 212.33310), a deleterious contaminant of milk and other dairy products; *Pseudomonas campestris* (Ps. 211.33315), the cause of bacterial rot in cabbages; and, *Bacterium suicida* (Bact. 212.2320) which was associated with swine plague. The choice of exemplars appears strategic, even if less than obvious. Whether the card user practiced in sanitary science, dairy bacteriology, plant pathology, or veterinary medicine, the examples demonstrated the utility of assigning a group number. Moreover, by suggesting that the group number suited all bacterial forms, the Committee intimated that there were indeed some grounds for unifying the science.

At the 1905 annual meeting, SAB members discussed the relative merits of the preliminary report and provisional card. The discussants voiced favorable assessments, along with two criticisms regarding the card's lay-out. First, the two-sided sheet proved cumbersome. Second, the spaces in the "Salient Features" section for pluses and minuses rested too far from the card's actual margin. The Committee reformatted and reissued the chart in the Fall of 1906. In order to accommodate all of the "Salient Features" and "Detailed Features" on one side, the card now measured 8 x 10 inches, with the spaces for pluses and minuses moved to the uppermost edge of the top margin. The back side contained only the instructions for completion. In addition, Chester revised individual items of the card, rendering it even more exhaustive. Among the "Salient Features," he added spaces for motility and chromogenesis in agar. Under "Detailed Features," Chester provided a table for fermentation of sugars and more a detailed

section for pathogenesis.³⁵ The group number remained largely the same, with a minor change to the group number assigned to the example of *Bacterium suicida*.³⁶

In 1906, two separate studies attempted to employ the SAB's first card. At the University of Pennsylvania's Laboratory of Hygiene, David Bergey and H.L. Bates assigned group numbers to eighty-six recognized bacterial types. In seventy samples from medical, water, and veterinary bacteriology, the authors found that the group numbers provided a distinctive identification for most of the organisms. However, the card's numerical system failed to designate unique formulae for sixteen forms, particularly soil bacteria. Despite these imperfections, the authors endorsed the SAB's card and group numbering.³⁷ At the Storrs Agricultural Experiment Station in Connecticut, Herbert W. Conn, William Esten, and W.A. Stocking published their revised survey of dairy bacteria. In this endeavor, they partially followed the SAB's descriptive chart in order to characterize 160 individual types.³⁸ The authors maintained that the Gage and Phelps group numbering proved "far more satisfactory and far more usable" than the SAB system. Nonetheless, they reasoned that it seemed "better to have uniformity in the matter even at the expense of some loss" of convenience, and adopted the Society's card as their descriptive scheme.³⁹ Upon initial scrutiny, then, the Society's card garnered approval, however conditional it might have been.

³⁵ The revised card inquired as to experimental animal employed (*e.g.*, mice, rats, guinea pigs, rabbits, man), and provided spaces for "toxin forming," and "immunity to bactericidal."

³⁶ *Bact. suicida* was found to be a facultative anaerobe, and not a strict aerobe.

³⁷ Bergey and Bates, "The Numerical Classification of Bacteria," University of Pennsylvania Medical Bulletin (July 1906): 116-118.

³⁸ Conn, Esten, and Stocking, "A Classification of Dairy Bacteria," 91-201. The authors did not determine indol production or reduction of nitrates among their cultures, believing that these factors were of little significance to dairy problems.

³⁹ Conn, Esten, and Stocking, "A Classification of Dairy Bacteria," 105.

The SAB's card did not comprise the only descriptive aid for determinative bacteriology. In fact, a few university teachers drafted their own charts for undergraduate instruction. Wilfred H. Manwaring, an Associate Professor of Pathology and Bacteriology at the University of Indiana, assigned a schematic "Bacterial Culture Chart" for use in his laboratory sections. In contrast to the SAB's comprehensive card, Manwaring's two-page chart requested limited information. The Indiana instructional guide emphasized morphological features, providing ample room for "sketches" of cultures grown in various media. (Fig. 5.7) Lacking both the group number and graphical tabulation of "salient features," Manwaring's chart served only to introduce students to bacteriological determination. It was not designed to guide research or even routine examinations.⁴⁰ Notwithstanding its limited aims, Manwaring's instructional chart demonstrated a willingness among bacteriologists to adopt and teach shared determinative formula. The lingering questions concerned the inclusiveness of the chart. How much detail was enough, when was it too much, and in what contexts was the completion of the chart necessary?

The Committee on the Identification of Bacterial Species addressed these questions directly. At the 1906 SAB meeting, Gorham submitted the Committee's report, which elicited inquiries from the likes of Herbert Conn, C.E.-A. Winslow, William H. Park, and Samuel C. Prescott. In response, Gorham explained that the Committee believed that the card was "now inclusive enough to meet the demands of workers in every line of bacteriological investigation," while remaining "simple enough to be adapted to ordinary identification of bacterial species."

⁴⁰ In addition to requesting sketches of cultures on agar slants, potato, bouillon, litmus milk, glucose agar, and gelatin, Manwaring's chart listed fermentation reactions (*i.e.*, in dextrose, lactose, and saccharose), indol production, "characteristic odor," and "pathogenicity, serum reaction, etc." Manwaring, The Indiana University Bacterial Culture Chart (Bloomington, Ind.: World-Courier Press, 1905). In many respects, Manwaring based his instructional aid on Cheeseman's chart for the APHA.

When asked whether the card was too detailed, Gorham insisted that “as much or as little of the material which appears on the card may be used as desired.” The group number, for example, was “retained for those who wish to make use of it,” but not required of every determination.⁴¹ Despite these accommodating declarations, the Committee “hoped and recommended” that the card “in its present form, be adopted by the Society as the Standard Descriptive Chart, and that its use be urged upon all who may have occasion to identify, classify, or describe bacterial species.”⁴² SAB leaders discussed the relative merits of the chart, and suggested that the Society continue the Committee’s work, but not embrace the card as “standard” or “official.”

Chester’s participation on the Committee receded after the 1906 meeting, “as he went into commercial work and later severed his connection” with the SAB. Subsequently, the burden of revising the card “fell mainly on Dr. Erwin F. Smith.”⁴³ Smith, a botanist by training and plant pathologist by occupation, vowed to render the new Society’s Card even more inclusive and detailed.⁴⁴ The Committee issued its third chart in the Fall of 1907, an 8 ½ x 10 ½ card printed on two sides. As figure 5.8 demonstrates, the new revision differed greatly from its predecessors. The section for “Brief Characterization” now occupied the right hand margin, and recommended marks of “+” and “0” rather than pluses and minuses. More substantially, a “Brief Characterization” prompted the bacteriologist to fifty-two lines of information, as compared to

⁴¹ Frederic P. Gorham, “Report of the Committee on the Identification of Bacterial Species, 1906, SAB Book of Minutes,” [ASM] box 1-IVA, folder 1, p. 75.

⁴² Gorham, “Report of the Committee on the Identification of Bacterial Species, 1906,” 75.

⁴³ Harding, “Constancy of Certain Physiological Characters,” 28. Chester was listed as a member of the SAB’s Executive Council in 1907, but did not attend that year’s annual meeting. He was removed from the Society’s roster in 1909 for non-payment of dues.

⁴⁴ Harold J. Conn, “Section I: Historical Introduction,” Manual of Methods for Pure Culture Study (1938): 5. For biographical material on Smith, see, L.R. Jones, “Erwin Frick Smith,” Biographical Memoirs, National Academy of Sciences 21 (1939): 1-71; and, Andrew D. Rogers, III, Erwin F. Smith: A Story of North American Plant Pathology (Philadelphia: American Philosophical Society, 1952).

thirty-two in the 1906 edition.

Within the subsection on "Morphology," the Committee added spaces for "capsules," "zoogloea and pseudozoogloea," and "involution forms." The previous card placed "capsules" within its "Detailed Features," but did not deem it a "salient" or "diagnostic" characteristic. As for zoogloea and involution forms, both were entirely new to the 1907 chart. Zoogloea designated the phenomena wherein capsules become enormously swollen with the absorption of water, coalescing to form "a common gelatinous envelope surrounding a number" of individual bacteria.⁴⁵ *Streptococcus mesenterioides* provided the most typical example, an organism that spoiled sugar vats. Other instances of zoogloea pervaded industrial bacteriology, but were relatively rare in other branches of the sciences. The Committee's inclusion of this cytological characteristic represents a small, yet significant, recognition of industrial pursuits.⁴⁶ The space for "involution forms," demonstrated, at best, a growing uneasiness in describing morphological characters. Almost every bacteriologist acknowledged the atypical shapes that appeared in pure cultures maintained for long periods. For many practitioners, they represented nothing more than examples of "degenerations," evidence of a culture that had exhausted its normal life-span. For others, "involution forms" generated continuing speculation.⁴⁷ The Committee's addition of this phenomenon to the 1907 card's "Brief Characterization" had more to do with their diagnostic value than any scientific consensus as to the nature and causes of bacterial involution.

Additions to the subsection on "Cultural Features" reflected changes in the routine

⁴⁵ Chester, *Manual of Determinative Bacteriology*, 2nd ed., 4-5.

⁴⁶ *Bacterium Pasteurianum*, a common inhabitant of beer and beer-wort, typified the "pseudozoogloea."

⁴⁷ For a discussion of the vexing question of morphological variation among bacteria in the early 20th century, see, Olga Amstadamska, "Medical and Biological Constraints: Early Research on Variation in Bacteriology," *Social Studies of Science* 17 (1987): 657-687.

practice of culture methods. The new card now inquired as to the presence of rings and pellicles in broth, a shine in agar, the destruction of starch in potato strokes, and the ability to grow in Cohn's and Uschinsky's solutions.⁴⁸ Under the heading of "Biochemical Features," the Committee appended liquefaction of "agar, mannan," the curdling of milk rennet, the peptonization of casein, and the appearance of fluorescence and luminescence. Most notably, the 1907 "Brief Characterization" affixed a new subheading for "Distribution," which encouraged a bacteriologist to identify the form as an animal or plant pathogen, or as a resident of soil, milk, fresh water, salt water, or sewage. The subsection even included spaces for iron and sulphur bacteria, truly specialized topics of concern among soil bacteriologists. The Committee's catholic listing of habitats spoke to both the variety of bacteriological interests, and the sweep of the discipline's applications. Contiguously placed in tabular form, the spaces for "Distribution" broadcast that human pathology comprised merely one phase of a diverse enterprise, no more and no less important than plant pathology, dairying, or soil science.

Within the section for "Detailed Features," the 1907 card introduced a host of changes, many of which were indicated by the new entries in "Brief Characterization" (*e.g.*, zoogloea and involution forms). The Committee nearly doubled the number of tests for "Cultural Features," while it detailed minor modifications to previously listed examinations. Some of these additions stemmed from Smith's greater willingness to admit "qualitative" characteristics (*e.g.*, odor, extent of growth, size of majority of cells). Others constituted newly accepted cultural tests (*e.g.*, silicate jelly). The revised chart added "Litmus Milk" to its catalogue of culture media, a cultural

⁴⁸Uschinsky's solution provided a "proteid-free medium," employed typically for those organisms which grew poorly in nutrient broth.

practice indispensable to dairy bacteriology, but with minor appreciation in other fields. The fifteenth test specified growth in bouillon containing sodium chloride, an instrumental consideration in the salt curing of fish and meats. The seventeenth queried whether an organism produced nitrogen from complex proteins, a pivotal concern to soil scientists. The Committee recognized that its expansive inclusion of nearly every major cultural method might prove tiresome in daily determinations. Most organisms supplied meaningful data for only a few of the cultural examinations. The Committee did, however, recommend that the investigator attempt each and every one of the tests. Those researchers completing the card for routine examinations would be unwittingly exposed to the methods of most bacteriological specialties. The Committee openly admitted their desire for bacteriological specialists to become conversant with the technical arsenal of other sub-fields. Nonetheless, the eighteenth and nineteenth characteristics, "Best Media for Long-Continued Growth," and "Quick Tests for Differential Purposes," offered at least mild consolation to the lowly practitioner inundated with daily routine cultures, answering the basic questions "how do I culture it?" and "what is it?"

As for the section on "Biochemical Features," the Committee offered a new title, "Physical and Biochemical Features." In the same manner as its immediate predecessor, the 1907 card provided a table to record the fermentation of sugars, as it requested information on the reduction of nitrates, and the production of ammonia.⁴⁹ It was the physical characteristics

⁴⁹ To the list of sugar fermentations, the new chart added maltose, glycerin, and mannit. The 1907 chart also provided space to indicate the production of bacterial "ferments" (*e.g.*, enzymes), such as trypsin, diastase, pectase, oxidase, glucase, etc. This early mention of bacterial enzymes garnered little notice. While many microbiologists recognized the importance of enzymatic action in bacterial applications, most lacked the skills in physiological chemistry necessary to make these determinations. Chester, for example, considered proteolytic enzymes to be relevant to the liquefaction of gelatin and blood serum, two tests contained elsewhere on the chart. Chester, A Manual of Determinative Bacteriology, 40.

that comprised the bulk of new entries: toleration of acids; optimum reaction for growth; temperature relations; resistance to drying, freezing, and sunlight; and crystals formed. In addition, the 1907 chart inserted a table for the "effect of germicides," qualities relevant not only to hygienists and sanitarians, but also instructive to the student faced with sterilizing laboratory equipment. The Committee similarly expanded the sub-heading for "Pathogenicity," enumerating several possible hosts (*e.g.*, insects, crustaceans, fishes, reptiles, plants), and offering space to indicate a loss of virulence.

The back side of the 1907 Descriptive Chart contained a glossary of terms, reference notes on culture methods, and the explanatory table for recording the group number. The glossary presented thirty-six new words, from the most mundane (*e.g.*, "brief," "cloudy," "long," "medium," "rapid," and "scum") to the arcane (*e.g.*, "grumose," "repand," and "umbonate"). In an unconventional manner, the glossary also supplied definitions that described methods and techniques absent from the APHA's revised "Revised Standard Methods." Read as such, the glossary not only delineated such qualities as "stratiform" and "turbid," but designated procedures for performing "agar hanging blocks" and determining "thermal death-points," "nitrogen requirements," "diastasic action," and "peptonization of curds." The Society's "Descriptive Chart," in its 1907 incarnation, tentatively proffered a new manual of methods, one serving the demands of both research and routine work.

Regarding the group number, the Committee submitted only minor alterations. The 1907 "Descriptive Chart" prescribed a ten-digit number, two more than the 1906 card. The extra numerals denoted diastasic action (*i.e.*, conversion of potato starch to sugar), and the production of acid and gas from glycerin. The revision allowed for a modicum of continuity in group

numbers, as the new system simply appended a couple of decimal places.

The Society responded favorably to the new "Descriptive Chart." Members discussed the card at the 1907 annual meeting, and passed a resolution of appreciation for the Committee's efforts. Furthermore, the SAB voted to "endorse" the "Descriptive Chart" for general use. The "endorsement" did not mandate that SAB members employ the card. It only recognized the chart's utility in determinative work and in describing new species.⁵⁰ Harry A. Harding and Martin J. Prucha, of the Geneva Agricultural Experiment Station, reported to the 1908 gathering their own experience of employing the new card in surveying cheese flora. They commended the "increased accuracy with which different workers assign germs to like groups, in the quickness with which such assignments can be made and in the ease with which duplicates can be detected or accumulated stock of records be consulted." As use of the chart increased, Harding and Prucha anticipated a collective disciplinary advance, for the "results of one worker are made immediately available to succeeding workers and each can recognize the forms which have been already described and build upon the foundation already laid." By accumulating data in this fashion, the authors predicted that it would be "possible to have as exact a knowledge of the bacterial flora of any given class of objects as we now have of the higher flora of a region." Harding and Prucha maintained that development would render bacteriology more biological. The introduction of the "society's card," they confidently asserted, "will prove the most important addition to the laboratory and classroom since Robert Koch brought out the gelatin plate."⁵¹

⁵⁰ "SAB Book of Minutes," 81.

⁵¹ Harding and Prucha, "The Utility of the Society's Card in Classifying the Cheese Flora," paper presented before the 10th Annual SAB Meeting (1908), abstracted in *Science* 29 (1909): 1012. See also, Harding

Harding and Prucha's enthusiasm exceeded the actual impact of the card. Indeed, within a few years, an increasing number of bacteriologists employed the Society's Card. The discipline remained, however, disjointed. Harding, in turn, directed his attention to the implications of the Society's Card. In a 1910 technical bulletin that served as his doctoral thesis from Cornell, Harding noted that the card's expedience depended upon the constancy of certain physiological characters. The group number in particular operated on the assumption that a bacterial type produced invariable results when subjected to the chart's ten salient examinations. In order to test this assumption, he subjected forty-three cultures of *Pseudomonas campestris* to a wide variety of conditions, seeking to determine the "maximum variation" of the species. Harding deliberately selected *Ps. campestris*. This plant pathogen, which had been used to illustrate the group numbering system on each of the three SAB cards, displayed an unusual yellow color. Bacteriologists could immediately recognize the organism, and questions of contamination "could be easily settled." Harding found that all forty-three cultures produced the same group number, 211.3332513. He did not deny that most organisms displayed some variability. Rather, Harding validated the choice of physiological tests specified in the "Descriptive Chart."⁵² In his conclusion, Harding touted the card as the "logical outcome of forces which have been at work among bacteriologists for at least fifteen years." If universally and intelligently applied, the chart could "bring order out of chaos," and thereby elevate

and Prucha, "The Bacterial Flora of Cheddar Cheese," Technical Bulletin of the New York Agricultural Experiment Station no. 8 (1909): 186, 187 & 191. At the 11th SAB meeting (1909), the Committee reported that the card "has proved highly satisfactory in the hands of those who have given it a thorough trial." The "maximum benefit," however, could only be realized as the card's "use becomes still more general." F.P. Gorham and C-E.A. Winslow, "Report of the Committee on the Identification of Bacterial Species, 1909," abstracted in Science 31 (1910): 546.

⁵² Harding, "Constancy of Certain Physiological Characters," 3, 6 & 29. Harding insisted that the "qualitative variations" normally attributed to the bacteria themselves were "probably due largely to faults either in observation or in technique," 41.

“bacteriology to the dignity of a true science.”⁵³

It is possible that other Society representatives shared Harding's contentment with the “Descriptive Chart.” However, while the Committee on the Identification of Bacterial Species persisted after 1907, it did so in name only. The SAB nominated Committee members, and renewed their status annually. The Committee, nevertheless, failed to convene and neglected to revise the chart. In the meantime, sales of the card continued without interruption, although some noticed that it no longer contained the most current methods and tests.⁵⁴ Even Harding's ardor waned. Now a member of the Committee himself, Harding delivered, before the 1913 annual meeting, a brief assessment of the 1907 chart. Initially, he acknowledged that the card “has not appealed to the pathologists, because they could test unknown cultures more quickly on animals.” Likewise, water bacteriologists shunned the card, as their “attention has been focused on *B. coli* and special media . . .” Harding did find solace in noting that “it has been very valuable to students of bacterial ecology,” however few they were in number. He called for an extensive overhaul, one aimed at rendering the chart and group number less “unwieldy,” and easier to record. Given more accurate and convenient cultural tests, Harding believed, a revised card might still unify the discipline.⁵⁵

At first glance, Harding's comments appear oddly timed. The Committee introduced a new edition of the “Descriptive Chart” at that same 15th annual meeting. The back of the chart listed the members of the Committee as Gorham, Winslow, Simon Flexner, Harding, and E.O.

⁵³ Harding, “Constancy of Certain Physiological Characters,” 41.

⁵⁴ “The 1907 Chart,” [ASM], box 8-C, folder 1.

⁵⁵ Harding, “The Classification Card and the Type of Study which it Merits,” paper presented before the 15 Annual SAB Meeting (1913), abstracted in Science 39 (1914): 789.

Jordan. The new card was not, however, a collective effort. Instead, Gorham revised the chart himself. Whereas Erwin F. Smith choose to issue a detailed and expansive card, Gorham favored simplicity. In the section for "Brief Characterization," Gorham eliminated more than half the lines of requested information. (Fig. 5.9) From the subheading of "Morphology," Gorham erased Smith's additions of endospores, zoogloea, and involution forms. Among the "Cultural Features," Gorham entirely removed examinations on gelatin plate, gelatin stab, and potato. Furthermore, Gorham did not consider viability at 37 degrees C., or growth in Cohn's and Uschinsky's solution, to be of determinative value.⁵⁶ The "Biochemical Features" winnowed out tests for liquefaction of gelatin and "agar, mannan," all three examinations of effect on milk, and the characters of "flourescent" and "luminous." "Distribution" was now limited to a question of animal or plant pathogen. By glancing only at the "Brief Characterization," it is clear that Gorham did not share Smith's vision of an inclusive chart. There were scant entries to lure dairy, soil, or industrial bacteriologists to the new card.

Regarding the section for "Detailed Features," Gorham followed the general outline of the 1907 chart, but with fewer entries. The new chart did not include cultural tests on potato, agar stab, litmus milk, gelatin colonies, silicate jelly, and Cohn's and Uschinsky's solutions. Gorham also rejected the need for determining the effect of sodium chloride and chloroform, as well as for the production of nitrogen from protein substances. The "Physical and Biochemical Features" lacked tests for the toleration to acids, drying, freezing, sunlight, and germicides. Even the list of sugar fermentations was halved. In contrast, Gorham expanded the sub-section on "Pathogenicity," adding spaces for clinical picture, serum reactions, autopsy findings, and site for

⁵⁶ To "Cultural Features," Gorham added five lines for information of growth in agar colonies.

removal of organism. Gorham altered very little of the group number, only removing the exemplars of *B. alcaligenes* and *Bact. suicida* -- organisms familiar to dairy and veterinary bacteriologists -- and adding *Bact. mycoides* -- a microbe enlisted by water bacteriologists to indicate contamination with surface drainage. If medical and sanitary bacteriologists viewed the 1907 chart as cumbersome and superfluous, Gorham's edition might have been more to their liking.⁵⁷ Dairy, soil, and industrial bacteriologists, in contrast, likely judged the new chart as a retreat to the narrow confines of medical and public health practice.

Gorham's stratagem to propitiate medical and sanitary bacteriologists failed. His chart was never "endorsed" by the SAB, and the Society records suggest that "probably no copies of this chart were sold." Moreover, "because of the dissatisfaction with this chart, a new Committee was appointed" without Gorham as member.⁵⁸ It is difficult to locate the exact nature of this disapprobation. There is suggestive evidence that the Society did not partake in Gorham's desire for a simplified chart. In fact, the annual meeting program for 1913 was replete with papers probing the more problematic aspects of the 1907 card. Whereas Gorham sought to eliminate those demanding and perplexing tests, other SAB members aspired to explore and refine the examinations.⁵⁹ The newly appointed Committee on the Revision of the Chart for the Identification of Bacterial Species consisted of Harding, Harold J. Conn, William D. Frost, I.J.

⁵⁷ Gorham's chart appended the biochemical test for "typhoid-phenol coefficient," a method particular to water and medical bacteriology.

⁵⁸ "Gorham's Chart," [ASM], box 8-C, folder 1.

⁵⁹ See, for example, Jean Broadhurst, "Constancy in Fermentative Reactions of Streptococci," Lore A. Rogers and Arnold Dahlberg, "The Relation of Habitat and Physiological Characters in the Streptococci," Rogers, William M. Clark, and Alice Evans, "The Significant Characters of the Colon Group Isolated from Cow Feces," Joel A. Sperry, "A Biochemical Study of Proteins with Reference to the Ability of Bacteria to Break Down and Utilize Pure Animal and Vegetable Proteins," Philip B. Hadley, "Capsule Formation by the Bacteria of Hemorrhagic Septicemia," and Joseph Leidy, "The Morphology of Bacteria -- An Early Research in Classification," papers presented at the 15th Annual SAB Meeting (1913), abstracted in *Science* 39 (1914): 763-769 & 798-808.

Kligler and Otto Rahn. Only Harding had served as member of the previous committees. (In the Summer of 1914, Rahn left the country to return to Germany, and Martin J. Prucha took his place on the Committee.) The composition of this new Committee is revealing. Harding and Prucha, in 1913, moved to the Illinois Agricultural Experiment Station, and continued their studies in soil and dairy bacteriology, as well as plant pathology. Harold J. Conn replaced Harding at the Geneva Station, and pursued research on soil microbes. Rahn, who also resided at the University of Illinois before leaving for Germany, investigated dairy and soil bacteria. Only Frost, from the University of Wisconsin, and Kligler, from the American Museum of Natural History, worked in sanitary and medical bacteriology (although they maintained lasting interests in taxonomic questions and determinative techniques).⁶⁰ Not surprisingly, the new members embraced the 1907 model of the descriptive chart, one that was both inclusive and extensive.

The Committee submitted its revised chart to the 16th annual meeting (1914), one that bore a keen resemblance to the 1907 edition. (Fig. 5.10) As a point of fact, the sections on "Brief Characterization" and "Group Number" reproduced the 1907 version in their entirety. Even the "Detailed Features" closely paralleled the earlier card, with only minimal additions (*e.g.*, post-fission movements, and production of hydrogen sulphide, etc.). The only significant subtractions came in the removal of the table for "Effect of Germicides," and the tests for action of sodium chloride and chloroform. The most striking change was found in the complete absence of a glossary or supplemental instructions on method. The Committee acted deliberately, intending to compose a comprehensive "manual of methods to be used in connection" with the chart. They

⁶⁰ Kligler, for example, presented "A Systematic Study of the *Coccaceae* in the American Museum of Natural History Collection" at the 14th Annual SAB Meeting (1912).

rendered this decision without Society sanction, acting instead on Harding and Conn's personal belief that this was "one of the most urgent demands of bacteriology to-day . . ." The publication of that manual, however, was delayed, "pending investigation of the methods to be included in it." The Committee also promised a more "radical revision of the chart, which was felt to be badly needed."⁶¹ To illustrate this point, Harold J. Conn presented a study of the *B. subtilis* group using the Society's Card. Conn found that when he tried to distinguish members among this category of soil microbes, the chart's techniques and "'group numbers' do not always indicate different species." He concluded that "one of the first steps needed in revising the card is to establish the best methods for making the various determinations." Only after completing such a study could the Committee thoroughly overhaul the Descriptive Chart.⁶²

Other Society members already heeded Conn's plea. At the same 1914 meeting, the section on "Systematic Bacteriology" featured papers on induced changes in the fermentative powers of streptococci; the influence of concentration on gelatin liquefaction; variations in the chromogenic and cultural characteristics of *B. coli*; and, the inadequacy of the APHA's standard method of determining nitrate reduction.⁶³ These presentations demonstrated both an awareness of the Descriptive Chart's limitations, as well as a willingness to work toward its improvement. While many viewed the 1914 card as vastly superior to Gorham's edition, the "general sentiment

⁶¹ Conn, "Historical Introduction," 6; and, Harding, "The Classification Card and the Type of Study which it Merits" 798.

⁶² Conn, "A Study of *B. Subtilis* by Means of the Classification Card," paper presented before the 16th Annual SAB Meeting (1914), abstracted in *Science* 41 (1915): 618.

⁶³ Jean Broadhurst, "Some Induced Changes in Streptococci," Zae Northrup, "The Influence of the Concentration of the Gelatin in Gelatin Media upon Liquefying and Non-liquefying Bacteria," M.R. Smirnow, "Induced Variations in Chromogenesis," Smirnow, "Induced Variations in the Cultural Characteristics of *B. Coli*," and, Robert S. Breed, "The Standard Method of Determining Nitrate Reduction," papers presented at the 16th Annual SAB Meeting (1914), abstracted in *Science* 41 (1914): 618-624, 661.

was that the changes from the 1907 chart were not sufficiently radical.”⁶⁴

The Committee provided its next substantive report to the SAB meeting in 1916, acknowledging that the card had “stood essentially unchanged for practically ten years.” While each year brought a “growing appreciation of the value of the card,” they admitted that it remained “not entirely satisfactory at all points.” In particular, they pointed to a lack of “specific directions for the determination of the group number” and readily available “definitions of the terms used upon the card,” two features eliminated in the 1914 card while they developed a manual of methods. For practicing bacteriologists, this wait might have caused some consternation. Still, the Committee rationalized that “progress should be by evolution rather than revolution.” In the interim, they submitted tentative methods for the determination of spore formation, oxygen relations, liquefaction of gelatin, fermentation of sugars and glycerin, chromogenesis, reduction of nitrates, and hydrolysis of starch.⁶⁵ At the program sessions of the 1916 meeting, two methodological innovations pertinent to the Descriptive chart were introduced. William M. Clark and Herbert A. Lubs, of the Bureau of Animal Industry, detailed their new method of adjusting the reaction of culture media, using a set of indicators based on hydrogen-ion (pH) concentration, while F.M. Huntoon described a simple technique for staining capsules.⁶⁶ Even before the completion of the full manual of methods, SAB members could familiarize themselves with the latest techniques.

The Committee announced a new project at the 1916 annual gathering, that of

⁶⁴ “The 1914 Chart,” [ASM], box 8-C, folder 1

⁶⁵ Harry A. Harding et al, “Report of the Committee on Revision of the Chart for the Identification of Bacterial Species. Minutes, 18th Annual SAB Meeting,” [ASM], box 1-IVA, folder 2, pp. 11-12.

⁶⁶ Clark and Lubs, “New Indicators Useful in Bacteriology,” Clark and Lubs, “A Substitute for Litmus in Litmus Milk,” and Huntoon, “A Reliable and Simple Method of Staining the Capsules of Bacteria,” papers presented at the 18th Annual SAB Meeting (1916), abstracted in Journal of Bacteriology 2 (1917): 58-59, 63-64.

constructing a card suited to the “needs of the beginning classes in bacteriology.” The cards’ authors, dating back to Chester and Smith, always intended for the Descriptive Chart to form the basis of classroom and laboratory instruction.⁶⁷ For beginning students, the 1914 card elicited confusion, as many of the descriptive tests were not taught in introductory courses. In addition, the chart lacked space for detailed records and sketches “which are usually considered desirable in connection with the work of such beginning students.” Harding reported that many universities addressed this problem by devising four page folders, based on the Society’s Card, which could be filed in student notebooks. He recommended that the Committee co-ordinate with these institutions such that the folders would “more naturally lead up to the use of the classification card by the more advanced students.” When taught in this manner, Harding predicted that students would be “able to use the present card with profit.”⁶⁸ David Bergey, then president of the SAB, concurred. In his presidential address on the “Pedagogics of Bacteriology,” Bergey recommended that an introductory course follow “the general plan of description contained in the Society card.” Bergey reasoned that the card would acquaint the student “with the vocabulary generally employed in this work and will help him to recognize some of the activities of the bacteria.”⁶⁹ If the SAB’s Descriptive Chart was to become universally adopted, Harding and Bergey declared it imperative to reach students early, and teach them to think according to the card’s scheme.

During 1917, the Committee studied revisions to the chart, solicited suggestions for new

⁶⁷ See, Chester, “Preface,” A Manual of Determinative Bacteriology, v.

⁶⁸ Harding, “Minutes, 18th Annual Meeting,” 11.

⁶⁹ Bergey, “Pedagogics of Bacteriology,” 10-11. Three years later, Bergey presented a paper on the “Teaching of Elementary Systematic Bacteriology,” in which he described a course where students learned bacterial taxonomy through an introduction to the Society’s Card. Paper presented at the 21st Annual SAB Meeting (1919), summarized in Abstracts of Bacteriology 4 (1920): 1.

techniques, and drafted its manual of methods.⁷⁰ Meanwhile, sales of the 1914 card continued apace.⁷¹ Harding resigned his position as chair, citing his growing obligations to the Illinois Agricultural Experiment Station, and Harold J. Conn assumed leadership of the Committee. Shortly thereafter, Conn enlisted Kenneth N. Atkins, of Dartmouth College, to serve as the Committee's expert in staining techniques. At the 1917 annual SAB meeting, the Committee issued a "Descriptive Chart for Use in Bacteriological Instruction." The three page pamphlet represented a radical departure from earlier cards. It furnished ample room for students to sketch cultures, and contained substantially fewer determinative tests.⁷² The section on "Brief Characterization," for example, requested thirty-nine lines of information, as compared to the fifty-two lines of the 1914 card. (Fig. 5.11) The instructional chart removed "Zoologoea" and "Involution Forms" from the appraisal of morphological traits, while it added five new queries regarding endospores. Among the cultural and biochemical features, now retitled "Physiology," the 1917 chart eliminated all measures in nutrient broth, gelatin stab, and potato. Moreover, the "Brief Characterization" did not leave room for growth at body temperature, viability on Cohn's and Uchinsky's solution, liquefaction of gelatin, nitrate reduction, or the production of indol, hydrogen sulphide and ammonia. The instructional chart stressed colony characteristics and aggregate action on agar, gelatin, and milk media, while it eschewed chemical measures of

⁷⁰ In some instances, the *Journal of Bacteriology* published the proposed improvements in the Chart's tests. See, for example, Paul W. Allen, "A Simple Method for the Classification of Bacteria as to the Diastase Production," *Journal of Bacteriology* 3 (1918): 15-17. Allen found that potato slants rarely exhibited a uniform quality, and offered instead a recipe for water-soluble starch added to plain agar.

⁷¹ SAB Secretary A.P. Hitchens indicated that there had been "a steady demand for the Society's classification card ever since its preparation several years ago. This card has evidently served a useful purpose." Hitchens, Glenolden, Newsletter to Members of the SAB, 20 July 1917, [ASM], box 1-IVA, folder 2, p. 1.

⁷² Zae Northrup, an active member in the SAB's efforts to revise bacteriological education, lauded the inclusion of room for sketches in the new chart, in her paper, "Bacteria, Yeasts, and Mold Charts as a Valuable Addition to the Notebook of the Beginning Student in Bacteriology," presented before the 19th Annual SAB Meeting (1917).

bacterial physiology. This emphasis reflected the Committee's belief that beginning students struggled enough with the rudiments of pure cultures. Curiously, the 1917 card narrowed the range of possible "distributions," allotting only three choices of "animal pathogen," "plant pathogen," and "saprophyte." As far as the "Brief Characterization" allowed, "soil," "milk," "fresh water," "salt water," "sewage," "iron," and "sulphur" bacteria were to be grouped under "saprophytes," organisms reserved for later scrutiny in more advanced courses.

The Committee similarly streamlined the section on "Detailed Features." They did not expect the beginning student to examine cultures in hanging-blocks, on potato, Loeffler's blood serum, Cohn's solution, Uchinsky's solution, or silicate jelly. Nor was the student required to determine pathogenic properties, or the production of indol, hydrogen sulphide, ammonia, acids, alkalies, and alcohols. Instead, the 1917 instructional chart retained lines for sugar fermentation, nitrate reduction, diastatic action, and chromogenesis. Given these techniques, the beginners' card did not prepare a student for immediate employ in any of the bacteriological specialties. Rather, the Committee furnished a pedagogical guide to the shared aspects of bacteriological pursuits, however indeterminate they might be.

More importantly, the Committee submitted its first report on the "Methods of Pure Culture Study" at the 1917 meeting. The methods, intended "for use in instruction in bacteriology," were offered as provisional, subject to revision and "adoption" at the next SAB meeting. For those bacteriologists who still used the 1914 chart, the new methods applied, with the understanding that "many of the determinations called for by the older chart have not yet

been studied by the Committee, and are not included in this report.”⁷³ The Committee clearly expressed, however, its aim to construct, *de novo*, a new chart and manual. The report began with cookbook recipes for media preparation, even recommending particular brands of commercial peptone and gelatin.

In many instances, the Committee specified the latest APHA methods for milk and water analysis, with the substitution of different indicators for determining pH. The report paid careful attention to the techniques of “invigorating” a culture, insisting that it be studied under conditions of luxuriant growth. In contrast to the APHA standards, the Committee’s methods allowed for great flexibility, explaining that if the organism did not grow well at the temperature or on the media listed, it should be cultured “with any medium and at any temperature known to adapted to its growth.” Many pathogens, for example, required more peptone than other bacteria, while most soil microbes demanded an atypical hydrogen-ion concentration. “In such cases the individual is free to modify” the media formulae “to suit his own purposes,” so long as he records his alterations on the chart. If the organism failed to grow on any known artificial media, “the results of the study called for by the chart will have little significance.”⁷⁴ As far as the 1917 chart and methods were concerned, bacteria displayed their ‘true’ characteristics only during periods of rapid multiplication.

The preliminary report then provided instructions for the study of motility, the presence of spores, capsules and irregular forms. Among the examinations in “Physiology,” the

⁷³ H.J. Conn et al., “Methods of Pure Culture Study: Preliminary Report of the Committee on the Chart for Identification of Bacterial Species,” Journal of Bacteriology 3 (1918): 115. Among the specific tests excluded from the 1917 chart and methods were: Loeffler’s blood serum, potato cultures, silicate jelly, Cohn’s and Uschinsky’s solutions, and production of indol or ammonia.

⁷⁴ Conn et al., “Preliminary Report,” 116-119. See also, American Public Health Association, Standard Methods for the Examination of Water and Sewage, 2nd ed. (New York: APHA, 1912).

Committee introduced “provisional” methods for liquefaction of gelatin and relation to free oxygen. The former technique aimed to distinguish “true liquefiers” (organisms producing ecto-enzymes) from those that released proteolytic endo-enzymes from the cell only after death. The latter examination struggled with organisms that acquired their oxygen through the reduction of certain carbohydrates.⁷⁵ While both of these guidelines ostensibly dealt with the technical demands of completing the 1917 chart, they focused critical attention on the nutritional and metabolic activities of bacteria. In this regard, the Committee vetted the very biological features that underlay their determinative tests.⁷⁶ If the Committee struggled to ensconce reliable methods, it was only because their endeavor presupposed much more than a review of routine procedures.

The Committee concluded their report with a short discussion on the group number. Whereas earlier committees hoped that the number could replace both traditional species names and lengthy descriptions (*i.e.*, the number would indicate *all* relevant characteristics), Conn conceded that it constituted simply a “brief means of recording the salient features” of the microbe, one more suited to summarize the physiological, rather than morphological or cultural, features. Furthermore, the group number relied on the generic names of Migula, a taxonomy less commonly employed in 1917 than it was in 1907. The report succinctly stated that “a revision of the group number on some other basis will be necessary in the near future.”⁷⁷

At the same 1917 meeting, Conn summarized the Committee’s preliminary report. He

⁷⁵ Conn et al., “Preliminary Report,” 121.

⁷⁶ Conn and company did not hold great confidence in all of the report’s methods. The test for nitrate reduction, for example, continued to offer inconclusive results, despite numerous revisions.

⁷⁷ Conn et al., “Preliminary Report,” 121.

explained that Committee removed many of the 1914 chart's "little used tests," and acknowledged that the group number may have reached the limit of its usefulness.⁷⁸ Within the program session for "General and Technical Bacteriology," William M. Clark and Barnett Cohen remarked on the use of the new indicators for determining the pH of culture media. In addition to describing the influence of certain pH ranges on the reproduction of common bacteria, the two USDA Dairy Division scientists strongly discouraged the Committee from "standardizing either the degree of accuracy of measurement or the reactions required in the adjustment of media." Meanwhile, S. Henry Ayers and Philip Rupp, also from the Dairy Division, warned against drawing hasty conclusions from fermentation reactions. They presented several organisms that simultaneously produced acid and alkali when cultured in dextrose, an outcome likely to confuse most users of the SAB chart.⁷⁹ Neither of the papers argued against the utility of the Society's card. Rather, they suggested that even the instructional chart highlighted the complex and variable physiology of certain bacteria.

At the conclusion of the annual gathering, the Committee reminded the Society that, unlike previous editions, this was the "first Chart on which Society endorsement was not requested." Although intended for "instruction only and not to replace the 1914 Chart in research work," it soon became the only form sold.⁸⁰ For the moment, the Committee found little

⁷⁸ H.J. Conn, "Report of the Committee on the Chart for the Identification of Bacterial Species," presented before the 19th Annual SAB Meeting (1917), summarized in Abstracts of Bacteriology 2 (1918): 8. The discussion at the meeting continued the criticism of Lawrence Burton and Leo Rettger's paper before the 18th Annual SAB Meeting (1916), "The Habitat and Characters of Certain Members of the Colon-Aerogenes Group," in which they found the group number "inapplicable" due to the "marked variability" of this noted class of bacteria.

⁷⁹ Clark, "Remarks upon the Use of Indicators," Cohen and Clark, "The Influence of the pH of Media upon the Reproduction of Some Common Bacteria," and, Ayers and Rupp, "Simultaneous Acid and Alkaline Bacterial Fermentations from Dextrose and the Salts of the Organic Acids Respectively," papers presented before the 19th Annual SAB Meeting (1917), summarized in Abstracts of Bacteriology 3 (1918): 10-11.

⁸⁰ "Instruction Chart of 1917," [ASM], box 8-C, folder 1.

cause for concern, reasoning that the instructional chart proved well suited to research in which a “general survey is desired of the bacterial flora of some particular medium, preliminary to a later, more intensive study of the individual species.”⁸¹

The Committee on the Descriptive Chart issued a “Progress Report” in October of 1918. Curiously, the report began with a lengthy and detailed account of the card’s history and purpose. The Committee feared that some SAB members might still believe that the group number could serve as a suitable replacement for traditional species designations. Conn reiterated the Committee’s intentions for the number to provide quick comparisons of cultures, and nothing more. Nevertheless, he remained unwilling to abandon the group number entirely, promising another revision, one “less arbitrary and more logical than the one now on the card.”⁸² On a more general level, the report reminded readers that the Committee’s own work showed “very plainly that (in regard to nitrate reduction and acid production at least) no standard medium can be adopted which will give consistent results with all kinds of bacteria.” Furthermore, Conn cautioned that the Committee could not revise the card frequently enough “to contain the more recently devised tests for special groups of bacteria,” and hence it “no longer helps secure uniformity in bacterial characterization . . .” As a consequence, the Committee would not ask that their methods be “adopted as standard” at the upcoming annual meeting. Rather than promising definitive determinative techniques, they offered to include merely the best methods

⁸¹ Conn et al., “Progress Report for 1918,” 111.

⁸² Conn et al., “Progress Report for 1918,” 107 & 111. Conn propounded that at that time, any group number would necessary be imperfect: “first, because the diagnostic importance of the various characteristics differs among different groups of bacteria; and secondly because the methods for making the determinations have never been perfected and the results correspondingly inaccurate,” p. 110. See also, H.J. Conn and R.S. Breed, “The Use of the Nitrate-Reduction Test in Characterizing Bacteria,” Journal of Bacteriology 4 (1919): 267.

known to the Committee in their reports.⁸³

The "Progress Report for 1918" marked another shift in the Committee's thinking. Earlier Committees viewed their role as one of evaluating available methods, selecting those techniques that proved most accurate in general use. The Committee now assumed an active role, assigning individual members the task of researching and developing particularly intractable aspects of the card and manual of methods. By the fall of 1918, these efforts began to bear fruit, and the Committee announced improvements in the Gram stain, detection of acid production, and reduction of nitrates. Moreover, the report provided a detailed explanation of the relation between hydrogen-ion concentration and acidity. For bacteriologists familiar with the work of Clark and Lubs, this account added little. Nonetheless, given that most contemporary bacteriological textbooks omitted the matter entirely, Conn believed that the lengthy biochemical digression would assist teachers in their use of the instructional chart.⁸⁴ Regarding nitrate reduction, Conn mentioned that the test was a "far more complicated matter than originally supposed." Previous investigators found fault with the APHA standard method on two accounts; some organisms grew poorly on the medium, while others converted nitrates to ammonia or free nitrogen. Conn's own research further indicated that select organisms assimilated nitrates and ammonia as fast as they were produced. Although the Committee failed to propose a standard method for the determination of nitrate-reduction, its efforts directly explored another uncharted

⁸³ Conn et al., "Progress Report for 1918," 110-111.

⁸⁴ Conn et al., "Progress Report for 1918," 116-127. The report encouraged the colorimetric method of determining pH, while it strongly discouraged the older techniques of titration. See also, W.M. Clark and Lubs, "The Colorimetric Determination of Hydrogen-Ion Concentration and its Application in Bacteriology," Journal of Bacteriology 2 (1917): 1-34, 109-136, 191-236.

aspect of bacterial metabolism.⁸⁵

At the next annual meeting (1918), the Committee's report drew little comment. Instead, Society members discussed aspects of the chart and methods during the session on "Systematic Bacteriology" and "Bacteriological Technique." University of Wisconsin's Paul F. Clark, for example, took issue with the Committee's insistence that all morphological traits be recorded on fresh (recently invigorated) cultures. Clark demonstrated that many organisms presented a vastly different picture during the period of rapid division (the first 20-24 hours) than afterwards. Other speakers commented on the fermentation of less common sugars, the discovery of bacteria that liquefied agar, and further modifications of the recipe for Gram's stain.⁸⁶ If the Committee busied themselves with diligently researching improvements in the card's methods, other SAB members were equally willing to follow their lead.

The Committee on the Descriptive Chart presented its next report to the 1919 meeting. Over the course of previous year, the SAB distributed to every member a free copy of the 1914 card, the 1917 instructional chart, and the preliminary methods. Moreover, several members purchased multiples of each, at a price of 10 to 15 cents apiece. In fact, from July of 1918 to December of 1919, the SAB sold 18,000 copies of its instructional chart, 4,400 of the 1914 card, and another 250 copies of the Committee report. Conn interpreted the staggering sales as a wholesale endorsement of the Committee's efforts, noting the popularity of the materials in both

⁸⁵ Conn et al., "Progress Report for 1918," 129-131. See also, Robert S. Breed, "The Standard Method of Determining Nitrate Reduction," presented at the 17th Annual SAB Meeting (1915); and, I.J. Kligler, "The Source of Ammonia and Nitrites in a Nitrate-Peptide Solution," American Journal of Public Health 8 (1913): 788-792.

⁸⁶ Clark, "Morphological Changes during the Growth of Bacteria," C.S. Hudson, "Bacteriological Sugars," Zae Northrup, "Agar-Liquefying Bacteria," and Joseph Leidy, "Modification of Gram's Stain for Bacteria," papers presented at the 20th Annual SAB Meeting (1918), summarized in Abstracts of Bacteriology 3 (1919): 2-7.

research laboratories and classrooms.⁸⁷ The Committee promised a revised research card for 1920. In the meantime, they pondered three lingering questions: Should the chart be a multiple-page folder or a single sheet? Should the group number be included? And, should a special space be devoted to pathogenesis? Given the experience with the 1917 instructional chart, the Committee concluded that “even research men prefer a chart considerably simpler than the old card,” and were using the instructional card, “although they don’t like its bulk.” In light of the fact that the 1914 card called for much “unneeded information,” the Committee believed it possible to use a single sheet of paper, printed on both sides, with the more salient characteristics on the front.⁸⁸

As for the group number, Conn again stated that it represented “the weakest part of the chart.” It remained unchanged largely due to inertia, and the lack of a suitable replacement. In fact, Committee members themselves stood divided over its value; some holding it to be the most important component of the chart, while others insisted on its removal. They decided to abandon the old number without hesitation, and devise an entirely new form “calling for the right information.” In order to avoid confusion with the prior number, the new designation was to be called an “index number.” So as to discourage the belief that number replaced formal species names, the new number would lack a generic symbol (*e.g.*, *B.* for bacillus, *Bact.* for bacterium, etc.). The Committee even promised to specify on the chart that the index number was entirely optional, as it recorded information contained elsewhere on the card.⁸⁹

⁸⁷ H.J. Conn, H.A. Harding, I.J. Kligler, W.D. Frost, M.J. Prucha, and K.N. Atkins, “Report of Committee on Descriptive Chart. Part II. Report of Progress during 1919,” *Journal of Bacteriology* 5 (1920): 315. The number of copies sold does not indicate the sum total of bacteriologists using the cards or methods. Rather, individual bacteriologists likely employed a single copy for each culture that they studied.

⁸⁸ Conn et al., “Report of Progress during 1919,” 316.

⁸⁹ Conn et al., “Report of Progress during 1919,” 317-318.

The Committee undoubtedly recognized the desirability, at least for some bacteriologists, of a designated space for recording pathogenicity. One option they considered was the listing of a heading for "pathogenesis," followed by a blank space. Of course, that inclusion was irrelevant for saprophytic organisms. Non-pathogenic forms, on the other hand, "generally must be investigated by special tests" which required their own blank space. For this reason, the Committee settled on a flexible heading, "Special Reactions and Environmental Relationships (e.g., Pathogenesis)."⁹⁰

The Committee's 1919 report also articulated tentative revisions to its Manual of Pure Culture Methods. The Manual provided instructions for all tests enumerated in the 1917 instructional chart, but not those included in only the 1914 chart. Reasoning that it "seemed wisest to give further attention to these few methods" than to attend to "less frequently used" determinations, they offered modifications to the formulae of indicator media, the method of Gram stains, the measurement of hydrogen-ion concentrations, and tests for nitrate reduction. Conn reiterated his insistence that SAB members not regard the revised methods as official, only the best that "have come to the attention of the Committee at the present time." The Committee continued to welcome criticisms and suggestions.⁹¹

At the Business Session of the 1919 annual meeting, Conn recommended the Committee

⁹⁰ Conn et al., "Report of Progress during 1919," 318.

⁹¹ H.J. Conn, H.A. Harding, I.J. Kligler, W.D. Frost, M.J. Prucha, and K.N. Atkins, "Report of the Committee on the Descriptive Chart for 1919," *Journal of Bacteriology* 5 (1920): 127; and, Atkins, "Report of the Committee on Descriptive Chart. Part III. Modification of the Gram Stain," *Journal of Bacteriology* 5 (1920): 321-324. These revised methods continued to elicit criticism. See, for example, Victor Burke, "Notes on the Gram Stain with Description of a New Method," *Journal of Bacteriology* 7 (1922): 159-160. At the annual SAB meeting, the General and Technical Session featured three papers relevant to the Manual revisions: W.M. Clark, "Reduction Potential in its Relation to Bacteriology," K.N. Atkins, "A Modification of the Gram Stain," and J. Bronfenbrenner and M.J. Schlesinger, "Study of Nitrate Reduction by Bacteria," papers presented at the 21st Annual SAB Meeting (1919), summarized in *Abstracts of Bacteriology* 4 (1920): 2-4.

on the Descriptive Chart be disbanded, and be replaced with a Committee on Bacteriological Technic (*sic*). Conn envisioned that the new Committee would assume a broader mandate, one charged with examining myriad bacteriological practices, and not simply those demanded by the determinative card. The Society's Executive Council allowed Conn to add or remove committee members annually, "in order that it may be composed of men doing actual work on problems of technic."⁹² Consequently, Conn removed Harding, Frost and Prucha, retained Kligler and Atkins, and added John F. Norton and Gaius E. Harmon. Ostensibly, these changes might have signaled a shift in disciplinary priorities. Norton and Harmon, two sanitary and medical bacteriologists, replaced Harding, Frost, and Prucha, practitioners of dairy bacteriology. Conn, however, selected committee members based on current technical research, rather than disciplinary diversity. Norton, an Associate Professor of Bacteriology at the University of Chicago, devoted three years to examining the production of indol by bacteria, a determinative test mandated by the 1914 Society's card, but not the 1917 instructional chart. The Committee wished to reintroduce the test, but found that with the exception of one or two organisms, the available methods proved indeterminate.⁹³ Harmon, an Assistant Professor of Hygiene and Bacteriology at Western Reserve Medical School, pursued reliable methods for determining nitrate reduction, a problem he began as an undergraduate at MIT under William T. Sedgwick.

The reconstituted Committee issued its revised Descriptive Chart in the fall of 1920, one "planned along the lines of the 1917" instructional chart, and representing a "very radical change

⁹² Conn et al., "Report of Progress during 1919," 316.

⁹³ See, for example, Norton, "Indol Production by Bacteria," *Journal of Bacteriology* 6 (1921): 471-478. In addition, Norton investigated pleomorphism among Streptococci, a phenomena crucially related the morphology section of the chart.

from that of 1914."⁹⁴ In his "Progress Report for 1920," Conn announced that demand for the instructional chart remained high. However, Conn revealed that an informal survey had indicated the four-page format restricted the chart to mostly instructional use. By removing the "old and illogical group number," and by reducing the space for sketches, the Committee was able to condense its 1920 edition to a single 8 ½ x 11 inch sheet, printed on both sides. Moreover, the new card reintroduced "a few of the more commonly used tests, omitted from the instruction chart," without risking the burdensome detail that rendered the 1914 chart so unappealing for routine employment.⁹⁵ Conn believed that such a balance might ensure its use among both investigators and students.

As for the group number, the Committee removed it entirely, believing that "all the useful purposes of the group number" could be met by the marginal column of the "Brief Characterization" section. (Fig. 5.12) In place of the group number, the 1920 card offered an optional "Index Number," one with the sole object of assisting the "student in filing a large number of the completed charts . . ." Conn insisted that this numerical designation was "intended for index purposes only; and as it does not contain the generic symbol, there is no danger of its suggesting to the novice that it is intended to supplant the specific name of an organism."⁹⁶ As far as the Committee on Technic was concerned, the descriptive chart facilitated determination and identification only. It could not settle questions of nomenclature and classification.

⁹⁴ "1920 Descriptive Chart," [ASM] box 8-C, folder 1.

⁹⁵ H.J. Conn, K.N. Atkins, I.J. Kligler, J.F. Norton, and G.E. Harmon, "Progress Report for 1920. Committee on Bacteriological Technic," *Journal of Bacteriology* 6 (1921): 136.

⁹⁶ Conn et al., "Progress Report for 1920," 136-137.

In many respects, the 1920 chart resembled its instructional predecessor of 1917. For example, the morphology section provided space for five sketches, referred to “irregular” rather than “involution” forms, and listed only the Gram’s and acid-fast stains, in lieu of the daunting catalog of the 1914 card.⁹⁷ (Fig. 5.13) The segment for “Cultural Characteristics” remained streamlined, inviting reports of growth on five media (*e.g.*, agar stroke, gelatin stab, nutrient broth, agar colonies, and gelatine colonies), and leaving blank spaces for three additional tests.⁹⁸ The Committee most noticeably redesigned the “Physiology” component, condensing the layout while reintroducing diagnostic tests for the production of indol and hydrogen sulfide. (Fig. 5.14) The 1920 card also appended questions concerning the “Relation to Oxygen,” while it modified the basic checks for effect on milk. As for fermentation reactions, the Committee retained tests on four carbohydrates (*e.g.*, dextrose, lactose, saccharose, and glycerin). The new chart added queries regarding “First appearance of alkali,” and “Max H-ion concentration,” indications that the Committee considered the fermentation reactions to be complex dynamic processes.

The most radical revisions appeared in the tables for “Brief Characterization” and “Index Number.” The chart distinguished between “Primary” and “Secondary” characteristics, with the former encompassing “Microscopic Features,” “Miscellaneous Biochemical Reactions,” and “Carbohydrates,” while the latter entailed “Vegetative Cells,” “Spores,” and “Cultural Features.” This hierarchical division represented a noted reversal of earlier determinative schemes, which prioritized all morphological characters over biochemical and physiological aspects of bacteria.

⁹⁷ The 1920 chart left room for “special tests,” rather than specifying such stains as fuchsin, gentian violet, Loeffler’s alkaline, or even methylene blue.

⁹⁸ Among the 1914 cultural tests excluded from the 1920 chart were: potato, potato starch jelly, Cohn’s solution, Uschinsky’s solution, Loeffler’s blood serum, milk, and litmus milk.

Regarding the index number, the Committee included a proviso indicating that the number was "optional; but its use will be found convenient if the charts are to be filed according to the salient characteristics of the organisms." The Index Number consisted of the first thirteen responses within the "Brief Characterization." It was, in essence, a tabulation of all the "Primary Characteristics." The student or researcher simply assigned the appropriate number for each of the prompted traits. For example, within "Microscopic Features," the chart solicited a description of "Form" for the first numeral of the Index Number. The bacteriologist could choose among nine options: 1, streptococci; 2, diplococci; 3, micrococci, etc. Compared to the earlier Group Number, the Index Number conveyed a strikingly dissimilar delineation of an organism. Thus, within the old system, the first three digits for *B. coli* were 222, for a microorganism which produced no endospores, grew as a facultative anaerobe, and did not liquify gelatin. Under the new scheme, *B. coli* bore 5312 as its initial four digits, indicating that it was rod-shaped, did not produce spores, showed peritrichic flagella, and stained Gram negative. Places for flagella and Gram stain were unique to the Index Number, holding no position in the earlier cards.

In the remaining nine digits, the 1920 chart included many of the characters of old number, albeit in a different order (*e.g.*, oxygen relations, gelatin liquifaction, fermentation of carbohydrates, nitrate reduction, chromogenesis, and diastatic action). The new Index Number omitted the place for fermentation of glycerin, adding instead a digit for "Pathogenicity, etc." which included numbers for such novel categories as "parasitic but not pathogenic" (*e.g.*, *B. coli*) and "autotrophic" (*e.g.*, iron and sulphur bacteria). This last addition might indicate a return to preeminence of medical and public health concerns among the chart's authors. In fact, the 1920

card did list "Pathogenicity" as the lone example of "Special Tests." Nonetheless, unlike earlier editions, this chart did not solicit information on host organisms; methods of recovery from the organism; change in virulence; toxins and antitoxins; resistance to dessication, freezing, and sunlight; and, effect of germicides. The undefined heading of "Pathogenicity," as well as the absence of spaces for distribution in water, milk, soil and sewage, more likely reflects the Committee's conviction that determinative practices cut across bacteriological applications, thereby effacing the *de facto* divisions within the discipline.

Aside from its revision of the Descriptive Chart, the Committee on Bacteriological Technic continued its study of various pure culture methods (*e.g.*, determining acid production, diastasic action, and Gram's stain). Curiously, the Committee devoted considerable energy to reviewing methods of counting bacteria, particularly in ketchup and other foodstuffs. On a superficial level, this survey closely resembled the sanitary control efforts of the APHA, and their Committees on Standard Methods. Conn insisted, however, that this matter concerned the SAB, and not just "organizations interested in disease or public health." Only by obtaining accurate counts could a bacteriologist "determine the abundance of the organisms in any particular habitat – a problem of value from the standpoint of pure science."⁹⁹ The SAB would, Conn reiterated, only pursue standardization of stains and equipment, and not methods.¹⁰⁰

During 1921, the Committee maintained investigations of diastasic action and the Gram's

⁹⁹ Conn et al., "Progress Report for 1920," 137-139.

¹⁰⁰ In pursuit of standard dyes and glassware, the Committee secured cooperation with several biological and zoological societies. The National Research Council sponsored the collaboration, enlisting 75 researchers from laboratories across the nation, and soliciting additional assistance from the U.S. Department of Agriculture's Color Laboratory. Conn maintained that these efforts required agreement from the American Chemical Society. H.J. Conn, "Report of the Committee on Bacteriological Technic, 1921," reported to the 23rd Annual SAB Meeting (1921), summarized in Abstracts of Bacteriology 6 (1922): 1.

stain, adding the indol test to its list of methods under scrutiny. The chart sold well during its first year of use, with Conn shipping some 16,000 copies to domestic and foreign laboratories. In his report to the annual SAB meeting, Conn mused that the Committee assumed "that the new chart is meeting the demands satisfactorily."¹⁰¹ During that year, Kligler and Norton left the Committee on Bacteriological Technic, replaced by Frederick Eberson, Fred W. Tanner, and Selman Waksman. Similar to Kligler and Norton, Eberson practiced in medical and public health bacteriology.¹⁰² Tanner practiced in similar fields, having directed the Illinois State Water Survey and supervised the State Board of Health's production of diphtheria antitoxin. In the early 1920's, Tanner became increasingly interested in food bacteriology.¹⁰³ Presumably, Conn tapped Tanner to guide the Committee's survey of bacterial counts in foodstuffs. The addition of Waksman was somewhat unexpected. During the late 1910's, Conn and Waksman engaged in a heated, and public, controversy over matters in soil bacteriology. Conn, in particular, challenged Waksman's emphasis on the role of fungi and actinomyces in soil processes. While the two eventually reached an academic detente, they nonetheless maintained dissimilar views of the field. What Conn and Waksman shared was commitment to revising the rudimentary methods of microbiology in order to investigate its more fundamental dimensions.¹⁰⁴

Within six months, the newly reformulated Committee issued its first modifications of to

¹⁰¹ Conn, "Report of the Committee on Bacteriological Technic, 1921," 1; and, A. Parker Hitchens, "Report of the Secretary upon the Philadelphia Meeting (1921) of the Society of American Bacteriologists," [ASM] box 1-VB, folder 1, p. 7.

¹⁰² Eberson received his M.S. in veterinary bacteriology from Iowa State College, studying the immunological reactions of hog cholera, in 1915. He earned his PhD from Columbia University, with a thesis focusing on the relation between diphtheroid organisms and Hodgkin's disease. Conn selected Eberson to the Committee on Bacteriological Technic in part due to his work developing novel yeast agar media.

¹⁰³ See, Fred W. Tanner, Bacteriology and Mycology of Foods 1st ed. (New York: John Wiley and Sons, 1919).

¹⁰⁴ Waksman, My Life with Microbes (New York: Simon and Schuster, 1954), 114.

the Methods of Pure Culture Study. They returned again to the Gram stain, choosing this time to endorse three variant techniques. In addition, the Committee outlined methods for determining sugar fermentation among alkali-formers, and nitrate reduction from organisms growing poorly on standard media. Concerning the production of indol and hydrogen-sulfide, the Committee offered only tentative endorsement of proposed determinative procedures.¹⁰⁵ At the 1922 SAB meeting, Conn reiterated the Committee's intention to published a compiled Manual of Pure Culture Methods, secured in a loose-leaf folder. As revisions of the methods were to be ongoing, the unbound format allowed for individual sections to be replaced without reprinting the entire Manual. Moreover, the loose-leaf format would keep printing costs low, a priority if universities were to purchase multiple copies for student use. Conn anticipated that demand for the Manual would parallel that for the Chart. During 1922, Conn proudly announced, sales of the Determinative Card approached 21,000. Publication of the Manual would likely increase demand even further.¹⁰⁶

The Committee's efforts to standardize stains and apparatus bore institutional fruit. The SAB's collaboration with the National Research Council (NRC), the USDA, and other scientific societies spawned the Commission on the Standardization of Biological Stains. Conn, as well as L.R. Jones, a plant pathologist from the University of Wisconsin, represented the SAB on the Commission. In fact, the Commission selected methylene blue as the first dye to be examined, a

¹⁰⁵ Conn et al., "Methods of Pure Culture Study: Report of the Committee on Bacteriological Technic," Journal of Bacteriology 7 (1922): 519-528. See also, G.J. Hucker, "Comparison of Various Methods of Gram Staining: Preliminary Report," Abstracts of Bacteriology 6 (1922): 2; and, Hucker and W.A. Wall, "The Use of Agar Slants in Detecting Ammonia Production and its Relation to the Reduction of Nitrates," Journal of Bacteriology 7 (1922): 513-516.

¹⁰⁶ H.J. Conn, "Report of the Committee on Bacteriological Technic, Minutes of the 24th Annual SAB Meeting, 1922," [ASM] box 1-IVA, folder 5, pp. 6-7; and, Conn, "Methods of Pure Culture Study," Abstracts of Bacteriology 7 (1922): 1.

stain critical to routine diagnosis of diphtheria and bacterial counts of market milk. The standardization aims of the Commission did not, however, conflict with the work of the Committee on Bacteriological Technic.¹⁰⁷ By 1923, the Commission operated entirely independently of other scientific organizations, drawing funds from the Chemical Foundation and publishing its own journal, *Stain Technology*.¹⁰⁸

The *Manual of Methods of Pure Culture Study* reached Society members in the spring of 1923. The Committee printed the *Manual* with monies from the sales of the card, and the early demand suggested that the pair filled "a long-felt want for an inexpensive and concise record of accepted methods."¹⁰⁹ Conn wondered if the *Manual* should remain in its initial form – as a mere guide to completing the chart – or should increase its "scope so as to make it a more complete manual of bacteriological methods."¹¹⁰ There is some indication that bacteriologists, both domestic and foreign, looked for the Committee to issue a comprehensive handbook, one covering both mundane and advanced techniques.¹¹¹ Nonetheless, Conn appreciated the

¹⁰⁷ While the Commission sought to "certify" or "approve" biological stains for use in routine work, the Committee on Bacteriological Technic would not ask that its methods of pure culture be adopted as "official." The Committee, Conn maintained, had "consistently taken a stand against official methods for research work and does not wish that these methods be construed as such." Conn et al., "Report of the Committee on Bacteriological Technic," 520.

¹⁰⁸ For a description of the Commission, its early history, and its relation to the SAB, see, H.J. Conn, "An Investigation of American Stains," *Journal of Bacteriology* 7 (1922): 127; Conn, "History of the Commission on Standardization of Biological Stains," *Stain Technology* 1 (1926): 1-3; Conn, "Progress in the Standardization of Stains – Five Years of Stain Standardization," *Stain Technology* 3 (1928): 105-109; and, Conn, "Biological Stains in the First Quarter of this Century," (1958), [ASM] box 12-IE, folder 1, pp. 1-9.

¹⁰⁹ J.M. Sherman, "Letter from the Secretary," Washington, D.C., 12 November 1923, [ASM] box 2-IXC, folder 5, pp. 1-2. During 1923, the Committee sold 33,504 copies of the descriptive chart, harvesting \$587 for the production costs of the *Manual*. SAB members purchased 701 copies of the *Manual*, bringing \$556 to the Committee's coffers.

¹¹⁰ H.J. Conn, "Report of the Committee on Bacteriological Technic, Minutes of the 25th Annual SAB meeting, 1923," [ASM] Box 1-IVA, folder 6, p.13; and, Conn, "Report of the Committee on Bacteriological Technic. II. Methods of Pure Culture Study," *Abstracts of Bacteriology* 8 (1924): 1.

¹¹¹ In his review of American bacteriology, Charles Barthel, of the Royal Agricultural Academy of Sweden, remarked that "Americans have begun to attempt to standardize the methods available at present, with respect to nutrient media and metabolism experiments. This is all the more necessary in view of the fact that there

difficulty of maintaining up-to-date methods for even a fraction of the tests required by the card, choosing to harbor only limited aims for the time being.¹¹²

At the 25th annual SAB meeting (1923), Conn narrated the Committee's continuing endeavor to settle on a procedure for the Gram's stain. After six years of research and scrutiny of more than a dozen formulae, the Committee found it "almost impossible . . . to standardize the technic sufficiently to make all results agree." The Gram's stain, despite its long-standing use in routine bacteriology, resisted routinization. Conn speculated that certain "organisms are really Gram variable," capable of displaying alternating characters, even under identical test conditions.¹¹³ Again, the Committee, in its effort to compose a manual of methods, approached the indeterminate biology of bacteria. Conn registered an expanding list of research tasks. In order for the Committee to recommend culture media, much less explore the labyrinthine physiological characteristics of microbes, the SAB would be forced to vet commercially manufactured ingredients of culture media. There existed not only a dizzying array of media formulae, but myriad brands of peptones, gelatins, etc., each with their own particular qualities.¹¹⁴ In response to Conn's petition, the SAB's Executive Council established a fellowship for the study of culture media. Digestive Ferments Company (Difco), Detroit, supplied a \$2,000 stipend for the inquiry, which was conducted by Henry W. Schoenlein, Max

is no international agreement as to common methods of working." Barthel, A Review of the Present Problems and Methods of Agricultural Bacteriology (Stockholm: Knut and Alice Wallenberg Foundation, 1923), 51. Conn proudly declared that "The business shows all signs of flourishing. Orders have been received from England, Holland, Denmark and Japan..." Conn, "Minutes of the 25th Annual SAB Meeting," p. 13.

¹¹² At the 25th annual meeting (1923), the Committee submitted revised instructions for the card's section on morphology, fermentation of sugars, and composition of media. The Committee felt compelled to revise these methods, despite their original publication only a few years prior.

¹¹³ Conn, "Minutes of the 25th Annual SAB Meeting," 14; and, Conn, "Report of the Committee on Bacteriological Technic. II.," 1.

¹¹⁴ Conn, "Minutes of the 25th Annual SAB Meeting," 15-16.

Levine, and Robert E Buchanan, at Iowa State College. Within a year, the investigators compiled recipes for some 2,500 media, promising to "reduce the number of 'new' media by at least 90 per cent."¹¹⁵ Conn may have eschewed standardized techniques, but he unhesitatingly welcomed simplified methods.¹¹⁶

Meanwhile, the Committee on Bacteriological Technic again rotated membership, with James H. Brown, Barnett Cohen, and George J. Hucker replacing Selman Waksman and Frederick Eberson. A member of the Rockefeller Institute's Division of Animal and Plant Pathology, Brown specialized in the differential characteristics of human and animal *Streptococci*. As part of his investigations, Brown developed a novel means of determining the buffer index of cultures, while he explored the use of transparent milk as bacteriological media.¹¹⁷ Cohen joined the Committee as an authority on determinations of hydrogen-ion concentrations, having extensively studied this aspect of bacteriological technique at the USDA's Dairy Division with William M. Clark. Cohen's expertise promised to keep the Committee

¹¹⁵ The SAB sponsored a conference, in concert with members of the American Public Health Association, Dairy Science Association, Dairy Inspectors Association, Water Works Association, and the American Chemical Society, to standardize ingredients for culture media. J.M. Sherman, "Minutes of the 25th Annual SAB Meeting," [ASM] box 1-IVA, folder 6, pp. 15-16, 34; Conn, "Report of the Committee on Bacteriological Technic. III. Standardization Activities," Abstracts of Bacteriology 9 (1925): 1; and, Sherman, "Minutes of the 26th Annual SAB Meeting," [ASM] box 1-IVA, folder 7, pp. 6-8. The final compendium appeared under the SAB's auspices as Max Levine and Henry W. Schoenlein, A Compilation of Culture Media: For the Cultivation of Microorganisms (Baltimore: Williams & Wilkins Co., 1930).

¹¹⁶ In what had become a yearly reminder, Conn insisted that his Committee had no intention of formulating "official methods." The task, he indicated, was to be "left to other bodies having closer relation to regulatory work; and the activities of this Committee should, on the other hand, be concerned with the development of new technic rather than the standardization of methods." Conn, "Report of the Committee on Bacteriological Technic. II.," 1.

¹¹⁷ See, for example, Brown, "Hydrogen Ions, Titration and the Buffer Index of Bacteriological Media," Journal of Bacteriology 6 (1921): 555-570; and, Brown and Paul E. Howe, "Transparent Milk as a Bacteriological Medium," Journal of Bacteriology 7 (1922): 511-514. A former student of Harry Harding and Martin J. Prucha at the University of Illinois, Brown was nearly groomed to be a member of the Committee. Even as a later assistant to Theobald Smith at the Rockefeller Institute, Brown developed an improved anaerobic jar, and an innovative technique for the micro-gas analysis of bacterial cultures.

abreast of rapid refinements in pH indicators.¹¹⁸ Hucker joined the Committee as the member most closely aligned with Conn's own research interests. A dairy and veterinary bacteriologist at the New York Agricultural Experiment Station, Geneva, Hucker worked closely with Conn, modifying methods for determining nitrate reduction and the fermentation of sugars. Hucker also performed ongoing comparisons of Gram staining techniques, embodying Conn's hope that the procedure might finally be fixed.¹¹⁹

At the 1924 annual meeting, the Committee on Bacteriological Technic heralded the flourishing demand for the *Manual*. Sales during its second year continued to increase, with some 288 institutions or persons being "interested enough in the work to enter subscriptions to have their copies kept up to date." In this arrangement, the Committee promised to deliver revised sections of the *Manual* as they became available.¹²⁰ During the course of the previous year, the Committee distributed updated methods for the preparation of media, study of morphology, fermentation reactions, determination of hydrogen-ion concentration, reduction of nitrates, hydrolysis of starch, and indol production. In the last four instances, the new procedures did not entirely supplant the older methods. Instead, the Committee hoped that users of the *Manual* and chart would compare the techniques, reporting their assessments to Conn and his associates. Conn envisioned the *Manual* as an ongoing collaborative effort, enlisting the assistance and allegiance of SAB members. In this manner, the card and *Manual* might tether

¹¹⁸ See, for example, Cohen, "Some New Sulfonphthalein Indicators," paper presented at the 24th Annual SAB Meeting (1922), summarized in Abstracts of Bacteriology 7 (1923): 3.

¹¹⁹ See, Hucker, "A New Modification and Application of the Gram Stain," Journal of Bacteriology 6 (1921): 395-399; and, "A Comparison of Various Methods of Gram Staining," paper presented at the 23rd Annual SAB Meeting, summarized in Abstracts of Bacteriology 6 (1922): 2.

¹²⁰ H.J. Conn, "Report of the Committee on Bacteriological Technic. II. Methods of Pure Culture Study," Abstracts of Bacteriology 9 (1925): 1.

disparate practitioners to a shared disciplinary task.

Conn advertised the completion of a newly revised Descriptive Chart, to be printed and shipped to SAB members in January of 1925. The Committee chose not to "make any radical revisions," only minor alterations "so that the chart will be more workable." In Conn's estimation, the new card remained "unchanged in its general form," although "considerably improved in detail."¹²¹ The terminology had been "slightly improved throughout the chart," with more space "allowed for the recording the size of vegetative cells as well as staining reactions."¹²² In particular, the 1924 chart prompted the investigator to specify the method or technique used for staining cells and spores, as well as the procedure for determining liquefaction of gelatin, and production of indol and hydrogen sulfide. Within the section on "Physiology," the Committee appended, for the first time, questions regarding the "Relation to Reaction of Media," an indication that it held confidence in routine indicators of media pH.¹²³

Regarding the Index Number and "Brief Characterization," the Committee introduced small, but consequential changes. Under the subheading "Miscellaneous Biochemical Reactions," the Committee replaced the term "Pathogenicity, etc." with "Biological Relationships." True, it constituted a minor modification, yet it served as further indication of the Committee's reduced emphasis on medical and public health aspects of bacteriology. In instances where a characteristic was indeterminate, the chart instructed the user to write a U (for undetermined), V (for variable), or X (for doubtful). Similarly, the 1924 card renumbered most

¹²¹ Conn, "II. Methods of Pure Culture Study," 1; and, Conn, "Report of the Committee on Bacteriological Technic. Minutes of the 26th Annual SAB Meeting," [ASM] box 1-IVA, folder 7, p 7.

¹²² H.J. Conn, "Recent Work on the Descriptive Chart and the Manual of Methods," Journal of Bacteriology 10 (1925): 316.

¹²³ In a similar gesture of methodological confidence, the Committee added production of indol to the table of "Brief Characterization."

of the entries in the "Brief Characterization," assigning a "0" for the absence of a trait. For example, whereas earlier charts designated the absence of flagella with a "3," the new tabulation provided a zero. Thus, *B. coli* took the number 5010-V2020, in place of its previous 5312-41220. The Committee acknowledged that these alterations rendered previous index numbers obsolete. Cataloguing, for all bacteriological institutions, might have to begin anew. Yet, Conn and his associates stood confident that the new Descriptive Chart would find even greater acceptance than before. They were correct. Sales during the card's first year surpassed their already high expectations, and the new edition "came into much wider use than any preceding chart."¹²⁴

The Utility of Loose Methods

The Society of American Bacteriologists, during its first quarter century of existence, declined to issue "standard" or "official" methods. Instead, the Society appointed Committees to compose a descriptive chart or "Society's Card." First issued in 1907, and revised in 1913, 1914, 1920, and 1924, this descriptive chart specified a list of tests common to all bacteriological specialties. Society officials and Committee members recognized that the determination of unknown cultures preceded most bacteriological applications, and every student and every researcher repeated these procedures beyond enumeration. The descriptive chart was included in most textbooks and nearly every laboratory manual. By 1924, sales of the card exceeded 30,000 annually. Committee Chairman Harold J. Conn envisioned parallel prominence for the *Manual of Pure Culture Methods*, anticipating that "in cases where the chart is used by classes of

¹²⁴ "1924 Descriptive Chart," [ASM] box 8-C, folder 1.

considerable size, the instructor might wish to have a copy of the *Manual of Methods* in the hands of each student using it.”¹²⁵

The employment of the “Society’s Card,” I suggest, distinguished bacteriologists from practitioners in neighboring fields. True, the Laboratory Section of the American Public Health Association (APHA) outlined bacteriological methods for the examination of water and milk. But these methods were intended for “control” work, and not research. They provided simple and rapid means to test for pathogenic forms in water and milk, but offered little help for the bacteriologist studying saprophytic types in soils, cheese, or silage. In contrast, the “Society’s Card” indicated an expansive list of tests, and encouraged its users to consider types and characteristics beyond their sphere of daily practice. For example, the chart asked that a bacteriologist determine if an organism reduced nitrates, a consideration vital to those seeking to increase soil fertility, but one of little importance for the production of cheese. Yet, because the completion of the chart comprised the minimum set of tests for any examination, bacteriologists were led to contemplate the more fundamental aspects of a microbe’s nitrogen and carbohydrate metabolism. With each revision, the Descriptive Chart prompted the investigator to consider what bacteria were, not simply what they do for humans. These imperfect tests were, in a largely hidden measure, ‘good to think with.’ They remained adjustable and re-combinable, and offered an opportunity for bacteriologists to dwell, if only momentarily, on the intricate biology of microorganisms.

The Society of American Bacteriologists never sanctioned the “Society’s Card” as its official methods. Unlike their counterparts in chemistry, these bacteriologists did not evince the

¹²⁵ Conn, “Recent Work,” 318.

confidence to render their methods standard and uniform. Even the most common procedures (*i.e.*, the Gram's stain, production of indol) were subject to constant scrutiny and criticism. The members of the Committee on Bacteriological Technic found themselves wracked with uncertainty. They managed to issue periodic revisions only by acknowledging that earlier editions were far worse than any of their newly proposed guidelines. For some members of the SAB, this methodological incertitude elicited unease. Francis C. Harrison, in his 1921 presidential address to the Society, espoused the "standard" methods of the APHA or the American Chemical Society, calling for the Society to cooperate with the APHA in order to "prevent any useless duplication of work." Harrison reasoned that "in biological problems, we cannot hope for the minute exactness of the chemist, but the chemist has his standard and authorised methods, which he dare not depart from." The departing president desired the same circumstance, believing that officially sanctioned methods might "help to ward aside many criticisms that are at present leveled at us."¹²⁶

Members of the Committee did not share Harrison's sentiment. They steadfastly refused to black-box bacteriological techniques. Rather, they supplied an elastic list of determinative tests, a compendium of versatile recipes and measures, each capable of being adjusted to a particular culture or organism. More importantly, the Committee welcomed the participation of non-Committee members. The serial editions of the card were co-constructed, products of a continuing negotiation between the Committee and practicing bacteriologists. As Conn reminded his disciplinary compatriots in 1925, the card and *Manual of Methods* remained

¹²⁶ F.C. Harrison, Presidential Address before the 23rd Annual SAB Meeting (1921), printed as "Our Society," Journal of Bacteriology 7 (1922): 152 & 153.

“cooperative undertakings in which it is hoped that the Society as a whole may have some part.” Consequently, the Committee stood willing not only to “obtain suggestions” for revision, but also receive criticism.¹²⁷ Participation in the Card’s fabrication, Conn maintained, engendered allegiance, and allegiance to a constellation of flexible techniques might be the SAB’s only path toward disciplinary unity.¹²⁸ If bacteriology remained a fragmented and disparate practice, the imperfect tasks of the routine, and not the cutting edge, defined the science.

¹²⁷ Conn, “Recent Work,” 318-319.

¹²⁸ A more mundane consideration rested on the fact that sales of the descriptive chart generated considerable funds for the Society. By 1924, these profits accounted for 25% of the SAB’s annual administrative operating budget. The Committee recognized, in very real terms, that their Descriptive Chart and Manual of Methods needed to be not only accurate, but acceptable.

The Expertise of Germs: Practice, Language and Authority in American Bacteriology, 1899-1924

by
Eric D. Kupferberg

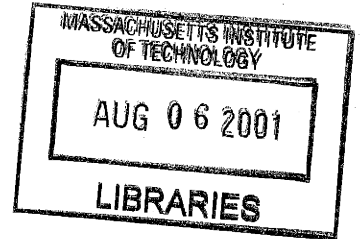
B.A. Political Science, University of Kentucky, 1987
M.A. History, University of Maryland, 1989

Submitted to the Doctoral Program in the History and Social Study of Science and Technology in Partial Fulfillment of the Requirements for the Degree of

Doctor of Philosophy at the
Massachusetts Institute of Technology

February 2001

© Eric D. Kupferberg, All Rights Reserved



The author hereby grants to MIT permission to reproduce and to distribute publicly paper and electronic copies of this thesis document in whole or in part.

ARCHIVES

V. 2

Signature of Author: _____

A handwritten signature in black ink, appearing to read "Eric D. Kupferberg".

Program in the History and Social Study of Science and Technology
February 8, 2001

Certified by: _____

Deborah Fitzgerald *1 May 2001*
Deborah Fitzgerald, Associate Professor of the History of Technology and
Director of Graduate Studies, Thesis Supervisor

Hugh Gusterson
Hugh Gusterson, Associate Professor of Anthropology and Science Studies

Everett Mendelsohn
Everett Mendelsohn, Professor of the History of Science, Harvard University

Accepted by: _____

M. Roe Smith *May 1, 2001*
Merritt Roe Smith, Professor of the History of Technology
Director, Program in the History and Social Study of Science and Technology



CHAPTER SIX

FIXING A NAME: THE SAB AND THE *BERGEY'S MANUAL OF DETERMINATIVE BACTERIOLOGY*

Is it not that we have groped about in an orderly world shouting 'chaos' when we ourselves were but ignorant and blind to the orderliness about us? It is our knowledge of the natural relationships and evolutionary development of this great group of living things that is chaotic, not nature. Moreover many of us are too indolent or too self-satisfied with our own field of research to learn even the principles underlying the science of taxonomy. Thereby we do but contribute to the existing confusion.

Robert S. Breed¹

Robert Breed, speaking before the Society of American Bacteriologists as its outgoing president, echoed a now familiar refrain. Bacteriology, in his calculation, remained somehow un-biological, lacking in the fundamental and theoretical foundations that oriented other biological disciplines. The blame, according to Breed, should not be placed on the intractable nature of bacteria, their minute structure or their variable traits. Rather, it was bacteriologists themselves that lacked either the training or inclination to taxonomically order the microbial

¹ Robert S. Breed, "The Present Status of Systematic Bacteriology," Presidential Address to the 29th Annual SAB Meeting, 1927, printed in *Journal of Bacteriology* 15 (1928): 143.

world. For Breed, and other leaders of the SAB, the shortcomings of systematics threatened the conceptual and disciplinary progress of bacteriology. In Linnaeus' *System of Nature*, the eighteenth-century prince of flowers provided apt designation for the microscopic infusoria, "chaos." At the dawn of the twentieth century, the entire state of bacterial taxonomy barely escaped that moniker. A quarter century later, in 1925, the condition had radically changed.

This chapter explores the attempts of American bacteriologists to develop a biological system of nomenclature and classification. The source of the taxonomic confusion can be explained, at first glance, by reference to the institutional context of bacteriology. As members of a young science devoted to controlling the activities of microbes in various applied contexts, bacteriologists attended to what bacteria did, rather than their taxonomic position among living things. Bacteriology comprised an experimental endeavor far removed from the nineteenth century field tradition of natural history. Its disciplinary contours discouraged the kind of panoramic perspective required for a systematic survey of the microbial realm. Additionally, most bacteriologists received only scant instruction in botany and zoology, and remained largely unfamiliar with the practices exercised by the more established taxonomic sciences. In contrast, botanical and zoological systematics constituted, at the turn of the century, a highly specialized field, employing a set of exacting techniques and crafting published papers in an arcane language. Those few bacteriologists nurturing predilections toward studies in nomenclature and classification faced an alien and uninviting domain.²

² "Nomenclature" is the task of identifying and naming organisms. Traditionally, these names have taken the form of Latin binomials, such as *homo sapiens*. "Classification" is process of grouping organisms and determining the relationships between groups. For example, the Latin binomial reveals the species and genera classification of an organism. Organisms that are part of the same genera, family or order are considered evolutionarily closer than those members of divergent taxa. While the constructions of nomenclature and classification are not inherently tied, they have been substantially integrated since the 1870's.

Nonetheless, American bacteriologists languished under the weight of an increasingly inadequate taxonomic system. A brief survey of the classifications available in the first years of the twentieth century reveals a linguistic and cognitive dissonance between the technical needs of bacteriologists and the taxonomies they employed. By 1910, several observers found the situation intolerable. New species and varieties multiplied in the literature without check, many without adequate descriptions or formal Latin names. Typically, authors devoted little effort to determining whether their suspected new species had been previously identified, or whether their chosen moniker had already been assigned to another microbe. As a consequence, American bacteriologists faced a deluge of designations, each with a slim chance of garnering general approbation. In order to manage the taxonomic clutter, practitioners employed informal names (e.g., "the tubercle bacillus," "the diphtheria bacillus," etc.) and *ad hoc* groupings particular to individual bacteriological specialties (e.g., "the colon-typhoid group" for sanitary bacteriology, "the influenza group" for medical bacteriology, the "anthrax group" for veterinary bacteriology, or "the lactic acid group" for dairy and industrial bacteriology). During the second decade of the twentieth century, the chaos developed its own momentum, threatening to make communication among bacteriological fields nearly incomprehensible.

In several respects, this chapter is a continuation of themes from earlier pages, narrating the actions of a disciplinary society struggling to articulate the biological component of bacteriology. The SAB, during the second decade of its existence, maintained that the correct naming and classifying of bacteria constituted a central element of a more biological bacteriology. In 1914, the Society established a Committee on the Characterization and Classification of Bacterial Types (CCCBT), under the belief that taxonomic reform could

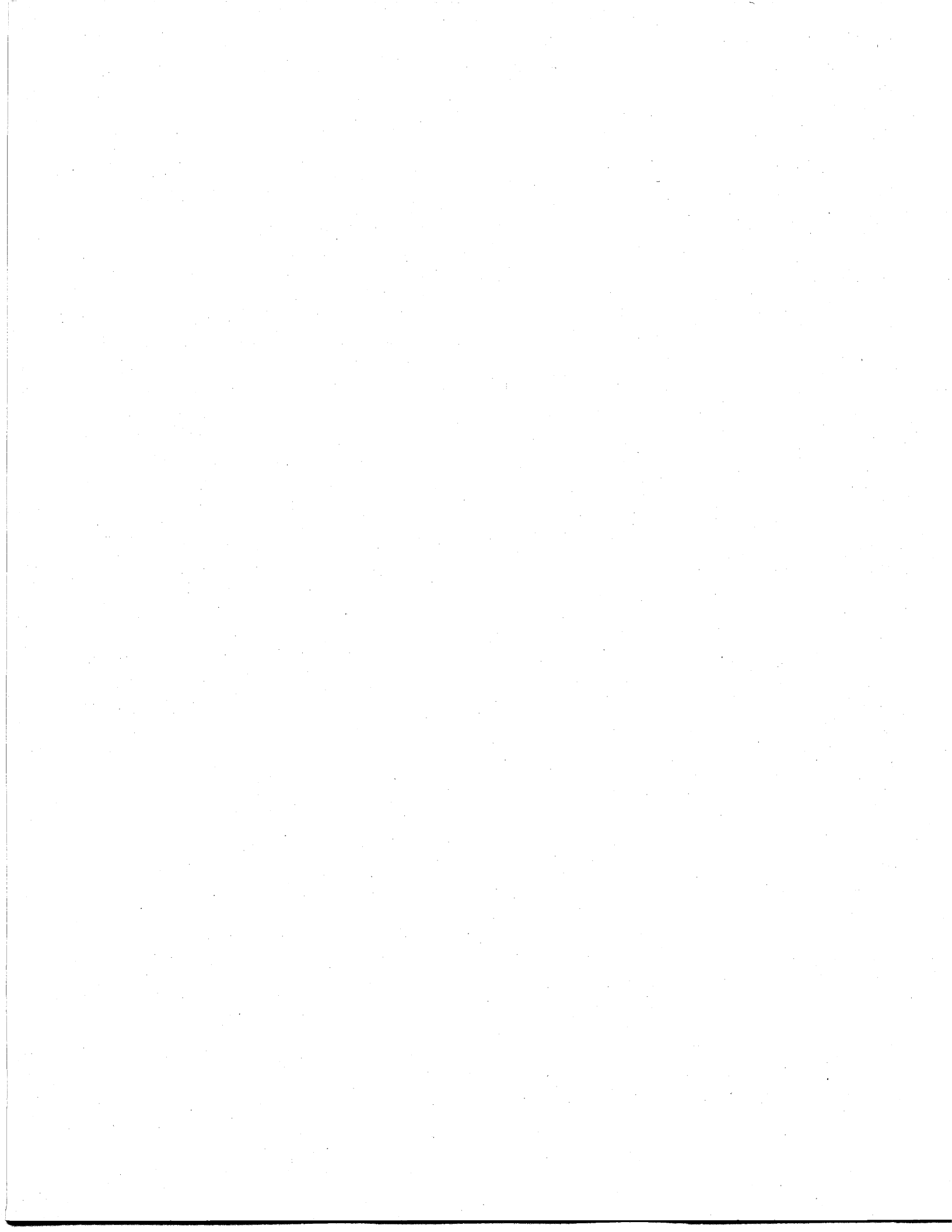
bacteriologists, in learning and employing the new nomenclature and classification, were led to consider bacteria more broadly. Just as the Descriptive Chart forced its user to record a multitude of characters and traits, so too did the new taxonomy prompt bacteriologists to consider a combination of morphological, tinctoral, physiological, and cultural traits. Moreover, each genus was defined in relation to other genera. Therefore, the process of determination, using the *Bergey's Manual*, required the investigator/student to appraise the relation of his unknown culture to a broad range of organisms. The SAB committees deliberately fashioned the comparative determination in such a way that the user might reflect on the evolutionary relationships among different taxa, as well explore the relationship between the organism and its environment. If the Society of American Bacteriologists achieved some measure of success in forging a more unified and fundamental science, it was the Chart and the *Manual* that most enabled that end.

This chapter relies heavily on the recent work of Geoffrey C. Bowker and Susan Leigh Star, and their book *Sorting Things Out: Classification and its Consequences*. Bowker and Star consider the “creation and maintenance of complex classifications as a kind of work practice,” one that orders human and material interactions in often unnoticed ways.⁷ While the SAB’s classification did not become “invisible,” that is taken for granted, until the late 1930’s, its taxonomy and the *Bergey's Manual* provided the basis for ongoing objections, negotiations, and resolutions of important theoretical and practical issues in bacteriology. Every classification and

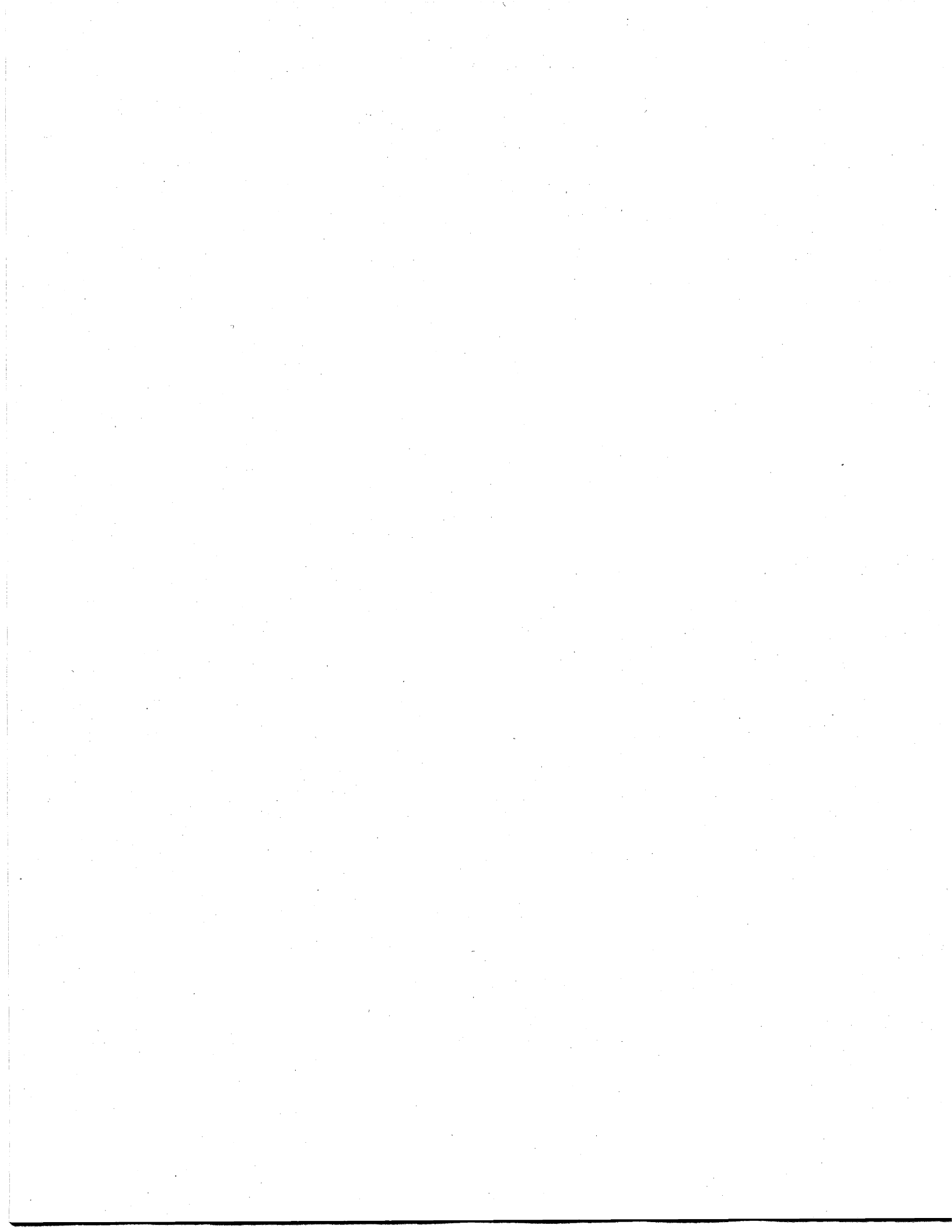
Ecologies of Knowledge: Work and Politics in Science and Technology (Albany, NY: SUNY Press, 1995); Star, “Work and Practice in Social Studies of Science, Medicine, and Technology,” Science, Technology and Human Values 20 (1995): 501-507.

⁷ Bowker and Star, Sorting Things Out: Classification and its Consequences (Cambridge: MIT Press, 2000), 5.

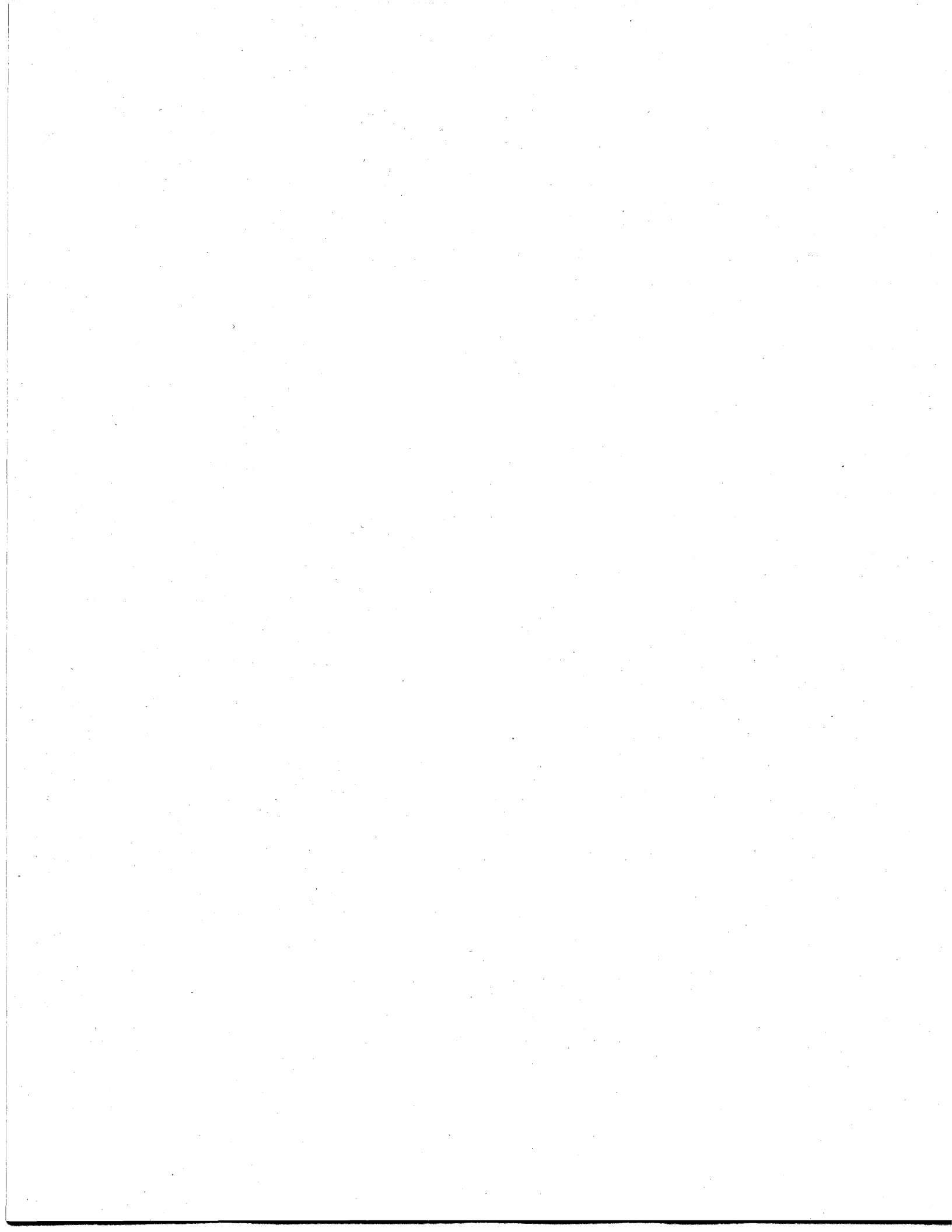
PAGES 390-391
ARE MISSING



PAGES 390-391, 393-394, AND
396-397, ARE MISSING



PAGES 390-391, 393-394, AND
396-397, ARE MISSING



cultures for research and instruction. The cultures arrived bearing the SAB's taxonomic labels, their characters listed according to the SAB's Descriptive Chart. The ATCC published a catalogue of available cultures, mailed to nearly every research center. The catalogue itself embodied the outlines of the *Bergey's Manual*. Bowker and Star stress the conjunction between classifications and mundane practices. This chapter outlines a number of such mechanisms in which the SAB's taxonomy became known and accepted.

The ascendancy of the SAB's taxonomy did not proceed without dissension. The classification and *Manual* emerged from a blend of "negotiation, organizational processes, and conflict."¹¹ Not all areas and interests of bacteriology were served evenly by the nomenclature and classification, and the SAB committees faced persistent opposition and criticism. We are fortunate that archival records of those events are extant, documenting several bacteriological communities articulating their own linguistic and methodological interests. Because taxonomic disputes frequently demanded resolution, their debates serve as a written record of conflicting visions for bacteriology, a snapshot of particular moments in the development of the discipline. What the records reveal is a disproportionate power among those bacteriologists seeking a radical overhaul of the classifications then in use. Specifically, the documents suggest a relative weakness among medically oriented bacteriologists. If taxonomies invariably result in "winners" and "losers," those working with pathogens fell into the latter category. By the mid-1920's,

¹¹ Bowker and Star, *Sorting Things Out*, 5 & 324. Methodologically, this chapter considers *consensus building* as the promotion of a unified set of goals or methods among groups that share a common research domain but not a common set of institutional interests and background. In this case, some consensus needed to be reached such that a single classification and nomenclature could be used by bacteriologists in the medical, veterinary, agricultural, and industrial communities. The *negotiation* transpired between bacteriological taxonomists and their botanical counterparts, where the former appropriated enough of the latter's methods to construct a stable taxonomy, without being restricted in other ways. For bacteriologists, the tradition individual and specialized research needed to be compromised in favor of linguistic stability.

rule. They contend that "a classification system is an important tool in the struggle for professional recognition." A classification might be considered, in some circumstances, as a "political actor" in the attempts to "promote a professional group."¹⁹ It functions by filtering out "irrelevant" facts, while highlighting others, thereby enhancing the professional authority of particular community. The process, Bowker and Star maintain, can be enacted by such pedantic procedures as writing elementary textbooks and laboratory manuals. Lavoisier vanquished his rivals' theory of affinities, they suggest, by outlining a new list of names and elements, and by publishing a comprehensive textbook. Education, even within a single generation or two, enables a "complete wiping of the slate so that one can start anew as if nothing had ever happened." True, in the short-term disciplinary members may cling to an older system. "In the long term, however, by the time that the curricula have been redesigned, the manuals rewritten," re-education "can become a highly effective tool."²⁰ The following pages suggest that the power to name and classify is not only the product of struggles for disciplinary authority, but constitutive of them.²¹

This chapter follows in five parts. The first section explores the chaos in bacterial systematics. During the first decade of the twentieth century, bacteriologists faced an increasing number of microbes and a bewildering system of names. In the published literature and at the

17 (1984): 249-270; Keith Vernon, "Desperately Seeking Status: Evolutionary Systematics and the Taxonomists' Search for Respectability, 1940-1960," *British Journal for the History of Science* 26 (1993): 207-227; and, V.B. Smocovitis, "'Disciplining Botany': A Taxonomic Problem," *Taxon* 41 (1992): 459-470

¹⁹ Bowker and Star, *Sorting Things Out*, 253.

²⁰ Bowker and Star, *Sorting Things Out*, 267, 271, & 278-279. See also, Bensaude-Vincent, "Lavoisier," 363-386.

²¹ Gordon McQuat, in his account of biological systematics in the 19th and 20th centuries, argues that as the science specialized, each area of study "looked for its own grounding of the 'fundamental units' of biology." McQuat. "Species, Names and Things: From Darwin to the Experimentalists," (Ph.D. diss., University of Toronto, 1993), 2-3.

annual SAB meetings, commentators lamented the taxonomic disarray. The confusion derived, in part, from the demands of routine practice. Most bacteriologists sought quick determinations, worked in isolated institutional contexts, and maintained interest only in a small number of species. Typically, their education did not include an exploration of the methods of biological systematics. As such, American bacteriologists were ill-prepared and disinclined to conduct detailed and comprehensive taxonomic studies. When researchers did identify new species, they often ignored the established rules of botanical nomenclature, employing casual terms rather than Latin binomials, and furnished multiple names for the same species. The task of naming and classifying bacteria proved inherently difficult. The microorganisms themselves defied simple species categorization. Bacteria displayed variable traits, offering no sharp morphological distinctions between types. As the number of species bearing the generic label *Bacillus* and *Bacterium* increased, several SAB commentators feared that systematic shortcomings would severely limit the development of the discipline.

The second chapter section reviews the available bacterial taxonomies, circa 1895-1915. In the first decade of the twentieth century, American bacteriologists could choose among several rival taxonomies, each with its own advantages and limitations. One of the classifications, devised by Walter Migula, was ensconced in the dominant American determinative guide, Frederick D. Chester's *Manual of Determinative Bacteriology*.²² As a consequence, most American bacteriologists followed Migula's designation of genera based on the presence of flagella. They did, however, voice continued dissatisfaction with Migula's scheme. In response, many American researchers and writers employed practical, or *ad hoc*, taxonomies, grouping

²² Chester, *A Manual of Determinative Bacteriology* (New York: The Macmillan Co., 1901).

bacteria on the basis of a noticeable or useful physiological trait (*e.g.*, the chromogenic group, the pyogenic group, the anaerobic group, etc.) while shunning the use of formal classifications.

This chapter's third segment details the Society of American Bacteriology's response to the disorder in microbial systematics. From its earliest gatherings, the SAB included papers deliberating the intractable issues of bacterial nomenclature and classification. It was these early gatherings that established the Society's enduring pursuit of a stable systematics. The Committee on Identification of Bacterial Species, discussed in the preceding chapter, offered a partial solution to taxonomic troubles. By standardizing methods of pure culture study and characterization, the Descriptive Chart removed a significant source of variation and confusion. The Society's Card and its group number, however, did not lessen the need for a new taxonomy.

The Society's annual meetings introduced American bacteriologists to innovative methods for classifying microorganisms. Charles-Edward Amory Winslow, from MIT's Department of Sanitary Biology and the Lawrence Experiment Station, advocated the use of a "biometrical" method of arranging types. These statistical techniques, endorsed by biologists in other fields (*e.g.*, Francis Galton, Charles Davenport), demanded that genera and higher taxa be based on the correlation of many stable characters, and not defined by one or two conspicuous traits. Several SAB members adopted Winslow's biometrical methods, and published a flurry of statistical papers between 1905 and 1915 that revised Migula's families and genera. Other SAB members contemplated abandoning Migula entirely, adopting a taxonomy based not on the morphology of bacteria, but their physiology. Winslow, in his 1913 presidential address to SAB, proposed the creation of a committee to evaluate the state of bacterial systematics. By all accounts, the resultant Committee on the Characterization and Classification of Bacterial Types

(CCCBT) constituted the first institutional body, in any nation, to engage in the task of naming and classifying bacteria. Following three years of careful study, the CCCBT issued its "Preliminary Report," a document received with great interest and skepticism.

The SAB and CCCBT pursued other avenues of taxonomic reform. The Society sponsored the creation and maintenance of the American Type Culture Collection (ATCC), housed at the American Museum of Natural History and managed by Winslow and his students. The Society meetings, during the 1910's, featured sessions on bacterial variations, and round tables on the applicability of the International Codes of Botanical and Zoological Nomenclature. More importantly, SAB members during this period explored the phylogenetic, or evolutionary, relationships among microbes, considerations largely absent in prior taxonomic treatments. Even those not absorbed in such theoretical speculations honed techniques for measuring taxonomic traits, and proposed revisions of individual of groups.

The fourth portion of this chapter reviews the objections to the CCCBT's "Preliminary Report." Criticisms arrived from all quarters of the SAB, with some members contending that the proposed revisions were too drastic, while others maintaining that the Committee did not go far enough. A few taxonomically minded researchers found particular fault with the evolutionary bent of the CCCBT's taxonomy, believing that phylogenetic histories of microbes were impossible to determine. The Committee responded by incorporating many of these criticisms, even recruiting one of its critics to assist in composing the report's revision. As a result, the "Final Report," issued in 1920, received greater approval than its predecessor. Nonetheless, practicing bacteriologists did not immediately employ the SAB's taxonomy in published papers or textbooks.

The final section details the creation and efforts of the SAB's Committee on the Determinative Manual, directed by University Pennsylvania's David H. Bergey. The Bergey's Committee, as it came to be known, employed the CCCBT's "Final Report" in writing a new determinative manual. The Bergey's Committee updated and revised the principle identification keys, seeking to entirely supplant Chester's *Manual of Determinative Bacteriology*. While the *Bergey's Manual* modified the CCCBT's scheme in some instances, on the whole, it embodied the SAB's classification of orders, families and genera, assigning new names to hundreds of bacterial species. This extensive overhaul garnered both enthusiastic endorsement and scathing criticism. Within two years, the Bergey's Committee published a second edition of the *Manual*. The revised guide answered few of its critics, choosing instead to remain steadfastly confident in the desirability of its comprehensive scheme. The debate over bacterial systems threatened to continue unabated. Nonetheless, the *Bergey's Manual* soon found its way into laboratories nationwide, and authors quickly incorporated the *Manual's* taxonomy into new textbook editions. The controversy dissipated not through formal resolution, but through a process of subtle indoctrination. Routine practice and education rendered the SAB's classification not only favorable, but nearly assumed. The chapter concludes with a few remarks on the importance of taxonomies, laboratory manuals, and routine practice in defining the discipline of bacteriology in America.

The Reign of Chaos

Throughout the first quarter of the twentieth century, American bacteriologists recognized the preeminent importance of nomenclature and classification. Bacteriology's rapid

disciplinary growth ensured a continued onslaught of new species. Almost immediately upon publication, textbooks and manuals became outdated. Taxonomy, as an ordering activity, proffered a means of stemming the tide of confusion, a mechanism to unify a science that remained strikingly fragmented. Joseph and Ethelyn Greaves, bacteriologists at the Utah Agricultural College and Experiment Station, propounded that:

When very great masses of information or great numbers of objects are to be dealt with, man must organize and classify. The librarian classifies the books of the library. The soil chemist classifies the soils of the nation or of the state. The business man classifies the materials with which he deals. Otherwise, in each case, it would be impossible to deal with the numerous complexes. Likewise, the biologist, if he is going to have anything other than chaos, must classify the plants and animals with which he works.²³

Bacteria, as many observers noted, did not resemble books, soils, client files, or even higher plants. As a result, declarations of taxonomic chaos became nearly ubiquitous during the first decades of the twentieth century. Simon DeM. Gage and Earl B. Phelps, of the Lawrence Experiment Station, remarked that "among the various branches of natural science there is probably not one which in comparison to the volume of its data has so slight a basis for classification as bacteriology."²⁴ Writing in 1915, Robert E. Buchanan, head of the Department of Bacteriology at Iowa State College, demurred: "The naming of bacterial species, genera, and higher groups, indeed the whole subject of bacterial nomenclature, is in a condition which can best be described as chaotic. Little, if any, advance has been made in the last two decades."²⁵

²³ Greaves and Greaves, Bacteria in Relation to Soil Fertility (New York: D. Van Nostrand Co., 1925), 38.

²⁴ Gage and Phelps, "On the Classification and Identification of Bacteria with a Description of the Card System in Use at the Lawrence Experiment Station for Records of Species," American Public Health Association. Proceedings, 1902 28 (1903): 494. Allen J. Smith lamented the "lack of a satisfactory system of classification and the chaotic condition of the general study" in bacteriology. Smith, Lessons and Laboratory Exercises in Bacteriology: An Outline of Technical Methods Introductory to the Systematic Study and Identification of Bacteria. Arranged for the Use of Students (Philadelphia: P. Blakiston's Son & Co., 1902), iv

²⁵ Buchanan, "Nomenclature of the *Coccaceae*," Journal of Infectious Diseases 17 (Nov. 1915): 528. The next year, he reiterated: "To state that the classification of bacteria is in a chaotic condition is to express a truism."

A characteristic of these remonstrations was an unease that bacteriology, in lacking a coherent taxonomy, remained undeveloped, if not unscientific. Buchanan worried that if a science embodied a "system of classified knowledge, the subject of bacteriology is laboring under a serious handicap in lacking, probably more than any other branch of science, the advantages conferred by a satisfactory system of terminology or nomenclature."²⁶ Ideally, bacterial systematics should advance two aims. First, a taxonomy should present, in a written and graphic form, "our present conception of the phylogeny and of the relationships of various groups of bacteria." The second and more pedantic task was to provide stability to names given to "particular groups of organisms," thereby preventing "unnecessary nomenclature confusion in literature." The available taxonomies met neither of these aims.²⁷ In a historical survey, Buchanan documented 900 separate generic names, and 66 complete classifications proposed between 1789 and 1924. As Case-Western's Roger G. Perkins observed, the bacteriological "literature is crowded with classifications of every sort, prepared by thoughtful workers, with painstaking labor. The literature is also crowded with criticisms of the classifications for reasons

Buchanan, "Studies in the Nomenclature and Classification of Bacteria: The Problem of Bacterial Nomenclature." Journal of Bacteriology 1 (1916): 591. C.-E.A. Winslow and Anne Rogers Winslow similarly mentioned that "the science of systematic bacteriology has remained in a notably undeveloped state." Winslow and Winslow, The Systematic Relationship of the Coccaceae, with Discussion of the Principles of Bacterial Classification (New York: John Wiley & Sons, 1908), 3.

²⁶ Buchanan, General Systematic Bacteriology: History, Nomenclature, Groups of Bacteria (Baltimore: Williams and Wilkins, 1925), 9. Ivan C. Hall, of the Colorado Medical School, insisted that "More than any other science, bacteriology suffers for the lack of a satisfactory classification and nomenclature." Hall, "Some Fallacious Tendencies in Bacteriologic Taxonomy," paper delivered to the 27th Annual SAB Meeting, 1925, Journal of Bacteriology 8 (1926): 245.

²⁷ Buchanan, General Systematic Bacteriology, 9. E.R. Stitt noted that "At present the classification of the bacteria is very unsatisfactory from a scientific standpoint." Stitt, Practical Bacteriology, Blood Work and Animal Parasitology, Including Bacteriological Keys, Zoological Tables and Explanatory Clinical Notes, 6th ed. (Philadelphia: P. Blakiston's Son & Co., 1920), 63.

which seem good to each author, though at times he is alone in his opinion."²⁸

The state of chaos owed its origins to a number of disciplinary conditions. Initially, bacteriology, in contrast to botany and zoology, never underwent a "taxonomic" or "natural history" period. During the eighteenth and nineteenth centuries, biologists engaged in what some scholars term a morphological or naturalist tradition. This tradition emphasized field studies, descriptive methods, and a concern with the relationship between organisms. In botany, these practices drew attention to the preeminent importance of nomenclature and classification. Enlightenment era collectors and naturalists traveled the globe, amassed new flora and fauna, meticulously described their morphological features, and preserved their specimens in natural history museums, herbariums, and zoos. Professional botanists identified the important taxonomic characters of each organism, published descriptive histories, prepared type specimens, and assigned binomial names. In the years following Charles Darwin's *Origin of Species*, they constructed their classifications to reveal the "natural" or evolutionary relationships among species, genera, families, and orders.²⁹ American botanists participated in this naturalist tradition, even as they embraced a "New Botany" stressing the economic uses of plants. William Trelease observed in his 1899 vice-presidential Address of the Botany Section of AAAS that taxonomic and descriptive botany still accounted for 42% of all journal articles. For Trelease, the persistence of systematic studies came as no surprise, as attempts to name and classify plants

²⁸ Buchanan, General Systematic Bacteriology, 113; and, Perkins, "Classification of Bacteria," in New Knowledge of Bacteriology and Immunology, eds. E.O. Jordan and I.S. Falk (Chicago: University of Chicago Press, 1928), 120.

²⁹ See, Garland Allen, Life Science in the Twentieth Century, (Cambridge: Cambridge University Press, 1978): chpts. 1-3; and, Jane Maienschein, Ronald Rainger, and Keith R. Benson, "Were American Morphologists in Revolt?" Journal of the History of Biology 14 (1981): 85

greatly aided in the exploitation of their possible uses.³⁰

In the waning years of the nineteenth century, and during the first years of the next, American biology developed a rival to the natural history tradition, one based on experimental and laboratory methods. The experimentalist program did not completely vanquish taxonomic studies. Rather, it redefined the goals and techniques of biological systematics, moving the field away from a 'historical view' of evolutionary descent, and toward a statistical and experimental approach to defining related taxonomic groups.³¹ In 1905, the Botanical Society of America (BSA) merged with the Society for Plant Morphology and Physiology and the American Mycological Society. The expanded BSA advanced a decidedly experimentalist agenda, while seeking means of accommodating representatives of the older natural history perspective. The questions of nomenclature and classification proved, however, highly contentious, and the BSA organized a number of sessions to examine the "species question" within a new experimentalist program.³²

American zoologists followed a similar course. Charles B. Davenport, in his 1901 presidential address to the Zoology Section of the AAAS, portrayed the previous hundred years

³⁰ Trelease, "Some Twentieth Century Problems," *Science* 12 (1900): 49. For an overview of the "New Botany," see, Byron D. Halsted, "Botany as it May be Taught," *Popular Science Monthly* 33 (July 1888): 369-372. Systematics, prior to the "New Botany," embraced other aims, such as the desire to furnish to "the average layman a more continuous incentive for pleasurable and inspiring contact with the world about him . . ." Aven Nelson, "The Trend and Influence of Certain Phases of Taxonomy," *Science* 39 (1914): 254.

³¹ Hamilton Cravens, "The Role of Universities in the Rise of Experimental Biology," *Science Teacher* 44 (1977): 33-37. For its impact on biological systematics, see, Dean, "Controversy over Classification," 211-220; Emanuel D. Rudolph, "The Introduction of the Natural System of Classification of Plants to Nineteenth Century American Students," *Archives of Natural History* 10 (1982): 461-468; Hagen, "Experimentalists and Naturalists in Twentieth-Century Botany," 249-255; and McQuat, "Species Names, and Things," 18. For a contemporary elucidation of the new experimental approach to biology, see, Edmund B. Wilson, "Aims and Methods of Study in Natural History," *Science* 13 (1901): 14-23.

³² McQuat, "Species, Names and Things," 327-329; and, William Trelease, "Report of the Secretary: The Botanical Society of America," *Science* 33 (1905): 221-222.

as the "morphological century." In contrast, Davenport envisioned a new "experimental" approach for the twentieth century. Davenport disparaged zoological systematics as an unregulated pastime devoted to the rapid naming of new species and genera. In its place, Davenport called for the adoption of rigorous quantitative measurements and statistical analyses. "There is every reason to expect," Davenport predicted, "that the future systematic work will look less like a dictionary and more like a table of logarithms." The older taxonomic system, Davenport presaged, could only "break down from its own weight."³³ Not all American biologists shared Davenport's penchant for the death of traditional systematics. Liberty H. Bailey, a professor of Horticulture and Nature-Study at the University of Cornell, argued that customary botanical systematics would be strengthened by experimental methods, but not supplanted. The new techniques allowed taxonomists to define species and genera on the basis of *both* morphology and physiology, correlating detailed structures with the physiological function. The laboratory would simply augment, and not displace, the herbarium, museum and field.³⁴

American interest in bacterial systematics emerges just at this historic juncture. During the nineteenth century, very few American bacteriologists cultivated an interest in nomenclature and classification. Bacteriology lacked an established or rigorous taxonomic tradition. Among young bacteriologists, the rites of passage transpired in the laboratory, and not in the field. Unlike botany or zoology, bacteriology evolved predominantly as an experimental endeavor,

³³ McQuat, "Species, Names and Things," 277-278, quoting Davenport, "The Zoology of the Twentieth Century," *Nature* 64 (1901): 567.

³⁴ McQuat, "Species, Names and Things," 300; Bailey, "Systematic Words and Evolution," *Science* 21 (1905): 532-533; Bailey, "The Philosophy of Species Making," *Botanical Gazette* 22 (1896): 454-462; Bailey, "The Modern Systematist," *Science* 46 (1917): 623-629; and, Andrew D. Rogers, *Liberty Hyde Bailey: A Story of American Plant Sciences* (Princeton: Princeton University Press, 1949).

dedicated to the solution of specific medical, sanitary, veterinary, agricultural, and industrial problems. As such, bacteriologists developed determinative keys for the identification of important forms only. They did not issue comprehensive guides to the flora or fauna of the microscopic realm. For example, many American researchers and instructors turned to the tables and determinative keys of James Eisenberg's *Bacteriological Diagnosis*.³⁵ Eisenberg listed "only the most important" characteristics of bacteria, making no claims to providing an exhaustive study of bacteria. Instead, Eisenberg supplied tables for "quick diagnosis," following a plan that was admittedly "quite arbitrary."³⁶ Later American authors revised and rewrote Eisenberg's determinative tables, but nearly all agreed that rapid identification superceded formal systematics.³⁷

Unfortunately, the determinative schemes reflected the diverse institutional settings of American bacteriology. Each specialty developed its own arrangement of species, and cultivated

³⁵ James Eisenberg, Bacteriological Diagnosis: Tabular Aids for Use in Practical Work, trans. Norval H. Peirce (Philadelphia: F.A. Davis Co., 1892).

³⁶ Eisenberg, Bacteriological Diagnosis, v-vi. Eisenberg compared his tables to the "'Chemical Analysis Chart' which the chemist finds so essential in laboratory work, v. While arbitrarily arranged, the determinative charts did force the student/researcher to examine several traits of the unknown unknown culture. Joseph McFarland believed that "differentiation of bacteria resembles the determination of the higher plants with the aid of a botanic key, or the qualitative analysis for the determination of unknown chemic compounds. Such a key for specific bacterial differentiation is really indispensable even though it be imperfect, and every student engaged in research should have one." McFarland, Textbook upon the Pathogenic Bacteria, for Students of Medicine and Physicians, 4th ed. (Philadelphia: W.B. Saunders Co., 1903), 225-226.

³⁷ See, for example, George W. Fuller and George A. Johnson, "The Classification of Water Bacteria," Journal of Experimental Medicine 4 (1899): 609; Chester, Manual of Determinative Bacteriology, v; C-E.A. Winslow, "The First Forty Years of the Society of American Bacteriologists," Science 91 (1940): 125-129; and Kenelm Winslow and Hibbert W. Hill, the Production and Handling of Clean Milk, Including Practical Milk Inspection, 2nd ed. (New York: W.R. Jenkins Co., 1909), 40 & 240. In routine determinations, characteristics normally excluded from formal taxonomies (e.g., odor) could be employed for quick identification. See, for example, Veranus A. Moore, Laboratory Directions for Beginners in Bacteriology, 2nd ed. (New York: Ginn & Company, 1901), 75. As Herbert Conn informed his students in dairy bacteriology, "the detailed classification is rather complicated and difficult, and need not detain the dair. student." Conn, Practical Dairy Bacteriology (New York: O. Judd Company, 1907), 11.

little interest in forms not immediately relevant to its work.³⁸ University of Minnesota's Arthur T. Henrici reasoned that most bacteriologists had "little biological training or interest." For the most part, they "needed an acquaintance with only a few species important" to their particular field. "Medical bacteriologists had no interest in organisms important in industry, and conversely industrial bacteriologists had not interest in pathogens." As a consequence, there existed "no great need for a classification on the practical side, and very little interest on the theoretical side."³⁹ College textbooks reflected this taxonomic fragmentation, ignoring entire sections of the microbial world. "Higher bacteria," or those branching forms with complicated life histories, largely escaped discussion. Among the "lower," or "true bacteria," most texts devoted little attention to those forms without pathogenic or practical import.⁴⁰ American bacteriology texts frequently arranged chapters according to pathological consequence (*e.g.*, typhoid fever, diphtheria, pneumonia, anthrax, etc.), shunning arrangements of morphological or physiological groups.⁴¹

A few commentators blamed the disorderly state of bacterial systematics on the influence

³⁸ Fred W. Tanner, Bacteriology and Mycology of Foods, 1st ed. (New York: John Wiley & Sons, 1919).
46. Joseph E. Greaves explained that "Bacteria play a part in many fields of activity, and hence the criteria whereby they are recognized vary greatly according to the art or science in which they are studied." Greaves, Agricultural Bacteriology (Philadelphia: Lea & Febiger, 1922), 46. For examples, see, William W. Ford, "Classification of Intestinal Bacteria: Preliminary Note," Journal of Medical Research 6 (1901): 211-219; Ford, "Classification and Distribution of the Intestinal Bacteria in Man," Studies from the Royal Victoria Hospital, Montreal 1 (1903): 487; and, E.O. Jordan, "The Kinds of Bacteria in River Water," Journal of Hygiene 3 (1903): 1-27.

³⁹ Henrici, The Biology of Bacteria: An Introduction to General Microbiology (Boston: D.C. Heath and Co., 1934), 276.

⁴⁰ William W. Ford, "Aerobic Spore-Bearing Non-Pathogenic Bacteria: Classification," Journal of Bacteriology 1 (1916): 273-274. See, for example, Moore, Laboratory Directions for Beginners in Bacteriology, 55; and, Moore, Principles of Microbiology: A Treatise on Bacteria, Fungi and Protozoa Pathogenic for Domesticated Animals (Ithaca: Carpenter and Company, 1912), 17 & 315-319.

⁴¹ See, for example, William H. Park and Arthur R. Guerard, Bacteriology in medicine and Surgery: A Practical Manual for Physicians, Health Officers and Students (New York, Philadelphia: Lea Brothers & Co., 1899); Park and Anna W. Williams, Pathogenic Microorganisms, 4th ed. (Philadelphia: Lea & Febiger, 1910); and, E.R. Stitt, Practical Bacteriology, Blood Work and Animal Parasitology: Including Bacteriological Keys, Zoological Tables and Explanatory Notes, 3rd ed. (Philadelphia: Blakiston, 1914), x.

of medicine and pathology. The medical school curriculum rarely placed any emphasis on bacterial taxonomy, much less questions of phylogeny.⁴² When students studied classifications, they memorized artificial arrangements built around a few well-known pathogens. While useful in a clinical context, these schemes embodied a logic that organized the animal and plant kingdom around the handful of species harmful to man. Given that saprophytes vastly outnumbered the parasitic bacteria, some dissenters advocated ordering the non-pathogenic forms first.⁴³ Few bacteriologists bothered with such priorities. Instead, medical texts sanctioned decidedly un-biological schemes. Columbia University's Philip Hiss and Hans Zinsser maintained that:

. . . while the botanic classification of the bacteria offers great difficulties, identification is not so complicated a task as this would indicate. Identification, once roughly made on a morphological basis, is further carried on by the aid of cultural characteristics, by biochemical reactions and by pathogenic properties. The bacteria occupy so important a place in agriculture, in medicine and in hygiene, that it rarely becomes necessary for a worker in any particular field to survey the entire group.⁴⁴

⁴² Buchanan, General Systematic Bacteriology, 10. William D. Frost believed that the taxonomic confusion had "largely arisen on account of the fact that the majority of the work on the subject of bacteriology has been done by pathologists and others interested in the results of the vital activity of bacteria rather than their exact position among the plants. Very little systematic work has been done on the bacteria by botanists." Frost and Eugene McCampbell, A Textbook of General Bacteriology (New York: Macmillan Co., 1910), 102. In contrast, the yeasts, molds, and protozoa, had been studied "by those who have had technical training in nomenclature, consequently the classification of these forms is on a much more satisfactory basis." Robert E. Buchanan and Charles Murray, Veterinary Bacteriology: A Treatise on the Bacteria, Yeasts, molds, and Protozoa Pathogenic for Domestic Animals, 2nd ed. (Philadelphia: W.B. Saunders, 1916), 78.

⁴³ S. Orla-Jensen, "The Main Lines of the Natural Bacterial System," Journal of Bacteriology 6 (1921): 267. Lore A. Rogers noticed that these classifications of convenience tended to "separate closely related bacteria and bring together types agreeing only in superficial characters." Rogers, "Characteristics and Distribution of the Colon-Aerogenes Group," in Papers on Bacteriology and Allied Subjects, by Former Students of Harry Luman Russell (Madison: University of Wisconsin Press, 1921), 77. However, there existed good reasons for not founding a taxonomy on the saprophytic forms. Hilda H. Heller posited that few workers paid close attention to non-pathogenic forms, "knowing that their path would be crossed by so many new species that no end but the mere description of new species would be attained. But these undescribed forms are just as important, theoretically, to the systematists, as are the pathogenic ones." Heller, "Suggestions Concerning a Rational Basis for the Classification of the Anaerobic Bacteria," Journal of Bacteriology 6 (1921): 539.

⁴⁴ Hiss and Zinsser, Textbook of Bacteriology, 4th ed. (New York: D. Appleton and Co., 1918), 38. Thomas Bowhill, in his Manual of Bacteriological Technique and Special Bacteriology (New York: W. Wood &

Sixteen years and three editions later, Zinsser admitted that medical bacteriologists had “contributed greatly to the difficulties in classification.” Then again, Zinsser reasoned, the “medical bacteriologist has rarely been a systematist.”⁴⁵ Other applied specialties committed equivalent sins of omission. Dairy, sanitary, soil, and veterinary bacteriologists forged equally myopic classifications that rarely acknowledged the relevance of outside forms.⁴⁶

The sheer number of bacterial species confounded taxonomic efforts. By 1909, the English language literature listed more than 1,500 bacterial forms. In fact, nearly 200 kinds of milk bacteria had been described, most of which would be “found to be identical when they are subject to more critical study.”⁴⁷ Particularly among nineteenth-century bacteriologists, laboratories and research institutions cultivated an incentive to name new species, based upon the slightest variation in morphological or cultural characteristics. Often furnished with eponymous designations, these freshly minted “species” were rarely compared to other forms described in the literature.⁴⁸ C.-E.A. Winslow quipped that the “result of this condition of affairs is that

Co., 1899) offered only simplest of classification, one which he asserts “has been found convenient by medical bacteriologists, though perhaps not quite correct from a botanical point of view,” pp.3-4.

⁴⁵Hans Zinsser and Stanhope Bayne-Jones, A Textbook of Bacteriology (New York: D. Appleton-Century Co., 1934), 156. Fred Tanner suggested that many instructors in medical bacteriology were “reticent” to even “discuss such subjects” as bacterial classification. Tanner, Bacteriology: A Text-book of Microorganisms (New York: John Wiley & Sons, 1928), viii.

⁴⁶Perkins, “Classification of Bacteria,” 123-124. For examples, see, Herbert W. Conn, Agricultural Bacteriology (Philadelphia: Blakiston’s Son & Co., 1901); and, Moore, Principles of Microbiology, 40. There were exceptions to this characterization. Walker E. King called for comprehensive surveys of the bacterial realm, much as “the botanists may be interested in the botanical flora of a certain territory, or the zoologist in the fauna of a particular region.” King, Synopsis of Lectures. Bacteriology I. for Students in the General Fundamental Course (Manhattan, KS: Kansas State Agricultural College, 1909), 28.

⁴⁷Harry L. Russell, Outlines of Dairy Bacteriology: A Concise Manual for the use of Students in Dairying, 3rd ed. (Madison: H.L. Russell, 1902), 55. For estimations of the number of described species, see, King, Synopsis of Lectures. Bacteriology I, 90-95; Buchanan, “The Problem of Bacterial Nomenclature,” 591; and, Fred W. Tanner, “A Study of Green Fluorescent Bacteria From Water,” Journal of Bacteriology 3 (1918): 63.

⁴⁸Fuller and Johnson, “The Classification of Water Bacteria,” 609; Frederick D. Chester, “Observations of an Important Group of Soil Bacteria; Organisms Related to *Bacillus Subtilis*” Fifteenth Annual Report of the Delaware College Agricultural Experiment Station, 1903 (Newark, Del.: Delaware College Agricultural Experiment Station, 1903), 42; John Percival, Agricultural Bacteriology (London: Duckworth, 1910); Park and Williams.

systematic bacteriology has fallen almost into desuetude. After a brave beginning in the way of describing bacterial species, the conviction gradually gained ground that of the making of species there is no end."⁴⁹

In the rush to christen new species and genera, many bacteriologists ignored even the most rudimentary rules of biological nomenclature. Medical bacteriologists, in particular, employed vaguely descriptive terms, rather than Latin binomials, constructing pathologic taxonomies based "upon the character of the disease produced." A biological classification, one that emphasized the microbe itself, would be based on "morphologic, physiologic, and cultural characters," and not the microbe's relation to man.⁵⁰ Eisenberg's *Bacteriological Diagnosis* listed such pathogens as the "Bacterial of Thready Urine," "Finckler-Prior Bacillus," "Bacillus of Intestinal Diphtheria in Rabbits," "Bacillus of Senile Gangrene," and "Bacillus of Conjunctivitis."⁵¹ During the late 1890's and the early 1900's, textbook authors gradually replaced these pathological terms with more formal binomials. Thomas Bowhill, for example, revised many of the casual names in the second edition of his *Manual of Bacteriological Technique and Special Bacteriology*. Thus, "Bacillus of tuberculosis," became *Bacillus tuberculosis*, "Bacillus of Mouse Septicaemia" became *Bacillus murisepticus*, and the "Organism

Pathogenic Microorganisms, 4th ed., 23; and, Tanner, *Bacteriology and Mycology of Foods*, 1st ed., 93.

⁴⁹ Winslow, "A Statistical Criterion for Species and Genera among the Bacteria," *Bulletin of the Torrey Botanical Club* 36 (1909): 32.

⁵⁰ Buchanan, *Veterinary Bacteriology*, 1st ed., 188. See also, Frederick D. Chester, "Some Suggestions on the Study of Systematic Bacteriology," *Science* 11 (1900): 461.

⁵¹ Eisenberg, *Bacteriological Diagnosis*, ix-xi. Milton J. Rosenau, in his bacteriology text for officers of U.S. Public Health Service, employed names as "Moller's Grass Bacillus," "Rabinowitch's Butter Bacillus," "Karlinsky's Nasal Secretion Organism," and "The Smegma Bacillus." Rosenau, "Laboratory Course in Pathology and Bacteriology," *Bulletin of the Public Health and Marine Hospital Service of the United States Hygienic Laboratory* 8 (1902): 24-26.

symptom of a deep-seated trouble. Everywhere we find disregard of law and precedent, and everywhere the loose thinking and writing which are the consequence."⁵⁵ A more profane practice was the proclivity to violate the law of priority. In botanical nomenclature, "nobody is authorized to change a name because it is badly chosen or disagreeable, or another is preferable or better known, or for any other motive, either contestable or of little import." Thus, the agent of mouse septicemia should be termed *Bacterium insidiosum* (Trevisan) Migula, its first published designation. While *B. murispeticus* might be more descriptive, or even easier to remember, that term appeared more than decade after Trevisan's original publication.⁵⁶ For Buchanan, and Robert S. Breed, the rules of "biological nomenclature, drawn up as they are in codes, are as distasteful to the bacteriologists as are the rules of grammar to the schoolboy." Yet, like the rules of any formal language, taxonomic guidelines provided the coherence to a science seeking to become "a subdivision of the great mother of botany . . ."⁵⁷

Not every biologist believed that bacteria fit neatly within the plant kingdom. Ferdinand Cohn, in the 1870's, first argued for their classification as plants rather than animals. Several forms, however, seemed to occupy a position between the two great kingdoms, and in the 1880's Ernst Haeckel proposed a third kingdom, "Protista" for all one-celled organisms. Although most American bacteriologists rejected Haeckel's proposition, bacteria continued to display an awkward fit as *Schizomycetes*, or fission fungi, as some species resembled algae, protozoa, or

⁵⁵ Buchanan, "Some Problems in Bacterial Nomenclature," 591-592.

⁵⁶ Chester, Manual of Determinative Bacteriology, 48, citing Article 59 of the Paris Code of Botanical Nomenclature.

⁵⁷ Breed, "Present Status of Systematic Bacteriology," 146; and, Buchanan, Veterinary Bacteriology, 1st ed., 17. Curiously, Buchanan removed the reference to the "great mother of botany" in the 2nd edition of his textbook.

even slime molds.⁵⁸ Curiously, these larger questions were effectively bracketed out of consideration by 1908.

The taxonomic chaos emanated from factors beyond sloven usage, deficient botanical background, or queries regarding the appropriate kingdom. Bacteria themselves appeared to defy species categorization. Among higher plants and animals, systematists distinguished species by reference to morphological similarity coupled with the "ability to produce fertile offspring." Neither standard aided in the classification of bacteria, owing to their exceedingly simple morphology and presumed asexual reproduction. Instead, many nineteenth-century bacteriologists identified species based on their pathological powers, a readily recognizable trait that reflected the principal interests of these workers.⁵⁹ For example, veterinary scientists assigned separate species names to the etiological causes of hog cholera (*B. suispestifer*), parrot plague (*B. psittacosis*), mouse typhoid (*B. typhi murium*), and white diarrhea in chickens (*B. pullorum*). The assumption among veterinary specialists was that each host-specific pathogen constituted, by definition, a distinct species. Yet, these four organisms bore a striking resemblance to each other. In other instances this intuitive sense of species demarcation raised more pressing questions. *Streptococcus lacticus* and *Streptococcus pyogenes* agreed in nearly every regard, with the lone exception that the former resided as a harmless milk inhabitant, while the latter comprised a common pus former. If taxonomists declared these two to be one and the

⁵⁸ William Trelease, "Bacteria from a Botanical Standpoint," Weekly Medical Review 17 (1888): 88; Erwin F. Smith, "Are Bacteria Fungi?" American Naturalist 33 (1899): 169-170; Conn and Conn, Bacteriology, 1st ed., 92; Carl R. Woese, "There Must be a Prokaryote Somewhere: Microbiology's Search for Itself," Microbiological Reviews 58 (1994): 1-19; and, Woese, "Default Taxonomy: Ernst Mayr's View of the Microbial World," Proceedings of the National Academy of Science 95 (1998): 11043-11046.

⁵⁹ Harry A. Harding and Martin J. Prucha, "The Bacterial Flora of Cheddar Cheese," Technical Bulletin of the New York Agricultural Experiment Station, Geneva no. 8 (Dec. 1909): 123.

PAGE 413 IS MISSING



same, most market milk could be reasonably declared a public health hazard. If they remained separate species, bacterial taxonomists would be hard pressed to offer the constant character to distinguish the two.⁶⁰

Bacteriologists faced even great difficulties designating species among non-pathogenic forms. Each slight variation could, in theory, constitute a separate species. As Herbert W. Conn wrote repeatedly, no one could state precisely "what is meant by the term 'species' among bacteria. The term 'species,' whatever its significance among higher animals and plants, seems to have no meaning among bacteria." Between each designated species lay several integrating forms. What measure of difference constituted a species, or a mere variety, no one could tell.⁶¹ Despite this conceptual quandary, bacteriologists clung to the belief that bacterial species did exist, presenting "definite morphologic, biologic, cultural, and perhaps pathogenic characters which establish the types independent of variations."⁶² Had microbial taxonomists kept abreast of the debates within the biological literature, they might have taken solace in noticing a similar set of problems vexing botanists and zoologists.⁶³ Instead, only Herbert W. Conn, who taught

⁶⁰ Buchanan, Veterinary Bacteriology, 1st ed., 197, 200, 205 & 268; and, Moore, Principles of Microbiology, 193.

⁶¹ Conn, Practical Dairy Bacteriology, 25; Conn, Agricultural Bacteriology: A Study of the Relation of Germ Life to the Farm with Laboratory Experiments for Students, 2nd ed. (Philadelphia: P. Blakiston's Sons, 1909), 146. See also, Percival, Agricultural Bacteriology, 269-270; Buchanan, Veterinary Bacteriology, 1st ed., 261; and, Felix Lohnis, William Stevenson, and J. Hunter-Smith, Laboratory Methods in Agricultural Bacteriology (London: Charles Griffin & Co., 1913), 72.

⁶² Chester, Manual of Determinative Bacteriology, 51. The question of bacterial species lingered for several more decades. See, J.J. von Leoghem, "The Significance of the Conceptions of Genotypus and Paenotypus to Bacteriology," in, Third International Congress for Microbiology, New York, September 2-9, 1939, ed. M. Henry Dawson (Baltimore: Waverly Press, 1940), 98-106; and, Sam T. Cowan, "The Microbial Species - A Marcomyth?" Symposium of the Society for General Microbiology 12 (1962): 433-455.

⁶³ Charles Bessey, for example, denied the natural existence of species, arguing that they were nothing more than mental concepts invented to remember great numbers of forms. See, Bessey, "Evolution and Classification," Proceedings of the American Association for the Advancement of Science 42 (1893): 237-251; Bessey, "The Taxonomic Aspect of the Species Concept," American Naturalist 42 (1908), quoted in McQuat, "Species, Names and Things," 23. Many opposed Bessey's nominalist view, insisting upon the reality of species and genera. See, Albert S. Hitchcock, The Methods of Descriptive Systematic Botany (New York: Wiley, 1925);

both bacteriology and biology at Wesleyan, mentioned that biologists themselves were "not always in perfect agreement as to what constitutes a species."⁶⁴

Where bacteriologists departed from the botanical and zoological counterparts was in their ability to formulate taxa on the basis of morphology alone. Among higher plants and animals, morphological, and not physiological or functional characters defined orders, families, tribes and genera. Taxonomists in the seventeenth and eighteenth centuries established that walking mammals (horses), flying mammals (bats), and swimming mammals (whales) shared more fundamental characteristics than did flying mammals and flying insects. Both the wing of a wasp and the wing of a bird serve the purpose of flight, but Enlightenment naturalists noticed their structural dissimilarity and classified these animals in widely separate branches of the animal kingdom. Within bacteriology, the dominant taxonomic practice during the first decade of the twentieth century founded genera and higher taxa on the basis of morphology (e.g., shape, arrangement in groups, capsules, spores, staining reactions, and granule formation), and differentiated species by their "physiologic, biochemic or pathogenic properties."⁶⁵ However, these criteria failed in several aspects. Even under the most exacting conditions, bacterial shapes rarely displayed sharp dividing lines. Rods blended into misshapen spheres, and singular cocci occasionally formed short chains or clusters. As a result, dairy bacteriologists debated whether

and, A.B. Cook, "Bernard's Symposium: The Species Concept in 1900," Biological Journal of the Linnean Society 9 (1977): 1-30.

⁶⁴ Herbert W. Conn and Harold J. Conn, Bacteriology, 1st ed. (Baltimore: Williams and Wilkins, 1923), 94-95. See also, Herbert W. Conn, "The Significance of 'Variety' and Species," Science 11 (1888): 253.

⁶⁵ Moore, Principles of Microbiology, 29. Most bacteriologists found little fault with defining species on the basis of physiology, rather than morphology. See, Fuller and Johnson, "Classification of Bacteria," 619; Theobald Smith, "Variations among Pathogenic Bacteria," Journal of the American Medical Association 34 (1900): 562; and, Smith, "Variations among Pathogenic Bacteria," Journal of the Boston Society of Medical Sciences 4 (1900): 96. Bacteriologists were not alone in this regard. Joseph C. Arthur argued, at the 1907 meeting of the Botanical Society of America, for a greater reliance on physiological traits when classifying molds and rusts. Arthur, "Physiological Aspects of the Species Problem," American Naturalist 42 (1908): 243-248.

their predominant lactic acid forms represented bacilli, micrococci, or even streptococci.⁶⁶

Moreover, morphological traits proved too coarse a basis for differentiation. For example, in most taxonomic schemes, all spherical shaped bacteria, dividing in two planes but not forming chains or packets carried the generic label *Micrococcus*. However, that genus would contain the organisms responsible for gonorrhea in humans, the formation of slime in industrial sugar solutions, and the reduction of nitrates in soils. These physiological differences appeared to some observers as wide as the morphological dissimilarities "between the kangaroo and man," although no taxonomist would place the two mammals in the same genus.⁶⁷ Other bacteriologists held out the possibility that further taxonomic divisions could be created once research revealed the more detailed features of bacterial cytology.⁶⁸ In the meantime, students, teachers and researchers would simply have to operate under an imperfect taxonomic system. University of Michigan's Frederick G. Novy admitted that "a similar classification applied to the higher forms of life would lead to gross error. Thus, the worm, eel and snake, viewed at a distance, show the same general appearance, and yet they are wholly different, unrelated types of life." In his own textbook, however, Novy relied on such a rudimentary scheme.⁶⁹ Not every American

⁶⁶ Harding and Prucha, "Bacterial Flora of Cheese," 122; Herbert W. Conn, William M. Esten, and William A. Stocking, "Classification of Dairy Bacteria," Annual Report, Storrs Agricultural Experiment Station (1906): 98; and, Conn, Practical Dairy Bacteriology, 28 & 57.

⁶⁷ Winslow and Winslow, Systematic Relationships of the Coccaceae, 28. E.O. Jordan believed that any morphological system was "hardly likely at present to meet with general success." Jordan, Text-book of General Bacteriology (Philadelphia: W.B. Saunders Co., 1908), 102.

⁶⁸ See, A. Guilliermond, "Cytology," in Microbiology: A Text-book of Microorganisms. General and Applied, 2nd ed., ed. Charles E. Marshall (Philadelphia: Blakiston's Son & Co., 1917), 88; Marshall, "Bacteria: What they Are, What they Do, and How they are Cultivated," Bulletin of the Michigan State Agricultural College Experiment Station 139 (1896): 62; and, H.M. Ward, "On the Characters, or Marks, Employed for Classifying the *Schizomycetes*," Ann. of Botany 6 (1892): 103.

⁶⁹ Novy, Laboratory Work in Bacteriology, 2nd ed. (Ann Arbor: George Wahr, 1899), 18. Interestingly, two decades later the Bergey's Committee accepted Novy's analysis of the situation, reasoning that simple morphological taxonomies proved unavoidable, given that the "biologic characters of so few of the bacteria had been determined. With the accumulation of knowledge of the biologic characters of many bacteria it was realized

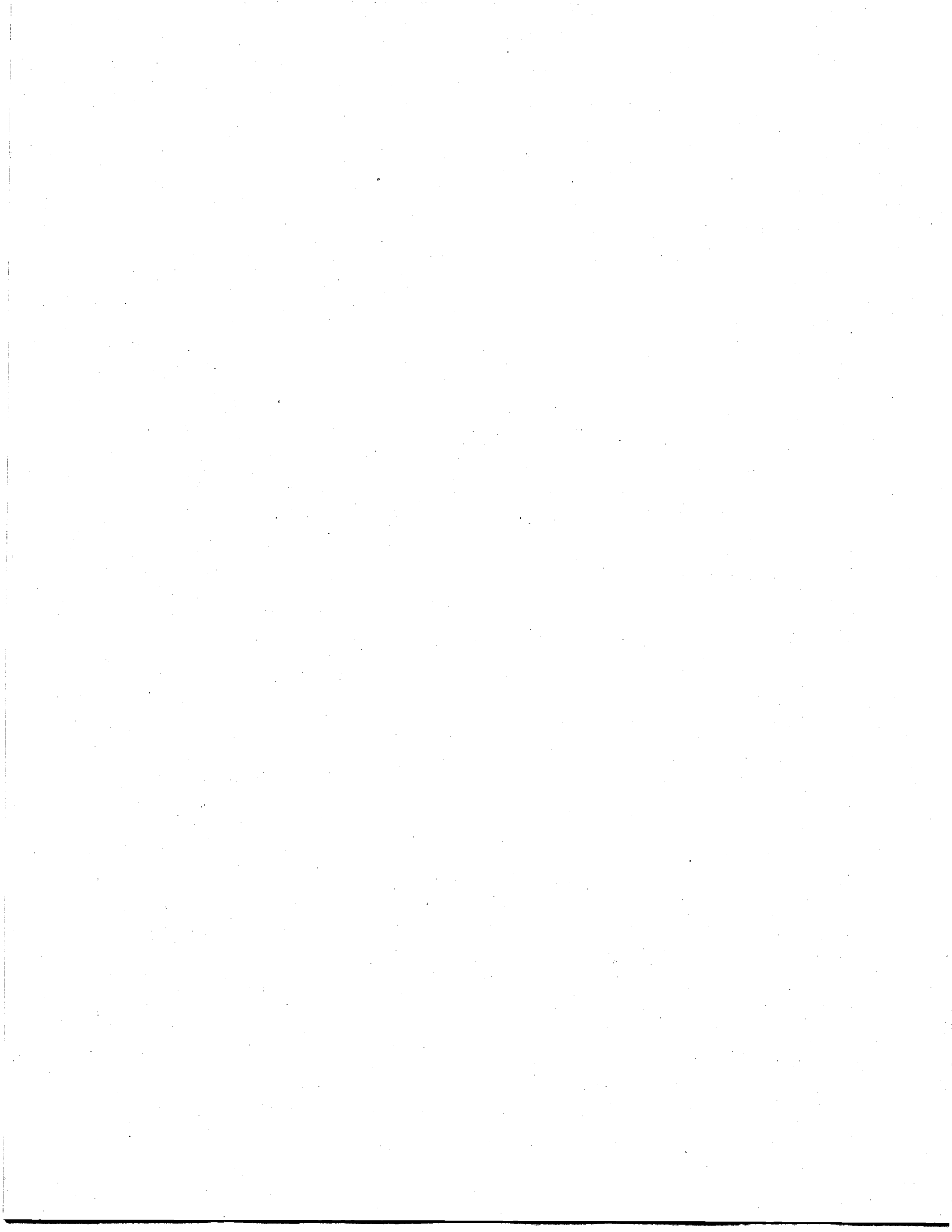
study. Bacteria, in contrast, had to be kept alive, demanding continuous culturing that invariably altered the "type" characteristics. Owing to their simple structure, and rapid multiplication, bacteria were "readily influenced, in some way or another, by the slightest change in their environment." Even novice students understood the maxim that pure cultures tended to vary in "form, habitat, and function."⁷³

Bacterial variation posed a particular challenge to those advocating pathological taxonomies. Even under controlled conditions, virulence varied, and suspected pathogens extracted from human and animal sources deviated considerably from textbook characterizations. Bacteriologists faced the difficult decisions of whether to classify an organism as *B. diphtheriae*, even when it lacked the power to produce diphtheria, or whether to declare a microbe, capable of producing tubercles, as *B. tuberculosis*, when it lacked the defining tendency to branch.⁷⁴ *Streptococci*, in particular, varied greatly in their pathogenic powers, and individual "types" were subject to noticeable changes in physiological activities. If each departure from previously described forms constituted a new species, members of the genus *Streptococci* could number in the hundreds. As Veranus A. Moore counseled, bacteriologists had yet to agree upon "what constitutes specific characters or to what extent variation in the cultural or physiological

⁷³ Novy, Laboratory Work in Bacteriology, 2nd ed., 19; and, King, Synopsis of Lectures. Bacteriology I. 90. William Trelease, writing in 1888, warned against classifying bacteria according to their effects, as the same species may display variable powers. Trelease pointed to the example of virulent bacteria, which occasionally lost their power to produce illness. "Bacteria from a Botanical Standpoint," 88.

⁷⁴ See, Theobald Smith, "Observations on the Variability of Disease Germs," New York Medical Journal 52 (1890): 485; Smith, "Modification, Temporary and Permanent, of the Physiological Characters of Bacteria in Mixed Cultures," Trans. Assn. Am. Physicians 9 (1894): 85-106; Smith, "Variations among Pathogenic Bacteria," 97-98; Frederic P. Gorham, "The Morphology of *Bacillus Diphtheriae*," Science 15 (1902): 370-371; Gorham. "Morphological Varieties of *Bacillus Diphtheriae*," Journal of Medical Research 6 (1901): 201-210; Herbert M. Goodman, "Variability in the Diphtheria Groups of Bacilli," Journal of Infectious Diseases 5 (1908): 421-440; A.P. Ohlmacher, "Observations Upon the Morphological Variation of Certain Pathogenic Bacteria," Science 15 (1902): 374; Theobald Smith, "Some Problems in the Life History of Pathogenic Microorganisms," Science 20 (1904): 807; and, Hibbert W. Hill, "Introductory Remarks on Morphology of Bacteria," Science 21 (March 31 1905): 489.

PAGE 419 IS MISSING



properties may be accepted. The very close resemblance in the growth of many bacteria belonging to the same genus has made it difficult in many cases to identify the species."⁷⁵

Some believed that environmentally induced variations might be inherited. If this were the case, "hothouse varieties" could become new species via natural or artificial selection.⁷⁶ Conversely, variations might be a product of mutations, rather than environmental factors. A handful of American investigators vetted instances of these natural "sports," exploring the possibility that they may give "rise to permanent new races."⁷⁷ The geneticist Hugo DeVries argued that mutations within higher plants led to creation of novel species. University of Kansas bacteriologist Marshall A. Barber reasoned that if mutations "occur among the cells of higher plants, we would expect on *a priori* grounds to find them in the lower also, and perhaps more frequently in these less differentiated and more plastic types."⁷⁸ Bacteriologists quickly recognized that mutations, if they did occur among bacteria, might further hinder taxonomic efforts.

For a select number of bacteriologists, variation provoked little disquiet. As the simplest life forms, bacterial types, according to certain evolutionary theories, would be expected to vary

⁷⁵ Moore, Principles of Microbiology, 38; and, Moore, The Pathology and Differential Diagnosis of Infectious Diseases of Animals (Ithica: Taylor & Carpenter, 1902), 33-34.

⁷⁶ Herbert W. Conn, "Natural Varieties of Bacteria," paper delivered to the 1st Annual SAB Meeting, 1899, abstracted in Science 11 (1900): 455-456; and, Smith, "Variations among Pathogenic Bacteria," 104.

⁷⁷ Marshall A. Barber, "On Heredity in Certain Microorganisms," Kansas University Science Bulletin 4 (March 1907): 1-48; and, Nelson F. Davis, "Variations of *Bacillus Rosaceous Metalloides* (Dowdeswell)," Science 13 (1901): 324. For a critical view of this perspective, see, William M. Clark, "Penfold's Modification of *Bacilli Coli Communis*," Science 38 (1913): 669-672.

⁷⁸ Barber, "On Heredity in Certain Microorganisms," 41. See also, Hugo DeVries, "The Aim of Experimental Evolution," Carnegie Institution Yearbook 3 (1904): 39-49; C. Stuart Gager, "De Vries and his Critics," Science 25 (1906): 81-89; Charles B. Davenport, "De Vries' Species and Varieties," American Naturalist 39 (1905): 747-751; Davenport, "Review of *Species and Varieties, Their Origin by Mutation*," Science 22 (1905): 369-372. McQuat documents DeVries' considerable influence among American biologists between 1904 and 1912. By 1915, however, "mutationism, at least in its extreme De Vriesian form, was a spent force." "Species, Names and Things," 298 & 314.

greatly.⁷⁹ Moreover, the tendency to vary could be employed taxonomically. Walter E. King, in his textbook and course at the University of Kansas, defined species as the "sum total of the separate individuals and generations which during the time afforded for observation exhibit the same periodically represented development within certain empirically determined limits of variation." King maintained that species characters fluctuate within a certain range particular to that species. Defining the limits of variance, for King, comprised a central component in the characterization of bacteria.⁸⁰ For other taxonomists, bacterial variation confounded every attempt at classification. Herbert W. Conn and his colleagues at the Storrs Agricultural Experiment Station indicated that given "the extreme variability of bacteria types, especially physiological characters," defining distinct species became "almost an impossibility." In arranging forms found in dairy products, each type tended to "vary in all directions and run into each other by more or less complete intermediate links. Every new set of cultures which we obtain from even similar sources show variations in various properties connecting them more or less with other types." They surmised that "the task of arranging these forms into species or even groups" might indeed be "hopeless."⁸¹ Fortunately, a majority of American taxonomists held a

⁷⁹ See, Hibbert W. Hill, "Branching in Bacteria, with Special Reference to *B. Diphtheriae*," Science 15 (1902): 369; and, Conn, Esten, and Stocking, "Classification of Dairy Bacteria," 97. C.-E.A. Winslow and L.T. Walker offered bacteria as ideal organisms for the study of experimental evolution, suggesting that such research "will some day throw important light on such central problems of general as the origin of species." Winslow and Walker, "A Case of Non-Inheritance of Fluctuating Variations among Bacteria," Journal of Infectious Diseases 6 (1909): 90. See also, Winslow, "The Foundations of Heredity," Dial 47 (1909): 282; and, Robert E. Buchanan, "The Bacterioids of *Bacillus Radicicola*," Centrl. f. Bakt. 2 abt., no 23 (1909): 60.

⁸⁰ King, Synopsis of Lectures. Bacteriology I, 23-24. See also, Leo F. Rettger and J.L. Sherrick, "Studies on Bacterial Variation," Journal of Medical Research 24 (1911): 265; and, David H. Bergey, "Mutations in Microorganisms," paper presented before the 13th Annual SAB Meeting, 1911, abstracted in Science 35 (1912): 236.

⁸¹ Conn, Esten, and Stocking, "Classification of Dairy Bacteria," 94.

more sanguine outlook, choosing instead to employ only consistent characters.⁸²

An additional source of confusion arose from the changing determinative techniques in bacteriology. The characterizations that accompanied many organisms identified in the 1880's and 1890's were "worse than useless at the present time, for no one would be able to identify the bacteria from these meager descriptions or even to tell whether the bacteria described belong to one or another group of bacteria."⁸³ As a result, it proved difficult to determine whether a species described by one bacteriologist was identical with that described by another under the same name.⁸⁴ While the Standard Methods of American Public Health Association, and later the SAB's Descriptive Chart, provided a degree of uniformity in bacterial determinations, each introduction of new methods threatened to redefine the characterizations of myriad microbes.⁸⁵ Frederick Chester, writing in 1901, charged that "probably nine-tenths of the forms of bacteria already described might as well be forgotten or given a respectful burial." Others, such as University of Texas' Allen J. Smith, predicted that no "thoroughly satisfactory classification of bacteria" would be developed until the methods of study improved to "permit a stable

⁸² The ability to ferment carbohydrates, for example, might distinguish bacterial species. However, that power varied with the age of the culture, reaction of the solution, etc., and was therefore excluded from most formal taxonomies in favor of more uniform traits. Fuller and Johnson, "Classification of Water Bacteria," 611 & 616; Goodman, "Variability in the Diphtheria Groups of Bacilli," 429; and, Chester, "Observations of an Important Group of Soil Bacteria," 54.

⁸³ Conn, Esten, and Stocking, "Classification of Dairy Bacteria," 92-93. McFarland complained that practicing bacteriologists "constantly meet species described so insufficiently as to make it impossible to properly classify and tabulate them." McFarland, A Text-book upon the Pathogenic Bacteria, 4th ed., 225.

⁸⁴ Conn, Agricultural Bacteriology, 29. Robert Breed estimated that "more than one-fourth of all published bacteriological work is seriously impaired because the authors of the papers have not appreciated the necessity of explaining the systematic relationships of the organisms studied, of giving the reading some idea of the authenticity of the cultures or of preserving cultures." "Present Status of Systematic Bacteriology," 160.

⁸⁵ "Differentiation of Species by the Bacteriologists," Journal of the American Medical Association 24 (1895): 342; Park and Guerard, Bacteriology in Medicine, 260; Frederic Gorham, A Laboratory Course in Bacteriology for the Use of Medical, Agricultural, and Industrial Students (Philadelphia: W.B. Saunders, 1901), 86-87; and, Moore, Principles of Microbiology, 39.

arrangement such as is established in the studies of higher botany and zoology.”⁸⁶

For taxonomically minded microbiologists mining the literature to compare previously described forms, they found many species bearing multiple monikers. The agent of pneumonia endured the labels *Streptococcus pneumoniae*, *Diplococcus lanceolatus* and *Micrococcus lanceolatus*. The cause of meningitis could be *Micrococcus meningitidis*, *Diplococcus intracellularis meningitidis*, *Micrococcus weishselbaumii*, or *Streptococcus meningitidis*. And, the germ of gas gangrene carried the appellations *Clostridium welchii*, *B. aerogenes capsulatus*, *B. phlegmonis emphysematosae*, *B. perfringens*, and, *B. enteritidis sporogenes*. Such duplicative designations littered the literature.⁸⁷ Chester chastised those bacteriologists who believed that it made “little difference what the organism is called, provided it is understood what is meant. There are certain rules governing the naming of species, and these should be observed. Each bacillus should be given its proper name, as determined by these rules, and it should become the practice to use such names only, and not one of its various synonyms indiscriminately.”⁸⁸ Yet, several textbook authors provided multiple synonyms for each organism, believing that the practicing bacteriologist needed to know the sundry names in order to comprehend published articles and reports.⁸⁹

⁸⁶ Chester, Manual of Determinative Bacteriology, 51; and, Smith, Lessons and Laboratory Exercises in Bacteriology, 262.

⁸⁷ Tanner, Bacteriology: A Text-book of Microorganisms, 81; Buchanan, General Systematic Bacteriology, 113; Conn, Esten and Stocking, “Classification of Dairy Bacteria,” 103-104; Moore, Laboratory Directions for Beginners, 70; Lohnis, Stevenson and Hunter-Smith, Laboratory Methods in Agricultural Bacteriology, 52; and, Lohnis and Fred, Textbook of Agricultural Bacteriology, 1st ed., 35. William W. Ford, in his review of the aerobic spore-bearing bacteria noted the inverse tendency, where the same name was applied to several different species. Ford, “Aerobic Spore-Bearing Non-Pathogenic Bacteria,” 274.

⁸⁸ Chester, Manual of Determinative Bacteriology, 48. See also, Buchanan, Veterinary Bacteriology, 1st ed., 76; and, Stitt, Practical Bacteriology, 3rd ed., 43.

⁸⁹ Rosenau, for example, listed the following bacteria and their taxonomic doubles: *B. vulgaris* (*Proteus vulgaris*); *Pseudomonas aeruginosa* (*Bacillus pyocynaeus*); *Planosarcina agilis* (*Micrococcus agilis*); *Microspira aquatilis* (*Vibrio aquatilis*); *Micrococcus aureus* (*Staphylococcus pyognes aureau*); *Micoroccus pyognes*

By the first decade of the twentieth century, SAB members joined a chorus of consternation, warning that disarray in bacterial systematics threatened the development of the discipline. Harry Harding, writing in 1910, argued that taxonomy comprised the fundamental basis of any science:

Science is commonly defined as an orderly arrangement of facts, and in practically all branches of biology a classification of species is the basis on which the facts are arranged. Bacteriology, if it can be said to have attained the dignity of a science, has thus far developed so primitive a plan of classification that the observed facts are in many cases in a condition little short of chaos.⁹⁰

Harding further insisted that systematics aided in the practical program of microbial manipulation and exploitation. Such knowledge was fundamental to "a proper understanding of diseases and fermentations and must be obtained before we can expect to control successfully the action of micro-organisms." The taxonomic confusion hindered replication and comparison of work performed in different laboratories, in different fields, or in different nations. As a result, many researchers were forced to begin each problem anew. "The absence of a common basis for comparing these isolated facts," Harding contended, "has prevented their orderly arrangement and has made accurate generalizations impossible."⁹¹ William L. Holman, in his review of the classifications of *Streptococci*, provided an apt illustration of Harding's worries. The University of Pittsburgh pathologist agreed that a stable ordering of this group was required "before any real

(*Staphylococcus pyogenes albus*); and, *Bacterium pneumoniae* (*Diplococcus pneumoniae*). Rosenau, "Laboratory Course in Pathology and Bacteriology," 24-32.

⁹⁰ Harding, "The Constancy of Certain Physiological Characters in the Classification of Bacteria," Technical Bulletin of the New York Agricultural Experiment Station, no. 13 (1910): 4.

⁹¹ Harding, "Constancy of Certain Physiological Characters," 9-10. For similar assertions, see, Conn, "Classification of Dairy Bacteria," Storrs Agricultural Experiment Station. Annual Report (1899): 14-15; Moore, Laboratory Directions for Beginners, 56; Jordan, Text-book of General Bacteriology, 1st ed., 101; and, Tanner, "A Study of Green Fluorescent Bacteria," 63. Buchanan charged that taxonomy was "of great importance from the standpoint of bacteriologists, sanitarians, hygienists, physicians and pathologists. Our present system, or lack of system, lead to inaccuracies, misconceptions, and misstatements." Buchanan, "Some Problems in Bacterial Nomenclature," 592.

advance can be made in its study." Unfortunately, "almost every investigator has used his own method of classification," employing morphology, pathogenecity, hemolytic power, fermentation of carbohydrates, etc. "The hygienist has largely used the fermentation tests, while the obstetrician and the medical bacteriologist have observed the hemolytic character, so that the findings of these workers cannot be compared." Given the "general lack of correlation," the "majority of these reports are valueless."⁹²

Conversely, these same critics posited that a stable, unified taxonomy could integrate a fragmented discipline. Robert Buchanan, in an address before the 1915 meeting of the SAB, quoted the British biologist H. Marshall Ward. Ward held that there existed two types of bacteriologists. "On the one hand, we have the botanists, who direct their attention to the organism, the Schizomycete itself, as a biological phenomenon to be examined and reported upon as thoroughly as possible, for them no classification is complete which does not record, or (which amounts to the same thing) imply in its records, all of the life phenomena of the organism including its pedigree." In contrast stood the "pathologists, hygienists, brewers, chemists, etc., who regard the organism simply as an object to be named for convenience in reference, because it brings about certain changes in the tissues, waters, and other media which they are more specially concerned with." For these practical workers, the principal interest lay in determination, not classification. It was, however, the same considerations of life phenomena that "bring about the sources of error" plaguing all bacteriologists. In this light, both kinds of

⁹² Holman, "Classification of the *Streptococci*, Journal of Medical Research 29 (1916): 377. Park and Guerard feared that the situation would only worsen as specialties developed particular techniques and proposed new classifications. Park and Guerard, Bacteriology in Medicine, 260. Fred W. Tanner, in contrast, held that "no harm will come to anyone if all of these perplexing questions are not settled definitely within his own generation." Tanner, Bacteriology and Mycology of Foods, 1st ed., 98.

researchers would be well served by systematic studies.⁹³ At the very least, a well-founded taxonomy could greatly aid in the instruction of bacteriology.⁹⁴

For these critics, the taxonomic confusion provided an enduring source of disciplinary anxiety. Buchanan confessed, "It is probably safe to state that practically every other branch of biological science has left us in the rear in this matter."⁹⁵ Buchanan may have been mistaken. Franklin S. Earle, in an address before the Botany Section of the AAAS, declared that mycological taxonomy stood in a state of chaos. Systematic textbooks of fungi listed between 1,800 and 2,300 genera, and none followed "any recognizable or consistent rule of nomenclature. The case of each genus seems to have been settled on an independent basis and according to the whim of the moment."⁹⁶ Similarly, C.L. Shear and Frederick Clements argued that since mycology developed "many practical and important relations to human industry," it had not received its full share of "biological" attention. They noted that very few taxonomists examined fungi, and those that did lacked proper training, materials, and financial support. Among the 100,000 documented species, many displayed pleomorphic traits. The lack of "uniformity and stability in the use of Latin names and the endless subdivision and duplication of genera and species" rendered it "impossible for the student or general worker to take up the subject with any degree of interest or satisfaction." In Shear and Clements' estimation, the taxonomic confusion

⁹³ Buchanan, "Some Problems in Bacterial Nomenclature," 594-595, quoting H. Marshall Ward, "On the Characters, or Markers, Employed for Classifying the *Schizomycetes*," Ann. of Botany 6 (1892): 103. Charles B. Morrey similarly argued that a system of fixed names could greatly facilitate scientific study. Morrey, The Fundamentals of Bacteriology, 1st ed. (Philadelphia: Lea & Febiger, 1917), 56.

⁹⁴ Joseph E. Greaves advised that "Until some such reform in nomenclature is brought about, the names used to designate different kinds of bacterial will fail to make clear the group relationships which undoubtedly exist, and will continue to be a stumbling block to all students of the subject." Greaves, Agricultural Bacteriology, 46.

⁹⁵ Buchanan, "Some Problems in Bacterial Nomenclature," 592.

⁹⁶ Earle, "The Necessity for Reform in the Nomenclature of the Fungi," Science 19 (1904): 510.

had to be resolved "if mycology is to command respect and scientific support, and render the practical service that it should."⁹⁷ Mycology, according to these commentators, had much in common with bacteriology.

Even the broader discipline of botany suffered under the decline of systematic studies. In his address as retiring president of the Botanical Society of America, Albert S. Hitchcock declared that taxonomy "in the conventional sense is almost taboo." Most botany graduate students believed that taxonomic studies "offered little in the way of reputation or financial return," and few penned doctoral theses on such topics. Instead, the younger botanists preferred an "experimental method," applied to one or two organisms, rather than a taxonomic approach requiring repeated observations of an entire flora. Hitchcock cautioned against this retreat from taxonomy, exhorting that "plant names become, as it were, units of precision by which all branches of botany are standardized. From this standpoint taxonomy is fundamental because it furnishes the standard units of comparison and coordination, these units being not merely the names but the ideas which these names represent."⁹⁸ The wearisome circumstances of systematic biological studies escaped the attention of most bacteriologists. Robert Breed rhetorically inquired:

I wonder if anyone who feels that it is difficult if not impossible to work out natural relationships among bacteria has ever tried to work out these relationships among such a group of individual animals as the black bears of North America Those who know, tell me that if bacteriologists would but try their hands at some of these problems they would return to their cultures with a sigh of relief that among bacteria at least, characters

⁹⁷ Shear and Clements, "The Condition and Needs of Systematic Mycology," *Science* 63 (1926): 393-395.

⁹⁸ A.S. Hitchcock, "The Scope and Relations of Taxonomic Botany," *Science* 43 (1916): 332, 334, & 338. See also, Nelson, "The Trend and Influence of Certain Phases of Taxonomy," 922 & 925; W.E. Ritter, "Place of Description and Classification in Systematic Biology," *Scientific Monthly* 3 (1916): 455-470; and, Hitchcock, "Genera and Super Genera," *Science* 52 (1920): 1078.

show some fixity.⁹⁹

Breed failed to consider the possibility that neither zoologists, nor bacteriologists, looked favorably to the task of systematics. Each discipline shouldered the frustration arising from the incomplete and confusing taxonomies. Bacteriology merely arrived late to this discontent.

An Unwelcome Inheritance

At the turn of the twentieth century, American bacteriologists encountered a number of rival taxonomies, each with its own advantages and shortcomings. While bacteriology comprised a relatively new research endeavor at that time, attempts at classifying the microbial realm date to the mid-eighteenth century. Linnaeus's *Systema Naturae* placed the minuscule infusoria in the genus *Chaos*, with no further attempt at differentiation. In a similar manner, Otto F. Mueller, in 1786, divided the *Animalcule Infusoria* into two genera, *Monas* and *Vibrio*, to describe the rod and spiral shaped organisms. In the 1830's, German naturalist Christian G. Ehrenberg subdivided Mueller's two groups into five genera, based on cell morphology and motility (*i.e.*, *Bacterium*, *Vibrio*, *Spirochaeta*, *Spirillum*, and *Spirociscus*).¹⁰⁰ With the improvement of microscopic and staining techniques in the middle of nineteenth century, a few botanists ventured more detailed arrangements of these minute living bodies. In 1858, the German botanist Carl Wilhelm von Naegeli placed bacteria within the vegetable rather than animal kingdom, and proposed the class *Schizomycetes* for the colorless fission fungi. It was Ferdinand Cohn, the

⁹⁹ Breed, "Present Status of Systematic Bacteriology," 144-145.

¹⁰⁰ Carl von Linne, *Systema Naturae* 10th ed. (New York: Stechert-Hafner Service, 1759, 1964); Mueller, *Animalcula Infusoria: Fluvia Tilia et Marina* (Haunia: Typis N. Moelleri, 1786); Ehrenberg, *Die Infusionsthierchen als Vokommene Organismen*, 2 vols. (Leipzig: L. Voss, 1838); Patrick Collard, *The Development of Microbiology* (London: Cambridge University Press, 1976), 151; and, Buchanan, *General Systematic Bacteriology*, 11-18.

professor of botany at the University of Breslau, who set a high standard for precise microscopic studies of bacteria in the mid 1870's. Cohn expanded the classification of bacteria to include two tribes and forty genera, based on detailed morphological characteristics that Cohn displayed in dozens of meticulous drawings.¹⁰¹ Several European authors followed Cohn in creating multiple genera, but none gained ascendancy. Deputy Surgeon General George Sternberg proffered the first American authored taxonomy in 1892. Sternberg's simple scheme merged many published genera, lumping nearly all rod-shaped forms into the genus *Bacillus*. Most American medical bacteriologists adopted Sternberg's taxonomy, retreating from any attempts to classify further.¹⁰²

Their refuge might have been wise. The minute size of bacteria and their structural similarity doomed to failure any classification based on morphologic characters. By 1880, bacteriologists found that these classifications could not account for the myriad organisms. They noted that structurally similar bacteria differed drastically with regard to their biochemical properties or pathogenic potential. Of course, bacteriologists found these physiological differences of most interest. For those bacteriologists who sought to apply a developed nomenclature and classification, they encountered many from which to choose. As William D. Frost mentioned, in the 1890's "every author of a textbook on the subject of bacteria made a new classification. The workers in the various fields also made classifications, as, for example, the botanists, pathologists, agriculturalists, brewers, etc. Until recently, no attempt at uniformity has

¹⁰¹ Cohn, Über die Bakterien, die Kleinsten Lebenden Wesen, translated as *Bacteria: The Smallest of Living Organisms*, Bulletin of the History of Medicine 7 (1939): 49-92; Cohn, "Untersuchungen über Bakterien. II. (Heft. 3), Beitr. Biol. Pflanz. 1 (1875): 141-208; Naegeli, Beiträge zur Wissenschaftlichen Botanik, 4 vols. (Leipzig, 1858); Park and Guerard, Bacteriology in Medicine, 35; and, Buchanan, General Systematic Bacteriology, 22-24.

¹⁰² Buchanan, General Systematic Bacteriology, 26-27, & 47; and, Sternberg, Manual of Bacteriology (New York: W. Wood & Co., 1892).

been made.”¹⁰³

The attempts at uniformity arrived in the first years of the twentieth century, when three systems emerged as dominant. Walter Migula, in 1890, proposed a simple arrangement based on cell shape, grouping, and spore formation. Migula offered a revised classification in 1894, but this time rejected spore formation as a taxonomic character in favor of motility and the distribution of flagella. Three years later, Migula incorporated his scheme into a detailed determinative manual, a publication that did much to encourage adherence to his classification. Migula divided the *Schizomycetes* into two orders, *Eubacteria* for the “true bacteria” and *Thiobacteria* for those bacteria containing sulphur granules or bacteriopurpurin. Within *Eubacteria*, Migula proposed five families, based primarily on shape: *Coccaceae* (spherical forms); *Bacteroidaceae* (rods); *Spirillaceae* (spirals); *Chlamydobacteriaceae* (branched and sheathed forms); and *Beggiatoaceae* (motile sheathed forms containing granules of iron). In the diagnosis of genera, Migula placed particular emphasis on motility. (Fig. 6.1) For example, besides the accepted spherical genera of *Streptococcus* (pairs or chains reproducing in one plane of division), *Micrococcus* (dividing in two planes but not forming chains or packets), and *Sarcina* (dividing in three planes and forming regular packets), Migula submitted *Planococcus* and *Planosarcina* for chains and packets motile by means of flagella. Migula was, however, hard pressed to identify any species belonging to those two genera. Moreover, Migula ignored physiological characters, staining reactions, or spore formation, relying exclusively on morphology and motility to define generic categories.¹⁰⁴

¹⁰³ Frost and McCampbell, A Text-book of General Bacteriology, 103.

¹⁰⁴ Migula, “Ueber ein Neues System der Bakterien,” Arb. Bakt. Inst. Tehn. Hoschs. Karlsruhe 1 (1894): 235-238; Migula, Compendium der Bakteriologischen Wasseruntersuchung nebst Vollständiger uebersicht der

Migula's division of the bacterial rods prompted the greatest dissension. *Bacterium*, according Migula, described all nonmotile rods, regardless of spore formation. *Bacillus* encompassed motile forms, mostly forming spores. And, *Pseudomonas* distinguished rods with polar flagella. Migula's motility-based differentiation stood in stark contrast to most earlier taxonomies, which distinguished *Bacillus* and *Bacterium* according to spore formation. Under Migula's definition, many widely divergent types resided in the same genus, such as *B. subtilis* and *B. typhosus*, while similar organisms such as *B. subtilis* and *Bact. anthracis* inhabited different genera. Motility appeared to arbitrarily arrange rods, rather than assemble similar forms. Furthermore, the techniques for detecting flagella vexed American bacteriologists, often mislabeling motile forms as nonmotile.¹⁰⁵

Notwithstanding these criticisms, Migula surfaced as the taxonomist of choice among American textbook authors, albeit with considerable ambivalence.¹⁰⁶ Many writers modified Migula's scheme, whether by appending additional genera, or refusing to alter the generic names

Trinkwasserbakterien (Wiesbaden: O. Nernich, 1901); Migula, Die Bakterien (Leipzig: J.J. Weber, 1903); William W. Ford, Bacteriology (New York: P.B. Hoeber, 1939), 144; and, Collard, Development of Microbiology, 152.

¹⁰⁵ A.I. Kendall, "A Proposed Classification and Method of Graphical Tabulation of the Characters of Bacteria," American Public Health Association. Proceedings. 1902 28 (1903): 483; Jordan, A Text-book of General Bacteriology, 1st ed., 104; and, Buchanan, Veterinary Bacteriology, 1st ed., 79. In 1904, Migula again outlined his scheme and "vigorously defended it against criticisms that had been made against it." Buchanan, General Systematic Bacteriology, 79.

¹⁰⁶ A partial list of American textbooks employing Migula's taxonomy includes: Moore, Laboratory Directions for Beginners, 2nd ed., 53-55; Rosenau, "Laboratory Course in Pathology and Bacteriology," 4; William D. Frost, A Laboratory Guide in Elementary Bacteriology, 3rd ed. (New York: MacMillan Co., 1903), v; and, Ward Giltner, Laboratory Manual in General Microbiology, 1st ed. (New York: John Wiley & Sons, 1916). Frost and McCampbell surmised that Migula's scheme represented a taxonomy "as accurate and systematic as has been made. This classification has been adopted by the leading American bacteriologists." Frost and McCampbell, A Text-book of General Bacteriology, 103. Charles B. Morrey mistakenly believed that Migula's classification had been adopted by both the Laboratory Section of the APHA and the SAB, and was "practically standard in this country." Morrey, Fundamentals of Bacteriology, 1st ed., 57.

of select forms.¹⁰⁷ In the estimation of some observers, Migula stood as the lessor of taxonomic evils, demanding the least number of changes in nomenclature while requiring students to memorize only a rudimentary arrangement. Migula's comprehensive diagnostic manual influence many bacteriologists of the utility of his system. William W. Ford suggested:

Despite the fact that Migula, in working out his system of classification, employed old terms with a new significance not always strictly in accord with the original meaning of the term, as in his use of *Bacillus* and *Bacterium*, the classification he established has been largely followed by bacteriologists all over the world. This is partly due to the subsequent publication of his *System der Bakterien* in which he arranged in an orderly many nearly 2000 species of microorganisms described by hundreds of different observers.¹⁰⁸

Migula may have achieved some level of taxonomic acceptance, but it occurred only begrudgingly.

Karl B. Lehmann and Rudolph O. Neumann outlined an alternative to Migula's classification, one that placed a lesser importance on the characteristic of motility. Instead, Lehmann and Neumann directed attention to the branching forms of pathogenic species. They placed the tubercular and diphtheria organisms in a separate family, *Actinomycetes*, and supplied them with new generic names, *Mycobacterium* and *Corynebacterium*. More importantly, Lehmann and Neumann distinguished *Bacterium* from *Bacillus* on the basis of spore formation,

¹⁰⁷ Buchanan believed that many of Migula's shortcomings derived from the advance of knowledge since 1897. Buchanan offered five additional genera to Migula's scheme. Buchanan and Murray, Veterinary Bacteriology, 2nd ed., 79. Joseph McFarland predicted that many practitioners would simply cling to the older terms. McFarland, A Text-book of Pathology for Practitioners and Students, 2nd ed. (Philadelphia: W.B. Saunders, 1910), 278-279. Both Fred Tanner and William Park complained that Migula's taxonomy appeared arbitrary in places, yet both textbooks acknowledge that Migula's scheme offered "as good a working basis as any which is available." Tanner, Bacteriology and Mycology of Foods, 1st ed., 95; and, Park and Williams, Pathogenic Microorganisms, 4th ed., 24.

¹⁰⁸ Ford, Text-book of Bacteriology (Philadelphia: W.B. Saunders Co., 1927), 176-177; and, Migula, System der Bakterien: Handbuch der Morphologie, Entwicklungsgeschichte und Systematik der Bakterien (Jena: Fischer, 1897, 1900); and Frost, "Bacteria," in Microbiology, 1st ed., 56. Only Lohnis and Fred stated their disbelief that Migula's system found such a foothold in America, while remaining "almost unanimously reject b the European bacteriologists..." Lohnis and Fred, Textbook of Agricultural Bacteriology, 1st ed., 36.

and not flagella.¹⁰⁹ Lehmann and Neumann's taxonomy rivaled that of Migula, and in the first decade of the twentieth century, American bacteriologists vacillated between the two systems.¹¹⁰

In 1901, Frederick D. Chester published his *Manual of Determinative Bacteriology*, the first truly systematic treatise on both agricultural and medical bacteriology. Trained in plant pathology, soil science, and veterinary medicine, Chester offered an exhaustive bacterial taxonomy. Chester adopted Migula's system, appending the additional family *Mycobacteriaceae* for the branching and filamentous forms. More significantly, Chester assembled his systematic groups around well-recognized morphological types. Chester argued that cultural and physiological traits, in combination with morphological characteristics, defined bacterial genera. As such, Chester's system recognized qualities normally excluded from previous taxonomies.¹¹¹ Chester aimed to winnow away many poorly described forms, leaving "comparatively few well-defined species to form the nuclei of groups . . ."¹¹² From a careful survey of the available literature, Chester assembled a taxonomy of the genus *Bacterium*, defining twenty-seven groups based on habitat, morphology, cultural characteristics and physiology. These *ad hoc* groups,

¹⁰⁹ Karl B. Lehmann and R.O. Neumann, Atlas und Grundriss der Bakteriologie und Lehrbuch der Speziellen Bakteriologischen Diagnostik (Munich: J.F. Lehmann, 1896 & 1899); Lehmann and Neumann, Atlas and Essentials of Bacteriology (New York: Wood, 1897); Lehmann and Neumann, Atlas and Principles of Bacteriology, trans. George H. Weaver (Philadelphia: W.B. Saunders, 1901); and, Lehmann and Neumann, Bacteriology: Especially Determinative Bacteriology 7th ed., trans. Robert S. Breed. (New York: Stechert, 1930).

¹¹⁰ Ford, A Text-book of Bacteriology, 178-179; Smith, Lessons and Laboratory Exercises in Bacteriology, iv; and, Tanner, Bacteriology and Mycology of Foods, 1st ed., 97.

¹¹¹ Frederick D. Chester, "A Preliminary Arrangement of Species of the Genus *Bacterium*," and "Classification of the *Schizomycetes*," 9th Annual Report, Delaware College of Agriculture and Experiment Station (Newark, 1897): 62-63; Chester, "Soil Bacteria in their Relation to Agriculture, Part I." Bulletin of the Delaware Agricultural Experiment Station, no. 40 (1898): 3-16; Chester, "A Review of the *Bacillus Subtilis* Group of Bacteria," Centr. f. Bakt 2 te. abt. 8 (1904): 739; Chester, "Some Suggestions on the Study of Systematic Bacteriology," 460; Chester, "Observations of an Important Group of Soil Bacteria," 47 & 54; Chester, Manual of Determinative Bacteriology, v; and, Ford, A Text-book of Bacteriology, 179.

¹¹² Chester, "Observations of an Important Group of Soil Bacteria," 54; and, McFarland, A Text-book upon the Pathogenic Bacteria, 226.

individually represented by a “type” or model species, formed the basis of his determinative keys. For example, Chester cleaved the nonmotile rods (*Bacterium*) according to spore formation, gelatin liquefaction, Gram stain, oxygen relations, and fermentation reactions. As such, the *Bacterium Aerogenes* Group included non-spore-forming rods, not liquefying gelatin, growing as aerobes or facultative anaerobes, which generated gas in glucose and lactose bouillon. It was distinguished from the neighboring Friedlander Group in that members of this latter category did not product gas from lactose bouillon.¹¹³ (Fig. 6.2)

In many regards, Chester’s construction of determinative keys failed to furnish a formal bacterial systematics. His twenty-seven groups covered only rods, excluding cocci, branching forms, and rods not resembling one of the well-known type species. Chester divided each genus into “classes,” a term he employed not in the traditional sense indicating the taxa between phylum and order, but suggesting a loose collective between genus and species.¹¹⁴ The determinative keys established uneven and burgeoning genera. *Bacterium*, for example, included 216 species, divided into sixteen classes according to spore formation, oxygen relations, pigment production, temperature relations, spore characteristics, gelatin liquefaction, and Gram stain. Chester established these classes as determinative aids, intended to assist the student or researcher in the identification of unknown forms. He made no claim that they actually defined

¹¹³ Chester, Manual of Bacteriology, 52. Chester organized his groups around well-known type species: Thermophilis Group (*Bact. termophilum*); Anthrax Group (*Bact. anthracis*); Acetic Ferment Group (*Bact. aceti*); Group; Friedlander Group (*Bact. pneumonicum*); Fowl-Cholera Group (*Bact. cuniculcida*); Lactic Ferment Group (*Bact. lacticum*); Glanders Group (*Bact. mallei*); Diphtheria Group (*Bact. diphtheriae*); Leprosy Group (*Bact. leprae*); Influenza Group (*Bact. influenza*); Potato-Bacillus Group (*B. mesentericus*); Malignant Edema Group (*B. chauvavei*); Tetanus Group (*B. tetani*); Colon Group (*B. coli*); Hog-Cholera Group (*B. suipestifer*); Typhoid Group (*B. typhosus*); and, Proteus Group (*B. Vulgaris*).

¹¹⁴ For example, the 36 species of the *Streptococci* comprised four classes, differentiated on the basis of pigment production, growth at room temperature, and liquefaction of gelatin. Each class was then separated into species by reference to other morphological, cultural, or physiological criteria. Chester, Manual of Determinative Bacteriology, 55-56.

related organisms, and many of the classes included highly divergent forms.¹¹⁵ Chester's achievement lay in his emphasis on non-morphological criteria (e.g., gelatin liquefaction, proteolytic action, fermentation of carbohydrates, diastatic action, reduction of nitrates, formation of volatile and fixed organic acids, production of lactic acid, etc.).¹¹⁶ As such, his *Manual* defined many forms overlooked by other taxonomies and determinative guides.¹¹⁷

Additionally, Chester did not resolve the chief shortcoming of Migula's scheme. *Bacterium* and *Bacillus* remained divided by motility, and not spore formation. In his chapter on bacteriological methods, Chester devoted considerable space to the techniques for staining flagella, but admitted that all were problematic. When he introduced the genus *Bacillus*, Chester offered the prefatory apology that "Our imperfect knowledge of the great majority of the described species of bacteria, especially as regards the nature of their flagella, makes it impossible to properly classify many of them." Within *Bacillus* he included all motile forms, designating those known to possess flagella with a bold "B.", and those motile species without demonstrated flagella a plain "B." Chester acknowledged that this genus included "great lumber room into which are thrown all indefinitely motile forms. It is likely that many of the species here included, although they have been described as motile, or slightly so, are in reality non-motile, or at least devoid of flagella, and are therefore members of the genus *Bacterium*."¹¹⁸

¹¹⁵ See, Jordan, Text-book of General Bacteriology, 1st ed., 104.

¹¹⁶ Chester, Manual of Determinative Bacteriology, 17.

¹¹⁷ Chester, for example, characterized many non-pathogenic members of the genus *Microspira*, provided a detailed study of the branching genera *Mycobacterium* and *Streptothrix*, and offered the first determinative keys to the genera within *Chlamydoacteriaceae* and *Beggiatoaceae*?, two families featuring mostly non-pathogenic iron and sulphur bacteria found in water. It would be years before taxonomists began to challenge Chester's arrangement of the "higher" bacteria. See, Edith J. Claypole, "On the Classification of the *Streptothrices*, Particularly in their Relation to Bacteria," Journal of Experimental Medicine 17 (1913): 99-116.

¹¹⁸ Chester, Manual of Determinative Bacteriology, 6-7, 117, & 199-200. Veranus Moore explained that the value of the techniques for demonstrating flagella rested "largely on the skill of the individual using them, as some workers succeed with one method while others fail with it but obtain excellent results with one of the other

Those bacteriologists critical of Migula leveled the same grievances against Chester's taxonomy. Allen J. Smith, while mostly countenancing Chester's determinative scheme, remarked that "it is unfortunate that its generic system is based upon a structure feature of bacteria which is difficult of demonstration and apparently not invariable through the life-history of the individual cells or under all conditions . . ." While Smith believed that flagella staining might improve, it was more likely that increased "knowledge of the chemistry of bacterial constitution" would reveal a "more constant feature," thus obviating the reliance on such problematic techniques.¹¹⁹

In spite of this drawback, many American bacteriologists adopted Chester and Migula's classification. Chester's *ad hoc* groups and determinative keys appeared in dozens of textbooks, and his terminology guided published articles for nearly two decades.¹²⁰ Nonetheless, two difficulties remained. The first concerned the number of changes Chester required of prevailing nomenclature. Mostly due to his reliance on motility to separate *Bacterium* from *Bacillus*, but also as a result of his elimination of the genus *Staphylococcus*, Chester's guide mandated the re-designation of more than fifty exemplary forms.¹²¹ In particular, the *Manual of Determinative Bacteriology* indicated that the etiological agent of tuberculosis should bear the name *Bacterium tuberculosis*, rather than *Bacillus tuberculosis*, and the cause of diphtheria *Bacillus diphtheriae*

processes." Moore, Laboratory Directions for Beginners, 62.

¹¹⁹ Smith, Lessons and Laboratory Exercises in Bacteriology, 262.

¹²⁰ McFarland, Text-book upon the Pathogenic Bacteria, 4th ed., 28-29; Gage and Phelps, "On the Classification and Identification of Bacteria," 495; Fuller and Johnson, "Classification of Water Bacteria," 618; Conn, Esten and Stocking, "Classification of Dairy Bacteria," 98-99; Bergey et al., Bergey's Manual, 12; and Tanner, Bacteriology, 78. Only Erwin F. Smith's, Bacteria in Relation to Plant Diseases (Washington, D.C.: Carnegie Institution, 1905-1907), rivaled Chester's taxonomic authority. See, Buchanan, General Systematic Bacteriology, 62; and Ford, Text-book of Bacteriology, 179.

¹²¹ For example, Chester re-designated *B. phosphorescens* as *Microspira phosphorescens*; *B. naepolitanus* as *B. coli*, *B. oedematis maignia* as *B. oedematis*, and, *B. coprogenes foetidus* as *B. Schottelii*. Other recognized species were simply not included in Chester's keys: *B. scarlatinae*, *B. cavicida*, and, *B. necrophorus*. For a list of the Chester's new designations, see, Moore, Laboratory Directions for Beginners, 2nd ed., 53; and, Gorham, A Laboratory Course in Bacteriology, 175-176.

rather than *Bacterium diphtheria*.¹²² Other nomenclatural quandaries arose from the red-pigment producing rods (i.e., *Bacillus prodigiosus*, *Monas Prodigiosa*, *Serratia marscens*, etc.),¹²³ the bacterial organisms associated with hog cholera and swine plague,¹²⁴ the predominant forms of lactic acid bacteria (e.g., *Bacterium lactis acidi*, *Bacterium acidi lactici*, *Bacterium lactarii*, *Streptococcus acidi lactici*, *Streptococcus lacticus*, *Bacillus guntherii*, *Streptococci pyogenes*, etc.),¹²⁵ the etiological agents of soft-rot in vegetables (e.g., *Micrococcus amylovorus*, *Bacillus amylovorus*, *Bacillus carotovorus*, *Bacillus aroideae*, *Bacillus omnivorus* and *Bacillus oleraceae*),¹²⁶ the microbial means of nitrification and nitrogen fixation,¹²⁷ and the microbes responsible for acetic fermentations (e.g., *Mycoderma aceti*, *Bacterium aceti*, *Acetobacter plicatum*, *Bacillus pasteurinum*, and *Bacillus xylinum*).¹²⁸

The second dilemma involved the choice between a natural and artificial classification.

¹²² Conn, Agricultural Bacteriology, 28 & 350.

¹²³ Mary Hefferan, A Comparative and Experimental Study of Bacilli Producing Red Pigment (Jena: G. Fisher, 1904); and, Robert S. Breed, "Taxonomic Studies of the Red Chromogenic Rods," paper presented to the 25th Annual SAB Meeting (1923), summarized in Abstracts of Bacteriology 8 (1924): 404.

¹²⁴ Marion Dorset, "Variety of the Hog Cholera Bacillus which Closely Resembles *Bacillus Typhosus*," Science 15 (1902): 370.

¹²⁵ Esten suggested that there was "probably no organisms which has received so many different names. by so many different investigators . . ." Esten documents that sixteen investigators appointed thirteen different names to the same organism. Esten, "*Bacterium Lactis Acidi* and its Sources," Bulletin of the Storrs Agricultural Experiment Station, no. 49 (1909): 8-10; and, Lore A. Rogers and Brooke J. Davis, "Methods of Classifying the Lactic Acid Bacteria," Bulletin of the USDA Bureau of Animal Industry, no. 154 (1912): 1-30.

¹²⁶ Vaughan MacCaughy, Identification Tables for Certain Important Bacteria: List of Bacteria Producing Important Plant Diseases. for Use in Courses in Bacteriology (Honolulu: College of Hawaii, 1910).

¹²⁷ Under Migula and Chester's scheme, Sergei Winogradsky's *Nitrosomas europea* and *Nitrosconomas javensis* became members of the genus *Pseudomonas*. Similarly, the germ responsible for nitrogen fixation in legume root nodules bore the sundry labels of: *Schnizia cellulicola*, *Phytomyxa lupini*, *Rhizobium leguminosarum*, *Bacillus radicolica*, and *Pseudomonas radicolica*. For a discussion, see, Diane Johnson, Edwin Broun Fred: Scientist. Administrator. Gentleman (Madison: University of Wisconsin Press, 1974), 60-61; Lohnis and Fred, Textbook of Agricultural Bacteriology, 1st ed., 112; George T. Moore, "Soil Inoculation for Legumes, with Reports upon the Successful Use of Artificial Cultures by Practical Farmers," Bulletin of the Bureau of Plant Industry, no. 71 (1905): 22-23; and, Robert E. Buchanan, "The Bacterioids of *Bacillus Radicolica*," Centrl. f. Bakt 2te, no. 23 (1909): 59-91.

¹²⁸ Edna E. Dean, "The Group of Acetic Acid Bacteria," (Masters thesis, Iowa State College, 1921), 3-4. & 55-56.

While most bacteriologists sought a taxonomic system that would reveal the real, that is phylogenetic, relationships between microbial forms, many resigned themselves to arrangements of mere expedience.¹²⁹ In his presidential address before the 1905 meeting of the SAB, E.O. Jordan counseled that "we should frankly acknowledge to ourselves that the so-called genera and species of bacteria are simply attempts at grouping according to existing information" and represent "purely artificial."¹³⁰ The taxonomies of higher plants and animals disclosed relationships by descent, but the less specialized "structure, metabolism, and biological activity" of bacteria rendered it "necessary to resort to the expedient of utilizing some one characteristic that remains constant" for a particular grouping.¹³¹ Yet, Jordan, among others, harbored hope for a natural classification. Theobald Smith, for example, speculated as to the evolutionary relationships among members of the colon-typhoid group, and Joseph McFarland posited a common ancestry of all acid-fast organisms (e.g., the human, bovine and avian forms of *B. tuberculosis*, *B. leprae*, etc.).¹³² Smith and McFarland, however, represented exceptions to the rule. Instead, taxonomically-minded bacteriologists, like Frederick Chester, organized bacteria

¹²⁹ See, Fuller and Johnson, "Classification of Water Bacteria," 618-619; and, Kendall, "A Proposed Classification," 483 & 487.

¹³⁰ E.O. Jordan, "Variation in Bacteria, Presidential Address of the Society of American Bacteriologists. Ann Arbor, December 1905," [ASM], Presidential Collections, box 9-B, folder 14, pp. 8-9. In his textbook, Jordan reiterated his insistence that "Classifications of bacteria, as of other natural objects, are to be looked upon as arrangements of convenience, and nothing more." Jordan, Text-book of General Bacteriology, 1st ed., 102.

¹³¹ Hiss and Zinsser, Text-book of Bacteriology, 4th ed., 35-36. Harding argued that as bacterial protoplasm is constantly responding to the stimuli of its environment and becoming modified in new ways . . . the original forms have long since disappeared until the forms which are now encountered present a bewildering complex of modifications." Harding contended that "attempts at formulating such a natural classification are guesswork and are not worthy of serious scientific consideration." Harding, "Constancy of Certain Physiological Characters," 11.

¹³² Jordan, Text-book of General Bacteriology, 1st ed., 102; Theobald Smith, "Variations among Pathogenic Bacteria," 100; and, McFarland, Text-book upon the Pathogenic Bacteria, 4th ed., 344.

into practical *ad hoc* categories.¹³³ The taxonomic method predates Chester's *Manual*, as both Eisenberg (1892) and Kruse (1896) divided microbes into categories based on physiological similarities. Following Chester's publication in 1901, other American bacteriologists amended his twenty-seven groups. William D. Frost, for example, added units for saprophytic forms (*e.g.*, Chromogenic Class, Saprophylic Class, Zymogenic Class, Phosphorescent Class), and modified the definitions of some pathogenic groups. Still others blended physiological with morphological traits, in combination with habitat, to designate related groups (*e.g.*, Capsulated Group, Intestinal Group). An underlying hope lingered that if these *ad hoc* categories were properly formulated, further study would finally reveal descent from shared ancestral types.¹³⁴

An Institutional Response

From its initial meetings, the Society of American Bacteriologists attended to the problems of bacterial systematics. The inaugural gathering (1899), in fact, assigned its first five papers to taxonomic topics, including Chester's "Suggestions in the Study of Systematic Bacteriology" and Erwin F. Smith's "Generic Nomenclature of Bacteria." In subsequent meetings, SAB members returned to the difficulties of determining the boundaries of species and genera, and the complexities of bacterial variations.¹³⁵ These early conclaves also featured

¹³³ Some botanists and zoologists joined bacteriologists in their suspicion of "natural" classifications. See Trelease, "Some Twentieth Century Problems," 51; Charles E. Bessey, "The Phyletic Idea in Taxonomy," *Science* 29 (1909): 81-100; and, McQuat, "Species, Names and Things," 197.

¹³⁴ Frost, *Laboratory Guide in Elementary Bacteriology*, 2nd ed. (Madison: M.J. Cantwell Printers, 1902), chapt. 8; Paul G. Heinemann, *A Laboratory Guide in Bacteriology for the Use of Students, Teachers and Practitioners*, 1st ed. (Chicago: University of Chicago Press, 1905); Gorham, *A Laboratory Course*, 107; Ford, *Text-book of Bacteriology*, 178; Tanner, *Bacteriology and Mycology of Foods*, 1st ed., 99; and, Jordan, *Text-book of General Bacteriology*, 1st ed., 104.

¹³⁵ E.F. Smith, "Generic Nomenclature of Bacteria"; H.W. Conn, "Natural Varieties of Bacteria"; Chester, "Some Suggestions in the Study of Systematic Bacteriology"; and, Theobald Smith, "The Significance of Varieties among Pathogenic Bacteria," papers presented to the 1st Annual SAB Meeting, 1899, abstracted in *Science* 11 (1900): 455-456. A.P. Ohlmacher, "Observations upon the Morphological Variations of Certain Pathogenic

discussions on the arrangement of particular groups, from Winslow's revision of the *Coccaceae* to Marion F. Dorset and Emil de Schweinitz's exploration of the relations between hog cholera-, colon- and typhoid bacilli.¹³⁶ The SAB's systematic efforts even spanned the months between meetings. From its creation in 1904, the SAB's Committee on the Identification of Bacterial Species combined the goals of determination and classification. The Committee's first chairman, Frederick D. Chester, endeavored to integrate the Society's Determinative Chart with his *Manual of Determinative Bacteriology*. Chester himself sometimes referred to the body as the "Committee on Classification," and many SAB members assumed that the group number on the card could replace Latin binomials, forming the basis of a new bacterial taxonomy.¹³⁷ Only at the 11th Annual SAB Meeting, in 1909, did the Committee publically recant its intention to fabricate a formal classification. The Committee's Frederic P. Gorham and C.-E.A. Winslow informed the Society that "The numerical system of recording bacterial cultures must necessarily fail to approximate the natural classification of species."¹³⁸ Some SAB members, such as Cornell's

Bacteria." paper presented to the 3rd Annual SAB Meeting, 1901, abstracted in *Science* 15 (1902): 374; S. De.M. Gage. "Naming Species of Bacteria and the Indexing of Bacterial Names," paper presented to the 5th Annual SAB Meeting, 1903; Chester, "Principles of Classification of Bacteria," paper presented to the 6th Annual SAB Meeting, 1904, abstracted in *Science* 23 (1905): 485-486; and, David H. Bergey, "Involution and Degeneration Forms of Bacteria," paper presented to the 8th Annual SAB Meeting, 1906, abstracted in *Science* 25 (1907): 807-808.

¹³⁶ Dorset and de Schweinitz, "Some Considerations in Regard to the Relations Between Hog Cholera, Colon and Typhoid Bacilli," paper presented to the 3rd Annual SAB Meeting, 1901, abstracted in *Science* 15 (1902): 370; Frederick D. Chester, "Notes on the *B. Subtilis* Group," paper presented to the 5th Annual SAB Meeting, 1903; C.-E.A. Winslow, "Preliminary Report on the Revision of the *Coccaceae*," paper presented to the 6th Annual SAB Meeting, 1904, abstracted in *Science* 21 (1905): 486-487; and, Harry A. Harding and Martin J. Prucha, "The Classification of Bacteria Producing Soft Rot of Vegetables," and Mary Hefferan, "Agglutination and Biological Relationships in the Prodigiosus Group," papers presented to the 7th Annual SAB Meeting, 1905.

¹³⁷ See, for example, David H. Bergey and H.L. Bates, "The Numerical Classification of Bacteria," *University of Pennsylvania Medical Bulletin* (July 1906): 116-118; and, Harry A. Harding and Martin J. Prucha, "The Utility of the Society's Card in Classifying the Cheese Flora," paper presented to the 10th Annual SAB Meeting, 1908, summarized in *Science* 29 (1909): 1012. For a consideration of numerical designations in biological fields other than bacteriology, see, David S. Jordan, "Use of Numeral for Specific Names in Systematic Zoology," *Science* 33 (1911): 370-373.

¹³⁸ Gorham and Winslow, "Report of the Committee on the Identification of Bacterial Species," *Science* 31 (1910): 546.

Harry Harding, refused to relinquish the aim of numerical designations. Curiously, when Harding joined Committee in 1911, he ceded that the group number comprised a poor basis for nomenclature.¹³⁹ During the next several years, members of Committee on the Identification of Bacterial Species repeatedly explained the difference between determination and classification, holding that the former could only partly serve the purposes of the latter.¹⁴⁰

With the Committee on the Identification of Bacterial Types focusing its attention on the Descriptive Chart, taxonomic endeavors became the responsibility of other Society members. Charles-Edward Amory Winslow, in particular, cultivated a lasting interest in systematic reforms. Trained in sanitary bacteriology at MIT under William T. Sedgwick and Samuel Prescott, Winslow served as Biologist in Charge of Sanitary Research at the Lawrence Experiment Station between 1903 and 1910. Beginning in 1908, Winslow served on the SAB's Committee on the Identification of Bacterial Species, and in 1913 ascended to the presidency of the Society.¹⁴¹ At the 1904 SAB meeting, Winslow and Anne Fuller Rogers presented a tentative revision of the *Coccaceae*. In that communication, Winslow and Rogers described their survey of 445 described spherical forms, in which they posited thirty-one separate species, assembled

¹³⁹ Harding, "Constancy of Certain Physiological Characters," 3; Harding, "Does the Group Number on the Society Card Carry the Classification far Enough to Break Up the Species?" *Science* 31 (1910): 551; and, Harding, "The Classification Card and the Type of Study which it Merits," *Science* 39 (1914): 798. In contrast, Gorham remained adamant that the two aims should not be confused. In his review of Veranus A. Moore's *Principles of Microbiology*, Gorham objected to the inclusion of the SAB's card within the chapter on classification, "where it does not belong," rather than as part of the chapter on pure culture study. Gorham, "Review of *Principles of Microbiology*," *Science* 36 (1912): 905.

¹⁴⁰ See, Herbert J. Conn, "A Study of *B. Subtilis* by Means of the Classification Card," paper presented to the 16th Annual SAB Meeting, 1914, abstracted in *Science* 41 (1915): 618; Tanner, *Bacteriology and Mycology of Foods*, 1st ed., 100; and, Conn, "Taxonomy in Relation to Pure Culture Study," *Pure Culture Study of Bacteria* 1 (1933): 13-16.

¹⁴¹ For details of Winslow's training and early research, see, Robert S. Breed, "Charles-Edward Amory Winslow, 1877-1957," *American Journal of Public Health* 47 (1957): 157; and, Ira V. Hiscock, "Charles-Edward Amory Winslow," *Journal of Bacteriology* 73 (1957): 295-296

under five genera and two subfamilies. Like Chester, they began with the assumption that bacteria rarely displayed "true species," but rather showed "an infinite series of minutely different but constant races." The only practical method of handling and "systematizing these is to establish certain fairly distinct groups or types about which the lesser individual variations may be grouped."¹⁴² On this point, Chester concurred. Where Winslow and Rogers departed was their insistence on shunning "variable," "isolated," or "unimportant" traits in the construction of genera and families. Instead, they sought to identify those characters that strongly correlated with one another.

Winslow and Rogers returned to the SAB program for the 1906 meeting, this time to detail their statistical analysis of more than 500 cultures, involving dozens of morphological, cultural and physiological characters. They were able to determine normal "curves of frequency," around many "single modes" (e.g., fermentation of dextrose) and a few multiple modes. Again, they outlined the same thirty-one species, five genera, and two subfamilies. This second report did, however, inaugurate a discussion among bacteriologists on the applicability of statistical or "biometrical" methods to problems of bacterial systematics. The "most striking result" of their study came from the "fact that differences in the various characters are striking correlated with each other and with the source from which the organisms were derived." Their two families separated nicely into parasites and saprophytes. Habitat and pathogenicity might be taxonomically determinative after all. (Fig. 6.3) Winslow and Rogers' method might have been

¹⁴² Winslow and Rogers, "A Preliminary Note on the Revision of the *Coccaceae*," paper presented to the 6th Annual SAB Meeting, 1904.

novel, but the result was not.¹⁴³

In 1908, C.-E.A. Winslow and Anne Rogers Winslow published their monograph on *The Systematic Relationship of the Coccaceae, with a Discussion of the Principles of Bacterial Classification*. By charting the “numerical frequency with which various characters occur,” determining which combination of characters were exhibited by a large number of “races” and serve “true centers of variation,” the Winslows believed that they could identify the “natural types.” In fashioning genera, they looked for “aggregates of those specific types which are most nearly related.”¹⁴⁴ This establishment of genera abandoned the search for universal criteria, as each genera should be constructed fresh. One genus might be distinguished by its carbohydrate fermentation, while another for its parasitic activity on humans, and the third by its spore formation. The Winslows held that biometrical methods could remove the subjective element in systematics, founding a bacterial taxonomy upon which all investigators could agree. As evidence of its worth, they pointed to application of biometrical techniques to the “study of human races,” where “this method alone has brought order out of chaos . . . The same biometrical methods are laying for the first time a foundation for a real science of mental and social phenomena.”¹⁴⁵

¹⁴³ Winslow and Rogers, “Generic Characters in the *Coccaceae*,” paper presented to the 8th Annual SAB Meeting, 1906, abstracted in *Science* 25 (1907): 813, and printed in full as “A Statistical Study of Generic Characters in the *Coccaceae*,” *Journal of Infectious Diseases* 3 (1906): 546. Parasitic forms tended to occur in chains and irregular groupings, stained by Gram, produce meager surface growth, form acid in sugar solutions, but producing either no pigment, or a white or orange color. The other group, found in soil and water, often occurred in packets, were Gram negative, grew well on artificial media, failed to ferment carbohydrates, and produced yellow or red pigment.

¹⁴⁴ Winslow and Winslow, *The Systematic Relationship of the Coccaceae, with a Discussion of the Principles of Bacterial Classification* (New York: John Wiley & Sons, 1908), v & 13.

¹⁴⁵ Winslow and Winslow, *Systematic Relationship of the Coccaceae*, 12-13. C.-E.A. Winslow insisted that “in the study of the races of man the statistical method has proved of the highest service. Curiously enough, among the micro-organisms, where some method of this sort is most urgently needed, statistical study has until very recently been wholly lacking.” Winslow, “A Statistical Criterion for Species and Genera among the Bacteria,”

At first glance, the Winslows' appropriation of Francis Galton's and Karl Pearson's biometrics might seem incongruous. Arguably, these bacteriologists shared little in common with leading eugenicists. Yet, they participated in a more general movement toward statistical techniques in biological systematics. Galton and Pearson applied biometrical methods to the problems of variation and type within species, seeking to detect the limits of fluctuations and outline the possible evolutionary significance of slight hereditary differences.¹⁴⁶ In this country, University of Chicago zoologist Charles B. Davenport introduced Karl Pearson's methods in his manual on *Statistical Methods with Special Reference to Biological Variation* (1899 & 1904). Moreover, Davenport applied biometrical techniques to describe a precise criterion for determining species. Davenport believed that individual members of a genus naturally fell around certain modes, or centers of variation, and that the naturalist could identify varieties and species by measuring the distance between statistical modes.¹⁴⁷ The Winslows held that this use of biometrics could lead to a natural classification of bacteria. In their appraisal, artificial arrangements were "commonly the result of hasty work where the perpetrator has been too busy to work out natural affinities through a comparison of intergrading forms accompanied by field study."¹⁴⁸ Their parasitic and sarpophytic groups correlated closely with other characteristics, such as Gram stain, cell groupings, surface growth on agar, fermentation powers, and pigment

Bulletin of the Torrey Botanical Club 36 (1909): 33.

¹⁴⁶ McQuat, "Species, Names and Things," 280-281; and, Pearson, "Contributions to the Mathematical Theory of Evolution," Philosophical Transactions. A. 185 (1894): 75-110.

¹⁴⁷ Davenport, "A Precise Criterion of Species," paper read before the Boston Society of Natural History, 6 April 1898, printed in Science 7 (1898): 685-695; Davenport, "Statistical Study of Biological Problems," Popular Science Monthly (1901): 447; C.L. Edwards, "Biometry as Method in Taxonomy," American Naturalist 42 (1908): 537-540; and, McQuat, "Species, Names and Things," 279-281.

¹⁴⁸ Winslow and Winslow, Systematic Relationship of the Coccaceae, 4-5, quoting from Harvey M. Hall. Compositae of California (Berkeley: University of California Press, 1907); and, Winslow, "A Statistical Criterion." 32.

production. The Winslows even offered a phylogenetic account, as they reasoned that bacteria surviving in an animal body or in frozen soils would likely adapt to their particular inhospitable environments.¹⁴⁹

Beyond introducing a new set of techniques to bacterial systematics, and revitalizing the goal of a natural classification, the Winslows placed a high value on physiological characteristics. Anticipating criticism from those relying exclusively on morphological traits, the Winslows argued that the distinction was “merely a superficial one.” Both physiological and morphological characters arose “due to chemical modifications of protoplasm; and there is no reason to suppose that a protoplasmic property which manifests itself in the size and arrangement of parts is any more fundamental than one which manifests itself in the ability to utilize a certain food stuff.” Environmental contingencies impinged upon an organism’s morphology and physiology.¹⁵⁰

C.-E.A. Winslow used his position on the Committee on the Identification of Bacterial Species to champion biometrical methods. The same year that the Committee disavowed the aim of replacing formal nomenclature with the Descriptive Chart’s group number, Winslow included within the Committee’s report an endorsement of statistics “for determining the true relationships of these microorganisms.” Just as the Committee turned its attention away from classification and exclusively toward determination, it advocated the “quantitative study of measurable characters in a considerable series of cultures, the modal points or centers of frequency being given specific names, and larger groups having a number of common characters receiving the

¹⁴⁹ Winslow and Winslow, *Systematic Relationship of the Coccaceae*, 20.

¹⁵⁰ C.-E.A. Winslow, “A Statistical Criterion,” 35.

rank of genera or families. The committee urges upon the members of the society the importance of further systematic investigation along this general line." Moreover, the Committee recommended that the SAB adopt a resolution recognizing the "importance of a systematic study of bacterial species by the statistical method" and actively seek sources of "financial assistance in carrying out work which involves so large a proportion of routine . . ." ¹⁵¹

While the SAB's Executive Council declined to submit such a resolution for general consideration, the biometrical method occupied the focus of several systematic studies. C.-E.A. Winslow's students and colleagues at MIT, many of whom Winslow "introduced" to the SAB and nominated for membership, issued statistical examinations of several taxonomic groups. ¹⁵² Upon traveling to New York City in 1911 to assume the Curatorship of Public Health for the American Museum of Natural History (AMNH) and an Associate Professorship in Biology at City College, Winslow garnered a similar legion of converts to the biometrical method of classification. With his junior collaborator I.J. Kligler, Winslow turned his attention to members of the Colon-Typhoid Group, as well as pathogenic *Streptococci*. These rods, however, did not conform to the unimodal curves of the cocci, nor did the characters correlate neatly around such obvious traits as pathogenicity or pigment formation. ¹⁵³ Winslow and Kligler's belief in

¹⁵¹ Frederic P. Gorham and C.-E.A. Winslow, "Report of the Committee on the Identification of Bacterial Species, 1909," *Science* 31 (1910): 546.

¹⁵² Stephen DeM. Gage, "A Study of the Variation in the Biochemical Reactions Produced by Cultures of the Colon Type," paper presented to the 8th Annual SAB Meeting, 1906, abstracted in *Science* 25 (1907): 807; Eugene C. Howe, "A Biometric Investigation of Certain Non-Spore Forming Intestinal Bacilli," paper presented at the 13th Annual SAB Meeting, 1911, abstracted in *Science* 35 (1912): 225; Mary E. Morse, "A Study of the Diphtheria Group of Organisms by the Biometrical Method," paper presented at the 13th Annual SAB Meeting, 1911, printed in *Journal of Infectious Diseases* 11 (1912): 253-284; E.C. Stowell, C.M. Hilliard, and M.J. Schlesinger, "A Biometric Study of the Streptococci from Milk and from the Human Throat," paper presented to the 14th Annual SAB Meeting, abstracted in *Science* 38 (1913): 373-374, and printed in full as "A Statistical Study of the Streptococci from Milk and from the Human Throat," *Journal of Infectious Diseases* 12 (1913): 144-164.

¹⁵³ See, C.-E.A. Winslow, "The Classification of the Streptococci by Their Action Upon Carbohydrates and Related Organic Media," *Journal of Infectious Diseases* 10 (May 1912): 285-293; I.F. Kligler, "A Systematic

statistical techniques did not waver. Instead, they advocated their use in winnowing away duplicate species designations (*i.e.*, homonyms) and in correlating habitat with certain physiological powers.¹⁵⁴

Curiously, enthusiasm for biometrical methods diminished in the latter half of the 1910's. Among bacteriologists, only Robert E. Buchanan published a trenchant critique. Buchanan, in fact, objected to Winslow's choice of nomenclature and not his methods, noting that Winslow violated several articles of the International Rules of Botanical Nomenclature. Instead, there is some evidence that statistical techniques were slowly integrated within traditional bacterial taxonomy, where investigators merely listed the full complement of correlated characters within a generic diagnosis.¹⁵⁵ Nonetheless, Winslow influenced taxonomic practice in other profound ways. For his presidential address to the 15th Annual SAB Meeting (1913) in Montreal, Winslow chose as his topic, "The Characterization and Classification of Bacterial Types." The speech represented not only a summary of Winslow's taxonomic thinking at the time, but a public chastisement of Society members for neglecting the biological aspect of bacteriology. Winslow recognized that most members worked within institutional settings devoted to practical ventures.

Study of the *Coccaceae* in the American Museum of Natural History," paper presented at the 14th Annual SAB Meeting, 1912, abstracted in Science 38 (1913): 374, and printed in full in Journal of Infectious Diseases 12 (1913): 432-448; Kligler, "Studies on the Classification of the Colon Group," paper presented to the 15th Annual SAB Meeting, 1913, abstracted in Science 39 (1914): 799, and printed in Journal of Infectious Diseases 15 (1914): 187-204; Kligler, "A Study of the Correlation of the Agglutination and the Fermentation Reactions among the *Streptococci*," paper presented before the 16th Annual SAB Meeting, 1914, abstracted in Science 41 (1915): 618-619.

¹⁵⁴ Kligler, "A Systematic Study of the *Coccaceae*," 438. See also, Max Levine, "A Statistical Classification of the Colon-Cloaceae Group," Journal of Bacteriology 3 (1918): 253-276; and, Lore A. Rogers and Arnold Dahlberg, "The Relation of Habitat and Physiological Characters in the *Streptococci*," paper presented to the 15th Annual SAB Meeting, 1913, abstracted in Science 39 (1914): 789-799.

¹⁵⁵ Buchanan, "Nomenclature of the *Coccaceae*," Journal of Infectious Diseases 17 (1915): 528-541; and, Hilda H. Heller, "Suggestions Concerning a Rational Basis for the Classification of the Anaerobic Bacteria," Journal of Bacteriology 6 (1921): 539.

but he reminded his audience that the SAB originated as a “protest against such necessary but dangerous specialization.” The SAB was to serve the underlying and unifying principles of bacteriology. “It is this ideal which distinguishes our society from any other organization in America which deals with microbic life and its effect.” Taxonomy, for Winslow, comprised the most basic biological aspect and also “one of the most pressing needs of bacteriology.”¹⁵⁶

Unsurprisingly, Winslow again championed a biometrical approach to disentangling closely related forms, illustrating its utility with examples from bacteria, rhinoceros beetles, and *Chrysanthemums*. Winslow pointed to the illogic of Migula’s taxonomic system, in which a motile rod such as *B. coli* would be classed along side myriad dissimilar forms (e.g., *B. mycoides*, *B. aerogenes*, *B. prodigiosus*, *B. radicio’a*, *B. tetani*) while separated from organisms sharing all characters save the presence of flagella. Winslow reminded bacteriologists that defining a genus primarily on motility would be analogous to a “division of animals into those with wings and those without, which would place bats and birds and flying fishes and bees in one group and cats and ordinary fishes and worker ants in another.”¹⁵⁷ If American bacteriologists desired to study an existing classification, Winslow suggested they turn their attention to the physiological system of Orla-Jensen. Publishing in German in 1909, Orla-Jensen arranged bacteria according to the sources of metabolic energy and likely evolutionary descent.¹⁵⁸ He

¹⁵⁶ Winslow, “The Characterization and Classification of Bacterial Types,” presidential address to the 15th Annual SAB Meeting, 1913, printed in *Science* 39 (1914): 77-78. At another occasion, Winslow publically declared that microbiology was “not a technical tool for the doctor, the agriculturalist or engineer. It is a basic biological science and it may well be claimed that it has rendered greater service to mankind than any other science of this class. This service has been made possible because it is a basic science.” Hiscock, “Winslow (Obituary),” 295-296.

¹⁵⁷ Winslow, “Characterization and Classification,” 83-84. Similarly, Winslow noted that the group number included in the Society’s Card constituted a plainly artificial catalogue, and prompted his audience to bear in mind the distinction between the group number and a “real biological classification,” 84.

¹⁵⁸ S. Orla-Jensen, “Die Hauptlinien des Naturlichen Bakterien Systems,” *Centrl. f. Bakt.* abt. ii, 22 (1909): 305-346, translated in *Microbiology: Historical Contributions form 1776 to 1908* (New Burnswick: Rutgers

posited, for example, two orders of bacteria. The *Cephalotrichinae* included those microorganisms featuring a more primitive metabolism, securing their energy through oxidation of inorganic compounds; typically water and soil forms, growing poorly on most ordinary media; endospores rarely present; and, flagella, when present, polar. The *Peritrichinae* featured those types with a more specialized metabolism, securing energy through splitting carbohydrates or amino-acids; either nonmotile or possessing peritrichous flagella; and, including most parasitic and putrefactive forms. According to Orla-Jensen, bacteria capable of utilizing urea, milk sugar, or bodily fluids comprised the youngest branch of microbial evolution, and hence should be taxonomically separated from bacteria oxidizing inorganic compounds, regardless of their similarities in shape.¹⁵⁹

Orla-Jensen proposed a radical renaming of bacterial types, where designations would serve as mnemonic devices for comprehending the range of bacterial activities. As such, his family names indicated the general physiological characters of a group (e.g., *Reducibacteriaceae*, *Acidobacteriaceae*, *Alkalibacteriaceae*, *Butyribacteriaceae*, and *Putribacteriaceae*), while his generic terms suggested either the specific end-products or particular source of food (e.g., *Pectobacillus*, *Cellulobacillus*, *Botulobacillus*, *Denitrobacterium*, *Propionibacterium*). Most American reviewers found Orla-Jensen's nomenclature cumbersome, if not distasteful. Winslow, on the contrary, found much to be valued in Orla-Jensen's classification, insisting that "no one who has thought seriously about bacterial relationships can study it carefully without feeling that

University Press, 1960).

¹⁵⁹ See also, Orla-Jensen, "The Main Lines of the Natural Bacterial System," *Journal of Bacteriology* 6 (1921): 264; and, Paul G. Heinemann, "Orla-Jensen's Classification of Lactic Acid Bacteria," *Journal of Dairy Science* 3 (1920): 143-155.

it is by far the most successful attempt yet made at a real biological classification of the group and that future progress will probably consist in its modification and extension rather than in any profound reversal of its basic principles."¹⁶⁰

Winslow did not suggest that SAB members endorse Orla-Jensen's taxonomy, nor any other existing system. Instead, Winslow called for collective, organizational action. Winslow noted that "inertia in terminology is strong and it is the business of no one in particular to criticize and report on the value and suggestions as to bacterial classifications and nomenclature." In general bacteriologists were far too busy "to undertake such a task of our own accord," particularly since taxonomic work rarely led to professional advancement. Winslow envisioned a "court of appeal on matters of systematic bacteriology," one endowed with near absolute powers and charged with the responsibility of issuing a new and comprehensive taxonomy. This committee, if composed of fifteen or more bacteriologists from "the principal scientific countries" might command unparalleled authority. A report "from a commission of proper caliber," Winslow predicted, "would not be ignored as a work of any single worker may be, but would be adopted and would become at once a part of the practical working machinery of our science." This proposal, he reasoned, was not entirely utopian. After all, the 3rd International Zoological Congress (1895) created a similar body for zoology, and the SAB itself established an analogous precedent through its "standard card."¹⁶¹ Winslow's sentiments had also been voiced earlier, by the likes of William Park and Charles E. Marshall, who each called for official action

¹⁶⁰ Buchanan, General Systematic Bacteriology, 69; Collard, Development of Microbiology, 154; Tanner, Bacteriology and Mycology of Foods, 1st ed., 98; and, Winslow, "Characterization and Classification," 89.

¹⁶¹ Winslow, "Characterization and Classification," 89-90. See also, Richard S. Cowan, "The Origins and Early History of the International Association for Plant Taxonomy," Taxon 31 (1982): 415-420; and, Frans A. Stafleu, "The Prehistory of the International Association for Plant Taxonomy," Taxon 37 (1988): 791-800.

to settle matters of nomenclature. Despite Winslow's appeal, the SAB at its 1913 annual meeting declined to act upon his recommendation, turning its attention instead to the six papers delivered as part of the session on "Systematic Bacteriology."¹⁶²

Two years later, the Society assembled the Committee on the Characterization and Classification of Bacterial Types (CCCBT). Winslow acted as chair of the Committee, which included five other members representing different aspects of the discipline. Lore A. Rogers served as Chief of the Bureau of Animal Industry's Dairy Division. Under his direction in the mid-1910's, the Division studied aspects of butter and cheese flavor. As part of that research, Rogers maintained a strong interest in the classification of lactic acid bacteria.¹⁶³ The Committee included two medical bacteriologists, Jean Broadhurst and George H. Smith. Broadhurst was a little known Assistant Professor of Biology at Columbia Teachers College, who completed her PhD at Cornell University with a dissertation on environmentally induced changes in the fermentative reactions of *Streptococci*. Smith too had recently received his PhD, from Brown University, and served as Bacteriologist to the New Haven Hospital and Dispensary. Robert E. Buchanan occupied the final position on the Committee. Buchanan might have been the only member with a rigorous background in systematics, receiving his training under L.H. Pammel at Iowa State College in bacteriology *and* botany, and publishing extensively on bacterial taxonomy.¹⁶⁴

¹⁶² Park and Guerard, Bacteriology in Medicine, 260; Marshall, Microbiology: A Text-book of Microorganisms, 1st ed., vii-ix.

¹⁶³ John A. Alford, "Lore A. Rogers, A Rare Species," ASM News 41 (1975): 85-91.

¹⁶⁴ Norman E. Gibbons, "Robert Earle Buchanan," Biological Abstracts 55 (1973): xxvi; Sam T. Cowan, "Obituary, Robert E. Buchanan, 1883-1973," Journal of General Microbiology 77 (1973): 1-4; W.R. Lockhart, "Obituary, Robert Earle Buchanan, 1883-1973," ASM News 39 (1973): 732-734; and, V.B.D. Skerman, "Robert Earle Buchanan, 1883-1973," International Journal of Systematic Bacteriology 23 (1973): 291-294.

At the time of the Committee's creation, Winslow himself had just left City College of New York and the American Museum of Natural History to assume the Chair of the Department of Public Health at Yale University's Medical School. Given that three out of five members worked in either medical or public health bacteriology, the Committee appeared oddly unrepresentative of the SAB at large. Winslow, however, recognized that pathogenic practitioners presented the greatest challenge to taxonomic reform. If the Committee were to succeed, they would need to persuade those bacteriologists having the least inclination to adopt a new taxonomy. Additionally, medical bacteriologists had come to increasingly rely on serological methods to differentiate strains of related pathogens. If the Committee could somehow integrate those agglutination and complement fixation techniques employed to distinguish the variant agents of well-known communicable diseases (*e.g.*, pneumonia, scarlet fever, meningitis, and typhoid) they stood a reasonable chance of convincing non-SAB bacteriologists to adopt their scheme.¹⁶⁵

The Committee delivered its first progress report to the 1916 SAB meeting at Yale University, Winslow's home institution. Winslow, who also chaired the session on

¹⁶⁵ Sometime SAB member Simon Flexner remarked that immune reactions "provide more delicate and precise means of discriminating bacterial species than the qualities of form, growth appearances and the physiological activities..." Flexner contended that the animal body acquired "an appreciation of the inner constitution of the protein molecule, classifying it, as it were, not according to its ordinary chemical nature, but according to its species origin." Flexner, "Twenty-five Years of Bacteriology: A Fragment of Medical Research," Science 52 (1920): 621. See also, Pauline M.H. Mazumdar, Species and Specificity: An Interpretation of the History of Immunology (Cambridge: Cambridge University Press, 1994); A.R. Dochez and Louis J.A. Gillespie, "A Biological Classification by Means of Immunity Reactions," Journal of the American Medical Association 61 (1913): 727-730; Charles Krumwiede, and Eugenia L. Valentine, "A Study of the Agglutination and Cultural Relationships of Members of the So-called *Streptococcus Viridans* Group," Journal of Infectious Diseases 19 (1916): 760-766; Miriam Olmstead, "A Preliminary Report on the Classification of *Pneumococcus IV*," Proceedings of the Society of Experimental Biology and Medicine 14 (1916): 29-31; and, Harry Weiss, "Studies on the Paratyphoid Group and Antigenic and Cultural Differences in Strains of *B. Typhosus*," Proc. New York Pathological Society 16 (1916): 139-147.

Characterization and Classification, articulated the Committee's intention to follow the International Rules of Botanical Nomenclature. In addition, the Committee hoped to submit a list of generic names to be preserved (*i.e.*, *genera conservanda*) to next international botanical congress, as well as suggest modifications to the code in order meet the needs of bacteriological systematics.¹⁶⁶ At that meeting, Winslow indicated that he envisioned his Committee as analogous to the committee responsible for the Descriptive Chart. The annual reports were to be submitted to entire Society for general "approval," but only in a non-binding manner. Winslow hoped to produce linguistic uniformity, but his experience on the Committee on the Identification of Bacterial Type taught him that he could not legislate it. Rather, Winslow firmly believed that the conceptual and practical merit of a reformed taxonomy would encourage conformity.

Winslow originally planned to distribute the Committee's formal "Preliminary Report on the Families and General of the Bacteria" at the 19th Annual SAB Meeting in December of 1917. However, the CCCBT finished six months early, and Winslow asked the SAB Secretary to distribute the report immediately "so as to make it easy to try out this classification in the classroom and laboratory before the December meeting." Secretary A.P. Hitchens complied, and in a July 1917 Newsletter to SAB members asked: "Will you not order enough for your laboratory to ensure a thorough test of the proposed scheme of classification?"¹⁶⁷ In the fall of 1917, SAB officials marshaled their entire organizational powers in support of the Committee's efforts. Hitchens, in an October newsletter to Society members, referred to the "magnificent report of the

¹⁶⁶ Winslow, "Minutes, 18th Annual SAB Meeting, 1916, New Haven," [ASM] box 1-IVA, folder 2, pp. 3-4, also summarized in Abstracts of Bacteriology 1 (1917): 25-26.

¹⁶⁷ A.P. Hitchens, Glenolden PA, Newsletter to SAB Members, July 1917, [ASM] box 1-IVA, folder 2, p.2.

Committee on Characterization and Classification” as welcome solution to the pervasive taxonomic chaos. Hitchens appealed to the chartered goals of the SAB. Given that “previous systems of classification suggested heretofore have been largely the work of individuals,” each difference of opinion “has led to the formulation of a new system of classification with resultant confusion.” For Hitchens, “the superiority of our collective action is obvious.” The Committee had surveyed the vast expanse of all “previous work, and as the result of the best thought of members of our Society we have evolved a tentative classification,” available to any member upon request. Hitchens assured attendees of the 1917 meeting that all aspects of the Committee’s report were “subject to discussion and revision according to the ideas of the great body of workers representing our entire country.” Collectively, they would evaluate the “far-reaching importance” of the Committee’s report.¹⁶⁸ Similarly, SAB President Leo Rettger exhorted members that they were “in a position to render untold service in devising and, after thorough consideration, adopting a modern system of classification, the need of which cannot be too strongly emphasized.”¹⁶⁹

The 19th Annual SAB Meeting (1917) itself showcased presentations on bacterial systematics. Instead of the traditional “Smoker” the night before formal paper sessions, Hitchens and Rettger directed Robert S. Breed to organize a roundtable discussion on “Biological Classification with Special Reference to Bacterial Classification.”¹⁷⁰ This choice of topics assumed unusual importance given the backdrop of American involvement in World War I. For

¹⁶⁸ Hitchens, Glenolden, Newsletter to SAB Members, 20 October 1917, [ASM] box 1-IVA, folder 2, p. 1. Hitchens had “an indication of the interest already displayed in this report by the number of requests for reprints which have been received from various parts of the country,” p. 1.

¹⁶⁹ Rettger, New Haven, Letter to SAB Members, 25 October 1917, [ASM] box1-IVA, folder 2.

¹⁷⁰ SAB annual meetings regularly included a evening of wine, humorous skits, and casual conversation. hosted by the local organizing committee.

bacteriologists enmeshed in the duties of the U.S. Army Medical Corps, systematics must have appeared a distant concern. Nevertheless, the symposium took place, with Robert Buchanan delivering the opening address on "Bacteriological Nomenclature and its Problems," followed by mycologist George F. Atkinson who recounted "The Development of Botanical Codes of Nomenclature," and herpetologist Leon Stegner describing "The Work of the International Commission of Zoological Nomenclature."¹⁷¹ As part of the formal scientific program, Jean Broadhurst organized the session on "Characterization and Classification," scheduling ample time for Society members to discuss the Committee's report. Initially, Harold J. Conn, from the SAB's other Committee on the Identification of Bacterial Types, reminded attendees that the group number of the Society's Card had reached the limit of usefulness. Conn explicitly ceded the task of taxonomic reform to Winslow's Committee on the Characterization and Classification of Bacterial Types. Following Conn, Winslow introduced the CCCBT's "Preliminary Report," portraying it as only a marginal revision of Chester's *Manual of Determinative Bacteriology*, a gesture that did little to disguise the radical recommendations of the CCCBT's proposal.

The opening paragraphs of the "Preliminary Report" offered a justification for immoderate reform. Winslow explained that as bacteriology had "never passed through a taxonomic phase," the characterization of species and the formation of "larger generic and family groups" were haphazard and "almost ludicrously artificial." The "chaotic condition of bacterial classification" arose from the emphasis on morphology as the organizing taxonomic principle. On the whole, American bacteriologists inclined toward Migula's, and not Lehmann and

¹⁷¹ Hitchens, Glenholden, Circular to SAB Members, 21 November 1917, [ASM] box4-IIA, folder 13, pp. 1-2.

Neumann's system. As a consequence, they employed a scheme which accentuated motility as a generic character, a trait of "singularly slight taxonomic importance among the bacteria."¹⁷²

Winslow and the Committee recommended that SAB members appraise the general features of Orla-Jensen's physiological system. Given a goal of constructing a natural taxonomy, Orla-Jensen's scheme appeared "highly suggestive, and the emphasis on biochemical properties is a long step in the right direction." True, Orla-Jensen disregarded many morphological characters, thereby bypassing opportunities to "mark natural biological subdivisions," but the Committee considered the remedy to be a more balanced combination of taxonomic traits.¹⁷³ Winslow realized that reform would likely meet with stern resistance, particularly from medical or other specialized workers, "who deal with only a few recognized species," and "may perhaps feel no need for any change in current practice." Yet, he implored his listeners to acknowledge the "serious inconvenience" presented by the confused taxonomy.¹⁷⁴

The Committee's introductory comments also appealed to bacteriologists' sense of disciplinary identity, warning that if these revisions "were not undertaken by bacteriologists it would probably be attempted by botanists, unfamiliar with the peculiar characteristics of the organisms concerned." Indeed, the CCCBT intended to rely on the International Botanical Code of Nomenclature, but only on terms suitable to bacteriology. The Committee would, for instance, demand that every taxonomic group be given a Latin name, but refused to mandate that the definitions or diagnoses be published in Latin. Whereas the International Botanical Code had

¹⁷² Winslow et al., "Preliminary Report," 505-506, 510 & 516.

¹⁷³ The Committee additionally criticized Orla-Jensen's disregard for the "rudimentary principles of terminology," replacing well-established names with terms of his own choosing. Winslow et al., "Preliminary Report," 523-525.

¹⁷⁴ Winslow et al., "Preliminary Report," 530.

rejected the principle of type species, the Committee offered to provide type species for each of their proposed genera. Finally, while the Committee firmly supported the law of priority, it did propose a list of *genera conservanda*, or a short index of names to be preserved even if they were technically incorrect.¹⁷⁵

In explaining its own taxonomic guidelines, the Committee's "Preliminary Report" declared its intent to break up the "great mass of rod-shaped bacteria, including hundreds of enormously varied types" left in *Bacterium* and *Bacillus* by employing a range of morphological and physiological features (*e.g.*, capsule formation, spore shape, involution forms, staining reactions, ability to grow on certain media, relations to temperature and oxygen, fermentation reactions, pigment production and pathogenesis). Like Chester, the Committee began with Kruse's twenty-two physiological groups of rod forms, coupled with Winslow's taxonomy of the *Coccaceae*. They promised to winnow away "what is arbitrary in the older classifications – with no idealistic conceptions, either morphological or physiological in mind – but with the sole purpose of recognizing and defining the principal groups of bacteria that exhibit circumstantial evidence of common evolutionary relationship."¹⁷⁶

The CCCBT sought to taxonomize the entirety of the bacteriological domain, but found it difficult to set the boundaries of that realm. Would it classify members of myxobacteria, sporothrix, and spirochaetes? Despite the family's complex life cycle, which included an

¹⁷⁵ The Committee also approved of the botanical guideline that all new generic names not be "very long or difficult to pronounce," that they not be dedicated to persons outside of the science or taken from "barbarous tongues, unless those names are frequently quoted in books of travel, and have an agreeable form that is readily adapted to the Latin Tongue and to the tongues of civilized countries..." Winslow et al., "Preliminary Report," 529-536; and, Buchanan, *General Systematic Bacteriology*, 110.

¹⁷⁶ Winslow et al., "Preliminary Report," 517, 521, & 537. On this point, the Committee cited extensively from Jordan's *Text-book of General Bacteriology*, 1st ed., 105.

amoeboid stage, the Committee chose to include myxobacteria within its report. Likewise, it elected to cover spirochaetes, though these forms displayed many protozoan traits. In contrast, the Committee declined to review the sporothrix, which they considered part of mycology proper. As a result, the preliminary report listed four orders of the class *Schizomycetes*, and a category for "Organisms Intermediate between Bacteria and Protozoa." However, the "Preliminary Report" dispensed with the higher bacteria quickly, loosely defining the orders *Myxobacteriales*, *Thiobacteriales*, and *Chlamydo bacteriales* merely to provide the "complete setting" for *Eubacteriales*, "with which we are primarily concerned." Compared with earlier taxonomic efforts, the Committee devoted more attention to these unusual forms, noting for example, that *Thiobacteriales* should be separated from the *Chlamydo bacteriales*, owing to the divergent metabolisms of these iron and sulphur organisms. Still, the Committee declined to discuss the genera of these families, "as they are beyond the scope of the world of the ordinary bacteriologist."¹⁷⁷

Instead, the Committee focused its attention on the "true bacteria," or the order *Eubacteriales*, which they divided into seven families: *Nitrobacteriaceae*, *Mycobacteriaceae*, *Pseudomonadaceae*, *Spirillaceae*, *Coccaceae*, *Bacteriaceae*, *Lactobacillaceae*, and *Bacillaceae*. The Committee created two of these families anew, and dramatically redefined two of the remaining five. (Fig. 6.4) They defined their new *Nitrobacteriaceae* largely by physiology, for those forms securing their growth energy from the oxidation of carbon, hydrogen, or other simple compounds. Likewise, the Committee established the family *Lactobacillaceae* to delineate those

¹⁷⁷ Winslow et al., "Preliminary Report," 538-540. The Committee explained: "The orders *Chlamydo bacteriales* and *Thiobacteriales* as defined belong largely to the botanist, the group of *Eubacteriales* with its cultivable forms, studied by a special physiological technique, to the bacteriologist," p. 540.

types producing high amounts of acid. While the groups *Mycobacteriaceae* and *Pseudomonadaceae* were in use before the CCCBT's "Preliminary Report," the Committee broadened the former to include many new branching genera, and elevated the latter's status from a simple genus to a family.

The Committee recommended a host of changes to the genera of the *Eubacteriales*. Whereas Migula and Chester had listed only a handful of generic groups, the CCCBT defined thirty-one. (Fig. 6.5) The suggested alternations were manifold. Within the *Nitrobacteriaceae*, the Committee recommended eight separate genera; six defined by their oxidation reactions (*Hydrogenomonas*, *Methanomonas*, *Carboxydomonas*, *Mycoderma*, and *Nitrosomonas*), and two by their ability to fix atmospheric nitrogen in soils or the roots of leguminous plants (*Azotobacter*, *Rhizobium*). The "Preliminary Report" endorsed Orla-Jensen's claim that members of the *Nitrobacteriaceae* featured a primitive metabolism and structure, suggesting that they flourished "at a very early period in the world's history," and probably represented the "ancestral types of all other bacteria."¹⁷⁸ In fact, the Committee employed Orla-Jensen's terms for the first three genera of *Nitrobacteriaceae*. For the other genera, they offered several corrections, citing the law priority as they substituted *Mycoderma* for forms previously known as *Acetobacter*, and *Nitrosomonas* and *Nitrobacter* for nitrifying bacteria often classed as *Bacterium*. Curiously, for the symbiotic nitrogen fixers commonly classed as *Bact.* or *B. radicum*, the Committee selected the genus name *Rhizobium* Frank 1889, rather than the older designation *Phytomyxa* Schroeter 1886, believing that substituting the "older correct name for

¹⁷⁸ Winslow et al., "Preliminary Report," 542. The Committee even posited the phylogenetic relationship between *Nitrobacteriaceae* and other families. *Rhizobium*, for example, resembled the *Mycobacteriaceae* in involution forms, which bordered on branching. Likewise, the sizable *Azotobacteria* appeared at time yeast-like.

the better-known term *Rhizobium*” would produce undue confusion. The CCCBT would in some instances sacrifice systematic exactitude in support of common usage.¹⁷⁹

The Committee greatly expanded the family *Mycobacteriaceae*. Originally, Lehmann and Neumann recommended three genera for the branching bacteria, *Mycobacterium* for the tubercle group, *Corynebacterium* for the diphtheria group, and *Actinomyces* for the mycelial forms found in soils and certain animal diseases. The CCCBT split this family further, creating three additional genera (*Nocardia*, *Leptotrichia*, and *Fusiformis*), and defining all six by reference to detailed morphological features and staining reactions. The Committee admitted some uncertainty regarding this group, allowing that *Fusiformis* might be moved to another family, and that *Actinomyces* might constitute a family in its own right. In contradistinction, the “Preliminary Report” assuredly defined *Mycobacterium* to encompass the familiar pathogens of leprosy, glanders, and tuberculosis, choosing *Mycobacterium tuberculosis* as its type species. Continuing with their evolutionary speculations, the Committee suggested that *Corynebacterium* allied in “many respects with the *Streptococci*, and very possibly may have formed a connecting link with this group.”¹⁸⁰

Migula included the genus *Pseudomonas* as part of his family *Bacteriaceae*. The Committee elevated the genus to the rank of family, and offered an altered diagnosis for the newly created *Pseudomonadaceae*. While Migula had stressed the unusual character of polar flagella, the CCCBT appended the physiological traits of yellow/green pigment formation, occasional fluorescence or phosphorescence, and a limited carbohydrate metabolism with active

¹⁷⁹ Winslow et al., “Preliminary Report,” 553.

¹⁸⁰ Winslow et al., “Preliminary Report,” 544.

oxidative action. Both taxonomies included the same water bacteria and plant pathogens, but the Committee took the opportunity to redefine the morphological group on the basis of physiology. Additionally, the CCCBT instilled phylogenetic considerations, depicting the *Pseudomonadaceae* as "another distinctly primitive family" given its oxidative metabolism, production of ammonia, and predominant water habitat. *Pseudomonas*, according to the "Preliminary Report," denoted far more than polar flagella.¹⁸¹

Regarding the *Coccaceae*, the Committee predictably endorsed Winslow and Winslow's final report of 1908, which divided the spherical forms into two primary groups, one saprophytic and one parasitic. Winslow reiterated his earlier instance on the correlation characters, noting that the first four genera (*Neisseria*, *Streptococcus*, *Staphylococcus*, and *Albococcus*) reproduce best under anaerobic conditions, display slow culture growth, produce acid but no gas in carbohydrates, and form only white or orange pigments, while the last three genera (*Micrococcus*, *Sarcina*, and *Rhodococcus*) tended to be saprophytes growing best under aerobic conditions, stain positive by Gram's method, and produce only yellow and red pigments. Still, the CCCBT did amend the Winslows' earlier scheme in a few respects. They eliminated the genus *Diplococcus*, moving the gonococci and meningococci to *Neisseria*, and pneumonococci to *Streptococci*. The Committee considered combining *Micrococcus* and *Sarcinia*, noting that the grouping of cells into regular packets constituted a "slender basis for distinction" between genera. However, citing the need for compromise and consensus, they decided it "best to retain a name which has nearly a century of usage behind it until more definite proof of invalidity is forthcoming." Instead, the Committee exercised its conceptual ambitions by suggesting that the

¹⁸¹ Winslow et al., "Preliminary Report," 542-544.

parasitic group, through the *Streptococci*, evolved in relation to *Corynebacterium*, and possibly to the colon-typhoid group, while the saprophytic genera allied phylogenetically with *Pseudomonas*.¹⁸²

Migula and Chester allotted three genera to rod-shaped *Bacteriaceae*, namely *Bacterium*, *Bacillus*, and *Pseudomonas*. The CCCBT sequestered *Pseudomonas* to its own family, and altered the elemental separation between *Bacillus* and *Bacterium*, abandoning Migula's criteria of motility and flagella. The Committee reserved the family *Bacillaceae* for two genera, *Clostridium* and *Bacillus*, which they defined by spore formation and oxygen relations. Winslow and his colleagues believed the spore formation constituted a fundamental taxonomic character, and "its combination with a very complex metabolism, Gram-positive staining, and the peritrichic arrangement of flagella, when present, marks off the *Bacillaceae* as one of the highest groups of bacteria." These spore formers represented "probably the most complex family," as its members decomposed protein media through a series of enzymes.¹⁸³ Whereas Migula and Chester drew attention to the wearisome techniques of staining flagella, the Committee asked bacteriologists to regard these forms as outcomes of evolutionary adaptations.

The "Preliminary Report" assembled yet another new family, *Lactobacillaceae*, for those microbes displaying a high tolerance to acid. Although many bacteria produced lactic acid in milk, organisms such as *B. acidophilus*, *B. figidus*, and *B. bulgaricus* produced amounts well beyond the normal range. The CCCBT considered the characteristic "so significant as to warrant for them" a new family. Curiously, the Committee introduced this physiological group with little

¹⁸² Winslow et al., "Preliminary Report," 521-522.

¹⁸³ Winslow et al., "Preliminary Report," 541, & 547-548.

additional explanation, simply choosing to quarantine these dairy forms to the genus

Lactobacillus.¹⁸⁴

The Committee placed the remaining rod-shaped bacteria within the "classic family *Bacteriaceae*," a category that they admitted was in need of "most radical revision." It included "a great complex of organisms differing from each other radically in structure and metabolism, and might conveniently be split up into at least five distinct families." The CCCBT regarded the family as an "*omnium gatherum*," a junk heap of undifferentiated form likely to be split as knowledge accumulated. In the interim, the Committee hesitated "to the literature with unnecessary terminology," leaving *Bacteriaceae* with only slight revisions until "further study indicates that a sharper differentiation is desirable."¹⁸⁵

Even so, the "Preliminary Report" provided for four genera of the *Bacteriaceae*, defined by a host of varied characteristics. The family itself featured rod-shaped cells without spores, that were Gram-negative and featured a complex metabolism capable of utilizing amino-acids and carbohydrates. The Committee narrowed genus *Bacterium* to include only those easily cultivable animal pathogens and saprophytes, often chromogenic and motile, that were capable of active carbohydrate fermentation. For most practicing bacteriologists, this genus would look familiar, albeit smaller. The Committee assigned the intestinal *B. coli* as its type species, and defined the core of the genus by reference to the parasitic forms of the colon-typhoid-dysentery group. The genus also included the *B. abortus* group, "in spite of its peculiar oxygen requirements," the proteus and aerogenes groups, and many chromogenic water bacteria. The

¹⁸⁴ Winslow et al., "Preliminary Report," 547.

¹⁸⁵ Winslow et al., "Preliminary Report," 542.

Committee considered splitting the genus further, but owing to the "fact that this group includes many of the common pathogenic forms universally designated by medical workers" as either *Bacillus* or *Bacterium*, they feared that any "new and unfamiliar name" or any "old and equally unfamiliar one which might be dug out of the literature" would face certain resistance.¹⁸⁶

The remaining three genera of *Bacteriaceae* were creations of the CCCBT. The Committee formulated *Erwinia* for the group of slim rods pathogenic for plants, producing white pigment, forming acid but not gas in carbohydrate solutions, and incapable of eliciting indol (e.g., *B. amylovorus*, *B. phytophthorus*, *B. caratovor*, *B. melonis*, and *B. colanacearum*). True, these organisms shared many of the morphological and cultural characteristics of *Bacterium*, but their particular fermentative powers warranted "distinct generic rank."¹⁸⁷ *Pasteurella* displayed equally unique generic characteristics. As members of the hemorrhagic-septicemia group these species tended to be pathogenic for animals (e.g., fowl cholera, swine plague, rabbit septicemia, and bubonic plague), feature distinct bipolar staining, and possess poor powers of fermentation and liquefaction. *Hemophilus* encompassed a set recently described organisms (e.g., the Koch-Weeks bacillus, the Bordet-Gengou bacillus, the influenza bacillus), minute rods, strictly parasitic, and growing best on hemoglobin/blood serum or ascitic fluid.

The "Preliminary Report" concluded with an invitation for comment and criticism. The Committee proposed its system as a template for additional refinements, leading eventually to a classification which "more and more closely approximates the facts of evolutionary history."

¹⁸⁶ Winslow et al., "Preliminary Report," 546.

¹⁸⁷ Winslow et al., "Preliminary Report," 574. Given that this genus was the eponymous tribute to the "American Pasteur of bacterial plant pathology," Erwin F. Smith, the Committee provided a nice gesture to the one SAB member likely to object.

The Committee requested that the SAB distribute the report to all Society members, giving the body a full year to review and adopt the new taxonomy. The CCCBT understood that official sanction meant little unless "the names suggested are used in actual practice in written papers, and in the teaching" of novice bacteriologists. Winslow reproached those unwilling to consider the changes, warning that it was "easy to continue in the old slipshod ways and there will be a powerful force of inertia to overcome." In fact, neither the SAB nor Committee members could mandate its implementation, although Winslow did edit the SAB's *Journal of Bacteriology*. Rather, the CCCBT's "Preliminary Report" concluded with the confidence that the revisions would speak for themselves.¹⁸⁸ The immediate response to the Committee's "Preliminary Report" was tentative, although somewhat positive. University of Illinois' Fred W. Tanner, for example, portrayed the Committee's initial effort as "interesting." Tanner suggested that the proposed classification that "will probably demand much more study before a satisfactory one has been developed. Much more data may have to be secured with regard to the life histories of bacteria." Tanner did regard the Committee's taxonomy as significant improvement over the available schemes.

In the years leading up to the publication of the "Preliminary Report," and the months immediately following, members of the CCCBT contributed in three other ways to the consideration of systematic reform. Initially, Winslow himself supervised many of the sessions on "Characterization and Classification" at annual SAB meeting during the 1910's, recruiting papers and fostering discussions on the problems of bacterial variations.¹⁸⁹ While Winslow

¹⁸⁸ Winslow et al., "Preliminary Report," 547-549.

¹⁸⁹ See, Jean Broadhurst, "Constancy in the Fermentative Activity of Streptococci," paper presented to the 15th Annual SAB Meeting, 1913, abstracted in *Science* 39 (1914): 789; Broadhurst, "Some Induced Changes in

understood that the specter of mutations, life-cycles or pleomorphism might threaten a stable taxonomy, he stood convinced that these phenomena occurred within predictable limits, and might even be employed taxonomically to differentiate bacterial types.¹⁹⁰

Secondly, Winslow established and operated the American Type Culture Collection (ATCC) at the American Museum of Natural History as self-appointed center for taxonomic standardization. Society of American Bacteriologists members first considered the need for a culture collection at its 2nd Meeting in December of 1900, when Herbert W. Conn presented "How Can Bacteria Be Satisfactorily Preserved for Museum Specimens?" In the discussion that followed, Joseph McFarland, Frederick D. Chester, William Park and Frederic Gorham each expressed the need for a central depository where cultures bearing the same name could be compared.¹⁹¹ In Prague, Franz Kral operated such a culture collection. Kral's "Kral'sch Sammlung von Micro-organismen" distributed bacterial types, at a nominal cost, to researchers throughout Europe and America.¹⁹² Additionally, bacteriologists informally exchanged new

Streptococci," paper presented to the 16th Annual SAB Meeting, 1914, abstracted in Science 41 (1915): 618. and printed as "Environmental Studies of *Streptococci*," Journal of Infectious Diseases 17 (1915): 227; Paul G. Heinemann, "The Variability of Two Strains of *Streptococci Lacticus*," paper presented to the 16th Annual SAB Meeting, 1914, printed in Journal of Infectious Diseases 16 (1915): 221-239; M.R. Smirnow, "Induced Variations in Chromogenesis," paper presented to the 16th Annual SAB Meeting, 1914, abstracted in Science 41 (1915): 621; E.O. Jordan, "Variation in *B. coli*," paper presented to the 17th Annual SAB Meeting, 1915; Max R. Smirnow, "Theoretical Discussions as to the Cause of Bacterial Variations," paper presented to the 17th Annual SAB Meeting, 1915, and Smirnow, "Further Observations on the Biological Variations of Bacteria," paper presented to the 17th Annual SAB Meeting, 1915, both published as, "Biological Variations of Bacteria: Induced Variations in the Cultural Characteristics of *B. Coli*," Journal of Bacteriology 1 (1916): 385-410; and, Percy D. Meader, "Variation in the Diphtheria Group," Journal of Infectious Diseases 24 (1919): 145-157.

¹⁹⁰ See, for example, Nobel Peirce Sherwood, "A Study of Several Strains of Pleomorphic *Streptococci*," University of Kansas Science Bulletin 10 (1917): 245-257; F.M. Scales, "Environment as Stimulus to Morphological Variations," paper presented to the 18th Annual SAB Meeting, 1916; and, Andrew I. Dawson, "Bacterial Variations Induced by Changes in the Composition Culture Media," Journal of Bacteriology 4 (1919): 133-148.

¹⁹¹ Herbert W. Conn, "How Can Bacteria Be Satisfactorily Preserved for Museum Specimens?" paper presented to the 2nd Annual SAB Meeting, 1900, abstracted in Science 13 (1901): 326.

¹⁹² The International Association of Botanists founded a similar collection of mycological specimens as part of the "Central Bureau of Cultures of Fungi," in Baarn, Holland.

strains since the 1880's, and American researchers, particularly at Agricultural Experiment Stations, traded samples of unusual bacteria.¹⁹³ At the SAB's 1909 meeting, Winslow, as a member of the committee revising the Society's Card, proposed a central bureau where species "might be studied and compared and kept in such condition that bacteriologists could at anytime obtain duplicate descriptions and subcultures for their own use."¹⁹⁴

The next year, Winslow returned to the SAB program to announce the establishment of a "Bacteriological Collection and Bureau for the Distribution of Bacterial Cultures" at the AMNH. The collection offered to preserve and distribute both pathogenic and nonpathogenic organisms, particularly new types and varieties. Winslow requested that SAB members from medical schools, colleges, boards of health, and experiment stations donate cultures to the Bureau, affixed with a "history of the organism in as full detail as possible." In turn, the Museum offered to pay the expense of transferring and transcribing records, and distribute cultures without charge to authorized institutions.¹⁹⁵ In the AMNH's own announcement of the collection, Winslow indicated that it was the "first museum of its kind to recognize that the relation between man and his microbic foes is fundamentally a problem in natural history and a problem of such interest and importance as to warrant the creation of a special museum Department of Public Health." The AMNH directors requested that the main function of the Department be the presentation of

¹⁹³ Conn, Esten and Stocking's comprehensive "Classification of Dairy Bacteria," acknowledges numerous strains sent from Harry Harding at Geneva, New York, F.C. Harrison at Guelph, and Charles Marshall from East Lansing, pp. 91-92.

¹⁹⁴ C.-E.A. Winslow and Frederic P. Gorham, "Report of the Committee on the Identification of Bacterial Species, 1909," *Science* 31 (191): 546.

¹⁹⁵ Winslow, "A Bacteriological Museum and Bureau of the Exchange of Bacterial Cultures at the American Museum of Natural History," report presented to the 12th Annual SAB Meeting, 1910, abstracted in *Science* 33 (1911): 539; and, Winslow, "Bacteriological Museum and Bureau for the Distribution of Bacterial Cultures," *Journal of the American Public Health Association* 1 (1911): 152.

“effective exhibits” displaying the role of germs in the spread of infectious diseases, and not maintaining a culture collection. Still, Winslow emphasized the “unique opportunity for maintaining, as a sort of study collection, a museum of living bacteria for the benefit of working laboratories all over the country.” Previously, American workers relied on the Kral collection to provide samples, and lost many domestic types because laboratories did not have facilities to maintain continuous cultures. The “authorities of the Museum were quick to appreciate the importance of the public service that could be rendered,” and agreed to expand the Department’s function beyond simple exhibit displays.¹⁹⁶

Winslow launched the Bureau in 1911 with about 160 strains, sent from forty-five different institutions. Within a year and half, the collection sustained 578 strains, representing 374 named types. The collection quickly accumulated a majority of the important pathogenic and saprophytic species. During that time, the Bureau distributed nearly 17,000 “authenticated” cultures to 122 colleges and research laboratories. In Winslow’s estimation, the most important services the Bureau offered had been “in furnishing authentic cultures to investigators who have been making a study of certain special groups, and the published papers which have resulted, in which various detailed characters of the museum types are described . . .”¹⁹⁷ By employing the Bureau’s cultures, researchers could study identical strains, comparing characterizations to arrive at sanctioned, if not standardized, descriptions. Winslow also inserted his own preferred nomenclature in the Bureau’s catalogue of available strains, and onto the identifying labels and

¹⁹⁶ Winslow, Bacteriological Collection and Bureau for the Distribution of Bacterial Cultures (New York: American Museum of Natural History, 1912), 1.

¹⁹⁷ Winslow, “Bacteriological Collection and Bureau for the Distribution of Bacterial Cultures at the American Museum of Natural History,” report presented to the 14th Annual SAB Meeting, 1912, abstracted in Science 38 (1913): 374-375.

culture histories for each distributed sample. Thus, an instructor or research laboratory might request a culture of *Staphylococcus pyogenes ablus* or *Bacillus erysipelatus suis*, only to receive samples marked *Albococcus pyogenes* and *Mycobacterium rhusiopathiae*.¹⁹⁸ Almost immediately upon its foundation, textbook authors and instructors looked to the Bureau to act as an unofficial arbiter of new species and genera, cross-checking arriving cultures against previously described forms. Furthermore, Winslow offered the AMNH's laboratory for anyone desiring to conduct work in systematic bacteriology. His own assistant, I.J. Kligler, busied himself surveying members of the *Coccaceae*, and John Hopkins' bacteriologist John W. Churchman spent several weeks researching species of the *Bacteriaceae*. In this fashion the Bureau operated analogously to the British Museum of Natural of Natural History, which mediated taxonomic disputes in botany and zoology during the nineteenth-century, and "fixed itself at the center of a wide web of authority and naming of species."¹⁹⁹

During the 1910's, the American Type Culture Collection (ATCC), as it came be to known, assumed even greater international importance. The collection at Kral fell into decline after Franz Kral's death, and by mid-decade the ATCC possessed more than 700 separate strains.²⁰⁰ Only *Pasteurella pestis*, the agent of bubonic plague, was excluded, owing to the risk

¹⁹⁸ Winslow, *Bacteriological Collection*, 2-3. Robert Kohler describes a contemporary and analogous circumstance among Thomas H. Morgan's *Drosophila* group, who maintained a collection that helped define a changing research front. See, Kohler, *Lords of the Fly: Drosophila Genetics and the Experimental Life* (Chicago: University of Chicago Press, 1994), 82.

¹⁹⁹ Lohnis, Stevenson, and Hunter-Smith, *Laboratory Methods in Agricultural Bacteriology*, 52; McQuat, "Species, Names and Things," 15. The AMNH itself comprised an institutional site of enormous disciplinary authority. See, Ronald Rainger, "Vertebrate Paleontology as Biology: Henry Fairfield Osborn and the American Museum of Natural History," in *American Development of Biology*, eds. Keith Bensen, Jane Maienschein, and Ranger (New Brunswick: Rutgers University Press, 1991), 219-256.

²⁰⁰ After its founder's death, the Kral collection moved to Vienna, under the direction of Ernst Pribram. While Pribram still published a list of cultures in 1919, the effects of the first world war depleted much of his inventory, and seriously hindered his ability to ship cultures internationally. The next European culture collection was founded in Britain in 1919, sponsored jointly by the Lister Institute and the Medical Research Council. See.

of accidental exposure. In 1915, the Museum's "Garden of Germs" distributed more than 3,600 "standard types" to some 400 institutions world wide. Winslow boasted that "Systematic bacteriology a decade ago was in a pre-Linnaean stage; but it has developed rapidly in the United States during recent years; and scarcely a paper upon bacterial classification can be found in which the types sent out from the American Museum do not play a primary part." At the ATCC, Kligler had taken up study of the typhoid group, joined by a second assistant William Rothberg. Winslow hoped that by "attacking group after group the whole family of the bacteria, which has presented so difficult a problem in the past, may be mapped out and brought together in a work which shall be as fundamental as the contributions of the American Museum to systematic biology in other fields."²⁰¹

Aside from the SAB meeting sessions on "Characterization and Classification," and the operation of the ATCC, Committee members contributed to the consideration of systematics in another important respect. Robert E. Buchanan, in particular, negotiated the intricate rules and regulations of the International Codes of Botanical and Zoological Nomenclature, interpreting those rules directly applicable to bacteriology, and suggesting modifications to those guidelines distasteful to SAB members. His efforts actually predate the formation of the CCCBT, when 1915 he recommended the creation of a committee to consider the two codes. Buchanan noted

James H. Dible, "A History of the Pathological Society of Great Britain and Ireland," Journal of Pathology and Bacteriology 73 (1957): 11.

²⁰¹ Winslow, "A Garden of Germs: Museum of Living Bacteria a Unique Public Service," American Museum Journal 16 (May 1916): 300; Winslow and Kligler, "Studies on the Classification of the Colon-Typhoid Group," paper presented to the 17th Annual SAB Meeting, 1915, summarized in Journal of Bacteriology 1 (1916): 81; and, Winslow, Kligler and Rothberg, "Further Studies on the Colon-Typhoid Group of Bacteria," Abstracts of Bacteriology 1 (1917): 27-28; and, Winslow, Kligler and Rothberg, "Studies on the Classification of the Colon Typhoid Group of Bacteria with Special Reference to Their Fermentative Reactions," Journal of Bacteriology 4 (1919): 429-503.

the success that protozoologists and helminthologists experienced applying the zoological code, and the ease with which the algologists and mycologists adopted the botanical system.²⁰² Buchanan assumed the role of self-appointed pedant of exacting nomenclature, publically correcting the "errors" of various authors. He viewed the problems of nomenclature as being prior to considerations of classification, and called for the SAB to cooperate with international biological societies. Buchanan pointed to the next International Botanical Congress as opportunity for bacteriologists to seek an exemption from the requirement of Latin diagnoses, as well as the proper venue for announcing its list of *genera conservanda*.²⁰³

As a member of the CCCBT, Buchanan found further support for the Committee's efforts in the International Rules of Botanic Nomenclature. In addition to the Code's adherence to the law of priority, Article 3 maintained that the "rules of nomenclature should neither be arbitrary nor imposed by authority. They must be simple and founded on considerations clear and forcible enough for everyone to comprehend and be disposed to accept." Similarly, the CCCBT believed that the logic and clarity of its report would obviate any need for mandating adherence to its taxonomy. Article 4, however, authorized legitimate bodies to "reject the use of forms and names which may cause error or ambiguity or throw science into confusion." For Buchanan, this provision bolstered the International Rules allowance (Article 16) that taxonomic designations

²⁰² "The bacteriologists on the other hand have thus far failed to agree on any scheme of classification, and many are rebellious against any of the restraints imposed by formal nomenclature." Buchanan, "The Problem of Bacterial Nomenclature," 593. See also, C.W. Stiles, "The International Code of Zoological Nomenclature as Applied to Medicine," *Hygienic Laboratory Bulletin*, no. 24 (Sept. 1905): 26-28; and, "The International Botanic Congress at Brussels," *Nature* 83 (1910): 534-536.

²⁰³ Buchanan, "The Correct Generic Name for Soil *Trichomyces*," paper presented to the 18th Annual SAB Meeting, 1916; and, Buchanan, "The Problem of Bacterial Nomenclature," 591 & 596. Buchanan did believe, however, that the long-term solution to taxonomic confusion lay in training of a new generation of bacteriologists steeped in the principles of systematics. See, Buchanan, "The Pedagogics of Systematic Bacteriology: The Place of Systematic Bacteriology and Bacterial Philogeny (sic) in the Teaching of Bacteriology, paper presented to the 18th Annual SAB Meeting, 1916.

need not serve as shorthand for the organism's full diagnosis. In fact, most biological names did not reveal the essential features of a species (*homo sapiens* excepted). Unlike terms in chemistry, anatomy, and pathology, specific names were simply labels. They were arbitrary signs, constrained only by the requirement that they remain stable and easy to remember. Thus, the Committee could justly rename the glanders bacillus *Mycobacterium mallei*.²⁰⁴

Buchanan's appeal to the International Rules of Botanic Nomenclature appears ironic, given that the Code itself drew increasing opposition at the time. For nearly two decades, domestic botanists had expressed dissatisfaction with the International Rules, twice proposing alternative American Codes.²⁰⁵ Certain members of the Botanical Society of America even denied the authority of international congresses to settle taxonomic disputes, and in 1918 the Botanical Society appointed a special committee to resolve differences between the American Code and Vienna Code.²⁰⁶ The International Rules rejected the idea of a type basis code, a system largely employed by American botanists and adopted by the CCCBT. Fortunately, most botanists did not consider the type system "antagonistic" to the Vienna Code, and the Botanical

²⁰⁴ Buchanan, General Systematic Bacteriology, 114; McQuat, "Species, Names and Things," 108; and Bowker and Star, Sorting Things Out, 80.

²⁰⁵ McQuat, "Species, Names and Things," 324-326; Charles Bessey, "Recommendations Regarding the Nomenclature of Systematic Botany," Journal of Botany 33 (1895): 212-216; Bessey, "A Protest Against the Rochester Rules," American Naturalist 29 (1895): 668-669; Joseph C. Arthur et al., "Code of Botanical Nomenclature," Bulletin of the Torrey Botanical Club 31 (1904): 249-290; Arthur, "International Congress on Zoological Nomenclature," Science 32 (1910): 301-303; W.L. Tjaden, "Botanical Nomenclature and the Pitfalls in Relevant History," in History in the Service of Systematics, eds. Alwyne Wheeler and James H. Price (London: Society for the Bibliography of Natural History), 129-133.

²⁰⁶ A.S. Hitchcock, "Scope and Relations of Taxonomic Botany," 341-342; Nathaniel L. Britton, "Nomenclature at the Vienna International Botanical Congress," Science 32 (1905): 217-210; "Type Basis Code of Botanical Nomenclature," Science 49 (1919): 333-336, and Science 53 (1921): 312-314; Hitchcock, "Report on the Commission on Nomenclature of the Botanical Society of America," Science 53 (1921): 312-314; and, Andrew D. Rogers, Liberty Hyde Bailey: A Story of American Plant Sciences (Princeton: Princeton University Press, 1949).

Society provided formulae for meeting the requirement of both competing systems.²⁰⁷ For bacteriologists, the International Rules posed additional quandaries. Article 24, for example, mandated that genera begin with a capital letter and appear in italics, a stipulation that medical journals rejected due to the added printing costs. Additionally, strict adherence to the law of priority might create undue confusion since many early authors dealt with mixed or impure cultures, and provided inadequate descriptions. Even so, Buchanan and his colleagues looked to these international bodies to settle lingering questions of bacterial systematics.²⁰⁸

These measures by Winslow and Buchanan to promote discussion of bacterial variations, create a central culture collection, and decipher the intricacies of the International Rules of Botanical Nomenclature did much to prepare SAB members for the drastic proposals contained in the CCCBT's "Preliminary Report." Despite these efforts, the Committee recognized that their suggested taxonomy would likely engender confusion, indifference, and antipathy. In fact, the CCCBT acted in ways to fuel these responses. Initially, the Committee enthusiastically endorsed a phylogenetic arrangement of bacteria. Most observers assumed that microbes lacked a fossil record. However, in 1915, paleontologist Charles D. Walcott announced the "Discovery of Algonkin Bacteria," markings in series of limestone fossils that resembled *Micrococci* or *Azotobacter*.²⁰⁹ His friend and fellow paleontologist at the American Museum of Natural

²⁰⁷ Buchanan, General Systematic Bacteriology, 147-148; A.S. Hitchcock, "Report of the Committee on Generic Types of the Botanical Society of America," Science 49 (1919): 333-336; and, Hitchcock, "The Type Concept in Systematic Botany," American Journal of Botany 8 (1921): 251-255

²⁰⁸ Buchanan, General Systematic Bacteriology, 117-118. Charles Morrey explained to readers of his Fundamentals of Bacteriology that "For animal forms and for the higher plants this classification is gradually becoming fixed through the International Congress of Zoologists and botanists respectively. Unfortunately, the naming of the bacteria has not as yet been taken up by the latter body, though announced as one of the subjects for the Congress of 1916 (postponed on account of the war). Hence there is at present no system which can be regarded as either fixed or official," p. 56.

²⁰⁹ Walcott, "Discovery of Algonkin Bacteria," Proceedings of the National Academy of Science 1 (1915): 256-247. See also, Ellis L. Yochelson, Charles Doolittle Walcott, Paleontologist (Kent, OH: Kent University Press,

History, Henry Fairfield Osborn, outlined the implications of this finding for the evolution of bacteria. According to Osborn, bacteria “lie half way between the hypothetical chemical pre-cellular stages and the chemistry and definite cell structure of the lowliest plants.”²¹⁰

In a lecture delivered to the National Academy of Science, Osborn drew attention to the genera *Nitrobacter*, *Nitrosomonas*, *Hydrogenomonas*, *Carboxydomonas*, and *Methanomonas*, autotrophic organisms that derived their energy from the oxidation of inorganic compounds (e.g., nitrogen, ammonium, hydrogen, carbon monoxide, methane). Their ability to transform chemical “life elements” such as potassium, phosphorus, magnesium, sulphur, ferrous oxide, and the like, placed them as “primitive feeders.” More specifically, these *Nitrobacteriaceae* flourished in hot environments without sunlight, conditions likely present in the pre-carbon stage of the earth’s development. As such, Osborn marked these microbes as the earliest living organisms, an assertion with which most bacteriologists would have agreed. From this initial premise, however, the paleontologist assembled a phylogenetic tree of microbial descent. The nitrogen fixers, *Rhizobium* and *Azotobacter*, possessed a slightly more complex metabolism and cell structure, and therefore must have succeeded the other autotrophs, followed by *Clostridium*, and then types capable of secreting enzymes. Osborn surmised that once “Armed with these physico-chemical powers, which may have been acquired one by one, the primordial bacteria mimic the evolution of the higher plant and animal world by an adaptive radiation . . .”²¹¹

I.J. Kligler, a trained bacteriologist working at the AMNH, corroborated Osborn’s

1998).

²¹⁰ Osborn, “The Origin and Evolution of Life Upon the Earth,” *Scientific Monthly* 3 (1916): 289.

²¹¹ Osborn, “Origin and Evolution of Life,” 290-295. See also, Roy L. Moodie, “Mesozoic Pathology and Bacteriology,” *Science* 43 (1916): 425-426.

hypothesis. Kligler conceded that reconstructing a phylogenetic history of bacteria posed considerable challenges. Whereas the paleontologist usually relied on "gross structural distinctions" to identify divergent taxa, the bacteriologist, by necessity, vetted "biochemical and metabolic differences." Nonetheless, Kligler asserted that tracing "the evolution of these simple cells may well lead to a clearer conception of the character of the organisms and the nature of their adaptation to a saprophytic, parasitic or pathogenic mode of life."²¹² Kligler agreed with Osborn that autotrophic bacteria comprised the earliest forms of life, and that their evolution proceeded from simple to complex metabolism. In the case of microbes, this implied the capacity to mobilize increasingly complex molecules for their energy and growth. Kligler posited that during the earth's development, the arrival of decaying nitrogenous matter encouraged a new line of microbial adaptation, one capable of assimilating a wider range of compounds (e.g., amino-acids, the proteoses, and even proteins). From this premise, Kligler offered a detailed account of the "probable" order of bacterial types.²¹³ (Fig. 6.6) To Osborn's original theory, Kligler added the corollary that parasitic forms emerged only after the development of plants and animals. Parasite and host co-evolved, usually with the loss of metabolic functions among members of the former. This hypothesis explained why almost every taxonomic group of bacteria included both parasites and saprophytes.²¹⁴

²¹² Kligler, "The Evolution and Relationship of the Great Groups of Bacteria," Journal of Bacteriology 2 (1917): 165.

²¹³ "From the original oxidizing types two main lines of development are pictured. The first, still predominately oxidative in nature, leads through the nitrogen-fixers, acid fasts and diphtherioids to actinomyces and sporothrix forms and the micrococci." The other line moves from the "denitrifiers and *B. aerogenes* along three secondary paths to (a) the streptococci and aciduric bacilli; (b) the colon-typhoid-dysentery and hemorrhagic septicemia group; and (c) through *B. cloacea* and *B. proteus* to the anaerobic and aerobic spore-bearers and the pigment bacteria, respectively." Kligler, "The Evolution and Relationship of the Great Groups of Bacteria," Abstracts of Bacteriology 1 (1917): 215-216.

²¹⁴ Kligler, "Evolution and Relationship," 169.

The speculations of the Museum research staff elicited immediate protest. Robert S. Breed, who had received his graduate training in zoology before migrating to bacteriology, objected to several of Osborn and Kligler's assumptions. At the onset, he policed disciplinary boundaries, noting that the "Unwarranted deductions have been drawn in recent popularization of science by one of our eminent paleontologists, Dr. H.F. Osborn, not however in his own field, but in a special field apparently unfamiliar to him." Osborn's mistakes were manifold. The fossil bacterium was a marine organism, most likely a denitrifer, possessing the inverse metabolism of the primitive members of *Nitrobacteriaceae*. Osborn had also confused the autotrophic *Nitrosococcus* or *Nitrosomonas* with the nitrogen fixers, which required complex carbon sources for their growth. The mistake was analogous to confusing carnivores with herbivores. Furthermore, Breed doubted the reliability of reading bacterial structure from the "uniform black of fossil organisms," and dismissed Osborn's conclusions as "a pyramid of speculation supported by an apex of fact."²¹⁵

Breed's censure might have represented simple disciplinary territoriality, particularly as he attacked only the paleontologist Osborn, while remaining silent regarding Kligler's contribution to the phylogenetic hypothesis. Instead, Breed waited until the next SAB gathering to articulate a more general denouncement of evolutionary speculations. At the 1917 SAB meeting, Breed, along with his colleagues at the Geneva station Harold J. Conn and J.C. Baker, challenged the premise that members of the family *Nitrobacteriaceae* represented the primeval microbial types. After all, if the earliest forms displayed the unusual capacity to utilize inorganic material, it seemed strange that "all but a few of the organisms found today should have lost that

²¹⁵ Breed, "Popular Science," Science 46 (1917): 238-239.

power.” Also, they noted that Orla-Jensen’s exemplar of primitive bacteria, *B. methanicus*, oxidized methane arising from decomposing matter, and therefore received its energy indirectly from sunlight and plant growth. This most primeval form, it turns out, flourished under conditions arising well after the emergence of higher plants.²¹⁶

Although he remained committed to a natural system of classification, Robert Buchanan similarly criticized Osborn and Kligler’s account. Buchanan found Kligler’s conclusions “so surprising and so in conflict with commonly held opinions,” that he elected to break from disciplinary norm and challenge his taxonomic collaborator in print. Much as present plants and animals did not resemble their ancestral forms, Buchanan warned against assuming that current bacteria were “identical with, or even closely related to, the original types of bacteria which appeared upon the earth.” Without fossil records, constructing a phylogenetic account of bacteria can only be based on viewing the “tips of the ultimate twigs of the branches of the evolutionary tree.”²¹⁷ More generally, Buchanan objected to Kligler’s method of constructing phylogenetic lineages, a process by which the author simply searched for morphological and physiological similarities between types and presumed an evolutionary relationship. For Buchanan, similarities among present day forms suggested a relationship between “brothers and cousins,” not “parents and offspring.” In addition, these coinciding bacterial groups may have actually descended from different ancestries. Botanists, for example, considered it possible that seeded plants might not share the same origin. Analogously, members of the *Nitrobacteriaceae* might have arrived from

²¹⁶ Breed, Conn and Backer, “Comments on the Evolution and Classification of Bacteria,” paper presented to the 19th Annual SAB Meeting, 1917, printed in *Journal of Bacteriology* 3 (1918): 455-459.

²¹⁷ Buchanan, “The Evolution of Bacteria,” *Science* 47 (1918): 320-321; and, Buchanan, “Bacterial Phylogeny as Indicated by Modern Types,” *American Naturalist* 52 (1918): 233.

divergent evolutionary paths.²¹⁸ These criticisms aside, Buchanan willingly advanced his own phylogenetic system, detailing the junctions between *Thiobacteriales* and the blue-green algae and the *Actinomycetelas* and the fungi, along with the specific affinities among the various families and genera contained in the Committee on the Characterization and Classification of Bacterial Types' "Preliminary Report". (Fig. 6.7) While Buchanan squabbled with Kligler over the details, both endorsed the CCCBT's goal of forging a phylogenetic bacterial taxonomy.²¹⁹

In addition to disagreements generated by various attempts to outline the evolutionary affiliations among bacterial groups, the Committee understood that the very physiological tests they employed to distinguish their genera were subject to change.²²⁰ The development of serological typing threatened to complicate the CCCBT's categorizations, although most bacteriologists agreed that agglutination tests proved more useful in differentiating species, rather than separating genera.²²¹ For most part, however, the CCCBT's efforts prompted non-

²¹⁸ Buchanan, "Bacterial Phylogeny," 233-234. Buchanan insisted that the "family tree of bacteria suggested by Dr. Kligler is based upon many misconceptions and misinterpretations and can scarcely be accepted without much more adequate proof." Buchanan, "Evolution of Bacteria," 324.

²¹⁹ "The foregoing analysis would seem to indicate that the grouping of genera by the Committee on Classification, with some slight modifications possibly, represents fairly well true phylogenetic relationships of the bacteria. The exact boundaries of the families are of course of little importance providing the scheme of classification tends to show relationships." Buchanan, "Bacterial Phylogeny," 246.

²²⁰ See, for example, Max Levine, "Preliminary Note on the Classification of Some Lactose Fermenting Bacteria," Journal of Bacteriology 1 (1916): 619-621; Levine, "On the Significance of the Voges-Proskauer Reaction," Journal of Bacteriology 1 (1916): 153-164; Lore Rogers, William M. Clark and Herbert A. Lubs, "The Characteristics of Bacteria of the Colon Type Occurring in Human Feces," Journal of Bacteriology 3 (1918): 231-252; Clark and Lubs, "An Improved Differential Test for Bacteria of the Colon-Aerogenes Group," paper presented to the 18th Annual SAB meeting, 1916; and, J.J. Bronfenbrenner and M.J. Schelsinger, "The Effect of the Composition of the Medium upon the Carbohydrate Fermentation by the Bacteria of the Colon-Typhoid Group," paper presented to the 20th Annual SAB Meeting, 1918, summarized in Abstracts of Bacteriology 3 (1919): 8.

²²¹ See, Charles Krumwiede, Josephine S. Pratt, and L.A. Kohn, "Studies on the Paratyphoid-Enteritidis Group," paper presented to the 18th Annual SAB Meeting, 1916, reported in Abstracts of Bacteriology 1 (1917): 28-29, and printed in Journal of Medical Research 34 (1916): 355-358; E.O. Jordan, "The Differentiation of the Paratyphoid-Enteritidis Group," Journal of Infectious Diseases 20 (1917): 457-483; C.G.A. Roos and E. May Gray, "Studies Upon Streptococcus. II. Cultural Versus Biological Classification," paper presented at the 21st Annual SAB Meeting, 1919, summarized in Abstracts of Bacteriology 5 (1920): 15; and, Ruth Tunnicliff, "Further Studies on the Specificity of Streptococci," Journal of the American Medical Association 75 (1920): 1339.

Committee members to conduct their own systematic surveys of individual genera or physiological groups, often with the methods of the "Preliminary Report" in mind. Leo Rettger and his associates at Yale University appraised members of the proteus and colon-aerogenes groups, Fred W. Tanner of the Illinois State Water Survey arranged the green fluorescent bacteria, Alfred H. Rahe of the Cornell Medical College reviewed the aciduric forms, Iowa State's Max Levine studied the differential characters of the dysentery group. Winslow, as editor of the *Journal of Bacteriology*, ensured rapid publication of these studies in the Society's journal.²²² Meanwhile, Winslow and his colleagues at Yale Medical College returned to the *Coccaceae*, identifying additional traits in support of the CCCBT's classification.²²³

As other SAB members reexamined the families and genera of the *Eubacteriales*, Buchanan constructed taxonomies for the orders of *Schizomycetes* not detailed in the Committee's "Preliminary Report." These representatives of the "higher bacteria" (e.g., *Thiobacteriales*, *Myxobacteriales*, *Chlamydobacteriales*, and *Spirocheatales*) escaped the attention of most writers, owing to their marginal importance to medicine, agriculture, or industry. Buchanan recognized that classification of these groups remained "in a very unsatisfactory and very superficial state. Few investigators have studied these forms, and most

²²² John J. Wenner and Leo F. Rettger, "A Systematic Study of the Proteus Group of *Bacteriaceae*," *Journal of Bacteriology* 4 (1919): 331-354; Chen Chong Chen and Rettger, "A Correlation Study of the *Colon-Aerogenes* Group of Bacteria, with Special Reference to the Organisms Occuring in the Soil," *Journal of Bacteriology* 5 (1920): 253-256; Tanner, "A Study of Green Fluorescent Bacteria," *Journal of Bacteriology* 3 (1918): 63-102; Rahe, "The Classification of the Aciduric Bacteria," *Journal of Bacteriology* 3 (1918): 407-422; and Levine, "Some Differential Characters of the Group of Dysentery Bacilli," summarized in *Abstracts of Bacteriology* 4 (1920): 15, published as "Dysentery and Allied Bacilli," *Journal of Infectious Diseases* 27 (1920): 31-43.

²²³ Winslow, Elizabeth I. Parsons, and Rebecca Berland, "The Relationship between the White and Orange *Staphylococci*," paper presented to the 20th Annual SAB Meeting, 1918; and, Winslow, William Rothberg, and Parsons, "Notes on the Classification of White and Orange *Staphylococci*," *Journal of Bacteriology* 5 (1920): 145-167.

of the work is old, and in need of careful revision.” The other Committee members eagerly ceded the chore of revision to Buchanan, who formulated families and genera of these unusual forms according to their complex morphologies and life histories.²²⁴ Buchanan’s yeoman’s effort arranging these intractable types went largely unnoticed, drawing little comment from either the SAB or members of the Committee.

Resistance and Revision

In the years immediately following publication of the “Preliminary Report,” the Committee faced a few direct challenges to its taxonomic system. Correspondence between SAB members and the Committee reveals that some American bacteriologists perceived neither the need nor the desirability for radical reform. The Committee’s ardor for change was matched by equally fervent commitment to the status quo among medical and non-medical members. Most objections concerned the myriad generic terms replacing the familiar names *Bacillus* and *Bacterium*. The Committee anticipated this source of discontent, reasoning that time and familiarity would eventually sway the more reluctant practitioners to the new terminology. They encountered greater difficulty, however, in answering those who objected to the Committee’s classification. Some criticized the “Preliminary Report” for offering a physiology-based system on par with Orla-Jensen’s scheme. Others found the Committee’s many families and genera

²²⁴ Buchanan, “Studies in the Classification and Nomenclature of the Bacteria. VII. The Subgroups and Genera of the *Chlamydo bacteriales*,” *Journal of Bacteriology* 3 (1918): 301-306; Buchanan, “Studies in the Classification and Nomenclature. IX. The Subgroups and Genera of *Thiobacteriales*,” *Journal of Bacteriology* 3 (1918): 461-474; and, Buchanan, “Studies in the Classification and Nomenclature of the Bacteria. X. Subgroups and Genera of the *Myxobacteriales* and *Spirocheatales*,” *Journal of Bacteriology* 3 (1918): 541-543. At Iowa State College, Dean Robert Buchanan’s influence prompted the founding of a small cottage industry in bacterial systematics. See, for example, Hans A. Bendixen, “A Study of the *Streptococci*” (Masters thesis, Iowa State College, 1921); and, Edna E. Dean, “The Group of Acetic Acid Bacteria” (Masters thesis, Iowa State College, 1921).

confusing, and difficult to remember.

Curiously, Robert Buchanan complicated the CCCBT's chore of coaxing Society members to the new systematics. Between 1916 and 1918, Buchanan published ten articles in the *Journal of Bacteriology* entitled "Studies in the Nomenclature and Classification of Bacteria." Half these contributions directly supported the Committee's efforts, either by deciphering the International Rules of Botanical Nomenclature or by outlining the orders of higher bacteria not covered by the "Preliminary Report." Even so, Buchanan disagreed with other Committee members on several points, and recommended splitting genera in some instances, and lumping them in others.²²⁵ Buchanan outlined an entire classification more detailed and varied than the CCCBT's. For example, Buchanan created tribes between families and genera, and sub-genera between genera and species. These added taxa allowed Buchanan to assemble groups familiar to practicing bacteriologists while still adhering to CCCBT's general scheme.²²⁶ He too employed a combination of morphological, cultural and physiological characters, believing the latter two categories separated similar forms into related groups. However, Buchanan hesitated to erect families primarily on the basis of physiology. He offered only four families of the *Eubacteriales* (*Coccaceae*, *Bacteriaceae*, *Spirillaceae*, and *Nitrobacteriaceae*), compared with the CCCBT's eight.²²⁷ (Fig. 6.8)

²²⁵ Buchanan, "Some Possible Additions to the Genera of Bacteria Recognized by the Committee," paper presented to the 19th Annual SAB Meeting, 1917, reported in *Abstracts of Bacteriology* 2 (1918): 8-9.

²²⁶ Buchanan, "Studies in the Nomenclature and Classification of Bacteria. II. The Primary Subdivisions of the *Schizomycetes*," *Journal of Bacteriology* 2 (1917): 155-164, esp. 161-163.

²²⁷ Buchanan elevated the rank of *Actinomycetes* from a family to an order, reduced *Mycobacteriaceae* and *Bacillaceae* from families to tribes, and reduced *Pseudomonadaceae* and *Lactobacillaceae* from families to genera. Buchanan, "Studies in the Nomenclature and Classification of Bacteria. III. The Families of the *Eubacteriales*," *Journal of Bacteriology* 2 (1917): 347-350; and, Buchanan, "Studies in the Nomenclature and Classification of the Bacteria. III. The Subgroups and Genera of the *Actinomycetales*," *Journal of Bacteriology* 3 (1918): 403-407.

Within the *Coccaceae* and *Bacteriaceae*, Buchanan suggested several changes to the "Preliminary Report." Regarding the *Coccaceae*, Buchanan proposed nine genera, removing the white pigmented *Albococcus*, and adding *Leuconostoc* for the zoogloal masses growing in sugar solutions, *Diplococcus* for the Gram-positive pairs, and *Siderocapsa* for unusual oval form, containing iron sheaths, found on water plants. Despite these changes, most bacteriologists noticed little difference between Buchanan's system and the Committee's. The common or notorious forms remained in the familiar categories of *Streptococcus*, *Micrococcus*, *Staphylococcus* or *Neisseria*.²²⁸

Buchanan's organization of the *Bacteriaceae* constituted a radical departure from the CCCBT's "Preliminary Report." Initially, his family included the tribes *Bacilleae* and *Mycobacterieae*, divisions that represented their own families for the Committee. Within the *Bacilleae*, Buchanan offered four genera, compared with the CCCBT's two, distinguished on the basis of oxygen relations and spore characteristics. In addition to the Committee's *Bacillus* and *Clostridium*, Buchanan offered the new genus *Plectridium* for anaerobic forms producing spores at the extreme tips of cells, and *Metabacterium* for types developing several spores simultaneously. He even considered dividing *Bacillus* into smaller units, proposing the sub-generic categories *Eu-bacillus*, *Bacteridium*, and *Astasia* to describe the specific morphology of the spores. In contrast to the cleaving of *Bacilleae*, Buchanan circumscribed the tribe *Mycobacterieae* to a limited number of acid-fast branching forms (e.g., *Mycobacterium tuberculosis*) contained in one genus. In Buchanan's taxonomy, the six genera of the CCCBT's

²²⁸ Buchanan, "Studies in the Nomenclature and Classification of the Bacteria. IV. The Groups and Genera of the *Coccaceae*," *Journal of Bacteriology* 2 (1917): 603-617.

expansive *Mycobacteriaceae* found new homes in different tribes and families.²²⁹

Within the tribe *Bacteriae* Buchanan fashioned four sub-tribes (*Fusiforminae*, *Hemophilinae*, *Rhizobiinae*, and *Bacteriinae*), split into sixteen genera. The CCCBT placed many of these genera in families other than *Bacteriaceae*. The "Preliminary Report," for example, lodged *Rhizobium* (symbiotic nitrogen fixing forms), *Azotobacter* (non-symbiotic nitrogen fixers), and *Mycoderma* (acetic acid oxidizers termed *Acetobacter*) within their *Nitrobacteriaceae*. By transferring these rods to *Bacteriaceae* Buchanan suggested that their metabolism, which required carbon substances, did not resemble the autotrophic organisms capable of deriving their energy entirely from inorganic compounds (e.g., *Nitrosomonas*, *Nitrobacter*, *Carboxydomonas*, and *Methanomonas*).²³⁰ For *Pseudomonas* and *Lactobacillus*, which the Committee assigned to their own families, Buchanan's relocation to simple genera within *Bacteriae* indicated that he did not consider their distinguishing traits worthy of their own high taxa.

Buchanan created six new genera for the rod-shaped bacteria. Within *Hemophilinae*, he added *Asterococcus* as another group of parasites requiring hemoglobin culture media. Under the sub-tribe *Bacteriinae*, Buchanan introduced *Serratia* for the red pigmented aerobes, *Chromobacterium* for the violet pigmented water forms, *Proteus* for pleomorphic sources of

²²⁹ Buchanan, "Studies in the Nomenclature and Classification of the Bacteria. V. Subgroups and Genera of the *Bacteriaceae*," *Journal of Bacteriology* 3 (1918): 27-61. Curiously, Buchanan placed the filamentous *Fusiformis* and the clubbed *Corynebacterium* in the tribe *Bacterieae*, rather than *Mycobacterieae*.

²³⁰ Buchanan noted that there was "some doubt as to the appropriateness of *Mycoderma* as the name of the genus," as it was used also for yeasts. As for *Rhizobium*, Buchanan mentioned that "the name of this genus has been a source of confusion," as Beijerinck termed it *B. radicola*. The status of *Azotobacter* remained similarly in doubt. Felix Lohnis reported having demonstrated spores, which would force its removal to the genus *Bacillus*. Buchanan, "Subgroups and Genera of the *Bacteriaceae*," 45-46; and, Buchanan, "Studies in the Nomenclature and Classification of Bacteria. VI. Subdivisions and Genera of the *Spirillaceae* and *Nitrobacteriaceae*," *Journal of Bacteriology* 3 (1918): 175-181.

putrefaction, *Pfeifferella* for the slender branching agent of glanders, and *Erysipelothrix* for the parasitic types displaying slender, long filaments. Regarding the genus *Bacterium*, Buchanan noted that even with six additional genera, *Bacterium* continued to encompass a great diversity and number of forms. Guided by his predilection toward splitting, Buchanan proffered three subgenera (*Aerobacter*, *Salmonella*, and *Eberthella*) differentiated on the basis of fermentation reactions.²³¹

Buchanan understood that the publication of his alternative taxonomy would likely elicit confusion, if not animosity, among members of the SAB and even the CCCBT. Buchanan served on the Committee, acting as the authority on matters of nomenclatural rules, and a specialist on the orders of higher bacteria. Chairman of the Committee C.-E.A. Winslow publically entreated SAB members to criticize and debate the CCCBT's "Preliminary Report." Buchanan honored that request, offering a classification system congruent with the Committee's aims, but differing in detail and taxonomic divisions. Nonetheless, Buchanan's articles enervated the appeal of the "Preliminary Report." The same year that the Committee issued its proposed taxonomy, Buchanan ascended to the presidency of the SAB. The Committee could hardly expect society members to adopt a radically different nomenclature and classification when the CCCBT itself could not reach a consensus.

If Buchanan's "Studies in the Nomenclature and Classification of Bacteria" represented a loose challenge to the authority of CCCBT's "Preliminary Report," criticisms from other SAB members presented a forceful indictment of the Committee's taxonomic reform. Robert S. Breed, Harold J. Conn and J.C. Baker, from the New York Agricultural Experiment Station in

²³¹ Buchanan, "Subgroups and Genera of the *Bacteriaceae*," 49-50.

Geneva, impugned the Committee's endeavor on several grounds. Initially, they repeated their disapproval of phylogenetic conjectures, arguing that every natural classification stood "open to equal criticism." Breed, Conn and Baker warned that the CCCBT's classification "implies the acceptance of certain evolutionary theories which the society will endorse if it accepts their reports." They pointed to the family *Nitrobacteriaceae*, which the Committee created based on Orla-Jensen's premise that these autotrophic forms represented the most primitive organisms. But Breed, Conn and Baker argued that all ancient bacterial types were most likely extinct. "To accept this family, then is really to endorse the theory that its members are modern representatives of the primordial bacteria," a suspect theory that would "hardly be accepted by conservative bacteriologists."²³²

Breed and company railed against the Committee's genera of the *Bacteriaceae*, insisting that *Hemophilus*, *Pasteurella* and *Erwinia* violated good taxonomic sense by forging taxa based on pathogenicity. They doubted whether the "peritrichic plant parasites" of *Erwinia* were "sufficiently distinct from saprophytes to be put in a genus by themselves." As for the genus *Bacterium*, the Geneva bacteriologists believed that the Committee's choice of type species, *B. coli*, did not represent the eclectic species contained in the group. Rather than establish genera on tenuous premises, Breed, Conn and Baker suggested an appendix to the families of *Eubacteriales* to contain all poorly defined types. "The mycologists recognize a group which they call *Fungi Imperfecti*. Bacteriologists might equally well create a group of *Bacteria*

²³² "It is evident that if the society adopts the committee report, it will be committing itself as favoring Jensen's arguments, and before doing this it is necessary to be sure that there are no other equally tenable theories as to primordial life." Breed, Conn and Baker, "Comments on the Evolution and Classification of Bacteria," paper presented to the 19th Annual SAB Meeting, 1917, published in *Journal of Bacteriology* 3 (1918): 455, 448 & 449.

Imperfecta."²³³

More generally, Breed and his associates protested the authority granted to the Committee on the Characterization and Classification of Bacterial Types. They noted that the Committee adopted the guidelines of the International Code of Botanic Nomenclature, although "No opportunity had been given to the society to study the matter, and naturally the resolution was passed." They worry that the SAB granted undue deference to the Committee:

No other committee on systematic biology appointed by a national or international society has ever undertaken such an ambitious task as a complete classification of any group of animals or plants. Other committees of this sort have done nothing further than to pass upon the validity of generic and specific names submitted to them, leaving it to individual initiatives to propose new names, to classify and to define the groups.²³⁴

Given the authority granted to the Committee, Breed, Conn and Baker believed that the "Preliminary Report" might actually truncate meaningful debate.

Felix Lohnis and Freeman M. Scales, from the Bureau of Plant Industry, echoed Breed's critique. While they lauded the Committee's attempt to "free American bacteriology from the highly artificial system of Migula," they doubted the reliability of Orla-Jensen's "natural system." The Committee mistakenly borrowed from Orla-Jensen physiological scheme, where "hypothesis and fiction reign supreme," creating such taxa as the *Nitrobacteriaceae* to assemble a "collection of the most heterogenous bacteria brought together on an entirely fictitious basis."

Like Breed and his colleagues, Lohnis and Scales believed that the Committee composed its

²³³ Breed, Conn and Baker, "Comments on the Evolution and Classification of Bacteria," 454-455. Similarly, they found "very little reason for putting the *Bulgaricus* type of organisms in a family by themselves." True, they differed greatly from most Gram-negative rods, but these differences justified only the creation of a new genus *Lactobacillus*, and not an entire family, 455. Breed and company stressed the priority of morphological traits, proposing that *Actinomycetales* should constitute its own order, while *Rhizobium* should be moved to *Pseudomonadaceae* on account of its flagella.

²³⁴ Breed, Conn and Baker, "Comments on the Evolution and Classification of Bacteria," 456-457.

reports in an insular manner, disregarding the opinion of those "men who are already well acquainted with one or the other of the important groups of bacteria . . ." ²³⁵

The Committee entertained these criticisms in all seriousness. In 1919, Winslow asked Robert S. Breed to join the CCCBT, and promptly assigned Breed the task of selecting type species for the genera *Pseudomonas*, *Actinomyces* and *Nocardia*. Upon his arrival, the Committee also accepted Breed's recommendation that *Actinomyces* be removed from the *Mycobacteriaceae* and elevated to its own family. ²³⁶ The next year, Breed earned membership to the Botanical Society of America's Committee on Code Revision, in order to ensure that botanists considered the interests of bacteriologists as they debated the provisions of the International Code of Botanical Nomenclature. ²³⁷ Breed's participation on these two committees effected a profound change in his taxonomic thinking. Not only did Breed become a supporter of the International Code, but he soon advocated that "observations on the habitat and distribution of bacteria," including pathogenicity, should be employed in "interpreting the probable evolutionary development of this group of plants." ²³⁸

²³⁵ Lohnis and Smith, "Some Remarks Concerning the Characterization and Classification of Bacteria," paper presented to the 19th Annual SAB Meeting, 1917, reported in Abstracts of Bacteriology 2 (1918): 9. Reaction from foreign bacteriologist was initially critical. Otto Rahn, who spent six years in this country (1908-1914) at Michigan Agricultural College and the University of Illinois, objected to the Committee's "Attempt at a Natural Classification of Bacteria," Centralbl. f. Bakt. Abt. II, 50 (1920): 273-293. In Rahn's opinion, the many transition and intermediate forms of bacteria rendered the Committee's taxonomic groups suspect.

²³⁶ See, Robert S. Breed and Harold J. Conn, "The Nomenclature of the *Actinomycetaceae*," Journal of Bacteriology 4 (1919): 584-602. Breed and Conn began by documenting the great diversity in nomenclature for these types, including *Streptothrix*, *Discomyces*, *Carterii*, *Actinocladothrix*, and *Oospora*. The confusion was due in part to inadequate descriptions of several type species, the development of new techniques for studying the variant forms, and the disregard for the rules of nomenclature.

²³⁷ Breed, "The Work of the Committee on Nomenclature of the Botanical Society of America," report delivered to the 22nd Annual SAB Meeting, 1920, summarized in Abstracts of Bacteriology 5 (1921): 1.

²³⁸ Breed, "Some Observations on the Habitat and Distribution of Bacteria," paper presented to the 23rd Annual SAB Meeting, 1921, reported in Abstracts of Bacteriology 6 (1922): 11. See also, Breed, "Some Problems in the Nomenclature of Bacteria," Abstracts of Bacteriology 6 (1922): 484-485.

In composing its "Final Report," the Committee incorporated many of Breed's and Buchanan's suggestions.²³⁹ At the onset, the CCCBT now emphasized the role of type species in distinguishing genera, rather than rely entirely on generic descriptions. This decision aligned the SAB with Botanical Society of America, who repeatedly petitioned International Botanical Congresses to recognize type-based generic diagnoses.²⁴⁰ The Committee also issued its list of *genera conservanda* for review at the next International Botanical Congress. The list included seventeen generic names which the Committee sought to preserve, even though they violated the law of priority. According to the "Final Report," these generic names had "come into such general use that their abandonment would cause confusion, particularly in dealing with the large number of medical bacteriologists who are not familiar with the principles of botanical taxonomy." Certainly, the Committee recognized that medical practitioners would want to retain the familiar generic terms *Micrococcus*, *Bacterium*, *Bacillus* and *Sarcina*. Yet, the Committee also placed a series of their own taxonomic creations on the list (e.g., *Acetobacter*, *Chromobacterium*, *Erythrobacillus*), names which very few medical bacteriologists knew.

Winslow acknowledged Breed's concern that the CCCBT's "Final Report" might be seen as undeservedly authoritative, thereby imposing "arbitrary limits upon the development of the changing science of systematic bacteriology." In Winslow's opinion, however, the Committee's

²³⁹ Winslow et al., "Final Report," 191-229. In a footnote to the title page of the report, Winslow indicated that Breed "cooperated actively in the work of the Committee during the past two years, but has not felt that he could accept formal membership on the Committee."

²⁴⁰ I.S. Falk, summary of the "Report of the Committee on the Characterization and Classification of Bacterial Types," *Abstracts of Bacteriology* 5 (1921): 348. The Committee realized that the status of type species differed in bacteriology than in botany. "In the latter case actual type species have been deposited in herbaria and are available for reference; while among the bacteria this is not the case except for a few type species which have recently been deposited in the collection of the American Museum of Natural History in New York." Winslow et al., "Final Report," 193.

"Final Report" served only as an outline, one subject to modification "with the progress of investigation by individual systematists of the future," particularly regarding its families. The CCCBT offered only a "Final Report" not a final classification. Moreover, the Committee's generic names were "in no sense presented as official or binding."²⁴¹ Nonetheless, in the interest of "stability of nomenclature," the Committee asserted that it was "essential that certain generic names should be formally adopted by the Society . . ."²⁴²

As for the content of the "Final Report," the Committee altered many details of their earlier scheme. (Fig. 6.9) They acceded to Buchanan's and Breed's call for elevating *Actinomycetes* to its own order, owing to the unique morphology of these branching and filamentous forms. While they accepted many of Buchanan's proposed genera (*e.g.*, *Actinobacillus*, *Pfeifferella*, and *Erysipelothrix*), the Committee maintained its burgeoning families of *Actinomycetaceae* and *Mycobacteriaceae*.²⁴³ Among the true bacteria of *Eubacteriales*, the Committee followed Buchanan precedent in creating tribes between families and genera. For the most part, the families *Nitrobacteriaceae*, *Pseudomonadaceae*, *Spirillaceae*, and *Bacillaceae* remained unchanged.²⁴⁴ Within the *Coccaceae*, Winslow and company added a third tribe, *Neisseria*, to distinguish these Gram-negative pathogenic cocci from the Gram-positive parasites of the *Streptococci*. In addition, the Committee headed Buchanan's counsel

²⁴¹ Winslow et al., "Final Report," 192 & 194.

²⁴² Winslow et al., "Final Report," 194-195.

²⁴³ In a curious qualification, the Committee admitted that the "real lines of demarcation between the genera *Actinobacillus*, *Erysipelothrix*, *Fusiformis* and *Pfeifferella* and their relations to *Actinomyces* on the one hand, and to *Mycobacterium* on the other seem very obscure and the above arrangement can be considered as only tentative." Winslow et al., "Final Report," 200.

²⁴⁴ Breed, Conn and Baker had argued that *Rhizobium* should be moved from *Nitrobacteriaceae* to *Pseudomonadaceae*, owing to the presence of polar flagella. The Committee rejected this appeal, choosing to keep these nitrogen fixers with physiologically similar forms. Similarly, the Committee disagreed with Buchanan's recommendation that *Pseudomonadaceae* be demoted to genus within *Bacteriaceae*. Winslow et al., "Final Report," 193-194.

to fold *Albococcus* into *Staphylococcus*, create *Diplococcus* for pairs of cocci not forming longer chains, and establish *Leuconostoc* for the usual saprophytes forming zoogloal masses on cane sugar solutions. Moreover, the Committee attached detailed physiological characterizations to each genus of the *Coccaceae*. For example, the "Final Report" distinguished *Streptococcus* and *Diplococcus* on the basis of inulin fermentation, a differential test entirely absent from the "Preliminary Report." Likewise, *Staphylococcus* differed from *Streptococcus* not only in chain formation among the latter, but also active gelatin liquefaction among members of the former.²⁴⁵

In the CCCBT's "Preliminary Report," the Committee assigned only four genera to the family *Bacteriaceae*. Three years later, the Committee adopted many of Buchanan's proposals, offering seven tribes and nine genera. The "Final Report" reduced *Lactobacillaceae* from a family to a genus, while it added *Chromobacterium* and *Erythrobacillus* for the pigmented water forms, *Proteus* for the pleomorphic putrefiers, and *Zopfius* for Gram-positive rods lacking any fermentative power. Even so, the CCCBT did not show a willingness to split *Bacteriaceae* as far as Buchanan recommended, declining to adopt the genus *Asterococcus* or create three sub-genera for *Bacterium*. In an analogous manner, the Committee decided against dividing *Bacillus* into several genera on the basis of spore morphology. The "Final Report," in many regards, represented the Committee's attempts to balance the splitting tendencies of Buchanan with the conservatism of Breed.

The Committee on the Characterization and Classification of Bacterial types found response to their "Final Report" somewhat discouraging. Much to Winslow's dismay, the report's publication did not immediately transform taxonomic practices. Bacteriologists

²⁴⁵ Winslow et al., "Final Report," 205.

continued to teach and employ the *ad hoc* physiological groups, paying only mock deference to the list of *genera conservanda*. The CCCBT may have been able to reach a consensus amongst themselves, but found that achievement difficult to duplicate writ large. SAB members criticized the "Final Report" for being simultaneously too immoderate and too conservative. For the medical community in particular, the SAB's new taxonomy introduced too many unfamiliar designations, replacing several names anchored by decades of use. For non-medical practitioners, the Committee failed to provide a convincing argument for the phylogenetic theory underlying its "natural" classification.²⁴⁶

The Committee did take a few steps to encourage acceptance of its new scheme. The "Final Report" included an "artificial key," to aid in bacterial determination. With an eye toward the younger generation of bacteriologists, the Committee explained that it "should be possible to place a key of this kind in the hands of a student and enable him at least to determine the general generic group to which an organism belongs." A year later, Harold Macy of the University of Minnesota produced a simplified "Chart of the Families and Genera of the Bacteria." Like the Artificial Key, Macy intended his Chart to be use for instruction. (Fig. 6.10) As a short, half-page visual summary of the Committee's efforts, the Chart could be incorporate with ease in bacteriological textbooks.²⁴⁷ The final report also included a "generic index of the commoner species of bacteria with the names ordinarily used in the texts and wit the new nomenclature indicated by the proposed classification." Prepared by Dorothy F. Holland, a colleague of

²⁴⁶ David H. Bergey, "Difficulties Encountered in the Classification of Bacteria," Abstracts of Bacteriology 7 (1923): 276.

²⁴⁷ Falk, "Report of the Committee on the Characterization and Classification," 348-349; Winslow et al., "Final Report," 194; and, Macy, "Chart of the Families and Genera of the Bacteria," Journal of Bacteriology 6 (1921); 575-576.

Winslow's at Yale, the index offered a translational guide to the new genera.²⁴⁸ Holland's catalog, however, equally reminded some SAB members of the magnitude of the proposed changes.²⁴⁹ As Roland Cowart observed in his Master's thesis at the Mississippi A&M, the objection to the system was "not so much that it is inaccurate, as it is long and cumbersome."²⁵⁰

To other sympathetic observers, the changes were warranted, even if unpleasant. At the very least, the Committee's two reports instilled a growing acceptance of physiological characters in the classification of bacteria.²⁵¹

After the publication of the "Final Report," the SAB dissolved the Committee on the Characterization and Classification of Bacterial Types, creating in its stead a Committee on Taxonomy, chaired by Robert Buchanan.²⁵² In his first report to Society, Buchanan suggested

²⁴⁸ Winslow et al., "Final Report," 194.

²⁴⁹ When viewed against Migula's or Chester's schemes, the CCCBT's taxonomy forced a change in the names of numerous types. From from *Bacillus* to *Bacterium* were the species: *abortus*, *acidi-lactici*, *aerogenes*, *alcaligenes*, *anthracis*, *capsulatus*, *cholerae-suis*, *coli*, *syseneriae*, *enteritidis*, *gallinarum*, *melitensis*, *paratyphosus*, *pneumonia*, *psittacosis*, *pullorum*, *sanguinarium*, *Shiga*, *suipestifer*, *typhii*, and *typhosus*. Several species moved to the new genus *Erythrobacillus*: *arborescens*, *erythrogenes*, *indicus*, *mycoides-roseus*, *prodigosus*, *rosaceus*, and *ruber*. Many pathogens showing a tendency to branch transferred to either *Mycobacterium* (*leprae*, *smegmatis*, and *tuberculosis*), *Corynebacterium* (*diphtheria*, *Hoffmanii*, *pseudodiphtheriae*), or *Fusiformis*. Those curved pathogens became members of *Vibrio*: *cholera*, *comma* and *phosphorescens*. *Erwinia* received the plant pathogens: *carotovorus*, *lathyri*, *melonis*, *oleraceae*, and *phytophthora*. *Zopfius* picked up *Zenkeri*. The pleomorphic forms went to *Proteus*: *mirabilis*, and *vulgaris*. Lactic acid forms went to *Lactobacillus*: *acidificans-longissimus*, *acidophilus*, *bifidus*, *bulgaricus*, *caucasicus*, and *Delbrucki*. Some of the parasitic forms found a home in *Pasteurella*: *avisepticus*, *bovisepticus*, *cholerae-gallinarum*, *pestis*, and *suisepiticus*. Others shifted to *Hemophilus*: *influenzae* and *pertusis*. Moving from *Bacillus* to *Clostridium* were: *aerogenes-capsulatus*, *amylobacter*, *anthracis symptomatici*, *botulinus*, *butyricum*, *chauvei*, *enteritidis-sporogenes*, *perfringens*, *putrificum*, *sporogenes*, *tetani*, and *Welchii*.

²⁵⁰ Cowart, "Colon Characters as a Factor in Determining Species," (Masters thesis, Mississippi Agricultural and Mechanical College, 1921), 1.

²⁵¹ Joseph Greaves, in his textbook, attributed the necessary revisions to a process of disciplinary maturation: "When one passes from a study of the practical effects of the activity of some particular microbe to a consideration of its relationship to other forms it becomes essential not only to have a name for each kind of organism but to have also a system of nomenclature which will make it possible to express such relationship with reasonable clearness and accuracy." Greaves, Agricultural Bacteriology, 48. See also, Frost, "Classification," in Microbiology, 3rd ed, 112.

²⁵² The SAB authorized the new Committee to appoint new members "from time to time as new points should come up." C.-E.A. Winslow, "Report of the Committee on the Characterization and Classification, Minutes of the 21st Annual SAB Meeting, 1919," [ASM] box1-IVA, folder 3, pp. 5-6, and 14.

that the new Committee would gladly provide assistance to any bacteriologist "puzzled as to the correct use" of bacterial names. In fact, "several members of the Society and others have availed themselves during the past year of this opportunity, and have received suggestions from the Committee."²⁵³ Buchanan, in fact, suggested that the Committee on Taxonomy produce "abridged keys to the recognized genera of bacteria" tailored for specific use among medical bacteriologists, phytopathologists, soil scientists, dairymen, etc. Buchanan expected that authors would eagerly integrate such customized keys into their textbooks.²⁵⁴ Within a year Buchanan transformed his Committee on Taxonomy into a full-time service agency, offering advice to those coining generic and specific terms for newly described forms. Buchanan reasoned that many "generic terms have been proposed in good faith," only to be challenged on the ground that they have not been "properly formed." The Committee on Taxonomy assumed the role of arbiter, approving those names that met the strident conventions of botanical nomenclature. In other actions, the Committee selected a single designation for the common lactic acid dairy microbe (*Streptococcus lactis* Lister), debated the desirability of splitting the genus *Bacterium* into smaller categories, and pursued changes in the Type Basis Code of the Botanical of America.²⁵⁵

The "Final Report" and the Committee on Taxonomy enkindled efforts to reexamine the status of problematic taxa. More importantly, the Committee directed bacteriologists to revise the taxonomy of species, and not just genera, tribes and families. Lore Rogers, who served as a

²⁵³ Buchanan, "Report of the Committee on Taxonomy, Minutes of the 22nd Annual SAB Meeting, 1920," [ASM] box1-VA, folder 4, pp. 14-16.

²⁵⁴ Buchanan, "Report of the Committee on Taxonomy, 1920," 15. See also, A.P. Hitchens, Washington D.C., 27 March 1922, "Report of the Secretary upon the Philadelphia Meeting of the Society of American Bacteriologists," [ASM] box 1-VB, folder 1, p. 9.

²⁵⁵ Hitchens, "Report the Secretary upon the Philadelphia Meeting," p. 9.

member of the CCCBT as well as the new Committee on Taxonomy, argued for division of *Bacterium*'s colon-aerogenes group according to the "actual relationships and lines of descent." True, fermentation reactions supplied four defined clusters, but there was "no evidence to show that it has any relation to the evolution of the group . . ." ²⁵⁶ John C. Weldin heeded Roger's call, penning his Master's thesis on the "Species of the Genus *Bacterium*." Weldin maintained that the "Final Report" failed to properly classify these non-spore forming rods, leaving *Bacterium* as a quintessential "not as above" category. Its members did not display oxidative metabolism, were not given to extreme pleomorphism, did show polar flagella, did not stain in a bipolar fashion, and did not produce pigments. As the genus of exclusion, *Bacterium* included a vast range of unrelated forms. Weldin advocated dividing the genus into five groups (*Escherichia*, *Salmonella*, *Eberthella*, *Shiga*, and *Alcaligenes*), based on a detailed combination of fermentation powers and morphological characters. ²⁵⁷

In a similar manner, Hilda H. Heller, from the University of California Medical School's Hooper Foundation, sought to reorganize the anaerobic spore-forming rods. The CCCBT assigned these forms to a single genus, *Clostridium*, within the family *Bacillaceae*, a "chaotic and unsatisfactory" arrangement of nearly one hundred species displaying "great differences in their behavior." ²⁵⁸ Heller argued that former Committee committed an error in assigning taxonomic priority to spore formation. In Heller's estimation, sporulating anaerobic rods shared

²⁵⁶ Rogers, "Characteristics and Distribution of the Colon-Aerogenes Group," 78.

²⁵⁷ Weldin, "The Species of the Genus *Bacterium* Ehrenberg, Emend. Jensen," (Master's thesis, Iowa State College, 1921), 5-12. Weldin drew from Aldo Castellani and Albert J. Chalmer's taxonomy presented in their *Manual of Tropical Medicine*, 3rd ed. (New York: William Wood and Co., 1919). See also, Weldin and Max Levine, "An Artificial Key to the Species and Varieties of the Colon Typhoid or Intestinal Group of Bacilli," paper presented to the 24th Annual SAB meeting, 1922, summarized in *Abstracts of Bacteriology* 7 (1923): 13-14.

²⁵⁸ Heller, "Suggestions Concerning a Rational Basis for the Classification of Anaerobic Bacteria." *Journal of Bacteriology* 6 (1921): 522-523.

many similarities with non-sporulating forms. She drew a comparison to systematic entomology, where wingless insects often resembled winged forms. As a consequence, the possession of "wings, conspicuous insect characteristic that it is, has been discarded as a character for the separation of insects from other forms." The "Final Report," according to Heller, superimposed a morphological taxonomy of *Bacillaceae* upon a physiological one, resulting in a "division that is impossible to carry out."²⁵⁹ Unlike other SAB members, who found fault with the CCCBT's reliance on physiological characters, Heller called for a "natural classification" based on metabolic properties. Moreover, Heller believed that "after a logically and fundamentally historical chemical classification has been made, morphological characteristics will be found which will be consistent with it."²⁶⁰ Heller constructed more than a dozen new genera for anaerobic rods based on "susceptibility to free oxygen," ability to ferment carbohydrates, source of nitrogen, proteolytic power, and production of hydrogen sulphide.²⁶¹

In several respects, Heller's appeal recalled the 1909 physiological classification of Orla-

²⁵⁹ Heller, "Suggestions Concerning a Rational Basis for the Classification of Anaerobic Bacteria," 529-530. Heller complained that CCCBT slighted anaerobic bacteria only "because these organisms have been so slightly studied Probably none of the botanical or zoological families contain nearly as many species as may be found among the anaerobic rods." Heller, in fact, suggested that the group deserved the rank of an entire order, but conceded that "we must be modest in our demands," p. 537.

²⁶⁰ These traits were not likely to be the gross form of rods, or the position of spores, for those were "not fundamental morphological characters . . ." Rather, "a highly refined cytological technique such as has never been generally applied to our organisms might reveal consistent morphological characters." Heller, "Classification of the Anaerobic Bacteria," *Journal of Bacteriology* 6 (1921): 533.

²⁶¹ Heller, "Certain Genera of the *Clostridiaceae*," (*Journal of Bacteriology* 7 (1922): 1-21. Not all researchers of spore-forming anaerobes agreed with Heller. Ivan C. Hall, also from the University of California, maintained the emphasis on morphological features, differentiating the group by position and characteristic of spores during formation. Hall, "A Differential Key for the Identification of the Sporulating Anaerobes," paper presented to the 23rd Annual SAB meeting, summarized in, *Abstracts of Bacteriology* 6 (1922): 8, and published as, "Differentiation and Identification of the Sporulating Anaerobes," *Journal of Infectious Diseases* 30 (1922): 445-504. Morton C. Kahn, speaking before the same meeting, disagreed, advocating that the sporulating anaerobes could be differentiated only on the basis of "carbohydrate splitting properties." Kahn, "A Cultural Study of Anaerobic Spore-bearing Bacteria with Stains Purified by the Barber Single Cell Technique," paper presented to the 23rd Annual SAB meeting, summarized in *Abstracts of Bacteriology* 6 (1922): 9.

Jensen. The Dutch bacteriologist, however, provided his own critique of the "Final Report." Writing in the SAB's *Journal of Bacteriology*, Orla-Jensen reproached the Society for unilaterally issuing a revised taxonomy, and called for the establishment of international body. Substantively, Orla-Jensen argued that the CCCBT "displayed a great deal of conservatism" in the construction of its thirty-eight genera. The Committee, Orla-Jensen noted, still retained morphology as the preeminent criteria for many of its taxa, "simply adding to the old designations a prefix which characterizes the genus more closely."²⁶² Writing from Germany, Felix Lohnis delivered the opposite critique of the "Final Report." Lohnis wondered why the SAB rejected Migula's taxonomy, only to embrace Orla-Jensen's, a scheme relying on "more or less uncertain biochemical facts and hypotheses . . ." In Lohnis' opinion, the CCCBT endorsed a hopeless search for a natural classification, one producing greater confusion and frustration.²⁶³

Buchanan and the Committee on Taxonomy remained largely impervious to these criticisms. In the second report of the new Committee, Breed, speaking in the absence of Buchanan, acknowledged a lingering dissatisfaction among some bacteriologists. Nonetheless, the Committee maintained that it was "unlikely that there will ever be unanimous agreement upon every point, and certain groups of bacteriologists are likely to adopt the Society's report with reluctance, if at all. Such individuals cannot be permitted to interfere with this important phase in the development of our science."²⁶⁴ Undaunted, the Committee continued with its

²⁶² S. Orla-Jensen, "The Main Lines of the Natural Bacterial System," *Journal of Bacteriology* 6 (1921): 263-273. See also, Orla-Jensen, "The Lactic Acid Bacteria," *Memoirs de l'Academy Royale des Sciences et des Lettres de Danemark* 5 (1919): 81-196, summarized in *Abstracts of Bacteriology* 4 (1920): 102; and, Paul G. Heinemann, "Orla-Jensen's Classification of Lactic Acid Bacteria," *Journal of Dairy Science* 3 (1920): 143-155.

²⁶³ Lohnis and Fred, *Textbook of Agricultural Bacteriology*, 1st ed., 34-37.

²⁶⁴ Breed, "Report of the Committee on Taxonomy," in Hitchens, "Report of the Secretary upon the Philadelphia Meeting," p. 9.

revision of individual taxonomic groups. Buchanan and his associates at Iowa State reexamined the genus *Bacterium*, Breed canvassed the red chromogenic rods, and Breed's junior colleague George J. Hucker scrutinized the genera of the *Coccaceae*.²⁶⁵ The Committee acted with the full sanction of the SAB's executive council. Society President Francis C. Harrison insisted that the "intrinsic value" of the new taxonomy "would find a place in every laboratory and succeeding generations of students and workers would rise up and called us blessed."²⁶⁶

Harrison, a former CCCBT member, cultivated a penchant for hyperbole. Even so, many SAB members recognized the opportunity for meaningful taxonomic reform. New York City Department of Public Health's William H. Park and Anna W. Williams revised the 8th edition of their textbook of *Pathogenic Microorganisms* such that "the grouping of different microorganisms conforms more closely to the classification adopted by the Society of American Bacteriologists." They introduce the "Final Report" with the note that it reveals "how little we still know" concerning taxonomic relationships. Park and Williams held that microbial systematics remained "still in the transition stage." In this light, they chose to provide only the "broad simple grouping" of the CCCBT's genera, referring the student "to the bibliography for

²⁶⁵ See, Robert and Margaret E. Breed, "The Type Species of the Genus *Serratia* Bizio, Commonly Known as *Bacillus Prodigiosus*," paper presented to the 25th Annual SAB meeting, 1923, printed in Journal of Bacteriology 9 (1924): 545-557; Robert S. Breed, "Taxonomic Studies of the Red Chromogenic Rods," Abstracts of Bacteriology 8 (1924): 404; Robert and Margaret E. Breed, "The Red and Pink Chromogenic Bacteria," paper presented to the 26th Annual SAB meeting, 1924, summarized in Abstracts of Bacteriology 9 (1925): 2; Robert and Margaret E. Breed, "*Serratia Indica* Bergey, the Red Chromogenic Bacterium Originally Isolated by Koch in India," paper presented to the 27th Annual SAB Meeting, 1925; Hucker, "Studies on the *Coccaceae*. I. Previous Taxonomic Studies Concerning the Genera of the *Coccaceae*," Technical Bulletin of the New York Agricultural Experiment Station no. 99 (1924); Hucker, "Studies on the *Coccaceae*. IV. The Classification of the Genus *Micrococcus* Cohn," Technical Bulletin of the New York State Agricultural Experiment Station no. 102 (1924); Hucker, "The Classification of the *Micrococci*," paper presented to the 26th Annual SAB Meeting, 1924, summarized in Abstracts of Bacteriology 9 (1925): 1-2; and, Hucker and Breed, "The Validity of Names Applied to Genera and Sub-Genera of the *Coccaceae*," Centr. f. Bakt. II, abt. 64 (1925): 321-328.

²⁶⁶ Harrison, "Our Society," presidential address to the 23rd Annual SAB Meeting, 1921, published in Journal of Bacteriology 7 (1922): 156.

further information in regard to attempts at classification, and the laws to be observed in identifying and naming a new organism."²⁶⁷ John Hopkins' William W. Ford endorsed the "Final Report" more assuredly, noting its comprehensive inclusion of saprophytic forms, and its consideration of non-morphological characters.²⁶⁸ Harold J. Conn, in contrast, pointed to the "extreme difference in opinion among bacteriologists as to how to classify bacteria." For the beginner, Conn found it more productive to "learn the large groups and only those of the small groups upon which there is something like general agreement." Conn indicated that the "Final Report" included "quite a detailed classification of bacteria," naming many more genera than was contained in his textbook. For this reason, Conn held that it was unnecessary for "a beginning student to learn the details of this classification. In a general way the classification given in this chapter follows the committee report but is less detailed and differs from it in mentioning other usages of some of the generic names besides those employed by the committee."²⁶⁹

While textbook authors deliberated the pedagogic benefit of the "Final Report," the American Type Culture Collection faltered in its role in promoting the new systematics. Following C.-E.A. Winslow and Kligler's departure from the American Museum of Natural History, the Collection languished from institutional inattention. In the final days of 1921,

²⁶⁷ Park, Williams and Charles Krumwiede, Pathogenic Microorganisms: A Practical Manual for Students. Physicians and Health Officers, 8th ed. (Philadelphia: Lea & Febiger, 1924), iii).

²⁶⁸ Ford, A Text-book of Bacteriology, 180. Joseph and Ethelyn Greaves recommend the SAB's scheme on similar grounds. See, Bacteria in Relation to Soil Fertility, 95.

²⁶⁹ Conn and Conn, Bacteriology, 1st ed., 97-97. Harold Conn, it should be remembered, objected to the taxonomic system of the "Final Report." In particular, Conn rejected families and genera founded on physiological criteria (e.g., *Neisseria*, *Leuconostoc*, *Rhodococcus*, *Acetobacter*, *Erythrobacillus*, *Hemophilus*). However, Conn predicted that taxonomists would soon divide the genus *Bacterium* based on fermentation reactions. Conn and Conn, Bacteriology, 1st ed., 99.

Winslow reported that the American Museum of Natural History chose to withdraw its support for the collection. Winslow himself appealed to the Society, pointing to the "great importance of promptly depositing" newly described forms such that they might "be available for comparative study of systematists in future years." In light of the museum's abnegation, Winslow argued that it remained a "duty of our Society to take over this work."²⁷⁰ After a lengthy consideration, Secretary Hitchens recommended that the collection move to the Army Medical College in Washington, D.C., where area bacteriologists represented every aspect of the discipline.²⁷¹ Although the SAB agreed to subsidize the \$400 annual cost of distributing more than 2,000 cultures, certain members considered transforming the collection from an academic depository to a for-profit warehouse of marketable microbes. In particular, Lore A. Rogers proposed that the SAB vend *Lactobacillus acidophilus* milk, a fermented dairy product implicated in the maintenance of good health. While the Society stood to make three to five thousand dollars a year from such a venture, several members objected to any commercialization of the SAB activities.²⁷² Instead, the Executive Council appointed two members to solicit the National Research Council for supporting funds.

The SAB's initial appeal to National Research Council failed, and newly transported collection suffered from inadequate resources. Only a \$24,000 subvention from the General Education Board of the Rockefeller Foundation preserved the ATCC. The grant, however, stipulated that the collection be governed by not only the SAB, but also the Phyto-pathological

²⁷⁰ Winslow, "The Importance of Preserving the Original Types of Newly Described Species of Bacteria," *Journal of Bacteriology* 6 (1921): 133-134. See also, Harrison, "Our Society," 154-155.

²⁷¹ "Minutes, SAB Local Branch, Washington D.C., 1917-1934," [ASM Local Branch History Collections], box 11-IIAJ, folder 3.1, pp. 43-48.

²⁷² James M. Sherman, "Report of the Committee on Culture Collections, Minutes of the 24th Annual SAB Meeting, 1922," [ASM], box 1-IVA, folder 5, pp. 32-35.

Society, the American Zoological Society, and the Society of Bacteriologists and Pathologists. The collection moved again in 1924, to the McCormick Institute in Chicago, and while this relocation secured institutional stability for the collection, it reduced the ATCC's ability to serve as a broker of taxonomic reform.²⁷³

The Bergey's Committee and a New Determinative Manual

In the early 1920's, Buchanan's Committee on Taxonomy campaigned on behalf of the CCCBT's "Final Report." For the most part, the new Committee focused on refining bacterial genera, devoting less attention to chaos in the nomenclature and classification of species. As a result, practicing bacteriologists faced the bewildering situation of learning the CCCBT's new taxonomy while still using Chester's old determinative manual to identify unknown forms.

Chester's *Manual of Determinative Bacteriology* embodied Migula's morphological classification, and stood in stark contrast to the SAB's revamped systematics.

In 1921, the SAB acted to remove the dissonance between its taxonomic scheme and determinative practice, creating a Committee on Determinative Bacteriology, under the direction of University of Pennsylvania's David H. Bergey. The Bergey's Committee, as it was quickly deemed, endeavored to "make the system of classification promulgated by the Society of American Bacteriologists of greater value to students by extending the classification to the individual species of genera that have been recognized as valid by the Committee."²⁷⁴ At the 1921 annual meeting, Bergey revealed his long-standing project to pen "a new Chester." Bergey

²⁷³ James M. Sherman, Washington, Circular to SAB Members, 12 November 1923, [ASM], box 2-IXC, folder 5, p.3; Sherman, "Report of the Committee on Culture Collections, Minutes of the 25th Annual SAB Meeting, 1923," [ASM], box 1-IVA, folder 6, pp. 47; Sherman, "Minutes of the 27th Annual SAB Meeting, 1925," [ASM], box 1-IVB, folder 1, pp. 4-8.

²⁷⁴ Collard, Development of Microbiology, 154.

explained that "one of the most difficult tasks confronting a worker in bacteriology is the identification of a bacterium not belonging to the group of ten or twenty with which he is constantly working." Only after a decade of effort did Bergey realize that "to do such work thoroughly and turn out a product satisfying the requirements of persons engaged in all the different fields of bacteriology is a task too great to be accomplished by a single individual."²⁷⁵

The Bergey's Committee consisted of four members besides its chair: Robert S. Breed, Bernard W. Hammer, Francis C. Harrison, and Frank M. Huntoon. Breed, of course, also served on Buchanan's Committee on Taxonomy. Similarly, Hammer held a position as Chief of Dairy Bacteriology at Iowa State, where Buchanan acted as Dean and Director of the Agricultural Experiment Station. During his tenure as SAB President, Harrison had championed the CCCBT's "Final Report," both at the annual meeting, and in informal correspondence with Society leaders. Only Huntoon arrived to Bergey's Committee with little experience in taxonomic reform.

Bergey envisioned his Committee as an adjunct to Buchanan's Committee on Taxonomy, and the Executive Council directed the two bodies to cooperate closely.²⁷⁶ Within a year, the Bergey's Committee had collected the "systematic descriptions of a large number of species of bacteria from the available literature," arranging them as far as possible according to the thirty-eight genera of the "Final Report."²⁷⁷ The task of composing the new determinative manual, however, posed several challenges. For example, the Bergey's Committee excluded several

²⁷⁵ Hitchens, "Report of the Secretary upon the Philadelphia Meeting," 8.

²⁷⁶ Hitchens, "Report of the Secretary upon the Philadelphia Meeting," 8.

²⁷⁷ Bergey, "Minutes of the 24th Annual SAB Meeting, 1922," 12; Bergey, "Report of the Committee on Determinative Bacteriology," Abstracts of Bacteriology 7 (1923): 2.

species listed in Chester's *Manual* because their "descriptions were so incomplete as to leave doubt as to their proper place in a system of classification." For the same reason, Bergey warned that it was "possible that in a few instances we have included the same organism under different names, because we did not have sufficient data to decide definitely whether or not we were dealing with separate species."²⁷⁸ In some instances, the Bergey's Committee solicited the assistance of specialists in determining names and relationships among particular bacterial groups: Rutgers' Selman Waksman for the *Actinomyces* and *Thiobacillus*; Colorado State's Walter G. Sackett for plant pathogens; Rockefeller Institute's Thomas Rivers for *Hemophilus*; and Iowa State's Max Levine for colon-typhoid group of *Bacterium*.²⁷⁹ More significantly, Bergey proposed that his committee become a permanent and active body. The committee chair recommended that the SAB divert any royalties from the new manual to "stimulate further work in this field," and issue revised editions.²⁸⁰

In a report issued just months prior to the publication of the *Manual*, Bergey explained "Some of the Difficulties Encountered in the Classification of Bacteria." Initially, the Bergey's Committee expanded its role to include revisions of the CCCBT's taxonomy. In particular, the "Final Report" failed to provide suitable genera for the "large number of Gram-negative, non-spore forming bacteria in water and soil that form yellow pigment or that are without pigment formation." These had been placed under genus *Bacterium*, but differed in so many regards from the principal intestinal organisms of the genus that the Bergey's Committee

²⁷⁸ Bergey, "Report of the Committee on Determinative Bacteriology," 2.

²⁷⁹ *Bergey's Manual*, 1st ed., iii.

²⁸⁰ Bergey, "Report of the Committee on Determinative Bacteriology," 2.

considered “the recognition of several additional genera.”²⁸¹ The Bergey’s Committee reviewed the divisions of *Bacterium* proposed by Weldin and Levine, accepting their five new genera: *Escherichia* for the colon group; *Eberthella* for the typhoid group; *Salmonella* for the paratyphoid group; *Aerobacter* for the aerogenes group; and *Alcaligines* for species producing alkali in carbohydrate solutions.

More shockingly, the Committee chose to discard the generic name *Bacterium* entirely, “because of the great confusion existing in the literature as to the proper characterization of this group . . .” Consequently, Bergey and his fellow committee members felt obliged to create categories for the rod forms not covered by Weldin and Levine’s five new genera, proposing *Encapsulatus* for the capsulated members of the Friedlander group (e.g., *En. pneumoniae*, *En. Pfeifferi*). In a separate challenge, the Bergey’s Committee redefined the genus *Pseudomonas*. If they followed Chester’s determinative definition, *Pseudomonas* would cover all Gram-negative rods with polar flagella, including many forms “very closely related, biologically, with organisms that are now classed under the other genera.” Rather than split other genera, Bergey chose to distinguish *Pseudomonas* by its yellow-green pigment, and not by the presence of polar flagella. This decision effectively effaced one of the last vestiges of Migula’s motility-based taxonomy.²⁸²

Anticipating dissension among SAB members, the *Bergey’s Manual of Determinative Bacteriology* contained a peremptory preface, indicating that its authors considered the *Manual* “merely as a progress report,” one that might “stimulate efforts to perfect the classification of

²⁸¹ Bergey, “Some of the Difficulties Encountered in the Classification of Bacteria,” *Abstracts of Bacteriology* 7 (1923): 276.

²⁸² Bergey, “Difficulties Encountered,” 276.

bacteria, especially by emphasizing the valuable features as well as the weaker points in the new system which the Committee of the Society of American Bacteriologists has promulgated." The Bergey's Committee did not regard the classification as "in any sense final," and "earnestly solicited" the assistance of all bacteriologists "in the correction of possible errors in the text," particularly regarding newly described forms.²⁸³ Upon publication in August of 1923, SAB officials launched a determined campaign to promote the *Bergey's Manual*. In November, outgoing Secretary and soon to be President A.P. Hitchens reported that most Society members ordered copies of the manual prior to publication. Hitchens entreated: "Every member who has not done so should hasten to procure a copy. It is as fundamental a part of the equipment of a bacteriologist as is his platinum wire." In Hitchens' judgment, if the SAB had only produced the *Bergey's Manual*, "this would fully justify its existence; for this volume represented the combined efforts of those persons best equipped to put bacteriological nomenclature on par at least with that attained for botany and zoology." True, Hitchens admitted, many bacteriologists were likely to resist yet another revision of bacterial taxonomy. Yet, Hitchens appealed to the expertise and authority of the Bergey's Committee, reasoning that "while the new names, especially for the genera, may seem strange and to some of us even forbidding at present, we can assure ourselves, through the evidence presented, that there is good scientific basis for every change made." If the complaints of the *Bergey's Manual* proved convincing, Hitchens' assured Society members that guide would "always be kept authoritative through the cooperation of committees composed of the best systematists in our Society." Moreover, Hitchens believed that the *Bergey's Manual* could orchestrate an international commission of bacterial taxonomy, if that

²⁸³ Bergey's Manual, 1st ed., iii-iv.

would seem more authoritative.²⁸⁴

The *Bergey's Manual* reached SAB members in the fall of 1923, and introduced a series of changes to the CCCBT's 1920 "Final Report." (Fig. 6.11) As forewarned in Bergey's earlier report, the *Manual* discarded the genus *Bacterium*, and distributed the colon-typhoid group among *Escherichia*, *Aerobacter*, *Eberthella*, *Salmonella*, and *Alcaligines*. Likewise, the Bergey's Committee fulfilled its pledge to add *Encapsulatus* for the capsulated members of the Friedlander group. Regarding *Pseudomonas*, the Bergey's Committee defined the genus as "small, aerobic rods, producing a green or blue-green pigment," making no mention of polar flagella.

The *Bergey's Manual* submitted several changes to the CCCBT's classification not prefaced in its earlier report. Concerning the species of Gram-negative, pigment formers found in water and soil, the Bergey's Committee expanded the tribe *Chromobacterieae*, replacing the generic term *Erythrobacillus* with *Serratia* (red pigment), and adding *Flavobacterium* (yellow pigment).²⁸⁵ The Committee removed the yellow pigmented plant pathogens from *Erwinia* and created the new genus *Phytomonas*. In a nod to the growing importance of soil bacteriology, the *Manual* established *Cellulomonas* for the cellulose digesting species, and *Achromobacter* for the Gram-negative soil forms not producing pigment on agar or gelatin.²⁸⁶

²⁸⁴ A.P. Hitchens, Washington, "Letter to SAB Members," 12 November 1923, [ASM], box 2-IXC, folder 5, p. 2.

²⁸⁵ The Bergey's Committee found the genus *Erythrobacillus* "invalid, as the type species described by Fortinaeu is not representative of the group." In its place, they substituted the older term *Serratia* Bizio. Unfortunately, this decision renamed the former *B. prodigiosus* once again, which became *Serratia marcenscens*. See, Robert S. Breed, "Taxonomic Studies of the Red Chromogenic Rods," 8; and, Robert and Margaret Breed, "The Type Species of the Genus *Serratia*, Commonly Known as *Bacillus prodigiosus*," Journal of Bacteriology 9 (1924): 545-557.

²⁸⁶ The *Bergey's Manual* also introduced *Dialister* for the minute anaerobic parasites growing only in the presence of haemoglobin. Within the family *Nitrobacteriaceae*, the Committee added a seventh genus, *Thiobacillus*, for species capable of oxidizing sulphur compounds.

The Bergey's Committee succeeded in eliminating "all incomplete described species" of bacteria. From the more than 1,500 species described in the bacteriological literature, the Committee deemed just under 900 worthy of inclusion in the *Bergey's Manual*.²⁸⁷ However, the Bergey's Committee struggled to distribute these species evenly across genera. For example, *Diplococcus*, *Actinobacillus*, and *Leptothricia* each contained just one species, while *Actinomyces* featured sixty-four. For the spore forming members of *Bacilliaceae*, *Clostridium* contained forty-one species, and *Bacillus* seventy-five. The determinative keys themselves were strikingly inconsistent, employing any combination of morphological, cultural, physiology and pathological characters to distinguish species.²⁸⁸ In some instances, the keys failed to offer sufficient criteria for identifying truly unknown microorganisms. In other cases, the goal of constructing a natural system of classification complicated the task of constructing determinative keys. *Erwinia*, for example, defined the Gram-negative motile rods pathogenic for plants. Given that their habitat was restrictive (*i.e.*, plant tissues), taxonomists found theoretical grounds for believing that the genus defined a phylogenetically related group. However, not all Gram-negative motile rods were plant pathogens. Thus, if a bacteriologist examined an unknown organism, Gram-negative, with peritrichous flagella, the *Bergey's Manual* offered little guidance for confirming whether the organisms belong to the genus *Erwinia*. One could inoculate the unknown organism in all possible plant hosts, but this impracticality merely illustrated how the taxonomy of the *Bergey's Manual* remained compelling in theory, but disheartening in

²⁸⁷ *Bergey's Manual*, 1st ed., 22. Chester listed nearly 800 species in his 1901 *Manual of Determinative Bacteriology*.

²⁸⁸ For example, the Bergey's Committee chose to prioritize serological relations, over fermentation reactions, in their classification of *Streptococci*. Yet, with regard to the arrangement *Staphylococci*, the Committee stressed pigment formation and fermentation of carbohydrates over agglutination absorption tests. See, *Bergey's Manual*, pp. 48 & 57.

practice.²⁸⁹

At the level of routine practice, the *Bergey's Manual* presented many other inconveniences, which reviewers of the publication quickly noticed. The *Journal of the American Veterinary Medical Association*, for one, acknowledged that Chester's 1901 determinative guide no longer sufficed. But the anonymous reviewer protested the lack of a cross index between old and new monikers in the new *Manual*: "Only after quite a search were we able to locate old friends, listed in this new manual under their latest names only. Even after locating some of these organisms we find that in many cases few or no synonyms are given." For example, the reviewer struggled to find the "colon organism, which we found hiding as *Esherichia coli*." On the positive side, the reviewer found many areas of taxonomic betterment, particularly in the revised key for the genus *Pasteurella*. He concluded that the *Manual* represented "a vast amount of work, but as is so often the case with first editions, it is replete with inaccuracies, which will undoubtedly be corrected in future editions."²⁹⁰

An anonymous reviewer for *Dental Cosmos* expressed similarly equivocal comments. He too noted the "urgent" need for an updated determinative manual, and held that the *Bergey's* general taxonomic scheme would stand the test of time. Even so, he found the most "striking and radical feature of the book" the "large number of genera" and the "very unusual and unfamiliar names given" to them. He supplies the examples of *Serratia marescens*, which was "none other than the miraculous *Bacillus prodigiosus* of the older dispensation. Among the pathogenic bacteria the changes are still more novel: e.g., the gonococcus becomes *Neisseria*

²⁸⁹ Henrici provided this example in his *Biology of Bacteria*, 275.

²⁹⁰ "Review of the *Bergey's Manual of Determinative Bacteriology*," *Journal of American Veterinary Medical Association* 64 (1924): 233-234.

gonorrhoeae; *Bacillus coli* becomes *Escherichia coli*; *B. typhosus* becomes *Eberthella typhi*; Pfeiffer's influenza bacillus becomes *Hemophilus influenzae*.”²⁹¹ The dental writer cautions his readers to remain patient. True, the overhaul in nomenclature butted against the “prejudices and traditions in which the present generation of bacteriologists have been raised,” but the reviewer believed it would be of great “advantage for the beginner to learn to speak of the genera, *Hemophilus*, *Encapsulatus*, *Escherichia* and *Eberthella*, rather than to learn the awkward circumlocutions in use today of the hemoglobinophilic bacteria, the Friedlander bacillus and its relatives, or the typhoid-colon-dysentery group.” Over time, the *Bergey's Manual* would prove “most useful to the laboratory worker. Its very peculiarities, its radicalness, will arouse controversy and out of this controversy will come greater knowledge, and perhaps some day a genetically satisfactory classification.” Even the clinical worker would come to view the guide as “indispensable.”²⁹²

A less sanguine judgement arrived from the 18th Annual Meeting of the Southern Medical Association. Speaking before the Section on Pathology, Charles Phillips divulged that many pathologists opposed the aims of the Bergey's Committee, with some “wishing to adhere to old well established names,” while others “do not like standardization at all,” particularly when arrived from an outside discipline. The physician's problems, Phillips insisted, were “distinctly narrower than those of bacteriology in general and often he is not disposed to bother his head about the subject in the large, provided it does not bother him.” At the onset, Phillips reminded

²⁹¹ M.J.L., “*Bergey's Manual of Determinative Bacteriology*, Book Review,” *Dental Cosmos* 66 (1924): 225

²⁹² The writer concluded: “The book is an achievement worthy of the time, patience, industry and intelligence of the Committee.” M.J.L., “*Bergey's Manual*,” 226.

his audience that the SAB represented all aspects of bacteriology, and not just the medical side. The *Bergey's Manual* emerged from a "tremendous volume" of work. "Naturally, medical bacteriology had to fall in line and the result has been that the names of many of our familiar organisms are so disguised that they are scarcely recognizable."²⁹³

The absence of a cross-index baffled Phillips: "...to one only a little familiar with bacteriology the absence of a ready means of finding old friends by index of names is not only perplexing, but almost disgusting at unwonted liberties taken." Correctly, Phillips remarked that the pathologist or medical bacteriologist would likely be "surprised and confused by there being no ready way by index to locate the organisms he most often works with." If the hypothetical bacteriologist looked for *B. coli communis*, he would "finally locate this under the name *Escheridia* (sic) coli, which is not at all familiar and with no indication as to the morphology." The *Bergey's Manual* offered scant explanation of the rationale for changing the typhoid bacillus, the meningococcus, the diphtheria bacillus or the tubercle bacillus to *Eberthella typhi*, *Neisseria intracellularis*, *Corynebacterium diphtheriae*, and *Mycobacterium tuberculosis*. The sanitary bacteriologist might find it equally confusion to see "groupings of organisms of similar habitat such as the typhoid-colon-dysentery group" separated simply based on "growth and staining characteristics."²⁹⁴ Despite these grievances, Phillips cautions his fellow pathologists not to dismiss the *Manual* without consideration. The Bergey's Committee, Phillips contended, kept the needs of physicians and pathologists in mind, ensuring that "medical bacteriology was

²⁹³ Phillips, "The New Nomenclature in Bacteriology," *Southern Medical Journal* 18 (1925): 788.

²⁹⁴ "The medical user "probably has not time to dig out for himself by study and much reading the reasons for changing the older terms bacillus, and coccus which had reference originally to morphology, to such monumental names as *Eberthella*, *Pasteurella*, *Neisseria*, *Escheridia* (sic)...Without rather careful study the physician is not only puzzled at the changes proposed, but wonders if it is necessary." Phillips, "The New Nomenclature," 789.

well represented by men who know the subject.”²⁹⁵ He asked his audience to review a list he prepared of the “Pathogenic Organisms Most Commonly Worked With,” supplied with their new designations. (Fig. 6.12)

Phillips’ address drew a vigorous discussion. Arthur I. Kendall, of the Washington University School of Medicine, provided the first comments. A formerly active member of the SAB, who maintained a keen research interest bacterial taxonomy, Kendall represented an unlikely critic of the Bergey’s Committee. Nevertheless, Kendall depicted the taxonomic changes as simple window dressing. The new systematics remained arbitrary, inconsistently applying differential criteria to distinguish genera and species. Given the poor state of knowledge concerning bacterial phylogenies, Kendall believed it impossible to construct a classification “obviously satisfactorily enough to supplant the present admittedly imperfect system.”²⁹⁶ Charles W. Duvall, a former SAB members and student of William W. Ford, agreed with Kendall, maintained that the *Bergey’s Manual* did not present anything “that is very much better than we have had before. If the new nomenclature is accepted, teachers of bacteriology will be obliged to learn all over again this very new classification.” Harry M. Weeter, a current SAB Member and colleague of Harry Harding and Martin J. Prucha at the University of Illinois worried that the Bergey’s taxonomy might not be “satisfactory enough to be adopted as permanent.” Weeter, however, believed that this shortcoming did not warrant rejection of the *Manual*. Instead, Weeter called for teaching laboratories to employ the *Bergey’s Manual* in their

²⁹⁵ Phillips, “The New Nomenclature,” 789.

²⁹⁶ “I do not believe the proposed classification will advance existing and well established procedure very materially. It is a fine sentiment to rename the typhoid bacillus in honor of one of the men who discovered it, but merely changing the name of a strain, type, species, or genus of bacterial will add very little to existing knowledge. . .” Kendall, “Discussion of the New Nomenclature of Bacteriology,” 790.

regular instruction: "Under the most favorable conditions, a new terminology hardly will be use extensively until a generation of workers arise who have learned it through the standard texts in bacteriology." Harold E. Robertson, of the University of Minnesota Medical School endorsed the *Bergey's Manual* enthusiastically, believing on principle that the "pathologist should give hearty support to any effort to standardize the classification in bacteriology."²⁹⁷

In his concluding remarks, Phillips advocates deference to the Bergey's Committee, if only to ease communication across scientific professions. Phillips reasoned that "Even though we may not like to use new terms, we must recognize that the physician who refers a case to the pathologist, or who is doing postgraduate work, when he receives his report back must find them in a language that can be interpreted correctly. So it is important that the pathologist and bacteriologist should understand each other." Moreover, Phillips anticipated that bacteriologists were likely to adopt the new nomenclature with or without support from physicians and pathologists. Faced with such a taxonomic gulf, Phillips contended that "there is really a problem before us."²⁹⁸

Throughout the process of researching and writing the *Manual*, the Bergey's Committee maintained a keen eye toward the role of the determinative manual in bacteriological instruction. In the late 1910's, Bergey served as chair of the SAB Committee on Instruction, and at the 21st Annual SAB Meeting (1919), he delivered paper on the "Teaching of Elementary Systematic Bacteriology."²⁹⁹ Before the 1922 annual meeting, Bergey reported that his Committee would

²⁹⁷ Duval, Weeter, and Robertson, "Discussion of the New Nomenclature in Bacteriology," 790.

²⁹⁸ Phillips, "Discussion of the New Nomenclature in Bacteriology," 790.

²⁹⁹ Bergey, "Teaching of Elementary Systematic Bacteriology," summarized in Abstracts of Bacteriology 4 (1920): 1-2.

compose artificial and simple keys to the species of each genus, "designed to assist the student in tracing unknown organisms." At the same gathering, Bergey outlined his "Course in General Bacteriology," a syllabus organized around the theme of systematics.³⁰⁰ Bergey understood that the dissonance between taxonomic theory and determinative practice could only be effectively removed by a process of education and routine use. The *Manual* itself combined determination with classification, and while use of its determinative keys did not demand adherence to the new classification, the keys were **congruent** with and **derived** from that taxonomic scheme. For the new generation researchers who weaned themselves on the exercises, techniques, and identification keys of the manual, the taxonomic theory that pervaded the text began to appear not only acceptable, but natural and exclusive.

The introduction to the *Bergey's Manual* shows the close relationship between the task of determination and the aims of taxonomy. Initially, the *Manual's* preface declared that Chester's keys were "of very little assistance to the student," particularly since they arranged genera entirely based on morphological characters. In contrast, the *Bergey's Manual* sought to "make the system of classification promulgated by the Society of American Bacteriologists of greater value to students by extending the classification to the individual species . . ."³⁰¹ This prelude offered some "Suggestions for the Use of the Manual in Classifying Unknown Organisms." To begin with, the *Bergey's Manual* instructs the student/researcher to complete the entire SAB Descriptive Chart, in order to document the full "morphological, cultural and pathogenic characters." The *Manual* then offers the hypothetical example of a student/researcher presented

³⁰⁰ Bergey, "Report of the Committee on Bacteriological Education, Course in General Bacteriology. Minutes 24th Annual Meeting, 1922," 1-IVA, folder 5, pp. 21-27.

³⁰¹ *Bergey's Manual*, 1st ed., iii & 22.

with “a short, motile, Gram-negative rod that grows well on ordinary culture media, fermenting dextrose and lactose with production of gas, and not liquefying gelatin, producing no pigment on any culture media, and with a negative reaction for the acetyl-methyl-carbinol, producing indol and reducing nitrates . . .” In this instructive example, the *Bergey's Manual* directed the student/researcher to consult the general hierarchical determinative keys on page 29 of the *Manual*. Given that the unknown organisms presented as a non-branching rod-form, it belonged to Order 1, *Eubacteriales*.

At this point, the *Manual* led the student/researcher through the differential keys, considering physiological as well as morphological traits. Since the unknown microbe did not secure its energy through the direct oxidation of inorganic compounds, it did not belong to *Family I. Nitrobacteriaceae*. Furthermore, its rod-shape disclosed that it resided in *Family IV. Bacteriaceae*. The *Bergey's Manual*, however, presented these differential tests as unproblematic taxonomic criteria. The *Manual* failed to acknowledge that it incorporated a hybrid of morphologic and physiological criteria, an amalgam wholly rejected by botanical and zoological systematists. Moreover, the *Bergey's Committee* provided no indication that its family *Nitrobacteriaceae* comprised a unique creation of the SAB, a category without sanction from any other taxonomic system.

At this point, the *Manual* instructed the student to consult the key, on page 84, to the family *Bacteriaceae*. In order to determine the tribe, the student/researcher confronted another series of questions. Did the organism produce pigment on agar? No. Did it digest cellulose in soil solutions? No. Was it a plant pathogen? No. Was this a Gram-positive rod, growing freely on artificial media without the ability to ferment carbohydrates? No, this form fermented both

dextrose and lactose. Was this a Gram-negative rod growing freely on artificial media with the general ability to ferment carbohydrates? Yes. Given this answer, the unknown organism belonged to *Tribe VI. Bacterieae*. Again, the *Manual* introduced this tribe without comment. Yet, it too provoked dissension, given that the Bergey's Committee affixed pathogenic and nutritional criteria to morphological and cultural considerations. Similarly, the third and fourth tribes, encompassing cellulose digesters and plant pathogens, were entirely the creations of the SAB committees. The student or researcher employing the *Manual* for the first time would never know.

At this point, the *Manual* directed the user to refer to *Tribe VI. Bacteriaeae* determinative key on page 194. Here, the Committee provided the generic key in a perfunctory manner:

- A. Ferment dextrose with the production of acid or acid and gas.
 - 1. Gas formed from dextrose.
 - a. Gas formed from lactose.
 - b. Acetyl-methyl-carbinol not formed from dextrose.
Genus X. *Escherichia*.

The key accompanied the final identification: "This description appears to correspond with that of our unknown organism. We find the key to the species of the genus *Escherichia* follows the key to the tribe *Bacterieae*. On tracing our organism in this key we find that it corresponds to *Escherichia coli*. Brief description is found on page 196."³⁰² It is no accident that the Bergey's Committee employed *E. coli* as its illustrative example. That organism resided in the much studied "colon group" of medical and sanitary bacteriology, and featured prominently in nearly every introductory laboratory course. Beginning with this prefatorial illustration and continuing

³⁰² Bergey's Manual, 1st ed., vii.

through each successive determination, the *Bergey's Manual* indoctrinated the student or researcher into a controversial system of classification. Names would be memorized and their categorical criteria accentuated beyond previous importance. The identification keys presented the hierarchies as natural entities, embraced by practical usage and common sense. The preface concluded with instructions on where to place blame for failed determinations:

If for any reason the student is unable to trace his unknown organism, several explanations may be suggested: (1) Failure to follow the proper leads in the keys in tracing the organism. (2) Incomplete data regarding the characters of the organism he is trying to classify. (3) Incomplete description in the MANUAL of the organism under investigation. (4) The organism was not included in the MANUAL because no detailed study of it was found in the literature.³⁰³

The Committee did not allow for the possibility that they constructed the taxonomic scheme poorly. Rather, the *Manual* encouraged the student or researcher to try harder, while the Committee pledged to revise the keys as new information came to their attention.

A few SAB members noted the revolutionary nature of the *Bergey's Manual*. Western Reserve's Roger Perkins argued that the *Manual* might render prior knowledge difficult to comprehend: "...even now the bacteriologist has to have at least one (of *Bergey's*) key, if not more, at his elbow when he reads his literature," as a consequence, "historical articles will soon be unusable, a mere hieroglyphic literature, understandable only by a few."³⁰⁴ Most Society members, however, directed their efforts to adjusting individual keys, or supplying the *Bergey's* Committee with descriptions of new species.³⁰⁵ Within eighteen months of the *Manual's* first

³⁰³ *Bergey's Manual*, 1st ed., vii.

³⁰⁴ Perkins, "Classification of Bacteria," 121.

³⁰⁵ See, for example, Roger Perkins, "Classification of Spore-Free Gram-Negative Aerobic Rods, with Special Reference to Fermentation and Proteolysis," *Journal of Infectious Diseases* 37 (1925): 32.

edition, the Bergey's Committee completed galleys for the second. The most notable change was Breed's compilation of a comprehensive cross-index of old and new generic and specific names.³⁰⁶ The second edition listed 867 species, roughly the same number as the first. While the Committee included several new forms, it eliminated dozens of duplicate descriptions, particularly among pathogens. As a result, the new *Manual* represented a balanced survey of known forms: 174 isolated from soil, 187 from water, 65 from milk or milk products, 194 from human sources (a majority from the intestinal canal), 43 from food or food products, 62 from plants, 72 from animals or insects, 23 from air, and 47 from miscellaneous sources.

The Bergey's Committee, nonetheless, failed to address a principal criticism leveled against the first edition of the *Manual*, that it split recognized groups into tiny genera, affixed with arcane and difficult to remember names. In fact, the Committee found that "several of the generic names that were adopted" for the first edition, had "been found to be invalid," and replaced by earlier and valid terms. Specifically, the Committee replaced *Encapsulatus* with *Klebsiella*, *Zopfius* with *Kurthia*, *Rhodosphaera* with *Rhodorrhagus*, and *Spironema* with *Borrelia*. The first two substitutions elicited disgruntlement from medical practitioners. (Fig. 6.13) The term *Encapsulatus* suggested the most striking feature of the group, its capsules. *Klebsiella* did not. *Kurthia* replaced *Zopfius*, which replaced *Proteus*, a generic designation listed by almost every textbook before 1923. With regard to these two changes, the Committee engendered little support.³⁰⁷ Moreover, the criteria for differentiating tribes, genera and species

³⁰⁶ David H. Bergey, "Minutes, 26th Annual SAB Meeting, 1924," [ASM] 1-IVA, folder 7, p. 16.

³⁰⁷ Other changes included the addition of *Nitrosococcus*, for spherical forms changing nitrates to nitrites, to the tribe *Nitrobacteriae*, and *Gaffkya* within the tribe *Neisserieae*, to include the Gram-positive tetrad forms (formerly *Micrococcus tetragenus*). Interestingly, the "tribes of Family *Coccaceae* have been transposed so as to bring genus *Staphylococcus* into Tribe *Micrococceae*. They appear to be more definitely related to the bacteria in this tribe than to the bacteria of the tribe *Streptococceae* in which they had been placed by the Committee on

remained inconsistent. Of the eleven tribes included in the family *Bacteriaceae*, the Bergey's Committee defined two on the basis of pigment formation, three on parasitism, five on cultural characteristics, and one by its morphology.³⁰⁸ The Committee did take steps to render the *Manual* easier to use. It revised the "keys to the species of several of the genera" (e.g., *Micrococcus*, *Lactobacillus*, *Aerobacter*, and *Proteus*) in order to "make the tracing of unknown species less difficult," but these changes did not alter the general character of the *Manual*.³⁰⁹

In the two intervening years between the publication of the first and second editions of the *Bergey's Manual*, Robert Buchanan's Committee on Taxonomy continued its activities. In fact, Buchanan proposed to the 1923 SAB meeting that the Society sponsor a multi-volume monograph series on bacterial systematics. Buchanan envisioned this collection as a publishing outlet for ongoing taxonomic studies conducted at Iowa State. In fact, Buchanan had already completed the first volume, a "historical discussion of bacterial classification, a discussion of the application of codes of nomenclature (with copies of the pertinent parts of such codes), an alphabetic list of all names which have been proposed," and the "various usages of names . . ."³¹⁰ Importantly, Buchanan portrayed the monograph series as an adjunct to, not a replacement of, the *Bergey's Manual*. These monographs would represent continuing reflection of taxonomical issues removed from the pressing demands of routine determination. He submitted his plan for the second volume, a detailed exploration of *Bacteriaceae*, with special focus on the colon-

Classification and Nomenclature in their reports of 1917 and 1920." *Bergey's Manual*, 2nd ed., vii.

³⁰⁸ Perkins, "Classification of Bacteria," 133.

³⁰⁹ "The comparative study of several groups of bacteria made available considerable material which enabled to the Committee to amplify the descriptions of some of the species and hence make their identification more definite. The attention of bacteriologists is directed to the great need for further studies along these lines so that the descriptions of other species may be amplified and corrected." *Bergey's Manual*, 2nd ed., viii.

³¹⁰ Sherman, "Minutes of the 25th Annual SAB Meeting," p.27.

typhoid group. Unlike the Bergey's Committee, Buchanan planned to include "a discussion of the reliability of various characters and their value for differentiation within this group." Additionally, Buchanan proposed "a list of all names of organisms which have been recognized or considered as members of the genera discussed with suggestions as to their probable relationships . . ."³¹¹ If the Bergey's Committee sought to construct an easy-to-use and authoritative guide to bacterial determination, Buchanan aimed to establish bacterial systematics as its own field of study, replete with conceptual questions and methodological quandaries. Curiously, SAB members responded with ambivalence. Bergey's Committee member Frank Huntoon and former CCCBT participant Leo Rettger argued that the SAB should not publish the series. A majority held that the Society ought to support the effort, with the reservation that each publication be prefaced with the disclaimer that the work was simply "one person's view."³¹² Buchanan's *General Systematic Bacteriology* would not be allowed to rival the authority of the *Bergey's Manual*.

At Iowa State, Buchanan continued to supervise masters and doctoral theses on bacterial systematics. John C. Weldin composed his 1926 dissertation on "The Colon-Typhoid Group of Bacteria and Related Forms: Relationships and Classification." Weldin's master's thesis helped prompt the Bergey's Committee into creating several new genera for the group in the first edition of the *Manual*, but Weldin deliberated whether this trend toward splitting should continue. On the one hand "New species are constantly being described until the group as such is becoming almost unwieldy," and demanding further division. On the other hand, multiplying generic

³¹¹ Sherman, "Minutes of the 25th Annual SAB Meeting," pp.27-28.

³¹² Sherman, "Minutes of the 25th Annual SAB Meeting," pp. 30-31.

names "tends toward confusion, in that it increases the number of characteristics which must be held in mind by the bacteriologist."³¹³ Weldin settled on the side of continued division, advocating the creation of *Shigella* to define the non-motile forms producing acid but not gas from glucose (*e.g.*, the etiological agent of typhoid). Even so, he feared that practitioners stood poised for a taxonomic backlash. Regarding the recently abolished genus *Bacterium*, Weldin noticed that "general use has tended more than ever to establish the name and it is feared that its abandonment would result in more bacteriologists using, as too many already do, the term *Bacillus* for all rod-shaped organisms regardless of their other characters, morphological or physiological."³¹⁴

Among bacteriologists not included within Breed's and Buchanan's sphere of influence, some castigated the SAB's for its efforts to instate their particular vision of systematics. At the 1925 SAB meeting, University of Colorado Medical School's Ivan C. Hall leveled a scathing critique of the CCCBT, the Bergey's Committee, and the Committee on Taxonomy. Regarding the CCCBT's "Final Report," Hall accused the former committee of acting clandestinely, providing "no opportunity for scientific consideration (outside the committee) of its contents prior to its adoption, and the approval of the report involved practically no discussion because only a few knew what was coming." Given that the *Bergey's Manual* embodied most recommendations of the "Final Report," Hall worried that the second edition would be seen as officially adopted by the SAB.³¹⁵ On principle, Hall maintained that "taxonomic questions

³¹³ Weldin, "The Colon-Typhoid Group of Bacteria and Related Forms: Relationships and Classification" (Ph.D. diss., Iowa State College, 1926), 4 & 6.

³¹⁴ Weldin, "The Colon-Typhoid Group," 12 & 16.

³¹⁵ Hall, "Some Fallacious Tendencies," 245-246.

cannot be settled by committee action any more than any other scientific question can be settled. . . .The task was too great for even these masters of the subject and the time too short for a work which should have occupied not a half-dozen men but a half hundred and not five years but fifty or a hundred and fifty.”³¹⁶

Hall decried the general trend toward from physiological taxonomies, believing that “orders, families, and genera should be based solely upon morphological data,” including staining reactions. Fermentation powers, habitat, colony characteristics, and serological reactions provided an unsure foundation for the arrangement of taxa. The *Bergey’s Manual*, for example, defined the family *Nitrobacteriaceae* by its ability to oxidize inorganic compounds. Hall, however, insisted that members of other families showed the capacity to oxidize carbon, hydrogen and nitrogen compounds, although in smaller quantities. Similarly, Hall found the division between anaerobes and aerobes to be so slight in some instances as to be meaningless. Physiological characters, Hall reminded Society members, varied with slight deviations in technique, factors not subject to the control of even “standard methods.”³¹⁷ Even when the Bergey’s Committee employed morphological traits as defining criteria, they managed to couple them with physiological characters or habitat. Regarding the order *Actinomycetales*, Hall found “meaningless references to parasitic habitat, and to oxygen and protein requirements in the synopsis of the order as well as in the subjoined key to the families.” Within *Chlamydo bacteriales*, Hall asked what is “the use of such expressions” as “alga like, typically water forms,” or “protozoan like in many characters?”

³¹⁶ Hall, “Some Fallacious Tendencies,” 247.

³¹⁷ Hall, “Some Fallacious Tendencies,” 246-247. & 251.

Hall especially disliked the Bergey's Committee's inclusion of his name after the definition of *Clostridium*. True, Hall published the definitive keys for the anaerobic spore-formers, but the Bergey's incorporation comprised an "unauthorized and unscientific" decision. Hall accused the Committee of distorting his keys by the "insertion of 'species' which probably exist only" in the literature. Hall reserved his most vituperative remarks for the use of habitat as a taxonomic character, which he regarded as illegitimate for all branches of systematic biology. Hall admitted that habitat correlated with other characters, but he objected to "habitat as a criterion in the identification or classification of any living thing."³¹⁸ Hall predicted that the *Bergey's Manual* would only add to taxonomic confusion, reporting not only bewilderment but "actual disdain in which the new nomenclature is held by some" bacteriologists outside the Society. After citing the published reviews critical of the first edition, Hall vaguely references "others who have similarly expressed themselves to me but I shall not take the liberty of quoting unpublished utterances, given in confidence."³¹⁹

Other reviewers of the *Bergey's Manual* second edition offered a more measured evaluation. Clifford C. Young, Director of Laboratories for the Michigan Department of Health, penned the review for the *American Journal of Public Health*. Young applauded the "boundless enthusiasm," the "endless courage, and the tremendous volume of work" of the Bergey's

³¹⁸ Hall, "Some Fallacious Tendencies," 247. Hall offered racially charged examples. "If I am found in Africa, does that classify me as a negro?" Hall insisted: "The criteria used in the identification of living forms should be such as to enable one to identify them no matter where they are found and the ubiquity of the bacteria emphasizes the desirability of this need in that group of living things more than any other." Hall, "Some Fallacious Tendencies," 248.

³¹⁹ Hall, "Some Fallacious Tendencies," 249-250. Hall cited William W.C. Topley's review of the *Bergey's Manual* 2nd edition as suggesting "Any attempt to adopt such a classification as that proposed by Professor Bergey can only serve, in the present state of our knowledge of bacteria, to obstruct any reasonable measure of reform." Topley, *Bulletin of Hygiene* 1 (1926): 278.

Committee. Yet, Young recognized that “opinions have been, and undoubtedly will be, divided.”³²⁰ He noted that the changes in the second edition “will perhaps be considered too conservative by many,” and hoped that the future revisions would occur less frequently, “but more radically.” In contrast to Hall’s insistence that taxonomic reform involve numerous researchers, Young believes that there were inherent drawbacks in a communal approach.³²¹ While Young yearned for a simpler, morphological taxonomy, he understood the Committee’s decision to employ physiological and cultural traits. His complaint lay in the Committee’s assumption that the user of the *Manual* possessed a working knowledge of the SAB’s pure culture methods. The second edition, like the first, included “such statements as ‘Agar colonies’ without further comment, presumably indicating that agar colonies may be grown, but that no description has been found.” Young correctly ascertained that one set of SAB. routine practices required adherence to another set.³²²

Given that the *Bergey’s Manual* was “hardly indispensable to the diagnostic bacteriologist,” Young predicted that public health and medical bacteriologists might dismiss the SAB’s taxonomy. “The average doctor,” Young asserted, faced too many tasks “to have *Salmonella schottmulleri* inflicted on him when *B. paratyphosus* B means something to him, and the bacteriologists will probably speak of ‘para B’ or ‘905’ rather than of the Bergey titles for some time to come.” Furthermore, the *Bergey’s Manual* specified bacteriological techniques, almost to the exclusion of pathology. “The diagnostic bacteriologist might wish that the species

³²⁰ Young, “Review of *The Bergey’s Manual of Determinative Bacteriology*,” *American Journal of Public Health* 16 (1926): 520.

³²¹ “There are too many opinions to be averaged and satisfied. If one man were to assume the full responsibility and were to be perfectly free to use his own judgment in the selection of material and advice, progress might be simplified.” Young, “Review,” 520.

³²² Young, “Review,” 521.

with which he was concerned were treated more from a diagnostic standpoint. The authors have presumably emphasized uniformity rather than laying too much stress on applicability.” The *Bergey's Manual* supplied an exhaustive listing of all known bacterial forms, a feature comprising the *Manual's* strength and weakness, as it listed “approximately 600 species of little interest to those involved in public health bacteriology, and only some 200 which are of greater interest” to public health workers. Nonetheless, Young believed that the routine worker could employ the *Manual* for determinations without adopting the entire classification.³²³ Ultimately, Young endorsed the *Bergey's Manual*, and advocated a swift transition to the new taxonomy. Nearly three years after the publication of the first edition, few “of the leading scientific publications required adherence to it, and many bacteriologists decline to follow it. It will be a pity if the classification goes half way, for our literature of the future will contain a variety of genera and species which will make for a considerable amount of confusion.”³²⁴

The Sway of the Routine

During the years following the publication of its second edition, the *Bergey's Manual of Determinative Bacteriology* effectively shaped all future taxonomic considerations. In some quarters, bacteriologists adopted the new taxonomy with enthusiasm. In others, only a lengthy employment of the determinative keys rendered the Committee's nomenclature less alien. Abroad, the SAB's classification held less sway than domestically. Even so, the *Manual's* influence reached across the Atlantic Ocean. For example, The Pathological Society of Great

³²³ “In short, there is much to be absorbed, and the fact that *Bacillus typhosus* has become *Eberthella typhii* should not prove an immovable obstruction to the securing of this information.” Young, “Review,” 521.

³²⁴ Young, “Review,” 521.

Britain and Ireland contemplated forming a committee on classification in 1925, only to decide against the plan in deference to the SAB's efforts.³²⁵ Similarly, British textbook authors incorporated the SAB's scheme without much comment. Joseph Bigger, a Professor of Bacteriology at the University of London, listed both the "common names" and the *Bergey's* terms in his textbook of medical bacteriology, correcting only spelling in cases "where the Latin seemed doubtful."³²⁶

At home, the *Bergey's Manual* steadily effaced the relevance of rival taxonomies. Immediately after the publication of the second edition, Veranus A. Moore and William A. Hagan informed their textbook readers that the *Bergey's Manual* would soon render all previous taxonomies and determinative aids "more or less obsolete." Writing in 1928, Perkins found "a great deal of acceptance" for the *Bergey's* general outline of families, tribes and genera, with resistance usually coming from "persons studying a comparatively small group and believing that their arrangement is the only proper one."³²⁷ Seven years later, University of Minnesota's Arthur T. Henrici mentioned that the *Bergey's* classification did not "please everyone, and probably does not completely satisfy anyone. . . . Nevertheless this classification comes nearer to being a standard classification than any that has been used before, and is now in almost general use in America." By 1937, Joseph McFarland could remark that the *Bergey's Manual* had

³²⁵ Dible, "A History of the Pathological Society," 11. That decision might simply reflect the relatively low interest in bacterial systematics in Britain, where textbook authors and showed a greater willingness to ignore the intractable taxonomic issues. See, for example, David Ellis' unproblematic employment of Migula's classification in his Outlines of Bacteriology: Technical and Agricultural (London: Longmans, Green and Co., 1909).

³²⁶ Bigger, Handbook of Bacteriology for Students and Practitioners of Medicine, 1st ed. (London: Bailliere, Tindall and Cox, 1925), viii-ix. Roger G. Perkins noted that the Manual was "accepted abroad as the final word on American opinion." Perkins, "Review: *Bergey's Manual of Determinative Bacteriology*," American Journal of Public Health 20 (1930): 565.

³²⁷ Moore and Hagan, Laboratory Manual in General and Pathogenic Bacteriology and Immunity (Boston: Ginn, 1925), 142; and, Perkins, "Classification of Bacteria," 122.

“relegated to the scrap heap all of its predecessors. . . . It is undoubtedly the most important of the modern taxonomic works.”³²⁸

The *Bergey's Manual* sold extremely well, with the Committee shipping 2,048 copies of the first and 1,475 copies of the second to bacteriologists both inside and outside of the SAB. While these numbers might seem modest, they easily exceeded the subscriptions to the *Journal of Bacteriology*, and rivaled sales of the more preferred bacteriology textbooks. The influence of the *Bergey's Manual* extended beyond the number of purchased copies. It served as the organizing framework for subsequent textbooks and laboratory manuals. Instead of devoting chapters and sections to Dairy or Veterinary or Soil Bacteriology, authors organized their works around the families, tribes and genera of the SAB. For example, Park and Williams revised the 8th edition of their textbook on medical bacteriology so that “the grouping of different microorganisms conforms more closely to the classification adopted by the Society of American Bacteriologists. The new terminology suggested by this Society has been added to the older common names and several new comprehensive tabulations are given.” Writing in 1924, Park and Williams in this edition depict bacterial systematics as undergoing a “transition stage,” as the first edition of the *Bergey's Manual* merely illustrated “how little we still know.”³²⁹ E.O. Jordan, who had previously employed Migula's scheme in his textbook, endorsed the *Bergey's* taxonomy in the 9th edition (1928). While Migula had “served a useful purpose for some years,” it proved “open to objection in many details, and the morphologic classification has long been in

³²⁸ Henrici, *Biology of Bacteria*, 285-286; and, McFarland, “The Beginnings of Bacteriology in Philadelphia.” *Bulletin of the History of Medicine* 5 (1937): 194.

³²⁹ Park, Williams and Krumwiede, *Pathogenic Microorganisms*, 8th ed., iii.

admittedly confused and unsatisfactory condition.”³³⁰ Martin Frobisher organized his 1937 text along systematic groups, not areas of application (e.g., medicine, water, soil, etc.). Even the most notorious medical pathogens bore *Bergey's* designations. Frobisher supplied a lengthy chapter on bacterial classification, and detailed descriptions of the type species for each genus.³³¹

Other textbook authors adopted the *Bergey's* taxonomy with some hesitation or confusion. Ward Giltner, in the 3rd edition of his instructional manual thought it “best to retain the old system” in his text, while referring the student to the *Bergey's Manual* for further study. As a matter of fact, Giltner shifted to the new nomenclature in the middle of the manual. He explained that while the physiological system of classification proved unsatisfactory at points, “it is probable that the *Bergey's* outline will serve as the point of departure for future work.” If his reversal in systematics produced confusion among his students, Giltner placed the blame elsewhere:

Since bacteriologists have utilized so many differing classifications, the student should be prepared for much confusion as a result of the use in bacteriological literature of several different names for the same species. The germ that causes tuberculosis may be called, *Bacillus*, *Bacterium* or *Mycobacterium*; but it is, of course, the same organism. It is the classification that is variable, not the organism.³³²

Frederick P. Gay offered an unusual compromise of taxonomic systems in his manual for students at Columbia's College of Physicians and Surgeons. Gay described the *Bergey's*

³³⁰ Jordan, Text-book of General Bacteriology, 9th ed. (Philadelphia: W.B. Saunders Co., 1928), 121. Jordan maintained that the Bergey's Manual “crystallized much of the current practice in the grouping of bacteria, and while the introduction of new generic names presents some real difficulties, it is believed that in the long run the use of terms like *Neisseria* for the gonococcus-meningococcus group and *Hemophilus* for the hemophilic bacilli will make for clearness and simplicity.” Jordan, Text-book of General Bacteriology, 9th ed., 125.

³³¹ Frobisher, Fundamentals of Bacteriology, 1st ed. (Philadelphia: W.B. Saunders Co., 1937).

³³² Giltner, Laboratory Manual in General Microbiology, 3rd ed. (New York: John Wiley & Sons, 1926), v. Other textbook authors similarly appropriated only portions of the new systematics. See, for example, John F. Norton and I.S. Falk, Laboratory Outlines in Bacteriology and Immunology (Chicago: University of Chicago Press, 1926); and, Frederick H. Billings, Benjamin J. Clawson, and Noble P. Sherwood, Laboratory Exercises in Bacteriology, 3rd ed. (Lawrence: The World Co., 1927).

Committee as representing the most "modern progress in classification," and advised that his novice bacteriologists understand the general aspects of all systematic groups. However, Gay still tailored his text along medical lines and referred to the *ad hoc* groups of Kruse and Chester (e.g., Hemolytic Group, Viridans Group, etc.). While Gay described all seventeen species of *Salmonella*, he barely mentioned the genera of non-pathogenic rods (e.g., *Serratia*, *Flavobacterium*, *Chromobacterium*).³³³ William F. Ford, who had devoted several years of taxonomic studies, adopted the *Bergey's* taxonomy with only minor modifications. Yet, he included both old and new designations in several instances, noting that the names were "so firmly entrenched in the literature of bacteriology that considerable confusion will result if they are discarded at the present time."³³⁴

Textbook authors occasionally commented on the increasing authority of the *Bergey's* Committee and the Committee on Taxonomy. Fred W. Tanner registered that *Bergey's Manual* had "been criticized destructively -- but what classification has not? Those who prepared these classifications gave them much study, probably much more than the critics. These new classifications prepared by committees are certainly an improvement over the older ones which, with few exceptions, were prepared by one individual." As evidence of support, Tanner pointed to the increasing number of journals employing the *Bergey's* nomenclature. If confusion continued to linger, it was only due to "the fact that these subjects have not been faced squarely by teachers." He accepted some of their hesitation, but inquired "Why wait for the perfect classification instead of stating the actual situation as it exists?"³³⁵ Jordan listed other reasons for

³³³ Gay, *Laboratory Manual in Medical Bacteriology*, 2nd ed. (New York: James T. Dougherty, 1926), 204.

³³⁴ Ford, *Text-book of Bacteriology*, 180.

³³⁵ Tanner, *Bacteriology*, 84.

lingering resistance. Writing in 1935, Jordan indicated that some bacteriologists, both domestic and foreign, continued to oppose the new systematics:

This is partly because of the doubt some bacteriologists have felt as to the generic validity of the new grouping, as "*Aerobacter*" or "*Alcaligenes*"; partly because the names proposed are cacophonous, as "*Escherichia*"; partly because the old names that they are intended to replace are firmly imbedded in hundreds of books and thousands of separate articles; but also in large part because some of the new names have made their debut before the world of bacteriologists too suddenly, without sufficient familiarizing discussion.³³⁶

The scattered dissension did little to slow the increasing dominance of the *Bergey's Manual*. From 1925 onward, the *Manual's* scheme framed all taxonomic debates.³³⁷ Few systematists advocated a return to morphological systems, and most acknowledged the need for multiple genera within each family. More importantly, the SAB's committees succeeded in introducing phylogenetic considerations to bacterial systematics. Future and rival classifications implicitly aimed to disclose evolutionary relationships among natural groups.³³⁸ When bacteriologists organized their own international congress in the late 1920's and 1930's, the recommendations of the Bergey's Committee and Buchanan's Committee on Taxonomy served as the framework to resolve taxonomic disputes.³³⁹

³³⁶ Jordan, *A Textbook of General Bacteriology*, 11th ed. (Philadelphia: W.B. Saunders Co., 1935), 129.

³³⁷ Perkins portrayed the taxonomic situation in 1928 as one of increasing consensus: "On the whole it seems as though, in spite of its defects, the work of the last twenty years has established sufficient recognized groups, especially of the higher ranks, to enable us, with the appreciation that bacteriology is a young subject, to develop these rationally, without any complete upset. At present there are certainly sufficient shades of difference between the extremes to accommodate anyone." Perkins, "Classification of Bacteria," 121.

³³⁸ See, for example, Ernst A. Pribram, "A Contribution to the Classification of Microorganisms," *Journal of Bacteriology* 18 (1929): 361-394; Otto Rahn, "Contribution to the Classification of Bacteria," *Centrblatt f. Bakt. II abt.* 78 (1929): 1-21; Pribram, "Pathogenicity and Classification of Microorganisms," *Journal of Bacteriology* 22 (1931): 427-432; Robert Buchanan, "Taxonomy," *Annual Review of Microbiology* 9 (1955): 1; and, Sam T. Cowan, "Bacterial Classification -- Problems and Developments," in *Microbiology, Yesterday and Today*, ed. by V. Bryson (New Brunswick: Institute of Microbiology, Rutgers, 1959), 55-79.

³³⁹ See, R S. Breed, "Problems in Nomenclature and Classification Now Before the International Committee on Bacteriological Nomenclature," *Journal of Bacteriology* 30 (1935): 329; Breed, "Report on Proposals Relative to the Conservation of *Bacillus* as a Bacterial Generic Name, Fixing of the Type Species and of the Type

Like the SAB's Descriptive Card, the *Bergey's Manual of Determinative Bacteriology* comprised a common, if not pedantic, aid for routine work in bacteriology. Yet, its ability to lead American bacteriologists to consider non-routine factors, those elements often identified as the biological components of bacteriology, should not be understated. The determinative keys, and the classification they embodied, greatly defined what it meant to do bacteriology. Even as late as 1925, bacteriologists frequently maintained multiple professional identities. One was a bacteriologist and dairy scientist, a bacteriologist and public health official, a bacteriologist and plant pathologist. Bowker and Star assert that this condition is not unusual in science, and boundary objects and infrastructures often facilitate this state of multiplicity. The *Bergey's Manual* and the Descriptive Card established, in part, a sense of collective proficiency, allowing these diverse practitioners to feel "a part of multiple communities of practice." Classifications, by their ability to direct scientific language and routine practice, constitute "powerful artifacts that may link thousands of communities and span highly complex boundaries."³⁴⁰ In the decades leading to the publication of the second *Bergey's Manual*, taxonomic debates encouraged bacteriologists to deliberate what constituted the defining features of a microbe. Any agreement, taxonomists discovered, had to meet the needs of several communities and incorporate diverse conventions. Most commentators called for bacteriology to become more biological. Yet, these same authors chafed at the strictures conveyed by botanical or zoological codes of

or Standard Culture," *Centr. Bakt. Parasiten*, abt. II 92 (1935): 481-490; Ralph St. John-Brooks and Robert S. Breed. "Actions Taken by the 2nd. International Microbiological Congress in London, 1936, Regarding Bacterial Nomenclature," *Journal of Bacteriology* 33 (1937): 445-447; Buchanan, "Rules of Nomenclature Annotated: With Suggestions for Rules of Bacteriological Nomenclature," in, *Third International Congress for Microbiology, New York, September 2-9, 1939*, ed., Henry M. Dawson (Baltimore: Waverly Press, 1939); and, Buchanan, St. John-Brooks, and Breed, "International Bacteriological Code of Nomenclature," *Journal of Bacteriology* 55 (1948): 287-306

³⁴⁰ Bowker and Star, *Sorting Things Out*, 287.

nomenclature.

If the Descriptive Card and *Bergey's Manual* represented a process of negotiation and compromise, they in turn partially comprised what sociologists Anselm Strauss and Howard Baker deem a "social world." It is a community's "activities with their stuff, their routines, and exceptions" that comprise "the community structure." The Chart and *Manual* directed novices and outsiders to the objects of practice, provided them with shared language to discuss the practices, and a loose theoretical framework to understand unresolved questions.³⁴¹ These mundane objects help "naturalize" newcomers. In most cases, familiarity with these objects, and not proficiency, is sufficient to produce a "measure of taken-for-grantedness." If after a process of education and laboratory practice, a bacteriologist could fully employ the Descriptive Chart and *Bergey's Manual*, very few aspects of the science would appear strange.

³⁴¹ Bowker and Star, *Sorting Things Out*, 294 & 297; Strauss, "A Social World Perspective," *Studies in Symbolic Action* 1 (1978): 119-128; and, Becker, *Tricks of the Trade* (Chicago: University of Chicago Press, 1988).

CONCLUSION

Bacteriology, in 1925, remained a disunified discipline. While American researchers increasingly employed the SAB's Descriptive Chart and the *Bergey's Manual of Determinative Bacteriology*, the science still lacked a unifying theory, common set of concerns, or even a shared language. By some measures, the specialization and fragmentation of bacteriology continued without interruption during the first quarter of the twentieth century. It is not surprising then to find SAB leaders reiterating their pleas for a more biological bacteriology. The disciplinary anxiety persisted despite their best efforts. Nonetheless, bacteriology in 1925 differed greatly from the science practiced at the turn of the century. Owing to the efforts of the Society of American Bacteriologists, and the ascending authority of dairy and soil bacteriology, researchers began to consider organisms and phenomena formerly occluded by the hygienic vision of microbial exclusion. Even within medical, public health, and sanitary bacteriology, investigators probed the enigmatic aspects of bacterial physiology, variation, and physical chemistry. Microbes, by 1925, slowly emerged as biological organisms with phylogenetic histories, associative relationships, and complex metabolisms.

This thesis has documented the sources for disciplinary anxiety. Initially, bacteriology, as a form of scientific work, differed from one institutional context to another. Within medical colleges and hospitals, bacteriologists lent their technical expertise in service to pathologists and

physicians; their work helped identify and eliminate microbial pathogens for individual patients. Within departments of public health and water filtration plants, bacteriologists proffered techniques for determining sources of disease transmission, whether they be from infected individuals or contaminated milk and water. This hygienic vision underscored the utility of routine procedures, where minimally trained laboratory technicians could perform innumerable tissue stains, throat cultures, and fermentation tests in a cost-efficient manner. Medical, public health, and sanitary bacteriologists garnered institutional favor by aiding the elimination of a select number of pathogens. The routine work that these bacteriologists performed sustained a rapid professional growth, as bacteriology emerged in the early twentieth century as a central component of scientific medicine and modern public health. Nonetheless, the hygienic vision and its supporting institutional contexts offered little encouragement for original research in areas not immediately relevant to the elimination of disease germs. For most medical, public health, and sanitary bacteriologists, microbes were worthy only of eradication, and not careful or prolonged scrutiny.

Veterinary bacteriology closely paralleled the development of medical bacteriology. Like their medical counterparts, veterinarians received brief instruction in bacteriology (four to eight week courses) as part of their professional training, often employing the same textbooks and manuals. By 1925, a majority of veterinarians held some familiarity with the methods of isolating, identifying, and eliminating the microbial agents of animal illness. Yet, these same veterinary scientists simply rehearsed the routine techniques of pure culture methods, employing only the cookbook and recipe formulae needed to determine the causative organisms of bovine tuberculosis, black-leg, contagious abortion, pullorum, swine plague, and fowl cholera.

Veterinary bacteriologists, like their medical counterparts, attended to a limited number of organisms and a narrow range of phenomena. For the few who sustained active research programs, they focused their efforts on resolving the etiological uncertainties of infectious diseases, rather than exploring the life histories and complex ecological relationships among the broad class of bacteria. Despite this conceptual constriction, veterinary bacteriology contributed greatly to the reduction of livestock mortality, offering diagnostic tests for bovine tuberculosis and glanders, vaccines against chicken cholera and blackleg, and therapeutic sera to treat hemorrhagic septicemia. In an institutional environment removed from the established patterns of hospitals, public health departments, or water filtration plants, veterinary bacteriologists reproduced a similar technical enterprise that encouraged the routine, rather than a search of the fundamental.

In contrast, dairying and soil science prompted the development of an alternative set of bacteriological practices. In particular, dairy and soil bacteriologists endeavored to *manage* and *exploit*, rather than eliminate, microbes. Bacteriology, according to some observers, represented the pinnacle of scientific farming, and a perfect compromise between the conflicting demands of science and service vexing most staff members of agricultural colleges and experiment stations. These agricultural scientists sought to identify efficient starter cultures to aid in the production of quality cheese and butter, legume cultures to encourage symbiotic nitrogen fixation, and tillage practices to stimulate nitrification in soils. As a result, they attended to a wide range of microorganisms, and investigated phenomena normally overlooked by the "hygienic vision" (e.g., bacterial physiology, cytology, associative behavior, variation, systematics, phylogenetic relationships, hydrogen-ion concentrations). Dairy and soil bacteriologists shunned the hygienic

vision's preference for pure culture methods, employing instead enrichment techniques that demonstrated a full range of variations, demanded a consideration of microbial populations, and facilitated a careful regard of taxonomic issues. Rather than annihilate the object of their study, dairy and soil bacteriologists aimed to make microbes do more. In effort to improve microbial efficiency, these investigators surveyed the mixed and dynamic flora of soils and dairy products while probing the nutritive requirements and metabolic by-products of bacterial growth.

Bacteria, within this alternative vision, constituted an agricultural resource – much like soils, seeds, and livestock – rather than pests. Compared with medical, public health, sanitary, and veterinary bacteriologists, dairy and soil investigators approached the microscopic world with a different set of tools, tendencies, and institutional goals. In many respects, they practiced a different science. By 1925, State Agricultural Experiment Stations and Bureaus of U.S. Department of Agriculture employed more than a hundred dairy and soil bacteriologists, while more than two dozen colleges offered distinct courses in dairy and soil bacteriology. Agricultural bacteriologists regularly proclaimed that modern scientific farming required a thorough knowledge of microbiology. Yet, these same researchers remained highly self-conscious and self-critical, believing that they had fallen short of their disciplinary promise of high quality dairy products and unending soil fertility. Judged against other agricultural sciences such as horticulture, animal husbandry, or agricultural chemistry, bacteriology's achievements were noticeably few. Paradoxically, the more institutionally successful branches of bacteriology suffered from conceptual constriction, while the methodologically capacious specialties never witnessed comparable institutional growth. Unlike the transformations in medicine, public health, or sanitary engineering, bacteriology never revolutionized dairying or soil fertility; it

failed to furnish the kinds routine methods or products that would guarantee long-term institutional support. Dairy and soil bacteriologists, in contrast to their medical, public health, or veterinary counterparts, continually measured their own scientific shortcomings. Even so, this disciplinary anxiety might have spurred methodological and conceptual advancement.

The Society of American Bacteriologists emerged in initial decades of the twentieth century partly in response to the growing sense of disciplinary fragmentation and methodological discontent. Its founders explicitly dedicated the organization to promoting bacteriology as "one of the biological sciences." Through its meetings, committees, and publications, the SAB brought together bacteriologists of diverse interests and training, offering collective avenues for researchers to exchange technical details and methodological innovations, while exploring those aspects of the science that might unite dissimilar practitioners. In particular, the Society confronted three related questions of identity: 1) Who were bacteriologists? 2) What was bacteriology? 3) What was *that* bacteria? Answers to these queries rarely proved satisfying, and the SAB raised them again and again. At the onset, the Society identified bacteriologists as those who employed techniques for handling microbes. This open-ended definition found additional support from the SAB's lenient standards for membership. Yet, these same SAB leaders chafed at the prospect that bacteriology might remain a "handmaiden" to other disciplines, a diverse collection of laboratory manipulations rather than a "biological science." The SAB stood as an association of catholic interests, and many of its members retained affiliations with other disciplinary societies. The Society's officers viewed the SAB's eclectic membership as both a source of professional strength, and a disciplinary liability.

In response, the SAB endeavored to bridge the divergent interests and practices of its

membership. For example, the Society's presidential addresses and committee reports repeatedly entreated bacteriologists to explore the underlying, or fundamental, dimensions of their science. Unfortunately, SAB officials never settled on the list of characteristics and questions that would render bacteriology more biological. While most conversants in this continuing dialogue concurred with the aim of the SAB founders, they failed to agree upon its execution. Nonetheless, the actions of the Society do indicate some dominant themes in the organization's efforts to define bacteriology. In particular, its membership rosters, its selection of officers, and its annual meeting programs reveal a decreasing emphasis on the medical and public health aspects of the science. Similarly, the editors of the *Journal of Bacteriology* eschewed papers merely reporting the isolation and identification of new pathogens. Instead, the annual meetings and the SAB publications stressed issues of physical chemistry, cytology, nutrition, metabolism, variation, and taxonomy. In the 1910's and 1920's, the SAB aimed to directly influence the development of bacteriology, establishing committees on research and education. Although neither committee successfully persuaded Society members to adopt its recommendations, both offered a means for reflecting on the perceived deficiencies of the discipline and contemplating possible remedies.

While the Society of American Bacteriologists struggled to identify bacteriologists and bacteriology, it also sought to assist in the identification of *that* bacteria. The determination of unknown cultures constituted the principal shared practice of the discipline. In fact, it may have comprised the only task common to all bacteriologists. It represented *both* the most prosaic and most challenging aspects of bacteriology, and the SAB, from its initial years onward, sought to aid in that omnipresent endeavor. The Society published five editions of the "Society's Card," a

determinative chart that guided a bacteriologist as he or she described and identified unknown cultures. By the late 1910's, the Society's Card was nearly ubiquitous to American laboratories. Although the SAB never formally adopted the chart as its "official methods," the Society's Card formed the basis of undergraduate and graduate training, and organized data for published papers in most bacteriological fields. In an unintended fashion, the SAB's attempts to answer the question, "What is *that* bacteria?" addressed the questions "who were bacteriologists and what is bacteriology?" At some level, bacteriologists were simply those who employed the Society's Card, and bacteriology was defined by the kinds of information requested by that chart.

Furthermore, in its effort to devise and refine the Society's Card, the SAB squarely confronted the task of earmarking the biological components of bacteriology. The chart itself directed bacteriologists to negotiate a shared set of imperfect tests. A researcher or student completing the Society's Card would detail an organism's morphology (*i.e.*, shape, size, presence of flagella and spores, involution forms, staining reactions, etc.), its cultural features (*i.e.*, growth and changes produced in agar, potato, blood serum, gelatin, milk, chromogenesis, etc.), and its biochemical or physiological behavior (*i.e.*, production of gas and acid from various sugars, formation of ammonia and indol, reduction of nitrates, diastasic action, temperature and oxygen relations, tolerance to sunlight and drying, relation to reaction of media, etc.). Each of these measures, however, presented a number of problems and ambiguities. The acknowledged shortcomings these methods led SAB officials to reflect, time and again, upon the biology of bacteria. They believed that such considerations were essential to formulating a set of determinative techniques applicable to all areas of bacteriology.

In formulating the Society's Card, the SAB eschewed the methods of the American

Public Health Association and other public health organizations. Sanitary and public health workers monitored bacterial contamination of water, milk, and foods, and naturally desired methods rendering uniform results with minimal time and effort. Specifically, these technicians sought standardized techniques for identifying the presence of a select number of pathogens. In contrast, bacteriologists, SAB officials insisted, remained more interested in accuracy than simplicity or cost. The SAB's chart provided information on the activities and characteristics, and not simply presence, of microorganisms. The Society's Card, in its serial editions, remained both comprehensive and flexible, allowing its users to exhaustively detail an unknown culture. Its completion, however, required extensive and careful study, leading users to consider types and characteristics beyond their normal sphere of daily practice. A researcher or student completing the chart was strongly discouraged from conducting a few diagnostic tests (*e.g.*, pathogenesis) to determine an organism's likely identity. In fact, the Society's Card placed only slight emphasis on methods common to medical bacteriology (*e.g.*, inoculation of animals, serological reactions, loss of virulence, production of toxins). Instead, the chart stressed the utility of biochemical and physiological measures, traits critical to dairying and soil science, but only of tangential importance to public health officials and sanitary engineers. As the chart itself grew more expansive in its list of technical explorations, the discipline broadened its range of conceptual considerations.

The SAB's attempt to identify the biological component of bacteriology through its methods was paralleled by their efforts to reform bacterial systematics. American bacteriology, at the time of the SAB's founding, languished under a state of taxonomic chaos. A single bacterium could bear multiple names. Likewise, the same name could designate several distinct

species. Bacteriologists, particularly medical bacteriologists, rarely followed formal principles of biological nomenclature, shunning, for example, binomial Latin designations in favor of tri- or even quadrimials. In practice and in print, the language of bacteriology did not resemble that of botany or zoology. More importantly, each bacteriological specialty developed its own scheme for naming and grouping bacteria. The taxonomic chaos reflected the disunity of bacteriology; it also threatened to sustain it. The SAB, through its Committee on the Characterization and its Committee on the Classification of Bacterial Types and Committee on Taxonomy, labored to forge a stable, unified bacterial systematics. In particular, these committees believed that a taxonomic scheme should reveal the *natural relationships* among bacteria (*i.e.*, the evolutionary lines of descent), a consideration largely ignored by earlier systems of classification. Genera and families, they contended, ought to assemble physiologically similar organisms. Advocates of the taxonomic reform insisted that the correct naming and classifying of bacteria constituted a central element of a more biological bacteriology. As a result, Society officials and committee members grappled with the problem of bacterial variation, explored the minutiae of nutrition and metabolism, and pondered possible evolutionary scenarios.

In 1920, the SAB published a radically new taxonomy, one featuring several new families and genera based on physiological properties and fashioned from phylogenetic accounts. Many bacteriologists resisted the SAB's efforts, remaining unwilling to surrender their familiar names and *ad hoc* schemes. In fact, the ensuing debate never found formal resolution. Rather, the new systematics became authoritative by way of the classroom and laboratory. In 1921, the Society established a committee to author a new manual of determinative bacteriology. The Committee

on the Determinative Manual embraced the SAB's taxonomy, embedding the new scheme in its myriad keys for identifying unknown bacterial forms. As a result, the next generation of bacteriologist trained by using the *Bergey's Manual of Determinative Bacteriology*, acquiring both a shared language and a common outlook on constituent traits of taxonomic groups. In instructional laboratories, public health departments, and agricultural experiment stations, each time a practitioner employed the *Bergey's Manual* he (or more commonly she) unwittingly absorbed the SAB's taxonomy. Within a decade of the *Bergey's Manual's* first printing, the debate over bacterial systematics evanesced, not by way of any organization consensus, but through a process of routine practice and education. And, just as the Society's Card forced its user to record a plethora of characters and traits, so too did the new taxonomy prompt bacteriologists to consider a broad range of morphological, physiological and cultural characteristics.

If the Society of American Bacteriologists achieved some measure of success in forging a more unified and fundamental science, it was the descriptive chart and determinative manual that most enabled that end. The Society's Card and *Bergey's Manual* created the basis of a social world for American bacteriology, a "universe of regularized mutual response" among divergent practitioners. The SAB's taxonomy and collection of methods stood as core components in the work of the discipline, enabling bacteriologists of dissimilar interests and training to do things together. Novices and outsiders entered this social world by becoming acquainted and proficient with tools and language of the science. Yet, neither the Society's Card nor the *Bergey's Manual* eliminated the lingering sense of collective unease. A worry persisted that bacteriology might still lack a theoretical grounding and remain unable to duplicate the heroic achievements of its

bygone "Golden Age." This thesis has suggested that disciplinary unease, can, in some circumstances, be productive. The Society leaders endeavored to move the science of bacteriology beyond its hodgepodge of technical procedures. As a community, American bacteriologists comprised a social world whose members believed that their object of study remained elusive, and their recurrent successes difficult to reproduce. That SAB leaders continued to voice discontent does not imply that organization's efforts produced little effect. To the contrary, the preceding pages demonstrated that these disciplinary anxieties cast a collective spotlight in search of bacteriology's missing conceptual or theoretical elements.

nomenclature.

If the Descriptive Card and *Bergey's Manual* represented a process of negotiation and compromise, they in turn partially comprised what sociologists Anselm Strauss and Howard Baker deem a "social world." It is a community's "activities with their stuff, their routines, and exceptions" that comprise "the community structure." The Chart and *Manual* directed novices and outsiders to the objects of practice, provided them with shared language to discuss the practices, and a loose theoretical framework to understand unresolved questions.³⁴¹ These mundane objects help "naturalize" newcomers. In most cases, familiarity with these objects, and not proficiency, is sufficient to produce a "measure of taken-for-grantedness." If after a process of education and laboratory practice, a bacteriologist could fully employ the Descriptive Chart and *Bergey's Manual*, very few aspects of the science would appear strange.

³⁴¹ Bowker and Star, Sorting Things Out, 294 & 297; Strauss, "A Social World Perspective," Studies in Symbolic Action 1 (1978): 119-128; and, Becker, Tricks of the Trade (Chicago: University of Chicago Press, 1988).

CONCLUSION

Bacteriology, in 1925, remained a disunified discipline. While American researchers increasingly employed the SAB's Descriptive Chart and the *Bergey's Manual of Determinative Bacteriology*, the science still lacked a unifying theory, common set of concerns, or even a shared language. By some measures, the specialization and fragmentation of bacteriology continued without interruption during the first quarter of the twentieth century. It is not surprising then to find SAB leaders reiterating their pleas for a more biological bacteriology. The disciplinary anxiety persisted despite their best efforts. Nonetheless, bacteriology in 1925 differed greatly from the science practiced at the turn of the century. Owing to the efforts of the Society of American Bacteriologists, and the ascending authority of dairy and soil bacteriology, researchers began to consider organisms and phenomena formerly occluded by the hygienic vision of microbial exclusion. Even within medical, public health, and sanitary bacteriology, investigators probed the enigmatic aspects of bacterial physiology, variation, and physical chemistry. Microbes, by 1925, slowly emerged as biological organisms with phylogenetic histories, associative relationships, and complex metabolisms.

This thesis has documented the sources for disciplinary anxiety. Initially, bacteriology, as a form of scientific work, differed from one institutional context to another. Within medical colleges and hospitals, bacteriologists lent their technical expertise in service to pathologists and

physicians; their work helped identify and eliminate microbial pathogens for individual patients. Within departments of public health and water filtration plants, bacteriologists proffered techniques for determining sources of disease transmission, whether they be from infected individuals or contaminated milk and water. This hygienic vision underscored the utility of routine procedures, where minimally trained laboratory technicians could perform innumerable tissue stains, throat cultures, and fermentation tests in a cost-efficient manner. Medical, public health, and sanitary bacteriologists garnered institutional favor by aiding the elimination of a select number of pathogens. The routine work that these bacteriologists performed sustained a rapid professional growth, as bacteriology emerged in the early twentieth century as a central component of scientific medicine and modern public health. Nonetheless, the hygienic vision and its supporting institutional contexts offered little encouragement for original research in areas not immediately relevant to the elimination of disease germs. For most medical, public health, and sanitary bacteriologists, microbes were worthy only of eradication, and not careful or prolonged scrutiny.

Veterinary bacteriology closely paralleled the development of medical bacteriology. Like their medical counterparts, veterinarians received brief instruction in bacteriology (four to eight week courses) as part of their professional training, often employing the same textbooks and manuals. By 1925, a majority of veterinarians held some familiarity with the methods of isolating, identifying, and eliminating the microbial agents of animal illness. Yet, these same veterinary scientists simply rehearsed the routine techniques of pure culture methods, employing only the cookbook and recipe formulae needed to determine the causative organisms of bovine tuberculosis, black-leg, contagious abortion, pullorum, swine plague, and fowl cholera.

Veterinary bacteriologists, like their medical counterparts, attended to a limited number of organisms and a narrow range of phenomena. For the few who sustained active research programs, they focused their efforts on resolving the etiological uncertainties of infectious diseases, rather than exploring the life histories and complex ecological relationships among the broad class of bacteria. Despite this conceptual constriction, veterinary bacteriology contributed greatly to the reduction of livestock mortality, offering diagnostic tests for bovine tuberculosis and glanders, vaccines against chicken cholera and blackleg, and therapeutic sera to treat hemorrhagic septicemia. In an institutional environment removed from the established patterns of hospitals, public health departments, or water filtration plants, veterinary bacteriologists reproduced a similar technical enterprise that encouraged the routine, rather than a search of the fundamental.

In contrast, dairying and soil science prompted the development of an alternative set of bacteriological practices. In particular, dairy and soil bacteriologists endeavored to *manage* and *exploit*, rather than eliminate, microbes. Bacteriology, according to some observers, represented the pinnacle of scientific farming, and a perfect compromise between the conflicting demands of science and service vexing most staff members of agricultural colleges and experiment stations. These agricultural scientists sought to identify efficient starter cultures to aid in the production of quality cheese and butter, legume cultures to encourage symbiotic nitrogen fixation, and tillage practices to stimulate nitrification in soils. As a result, they attended to a wide range of microorganisms, and investigated phenomena normally overlooked by the "hygienic vision" (e.g., bacterial physiology, cytology, associative behavior, variation, systematics, phylogenetic relationships, hydrogen-ion concentrations). Dairy and soil bacteriologists shunned the hygienic

APPENDIX 1: TABLES FOR CHAPTERS 1-3

TABLE 1.1

INSTRUCTION IN MEDICAL BACTERIOLOGY BEGUN PRIOR 1900

<u>Name</u>	<u>Date</u>	<u>Personnel Prior to 1900</u>
Bellevue Medical Hospital College and New York University	1879	W. Welch; H.M. Biggs; B.H. Buxton; J. Weeks J.A. Byron; F.A. Abbott; W. Coleman; W.H. Park A.L. Loomis; E.K. Dunham; A.L. Beebe
Columbia Univ. College of Phys. & Surg.	1879	T.M. Prudden; T.M. Cheeseman; P.H. Hiss
University of Pennsylvania, Medical and Laboratory of Hygiene	1883	H.F. Formad; J. Guiteras; J. McFarland; S. Flexner A.C. Abbott; D.H. Bergey; S. Flexner; C.Y. White
University of Michigan	1884	V.C. Vaughan; F.G. Novy
Massachusetts Institute of Technology	1884	W.T. Sedgwick; S.C. Prescott
Harvard Medical School	1885	H.C. Ernst; T. Smith; J.H. Wright; W. Councilman
Johns Hopkins University	1886	W.H. Welch; A.C. Abbott; G.H. Nuttall; N. Harris W. Councilman; H. Pease; W. Ford; A. Bloomfield
University of Illinois College of Medicine	1886	R. Curtiss; B. Holmes; W. Coates; A. Gehrman
Columbian University/National Med. Coll.	1886	T. Smith
Long Island College Hospital	1887	G.M. Sternberg; J. van Cott; G.T. Kemp; B. Bolton E.H. Wilson; B. White
Blackswell Medical College	1887	A. Kuno
Northwestern Medical College	1888	B. Holmes; J. Kales; F.R. Zeit
Beaumont Medical College	1888	W.N. Beggs; B.M. Bolton
Jefferson Medical College	1888	W.M. Coplin; R. Rosenberger; D. Brandon; S. Gross
Western Reserve School of Medicine	1888	F. Herrick; J.P. Sawyer; W.T. Howard; R.C. Perkins
Chicago College Physicians & Surgeons	1889	R.J. Curtis; B. Holmes; L. Hektoen
Medico-Chirurgical College	1889	E. Laplace; J. McFarland; E.B. Sangree
University of Iowa	1890	L.W. Littig; W.L. Bierring; H. Albert
Yale Medical School	1890	C.J. Foote; C.J. Bartlett
University of Missouri & Medical Schol	1890	P. Paquin; B.M. Bolton; P. Kaufmann
Ohio Agricultural & Mechanical College	1890	A.M. Bleile; C.B. Morrey
Rush Medical College	1891	W. Belfield; G.H. Weaver; L. Hekteon; H.G. Wells
Marion Sims	1891	G. Campbell
Washington University, St. Louis	1891	A.N. Ravold
Detroit Medical College	1892	G. Duffield; W.C. Martin; E.H. Sargent; E.H. Troy C.T. McClintock
Northwestern Women's Medical College	1892	L. Hekteon; G.H. Weaver
Wabash College	1892	M.B. Thomas; H.W. Anderson; R.M. Holman
University of Maryland Medical School	1893	W.R. Stokes
Boston University School of Medicine	1893	O. Caldwell
Cooper Medical College / Stanford	1893	W. Ophuls
University of California, Berkeley	1893	T. Bowhill; J.C. Spencer; H.A. Ryfkogel
Brown University	1893	G.W. Field; F.P. Gorham; C.V. Chapin
University of Buffalo Medical School	1893	H.U. Williams
University of Wisconsin	1894	H.L. Russell; W.D. Frost
University of Kansas	1894	W.C. Stevens; M.A. Barber

TABLE 1.1 – *Continued*

INSTRUCTION IN MEDICAL BACTERIOLOGY BEGUN PRIOR 1900

<u>Name</u>	<u>Date</u>	<u>Personnel Prior to 1900</u>
University of Minnesota Medical School	1895	C.N. Hewitt; F.F. Wesbrook; E.B. Block; J. Stewart
University of Chicago	1895	E.O. Jordan; H. Davies; H.G. Wells; W.B. Wherry
Tufts College Medical School	1895	H.W. Dudley; T. Leary
University of Pittsburgh	1896	A.B. Wallgren; J.C. Fetterman; O. Klotz
Albany Medical College	1896	G. Blumer; H.D. Pease
University of Nebraska	1896	H.H. Waite
Women's Medical College, Pennsylvania	1896	L. Rabinowitsch; A.W. Peckham
Indiana University	1896	R.E. Lyons
Army Medical College	1896	G.M. Sternberg
Cornell University Medical School	1898	J. Ewing; B.H. Buxton
University of Oklahoma	1898	V. Vleet
West Virginia University	1899	A.E. Thayer; W.S. MacGill

TABLE 1.2

INSTRUCTION IN MEDICAL BACTERIOLOGY, BEGUN 1900-1919

<u>Name</u>	<u>Date</u>	<u>Personnel</u>
University of Southern California	1900	S.P. Black; E.B. Hoag; R.A. Bebb; A.F. Wagner E. Leonard; W.B. Brem; T.H. Glenn; A.L. Grover
Medical College of Virginia, Richmond	1900	H.T. Marshall; E.C. Miller; A.H. Straus
St. Louis University School of Medicine	1900	B.M. Bolton; R.L. Thompson
University Texas, Galveston	1902	A.J. Smith; M.F. Boyd
Michigan Agricultural College	1903	C.E. Marshall; O. Rahn; I.F. Huddleson
Baylor University College of Medicine	1904	P. Wilson; A.E. Thayer; W.H. Moursund; J.H. Black
University of Utah, College of Medicine	1905	R. Anderson; D.L. Daines
Valparaiso University	1906	
Miami University	1906	B. Fink
University of Washington	1907	J.W. Weinzirl
University of Illinois	1908	W.J. MacNeal; J.A. Sperry
Oregon State University	1909	E.F. Pernot; T.D. Beckwith
Loyola (Bennett) Medical College	1909	M.J. Herzog
Franklin College	1909	J.W. Adams
Medical College of Georgia	1909	R.V. Lamar
Fordham College	1909	C.Z. Garside
Philadelphia Womens' Medical College	1910	J. McFarland
Syracuse University, College of Medicine	1911	F.M. Meader; H.N. Jones; J.L. Rice
University of Toledo	1911	H.H. Bowman; P.E. Bethards
Utah Agricultural College	1912	E.G. Peterson; J.E. Greaves; E.G. Carter
College Medical Evangelists	1912	W.A. Ruble; F.E. Heryer
University of Oregon Medical School	1912	R. Matson; H.J. Sears
New York Post-Graduate Medical School	1912	W.J. MacNeal; R.M. Taylor
University of Cincinnati	1913	W.B. Wherry; W.W. Oliver
Carnegie Institute of Technology	1913	J.E. Rush; H.L. Lang
Tulane University Medical School	1913	C.C. Bass
Purdue University	1914	C.A. Behrens
Vanderbilt University	1915	J.W. Jobling
Notre Dame	1916	R.M. Kaczmarek; G. Albertson
University of Tennessee	1919	M. Mulvania
Mulford School of Bacteriology & Immun.	1919	F.M. Huntoon

TABLE 1.3

RESEARCH INSTITUTIONS IN MEDICAL BACTERIOLOGY PRIOR TO 1920

<u>Name</u>	<u>Date</u>	<u>Personnel</u>
Bellevue Medical Center, Carnegie Laboratory, New York University	1879	W.H. Welch; A.L. Loomis; H.M. Biggs; J.E. Weeks E.K. Dunham; W. Coleman; B. Buxton; W.H. Park F.W. Shipman; C.F. Bolduan; T. Flournoy A.F. Hess; C. Norris; C. Krumwiede; W. Noble, Jr. A.M. Pappenheimer; E.G. Clifton; L.W. Famulener
College Physicians & Surgeons Columbia University	1879	T.M. Prudden; E. Hodenpyl; W.H. Park; P.H. Hiss C.A. Herter; F.C. Wood; H. Zinsser; C. Norris C.B. Fitzpatrick; A.B. Wadsworth; H. Heinman J.G. Hopkins; C.B. Coulter; G. Draper; C.B. Knapp F.B. Humphreys; A. Kuttner; J.T. Parker; J. Mueller
Harvard Medical School and School of Public Health	1884	H.C. Ernst; T. Smith; R.P. Strong; J.H. Brown W.T. Councilman; F.B. Mallory; R.M. Pearce F.H. Williams; M.J. Rosenau; A.I. Kendall J.J. Bronfenbrenner; D. Soletsky; M.J. Schlesinger B. Aronovitch; R.R. Mellon
Johns Hopkins University, Medical School, Hospital, and School of Hygiene and Public Health	1885	W.H. Welch; A.C. Abbott; S. Flexner; W.W. Ford G.H. Nuttall; W.T. Councilman; W.D. Becker H.D. Pease; F.P. Mall; B. Bolton; N. Harris C.G. Bull; S. Bayne-Jones; G.H. Robinson I.W. Pritchett; M.D. Batchelor; T.M. Rivers J.T. Halsey; P.D. Meader; W.C. Davison
Hygienic Laboratory, U.S.P.H.S.	1887	J.J. Kinyoun; M.J. Rosenau; J.F. Anderson A.C. Evans; M.H. Neill; H.D. Geddings; J.W. Kerr A.M. Stimson; J. Goldberger; G.W. McCoy C.W. Chapin; H.E. Hesseltine; H.B. Corbitt J.W. Trask; J.P. Leake; I. Bengston; E. Francis G.C. Lake
Hoagland Laboratory	1889	B.M. Bolton; J. van Cott; G.T. Kemp; E.H. Wilson A. Stub; P.C. Jameson; R.B. Randolph; A. Murray B. White; O.T. Avery; J.B. Thomas; W. Lintz C.Z. Garside; H.W. Lyall; W.W. Oliver; A. Eggerth
University of Michigan	1889	V.C. Vaughan; F.G. Novy; C.E. Marshall H.H. Waite; W.J. MacNeal; H.N. Torrey A.S. Warthin; R.S. Knapp; P.H. de Kruif; W. Starin G.M. Sternberg
Surgeon General, U.S. Army	1889	H.M. Biggs; W.H. Park; J. Billings, Jr.; R.J. Wilson
New York City Department of Health	1892	A.W. Williams; A.L. Beebe; C.B. Fitzpatrick C.W. Field; A.F. Hess; C.F. Bolduan; E.J. Banzaf C.K. Greenwald; J. Koopmann; M.C. Schroeder A. Sholly; C. Krumweide; J.B. Neal; E. Applebaum M.E. Goodwin; P. Du Bois; E.L. Valentine L.A. Kohn; J.S. Pratt; A. Sophian; G.M. Cooper

TABLE 1.3 – *Continued*

RESEARCH INSTITUTIONS IN MEDICAL BACTERIOLOGY PRIOR TO 1920

<u>Name</u>	<u>Date</u>	<u>Personnel</u>
University of Pennsylvania, Hygienic Lab. and Medical School	1892	J.S. Billings; A.C. Abbott; D.H. Bergey; S. Flexner A.A. Ghriskey; N. Gildersleeve; F.P. Gay J.H. Wright; J.A. Kolmer; P.A. Lewis; A.J. Smith E.L. Moshage
University of Iowa	1893	W.L. Bierring; H. Albert
Western Reserve School of Medical	1894	W.T. Howard; R.G. Perkins; E.E. Ecker; O. Ishii O.T. Schultz
Boston City Hospital	1894	F.H. Williams; L.W. Strong
University of Wisconsin	1895	H.L. Russell; W.D. Frost; M.P. Ravenel; P.F. Clark W.D. Stovall; E.J. Murphy
William Pepper Laboratory, Univ. Penn	1895	S.S. Kneass; C.Y. White
Beaumont Medical College	1895	B.M. Bolton
Parke, Davis & Company	1896	C.T. McClintock; E.M. Houghton; W.E. King R.H. Wilson; E.C. Miller; W.A. Pearson L.T. Clark; F.O. Northey; N.S. Ferry; J. McFarland A. Noble; H.C. Klix; L.D. Davis; M.C. Worth L.W. Fisher
H.K. Mulford Company	1896	J. McFarland; L. Pearson; W.F. Elgin; C.W. Lincoln H.C. Campbell; A.P. Hitchens; J.J. Kinyoun J. Adam; W.R. Albus; M.A. Corsa; G.H. Robinson O.W. Schobl; C.P. Brown; G. Hanson; D. Rogers G.H. Smith; M. Cook; J. Reichel; O.T. Avery M.J. Harkins; C.G. Roos; F.A. Boudart; T.G. Finley D. Rogers; F.M. Huntoon; E.M. Gray; G. Hansen G.H. Smith; E.L. Hannum; S.J. Thomas
University of Minnesota Medical School	1897	F.F. Wesbrook; E. Fidler; L.B. Wilson; W. Chowling W.P. Larson; A.T. Henrici; E. Fidler
Brown University	1897	F.P. Gorham; M.X. Sullivan; G.H. Robinson A.W. Street
Army Medical College & Museum	1897	G.M. Sternberg; W. Reed; J. Carroll; F.G. Blake H.J. Nichols; C.G. Snow; C.O. Stimmel; J.F. Siler E.R. Whitmore; F.F. Russell
USPHS Marine Hospital, San Francisco and Federal Plague Laboratory	1900	J.J. Kinyoun; G.W. McCoy; J.N. Force; C.W. Chapin W.B. Wherry
University of Chicago & Howard Taylor Ricketts Laboratory	1900	E.O. Jordan; H.G. Wells; W.B. Wherry; L. Hektoen E.R. Le Count; M. Hefferan; W.H. Manwaring N. Harris; H.T. Ricketts; P.G. Heinemann E.E. Irons; R.M. Wilder; W.B. Sharp; P.R. Cannon E.B. Fink; H.M. Goodman; J.E. Gordon; I.C. Hall F.R. Zeit; A.P. Ohlmacher; A.I. Kendall; A.A. Day A.W. Walker; M. Ryan
Northwestern Medical School	1900	W. Ophuls; H.C. Moffitt
Cooper Medical College, California	1900	O. McDaniel
Minnesota State Board of Health	1900	

TABLE 1.3 – *Continued*

RESEARCH INSTITUTIONS IN MEDICAL BACTERIOLOGY PRIOR TO 1920

<u>Name</u>	<u>Date</u>	<u>Personnel</u>
University of Buffalo	1901	H.U. Williams
St. Louis University School of Medicine	1901	B.M. Bolton; R.L. Thompson; M.S. Fleisher
Albany Medical College and New York State Dept. of Health	1901	G. Blumer; H.D. Pease; A.B. Wadsworth; E. Carey H.W. Lyall; H.R. Odell; F.M. Meader
Rockefeller Institute Medical Research	1901	S. Flexner; H. Noguchi; J.W. Jobling; S.J. Meltzer A.R. Dochez; M. Wollstein; E.L. Opie; G. Draper W.H. Manwaring; P. Rous; J.B. Murphy; L. Lange F.G. Blake; J. Defendorf; J.D. Trask; R.I. Cole I.J. Kligler; P.K. Olitsky; O.T. Avery; M.A. Barber S.T. Darling; H.P. Hacker; R.L. Cecil; P.F. Clark L.J. Gillespie; R. Godsmith; O. Teague; R.P. Strong J.P. Simonds; I.W. Pritchett; R.V. Lamar; H.F. Swift F. Ebersson
McCormick Institute for Infectious Diseases	1902	L. Hektoen; G.H. Weaver; H.G. Wells; D.J. Davis A. Hamilton'; E.C. Rosenow; E.O. Jordan G.F. Ruediger; P.G. Heinemann; R. Tunnicliff
Lederle Laboratories	1902	E.J. Lederle; C.Z. Garside; L.C. Himebaugh C.E. North; P.B. Parsons; H.D. Pease
Henry Phipps Institute	1903	M.P. Ravenel; L.F. Flick; P.A. Lewis; C.Y. White J. McFarland
Medical College of Virginia, Richmond	1905	E.C. Miller; A.H. Straus
Medico-Chirurgical College, Philadelphia	1905	J. McFarland; E.M. L'Engle; R.L. Pitfield
Cornell University Medical School	1906	W.J. Elser; B. Buxton; F.M. Huntoon; J.C. Torrey J. Ewing; O. Teague; J.H. Richards; A.H. Rahe G.W. Wheeler
Columbian University/National Med. Coll.	1907	J.J. Kinyoun; F.F. Russell; E.W. Price
Tufts University Medical College	1907	T. Leary
University of Kansas	1907	M.A. Barber; B.J. Clawson; C.M. Downs; W. Starin N.P. Sherwood; E.L. Treece
Smith, Line and French Co.	1908	W.A. Pearson
University of Nebraska	1908	H.H. Waite
Stanford University	1909	H. Zinsser; W.H. Manwaring; W. Ophuls R.L. Wilbur; Y. Kusama; E.W. Shultz; J.T. Connell
Ohio Agricultural and Mechanical College	1909	E.F. McCampbell; C.B. Morrey; W.A. Starin V.M. Masters
Health Department, City of Boston	1909	B.L. Arms; E.M. Wade
University of California, Berkeley, and the Hooper Foundation	1901	W.H. Kellogg; F.P. Gay; W.A. Sawyer; G.Y. Rusk E.J. Claypole; I.C. Hall; K.F. Meyer; J.N. Force J.G. Fitzgerald; H.T. Chickering; S.B. Hooker
Nelson-Morris Institute	1910	J.W. Jobling; C. Howell
University of Missouri	1910	D.H. Dolley; M.P. Ravenel; O.W. Mitchell
Washington University, St. Louis	1910	E.L. Opie; F. Ebersson; M.F. Engman
Research Laboratory, Trudeau Sanitorium	1910	E. L. Trudeau; S.A. Petroff

TABLE 1.3 – *Continued*

RESEARCH INSTITUTIONS IN MEDICAL BACTERIOLOGY PRIOR TO 1920

<u>Name</u>	<u>Date</u>	<u>Personnel</u>
University of Pittsburgh	1911	O. Klotz; W.L. Holman
Otho S.A. Sprague Memorial Institute	1911	H.G. Wells; L. Dewitt
New York Post-Graduate Medical School	1912	W.J. MacNeal; R.M. Taylor
E.R. Squibb & Sons	1912	J.F. Anderson; A. Sophian; G.F. Leonard
New England Hosp. Women & Children	1912	M.E. Morse
Pathological Lab., St. Lukes Hospital	1913	L.W. Famulener; J.G. Hopkins
Tulane University Medical School	1913	C.C. Bass
Dublin Chemical & Bacteriological Labs	1913	E.C. Stowall; M.J. Schlesinger; C.M. Hilliard M.H. Boyce
Cutter Biological Laboratories	1913	I.C. Hall; R.V. Stone; S.A. Waksman; G.W. Clark H.E. Foster; F.E. Twining
University of Cincinnati	1914	W.B. Wherry; W.W. Oliver; B.H. Lamb
University of Illinois College of Medicine	1914	D.J. Davis; J.J. Moore
Yale University Medical School	1914	C.J. Bartlett; G.H. Smith; S.A. Koser; L. Rettger T.G. Hull; G.E. Gage; J.R. McClelland M.R. Smirnow; D. Greenberg; S.J. Maher; H. Ito H. Ozaki; A.L. O'Shansky; H.A. Cheplin G.D. Horton; R.L. Kahn; F.B. Kinne; J.A. Sperry
Mayo Foundation Clinic, Rochester	1915	E.C. Rosenow
West Virginia Univ., School of Medicine	1915	A. Arkin
City Department of Health, Detroit	1918	R.W. Pryer
Maryland State Board of Health	1919	M.S. Bailey; F.W. Hachtel

TABLE 1.4

PUBLIC HEALTH BACTERIOLOGY LABORATORIES PRIOR TO 1920

<u>Name</u>	<u>Date</u>	<u>Personnel</u>
Providence City Health Department	1884	C.V. Chapin
Hygienic Laboratory, U.S.P.H.S.	1887	J.J. Kinyoun; M.J. Rosenau; J.F. Anderson
Michigan State Department of Health, Hygienic Laboratory	1887	V.C. Vaughan; F.G. Novy; T.B. Cooley; M.L. Holm J.G. Cumming; H.W. Emerson; A.A. Spoor
Rhode Island Department of Health	1888	G.T. Swarts; J. Perkins; H.S. Bernton; H.W. Lyall L.A. Round; A.G. Gigger
Minnesota State Board of Health	1892	C.N. Hewitt; W.D. Frost; F.F. Wesbrook O. McDaniel; H.W. Hill; E.M. Wade
New York City Health Department	1892	H.M. Biggs; E.K. Dunham; W.H. Park; A.L. Beebe P.H. Hiss; A.W. Williams; A.R. Guerard A. Agramonte; R.J. Wilson; A. Lambert T.A. Watson; A.H. Doty; O.R. Povitsky G.A. Soper; A.F. Hess; C.B. Fitzpatrick C. Krumweide; C.F. Bolduan; B. Bradford J.B. Neal; E. Applebaum; G.M. Cooper E.J. Banzhof; G.V. Stoughton; M.C. Schroeder A. Sophian; P.H. Du Bois; B. White; H.W. Lyall J.S. Pratt; E.L. Valentine; A. von Sholly
Brooklyn Bur. Path., Bact. & Disinfect., and Hoagland Laboratory	1894	J. van Cott; R. Slee; E.H. Wilson; J.B. Thomas; R.B. Randolph; A. Murray; H.W. Lyall; A. Wieber
Chicago Health Department	1894	A. Gehrman; J.F. Biehn; F.O. Tonney; H.J. Corper H.C. Sweany
Health Department, City of Boston	1894	H.C. Ernst; H.W. Hill; B.R. Rickards; B.L. Arms A.K. Stone; F.H. Slack; E.M. Wade; F. Joyner W.S. Blanchard; P. Castleman
St. Louis Health Department	1894	A.N. Ravold; C.A. Snodgras; D.L. Harris W.C. Kirchner; C.W. Schery
Philadelphia Bureau of Health	1894	A.C. Abbott; J. McFarland; B. Bolton; H.D. Pease C.Y. White
Illinois State Board of Health	1894	W.H. Hoyt; H. Blankenmeyer; W. G. Bain
Diagnostic Laboratory, Massachusetts Department of Public Health	1895	T. Smith; H.H. Gillette; H.N. Jones; E.A. Beckler C. Harrington; J.L. Goodale; M.J. Rosenau E.L. Walker; R. Bryant; K. Marden; A.P. Hale F. Joyner
Pittsburgh Bureau of Health	1895	E.G. Matson; G.B. Taylor; M.C. Cunningham
Cleveland Department of Health	1895	W.T. Howard; R.G. Perkins
New Jersey State Board of Health	1896	B.M. Bolton; R.B. Randolph
New Haven Board of Health	1896	C.J. Bartlett; A.L. O'Shansky
Bender Hygienic Laboratory, Albany	1896	G. Blumer; H.D. Pease; R.M. Pearce
Buffalo Board of Health	1897	W.G. Bissell
Los Angeles City Health Department	1898	E. Leonard; J. Horton
Montclair, NJ, Board of Health	1899	M.O. Leighton

TABLE 1.4 – *Continued*

PUBLIC HEALTH BACTERIOLOGY LABORATORIES PRIOR TO 1920

<u>Name</u>	<u>Date</u>	<u>Personnel</u>
Salt Lake City Health Department	1900	H. Harmes; S.G. Paul; R.W. Ashley
San Francisco Board of Health	1900	W.H. Kellogg
New York State Department of Health	1901	H.D. Pease; W.S. Magill; A.B. Wadsworth W.S. Magill; F.M. Meader; H.W. Lyall; H.R. Odell B.R. Rickards; E. Carey
Ohio State Health Department	1902	C.B. Morrey; E.F. McCampbell; F. Berry
Wisconsin State Hygienic Laboratory	1903	H.L. Russell; M.P. Ravenel; W.D. Stovall
Iowa State Board of Health Laboratory	1904	H. Albert
Connecticut Board of Health	1905	H.W. Conn; C.J. Bartlett; C.A. Lindsley
California State Hygienic Laboratory	1905	G.F. Reinhardt; A.R. Ward; W.A. Sawyer; W. Brem C.W. Bonyng; C.B. McGlumphy; E.C. Seymour M. Henderson; J.C. Geiger; J.N. Force; E. Skolfield G.A. Macmillan; W.H. Kellogg; V.M. Bathgate
Florida State Board of Health	1905	E. Andrade; E.G. Birge
Health Department, Washington, D.C.	1907	J.J. Kinyoun; L.V. Deiter
West Virginia Hygienic Laboratory	1906	A. Arkin
Missouri State Board of Health	1906	G. McConnell; M.C. Stone; G.C. Jones; N. McVay M.P. Ravenel
Savannah Bd. of Sanitary Commissioners	1908	V.H. Bassett
Virginia State Department of Health	1909	M. Ferguson; A.H. Straus
Toledo Health Department	1911	P.E. Bethards
Texas State Department of Health	1911	M. Graham
Baltimore City Health Department	1912	J.B. Thomas; W.R. Stokes; W.T. Howard H.W. Stoner
Richmond Department of Health	1912	E.C. Levy; W.F. Lawrence; H.V. Stewart
Indiana State Board of Health	1915	W. Shimer
LaSalle Health Commission	1915	G.F. Ruediger
Berkeley Department of Health	1916	C.L. Schmidt; H.J. Sears
Utah Department of Health	1916	D.L. Daines
City Department of Health, Detroit	1917	R.W. Pryer
Syracuse Department of Health	1918	A.G. Gigger; H.N. Jones
Maryland Board of Health	1919	M.S. Bailey; F.W. Hachtel

TABLE 1.5

INSTRUCTION PUBLIC HEALTH BACTERIOLOGY PRIOR TO 1920

<u>Name</u>	<u>Date</u>	<u>Personnel</u>
Columbia Univ., College of Physicians & Surgeons, and Inst. of Pub. Health	1879	T.M. Prudden; T.M. Cheeseman; P.H. Hiss H. Zinsser; H. Emerson
Massachusetts Institutes of Technology	1886	W.T. Sedgwick; C.-E.A. Winslow; F.H. Slack S.C. Prescott; E.C. Howe; M.P. Horwood S.M. Gunn; E.A. Ingham; C.E. Turner
Long Island College Hospital	1887	G.M. Sternberg; G.T. Kemp; E.H. Wilson; B. White W. Lintz; H.W. Lyall
University of Michigan	1888	V.C. Vaughan; F.G. Novy; C.A. Behrens; P. deKruif
New York University	1894	W.H. Park
University Illinois College of Medicine	1894	A. Gehrmann
University of Wisconsin	1894	H.L. Russell; W.D. Frost; M.P. Ravenel; W. Stovall
Brown University	1895	F.P. Gorham; C.V. Chapin; A.G. Wing
Purdue University	1895	S. Burrage; C.M. Hilliard; C.A. Behrens
University of Minnesota	1895	F.F. Wesbrook; C.N. Hewitt; H.W. Hill H.E. Robertson; L.B. Wilson; A.T. Henrici
University of Chicago	1897	E.O. Jordan; A.L. Smith; N. Harris; P.G. Heinemann E.E. Irons
University of Pittsburgh	1897	A.B. Wallgren
Army Medical College	1897	G.M. Sternberg; F.G. Blake; H.J. Nichols C.O. Stimmel; F.F. Russell; E.R. Whitmore
Indiana University	1902	R.E. Lyons; W.H. Manwaring
Simmons College	1902	W.T. Sedgwick; S.C. Prescott; S.M. Elliott; S.M. Gunn; E.A. Beckler; C.M. Hilliard; J.B. Patten
Virginia Polytechnic Institute	1904	E.B. Fred
University of New Mexico	1905	J.W. Weinzirl
Yale University	1905	C.J. Bartlett; C.-E.A. Winslow
University of Penn. School of Hygiene	1906	A.C. Abbott
University of Texas, Galveston	1906	A.J. Smith; M.F. Boyd; W.B. Sharp; B.L. Arms
University of Washington	1907	J.W. Weinzirl
University of California, Berkeley	1908	M. Henderson; J.N. Force; I.C. Hall; G.F. Reinhardt
Harvard Medical School and School Public Health Officers	1909	M.J. Rosenau; G.C. Whipple; T. Smith; A. Hamilton G.M. Fair; J.W. Bunker
Cornell University Medical College	1909	J.C. Torrey
Stanford University	1909	H. Zinsser; E.C. Dickson
Western Reserve Medical School	1910	R.G. Perkins
City College of New York	1910	W.W. Browne; C.-E.A. Winslow
Oregon State University	1912	T.D. Beckwith
University of Illinois	1912	O. Rahn; W.J. MacNeal
West Virginia Univ. School of Medicine	1913	A. Arkin
Kansas University	1913	N.P. Sherwood; C.M. Downs; E.L. Treece
University of Missouri	1914	M.P. Ravenel
Miami University	1916	B. Fink
Johns Hopkins Sch. Hyg. & Pub. Health	1916	W.H. Welch; W.W. Ford; C.G. Bull; P.D. Meader
University of Tennessee	1919	M. Mulvania; W.L. Holt

TABLE 1.6

INSTITUTIONS PERFORMING BACTERIOLOGICAL EXAMINATIONS
OF WATER, MILK OR FOOD

<u>Name</u>	<u>Date</u>	<u>Personnel</u>
Illinois State Board of Health	1885	J.H. Long; F.R. Zeit; G. Gruterrer
Lawrence Experiment Station, Boston Water Works, and Metropolitan Water & Sewage Board	1887	W.T. Sedgwick; E.O. Jordan; S. DeM. Gage W.R. Copeland; A. Hazen; G.C. Whipple H.W. Clark; A.I. Kendall; S.C. Prescott; E.B. Phelps B.G. Philbrick
Hygienic Laboratory, Yale	1887	C.J. Foote; T.G. Lee; C.J. Bartlett
Michigan State Department of Health	1887	V.C. Vaughan; F.G. Novy; M.L. Holm; A.A. Spoor C.C. Young
Rhode Island Department of Health	1888	G.T. Swarts; J. Perkins; H.S. Bernton; L.A. Round
Providence Health Department	1888	C.V. Chapin; F.P. Gorham
Connecticut State Board of Health	1890	C.J. Foote; H.W. Conn; C.J. Bartlett; W.H. Parker
Ohio State Health Department	1891	A.M. Biele; E.F. McCampbell
Minnesota State Board of Health	1892	C.N. Hewitt; W.D. Frost; F.F. Wesbrook; H.W. Hill E.M. Wade; H.A. Whittaker; J.A. Childs
Chicago Department of Health	1893	A. Gehrman; J.F. Biehn; P. Heinemann; E.B. Stuart F.O. Tonney; J.L. White
Los Angeles City Health Department	1893	E. Leonard; A.F. Wagner; J. Horton
Mt. Prospect Laboratory, Brooklyn	1895	T.M. de Varona; G.C. Whipple; H.W. Hill; L. Sawin
Rockville Center Laboratory Brooklyn	1895	H.W. Hill
Illinois State Water Survey	1895	E. Bartow; R.L. Russell; R.E. Greenfield F.W. Tanner; W.D. Hatfield; F.L. Mickle; M. Perry
Boston Board of Health	1895	H.C. Ernst; F.H. Slack; E.M. Wade; H.W. Hill
Pittsburgh Bureau of Health and Bureau of Water Supply	1896	E.G. Matson; A.B. Wallgren; W.U. Baton W.R. Copeland
Wisconsin Hygienic Laboratory	1896	H.L. Russell; W.D. Frost; E.G. Smith; W.D. Stovall
New York City Department of Health, and Department of Water Supply, Gas & Electricity	1897	H.M. Biggs; W.H. Park; M.C. Schroeder; R.A. Bebe R.J. Wilson; D.D. Jackson; S.B. Belcher W.E. Spear; G.V. Stoughton; G.A. Soper
Buffalo Board of Health	1897	W.G. Bissell
Philadelphia Bureau of Health	1898	W.J. Gillespie; H.D. Pease; A.H. Stewart M.E. Pennington
Pennsylvania State Board of Health	1898	D.H. Bergey
Commission of Water Works, Cincinnati	1898	G.A. Johnson; G.W. Fuller
Worcester Board of Health	1899	L.P. Kinnicutt; H.P. Eddy
Montclair, NJ, Board of Health	1899	M.O. Leighton
Hoagland Laboratory	1899	E.H. Wilson; H. Moak; A. Wieber
Pennsylvania Railroad Company	1899	M.E. McDonnell; E.G. Birge
St. Louis Health Department	1900	W.C. Kirchner; G.A. Johnson, C.A. Snodgras A.N. Ravold; C.W. Schery

TABLE 1.6

INSTITUTIONS PERFORMING BACTERIOLOGICAL EXAMINATIONS
OF WATER, MILK OR FOOD

<u>Name</u>	<u>Date</u>	<u>Personnel</u>
Cleveland Department of Health	1901	W.T. Howard; R.G. Perkins
Oklahoma Agricultural Experiment Station	1904	J.F. Nicholson; B.J. Clawson
Florida State Board of Health	1905	E. Andrade; E.G. Birge
Baltimore City Department of Health and Sewage Commission	1905	W.W. Ford; W.T. Howard; J.B. Thomas; R. Freas E.G. Birge; E.S. Sandman; W.R. Stokes T.M. Wright; F.W. Hachtel; R.S. Craig; C. Vincent E.M. Watson
Washington, D.C. Filtration Plant	1906	W.U. Baton; F.F. Longley; E.B. Phelps
New Haven Board of Health	1906	C.H. Bartlett; W.S. Sturges
West Virginia Hygienic Laboratory	1906	J.L. Sheldon; A. Arkin; E.B. Fink; L.M. Bonar
Missouri State Board of Health	1906	G. McConnell; M.C. Stone; G.C. Jones; N. McVay
California State Hygienic Laboratory	1906	A.R. Ward; M. Henderson; D. Van Orden E. Cole; W.A. Sawyer; C.W. Bonyng; C.F. Hoyt C.B. McGlumphy; E.C. Seymour; J.C. Geiger E. Skolfield; G.A. Macmillan; W.H. Kellogg V.M. Bathgate
Oregon Agricultural Experiment Station	1907	E.F. Pernot; E.G. Peterson; G.V. Copson
Maryland State Board of Health	1907	W.R. Stokes; H.W. Stoner; F.W. Hachtel
Health Department, Washington, D.C.	1907	J.J. Kinyoun; L.V. Deiter
Kansas Water & Sewer Laboratory	1908	E. Bartow; C.C. Young; N.P. Sherwood
N.J. State Board of Health	1908	R.B. Randolph
Savannah Bd. of Sanitary Commissioners	1908	V.H. Bassett
Virginia State Department of Health	1909	M. Ferguson
Diagnositic Laboratory, Mass. Bd. Health	1910	H.N. Jones; A.P. Hale
Harrisburg Department of Health	1910	R.E. Irwin
Texas State Department of Health	1911	M. Graham; V.M. Ehlers; I.M. Lewis
Richmond Department of Health	1912	E.C. Levy; W.F. Lawrence; H.V. Stewart
North Public Health Bur., New York City	1914	C.E. North

TABLE 1.7

INSTRUCTION IN WATER, MILK, FOOD OR SANITARY BACTERIOLOGY
PRIOR TO 1920

<u>Name</u>	<u>Date</u>	<u>Personnel</u>
University of Michigan	1884	V.C. Vaughan
Massachusetts Institute of Technology and Lawrence Experiment Station	1884	W.T. Sedgwick; C.-E.A. Winslow; C.G. Whipple S.C. Prescott; E.A. Ingham; E.H. Richards P. Stiles; W.L. Underwood; G.W. Fuller; S.C. Keith F.H. Slack; E.C. Howe; F.J. Funk; M.P. Horwood
Chicago Medical School	1884	H. Gradle
Beaumont Medical College	1890	W.N. Beggs
University of Louisville Medical School	1890	E.R. Palmer
University of Chicago	1892	E.O. Jordan; A.L. Smith; P.G. Heinemann; M. Jones J.F. Norton; W.B. Sharp
University of Illinois	1893	T.J. Burrill; W.J. Fraser; A.W. Palmer; E. Bartow O. Rahn; H.A. Harding; M.J. Prucha; F.W. Tanner H.E. Babbitt
University of Wisconsin	1894	H.L. Russell; E.G. Hastings; W.D. Frost M.P. Ravenel; V.A. Armstrong; W.D. Stovall
New York University	1894	R.G. Freeman
University of Minnesota	1895	C.N. Hewitt; F.F. Wesbrook; H.E. Robertson H.W. Hill; C.E. Pyle; S. Haugdahl; O.I. Dybevic J.C. Arthur; S. Burrage; C.M. Hilliard; C.A. Behrens K.G. Golden; A.W. Bitting; H.M. Weeter
Purdue University	1895	H.B. Switzer
University of California, Berkeley	1897	F.T. Bioletti; A.R. Ward; C.G. Hyde
Brown University	1897	F.P. Gorham; A.G. Wing
University of Iowa	1897	W.L. Bierring; H. Albert
Rutgers University	1897	J. Nelson; W. Rudolfs
University of Pittsburgh	1897	A.B. Wallgren; J.C. Fetterman
Oklahoma Agric. and Mech. College	1898	L.L. Lewis
Michigan Agricultural College	1899	C.E. Marshall; W. Giltner; W.L. Mallmann F.W. Fabian; G.L. Ruehle; Z. Northrup
Indiana University	1899	R.E. Lyons; W.H. Manwaring; L.W. Famulener
Worcester Polytechnic Institute	1899	L.P. Kinnicutt
Oregon State University	1899	E.F. Pernot; T.D. Beckwith; A.F. Vass; G.V. Copson
Cornell University	1901	A.R. Ward; O.F. Hunziker; W.A. Stocking C.A. Publow; R.S. Breed; G.L. Ruehle; H.J. Conn
Kansas Agricultural College	1901	E.H. Webster; J.B. Fitch
Sheffield Scientific School, Yale	1901	H.D. Pease
Simmons College	1902	E.A. Beckler; S.M. Gunn; C.M. Hilliard; R. Bryant
Connecticut State College	1902	W.A. Stocking; H.W. Conn; W.M. Esten; C. Beach
Pennsylvania State College	1904	E.B. Meek; W.E. Tripp; J.M. Sherman; C.A. Hunter
Virginia Polytechnic Institute	1904	E.B. Fred; M. Ferguson

TABLE 1.7 - *Continued*INSTRUCTION IN WATER, MILK, FOOD OR SANITARY BACTERIOLOGY
PRIOR TO 1920

<u>Name</u>	<u>Date</u>	<u>Personnel</u>
Western University of Pennsylvania	1905	J.C. Fetterman
University of Penn., Hygienic Laboratory	1905	A.C. Abbott; D.H. Bergey
Beloit College	1905	E.G. Smith
Miami University	1906	B. Fink
University of Texas, Galveston	1906	A.J. Smith; M.F. Boyd; B.L. Arms
Kansas University	1907	F.H. Billings; C.C. Young; E.L. Treece M. Greenfield
University of Washington	1907	J. Weinzirl
USPHS, Hygienic Laboratory	1909	J.F. Anderson
University of Penn. Veterinary College	1909	H.C. Campbell
Cornell University Medical School	1909	J.C. Torrey
Duquense University	1910	W.H. Glynn
California State Hygienic Laboratory	1910	C.W. Bonyng; C.F. Hoyt
Harvard College, School of Pub. Health	1911	G.C. Whipple; C.E. Renn; J.W. Bunker; G.M. Fair E.G. Birge
Wellesley College	1912	E.C. Howe
Utah Agricultural College	1912	E.G. Peterson; J.E. Greaves; E.G. Carter
University of Vermont	1912	G.P. Burns
City College of New York	1912	W.W. Browne; C.-E.A. Winslow
Ohio Agricultural & Mechanical College	1913	H.H. Weiser
Carnegie Institute of Technology	1913	J.E. Rush; H.L. Lang
West Virginia Medical School	1913	A. Arkin
Columbia University, Teachers College	1914	J. Broadhurst
University of Missouri	1914	M.P. Ravenel
Lehigh University	1915	S.J. Thomas
California College of Pharmacy, San Fran.	1915	A. Schneider
Utah State Agricultural College	1916	J.E. Greaves
University of Tennessee	1916	M. Mulvania; W.L. Holt

TABLE 1.8

RESEARCH IN WATER, MILK, FOOD OR SANITARY BACTERIOLOGY PRIOR TO 1920

<u>Name</u>	<u>Date</u>	<u>Personnel</u>
Massachusetts Institute of Technology and Lawrence Experiment Station	1887	W. Sedgwick; E.O. Jordan; G.C. Whipple; G. Fuller W.R. Copeland; A.I. Kendall; H.F. Mills; S.C. Keith A. Hazen; H.W. Clark; E.H. Richards; S.C. Prescott C.-E.A. Winslow; S. DeM. Gage; G.V. Stoughton W.L. Underwood; S. Burrage; E.B. Phelps; B.G. Philbrick; E.G. Smith; H.C. Colson; R.N. Hoyt R.S. Weston; G.W. Field; A.F. Rogers; G.T. Palmer F.S. Hammond; C.A. Magoon; A.P. Matthews W.F. Wells; F.J. Funk; S.M. Gunn; H.W. Hamilton M.P. Horwood
Chicago Medical School	1887	H. Gradle
University of Michigan, and State Department of Health	1887	V.C. Vaughan; F.G. Novy; M.L. Holm; A.A. Spoor R.W. Pryer
University of Penn., Hygienic Laboratory	1887	J.S. Billings; A.C. Abbott; D.H. Bergey
Storrs Agricultural Experiment Station	1888	H.W. Conn; W.A. Stocking; W.E. Esten; C. Beach G.E. Seage; C.J. Mason; G.C. White; R.C. Fisher
Laboratory of the Boston Water Works	1889	G.C. Whipple; D. Fitzgerald
Johns Hopkins University	1890	A.C. Abbott; W.W. Ford
H.J. Heinz Company	1890	A.W. Wallgren
College of Physicians & Surgeons, Columbia University	1892	T.M. Prudden; T. Cheeseman; H. Dyar; E.W. Firth R.G. Freeman; C.E. North; H.A. Higley; F.F. Russell K.I. Morishima; W.A. Manheimer
University of Chicago	1893	E.O. Jordan; P.G. Heinemann; A.C. Hicks J.F. Norton; E.E. Irons; W.L. Lewis; M. Jones A.B. Luckhardt; J.T. Myers; R.M. Victorson C.J. Foote; H.W. Conn; C.J. Bartlett
Connecticut State Board of Health	1894	W.G. Freeman
New York University	1894	A.W. Peckham
Womens' Medical College, Philadelphia	1894	H.C. Ernst; H.W. Hill
Boston City Health Department	1895	H.L. Russell; W.D. Frost; V.H. Bassett; E.G. Smith H.A. Harding; C. Hoffmann; E.G. Hastings V.A. Armstrong; A.C. Evans; F. Bachmann
University of Wisconsin and Agricultural Experiment Station	1895	K.W. Smith; J.E. Simmons; M.P. Ravenel; H. Gray M.W. Swenson; M.F. Litte; P.F. Clark; G. Moore J.A. Anderson; D.F. Pettibone
University Illinois College of Medicine	1895	A. Gehrman
N. Dakota Agricultural Experiment Sta.	1895	H.L. Bolley; G.F. Ruediger

TABLE 1.8 – *Continued*

RESEARCH IN WATER, MILK, FOOD OR SANITARY BACTERIOLOGY PRIOR TO 1920

<u>Name</u>	<u>Date</u>	<u>Personnel</u>
N.J. Agricultural Experiment Station	1896	J. Nelson; W. Rudolfs
Bureau of Animal Industry, Dairy & Pathological Divisions, USDA	1896	L.A. Rogers; S. Ayers; W.T. Johnson; P. Clemmer L.B. Cook; E.H. Webster; G.M. Whitaker; S. Ayers C. Thom; E.C. Schroeder; W.E. Cotton; J. Mohler C.F. Doane; C.B. Lane; J.T. Bowen; W.M. Clark M.J. Rosenau; C.S. Mudge; P. Rupp; J.M. Sherman E. Kelly
Michigan Agricultural Exp. Station	1896	E. Grange; C.E. Marshall; F.W. Fabian C.W. Brown; M. Wetmore; Z. Northrup W.L. Mallmann; L. Cooledge; R.W. Wyant R. Normington; G.L. Ruehle
Harvard University Medical School	1896	T. Smith; E.H. Schorer
Mt. Prospect Laboratory, Brooklyn	1897	G.C. Whipple
New York City Department of Health, and Dept. Water Supply, Gas & Elect.	1892	W.H. Park; A.F. Hess; M.C. Schroeder; D.J. Provost H.M. Biggs; E.K. Dunham; C. Kruwmiede D.D. Jackson; G.A. Soper
Brown University	1897	F.P. Gorham; M.X. Sullivan; M.L. Dolt; F.G. Keyes R.C. Colwell; L.J. Gillespie; W.W. Browne G.W. Field; L.A. Round; J.W. Bunker; C.A. Fuller W.C. Nelson
Oregon Agricultural Experiment Station	1897	E.F. Pernot; G. Dehaven; G.V. Copson
Philadelphia Bureau of Health	1898	H.D. Pease; A.H. Stewart; M.E. Pennington
Alabama Agricultural Experiment Station	1898	C.A. Cary
N.Y. Agricultural Experiment Station, Geneva	1899	H.A. Harding; L.A. Rogers; R.S. Breed; M.J. Prucha L. Van Slyke; J.F. Nicholson; J. Brew; G.A. Smith W.L. Kulp; G.L. Ruehle; W.D. Dotterrer; J. Bright H.J. Conn; G.J. Hucker
West Virginia Agricultural Exp. Station	1899	B.H. Hite; N.J. Giddings; H. Atwood; N.J. Giddings C.E. Weakley
Chicago Department of Health	1899	A. Gehrmann; J.F. Biehn; P.G. Heinemann F.O. Tonney; H.N. Bundesen; J.L. White
Commission of Water Works, Cincinnati	1899	G.A. Johnson; G.W. Fuller
Worcester Polytech. Inst. & Bd. of Health	1899	L.P. Kinnicutt
N.Y. Agricultural Experiment Station, Cornell	1899	V.A. Moore; A.R. Ward; O. Hunziker; W. Stocking; C.A. Publow; J.K. Wilson; G.A. Wilson; E. Guthrie G.C. Suplee
Pennsylvania School of Veterinary Med.	1899	M.P. Ravenel; L.A. Klein
Oklahoma Agricultural Experiment Station	1899	L.L. Lewis; M. English

TABLE 1.8 – *Continued*

RESEARCH IN WATER, MILK, FOOD OR SANITARY BACTERIOLOGY PRIOR TO 1920

<u>Name</u>	<u>Date</u>	<u>Personnel</u>
Iowa State University and Agricultural Experiment Station	1900	L.H. Pammel; B.W. Hammer; M. Levine; P.F. Orr R.E. Buchanan; J.C. Weldin; G.E. Thompson E.M. Bruett; E.F. Goss
St. Louis Health Department	1900	A.N. Ravold
Boston Health Department	1900	F.H. Slack; E.M. Wade; B.R. Rickards W. Blandard
Bureau of Water Filtration, Philadelphia	1900	W.R. Copeland; P. Boynton
Maryland Agricultural Experiment Station	1901	C.F. Doane; C. Melick; R.W. Lamson; S. Buckley R.W. Lamson
University of Minnesota	1901	S. Haugdahl; O.I. Dybevic; C.H. Eckles
Kansas Agricultural College & Exp. Sta.	1901	E.H. Webster; J.B. Fitch; L.D. Bushnell; O. Maurer
University of Illinois and Agricultural Experiment Station	1902	W.J. Fraser; O. Rahn; H.A. Harding; M.J. Prucha O. Erf; H.M. Weeter; F.W. Tanner; W.H. Chambers H.L. Ritte; E. Bartow; F.W. Mohlman J.F. Schnellbach
Hoagland Laboratory	1902	E.H. Wilson; H. Moak; B. White; T.W. Melia
Univ. California, Berkeley, Agricultural Exp. Sta., and Hygienic Lab.	1903	A.R. Ward; C.G. Hyde; I.C. Hall; L.J. Ellefson J.C. Geiger
Clemson College	1904	H. Metcalf
Virginia Agricultural Experiment Station	1904	E.B. Fred; M. Ferguson; R.R. Reynolds W.L. Mallory; W.K. Brainerd; M.A. Jacobson
Iowa State Board of Health Laboratory	1904	H. Albert; J.J. Hinman; G. Jordan
Baltimore Department of Health	1905	W.W. Ford; W.T. Howard; C. Vincent; J.B. Thomas E.S. Sandman; R. Freas; T.M. Wright; H.W. Stoner F.W. Hachtel; C. Vincent; R.S. Craig
Nebraska Agricultural Experiment Station	1906	C.W. Melick; A.L. Haecker
New Haven Board of Health & Yale Univ.	1906	C.H. Bartlett; F.B. Kinne; I.F. Falk; W.S. Sturges C.-E.A. Winslow; L.F. Rettger; J.J. Wenner L.V. Burton; B. Cohen
Vermont Agricultural Experiment Station	1906	C.L. Beach
Bureau of Plant Industry, USDA	1906	K.F. Kellerman; R.W. Pratt; A.E. Kimberly T.D. Beckwith; H.A. Whittaker
N. Dakota Agricultural Experiment Station	1906	E.F. Ladd; A.G. Nickles
Maryland State Board of Health	1907	W.R. Stokes; H.W. Stoner; F.W. Hachtel
Bureau of Chemistry, USDA	1907	W.D. Bigelow; A.W. Bitting; G.G. De Bord C. Thom; L.T. Giltner; R.B. Edmondson; E. LeFevre A.C. Hunter; H.W. Redfield; M. L. Obst; L. Round M. Jenkins; G.W. Stiles; H.B. Switzer
National Canners Association Res. Lab.	1907	R.S. Page; W.D. Bigelow; J.R. Esty; H. James E.C. Dickson; C.S. Mudge; E.J. Cameron; P.J. Donk P.H. Cathcart; K.F. Meyer; C.C. Williams
Hygienic Laboratory, U.S.P.H.S.	1907	J.F. Anderson; M.J. Rosenau

TABLE 1.8 – *Continued*

RESEARCH IN WATER, MILK, FOOD OR SANITARY BACTERIOLOGY PRIOR TO 1920

<u>Name</u>	<u>Date</u>	<u>Personnel</u>
Minnesota State Board of Health	1909	F.F. Wesbrook; H.A. Whittaker; H.W. Hill E.M. Wade; J.A. Childs
Virginia State Department of Health	1909	M. Ferguson
Allegheny College	1909	R.S. Breed; E.M. Edson
University of Washington	1909	J.W. Weinzirl; M.V. Fos; J.B. Thomas; E.B. Newton
Harrisburg Department of Health	1910	R.E. Irwin
Washington Agricultural Exp. Station	1911	C.A. Magoon
Louisiana Agricultural Experiment Sta.	1911	W.L. Owen; N. Kopeloff; L. Kopeloff
Kansas University and Water & Sewage Laboratory	1911	N.P. Sherwood; C.C. Young; M. Greenfield; C. Utt M.A. Barber; N.P. Sherwood; N. Ritter E.L. Treece; L.D. Bushnell
Columbia University, Teachers College	1911	J. Broadhurst
New York State Department of Health	1912	H.D. Pease; T. Horton; E.S. Chase
Water Experiment Station, U.S.P.H.S.	1912	E.M. Meyer; E.B. Phelps
Washington D.C. Health Department	1912	J.J. Kinyoun; L.V. Deiter; E.B. Phelps
City College of New York	1912	W.W. Browne; C.-E.A. Winslow
Harvard University and School of Public Health Officers	1913	J.W. Bunker; G.C. Whipple; M.J. Rosenau J.W. Weinzirl; F.M. Fair; L.R. Bartlet; R. Bryant M.R. Edwards; M.J. Schlesinger; W.D. Frost
Stanford University	1914	W. Ophuls; R.L. Wilbur; E.C. Dickson; G.S. Burke V. Burke; H.J. Sears; E.W. Schultz
University of Nebraska	1914	H.H. Waite
University of Missouri	1914	M.P. Ravenel
Penn State Univ. and Agric. Exp. Station	1914	J.M. Sherman; W.R. Albus; C.A. Hunter
Ohio Agricultural and Mechanical College	1914	E.F. McCampbell; W.H. Dittoe
Ohio State Health Department Laboratory	1914	F. Berry
University of Nebraska	1914	H.H. Waite
Purdue Agricultural Experiment Station	1914	A.W. Bitting; K.G. Golden; H.B. Switzer
Great Bear Spring Co., Brooklyn	1914	F.L. Rector; H.J. Daube
Simmons College	1915	C.M. Hilliard; M.A. Davis
Lehigh University	1915	S.J. Thomas
Illinois State Water Survey	1915	E. Bartow; R.E. Greenfield; W.F. Monfort F.W. Tanner; W.D. Hatfield; R.L. Russell L.V. Burton; M.C. Perry
University of Texas, Galveston	1915	B.L. Arms
University of Texas, Austin	1917	I.M. Lewis
New Haven Sewage Experiment Station	1917	C.-E.A. Winslow
Welch Grape Juice Company	1917	H.A. Noyes
Massachusetts Agric. College & Station	1918	C.E. Marshall; A. Itano; J.M. Neill; M.E. Garvey E.G. Hood
University of Oregon	1918	H.J. Sears
Rhode Island Department of Health	1918	L.A. Round
Beech-Nut Packing Company	1919	E.R. Pickett

TABLE 2.1

INSTRUCTION IN VETERINARY BACTERIOLOGY PRIOR TO 1920

<u>Name</u>	<u>Date</u>	<u>Personnel</u>
Ohio Agricultural and Mechanical College	1885	H.J. Detmers; W.A. Starin; C.B. Morrey; A. Jense O. Brumley
Iowa State College	1888	L.H. Pammel; W.B. Niles; L.A. Klein; W. Dimock R. Buchanan; C. Murray; R. Dykstra; C.D. Rice
Johns Hopkins University	1889	A.W. Clement
South Carolina Agricultural College	1889	H. Metcalf; L.A. Klein; W.B. Niles
Bussy Institute, Harvard University	1889	C.P. Lyman; T. Smith; K. Winslow
University of Nebraska	1890	F.S. Billings; A.T. Peters; L. Van Es; J.H. Gain H.M. Martin
University of Missouri	1890	P. Paquin; H. J. Detmers; J.W. Connaway; P. Evans W.M. Miller
Chicago Veterinary College	1891	F.S. Billings; A.R. Edwards
University of Pennsylvania, School of Veterinary Medicine	1892	L. Pearson; R. Formad; M. Ravenel; J. Hardenbergh U.G. Houck; K.F. Meyer; M.J. Harkins; A.J. Smith W.J. Crocker L.A. Klein; J.A. Kolmer; C.Y. White J.G. Moon; C. Newton
National Veterinary College	1892	D.E. Salmon; V.A. Moore
University of Vermont	1892	F.A. Rich
Purdue University	1893	A.W. Bitting; R.A. Craig
Virginia Polytechnic Institute	1893	E.P. Niles; N.S. Mayo
University of California, Berkeley	1894	T. Bowhill; H.B. Kugeler; P.T. Brown; A.R. Ward C.M. Haring; K.F. Meyer
McKillip Veterinary College	1894	O. Schwarzkopf; F.S. Schoenleber
Maine State College	1894	F.L. Russell
Kansas City Veterinary College	1895	C.J. Sihler; A.T. Kinsley; L. Rosenwold
Utah Agricultural College	1895	F.W. Brewer; H.J. Frederick
Alabama Polytechnic Institute	1895	C.A. Cary; F.D. Patterson
California Veterinary College, Berkeley	1895	T. Bowhill
New York State Veterinary College and Cornell University	1896	J. Law; V.A. Moore; R.C. Reed; F.R. Wright S. Burnett; W.J. Taylor; R.R. Birch; E.G. Peterson C.P. Fitch; W.E. King; W.A. Hagan
New York College Veterinary Surgeons	1896	A. Liautard; J.J. Huddleston
Kansas Agricultural College	1896	P. Fischer; N.S. Mayo; T. Butler; F.S. Schoenleber L. Bushnell; L. Goss; W.E. King; H.F. Lienhardt W.A. Hagan
Louisiana Agricultural College	1896	W.H. Dalrymple; S.B. Staples; H.A. Morgan W.R. Dodson
North Carolina Agr. & Mech. College	1896	C. Curtice

TABLE 2.1 – *Continued*

INSTRUCTION IN VETERINARY BACTERIOLOGY PRIOR TO 1920

<u>Name</u>	<u>Date</u>	<u>Personnel</u>
University of Vermont	1897	F.A. Rich; J.L. Hills;
Michigan Agricultural College	1897	E.E. Grange; W. Giltner; F. H. van Suchtelen I.F. Huddleson; R. Benham; E.T. Hallmann R.P. Lyman; L.H. Cooledge; H.J. Stafseth
University of Minnesota	1897	M.H. Reynolds; C.P. Fitch; D.C. Beaver W.S. Billings
American Veterinary College	1897	W.C. Siegmund
North Dakota Agricultural College	1897	L. Van Es
University of Delaware	1898	F.D. Chester; H.D. Eves
Oklahoma Agric. & Mech. College	1898	L.L. Lewis; E.A. Benbrook; C.H. McElroy
Washington State School of Veterinary Medicine	1898	S.B. Nelson; F.B. Hadley; C.E. Munn; W.E. Ralston C.E. Munn; M. Rosenberger; E.E. Wegner J.W. Kalkus
Connecticut State College	1899	N.S. Mayo; E.H. Lehnert; C.L. Beach
Texas Agricultural & Mechanical College	1899	M. Francis
University of Wisconsin	1899	H.L. Russell; E.G. Hastings; F.B. Hadley B.A. Beach; C. Hoffmann
Rhode Island Agricultural College	1900	C. Curtice; P.B. Hadley
North Carolina Agricultural College	1900	T. Butler
Colorado Agricultural College	1900	G.F. Glover; I.E. Newsom
Cincinnati Veterinary College	1900	F. Kebler
University of Tennessee	1901	M. Jacob
St. Joseph Veterinary College	1905	R.C. Moore
University of Arkansas	1906	R.R. Dinwiddie; C.L. McArthur; J.F. Stanford W.L. Bleecker
Rutgers University	1907	J. Nelson; G.F. Leonard
University of Illinois	1908	W.J. MacNeal; R. Graham
Oregon State University	1908	E.F. Pernot; T.D. Beckwith; B.T. Simms
University of Kentucky	1909	R. Graham; E.S. Good; W.W. Dimock; F. Surface
San Francisco Veterinary College	1909	A.R. Ward; R.A. Archibald; T.G. Anderson
Purdue University	1909	A.W. Biting; H.B. Switzer
Massachusetts Agricultural College	1911	G.S. Gage; C.E. Marshall; F.H. van Suchtelen
University of Wyoming	1918	E.H. Lehnert; H.M. Martin
Georgia State Agricultural College	1918	
Prairie View A & M University	1918	E.B. Evans

TABLE 2.2

RESEARCH IN VETERINARY BACTERIOLOGY PRIOR TO 1920

<u>Name</u>	<u>Date</u>	<u>Personnel</u>
Bureau of Animal Industry, USDA	1879	D.E. Salmon; T. Smith; H.J. Detmers; V.A. Moore C. Curtice; M. Dorset; J.R. Mohler; A.D. Melvin W.B. Niles; R. Formad; J.S. Koen; T. Bowhill B.M. Bolton; E.A. de Schweinitz; F.L. Kilborne N.S. Mayo; E.O. Shakespeare; V.A. Norgaard H.J. Washburn; J.S. Buckley; C.N. McBryde L.A. Klein; E.C. Schroeder; W.E. Cotton; J. Traum A. Eichhorn; A.R. Ward; C.F. Dawson; A.E. Wright W.S. Gochenour; H. Bunyea; J.A. Kiernan
Ohio Agricultural & Mechanical College	1885	H.J. Detmers; C.B. Morrey; E.E. Boyer
Nebraska Agricultural Experiment Station	1887	F.S. Billings; A. Peters; L. Van Es; J.H. Gain H.M. Martin
Missouri Agricultural Experiment Station	1887	P. Paquin; J.W. Connaway; P. Evans; A.J. Durant
Maryland Agricultural Experiment Station	1888	G.S. Gage; J.S. Buckley; S. Isaacson; R.S. Allen R.C. Reed
S. Carolina Agricultural Experiment Station	1889	W.B. Niles; H. Metcalf; L.A. Klein; J. Michels G.E. Nesom; M.R. Powers; E. Barnett
Michigan Agricultural Experiment Station	1890	E. Grange; W. Giltner; E.T. Hallmann; L. Cooledge C.E. Marshall; H.J. Stafseth; I.F. Huddleson M. Justo; F.H. van Suchtelen; W.A. Wentworth A. Itano; S.G. Bandeen; L.C. Ludlum
Arkansas Agricultural Experiment Station	1891	R.R. Dinwiddie; C.L. McArthur; J.F. Stanford W.L. Bleecker
Iowa Agricultural Experiment Station	1891	W.B. Niles; W.W. Dimock; R.E. Buchanan; C. Rice W.B. Niles; C.H. Stange; C. Murray; L.A. Klein C.G. Cole; S.H. McNutt; F. Eberson
Kansas Agricultural Experiment Station	1891	N.S. Mayo; P. Fischer; F.S. Schoenleber; W.E. King O.M. Franklin; T.P. Haslam; A.T. Kinsley L.D. Bushnell
Yale University	1891	L. Frothingham; L.F. Rettger; T.G. Hull
Illinois Agricultural Experiment Station	1891	T.J. Burill; C.C. Hayden; W.J. MacNeal; J.E. Kerr C.F. Briscoe; R. Graham; E.A. Tunnicliff I.B. Boughton
S. Dakota Agricultural Experiment Station	1891	C.A. Cary
Penn. School of Veterinary Medicine and Penn. State Dept. of Agriculture	1892	L. Pearson; R. Formad; M.P. Ravenel; K.F. Meyer S.H. Gilliland; J.B. Hardenbergh; H.F. Lienhardt E.L. Stubbs; J. Reichel; C.Y. White; J.G. Moon L.A. Klein; J.A. Kolmer; M.J. Harkins; F. Boerner E.K. Tingley; C.C. Whitney

TABLE 2.2 – *Continued*

RESEARCH IN VETERINARY BACTERIOLOGY PRIOR TO 1920

<u>Name</u>	<u>Date</u>	<u>Personnel</u>
Virginia Agricultural Experiment Station	1893	E.P. Niles; N.S. Mayo; C. McCulloch; J. Spencer J.G. Ferneyhough
Delaware Agricultural Experiment Station	1893	A.T. Neale; C.F. Dawson
N.J. Agricultural Experiment Station	1893	J. Nelson
Alabama Agricultural Experiment Station	1893	C.A. Cary; F.D. Patterson; F. Matthews
N.Y. Agricultural Experiment Station, Cornell	1894	J. Law; V. Moore; R.C. Reed; C. Way; E. Peterson R.R. Birch; C.P. Fitch; F.S. Jones; W.A. Hagan
Purdue Univ. Agricultural Experiment Sta.	1894	A.W. Biting; R.A. Craig; R.A. Whiting
Maine Agricultural Experiment Station	1894	F.L. Russell
Vermont Agricultural Experiment Station	1894	F.A. Rich; J.L. Hills; R.C. Downing
Utah Agricultural Experiment Station	1895	F.W. Brewer; P. Fischer; H.J. Frederick
Nevada Agricultural Experiment Station	1895	W.M. Miller; W.B. Mack; P. Frandsen; E. Records S. Lockett; H.W. Jakeman; L.H. Wright L.R. Vawter
Louisiana Agricultural Experiment Station	1896	W.H. Darlymple; S.B. Staples; H. Morris
Minnesota Agricultural Experiment Station	1896	M.H. Reynolds; C.P. Fitch; W.S. Billings R.G. Green C. Curtice
N. Carolina Agricultural Experiment Sta.	1896	S.B. Nelson
Washington St. Agricultural Exp. Sta.	1896	L. Van Es; E.D. Harris; A.F. Schalk
N. Dakota Agricultural Experiment Station	1897	E.F. Pernot; B.T. Simms
Oregon Agricultural Experiment Station	1898	L.L. Lewis; W.A. Starin; E.A. Benbrook
Oklahoma Agricultural Experiment Station	1898	C.H. McElroy; B.J. Clawson
Wisconsin Agricultural Experiment Station	1899	H.L. Russell; W.G. Clark; E.G. Hastings E. Roberts; F.B. Hadley; B.A. Beach; C. Hoffmann
Storrs Agricultural Experiment Station	1899	H.W. Conn; C.L. Beach; G.C. White; L. Chapman L. Rettger; C.L. Beach
Texas Agricultural Experiment Station	1899	M. Francis; H. Schmidt
New Hampshire Agric. Exp. Sta.	1900	H. Lamson
Colorado Agricultural Experiment Station	1900	G.F. Glover; I.E. Newsom
Rhode Island Agricultural Experiment Sta.	1900	C. Curtice; P.B. Hadley; B.H. Heath; W.H. Scott H.A. Tibbetts; R.P. Tittsler
Kansas City Veterinary College	1900	A.T. Kinsley
California Agricultural Experiment Station	1901	A.R. Ward; C.M. Haring; J.R. Beach; K.F. Meyer H.H. Heller; J. Traum; G.S. Baker; E.C. Fleischner
Florida Agricultural Experiment Station	1902	C.F. Dwason
N.Y. Agricultural Experiment Sta., Geneva	1905	H.A. Harding; G.A. Smith
Parke, Davis & Co.	1909	F.W. Baeslack; W.E. King; R.H. Drake; R. Wilson C. Boxmeyer; N.S. Ferry; G.L. Hoffman H.P. Hoskins; C.T. McClintock; J.J. Siffer
Kentucky Agricultural Experiment Station	1909	L. Himmelberger; W.W. Dimock; F.M. Surface E.S. Good; L. Corbett; R. Graham; A.L. Brueckner

TABLE 2.2 – *Continued*

RESEARCH IN VETERINARY BACTERIOLOGY PRIOR TO 1920

<u>Name</u>	<u>Date</u>	<u>Personnel</u>
Mass. Agricultural Experiment Station	1911	J.B. Paige; G.S. Gage; C.E. Marshall
H.K. Mulford Company	1912	M.J. Harkins; J. Reichel; E.K. Tingley
University of Minnesota Medical School	1913	W.P. Larson
Hoagland Lab. & Long Island Med. Coll.	1913	W. Lintz; J. Van Cott
Mississippi Agricultural Experiment Sta.	1914	C.F. Briscoe
Rockefeller Institute, Division of Animal Pathology	1914	T. Smith; C. Ten Broeck; J.H. Brown; R.E. Shope F.S. Jones; R.B. Little; E.W. Smillie; P.E. Howe M.L. Orcutt; L. Florence
Montana Agricultural Experiment Station	1915	W.H. Welch
Wyoming Agricultural Experiment Station	1915	J.I. Kirkpatrick; E.H. Lehnert; C. Elder
Veterinary Laboratory Service, U.S. Army	1917	R.A. Kelsner

TABLE 2.3

SOME PRODUCERS OF VETERINARY BIOLOGICS

<u>Name</u>	<u>Date</u>	<u>Personnel</u>
Missouri Agricultural Experiment Station Bureau of Animal Industry, USDA	1888 1896	P. Paquin; J.W. Connaway; A.J. Durant E.A. de Schwienitz; V.A. Norgaard; C.N. McBryde A.D. Melvin; D.I. Skidmore; H.J. Shore
Virginia Agricultural Experiment Station	1896	E.P. Niles
Kansas Agricultural Experiment Station	1898	P. Fischer; F.S. Schoenleber; O.M. Franklin T.P. Haslam
Oklahoma Agricultural Experiment Station	1899	L.L. Lewis; W.A. Starin; C.H. McElroy B.J. Clawson; E.A. Benbrook
Cutter Biological Laboratories	1903	F.E. Twining
Arkansas Agricultural Experiment Station	1903	R.W. Dinwiddie
Iowa Agricultural Experiment Station	1908	W.B. Niles
Michigan Agricultural Experiment Station	1908	W. Giltner; W.S. Robbins
Minnesota Agricultural Experiment Station	1908	M.H. Reynolds; D.C. Beaver
Parke, Davis & Company	1909	F.W. Baeslack; N.S. Ferry; C.T. McClintock C.M. Boxmeyer; R.H. Drake; J.J. Siffer
Nebraska Agricultural Experiment Station	1911	J.H. Gain; L. Van Es
H.K. Mulford Company	1911	O.W. Schobl; J. Reichel; M.J. Harkins E.K. Tingley
Wisconsin Agricultural Experiment Station	1912	J.G. Halpin; F.B. Hadley; B.A. Beach
Penn. State Department of Agriculture	1913	E.L. Stubbs
Pitman-Moore Biological Laboratory	1913	
Wyoming Agricultural Experiment Station	1915	J.I. Kirkpatrick; E.H. Lehnert; C. Elder
Texas Agricultural Experiment Station	1920	M. Francis; R.C. Dunn
California Agricultural Experiment Station	1920	J.R. Beach
Oregon Agricultural Experiment Station	1921	J.E. Simmons

TABLE 2.4

RESEARCH IN POULTRY PATHOLOGY PRIOR TO 1925

<u>Name</u>	<u>Date</u>	<u>Personnel</u>
Rhode Island Agricultural Experiment Station	1900	C. Curtice; P.B. Hadley; D.W. Caldwell; E. Amison W.A. Kirkpatrick; L.J. Cole; R. Waite; C. Magoon H.A. Tibbetts; H.G. May; B.M. Heath; R.P. Tittsler M.W. Elkins; K. Goodner; D.J. Lambert
Oregon Agricultural Experiment Station	1900	E.F. Pernot; W.G. Johnson
Delaware Agricultural Experiment Station	1900	F.C. Chester
Nebraska Agricultural Experiment Station	1902	A.T. Peters
Alabama Polytechnic Institute	1903	C.A. Cary; F.D. Patterson
California Agricultural Experiment Station	1904	A.R. Ward; J.R. Beach; W. Lippincott; D.E. Davis H.H. Heller; W.A. Lippincott; W.R. Hinshaw
Bureau of Animal Industry, USDA	1906	R.R. Slocum; H.W. Graybill; A.R. Ward B.A. Gallagher; J.R. Mohler
Storrs Agricultural Experiment Station	1908	L.F. Rettger; F.H. Stonburn; W. Sturges; S. Harvey S.A. Koser; J.G. McAlpine; M.M. Scoville
Nevada Agricultural Experiment Station	1908	W.B. Mack; E. Records
Maine Agricultural Experiment Station	1910	F.M. Surface; R. Pearl; M.R. Curtis
N.Y. Agricultural Experiment Sta., Cornell	1911	J.E. Rice; C.A. Rogers; F.S. Jones; W.B. Mack
Missouri Agricultural Experiment Station	1911	H.L. Kempster, A.J. Durant; E.W. Henderson
Kansas Agricultural Experiment Station	1912	L.D. Bushnell; J.G. Jackley; W.A. Lippincott W.R. Hinshaw; L.F. Payne; C.B. Hudson
Wisconsin Agricultural Experiment Station	1913	E.G. Hastings; J.G. Halpin; B.A. Beach
Rockefeller Inst., Div. Animal Pathology	1913	T. Smith; H.W. Graybill; F.S. Jones; R.B. Little J.B. Murphy; P. Rous; E.W. Smillie
Michigan Agricultural Experiment Station	1913	L.R. Himmelberger; L.A. Mosher; H.J. Stafseth W.L. Chandler; C.G. Card
N. Dakota Agricultural Experiment Station	1914	L. Van Es; A.F. Schalk
N.J. Agricultural Experiment Station	1914	W.C. Thompson; F.R. Beaudette; J.J. Black C.B. Hudson; W.P. Thorpe; R.R. Hannas
Ohio Agricultural & Mechanical College	1915	O.V. Brunley; J.H. Snook
Minnesota Agricultural Experiment Station	1917	
Iowa Agricultural Experiment Station	1918	P.F. Orr
Washington Agricultural Experiment Sta.	1919	R.V. Mitchell
Texas Agricultural Experiment Station	1922	R.C. Dunn; M. Francis
Penn. Agricultural Experiment Station	1924	R.P. Tittsler; J.A. Sperry
Wyoming Agricultural Experiment Station	1924	C. Elder; A.M. Lee; F.J. Kohn

TABLE 2.5

INSTRUCTION IN POULTRY PATHOLOGY PRIOR TO 1925

<u>Name</u>	<u>Date</u>	<u>Personnel</u>
University of Rhode Island	1900	P.B. Hadley; H.G. May; J.C. Weldin
University of Delaware	1901	F.D. Chester
Cornell University	1906	J.E. Rice; W.B. Mack; C.A. Rogers; F.S. Jones
Kansas State Agricultural College	1912	L.D. Bushnell; W.A. Lippincott; L.F. Payne
Oregon Agricultural & Mechanical College	1913	T.D. Beckwith; W.T. Johnson
University of California, Berkeley	1917	J.R. Beach; W.A. Lippincott
Alabama Polytechnical Institute	1924	F.D. Patterson
Pennsylvania State College	1924	R.P. Tittsler; J.A. Sperry
Pennsylvania School Veterinary Medicine	1925	E.L. Stubbs

TABLE 3.1

INSTRUCTION IN DAIRY BACTERIOLOGY PRIOR TO 1925

<u>Name</u>	<u>Date</u>	<u>Personnel</u>
Wesleyan	1889	H.W. Conn
Purdue University	1895	K. Golden; H.B. Switzer; O.F. Hunziker F. Rasmussen; H.M. Weeter
Michigan Agricultural College	1896	E. Grange; C.E. Marshall; G.L. Ruchle; K. Peiser
University of Wisconsin	1897	H.L. Russell; E.G. Hastings; E.H. Farrington E.B. Hart; W.H. Whiting; W.D. Frost; C.E. Lee J. Michaels
University of Illinois	1899	W.J. Fraser; O. Rahn; H.A. Harding; J.J. Prucha
Oregon State University	1899	E.F. Pernot; C.V. Copson; T.D. Beckwith W.V. Halversen; J.E. Simmons
Kansas Agricultural College	1901	E.H. Webster; O. Erf; J.B. Fitch; O.W. Hunter
Cornell University	1901	A.R. Ward; O. Hunziker; W.A. Stocking R.A. Pearson; C.A. Publow; R.S. Breed; H.E. Ross E.S. Guthrie; J.M. Sherman; W.A. Whiting W.W. Fisk; G.L. Ruehle
University of Minnesota	1901	S. Haugdahl; O.I. Dybevic; C.H. Eckles; J.B. Fitch E. Erickson; H.T. Sondergaard; L.S. Palmer W.B. Combs
Connecticut State College	1902	W.A. Stocking; H.W. Conn; W.E. Esten
University of Missouri	1902	C.H. Eckles; A.C. Ragsdale; S. Bordy
Pennsylvania State College	1904	E.B. Meek; W.E. Tripp; J.M. Sherman W.R. Albus; H.L. Fulmer; C.A. Hunter
Virginia Polytechnic Institute	1904	M. Ferguson
University of Nebraska	1905	J.H. Frandsen
Oklahoma Agric. & Mechanical College	1905	L.L. Lewis; R.C. Potts; G.M. Lambert
Clemson College	1906	J. Michels
University of New Hampshire	1906	F. Tinkham; F.R. Rasmussen; W.R. Wilson
Ohio Agricultural & Mechanical College	1906	E.S. Guthrie; H.H. Weiser; C.C. Hayden
N. Carolina Agricultural & Mech. College	1908	J. Michels
Kansas University	1908	F.H. Billings; B. Clawson
University of Penn. Veterinary College	1909	H.C. Campbell
Iowa State College	1910	C.H. Eckles; R.E. Buchanan; F. Rasmussen B.W. Hammer
Texas Agricultural & Mechanical College	1910	H. Cassidy; E.H. Gibbons
Utah State Agricultural College	1911	J.E. Greaves; H.P. Anderson; E.G. Carter
University of Tennessee	1911	E.S. Reynolds; M.A. Jacobson; M. Mulvania
Duquesne University	1912	W.H. Glynn
Kansas Agricultural College	1916	O.W. Hunter
Ball State University	1918	O.B. Christy
Rutgers University	1921	T.J. Murray
University of California, Davis	1922	C.S. Mudge
University of Maine	1923	F.L. Russell

TABLE 3.2

RESEARCH IN DAIRY BACTERIOLOGY PRIOR TO 1920

<u>Name</u>	<u>Date</u>	<u>Personnel</u>
Storrs Agricultural Experiment Station	1888	H.W. Conn; W. Stocking; W.E. Esten; C.L. Beach G.E. Seage; C.J. Mason
Minnesota Agricultural Experiment Station	1892	T.L. Haecker; C.H. Eckles; C.B. Moak; W.B. Combs
Iowa Agricultural Experiment Station	1896	C.H. Eckles; F. Rasmussen; R.E. Buchanan B.W. Hammer; A. Hauser; R.H. Hix; D.E. Bailey W.A. Cordes; P. Toens; E.F. Goss
Wisconsin Agric. Experiment Station	1896	H.L. Russell; S. M. Babcock; E.H. Farrington J. Weinzirl; E.G. Hastings; W.D. Frost; K.W. Smith
Bureau Animal Industry, and Dairy Division, USDA	1896	H.E. Alvord, L.A. Rogers; S.H. Ayers; C.F. Doane C. Thom; R.A. Pearson; E.E. Eldridge; A.C. Evans W.T. Johnson; W.R. Albus; C.B. Lane; P. Rupp J.M. Sherman; W.C. Frazier; W.M. Clark E.F. Deysher; F.R. Evans; R.S. Shaw
Michigan Agricultural Experiment Station	1896	C.E. Marshall; O. Rahn; B. Farrand; C.W. Brown S.S. Sayer; K. Peiser; G.L. Ruehle; B. Farrand F.W. Fabian
N. Dakota Agricultural Experiment Station	1896	E.E. Kaufman
Nevada Agricultural Experiment Station	1898	N.E. Wilson
Massachusetts Institute of Technology	1899	S.C. Keith; S.C. Prescott; H.C. Colson; R.N. Hoyt
N.Y. Agricultural Experiment Station, Geneva	1899	H.A. Harding; L.A. Rogers; M.J. Prucha; R.S. Breed L. van Slyke; G.A. Smith; J.D. Brew; W.L. Kulp G.J. Hucker; A.O. Dahlberg; G.L. Ruehle
N.Y. Agricultural Experiment Station, Cornell	1899	V.A. Moore; A.R. Ward; O.F. Hunziker; C. Publow W.A. Stocking; E. Guthrie; M. Jenkins; L.W. Wing J.M. Sherman; G.C. Supplee
Illinois Agricultural Experiment Station	1899	W.J. Fraser; O. Erf; C.E. Lee; C.C. Hayden; O. Rahn H.A. Harding; M.J. Prucha; H.M. Weeter W.H. Chambers; P.W. Allen
Oklahoma Agricultural Experiment Station	1899	L.L. Lewis; J.F. Nicholson; W.R. Wright; R.C. Potts
Philadelphia Bureau of Health	1899	A.H. Stewart
Purdue Univ. Agricultural Experiment Sta.	1901	O.F. Hunziker; F. Rasumussen; H.M. Weeter H.B. Switzer
Kansas Agricultural Experiment Station	1901	E.H. Webster; O.W. Hunter; J.B. Fitch; A.C. Fay R.S. Shaw
California Agricultural Experiment Station	1901	A.R. Ward
Missouri Agricultural Experiment Station	1901	C.H. Eckles; A.C. Ragsdale; S. Bordy
Oregon Agricultural Experiment Station	1902	E.F. Pernot
Maryland Agricultural Experiment Station	1902	C.F. Doane; J.S. Buckley
Virginia Agricultural Experiment Station	1903	M. Ferguson; W.K. Brainard; W.L. Mallory A.M. Soule; J.F. Fain; H.S. Reed; R.R. Reynolds
Chicago Department of Health	1903	J.F. Biehn; F.O. Tonney
University of Chicago	1903	E.O. Jordan; P.G. Heinemann
Hoagland Laboratory	1903	H. Moak; B. White; O.T. Avery

TABLE 3.2 – *Continued*

RESEARCH IN DAIRY BACTERIOLOGY PRIOR TO 1920

<u>Name</u>	<u>Date</u>	<u>Personnel</u>
Ohio Agricultural & Mechanical College	1905	E.S. Guthrie; H.H. Weiser; C.C. Hayden
Ohio Agricultural Experiment Station	1906	C.C. Hayden; A. Perkins; T. Middaugh; R. Grady
Vermont Agricultural Experiment Station	1906	C.L. Beach; R.M. Washburn
Yale Medical School	1906	C.J. Bartlett
West Va. Agricultural Experiment Sta.	1908	H. Atwood; N.J. Giddings
S. Carolina Agricultural Experiment Sta.	1908	J. Michels
N. Carolina Agricultural Experiment Sta.	1909	J. Michels
Allegheny College	1909	R.S. Breed; E.M. Edson
New Hampshire Agricultural Exp. Station	1909	F.R. Rasmussen; F. Tinkham
University of Penn. Veterinary College	1909	H.C. Campbell
Rhode Island Agricultural Experiment Sta.	1909	P.B. Hadley
S. Dakota Agricultural Experiment Station	1909	C. Larsen; L.F. Miller; T.H. Lund
Colorado Agricultural Experiment Station	1911	W.G. Sackett; H.M. Bainer
N. Dakota Agricultural Experiment Station	1911	G.F. Ruediger
Mass. Agricultural Experiment Station	1912	C.E. Marshall; A. Itano
Pennsylvania State College	1914	C.W. Larson; J.M. Sherman; W.R. Albus
		E.R. Hitchner; C.A. Hunter
Univ. California College of Agriculture	1919	C.F. Hoyt; C.M. Mudge

TABLE 3.3

COMMERCIAL PRODUCERS OF LEGUME INOCULATION CULTURES

<u>Name of Producer</u>	<u>Location</u>	<u>Product Name</u>
American Mutual Seed Company	Chicago	Tubercle-Germ
American Cultures Company	Richmond, VA	Farmogerm
Armor Fertilizer Works	Chicago	
Earp-Thomas Company	Bloomfield, NJ	Earp-Thomas Farmogerm
Edwards Laboratories	Lansing, MI	Edwards Legume Bacteria
H.K. Mulford Company	Philadelphia	Nitro-Germ and Mulford Culture
Homewood Nitrogen Company	New York City	
Lockhart Laboratories	Atlanta	Lockhart's Bacteria
McQueen Bacteria Company	Baltic, OH	McQueen's Inoculator
National Soil Improvement Company	Charlottesville, VA	Farmogerm
Nitragin Company	Waterloo, IA	Nitragin
Nitro-Germ Company	Savannah, GA	Nitra-Germ
Standard Seed & Soil Inoculation Co.	Troy & Syracuse, NY	Nodule Bacter
Western Soil Bacteria Company	San Francisco	Westrobact

TABLE 3.4

STATIONS DISTRIBUTING LEGUME INOCULATION CULTURES

<u>Name</u>	<u>Date</u>	<u>Personnel</u>
Bureau of Plant Industry, USDA	1904	G.T. Moore; K.F. Kellerman; T.R. Robinson F.L. Goll
Virginia Agricultural Experiment Station	1905	M. Ferguson; E.B. Fred; T.J. Murray
Kansas Agricultural Experiment Station	1905	L.D. Bushnell; P.L. Gainey
Michigan Agricultural Experiment Station	1908	W.S. Sayer; O. Rahn; F.O. Ockerblad
N.Y. Agricultural Experiment Sta., Cornell	1912	B.M. Duggar; M.J. Prucha; J.K. Wilson
N. Carolina Agricultural Experiment Sta.	1912	
S. Carolina Agricultural Experiment Sta.	1912	H.D. House; H.W. Barre; F.M. Rolfs
Oregon Agricultural Experiment Station	1912	T.D. Beckwith; A.F. Vass
Georgia Department of Agriculture	1913	J.C. Temple
Missouri Agricultural Experiment Station	1914	W.A. Albrecht; H. Rhodes
Mass. Agricultural Experiment Station	1914	F.H. van Suchtelen; H.A. Noyes
Washington Agricultural Experiment Sta.	1915	C.A. Magoon; T.J. Murray; P.W. Allen; B.F. Dana
Wisconsin Agricultural Experiment Station	1917	E.B. Fred; A.L. Whiting; E.J. Gaul; W. Griem
Idaho Agricultural Experiment Station	1917	P. Emerson
Maryland Agricultural Experiment Station	1917	P. Emerson; A.G. McCall; L.W. Erdman
Wyoming Agricultural Experiment Station	1919	A.F. Vass

TABLE 3.5

RESEARCH IN SOIL BACTERIOLOGY

<u>Name</u>	<u>Date</u>	<u>Personnel</u>
Storrs Agricultural Experiment Station	1891	H.W. Conn; W.M. Esten
N.J. Agricultural Experiment Station	1893	E.B. Voorhees; B.D. Halsted; J.G. Lipman G.M. Lummis; P.E. Brown; I. Owen; A.W. Blair H.C. McLean; M. Lewis; R.E. Curtis; G.P. Koch C.J. Doryland; N. Kopeloff; J.R. Neller; H.C. Lint R.C. Cook; S. Waksman; C.R. Fellers; J.S. Joffe R.V. Allison; H. Heukelekian; C.D. Jones C.E. Skinner; C.S. Lamson; G.W. Wilson A.T. Perkins; D.A. Coleman; W. Debus; G. Giobel R. Dubos; R.S. Starkey; F.T. Starkey
Illinois Agricultural Experiment Station	1895	H.E. Ward; C.G. Hopkins; A.L. Whiting; O. Rahn R. Hansen; F.C. Bauer; M.J. Prucha; F. Lohnis T.J. Burrill; R. Stewart; T.E. Richmond; J.H. Pettit W.A. Albrecht
Michigan Agricultural Experiment Station	1896	J. Briley; S.F. Edwards; W. Sackett; W.T. Barnum L.D. Bushnell; H.F. Tuttle; L.T. Clark; O. Rahn H.V. Langworthy; F.O. Ockerblad; O. Gruzit F.H. van Suchtelen; C.D. Brown; J.F. Morgan Z.N. Wyant; C.G. Nobles
Mass. Agricultural Experiment Station	1897	W.P. Brooks; F.H. van Suchtelen; H.A. Noyes A.L. Prince; A. Itano; J.R. Sanborn
Maine Agricultural Experiment Station	1897	W.M. Munson
Delaware Agricultural Experiment Station	1898	F.D. Chester; L. Green; T.F. Manns; J. Goheen
N. Dakota Agricultural Experiment Station	1899	E.F. Ladd; T.D. Beckwith; H.L. Bolley; J. Ince C.J. Doryland
Oregon Agricultural Experiment Station	1900	E.F. Pernot; T.D. Beckwith; A.F. Vass; W.B. Bollen R.E. Stephenson; R.H. Robinson; W.V. Halversen
Bureau of Plant Industry, USDA	1900	E.F. Smith; G.T. Moore; K.F. Kellerman; F. Hedges I. McBeth; E.H. Fawcett; T.D. Beckwith; F.L. Goll A.F. Woods; D.B. Swingle; W.T. Swingle R.C. Wright; T.R. Robinson; E.R. Allen; F. Lohnis F.M. Scales; H.A. Edson; N.R. Smith; L.T. Leonard H. Metcalf; J. Breazeale; L.J. Gillespie; C. Richards
Kansas Agricultural Experiment Station	1902	W.E. King; C.J. Doryland; P. Gainey; H. Batchelor
Wisconsin Agricultural Experiment Station	1903	A.R. Whitson; E.R. Jones; T.L. Hills; B.W. Hammer C. Hoffman; W.E. Tottingham; W.H. Wright E.B. Fred; A. Davenport; H.L. Fulmer; R. Primm E. Graul; O.C. Bryan; W.C. Frazier; E.G. Hastings W.M. Gibbs; J.W. Stevens; A.L. Whiting
Bureau of Soils, USDA	1903	M. Whitney; M.X. Sullivan; O. Schreiner; H.S. Reed E.C. Shorey; J.J. Skinner; J. Breazeale; F.R. Pember B.E. Livingston; C.A. Jensen; C. Thom

TABLE 3.5 – Continued

RESEARCH IN SOIL BACTERIOLOGY

<u>Name</u>	<u>Date</u>	<u>Personnel</u>
N. Carolina Agricultural Experiment Sta.	1904	F.L. Stevens; W.A. Withers; J. Temple; W. Syme P.L. Gainey; J.K. Plummer; W.G. Sackett F.F. Sherwood
Virginia Agricultural Experiment Station	1904	M. Ferguson; A.M. Soule; E.B. Fred; H.S. Reed B. Williams; P.D. Heuser; T.J. Murray; W.B. Ellett R.J. Davidson; F. Fromme; S.A. Buchan; K. Quantz
West Va. Agricultural Experiment Station	1904	J.L. Sheldon; A.L. Post; F.E. Bear; H. Hill R.M. Salter; R.E. Stephenson
Oklahoma Agricultural Experiment Station	1904	L.L. Lewis; J.F. Nicholson; W.R. Wright F. McBurney
Rhode Island Agricultural Experiment Sta.	1904	B.L. Hartwell; J.F. Morgan; L. Whipple; F. Pember A.L. Whiting; H.J. Wheeler; P.S. Burgess W.G. Sackett; W.P. Headden
Colorado Agricultural Experiment Station	1905	E.J. Macy; A.W. Blair; S.N. Wilson; R.V. Allison
Florida Agricultural Experiment Station	1905	T.L. Lyon; J.A. Bizzell; B.M. Duggar; M.J. Prucha
N.Y. Agricultural Experiment Station, Cornell	1905	J.K. Wilson; J.K. Plummer; A.F. Vass; B.D. Wilson T.L. Martin
N.Y. Agricultural Experiment Station, Geneva	1905	H.A. Harding; M.J. Prucha; J.K. Wilson; F. Stewart R.S. Breed; H.J. Conn; G.T. French; R. Collison J.S. Joffe; M.E. Breed
Texas Agricultural Experiment Station	1906	O.M. Ball; G.S. Fraps; S. Lomanitz
S. Carolina Agricultural Experiment Sta.	1907	H.D. House; H.W. Barre; F.M. Rolfs
Washington University, St. Louis	1909	G.T. Moore
California Agricultural Experiment Station	1909	C.B. Lipman; P.S. Burgess; L.T. Sharp; W.P. Kelley H.W. Johnson; D.D. Waynick; D. Wright
Iowa Agricultural Experiment Station	1909	R.E. Buchanan; P.E. Brown; R.E. Smith; R. Snyder G. Williams; A.R. Gwinn; C.W. Davis; T.H. Benton P. Emerson; G.E. Corson; W.V. Halverson F.B. Smith; L. Erdman; L.W. Forman; F.E. Allison W.H. Stevenson; E. Kellogg; H.W. Johnson B.R. Johnson; W.B. Bollen; H. Liu; R.N. Gowda C.S. Linton; R.E. Stephenson; F.S. Wilkins C.C. Prouty
Georgia Agricultural Experiment Station	1909	J.C. Temple; W.L. Owen
Nebraska Agricultural Experiment Station	1910	H.H. Waite; D.H. Squires
Ohio Agricultural & Mechanical College	1911	F.E. Bear
Ohio Agricultural Experiment Station	1912	R.C. Collison; A. Bonazzi; E.R. Allen; J.W. Ames E.F. Tuttle; B.S. Davisson; O.H. Smith
Hawaii Agricultural Experiment Station	1912	W.P. Kelley; S.S. Peck
Wellesley College	1912	L.F. Snow
Univ. Nebraska & Agricultural Exp. Sta.	1913	J.J. Putnam
Utah Agricultural Experiment Station	1913	J.E. Greaves; E.G. Carter; R. Stewart; C. Hirst L.A. Smith; H.P. Anderson; E.C. Mohr; Y. Lund W. Peterson; E.O. Greaves; D.H. Nelson; L.A. Smith

TABLE 3.5 – *Continued*

RESEARCH IN SOIL BACTERIOLOGY

<u>Name</u>	<u>Date</u>	<u>Personnel</u>
Idaho Agricultural Experiment Station	1914	W.M. Gibbs; P. Emerson; R.S. Snyder; R.E. Neidig J.J. Putnam
Missouri Agricultural Experiment Station	1914	W.A. Albrech; L.M. Turk
Kentucky Agricultural Experiment Station	1914	H. Garman; M. Didlake
Mississippi Agricultural Experiment Sta.	1915	C.F. Briscoe; R.W. Harned; H.H. Harned; S.S. Chen J.P. Torrey
Tennessee Agricultural Experiment Station	1915	M. Mulvania; H.P. Ogden
Montana Agricultural Experiment Station	1915	D.B. Swingle; G.B. Nutting
Purdue Univ. Agricultural Experiment Sta.	1915	T.J. Murray; H.A. Noyes; I.L. Baldwin; H.D. Brown E. Voight; S.C. Conner; J. Oskamp; C.G. Woodbury
Pennsylvania Agricultural Experiment Sta.	1915	J.M. Sherman
Maryland Agricultural Experiment Station	1916	P. Emerson; A.G. McCall; L.W. Erdman; C. Chen
Alabama Agricultural Experiment Station	1916	A.E. Elizando; W.J. Robbins; W.A. Gardner
Washington Agricultural Experiment Sta.	1918	B.F. Dana; C.A. Magoon; P.W. Allen
Wyoming Agricultural Experiment Station	1918	A.F. Vass; J.P. Poole
N.Y. St. College of Forestry, Syracuse	1919	C.L. Brightman; S.F. Acree; M.R. Meachem
University of Washington	1922	E.M. Johnson
Minnesota Agricultural Experiment Station	1924	R.S. Starkey; C. Skinner
Louisanna Agricultural Experiment Station	1925	E.V. Abbott

TABLE 3.6

RESEARCH IN PLANT PATHOLOGY PRIOR TO 1915

<u>Name</u>	<u>Date</u>	<u>Personnel</u>
University of Illinois & Agricultural Experiment Station	1870	T.J. Burrill; F.L. Stevens; E.Y. True; G.P. Clinton G.L. Peltier; E.Y. True
Purdue Agricultural Experiment Station	1885	J.C. Arthur
N. Dakota Agricultural Experiment Station	1889	H.L. Bolley; F.J. Pritchard; T.D. Beckwith F.J. Seaver; H.F. Bergman
Kansas Agricultural Experiment Station	1889	W.T. Swingle; W.A. Kellerman
Vermont Agricultural Experiment Station	1890	L.R. Jones; B.F. Lutman; N.J. Giddings G.C. Cunningham; H.A. Edson; H.E. Bartram
Connecticut Agricultural Experiment Sta.	1890	R. Thaxter; G.P. Clinton
Iowa Agricultural Experiment Station	1891	L.H. Pammel; R.E. Buchanan; I.E. Melhus
California Agricultural Experiment Station	1891	F.T. Bioletti; C.W. Woodworth; R.E. Smith C.B. Lipman; L.D. Batchelor; H.S. Reed
Delaware Agricultural Experiment Station	1891	F.D. Chester; M.H. Beckwith; E.D. Sanderson C.O. Smith; H.S. Jackson; T.F. Manns J.J. Taubenhause
Shaw School of Botany, Washington Univ.	1892	W. Trelease
Bureau Plant Industry, USDA	1893	E.F. Smith; B. Galloway; A.F. Woods; E.A. Bessey W.T. Swingle; F. Hedges; P.D. Dorsett; H. Metcalf M.B. Waite; F.W. Patterson; W.A. Orton J.F. Collins; I. McBeth; J.B. Rorer; W.M. Scott C. Brooks; L.J. Gillespie; L.S. Tenny C.O. Townsend; C.L. Shear
N.J. Agricultural Experiment Station	1894	B.D. Halsted; M.T. Cook; G.W. Martin W.H. Martin; H.C. Lint; W.S. Krout; R.F. Poole
Wisconsin Agricultural Experiment Station	1894	H.L. Russell; L.R. Jones; H.A. Harding V.B. Stewart; I.D. Cardiff; I. Melhus; R.E. Vaughan G.W. Kiett
New Hampshire Agricultural Exp. Station	1895	H.H. Lamson; C. Brooks; I.M. Lewis
N. Carolina Agricultural Experiment Sta.	1896	F.L. Stevens; F. Sherman; W.G. Sackett; J.G. Hall R.I. Smith
Nebraska Agricultural Experiment Station	1898	A.F. Woods; F.D. Heald
N.Y. Agricultural Experiment Station, Cornell	1898	B. Duggar; F.C. Stewart; H.H. Whetzel; D. Reddick F.M. Rolfs; V.B. Stewart; M. Barrus; C. Gregory J.J. Taubenhause; I.C. Jagger
West Va. Agricultural Experiment Station	1903	J.L. Sheldon; A.L. Post; N.J. Giddings R.C. Spangler; D.C. Neal; A. Berg
Missouri Agricultural Experiment Station	1903	H.S. Reed
Oregon Agricultural Experiment Station	1903	E.F. Pernot; R.E. Stephenson
N.Y. Agricultural Experiment Station Geneva	1904	F.C. Stewart; H.A. Harding; M.J. Prucha; G. French B.M. Duggar; J.K. Wilson; W.J. Morse W.O. Gloyer

TABLE 3.6 – *Continued*

RESEARCH IN PLANT PATHOLOGY PRIOR TO 1915

<u>Name</u>	<u>Date</u>	<u>Personnel</u>
Mass. Agricultural Experiment Station	1905	P.C. Brooks; W.S. Krout
Michigan Agricultural Experiment Station	1905	W.G. Sackett
Minnesota Agricultural Experiment Station	1905	A.F. Woods; E.M. Freeman; E.C. Stakman
Washington Agricultural Experiment Sta.	1906	R.K. Beattie; W.H. Lawrence; H.B. Humphrey F.D. Heald; T.J. Murray; D.C. George; B.F. Dana H.M. Woolman; I.D. Cardiff
University of Texas, Austin	1906	F.D. Heald; I.M. Lewis
S. Carolina Agricultural Experiment Sta.	1906	H. Metcalf; H.D. House; H.W. Barre; F.M. Rolfs
Maine Agricultural Experiment Station	1907	W.J. Morse; C.E. Lewis
Virginia Agricultural Experiment Station	1907	E.B. Fred; H.S. Reed; J.T. Rogers; J.S. Cooley C.H. Crabhill; T.J. Murray; F.D. Fromme; J. Quantz
Colorado Agricultural Experiment Station	1908	W.G. Sackett; L. Kezer
Nevada Agricultural Experiment Station	1908	W.B. Mack
Ohio Agricultural Exp. Sta., Wooster	1908	A.D. Selby; T.F. Manns; W.O. Gloyer
Washington University, St. Louis	1910	G.T. Moore; G.L. Peltier
Utah Agricultural Experiment Station	1910	C.N. Jensen
Hawaii Agricultural Experiment Station	1910	V. MacCaughey
Montana Agricultural Experiment Station	1911	D.B. Swingle
Tennessee Agricultural Experiment Station	1911	S.H. Essary
Shaw School Botany, Missouri	1912	B.M. Duggar; C.W. Dodge
Maryland Agricultural Experiment Station	1912	J.B. Norton; E.S. Johnson; J.E. McMurtrey E.S. Johnston
Texas Agricultural Experiment Station	1912	J.J. Taubenhause; B.F. Dana; F.D. Heald
Georgia Agricultural Experiment Station	1914	C.A. McLendon; B.B. Higgins
Rockefeller Institute, Div. of Plant Path.	1914	T. Smith

TABLE 3.7

INSTRUCTION IN PLANT PATHOLOGY PRIOR TO 1915

<u>Name</u>	<u>Date</u>	<u>Personnel</u>
University of Illinois	1887	T.J. Burrill; F.L. Stevens
Harvard College	1889	W.G. Farlow
University of Missouri	1890	W. Trelease; H.S. Reed; W.J. Robbins
University of Vermont	1890	L.R. Jones; B.F. Lutman
Iowa State College	1891	L.H. Pammel; R.E. Buchanan; I.E. Melhus
Shaw School of Botany, Washington Univ.	1892	W. Trelease; G.T. Moore; B.M. Duggar
Rutgers College	1893	B.D. Halsted; M.T. Cook
University of Wisconsin	1894	H.L. Russell; L.R. Jones; I.E. Melhus
Purdue University	1894	J.C. Arthur
New Hampshire College	1894	H.H. Lamson; C. Brooks; C.A. Black; M.M. Brown
University of California, Berkeley	1898	F.T. Bioletti; C.W. Woodworth; R.E. Smith A.M. West; E.H. Smith
Cornell University	1898	B. Duggar; V.B. Stewart; H.H. Whetzel; D. Reddick M. Barrus; J.J. Taubenhaus; C. Gregory
University of West Virginia	1903	J.L. Sheldon; A.L. Post; N.J. Giddings; R. Spangler
Michigan Agricultural College	1903	W.G. Sackett; R.S. Snyder
North Dakota Agricultural College	1904	H.L. Bolley; F.J. Pritchard; T.D. Beckwith
North Carolina College of A & M	1904	F.L. Stevens; F. Sherman; R.I. Smith
University of Texas, Austin	1906	H.H. Rok; F.D. Heald; I.M. Lewis
Virginia Polytechnic Institute	1907	E.B. Fred; H.S. Reed; F.D. Fromme
Middlebury College	1909	E.A. Burt
Texas Agricultural & Mechanical College	1910	H. Cassidy; E.H. Gibbons; J.J. Taubenhaus
College of Hawaii	1910	V. MacCaughy
University of Tennessee	1912	S.H. Essary
University of Minnesota	1912	E.M. Freeman
Utah Agricultural Experiment Station	1912	H. Schweitzer
Clemson College	1914	F.M. Rolfs

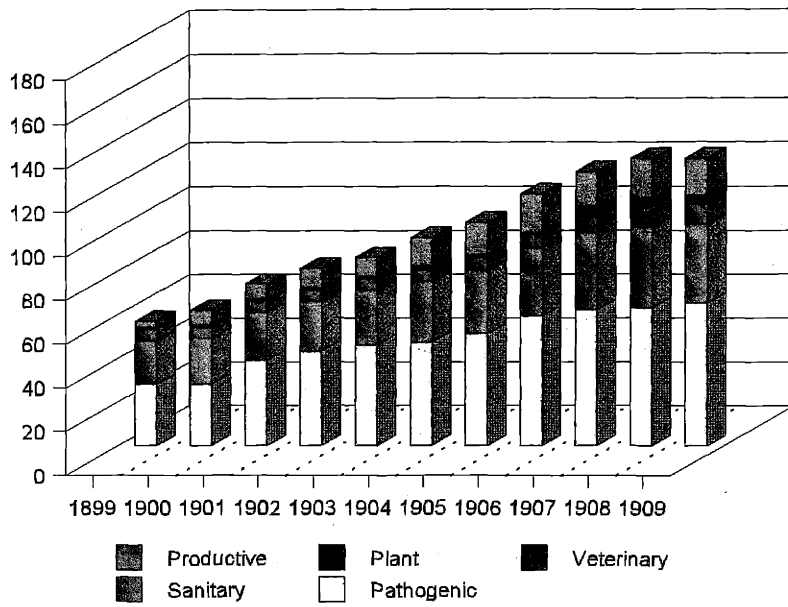
TABLE 3.8

INSTRUCTION IN SOIL BACTERIOLOGY PRIOR TO 1925

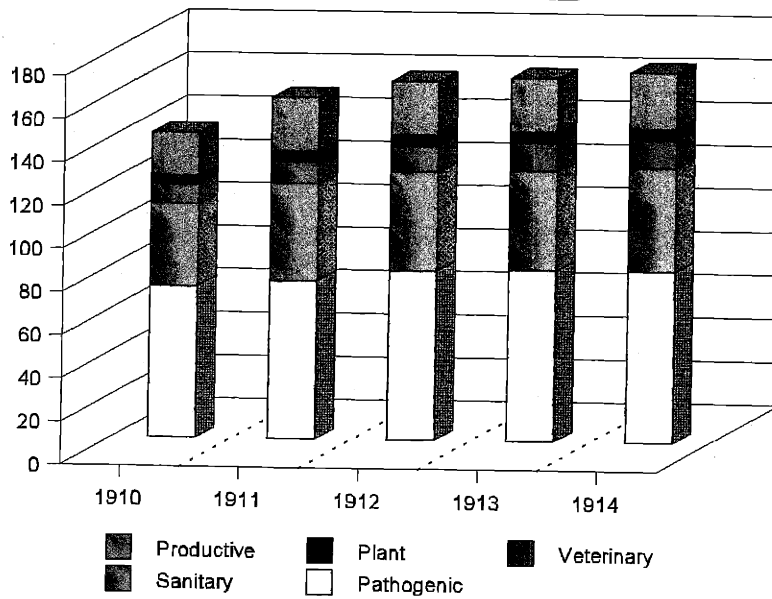
<u>Name</u>	<u>Date</u>	<u>Personnel</u>
Utah State Agricultural College	1895	F.W. Brewer; E.G. Peterson; J.E. Greaves; Y. Lund H. Goldthorpe; E.G. Carter; H.P. Anderson
Michigan Agricultural College	1895	C.E. Marshall; O. Rahn; R.S. Snyder; R. Tweed
Stanford University	1898	G.J. Pierce
University of Illinois	1899	H.E. Ward; O. Rahn; F. Lohnis; C.G. Hopkins J.H. Pettit
Oregon State University	1899	E. Pernot; E.G. Peterson; T. Beckwith; A.F. Vass G. Copson; R.H. Robinson; W.B. Bollen W. Halversen; J.A. Berry
Virginia Polytechnic Institute	1905	M. Ferguson; E.B. Fred; H.S. Reed; T.J. Murray
Cornell University	1905	T.L. Lyon; J.A. Bizzell; M.J. Prucha; J.K. Wilson H.J. Conn
Rutgers University	1906	J.G. Lipman; R.E. Curtis; S.A. Waksman
Brigham Young University	1906	J.A. Widtsoe; T.L. Martin
North Carolina College of A & M	1907	F.L. Stevens; W.A. Withers; J. Temple
University of Tennessee	1908	E.S. Reynolds; M. Mulvinia
Shaw School of Botany, Washington Univ.	1909	G.T. Moore; B.M. Duggar
University of Wisconsin	1909	C. Hoffmann; E.R. Jones; E.B. Fred; P. Peterson A.R. Whitson; E.J. Sievers; T.L. Hills; A. Whiting O.C. Bryan; E.G. Hastings; W.H. Wright
University of California, Berkeley	1909	C.B. Lipman; P.S. Burgess
Iowa State College	1910	R.E. Buchanan; P.E. Brown; E.H. Kellogg W.H. Stevenson; R.S. Potter; P. Emerson
Ohio Agricultural & Mechanical College	1911	F.E. Bear
University of Maine	1912	F.L. Russell
University of West Virginia	1912	J.L. Sheldon; F.E. Bear; R.M. Saltey R.E. Stephenson
Cornell University	1914	J.K. Wilson
Purdue University	1915	T.J. Murray; I.L. Baldwin
University of Missouri	1916	W.A. Albrecht
Ball State University	1918	O.B. Christy
Rhode Island State College	1923	P.S. Burgess
University of Tennessee	1923	P.W. Allen
University of Minnesota	1924	R.S. Starkey; C. Skinner

APPENDIX 2: GRAPHS FOR CHAPTER FOUR

4.1 SAB Membership, 1899-1909

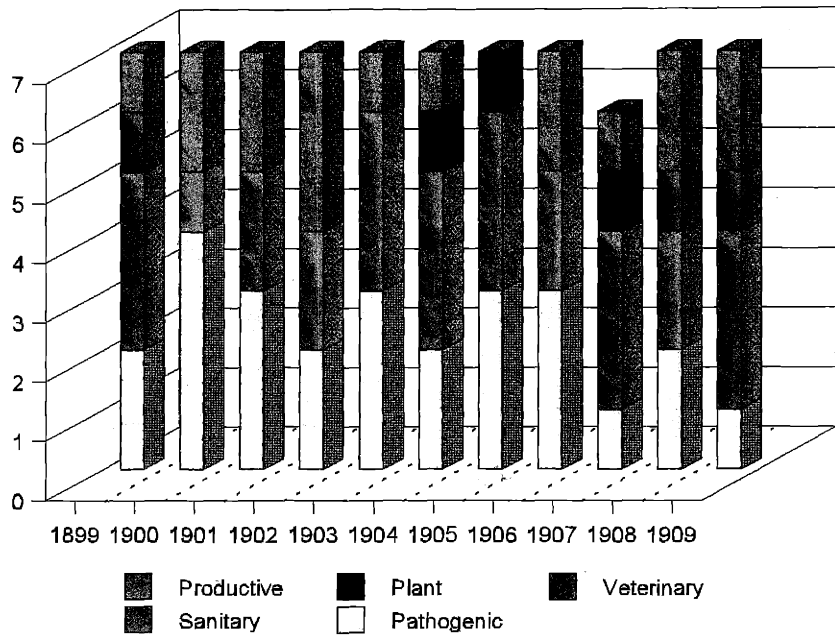


4.2 SAB Membership, 1909-1914

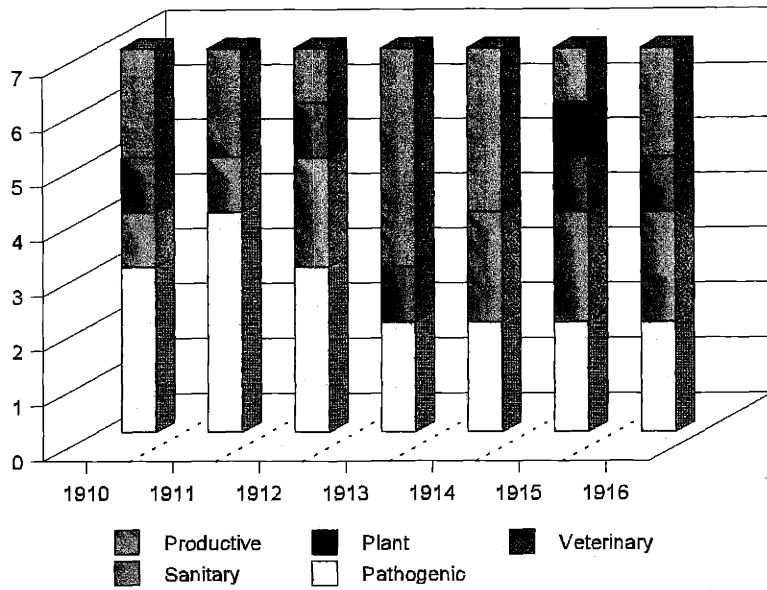




4.3 SAB Executive Council, 1899-1909

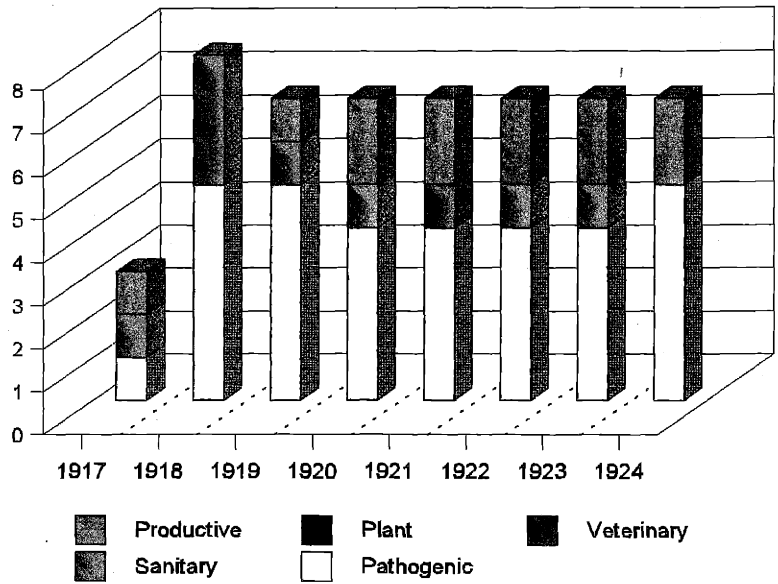


4.4 SAB Executive Council, 1910-1916

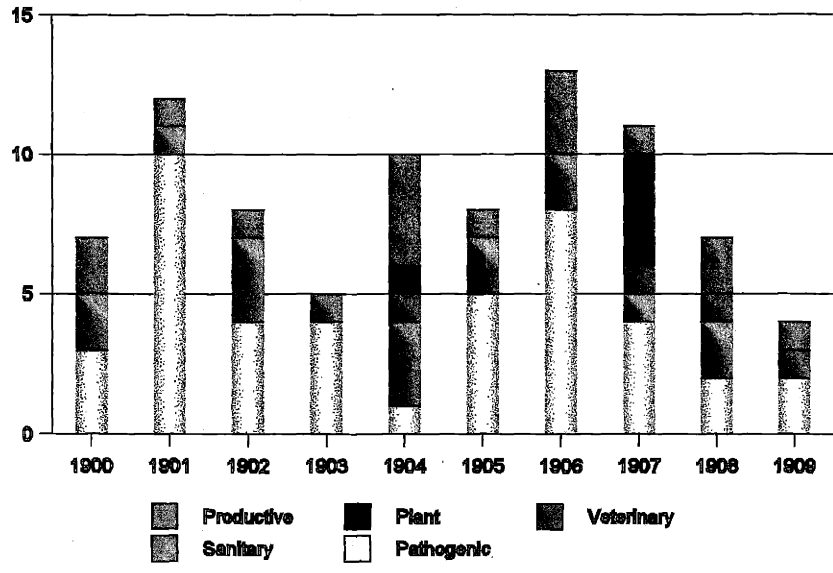




4.5 SAB Executive Council, 1917-1924

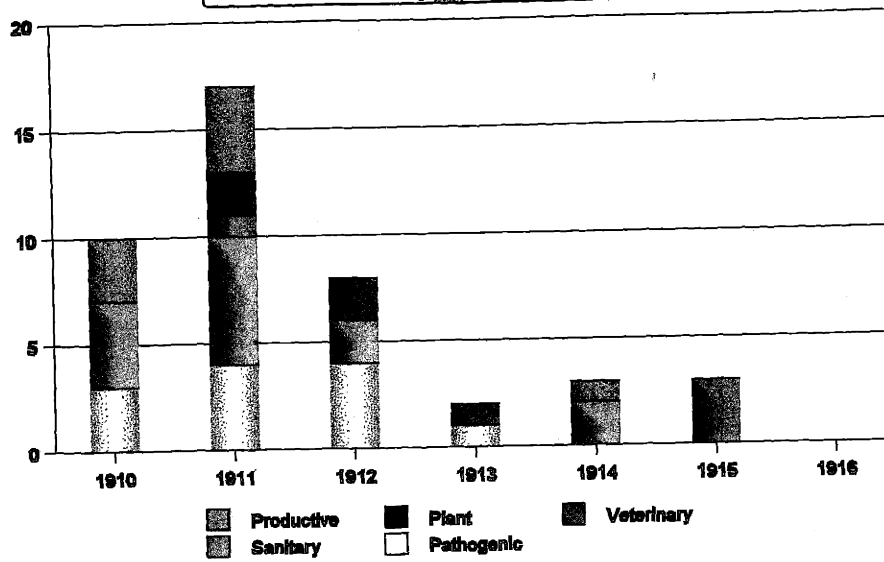


4.6 SAB Elections, 1900-1909

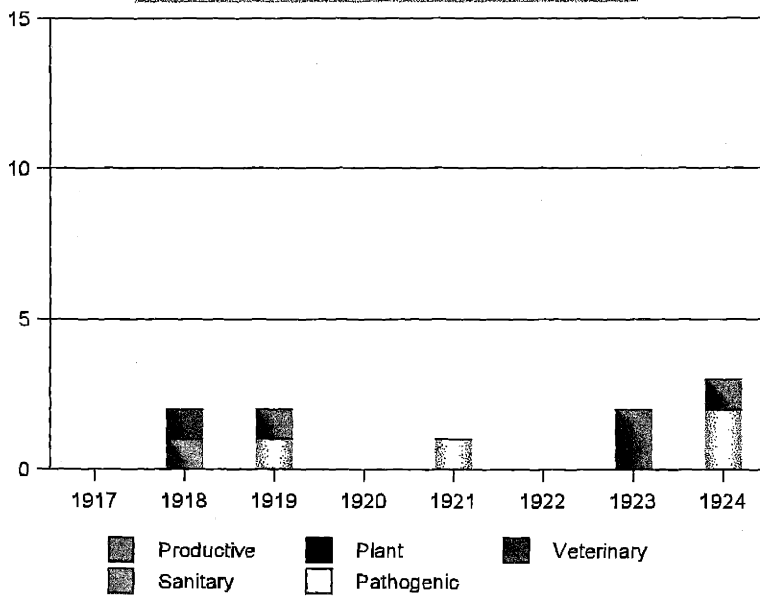


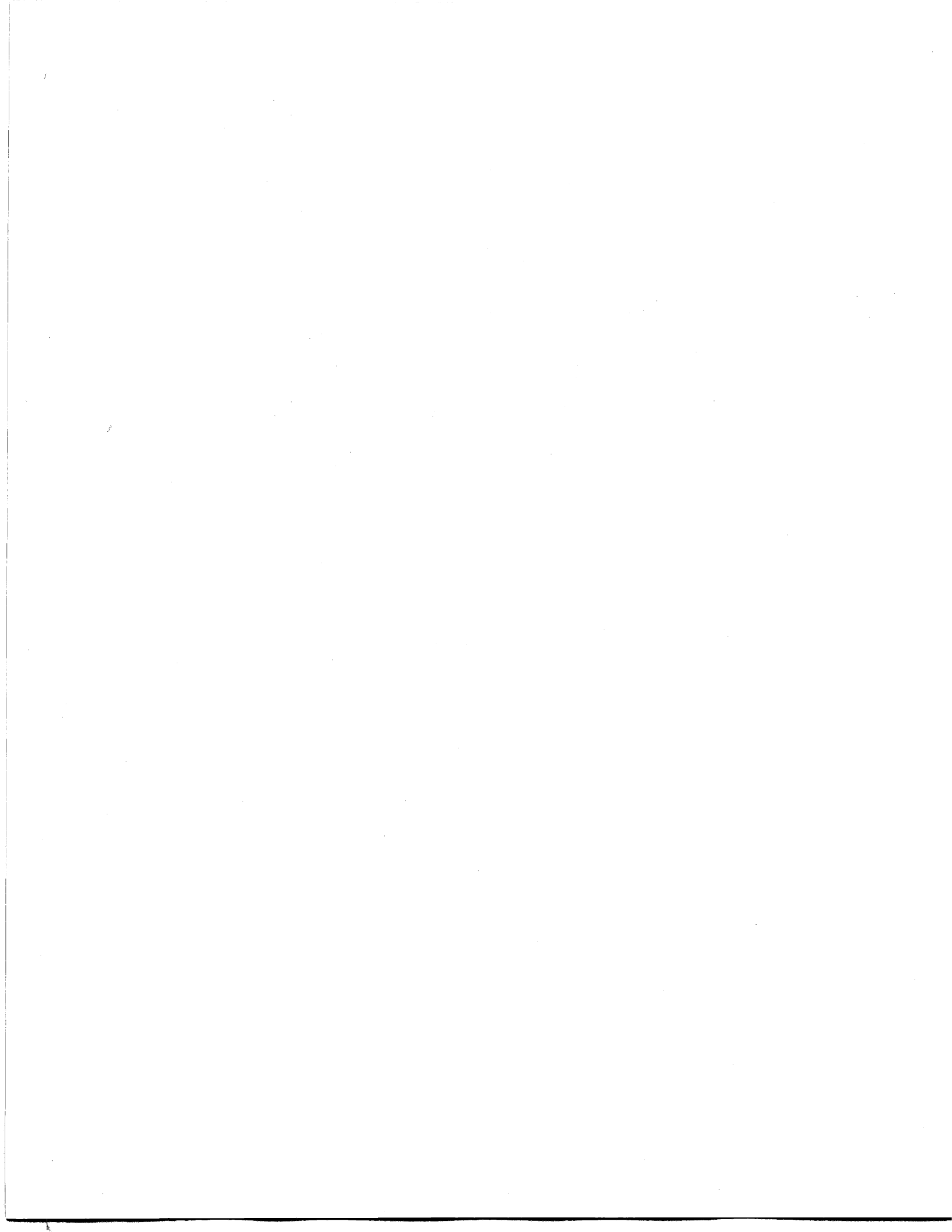


4.7 SAB Membership Nominations, 1910-1916

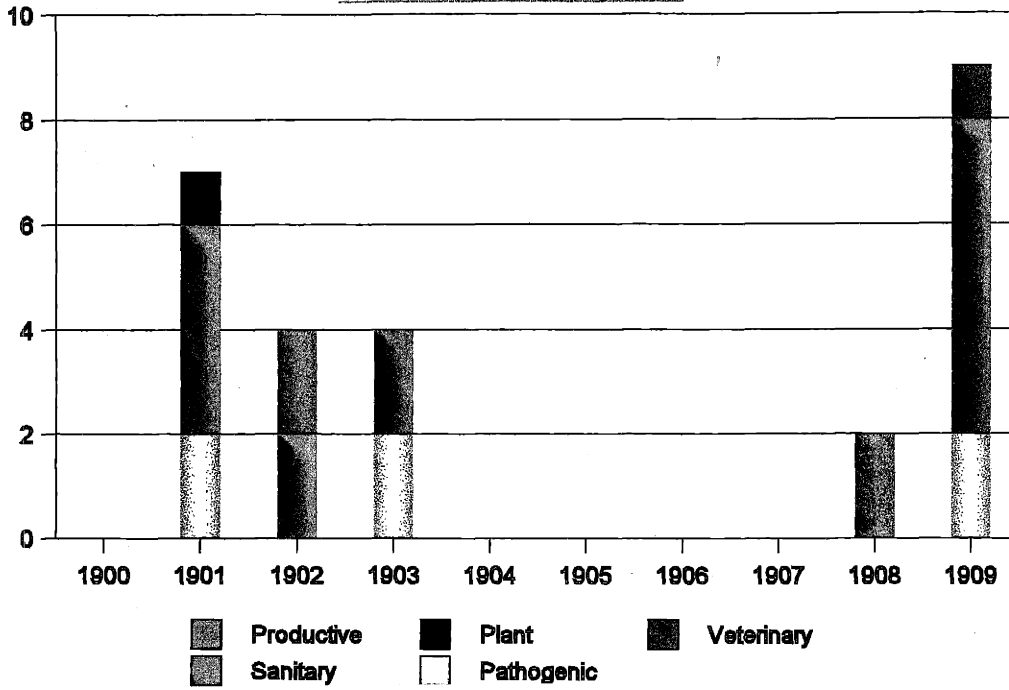


4.8 SAB Membership Nominations, 1917-1924

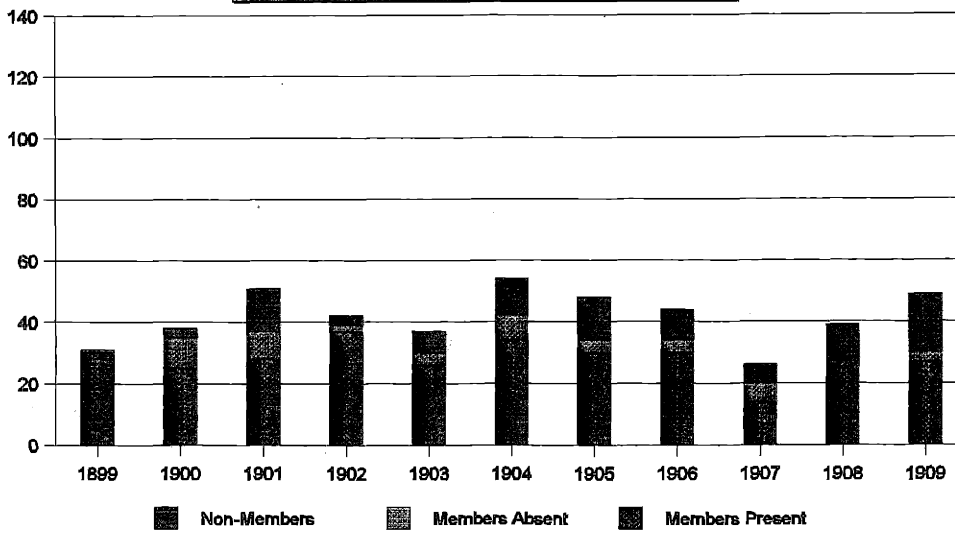




4.9 Nominated, Not Elected

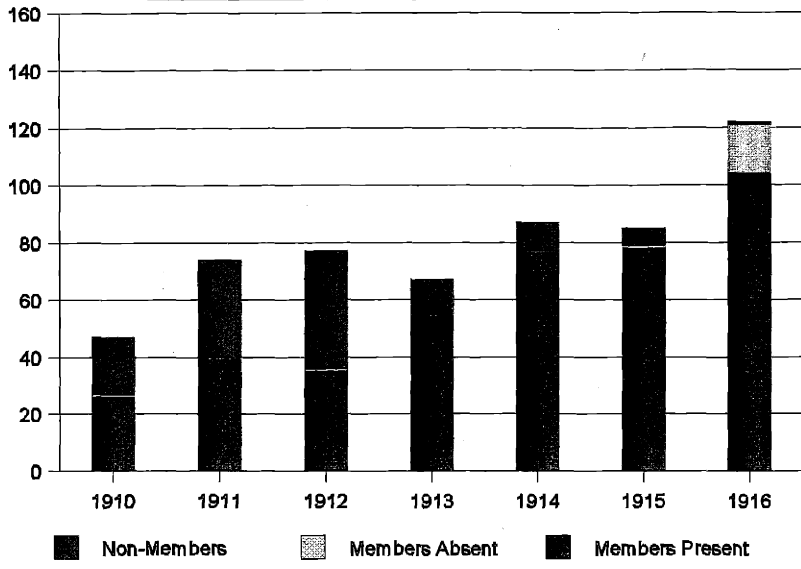


4.10 SAS Annual Meeting, Barrowland, 1899-1909

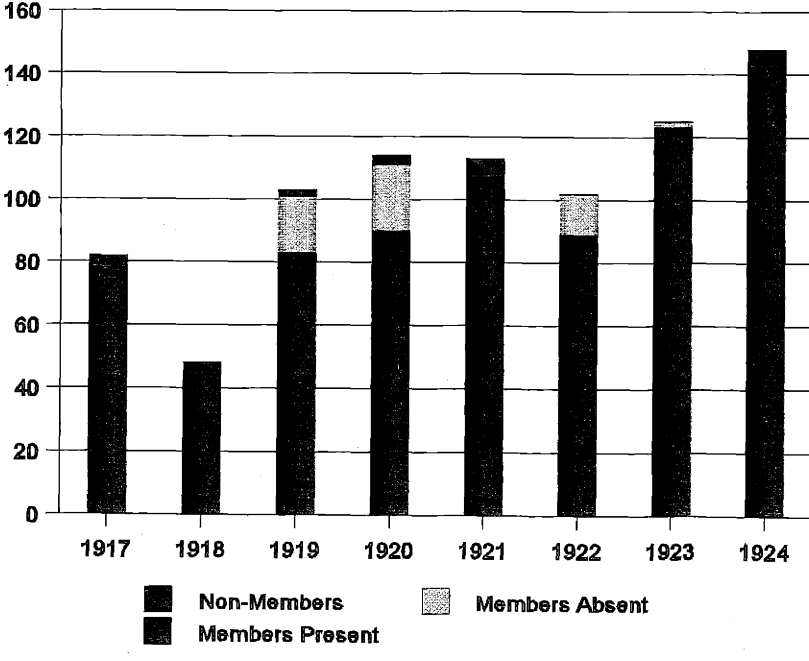




4.11 SAB Annual Meeting Participants, 1910-1916

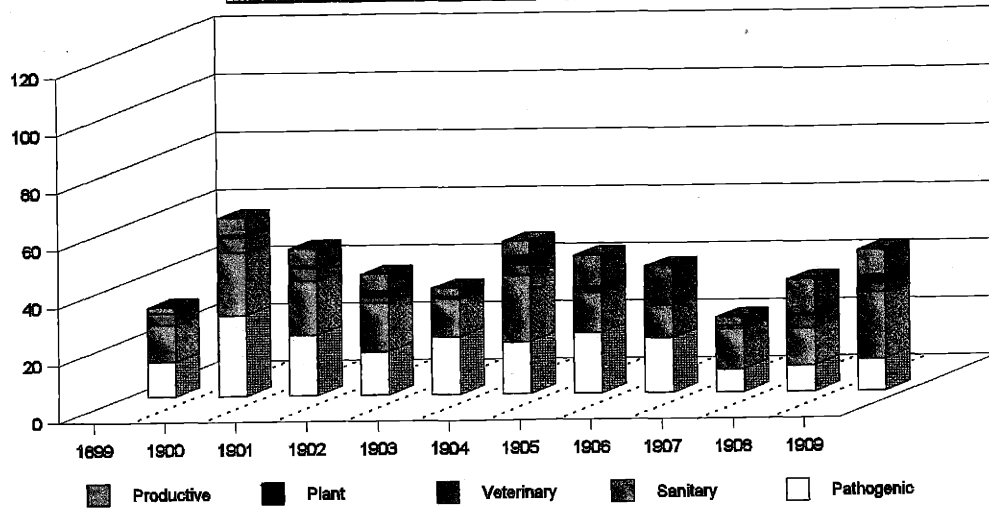


4.12 SAB Annual Meeting Participants, 1917-1924

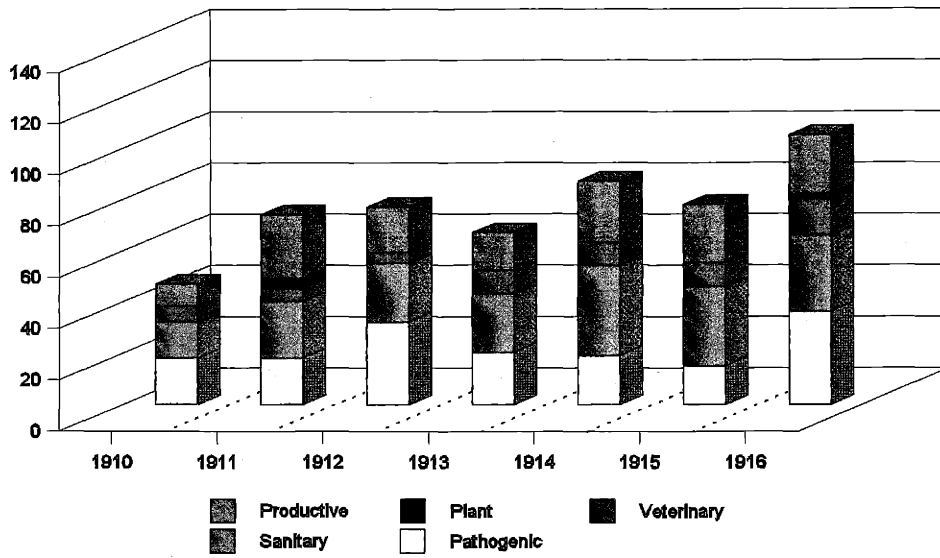




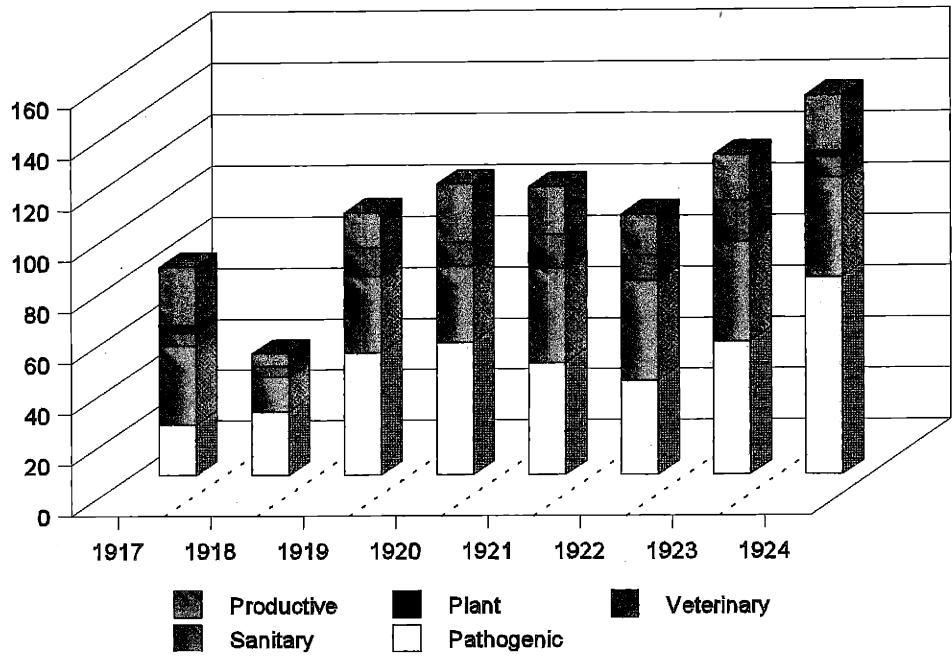
4.13 SAB Meeting Participants, 1899-1909: By Category



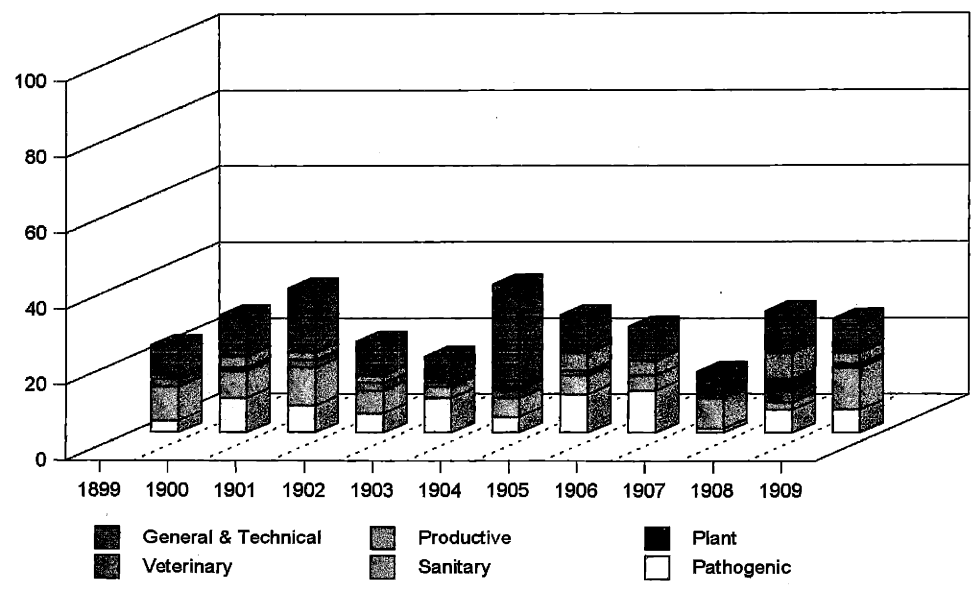
4.14 SAB Meeting Participants, 1910-1916: By Category



4.15 SAB Meeting Participants, 1917-1924: By Category

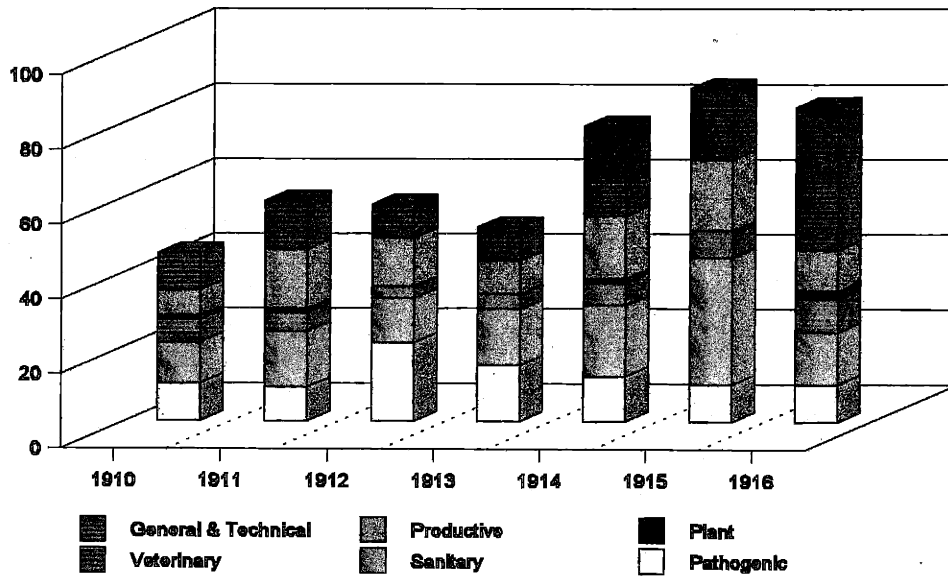


4.16 SAB Meeting Papers, 1899-1909

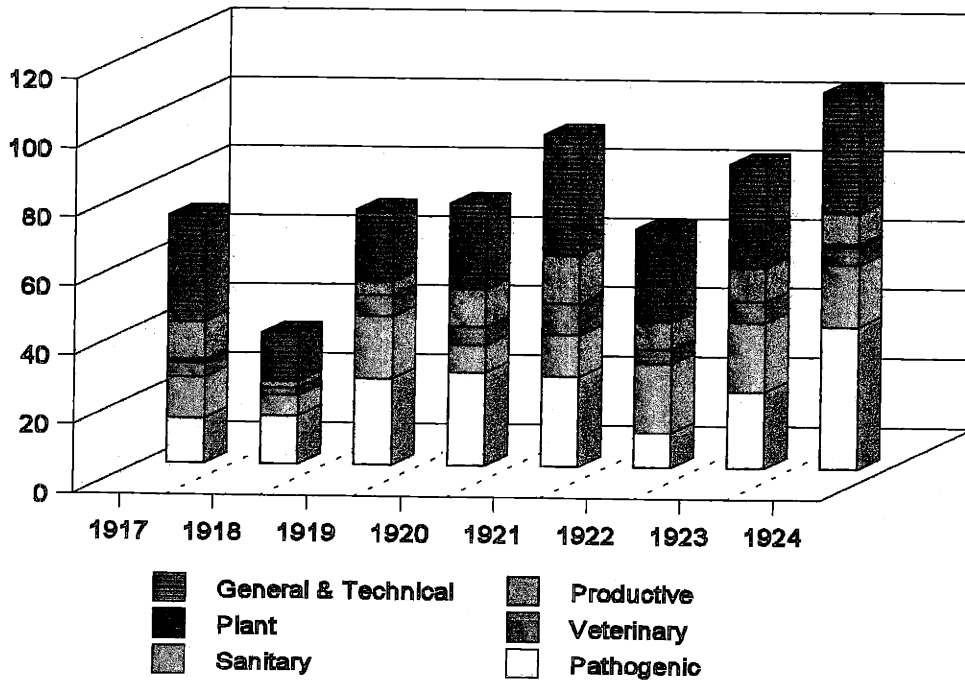




4.17 SAB Meeting Papers, 1910-1916

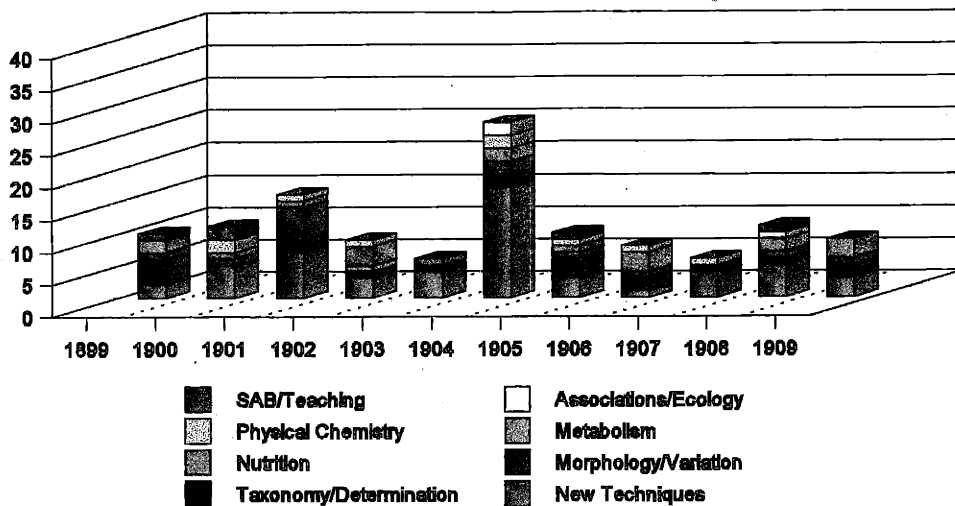


4.18 SAB Meeting Papers, 1917-1924

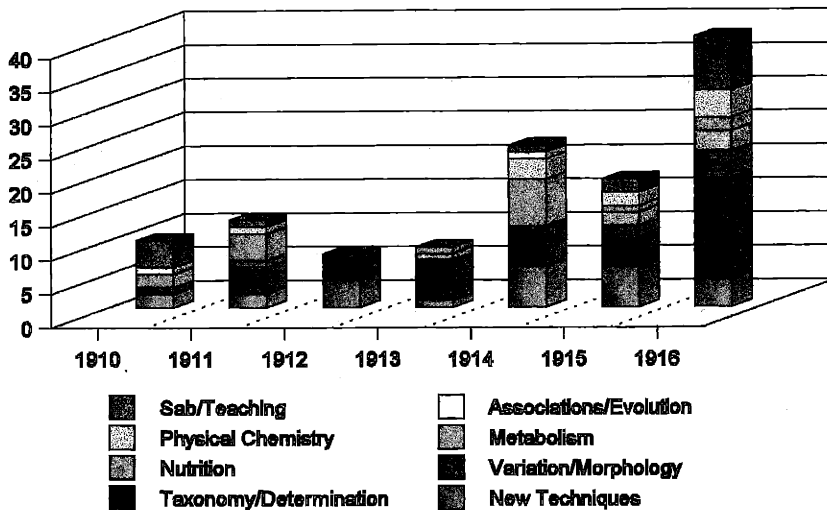




4.19 General & Technical Papers, 1899-1909

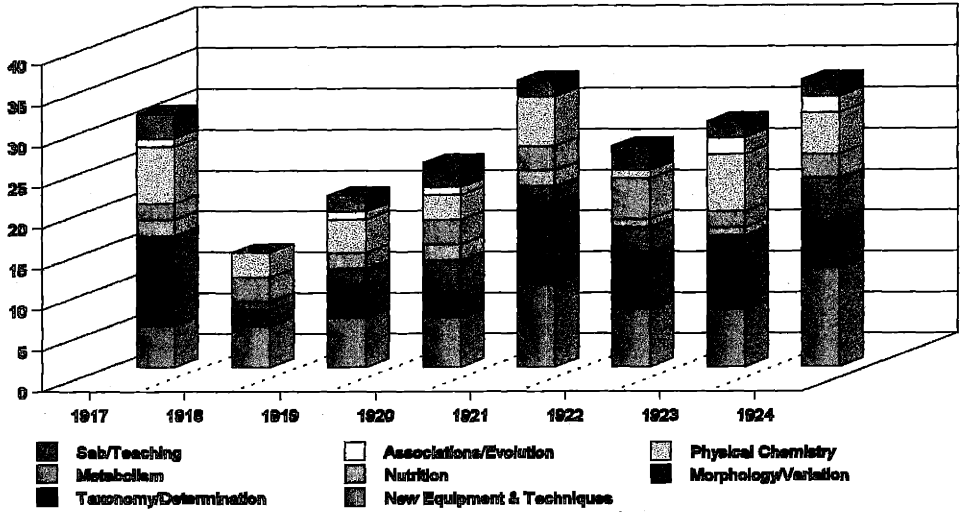


4.20 General & Technical Papers, 1910-1916





4.21 General & Technical Papers, 1917-1924





APPENDIX 3: FIGURES FOR CHAPTERS FIVE AND SIX

FIGURE 5.1

SAB DESCRIPTIVE CHART GROUP NUMBER, 1907

TABLE I.

A Numerical System of Recording the Salient Characters
of an Organism.

100.	Endospores produced
200.	Endospores not produced.
10.	Aerobic (Strict)
20.	Facultative anaerobic
30.	Anaerobic (Strict)
1.	Gelatin liquefied
2.	Gelatin not liquefied
0.1	Acid and gas from dextrose
0.2	Acid without gas from dextrose
0.3	No acid from dextrose
.01	Acid and gas from lactose
.02	Acid without gas from lactose
.03	No acid from lactose
.001	Acid and gas from saccharose
.002	Acid without gas from saccharose
.003	No acid from saccharose
.0001	Nitrates reduced
.0002	Nitrates not reduced
.00001	Fluorescent
.00002	Violet chromogens
.00003	Blue "
.00004	Green "
.00005	Yellow "
.00006	Orange "
.00007	Red "
.00008	Brown "
.00009	" "
.00000	Non-chromogenic

The genus according to the system of Migula is given its proper symbol which precedes the number thus:

BACILLUS COLI (Escherich) Migula becomes	B. 222.11110
BACILLUS ALCALIGENES Petruschky "	B. 212.33310
PSEUDOMONAS CAMPESTRIS (Pammel) Smith	Ps. 211.33315
BACTERIUM SUICIDA Migula "	Bact. 222.2320

FIGURE 5.4

HERBERT W. CONN'S SECOND CHART, 1901

Group	month	Lic	Tex.	Loak	Sac	Milk	KNO ₃	Indol	Froth	Gel	St	Agar	Potato	Temp	Germe	Path	Culture		
NAME		INVESTIGATOR.					SOURCE			ISOLATED.									
Morphology										Spores	Length	Diameter	Form						
										Capsule	Grams	Flagella	motile						
Gelatin Stab										Begins	Complete	Form	Liq						
Gelatin Colony										Large	Small	Form	Liq						
Litmus Gelatin Colony										Acid	Form	Liq							
Fermentation Tube										3 Days	C. A.	Acid	Gas						
Dextrose										later									
Lactose										3 Days	C. A.	Acid	Gas						
										later									
Saccharose										3 Days	C. A.	Acid	Gas						
										later									
Agar Streak										Lux	Viscous	Irregular	Full						
												Chrom	Fluor						
Temperature												20°	35°						
Broth										3 Days	Sediment	Pellicle	Turbid						
										later									
Milk										3 Days	Acid 20°	Acid 35°	Alk 20°	Alk 35°					
										later									
Curdling										3 Days	20°	35°	Dig 20°	Dig 35°					
										later									
											Color	Odor	Slimy						
Potato											Bicolor	Lux	Visible						
Indol																			
Pathogenesis																			
Litmus Lactose Agar												T.B	Rea						
Nitrates											N	NH ₃	HNO ₂						

FIGURE 5.5

SALIENT FEATURES AND DETAILED FEATURES, SAB CHART, 1905

— FRONT OF FIRST SOCIETY CARD

SALIENT FEATURES (Partly included in Group No.)

Genus	Group No. or Character Complex	Morph.	CULTURAL FEATURES										BIOCHEMICAL FEATURES					ADDITIONAL SALIENT OR DIAGNOSTIC FEATURES														
			Broth		Agar		Gel. Plate		Gel. Stab		Potato		Liquefaction		Milk																	
Name		Diagn. over 1 micron	Chains	Spores	Turbidity	Scum	Sediment	Pull	Wrinkled	Round, Compact	Pottery-like	Horizontal	Filamentous	Curled	Funnel	Surface Growth	Needle Growth	Starch destroyed	Abundant	Discolored	Grows at 37°C	Gelatin	Casain	Blood Serum	Curdled	Acid	Alkaline	Indol	H ₂ S	Ammonia	Nitrates reduced	Urease's stain
Source																																
Cult. No.																																

DETAILED FEATURES.

I. MORPHOLOGY.

- Vegetative Cells.
 - Form. *round, short rods, long rods, filaments, coccous, short spirals, long spirals, clostridium, cuneate, clavate.*
 - Limits of Size. ¹
 - Ends. *rounded, truncate, concave.*
 - Orientation (grouping).
 - Agar Block { Chains (No. of elements), *short chains, long chains.*
 - Orientation of Chains. *parallel, irregular.*
- Sporangia.
 - Form. *elliptical, short rods, spindle, clavate.*
 - Limits of Size.
 - Orientation (grouping).
 - Agar Block { Chains (No. of elements).
 - Orientation of Chains.
 - Location of Spores.
- Spores.
 - Form. *round, elliptical. (2X diam.) elongated.*
 - Limits of Size.
 - Wall.
 - Naked.
 - Sporangium wall adherent. ⁵

- Germination, *equatorial, oblique, polar, bipolar, by stretching.*
- Flagella No.
 - Arrangement.
 - Capsules, present on.
 - Staining Reactions.
 - 1:10 watery fuchsin.
 - Special Stains.
 - Fat.
 - Neisser.
 - Glycogen.
- II. CULTURAL FEATURES. ⁶
- Agar Stroke.
 - Form of growth. *filiform, echinulate, beaded, spreading, plumose, arborescent, rhizoid.*
 - Elevation of growth. *flat, effused, raised, convex.*
 - Lustre. *glistening, dull, cretaceous.*
 - Topography. *smooth, contoured, rugose, verrucose.*
 - Optical Characters. *opaque, opalescent.*
 - Chromogenesis.
 - Consistency. *slimy, butyrous, viscid, membranous, coriaceous, brittle.*
 - Medium discolored.

- Potato.
 - Form of growth (as before).
 - Elevation " " "
 - Lustre " " "
 - Chromogenesis.
 - Consistency as before.
 - Medium discolored.
 - Blood serum.
 - Form of growth (as before).
 - Elevation " " "
 - Lustre " " "
 - Topography " " "
 - Chromogenesis.
 - Medium discolored.
 - Liquefaction. 10d. 4w.
 - Agar Stab.
 - Line of puncture. *filiform, beaded, papillate, villous, plumose, arborescent.*
 - Gelatin Stab.
 - Line of puncture (as before).
 - Form of liquefaction. *crateriform, napiform, infundibuliform, saccate, stratiform.*
 - Surface growth.
- NOTE—Under-score required terms. Observe accompanying notes and glossary of terms.

FIG. 7.—BACK OF FIRST SOCIETY CARD.

- Broth.
 - Surface growth. *ring, scum, flocculent, membranous, none.*
 - Turbidity. *slight, moderate, strong, transient, persistent, none.*
- Milk.
 - Coagulation.
 - Liquefaction. 10d. 4w.
 - Reaction in 2 d⁹. 4d. 10d.
 - Consistency. *slimy, viscid, unchanged.*
 - Medium discolored.
 - Milk agar.
- Gelatin Colonies.
 - Form. *punctiform, round, irregular, ameboid, mycelioid, filamentous, rhizoid.*
 - Elevation. *flat, effused, raised, convex, papillate, crateriform, (liquefying).*
 - Edge. *entire, undulate, lobate, erose, lacinate, fibrillate, ciliate, filamentous, floccose, curled.*
 - Internal structure. *amorphous, finely-coarsely-granular, gramose, filamentous, floccose, curled.*

- Agar colonies.
 - Form (as before)
 - Elevation " "
 - Edge " "
 - Internal Structure (as before)
 - Relative growth at 20° and 37°C.
- III. BIOCHEMICAL FEATURES.
- Fermentation of dextrose.
 - Gas production.
 - H. CO₂ ratio.
 - Growth in closed arm.
 - Acidifying coefficient 2 d. 4 d. 10 d.
 - Fermentation of lactose.
 - Gas production.
 - H. CO₂ ratio.
 - Growth in closed arm.
 - Acidifying coefficient 2 d. 4 d. 10 d.
 - Fermentation of saccharose.
 - Gas production.
 - H. CO₂ ratio.

- Growth in closed arm.
- Acidifying coefficient 2 d. 4 d. 10 d.
- Fermentation of.
- Ammonia production. ¹⁰ *feeble, moderate, strong.*
- Reduction of nitrates in nitrate broth. ¹¹
 - Presence of nitrates.
 - " ammonia.
 - " nitrates.
 - " free nitrogen.
- Indol.
- H₂S.
- Starch Jelly.

IV. PATHOGENESIS.

V. ADDITIONAL DATA.

FIGURE 5.6

GROUP NUMBER, SAB CHART, 1905

A Numerical System of Recording the Salient Characters
of an Organism.

100.	Endospores produced
200.	Endospores not produced
10.	Aerobic (Strict)
20.	Facultative anaerobic
30.	Anaerobic (Strict)
1.	Gelatin liquefied
2.	Gelatin not liquefied
0.1	Acid and gas from dextrose
0.2	Acid without gas from dextrose
0.3	No acid from dextrose
.01	Acid and gas from lactose
.02	Acid without gas from lactose
.03	No acid from lactose
.001	Acid and gas from saccharose
.002	Acid without gas from saccharose
.003	No acid from saccharose
.0001	Nitrates reduced
.0002	Nitrates not reduced
.00001	Fluorescent
.00002	Violet chromogens
.00003	Blue chromogens
.00004	Green chromogens
.00005	Yellow chromogens
.00006	Orange chromogens
.00007	Red chromogens
.00008	Brown chromogens
.00009	chromogens
.00000	Non-chromogenic

The genus according to the system of Migula is given its proper symbol which precedes the number thus:

BACILLUS COLI (Escherich) Migula becomes	B. 212.11110
BACILLUS ALCALIGENES Petruschky becomes	B. 212.33310
PSEUDOMONAS CAMPESTRIS (Pammel) Smith	Ps. 211.33315
BACTERIUM SUICIDA Migula (Pammel) Smith	Bact. 212.2320

FIGURE 5.7

MANWARING'S INSTRUCTIONAL CHART, 1905

CULTURAL CHARACTERISTICS:

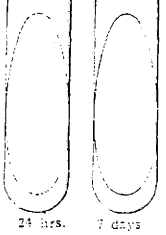
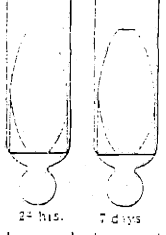
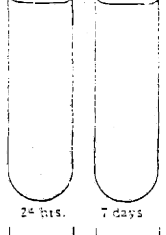
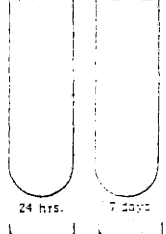
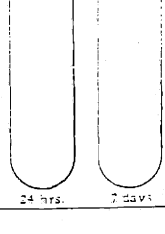
		SKETCHES			
PLATE	Surface Colonies:				
	Deep Colonies:				
1.		24 hours at 37.5° C.	48 hours at 37.5° C.	5 days later at 20° C.	SKETCHES
2. AGAR STREAK					 24 hrs. 7 days
3. POTATO					 24 hrs. 7 days
4. BOUILLON					 24 hrs. 7 days
5. LITMUS MILK					 24 hrs. 7 days
GLUCOSE AGAR					 24 hrs. 7 days

FIGURE 5.13

SAB DESCRIBE CHART, REVERSE SIDE, 1920

<p>Age: Colours: Temperature: Age:</p>	<p>Growth, slow, rapid, form, penicillium, circular, irregular, myceloid, filamentous, rhizoid, surface, rough, concentrically ringed, radiate, elevation, flat, effuse, raised, convex, pulvinate, lobulate, entire, radiate, lobate, rosette, filamentous, equal, internal structure, amorphous, finely, coarsely granular, filamentous, striated, concentric.</p>	<p>SKELETS:</p> <p>Growth, slow, rapid, form, penicillium, circular, irregular, myceloid, filamentous, rhizoid, surface, rough, concentrically ringed, radiate, elevation, flat, effuse, raised, convex, pulvinate, lobulate, entire, radiate, lobate, rosette, filamentous, equal, internal structure, amorphous, finely, coarsely granular, filamentous, striated, concentric.</p>	<p>SKELETS:</p> <p>Growth, slow, rapid, form, penicillium, circular, irregular, myceloid, filamentous, rhizoid, surface, rough, concentrically ringed, radiate, elevation, flat, effuse, raised, convex, pulvinate, lobulate, entire, radiate, lobate, rosette, filamentous, equal, internal structure, amorphous, finely, coarsely granular, filamentous, striated, concentric.</p>
PHYSIOLOGY			
RELATION TO OXYGEN			
<p>Method used: Medium: Aerobic growth: absent, present, better than anaerobic growth. Temperature: Anaerobic growth: absent, occurs in presence of dextrose, of sucrose, of lactose, of nitrate, better than aerobic growth. Temperature: Breath of clear zone on starch agar plates. Temperature: In: Additional data: Diastatic action: Reduction of nitrate to nitrite: Reduction of nitrite to ammonia: Reduction of nitrate to nitrogen: Reduction of nitrate to nitrous oxide: Reduction of nitrate to nitrogen gas: Reduction of nitrate to ammonia gas: Reduction of nitrate to nitrogen gas: Reduction of nitrate to nitrogen gas: Reduction of nitrate to nitrogen gas:</p>			
EMMENTATION			
<p>Medium containing: Gas: First appearance of acid: First appearance of alkali: Reaction after: days Reaction after: days Reaction after: days Max. H₂ ion Conc.:</p>			
TEMPERATURE RELATIONS			
<p>Optimum temperature for growth: Maximum temperature for growth: Minimum temperature for growth: Minimum temperature for growth:</p>			
CHROMOGENESIS			
<p>Nutrient broth: Nutrient gelatin: Nutrient agar: Inocula:</p>			
PRODUCTION OF INDOL			
<p>Medium: Indol absent, present in: days</p>			
PRODUCTION OF HYDROGEN SULFIDE			
<p>Medium: H₂S absent, present in: days</p>			
NITRATE REDUCTION			
<p>Medium: Nitrate: Gas: Nitrite: Gas:</p>			
MILK			
<p>Reaction: Acid rend: Remond rend: Peptonization: Production of firmness in: Influence of indicator on growth:</p>			
SPECIAL TESTS (e. g. PATHOGENICITY)			

FIGURE 5.14

SAB DESCRIPTIVE CHART, 1924

Name of organism:		History:		Culture No.:		Series No.:	
Date of isolation:		MORPHOLOGY		SKELETONS		Classification according to optimum conditions:	
Understore required terms:		Vegetative Cells:		Spores:		Microscopic Features:	
Primary Characteristics:		Secondary Characteristics:		Cultural Features:		DIME CHARACTERIZATION:	
Staining Reactions:		Carbohydrate Reactions:		Miscellaneous Biochemical Reactions:		Other:	
Motility:		Nitrogen:		Agar Stroke:		Milk:	
Pathogenicity:		Spore Production:		Penetration:		Other:	
Spore Production:		Penetration:		Other:		Other:	
Spore Production:		Penetration:		Other:		Other:	

* As each of the following characteristics is determined, indicate in proper marginal square by means of figure, as designated below. In case any of these characteristics are not observed, do not insert determination, indicate with "0" (underlined) as shown in the following code:
 1, positive; 2, variable; 3, negative; 4, indeterminate; 5, not tested; 6, not applicable; 7, not determined; 8, not applicable; 9, not tested; 10, not applicable; 11, not determined; 12, not applicable; 13, not tested; 14, not applicable; 15, not determined; 16, not applicable; 17, not tested; 18, not applicable; 19, not determined; 20, not applicable; 21, not tested; 22, not applicable; 23, not determined; 24, not applicable; 25, not tested; 26, not applicable; 27, not determined; 28, not applicable; 29, not tested; 30, not applicable; 31, not determined; 32, not applicable; 33, not tested; 34, not applicable; 35, not determined; 36, not applicable; 37, not tested; 38, not applicable; 39, not determined; 40, not applicable; 41, not tested; 42, not applicable; 43, not determined; 44, not applicable; 45, not tested; 46, not applicable; 47, not determined; 48, not applicable; 49, not tested; 50, not applicable; 51, not determined; 52, not applicable; 53, not tested; 54, not applicable; 55, not determined; 56, not applicable; 57, not tested; 58, not applicable; 59, not determined; 60, not applicable; 61, not tested; 62, not applicable; 63, not determined; 64, not applicable; 65, not tested; 66, not applicable; 67, not determined; 68, not applicable; 69, not tested; 70, not applicable; 71, not determined; 72, not applicable; 73, not tested; 74, not applicable; 75, not determined; 76, not applicable; 77, not tested; 78, not applicable; 79, not determined; 80, not applicable; 81, not tested; 82, not applicable; 83, not determined; 84, not applicable; 85, not tested; 86, not applicable; 87, not determined; 88, not applicable; 89, not tested; 90, not applicable; 91, not determined; 92, not applicable; 93, not tested; 94, not applicable; 95, not determined; 96, not applicable; 97, not tested; 98, not applicable; 99, not determined; 100, not applicable.

FIGURE 6.1

MIGULA'S CLASSIFICATION OF BACTERIA

- I. Cells globose in a free state, not elongated in any direction before divisions in 1, 2, or 3 planes. COCCACEAE ZOPH emend. MIG.
 - A. Cells without organs of motion.
 - a. Division in one plane, - - - 1. *Streptococcus* BILLROTH.
 - b. Division in two planes, - - - 2. *Micrococcus* (HALLIER) COHN.
 - c. Division in three planes, - - - 3. *Sarcina* Goodsir.
 - B. Cells with organs of motion.
 - a. Division in two planes, - - - 4. *Planococcus* MIGULA.
 - b. Division in three planes, - - - 5. *Planosarcina* MIGULA.
- II. Cells cylindrical, longer or shorter, and only divided in one plane, and elongated to twice the normal length before the division.
 - (1) Cells straight, rod-shaped without sheath, non-motile by means of flagella. BACTERIACEAE MIGULA.
 - A. Cells without organs of motion, - - - 6. *Bacterium* EHRENB.
 - B. Cells with organs of motion (flagella).
 - a. Flagella distributed over the whole body, - - - - - 7. *Bacillus* COHN.
 - b. Flagella polar, - - - - - 8. *Pseudomonas* MIGULA.
 - (2) Cells crooked, without sheath. SPIRILLACEAE MIGULA.
 - A. Cells rigid, not snake-like or flexuous.
 - a. Cells without organs of motion (flagella), - - - - - 9. *Spirosoma* MIGULA.
 - b. Cells with organs of motion (flagella)
 - 1. Cells with 1, very rarely 2-3 polar flagella, - - - - - 10. *Microspira* SCHROETER.
 - 2. Cells with polar flagella-tufts, - - - - - 11. *Spirillum* EHRENB.
 - 12. *Spirochaeta* EHRENB.
 - B. Cells flexuous, - - - - -
 - (3) Cells enclosed in a sheath. CHLAMYDOBACTERIACEAE MIGULA.
 - A. Cell contents without granules of sulphur.
 - a. Cell threads unbranched.
 - 1). Cells division always only in one plane, - - - - - 13. *Streptothrix* COHN.
 - 2). Cell division in three planes previous to the formation of conidia.
 - i). Cells surrounded by very delicate scarcely visible sheath (marine), - - - - - 14. *Phragmidiothrix* ENGLER.
 - ii). Sheath clearly visible (fresh water), - - - - - 15. *Crenothrix* COHN.
 - 16. *Cladothrix* COHN.
 - b. Cell threads branched, - - - - - 17. *Thiothrix* WINOGRADSKY.
 - B. Cell contents containing sulphur granules.
 - (4) Cells destitute of a sheath, united into threads motile by means of an undulating membrane. BEGGIATOACEAE.
 - Only one genus. (The single species is scarcely separable from *Oscillaria*) - 18. *Beggiatoa* TRAVISAN.

FIGURE 6.2

CHESTER'S CLASSIFICATION OF BACTERIA, 1901

Bacterium

- I. Without endospores.
 - A. Aerobic and facultative anaerobic.
 - a. Gelatin not liquefied.
 - * Decolorized by Gram's method.
 - † Obligate aerobic. ACETIC FERMENT GROUP.
 - †† Aerobic and facultative anaerobic.
 - Gas generated in glucose bouillon.
 - Gas generated in lactose bouillon. BACT. AEROGENES GROUP.
 - Little or no gas generated in lactose bouillon. FRIEDLANDER GROUP.
 - No gas generated in glucose bouillon.
 - Milk coagulated. FOWL CHOLERA GROUP.
 - Milk not coagulated. SWINE PLAGUE GROUP.
 - ** Stained by Gram's method.
 - † Gas generated in glucose bouillon. LACTIC FERMENT GROUP.
 - b. Gelatin liquefied.
 - * Colonies on gelatin ameboid or proteus-like. BACT. RADIATUM GROUP.
 - ** Colonies on gelatin round, not ameboid. BACT. AMBIGUUM GROUP.
- II. Produce endospores.
 - 1. No growth at room temperature, or below 22°-25° C. THERMOPHILLIC GROUP.
 - 2. Grow at room temperatures.
 - a. Gelatin liquefied. ANTHRAX GROUP.
 - b. Gelatin not liquefied. BACT. FÆCALIS GROUP.

FIGURE 6.3

WINSLOW AND ROGER'S CLASSIFICATION OF THE COCCACEAE, 1908

Winslows' Classification of the Coccaceae (1908)

Cells spherical. Family *Coccaceae*

- I. Parasites. Growth not abundant (or one species, zooglea-forming saprophytes growth abundant in saccharose media). Generally gram+. Acid formers.....Subfamily *Paracoccaceae*
 - A. Cells in capsulated pairs. Parasites. Growth very meagre. Inulin fermented. No pigment.
 - Diplococcus* (Weichselbaum) Winslow and Rogers
 - B. Cells in chains occurring in masses of zoogloea in sugar refineries. Aberrant saprophytic forms. Growth abundant in saccharose media. No pigment.....*Ascococcus* (Cohn) Winslow and Rogers
 - C. Cells in chains. Parasites. Growth meagre. Inulin not fermented. No pigment.....*Streptococcus* (Billroth)
 - D. Cells in irregular groups.....*Staphylococcus*
 - 1. Parasites. Growth fair. Orange pigment.
 - Aurococcus* Winslow and Rogers
 - 2. Parasites. Growth good. White pigment.
 - Albococcus* Winslow and Rogers
- II. Saprophytes. Growth abundant. No zoogloea. Gram—generally. Not acid formers.....Subfamily *Metacoccaceae*
 - A. Cells in irregular groups. Pigment generally yellow.
 - Micrococcus* (Hallier, Cohn), Winslow & Rogers
 - B. Cells in packets. Pigment yellow.
 - Sarcina* (Goodsir) Winslow and Rogers
 - C. Cells in irregular groups or packets, pigment red.
 - Rhodococcus* Winslow and Rogers

FIGURE 6.4

THE CCCBT'S ARTIFICIAL KEY TO THE FAMILIES OF THE *EUBACTERIALES*, 1917

- Cells spiral with polar flagella.....IV. SPIRILLACEAE
- Not as above
 - Cells spherical; rarely, if ever, motile; spores never produced; never securing growth energy from nitrogen or ammonia.....V. COCCACEAE
- Not as above
 - Cells short rod-shaped with a single rarely two polar flagellum; usually forming green or yellow pigment.....III. PSEUDOMONADACEAE
 - Not wholly as above
 - Spores formed.....VIII. BACILLACEAE
 - Spores never formed
 - Metabolism simple, securing growth energy from carbon, hydrogen, or their simple compounds; flagella, if present, polar
 - I. NITROBACTERIACEAE
 - Metabolism complex, dependent upon more complex carbohydrate and protein substances; flagella, if present, peritrichic
 - Cells clubbed, fusiform, filamentous, branching or mycelial; those not distinctly so are either acid-fast or show barred irregular staining.....II. MYCOBACTERIACEAE
 - Not as above
 - Gram-positive; non-motile.....VII. LACTOBACILLACEAE
 - Gram-negative; often motile.....VI. BACTERIACEAE

FIGURE 6.5

THE CCCBT'S ORDERS, FAMILIES AND GENERA OF THE *EUBACTERIALES*, 1917

- A. Order. *Myxobacteriales*.
- B. Order. *Thiobacteriales*.
- C. Order. *Chlamydobacteriales*.
- D. Order. *Eubacteriales*.
 - I. Family. *Nitrobacteriaceae*.
 - 1. Genus. *Hydrogenomonas*.
 - 2. Genus. *Methanomonas*.
 - 3. Genus. *Carboxydomonas*.
 - 4. Genus. *Mycoderma*.
 - 5. Genus. *Nitrosomonas*.
 - 6. Genus. *Nitrobacter*.
 - 7. Genus. *Azotobacter*.
 - 8. Genus. *Rhizobium*.
 - II. Family. *Mycobacteriaceae*.
 - 1. Genus. *Actinomyces*.
 - 2. Genus. *Nocardia*.
 - 3. Genus. *Mycobacterium*.
 - 4. Genus. *Corynebacterium*.
 - 5. Genus. *Fusiformis*.
 - 6. Genus. *Leptotrichia*.
 - III. Family. *Pseudomonadaceae*.
 - 1. Genus. *Pseudomonas*.
 - IV. Family. *Spirillaceae*.
 - 1. Genus. *Vibrio*.
 - 2. Genus. *Spirillum*.
 - V. Family. *Coccaceae*.
 - a. Tribe. *Streptococceae*.
 - 1. Genus. *Neisseria*.
 - 2. Genus. *Streptococcus*.
 - 3. Genus. *Staphylococcus*.
 - 4. Genus. *Albococcus*.
 - b. Tribe. *Micrococceae*.
 - 1. Genus. *Micrococcus*.
 - 2. Genus. *Sarcina*.
 - 3. Genus. *Rhodococcus*.
 - VI. Family. *Bacteriaceae*.
 - 1. Genus. *Bacterium*.
 - 2. Genus. *Erwinia*.
 - 3. Genus. *Pasteurella*.
 - 4. Genus. *Hemophilus*.
 - VII. Family. *Lactobacillaceae*.
 - 1. Genus. *Lactobacillus*.
 - VIII. Family. *Bacillaceae*.
 - 1. Genus. *Bacillus*.
 - 2. Genus. *Clostridium*.

FIGURE 6.6

KLIGLER'S OUTLINE OF THE RELATIONSHIPS OF BACTERIAL GROUPS, 1917

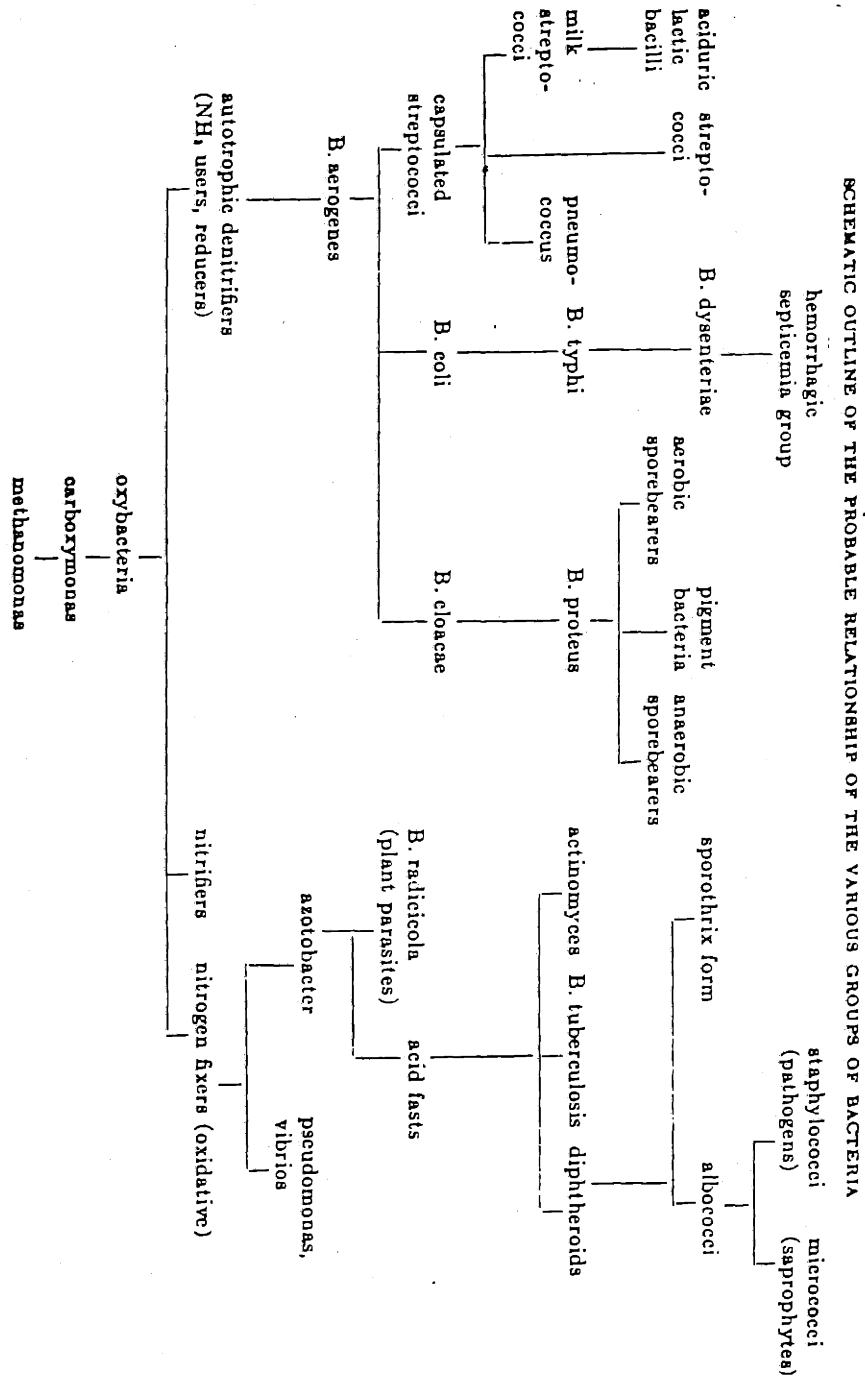


FIGURE 6.7

BUCHANAN'S OUTLINE OF PHYLOGENETIC RELATIONSHIP
AMONG BACTERIA, 1918

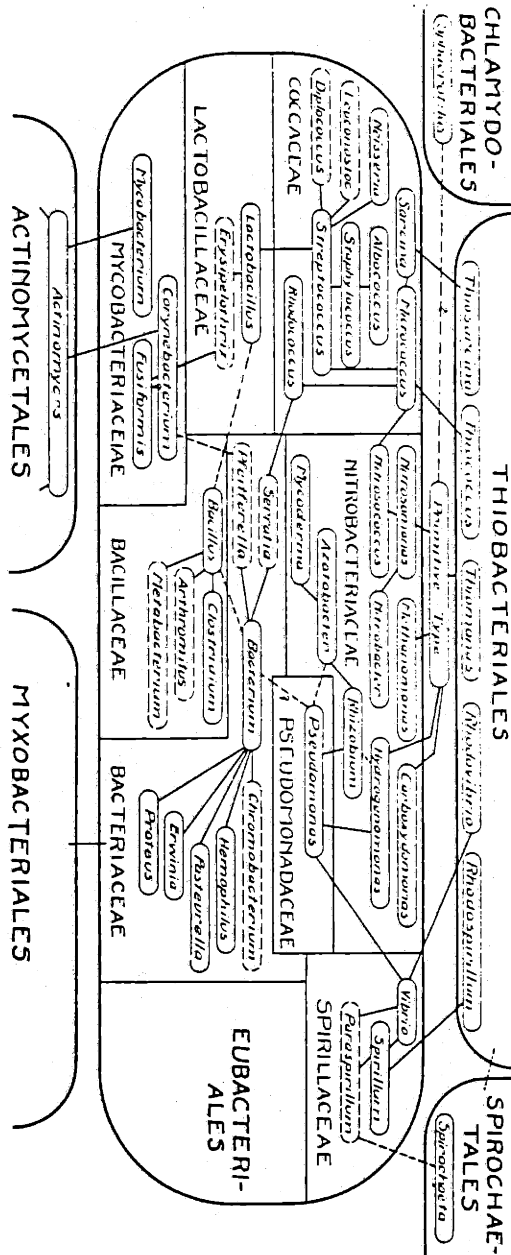


FIG. 3. SUGGESTED INTERRELATIONSHIP OF THE GENERA, FAMILIES AND ORDERS OF BACTERIA.

FIGURE 6.8

BUCHANAN'S KEY TO THE ORDERS OF THE CLASS *SCHIZOMYCETES*, 1917

- A. Plant-like in the principal characters, not protozoan like, cells never slender, flexuous spirals; cell divisions never longitudinal.
 - I. Not producing a pseudoplasmodium during the vegetative stage; without a highly developed, cyst-producing, resting stage.
 - a. Containing neither granules of free sulphur, nor bacteriopurpurin, nor requiring the presence of hydrogen sulphid for the best development.
 - 1. Not typically producing filaments as a regular growth form, though chains of cells may be developed. Conidia not developed, spores when formed are endospores.
 - Order I. *Eubacteriales*
 - 2. Typically producing true filaments as a regular growth form. Conidia may be developed, but never endospores.
 - (a) Alga-like, typically water forms. Filaments never showing true branching; false branching may be present. A sheath usually evident, and usually impregnated with iron.
 - Order II. *Chlamydo bacteriales*
 - (b) Mold like, not typically water forms, not with the sheath impregnated with iron. True branching often evident.
 - Order III. *Actinomycetales*
 - b. Cells typically containing either granules of free sulphur or bacteriopurpurin or both, usually growing best in the presence of hydrogen sulphid.
 - Order IV. *Thiobacteriales*
 - II. Cells united during the vegetative stage into a pseudoplasmodium which passes over into a highly developed, cyst-producing, resting stage. Order V. *Myxobacteriales*
 - B. Protozoan-like in many characters. Cells usually relatively slender flexuous spirals; multiplication of cells apparently by longitudinal division in some types, by transverse division in others, or both.
 - Order VI. *Spirochaetales*

Key to the families of the Eubacteriales

- A. Organisms usually growing more or less readily upon organic media, not securing growth energy primarily by the oxidation of ammonia or nitrites.
 - I. Cells typically spherical. . . Family I. *Coccaceae*
 - II. Cells not spherical, elongate.
 - a. Cells not spiral. . . . Family II. *Bacteriaceae*
 - b. Cells spiral, or at least curved.
 - Family III. *Spirillaceae*
- B. Not growing readily or at all on media containing considerable amounts of organic material; nitrifying bacteria, securing growth energy primarily by the oxidation of ammonia or nitrites.
 - Cells may be either spherical or rod-shaped.
 - Family IV. *Nitrobacteriaceae*

FIGURE 6.9

THE CCCBT'S FINAL KEY TO THE CLASS SCHIZOMYCETES, 1920

CLASS SCHIZOMYCETES			
ORDER	FAMILY	TRIBE	GENUS
Myxobacteriales Thiobacteriales Chlamydobacteriales	Actinomycetaceae.....		{ Actinobacillus Leptotrichia Actinomyces Erysipelothrix
		Mycobacteriaceae.....	{ Mycobacterium Corynebacterium Fusiformis Pfeifferella
Actinomycetales.....	Nitrobacteriaceae.....	Nitrobactereae.....	{ Hydrogenomonas Methanomonas Carboxydomonas Acetobacter Nitrosomonas Nitrobacter
		Azotobactereae.....	{ Azotobacter Rhizobium
	Pseudomonadaceae.....		Pseudomonas
	Spirillaceae.....		{ Vibrio Spirillum Neisseria
	Coccaceae.....	Neissereae.....	{ Diplococcus Leuconostoc Streptococcus Staphylococcus
		Streptococcaeae.....	{ Micrococcus Sarcina Rhodococcus
Eubacteriales.....	Bacteriaceae.....	Micrococcaeae.....	{ Erythrobacillus Chromobacterium
		Chromobactereae.....	Erwinia
		Erwineae.....	Zopfius
		Zopfeae.....	{ Proteus Bacterium
		Bactereae.....	Lactobacillus
		Lactobacilleae.....	Pasteurella
		Pasteurelleae.....	Hemophilus
		Hemophilaeae.....	{ Bacillus Clostridium
	Bacillaceae.....		

FIGURE 6.10

MACY'S KEY TO THE SCHIZOMYCETES, 1921

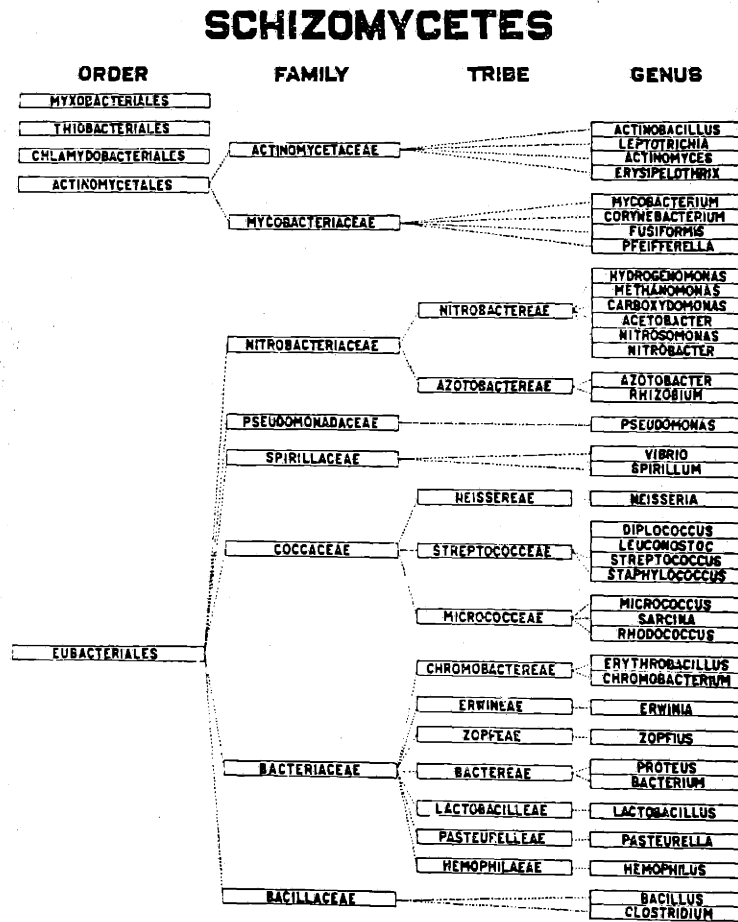


FIGURE 6.11

BERGEY'S MANUAL'S KEY TO THE ORDERS, FAMILIES, TRIBES AND GENERA OF THE CLASS SCHIZOMYCETES, 1923

- Key to the Tribes and Genera of the Family Nitrobacteraceae*
1. Organisms oxidize simple compounds of carbon and nitrogen.
 - Nitrobacteraceae*
 - a. Cells capable of securing growth energy by the oxidation of hydrogen to form water. *Hydrogenomonas*
 - b. Cells oxidize methane to form CO₂ and water. *Methanomonas*
 - c. Cells oxidize CO to form CO₂. *Carboxydomonas*
 - d. Cells oxidize ammonia to form nitrites. *Nitrosomonas*
 - e. Cells oxidize nitrites to nitrates. *Nitrobacter*
 - f. Cells oxidize alcohol to form acetic acid. *Acetobacter*
 - g. Cells oxidize compounds of sulphur. *Thiobacillus*
 2. Organisms capable of fixing free nitrogen of the air.
 - Azotobacteraceae*
 - a. Cells capable of fixing free atmospheric nitrogen when growing in solutions of carbohydrates. *Azotobacter*
 - b. Cells capable of fixing free nitrogen when growing symbiotically on the roots of Leguminosae. *Rhizobium*

- Key to the Tribes of the Family Coccaceae*
- I. Strict parasites, failing to grow or growing very poorly on usual artificial media. Cells normally in pairs, occasionally in tetrads. *Neisseria*
 - II. Parasites (except *Leuconostoc*) growing best in media containing serum. Occur in pairs or chains. *Streptococcus*
 - III. Facultative parasites or saprophytes. Cell aggregates of groups, packets or zoogeal masses. Growth abundant. *Micrococcus*

- Key to the Genera of the Tribe Neisseriae*
- One genus only: *Neisseria*.
- Key to the Genera of Tribe Streptococci*
1. Parasites growing poorly, or not at all, on artificial media. Cells usually in pairs. *Diplococcus*
 2. Saprophytes, usually growing in cane sugar solutions. Cells in pairs or chains. *Leuconostoc*
 3. Chiefly parasites. Normally forming short or long chains, sometimes pairs, but never packets. *Streptococcus*
 4. Parasites. Cells in groups or short chains, rarely in packets. *Staphylococcus*

- Key to Genera of Tribe Micrococci*
1. Facultative parasites or saprophytes. Cells in plates or irregular masses (never in long chains or in packets). *Micrococcus*
 2. Cell division occurs in three planes forming packets. *Sarcina*
 3. Saprophytes. Cells in groups or packets. Form red pigment on agar. *Rhodococcus*

- Key to the Genera of Family Spirillaceae*
1. Cells short, bent rods, rigid, single or united into spirals. *Vibrio*
 2. Cells rigid, of various thickness and length and pitch of the spiral, forming either long curves or portions of a turn. *Spirillum*

- Key to the Tribes of Family Bacteriaceae*
1. Produce pigment on solid media. The pigment may be red, yellow, violet green or blue. *Chromobacteriaceae*
 2. Without pigment formation on agar or gelatin. *Achromobacteriaceae*
 3. Cellulose digesting organisms occurring in soil. *Cellulomonadaceae*
 4. Plant pathogens, growth usually whitish. *Erysipelotrichaceae*
 5. Gram-positive rods, growing freely on artificial media. Do not attack carbohydrates. *Zoopaceae*
 6. Gram-negative rods growing freely on artificial media. Generally act on carbohydrates with formation of acid and gas.
 - a. Without capsules. *Bacterene*
 - b. Encapsulated. *Encapsulantes*
 8. Rods often long and slender. Gram-positive. Non-motile. Usually produce lactic acid from carbohydrates. *Lactobacillaceae*
 9. Anaerobic, non-spore-forming rods. *Bacteroidaceae*
 10. Gram-negative rods, showing bipolar staining. Parasitic forms. *Pasteurellaceae*
 11. Minute parasitic forms growing only (or best) in the presence of hemoglobin, casein fluid or other body fluids. *Hemophilaceae*

- Key to the Genera of Tribe Chromobacteriae*
1. Small, aerobic rods, producing a red or pink pigment on agar or gelatin. *Serratia*
 2. Small, aerobic rods, producing a yellow pigment on gelatin or agar. *Flavobacterium*
 3. Small, aerobic rods, producing a violet pigment on solid media. *Chromobacterium*
 4. Small, aerobic rods, producing a green or blue-green pigment. *Pseudomonas*

- Key to the Genera of the Tribe Achromobacteriae*
- One genus only: *Achromobacter*.
- Key to the Genera of the Tribe Cellulomonadaceae*
- One genus only: *Cellulomonas*.

- Key to Genera of Tribe Erysipelae*
1. Motile rods.
 - a. Flagella peritrichous. *Erysipia*
 2. Rods motile or non-motile. Motile forms possess polar flagella. *Phytomonas*

- Key to the Genera of the Tribe Zoopaceae*
- One genus only: *Zoopus*.

- Key to the Genera of Tribe Bacterene*
- A. Ferment dextrose with production of acid or acid and gas.
 1. Gas formed from dextrose.
 - a. Gas formed from lactose.
 - b. Acetyl-methyl-carbinol not formed from dextrose. *Escherichia*
 - bb. Acetyl-methyl-carbinol formed. *Aerobacter*
 - aa. Gas not formed from lactose.
 - b. Gas formed from sucrose. *Proteus*
 - bb. Gas not formed from sucrose. *Salmoneilla*
 2. Gas not formed from dextrose.
 - a. Acid formed from dextrose. *Eberthella*
 - AA. Do not form acid or gas from any of the carbohydrates. *Alcaligenes*

- Key to the Genera of the Tribe Encapsulantes*
- One genus only: *Encapsulans*.

- Key to the Genera of the Tribe Lactococillae*
- One genus only: *Lactobacillus*.

- Key to the Genera of the Tribe Bacteroidae*
- One genus only: *Bacteroides*.

- Key to the Genera of the Tribe Pasteurellae*
- One genus only: *Pasteurella*.

- Key to Genera of Tribe Hemophilae*
1. Aerobic species. *Hemophilus*
 2. Anaerobic species. *Drahtler*

- Key to the Genera of Family Bacillaceae*
- A. Aerobic forms, mostly saprophytes. *Bacillus*
 - B. Anaerobic forms. Often parasitic. *Clostridium*

- Key to the Families of the Order Actinomycetales*
- A. Filamentous forms, often branched, sometimes forming mycelia. Conidia sometimes present. Some species parasitic. *Actinomycetaceae*
 - B. Parasitic forms. Rod-shaped, rarely filamentous, and with only slight and occasional branching. No conidia. *Mycobacteriaceae*

- Key to the Genera of Family Actinomycetaceae*
- A. Parasitic forms.
 - a. Aerobic. *Actinobacillus*
 - b. Anaerobic or facultative. *Leptotrichia*
 - B. A few parasitic forms; mostly soil forms.
 - a. Filamentous, often branched, sometimes forming mycelia. *Actinomyces*
 - b. Rods forming long filaments which rarely show branching. *Eryniopelathrix*

- Key to the Genera of Family Mycobacteriaceae*
- A. Slender rods; acid fast. *Mycobacterium*
 - B. Slender, often slightly curved rods; not acid-fast. *Corynebacterium*
 - C. Obligate parasites. Cells frequently fusiform. *Fastiformis*
 - D. Slender, Gram-negative rods. *Pleurocella*

- Key to the Families of the Order Chlamydothricales*
- One family only: *Chlamydothricaceae*.

- Key to the Genera of the Family Chlamydothricaceae*
1. Filaments usually not permanently attached.
 - a. Filaments straight or at least not twisted. *Leptothrix*
 - b. Filaments twisted. *Diplothelex*
 2. Filaments attached.
 - a. Filaments unbranched. *Crenothrix*
 - b. Filaments show pseudodichotomous branching.
 1. Swarm cells developed (motile conidia). Usually without a deposit of iron in the sheath. *Sphaerotilus*
 2. Spherical, non-motile conidia. Usually with iron oxide. *Clonothrix*

Key to the Families of the Tribe Thiobacteriales

The keys to the subgroups and genera of this order are the same in general as those of Buchana (1917-18) q.v.

- Key to the Families of the Order Myxobacteriales*
- One family only: *Myxobacteriaceae*.

- Key to the Genera of Family Myxobacteriaceae*
- I. Rods transformed into coccus-like spores when encysted, sessile or stalked masses of coccus-like spores. *Myxococcus*
 - II. Cells not transformed into coccus-like spores when encysted.
 - A. Rods forming large, rounded cysts, one or more within a gelatinous matrix raised above the substratum. *Polyosporum*
 - B. Rods forming cysts in which they remain unmodified. Cysts various, sessile or borne on a more or less highly developed cystophore. *Chlamydomyces*

- Key to the Families of the Order Spirochaetales*
- One family only: *Spirochaetaceae*.

- Key to the Genera of Family Spirochaetaceae*
- A. Usually saprophytic, free-living in water.
 1. Protoplasm spirally wound around an elastic axis filament. *Spirochaeta*
 2. Cross section circular. *Saprospirra*
 - B. Usually parasitic.
 1. Possessing a "crest" or ridge. Parasitic in mussels. *Cristispira*
 2. Without crest. Parasitic in warm blooded animals and in man. *Spirochaeta*, *Treponema*
 3. Short, sharply twisted spirals. Parasitic in rodents and in man. *Leptospira*

FIGURE 6.12

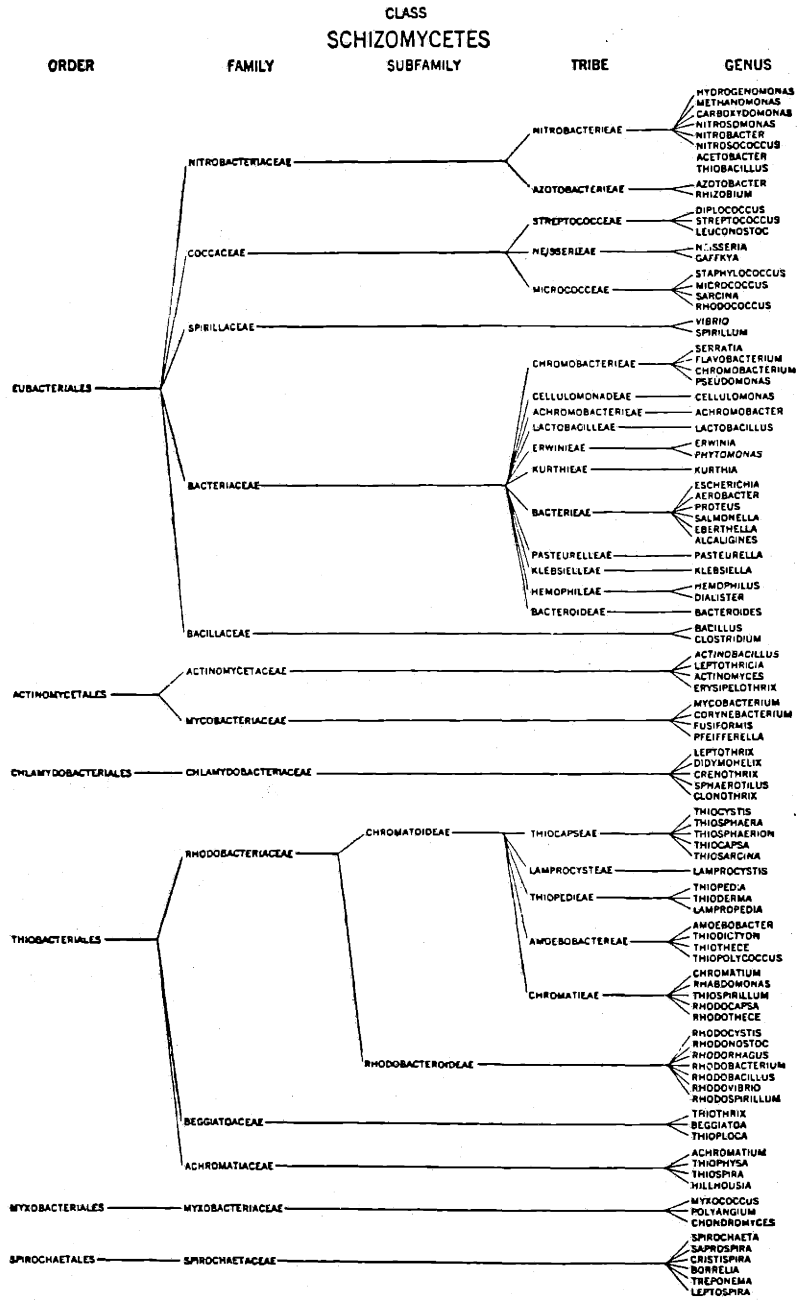
PHILLIPS' LIST OF PATHOGENIC ORGANISMS
AND THEIR NEW DESIGNATIONS. 1925

PATHOGENIC ORGANISM MOST COMMONLY

Familiar Name	Proposed Name
B. typhosus	Eberthella typhi
B. paratyphosus A	Salmonella paratyphi
B. paratyphosus B	Salmonella schotmulleri
B. coli communis	Escheridia coli
B. coli communior	Escheridia communior
B. dysentriae-Shiga	Eberthella dysenteriae
B. para-dysenteriae-Flexner	Eberthella para-dysenteriae Flexner
B. para-dysenteriae-Hiss	Eberthella para-dysenteriae Hiss
B. para-dysenteriae-Strong	Eberthella para-dysenteriae Strong
Staphylococcus albus	Staph. albus Rosenbach
Streptococcus hemol.	Strept. pyogenes Rosenbach Type I
Streptococcus Viridans	Strept. mitior Schotmuller
Pneumococcus	Diploc. pneumoniae (Weichs.)
Meningococcus	Neisseria intracelli. (Weichs.)
Gonococcus	Neisseria gonorrhoeae (Neiss.)
Micr. catarrhalis	Neisseria catarrhalis (Pfeiff.)
B. diphtheriae	Corynebact. diphtheriae (Klebs-Löffler)
B. Influenzae	Hemophilus influenzae (Pfeiffer)
B. muc. capsalatus	Encapsulatus pneumoniae (Friedlander)
B. tuberculosis	Mycobacterium tuberculosis (hominis) (Koch)
B. lactis aerogenes	Aerobacter aerogenes (Escherich)
B. bulgaricus	Lactobacillus bulgaricus (Grigoroff)
B. acidophilus	Lactobacillus acidophilus (Moro)
B. aerog. capculatus	Clostridium welchii (4 types)
B. botulinus	Clostridium botulinum
B. edematis maligni	Clostridium edematis maligni
B. tetanus	Clostridium tetani
B. anthracis	B. anthracis Koch
Treponema pallida	Treponema pallida Schaudinn and Hoffman
B. pyocyaneus	Pseudomonas aeruginosa Migula
Bact. tularense	Pasteurella tularensis
Bact. pneumosintes	Dialister pneumosintes

FIGURE 6.13

BERGEY'S MANUAL'S REVISED KEY TO THE ORDERS, FAMILIES, TRIBES AND GENERA OF THE CLASS SCHIZOMYCETES, 1925



PRIMARY PUBLISHED SOURCES

- "Advance of Sanitary Science." Science 68, supp 10 (13 July 1928).
- "Annual Discussion of the American Society of Naturalists, Ithaca Meeting, December 1897." Science 7 (14 January & 4 February 1898): 37-44, 145-161.
- "The Bacterial Beds of Modern Sanitation." Living Age 7 (April-June 1901): 496.
- "Chemistry in the Field of Microbiology." Science 60, no. supp 10 (10 April 1925).
- "Civilization and the Microbe." Scientific American 130 (March 1924): 172.
- "Creates a New Microbe. Woman Bacteriologists Develops It from Bacillus of Anthrax." New York Times, (7 April 1914): 1.
- "Differentiation of Species by the Bacteriologists." Journal of the American Medical Association 24 (27 April 1895): 342.
- "Friendly Germs." Scientific American 129 (September 1923): 185.
- "The Fourteenth International Congress of Hygiene and Demography." Nature 76 (3 October 1907): 570-2.
- "Germs Inherit Strong or Weak Constitutions." Science Digest 9 (March 1941): 47.
- "The International Botanic Congress at Brussels." Nature 83 (30 June 1910): 534-6.
- "The International Congress on Tuberculosis at Washington." Nature 79 (12 November 1908): 48-50.
- "International Congress on Zoological Nomenclature." Science 32 (1910): 301-3.
- "The International Congress on Tuberculosis." Science 28 (2 October 1908): 438-9.
- "Iron Ores Formed by Bacteria." Scientific American 121 (27 September 1919): 303.
- "Like Humans, Bacteria Have Their Own Periods of Weakness." Scientific American 164 (May 1941): 287.

- "The Ninth International Conference on Tuberculosis." Nature 84 (20 October 1910): 507-9.
- "A Plea for the Microbes." American Analyst: A Popular Semi-Monthly Review Devoted to Industrial Progress, Sanitation, and the Chemistry of Commercial Products 1, no. 23 (1 December 1886): 2.
- "Reality of Disease Germs." World Magazine, (20 June 1920): 11.
- "Review of the *Bergey's Manual of Determinative Bacteriology*." Journal of the American Veterinary Medical Association 64 (1924): 233-4.
- "Sanitation More Than Medicine." Literary Digest 45 (16 November 1911): 899.
- "Symposium on Industrial Fermentations." Ind. Eng. Chem. 22 (1930): 1148-76.
- "Type Basis Code of Botanical Nomenclature." Science 49 (1919): 333-6.
- "Variation Among Pathogenic Bacteria." Journal of the American Medical Association 34 (1900): 562-3.
- Veterinary Medicine as a Career. Chicago: The Institute, 1936.
- "What Microbes Did Ages Ago." Literary Digest 78 (25 August 1923): 24.
- Abbott, Alexander C. "Infection and Immunity: Review." Practitioner 47, no. 6 (1891): 415-29.
- Abbott, Alexander C., and Nathaniel Gildersleeve. "The Etiological Significance of the Acid-resisting Group of Bacteria, and the Evidence in Favor of Their Botanical Relation to *Bacillus Tuberculosis*." University of Pennsylvania Medical Bulletin, June 1902.
- Agramonte, A. "Research Laboratory and the Public Health." American Journal of Public Health 21 (1931): 19-25.
- Albert, Henry. "Typhoid Bacilli Carriers." American Journal of Public Hygiene 19 (1909): 260-7.
- Albrecht, William A. "Soil Inoculation for Legumes." Circular of the Missouri Agricultural Experiment Station, no. 86 (March 1919): 1-15.
- _____. "Symbiotic Nitrogen Fixation as Influenced by the Nitrogen in the Soil." Soil Science 4 (1920): 275-327.
- Albrecht, William A., and Lloyd M. Turk. "Legume Bacteria with Reference to Light and Longevity." Research Bulletin of the University of Missouri Agricultural Experiment Station, no. 132 (1929): 1-19.
- Albsberg, Carl, and National Association Ice Cream Manufacturers. Reports of Experiments Referred to at Hearings on Ice Cream Before Dr. C.L. Alsberg, Chief of the Bureau of Chemistry, United States Department of Agriculture. Chicago: National Association of Ice Cream Manufacturers,

1914.

- Allen, William H. "Sanitation and Social Progress." American Journal of Sociology 8 (1902): 631.
- Allen, E.R., and A. Bonazzi. "On Nitrification: Preliminary Observations." Technical Series, Bulletin of the Ohio Agricultural Experiment Station, no. 7 (April 1915): 1-42.
- Allen, Paul W. The Story of Microbes. Knoxville: The Bookmill Company, 1932.
- Allen, Paul W., D. Frank Holtman, and Louise Allen McBee. Microbes Which Help or Destroy Us. St. Louis: C.V. Mosby Company, 1941.
- Anderson, John F. "The Differentiation of Outbreaks of Typhoid Fever Due to Water, Milk, Flies, and Contact." American Journal of Public Hygiene 19 (1909): 251-9.
- Andrewes, F.W. "Dysentery Bacilli. The Differentiation of the True Dysentery Bacilli from Allied Species." Lancet 1 (1918): 560-.
- American Public Health Association. "Proceedings of the Bacteriological Convention, New York, June 21 and 22, 1895." Public Health, Papers and Reports 20 (1895): 459-516.
- Committee of American Bacteriologists to the Committee on the Pollution of Water Supplies of the American Public Health Association. American Public Health Association, Proceedings. Vol. 23, Procedures Recommended for the Study of Bacteria, with Especial Reference to Uniformity in the Description and Definition of Species. Concord N.H.: Rumford Co., 1897.
- American Public Health Association. "Report of the Committee on Standard Methods of Water Analysis to the Laboratory Section of the American Public Health Association." Journal of Infectious Diseases, no. Supp. 1 (May 1905): 1-141.
- _____. "Report of the Committee on Standard Methods of Water Analysis." American Journal of Public Hygiene 17, no. 4 (November 1907): 365-7.
- _____. "Preliminary Statement by the Committee on Standard Methods of Bacterial Milk Analysis." American Journal of Public Hygiene 17, no. 4 (Nov. 1907): 331-61.
- _____. Standard Methods for the Examination of Dairy Products, Microbiological and Chemical. New York: American Public Health Association, 1910.
- American Public Health Association, Committee on Standard Methods of Water Analysis, American Chemical Society, Association of Official Agricultural Chemists, and American Water Works Association. "Standard Methods for the Examination of Water and Sewage." 2nd-9th editions, Boston, 1912.
- American Public Health Association. "Standard Methods of Bacteriological Analysis of Milk: Provisional Report of the Laboratory Section of the American Public Health Association." American Journal of Public Health 6, no. 12 (1916).

American Public Health Association, American Dairy Science Association, Food, and Environmental Sanitarians International Association of Milk, and Association of Official Agricultural Chemists. Standard Methods of Milk Analysis, Bacteriological and Chemical. 4th ed. Boston, New York: American Public Health Association, 1923.

Arkwright, Joseph A. "Variation in Bacteria in Relation to Agglutination Both by Salt and by Specific Serum." Journal of Pathology and Bacteriology 24 (1921): 36-60.

Arthur, Joseph C. "Physiological Aspects of the Species Problem." American Naturalist 42 (1908): 243-8.

American Society of Naturalists. Science Teaching in the Schools, Report of the Committee of the American Society of Naturalists, 1891. Boston, 1892.

Ayers, S. Henry, and William T. Johnson. "The Bacteriology of Commercially Pasteurized and Raw Market Milk." Bulleting of the U.S. Department of Agriculture, Bureau of Animal Industry, no. 126 (1910): 1-98.

Ayers, S. Henry. "The Pasteurization of Milk." Circular of the Bureau of Animal Industry, USDA, no. 184 (1912).

Ayers, S. Henry, and William T. Johnson. "A Study of the Bacteria Which Survive Pasteurization." Bulletin of the U.S. Department of Agriculture, Bureau of Animal Industry, no. 161 (1913).

_____. "Ability of *Streptococci* to Survive Pasteurization." Journal of Agricultural Research 2, no. 4 (1914): 321-30.

Ayers, S. Henry, and William T. Johnson. "Ability of the Colon Bacilli to Survive Pasteurization." Journal of Agricultural Research 3, no. 5 (1915): 401-11.

Ayers, S. Henry. "The Present Status of the Pasteurization of Milk." Bulletin of the United States Department of Agriculture, no. 342 (Jan. 8 1916): 1-16.

Ayers, S. Henry, Philip Rupp, and William T. Johnson. "A Study of the Alkali-forming Bacteria Found in Milk." Bulletin of the United States Department of Agriculture, no. 782 (June 17 1919).

Bailey, Liberty H., and et al. "Recommendations Regarding the Nomenclature of Systematic Botany." Journal of Botany 33 (1895): 212-6.

Bailey, Liberty H. "The Philosophy of Species Making." Botanical Gazette 22 (1896): 454-62.

_____. "How Plants Live Together." Cornell Nature-Study Quarterly, no. 6 (October 1900): 279-84.

_____. "A Chat with the Reader." Cornell Nature-Study Quarterly, no. 9 (May 1901): 319-24.

_____. "Systematic Works and Evolution." Science 21 (1905): 532-3.

- _____. "Modern Systematist." Science 46 (1917): 623-9.
- Baker, Moses N. Municipal Engineering and Sanitation. New York: Macmillan, 1901.
- Barber, Marshall A. "On Heredity in Certain Microorganisms." Kansas University Science Bulletin 4, no. 1 (March 1907): 1-48.
- Barnum, Wirt T. "Thesis on Bacteriology of the Soil." Michigan State College of Agriculture, B.S., 1896.
- Barthel, Charles. A Review of the Present Problems and Methods of Agricultural Bacteriology. Stockholm: Knut and Alice Wallenberg Foundation, 1923.
- Bartow, E. "Progress in Sanitation." Science 84 (October 9 1936): 317-22.
- Bather, F.A. "Biological Classification: Past and Future." Quarterly Journal of the Geological Society of London 83 (1927): xxii.
- Bayne-Jones, Stanhope. The School of Medicine and Dentistry of the University of Rochester, at Rochester, New York. In Rockefeller Foundation. Division of Medical Education. New York: Rockefeller Foundation, 1927.
- _____. "Reciprocal Effects of the Relationship of Bacteriology and Medicine ." Journal of Bacteriology 21 (1931): 61-73.
- _____. Man and Microbes. In A Century of Progress Series. Baltimore: Williams & Wilkins Company, 1932.
- Beaver, Donald C., W.L. Boyd, and C.P. Fitch. "Bacteriology and Pathology of Sterility in Cattle." Technical Bulletin of the University of Minnesota Agricultural Experiment Station, no. 5 (May 1922).
- Ben Meyr, Berl. The Story of Microbes: Your Germs and Mine. New York: Blue Ribbon Books, 1934.
- Bendixen, Hans A. "A Study of the Streptococci." In M.S. Thesis, Iowa State College. 1920.
- Bergey, David H. "Sanitary Supervision of the Collection and Marketing of Milk." University of Pennsylvania Medical Bulletin 17 (1904): 187-92.
- Bergey, David H., and H.L. Bates. "The Numerical Classification of Bacteria." University of Pennsylvania Medical Bulletin, July 1906.
- Bergey, David H. "Involution and Degeneration Forms of Bacteria." Science 25 (1907): 807-8.
- Bergey, David H., and S.T. Deehan. "The Colon-Aerogenes Group of Bacteria." Journal of Medical Research 19 (1908): 175-.

- Bergey, David H. "Mutations in Microorganisms." Science 35 (1912): 236.
- _____. "The Pedagogics of Bacteriology." Journal of Bacteriology 1 (1916): 5-14.
- _____. "Report of the Committee on Determinative Bacteriology, 24th Annual Meeting of the Society of American Bacteriologists, Dec. 1922." Abstracts of Bacteriology 7 (1923): 2.
- _____. "Difficulties Encountered in the Classification of Bacteria." Abstracts of Bacteriology 7 (1923): 276.
- Bergstrand, H. "On the Nature of Bacteria." Journal of Infectious Disease 27 (1920): 1-22.
- Bessey, Charles E. "The Demands Made by Agriculture Upon the Science of Botany." Society for the Promotion of Agricultural Science, 16-8. 1885.
- _____. "Evolution and Classification." Proceedings of the American Association for the Advancement of Science 42 (1893): 237-51.
- Bessey, Charles E. "A Protest Against the Rochester Rules." American Naturalist 29 (1895): 668-9.
- Bessey, Charles E. "The Bacteriological Analysis of Soils." Science 19 (1904): 769.
- Bessey, Charles E. "The Taxonomic Aspect of the Species Concept." American Naturalist 42 (1908): 218-24.
- Bessey, Charles E. "The Phyletic Idea in Taxonomy." Science 29 (1909): 81-100.
- _____. "Some of the Next Steps in Botanical Science." Science 37 (1913): 1-13.
- Bettman, Henry W. "Diphtheria: Its Bacterial Diagnosis and Treatment with the Antitoxin." Medical News 67 (6 July 1895): 1-5.
- Bigger, Joseph. Man Against Microbe. New York: The Macmillan Company, 1939.
- Biggs, Hermann M. "The Organization, Equipment, and Method of Work of the Division of Pathology, Bacteriology, and Disinfection of the New York City Health Department." Transactions of the New York Academy of Medicine 10 second series (1893): 303-20.
- _____. "The Health of the City of New York." Transactions of the New York Academy of Medicine 12, no. second series (1895): 420-48.
- _____. "Discoveries in Bacteriology." The Independent 49 (October 7 1897): 4-5.
- _____. "Preventive Medicine in the City of New York." British Medical Journal 2 (September 11 1897): 629-38.

- _____. "The Serum-treatment and Its Results." Medical News 85 (July 22 1899): 97-105, 137-143.
- _____. "Preventive Medicine: Its Achievements, Scope, and Possibilities." American Medicine 7 (4 June 1904): 946-50.
- Billings, John Shaw Sr. "Germs and Epidemics." Sanitary Engineer 7 (1883): 389.
- Birge, Edward G. "The Action of Certain Bacteria on the Nitrogenous Material of Sewage." In University of Wisconsin Studies, Science No. 2 In Papers on Bacteriology and Allied Subjects, by Former Students of Harry Luman Russell. Madison: University of Wisconsin, 1921.
- Bisset, K.A. "The Physiological Concept in Bacterial Taxonomy." Symp. Society of General Microbiology 12 (1962): 361-73.
- Bittwing, A.W. "The Application of Bacteriology to Food Production." Abstracts of Bacteriology 6 (1922): 22-3.
- Black, Greene Vardiman. The Formation of Poisons by Microorganisms: A Biological Study of the Germ Theory of Disease. Philadelphia: P. Blakiston, Son & Co., 1884.
- Bolduan, Charles F. "A Guide to Some of the Hygienic Features of New York City." New York Department of Health Monograph Series, no. 6 (1912): 1-66.
- _____. "Typhoid Fever in New York City, Together with a Discussion of the Methods Found Serviceable in Studying Its Occurrence." New York Department of Health Monograph Series, no. 3 (1912): 1-52.
- _____. "Bacteriology and Your Health: Serums and Vaccines in the Diagnosis, Treatment and Prevention of Disease." Scientific American, June 14 1913, 540-541, 549-550.
- _____. "Over a Century of Health Administration in New York City." New York Department of Health Monograph Series, no. 13 (1916): 1-39.
- Bolton, B. Meade. "Theory of Serum Therapy: Contribution from the Bacteriologic Laboratory of the City of Philadelphia." Journal of the American Medical Association 27 (1896): 26-7.
- Breazeale, James F. "Fundamental Concepts in Plant Research." Bulletin of the Arizona Agricultural Experiment Station, no. 147 (June 1934): 59-84.
- Breed, Robert S. "Cells in Milk Derived from the Udder." Bulletin of the New York Agricultural Experiment Station, no. 380 (March 1914): 139-200.
- Breed, Robert S., and James D. Brew. "The Control of Bacteria in Market Milk by Direct Microscopic Examination." Bulletin of the New York Agricultural Experiment Station, no. 443 (1917): 717-46.
- Breed, Robert S. "Bacteriological Methods for Market Milk Analysis." Journal of Dairy Science 1

- (1917): 380-2.
- _____. "Popular Science." Science 46 (1917): 238-9.
- Breed, Robert S., Harold J. Conn, and J.C. Baker. "Comments on the Evolution and Classification of Bacteria." Journal of Bacteriology 3 (1918): 455-9.
- Breed, Robert S. "Questions Concerning the Control of a City Milk Supply Answered." Bull. of the New York Agricultural Experiment Station, no. 456 (December 1918): 1-10.
- Breed, Robert S., and Harold J. Conn. "The Nomenclature of the *Actinomyetaceae*." Journal of Bacteriology 4 (1919): 584-602.
- Breed, Robert S. "Comments Upon the Present Standard Methods of Milk Examination." Abstracts of Bacteriology 6 (1922): 33.
- _____. "The Milk Problem in Cities." Health News, 84-90. 1922.
- _____. "Some Observations on the Habitat and Distribution of Bacteria." Abstracts of Bacteriology 6 (1922): 11-2.
- _____. "Some Problems in the Nomenclature of Bacteria." Abstracts of Bacteriology 6 (1922): 484-5.
- _____. "Agricultural Bacteriology in Italy, France and England as Seen by a Tourist." Journal of Dairy Science 7 (1924): 205-6.
- _____. "Taxonomic Studies of the Red Chromogenic Rods." Abstracts in Bacteriology 8 (1924): 404.
- Breed, Robert S., and Margaret E. Breed. "The Type Species of the Genus *Serratia*, Commonly Known as *Bacillus Prodigiosus*." Journal of Bacteriology 9 (1924): 545-57.
- Breed, Robert S. "The Terms 'Germs,' 'Bacteria,' and 'Dirt.'" American Speech 1 (1925): 107-10.
- Breed, Robert S., and Margaret E. Breed. "The Red and Pink Chromogenic Bacteria." Abstracts of Bacteriology 9 (1925): 2.
- Breed, Robert S. "International Dairy Congress -- Introduction." Journal of Dairy Science 9 (1926): 542.
- _____. "Standard Methods of Milk Analysis: Bacteriological Methods." American Journal of Public Health 16 (1926): 811-8.
- _____. "The Present Status of Systematic Bacteriology." Journal of Bacteriology 15 (1928): 143-63.
- _____. "Report: The Work of the Nomenclature Committee of the International Society for Microbiology." Journal of Bacteriology 23 (1932): 13-4.
- _____. "Problems in Nomenclature and Classification Now Before the International Committee on

- Bacteriological Nomenclature." Journal of Bacteriology 30 (1935): 329.
- _____. "Report on Proposals Relative to the Conservation of *Bacillus* as a Bacterial Generic Name, Fixing of the Type Species and of the Type or Standard Culture." Zentr. Bakt. Parasiten. Abt. II 92 (1935): 481-90.
- _____. "The Status of the Generic Term *Bacterium* Ehrenberg 1828." Journal of Bacteriology 3 (1936): 517-8.
- _____. "The Systematic Relationship of the Red Chromogenic Bacteria." Journal of Bacteriology 32 (1936): 355-60.
- Brew, James D. "A Comparison of the Microscopical Method and the Plate Method of Counting Bacteria in Milk." Bulletin of the New York Agricultural Experiment Station, no. 373 (1914).
- _____. "Milk Quality as Determined by Present Dairy Score Cards." Bulletin of the New York Agricultural Experiment Station, no. 398 (March 1915): 107-32.
- Brew, James D., and William D. Dotterrer. "The Number of Bacteria in Milk." Bulletin of the New York State Agricultural Experiment Station, no. 439 (1917): 477-522.
- Brigham, George D., and Leo F. Rettger. "A Systematic Study of the *Pasteurella* Genus and Certain Closely Related Organisms." Journal of Infectious Diseases 56 (1935): 225-37.
- Briley, James H. "Thesis on Soil Bacteria." B.S. thesis, Michigan State College of Agriculture, 1896.
- Britton, Nathaniel L. "Nomenclature at the Vienna International Botanical Congress." Science 32 (1905): 217-9.
- Broadhurst, Jean. "A Biometrical Study of Milk *Streptococci*." Science 35 (1912): 223-4.
- _____. "Constancy in the Fermentative Activity of *Streptococci*." Science 39 (1914): 789.
- _____. "Environmental Studies of *Streptococci*." Journal of Infectious Diseases 17 (1915): 227.
- _____. "Some Induced Changes in *Streptococci*." Science 41 (1915): 618.
- _____. How We Resist Disease: An Introduction to Immunity. Philadelphia: Lippincott, 1923.
- _____. "Peeps with Pepys at Hygiene and Medicine." Ann. Med. Hist. 10 (1928): 165-72.
- _____. "Friendly Microbes That Flavor Food." Ladies Home Journal 46 (June 1929): 85.
- Broadhurst, Jean, Y. Moriyama, and D. Pease. "Conjunction of Dissexual Forms in *Ascobacillus*: Preliminary Report." Journal of Bacteriology 21 (1931): 305-10.
- Broadhurst, Jean. "Observations on Amorphous Phases of Bacteria." Journal of Bacteriology 25 (1933):

545-63.

- Brown, Percy E. "Methods for the Bacteriological Examination of Soils, and Media for the Quantitative Determination of Bacteria in Soils." Research Bulletin of the Iowa Agricultural Experiment Station, no. 11 (1913): 382-407.
- _____. "Bacteriological Studies of Field Soils, III. The Effects of Barnyard Manure." Centl. f. Bakt., 1te Abt. 39 (1913): 532-42.
- _____. "Bacteria and Soil Fertility." Circular, Iowa Agricultural Experiment Station, no. 7 (April 1913): 3-16.
- Brown, Herbert R., and Theobald Smith. "Notes on Two 'Atoxic' Strains of Diphtheria Bacilli." Journal of Medical Research 30 (1914): 443-54.
- Brown, Percy E. "The Solution Versus the Soil Method for the Bacteriological Examination of Soils." Science 42 (Sept. 3 1915): 316.
- _____. "Bacterial Activities and Crop Production." Research Bulletin of the Iowa Agricultural Experiment Station, no. 25 (1915): 360-88.
- _____. "Soil Inoculation." Circular, Iowa Agricultural Experiment Station, no. 43 (March 1918): 1-7.
- _____. "The Teaching of Soil Bacteriology." American Society of Agronomy 13 (1921): 323-9.
- Brown, Percy E., and L.W. Erdman. "Inoculation of Legumes." Circular of the Iowa Agricultural Experiment Station, no. 102 (March 1927): 1-7.
- Brown, J. Howard. "The Biological Approach to Bacteriology." Journal of Bacteriology 23 (1932): 1-10.
- Burke, V. "Bacteria as Food for Vertebrates." Science 78 (September 1 1933): 194-5.
- Bryan, Benjamin. Kochism: Experiment, not Discovery. London: victoria Street Society, 1890.
- Buchan, Samuel A. "Bacteria of the Soil and Their Bearing on Soil Fertility." B.S. thesis, Virginia Polytechnic Institute, 1919.
- Buchanan, Robert E. "The Bacterioids of *Bacillus Radicicola*." Centr. f. Bakt. 23, no. 2te (1909): 59-91.
- Buchanan, Robert E., and B.W. Hammer. "Slimy and Ropy Milk." Science 42 (Sept. 3 1915): 320.
- Buchanan, Robert E. "Nomenclature of the *Coccaceae*." Journal of Infectious Diseases 17 (Nov. 1915): 528-541; reprint 1-5.
- _____. "Studies in the Nomenclature and Classification of Bacteria: The Problem of Bacterial Nomenclature." Journal of Bacteriology 1 (1916): 82-83; 591-596.

- _____. "Studies in the Nomenclature and Classification of the Bacteria. II. The Primary Subdivisions of the *Schizomycetes*." Journal of Bacteriology 2 (1917): 155-64.
- _____. "Studies in the Nomenclature and Classification of the Bacteria. III. The Families of the *Eubacteriales*." Journal of Bacteriology 2 (1917): 347-50.
- _____. "Studies in the Nomenclature and Classification of the Bacteria. IV. The Groups and Genera of the *Coccaceae*." Journal of Bacteriology 2 (1917): 603-17.
- _____. "The Evolution of Bacteria." Science 47 (1918): 320-4.
- _____. "Studies in the Nomenclature and Classification of the Bacteria. V. Subgroups and Genera of the *Bacteriaceae*." Journal of Bacteriology 3 (1918): 27-61.
- _____. "Studies in the Nomenclature and Classification of Bacteria. VI. Subdivisions and Genera of the *Spirillaceae*, and *Nitrobacteriaceae*." Journal of Bacteriology 3 (1918): 175-81.
- _____. "Studies in the Classification and Nomenclature. IX. The Subgroups and Genera of *Thiobacteriales*." Journal of Bacteriology 3 (1918): 461-74.
- _____. "Studies in the Classification and Nomenclature of the Bacteria. X. Subgroups and Genera of the *Myxobacteriales* and *Spirocheatales*." Journal of Bacteriology 3 (1918): 541-.
- _____. "Bacterial Phylogeny as Indicated by Modern Types." American Naturalist 52 (Apr.-May 1918): 233-46.
- _____. "Studies in the Nomenclature and Classification of the Bacteria. VIII. The Subgroups and Genera of the *Actinomycetales*." Journal of Bacteriology 3 (1918): 403-.
- _____. "Studies in the Classification and Nomenclature of the Bacteria. VII. The Subgroups and Genera of the *Chlamydothales*." Journal of Bacteriology 3 (1918): 301-6.
- _____. "Some Possible Additions to the Genera of Bacteria Recognized by the Committee." Abstracts of Bacteriology 2 (1918): 8-9.
- Buchanan, Robert E., Robert S. Breed, and Leo F. Rettger. "A Report of the Committee on Taxonomy. A Diagrammatic Summary of Various Bacterial Classification." Journal of Bacteriology 16 (1928): 387-96.
- Buchanan, Robert E. "Rules of Nomenclature Annotated: With Suggestions for Rules of Bacteriological Nomenclature." In Third International Congress for Microbiology, New York, September 2-9, 1939, edited by Henry M. Dawson. Baltimore: Waverly Press, 1939.
- Buchanan, Robert E., R. St. John-Brooks, and Robert Breed. "International Bacteriological Code of Nomenclature." Journal of Bacteriology 55 (1948): 287-306.
- Buckley, John S. "Activities of the Bureau of Animal Industry Laboratories in Washington." Journal of

American Veterinary Medical Association 59 (May 1921): 234-40.

Bunker, John W.M. "Studies of the Diphtheria Bacillus in Culture." Journal of Bacteriology 4 (1919): 379-408.

Burkett, Charles W. How to Teach Agriculture. Rev. ed. New York: Ginn and Co., 1914.

Burkholder, Walter H. "The Taxonomy and Nomenclature of the Phytopathogenic Bacteria." Phytopath. 29 (1939): 126-36.

Burrill, T.J. "Micro-organisms of Soil and Human Welfare." Science 20 (September 30 1904).

Cain, A.J. "Deductive and Inductive Methods in Post-Linnaean Taxonomy." Proc. Linn. Society, London 170 (1959): 234.

Cain, A.J., and G.A. Harrison. "Phylogenetic Weighting." Proc. Zoological Society of London 135 (1960): 1-.

Calmette, A., A. Boquet, and L. Negre. Manuel Technique de Microbiologie et Serology. 3rd. Paris: Masson & Co., 1933.

Cameron, F.K. "The Soil as an Economic Factor." Popular Science Monthly 60 (1902): 539.

Chapin, Charles V. Municipal Sanitation in the United States. Providence: Snow & Farnham, 1901.

_____. "The Fetich of Disinfection." Journal of the American Medical Association 47 (August 25 1906): 574-80.

_____. The Sources and Modes of Infection. Second edition revised and enlarged. New York: John Wiley & Sons, Inc, 1912.

_____. "The Evolution of Preventive Medicine." Journal of the American Medical Association 86 (January 22 1921): 215-22.

_____. "Changes in Type of Contagious Disease." Journal of Preventive Medicine 1 (1926): 7-35. In The Fourth William Thompson Sedgwick Memorial Lecture.

_____. A Review of Public Health Realities: The Papers of Charles V. Chapin. Edited by Clarence L. Scamman. New York: The Commonwealth Fund, 1934.

Chen, Chen Chong, and Leo F. Rettger. "A Correlation Study of the Colon-Aerogenes Group of Bacteria, with Special Reference to the Organisms Occurring in the Soil." Journal of Bacteriology 5 (1920): 253-.

Chester, Frederick D. "A Preliminary Arrangement of the Species of the Genus Bacterium." 9th Annual Report of the Delaware College Agricultural Experiment Station (Newark). , 1897.

- _____. "Classification of the *Schizomycetes*." 9th Annual Report, Delaware College of Agriculture Experiment Station, 62-3. 1897.
- _____. "Soil Bacteria in Their Relation to Agriculture, Part I." Bulletin of the Delaware Agriculture Experiment Station, no. 40 (1898): 3-16.
- _____. "Some Suggestions on the Study of Systematic Bacteriology." Science 11 (March 23 1900): 460-1.
- _____. "Bacteria of the Soil in Their Relation to Agriculture." Bulletin of the Delaware College Agricultural Experiment Station, no. 98 (1902): 5-82.
- _____. "Observations of an Important Group of Soil Bacteria; Organisms Related to *Bacillus Subtilis*." In Fifteenth Annual Report of the Delaware College Agricultural Experiment Station, 1903, 42-89. Newark, Del.: Delaware College Agricultural Experiment Station, 1903.
- _____. "A Review of the *Bacillus Subtilis* Group of Bacteria." Centralblatt f. Bakteriol., 2 te Abt. 8 (1904): 739.
- _____. "The Bacteriological Analysis of Soils." Bulletin of the Delaware Agricultural Experiment Station, no. 65 (1904): 51-76.
- _____. "Soil Bacteria and Nitrogen Assimilation." Bulletin of the Delaware College Agricultural Experiment Station 66 (1904): 3-17.
- _____. "Observations on an Important Group of Soil Bacteria." In Fifteenth Annual Report of the Delaware College Agricultural Experiment Station for 1903, 1904.
- _____. "Principles of Classification of Bacteria: Report of the Philadelphia Meeting of Dec. 27-8, 1904 of the Society of American Bacteriologists." Science 23 (1905): 485-6.
- Clark, William M. "Penfold's Modification of *Bacilli Coli Communis*." Science 38 (1913): 669-72.
- Clark, Paul F. "Morphological Changes During the Growth of Bacteria." Abstracts of Bacteriology 3 (1919): 2.
- Clark, Paul F., and W.H. Ruehl. "Morphological Changes During the Growth of Bacteria." Journal of Bacteriology 4 (1919): 615-29.
- Clark, William M. "Evolution Toward a Mature Scientific Literature." Journal of Bacteriology 27 (1934): 1-27.
- Clark, Paul F. Alice in Virusland. Presidential address delivered before the Society of American Bacteriologists, 14th Annual Meeting, San Francisco, August 31, 1938. Madison: Society of American Bacteriologists, 1938.
- _____. Annotated Bibliography of Paul F. Clark, 1969. Madison: University of Wisconsin, 1969.

- Clarke, H.F. "The Principles of Microbial Classification: Methods for Determining the Biochemical Activities of Microorganisms as Applied to Classification." Journal of General Microbiology 12 (1955): 337-.
- Claypole, Edith J. "On the Classification of the *Streptothrices*, Particularly in Their Relation to Bacteria." Journal of Experimental Medicine 17 (1913): 99-116.
- Clinton, G.P. "Botany in Relation to Agriculture." Science 43 (1916): 1-13.
- Cockerell, T.P.A. "Transformation of Bacteria." Science 80 (1934): 134-40.
- Cole, Leon J., and William H. Wright. "Applications of the Pure-Line Concept to Bacteria." Journal of Infectious Diseases 19 (1916): 209-21.
- Conn, Herbert W. Evolution of To-Day: A Summary of the Theory of Evolution as Held by Scientists at the Present Time, and an Account of the Progress Made by the Discussions and Investigations of a Quarter Century. New York, London: Putnam's Sons, 1886.
- _____. "The Limits of Organic Evolution." American Naturalist 20 (1886): 413-22.
- _____. "Scientific Fact and Scientific Inference." American Naturalist 21 (1887): 791-9.
- _____. "Bacteriology in Our Medical Schools." Science 11 (March 16 1888): 123-6.
- _____. "The Germ Theory as a Subject of Education." Science 11 (January 6 1888): 5-6.
- _____. "The Significance of 'Variety' and 'Species'" Science 11 (1888): 253-4.
- _____. "Germ Diseases." New Princeton Review 5 (1888): 141-4.
- _____. "The Bacteria of Milk." Report of the Conn. Board of Agriculture, 28-43. 1890.
- _____. The Living World: Whence It Came and Whither It is Drifting, a Review of the Speculations Concerning the Origin and Significance of Life and of the Facts Known in Regard to Its Development, with Suggestions as to the Direction in Which the Development is Now Tending. New York, London: G.P. Putnam's Sons, 1891.
- _____. "Some Uses of Bacteria." Connecticut Agricultural Report, 25th Annual Report, 1891., 1-24, 92-191. 1891.
- _____. "The Fermentations of Milk." Experimental Station Bulletin, no. 9 (1892).
- _____. "Bacteria in Our Dairy Products." Popular Science Monthly 40 (1892): 763-74.
- _____. "Some Uses of Bacteria." Science 19 (1892): 258-63.
- _____. "Review of H.L. Russell's *Outline of Dairy Bacteriology.*" Science 1 (1895): 189.

- _____. The Story of Germ Life. In The Library of Useful Stories. New York: D. Appleton and Company, 1897.
- _____. "Is There a Solution to the Nitrogen Problem?" In Pennsylvania Department of Agriculture, 4th Annual Report. 717-734, 1898.
- _____. "Classification of Dairy Bacteria." Storrs Agricultural Experiment Station, Annual Report. , 13-68. 1899.
- _____. The Story of Life's Mechanism: A Review of the Conclusions of Modern Biology in Regard to the Mechanism Which Controls the Phenomena of Living Activity. In The Library of Useful Stories. London: Hodder and Stoughton, 1899.
- _____. The Story of the Living Machine: A Review of the Conclusions of Modern Biology in Regard to the Mechanism Which Controls the Phenomena of Living Activity. London: Newnes, 1899.
- _____. The Method of Evolution. New York: G.P. Putnam's Sons, 1900.
- _____. "Natural Varieties of Bacteria." Science 11 (March 23 1900a): 455-45.
- Conn, Herbert W., and William M. Esten. "The Comparative Growth of Different Species of Bacteria in Normal Milk." 14th Annual Report of the Storrs Agricultural Experiment Station. , 13-76. 1901.
- Conn, Herbert W. "How Can Bacteria Be Satisfactorily Preserved for Museum Specimens?" Science 13 (March 1 1901): 326.
- Conn, Herbert W., and F.W. Headley. "Other Expositions of Organic Selection and Orthoplasmy." In Development and Evolution, Including Psychophysical Evolution, Evolution by Orthoplasmy and the Theory of Genetic Modes, edited by James M. Baldwin. New York: Macmillan Co., 1902.
- Conn, Herbert W. "The Relation of Bovine Tuberculosis to That of Man and Its Significance in the Dairy Herd." Bull. Storrs Agricultural Experiment Station, no. 23 (April 1902).
- _____. Bacteria, Yeasts, and Molds in the Home. Boston: Athenaeum Press, 1903.
- Conn, Herbert W., and William M. Esten. "The Effect of Different Temperatures in Determining the Species of Bacteria Which Grown in Milk." Storrs Agricultural Experiment Station, 16th Annual Report, 1904. , 27-88. 1904.
- Conn, Herbert W. "Bacteriology: Contagious Diseases." Chautauquan 40 (1904): 158-64.
- Conn, Herbert W., William M. Esten, and William A. Stocking. "Classification of Dairy Bacteria." Annual Report, Storrs Agricultural Experiment Station. , 91-203. 1906.
- Conn, Herbert W. "Bacteria in Cheesemaking." Scientific American, Supplement 63 (1907): 26322-3.
- Conn, Harold J. "Future Methods of Soil Bacteriological Investigations." Centl. f. Bakt. 2 abt. 25

- (1909): 454.
- Conn, Herbert W. "Courses in Bacteriology for Home Economics." Journal of Home Economics 2 (1910): 627-30.
- Conn, Harold J. "A Classification of the Bacteria in Two Soil Plots of Unequal Productivity." Bulletin of the New York (Cornell) Agricultural Experiment Station 338 (1913): 65-115.
- Conn, Herbert W. Social Heredity and Social Evolution: The Other Side of Eugenics. New York: Abingdon Press, 1914.
- _____. "Standards for Determining the Purity of Milk." U.S. Public Health Service, Public Health Reports 30 (1915): 2349-95.
- _____. "Standard Methods of Bacteriological Analysis of Milk." Science 42 (1915): 318.
- Conn, Herbert J. "A Study of *B. Subtilis* by Means of the Classification Card." Science 41 (1915): 618.
- Conn, Harold J. "Relative Importance of Fungi and Bacteria in Soil." Science 44 (1916): 857-8.
- _____. "The Proof of the Microbial Agency in the Chemical Transformation of Soil." Science 46 (1917): 252-5.
- _____. "Soil Flora Studies. II. Methods Best Adapted to the Study of the Soil Bacteria." Bulletin New York Agricultural Experiment Station, Geneva 57 (1917): 19-42.
- Conn, Harold J., H.A. Harding, I.J. Klinger, William D. Frost, M.J. Prucha, and K.N. Atkins. "Methods of Pure Culture Study (Preliminary Report of the Committee on the Chart for Identification of a Bacterial Species)." Journal of Bacteriology 3 (1918): 115-27.
- _____. "Methods of Pure Culture Study. Progress Report for 1918 of the Committee on the Description Chart of the Society of American Bacteriologists." Journal of Bacteriology 4 (1919): 104-32.
- _____. "Report on the Committee on the Descriptive Chart for 1919." Journal of Bacteriology 5 (1920): 127-143, 315-319.
- Conn, Harold J. "Standardized Nomenclatures of Biological Stains." Science 57 (1923).
- _____. "Recent Work on the Descriptive Chart and the Manual of Methods." Journal of Bacteriology 10 (1925): 315-9.
- _____. "Studies on the General Soil Flora." Journal of Bacteriology 13 (1926): 51-2.
- _____. "Bacterial Dissociation." Pure Culture Study of Bacteria 1 (1933): 21-4.
- _____. "Taxonomy in Relation to Pure Culture Study." Pure Culture Study of Bacteria 1 (1933): 13-6.

- Copeland, H.F. The Classification of Lower Organisms. Palo Alto: Pacific Books, 1956.
- _____. "Progress Report on Basic Classification." American Naturalist 81 (1947): 340.
- Coulter, John M. "Public Interest in Medicine." Popular Science Monthly 62 (August 1905): 306-8.
- Councilman, William T. "Recent Progress in Pathology and Bacteriology." Boston M. & S.J. 128 (1893): 188-92.
- Cowan, Sam T. "Classification of *Staphylococci* by Precipitin and Biological Reactions." Journal of Pathology and Bacteriology 46 (1938): 31-45.
- _____. "The Philosophy of Classification." Journal of General Microbiology 12 (1955): 314-.
- _____. "The Microbial Species -- a Macromyth?" Symp. Society for General Microbiology 12 (1962): 433-55.
- Cowart, Roland. "Colon Characters as a Factor in Determining Species." In M.S. Thesis, Mississippi Agricultural and Mechanical College. 1921.
- Cummings, George D. "An Analysis of Public Health Training in the United States and Canada with a Statement of Present Needs." B.S. Thesis, Department of Biology and Public Health, 1926. , 66 p. 1926.
- Curran, H.R., Lore A. Rogers, and E.O. Whittier. "The Distinguishing Characteristics of *Lactobacillus Acidophilus*." Journal of Bacteriology 25 (1933): 595-621.
- Dack, Gail M. "Microbiologists in Transition." Bacteriological Reviews 17 (1953): 249-52.
- Davenport, Charles B. "Statistical Study of Biological Problems." Popular Science Monthly 59 (1901): 447.
- _____. "De Vries' Species and Varieties." American Naturalist 39 (1905): 747-51.
- _____. "Review of Species and Varieties, Their Origin by Mutation." Science 22 (1905): 369-72.
- Davis, Nelson F. "Variations of *Bacillus Rosaceous Metalloides* (Dowdeswell)." Science 13 (1901): 324.
- Dawson, Andrew I. "Bacterial Variations Induced by Changes in the Composition Culture Media." Journal of Bacteriology 4 (1919): 133-48.
- De Kruif, Paul. "Before You Drink a Glass of Milk; Alice C. Evan's Research on Bacteria of Contagious Abortion and Undulant Fever." Ladies Home Journal 46 (September 1929): 8-9.
- De Schweinitz, Emil Alexander, and Marion Dorset. The Serum Treatment of Swine Plague and Hog Cholera. Washington: GPO, 1899.

- De Schweinitz, E.A. "Tuberculin and its Use." Journal of the American Medical Association 34 (1900): 899.
- Dean, Edna E. "The Group of Acetic Acid Bacteria." In Masters Thesis, Iowa State College of Agriculture and Mechanical Arts, 1-136. 1921.
- DeKruif, P.H. "Dissociation of Microbic Species, I. Coexistence of Individuals of Different Degrees of Virulence in Cultures of Bacillus of Rabbit Septicemia." Journal of Experimental Medicine 33 (1921): 773-89.
- _____. "Virulence and Mutation of the Bacillus of Rabbit Septicemia." Journal of Experimental Medicine 35 (1922): 621-33.
- Dinwiddie, Robert R., and J.F. Stanford. "Studies on the Bacteriology of Infectious Swine Diseases." Technical Bulletin of the Arkansas Agricultural Experiment Station, no. 105 (1910).
- Dochez, A.R., and Louis J.A. Gillespie. "A Biological Classification by Means of Immunity Reactions." Journal of the American Medical Association 61 (1913): 727-30.
- Dorset, Marion. "Variety of the Hog Cholera Bacillus Which Closely Resembles *Bacillus Typhosus*." Science 15 (1902): 370.
- _____. "Experiments Concerning Tuberculosis." Bulletin of the Bureau of Animal Industry, no. 52 (1904).
- Dotterer, William D., and Robert S. Breed. "The Pasteurization of Dairy By-products." Bull. of New York Agricultural Experiment Station, no. 412 (December 1915): 581-610.
- Dougherty, E.C. "Neologisms Needed for Structure of Primitive Organisms. I. Types of Nuclei." Journal of Protozoology 4, no. suppl. (1957): 14-.
- Downing, Elliot R. Science in the Service of Health. New York: Longmans, Green, 1930.
- Dowson, W.J. "On the Systematic Position and Generic Names of the Gram Negative Bacterial Plant Pathogens." Zentralblatt Bact. II/Abt. 100, no. 9/13 (1939): 177-93.
- Drechsler, Charles. "Morphology of the Genus *Actinomyces*. II. Taxonomy of Species." Botanical Gaz. 67 (1919): 147-68.
- Dublin, Louis I. "The Biologist's Bias." American Journal of Public Health 13 (1923): 853-4.
- Dyar, Harrison G. "On Certain Bacteria from the Air of New York City." Annals of the New York Academy of Sciences 8, no. article 12 (1895): 322-80.
- Earle, Franklin S. "The Necessity for Reform in the Nomenclature of the Fungi." Science 19 (1904): 508-10.

- Eberson, Frederick. The Microbe's Challenge. Lancaster: The Jaques Cattell Press, 1941.
- Edwards, C.L. "Biometry as a Method in Taxonomy." American Naturalist 452 (1908): 537-40.
- Elliott, L.B. "Representative American Laboratories, I: Cornell University." Journal of Applied Microscopy 1 (1898): 22-32.
- Elliott, S. Maria. "Dust as Related to Food." Reading-Course for Farmers' Wives, no. 18 (December 1905): 635-56.
- Elwood, M.K. "Power from Bacteria: Pulp Mill Waste Supplies Gas for Power, Swamp Bacteria Do the Work ." Scientific American 158 (April 1938): 208-9.
- Emerson, Paul. "Tests of an 'All Crops' Soil Inoculum." Bulletin of the Maryland Agricultural Experiment Station, no. 214 (March 1918): 127-49.
- _____. "Soil Inoculation with *Azotobacter*." Research Bulletin of the Iowa Agricultural Experiment Station, no. 45 (1918): 27-64.
- _____. "A Chemical Classification of the Activities of Soil Micro-organisms." Iowa Academy of Science, Proceedings 29 (1922): 355-9.
- Emerson, Haven. Public Health Diagnosis. In The Sixth Sedgwick Memorial Lecture. Chicago: none listed, 1927.
- Enlows, Ella M.A. "The Generic Names of Bacteria." Bulletin of the Hygienic Laboratory, no. 121 (September 1920).
- Erdman, L.W., and Percy E. Brown. "The Inoculation of Non-legumes." Bulletin of the Iowa Agricultural Experiment Station, no. 262 (June 1929): 319-39.
- Ernst, Harold C. "Some of the Recent Advances in Bacteriology." Boston Medical & Surgical Journal 126 (1892): 543.
- Ernst, Charold Clarence. "The Etiology of Diphtheria and the Use of Antitoxin." Boston Medical and Surgical Journal 133 (1895): 228.
- Ernst, Harold C. "Instruction in Bacteriology in the Medical Schools of America and Europe." Journal of the Boston Society of Medical Sciences 4, no. 4 (January 10 1900): 67-71.
- _____. "The Progress in Medicine." Boston Medical and Surgical Journal 143 (1900): 135.
- _____. "Some Fermentations in Medical Education." Boston Medical and Surgical Journal 150 (1904): 661-7.
- Ernst, Harold Clarence. "The Department of Bacteriology." In The Harvard Medical School, 1782-1906: 150th Anniversary of the Medical School, 133. 1906.

- Esten, William M. "Lactic Acid Bacteria." Science 23 (1906): 210-1.
- Esten, William M., and Chirstie J. Mason. "Sources of Bacteria in Milk." Bulletin of the Storrs Agricultural Experiment Station, no. 51 (1908): 65-109.
- Esten, William H. "*Bacterium Lactis Acidi* and Its Sources." Bull. Storrs Agricultural Experiment Station, no. 59 (August 1909): 1-26.
- Esten, William M., and Christie J. Mason. "Bacteriological Studies." Bull. Storrs Agricultural Experiment Station, no. 83 (September 1915): 104-35.
- Evans, Alice C. "The Bacteria of Milk Freshly Drawn from Normal Udders." Journal of Infectious Diseases 18 (1916): 437-76.
- _____. "Life Cycles in Bacteria." Journal of Bacteriology 17 (1929): 63-77.
- Farlow, W.G. "Concept of Species as Affected by Recent Investigations of Fungi." American Naturalist 32 (1898): 375-96.
- _____. "The Change from the Old to the New Botany in the United States." Science 37 (1913): 80-6.
- Ferguson, Meade. "Soil Inoculation with Artificial Cultures." Bulletin of the Virginia Agricultural Experiment Station, no. 159 (January 1906): 83-96.
- Fitz, Reginald. "The Four Years' Course at the Harvard Medical School." Boston Medical and Surgical Journal 126 (1892): 600.
- Flexner, Simon. "The Bacteriology and Pathology of Diphtheria." Johns Hopkins Hospital Bulletin, no. 48 (March 1895).
- _____. "An Aspect of Modern Pathology." Science n.s. 18 (July 3 1903): 3-15.
- Ford, William W. "Classification of Intestinal Bacteria: Preliminary Note." Journal of Medical Research 6, no. 1 (1901): 211-9.
- _____. "Classification and Distribution of the Intestinal Bacteria in Man." Studies from the Royal Victoria Hospital, Montreal 1 (1903): 487-.
- _____. "Aerobic Spore-bearing Non-pathogenic Bacteria. Classification." Journal of Bacteriology 1 (1916): 273-; 493-; 527-.
- Frandsen, Peter P. "Nature and Causes of Infectious Diseases." University of Nevada Bulletin 7 (1913): 1-15.
- Frankland, Percy. Our Secret Friends and Foes. In The Romance of Science Series. 1st ed. London: Society for Promoting Christian Knowledge and E. & J.B. Young, 1893.

Frankland, Mrs. Percy. Bacteria in Daily Life. London, New York, Bombay: Longmans, Green, & Co., 1903.

Fred, E.B. "The Infection of Root-hairs by Means of *Bacillus Radicicola*." In Annual Report of the Virginia Polytechnic Institute Agricultural Experiment Station for 1909 and 1910, 123-37. Lynchburg, V.A.: J.P. Bell Company, 1911.

_____. "A Physiological Study of the Legume Bacteria." In Annual Report of the Virginia Polytechnic Institute Agricultural Experiment Station for 1911 and 1912, 145-73. Lynchburg, V.A.: J.P. Bell Company, 1913.

Fred, Edwin B. "The Effect of Phosphates and Sulphates on Soil Bacteria." Science 42 (Sept. 3 1915): 317-8.

_____. "Review of S.A. Waksman's Principles of Soil Microbiology." Ecology 9 (1928): 94-6.

_____. "On the Stability of Physiological Characters of Bacteria." Proc. National Academy of Sciences 18 (1932): 455-60.

Frizzell, Donald Leslie. Terminology of Types. Notre Dame, Ind.: The University Press, 1933.

Frost, William Dodge. "The Antagonism Exhibited by Certain Saprophytic Bacteria Against the *Bacillus Typhosus*." Journal of Infectious Diseases, Nov. 5 1904, 599-640.

_____. "Our Short Course for Janitors; and Bacteriological Tests of Methods of Cleaning." National Education Association of the United States, Journal of Proceedings and Addresses, 985-92. 1911.

Frost, W.D., and M.V O'Shea. The Great White Plague: Simple Lessons on Causes and Prevention, Intended Especially for Use in Schools. Madison, WI: Democrat Printing Company, State Printer, 1912.

Frost, William D. "Comparison of a Rapid Method of Counting Bacteria in Milk with the Standard Plate Method." Journal of Infectious Diseases 19 (1916): 273-87.

_____. "Counting the Living Bacteria in Milk -- a Practical Test." Journal of Bacteriology 2 (1917): 567-83.

_____. "Improved Technique for the Micro or Little Plate Method of Counting Bacteria in Milk." Journal of Infectious Diseases 28 (1921): 176-84.

_____. "The Detection of Pasteurized Milk." In University of Wisconsin Studies, Science No. 2. In Papers on Bacteriology and Allied Subjects, by Former Students of Harry Luman Russell. Madison: University of Wisconsin, 1921.

Frost, William Dodge, and Hazel Hankinson, comp. Lactobacillus Acidophilus, an Annotated Bibliography to 1931. Milton, Wisc.: Davis-Greene Corporation, 1931.

- Fuchs, F.W. "Microbiology of Coal." Science 89 (April 28 1939): 389-90.
- Fuller, George W., and George A. Johnson. "The Classification of Water Bacteria." Journal of Experimental Medicine 4 (1899): 609-26.
- Fuller, George W. "The Influence of Sanitary Engineering on Public Health." American Journal of Public Health 12 (1922): 16-23.
- Gage, Simon DeM., and Earl B. Phelps. "On the Classification and Identification of Bacteria with a Description of the Card System in Use at the Lawrence Experiment Station for Records of Species." American Public Health Association, Proceedings 1902 28 (1903): 494-505.
- Gage, Stephen DeM. "A Study of the Variation in the Biochemical Reactions Produced by Cultures of the Colon Type." Science 25 (1907): 807.
- Gage, Stephen M. "Apparatus and Expedients in the Bacteriological Laboratory." Technology Quarterly 21 (December 1908): 508-21.
- Gager, C. Stuart. "De Vries and His Critics." Science 25 (1906): 81-9.
- Galloway, Beverly T. "The Twentieth Century Botany." Science 19 (Jan. 1 1904): 11-8.
- Gay, Frederick P. "A Method of Correlated Teaching of Pathology and Bacteriology in the Second Year of Medical Instruction." Johns Hopkins Hospital Bulletin 23 (1912): 170-3.
- _____. "The Contribution of Medical Science to Medical Art as Shown in the Study of Typhoid Fever." Science n.s. 44 (July 28 1916): 109-24.
- _____. "Specialization and Research in the Medical Sciences." Science 45 (1917): 25-34.
- _____. Typhoid Fever Considered as a Problem of Scientific Medicine. In Semicentennial Publications of the University of California, 1868-1818. New York: Macmillan, 1918.
- _____. "Germany and Immunology." Journal of the American Medical Association 73 (1919): 781-2.
- _____. "Whose Business in the Public Health?" Science 54 (1921): 159-62.
- _____. "Research in the Medical Sciences." Science 57, no. 1474 (March 30 1923): 365-8.
- _____. "The Medical Sciences." Science 64 (1926): 511-3.
- Geddings, H.D. "Report of Official Experiments with the Koch Lymph in Progress." Abstract of Sanitary Reports 6 (1891).
- _____. "Research Work in the Hygienic Laboratory of the Public Health and Marine Hospital Service." Journal of the American Medical Association 42 (1904): 1686-7.

- Genung, Elizabeth F. "Some Problems in Teaching Bacteriology." Abstracts of Bacteriology 8 (1924): 1-2.
- Gibbs, W.M. "The Isolation and Study of Nitrifying Bacteria." Soil Science 8 (1919): 427-81.
- Gilmore, J.S.L. "Taxonomy and Philsophy." In The New Systematics, 461-90. Oxford: Clarendon Press, 1941.
- Giltner, Ward. "The American Veterinary Medical Association and Infectious Abortion in Cattle." Journal of the American Veterinary Medical Association 64 (1923): 469-74.
- _____. "The A.V.M.A. and Infectious Abortion of Cattle." Journal of American Veterinary Medicine 64 (1924): 469-74.
- _____. "Some Suggestions for Financing and Promoting Veterinary Education in America." Journal of the American Veterinary Medical Association 67 (1925): 8-15.
- Glaser, R.W. "Biological Studies on Intracellular Bacteria, No. 1." Biological Bulletin, Boston 39 (1920): 132-45.
- Goldwater, S.S. "Public Health and Sanitation." Proceedings of the Academy of Political Science 5 (April 1915): 17.
- Goodman, Herbert M. "Variability in the Diphtheria Groups of Bacilli." Journal of Infectious Diseases 5 (1908): 421-.
- Gorgas, W.C. "Sanitation and Morality." Constructive Quarterly 4 (1916): 320.
- Gorham, Frederic P. "The Morphology of *Bacillus Diphtheriae*." Science 15 (1902): 370-1.
- Gorham, F.P., and C.-E.A. Winslow. "Report of the Committee on the Identification of Bacterial Species, 1909." Science 31 (April 8 1910): 546.
- Gorham, F.P. "Some Biochemical Problems in Bactericology." Science 35 (1912): 357-62.
- Gowda, R. Nagan. "Nitrification and the Nitrifying Organism." Journal of Bacteriology 9 (1924): 251-72.
- Gradle, H. "The Germ-theory of Disease." Popular Science Monthly 23 (1883): 579.
- Greaves, Joseph E. "Some Factors Influencing Ammonification and Nitrification in Soils, I. Influence of Arsenic." Centl. f. Bakt., 1te abt. 39 (1913): 542-60.
- _____. "Azofication." Soil Science 6 (1918): 163-217.
- Greaves, Joseph E., and Ethelyn O. Greaves. Elementary Bacteriology. Vol. 3rd. ed., general; textbook. Philadelphia: W.B. Saunders, 1936.

- Grinnell, Alton G. "Our Army Versus a Bacillus." National Geographic Magazine, October 1913, 1146-52.
- Guyer, Michael F., M.A. Chrysler, and G.H. Parker. "The American Society of Naturalists Symposium on the Scope of Biological Teaching in the Relation to New Feilds of Discovery." Science 39 (March 13 1914): 371-84.
- Hagan, W.A. "Planning for the Future in Veterinary Medicine." Journal of the American Veterinary Medical Association 88 (1936): 503-13.
- _____. "Veterinary Education -- Its Evolution and Present Status." Journal of the American Veterinary Medical Association 118 (1951): 287-92.
- Haggard, Howard W. "The Laboratory." In Doctor in History. New Haven: Yale University Press, 1934.
- Hall, Ivan C. "Differentiation and Indentification of the Sporulating Anaerobes." Journal of Infectious Diseases 30 (1922): 445-504.
- _____. "A Differential Key for the Identification of the Sporulating Anaerobes." Abstracts of Bacteriology 6 (1922): 8.
- _____. "Some Fallaciaous Tendencies in Bacteriologic Taxonomy." Journal of Bacteriology 8 (1926): 245-53.
- Hallman, E.T. "Veterinary Education and Research." Journal of the American Veterinary Medical Association 70 (1926): 9-15.
- Halsted, Byron D. "Botany as It May Be Taught." Popular Science Monthly 33 (July 1888): 369-72.
- Hammer, Bernard W., and R.H. His. "Studies on the Numbers of Bacteria in Milk Showing Various Changes." Research Bulletin of the Iowa Stat College of Agriculture and Mechanic Arts, no. 29 (1916): 35-61.
- Harding, H.A., and M.J. Prucha. "Variations in the Gas Production by Bacteria Producing Soft Rot in Vegetables." Science 23 (1906): 214.
- _____. "The Utility of the Society's Card in Classify'ng the Cheese Flora." Science 29 (June 25 1909): 1012.
- _____. "The Bacterial Flora of Cheddar Cheese." Technical Bulletin, New York Agricultural Experiment Station, Geneva, no. 8 (December 1909): 121-93.
- Harding, Harry Alexis. "The Constancy of Certain Physiological Characters in the Classification of Bacteria." Technical Bulletin of the New York Agricultural Experiment Station, no. 13 (June 1910).
- Harding, H.A., and W.J. Morse. "The Society Card as a Basis for Classifying the Bacteria Producing Soft

- Rot in Vegetables." Science 31 (1910): 551.
- Harding, H.A. "Does the Group Number on the Society Card Carry the Classification Far Enough to Break up the Species?" Science 31 (1910): 551.
- _____. "What is the Value of Quantitative Bacteriological Determinations in the Control of City Milk Supply?" Science 33 (April 7 1911): 542.
- Harding, Harry A., and James D. Brew. "The Financial Stimulus in City Milk Production." Bull. of New York Agricultural Experiment Station, no. 363 (April 1913): 165-78.
- Harding, H.A., G.L. Ruehle, J.K. Wilson, and Smith G.A. "The Effect of Certain Dairy Operations Upon the Germ Content of Milk." Bulletin of the New York (Geneva) Agricultural Experiment Station, no. 365 (1913): 198-233.
- Harding, H.A., and J.K. Wilson. "A Study of the Udder Flora of Cows." Technical Bulletin of the New York (Geneva) Agricultural Experiment Station, no. 27 (1913).
- Harding, H.A. "The Classification Card and the Type of Study Which It Merits." Science 39 (May 29 1914): 798.
- _____. "Present Practicability of Federal Standards for Milk Handling." Creamery 4 (May 1916): 19-23.
- _____. "Bacterial Count as an Index of Cleanliness in Milk." Abstracts in Bacteriology 1 (1917): 53-4.
- Harding, H.A., Robert S. Breed, E.S. Hastings, and W.A. Stocking. "What is Meant by "Quality" in Milk?" Journal of Dairy Science 1 (1917): 199-217.
- Harding, H.A. "The Development of City Milk Supply Problems." In University of Wisconsin Studies, Science No. 2 In Papers on Bacteriology and Allied Subjects, 29-54. Madison: University of Wisconsin, 1921.
- Harris, Norman MacL. "Our Society -- In Retrospect and Prospect." Journal of Bacteriology 11 (1926): 153-64.
- Harrison, F.C. "Our Society." Journal of Bacteriology 7 (1922): 149-57.
- Hastings, E.G. "A Preliminary Note on a Group of Lactic Acid Bacteria not Previously Described in America." Science 28 (1908): 656.
- Hastings, E.G., Alice C. Evans, and E.B. Hart. "Studies on the Factors Concerned in the Ripening of Cheddar Cheese." Research Bulletin, University of Wisconsin Agricultural Experiment Station, no. 25 (1913): 1-54.
- Hastings, E.G. "Review of the Fourth Edition of the Standard Methods of Milk Analysis." Journal of Dairy Science 7 (1924): 210-1.

- _____. "Some Questions of Method in Bacteriology." Journal of Bacteriology 9 (1924): 95-110.
- Hayes, F.M. "Education and Research in Veterinary Medicine." Journal of the American Veterinary Medical Association 67 (1925): 773-9.
- Hefferan, Mary. "An Unusual Bacterial Grouping." Science 15 (1902): 375.
- _____. A Comparative and Experimental Study of Bacilli Producing Red Pigment. Jena: G. Fisher, 1904.
- Heinemann, Paul G. "The Variability of Two Strains of *Streptococcus Lacticus*." Journal of Infectious Diseases 16 (March 1915): 221-39.
- Heinemann, P.G. "Relation of the Number of *Streptococcus Lacticus* to the Amount of Acid Formed in Milk and Cream." Journal of Infectious Diseases 16 (March 1915): 285-91.
- _____. "Orla-Jensen's Classification of Lactic Acid Bacteria." Journal of Dairy Science 3 (1920): 143-55.
- Heinemann, Paul G. "Friendly Bacteria." Hygeia 17 (September 1939): 792-4.
- Hektoen, Ludvig, and E.B. Perry. "Scarlet Fever." Hygeia 2 (1924): 179-80.
- Hektoen, Ludvig. "Measles." Hygeia 2 (1924): 321-3.
- Hektoen, Ludvig, and B.R. Lovett. "Whooping Cough." Hygeia 3 (1925): 129-30.
- Hektoen, Ludvig. "Advances in the Study of *Streptococci*." Journal of Bacteriology 19 (1930): 57-72.
- Heller, Hilda Hempl. "Suggestions Concerning a Rational Basis for the Classification of the Anaerobic Bacteria." Journal of Bacteriology 6 (1921): 521-53.
- Heller, Hilda H. "Certain Genera of the Clostridiaceae." Journal of Bacteriology 7 (1922): 1-21.
- _____. "Classification of the Anaerobic Bacteria." Botanical Gazette 73 (1922).
- Hendrick, Ives. "Conquering Scarlet Fever." The World's Work. 30, 1925May.
- Henrici, Arthur T. "Specificity of *Streptococci*." Journal of Infectious Diseases 19 (1916): 572-625.
- _____. "A Statistical Study of the Form and Growth of a Spore-bearing Bacillus." Abstracts of Bacteriology 6 (1922): 8-9.
- _____. "On Cytomorphosis in Bacteria." Abstracts of Bacteriology 9 (1925): 3.
- _____. Morphologic Variation and the Rate of Growth of Bacteria. In Microbiology Monographs: General, Agricultural, Industrial... Baltimore: C.C. Thomas, 1928.

- Hess, A.F. "The Incidence of Tubercle Bacilli in New York City Milk." Journal of the American Medical Association, March 27 1909, 1011.
- Heuser, Paul D. "Soil Fertility and Microorganisms." In B.S. Thesis, Virginia Polytechnic Institute. 1916.
- Hilgard, E.W. "Methods of Physical and Chemical Soil Analysis." Circular of the California Agricultural Experiment Station, no. 6 (June 1903): 1-23.
- _____. "Soil Management, Discussion and Correspondence." Science 20 (November 4 1904): 605-8.
- Hill, Hibbert Winslow. "Branching Forms of *Bacillus Diphtheria*: Preliminary Note from the Laboratory of the Boston Board of Health." Boston Society of Medical Sciences 3 (Jan. 17 1899): 86-92.
- Hill, Hibbert W. "Branching in Bacteria, with Special Reference to *B. Diphtheriae*." Science 15 (1902): 369.
- Hill, Herbert W., and Frances H. Slack. "Bacterial Counts of Boston's Milk Supply." American Journal of Public Hygiene 14, no. 4 (1904): 236-48.
- Hill, Hibbert W. "Introductory Remarks on Morphology of Bacteria." Science 21 (March 31 1905): 489.
- Hill, Herbert W. "Chairman's Address: The Laboratory Section of the American Public Health Association." American Journal of Public Hygiene 17 (November 1907): 323-30.
- Hill, Hibbert W. "The Epidemiological Diagnosis and Treatment of Typhoid Outbreaks." American Journal of Public Hygiene 19 (1909): 289.
- _____. "Bacteriology as an Important Non-technical Study." Science 29 (June 25 1909): 1013.
- _____. "Non-relation of Natural Ice to Typhoid Fever and Dysentery, an Address." The Natural Ice Association, 1910.
- _____. The New Public Health. New York: Macmillan, 1918.
- _____. "What is the Matter with Public Health? Discussion." American Journal of Public Health 10 (1920): 673-.
- Hill, L.H. "The Adansonian Classification of the *Streptococci*." Journal of General Microbiology 20 (1959): 277-83.
- Hirschfelder, J.O. The Cure of Tuberculosis by Oxytuberculine, with Experiments on Patients, Animals and Cultures. n.p.: Medical Society of the State of California, 1897.
- Hiss, P.H. "A Contribution to the Physiological Differentiation of *Pneumococcus* and *Streptococcus*, and to Methods of Staining Capsules." Science 15 (1902): 367-8.

- Hiss, Philip Hanson. "Scientific Books." Science n.s. 17 (April 24 1903): 660-5.
- Hiss, Philip H. "On Fermentation and Agglutinative Characters of Bacilli of the Dysentery Group." 8, 1-. 1905.
- Hitchcock, Albert S. "Scope and Relations of Taxonomic Botany." Science 43 (1916): 331-2.
- _____. "Genera and Super Genera." Science 52 (1920): 1078.
- _____. "Report on the Commission on Nomenclature of the Botanical Society of America." Science 53 (1921): 312-4.
- _____. The Methods of Descriptive Systematic Botany. New York: Wiley, 1925.
- Hoffmann, Conrad. "A Contribution to the Subject of the Factors Concerned in Soil Productivity." Kansas University Science Bulletin 9 (December 1914): 81-99.
- Holman, W.L. "The Classification of *Streptococci*." Journal of Medical Research 29, no. n.s. (1916): 377-443.
- Holman, Herbert P., Vinnie A. Pease, Katharine Smith, M.T. Reid, and A. Crebassa. Index of Publications of the Bureau of Chemistry and Soils, Originally the Bureau of Chemistry and the Bureau of Soils: 75 Years -- 1862-1937. Washington: n.p., 1939.
- Holmes, Harry N. "Let the Yests, Moulds, and Bacteria Do the Work." In Out of the Test Tube, 279-88. New York: Long & Smith, 1934.
- Hoobler, B.R. "A Modern Bacteriological Laboratory." Journal of Applied Microscopy 5 (1902): 1909-16.
- Hopkins, Cyril G. "The Present Status of Soil Investigation." Science 19 (1904): 629.
- _____. "Nitrogen Bacteria and Legumes, with Special Reference to Red Clover, Cowpeas, Soybeans, Alfalfa, and Sweet Clover on Illinois Soil." Bulletin, University of Illinois Agricultural Experiment Station, no. 94 (1904). 307-328.
- _____. "The Duty of Chemistry to Agriculture." Bulletin, of the University of Illinois Agricultural Experiment Station, no. 105 (November 1906): 1-27.
- _____. "Science and Sense in the Inoculation of Legumes." Circular of the University of Illinois Agricultural Experiment Station, no. 86 (February 1906): 1-7.
- _____. "Chemical Principles of Soil Fertility." Circular, University of Illinois Agricultural Experiment Station, no. 124 (November 1908): 1-16.
- _____. "A Phosphate Problem for Illinois Landowners." Circular of the University of Illinois Agricultural Experiment, no. 130 (1909): 1-11.

- _____. "European Practice and American Theory Concerning Soil Fertility." Circular of the University of Illinois Agricultural Experiment Station, no. 142 (March 1910): 1-31.
- _____. The Story of the Soil: From the Basis of Absolute Science and Real Life. 6th rev. ed. Boston: Richard G. Badger, 1911.
- Hopkins, Cyril G., and Albert L. Whiting. "Soil Bacteria and Phosphates." Science 44 (1916): 246.
- _____. "Methods of Criticism of 'Soil Bacteria and Phosphates'" Science 44 (1916): 649.
- _____. "Soil Bacteria and Phosphates." Bulletin of the University of Illinois Agricultural Experiment Station, no. 190 (1916): 391-406.
- Hort, Edward C. "The Life History of Bacteria." British Medical Journal, no. 2940 (1917): 571-5.
- Houck, U.G. "Work of the Bureau of Animal Industry and the War." Journal of American Veterinary Medical Association 52 (March 1918): 798-809.
- Hough, Theodore, and William T. Sedgwick. The Human Mechanism: Its Physiology and Hygiene and the Sanitation of Its Surroundings. Boston: Ginn & Company, 1906.
- Houston, D.F. "Reorganization of the Work of the Bureau of Animal Industry." Hoard's Dairyman 52 (August 11 1916): .
- Howard L.O. The House Fly: Disease Carrier. An Account of Its Dangerous Activities and of the Means of Destroying It. 2nd ed. New York: Frederick A. Stockes, 1911.
- Howe, Eugene C. "A Biometric Investigation of Certain Non-spore Forming Intestinal Bacilli." Science 35 (1912): 225.
- _____. "Organized Hygiene." American Journal of Public Health 6 (1916): 1039-.
- _____. "Professional Instruction in Public Health in the United States and Canada." American Journal of Public Health 8 (Aug. 1918): 600-.
- Howland, George T. Bovine Tuberculosis: Its Cause, Symptoms, and Treatment. Norwich, Conn.: The Waters Press, 1911.
- Hucker, G.J. "Studies on the *Coccaceae*. IV. The Classification of the Genus *Micrococcus* Cohn." Technical Bulletin of the New York State Agricultural Experiment Station, no. 102 (1924).
- _____. "Studies on the *Coccaceae*. I. Previous Taxonomic Studies Concerning the Genera of the *Coccaceae*." New York Agricultural Experiment Station, Technical Bulletin, no. 99 (1924).
- _____. "The Classification of *Micrococci*." Abstracts of Bacteriology 9 (1925): 1-2.
- Hucker, G.J., and R.S. Breed. "The Validity of Names Applied to Genera and Sub-genera of the

- Coccaceae.* Centralblatt fur Bakt., II. abt. 64 (1925): 321-8.
- Hull, T.G. "Relation of Public Health and Clinical Laboratories." American Journal of Public Health 18 (January 1928): 33-5.
- Hunter, Charles. "General Bacteriology in the Curriculum." Abstracts of Bacteriology 6 (1922): 12.
- Huxley, Julian, ed. The New Systematics. Oxford: Clarendon Press, 1940.
- Jackson, Daniel D. "Classification of the *B. Coli* Group." Journal of the American Public Health Association 1 (1911): 930.
- Johnson, Wyatt. "On Grouping Water Bacteria." Journal of the American Public Health Association 20 (October 1895): 445-9.
- Jones, L.F. "The Relation of Plant Pathology to Other Branches of Botanical Science." Phytopathology 1 (1911).
- Jones, L.R. "Problems and Progress in Plant Pathology." American Journal of Botany 1 (1913): 97-111.
- Jones, D.H. "Bacteria -- Friends and Foes." Bulletin, Ontario Agricultural Bulletin, no. 265 (1918).
- Jordan, David S. "Use of Numerals for Specific Names in Systematic Zoology." Science 33 (1911): 370-3
- Jordan, Edwin O. "Biological Problem of To-day." Dial 22 (1897): 306-.
- _____. "The Field of Municipal Hygiene ." Popular Science Monthly, June 1903, 132-40.
- _____. Decennial Publications of the University of Chicago, First Series. Vol. volume 10, The Self Purification of Streams, 81-9. Chicago: University of Chicago Press, 1903.
- _____. "The Kinds of Bacteria in River Water." Journal of Hygiene 3 (1903): 1-27.
- _____. "The Sphere of Bacteriology." American Medicine 8, no. 21 (November 19 1904): 875-9.
- _____. "Variation in Bacteria." In Presidential Address, Meeting of the Society of American Bacteriologists, Ann Arbor, Dec. 1905. 1905.
- _____. "The Place of Pathology in the University." Journal of the American Medical Association 48 (1907): 917-9.
- _____. "The Problems of Sanitation." Harvey Lectures series 3 (1907-1908): 17.
- _____. "The Problems of Sanitation." Journal of the American Medical Association 50 (1908): 493-8.
- _____. "Profitable and Fruitless Lines of Endeavor in Public Health Work." Science 33 (June 2 1911):

833-9.

- _____. "School Diseases." National Education Association, Journal of Proceedings and Addresses, 1118-24. 1912.
- _____. "The Case for Pasteurization." Journal of the American Medical Association 59 (1912): 1450-7.
- _____. "The Differentiation of the Paratyphoid-enteritidis Group. I." Journal of Infectious Diseases 20 (1917): 457-83.
- _____. "The Relations of Bacteriology to the Public Health Movement Since 1872." American Journal of Public Health 12 (1922): 1042-7.
- _____. "Standard Methods of Milk Analysis. Bacteriological Methods." American Journal of Public Health, August 1926, 811-8.
- _____. "The Interconvertibility of 'Rough' and 'Smooth' Bacterial Types." Journal of the American Medical Association 86 (1926): 177-8.
- _____. Epidemic Influenza: A Survey. Chicago: American Medical Association, 1927.
- Jordan, Edward O., and I.S. Falk, eds. The Newer Knowledge of Bacteriology and Immunology. Chicago: University of Chicago Press, 1928.
- Kahn, Morton C. "A Cultural Study of Anaerobic Spore-bearing Bacteria with Stains Purified by the Barber Single Cell Technique." Abstracts of Bacteriology 6 (1922): 9.
- Kellerman, Karl F., and T.R. Robinson. "Conditions Affecting Legume Inoculation." Bulletin of the Bureau of Plant Industry, no. 100, pt. 8 (1906): 73-83.
- Kellerman, Karl F. "The Relation of Crown-gall to Legume Inoculation." Circular, Bureau of Plant Industry, no. 76 (March 30 1911): 3-6.
- _____. "Nitrogen-gathering Plants." In United States Department of Agriculture, Yearbook 1911, 213-8. Washington D.C.: USDA, 1911.
- Kellerman, Karl F., I.G. McBeth, F.M. Scales, and N.R. Smith. "Identification and Classification of Cellulose-dissolving Bacteria." Centl. f. Bakt., 1te abt.II 39 (1913): 502-25.
- Kellerman, Karl F., and Edna H. Fawcett. "Studies of the Subtilis Group." Science 38 (1913): 372-3.
- Kellerman, K.F., and F.M. Scales. "A Preliminary Report on the Life Cycle of *Bacillus Coli*." Abstracts of Bacteriology 1 (1917): 27.
- Kendall, Arthur I. "A Graphical Tabulation of the Morphological, Cultural and Biochemical Characters of Certain Bacteria, Together with References to Authorities, Synonyms, Literature, Etc." Science

15 (March 7 1902): 377.

_____. "A Proposed Classification and Method of Graphical Tabulation of the Characters of Bacteria." American Public Health Association, Proceedings 1902 28 (1903): 481-92.

_____. Civilization and the Microbe. Boston: Houghton Mifflin, 1923.

Killert, Ellis. "An Outline for the Combined Teaching of Pathology and Bacteriology in Small Medical Colleges." Journal of Laboratory and Clinical Medicine 3 (1918): 416-9.

Killifer, D.G. "Butanol and Acetone from Corn." Indust. Eng. Chem. 19 (1927): 46-50.

Kinnicutt, L.P., C.-E.A. Winslow, and R.W. Pratt. Sewage Disposal. (n.p. 1910).

Kligler, I.J. "A Systematic Study of the *Coccaceae* in the American Museum of Natural History Collection." Science 38 (Sept. 12 1913): 374.

_____. "A Systematic Study of the *Coccaceae* in the Collection of the Museum of Natural History." Journal of Infectious Diseases 12 (1913): 432.

_____. "Studies on the Classification of the Colon Group." Journal of Infectious Diseases 15, no. 1 (1914): 187-204.

_____. "Studies on the Classification of the Colon Group." Science 39 (May 29 1914): 799.

Kligler, I.J. "A Study of the Correlation of the Agglutination and the Fermentation Reactions Among the *Streptococci*." Science 41 (1915): 618-9.

Kligler, I.J. "Some Regulating Factors in Bacterial Metabolism." Journal of Bacteriology 1 (1916): 663-72.

_____. "The Evolution and Relationship of the Great Groups of Bacteria." Journal of Bacteriology 2 (1917): 165-76.

Kluyver, A.J., and C.B. van Niel. "Prospects for a Natural System of Classification of Bacteria." Centr. Bakt. (abt. II) 94 (1936): 369-403.

Kluyver, Albert J., and C.B. van Niel. The Microbe's Contribution to Biology. In (John M. Prather Lectures, 1954). Cambridge: Harvard University Press, 1956.

Knaggs, H. Valentine. The Misunderstood Microbe. London: C.W. Daniel Company, 1930.

Knause, B.F. "Disinfection as a Factor in the Control of Communicable Disease." New York City Health Department Reprint Series, no. 43 (March 1916).

Knaysi, G. "Cytology of Bacteria." Botanical Review 4 (1938): 83-112.

- Knox, Gordon D. The Spirit of the Soil; Or, An Account of Nitrogen Fixation in the Soil by Bacteria and of the Production of Auximones in BacterIALIZED Peat. New York: Frederick A. Stokes Co., 1915.
- Koch, Robert. "The Combatting of Tuberculosis in the Light of the Experience That Has Been Gained in the Successful Combating of Other Infectious Diseases." Popular Science Monthly 59 (1901): .
- Kopeloff, Nicholas. Lactobacillus Acidophilus. Baltimore: Williams & Wilkins Co., 1926.
- _____. Man Vs. Microbe. Garden City, N.Y.: Garden City Publishing Co., 1930.
- Krause, Allen. "Before the Bacillus." Journal of the Outdoor Life 15 (February 1918): 38-40.
- Krumbhaar, Edward B. "Letter from Dr. Theobald Smith." Journal of Bacteriology 27 (1934): 19-20.
- Krumwiede, Charles, and Eugenia L. Valentine. "A Study of the Agglutination and Cultural Relationships of Members of the So-called *Streptococcus Viridans* Group." Journal of Infectious Diseases 19 (1916): 760-6.
- Krumwiede, Charles, J.S. Pratt, and L.A. Kohn. "Studies on the Paratyphoid-enteridis Group." Journal of Medical Research 34 (1916): 355-8.
- Krumwiede, Charles. "Studies on the Paratyphoid-enteritidis Group." Abstracts of Bacteriology 1 (1917): 28-9.
- Lane, Clarence B., and George M. Whitaker. "The Score-card System of Dairy Inspection." Bureau of Animal Industry, Circular, no. 139 (April 16 1909).
- Lane, C.B., and Ivan C. Weld. "Competative Exhibitions of Milk and Cream, with Report of an Exhibition Held at Pittsburg, PA., in Cooperation with the Pittsburg Chamber of Commerce." Circular of the Bureau of Animal Industry, no. 151 (October 12 1909).
- Lederle, Ernst J. "The Function of Research in Municipal Health Administration." Monthly Bulletin of the Department of Health of the City of New York 1 (March 1911): 51-3.
- Ledingham, J.C.G., and J.A. Arkwright. The Carrier Problem in Infectious Diseases. London, 1912.
- Levine, Max. "Preliminary Note on the Classification of Some Lactose Fermenting Bacteria." Journal of Bacteriology 1, no. 6 (1916): 619-21.
- _____. "On the Significance of the Voges-Proskauer Reaction." Journal of Bacteriology 1 (1916): 153-64.
- _____. "A Statistical Classification of the Colon-coloacae Group." Journal of Bacteriology 3 (May 1918).
- _____. "Dysentery and Allied Bacilli." Journal of Infectious Diseases 27 (1920): 31-.

- _____. "Some Differential Characters of the Group of Dysnety Bacilli." Abstracts of Bacteriology 4 (1920): 15.
- Lewis, Lowery L. "Bacteriology of Milk." Bulletin of the Oklahoma Agricultural Experiment Station, no. 40 (1899): 3-16.
- Lewis, Lowery L., and John F. Nicholson. "Soil Inoculation." Bulletin of the Oklahoma Agricultural Experiment Station, no. 68 (December 1905): 1-9.
- Lewis, W. Lee. "Friendly Germs." Scientific Monthly 38 (March 1934): 267-9.
- Lewis, I.M. "Cell Inclusions and the Life Cycle of *Azotobacter*." Journal of Bacteriology 34 (1937): 191-206.
- _____. "Cell Inclusions and the Life-cycle of *Rhizobia*." Journal of Bacteriology 35 (1938): 573-83.
- Lewis, Isaac McKinney. "The Cytology of Bacteria." Bacteriological Reviews 5, no. 3 (September 1941): 181-230.
- Lillie, Frank R. "The American Society of Naturalists: Cooperation in Biological Research." Science 27 (March 6 1908): 369-72.
- Lindgren, Lawrence F. "Systematic Bacteriology: Abridged Keys to Certain Families, Genera, and Species of the Order *Eubacteriales*." Course Syllabii for University of Nebraska, 1-51. 1940.
- Lipman, Jacob G. "Nitrogen-fixing Bacteria." Popular Science Monthly 62 (Dec. 1902): 137-44.
- _____. "Soil Bacteriological Studies. Further Contributions to the Physiology and Morphology of Members of the *Azobacter* Group." In Twenty-fifth Annual Report of the New Jersey Statate Agricultural Experiment Station and the Seveneenth Annual Report of the New Jersey Agricultural College Experiment Station, for the Year Ending, October 31st, 1904, 235-79. Paterson, N.J.: News Printing Co., State Printers, 1905.
- _____. Bacteria in Relation to Country Life. In The Rural Science Series. Edited by L.H. Bailey. 1st ed. New York: The Macmillan Co., 1908.
- _____. "Suggestions Concerning the Terminology of Soil Bacteria." Botanical Gazette 51 (1911): 454-60.
- _____. "Problems in Soil Bacteriology." Science 42 (Sept. 3 1915): 316.
- _____. "Tendencies in Agricultural Research." Science 57 (January 19 1923): 71-6.
- _____. "Organic Evolution from the Point of View of the Soil Investigator." The Scientific Monthly 21 (1925): 310-2.
- Lipman, Jacob G., and Herbert R. Cox. Soil Science for the Layman: A Series of Four Talks. New

- Brunswick: State College of Agriculture, 1934.
- Lipman, Jacob G. The Stuff of Life. In The Chandler Lecture, 1935. New York: Columbia University Press, 1935.
- Lipman, Jacob G., and Robert L. Starkey. "Broad Relationships Between Microorganisms and Soil Fertility." Bulletin of the New Jersey Agricultural Experiment Station (New Brunswick), no. 595 (1935). : New Jersey Agricultural Experiment Station.
- Locy, William A. Biology and Its Makers. 1st ed. New York: Henry Holt and Co., 1908.
- Loeghem, J.J. von. "The Significance of the Conceptions of Genotypus and Paenotypus to Bacteriology." In Third International Congress for Microbiology, New York, September 2-9, 1939, edited by M. Henry Dawson, 98-106. Baltimore: Waverly Press, 1904.
- Lohnis, F., and J. Hanzawa. "The Classification of *Azotobacter*." Centr. f. Bakt. 42 (1914): 1.
- Lohnis, Felix, and Nathan R. Smith. "Life Cycles of the Bacteria: Preliminary Communication." Journal of Agriculture 6, no. 18 (July 31 1916): 675-702.
- Lohnis, F., and F.M. Scales. "Some Remarks Concerning the Characterization and Classification of Bacteria." Abstracts of Bacteriology 2 (1918): 9.
- Lohnis, Felix. "Studies Upon the Life Cycles of the Bacteria: Part One, Review of the Literature, 1838-1918." Memoirs of the National Academy of Sciences 16, no. 2nd memoir (1922): 1-246.
- Long, E.F., and Bernard W. Hammer. "Classification of the Organisms Important in Dairy Products." Research Bulletin of the Iowa Agricultural Experiment Station, no. 206 (1936): 220-51.
- Loomis, A.M. "Research Work of Dairy Division." Hoard's Dairyman 60 (August 6 1920): .
- Lysenko, O., and P.H.A. Sneath. "The Use of Models in Baterial Classification." Journal of General Microbiology 20 (1959): 284-.
- M.J.L. "Bergey's Manual of Determinative Bacteriology (Book Review)." Dental Cosmos 66 (1924): 224-6.
- Macbride, Thomas H. Botany: How Much and When? Des Moines: Iowa State Teachers' Association, 1898.
- _____. Lessons in Elementary Botany for Secondary Schools, and a Key to the More Common Species of Native and Cultivated Plants Occuring in the Norther United States. Boston, 1900.
- MacCaughey, Vaughan. Identification Tables for Certain Important Bacteria. List of Bacteria Producing Important Plant Diseases, for Use in Courses in Bacteriology. Honolulu: College of Hawaii, 1910.

- Macy, Harold. "Chart of the Families and Genera of the Bacteria." Journal of Bacteriology 6 (1921): 575-6.
- Magoon, C.A., and Bliss Dana. "Preparation and Use of Pure Cultures for Legume Inoculation." Bulletin of the Washington Agricultural Experiment Station, no. 149 (April 1918): 5-16.
- Magruder, G. Lloyd. "Milk as a Carrier of Contagious Disease, and the Desirability of Pasteurization." Circular of the Bureau of Animal Industry, no. 153 (1910): 7-26.
- Magruder, George L. The Solution of the Milk Problem. Washington: R. Beresford, 1913.
- Maher, Stephen J. "Bacterial Flora of Trees and Men." Presidential Address to the Connecticut State Medical Society, 1-12. 1915.
- Malcolm, James F. "The Classification of Coliform Bacteria." Journal of Hygiene 38 (1938): 395-423.
- Manwaring, W.H. "Research Trend of Medical Bacteriology." Science 76 (July 15 1932): 41-6.
- _____. "Application of Serological Technique to General Biological Research." Journal of Infectious Diseases 54 (1934): 81-4.
- _____. "Environmental Transformation of Bacteria." Science 79 (1934): 466-70.
- Marchal, J.-G. Variation et Mutation en Bacteriologie. Paris: Le Francios, 1932.
- Marsh, M.C. "The Biological Society of Washington." Science n.s. 25 (May 31 1907): 863-5.
- Marshall, Charles E. "Bacteria: What They Are, What They Do, and How They Are Cultivated." Bulletin of the Michigan State Agricultural College Experiment Station 139 (1896): 61-90.
- _____. "Bacteria and the Dairy." Bulletin of the Michigan State Agricultural Experiment Station 146 (1896).
- _____. "Combatting Disease-producing Germs." Bulletin of the Michigan State Agricultural College Experiment Station 172 (1899): 293-310.
- _____. "A Preliminary Note on the Associative Action on Bacteria in the Souring of Milk and in Other Milk Fermentations." Special Bulletin of the Michigan Agricultural Experiment Station, no. 23 (Jan. 1904).
- _____. "Additional Work Upon the Associative Action of Bacteria in the Souring of Milk and in Other Milk Fermentations." Special Bulletin of the Michigan Agricultural Experiment Station, no. 29 (May 1904).
- _____. "A Study of Associative Action of Bacteria in the Souring of Milk." American Public Health Association Report 31 (1905): 312-27.

- _____. "Extended Studies of the Associative Action of Bacteria in the Souring of Milk." Cent. Bakt. Parasiten. 2 (1905): 688-704.
- _____. "Extended Studies of the Associative Action of Bacteria in the Souring of Milk." Special Bulletin of the Michigan Agricultural Experiment Station, no. 33 (1905).
- _____. "Associative Action of Bacteria on the Souring of Milk." Science 21 (March 31 1905): 492.
- Marshall, Charles E., and Bell Farrand. "Bacterial Associations in the Souring of Milk." Michigan State Agricultural College Special Bulletin, no. 42 (1908): 63.
- Marshall, Charles E. "Technical Application of Microorganisms to Agriculture." Science 42 (1915): 257-64.
- _____. "Microbial Associations." Science 41 (1915): 306-12.
- Mayo, Nelson S., G.A. Dick, Reuben Hilty, C.D. McGilvray, and R.R. Birch. "Report of the Committee on Education." Journal of the American Veterinary Medical Association, 669-702. 1931.
- McBeth, Ira G., and Freeman M. Scales. "The Destruction of Cellulose by Bacteria and Filamentous Fungi." Bulletin of the Bureau of Plant Industry, no. 266 (September 1913): 3-50.
- McBeth, Ira G. "Studies on the Decomposition of Cellulose in Soils." Soil Science 1 (1916): 437-87.
- McBurney, Malcolm. "The Classification of Diphtheroid Bacilli by Fermentation Reactions." Proc. New York Pathological Society 16 (1916): 135-8.
- McCoy, Elizabeth. "A Cultural Study of the Acetone Butyl Alcohol Organism." Journal of Infectious Diseases 39, no. 6 (1926): 457-83.
- McCoy, Elizabeth, and L.S. McClung. "Serological Relations Among Spore Forming Anaerobic Bacteria." Bacteriological Reviews 2 (1938): 47-97.
- McCoy, Elizabeth, and Leland S. McClung. The Anaerobic Bacteria and Their Activities in Nature and Disease. Berkeley: University of California Press, 1939.
- McFarland, Joseph. New pathological and bacteriological laboratories of the Medico-Chirurgical College, Philadelphia 5 (1902): 2076-80.
- _____. Fighting Foes Too Small to See. Philadelphia: F.A. Davis Company, 1924.
- McShane, J., and T.G. Hull. "Control of the Public Health Laboratory." American Journal of Public Health 14 (November 1924): 950-3.
- Meador, Percy D. "Variation in the Diphtheria Group." Journal of Infectious Diseases 24 (1919): 145-57.
- Medical Research Council, Patrick Pl Laidlaw, John W.H. Eyre, Stewart R. Douglas, and Charles G.L.

Wolf. The Reaction of Culture Media. In Special Report Series, No. 35. Rev. ed. London: His Majesty's Stationery Office, 1927.

Medical Research Council. A System of Bacteriology in Relation to Medicine. London: His Majesty's Stationery Office, 1930.

_____. Catalogue of the National Collection of Type Cultures Maintained by the Council at the Lister Institute of Preventative Medicine. 4th. London: Medical Research Council, 1936.

Mellon, Ralph R. "A Study of the Diphtheroid Group of Organisms with Special Reference to Their Relation to the *Streptococci*. II. Classification of the Diphtheroid Group." Journal of Bacteriology 2 (1917): 269-307.

_____. "A Study of the Diphtheroid Group of Organisms with Special Reference to Their Relation to the *Streptococci*. I. Characteristics of a Peculiar Pleomorphic Diphtheroid." Journal of Bacteriology 2 (1917): 81-108.

_____. "Life Cycles of the Bacteria and Their Possible Role in Pathology." American Journal of Medical Science 159 (1920): 874-82.

_____. "The Life-cycle Changes of the So-called C. Hodgkini and Their Relation to the Mutation Changes in This Species." Journal of Medical Research 42 (1920): 61-76.

_____. "Further Studies in Diphtheroids: Fifth Paper." Journal of Medical Research 42 (1921): 111-26.

_____. "The *Diplococcus* and Bacilliary Stages of *B. Coli* and Their Possible Relation to Growth Cycles and Sexuality." Abstracts of Bacteriology 6 (1922): 24.

_____. "Observations on the Origins of Biotypes (Variants) in Pure Lines of Bacteria." Abstracts of Bacteriology 7 (1923): 18.

_____. "Observations on the Relation of Bacterial Giant Coccoids to Zygosporangium Formation." Abstracts of Bacteriology 7 (1923): 18.

_____. Studies in Microbic Heredity. n.p.: American Society for Microbiology, 1925.

_____. "Experiments on the Hereditary Origin of Group and Specific Agglutinins Among the Enteric Organisms." Abstracts of Bacteriology 9 (1925): 2-3.

Melvin, A.D. "Regulations Governing Entrance to the Veterinary Inspector Examination, and List of Accredited Veterinary Colleges." Circular of the Bureau of Animal Industry, no. 150 (1909).

Meyr, Berl ben. Your Germs and Mine: The Story of Good and Bad Microbes. Garden City, NY: Doubleday, Doran & Company, 1934.

Miller, J.N. "Test-tube Triumphs in the Laboratories of the National Institute of Health." Hygeia 19

(April 1941): 281-4.

Minot, Charles S. "The Relations of the American Society of Naturalists to Other Scientific Societies: The Annual Discussion Before the American Society of Naturalists at the Chicago Meeting, January 1, 1902." Science 15 (1902): 241-4.

Mitchell, O.W.H. "Bacteria and Disease." The University of Missouri Bulletin: Medical Series 1, no. 1 (January 1913): 1-40.

Mohler, John R. "Infectiveness of Milk Cows Which Have Reacted to the Tuberculin Test." Bulletin of Bureau of Animal Industry, no. 44 (1903).

Mohler, John R., and Henry J. Washburn. "Tuberculosis of Hogs: Its Causes and Suppression." Circular of the Bureau of Animal Industry, no. 144 (February 10 1909): 215-7.

Mohler, John R. "The Importance of a Wholesome Milk Supply." Circular of the U.S. Department of Agriculture, Bureau of Animal Industry, no. 153 (1910): 28-37.

Moledesky, M.D. "Are You Mobilized to Fight Germs?" Illustrated World 31 (March 1919): 22-6.

Moodie, Roy L. "Mesozoic Pathology and Bacteriology." Science 43 (1916): 425-6.

_____. "Ancient Bacteria and the Beginnings of Disease." Scientific Monthly 11 (October 1920): 362-4.

Moore, Veranus A. Observations on the Morphology, Etiology and Pathogenic Properties of Twenty-eight Streptococci Found in the Investigation of Animal Diseases. Washington, D.C.: G.P.O., 1893.

Moore, V.A., and F.A. Wright. "A Comparison of *B. Coli Communis* from Different Species of Animals." Science 11 (1900): 459.

Moore, Veranus A. Bacteria in Milk: A Summary of the Present Knowledge Concerning Their Source and Significance. Albany: J.B. Lyon Company, State Printers, 1902.

Moore, Veranus A., and Floyd R. Wright. "Observations on *Bacillus Coli Communis* from Certain Species of Domestical Animals." American Medicine 3 (March 29 1902): 504-7.

Moore, George T. "Bacteria and the Nitrogen Problem." In Yearbook of Department of Agriculture, 1902, 333-42. Washington: U.S. Department of Agriculture, 1902.

Moore, Veranus A. A Report on Bovine Tuberculosis. Albany: Argus Co., 1903.

_____. Bacillus Coli Communis. s.l.: William M. Warren, 1903.

Moore, George T. "Soil Inoculation for Legumes; with Reports Upon the Successful Use of Artificial Cultures by Practical Farmers." Bulletin, Bureau of Plant Industry, no. 71 (1905): 3-72.

- Moore, George T., and T.R. Robinson. "Beneficial Bacteria for Leguminous Crops." U.S. Department of Agriculture Farmers' Bulletin, no. 214 (1905).
- Moore, George T. "Applied Botany and Its Dependence Upon Scientific Research." Science 21 (March 3 1905): 321-32.
- Moore, Veranus A. "Bovine Tuberculosis." Bulletin of the Cornell University Agricultural Experiment Station, no. 250 (1908).
- Moore, V.A. "Veterinary Hygiene." American Journal of Public Health 18 (1908): 87-.
- Moore, Veranus A. "A Method for Tabulating the Description of Species of Bacteria." 1909.
- _____. "Observations on Bacillus Coli Communis from Certain Species of Domesticated Animals." 1909.
- _____. "Veterinary Science and Its Problems." American Veterinary Review, June 1910, 1-11.
- _____. "Bacteriology in General Education." Science 33 (1911): 277-84.
- _____. "The Elimination of Tubercle Bacilli from Infected Cattle." Journal of Medical Research 24, no. 3 (June 1911): 517-25.
- _____. "The Elimination of Tubercle Bacilli from Infected Cattle, and the Control of Bovine Tuberculosis and Infected Milk." Bulletin of the Cornell University Agricultural Experiment Station, no. 299 (May 1911): 697-711.
- Moore, Veranus A. "American Veterinary Education and Its Problems." Science 34 (October 13 1911): 457-64.
- Moore, George T. "Microorganisms of the Soil." Science 36 (November 8 1912): 609-16.
- Moore, Veranus A. Bovine Tuberculosis and Its Control. Ithica: Carpenter & Company, 1913.
- _____. "Protection of Domesticated Animals." Popular Science Monthly 83 (1913): 581-7.
- Moore, Veranus Alva. "Reports of Drs. Veranus A. Moore, Mazyeh P. Ravenel, and William T. Sedgwick Upon the Federal Meat Inspection." Circular of the USDA, Office of the Secretary no. 58 (1916): 1-10.
- Moore, Veranus A. "The Veterinarian and Conservation; Confidence and Cooperation." In The Report of the Conference at the New York State Veterinary College During the Semi-Centennial Celebration of Cornell University, June 1919. Ithica: Cornell University Press, 1919.
- _____. "The Address of the President." Journal of the American Veterinary Medical Association 56, n.s. 8, no. 3 (December 1919): 238-50.

- _____. "The Veterinary Curriculum." Journal of the American Veterinary Association, December 1922, 1-14.
- _____. "Veterinary Education." Journal of the American Veterinary Medical Association, March 1923, 1-3.
- _____. "The Significance of the Crises in the Veterinary Profession." Cornell Veterinarian, Oct. 1925, 392-7.
- _____. "Some Problems for the Veterinarian." Journal of the American Veterinary Medical Association 58, n.s. 20, no. 1 (April 1925): 1-9.
- _____. "Growth of Veterinary Science and the Application of New Knowledge." Cornell Veterinarian, April 1926, 1-9.
- _____. "Diseases of Animals Communicable to Man." American Journal of Public Health 17 (1927): 113-.
- Morishima, Kan-Ichiro. "Variations in Typhoid Bacilli." Journal of Bacteriology 6 (1921): 275-324.
- Morris, Robert T. Microbes and Men. Vol. 1. To-morrow's topics series. Garden City, NY: Doubleday, Page & Company, 1915.
- Morse, Mary E. "A Study of the Diphtheria Group of Organisms by the Biometrical Method." Journal of Infectious Diseases 11 (1912): 253-.
- _____. "A Study of the Diphtheria Group by the Biometric Method." Science 35 (1912): 224-5.
- Mount, H.A. "Our Smallest Toilers." Scientific American 128 (March 1923): 170-1.
- Mueller, J. Howard. "Studies on Cultural Requirements of Bacteria, I." Journal of Bacteriology 7 (1922): 309-30.
- Muir, Richard. Bacteriological Atlas: A Series of Coloured Plates Illustrating the Morphological Characters of Pathogenic Micro-organisms. Edinburgh: E. & S. Livingstone, 1927.
- Mulford, H.K. Catalog Describing the Production of Bacterins (Bacterial Vaccines), Tuberculins, Antitoxins, Curative Sera, Smallpox Vaccine, Etc. Philadelphia: Mulford, 1908.
- H.K. Mulford. The Evidence: In Picture and in Prose. Philadelphia: H.K. Mulford Company, 1915.
- Mulvania, Maurice. "Observations on *Azotobacter*." Science 42 (1915): 463.
- Murray, Thomas J. "A Comparative Study of Colon Bacilli Isolated from Horse, Cow and Man." Journal of Infectious Diseases 19 (1916): 161-74.
- Murray, T.J. "The Oxygen Requirements of Biological Soil Processes." Journal of Bacteriology 1

(1916): 597-614.

- _____. "Part I -- The Effect of Different Plant Tissues on Fixation of Atmospheric Nitrogen. Part II -- A Study of the Bacteriology of Fresh and Decomposing Manure." Technical Bulletin of the Virginia Agricultural Experiment Station, no. 15 (1917): 93-117.
- Nelson, Aven. "The Trend and Influence of Certain Phases of Taxonomy." Science 39 (Feb. & June 13 26 1914): 254-255; 921-927.
- North, Charles E. "Sanitation in Rural Communities." Annals of the American Academy of Political and Social Science 37 (1911): 371.
- Norton, John F., Katherine Rogers, and C. Georgieff. "Studies on Pleomorphic *Streptococci*." Abstracts of Bacteriology 5 (1921): 15.
- Novy, Frederick G. "Practical Benefits of Bacteriology." Rept. Michigan Academy of Sciences 1 (1894): 14-8.
- _____. "Germs, What They Are and How They Produce Disease." Teachers Sanitary Bulletin 1 (1898): 1-7.
- _____. "Bacteriology in Its Relation to Public Health." Proceedings of the 4th Annual Conference of Health Officers, 14-24. 1899.
- _____. "The Hygienic Laboratory." Michigan Alumnus 6 (1900): 242-4.
- Novy, Frederick G. "The Bubonic Plague." Popular Science Monthly 57 (1900): 576-92.
- Novy, Frederick G. "The Spirit of Research in Medicine." Physician and Surgeon 24 (1902): 385-405.
- _____. "Disease Carriers." Science 36 (1912): 1-10.
- Novy, F.G. "Some Results of Microscopical Research Which Have Been Significant for Human Welfare." Science 84 (August 7 1936): 124-7.
- Nuttall, George H.F. "On the Role of Insects, Arachnids, and Myriapods, as Carriers in the Spread of Bacterial and Parasitic Diseases of Man and Animals: A Critical and Historical Study." Johns Hopkins Hospital Reports 8 (1900): 1-37.
- Nuttall, G.H.F., and G.S. Graham-Smith, eds. The Bacteriology of Diphtheria, Including Sections on the History, Epidemiology and Pathology of the Disease, the Mortality Caused by It, the Toxins and Antitoxins and the Serum Disease. Cambridge: Cambridge University Press, 1908.
- Ohlmacher, A.P. "Observations Upon the Morphological Variation of Certain Pathogenic Bacteria." Science 15 (1902): 374.
- Olmstead, Miriam. "A Preliminary Report on the Classification of *Pneumococcus* IV." Proceedings of

- the Society of Experimental Biology and Medicine 14 (1916): 29-31.
- Orla-Jensen, S. "The Main Lines of the Natural Bacterial System." Journal of Bacteriology 6 (1921): 263-73.
- _____. "Die Hauptlinien Des Naturlichen Bacteriensystems." In Microbiology: Historical Contributions from 1776 to 1908, edited by Raymond Doetsch. New Brunswick: Rutgers University Press, 1909.
- _____. "The Lactic Acid Bacteria." Memoirs de l'Academy Royale des Sciences et des Lettres de Danemark, Copenhagen 5 (1919): 81-196.
- Osborn, Henry Fairfield. "The Origin and Evolution of Life Upon the Earth." Scientific Monthly 3 (1916): 298-307.
- Park, William H. "Contribution of Bacteriology to Therapeutics." Pediatrics 4 (November 1 1897): 385-398, 442-449.
- _____. "The Bacterial Condition of City Milk and the Need of Health Authorities to Prevent the Sale Fo Milk Containing Excessive Numbers of Bacteria." Science 13, no. 1 March (1901): 322-3.
- _____. "The Great Bacterial Contamination of the M.lk of the Cities. Can It Be Lessened by the Action of Health Authorities?" Journal of Hygiene 1 (July 1901): 391-406.
- Park, William H., and L.E. Holt. "Report Upon the Results with Different Kinds of Pure and Impure Milk in Infant Feeding in Tenement Houses and Institutions in New York City." Medical News. In Annual Report of the Department of Health, City of New York, 1902, 275-99. 1903.
- Park, William H., K.R. Collins, and M.E. Goodwin. "The Dysentery Bacillis Group and the Varieties Which Should Be Included in It." Journal of Medical Research 6 (May 1904): 553-68.
- Park, William H. "A Critical Study of the Results of Serum Therapy in Diseases in Man." Harvey Lectures, 101. 1905-1906.
- _____. "Typhoid Bacilli Carriers." Journal of the American Medical Association 51 (September 19 1908): 981-2.
- _____. "Health Laboratory Organization." Journal of the American Medical Association 67 (Dec. 30 1916): 2013-5.
- _____, ed. Public Health and Hygiene in Contributions by Eminent Authorities. Philadelphia: Lea & Febiger, 1920.
- Park, William H., and Charles, Jr. Krumwiede. "The Training of Laboratory Workers." American Journal of Public Health 14 (1924): 471-.
- Park, William H., and Anna W. Williams. Who's Who Among the Microbes. New York: The Century

Co., 1929.

- Patterson, A.M. "Meaning of Antiseptic, Disinfectant and Related Words." American Journal of Public Health 22 (May 1932): 465-72.
- Pearce, Richard M. "Research in Medicine." Popular Science Monthly, August 1912, 124-8.
- Pearson, Leonard. "Tuberculosis of Cattle." Bull. Penn. State College Agricultural Experiment Station, no. 29 (1894).
- _____. "The Pennsylvania Plan for Controlling Tuberculosis of Cattle and a Summary Review of Reasons Upon Which It is Based." Proceedings of the American Veterinary Medical Association 36 (1899): 161-82.
- Pearson, Leonard, Mazyck P. Ravenel, and Benard L.F. Bang. "Tuberculosis of Cattle and the Pennsylvania Plan for Its Repression." Bulletin of the Commonwealth of Pennsylvania, Dept. of Agriculture 75 (1901).
- Perkins, Roger G. "Report of the Committee on Standard Methods." American Journal of Public Health 12 (1922): 27-.
- _____. "The Wider Development of Standard Methods." American Journal of Public Health 12 (1922): 23-.
- _____. "Classification of Spore-free Gram-negative, Aerobic Rods with Special Reference to Fermentation and Proteolysis." Journal of Infectious Diseases 37 (1925): 232-.
- _____. "Review: Bergey's Manual of Determinative Bacteriology." American Journal of Public Health 20 (1930): 565.
- Peterson, Peter. "Lactic Acid Bacteria." Dairy Produce 26 (1919): 24-32.
- Phillips, Charles. "The New Nomenclature in Bacteriology." Southern Medical Journal 18 (1925): 787-90.
- Pirie, N.W. "The Principles of Microbial Classification: Summing-up." Journal of general microbiology 12 (1955): 382-.
- Plummer, J.K. "Some Effects of Oxygen and Carbon Dioxide on Nitrification and Ammonification in Soils." Bulletin of the Cornell University Agricultural Experiment Station (305-330), no. 384 (December 1916).
- Potts, Charles Shirley. "The Texas Cattle Fever: How Science is Winning a Long Fight." American Monthly Review of Reviews 29 (January 1904): 49-55.
- Prescott, S.C. "On the Apparent Identity of the Cultural Reactions of *B. Coli Communis* and Certain Lactic Bacteria." Science 15 (1902): 363.

- Prescott, Samuel C. "The Need for Uniform Methods in the Sanitary Examination of Milk." Papers and reports of the American Public Health Association 31, no. 2 (1905): 246-8.
- _____. "The Teaching of Microbiology in Colleges of the United States and Canada." Science 35 (1912): 362-6.
- Prescott, Samuel Cate. "The Research Laboratory of the United Fruit Company." Bulletin of the United Fruit Company Research Laboratory 1, no. 1 (1917): 1-22.
- _____. Examination of Tropical Soils. Boston: Research Laboratory, United Fruit Company, 1918.
- _____. "Laboratory in Public Health Work." American Journal of Public Health 16 (February 1926): 130-3.
- Prescott, S.C. "Training for the Public Health Engineer." American Journal of Public Health and the Nation's Health 21 (1931): 1091-.
- Prevot, A.-R. "Etudes de Systematique Bacterienne. III. Invalidite Du Genre Bacteriodes Castellani et Chalmer. Demembrement et Reclassification." Ann. Inst. Pasteur 60 (1938). 285-307.
- _____. "Etudes de Systematique Bacterienne. IV. Critique de la Conception Actuelle Du Genre Clostridium." Ann. Inst. Pasteur 61 (1938): 72-91.
- Pribam, E.A. "Classification and Pathogenicity of Microorganisms: III. Toxins and Toxic Products." Journal of Bacteriology 35 (1938): 12.
- Pribam, Ernst A. "A Contribution to the Classification of Microorganisms." Journal of Bacteriology 18 (1929): 361-94.
- Pribam, E.A. "Pathogenicity and Classification of Microorganisms." Journal of Bacteriology 22 (1931): 427-32.
- Prucha, Martin J. "Physiological Studies of *Bacillus Radicicola* of Canada Field Pea." Memoir, Cornell University Agricultural Experiment Station, no. 5 (March 1915): 1-83.
- Prucha, M.J., and H.M. Weeter. "Germ Content of Milk: I. As Influenced by Factors at the Barn." Bulletin of the Illinois Agricultural Experiment Station, no. 199 (1917).
- Prudden, T. Mitchell. "Our Ice-supply and Its Dangers." Popular Science Monthly 32 (March 1888): 668.
- _____. Story of Bacteria. 1st. ed. New York: Putnam, 1889.
- _____. Dust and Its Dangers. 1st ed. New York: Putnam, 1890.
- _____. Drinking-water and Ice Supplies and Their Relations to Health and Disease. 1st. ed. New York: Putnam, 1891.

- _____. "Glimpses of the Bacteria." Harper's Magazine 82 (April 1891): 711.
- _____. "New Outlooks in the Science and Art of Medicine." Popular Science Monthly 48 (1896): 359.
- _____. "Pathology and the Department of Pathology." Columbia University Bulletin no. 19 (1898): 103.
- Prudeen, T. Mitchell. "Progress and Drift in Pathology." Medical Record 57, no. 10 (March 10 1900): 397-403.
- Prudden, T. Mitchell. "Safeguards of the Body Against Disease: A Short Study of Immunity." Outlook 89 (1905): 589.
- _____. "On the Trail of the Yellow Fever Germ: From the Notes of a Bystander." American Review of Reviews 61 (1920): 386.
- _____. "A New Outlook in the Conquest of Disease: Chemotherapy." Review of Reviews 63 (January 1921): 65.
- Rahe, Alfred H. "The Classification of the Aciduric Bacteria." Journal of Bacteriology 3 (1918): 407-22.
- Rahn, Otto. "The Usefulness of Curves Inthe Interpretation of Biochemical Processes." Science 31 (1910): 550-1.
- _____. "The Fermenting Capacity of the Average Single Cell of Bacterium Lactis Acidi." 24th Annual Report of the Michigan Agricultural Experiment Station, 443-80. 1911.
- _____. "An Attempt at a Natural Classification of Bacteria." Centralbl. f. Backteriol., 2 50 (1920): 273-93.
- _____. "Contribution to the Classification of Bacteria." Centrablatt Bakt. 2 Abt. 78 (1929): 1-21.
- Ravenel, Mazyck P. "Notes on the Bacteriological Examiantion of the Soil of Philadelphia." Memoirs of the National Academy of Sciences 8 (1896): 1-41.
- _____. "Milk-supply from the Bacteriological Standpoint." Journal of Comparative Medicine and Veterinary Archives 19, no. 4 (April 1898): 1-7.
- _____. "The Intercommunicability of Human and Bovine Tuberculosis." Medicine, JulyandAugust 1902, 1-30.
- _____. "Disinfection and Commercial Disinfectants." Bulletin of the University of Wisconsin Agricultural Experiment Station no. 166 (1909): 1-19.
- _____. "The Control of Typhoid Fever by Vaccination." American Philosophical Society Proceedings 52 (1913): 226-33.

- Ravenel, Mazyeh P. "Preventive Medicine: Its Accomplishments and Its Aims." University of Missouri Bulletin 16, no. 9, med. ser. 8 (1915).
- Ravin, A.W. "The Origin of Bacterial Species. Genetic Recombination and Factors Limiting It Between Bacterial Populations." Bacteriological Reviews 24 (1960): 201-20.
- _____. "Experimental Approaches to the Study of Bacterial Phylogeny." American Naturalist 97 (1963): 297-318.
- Reed, Walter, and James Carroll. "A Comparative Study of the Biological Characters and Pathogenesis of *Bacillus X* (Sternberg), *Bacillus Icteroides* (Sanarelli), and the Hog-cholera Bacillus (Salmon and Smith)." Journal of Experimental Medicine 5 (1900): 215-.
- Reed, Howard S., and Bruce Williams. "The Effect of Some Organic Soil Constituents Upon Nitrogen Fixation by Azotobacter." Technical Bulletin of the Virginia Agricultural Experiment Station, no. 4 (1915): 81-91.
- _____. "Four Papers on Nitrogen Fixation and Nitrification in Various Soil Types." Technical Bulletin of the Virginia Agricultural Experiment Station, no. 3 (1915): 59-80.
- Reinhardt, George F. "Public Health Education." Journal of the American Medical Association. February 8 1913.
- Rettger, Leo F. "On the Antagonism of Bacteria and Their Products Towards Other Bacteria." Science 21 (March 31 1905): 491-2.
- Rettger, Leo F., and J.L. Sherrick. "Studies on Bacterial Variation." Journal of Medical Research 24 (1911): 265-.
- Rettger, Leo F. "Hygiene of the Bacteriological Laboratory." American Journal of Public Health 3 (1913): 697-.
- Rettger, Leo F., N. Berman, and W.S. Sturges. "Further Studies on Bacterial Nutrition: The Utilization of Proteid and Non-proteid Nitrogen." Journal of Bacteriology 1 (1916): 15-34.
- Rettger, Leo F. "The Science of Bacteriology and Its Relation to Other Sciences." Journal of Bacteriology 3 (1918): 103-13.
- _____. "Some Aspects of Intestinal Bacteriology in Relation to Health." American Journal of Public Health and the Nation's Health 19 (1929): 771-.
- Rice, Thurman B. The Conquest of Disease. New York: Macmillan Co., 1927.
- _____. "Conquest of Disease." Hygeia 5 (March 1927): 139-41.
- Richards, Ellen H. Sanitation in Daily Life. Boston: Whitcomb & Barrows, 1919.

- Ritchie, John W. Primer of Sanitation, Being a Simple Textbook on Disease Germs and How to Fight Them. Vol. 2. New world health series, revised edition. Yonkers-on-Hudson, NY: World Book Company, 1915.
- Ritter, W.E. "Place of Description Definition and Classification in Systematic Biology." Science Monthly 3 (1916): 455-70.
- Rogers, Lore A. "Bacteria of Pasteurized and Unpasteurized Milk Under Laboratory Conditions." Bulletin of Bureau of Animal Industry, no. 73 (1905).
- Rogers, Lore A., and S. Henry Ayers. "Interpretation of Results of Bacteriological Examination of Milk." Circular of the U.S. Department of Agriculture, Bureau of Animal Industry, no. 153 (1910): 46-52.
- Rogers, Lore A., and Brook J. Davis. "Methods of Classification the Lactic-acid Bacteria." Bulletin of the U.S. Department of Agriculture, Bureau of Animal Industry, no. 154 (September 17 1912): 1-30.
- Rogers, L.A., and Arnold Dahlberg. "The Relation of Habitat and Physiological Characters in the *Streptococci*." Science 39 (1914): 798-9.
- Rogers, Lore A., William Mansfield Clark, and Herbert A. Lubs. "The Characteristics of Bacteria of the Colon Type Occuring in Human Feces." Journal of Bacteriology 3 (1918): 231-52.
- Rogers, Lore A. "Characteristics and Distribution of the Colon-aerogenes Group." In University of Wisconsin Studies, Science No. 2 In Papers on Bacteriology and Allied Subjects, by Former Students of Harry Luman Russell, 77-103. Madison: University of Wisconsin Press, 1921.
- _____. "Preliminary Status of a Project for a Laboratory for Research in Abstract Bacteriology." Abstracts in Bacteriology 5 (1921): 1-2.
- _____. "What Constitutes Efficiency in Research." Journal of Bacteriology 8 (1923): 197-213.
- _____. "Research Work at the Bureau of Dairying." Journal of Dairy Science 8 (January 1925): 4-14.
- _____. "The Science and Art of Cheesemaking." Scientific Monthly 42 (1936): 437-43.
- Roos, C., and E. May Gray. "Studies Upon *Streptococcus*. II. Cultural Versus Biological Classification." Abstracts of Bacteriology 5 (1920): 15.
- Rosenau, Milton J. "Milk and Its Relation to the Public Health: Pasteurization." Bulletin of the Hygienic Lab, U.S. Public Health and Marine Hospital Service, no. 41 (1908): 589-624.
- _____. "Pasteurization, Its Advantages and Disadvantages." Circular of the U.S. Department of Agriculture, Bureau of Animal Industry, no. 153 (1910).
- Round, Lester A., and S. Coopersmith. "The Sauerkraut Industry of the United States." Canner 44

(1917): 15, 48, and succeeding nos.

Ruehle, G.L.A., and W.L. Kulp. "Germ Content of Stable Air and Its Effect Upon the Germ Content of Milk." Bulletin of the New York (Geneva) Agricultural Experiment Station, no. 409 (1915): 418-74.

Ruehle, G.L.A., Robert S. Breed, and George A. Smith. "Milking Machines." Bull. of New York Agricultural Experiment Station, no. 450 (July 1918): 113-81.

Russell, Harry L. "The Fixation of Free Nitrogen by Plants." Botanical Gazette 19 (1894): 284-93.

Russell, Harry L. . "Investigations on Bacteria." Botanical Gazette 20 (1895): 419-22.

Russell, H.L. "Typhoid Fever Disseminated Through the Milk Supply." Science, no. n.s. (November 15 1895): 682-3.

_____. "The Pasteurization of Milk." Pharmaceutical Review 14 (May 1896).

Russell, Harry L. "Summary of Experimental Work in Bacteriology for the Years 1893-1903." University of Wisconsin, Agricultural Experiment Station, Annual Report 20 (1904).

_____. "Description of the Laboratories of Agricultural Bacteriology." Annual Report of the Wisconsin Agricultural Experiment Station 21 (1905): 368.

Russell, Harry L., and Edwin G. Hastings. "A Catechism on Bovine Tuberculosis." Circular of Information of the University of Wisconsin Agricultural Experiment Station, no. 23 (1911): 1-24.

Russell, Edward J. The Fertility of the Soil. Cambridge: University Press, 1913.

Russell, Harry L., ed. Papers on Bacteriology and Allied Subjects. Madison: University of Wisconsin Press, 1921.

Sackett, Walter G. "Some Soil Changes Produced by Micro-organisms." Bulletin of the Colorado Agricultural Experiment Station, no. 196 (1914): 3-38.

_____. "The Nitrifying Efficiency of Certain Colorado Soils." Bulletin of the Colorado Agricultural Experiment Station, no. 193 (June 1914): 1-43.

Sadler, Wilfred. Bacteria as Friends and Foes of the Dairy Farmer. London: Methuen, 1912.

Salter, R.M., R.D. Lewis, and J.A. Slipher. "Our Heritage -- the Soil." Extension Bulletin of the Ohio State University, no. 175 (April 1936): 3-20.

Schroeder, E.C. "Milk and Its Products as Carriers of Tuberculosis Infection." Circular of Bureau of Animal Industry, no. 143 (January 1909): 183-96.

- _____. "The Relation of the Tuberculous Cow to Public Health." Circular of the Bureau of Animal Industry, no. 153 (1910): 38-45.
- Scott, Joseph P. "Blackleg Vaccines: Their Production and Use." Technical Bulletin of the Kansas State Agricultural Experiment Station, no. 10 (1923): 507.
- Sears, O.H. "A Nitrogen Factory on Every Farm." Circular of the University of Illinois Agriculture Experiment Station, no. 326 (February 1928): 2-12.
- Sedgwick, William T., and John L. Batchelder. "A Bacteriological Examination of the Boston Milk Supply." Boston Medical and Surgical Journal 126 (1892): 25-8.
- Sedgwick, William T., Henry F. Osborn, William B. Clark, L.O. Howard, and B.T. Galloway. "Attitude of the State Toward Scientific Investigation." Science 13 (Jan. 18 1901): 81.
- Sedgwick, William T. "The Origin, Scope and Significance of Bacteriology." Science 13 (Jan. 25 1901): 121-8.
- _____. "On the Modern Subjection of Science and Education to Propoganda: Presidential Address, American Society of Naturalists." Science 15, no. 10 Jan. (1902): 44.
- Sedgwick, William T., and Theodore Hough. "What Training in Physiology and Hygiene May We Reasonably Expect of the Public Schools?" Science 18, no. 445 (Sept. 1903): 353.
- Sedgwick, William T. "Sanitary Science and Public Health." In Encyclopedia Americana, vol. 14. New York, 1904.
- Sedgwick, William t. "The Relations of the Public Health Science to Other Sciences: Address Before the Public Health Section, Interntional Congress of Arts and Science, St. Louis, St. 1904." Science 15, no. 546 (June 16 1905): 905.
- Sedgwick, William T. "The Experimental Method in Sanitary Science and Sanitary Administration. Address of the Vice-President and Chairman for 1905 of Section K, A.A.A.S. Meeting, 1906." Science 23 (1906): 362.
- _____. "The Conquest of Famines." Youth's Companion 82, no. 17 (1908).
- _____. "Typhoid Fever: A Disease of Defective Civlization." In Typhoid Fever: Its Causation, Transmission, and Prevention, edited by George C. Whipple. New York: John Wiley & Sons, 1908.
- Sedgwick, A. "The Relation of Science to Human Life." Nature 82 (December 23 1909): 228-32.
- Sedgwick, William T. "On the Proper Correlation of Physicians, Engineers, and Other Specialists on Public Health Work." Journal of American Public Health Association 1 (January 1911): 28.
- _____. "Public Health and Hygiene." In American Year Book, New York: Appleton & Company,

1913.

- _____. "The Interpretation of Nature and the Teaching Laboratory. An Address at the Dedication of the Carnegie Science Hall of Bates College, January 14, 1913." Science 38, no. 8 Aug. (1913): 169-74.
- _____. "American Achievements and American Failures in Public Health Work. Address of the President, American Public Health Association." Science 42 (Sept. 17 1915): 361.
- _____. "What Massachusetts Has Done and May Yet Do for the Public Health." American Journal of Public Health 5 (July 1915): 637.
- _____. "Forward: The Genesis of a New Science: Bacteriology." Journal of Bacteriology 1 (1916): 1-4.
- _____. "Rats and Insects as Public Enemies." American Journal of Public Health 9 (January 1918): 34.
- _____. "Women's Colleges in War Time." Simmons College Review. January 1919.
- Selasin, S.L. "Our Friends, the Bacteria." Public Health News 18 (1934): 11-6.
- Senn, Nicholas. Away with Koch's Lymph!. Chicago: R.R. McCabe and Co., 1891.
- Shakespeare, Edwin O. "The New Municipal Laboratory of Bacteriology in Philadelphia." Dietetic and Hygiene Gaz. 11 (1895): 223-4.
- Shear, C.L., and F.E. Clements. "The Condition and Needs of Systematic Mycology." Science 63 (1926): 393-4.
- Sherman, James M. "Studies on the Production of Sanitary Milk." Annual Report of the Penn. State College, 1914-1915. 1915.
- Sherman, James M., and William R. Albus. "Some Characters Which Differentiate the Lactic-acid *Streptococcus* from *Streptococci* of the Pyogenes Type Occuring in Milk." Journal of Bacteriology 3 (1918): 153-74.
- Sherwood, Nobel Peirce. "A Study of Several Strains of Pleomorphic *Streptococci*." University of Kansas Science Bulletin 10, no. 11 (1917): 245-57.
- Shigley, J.F. "The Teaching of Veterinary Medicine to Agricultural Students." 67. , 16-23. 1925.
- Shimwell, J.L., and J.G. Carr. "Are Species of Bateria Unclassifiable." Leeuwenkoek ned. Tijdschr. 26 (1960): 383-.
- Simpson, George G. "The Principles of Classification and a Classification of Mammals." Bulletin of the American Museum of Natural History 85 (1945): 1-.

- Skerman, Vic B.D. "Species Concept in Bacteria." In Evolution of Living Organisms, Vol. 1, 213-21. Melbourne: Melbourne University Pres, 1961.
- Slack, Francis H. "Methods of Bacteriological Examination of Milk." Papers and reports of the American Public Health Association 31, no. 2 (1905): 214-22.
- _____. "The Practice of Exposing Food Stuffs to the Street Dust and Its Effect Upon the Public Health." American Journal of Public Hygiene 19 (1909): 167-8.
- Smirnow, M.R. "Induced Variations in Chromogenesis." Science 41 (1915): 621.
- Smirnow, Max R. "Biological Variations of Bateria: Induced Variations in the Cultural Characteristics of *B. Coli*." Journal of Bacteriology 1 (1916): 385-410.
- Smith, Theobald. "Some Observations on the Origin and Sources of Pathogenic Bacteria." Sanitarian 22 (1889): 110-9.
- _____. "Observations on the Variability of Disease Cerms." New York Medical Journal 52 (1890): 485-7.
- _____. "Channels of Infection, with Special Reference to Water and Milk." Popular Health Magazine 1 (1893): 279-87.
- _____. "Modification, Temporary and Permanent, of the Physiological Characters of Bacteria in Mixed Cultures." Trans. Assn. Am. Physicans 9 (1894): 85-106.
- _____. "The Conditions Which Influence the Appearance of Toxin in Cultures of the Diphtheria Bacillus." Transactions of the American Association of Physicians 11 (1896): 37-61.
- _____. "The Thermal Death-point of Tubercle Bacilli in Milk and Other Fluids." Journal of Experimental Medicine 4 (1899): 217-33.
- Smith, Erwin F. "Are Bacteria Fungi." American Naturalist 33 (1899): 169-70.
- Smith, Theobald. "Adaptation of Pathogenic Bacteria to Different Species of Animals." Boston Medical and Surgical Journal 142 (1900): 473.
- _____. "The Significance of Varieties Among Pathogenic Bacteria." Science 11 (March 23 1900): 456.
- _____. "Comparative Pathology: Its Relation to Biology and Medicine." Philadelphia Medical Journal 6 (1900): 409.
- _____. "Public Health Laboratories." Boston Medical and Surgical Journal 143 (1900): 491-3.
- _____. "Variations Among Pathogenic Bacteria." Journal of the Boston Society of Medical Sciences 4 (1900): 95-104.

- Smith, Erwin F. "Destruction of Cell Walls by Bacteria." Science 15 (1902): 405.
- Smith, Theobald. "Some Problems in the Life History of Pathogenic Microorganisms." Science 20 (1904): 807.
- Smith, Erwin F. Bacteria in Relation to Plant Diseases. Washington: Canegie Inst., 1905.
- Smith, Theobald. "Medical Research: Its Place in the University Medical School." Popular Science Monthly 66 (1905): 515-30.
- _____. "A Description of the New Antitoxin and Vaccine Laboratory Together with the Ten Year's Retrospect on the Production and Distribution of Antitoxin." Massachusetts Board of Health, 37th Annual Report, 527-46. 1906.
- _____. "The Channels of Infection in Tuberculosis, Together with Some Remarks on the Outlook Concerning a Speciefic Therapy." Transactions of the Massachusetts Medical Society, 1-26. 1907.
- _____. "The House-fly as an Agent in the Dissemination of Infectious Diseases." American Journal of Public Hygiene 18 (1908): 312.
- _____. "Some Neglected Facts in the Biology of the Tetanus Bacillus: Their Bearing on the Safety of the So-called Biological Products." Transactions of the Chicago Pathological Society 7 (March 1 1908).
- _____. "The Relation Between Human and Animal Tuberculosis, with Special Reference to the Question of Transformation of Human Other Types of the Tubercle Bacillus." Boston Medical and Surgical Journal 159, no. 22 (November 26 1908): 707-11.
- _____. Special Report on Diseases of Cattle. Washington: GPO, 1912.
- _____. "Scholarship in Medicine." Boston Medical and Surgical Journal, 1-10. 1915.
- _____. "Parasitism as a Factor in Disease." Science 54 (August 5 1921): 86-92.
- _____. "Koch's Views on the Stability of Species Among Bacteria." Annals of Medical History. 1932.
- _____. Parasitism and Disease. Princeton: Princeton University Press, 1934.
- Sneath, Peter. "The Application of Computers to Taxonomy." Journal of General Microbiology 17 (1957): 201-26.
- _____. "Some Thoughts on Bacterial Classification." Journal of General Microbiology 17 (1957): 184-.
- Sneath, Pter. "The Construction of Taxonomic Groups." In Microbial Clasification, Symposia of the Society for General Microbiology, 12, 289-332. Cambridge: Cambridge University Press, 1962.

- Sneath, Peter, and R.R. Sokal. Principles of Numerical Taxonomy. San Francisco: W.H. Freeman and Co., 1963.
- Committee on Bacteriological Technic of the Society of American Bacteriologists. Pure Culture Study of Bacteria 1-18 (1932-1950).
- Soper, George A. "The Curious Career of Typhoid Mary." Bulletin of the New York Academy of Medicine 15 (October 1939): 698-712.
- St. John-Brooks, Ralph, and Robert S. Breed. "Actions Taken by the 2nd. International Microbiological Congress in London, 1936, Regarding Bacterial Nomenclature." Journal of Bacteriology 33 (1937): 445-7.
- Stange, C.H. "Progress in Veterinary Education." Journal of the American Veterinary Medical Association 76 (1930): 820-5.
- Stanier, R.Y., and C.B. van Niel. "The Main Outlines of Bacterial Classification." Journal of Bacteriology 42 (1941): 437-.
- Stearn, Allen E., and Esther W. Stearn. The University of Missouri Studies. Vol. III, Studies in the Physico-chemical Behavior of Bacteria. 2. Columbia: University of Missouri, 1928.
- Stephenson, Mary Bowen. The World of Invisible Life. Chicago: Follett Publishing Co., 1934.
- Sternberg, George. "Disease Germs and Armies." New York Times, January 9 1885, 3.
- Sternberg, George M. "Disinfection and Individual Prophylaxis Against Infectious Diseases." In Lomb Prize Essay, 1-4. Concord, New Hampshire: American Public Health Association, 1886.
- _____. Sanitary Lessons of the War and Other Papers. Washington, D.C.: Press of Byron S. Adams, 1912.
- Stevens, F.L., W.A. Withers, J.C. Temple, and W.A. Syme. "Studies in Soil Bacteriology, I: Nitrification I Soils and in Solutions." In 31st Annual Report of the North Carolina Agricultural Experiment Station, 40-64. Raleigh: Edwards & Broughton Printing Co., 1908.
- Stevens, F.L., and W.A. Withers. "Studies in Soil Bacteriology, III -- Concerning Methods for Determination of Nitrifying and Ammonifying Powers of Soils." In 32nd Annual Report of the North Carolina Agricultural Experiment Station, 129-44. Raleigh: E.M. Uzzell & Co., State Printers and Binders, 1909.
- Stevens, F.L., W.A. Withers, J.C. Temple, and W.A. Syme. "Studies in Soil Bacteriology, II. Ammonification in Soils and in Solutions." Centr. f. Bakt., 2te Abt. 23 (1909): 776-373.
- Stevens, F.L. "Problems of Plant Pathology." Botanical Gazette 63-64 (1917): 297-306.
- Stewart, F.W. Segregation and Autogamy in Bacteria: A Contribution to Cellular Biology. London:

- Adlard, 1927.
- Stiles, C.W. "The International Code of Zoological Nomenclature as Applied to Medicine." Hygienic Laboratory Bulletin, no. 24 (Sept. 1905): 26-8.
- Stimson, Arthur M. "The Citizen and the Public Health." United States Public Health Service, Public Health Reports suppl. 4 (1914).
- Stockberger, W.W. "The Social Obligations of the Botanist." Science 39 (May 22 1914): 733-43.
- Stocking, William A. "The So-called 'Germicidal Property' of Milk." Bull. Storrs Agricultural Experiment Station, no. 37 (1905): 1-20.
- Stoughton, G. Van Everen. "Characteristics of Colon Bacilli and the Value of the Presumptive Test." In Annual Report of the Board of Health of the Department of Health of the City of New York for the Year Ending December 31, 1904, vol. vol. 1. New York: 456-468, 1904.
- Stowell, E.C., C.M. Hilliard, and M.J. Schlesinger. "A Statistical Study of the *Streptococci* from Milk and from the Human Throat." Journal of Infectious Diseases 12 (1913): 144-.
- Stowell, E.C., C.M. Hilliar, and M.J. Schlesinger. "A Biometric Study of the *Streptococci* from Milk and from the Human Throat." Science 38 (1913): 373-4.
- Strong, Lawrence Watson. "A Study of the Encapsulated Bacilli." Boston Society of Medical Sciences 3 (Feb. 1899): 185-96.
- Surface, Frank M. "Notes on Infectious Abortion in Cattle." Science 36 (Sept. 27 1912): 409-12.
- Swingle, W.T. "Types of Species in Botanical Taxonomy." Science 37 (1913): 864-7.
- Talbot, Marion. "Sanitation and Sociology." American Journal of Sociology 2 (1896): 74.
- Taliaferro, W.H. "Microorganisms and Their Roles in Nature." In World and Man as Science Sees Them, edited by Forest R. Moulton, 445-85. Chicago: University of Chicago Press, 1937.
- Tanner, Fred W. "A Study of Green Fluorescent Bacteria from Water." Journal of Bacteriology 3 (1918): 63-102.
- _____. "A Laboratory Chart for Recording Observations on Microorganisms." Journal of Laboratory and Clinical Medicine (St. Louis) 5 (1920): 792-7.
- Temple, J.C. "The Influence of Stall Manure Upon the Bacterial Flora of the Soil." Bulletin, Georgia Experiment Station, no. 95 (September 1911): 5-35.
- _____. "Studies of *Bacillus Radicicola*." Bulletin of the Georgia Agricultural Experiment Station, no. 120 (May 1916): 67-80.

- Tittsler, R.P. "Bacteriology." In Orientation in Science, by Ten Members of the University of Rochester Faculty, edited by Charles W. Watkeys. 1st ed., 404-40. McGraw, 1938.
- Tonney. "Tuberculosis in Market Milk of Chicago." Journal of the American Medical Association 55 (1910): 1252.
- Topley, William W.C. "Review of Phillips Commentary." Bulletin of Hygiene 1 (1926): 278-.
- Trask, J.W. "Milk and Its Relation to the Infectious Diseases." Journal of the American Medical Association, Oct. 31 1908, 1491.
- Trelease, William. "Bacteria from a Botanical Standpoint." Weekly Medical Review 17 (1888): 88-9.
- _____. "Some Twentieth Century Problems." Science n.s. 12, no. 289 (July 13 1900): 48-62.
- _____. "The Missouri Botanical Garden." Popular Science Monthly 62, no. 13 (1903): 193-222.
- _____. "Report of the Secretary: The Botanical Society of America." Science 33 (1905): 221-2.
- Tunnickliff, Ruth. "Further Studies on the Specificity of *Streptococci*." Journal of the American Medical Association 75 (1920): 1339.
- Turner, Clair E., and Ellen L. Lytle. The Nature of Bacteria: A Description of Units of Work. In School Health Bureau, Mongraph No. 7. New York: Metropolitan Life Insurance Company Press, 1932.
- United States Department of Agriculture. Index to Literature Relating to Animal Industry in Department of Agriculture Publications, 1837-1898. Washington, D.C., 1900.
- _____. List of Publications of the U.S. Department of Agriculture Issued Since July 1, 1913. Revised to Dec. 21, 1916. Washington, 1917.
- Agricultural Research Service, United States Department of Agriculture. Supplement to History of Hog Cholera Research in the U.S. Department of Agriculture: Research Work on Hog Cholera as Reported in the Annual Reports of the Chiefs of the Former Bureau of Animal Industry, 1903-1953. In Supplement to Agricultural Information Bulletin, No. 241. Washington: Agricultural Research Service, 1962.
- Van Niel, C.B. "The Classification and Natural Relationships of Bacteria." Cold Spring Harbor, Symposia in Quantitative Biology 11 (1946): 285-.
- _____. "Classification and Taxonomy of the Bacteria and Bluegreen Algae." In A Century of Progress in the Natural Sciences, 1853-1953: Published in Celebration of the Centennial of the California Academy of Sciences, 89-114. San Francisco: California Academy of Sciences, 1955.
- van Rensselaer, Martha. "Saving Steps." Cornell Reading-Course for Farmers' Wives, Supplement, no. 1 (Jan. 1901): 1-16.

- _____. "Home Sanitation." Cornell Reading-Course for Farmers' Wives, Supplement, no. 2 (April 1901): 497-513.
- _____. "Bacteriology of the Household." Cornell Reading-Course for Farmers' Wives, no. new series, 4 (February 1909): 717-34.
- Vass, A.F. "The Influence of Low Temperature on Soil Bacteria." Memoir, Cornell University Agricultural Experiment Station, no. 27 (June 1919): 1043-74.
- _____. "Legume Inoculation." Circular, University of Wyoming Agricultural Station, no. 15 (January 1920): no pages listed.
- Voorhees, Edward B. "A Popular Review of the Work of the Experiment Station." Bulletin of the New Jersey Agricultural Experiment Station 182 (1905).
- Voorhees, Edward B., and Jacob G. Lipman. Office of Experiment Stations, Bulletin (Washington, D.C.), no. 194 (1907). A Review of Investigations in Soil Bacteriology. : GPO.
- Waksman, Selman A. "Studies on Proteolytic Activities of Soil Microorganisms, with Special Reference to Fungi." Journal of Bacteriology 3 (1918): 475-92.
- _____. "Methods in Soil Microbiology." Abstracts in Bacteriology 7 (1923): 18-9.
- _____. "Microbes in a Changing World." Scientific Monthly, November 1940, 90-6.
- _____. "The Microbe as a Biological System." Journal of Bacteriology 45 (1943): 1-10. In Presidential Address Before the Society of American Bacteriologists.
- _____. "Soil Microbiology as a Field of Science." Science 102 (1945): 339-44.
- _____. Microbial Antagonisms and Antibiotic Substances. New York: Commonwealth Fund, 1945.
- _____. "An Institute of Microbiology -- Its Aims and Purposes." In Scientific Contributions of Selman A. Waksman, edited by H. Boyd Woodruff. New Brunswick, N.J.: Rutgers University Press, 1949.
- _____. "The Changing Concept in Microbiology." Scientific Monthly 76 (1953): 127-33.
- Walcott, C.D. "Discovery of Algonkin Bacteria." Proc. National Academy of Science 1 (1915): 256-7.
- Walker, W.F. "Advances in Sanitary Practices." American Journal of Public Health 16 (February 1926): 97-100.
- Walker, Rudger H. "Physiological Studies on the Nitrogen Fixing Bacterial of the Genus Rhizobium." Research bulletin of the Iowa Agricultural Experiment Station, no. 113 (1928): 373-406.
- Wallerstein, L. Enzyme preparations from microorganisms Ind. Eng. Chem., no. 31 (1939): 1218-24.

- Wallin, Ivan E. "A Note on the Morphology of Bacteria Symbiotic in the Tissues in Higher Organisms." Journal of Bacteriology 7 (1922): 471-4.
- Walling, Morton C. "Nature's Factories: Bacteria, Yeasts, and Molds, Revealed by Your Microscope." Popular Science Monthly 128 (May 1936): 44-45, 110-111.
- Ward, H.M. "On the Characters, or Markers, Employed for Classifying the Schizomycetes." Ann. of Botany 6 (1892): 103-.
- Ward, Archibald R. "The Invasion of the Udder by Bacteria." Bulletin of the New York (Cornell) Agricultural Experiment Station, no. 178 (1900).
- Warthin, Aldred S. The Creed of a Biologist; A Biologic Philosophy of Life. London: Constable, 1930.
- Waters, H.J. "The Duty of the Agricultural College." Science 30 (Decemberg 3 1909): 777-89.
- Webster, Edward H. "Some Important Factors in the Production of Sanitary Milk." Circular of Bureau of Animal Industry, no. 142 (January 23 1909): 161-78.
- Weiss, Harry. "Studies on the Paratyphoid Group and Antigenic and Cultural Differences in Strains of *B. Typhosus*." Proc. New York Pathological Society 16 (1916): 139-47.
- Welch, William H. "Bacteriological Investigations of Diphtheria in the United States." American Journal of Medical Science 57, no. n.s. (1894): 427-61.
- _____. "The Evolution of Modern Scientific Laboratories." Annual report of the board of regents of the Smithsonian Institution, July 1895, 498-500.
- _____. "Relations of Laboratories to Public Health." Public Health Papers and Reports 25 (1899): 460-5.
- _____. "The Interdependence of Medicine and Other Sciences." Nature 77 (January 23 1908): 283-5.
- Welch, William Henry. Papers and Addresses. Edited by Walter C. Burket. Vol. 3 vols. Baltimore: Johns Hopkins Press, 1920.
- Weldin, John C. "The Species of the Genus *Bacterium* Ehrenberg Emend. Jensen." In Masters Thesis, Iowa State College of Agriculture and Mechanical Arts, 1-42. 1921.
- Weldin, John C., and Max Levine. "An Artificial Key to the Species and Varieties of the Colon-typhoid or Intestinal Group of Bacilli." Abstracts of Bacteriology 7 (1923): 13-4.
- Weldin, John C. "The Colon-typhoid Group of Bacteria and Related Forms: Relationships and Classification." In Doctoral Thesis, Iowa State College. 1926.
- Wells, H. Gideon. "Education in Hospital and Laboratory." Bulletin, American Academy of Medicine 5 (1901): 540.

- Wells, P.A., and H.T. Herrick. "Citric Acid Industry." Ind. Eng. Chem. 30 (1938): 255-62.
- Wenner, John J., and Leo F. Rettger. "A Systematic Study of the Proteus Group of Bactericea." Journal of Bacteriology 4 (1919): 331-54.
- Wheeler, W.M. "The Dry Rot of Our Academic Biology." Science 57 (1923): 61-71.
- Whipple, George C. The Value of Pure Water. 1st ed. New York: J. Wiley and Sons, 1907.
- _____. Council on Health and Public Instruction. Pamphlets on the Communicable Diseases and Public Health. Vol. vol. 1, Pure Water. Chicago: American Medical Association, 1913.
- _____. "Broadening Science of Sanitation." The Atlantic Monthly 113 (1914): 630.
- _____. "The Element of Chance in Sanitation." Journal of the Franklin Institute, July and August 1916, 37-59, 206-228.
- White, David S. "Teaching Veterinary Medicine to Agricultural Students." Journal of the American Veterinary Medical Association 23 (November 1926): 185-95.
- Wilbur, Ray Lyman. "The Education of the Physician." Journal of Proceedings and Addresses, National Educational Association of the United States, 212-7. 1915.
- _____. A Philosophy of American Education. New York: National Industrial Conference Board, 1931.
- _____. "Medicine -- a Pace-maker for Civilization: Founder's Day Address 1932." Bulletin, Medical College of Virginia 29 (1932).
- _____. The March of Medicine: Selected Addresses and Articles on Medical Topics, 1913-1937. Stanford: Stanford University Press, 1939.
- Williams, Anna M. "Persistence of Varieties of *Bacillus Diphtheriae* and of the Diphtheria-like Bacilli." In Annual Report of the Board of Health of the Department of Health of the City of New York for the Year Ending December 31, 1902, 337-56. New York, 1904.
- Williams, Bruce. "The Effect of Certain Organic Soil Constituents on the Fixation of Nitrogen by Azotobacter." Science 42 (Sept. 3 1915): 320-1.
- Wilson, Edmund. "Aims and Methods of Study in Natural History." Science 13 (1901): 14-23.
- Wilson, J.K. "Physiological Studies of *Bacillus Radicicola* of Soybean (*Soja Max Piper*) and of Factors Influencing Nodules Production." Bulletin of the Cornell University Agricultural Experiment Station, no. 386 (January 1917): 369-412.
- Wilson, Perry W., and Edwin B. Fred. "The Growth Curve of a Scientific Literature." Scientific Monthly 41 (1935): 240-50.

- Wilson, Perry W. "Symbiotic Nitrogen Fixation by the Leguminosae." Botanical Review 3 (1937): 369-99.
- Winslow, C.-E.A., and Anne F. Rogers. "A Statistical Study of Generic Characters in the *Coccaceae*." Journal of Infectious Diseases 3 (1906): 546-.
- Winslow, C.-E.A., I.J. Kligler, and William Rothman. "Further Studies on the Colon-Typhoid Group of Bacteria." Abstracts of Bacteriology 1 (1917): 27-8.
- Winslow, C.-E.A., Jean Broadhurst, R.E. Buchanan, Charles, Jr. Krumwiede, L.A. Rogers, and G.H. Smith. "The Families and Genera of the Bacteria. Final Report of the Committee of the Society of American Bacteriologists on Characterization and Classification of Bacterial Types." Journal of Bacteriology 5 (May 1920): 191-229.
- Winogradsky, Sergei N. "The Direct Method in Soil Microbiology and Its Application to the Study of Nitrogen Fixation." Soil Science 24 (1928): 37-43.
- _____. "The Method in Soil Microbiology as Illustrated by Studies on Azotobacter and the Nitrifying Organisms." Soil Science 40 (1935): 59-76.
- _____. "The Doctrine of Pleomorphism in Bacteriology." Soil Science 43 (1937): 327-40.
- Winslow, C.-E.A. "The War Against Disease." Atlantic Monthly 91 (1903): 43.
- Winslow, C.-E.A., and Anne F. Rogers. "A Revision of the *Coccaceae*." Science 21 (March 31 1905): 486-7.
- Winslow, C.-E.A., and Anne F. Rogers. "Generic Characters in the *Cocaccaeae*." Science 25 (May 24 1907): 813-4.
- Winslow, Charles-Edward Amory, and Anne Rogers Winslow. The Systematic Relationship of the *Coccaceae*, with a Discussion of the Principles of Bacterial Classification. New York: John Wiley & Sons, 1908.
- Winslow, C.-E.A. "A Statistical Criterion for Species and Genera Among the Bacteria." Bulletin of the Torrey Botanical Club 36 (Jan. 29 1909): 31-9.
- Winslow, C.-E.A., and L.T. Walker. "A Case of Non-inheritance of Fluctuating Variations Among Bacteria." Journal of Infectious Diseases 6 (1909): 90-.
- Winslow, C.-E.A. "Bacteria in Sewer Air." American Journal of Public Hygiene 19 (Aug. 1909): 640-.
- Winslow, C.-E.A. "The Foundations of Heredity." Dial 47 (1909): 282.
- Winslow, C.-E.A., and G.T. Palmer. "A Comparative Study of Fecal *Streptococci* from the Horse, the Cow and Man." American Journal of Public Health 20, no. Aug. (1910): 661-.

- Winslow, C.-E.A. "Bacteriological Museum and Bureau for the Distribution of Bacterial Cultures." Journal of the American Public Health Association 1 (1911): 152.
- _____. "A Bacteriological Museum and Bureau of the Exchange of Bacterial Cultures at the American Museum of Natural History." Science 33 (April 7 1911): 539.
- _____. "The Classification of the *Streptococci* by Their Action Upon Carbohydrates and Related Organic Media." Journal of Infectious Diseases 10 (May 1912): 285-93.
- Winslow, C.-E.A., and I.J. Kligler. "A Quantitative Study of the Bacteria in City Dust with Special Reference to Intestinal and Buccal Forms." American Journal of Public Health 2 (Sept. 1912): 663-.
- Winslow, C.-E.A. "The Classification of the *Streptococci* by Their Action Upon Carbohydrate Media." Science 35 (1912): 222-3.
- _____. "Bacteriological Collection and Bureau for the Distribution of Bacterial Cultures at the American Museum of Natural History." Science 38 (1913): 374-5.
- _____. "Efficiency in the Public Health Campaign." Heath News Supp. June 1914.
- Winslow, C.E.-A. "The Characterization and Classification of Bacterial Types." Science 39 (January 16 1914): 77-90.
- Winslow, C.-E.A. "Public Health Education in the United States." Journal of the Royal Sanitary Institute 35 (1914): 263.
- _____. "The Neutrality of the Churches in the War Against Disease." Constructive Quarterly 3 (1915): 834-.
- Winslow, Charles -E. A. "The Laboratory in the Service of the State." American Journal of Public Health 6 (1916): 222-33.
- Winslow, C.-E.A. "A Garden of Germs: Museum of Living Bacteria a Unique Public Service." American Museum Journal 16 (May 1916): 295-300.
- Winslow, C.-E.A., and I.J. Kligler. "Studies on the Classification of the Colon-Typhoid Group." Journal of Bacteriology 1 (1916): 81.
- Winslow, C.-E.A. "Organization a State Campaign of Public Health Education." American Journal of Public Health 6 (1916): 805-.
- _____. Handbook of Health in War and Peace: A Manual of Personal Preparedness. New York: Depts. of Public Health and Public Education of the American Museum of Natural History, 1917.
- Winslow, C.-E.A., Jean Broadhurst, Robert E. Buchanan, Charles Jr. Krumwiede, L.A. Rogers, and George H. Smith. "The Families and Genera of the Bacteria: Preliminary Report of the

- Committee on Characterization and Classification of Bacterial Types." Journal of Bacteriology 2 (1917): 505-66.
- Winslow, C.-E.A., Jean Broadhurst, R.E. Buchanan, C. Krumwiede, L.A. Rogers, and G.H. Smith. "The Families and Genera of the Bacteria. Report of the Committee on Characterization and Classification of Bacterial Types." Abstracts of Bacteriology 1 (1917): 25-6.
- Winslow, C.-E.A., Jean Broadhurst, Robert E. Buchanan, Charles Jr. Krumwiede, L.A. Rogers, and George H. Smith. "The Families and Genera of the Bacteria: Preliminary Report of the Committee on Characterization and Classification of Bacterial Types." Journal of Bacteriology 2 (1917): 505-66.
- Winslow, C.-E.A., and David Greenberg. "The Effect of Putrefactive Odors Upon Growth and Upon Resistance to Disease." American Journal of Public Health 8 (Oct. 1918): 759-.
- Winslow, C.-E.A., I.J. Kligler, and William Rothberg. "Studies on the Classification of the Colon Typhoid Group of Bacteria with Special Reference to Their Fermentative Reactions." Journal of Bacteriology 4 (1919): 429-503.
- Winslow, Charles -E.A. Healthy Living. New York: Charles E. Merrill Company, 1920.
- Winslow, C.-E.A., W. Rothberg, and Elizabeth I. Parsons. "Notes on the Classification of White and Orange *Staphylococci*." Journal of Bacteriology 5 (1920): 145-67.
- Winslow, C.-E.A., Jean Broadhurst, R.E. Buchanan, Charles, Jr. Krumwiede, L.A. Rogers, and G.H. Smith. "The Families and Genera of the Bacteria. Final Report of the Committee of the Society of American Bacteriologists on Characterization and Classification of Bacterial Types." Journal of Bacteriology 5 (May 1920): 191-229.
- Winslow, C.-E.A. "The Importance of Preserving the Original Types of Newly Described Species of Bacteria." Journal of Bacteriology 6 (1921): 133-4.
- _____. "The Recruiting of Sanitarians for the Future Service of the State." American Journal of Public Health 13 (May 1923): 355-.
- Winslow, Charles -E.A. Man and the Microbe: How Communicable Diseases Are Controlled. New York and London: Funk & Wagnalls Co., 1924.
- Winslow, C.-E.A. "Public Health at the Crossroads." American Journal of Public Health 16, no. 11 (November 1926): 869-72.
- _____. "What Do We Mean by a Bacterial Life Cycle." Science 81 (1935): 314-5.
- Winters, S.R. "Who's Who in the U.S. Dairy Division." Hoard's Dairyman 63 (February 10 1922): 108-9.
- Wisehart, M.K. "Take a Census of Your Microbes: Interview with Robert T. Morris." American

Magazine 89 (April 1920): 72-3.

Withers, W.A. "The Formation of Nitrates in the Soil." Bulletin of the North Carolina Agricultural Experiment Station, no. 190 (May 1905): 3-8.

Woodhead, G. Sims. Bacteria and Their Products. In Contemporary Science Series. New York: Scribner and Sons, 1891.

Woods, Albert F. "Inoculation of Soil with Nitrogen-fixing Bacteria." Bulletin of the Bureau of Plant Industry, no. 72 (May 25 1905): 3-10.

_____. "The Present Status of the Nitrogen Problem." In United States Department of Agriculture, Yearbook, 1906, 125-35. Washington: USDA, 1906.

Woodward, W.C. "Some Problems in Municipal Sanitation." Journal of Social Science 40 (1902): 133-9.

Young, Clifford C. "Bergey's Manual of Determinative Bacteriology -- Review." American Journal of Public Health 16 (1926): 520-1.

Zhaled, A. "A Comparative Study of Bovine Abortion and Undulant Fever, from the Bacteriological Point of View." Journal of Hygiene 20 (1921): 319-.

Zinsser, Hans. "A Study of the Diphtheria Group of Organisms with Special Reference to Fermentation Reactions." Journal of Medical Research 17 (1907): 277.

_____. "The Control of Infectious Diseases in Industrial Communities." Journal of Industrial Hygiene 1 (1919-1920): 501.

_____. "Problems of the Bacteriologist in His Relation to Medicine and Public Health." Journal of Bacteriology 13 (1927): 147-62.

_____. "The Next Twenty Years." Science 74 (1931): 397.

_____. "On Postulates of Proof in Problems of the Bacterial Life Cycle." Science 75 (1932): 256.

Zinsser, Hans, and E.B. Wilson. "Bacterial Dissociation and a Theory of the Rise and Decline of Epidemic Waves." Journal of Preventative Medicine 6 (1932): 497.

BACTERIOLOGY TEXTBOOKS AND MANUALS

- Abbott, Alexander C. The Principles of Bacteriology: A Practical Manual for Students and Physicians. 1st ed. Philadelphia: Lea Brothers & Co., 1892.
- _____. The Principles of Bacteriology: A Practical Manual for Students and Physicians. 3rd ed., enl. and thor. rev. Philadelphia: Lea Brothers & Co., 1895.
- _____. The Hygiene of Transmissible Diseases: Their Causation, Modes of Dissemination, and Methods of Prevention. 1st ed. Philadelphia: W.B. Saunders Company, 1899.
- _____. The Principles of Bacteriology: A Practical Manual for Students and Physicians. 5th ed., enl. and thor. rev. Philadelphia: Lea Brothers & Co., 1899.
- _____. The Hygiene of Transmissible Diseases: Their Causation, Modes of Dissemination, and Methods of Prevention. 2nd ed., rev. & enl. Philadelphia: W.B. Saunders Company, 1901.
- _____. The Principles of Bacteriology: A Practical Manual for Students and Physicians. 7th ed. Philadelphia: Lea Brothers & Co., 1905.
- _____. The Principles of Bacteriology: A Practical Manual for Students and Physicians. 9th ed., thor. rev. Philadelphia: Lea Brothers & Co., 1915.
- Allen, Paul W. Industrial Fermentations. New York: Chemical Catalogue Co., 1926.
- Allen, Paul W., and D. Frank Holtman. Food Microbiology: Laboratory Manual. 2nd ed. n.p., 1932.
- Allen, Paul W., and George M. Cameron. Microbiology Laboratory Manual. 2nd ed. St. Louis: C.V. Mosby Co., 1935.
- Anderson, Cameron G. An Introduction to Bacteriological Chemistry . Baltimore: W. Wood & Co., 1938.
- Andress, Frank J. A Laboratory Manual for Public Health Students: Practical Chemical and Bacteriological Examination of Water, Food, Milk, and Disinfectants, Including Some of the Simpler Procedures of Toxicological Examinations. Ann Arbor, MI: Edwards Brothers, 1933.
- Bartles, Henry A. Outline of Bacteriology. New York: William Albert Broder, 1929.

- Batson, Herbert C. Laboratory Procedures in Bacteriology, Burgess. Minneapolis, 1936.
- Belding, David L., and Alice T. Marston. A Manual of Medical Bacteriology. Boston: unpublished, 1934.
- Belding, David L., Alice T. Marston, and Boston University School of Medicine. A Textbook of Medical Bacteriology. New York: D. Appleton-Century Co., 1938.
- Bergey, David, Francis C. Harrison, Robert C. Breed, Bernard W. Hammer, and Frank M. Huntoon. Bergey's Manual of Determinative Bacteriology: A Key for the Identification of Organisms of the Class Schizomycetes. 1st ed. Baltimore: Williams & Wilkins Co., 1923.
- Bergey, David H. Handbook of Practical Hygiene. Easton, PA: The Chemical Publishing Co., 1899.
- _____. The Principles of Hygiene: A Practical Manual for Students, Physicians, and Health Officers. Philadelphia: W.B. Saunders, 1901.
- _____. The Principles of Hygiene: A Practical Manual for Students, Physicians, and Health-officers. 6th ed., thor. rev. Philadelphia: W.B. Saunders Co., 1918.
- Bergey, David H., Francis C. Harrison, Robert S. Breed, Bernard W. Hammer, and Frank M. Huntoon. Bergey's Manual of Determinative Bacteriology: A Key for the Identification of Organisms of the Class Schizomycetes. 2nd ed. Baltimore: Williams and Wilkins, 1925.
- Bigger, Joseph W. Handbook of Bacteriology for Students and Practitioners of Medicine. 1st ed. London: Bailliere, Tindall and Cox, 1925.
- _____. Handbook of Bacteriology for Students and Practitioners of Medicine. 2nd ed. London: Bailliere, Tindall and Cox, 1929.
- Billings, Frederick H. Laboratory Exercises in Bacteriology and Diagnostic Methods. 1st ed. Madison, WI: State Journal Printing Co., 1913.
- Billings, Frederick H., Benjamin J. Clawson, and Noble P. Sherwood. Laboratory Exercises in Bacteriology. 3rd ed. Lawrence: The World Co., 1927.
- Birge, Edward Asahel. Synopsis of a Course of University Extension Lectures on Bacteriology. Madison: State Journal Printing Company, 1892.
- Bolduan, Charles F., and Marie Grund. Applied Bacteriology for Nurses. Philadelphia and London: W.B. Saunders Co., 1913.
- Bolduan, Charles F. Public Health and Hygiene: A Students Manual. Philadelphia and London: W.B. Saunders Co., 1929.
- Bowhill, Thomas. Manual of Bacteriological Technique and Special Bacteriology. New York: W. Wood & Co., 1899.

- _____. Manual of Bacteriological Technique and Special Bacteriology. 2nd rev. ed. New York: W. Wood & Co., 1902.
- _____. Manual of Bacteriological Technique and Special Bacteriology. 2nd ed., enl. and thor. rev. New York: W. Wood & Co., 1902.
- Broadhurst, Jean. Home and Community Hygiene: A Textbook of Personal and Public Health. Philadelphia: Lippincott, 1918.
- _____. Outline of an Elementary Course in Microbiology. New York: Columbia University Teachers' College, 1918.
- _____. Bacteria in Relation to Man: A Study-text in General Microbiology. Philadelphia: J.P. Lippincott Company, 1925.
- Broadhurst, Jean, and L.I. Given. Bacteriology Applied to Nursing: A Combined Textbook and Laboratory Guide in Microbiology. Philadelphia: Lippincott, 1930.
- Browning, Carl H. Bacteriology. In Home University Library of Modern Knowledge, No. 112. New York: H. Holt & Co., 1925.
- Buchanan, Estelle, and Robert Buchanan. Household Bacteriology for Students in Domestic Science. 1st ed. New York: Macmillan Company, 1913.
- Buchanan, Estelle D.F., and Robert E. Buchanan. Bacteriology for Students in General and Household Science. Rev. ed. New York: Macmillan Co., 1924.
- _____. Bacteriology for Students in General and Household Science. 3rd ed. New York: Macmillan Co., 1933.
- _____. Bacteriology for Students in General and Household Science. 4th ed. New York: Macmillan Co., 1938.
- Buchanan, Robert E. Veterinary Bacteriology: A Treatise on the Bacteria, Yeasts, Molds, and Protozoa Pathogenic for Domestic Animals. 1st. ed. Philadelphia: W.B. Saunders Company, 1911.
- Buchanan, Robert E., and Charles Murray. Veterinary Bacteriology: A Treatise on the Bacteria, Yeasts, Molds, and Protozoa Pathogenic for Domestic Animals. 2nd., thor. rev. Philadelphia: W.B. Saunders, 1916.
- Buchanan, Robert E. Agricultural and Industrial Bacteriology. Reprint ed. 1924. New York: D. Appleton and Co., 1921.
- _____. General Systematic Bacteriology: History, Nomenclature, Groups of Bacteria. In (Society of American Bacteriologists. Monographs on Systematic Bacteriology, Vol. 1). Baltimore: Williams & Wilkins, 1925.

- Buchanan, Robert E., and Ellis I. Fulmer. Physiology and Biochemistry of Bacteria. Vol. 3 vols. Baltimore: Williams and Wilkins, 1928-1930.
- Burdon, Kenneth L. A Textbook of Bacteriology. 1st ed. New York: The Macmillan Co., 1932.
- Burgess, Paul S. Soil Bacteriology Laboratory Manual. Easton, PA: The Chemical Publishing Co., 1914.
- Burkett, Charles W., Frank L. Stevens, and Daniel H. Hill. Agriculture for Beginners. Boston: Ginn & Co., 1903.
- Burkett, Charles W. Soils: Their Properties, Improvement, Management, and the Problems of Crop Growing and Crop Feeding. New York: Orange Judd Copmany, 1908.
- Castellani, Aldo, and Albert J. Chalmers. A Manual of Tropical Medicine. 3rd. ed. New York: William Wood and Co., 1919.
- Chester, Frederick D. A Manual of Determinative Bacteriology. New York: Macmillan & Co., 1901.
- Clark, Paul Franklin, and Frances E. Holford. Laboratory Outline in Medical Bacteriology for the University of Wisconsin. Madison: University of Wisconsin, 1936.
- Conn, Harold J. An Elementary Laboratory Guide in General Bacteriology. Baltimore: Williams and Wilkins, 1927.
- Conn, Herbert W. Agricultural Bacteriology: A Study of the Relation of Bacteria to Agriculture, with Special Reference to the Bacteria in the Soil, in Water, in the Dairy, in Miscellaneous Farm Products, and in Plants and Domestic Animals. Philadelphia: P. Blakiston's Son & Co., 1901.
- _____. Bacteria, Yeasts, and Molds in the Home. Boston: Ginn and Company, 1903.
- _____. Bacteria in Milk and Its Products: Designed for the Use of Students in Dairying and for All Others Concerned in the Handling of Milk, Butter or Cheese. Philadelphia: P. Blakiston's Sons, 1903.
- _____. Practical Dairy Bacteriology: Prepared for the Use of Students, Dairymen, and All Interested in the Problems of the Relation to Milk to Public Health. New York: O. Judd Company, 1907.
- _____. Agricultural Bacteriology: A Study of the Relation of Germ Life to the Farm with Laboratory Experiments for Students: Microorganisms of Soil, Fertilizers, Sewage, Water, Dairy Products, Miscellaneous Farm Products and of Diseases of Animals and Plants. 2nd. ed., rev. and enl. Philadelphia: P. Blakiston's Sons, 1909.
- _____. Biology: An Introductory Study for Use in Colleges. Boston, New York: Silver, Burdett and Co., 1912.
- _____. Bacteria, Yeasts, and Molds in the Home. Rev. ed. Boston: Ginn and Company, 1912.

Conn, Herbert W., and Harold J. Conn. Bacteriology: A Study of Microorganisms and Their Relation to Human Welfare, Discussion the History of Bacteriology, the Nature of Microorganisms, and Their Significance in Connection with Pathology, Hygiene, Agriculture and the Industries. Baltimore: Williams and Wilkins, 1923.

. Bacteriology: A Study of Microorganisms and Their Relation to Human Welfare, Discussing the History of Bacteriology, the Nature of Microorganisms, and Their Significance in Connection with Pathology, Hygiene, Agriculture and the Industries. 3rd ed. Baltimore: Williams & Wilkins, 1926.

Councilman, William T. Disease and Its Causes. New York: H. Holt & Co., 1913.

Crookshank, Edgar M. Manual of Bacteriology. 2nd ed., rev. and enl. New York: J.H. Vail and Co., 1887.

Cunningham, Andrew. Practical Bacteriology: An Introductory Course for Students of Agriculture. Edinburgh: Oliver and Boyd, 1934.

Curtis, Edward. Nature and Health: A Popular Treatise on the Hygiene of the Person and the Home. New York: H. Holt and Co., 1906.

Cutler, D. Ward, and M. Crump Lettice. Problems in Soil Microbiology. In Rothamsted Monographs on Agricultural Science. London: Longmans, Green and Co., 1935.

Davis, James W. Notes on Bacteriology. Charlotte, N.C.: Queen City Printing Co., 1927.

. Notes on Bacteriology. 2nd ed. Charlotte, N.C.: Lassiter, 1937.

Detmers. Contagious Diseases of Domesticated Animals. Washington, D.C.: GPO/USDA, 1881.

Dible, James H. Recent Advances in Bacteriology. Philadelphia: Blakiston, 1929.

Duckwall, Edward W. Bacteriology Applied to the Canning and Preserving of Food Products. Baltimore: The Trade, 1899.

. Canning and Preserving of Food Products with Bacteriological Technique: A Practical and Scientific Handbook for Manufacturers of Food Products, Bacteriologists, Chemists and Students of Food Problems, Also for Processors and Managers of Food Product Manufactories. Pittsburgh: Pittsburgh Printing Co., 1905.

Dukes, Cuthbert. The Bacteriology of Food. London: H.K. Lewis & Co., Ltd., 1925.

Eisenberg, Arthur A. Principles of Bacteriology. 4th ed. St. Louis: C.V. Mosby Co., 1928.

Eisenberg, James. Bacteriological Diagnosis: Tabular Aids for Use in Practical Work. Philadelphia: F.A. Davis Co., 1892.

- Elliott, Charlotte. Manual of Bacterial Plant Pathogens. Baltimore: Williams & Wilkins Co., 1930.
- Ellis, David. Outlines of Bacteriology: Technical and Agricultural. London, New York, Bombay and Calcutta: Longmans, Green and Co., 1909.
- Emerson, Paul. Principles of Soil Technology. New York: Macmillan Co., 1930.
- Ernst, Wilhem, and John Mohler. Text-book of Milk Hygiene. Chicago: A. Eger, 1915.
- Eyre, John W.H. The Elements of Bacteriological Technique: A Laboratory Guide for the Medical, Dental, and Technical Student. Philadelphia: W.B. Saunders, 1903.
- _____. The Elements of Bacteriological Technique: A Laboratory Guide for the Medical, Dental, and Technical Student. 2nd ed., rev. and enl. Philadelphia: W.B. Saunders Co., 1915.
- _____. Bacteriological Technique: A Laboratory Guide for Medical, Dental, and Technical Students. 3rd ed. New York: William Wood, 1930.
- Feinblatt, Henry M., and Arnold H. Eggerth. Clinical Laboratory Medicine: A Text-book of Clinical Laboratory Diagnostic and Therapeutic Procedures. New York: W. Wood and Co., 1925.
- Ferguson, Alexander M. Elementary Principles of Agriculture: A Text-book for the Common Schools. Sherman, TX: Ferguson Publishing Co., 1909.
- Fischer, Alfred. The Structure and Functions of Bacteria. Edited by A. Coppen, trans. Jones. Oxford: Clarendon Press, 1900.
- Ford, William W. Text-book of Bacteriology. Philadelphia: W.B. Saunders Co., 1927.
- Fowler, Gilbert J. An Introduction to the Bacteriological and Enzyme Chemistry. New York: Longmans, Green, 1911.
- Frankland, Percy F. Micro-organisms in Water: Their Significance, Identification and Removal, Together with an Account of the Bacteriological Methods Employed in Their Investigation. London: Longmans, Green, 1894.
- Fraps, G.S. Principles of Agricultural Chemistry. Easton, PA: The Chemical Publishing Co., 1913.
- Fred, Edwin B. A Laboratory Manual of Soil Bacteriology. Philadelphia and London: W.B. Saunders Co., 1916.
- Fred, Edwin Broun, and Selman A. Waksman. Laboratory Manual of General Microbiology, with Special Reference to the Microorganisms of the Soil. 1st ed. New York: McGraw-Hill, 1928.
- Freudenreich, Eduard von, and James Richard trans. Ainsworth-Davis. Dairy Bacteriology: A Short Manual for the Use of Students in Dairy Schools, Cheese-makers and Farmers. In Translation of Die Bakteriologie in der Milchwirtschaft. London: Methuen & Co., 1895.

- Frost, William D. A Laboratory Guide in Elementary Bacteriology. Madison, WI: Tracy, Gibbs & Co., and author, 1901.
- Frost, William D., and Mildred A. Engelbrecht. The Streptococci: Their Descriptions, Classification, and Distribution, with Special Reference to Those in Milk. Madison: Willdof Book Company, 1940.
- Frost, William Dodge. A Laboratory Guide in Elementary Bacteriology. 2nd ed. Madison: M.J. Cantwell Printers, 1902.
- _____. A Laboratory Guide in Elementary Bacteriology. 3rd ed. New York: MacMillan Company, 1903.
- Frost, William Dodge, and Eugene Franklin McCampbell. A Text-book of General Bacteriology. New York: Macmillan Company, 1910.
- Frost, William Dodge. A Laboratory Guide in Elementary Bacteriology. 5th rev. ed. New York: Macmillan Company, 1913.
- Gaiger, Sydney H., and Gwilym O. Davies. Veterinary Pathology and Bacteriology. London: Bailliere, Tindall and Cox, 1932.
- Galloway, Leslie D., and Robert Burgess. Applied Mycology and Bacteriology. In The Modern Chemical Industries Series. London: Leonard Hill, 1938.
- Gardner, Arthur D. Microbes and Ultramicrobes: An Account of Bacteria, Viruses and the Bacteriophage. London: Methuen, 1931.
- Gay, Frederick P., Karl F. Meyer, and Glanville Y. Rusk. Outline of Combined Courses in Pathology, Including Bacteriology and Protozoology, Infection and Immunity, Experimental Pathology, Histopathology and Morbid Anatomy. In University of California Syllabus Series, No. 61. Berkeley: University of California Press, 1915.
- Gay, Frederick P. Laboratory Manual in Medical Bacteriology. Edited by College of Physicians and Surgeons, Columbia University Staff of the Dept. of Bacteriology. 2nd ed. New York: James T. Dougherty, 1926.
- Gershenfeld, Louis. Bacteriology and Sanitary Science for Students in Pharmacy, Chemistry and Allied Sciences. Philadelphia: Lea & Febiger, 1929.
- _____. Bacteriology and Sanitary Science for Students in Pharmacy, Chemistry and Allied Sciences. 2nd ed., thoroughly rev. Philadelphia: Lea & Febiger, 1933.
- Giltner, Ward. Laboratory Manual in General Microbiology. New York: John Wiley & Sons, 1916.
- _____. Laboratory Manual in General Microbiology. In Wiley Technical Series for Vocational and Industrial Schools. Edited by Michigan State College of Agriculture and Applied Science

- Laboratory of Bacteriology and Hygiene. 3rd ed. New York: John Wiley & Sons, 1926.
- _____. An Elementary Text-book of General Microbiology. Philadelphia: P. Blakiston's Sons & Co., 1928.
- Giordano, Alfred S. "Studies in Postmortem Bacteriology." Minneapolis: n.p., 1922.
- Gorham, Frederic P. A Laboratory Course in Bacteriology: Prepared for the Use of Students in Brown University. Providence: Independent Citizen Press, 1897.
- _____. A Laboratory Course in Bacteriology, for the Use of Medical, Agricultural, and Industrial Students. Philadelphia: W.B. Saunders, 1901.
- Greaves, Joseph E. Agricultural Bacteriology. Philadelphia: Lea & Febiger, 1922.
- Greaves, Joseph E., and Ethelyn O. Greaves. Bacteria in Relation to Soil Fertility. New York: D. Van Nostrand Co., 1925.
- _____. Elementary Bacteriology. Philadelphia: W.B. Saunders, 1928.
- _____. Elementary Bacteriology. 2nd ed. Philadelphia: W.B. Saunders Co., 1932.
- Guiteras, Juan, and Joseph F. McFarland. Notes on the Lectures of Prof. John Guiteras on General and Special Pathology: Delivered Before the Second and Third Year Students of the University of Pennsylvania, and on the Lectures of Dr. Joseph McFarland on Bacteriology, Delivered Before the Third Year Class. Edited by William Carter. Philadelphia: Avil Printing Co., 1895.
- Hagan, William A., and Alexander Zeissig. A Laboratory Manual in General and Pathogenic Bacteriology and Immunity. Ann Arbor: Edwards Brothers, Inc., 1933.
- Halvorson, Halvor Orin, and Newell R. Ziegler. Quantitative Bacteriology. Minneapolis: Burgess, 1933.
- Hammer, Bernard W. Dairy Bacteriology. In Wiley Agricultural Series. New York: J. Wiley & Sons, 1928.
- Harrington, Charles. A Manual of Practical Hygiene: For Students, Physicians and Medical Officers. 1st ed. Philadelphia and New York: Lea Brothers & Co., 1901.
- Hastings, Edwin G., and William H. Wright. A Laboratory Manual of General Agricultural Bacteriology. 2nd rev. ed. Madison: Grimm Book Bindery, 1911.
- _____. A Laboratory Manual of General Agricultural Bacteriology. 1st ed. Madison: Grimm Book Bindery, 1913.
- _____. A Laboratory Manual of General Agricultural Bacteriology. 3rd rev. ed. Madison: Grimm Book Bindery, 1915.

Hastings, Edwin G., Ira L. Baldwin, and Harry E. Sagen. A Laboratory Manual of General Agricultural Bacteriology. 4th ed. Madison, Wisc.: Grimm Book Bindery, 1930.

Heald, Frederick D. Manual of Plant Diseases. 1st ed. New York: McGraw-Hill, 1926.

_____. Introduction to Plant Pathology. New York: McGraw-Hill, 1937.

Heinemann, Paul G. A Laboratory Guide in Bacteriology, for the Use of Students, Teachers, and Practitioners. 1st ed. Chicago: University of Chicago Press, 1905.

_____. A Laboratory Guide in Bacteriology, for the Use of Students, Teachers, and Practitioners. 2nd rev. ed. Chicago: University of Chicago Press, 1911.

_____. A Laboratory Guide in Bacteriology, for the Use of Students, Teachers, and Practitioners. 3rd rev. ed. Chicago: University of Chicago Press, 1915.

Henrici, Arthur T. Molds, Yeasts, and Actinomycetes: A Handbook for Students of Bacteriology. New York: J. Wiley & Sons, 1930.

_____. The Biology of Bacteria: An Introduction to General Microbiology. Boston, New York: D.C. Heath and Co., 1934.

Heuppe, Ferdinand, and Herman M. (trans.) Biggs. The Methods of Bacteriological Investigation. New York: D. Appleton and Company, 1890.

Heuppe, Ferdinand. The Principles of Bacteriology. Chicago: Open Court, 1899.

Hewlett, Richard T. A Manual of Bacteriology: Clinical and Applied. 8th ed. London: Churchill, 1926.

Hewlett, Richard T., and James McIntosh. A Manual of Bacteriology, Medical and Applied. 9th ed. London: J. & A. Churchill, 1932.

Hill, Hibbert W. The New Hygiene for Schools of Nursing, Normal Schools, and Colleges. New York: Macmillan Co., 1924.

Hilliard, Curtis M. A Textbook of Bacteriology and Its Applications. New York: Ginn and Co., 1928.

_____. The Prevention of Disease in the Community. New York: McGraw-Hill Co., 1931.

Hiss, Philip H., and Hans Zinnser. A Text-book of Bacteriology: A Practical Treatise for Students and Practitioners of Medicine. 4th ed. New York: D. Appleton and Co., 1918.

Holt, Emily. The Complete Housekeeper. Garden City: Doubleday, Page & Co., 1917.

Hopkins, Cyril G., and James H. Pettit. Soil Fertility Laboratory Manual. Boston: Ginn and Company, 1910.

- Hopkins, Cyril G. Soil Fertility and Permanent Agriculture. Boston: Ginn and Company, 1910.
- Howe, Eugene C. Syllabus of Personal Hygiene. Concord, N.H.: The Rumford Printing Co., 1914.
- Hunwicke, Robert F. The Essentials of Bacteriological Technique. London: William and Norgate Ltd., 1931.
- Hunziker, Otto F. The Butter Industry: Prepared for the Use of Creameries, Dairy Students and Pure Food Departments. 1st. ed. La Grange, Ill.: by author, 1920.
- Jensen, C.O., and Leonard Person. Essentials of Milk Hygiene: A Practical Treatise on Dairy and Milk Inspection and On the Hygienic Production and Handling of Milk, for Students of Dairying and Sanitarians. Philadelphia: J.B. Lippincott Co., 1907.
- Jewett, Mrs. Frances G. Physiology, Hygiene and Sanitation. In The Gulick Hygiene Series. Boston: Ginn & Co., 1916.
- Johnston, J.H., and R.H. Simpson. The Principles of Practical Bacteriology: For Scientific Workers. London: Churchill, 1927.
- Jordan, Edwin O. A Text-book of General Bacteriology. 1st ed. Philadelphia: W.B. Saunders Co., 1908.
- _____. Food Poisoning and Food-borne Infection. In The University of Chicago Science Series. Chicago: University of Chicago Press, 1917.
- _____. A Text-book of General Bacteriology. 7th ed., thor. rev. Philadelphia: W.B. Saunders Co., 1921.
- _____. A Textbook of General Bacteriology. 9th ed., thor. rev. Philadelphia: W.B. Saunders Co., 1928.
- _____. A Textbook of General Bacteriology. 11th ed. Philadelphia: W.B. Saunders Co., 1935.
- Kelser, Raymond A. Manual of Veterinary Bacteriology. 1st ed. Baltimore: Williams and Wilkins, 1927.
- _____. Manual of Veterinary Bacteriology. 3rd ed. Baltimore: Williams and Wilkins Co., 1938.
- Kendall, Arthur I. Bacteriology: General, Pathological, and Intestinal. 3rd ed. Philadelphia: Lea and Febiger, 1928.
- King, Walter E. Synopsis of Lectures, Bacteriology I, for Students in the General Fundamental Course. Manhattan: Kansas State Agricultural College, 1909.
- Kluyver, Albert J. The Chemical Activities of Micro-organisms. London: University of London Press, 1931.
- Knowles, Neale S. "Principles of Domestic Science, Applied to Preparation of Food." Commonwealth of Pennsylvania, Dept. of Agriculture, Bulletin no. 188 Harrisburg: C.E. Aughinbaugh, State

Printer, 1909

- Koser, Stewart A. Laboratory Directions for General Bacteriology. Ann Arbor, Mich: Edwards Bros., 1932.
- Lehman, Karl B., and R.O. Neumann. Bacteriology: Especially Determinative Bacteriology. In Trans. Robert S. Breed, 2 Vols. 7th ed. New York: Stechert, 1930.
- Lehmann, Karl B., and R.O. Neumann. Atlas and Principles of Bacteriology and Textbook of Special Bacteriologic Diagnosis. Edited by G.H., trans. Weaver. 2nd ed. Philadelphia: W.B. Saunders & Co., 1901.
- Levine, Max. An Introduction to Laboratory Technique in Bacteriology. New York: Macmillan, 1928.
- Levine, Max, and Henry W. Schoenlein. A Compilation of Culture Media for the Cultivation of Microorganisms. In Monographs on Systematic Bacteriology. Baltimore: Williams and Wilkins, 1930.
- Lewis, Isaac McKinney. A Laboratory Manual of General Bacteriology. 1st ed. Austin: University of Texas, 1929.
- Lipman, Jacob G., and Percy E. Brown. A Laboratory Guide in Soil Bacteriology. n.p., 1911.
- Lohnis, Felix, William Stevenson, and J. Hunter Smith. Laboratory Methods in Agricultural Bacteriology. London: Charles Griffin and Co., 1913.
- Lohnis, Felix, and Edwin B. Fred. Textbook of Agricultural Bacteriology. New York: McGraw-Hill Book Co., 1923.
- Lutman, Benjamin F. Microbiology. 1st ed. New York: McGraw-Hill, 1929.
- Mackie, T.J., and J.E. McCartney. An Introduction to Practical Bacteriology as Applied to Medicine and Public Health: A Guide to Bacteriological Laboratory Work for Students and Practitioners of Medicine. 1st ed. New York: William Wood, 1925.
- Mackie, Thomas J., and J.E. McCartney. Handbook of Practical Bacteriology: A Guide to Bacteriological Laboratory Work. 4th ed. Edinburgh: E. & S. Livingstone, 1934.
- MacNeal, Ward. Pathogenic Micro-organisms: A Text-book of Microbiology for Physicians and Students of Medicine. 1st ed. Philadelphia: P. Blakiston's Son & Co., 1914.
- . Pathogenic Micro-organisms: A Text-book of Microbiology for Physicians and Students of Medicine. 2nd ed. Philadelphia: P. Blakiston's Son & Co., 1920.
- Marshall, Charles E. Microbiology for Agricultural and Domestic Science Students. 1st ed. Philadelphia: P. Blakiston's Son & Co., 1911.

- _____, ed. Microbiology: A Text-book of Microorganisms, General and Applied. 1st ed. Philadelphia: P. Blakiston's Son & Co., 1912.
- _____, ed. Microbiology: A Text-book of Microorganisms, General and Applied. 2nd ed., rev. and enl. Philadelphia: Blakiston's Son & Co., 1917.
- _____, ed. Microbiology: A Text-book of Microorganisms, General and Applied. 3rd ed., rev. and enl. Philadelphia: P. Blakiston's Son & Co., 1921.
- Mayo, Nelson S. The Care of Animals: A Book of Brief and Popular Advice on the Diseases and Ailments of Farm Animals. 1st ed. New York: The Macmillan Co., 1903.
- McBurney, Ralph. A Laboratory Manual of Bacteriology, Serology and Immunity for Medical Students. 3rd ed., rev. Ann Arbor: Edwards, 1926.
- McCoy, Elizabeth, and L.S. McClung. The Anaerobic Bacteria and Their Activities in Nature and Disease: A Subject Bibliography. Berkeley: University of California Press, 1939.
- McFarland, Joseph. A Text-book Upon the Pathogenic Bacteria, for Students of Medicine and Physicians. 1st ed. Philadelphia: W.B. Saunders Company, 1896.
- _____. A Text-book Upon the Pathogenic Bacteria, for Students of Medicine and Physicians. 4th ed. Philadelphia: W.B. Saunders Company, 1903.
- _____. A Text-book of Pathology for Practitioners and Students. 2nd ed., thoroughly revised. Philadelphia: W.B. Saunders Company, 1910.
- McFarland, Joseph F. Prophylaxis, Personal Hygiene, Civic Hygiene, Care of the Sick. Philadelphia: P. Blakiston's Sons, 1902.
- _____. Biology, General and Medical. 1st ed. Philadelphia: W.B. Saunders, 1910.
- Merriman, Mansfield. Elements of Sanitary Engineering. New York: Wiley, 1918.
- Moldavan, Andrew. Introduction to Food Bacteriology. Lancaster, PA: The Science Press Printing Company, 1934.
- Moore, Veranus A. The Pathology and Differential Diagnosis of Infectious Diseases of Animals. Ithaca: Taylor & Carpenter, 1902.
- _____. Synopsis of Lectures in Bacteriology. In Cornell University, Dept. of Comparative Pathology and Bacteriology. Ithaca: n.p., 1905.
- _____. The Infectious Diseases of Animals. Ithaca, NY: Taylor & Carpenter, 1906.
- Moore, Veranus A., and William A. Hagen. Laboratory Manual in General and Pathogenic Bacteriology and Immunity. Boston: Ginn, 1925.

- Moore, Veranus A. Diseases of Animals Communicable to Man, n.p., 1927.
- Moore, Veranus Alva. Laboratory Directions for Beginners in Bacteriology: An Introduction to Practical Bacteriology for Students and Practitioners of Comparative and of Human Medicine. 2nd ed., enlarged and revised. New York & Boston: Ginn & Company, 1901.
- _____. Principles of Microbiology: A Treatise on Bacteria, Fungi and Protozoa Pathogenic for Domesticated Animals. Ithaca: Carpenter & Company, 1912.
- Moore, Veranus Alva, and Clifford P. Fitch. Exercises in Bacteriology and Diagnosis for Veterinary Students and Practitioners. New York: Ginn & Company, 1914.
- Morrey, Charles B. The Fundamentals of Bacteriology. 1st ed. Philadelphia: Lea & Febiger, 1917.
- _____. The Fundamentals of Bacteriology. 2nd ed. Philadelphia: Lea & Febiger, 1921.
- _____. The Fundamentals of Bacteriology. 3rd ed. Philadelphia: Lea & Febiger, 1923.
- _____. Laboratory Exercises in General Bacteriology. 9th ed. Columbus: Ohio State University, 1925.
- Morse, Mary E. First Lesson in Bacteriology for Nurses. Philadelphia: W.B. Saunders, 1919.
- Mosselman, Gustave, and R.R. (trans.) Dinwiddie. Manual of Veterinary Microbiology. New York: W.R. Jenkins, 1895.
- Mudge, Courtland S., and Floyd R. Smith. A Fundamental Approach to Bacteriology. San Francisco: Stacey, 1939.
- Muir, Richard. Bacteriological Atlas. 1st ed. Edinburgh: E. & S. Livingstone, 1927.
- Muir, Sir Robert, and James Ritchie. Manual of Bacteriology. Edinburgh and London: Young J. Pentland, 1897.
- Nichols, Henry J., and Raymond A. Kelsler. Carriers of Infectious Diseases; a Manual of the Importance, Pathology, Diagnosis and Treatment of Human Carriers. Baltimore: Williams & Wilkins, 1922.
- Norton, John F., and I.S. Falk. Laboratory Outlines in Bacteriology and Immunology. Chicago: University of Chicago Press, 1926.
- Novy, Frederick G. Direction for Laboratory Work in Bacteriology. Ann Arbor: George Wahr, 1894.
- _____. Laboratory Work in Bacteriology. Ann Arbor: George Wahr, 1899.
- Nuttall, George H.F. Hygienic Measures in Relation to Infectious Disease. New York: G.P. Putnam's Sons, 1893.
- Obold, Walter L., and Margaret M. Diehm. Manual of Microbiology for the Study of Bacteria, Yeasts

- and Molds. Philadelphia: F.A. Davis, 1932.
- Orla-Jensen, Sigurd, and Paul S. translator Arup. Dairy Bacteriology. Philadelphia: Blakiston, 1921.
- Park, William H., and Arthur R. Guerard. Bacteriology in Medicine and Surgery: A Practical Manual for Physicians, Health Officers, and Students. New York, Philadelphia: Lea Brothers & Co., 1899.
- Park, William H., and Anna W. Williams. Pathogenic Microorganisms: A Practical Manual for Students, Physicians, and Health Officers. 4th ed. Philadelphia: Lea & Febiger, 1910.
- _____. Pathogenic Microorganisms: A Practical Manual for Students, Physicians, and Heal Officers. 5th ed. Philadelphia: Lea & Febiger, 1914.
- Park, William H., Anna W. Williams, and Charles Krumwiede. Pathogenic Microorganisms: A Practical Manual for Students, Physicians and Health Officers. 8th ed. Philadelphia: Lea & Febiger, 1924.
- Partridge, William. Aids to Bacteriology. In Students' Aid Series. 5th ed. London: Bailliere, Tindall and Cox, 1930.
- Peltier, George L., Carl E. Georgi, and Lawrence F. Lindgren. Laboratory Manual for General Bacteriology. 2nd ed. New York: J. Wiley & Sons, Inc., 1939.
- Percival, John. Agricultural Bacteriology, Theoretical and Practical. London: Duckworth, 1910.
- Piccoli, Leonard J. Laboratory Technic in Bacteriology and Clinical Microscopy, Including the Microbiology of Foods. New York: Fordham University, College of Pharmacy, 1930.
- Pitfield, Robert L., and Howard W. (after 1930) Schaeffer. A Compend on Bacteriology Including Animal Parasites. 1st ed. Philadelphia: P. Blakiston's Son and Co., 1907.
- Prescott, Samuel C., and C.-E.A. Winslow. Elements of Water Bacteriology, with Special Reference to Sanitary Water Analysis. New York: J. Wiley & Sons, 1904.
- _____. Elements of Water Bacteriology, with Special Reference to Sanitary Water Analysis. 2nd ed., rewritten. New York: J. Wiley & Sons, 1911.
- _____. Elements of Water Bacteriology, with Special Reference to Sanitary Water Analysis. 3rd ed., rewritten. New York: J. Wiley & Sons, 1913.
- _____. Elements of Water Bacteriology, with Special Reference to Sanitary Water Analysis. 4th ed. New York: J. Wiley & Sons, 1924.
- Prescott, Samuel C., and Cecil G. Dunn. Industrial Microbiology. 1st ed. New York: McGraw-Hill, 1940.
- Prescott, Samuel Cate. Food Technology. 1st ed. New York and London: McGraw-Hill, 1937.
- Rahn, Otto. Physiology of Bacteria. Philadelphia: Blakiston, 1932.

- Reed, Howard S. A Manual of Bacteriology for Agricultural and General Science Students. Boston: Ginn and Company, 1914.
- Rice, Thurman B. Textbook of Bacteriology. Philadelphia: W.B. Saunders Co., 1936.
- Robbins, William J., and Harold W. Rickett. Botany: A Textbook for College and University Students. 2nd ed. New York: D. Van Nostrand Co., 1934.
- Roberts, Jay G. Manual of Bacteriology and Pathology for Nurses. Philadelphia: W.B. Saunders Co., 1912.
- Rogers, Lore A., ed. Fundamentals of Dairy Science. In American Chemical Society Monograph Series, No. 41. New York: Chemical Catalog Company, Inc., 1928.
- _____, ed. Fundamentals of Dairy Science. 2nd ed. New York, 1935.
- Rosenau, Milton J. "Laboratory Course in Pathology and Bacteriology." Public Health and Marine-Hospital Service of the United States Hygienic Laboratory Bulletin 8 (1902).
- _____. Preventive Medicine and Hygiene. 3rd ed. New York: D. Appleton and Company, 1920.
- _____, ed. Preventive Medicine and Hygiene. 6th ed. New York: D. Appleton-Century Co., 1935.
- Russell, Edward J. Lessons on Soil. Cambridge: University Press, 1911.
- _____. A Student's Book on Soils and Manures. 2nd ed., rev. and enl. Cambridge: Cambridge University Press, 1919.
- _____, ed. The Microorganisms of the Soil. London: Longmans, Green & Co., 1923.
- Russell, Harry L., and Edwin G. Hastings. Agricultural Bacteriology. Madison: State Journal Printing Company, 1909.
- _____. Experimental Dairy Bacteriology. Boston: Ginn and Co., 1909.
- _____. Agricultural Bacteriology. 2nd ed. Madison: State Journal Printing Company, 1915.
- Russell, Harry L., and E.G. Hastings. Outlines of Dairy Bacteriology: A Concise Manual for the Use of Students in Dairying. 11th ed. Madison: Cantwell Printing Co., 1920.
- Russell, Harry L., and Edwin G. Hastings. Agricultural Bacteriology for Students in General Agriculture. In The Century Agricultural Series, 3rd ed. New York: The Century Co., 1921.
- Russell, Harry Luman. Outlines of Dairy Bacteriology: A Concise Manual for the Use of Students in Dairying. 3rd ed. Madison, Wisc.: H.L. Russell, 1902.
- Salle, Anthony J. Fundamental Principles of Bacteriology with Laboratory Exercises. New York:

- McGraw-Hill, 1939.
- Sarles, William Bowen, Janet Ruth McCarter, and William C. Frazier. Bacteriology. Madison, Wisc.: Kramer Business Service, 1939.
- Schenk, Samuel L. Manual of Bacteriology for Practitioners and Students: With Special Reference to Practical Methods. London: Longmans, 1893.
- Schneider, Albert. Bacteriological Methods in Food and Drug Laboratories. Philadelphia: Blakiston, 1915.
- Schultz, Edwin W. A Laboratory Manual of Medical Bacteriology. Stanford: Stanford University Press, 1935.
- Scott, William. Clinical Bacteriology and Vaccine Therapy for Veterinary Surgeons. Chicago: A. Eger, 1913.
- Sedgwick, William T. Principles of Sanitary Science and the Public Health. New York: Macmillan Co., 1902.
- Sedgwick, William T., and E.B. Wilson. An Introduction to Biology. 1st ed. New York: H. Holt & Company, 1886.
- Sedgwick, William T., and Theodore Hough. The Human Mechanism: Its Physiology and Hygiene and the Sanitation of Its Surroundings. 1st ed. Boston: Ginn & Company, 1906.
- Sherman, James M., and C.N. Stark. Laboratory Exercises in General Elementary Bacteriology. Ithaca: Norton Printing Co., 1929.
- Shultz, Edwin W. A Laboratory Manual of Medical Bacteriology. Stanford: Stanford University Press, 1935.
- Simmons, James S., and Cleon J. Gentzkow. Laboratory Methods of the United States Army Surgeon-general's Office. 4th ed. Philadelphia: Lea & Febiger, 1935.
- Smiley, Dean Franklin, Adrian Gordon Gould, and Elizabeth Melby. The Principles of Practice of Hygiene. New York: Macmillan, 1930.
- Smith, Allen John. Lessons and Laboratory Exercises in Bacteriology: An Outline of Technical Methods Introductory to the Systematic Study and Identification of Bacteria, Arranged, for the Use of Students. Philadelphia: P. Blakiston's Son & Co., 1902.
- Smyth, Henry F., and Walter L. Obold. Industrial Microbiology: The Utilization of Bacteria, Yeasts and Molds in Industrial Processes. Baltimore: Williams and Wilkins, 1930.
- Society of American Bacteriologists, Committee on Bacteriological Technique. Manual of Methods for Pure Culture Study of Bacteria. Geneva, NY: SAB, 1930.

Soule, Andrew M., and Edna H.L. Turpin. Agriculture, Its Fundamental Principles. Atlanta: B.F. Johnson Publishing Company, 1907.

Stephenson, Marjory. Bacterial Metabolism. 1st ed. London: Longmans, Green, 1930.

Sternberg, George M. A Manual of Bacteriology. New York: W. Wood & Co., 1892.

_____. Infection and Immunity, with Special Reference to the Prevention of Infectious Diseases. New York: Knickerbocker Press, 1903.

Stevens, F.L. Plant Pathology: Laboratory Outline. Campaign, Ill.: Loyde's University Store, 1917.

Stitt, Edward R. Practical Bacteriology, Blood Work and Animal Parasitology: Including Bacteriological Keys, Zoological Tables and Explanatory Notes. 3rd ed. Philadelphia: Blakiston, 1914.

_____. Practical Bacteriology, Blood Work and Animal Parasitology, Including Bacteriological Keys, Zoological Tables and Explanatory Clinical Notes. 6th ed. Philadelphia: P. Blakiston's Son & Co., 1920.

Stocking, William A. Manual of Milk Products. New York: Macmillan Co., 1917.

Stovall, William Davison. Outline of Laboratory Work in Clinical Laboratory Diagnosis. Madison: n.p., 1900.

Tanner, Fred W. Bacteriology and Mycology of Foods. 1st ed. New York: John Wiley & Sons, 1919.

_____. Bacteriology: A Text-book of Microorganisms. New York: John Wiley & Sons, 1928.

_____. Practical Bacteriology: An Introduction to Bacteriological Technic. New York: J. Wiley & Sons, 1928.

_____. The Microbiology of Foods. 1st ed. Champaign: Twin City Print Co., 1932.

_____. Bacteriology, a Text-book of Microorganisms. New York: J. Wiley & Sons, 1933.

_____. Practical Bacteriology: An Introduction to Bacteriological Technic. 2nd ed. New York: J. Wiley & Sons, 1933.

_____. Bacteriology: A Text-book of Microorganisms. 3rd ed. New York: J. Wiley, 1937.

Thaysen, A.C., and H.J. Bunker. The Microbiology of Cellulose, Hemicellulose, Pectin and Gums. London: Oxford University Press, 1927.

Thaysen, A.C., and L.D. Galloway. The Microbiology of Starch and Sugars. London: Oxford University Press, 1930.

Theroux, Frank R., Edward F. Eldridge, and Walter LeRoy Mallman. Laboratory Manual for Chemical

- and Bacterial Analysis of Water and Sewage. 2nd ed., rev. and enl. New York: McGraw-Hill, 1936.
- Thomas, Stanley J. Bacteriology: A Textbook on Fundamentals. New York: McGraw-Hill, 1925.
- Topley, W.W.C., and G.S. Wilson. The Principles of Bacteriology and Immunology. Vol. 2 vols. New York: William Wood & Co., 1931.
- Van Slyke, Lucius L., and Charles A. Publow. Science and the Practice of Cheese Making: A Treatise on the Manufacture of American Cheddar Cheese and Other Varieties, Intended as a Text-book for the Use of Dairy Teachers and Students in Classroom and Workroom. New York: O. Judd Company, 1909.
- Waite, Herbert Harold. Disease Prevention. New York: Thomas Y. Crowell Company, 1926.
- Waksman, Selman A. Principles of Soil Microbiology. 1st ed. Baltimore: Williams and Wilkins, 1927.
- Waksman, Selman A., and Robert L. Starkey. The Soil and the Microbe: An Introduction to the Study of the Microscopic Population of the Soil and Its Role in the Soil Processes and Plant Growth. New York: John Wiley & Sons, Inc., 1931.
- Waksman, Selman A. Principles of Soil Microbiology. 2nd ed. Baltimore: Williams and Wilkins Co., 1932.
- Whipple, George C. The Microscopy of Drinking Water. 1st ed. New York: Wiley, 1899.
- _____. Typhoid Fever: Its Causation, Transmission and Prevention. 1st ed. New York: J. Wiley and Sons, 1908.
- Whitby, L.E.H. Medical Bacteriology: Descriptive, Applied, Including Elementary Helminthology. 2nd ed. London: J. & A. Churchill, 1934.
- Williams, Anna W. Streptococci in Relation to Man in Health and Disease. Baltimore: Williams & Wilkins Company, 1932.
- Williams, Herbert U. A Manual of Bacteriology. 2nd ed, rev. and enl. Philadelphia: Blakiston, 1901.
- _____. A Manual of Bacteriology. 5th ed., 466 pp. Philadelphia: Blakiston, 1909.
- Winslow, C.-E.A. Elements of Industrial Microscopy. 1905.
- _____. Winslow Health and Hygiene Charts. Chicago: Dennoyer-Geppert Co., 1929.
- _____. Health on the Farm and in the Village. New York: Macmillan, 1931.
- Winslow, Kenelm, and Hibbert W. Hill. The Production and Handling of Clean Milk, Including Practical Milk Inspection. 2nd ed. New York: W.R. Jenkins Co., 1909.

Wright, William H. Laboratory Outlines of Advanced Bacteriological Technique. 1st. ed. Ann Arbor: Edward Bros., 1924.

Zinsser, Hans. A Textbook of Bacteriology. 6th ed. New York: D. Appleton and Co., 1927.

Zinsser, Hans, and Stanhope Bayne-Jones. A Textbook of Bacteriology, with a Section on Pathogenic Protozoa. 7th ed. New York: D. Appleton-Century Co., 1934.

_____. A Textbook of Bacteriology. 8th ed. New York: D. Appleton-Century Co., 1939.

SECONDARY SOURCES: 1899-1965

"Fifty Years of Applied Bacteriology." American Journal of Public Health 11 (1931): 176.

A Historical Sketch of the Iowa State College of Agriculture and Mechanic Arts: Published for the Semi-centennial Celebration, June 6-9, 1920. Ames: Iowa State College, 1920.

In Memoriam, Cyril George Hopkins. Urbana: University of Illinois Press, 1922.

"Leonard Pearson, B.S., V.M.D." American Veterinary Review 36 (1909): 4.

The Ten Master Minds of Dairying. Des Moines, IA: Meredith Publishing, 1930.

Abbott, Alexander C. "The Development of Public Health Work in Philadelphia: An Historic Sketch." University of Pennsylvania Medical Bulletin. Sept. & Oct. 1909.

_____. "The Development of Public Health Work in Philadelphia." In Founder's Week Memorial Volume, edited by Frederick P. Henry, 563-92. Philadelphia: City of Philadelphia Press, 1909.

_____. "The Organization and Experiences of the School of Hygiene at University of Pennsylvania." Proceedings of the Association of American Medical Colleges 34 (1924): 174-80.

Abele, C.A. "Fifty Years of Progress in Dairy Farm Sanitation." Journal of Dairy Science 39 (1956): 783-8.

Ackerknecht, Erwin H. "Anticontagionism Between 1821 and 1867." Bulletin of the Institute for the History of Medicine 22 (1948): 562-93.

_____. A Short History of Medicine. New York: Ronald Press, 1955.

Alexander, A.S. A History of the Wisconsin Experiment Station. Madison: Wisconsin Agricultural Experiment Station, 1935.

Allen, E.W. "The Society for the Promotion of Agricultural Science: Its Present and Its Future." Science 57 (1923): 216.

Allen, Phyllis. "Americans the Germ Theory of Disease." Ph.D. diss., University of Pennsylvania, 1949.

- Allison, R.V. "Lipman, the Soil Scientist." In Lipman Hall: Being an Account of the Proceedings at the Dedication on June 12th, 1951, of a Building Named in Honor of Jacob Goodale Lipman, 23-35. New Brunswick: New Jersey Agricultural Experiment Station, 1952.
- Alvord, Henry E. "Dairy Development in the United States." In Yearbook of the United States Department of Agriculture, 1899, 381-402. Washington: GPO, 1900.
- Arbuckle, W.S. "Teaching of Dairy Manufacturing." Journal of Dairy Science 39 (1956): 876-8.
- Babcock, Donald C., Clarence W. Scott, Philip M. Marston, and John P. Hall. History of the University of New Hampshire, 1866-1941. Durham, New Hampshire: University of New Hampshire, 1941.
- Baker, M.N. The Quest for Pure Water. New York: American Water Works Association, 1949.
- Baker, Gladys L., ed. Century of Service: The First 100 Years of the United States Department of Agriculture. Washington, D.C.: USDA, 1963.
- Barber, Marshall A. A Malariologist in Many Lands. Lawrence: University of Kansas Press, 1946.
- Bather, Francis. "Biological Classification, Past and Future." Quarterly Journal of the Geological Society of London 83 (1927): lx-cix.
- Bay, J. "Some Vital Books in Science: 1848-1947." Science 107 (1948): 485-91.
- Beal, William J. History of the Michigan Agricultural College and Biographical Sketches of Trustees and Professors. East Lansing: Michigan Agricultural College, 1915.
- Beilin, A. "Louis Pasteur, Pioneer Biologist Who Made Modern Medicine Possible." Hygeia 12 (May 1935): 435.
- _____. "Paul Ehrlich, an Exceptionally Brilliant Laboratory Investigator." Hygeia 13 (1935): 829.
- _____. "Brief Biography of the Japanese Koch, Shibasaburo Kitasato." Hygeia 14 (October 1936): 914.
- Bell, Elexious Thompson. "The History of the Medical School of the University of Minnesota." Journal-Lancet 70, no. 2 ((Feb.) 1950): 51-4.
- Bergey, David H. "Early Instructors in Bacteriology in the United States." Journal of Bacteriology (or Abstracts of Bacteriology) 2 (1917): 595-601.
- _____. "Early Instruction in Bacteriology in the United States." Annals of Medical History 1 (December 1917): 426-7.
- Bierer, Bert W. History of Animal Plagues of North America, with an Occasional Reference to Other Diseases and Diseased Conditions. Washington: U.S. Dept. of Agriculture, 1939.

- _____. American Veterinary History. Fort Dodge, Iowa: American Veterinary Historical Society, 1940.
- _____. A Short History of Veterinary Medicine in America. East Lansing: Michigan State University Press, 1955.
- Bierring, Walter L. "The Story of Bacteriology at the University of Iowa." Journal of the Iowa State Medical Society 27 (1937): 555-606, 656-659.
- Biggs, Herman M. "The Development of the Research Laboratories." Monthly Bulletin of the Department of Health of the City of New York 1, no. 3 (March 1911): 54-6.
- Bishop, Morris. A History of Cornell, Cornell University Press. Ithaca, 1962.
- Bitting, Arvill W. Appertizing; Or, the Art of Canning: Its History and Development. San Francisco: n.p., 1937.
- Blair, A.W. "Jacob G. Lipman: Philosopher and Scientist." In Lipman Hall: Being an Account of the the Proceedings at the Dedication on June 12th, 1951, of a Building Named in Honor of Jacob Goodale Lipman. New Brunswick: New Jersey Agricultural Experiment Station, 1952.
- Blanton, Wyndham B. Medicine in Virginia in the Nineteenth Century. Richmond: Garrett & Massie, 1933.
- Bolduan, Charles. Over a Century of Health Administration in New York City. In Monograph Series. No. 13. New York: New York City Health Department, 1916.
- Bonner, Thomas. American Doctors and German Universities. Lincoln: University of Nebraska, 1963.
- Boss, Andrew. "Minnesota Agricultural Experiment Station, 1885-1935." Bulletin of the Minnesota Agricultural Experiment Station, no. 319 (1935): 1-69.
- _____, ed. "Agricultural Research Through Fifty Years, 1885-1935." Bulletin of the University of Minnesota Agricultural Experiment Station, no. 328 (1936).
- Breed, Robert S. "Forty Years of Progressive Dairy Sanitation." Journal Dairy Science 32 (1948): A16.
- Bridgeport Brass Company. The History of Sanitation: Plumbing Then and Now, an Illustrated Resume of Some of the Romantic Incidents in the History of Plumbing. Bridgeport, CT, 1927.
- Brock, Thomas, ed. Milestones in Microbiology. Englewood Cliffs, NJ: Prentice-Hall, 1961.
- Brodman, Estelle. "New York City Department of Health, Periodicals and Serials Published 1866-1939." Special Libraries 31, no. 1 (January 1940): 23-9.
- Brown, Percy E. "The Beginnings and Development of Soil Microbiology in the United States." Soil Science 40 (1935): 49-58.

- Brunel, Jules. "Antibiosis from Pasteur to Fleming." Journal of the History of Medicine and Allied Sciences 6 (1951): 287-301.
- Brunger, Eric. "Dairying and Urban Development in New York State, 1850-1900." Agricultural History 29 (1955): 169-74.
- Bryson, Vernon, ed. Microbiology, Yesterday and Today: A Symposium Held in Honor of the Seventieth Birthday of Selman A. Waksman, June 5, 1958. 1959.
- Buchanan, Robert. "Taxonomy." Annual Review of Microbiology 9 (1955): 1-.
- Bulloch, William. "Obituary Notice of Deceased Member: Theobald Smith, 1859-1934." Journal of Pathology and Bacteriology 40 (1935): 621-6635.
- Bulloch, William. The History of Bacteriology. New York: Dover (1938) 1979.
- Burrows, William. "Biographical Memoir of Edwin Oakes Jordan, 1866-1936." National Academy of Sciences, Biographical Memoirs 20, no. 7th memoir (1939): 197-228.
- Calkins, G.N. "Debt of Science to Pasteur." Scientific Monthly 17 (July 1923): 5-16.
- Cameron, Jenks. The Bureau of Dairy Industry: Its History, Activities, and Organization. In Institute for Government Research Service Monographs of the United State Government. No. 55. Baltimore: Johns Hopkins Press, 1929.
- Cannon, P.R. "H. Gideon Wells, M.D., PhD 1875-1943." Arch. Pathology 36 (1943): 331-4.
- Carstensen, Vernon, ed. The Growth of Agricultural Research in Wisconsin. Madison: Wisconsin Agricultural Experiment Station, 1958.
- Cary, Harold W. The University of Massachusetts: A History of One Hundred Years. Amherst: University of Massachusetts Press, 1962.
- Cassedy, James H. Charls V. Chapin and the Public Health Movement. Cambridge: Harvard University Press, 1962.
- Caswell, Lilley B. Brief History of the Massachusetts Agricultural College: Semicentennial, 1917. Amherst, Mass.: F.A. Bassette Co., 1917.
- Chapin, Charles V. "The Evolution of Preventive Medicine." Journal of the American Medical Association 86 (January 22 1921): 217.
- _____. "History of State and Municipal Control of Disease." In A Half Century of Public Health: Jubilee Historical Volume of the American Public Health Association, edited by M.P. Ravenel, 133-60. New York: American Public Health Association, 1921.
- Chesney, Alan M. The Johns Hopkins Hospital and the Johns Hopkins University School of Medicine:

- A Chronicle. Vol. 3 vols. Baltimore: Johns Hopkins Press, 1943.
- Cheyney, Edward Potts. History of the University of Pennsylvania, 1740-1940. Philadelphia: University of Pennsylvania Press, 1940.
- Chittenden, Russell H. History of the Sheffield Scientific School of Yale University, 1846-1922. Vol. 2 vols. 1928.
- Chittenden, R. The First Twenty-five Years of the American Society of Biological Chemists. New Haven: American Society of Biological Chemists, 1945.
- Clark, Paul F. Memorable Days in Medicine: A Calendar of Biology and Medicine. Madison: University of Wisconsin Press, 1942.
- _____. "A Half-century of Presidential Address of the Society of American Bacteriologists." Microbiological Reviews 17 (1953): 213-47.
- _____. "Theobald Smith, Student of Disease (1859-1934)." Journal of the History of Medicine 14 (1959): 490-514.
- _____. Pioneer Microbiologists in America. 1st ed. Madison: University of Wisconsin Press, 1961.
- Cochran, John P. "The Virginia Agricultural and Mechanical College: The Formative Half Century, 1872-1919, of the Virginia Polytechnic Institute." PhD. Diss., University of Alabama, 1961.
- Cohen, Barnett. "The History Program of the Society of American Bacteriologists." Bulletin of the History of Medicine 8 (1940): 312-21.
- _____. Chronicles of the Society of American Bacteriologists, 1899-1950. Baltimore: Williams and Wilkins, and the Waverly Press, 1950.
- _____. "Comments on the Relation of Dr. Welch to the Rise of Microbiology in America." Bulletin of the History of Medicine 24 (July-August 1950): 319-24.
- Cole, C.G. "History of Hog Cholera Research in the U.S. Department of Agriculture." Agricultural Information Bulletin, Supplement, no. 241 (1962).
- Coleman, Gould P. Education and Agriculture: A History of the New York State College of Agriculture at Cornell University. Ithaca: Cornell University, 1963.
- Conklin, E.G. "Fifty Years of the American Society of Naturalists." American Naturalist 68 (1934): 385-401.
- Conley, Albert R. History of Research Dealing with Problems Confronting the Dairy Industry Which Have Been Conducted by the Agricultural Experiment Stations, 1881-1947: Bibliography of the Research and General Index of Publications Resulting from the Research. Columbus: Ohio State University, 1949.

- Conn, Harold J. "History of the Commission on Standardization of Biological Stains." Stain Technology 1 (1926): 1-3.
- _____. "The History of Staining. A Preliminary Note." Stain Technology 2 (1927): 126-7.
- _____. "Progress in the Standardization of Stains -- Five Years of Stain Standardization." Stain Technology 3, , 105-9. 1928.
- Conn, Harold J., Llyod Aronld, Albert E. Blakeslee, Robert S. Cunningham, Sidney I. Kornhauser, and Frank B. Mallory. The History of Staining. Geneva, NY: Book Service of the Biological Stain Commission, 1933.
- Conn, H.J. "Professor Herbert William Conn and the Founding of the Society." Bacteriological Reviews 12 (1948): 275-96.
- Cope, Alexis, Thomas C. Mendenhall, Osman C. Hopper, and Wilbur H. Siebert. History of Ohio State University. Columbus: Ohio State University Press, 1920.
- Corner, George W. A History of the Rockefeller Institute, 1901-1953: Origins and Growth. New York: Rockefeller Institute Press, 1964.
- Cosgrove, John J. History of Sanitation. Pittsburgh: Standard Sanitary Mfg. Co., 1909.
- Cowan, Sam T. "Bacterial Classification -- Problems and Developments." In Microbiology, Yesterday and Today, edited by V. Bryson, 55-79. New Brunswick: Institute of Microbiology, Rutgers, 1959.
- Crawford, Robert P. "These Fifty Years: A History of the College of Agriculture of the University of Nebraska." Circular, University of Nebraska, College of Agriculture, Experiment Station, no. 26 (1925).
- Curti, Merle Eugene, Vernon R. Carstensen, Edmund D. Cronon, and John W. Jenkins. The University of Wisconsin: A History. 3 vols. Madison: University of Wisconsin Press, 1949.
- Davis, H.P. "Fifty Years of Progress in Dairy Production Teaching." Journal of Dairy Science 39 (1956): 795-7.
- De Kruif, Paul H. Microbe Hunters. New York: Harcourt, Brace & Co., 1926.
- De Kruif, Paul. "Flu-trappers." Readers Digest, , 15-8. 1936.
- de Sigmond, Alexis A.J. "Development of Soil Science." Soil Science 40 (1935): 77-86.
- Demarest, William H.S. A History of Rutgers College, 1766-1924. New Brunswick: Rutgers University Press, 1924.
- Dible, James H. "A History of the Pathological Society of Great Britain and Ireland." Journal of

Pathology and Bacteriology 73 (1957).

Dillon, John J. Seven Decades of Milk: A History of New York's Dairy Industry. New York: Organge Judd Publishing Co., 1941.

Dochez, Alphonse R. "Frederick Parker Gay, 1874-1939." National Academy of Sciences (U.S.) Biographical Memoirs 28, no. 4th memoir (1954): 99-116.

Draffin, Jasper D. The Story of Man's Quest for Water. Champaign, Ill.: Garrod Press, 1939.

Dubos, Rene. "The Gold-headed Cane in the Laboratory." Public Health Reports 69 (1954): 356-71.

Dunaway, Wayland F. History of the Pennsylvania State College. Lancaster: Lancaster Pres, Inc., 1946.

Eckstein, Gustav. Noguchi. New York: Harper & Brothers Publishers, 1931.

Edsall, Geoffrey. "Public Health and the Laboratory." American Journal of Public Health 40 (November 1950): 1368.

Eggerth, Arnold H. The History of the Hoagland Laboratory. Brooklyn: s.n., 1960.

Ervin, R.F., P.C. Trexler, and J.A. Reyniers. "History of Bacteriology at the University of Notre Dame." Proceedings of the Indiana Academy of Science 53 (1944): 52-65.

Ervin, R.F. "Lobund: Notre Dame's Contribution to Bacteriology." Notre Dame Scholastic 87, no. 4 (1946): 11-4.

Esten, W.M. "Professor H.W. Conn." Journal of Bacteriology 2, no. 5 (1917): 501-3.

Esty, J. Russell. "A Historical Review of the Bacteriological Studies on Commercially Canned Foods." In Paper Presented at the Annual Meeting of the Society of American Bacteriologists, San Francisco, August 10, 1953. 1953.

Faculty Veterinary Alumni, comp. History of the School of Veterinary Medicine of the University of Pennsylvania, 1884-1934. Philadelphia: Veterinary Alumni Society, 1935.

Fernald, Merritt C. History of the Maine State College and the University of Maine. Orono: University of Maine, 1916.

Fischer, M. William B. Wherry: Bacteriologist. Springfield: Charles C. Thomas, 1938.

Fishbein, Morris. A History of the American Medical Association, 1847-1947. Philadelphia: Saunders, 1947.

Fitzgerald, J.C. "Pasteur and the Science of Bacteriology." Scientific Monthly 17 (July 1923): 23-9.

Fleming, Alexander, ed. "History and Development of Penicillin." In Penicillin: Its Practical

- Applications. 2nd. London: Butterworth and Co. Ltd., 1950.
- Fleming, Donald. William H. Welch and the Rise of Modern Medicine. Boston: Little, Brown & Co., 1954.
- Flexner, Simon. "Twenty-five Years of Bacteriology: A Fragment of Medical Research." Science 52 (1920): 615-32.
- _____. "A Half Century of American Medicine." Science 85 (1937): 505-12.
- Flexner, Simon, and James T. Flexner. William Welch and the Heroic Age of American Medicine. New York: Viking Press, 1941.
- Flick, Lawrence F. Development of Our Knowledge of Tuberculosis. Philadelphia: Wickersham Printing Co., 1925.
- Folse, Jean D. "A Short History of Veterinary Medicine at Kansas State College." typescript, 1954.
- Foote, Charles J. "Early Years of Bacteriology in the Yale Medical School and in the City of New Haven." Yale Journal of Biology and Medicine 13 (1941): 309-14.
- Ford, William W. "The Life and Work of Robert Koch." The Johns Hopkins Hospital Bulletin 22 (December 1911): 1-29.
- _____. Bacteriology. In Clio Medica: A Series of Primers on the History of Medicine. New York: P.B. Hoeber, 1939.
- _____. "Robert Koch, Pioneer Bacteriologist." Science Digest 8 (September 1940): 88-93.
- Fraser, Wilber J. "The Formation of the American Dairy Science Association." Journal of Dairy Science 6 (1933): 583-6.
- Frost, Russell E. Beloved Professor: Life and Times of William Dodge Frost. New York: Vantage Press, 1961.
- Fulton, John F. "Introduction: Special Issue on the History of Antibiotics." Journal of the History of Medicine and Allied Sciences 6 (1951): 281-6.
- Gage, Simon H. "Theobald Smith, 1859-1934." Cornell Veterinarian 25 (1935): 207-28.
- _____. "Theobald Smith: Investigator and Man." Science 84 (1936): 117-22.
- Galloway, B.T. "Twenty Years Progress in Plant Pathology." Society for the Promotion of Agricultural Science, 90-102. 1900.
- Garrison, Fielding H. An Introduction to the History of Medicine. Vol. 4th ed. Philadelphia: W.B. Saunders Co., 1929.

- _____. "The History of Drainage, Irrigation, Sewage-disposal and Water Supply." Bulletin of the New York Academy of Medicine 5 (1929): 887-938.
- Gay, Frederick P. "Dr. Victor C. Vaughan and His Relations to the National Research Council." Journal of Laboratory and Clinical Medicine 15 (1930): 888-90.
- _____. "A Half Century of Bacteriology at Columbia." Columbia University Quarterly, 112-129, 203-217. 1939.
- _____. "Medical Logic." Bulletin of the History of Medicine 7 (1939): 6-27.
- Gilmore, J.S.L. "The Development of Taxonomy Since 1851." Advanc. Sci., London 8 (1951): 70-.
- Glover, Wilber H. Farm and College: The College of Agriculture of the University of Wisconsin, a History. Madison: University of Wisconsin Press, 1952.
- Good, Ruth. "Frederick G. Novy: Biographic Sketch." University of Michigan Medical Bulletin 16 (1950): 257-68.
- Gorham, Frederick P. "The History of Bacteriology and Its Contribution to Public Health Work." In A Half Century of Public Health: Jubilee Historical Volume of the American Public Health Association, edited by M.P. Ravenel, 66-. New York: American Public Health Association, 1921.
- Grainger, Thomas H. A Guide to the History of Bacteriology. New York: Ronald Press Company, 1958.
- Gray, James. The University of Minnesota, 1851-1951. Minneapolis: University of Minnesota, 1951.
- Hagan, William A. "Veterinary Medical Education -- Its Evolution and Present Status." Journal of the American Veterinary Medical Association, May 1951, 287-92.
- Hale, Harrison. University of Arkansas, 1871-1948. Fayetteville: University of Arkansas Alumni Association, 1948.
- Hallock, Grace T. A Tale of Soap and Water: The Historical Progress of Cleanliness. New York: Cleanliness Institute, 1937.
- Iowa State College of Agriculture and Mechanic Arts. B.W. Hammer: Panegyric. Ames, Iowa: Collegiate Press, Inc., 1937.
- Harding, T. Swann. Two Blades of Grass: A History of Scientific Development in the U.S. Department of Agriculture. Norman, OK: University of Oklahoma Press, 1947.
- Harris, Norman M. "Our Society -- in Retrospect and Prospect." Journal of Bacteriology 2 (1926): 153-64.
- Harris, Henry. California's Medical Story. San Francisco: Grabhorn Press, 1932.

- Harrison, F.C. "Our Society." Journal of Bacteriology 7 (1922): 149-57.
- Hastings, E.G., and C.B. Morrey. "Early Instructors in Bacteriology in the United States, Addenda." Journal of Bacteriology 2 (1917): 307-8.
- Hastings, E.G. "A Review of the Scientific Work of H.L. Russell." In University of Wisconsin Studies, Science No. 2, edited by H.A. Harding, E.G. Hastings, and W.D. Frost. In Papers on Bacteriology and Allied Subjects, by Former Students of Harry Luman Russell, 9-19. Madison: University of Wisconsin Press, 1921.
- Hektoen, Ludvig. The John McCormick Institute for Infectious Diseases: Brief History and Description. Chicago, 1915.
- _____. "Notes on the History of Bacteriology in Chicago." Bulletin of the Society of Medical History of Chicago 5 (1937): 3-21.
- Henderson, J. Lloyd. "Market Milk Operations, 1906 Versus 1956." Journal of Dairy Science 39 (1956): 812-8.
- Hepburn, William M., and Louis M. Sears. Purdue University: Fifty Years of Progress. Indianapolis: Hollenbeck press, 1925.
- Hobby, Gladys L. "Microbiology in Relation to Antibiotics." Journal of the History of Medicine and Allied Sciences 6 (1951): 369-87.
- Hodgson, R.E. "Dairy Production Research in the United States Department of Agriculture." Journal of Dairy Science 39 (1956): 766.
- Houck, U.G. "History and Activities of the Bureau of Animal Industry." Veterinary Medicine 18, no. 1 (January 1923): 82-8.
- Howard, William Travis. Public Health Administration and the Natural History of Disease in Baltimore, Maryland, 1797-1920. Washington: Carnegie Institute of Washington, 1924.
- Howard, L.O. Fighting the Insects: The Study of an Entomologist, Telling of the Life and Experiences of the Writer. New York: Macmillan, 1933.
- Hudson, N.P. "Edwin Oakes Jordan 1866-1936." Journal of Bacteriology 33 (1937): 243-8.
- Huth, Hans. Nature and the American: Three Centuries of Changing Attitudes. Berkeley: University of California Press, 1957.
- Israelson, O.W., ed. "Pioneering in Western Agriculture: A Resume of the First Half-century of Research, 1888-1938, ." Bulletin of the Utah Agricultural Experiment Station, no. 282 (October 1938): 3-129.
- Jaffe, Bernard. Men of Science in America. New York: Simon & Schuster, 1944.

- Jasper, Donald E. A Short History of the School of Veterinary Medicine, University of California. Davis: Simmon Publishing Company, 1961.
- Jenny, Hans. E.W. Hilgard and the Birth of Modern Soil Science. Pisa: Collan della Rivista Agrochimica, 1961.
- Jezeski, J.J. "Progress in Basic Bacteriology of Milk." Journal of Dairy Science 39 (1956): 657-62.
- Johnson, Elwin Bird. Forty Years of the University of Minnesota. Minneapolis: General Alumni Association, 1910.
- Jordan, Edwin O., G.C. Whipple, and C.-E.A. Winslow. A Pioneer of Public Health, William Thompson Sedgwick. New Haven: Yale University Press, 1924.
- Jordan, Philip D. The People's Health: A History of Public Health in Minnesota to 1948. St. Paul: Minnesota Historical Society, 1953.
- Kaufman, O.W. "Fifty Years of Progress in Dairy Plant Sanitation Methods." Journal of Dairy Science 39 (1956): 865-5.
- Kelley, Howard. Walter Reed and Yellow Fever. New York: McClure, Phillips, 1906.
- Kelly, Fred C. One Thing Leads to Another: The Growth of an Industry (The Commercial Solvents Corp.). Boston and New York: Houghton Mifflin Company, 1932.
- Kerr, J.W. "Scientific Research by the Public Health Service." Annals of the American Academy of Political and Social Science 37 (1911): 27-41.
- Kessell, Edward L. A Century of Progress in the Natural Sciences, 1853-1953. San Francisco: California Academy of Sciences, 1955.
- Knopf, S. Adolph. A History of the National Tuberculosis Association. New York: National Tuberculosis Association, 1922.
- Kohlmeyer, Fred W., and Floyd L. Herum. "Science and Engineering in Agriculture: A Historical Perspective." Technology and Culture 2 (1961): 368-81.
- Kolmer, J.A. "The History of Laboratory Research in the Past Fifty Years." Medical Life 34 (1927): 3-14.
- Koser, Stewart A. "Bacteriology at the University of Chicago." Bios 23 (1952): 175-91.
- Kramer, Howard D. "The Germ Theory and the Early Public Health Program in the United States." Bulletin of the History of Medicine 22 (May-June 1948): 233-47.
- Kuhn, Madison. Michigan State: The First Hundred Years, 1855-1955. East Lansing: Michigan State University Press, 1955.

- Kunkel, Louis Otto. "William Trelease, February 22, 1857 - January 1, 1945." National Academy of Sciences (U.S.) Biographical Memoirs 35, no. 12th memoir (1961): 307-22.
- Lampard, Eric E. The Rise of the Dairy Industry in Wisconsin: A Study in Agricultural Change, 1820-1920. Madison: State Historical Society of Wisconsin, 1963.
- Larsell, Olaf. The Doctor in Oregon. Portland, 1917.
- Law, James. "Half Century of Veterinary Medicine in Cornell University." In The Report of the Conference at the New York State Veterinary College During the Semi-Centennial Celebration of the Cornell University, June, 1919. Ithaca: Cornell University Official Publication, 1919.
- Link, V.B. History of Plague in the United States. In U.S. Public Health Monograph No. 26. Washington D.C.: G.P.O., 1955.
- Loeffler, F. "The History of Diphtheria." In The Bacteriological of Diphtheria, edited by G.H.F. Nuttall, and G.S. Graham-Smith. Cambridge: University Press, 1908.
- Long, E.R. "Biographical Memoir of Harry Gideon Wells 1875-1943." Biographical Memoirs of the National Academy of Sciences 26 (1950): 233-63.
- Long, Esmond R. "Tuberculosis in Modern Society." Bulletin of the History of Medicine 27 (1953): 302-4.
- Lucas, W.P. "Pasteur and the Science of Medicine." Scientific Monthly 17 (1923): 29-34.
- Lucas, P.S. "Ice Cream Manufacture." Journal of Dairy Science 39 (1956): 833-5.
- Ludovici, L.J. Fleming: Discoverer of Penicillin. London: Andrew Dakers Ltd., 1952.
- Macdonald, Eleanor. "A History of the Massachusetts Department of Public Health." Commonwealth 23, no. 2 (April, May, June 1936).
- Manning, Miriam. "Changing Problems of a Public Health Laboratory." Thesis in Course VII, Graduate School MIT 1943.
- Marshall, Clarence J., and et. al. In Memoriam: Leonard Pearson. Philadelphia, 1910.
- Matthews, L.G. History of Pharmacy in Britain. London: E. & S. Livingstone, 1962.
- Maurois, Andre. The Life of Sir. Alexander Fleming: Discoverer of Penicillin. New York: Rockefeller University Press, 1959.
- McCall, A.G. "The Development of Soil Science." Agricultural History 5, no. 2 (April 1931): 43-56.
- McClung, L.S. "Early American Publications Relating to Bacteriology." Bacteriological Reviews 8 (1944): 119-60.

- McClung, Leland S. "History of Bacteriology at Indiana University." Proceedings of the Indiana Academy of Science 53 (1944): 59-61.
- McFarland, Joseph. "The Beginnings of Bacteriology in Philadelphia: Recollections of What Took Place Before the Beginning of the Present Century, with Contemporary Portraits and a Bibliography of the Literature of That Period." Bulletin of the History of Medicine 5 (1937): 148-98.
- McKinley, Earl B. "Theobald Smith." Science 82 (1935): 575-86.
- Meisel. Bibliography of American Natural History, the Pioneer Century, 1769-1865. Vol. v. 2-3. Reprint 1967. New York: Hafner, 1929.
- Merillat, Louis A., and Delwin M. Campbell. Veterinary Military History of the United States, with a Brief Record of the Development of Veterinary Education, Practice, Organization and Legislation in Two Volumes. Chicago: Veterinary Magazine Corp., 1935.
- Michels, Nicholas A. "The American Association of Anatomists: A Sketch of Its Origin, Aims and Meetings." Anatomical Record 122 (1955): 685-714.
- Miller, Merritt F. "The Missouri College of Agriculture, Through a Half a Century -- in Retrospect." Bulletin of the University of Missouri Agricultural Experiment Station, no. 769 (1961): 3-66.
- Moore, Veranus A. "The Relation of the Veterinary College to the State." In The Report of the Conference at the New York State Veterinary College During the Semi-Centennial Celebration of the Cornell University, June, 1919, 35-43. Ithaca: Cornell University Press, 1919.
- Mumford, H.W. "A Half-century of Achievement by the Illinois Agricultural Experiment Station." Science 87 (June 17 1938): 539-42.
- Mumford, Frederick B. "History of the Missouri College of Agriculture." Missouri Agricultural Experiment Station Bulletin 483 (1944).
- Myers, Burton D. History of Medical Education in Indiana. Bloomington: Indiana Press, 1956.
- North, Charles E. "Milk and Its Relation to Public Health." In A Half Century of Public Health: Jubilee Historical Volume of the American Public Health Association, edited by M.P. Ravenel, 236-89. New York: American Public Health Association, 1921.
- Novy, Frederick G. "Victor Clarence Vaughan." Science 70 (1929): 624-6.
- Oliver, Wade W. The Man Who Lived for Tomorrow: A Biography of William Hallock Park, M.D. New York: E.P. Dutton & Co, 1941.
- Palmer, C.M. "History of Bacteriology at Butler University." Proceedings of the Indiana Academy of Science 53 (1943): 55-6.
- Parfitt, E.H. "The Development of the Evaporated Milk Industry in the United States." Journal of Dairy

- Science 39 (1956): 838-9.
- Park, William H. "The History of Diphtheria in New York City." American Journal of Diseases of Children 92 (December 1931): 1439-45.
- Phelps, Earle B., and John E. Kiker. "Rediscovering Our Heritage in Sanitation." American Journal of Public Health 43, no. 6 (June 1953): 7-13.
- Pirtle, Thomas R. History of the Dairy Industry. Chicago: Mojonier Bros. Co., 1926.
- Podach, E.F. "Pasteur's Heritage; Bacteriological Contributions to Medicine." Nineteenth Century 126 (July 1939): 83-91.
- Pounden, W.D. "Infectious and Metabolic Diseases of Dairy Cattle." Journal of Dairy Science 39 (1956): 769-72.
- Powell, Fred Wilbur. The Bureau of Animal Industry: Its History, Activities, and Organization. In Service Monographs of the United States Government. No. 41. Baltimore: Johns Hopkins Press, 1927.
- Prescott, Samuel C. When M.I.T. Was "Boston Tech" Cambridge: The Technology Press, 1954.
- Price, Walter V. "Cheese Manufacture." Journal of Dairy Science 39 (1956): 824-30.
- Proctor & Gamble. Story of Soap. Cincinnati, 1931.
- Prudden, T. Mitchell. "Safeguards of the Body Against Disease: A Short Study of Immunity." Outlook, March 4 1905, 589-97.
- _____. "Professor Theobald Smith and a New Outlook in Animal Pathology." Science 39 (May 22 1914): 751-4.
- Prudden, Lillian E., ed. Biographical Sketches and Letters of T. Mitchell Prudden, M.D. New Haven: Yale University Press, 1927.
- Rand, Frank P. Yesterdays at Massachusetts State College: 1863-1933. Amherst: Massachusetts State College, 1933.
- Ratcliff, J.D. Yellow Magic: The Story of Penicillin. New York: Random House, Inc., 1945.
- Ravenel, Mazyck P. "The America Public Health Association, Past, Present, Future." In A Half Century of Public Health: Jubilee Historical Volume of the American Public Health Association, edited by M.P. Ravenel. New York: American Public Health Association, 1921.
- Raymond, Joseph H. History of the Long Island College Hospital and Its Graduates, Together with the Hoagland Laboratory and the Polhemus Memorial Clinic. Brooklyn: Assn. of the Alumni, 1899.

- Redbook Magazine, Market Research Department. Household Soap. New York: Redbook Magazine, 1958.
- Reid, W.H.E. "The Dairy Products National Trade Associations." Journal of Dairy Science 39 (1956): 879-81.
- Richmond, Phyllis Allen. "Animalcular Theory: Etiological Theory in America Prior to the Civil War." Journal of the History of Medicine 2 (1947): 489-520.
- _____. "American Attitudes Toward the Germ Theory of Disease." Journal of the History of Medicine 9 (1954): 428-54.
- _____. "Some Variant Theories in Opposition to the Germ Theory of Disease." Journal of the History of Medicine and Allied Sciences 9 (1954): 290-303.
- Ricks, Joel E. The Utah State Agricultural College: A History of Fifty Years, 1888-1938. Logan: The Deseret News Press, 1938.
- Rodgers, A.D. Erwin Frink Smith; a Story of North American Plant Pathology. Philadelphia : American Philosophical Society, 1952.
- Rogers, Andrew D. Liberty Hyde Bailey: A Story of American Plant Sciences. Edited by Princeton. Princeton University Press, 1949.
- Rontondaro, Felice Angelico. "The Development of Bacteriology: Bibliography." University of Pittsburgh Bulletin 29 (1933): 199-205.
- Roos, C.C. "The Original Minutes of the Society of American Bacteriologists." Journal of Bacteriology 37 (1939): 103-.
- Rosen, George. A History of Public Health. New York: MD Publications, 1958.
- _____. "The Bacteriologic, Immunologic, and Chemiotherapeutic Period, 1875-1950." Bulletin of the New York Academy of Medicine 90 (1964): 491.
- Rosenberg, Charles E. "Martin Arrowsmith: The Scientist as Hero." American Quarterly 15 (1963): 447-58.
- Ross, Earle E. A History of the Iowa State College of Agriculture and Mechanic Arts. Ames: Iowa State College Press, 1942.
- Ross, Earle D. The Land-grant Idea at Iowa State College: A Centennial Trial Balance, 1858-1958. Ames: Iowa State College Press, 1958.
- Russell, Harry L. "The Development of American Bacteriology." In Papers and Reports of the American Public Health Association, Presented at the 31st Annual Meeting, October 1903, vol. 29, 329-37. Columbus: Press of Fred. J. Heer, 1904.

- Russell, E. John, and J.A. Voelcker. Fifty Years of Field Experiments at the Woburn Experimental Station. London: Longmans, Green and Co., 1936.
- Russell, Edward J., ed. Rothamsted, 1843-1943: The Work and History of the Departments. St. Albans, Herts: Gibbs & Bamforth Ltd., 1943.
- Salmon, Daniel E. "Some Examples of the Development of Knowledge Concerning Animal Diseases." In Yearbook of the United States Department of Agriculture, 1899, 98-134. Washington: GPO, 1900.
- Salmon, D.E. The United States Bureau of Animal Industry, at the Close of the Nineteenth Century, 1884-1900. In Souvenir Volume. Washington: published by the author, George E. Howard & Co. Printers, 1901.
- Schlebecker, John T., and Andrew W. Hopkins. A History of Dairy Journalism in the United States, 1810-1950. Madison: University of Wisconsin Press, 1957.
- Sedgwick, William T. "The Origin, Scope and Significance of Bacteriology." Science 13 (1901): 121-8.
- _____. "The Genesis of a New Science -- Bacteriology." Journal of Bacteriology 1 (1916): 1-4.
- Sexton, Anna M. "Wyatt Galt Johnston and the Founding of the Laboratory Section." American Journal of Public Health -- Year Book 40 (1950).
- _____. "Theobald Smith: The First Chairman of the Laboratory Section." American Journal of Public Health -- Yearbook 41 (1951).
- Shryock, Richard. "The Origins and Significance of the Public Health Movement in the United States." Ann. Medical History n.s. 1 (1929): 645-65.
- Shryock, Richard H. "American Indifference to Basic Sciences During the 19th Century." Archives Internationales d'Histoire de Science 5 (1948): 50.
- Shryock, Richard. The Unique Influence of the Johns Hopkins University on American Medicine. Copenhagen: Munksgaard, 1953.
- Shryock, Richard H. National Tuberculosis Association, 1904-1954: A Study of the Voluntary Health Movement in the United States. New York: National Tuberculosis Association, 1957.
- Sigerist, Henry E. "The Philosophy of Hygiene." Bulletin of the Institute of the History of Medicine 1, no. 8 (1933): 323-31.
- Sinclair, William J. Semmelweis: His Life and His Doctrine. Manchester: University Press, 1909.
- Smith, Erwin F. "In Memoriam, Thomas J. Burrill." Journal of Bacteriology 1 (1916): 269-171.
- _____. An Introduction to Bacterial Diseases of Plants. Philadelphia: W.B. Saunders Co., 1920.

- _____. "Fifty Years of Pathology." Proceedings of the International Congress of Pathology 1 (1926): 17.
- Smith, Theobald E. "Koch's Views on the Stability of Species Among Bacteria." Annals of Medical History, n.s. 4 (1932): 524-30.
- Smith, Howard R. The Conquest of Bovine Tuberculosis in the United States. Somerset, Michigan: s.n., 1958.
- Smithcors, J.F. Evolution of the Veterinary Art. Kansas City, Missouri: Veterinary Medicine Publishing Co., 1957.
- _____. "The History of Some Current Problems in Animal Diseases, VI. Hog Cholera." Veterinary Medicine, no. 52 (1957): 383-386, 403-405, 409.
- _____. "The Medical Men and Veterinary Medicine in America." Bulletin of the History of Medicine 33 (1959): 330-41.
- _____. The American Veterinary Profession, Its Background and Development. Ames: Iowa State University Press, 1963.
- Sokoloff, Boris. The Story of Penicillin. Chicago: Ziff-Davis Publishing Co., 1945.
- Stanford University School of Medicine. Recollection of Cooper Medical College (1883-1905). Palto Alto: Stanford Medical School, 1964.
- Stange, C.H. History of Veterinary Medicine at Iowa State College. Ames, Iowa: Iowa State Press, 1929.
- Starkey, R.L. "Microbiology and the Microbiologist." Microbiological Reviews 27 (1963): 243-52.
- Steere, William Campbell, ed. Botanical Society of America: Fifty Years of Botany. New York: McGraw-Hill, 1958.
- Stemmons, Walter, and Andre Schenker. Connecticut Agricultural College -- a History. New Haven: Tuttle, Morehouse & Taylor Co., 1931.
- Stephens, Frank F. A History of the University of Missouri. Columbia: University of Missouri Press, 1962.
- Sternberg, Martha L. George Miller Sternberg: A Biography. Chicago: American Medical Association, 1920.
- Stimson, A.M. "The Hygienic Laboratory of the U.S. Public Health Service." International Clinics 4, no. 35th ser. (1925): 199-208.
- _____. "A Brief History of Bacteriological Investigations of the United States Public Health Service." U.S. Public Health Reports Supplement, no. 141 (1938): 1-82.

- Strauss, Anselm L, and Lee Rainwater. The Professional Scientist: A Study of American Chemists. Chicago: Aldine, 1962.
- Stubbs, Evan L. A History of Veterinary Medicine in Pennsylvania. Philadelphia: University of Pennsylvania Press, 1960.
- Tetrault, P.A. "History of Bacteriology at Perdue University." Proceedings of the Indiana Academy of Sciences 53 (1944).
- Thom, Charles. "Soil Microbiology in America." In Lipman Hall: Being an Account of the Proceedings at the Dedication on June 12th, 1951, of a Building Named in Honor of Jacob Goodale Lipman, 36-51. New Brunswick: Rutgers University, 1952.
- Thomsen, L.C. "Butter Manufacture." Journal of Dairy Science 39 (1956): 819-21.
- Thornberry, H.H. "A History of Plant Pathology in Illinois." typewritten manuscript, 1-7. 1958.
- Thwing, Charles F. The American and the German University. New York: The Macmillan Company, 1928.
- Tooney, Fred O. "The Introduction of Bacteriology Into the Service of Public Health in Chicago." Bulletin of Society of Medical History of Chicago 5 (1937): 22-33.
- Tracy, Henry C. American Naturalists. New York: Dutton, 1931.
- Trout, G. Malcolm. "Fifty Years of the American Dairy Science Association." Journal of Dairy Science 39 (1956): 625-51.
- Truby, Albert E. The Memoir of Walter Reed. New York: P.B. Hoeber, Inc., 1943.
- True, A.C. "Agricultural Experiment Stations in the United States." In Yearbook of the United States Department of Agriculture, 1899, 513-48. Washington D.C.: GPO, 1900.
- True, Alfred Charles. "A History of Agricultural Education in the United States." United States Department of Agriculture, Miscellaneous Publication, no. 36 (1929): 1-420.
- True, Alfred C. "A History of Agricultural Experimentation in the United States, 1607-1925." USDA Miscellaneous Publications, no. 251 (1937).
- Tyzzer, E.E. "Theobald Smith." New England Journal of Medicine 212 (1935): 169-71.
- Unilever Ltd. The Story of Port Sunlight. Port Sunlight, England: Lever Brothers, 1953.
- van Niel, C.B. "The 'Delft School' and the Rise of General Microbiology." Microbiological Reviews. , 161-74. 1949.
- Vaughan, Victor C. A Doctor's Memories. Indianapolis: Bobbs-Merrill, 1926.

- _____. "The Michigan State Board of Health." Journal of Laboratory and Clinical Medicine 15 (1930): 923-4.
- Vaughan, W.T. Strange Malady. New York: Doubleday Doran & Co., 1941.
- Viles, John. The University of Missouri: A Centennial History. Columbia: University of Missouri, 1939.
- Voorhees, Edward B. "A Popular Review of the Work of the Experiment Station." Bulletin of the New Jersey Agricultural Experiment Stations, no. 182 (1905).
- Wails, James O. "First Bacteriologic Laboratory in Massachusetts." New England Journal of Medicine 234 (1946): 391.
- Waksman, Selman A. "Soil Microbiology in 1924: An Attempt at an Analysis and Synthesis." Soil Science 19 (1925): 20-46.
- _____. "Fifty Years of Soil Microbiology at Rutgers." In Lipman Hall, Being an Account of the Proceedings at the Dedication on June 12, 1951, of a Building Named in Honor of Jacob Goodale Lipman, 3-10. Rutgers University Press: New Brunswick, 1952.
- _____. Sergei N. Winogradsky, His Life and Work: The Story of a Great Bacteriologist. New Brunswick: Rutgers University Press, 1953.
- _____. My Life with the Microbes. New York: Simon and Schuster, 1954.
- Walters, John D. History of the Kansas State Agricultural College. Manhattan, Kansas: Kansas State Agricultural College, 1909.
- Weaver, George H. "The Introduction of Bacteriology Into the Medical Curriculum in Chicago." Bulletin of the Society of Medical History of Chicago 5 (1937): 1-2.
- Webber, Herbert J. Some Facts Concerning the New York State College of Agriculture at Cornell University. Ithaca: Ithaca Journal Print, 1910.
- Weber, Gustavus A. The Bureau of Chemistry and Soils: Its History, Activities and Organization. In Service Monographs of the U.S. Government, No. 52. Baltimore: Johns Hopkins Press, 1928.
- Weinstein, Israel. "Eighty Years of Public Health in New York City." Bull. N.Y. Acad. Med. 23 (1947): 221-37.
- Welch, William M. "The Municipal Hospital for Contagious and Infectious Diseases." In Founder's Week Memorial Volume, edited by Frederick P. Henry, 546-54. Philadelphia: City of Philadelphia Press, 1909.
- Welch, William H. Public Health in Theory and Practice: An Historical Review. New Haven: Yale University Press, 1925.

- Whipple, George C. "Sanitary Engineering at Harvard University." Bulletin of the Society for the Promotion of Engineering Education 2 (January 1912): 242-7.
- _____. State Sanitation: A Review of the Work of the Massachusetts State Board of Health. Cambridge: Harvard University Press, 1917.
- _____. "Fifty Years of Water Purification." In A Half Century of Public Health: Jubilee Historical Volume of the American Public Health Association, edited by M.P. Ravenel, 161-80. New York: American Public Health Association, 1921.
- White, Timothy P. "Retrospection: Depicting in Words the Story of the Bureau of Animal Industry, United States Department of Agriculture." Washington: Bureau of Animal Industry, 1920.
- Whitney, Milton. "Soil Investigations in the United States." In Yearbook of the United States Department of Agriculture, 1899, 335-46. Washington: GPO, 1900.
- Whittier, E.O. "Research by Federal Agencies on Dairy Manufacturing." Journal of Dairy Science 39 (1956): 800-803.
- Wiest, Edward. Agricultural Organization in the United States. Lexington: University of Kentucky Press, 1923.
- Wik, Rynold Millard. "Henry Ford's Science and Technology for Rural America." Technology and Culture 3 (1962): 247-58.
- Wiley, H.W. "Historical Sketch of the Association of Official Agricultural Chemists." Chemical Bulletin 57 (1899): 16.
- Willard, Julius T. History of Kansas State College of Agriculture and Applied Science. Manhattan: Kansas State College Press, 1940.
- Williams, Ralph C. The United States Public Health Service, 1798-1950. Washington, D.C.: Commissioned Officers Association of the United States Public Health Service, 1951.
- Wilson, Louis B. "The Development of Public Health Medicine in Minnesota." Proceedings, Minnesota Academy of Science, 4-12. 1936.
- Wilson, Perry W. "Biological Nitrogen Fixation -- Early American Style." Bacteriological Reviews 27 (1963): 405-16.
- Winogradsky, Sergei. Microbiologie Du Sol, Problems et Methodes: Cinquent Ans de Recheches, Oeuvres Completes. Paris: Masson, 1949.
- Winslow, C.-E.A. "The Teaching of Biology and Sanitary Science in the Massachusetts Institute of Technology." Technology Quarterly 19, no. 4 (December 1906): 416-25.
- _____. "William Thompson Sedgwick, 1855-1921." Journal of Bacteriology 6 (1921): 255-62.

- Winslow, Charles -E.A. The Evolution and Significance of the Modern Public Health Campaign. New Haven: Yale University Press, 1923.
- Winslow, Charles-Edward Amory. The Contributions of Herman Biggs to Public Health. New York: New York Tuberculosis and Health Association, 1928.
- Winslow, C.-E.A. The Life of Herm M. Biggs, M.D., D.Sc., LL.C.: Physician and Statesman of Public Health. Philadelphia: Lea & Febiger, 1929.
- _____. "The First Forty Years of the Society of American Bacteriologists." Science 91 (1940): 125-9.
- Winslow, Charles -E. A. The Conquest of Epidemic Disease. Princeton: Princeton University Press, 1944.
- _____. "Some Leaders and Landmarks in the History of Microbiology." Microbiological (Bacteriological) Reviews 14 (1950): 99-114.
- Winslow, C.-E.A. "There Were Giants in Those Days." American Journal of Public Health 34, no. 6 (June 1953): 15-9.
- Wiser, Vivian, and W. Rasmussen. "Background for Plenty: A National Center for Agricultural Research." Maryland History Magazine 61 (1961): 283-304.
- Wolbach, Simeon B. "Hans Zinsser, 1878-1940." National Academy of Sciences, Biographical Memoirs 24 (1947): 323-60.
- Woodward, Carl R., and Ingrid N. Waller. New Jersey's Agricultural Experiment Station, 1880-1930. New Brunswick: New Jersey Agricultural Experiment Station, 1932.
- Woodward, Carl R., and Ingrid N Waller. New Jersey's Agricultural Experiment Station, 1880-1930. New Brunswick: New Jersey Agricultural Experiment Station, 1932.
- Wynne, Shirley. "The History of Milk in New York City." Cornell Vet. 24 (1934): 299-309.
- Young, Clifford C. The Development, Organization and Operation of the Bureau of Laboratories of the Michigan Department of Health, 188 p. Lansing, Mich.: Robert Smith Co., 1925.
- Yuncker, T.G. "History of Bacteriology at DePauw University." Proceedings of the Indiana Academy of Science 53 (1943): 57-8.
- Zinsser, Hans. "Theobald Smith." National Academy of Sciences Biographical Memoirs 17 (1936): 261-303.
- _____. "The Transformation of Medicine by Public Health Development." Trans. College of Physicians, Philadelphia 4, no. Supplement (1937): 65.

SECONDARY SOURCES: 1965-2000

- Abbott, Andrew. The System of Professions: An Essay on the Division of Expert Labor. Chicago: University of Chicago Press, 1988.
- Abrams, Samuel J. "Germ Fighters of the 19th Century." Adler Museum Bulletin 22 (March 1996): 4-9.
- Adams, Annmarie. "Waste Not, Want Not: An Exhibition Review." Winterthur Portfolio 27 (1992): 75-82.
- Ainsworth, G.C. Introduction to the History of Mycology. Cambridge: Cambridge University Press, 1976.
- _____. Introduction to the History of Plant Pathology. Cambridge: Cambridge University Press, 1981.
- _____. Introduction to the History of Medical and Veterinary Mycology. Cambridge: Cambridge University Press, 1986.
- Aisenberg, Andrew R. "Contagious Disease and the Government of Paris in the Age of Pasteur." In Ph.D. Diss., Yale University. 1994.
- _____. Contagion: Disease, Government, and the 'Social Question' in 19th Century France. Stanford: Stanford University Press, 1999.
- Alborn, Timothy L. "A Plague Upon Your House: Commercial Crises and Epidemic Disease in Victorian England." In Biology as Society, Society as Biology: Metaphors, edited by Sabine Maasen, 281-310. Dordrecht: Kluwer Academic, 1995.
- Alewitz, Sam. Filthy Dirty: A Social History of Unsanitary Philadelphia in the Late 19th Century. New York: Garland, 1989.
- Allen, Garland. "Hugo DeVries and the Reception of Mutation Theory." Journal of the History of Biology 2 (1969): 55-87.
- Allen, Garland E. Life Sciences in the Twentieth Century. Cambridge: Cambridge University Press, 1978.
- _____. "Naturalists and Experimentalists: The Genotype and the Phenotype." Studies in the History

of Biology 3 (1979): 179-209.

_____. "The Transformation of a Science: T.H. Morgan and the Emergence of a New American Biology." In The Organization of Knowledge in Modern America, 1860-1920, edited by Alexandra Oleson, and John Voss. Baltimore: Johns Hopkins University Press, 1979.

Allen, Garland. "Morphology and Twentieth-century of Biology: A Response." Journal of the History of Biology 14 (1981): 159-76.

Amsterdamska, Olga. "Medical and Biological Constraints: Early Research on Variation in Bacteriology." Social Studies of Science 17 (1987): 657-87.

_____. "Surely You Are Joking, Monsieur Latour!." Science, Technology, and Human Values 14 (1990): 495-504.

_____. "Stabilizing Instability: The Controversy Over Cyclogenic Theories of Bacterial Variation During the Interwar Period." Journal of the History of Biology 24 (1991): 191-222.

_____. "Between Medicine and Science: The Research Career of Oswald T. Avery." In Medicine and Change: Historical and Sociological Studies of Medical Innovation, edited by Ilana Lowy. London: John Libby, 1993.

Anderson, Warwick, Myles Jackson, and Barbara G. Rosenkrantz. "Toward an Unnatural History of Immunology." Journal of the History of Biology 27 (1994): 575-94.

Anderson, Warwick. "Excremental Colonialism: Public Health and the Poetics of Pollution." Critical Inquiry 21 (1995): 641-59.

_____. "Race, Medicine and Empire." Bulletin of the History of Medicine 70 (1996): 62-75.

Veterinary Medicine in the West. Manhattan, KS: Sunflower University Press, 1988.

100 Years of Progress: The Oregon Agricultural Experiment Station, Oregon State University, 1888-1988. Corvallis, Oregon: Oregon State University, 1990.

Dirt & Domesticity: Constructions of the Feminine. New York: Whitney Museum of American Art, 1992.

Appel, Toby A. "Biological and Medical Societies and the Founding the American Physiological Society." In Physiology in the American Context, 1850-1940, edited by Gerald Geison. Bethesda: American Physiological Society, 1987.

_____. "Organizing Biology: The American Society of Naturalists and Its 'Affiliated Societies,' 1883-1923." In The American Development of Biology, edited by Ronald Rainger, Keith R. Bensen, and Jane Maienschein, 87-120. 1988.

Arnold, David, ed. Imperial Medicine and Indigenous Societies. New York: St. Martin's Press, 1988.

- _____. "Social Crises and Epidemic Disease in the Famines of 19th Century India." Social History of Medicine 6 (1993): 385-404.
- Aronson, N. "Nutrition as a Social Problem: A Case Study of Entrepreneurial Strategy in Science." Social Problems 29 (1982): 474-87.
- Aspin, Richard K. "Pasteur, a Hundred Years on." Friends of the Wellcome Institute, Newsletter, no. 8 (Sept. 1995).
- Athale, D.M. "Bacteriology and the Study of Immunity." Medi Theme 11, no. 3 (1992): 59-65.
- Atran, Scott. "Origin of the Species and Genus Concepts: An Anthropological Perspective." Journal of the History of Biology 20 (1987): 195-279.
- _____. Cognitive Foundations of Natural History: Towards an Anthropology of Science. Cambridge: Cambridge University Press, 1989.
- Austrian, Robert. "The *Pneumococcus* at the Millennium: Not Down, not Out." Journal of Infectious Diseases 179, no. suppl 2 (March 1999): S338-S241.
- Baatz, Simon. "Venerate the Plough": A History of the Philadelphia Society for Promoting Agriculture, 1785-1985. Philadelphia: PSPA, 1985.
- Baker, John Robin. "The Subspecific Taxonomy of *Tripanosoma Brucei*." Parasite 2 (March 1995): 3-12.
- Baldry, Peter. The Battle Against Bacteria: A Fresh Look. A History of Man's Fight Against Bacterial Disease with Special Reference to the Development of Antibacterial Drugs. Cambridge: Cambridge University Press, 1976.
- Baldwin, Peter. Contagion and the State in Europe, 1830-1930. Cambridge: Cambridge University Press, 1999.
- Barnes, Barry, and David Edge. "Science as Expertise." In Science in Context: Readings in the Sociology of Science, 233-49. Cambridge: MIT Press, 1982.
- Barns, William D. "Farmers Versus Scientists: The Grange, the Farmer's Alliance, and the West Virginia Agricultural Experiment Station." Proceedings fo the West Virginia Academy of Science 37 (1965): 197-206.
- Basalla, George. "Pop Science: The Depiction of Science in Popular Culture." In Science and Its Public, edited by Gerald Holton, and W.A. Blanpied, 261-78. Dordrecht: D. Reidel, 1976.
- Bastien, Joseph W. The Kiss of Death: Chagas' Disease in Americas. Salt Lake City: University of Utah Press, 1998.
- Bates, Barbara. Bargaining for Life: A Social History of Tuberculosis, 1876-1939. Philadelphia: Unviersity of Pennsylvania, 1992.

Beardsley, Edward H. "An Industry Revitalized: Harry Russell, Stephen Babcock and the Cold Curing of Cheese." Wisconsin Magazine of History 49 (1965): 122-37.

_____. "Making of a Scientist: Harry L. Russell in Europe." Wisconsin Magazine of History 49 (1965): 3-15.

_____. "Portrait of a Scientist: The Professional Career of Harry Luman Russell." In Diss., University of Wisconsin, 1966. 1966.

_____. Harry L. Russell and Agricultural Science in Wisconsin. Madison: University of Wisconsin Press, 1969.

Bechtel, William, ed. Integrating Scientific Disciplines. Dordrecht: Nijhoff, 1986.

_____. "Integrating Sciences by Creating New Disciplines: The Case of Cell Biology." Biology and Philosophy 8 (1993): 277-99.

Becker, Howard S. Doing Things Together: Selected Papers. Evanston, IL: Northwestern University Press, 1986.

_____. Tricks of the Trade. Chicago: University of Chicago Press, 1998.

Beeson, Paul B. "Infectious Diseases (Microbiology)." In Advances in American Medicine: Essays at the Bicentennial, edited by J.Z. Bowers, and E.F. Purcell, vol. 1, 100-156. New York: Josiah Macy Jr. Foundation, 1976.

Ben-David, Joseph. "Emergence of National Traditions in the Sociology of Science: The United States and Great Britain." In The Sociology of Science. San Francisco: Jossey-Bass, 1978.

Bender, Thomas. "Science and the Culture of American Communities: The Nineteenth Century." History of Education Quarterly 16 (1976): 63.

Bendiner, E. "Beijerinck and His Filterable Principles." Hospital Practice (Office Edition) 26, no. 4A (April 30 1991): .

Bensaude-Vincent, Bernadette. "Lavoisier: Une Revolution Scientifique." In Elements D'histoire Des Sciences, edited by Michel Serres, 363-86. Paris: Bordas, 1989.

Bensen, Keith R. "From Museum Research to Laboratory Research: The Transformation of Natural History in Academic Biology." In The American Development of Biology, edited by Ronald Rainger, Keith R. Bensen, and Jane Maienschein. Philadelphia: University of Pennsylvania Press, 1988.

Bensen, Keith R., and Brother C. Edward Quinn. "The American Society of Zoologists, 1889-1989: A Century of Integrating the Biological Sciences." American Zoologist 30 (1990): 353-96.

Benson, Keith R. "Problems of Individual Development: Descriptive Embryological Morphology in

- America at the Turn of the Century." Journal of the History of Biology 14 (1981): 115-28.
- Benson, Keith R., Jane Maienschein, and Ronald Rainger, eds. The American Development of Biology. Philadelphia: University of Pennsylvania Press, 1988.
- Benson, Keith, Jane Maienschein, and Rainger Ronald, eds. The Expansion of American Biology. New Brunswick, NJ: Rutgers University Press, 1991.
- Benson, Keith R., Jane Maienschein, and Ronald Rainger, eds. The Expansion of American Biology. New Brunswick: Rutgers University Press, 1991.
- Bergersen, F.J., and J.R. Postgate, eds. A Century of Nitrogen Fixation Research, 231 pp. London: Royal Society, 1987.
- Berliner, Howard S. "A Larger Perspective on the Flexner Report." International Journal of Health Services 5 (1975): 573-5.
- Beutner, E.H. "Tuberculosis of the Skin: Historical Perspectives on Tuberculin and Bacille Calmette Guerin." International Journal of Dermatology 36 (1997): 73-7.
- Birke, Lynda. Feminism, Animals and Science: The Naming of the Shrew. Buckingham, England: Open University Press, 1994.
- Blackwater, R.E. Taxonomy. New York: John Wiley & Sons, 1967.
- Blaisdell, John D. "With Certain Reservations: The American Veterinary Community's Reception of Pasteur's Work on Rabies." Agricultural History 70 (1996): 503.
- Bloor, David. "Durkheim and Mauss Revisited: Classification and the Sociology of Knowledge." Studies in the History and Philosophy of Science 13 (1982): 267-92.
- Blumer, Herbert. Symbolic Interactionism: Perspectives and Method. Englewood, N.J.: Prentice Hall, 1969.
- Blumhagen, Dan W. "The Doctor's White Coat: The Image of the Physician in Modern America." Annals of Internal Medicine 92 (1979): 111-6.
- Bodily, Howard. "The First Section: Laboratory." American Journal of Public Health 63 (August 1973): 668-9.
- Bohning, James J. "The Continental Chemical Society." Bulletin for the History of Chemistry 6 (1990): 15-21.
- Borell, Merriley. "Setting the Standards for a New Science: Edward Schafer and Endocrinology." Medical History 22 (1978): 282-90.
- _____. "Instrumentation and the Rise of Modern Physiology." Science and Technology Studies 5

(1987): 53-62.

_____. "Instruments and an Independent Physiology: The Harvard Physiological Laboratory, 1871-1906." In Physiology in the American Context, 1850-1940, edited by Gerald L. Geison. Bethesda: American Physiological Society, 1987.

Borges, Jorge Luis. "The Analytical Language of John Wilkins." In Other Inquisitions 1937-1952, 103. Austin: University of Texas Press, 1993 (1964).

Bos, L. "The Embryonic Beginning of Viology: Unbiased Thinking and Dogmatic Stagnation." Archives of Virology 140 (1995): 613-9.

Bourdieu, Pierre. "The Specificity of the Scientific Field and the Social Conditions of the Progress of Reason." Social Science Information 14 (1975): 19-47.

_____. "The Social Space and the Genesis of Groups." Social Science Information 24 (1985): 195-220.

_____. "The Genesis of the Concepts of 'Habitus' and 'Field'" Sociocriticism 2 (1985): 11-24.

_____. "The Struggle for Symbolic Order." Theory, Culture and Society 3 (1986): 35-51.

_____. "The Peculiar History of Scientific Reason." Sociological Forum 6 (March 1991): 3-26.

Bowden, Mary Ellen, and John K. Smith. American Chemical Enterprise: A Perspective on 100 Years of Innovation to Commemorate the Centennial of the Society of Chemical Industry (American Section). In Chemical Heritage Foundation, No. 14. Philadelphia: Chemical Heritage Foundation, 1994.

Bowden, Mary Ellen. "100 Years of Friendly Intercourse: American Section of the Society of Chemical Industry." Chemistry and Industry, October 3 1994, 780-1.

Bowker, Geoffrey C., and Susan Leigh Star. Sorting Things Out: Classification and Its Consequences. Cambridge: MIT Press, 2000.

Bowker, Geoffrey C. "The Game of the Name: Nomenclatural Instability in Botany." In History of Information Science, edited by Robert V. Williams. forthcoming, 2001.

Brandt, Allan. No Magic Bullet: A Social History of Venereal Disease in the United States Since 1880. New York: Oxford University Press, 1985.

Brock, Thomas D. "The Bacterial Nucleus: A History." Microbiological Reviews 52 (1988): 397-411.

_____. Robert Koch: A Life in Medicine and Bacteriology. Madison: Science Tech Publishers, 1988.

_____. The Emergence of Bacterial Genetics. Cold Spring Harbor, NY: Cold Spring Harbor Laboratory Press, 1990.

- _____. "The Road to Yellowstone, and Beyond." Annual Review of Microbiology 49 (1995): 1-28.
- Brooks, Stewart M. Ptomaine: The Story of Food Poisoning. New York: A.S. Barnes, 1974.
- Brown, JoAnne, and David K. Van Keuren, eds. The Estate of Knowledge; F-3. Baltimore: Johns Hopkins University Press, 1991.
- Brown, JoAnne. The Definition of a Profession: The Authority of Metaphor in the History of Intelligence Testing, 1890-1930. Princeton: Princeton University Press, 1992.
- Brown, Kevin. "Private Alexander Fleming." St. Mary's Gazette 99 (April 1993): 29-31.
- Brown, JoAnne. "Crime, Commerce, and Contagionism: The Political Languages of Public Health and the Popularization of Germ Theory in the United States, 1870-1950." In Scientific Authority in 20th-century America, edited by Ronald G. Walters, 53-81. 1997.
- Bruce, Darryl. "Lashley's Shift from Bacteriology to Neuropsychology, 1910-1917, and the Influence of Jennings, Watson, and Franz." Journal of the History of the Behavioral Sciences 22 (1986): 27-44.
- Brumberg, Joan Jacobs, and Nancy Tomes. "Women in the Professions: A Research Agenda for American Historians." Reviews in American History 10 (1982): 275-96.
- Bud, Robert. The Uses of Life: A History of Biotechnology. Cambridge: Cambridge University Press, 1993.
- Bullis, Kenneth L. "The History of Avian Medicine in the U.S.: II. Pullorum Disease and Fowl Typhoid." Avian Diseases 21, no. 3 (July-Sept. 1977): 422-9.
- _____. "The History of Avian Medicine in the U.S.: III. Salmonellosis." Avian Diseases 21, no. 3 (1977): 429-.
- Burke, D.S. "Of Postulates and Peccadilloes: Robert Koch and Vaccine (Tuberculin) Therapy of Tuberculosis." Vaccine 11 (1993): 795-804.
- Busch, Lawrence. "Structure and Negotiation in the Agricultural Sciences." Rural Sociology, 26-48. 1980.
- _____, ed. Science and Agricultural Development. Montclair, NJ: Allanheld, Osmun, 1981.
- _____. "History, Negotiation and Structure in Agricultural Research." Urban Life 11 (1982): 368-84.
- Busch, Lawrence, and William B. Lacy, eds. Science, Agriculture and the Politics of Research. Boulder, CO: Westview, 1983.
- _____. The Agricultural Scientific Enterprise: A System in Transition. Boulder, CO: Westview, 1986.

- Bushnell, O.I.A. The Gifts of Civilization: Germs and Genocide in Hawaii. Honolulu: University of Hawaii Press, 1993.
- Busvine, J.R. Insects, Hygiene, and History. London: Anthlone Press of the University of London, 1976.
- Bynum, W.F. "Darwin and the Doctors: Evolution, Diathesis, and Germs in Nineteenth-century Britain." Gesnerus 40 (1983): 43-52.
- Cain, Louis P. "Raising and Watering a City: Ellis Sylvester Chesbrough and Chicago's First Sanitation System." Technology and Culture 13 (1972): 353-72.
- _____. "Unfouling the Public's Nest: Chicago's Sanitary Diversion of Lake Michigan Water." Technology and Culture 15 (1974): 594-613.
- _____. Sanitation Strategy for a Lakefront Metropolis: The Case of Chicago. DeKalb: Northern Illinois University Press, 1978.
- _____. "The Search for an Optimum Sanitation Jurisdiction: The Metropolitan Sanitary District of Greater Chicago -- A Case Study." Essays in Pubic Works History 10, no. 1 (1980): 1-35.
- Caldwell, Marc. The Last Crusade: The War on Consumption, 1862-1954. New York: Antheneum, 1988.
- Callcott, George H. History of the University of Maryland. Baltimore: Maryland Historical Society, 1966.
- Callon, Michel. "Struggles and Negotiations to Decide What is Problematic and What is Not: The Sociology of Translation." In The Social Processes of Scientific Investigation, edited by Karin Knorr, Roger Krohn, and Richard Whitley, 197-220. Dordrecht: Reidel, 1980.
- Callon, M., and John Law. "On Interests and Their Transformation: Enrollment and Counter-enrollment." Social Studies of Science 12 (1982): 615-25.
- Callon, Michel. "Some Elements of a Sociology of Translation." In Power, Action, and Belief: A New Sociology of Knowledge?, edited by John Law, 191-233. London: Routledge and Kegan Paul, 1986.
- Callon, Michel, John Law, and Ari Rip, eds. Mapping the Dynamics of Science and Technology. London: Macmillan, 1986.
- Cambrosio, Alberto, and Peter Keating. "Going Monoclonal: Art, Science and Magic in the Day-to-day Use of Hybridoma Technology." Social Problems 35 (1988): 244-60.
- Campbell, C. Lee, trans. The Fisher-Smith Controversy: Are There Bacterial Diseases of Plants? St. Paul: American Phytopathological Society, 1981.
- Campbell, C. Lee, Paul D. Peterson, and Clay S. Griffith. The Formative Years of Plant Pathology in the

United States. St. Paul: APS Press, 1999.

Campbell, C.L. "Science in Transition: Lessons from the Past for Our Future." Phytopathology 89 (1999): 17-9.

Cambrosio, Alberto, and Peter Keating. "The Disciplinary Stake: The Case of Chronobiology." Social Studies of Science 13 (1983): 323-53.

Caron, Joseph. "'Biology' in the Life Sciences: A Historiographical Contribution." History of Science 26 (1988): 228-68.

Carter, K. Codell. "Ignaz Semmelweis, Carl Mayrhofer, and the Rise of Germ Theory." Medical History 29 (1985): 33-53.

_____. "Koch's Postulates in Relation to the Work of Jacob Henle and Edwin Klebs." Medical History 29 (1985): 353-74.

_____, trans. "Introduction." In Essays of Robert Koch. Westport: Greenwood Press, 1987.

_____. "The Development of Pasteur's Concept of Disease Causation and the Emergence of Specific Causes in Nineteenth-century Medicine." Bulletin of the History of Medicine 65 (1991): 528-48.

Chaiklin, Seth, and Jean Lave, eds. Understanding Practice: Perspectives on Activity and Context, 144-72. New York: Cambridge University Press, 1993.

Chambers, Frederick. "Historical Study of Arkansas Agricultural, Mechanical, and Normal College, 1873-1943." In PhD Diss., Ball State University. Muncie, Indiana, 1970.

Chase, Allan. Magic Shots: A Human and Scientific Account of the Long and Continuing Struggle to Eradicate Infectious Diseases by Vaccination. New York: Morrow, 1982.

Chase, H.V. "The History of Brucellosis in Maryland and the District of Columbia." Medical Medical Journal 42 (Jan. 1993): 37-42.

Chatelin, Yvon. Une Epistemologie Des Sciences Du Sol. Paris: ORSTOM, 1979.

Chayut, Michael. "The Hybridisation of Scientific Roles and Ideas in the Context of Centres and Peripheries." Minerva: Review of Science, Learning and Policy 32 (1994): 297-308.

Chen, K.K., ed. The American Society for Pharmacology and Experimental Therapeutics: The First Sixty-years, 1908-1969. Bethesda: American Society for Pharmacology and Experimental Therapeutics, 1969.

Chen, Wai. "The Laboratory as Business: Sir Almroth Wright's Vaccine Programme and the Construction of Penicillin." In The Laboratory Revolution in Medicine, edited by Andrew Cunningham, and Perry Williams. Cambridge: Cambridge University Press, 1992.

- Churchill, Frederick B. "In Search of the New Biology: An Epilogue." Journal of the History of Biology 14 (1981): 177-91.
- Cittandino, Eugene. "Ecology and the Professionalization of Botany in America, 1890-1905." Studies in the History of Biology 4 (1980): 171-98.
- Clark, W.A., and D.M. Geary. "The Story of the American Type Culture Collection -- Its History and Development." Advances in Applied Microbiology 17 (1974): 295-309.
- Clarke, Adele E., and Elihu M. Gerson. "Symbolic Interactionism in the Social Studies of Science." In Symbolic Interaction and Cultural Studies, edited by Howard S. Becker, and Michal M. McCall, 179-214. Chicago: University of Chicago, 1988.
- Clarke, Adele. "A Social Worlds Research Adventure: The Case of Reproductive Science." In Theories of Science in Society, edited by Thomas Gieryr, and Susan Cozzen. Bloomington: University of Indiana Press, 1990.
- _____. "Social Worlds/Arenas Theory as Organizational Theory." In Social Organization and Social Process: Essays in Honor of Anselm Strauss, edited by David Maines, 119-58. Hawthorn, NY: Aldine de Gruyter, 1991.
- _____. Disciplining Reproduction: Modernity, American Life Sciences, and the Problem of Sex. Berkeley: University of California Press, 1998.
- Clauss, Sidonie. "John Wilkins' Essay: Its Place in the 17th Century Episteme." Journal of the History of Ideas 43 (1982): 531-53.
- Cock, A.G. "Bernard's Symposium: The Species Concept in 1900." Biological Journal of the Linnean Society 9 (1977): 1-30.
- Coleman, William. Biology in the Nineteenth Century: Problems of Form, Function and Transformation. New York: Wiley, 1971.
- _____. "The Cognitive Basis of a Discipline: Claude Bernard on Physiology." Isis 76 (1985): 49-70.
- _____. Yellow Fever in the North. Madison: University of Wisconsin Press, 1987.
- Collard, Patrick. The Development of Microbiology. London: Cambridge University Press, 1976.
- Collee, J.G. "The Private Science of Louis Pasteur." Proc. Royal College of Physicians of Edinburgh 27 (1997): 108-11.
- Cooter, Roger, and Stephen Pumfrey. "Seperate Spheres and Public Places: Reflections on the History of Science Popularization and Science in Popular Culture." History of Science 32 (1994): 237-67.
- Corner, George. Two Centuries of Medicine: A History of the School of Medicine, University Pennsylvania. Philadelphia: J.P. Lippincott, 1965.

- Cossart, Y.E. "The Shadow of Pasteur: An Historical Review." Pathology 27 (1995): 302-5.
- Cowan, Richard S. "The Origins and Early History of I.A.P.T." Taxon 31 (1982): 415-20.
- Cowdrey, Albert E. War and Healing: Stanhope Bayne-Jones and the Maturing of American Medicine. Baton Rouge: Louisiana State University Press, 1992.
- Cozzens, Susan E. "Autonomy and Power in Science." In Theories of Science in Society, edited by Susan Cozzens, and Thomas F. Gieryn, 164-84. Bloomington, IN: Indiana University Press, 1990.
- Cravens, Hamilton. "The Role of Universities in the Rise of Experimental Biology." Science Teacher 44 (1977): 33-7.
- _____. "Establishing the Science of Nutrition at the USDA: Ellen Swallow Richards and Her Allies." Agricultural History 64 (1990): 122-33.
- Cravens, Hamilton, Alan I. Marcus, and David M. Katzman, eds. Technical Knowledge in American Culture: Science, Technology, and Medicine Since the Early 1800's. In History of American Science and Technology Series. Tuscaloosa: University of Alabama Press, 1996.
- Crellin, John K. "The Dawn of the Germ Theory: Particles, Infection and Biology." In Medicine, and Science in the 1860's, edited by F.N.L. Poynter, 57-76. London: Wellcome Institute for the History of Medicine, 1968.
- Crellin, John. "Antibiosis in the 19th Century." In The History of Antibiotics, edited by John Parascandola. Madison: American Institute of the History of Pharmacy, 1980.
- Crellin, John K. "Internal Antisepsis or the Dawn of Chemotherapy?" Journal of the History of Medicine and Allied Science 36 (1981): 9-18.
- Croce, P. "The Four Postulates of Robert Koch." Revista di Biologia 89 (1996): 275-8.
- Crowson, R.A. Classification and Biology. London: Heiman, 1970.
- Cunningham, Andrew, and Perry Williams, eds. The Laboratory Revolution in Medicine. Cambridge: Cambridge University Press, 1992.
- Curtis, Bruce. "From the Moral Thermometer to Money: Metrological Reform in Pre-confederation Canada." Social Studies of Science 28 (1998): 547-70.
- Danbom, David B. "The Agricultural Experiment Station and Professionalism: Scientists Goals for Agriculture, 1887-1910." Agricultural History 60 (1986): 246-55.
- Danesh, John, Robert Newton, and Valerie Beral. "The Bacteria Craze." The Lancet 353 (April 24 1999): 1447.

- Daniel, T.M. "Robert Koch, Tuberculosis, and the Subsequent History of Medicine." American Review of Respiratory Disease 125 (1982): 1-3.
- Davenport, F. Garvin. "The Sanitation Revolution in Illinois, 1870-1900." Journal of the Illinois State Historical Society/Illinois Historical Journal 66 (1973): 306.
- Davis, P.H., and V.H. Heywood. Principles of Angiosperm Taxonomy. New York: D. Van Nostrand Co., 1965.
- Davison, J. "The Role of Experimentation and Experimental Evidence in the Development of Bacteriology in Britain." In Ph.D. Diss., University of Northumbria at Newcastle (UK). 1993.
- Dean, John. "Controversy Over Classification: A Case Study from the History of Botany." In Natural Order: Historical Studies of Scientific Culture, edited by Barry Barnes, and Steve Shapin, 211-30. Beverly Hills: Sage, 1979.
- _____. "A Naturalistic Model of Classification and Its Relevance to Some Controversies in Botanical Systematics, 1900-1950." Ph.D. diss., Edinburgh University. 1995.
- Demain, Arnold L. "Stunning Achievements of Industrial Microbiology." ASM News 65 (1999): 311-6.
- Dent, John M. "Two Views of Bacteriology at Harvard." A.B. Honors thesis, Dept. of History and Science, Harvard University, 1982.
- Dethloff, Henry C. A Centennial History of Texas A&M University, 1876-1976, 346-8. College Station: Texas A&M University Press, 1975.
- Dethloff, Henry C., and Donald H. Dyal. A Special Kind of Doctor. College Station: Texas A&M University Press, 1991.
- Dettelbach, Michael S. "The Harvard University School of Veterinary Medicine, 1882-1901: Veterinarians and the Professional Vision of Charles W. Eliot." A.B. honors thesis, Harvard University, 1986.
- Devriese, Pieter P. "On the Discovery of '*Clostridium Boltulinum*'" Journal of the History of Neurosciences 8 (1999): 43-50.
- Dixon, Bernard. "Golden Past and a Glittering Future." New Scientist 147 (1995): 45-5.
- _____. "A Century of Society Meetings." ASM News 65 (1999): 282-7.
- Doetsch, R.N., and R.G.E. Murray. "Historical Notes on BACTERIOLOGICAL REVIEWS." ASM News 40 (1974): 2-3.
- Dolby, R.G.A. "The Transmission of Two New Scientific Disciplines from Europe to North America in the Late 19th Century." Annals of Science 34 (1977): 387-10.

- Dolman, C.E. "Theobald Smith and His Presidential Address to the Society of American Bacteriologists, 1903." ASM News 47 (1981): 231-5.
- _____. "Theobald Smith, 1859-1934: A Fiftieth Anniversary Tribute." ASM News 50 (1984): 577-80.
- Douglas, Mary. How Institutions Think. Syracuse: Syracuse University Press, 1986.
- Douglas, Mary, and David L. Hull. How Classification Works: Nelson Goodman Among the Social Sciences. Edinburgh: Edinburgh University Press, 1992.
- Dowling, Harry F. Fighting Infection: Conquests of the Twentieth Century. Cambridge: Harvard University Press, 1977.
- _____. "Politics, Medical Education, and the Control of Contagious Diseases: Sydenham Hospital of Baltimore." Journal of the History of Medicine and Allied Science 40 (1985): 5-21.
- Downs, Arthur Channing, Jr. "Andrew Jackson Downing and the American Bathroom." Historic Preservation 23 (1971): 30-5.
- Dubb, Asher. "The Germs Fight Back." Adler Museum Bulletin 22 (March 1996): 1-3.
- Dubos, Rene J. "Pasteur's Dilemma -- the Road not Taken." ASM News 40 (1974): 703-9.
- Dubovsky, H. "Koch's Remedy for Tuberculosis." South African Medical Journal 47 (1973): 1604-14.
- Duffy, John. A History of Public Health in New York City, 1866-1966. New York: Russell Sage Foundation, 1974.
- _____. "School Vaccination: The Precursor to School Medical Inspection." Journal of the History of Medicine and Allied Sciences 33 (1978): 344-55.
- _____. "The American Medical Profession and Public Health: From Support to Ambivalence." Bulletin of the History of Medicine 53 (1979): 1-9.
- _____. "Bacteriology Revolutionizes Public Health." In The Sanitarians: A History of American Public Health. Urbana: University of Illinois Press, 1990.
- Edler, Albert, ed. The History of Penicillin Production. New York: Science Press, 1970.
- Epstein, Steven. Impure Science: Aids, Activism, and the Politics of Knowledge. Berkeley: University of California Press, 1996.
- Eschenbacher, Herman F. The University of Rhode Island: A History of Land-grant Education in Rhode Island. New York: Appleton-Century-Crofts, 1967.
- Etheridge, Elizabeth. The Butterfly Caste: A Social History of Pellagra in the South. Westport, CT: Greenwood Publishing Company, 1972.

- Ewan, J., ed. A Short History of Botany in the United States. New York: Hafner, 1969.
- Farber, P.F. "The Transformation of Natural History in the Nineteenth Century." Journal of the History of Biology 15 (1982): 145-52.
- Farley, John. "Parasites and the Germ Theory of Disease." In Framing Disease: Studies in Cultural History, edited by Charles E. Rosenberg, and Janet Golden, 33-49. New Brunswick: Rutgers University Press, 1992.
- Fee, Elizabeth. Disease and Discovery: A History of the Johns Hopkins School of Hygiene and Public Health, 1916-1939. Baltimore: Johns Hopkins University Press, 1987.
- Fee, Elizabeth, and Evelyn M. Hammonds. "Science, Politics, and the Art of Persuasion: Promoting the New Scientific Medicine in New York City." In Hives of Sickness: Public Health and Epidemics in New York City, edited by David Rosner. New Brunswick, NJ: Rutgers University Press, 1995.
- Feldberg, Georgina D. Disease and Class: Tuberculosis and the Shaping of Modern North American Society. New Brunswick, NJ: Rutgers University Press, 1995.
- Fellman, Anita C., and Michael Fellman. Making Sense of Self: Medical Advice Literature in Late Nineteenth Century America. Philadelphia: University of Pennsylvania Press, 1981.
- Ferleger, Lou. "Uplifting American Agriculture: Experiment Station Scientists and the Office of Experiment Stations in the Early Years After the Hatch Act." Agricultural History 64, no. 2 (Spring 1991): 5-23.
- Figlio, Karl. "The Metaphor of Organization: An Historiographical Perspective on the Bio-medical Sciences in the Early Nineteenth Century." History of Science 14 (1976): 17-53.
- Finegold, Sydney M. "A Century of Anaerobes: A Lock Backward and a Call to Arms." Clinical Infectious Diseases 16, suppl. 4 (June 1993): S453-S457.
- _____. "Review of Early Research on Anaerobes." Clinical Infectious Diseases 18, suppl. 4 (May 1994): S248-S249.
- Fischer, Donald. "Rockefeller Philanthropy and the British Empire: The Creation of the London School of Hygiene and Tropical Medicine." History of Education 7 (1978): 129-43.
- Fisher, Donald. "Boundary-work and the Demarcation of Science from Non-science: Strains and Interests in Professional Ideologies of Scientists." American Sociological Review 48 (1990): 781-95.
- Fisher, John R. "Cattle Plagues Past and Present: The Mystery of Mad Cow Disease." Journal of Contemporary History 33 (1998): 215-28.
- Fitzgerald, Deborah. The Business of Breeding: Hybrid Corn in Illinois, 1890-1940. Ithaca: Cornell

University Press, 1990.

- _____. "Mastering Nature and Yeoman: Agricultural Science in the Twentieth Century." In Science in the Twentieth Century, edited by John Krige, and Dominique Pestre, 701-14. The Netherlands: Harwood Academic, 1997.
- Fitzharris, Joseph C. "Science for the Farmer: The Development of the Minnesota Agricultural Experiment Station, 1868-1910." Agricultural History 48, no. 4 (October 1974): 202-20.
- Flaumenhaft, Eugene, and Carol Flaumenhaft. "Evolution of America's Pioneer Bacteriologist: George M. Sternberg's Formative Years." Military Medicine 158 (1993): 448-57.
- Fontana, Elizabeth A. Centennial Celebration: 100 Years of Creating a Healthier Future for Animals and People. Edited by Judy Stewart. Ithaca: College of Veterinary Medicine, Cornell University, 1994.
- Foster, W.D. A History of Parasitology. London: E. & S. Livingstone Ltd., 1965.
- _____. History of Medical Bacteriology and Immunology. London: Heinemann, 1970.
- Foucault, Michel. "Governmentality." In The Foucault Effect: Studies in Governmentality, edited by Graham Burchill, Colin Gordon, and Peter Miller. Chicago: University of Chicago Press, 1991.
- Fox, Daniel M. "Recent Marxist Interpretations of the History of Medicine in the United States." Clio Medica 15 (1982): 225-31.
- Freidson, Eliot. Profession of Medicine: A Study of the Sociology of Applied Knowledge. Chicago: University of Chicago Press, 1988.
- Friedson, Eliot. Professional Powers: A Study of the Institutionalization of Formal Knowledge. Chicago: University of Chicago Press, 1986.
- Fruton, Joseph S. Contrasts in Scientific Style: Research Groups in the Chemical and Biochemical Sciences. In Memoirs of the American Philosophical Society, No. 191. Philadelphia: American Philosophical Society, 1990.
- Fry, William F. "Prince Hamlet and Professor Koch." Perspectives in Biology and Medicine 40 (Spring 1997): 419-25.
- Fujimura, Joan. "Constructing Doable Problems in Cancer Research: Articulation and Alignment." Social Studies of Science 17 (1987): 257-93.
- _____. "The Molecular Biology Bandwagon in Cancer Research: Where Social Worlds Meet." Social Problems 35 (1988): 261-83.
- Fujimura, Joan H. "Crafting Science: Standardized Packages, Boundary Objects, and 'Translation'" In Science as Practice and Culture, edited by Andrew Pickering, 168-211. Chicago: University of

Chicago Press, 1992.

Galishoff, Stuart. Safeguarding the Public Health: Newark, 1895-1918. Westport, CT: Greenwood Press, 1975.

_____. "Germs Know No Color Line: Black Health and Public Policy in Atlanta, 1900-1918." Journal of the History of Medicine and Allied Sciences 40, no. 1 (1985): 22-41.

Gallagher, Nancy Elizabeth. Egypt's Other Wars: Epidemics and the Politics of Public Health. Edited by N.Y. Syracuse. Syracuse University Press, 1990.

Garipey, Thomas J. "The Introduction and Acceptance of Listerian Antisepsis in the United States." Journal of the History of Medicine and Allied Sciences 49 (1994): 167-206.

Gaudilliere, Jean-Paul. "Biologists at Work: Experimental Practices in the Twentieth-century Life Sciences." In Sciences in the Twentieth Century, edited by John Krige, and Dominique Pestre, 683-700. The Netherlands: Harwood Academic, 1997.

Geiger, Roger L. To Advance Knowledge: The Growth of American Research Universities, 1900-1940. New York: Oxford University Press, 1986.

Geison, Gerald. "Divided We Stand: Physiologists and Clinicians in the American Context." In The Therapeutic Revolution: Essays in the Social History of American Medicine. Philadelphia: University of Pennsylvania Press, 1979.

Geison, Gerald L., and ed. Professions and Professional Ideologies in America. Chapel Hill, NC: University of North Carolina Press, 1983.

Geison, Gerald. The Private Side of Louis Pasteur. Princeton: Princeton University Press, 1994.

George, Wilman. The Naming of the Beasts: Natural History in the Medieval Bestiary. London: Duckworth, 1991.

Gerson, Elihu. "Scientific Work and Social Worlds." Knowledge: Creation, Diffusion, Utilization 4 (1983): 357-77.

Gerson, Elihu, and Susan Leigh Star. "Analyzing Due Process in the Workplace." ACM Transactions on Office Information Systems 4 (1986): 257-70.

Gibbons, R.V. "Germs, Dr. Billings and the Theory of Focal Infection." Clinical Infectious Diseases 27 (1998): 627-33.

Gieryn, Thomas F. "Boundary-Work and the Demarcation of Science from Non-science: Strains and Interests in Professional Ideologies of Scientists." American Sociological Review 48 (1983): 781-95.

Gieryn, Thomas F., G.F. Bevins, and S.G. Zehr. "The Professionalization of American Scientists."

- American Sociological Review 50 (1985): 392-409.
- Glawe, D.A. "Thomas J. Burrill, Pioneer in Plant Pathology." Annual Review of Phytopathology 30 (1992): 17-24.
- Goldberg, Michael, and Jeffrey L. Fox. "Leaders Share Views on ASM Past and Future." ASM News 65 (1999): 271-5.
- Goldstein, Jan. "Foucault Among the Sociologists: The 'Disciplines' and the History of the Professions." History and Theory 23 (1984): 170-92.
- Goldstein, E.J. "Anaerobes Under Assault: From Cottage Industry to Industrialization of Medicine and Microbiology." Clinical Infectious Diseases 20, suppl. 2 (June 1995): S112-S116.
- Goodfellow, M., and R.G. Board. Microbiological Classification and Identification. New York: Academic Press, 1980.
- Gossel, Patricia P. "The Emergence of American Bacteriology, 1875-1900." Ph.D. diss., Johns Hopkins University, 1988.
- Gossel, Patricia Peck. "A Need for Standard Methods: The Case of American Bacteriology." In The Right Tools for the Job: At Work in Twentieth-century Life Sciences, edited by Adele E. Clark, and Joan H. Fujimura. Princeton: Princeton University Press, 1992.
- _____. "When Bacteriologists Wore Black." ASM News 65 (1999): 296-301.
- Goulden, C.E., ed. Changing Scenes in the Life Sciences, 1776-1976. In Academy of Natural Sciences Special Publication, No. 12. Philadelphia: Academy of Natural Sciences, 1977.
- Grafe, Alfred. A History of Experimental Virology. Berlin: Springer-Verlag, 1991.
- Granovetter, Mark S. "The Strength of Weak Ties." American Journal of Sociology 78 (1973): 1360-80.
- Granovetter, Mark. "The Strength of Weak Ties: A Network Theory Revisited." Sociological Theory 1 (1983): 201-33.
- Greene, John C. "Review of Les Mots et les Choses." Social Sciences Information 6 (1967): 131-8.
- Greenwood, Anna. "Lawson Tait and Opposition to Germ Theory: Defining Science in Surgical Practice." Journal of the History of Medicine and Allied Sciences 53 (1998): 99-131.
- Gross, Alan G. "The Origin of Species: Evolutionary Taxonomy as an Example of the Rhetoric of Science." In Rhetorical Turn: Invention and Persuasion in the Context of Inquiry, edited by Herbert W. Simons, 91-115. Chicago: University of Chicago Press, 1990.
- Guenel, Annick. "The Creation of the First Overseas Pasteur Institute, or the Beginning of Albert Calmette's Pastorian Career." Medical History 43 (1999): 1-25.

- Hachten, Elizabeth A. "Science in the Service of Society: Bacteriology, Medicine, and Hygiene in Russia, 1855-1907." In Ph.D. Diss., University of Wisconsin. 1992.
- Hacking, Ian. "The Disunified Sciences." In The End of Science?, edited by Richard O. Elvec. Lanham, MD: University Press of America, 1991.
- _____. "The Self-vindication of the Laboratory Sciences." In Science as Practice and Culture, edited by Andrew Pickering, 29-64. Chicago: University of Chicago Press, 1992.
- Haddad, George F. "Germ Theories, Scientific Medicine, and the Buffalo Medical Community." In Medical History in Buffalo, 1846-1996: Collected Essays, edited by Lilli Sentz, and Ronald E. Batt, 115-62. Buffalo: Friends of the Health Sciences Library and School of Medicine and Biochemical Sciences, State University of New York at Buffalo, 1996.
- Hagen, Joel B. "Experimental Taxonomy, 1930-1950: The Impact of Cytology, Ecology, and Genetics on Ideas of Biological Classification." Ph.D. diss., Oregon State University, 1982.
- Hagan, Joel B. "The Development of Experimental Methods in Plant Taxonomy, 1920-1950." Taxon 32 (1983): 406-16.
- Hagen, Joel B. "Experimentalists and Naturalists in Twentieth-century Botany: Experimental Taxonomy, 1920-1950." Journal of the History of Biology 17, no. 2 (1984): 249-70.
- Haines, Barbara. "The Interrelations Between Social, Biological, and Medical Thought." British Journal of History of Science 11 (1978): 19-35.
- Hamlin, Christopher. "Edward Frankland's Early Career as London's Official Water Analyst, 1865-1880." Bulletin of the History of Medicine 56 (1982): 56-76.
- Hamlin, Christopher. "Providence and Putrefaction: Victorian Sanitarians and the Natural Theology of Health and Disease." Victorian Studies 28 (1985): 381-411.
- Hamlin, Christopher. "Politics and Germ Theories in Victorian Britain: The Metropolitan Water Commissions of 1867-9 and 1892-3." In Government and Expertise, edited by R. MacLeod, 110-27. Cambridge: Cambridge University Press, 1988.
- _____. A Science of Impurity: Water Analysis of Nineteenth Century Britain. Berkeley: University of California Press, 1990.
- Hammonds, Evelyn M. "The Search for Perfect Control: A Social History of Diphtheria, 1880-1930." In Ph.D. Diss., Harvard University. 1993.
- _____. "Science, Politics, and the Art of Persuasion: Promoting the New Scientific Medicine in New York City." In Hives of Sickness: Public Health and Epidemics in New York City. New Brunswick: Rutgers University Press, 1995.
- _____. Childhood's Deadly Scourge: The Campaign to Control Diphtheria in New York, 1880-1930.

- Baltimore: Johns Hopkins University Press, 1999.
- Haney, Robert L. Milestones: Marking Ten Decades of Research. n.p.: Texas Agricultural Experiment Station, 1989.
- Hanke, O.G., J.L. Skinner, and J.H. Florea, eds. American Poultry History. Madison: American Poultry Historical Society, 1974.
- Harden, Victoria A. Inventing the NIH: Federal Biomedical Research Policy, 1887-1937. Baltimore: Johns Hopkins University Press, 1986.
- _____. Rocky Mountain Spotted Fever: History of a Twentieth-century Disease. Baltimore: Johns Hopkins University Press, 1990.
- Hardy, Anne. "Water and the Search for Public Health in London in the 18th and 19th Centuries." Medical History 28 (1984): 250-82.
- _____. The Epidemic Streets: Infectious Disease and the Rise of Preventive Medicine, 1856-1900. Oxford: Oxford University Press, 1993.
- _____. "On the Cusp: Epidemiology and Bacteriology at the Local Government Board, 1890-1905." Medical History 42 (1998): 328-46.
- Harker, Richard, Cheleen Mahar, and Chris Wilkes, eds. An Introduction to the Work of Pierre Bourdieu: The Practice of Theory. London: Macmillan Press, 1990.
- Harris, John S. "The Naming of Parts: An Examination of the Origins of Technical and Scientific Vocabulary." Journal of Technical Writing and Communication 14 (1984): 183-91.
- Hartshorne, Donna Taylor. My Half Century at the University of Wisconsin, Ira L. Baldwin. Madison: Omnipress, 1995.
- Harvey, A. McGehee. "John Billings: Forgotten Hero of American Medicine." Perspectives on Biology and Medicine 21 (1978): 353-7.
- _____. "Stanhope Bayne-Jones, 1886-1970: The Story of a Lifetime Devoted to Country and to Medicine." Johns Hopkins Medical Journal 149 (1981): 150-66.
- Harwood, Jonathan. Styles of Scientific Thought: The German Genetics Community, 1900-1933. In Science and Its Conceptual Foundation Series. Chicago: University of Chicago Press, 1993.
- Hays, R.G. State Science in Illinois: The Scientific Surveys, 1850-1978. Carbondale, IL: Southern Illinois University Press, 1980.
- Heaman, E.A. "The Rise and Fall of Anticontagionism in France." Canadian Bulletin of Medical History 12 (1995): 3-12.

- Helvoort, Ton van. "Bacteriology and Physiological Research Styles in the Early Controversy on the Nature of the Bacteriophage Phenomenon." Medical History 36 (1992): 243-70.
- Heywood, V.H. Plant Taxonomy. New York: St. Martin's Press, 1967.
- Hiebert, Erwin N. "Discipline Identification in Chemistry and Physics." Science in Context 9 (1996): 93-119.
- Hilding, D.A. "Discovery of Penicillin." Mayo Clinic Proceedings 73 (Jan 1998): 98.
- Hilgartner, Stephen. "The Dominant View of Popularization: Conceptual Problems, Political Uses." Social Studies of Science 20 (1990): 519-39.
- Hine, Thomas. The Total Package: The Evolution and Secret Meanings of Boxes, Bottles, Cans, and Tubes. New York: Little, Brown, 1995.
- Hobby, Gladys L. Penicillin: Meeting the Challenge. New Haven: Yale University Press, 1985.
- Holt, Marilyn Irwin. Linoleum, Better Babies, and the Modern Farm Woman, 1890-1930. Albuquerque: University of New Mexico Press, 1995.
- Horsfall, James Gordon. The Pioneer Experiment Station, 1875-1975. Lexington, KY: Antiocha Press, 1992.
- Houston, Clifford W., Martin Dworkin, and W. Robert Fleishmann. "20th Century Evolution of Microbiological Education." ASM News 65 (1999): 366-7.
- Howard, D.H. "Friedrich Loeffler and His History of Bacteriology." ASM News 48 (1982): 297-302.
- Hoy, Suellen M. "'Municipal Housekeeping': The Role of Women in Improving Urban Sanitation Practices, 1880-1917." In Pollution and Reform in American Cities, 1870-1930, edited by Martin V. Melosi, 173-98. Austin: University of Texas Press, 1980.
- Hoy, Suellen. Chasing Dirt: The American Pursuit of Cleanliness. Oxford: Oxford University Press, 1995.
- Huch, Ronald K. "'Typhoid' Truelsen, Water and Politics in Duluth, 1896-1900." Minnesota History 47 (1981): 189-99.
- Hughes, Sally Smith. The Virus: A History of the Concept. New York: Science History Publications, 1977.
- Humphreys, Margaret. Yellow Fever and the South. New Brunswick: Rutgers University Press, 1992.
- Hurt, R. Douglas. American Agriculture: A Brief History. Ames: Iowa State University Press, 1994.
- _____. The History of Agricultural Science and Technology: An International Annotated

Bibliography. New York: Garland, 1994.

Hutchinson, John F. "Tsarist Russia and the Bacteriological Revolution." Journal of the History of Medicine and Allied Sciences 40 (1985): 420-39.

Hyde, Barbara. "Society Founded by 'Lost Souls' Among Naturalists." ASM News 65 (1999): 266-70.

Itersen, G.L. van, L.E. den Dooren de Jong, and A.J. Kluyver. Martinus Willem Beijerinck: His Life and His Work. Madison: Science Tech, 1983.

Jannasch, H.W., and T. Egli. "Microbial Growth Kinetics: A Historical Perspective." Antonie van Leeuwenhoek 63 (1993): 213-24.

Jenkins, Richard. Pierre Bourdieu. In Key Sociologists. Edited by Peter Hamilton. London: Routledge, 1992.

Jensen, Floyd B. "Illinois Society for Microbiology." ASM News 40 (1974): 685-7.

Johnson, Diane. Edwin Broun Fred: Scientist, Administrator, Gentleman. Madison: Wisconsin Alumni Research Foundation, University of Wisconsin Press, 1974.

Kalisch, Philip A. "The Black Death in Chinatown, Plague and Politics in San Francisco." Arizona and the West 14 (1972): 113-36.

Kamatani, Chikayoshi. "The Institute for Infectious Disease: The First Research Institute Attached to the Imperial Universities." Journal of the Japanese Society for the History of Chemistry 24 (1997): 105-47.

Kargon, Robert H., ed. The Maturing of American Science. Washington, D.C.: AAAS, 1974.

Kaufman, Martin, Stuart Galishoff, and Todd L. Savitt. Dictionary of American Medical Biography. Vol. 2 vols. Westport, CT: Greenwood Press, 1984.

Kaufmann, George B. Coordination Chemistry: A Century of Progress, 1893-1993. Washington, D.C.: American Chemical Society, 1994.

Kay, Lily E. The Molecular Vision of Life: Caltech, the Rockefeller Foundation, and the Rise of the New Biology. New York: Oxford University Press, 1993.

_____. Who Wrote the Book of Life? A History of the Genetic Code. Stanford: Stanford University Press, 2000.

Keating, Peter. "Vaccine Therapy and the Problem of Opsonins." Journal of the History of Medicine and Allied Sciences 43 (1988): 275-96.

Keating, Peter, and Abdelkerim Ousman. "The Problem of Natural Antibodies, 1894-1905." Journal of the History of Biology 24 (1991): 245-63.

- Keefer, Karen M. "Dirty Water and Clean Toilets: Medical Aspects of the 1904 Louisiana Purchase Exposition." Gateway Heritage 9, no. 1 (1988): 32-7.
- Keeney, Elizabeth B. The Botanizers: Amateur Scientists in 19th Century America. Chapel Hill: University of North Carolina Press, 1992.
- Kennedy, B.W., K.D. Wildin, and K.F. Baker. "Bacteria as the Cause of Disease in Plants: A Historical Perspective." ASM News 45 (1979): 1-5.
- Kerr, Norwood A. The Legacy: A Centennial History of the State Agricultural Experiment Stations, 1887-1987. Columbia, MO: Missouri Agricultural Experiment Station, 1987.
- Kessel, William G. "The Beginning of the 'Journal' and the Division of Chemical Education." Journal of Chemical Education 50 (1973): 803-7.
- Keuchel, Edward F. "Science, Technology and Food Preservation: The Introduction of Bacteriology to the American Canning Industry." In Essays in American History in Honor of James C. Malin, edited by Burton J. Williams. Lawrence, KS: Corondo Press, 1973.
- Kevles, Daniel J. "American Science." In The Professions in American History, edited by Nathan O. Hatch. Notre Dame, IN: University of Notre Dame Press, 1988.
- Kevles, Daniel J., and Gerald J. Geison. "The Experimental Life Science in the Twentieth Century." Osiris 10 (1995): 97-121.
- Kevles, Daniel J. The Physicists: The History of a Scientific Community in Modern America. Cambridge: Harvard University Press, 1995.
- Kierkegaard, Soren. Repetition, 56. Princeton: Princeton University Press, 1983 (1941).
- Kimmelman, Barbara A. "The American Breeders' Association: Genetics and Eugenics in the Agricultural Context, 1903-1913." Social Studies of Science 13 (1983): 163-204.
- _____. "A Progressive Era Discipline: Genetics at American Agricultural Colleges and Experiment Stations, 1890-1920." Ph.D. diss., University of Pennsylvania. 1987.
- Kirk, Stuart A., and Herb Kutchins. The Selling of the DSM: The Rhetoric of Science in Psychiatry. New York: Aldine de Gruyter, 1992.
- Knecht-van Eekelen, Annemarie de. "The Rise of the Science of Bacteriology in the Netherlands." In Actes Du XXXIe Congres International D'Histoire de la Medecine, Anvers, 3-7 Septembre 1990; Proceedings of the XXXIInd International Congress on the History of Medicine, Antwerp, 3-7 Sept. 1900, 351-60. Bruxells: Societas Belgica Historiae Medicinae, 1991.
- Knight, David M. Ordering the World: A History of Classifying Man, 215 p. London: Burnett, 1981.
- Knorr, Karin. "Germ Warfare." Social Studies of Science 15 (1985): 577-88.

- Knorr-Cetina, Karin D. "Scientific Communities or Transepistemic Arenas? A Critique of Quasi-economic Models of Science." Social Studies of Science 12 (1982): 101-30.
- Knorr-Cetina, Karin. "The Couch, the Cathedral, and the Laboratory: On the Relationship Between Experiment and Laboratory in Science." In Science as Practice and Culture, edited by Andrew Pickering, 113-38. Chicago: University of Chicago Press, 1992.
- _____. Epistemic Cultures: How Scientists Make Sense. Cambridge: Harvard University Press, 1999.
- Kohler, Robert E. "Medical Reform and Biomedical Science: Biochemistry: A Case Study." In The Therapeutic Revolution, edited by Morris J. Vogel, and Charles E. Rosenberg. Philadelphia: University of Pennsylvania Press, 1979.
- _____. From Medical Chemistry to Biochemistry: The Making of a Biomedical Discipline. Cambridge: Cambridge University Press, 1982.
- _____. "Innovation in Normal Science: Bacterial Physiology." Isis 76 (1985): 162-81.
- _____. "Bacterial Physiology: The Medical Context." Bulletin of the History of Medicine and Allied Sciences 59 (1985): 54-74.
- _____. "Drosophila: A Life in the Lab." Journal of the History of Biology 26 (1993): 281-310.
- _____. Lords of the Fly: Drosophila Genetics and the Experimental Life. Chicago: University of Chicago Press, 1994.
- Kohlstedt, Sally Gregory. "The Nineteenth-century Amateur Tradition: The Case of the Boston Society of Natural History." In Science and Its Public: The Changing Relationship, edited by Gerland Holton, and William A. Blanpied. Dordrecht: Reidel, 1976.
- _____. The Formation of the American Scientific Community: The American Association for the Advancement of Science. Urbana: University of Illinois Press, 1976.
- Kohn, George C., ed. Encyclopedia of Plague and Pestilence. New York: Facts on File, 1995.
- Kondratas, R.A. "Biologics Control Act of 1902." In The Early Years of Federal Food and Drug Control, edited by James Harvey Young. Madison: University of Wisconsin Press, 1982.
- Koppes, Clayton R., and William P. Norris. "Ethnicity, Class, and Mortality in the Industrial City: A Case Study of Typhoid Fever in Pittsburgh, 1890-1910." Journal of Urban History 11, no. 3 (1985): 259-79.
- Korf, R.P. "A Historical Perspective: Mycology in the Department of Botany and of Plant Pathology at Cornell University and the Geneva Agricultural Experiment Station." Mycotaxon 40 (Jan/Mar 1991): 107-28.
- Krauss, William E. "History: 1882-1982." Ohio Report on Research and Development in Agriculture.

Home Economics, and Natural Resources 67 (May-June 1982).

Krauss, R.E. "About the Experiment Station -- A Centennial Celebration." Special Report of the New York Agricultural Experiment Station, Geneva 48 (May 1983).

Kraut, Alan M. "Silent Travelers: Germs, Genes, and American Efficiency, 1890-1924." Social Science History 12 (Winter 1988): 377-94.

Kraut, Alan. Silent Travelers: Germs, Genes, and the 'Immigrant Menace' New York: Basic Books, 1994.

Kraut, Alan M. "Plagues and Prejudice: Nativism's Construction of Disease in 19th and 20th Century New York City." In Hives of Sickness: Public Health and Epidemics in New York City, edited by David Rosner. New Brunswick, NJ.: Rutgers University Press, 1995.

Kunitz, S.J. "Professionalism and Social Control in the Progressive Era: The Case of the Flexner Report." Journal of Social Problems 22 (October 1974): 18-23.

Kuritz, Hyman. "The Popularization of Science in Nineteenth-century America." History of Education Quarterly 21 (1981): 259-74.

Kuznick, Peter J. Beyond the Laboratory: Scientists as Political Activists in 1930's America. Chicago: University of Chicago Press, 1987.

LaFollette, Marcel C. Making Science Our Own: Public Images of Science, 1910-1955. Chicago: University of Chicago Press, 1990.

Larson, Lawrence. "Nineteenth-century Street Sanitation: A Study in Filth and Frustration." Wisconsin Magazine of History 52 (Spring 1969): 239-.

Larson, Magali Sarfatti. The Rise of Professionalism: A Sociological Analysis. Berkeley: University of California Press, 1977.

Latour, Bruno. "Give Me a Laboratory and I Will Raise the World." In Science Observed: New Perspectives in the Sociology of Science, edited by Karin Knorr-Cetina, and Michael Mulkey, 141-70. London: Sage, 1982.

_____. Science in Action: How to Follow Scientists and Engineers Through Society. Cambridge: Harvard University Press, 1987.

Latour, Bruno, Alan Sheridan, and John Law, trans. The Pasteurization of France. Cambridge: Harvard University Press, 1988.

Latour, Bruno. The Pasteurization of France. Cambridge: Harvard University Press, 1988.

Lavallard, Marie L., ed. "Arkansas Agricultural Experiment Station: The First Forty Years." In Agricultural Progress in Arkansas. Fayetteville: Arkansas Agricultural Experiment Station, 1976.

- Lave, J. Cognition in Practice: Mind, Mathematics and Culture in Everyday Life. Cambridge: Cambridge University Press, 1988.
- Lave, Jean, and Etienne Wenger. Situated Learning: Legitimate Peripheral Participation. Cambridge: Cambridge University Press, 1991.
- Lawrence, Christopher J., and Richard Dixey. "Practising on Principle: Joseph Lister and the Germ Theories of Disease." In Medical Theory, Surgical Practice: Studies in the History of Surgery, 153-215. London: Wellcome Institute in the History of Medicine, 1992.
- Lears, T.J. Jackson. "From Salvation to Self-realization: Advertising and the Therapeutic Roots of the Consumer Culture, 1880-1930." In The Culture of Consumption: Critical Essays in American History, 1880-1930, edited by Richard W. Fox, and T.J. Jackson Lears, 1-39. New York: Pantheon Books, 1983.
- Leavitt, Judith Walzer. "Politics and Public Health: Smallpox in Milwaukee, 1894-1895." Bulletin of the History of Medicine 50 (1976): 553-68.
- _____. The Healthiest City: Milwaukee and the Politics of Health Reform. Princeton: Princeton University Press, 1982.
- _____. "'Typhoid Mary' Strikes Back: Bacteriological Theory and Practice in Early Twentieth-Century Public Health." Isis 83 (1992): 608-29.
- _____. Typhoid Mary: Captive to the Public's Health. Boston: Beacon Press, 1996.
- Lechevalier, Hubert A., and Morris Solotorovsky. Three Centuries of Microbiology. New York: McGraw-Hill Book Co., 1965.
- Lechevalier, Hubert. "The Search for Antibiotics at Rutgers University." In The History of Antibiotics, edited by John Parascandola. Madison: American Institute of the History of Pharmacy, 1980.
- Lederberg, Joshua. "Postmature Scientific Discovery?" Nature 324 (1986): 629-31.
- _____. "Bacterial Variation Since Pasteur: Rummaging in the Attic: Antiquarian Ideas of Transmissible Heredity, 1880-1940." ASM News 58, no. 5 (1992): 261-5.
- Leibowitz, D. "Scientific Failure in an Age of Optimism: Public Reaction to Robert Koch's Tuberculin Cure." New York State Journal of Medicine 93 (1993): 41-8.
- Lemaine, Gerard, Roy Macleod, Michael Mulkay, and Peter Weingart, eds. Perspectives on the Emergence of Scientific Disciplines. Chicago: Aldine, 1976.
- Lenoir, Timothy. "Models and Instruments in the Development of Electrophysiology, 1845-1912." Historical Studies in the Physical and Biological Sciences 17 (1986): 365-417.
- Lenior, Timothy. Instituting Science: The Cultural Production of Scientific Disciplines. Stanford:

Stanford University Press, 1997.

Leonard, E.P. A Cornell Heritage: Veterinary Medicine, 1868-1908. Ithaca: New York State College of Veterinary Medicine, 1979.

Levitan, Karen B. "Function of Scientific Societies: Views of Biochemical Scientists." Ph.D. diss., University of Maryland. 1976.

Levy, Stuart B. "The First Centennial and on to the Next." ASM News 65 (1999): 258-9.

Liebenau, Jonathan. Medical Science and Medical Industry: The Formation of the American Pharmaceutical Industry. Baltimore: Johns Hopkins University Press, 1987.

_____. "The British Success with Penicillin." Social Studies of Science 17 (1987): 69-86.

Liebenau, Jonathan M. "Public Health and the Production and Use of Diphtheria Antitoxin in Philadelphia." Bulletin of the History of Medicine 61 (1987): 216-36.

Liebenau, Jonathan. "Paul Ehrlich as a Commercial Scientist and Research Administrator." Medical History 34 (1990): 65-78.

Link, William. "Privies, Progressivism and Public Schools, Health Reform and Education in the Rural South, 1909-1920." Journal of Southern History 54 (1988): 623-42.

Link, William A. "The Harvest is Ripe but the Laborers Are Few: The Hookworm Crusade in North Carolina, 1909-1915." North Carolina Historical Review 47 (1990): 1-17.

Logue, Jeanne. Beyond the Germ Theory: The Story of Dr. Cooper Curtice. College Station: Texas A&M University Press, 1995.

Long, Esmond R. A History of Pathology. New York: Dover Publications Inc., 1965.

_____. "History of the American Association of Pathologists and Bacteriologists." American Journal of Pathology 77 (1974): Suppl.

Lopez Sanchez, Jose. "Carlos J. Finlay and the Conception of Contagion." Indian Journal of History of Science 16 (1981): 156-68.

Lowy, Ilana. "Immunology and Literature in the Early Twentieth Century: Arrowsmith and The Doctor's Dilemma." Medical History 32 (1988): 314-32.

_____. "The Strength of Loose Concepts -- Boundary Concepts, Federative Experimental Strategies and Disciplinary Growth: The Case of Immunology." History of Science 30 (1992): 371-96.

_____. "On Hybridizations, Networks and New Disciplines: The Pasteur Institute and the Development of Microbiology in France." Studies in History and Philosophy of Science 25 (Oct. 1994): 655-88.

- _____. "Les Metaphors de L'immunologie: Guerre et Paix." Manguinhos 3 (1996): 7-23.
- Lowy, Ilana, and J.P. Gaudilliere, eds. The Invisible Industrialists: Manufactures and the Production of Scientific Knowledge. London: Macmillan, 1997.
- Ludmerer, Kenneth M. "Reform at the Harvard Medical School, 1869-1909." Bulletin of the History of Medicine 55 (1981): 342-270.
- Lutz, J. Fulton. "History of the Soil Science of America." Journal of the Soil Science Society of America 41 (1977): 152-73.
- Lynch, Michael. Art and Artifact in Laboratory Science: A Study of Shop Work and Shop Talk in a Research Laboratory. London: Routledge and Kegan Paul, 1985.
- Maasen, Sabine, Everett Mendelsohn, and Peter Weingart, eds. Biology as Society, Society as Biology: Metaphors. Boston: Kluwer Academic, 1995.
- Macfarlane, Gwyn. Alexander Fleming: The Man and the Myth. Cambridge: Harvard University Press, 1984.
- Maienschein, Jane, Ronald Rainger, and Keith R. Bensen. "Introduction: Were American Morphologists in Revolt?" Journal of the History of Biology 14 (1981): 83-7.
- Maienschein, Jane. "Shifting Assumptions in American Biology: Embryology, 1890-1910." Journal of the History of Biology 14 (1981): 89-113.
- _____. "Experimental Biology in Transition: Harrison's Embryology, 1895-1910." Studies in the History of Biology 6 (1983): 107-27.
- _____. "History of Biology." Osiris second ser., 1 (1985): 147-62.
- _____. Defining Biology: Lectures Form the 1890's. Cambridge: Harvard University Press, 1987.
- _____. "Whitman at Chicago: Establishing a Chicago Style of Biology?" In The American Development of Biology. Philadelphia: University of Pennsylvania Press, 1988.
- Mali, Joseph, and Gabriel Motzhin, eds. "Narrative Patterns in Scientific Disciplines." Science in Context 7 (1994): 3-158.
- Malkin, Harold M. "The Trails and Tribulations of George Miller Sternberg (1835-1915) -- America's First Bacteriologist." Perspectives in Biology and Medicine 36 (1992-1993): 666-78.
- Mallard, Alexandre. "Compare, Standardize, and Settle Agreement: On Some Usual Metrological Problems." Social Studies of Science 28 (1998): 571-602.
- Mallmann, Walter L. Recollections of Early Microbiology at Michigan State University. East Lansing: Dept. of Microbiology and Public Health, Michigan State University, 1974.

- Manley, L. "A Look Back: The Dawn of Bacteriology." Journal of Emergency Nursing 24 (Oct. 1998): 450.
- Marcus, Allen I. "From Ehrlich to Waksman: Chemotherapy and the Seamed Web of the Past." In Beyond the History of Science: Essays in Honor of Robert E. Schofield. Bethlehem, PA: Lehigh University Press, 1990.
- Marcus, Alan I. Agricultural Science and the Quest for Legitimacy: Farmers, Agricultural Colleges, and Experiment Stations, 1870-1890. Ames: Iowa State University Press, 1985.
- Marcus, Alan I., and Richard Lowitt, eds. The United States Department of Agriculture in Historical Perspective. Washington, D.C.: Agricultural History Society, 1991.
- Markowitz, Gerald E., and David Rosner. "Doctors in Crises: Medical Education and Medical Reform During the Progressive Era, 1895-1915." In Health Care in America: Essays in Social History, edited by Susan Reverby, and David Rosner. Philadelphia: Temple University Press, 1979, 1979.
- Marshall, Louise H. "Instruments, Techniques and Social Units in American Neurophysiology, 1870-1950." In Physiology in the American Context, 1850-1940, edited by Gerald Geison. Bethesda: American Physiological Society, 1987.
- Martin, Emily. "Toward and Anthropology of Immunology: The Body as a Nation-state." Medical Anthropology Quarterly. , 410-26. 1990.
- _____. Flexible Bodies: Tracking Immunity in American Culture -- from the Days of Polio to the Age of AIDS. Boston: Beacon Press, 1994.
- Matthews, R.E.F. A Critical Appraisal of Viral Taxonomy. Boca Raton: CRC Press, 1983.
- Maulitz, Russel C. "Physician vs. Bacteriologist: The Ideology of Science in Clinical Medicine." In The Therapeutic Revolution, edited by M.J. Vogel, and C.E. Rosen, 91-107. Philadelphia: University of Pennsylvania Press, 1979.
- Maulitz, Russell C. "Robert Koch and American Medicine." Annals of Internal Medicine 97 (1982): 761-6.
- _____. "Robert Koch in the United States of America." NTM: Zeitschrift fur Geschichte der Naturwissenschaft, Technik und Medizin 20 (1983): 75-84.
- Mayfield, Mary L. "The University of California Agricultural Experiment Station, 1868-1924." Master's thesis: University of California, Davis, 1966.
- Mazumdar, Pauline M.H. "Karl Landsteiner and the Problem of Species, 1838-1968." In PhD Thesis, Johns Hopkins University (1976). 1979.
- Mazumdar, Pauline M.H., and ed. Immunology, 1930-1980. Toronto: Wall and Thompson, 1989.

- Mazumder, Pauline M.H. Species and Specificity: An Interpretation of the History of Immunology. Cambridge: Cambridge University Press, 1994.
- McCall, Michal M., and Howard S. Becker. "Introduction." In Symbolic Interaction and Cultural Studies, 1-16. Chicago: University of Chicago Press, 1988.
- McCallan, Samuel E.A. A Personalized History of Boyce Thompson Institute. Yonkers: Boyce Thompson Inst., 1975.
- McCarthy, Michael P. Typhoid and the Politics of Public Health in Nineteenth-century Philadelphia. Philadelphia: American Philosophical Society, 1987.
- _____. "Should We Drink the Water? Typhoid Fever Worries at the Columbian Exposition." Illinois Historical Journal 86, no. 1 (1993): 2-14.
- McClain, Charles. "Of Medicine, Race, and American Law: The Bubonic Plague Outbreak of 1900." Law and Social Inquiry 13 (1988): 447-513.
- McClary, Andrew. "Beware the Deadly Books: A Forgotten Episode in Library History." Journal of Library History 20 (1985): 427-33.
- McClung, Leland S. "The History of Bacteriology in Indiana." Proceedings of the Indiana Academy of Science 76 (1967): 65-70.
- _____. "Oral History for Archives of the American Society for Microbiology." ASM News 35 (1969): 24-6.
- McClung, L.S., and K.F. Meyer. "Beginnings of Bacteriology in California." Bacteriological Reviews 38 (1974): 251-71.
- McClung, L.S. "The American Society for Microbiology/Society of American Bacteriologists: A Brief History." ASM News 44 (1978): 446-51.
- McGrew, Roderick E. Encyclopedia of Medical History. New York: McGraw-Hill Book Co., 1985.
- McMullen, Glenn L. Sources for the History of Agriculture and Rural Life in the Iowa State University Library. Ames, Iowa: Iowa State University Library, 1996.
- McMurry, Sally A. "Who Read the Agricultural Journals? Evidence from Chenango County, New York, 1839-1865." Agricultural History 63 (1989): 1-18.
- _____. "Women's Work in Agriculture: Divergent Trends in England and America, 1800-1930." Comparative Studies in Society and History 34 (1992): 248-70.
- _____. Transforming Rural Life: Dairy Families and Agricultural Change, 1820-1885. Baltimore: Johns Hopkins University Press, 1995.

- McQuat, Gordon R. "Species, Names and Things: From Darwin to the Experimentalists." Ph.D. diss., University of Toronto, 1993.
- _____. "Species, Rules and Meaning: The Politics of Language and the Ends of Definitions in 19th Century Natural History." Studies in the History and Philosophy of Science 27 (1996): 473-519.
- Meckel, Richard A. Save the Babies: American Public Health Reform and the Prevention of Infant Mortality, 1850-1929. Baltimore: Johns Hopkins University Press, 1990.
- Mendelsohn, John A. "Cultures of Bacteriology: Formation and Transformation of a Science in France and Germany, 1870-1914." Ph.D. diss., Princeton University. 1996.
- Miller, Julie. "To Stop the Slaughter of Babies: Nathan Straus and the Drive for Pasteurized Milk, 1893-1920." New York History 74, no. 2 (1993): 158-84.
- Millikan, D.F. "A History of Plant Pathology." Special Report, University of Missouri-Columbia, College of Agriculture, no. 362 (1988): 1-9.
- Mishler, E.G. "The Social Construction of Illness." In Social Contexts of Health, Illness and Patient Care. Cambridge: Cambridge University Press, 1981.
- Mitsuhashi, S. "Drug Resistance in Bacteria: History, Genetics, Biochemistry." Journal of International Medical Research 21 (Jan-Feb. 1993): 1-14.
- Moberg, Carol L., and Zanvil A. Cohn, eds. Launching the Antibiotic Era: Personal Accounts of the Discovery and Use of the First Antibiotics. New York: Rockefeller University Press, 1990.
- Moberg, Carol L. "Rene Dubos, a Harbinger of Microbial Resistance to Antibiotics." Perspectives in Biology and Medicine 42 (1999): 559-80.
- Moellering, R.C., Jr. "Past, Present and Future of Antimicrobial Agents." American Journal of Medicine 99, no. 6A (1995): 11S-18S.
- Monteiro, Eric, Ole Hanseth, and Morten Hatling. "Developing Information Infrastructure: The Tension Between Standardization and Flexibility." Science, Technology and Human Values 21 (1996): 407-26.
- Mooney, Graham. "Public Health Versus Private Practice: The Contested Development of Compulsory Infectious Disease Notification in Late-19th Century Britain." Bulletin of the History of Medicine 73 (1999): 238-67.
- Moore, Ernest G. The Agricultural Research Service. New York: Frederick A. Praeger, 1967.
- Moore, Richard G. Fields of Rich Toil: The Development of the University of Illinois, College of Agriculture. Urbana: University of Illinois Press, 1970.
- Morabia, A. "Epidemiology and Bacteriology in 1900: Who is the Handmaid of Whom?" Journal of

- Epidemiology and Community Health 52 (Oct. 1998): 617-8.
- Morgan, Neil. "The Development of Biochemistry in England Through Botany and the Brewing Industry (1870-1890)." History and Philosophy of the Life Science 2 (1980): 141-66.
- _____. "Pure Science and Applied Medicine: The Relationship Between Bacteriology and Biochemistry in England After 1880." Society for the Social History of Medicine Bulletin 37 (1985): 46-9.
- Morman, Edward T. "Scientific Medicine Comes to Philadelphia: Public Health Transformed, 1854-1899." In Ph.D. Diss., University of Pennsylvania. 1986.
- Morrill, Charles C. Veterinary Medicine in Michigan: An Illustrated History. East Lansing: Michigan State University, 1979.
- Mortimer, Philip P. "The Bacteria Craze of the 1880s." Lancet 353 (1999): 581-4.
- Moulin, Anne-Marie. "Bacteriological Research and Medical Practice in and Out of the Pasteurian School." Clio Medica (Amsterdam) 25 (1994): 327-49.
- Mulan, Fitzhugh. Plagues and Politics: The Story of the United States Public Health. New York: Basic Books, 1989.
- Muleran, E.N. "A Brief History of the Department of Plant Pathology at the University of California, Berkeley." California Plant Pathology -- Cooperative Extension, University of California 55 (Dec. 1981): 1-8.
- Murand, Lion, and Patrick Zylberman. "De L'hygiene comme Introduction a la Politique Experimentale, 1875-1925." Revue de Synthese 105 (1984): 313-42.
- Murand, Lion. "La Raison de L'expert Ou L'hygiene comme Science Social Appliquee." Archives Europeenes de Sociology 26 (1985): 58-89.
- Murray, Robert G.E. "A Structured Life." Annual Reviews of Microbiology 42 (1988): 1-34.
- Myers, Greg. Writing Biology: Texts in the Social Construction of Scientific Knowledge. Madison: University of Wisconsin Press, 1990.
- Neter, E. "INFECTION AND IMMUNITY: Its First Four Years." ASM News 40 (1974): 157-8.
- Neushul, Pter. "Science, Government, and the Mass Production of Penicillin." Journal of the History of Medicine and Allied Sciences 48 (1993): 371-95.
- O'Boyle, Lenore. "Learning for Its Own Sake: The German University as Nineteenth-century Model." Comparative Studies in Society and History 25 (1983): 20-5.
- O'Connell, James C. Chicago's Quest for Pure Water. In Essays in Public Works History Series. No. 1,

- 1-19. Chicago: Public Works Hist. Society, 1976.
- O'Connell, Joseph. "Metrology: The Creation of Universality by the Circulation of Particulars." Social Studies of Science 23 (1993): 129-73.
- O'Sullivan, Gerard Peter. "The Botanical Sublime: Natural Science, Aesthetics and the Cultural Politics of Beauty, 1750-1830." In PhD Thesis, University of Pennsylvania. 1994.
- O'Toole, Colleen K. The Search for Purity: A Retrospective Policy Analysis of the Decision to Chlorinate Cincinnati's Public Water Supply, 1890-1920. New York: Garland, 1990.
- O'Toole, D.K. "Factors Inhibiting and Stimulating Bacterial Growth in Milk: An Historical Perspective." Advances in Applied Microbiology 40 (1995): 45-94.
- Oldroyd, H. "The Future of Taxonomic Entomology." Systematic Zoology 15 (1966): 253-60.
- Osborn, June E., ed. History, Science, and Politics: Influenza in America, 1918-1976. New York: Prodist, 1977.
- Ott, Katherine. Fevered Lives: Tuberculosis in American Culture Since 1870. Cambridge: Harvard University Press, 1996.
- Overfield, Richard A. "Charles E. Bessey: The Impact of the 'New' Botany on American Agriculture, 1880-1910." Technology and Culture 16 (1975): 162-81.
- _____. "Hog Cholera, Texas Fever and Frank S. Billings." Nebraska History 57 (1976): 99-128.
- Packer, R.A. . The First 100 Years of the College of Veterinary Medicine, Iowa State University: A Pictorial History. Ames: Iowa State University Press, 1980.
- Palladino, Paolo. "Science for Whom? Agricultural Development and the Theory of Induced Innovation." Agriculture and Human Values 4 (1987): 53-64.
- _____. "The Professionalisation of Plant Breeding in the United States: The Technology of Hybridisation and Its Consequences." Minerva 29 (1991): 507-15.
- _____. "Between Craft and Science: Plant Breeding, Mendelian Genetics, and British Universities, 1900-1920." Technology and Culture 34 (1993): 300-323.
- _____. Entomology, Ecology and Agriculture: The Making of Scientific Careers in North America, 1885-1985. Amsterdam: Harwood Academic Publishers, 1996.
- _____. "Science, Technology, and the Economy: Plant Breeding in Great Britain, 1920-1970." Economic History Review 49 (1996): 116-36.
- Pappenheimer, Alwin Max. "The Story of a Toxic Protein, 1888-1992." Protein Science 2 (1993): 292-8.

Parascandola, John, ed. The History of Antibiotics: A Symposium, Sponsored by the Divisions of the History of Chemistry and Medicinal Chemistry, American Chemical Society Meeting, Honolulu, Hawaii, April 5, 1979. Madison: American Institute, 1979.

_____. "Reflections on the History of Pharmacology." Pharmacy in History 22 (1980): 131-40.

Parascandola, John, and Elizabeth Keeney, eds. Sources in the History of American Pharmacology. Madison: American Institute of the History of Pharmacy, 1983.

Parascandola, John, and John Swann. "Development of Pharmacology in American Schools of Pharmacy." Pharmacy in History 25 (1983): 95-115.

Parascandola, John. "The Beginning of Pharmacology in the Federal Government." Pharmacy in History 30 (1988): 179-87.

_____. The Development of American Pharmacology: John J. Abel and the Shaping of a Discipline. Baltimore: Johns Hopkins University Press, 1992.

_____. "Privies and the Public Health Service." Public Health Reports 112 (March/April 1997): 168-9.

_____. "Alice Evans: An Early Woman Scientist at NIH." Public Health Reports 113 (Sept.-Oct. 1998): 472-4.

Parr, Michael J.A. "Creativity in Science: Principles and Perspectives." Ph.D. diss., University of Toronto. 1992.

Parris, George Keith. A Chronology of Plant Pathology. Starkville, Miss.: Johnson, 1968.

Passano, William M. Jr. "A Brief History of the Williams & Wilkins Co. and Its Relationship with the American Society for Microbiology." ASM News 40 (1974): 5-7.

Pauly, Philip J. Controlling Life: Jacques Loeb and the Engineering Ideal in Biology. New York: Oxford University Press, 1987.

_____. "General Physiology and the Discipline of Physiology, 1890-1935." In Physiology in the American Context, 1850-1940, edited by Gerald Geison. American Physiology Society, 1987.

Pearson, Emmet F., and Wyndham Miles. "Disinfection of Mail in the United States." Bulletin of the History of Medicine 54 (1980): 111-24.

Pegram, Thomas R. "Public Health and Progressive Dairying in Illinois." Agricultural History 65, no. 1 (1991): 36-50.

Pelis, Kimberly Ann. "Pasteur's Imperial Missionary: Chales Nicolle (1866-1936) and the Pasteur Institute of Tunis." Ph.D. diss., Johns Hopkins University. 1995.

Pelis, Kim. "Prophet for Profit in French North Africa: Charles Nicolle and the Pasteur Institute of

- Tunis, 1903-1936." Bulletin of the History of Medicine 71 (1997): 583-622.
- Pelling, Margaret. "Contagion/Germ Theory/Specificity." In Companion Encyclopedia of the History of Medicine, Vol. 1, edited by W.F. Bynum, and Roy Porter, 309-34. New York: Routledge, 1993.
- Penn, M., and M. Dworkin. "Robert Koch and Two Visions of Microbiology." Bacteriological Reviews 40 (1976): 276-83.
- Pennington, T.H., and H. McKenzie. "The Bacteria Craze." 353, April 24 1999, 1447.
- Perleth, Matthias. Historical Aspects of American Trypanosomiasis (Chagas' Disease). Frankfurt am Main: P. Lang, 1997.
- Pernick, Martin. "The Ethics of Preventive Medicine: Thomas Edison's Tuberculosis Films; Mass Media and Health Propaganda." Hastings Center Report 8 (June 1978): 21-7.
- Peterson, Jon A. "The Impact of Sanitary Reform Upon American Urban Planning, 1840-1890." Journal of Social History 13 (1979): 83-104.
- Peterson, Paul D., Jr., Clay S Griffith, and C. Lee Campbell. "Frank Lamson-Scribner and American Plant Pathology, 1885-1888." Agricultural History 70 (1996): 33-56.
- Pickering, Andrew. "Knowledge, Practice and Mere Construction." Social Studies of Science 20 (1990): 682-729.
- _____. "From Science as Knowledge to Science as Practice." In Science as Practice and Culture, edited by Andrew Pickering, 1-26. Chicago: University of Chicago Press, 1992.
- Plesset, Isabel R. Noguchi and His Patron. London and Toronto: Associated University Presses, 1980.
- Podolsky, Scott H. "Cultural Divergence: Elie Metchnikoff's '*Bacillus Bulgaricus*' Therapy and His Underlying Concept of Health." Bulletin of the History of Medicine 72 (1998): 1-27.
- Porter, J.R. "History of the JOURNAL OF BACTERIOLOGY." ASM News 40 (1974): 585-94.
- Pound, Glenn S. 100 Years of Research: Wisconsin Agricultural Experiment Station, Centennial Celebration, March 24, 1983. Madison: College of Agricultural and Life Sciences, 1983.
- Powers, Richard D. Wisconsin's Agricultural Experiment Station: 100 Years of Research. Madison: College of Agricultural and Life Sciences, 1983.
- Quinn, Brother C. Edward. "Ancestry and Beginnings: The Early History of the American Society of Zoologists." American Zoologist 22 (1982): 735-48.
- Rader, Karen A. "Making Mice: C.C. Little, the Jackson Laboratory, and the Standardization of Mus Musculus for Research." In Ph.D. Diss., Indiana University. 1995.

- Rainger, Ronald. "The Continuation of the Morphological Tradition: American Paleontology, 1880-1910." Journal of the History of Biology 14 (1981): 129-58.
- _____. "Vertebrate Paleontology as Biology: Henry Fairfield Osborn and the American Museum of Natural History." In American Development of Biology, 219-56. 1988.
- Rainger, Ronald, Keith Benson, and Jane Maienschein, eds. The American Development of Biology. Philadelphia: University of Pennsylvania Press, 1988.
- Rainger, Ronald. An Agenda for Antiquity: Henry Fairfield Osborn and Vertebrate Paleontology at the American Museum of Natural History, 1890-1935. Tuscaloosa: Univ. of Alabama Press, 1991.
- Raju, Tonse N.K. "The Nobel Chronicles: 1919, Jules Bordet." Lancet 352 (Oct. 10 1998): 1232.
- Rasmussen, Nicholas. Picture Control: The Electron Microscope and the Transformation of American Biology, 1940-1959. Stanford: Stanford University Press, 1997.
- Raymond, Jean. "Science in the Service of Medicine: Germ Theory, Bacteriology and English Public Health, 1860-1914." Society for the Society History of Medicine, Bulletin 37 (1985): 43-5.
- Reese, K.M. "American Chemical Society, the First 100 Years." Chemical and Engineering News 54 (1976): 1-.
- Reid, Robert. Microbes and Men. New York: Saturday Review Press, 1975.
- Reiser, Stanley J. "Responsibility for Personal Health: A Historical Perspective." Journal of Medicine and Philosophy 10 (1985): 7-17.
- Rhess, David. "A New Voice for Science: Science Service Under Edwin E. Slosson, 1921-1929." University of North Carolina, no. M.A. thesis (1979).
- Ridley, M. "Evolution and Classification: The Reformation of Cladism." London: Longman, 1986.
- Riggs, James E., Laura A. Blinderman, and Charles S. Blinderman. "A Closer Look at the Language of Microbiology." ASM News 65 (1999): 290-5.
- Risse, Guenter. "'A Long Pull, a Strong Pull, and All Together': San Francisco and Bubonic Plague, 1907-1908." Bulletin of the History of Medicine, no. 66 (1992): 260-86.
- Ritvo, Harriet. "Zoological Taxonomy and Real Life." In Realism and Representation: Essays on the Problem of Realism in Relation to Science, Literature, and Culture, edited by George Levine, 235-54. Madison: University of Wisconsin, 1993.
- _____. The Platypus and the Mermaid, and Other Figments of the Classifying Imagination. Cambridge: Harvard University Press, 1997.
- _____. "Zoological Nomenclature and the Empire of Victorian Science." In Victorian Science in

- Context, edited by Bernard Lightman, 334-53. Chicago: University of Chicago Press, 1997.
- Roberts, Lissa. "A Word and the World: The Significance of Naming the Calorimeter." Isis 82 (1991): 182-222.
- Robinson, J.L. "100 Years of Dairy Science at the University of Illinois." Illinois Research 17 (Summer 1976): 14-5.
- Rockwood, S.W. "Tularemia: What's in a Name?" ASM News 49 (1983): 63-5.
- Roe, Daphne A. A Plague of Corn: The Social History of Pellagra. Ithaca: Cornell University Press, 1973.
- Rogers, Naomi. "Dirt, Flies and Immigrants: Explaining the Epistemology of Poliomyelitis, 1900-1916." Journal of the History of Medicine and Allied Sciences 44 (1989): 485-515.
- _____. "Germs with Legs: Flies, Disease and the New Public Health." Bulletin for the History of Medicine 63 (1989): 599-617.
- _____. Dirt and Disease: Polio in America Before FDR. New Brunswick, NJ: Rutgers University Press, 1992.
- _____. "A Disease of Cleanliness: Polio in New York City, 1900-1990." In Hives of Sickness: Public Health and Epidemics in New York City, edited by David Rosner. New Brunswick, NJ: Rutgers University Press, 1995.
- Roll-Hansen, Nils. "Pasteur: An Underestimated Hero of Science: An Essay Review." Centaurus 40 (1998): 81-93.
- Rose, Flora. "A Page of Modern Education, 1900-1940: Forty Years of Home Economics at Cornell University." In A Growing College: Home Economics at Cornell University, 22-3. Ithaca: New York State College of Ecology, 1969.
- Rosen, George. "Patterns of Health Research in the United States, 1900-1960." Bulletin of the History of Medicine 39 (1965): 201-21.
- _____. "Ellen H. Richards." American Journal of Public Health 64 (1974): 816-9.
- Rosenberg, Alexander. Instrumental Biology or the Disunity of Science. In Science and Its Conceptual Foundation Series. Cambridge: Cambridge University Press, 1994.
- Rosenberg, Charles E. "Rationalization and Reality in the Shaping of American Agricultural Research, 1875-1914." Social Studies of Science 7 (1977): 401-22.
- _____. "Toward an Ecology of Knowledge: On Discipline, Contexts and History." In The Organization of Knowledge in Modern America, 440-55. Baltimore: Johns Hopkins University Press, 1979.

- _____. "Florence Nightingale on Contagion: The Hospital as a Moral Universe." In Healing and History: Essays for George Rosen, edited by Charles E. Rosenberg, 116-36. New York: Science History, 1979.
- Rosenberg, Charles E., and ed. The Origins of Specialization in American Medicine: An Anthology of Sources. New York: Garland, 1989.
- Rosenberg, Charles E. "Making It in Urban Medicine: A Career in the Age of Scientific Medicine." Bulletin of the History of Medicine 64 (1990): 177.
- Rosenberg, Charles E. "Science in American Society: A Generation of Historical Debate, with Headnote and Afteward." In The Scientific Enterprise in America, edited by Ronald L. Numbers, and Charles E. Rosenberg. Chicago: University of Chicago Press, 1996.
- Rosenberg, Charles. No Other Gods: On Science and American Social Thought. Rev. and expand. ed. Baltimore: Johns Hopkins University Press, 1997.
- Rosenkrantz, Barbara G. Public Health and the State: Changing Views in Massachusetts, 1842-1936. Cambridge: Harvard University Press, 1972.
- _____. "Cart Before Horse: Theory, Practice, and Professional Image in American Public Health, 1870-1922." Journal of the History of Medicine and Allied Sciences 29 (January 1974): 55-74.
- _____. "The Trouble with Bovine Tuberculosis." Bulletin of the History of Medicine 59 (1985): 155-75.
- Rosenkrantz, Barbara Gutmann, ed. From Consumption to Tuberculosis: A Documentary History. New York: Garland, 1994.
- Ross, Dorothy. The Origins of American Social Science. Cambridge: Cambridge University Press, 1991.
- Rosser, W.M. "Corollary Development of the Professions of Veterinary and Human Medicine in the United States." Veterinary Heritage, March 1991, 3-29.
- Rossiter, Margaret W. The Emergence of Agricultural Science: Justus Liebig and the Americans, 1840-1880. In Yale Studies in the History of Science and Medicine, No. 9. New Haven: Yale University Press, 1975.
- _____. "The Agricultural Sciences in the United States, 1860-1920." In The Organization of Knowledge in Modern America, 1860-1920, edited by Alexandra Oleson, and John Voss. Baltimore: Johns Hopkins University Press, 1979.
- _____. A List of References for the History of Agricultural Science in America. Davis: Agricultural History Center, 1980.
- Rossiter, Margaret. Women Scientists in America: Struggles and Strategies to 1940. Baltimore: Johns Hopkins University Press, 1982.

- Rossiter, Margaret W. "'Women's Work' in Science, 1880-1910." In Science in American Society: A Generation of Historical Debate, with Headnote and Afteward. Chicago: University of Chicago Press, 1996.
- Rothstein, William. "Bacteriology and the Medical Profession." In American Physicians in the Nineteenth Century, 261-81. Baltimore: Johns Hopkins University Press, 1972.
- Rudolph, Emanuel D. "How It Developed That Botany Was the Science Thought to Be Most Suitable for Victorian Young Ladies." Children's Literature 2 (1973): 92-7.
- _____. "The Introduction of the Natural System of Classification of Plants to Nineteenth Century American Students." Archives of Natural History 10 (1982). 461-468.
- Russell, Colin A. Edward Frankland: Chemistry, Controversy and Conspiracy in Victorian England. Cambridge: Cambridge University Press, 1996.
- Salomon-Bayet, Claire. "Bacteriology and Nobel Prize Selections, 1901-1920." In Science, Technology and Society in the Time of Alfred Nobel, edited by C.G Berenhard, E. Crawford, and P. Sorbom, 377-400. Oxford: Pergamon, 1982.
- Sapp, Jan. Beyond the Gene: Cytoplasmic Inheritance and the Struggle for Authority in Genetics. New York: Oxford University Press, 1987.
- Savitt, Todd L., and James Harvey Young, eds. Disease and Distinctiveness in the American South. Knoxville: University of Tennessee Press, 1988.
- Sawyer, Richard. "Monopolizing the Insect Trade: Biological Control in the USDA, 1888-1951." Agricultural History 64 (1990).
- Sawyer, Richard C. To Make a Spotless Orange: Biological Control in California. Ames: Iowa State University Press, 1996.
- Sax, Boria. "Anthropomorphism in Animal Encyclopedias of Nineteenth Century America." New York Folklore 14, no. 1-2 (1988): 107-22.
- Schaechter, Moselio, and John L. Ingraham. "A Glipmse at Selected ASM Journals Through the Years." ASM News 65 (1999): 276-81.
- Schaeffer, Morris. "William H. Park (1863-1939). His Laboratory and His Legacy." American Journal of Public Health 75 (1985): 1296-1302.
- Schatzki, Stafan C. "Simon Flexner." American Journal of Roenteology 169 (1997): 1395-6.
- Schlebecker, John T. A History of American Dairying. Chicago: Rand McNally & Co., 1967.
- Schoenfeld, Clay. Edwin Broun Fred: Last of a Breed? A Personal Memoir, s.n., 1979.

- Schultz, Stanley K., and Clay McShane. "To Engineer the Metropolis: Sewers, Sanitation and City Planning in the Late Nineteenth-century America." Journal of American History 65 (1978): 389-411.
- Scott, Roy V. The Reluctant Farmer: The Rise of Agriculture Extension to 1914. Urbana: University of Illinois Press, 1970.
- Scriver, C.R. "Disease, War and Biology: Languages for Medicine -- and Pediatrics." Pediatric Research 38 (December 1995): 819-29.
- Secord, Anne. "Science in the Pub: Artisan Botanists in Early Nineteenth-century Lancashire." History of Science 32 (1994): 269-315.
- Sequeira, L. "Phytobacteriology and the Making of the Department." In With One Foot in the Furrow: A History of the First Seventy-five Years of the Department of Plant Pathology at the University of Wisconsin-Madison, edited by Paul H. Williams, and Melissa Marosy, 205-16. Dubuque, Iowa: Kendall, Hunt Pub. Co., 1986.
- Serres, Michel, and L.R. Schehr, trans. The Parasite. Baltimore: Johns Hopkins University Press, 1980.
- Servos, John. "Physical Chemistry in America, 1890-1933: Origins, Growth and Definition." In Ph.D. Diss., Johns Hopkins University. 1979.
- Sampo, Marc A. "Shibasaburo Kitasato: Japanese Bacteriologist." Mayo Clinic Proceedings 74 (1999): 146.
- Shapin, Steve. "The Invisible Technician." American Scientist 77 (1989).
- Shapin, Steven. "Here and Everywhere: Sociology of Scientific Knowledge." Annual Review of Sociology 21 (1995): 289-321.
- Shoemaker, Susan Turnbull. "The Philadelphia Pediatric Society and Its Milk Commission, 1896-1917: An Aspect of Urban Professional Reform." Pennsylvania History 53, no. 4 (1986): 273-88.
- Shryock, Richard H. "The Historical Significance of the Tuberculosis Movement." In Medicine in America: Historical Essays. Baltimore: Johns Hopkins University Press, 1966.
- Shryock, Richard Harrison. "Germ Theories in Medicine Prior to 1870." Clio Medica 7 (1972): 81-109.
- Silverstein, Arthur M. A History of Immunology. San Diego: Academic Press, 1989.
- _____. "On the Naming of Rickettsiae After Paul Ehrlich." Bulletin for the History of Medicine 72 (1998): 731-3.
- Skolnick, Herman, and Kenneth E. Reese, eds. A Century of Chemistry: The Role of Chemists and the American Chemical Society. Washington, D.C.: American Chemical Society, 1976.

- Slaughter, Mary M. Universal Languages and Scientific Taxonomy in the Seventeenth Century. Cambridge: Cambridge University Press, 1982.
- Small, Henry G., and Diane Crane. "Specialities and Disciplines in Science and Social Science: An Examination of Their Structure Using Citation Indexes." Scientometrics 1 (1979): 445-61.
- Smith, Wilson. "'Cow College' Mythology and Social History: A View of Centennial Literature." Agricultural History 44, no. 4 (October 1970): 299-310.
- Smith, David C. A History of the Maine Agricultural Experiment Station, 1885-1978. Orono: University of Maine Press, 1980.
- Smithcors, J.F.. The Veterinarian in America, 1625-1975. Santa Barbara: American Veterinary Publications, 1975.
- Smocovitis, V.B. "'Disciplining Botany': A Taxonomic Problem." Taxon 41 (1992): 459-70.
- Speck, Reinhard S. "Brucella and the Hooper Foundation." In Vignettes in California Medicine. San Francisco: Book Club of California, 1977.
- Spink, Wesley W. Infectious Diseases: Prevention and Treatment in the Nineteenth and Twentieth Centuries. Minneapolis: University of Minnesota Press, 1978.
- Stafleu, Frans A., and Richard S. Cowan, eds. Taxonomic Literature: A Selective Guide to Botanic Publications and Collection with Dates, Commentaries and Types. 2nd ed. Utrecht: Bohn, Scheltema & Holkema, 1981.
- Stafleu, Frans A. "The Prehistory of the International Association for Plant Taxonomy." Taxon 37 (1988): 791-800.
- Stage, Sarah. "From Domestic Science to Social Housekeeping: The Career of Ellen Richards." In Power and Responsibility: Case Studies in American Leadership, edited by David M. Kennedy, and Michael E. Parrish, 211-28. New York: Harcourt Brace Jovanovich, 1986.
- Stage, Sarah, and Virginia Vincenti, eds. Rethinking Home Economics: Women and the History of a Profession. Ithaca: Cornell University Press, 1997.
- Stalheim, Ole H.V. "Contributions of the Bureau of Animal Industry to the Veterinary Profession." Journal of the American Veterinary Medical Association 184 (May 15 1984): 1222-4.
- _____. "The Hog Cholera Battle and Veterinary Professionalism." Agricultural History 62, no. 2 (1988): 116-21.
- _____, ed. Veterinary Medicine in the West. Manhattan, Kansas: Sunflower University Press, 1988.
- _____. The Winning of Animal Health: 100 Years of Veterinary Medicine. Ames, Iowa: Iowa State University Press, 1994.

- Star, Susan Leigh. "Simplification in Scientific Work: An Example from Neuroscience Research." Social Studies of Science 13 (1983): 205-28.
- Star, Susan L. "Introduction: The Sociology of Science and Technology." Social Problems 35 (1988): 197-205.
- Star, Susan L., and James R. Griesemer. "Institutional Ecology, 'Translation,' and Boundary Objects: Amateurs and Professionals in Berkeley's Museum of Vertebrate Zoology, 1907-1939." Social Studies of Science 19 (1989): 387-420.
- Star, Susan Leigh. "The Sociology of the Invisible: The Primacy of Work in the Writings of Anselm Strauss." In Social Organization and Social Process: Essays in Honor of Anselm Strauss, edited by David Maines, 265-83. Hawthorn, NY: Aldine de Gruyter, 1991.
- _____, ed. Ecologies of Knowledge: Work and Politics in Science and Technology. Albany, NY: SUNY Press, 1995.
- _____. "Work and Practice in Social Studies of Science, Medicine, and Technology." Science, Technology and Human Values 20 (1995): 501-7.
- Star, Susan Leigh, and Karen Ruhleder. "Steps Toward an Ecology of Infrastructure: Design and Access for Large Information Spaces." Information Systems Research 7 (1996): 111-34.
- Star, Susan Leigh. "Grounded Classifications: Grounded Theory and Faceted Classification." Library Trends 47 (1998): 218-52.
- Starr, M.P., and Vic Skerman. "Bacterial Diversity: The Natural History of Selected Morphologically Unusual Bacteria." Annual Review of Microbiology 19 (1965): 407-54.
- Stepan, Nancy. "The Interplay Between Socio-economic Factors and Medical Science: Yellow Fever Research, Cuba, and the United States." Social Studies of Science 8 (1978): 397-423.
- Sterling, Keir B., ed. Contributions to American Systematics. New York: Arno, 1974.
- Sternbach, George L., and J. Varon. "Alexander Fleming: The Spectrum of Penicillin." Journal of Emergency Medicine 10 (1992): 89-91.
- Stevenson, Lloyd G. "Exemplary Disease: The Typhoid Pattern." Journal of the History of Medicine and Allied Sciences 33 (1982): 386-407.
- Stichweh, Rudolf. "The Sociology of Scientific Disciplines: On the Genesis and Stability of the Disciplinary Structure of Modern Science." Science in Context 5 (1992): 3-15.
- Strausberg, Stephen F. A Century of Research: Centennial History of the Arkansas Agricultural Experiment Station. Fayetteville: University of Arkansas, 1989.
- Strauss, Anselm. "A Social World Perspective." Studies in Symbolic Interaction 1 (1978): 119-28.

- Strauss, Anselm L. "Social Worlds and Legitimation Processes." Studies in Symbolic Interaction 4 (1982): 171-90.
- _____. "Social Worlds and Their Segmentation Processes." Studies in Symbolic Interaction 5 (1984): 123-79.
- Summers, William C. "From Culture as Organism to Organism as Cell: Historical Origins of Bacterial Genetics." Journal of the History Biology 24 (1991): 171-90.
- _____. "Beyond the Fringe of the Evolutionary Synthesis: The Case of Bacteria." Paper presented at HSS meeting, Madison, Oct. 1991, 1991.
- _____. "On the Origins of the Science in ARROWSMITH: Paul de Kruif, Felix D'Herelle, and Phage." Journal of the History of Medicine and Allied Sciences 46 (1991): 315-32.
- _____. "Cholera and Plague in India: The Bacteriophage Inquiry of 1927-1936." Journal of the History of Medicine and Allied Sciences 48 (July 1993): 275-301.
- Swann, John Patrick. "The Discovery and Early Development of Penicillin." Medical Heritage 1 (1985): 375-86.
- _____. "Paul Ehrlich and the Introduction of Salversan." Medical Heritage 1 (1985): 137-8.
- _____. Academic Scientists and the Pharmaceutical Industry: Cooperative Research in Twentieth-century America. Baltimore: Johns Hopkins Press, 1988.
- Tang, Ho Yin. "The Enigma of Hog Cholera: Controversies, Cause, and Control, 1833-1917." In Ph.D. Diss., University of Minnesota, 1986.
- Tarr, Joel A., James McCurley, Francis C. McMichael, and Terry Yosie. "Water and Wastes: A Retrospective Assessment of Wastewater Technology in the United States, 1800-1932." Technology and Culture 25, no. 2 (1984): 226-63.
- Tarr, Joel A. "'Water and Wastes': Society Values and User Values, an Addendum To..." Technology and Culture 26 (1985): 279-81.
- Tarr, Joel A., and Gabriel Dupuy, eds. Technology and the Rise of the Networked City in Europe and America. Philadelphia: Temple University Press, 1988.
- Tauber, Alfred I., and Leon Chernya. "History of Immunology: The Birth of Immunology, Pt. II. Metchnikoff and His Critics." Cellular Immunology 121 (1989): 447-73.
- Tauber, Alfred I. "The Immunological Self: A Centenary Perspective." Perspectives in Biology 35 (1991): 75-86.
- Tauber, Alfred I., and Leon Chernyak. Metchnikoff and the Origins of Immunology. New York: Oxford University Press, 1991.

- Tauber, Alfred I., and Scott H. Podolsky. "Frank Macfarlane Burnet and the Immune Self." Journal of the History of Biology 27 (1994): 531-73.
- Tauber, Alfred I. The Immune Self: Theory or Metaphor? Cambridge: Cambridge University Press, 1996.
- Taylor, Donna S. Paul F. Clark: An Interview. Madison: University of Wisconsin Press, 1972.
- _____. Edwin Broun Fred: An Interview. Madison: University of Wisconsin Archives Oral History Project, 1976.
- Taylor, K.L. "Two Centuries of Chemistry." In Issues and Ideas in America, edited by Benjamin Taylor, and Thurman J. White, 267-84. Norman, OK: University of Oklahoma Press, 1976.
- Teich, M. "Fermentation Theory and Practice: The Beginnings of Pure Yeast Culture and English Brewing, 1883-1913." History of Technology 8 (1983): 117-33.
- Teller, Michael. The Tuberculosis Movement: A Public Health Campaign in the Progressive Era. In Contributions in Medical Studies, No. 22. New York: Greenwood Press, 1988.
- Temkin, Oswei. "A Historical Analysis of the Concept of Infection." In The Double Face of Janus. Baltimore: Johns Hopkins University Press, 1977.
- Teranishi, Roy, ed. Agricultural and Food Chemistry: Past, Present, Future. Westport, CT: Avi Publishing Co., 1978.
- Terris, Milton. "Evolution of Public Health and Preventive Medicine in the United States." American Journal of Public Health 65 (February 1975): 61-71.
- Thagard, Paul. "Ulcers and Bacteria. I. Discovery and Acceptance." Studies in the History and Philosophy of Biological and Biomedical Sciences 29 (1998): 107-36.
- _____. "Ulcers and Bacteria. II. Instruments, Experiments, and Social Interactions." Studies in History and Philosophy of Biological and Biomedical Sciences 29C (1998): 317-42.
- Thomas, Keith. Man in the Natural World: A History of Modern Sensibility. New York: Pantheon, 1983.
- Timmermans, Stefan, and Marc Berg. "Standardization in Action: Achieving Local Universality Through Medical Protocols." Social Studies of Science 27 (1997): 273-305.
- Tomes, Nancy. "The Private Side of Public Health: Sanitary Science, Domestic Hygiene, and the Germ Theory, 1870-1900." Bulletin of the History of Medicine 64 (1990): 509-39.
- Tomes, Nancy J., and John Harley Warner. "Introduction to the Special Issue on Rethinking the Reception of the Germ Theory of Disease: Comparative Perspectives." Journal of the History of Medicine and Allied Science 52 (1997): 7-16.

- Tomes, Nancy. "American Attitudes Toward the Germ Theory of Disease: The Richmond Thesis Revisited." Journal of the History of Medicine and Allied Sciences 52 (1997): 17-50.
- _____. The Gospel of Germs: Men, Women, and the Microbe in American Life. Cambridge: Harvard University Press, 1998.
- Torchia, Marion M. "Tuberculosis Among American Negroes: Medical Research on a Racial Disease, 1830-1950." Journal of the History of Medicine 32 (1977): 252-79.
- Tort, Patrick. La Raison Classificatoire: Les Complexes Discursifs -- Quinze Etudes. Paris: Aubier, 1989.
- Trostle, James. "Early Work in Anthropology and Epidemiology: From Social Medicine to Germ Theory, 1840-1920." In Anthropology and Epidemiology: Interdisciplinary Approaches to the Study of Health and Disease, edited by Craig R. James, 35-57. Dordrecht: Reidel, 1986.
- Trulove, Susan. 1886-1986, Virginia's Agricultural Experiment Station: 100 Years of Research. Blacksburg, VA: Virginia Agricultural Experiment Station, 1986.
- Tuchman, Arleen M. "Institutions and Disciplines: Recent Work in the History of German Science." Journal of Modern History 69 (1997): 298-319.
- Tunevall, Ghosta. Periodicals Relevant to Microbiology and Immunology: A World List. London & New York: Wiley/Interscience, 1969.
- Underdahl, Norman R. "A Pioneer Microbiologist, Frank S. Billings (1845-1912)." ASM News 40 (1974): 265-68.
- Van Regenmortel, Marc H.V. "Virus Species, a Much Overlooked by Essential Concept in Virus Classification." Intervirology 31 (1990): 241-54.
- Vassallo, D.J. "The Saga of Brucellosis: Controversy Over Credit for Linking Malta Fever with Goats' Milk." Lancet 348 (1996): 804-8.
- Vermeulen, C.W. For the Greatest Good to the Greatest Number: A History of the Medical Center of the University of Chicago, 1927-1977. Chicago: University of Chicago Press, 1977.
- Vernon, Keith. "The Emergence of Numerical Taxonomy." Ph.D. diss., Manchester University, 1987.
- _____. "The Founding of Numerical Taxonomy." British Journal of the History of Science 21 (1988): 143-59.
- _____. "Pus, Sewage, Beer and Milk: Microbiology in Britain, 1870-1940." History of Science 28 (1990): 289-325.
- _____. "Desperately Seeking Status: Evolutionary Systematics and the Taxonomists' Search for Respectability, 1940-1960." British Journal for the History of Science 26 (1993): 207-27.

- _____. "Microbes at Work: Microorganisms, the D.S.I.R. and Industry in Britain, 1900-1936." Annals of Science 51 (November 1994): 593-613.
- Vidaver, Anne K. "Plant Microbiology: Century of Discovery, with Golden Years Ahead." ASM News 65 (1999): 358-63.
- Vigarello, Georges. Concepts of Cleanliness: Changing Attitudes in France Since the Middle Ages. New York: Cambridge University Press, 1988.
- Villavicencio, R.T. "The History of Blue Pus." Journal of the American College of Surgeons 187 (1998): 212-6.
- Vinkas, Vincent. Soft Sope, Hard Sell: American Hygiene in an Age of Advertisement. Ames, Iowa: Iowa State University Press, 1992.
- Volberg, Rachel A. "Constraints and Commitments in the Development of American Botany, 1880-1920." Ph.D. diss., University of California, San Francisco. 1983.
- _____. "Constraints and Commitments in the Development of American Botany, 1880-1920." In Ph.D. Diss., University of California, San Francisco. 1983.
- Wadler, Joyce. "Man of Precision Behind the Messy Microbes." new York, March(LateEdition,EastCoast) 11 1999, B-2.
- Wagner, W.H., Jr. "Construction of Classifications." In Proceedings of the International Conference on Systematic Biology. 1967.
- Wagner, R.F. "The JOURNAL OF VIROLOGY: Some Historical Notes and Reflections." ASM News 40 (1974): 79-85.
- Wain, Harry. A History of Preventive Medicine. Springfield, Ill.: Charles C. Thomas, 1970.
- Wainwright, Milton. Miracle Cure: The Story of Penicillin and the Golden Age of Antibiotics. Oxford: Basil Blackwell, 1990.
- _____. "Extreme Pleomorphism and the Bacterial Life Cycle: A Forgetton Controversy." Perspectives in Biology and Medicine 40 (1997): 407-14.
- _____. "James Young and the 'Cancer Germ'" Journal of Medical Biography 6 (1998): 203-5.
- Waksman, Selman A., Robert L. Starkey, Richard Donovick, Vernon Byson, and Richard Donovick. Microbiology in New Jersey: Origins and Developments. Washington D.C.: American Society for Microbiology, 1965.
- Waksman, Selman A. Jacob G. Lipman: Agricultural Scientist, Humanitarian. New Brunswick: Rutgers University Press, 1966.

- _____. "The Background of Soil Science." Soil Science 101 (1966): 6-10.
- Walker, J.C. "Beginnings: L.R. Jones, 1910-1925." In With One Foot in the Furrow: A History of the First Seventy-five Years of the Department of Plant Pathology at the University of Wisconsin-Madison, edited by Paul H. Williams, and Melissa Marosy, 3-17. Dubuque, Iowa: Kendall, Hunt Pub. Co., 1986.
- Wallin, Ivan E. "Symbioticism in the Light of Recent Cytological Investigations." Biosystems 31 (1993): 181-3.
- Ward, C.M. "Progress Toward a Higher Taxonomy of Viruses." Research in Virology 144 (1993): 419-53.
- Warner, John Harley. "The Fall and Rise of Professional Mystery: Epistemology, Authority, and the Emergence of Laboratory Medicine in Nineteenth-century America." In Laboratory Revolution in Medicine, edited by Andrew Cunningham, and Perry Williams. Cambridge: Cambridge University Press, 1992.
- Waterson, Anthony P., and Lise Wilkinson. An Introduction to the History of Virology. Cambridge: Cambridge University Press, 1978.
- Weatherall, Mark W. "1895-1995: A Hundred Years of Microbiology." Trends in Microbiology 3, no. 12 (1995): 454-5.
- Weigley, Emma S. "It Might Have Been Euthenics: The Lake Placid Conferences and the Home Economics Movement." American Quarterly 26 (1974): 79-96.
- Weindling, Paul. "From Bacteriology to Social Hygiene: The Papers of Martin H Hahn (1865-1934)." Wellcome Unit for the History of Medicine (Oxford) Research Publications 5 (1985).
- _____. "From Isolation to Therapy: Children's Hospital and Diphtheria Fin de Siecle Paris, London, and Berlin." In In the Name of the Child: Health and Welfare, 1880-1940. London and New York: Routledge, 1992.
- _____. "Scientific Elites and Laboratory Organization in Fin de Siecle Paris and Berlin. The Pasteur Institute and Robert Koch's Institute for Infectious Diseases Compared." In The Laboratory Revolution in Medicine, edited by Andrew Cunningham, and Perry Williams, 170-88. Cambridge: Cambridge University Press, 1992.
- _____. "Medicine and the Holocaust: The Case of Typhus." In Medicine and Change: Historical and Sociological Studies of Medical Innovation, edited by Illana Lowy. London: John Libby, 1993.
- Weindling, Paul J. "Between Bacteriology and Virology: The Development of Typhus Vaccines Between the First and Second World Wars." History and Philosophy of the Life Sciences 17 (1995): 81-90.
- Weindling, Paul. "A Virulent Strain: German Bacteriology as Scientific Racism, 1890-1920." In Race,

- Science and Medicine, 1700-1960, edited by Waltraud Ernst, and Bernard Harris, Routledge, London, 1999.
- Weinstein, Paul P. "Parasitology and the United State Public Health Service: A Relation of Science and Government." Journal of Parasitology 59, no. 1 (February 1973): 3-14.
- Weiss, E. "The Life and Career of Howard Taylor Ricketts." Reviews of Infectious Diseases 13 (1991): 1241-2.
- Wheeler, Alwyne, and James H. Price, eds. History in the Service of Systematics: Papers from the Conference to Celebrate the Centenary of the British Museum of Natural History, 13-16 April 1981. London: Society for the Bibliography of Natural History, 1981.
- Whitley, Richard. "Umbrella and Polytheistic Scientific Disciplines and Their Elites." Social Studies of Science 6 (1976): 471-97.
- _____. The Intellectual and Social Organization of the Sciences. New York: Oxford University Press, 1984.
- Wik, Reynold M. "Science and American Agriculture." In Science and Society in the United States, edited by D.D. Van Tassel, and M.G. Hall, 81-106. Homewood, Ill.: The Dorsey Press, 1966.
- Wilkinson, Lise. "The Development of the Virus Concept as Reflected in Corpora of Studies on Individual Pathogens." Medical History 18 (1974): 211-21.
- _____. "Glanders: Medicine and Veterinary Medicine in Pursuit of a Contagious Disease." Medical History 25 (1981): 363-84.
- _____. Animals and Disease: An Introduction to the History of Comparative Medicine. Cambridge: Cambridge University Press, 1992.
- Williams, Paul H., and Melissa Marosy, eds. With One Foot in the Furrow -- A History of the First Seventy Five Years of the Department of Plant Pathology at the University of Wisconsin-Madison. Dubuque: Kendall/Hunt, 1986.
- Wills, Christopher. Yellow Fever, Black Goddess: The Coevolution of People and Plagues. Reading, MA: Addison-Wesley, 1996.
- Wilson, G. "The Brown Animal Sanitary Institution." Journal of Hygiene 82 (1979): 171-9.
- Winsor, Mary P. "The English Debate on Taxonomy and Phylogeny, 1937-1940." History and Philosophy of the Life Sciences 17 (1995): 227-52.
- Wiser, Vivian D., Larry Mark, and H. Graham Purchase, eds. 100 Years of Animal Health, 1884-1984. Beltsville, Md.: Associates of the National Agricultural Library, Inc., 1986.
- Wiser, Vivian. "Healthy Livestock -- Wholesome Meat: A Short History." Medical History 2

(November 1986): 408-19.

_____. "Public Policy and USDA Science." Agricultural History 64 (1990): 24-.

Witter, J. Frank. "The History of Avian Medicine in the United States: I. Before the Big Changes." Avian Medicine 20, no. 4 (October-December 1976): 622-30.

Woese, Carl R. "There Must Be a Prokaryote Somewhere: Microbiology's Search for Itself." Microbiological Reviews 58, no. 1 (1994): 1-9.

_____. "Default Taxonomy: Ernst Mayr's View of the Microbial World." Proc. National Academy of Sciences 95 (1998): 11043-6.

Wood, Charles W. "Science and Politics in the War on Cattle Diseases: The Kansas Experience, 1900-1940." Agricultural History 54 (1980): 261-303.

Woodruff, H. Boyd. "APPLIED MICROBIOLOGY: The Soldier to Strengthen the Society." ASM News 40 (1974): 503-6.

_____. "A Soil Microbiologist's Odyssey." Annual Reviews of Microbiology 35 (1981): 1-28.

Woodruff, C.M. "A History of the Department of Soils and Soil Science at the University of Missouri." Special Report, College of Agriculture, University of Missouri, no. 413 (June 1990): 1-43.

Woodward, T.E. "Epidemiologic Classics of Carter, Maxcy, Trudeau and Smith." Journal of Infectious Disease 165 (1992): 235-44.

Worboys, Michael. "The Emergency of Tropical Medicine: A Study in the Establishment of a Scientific Speciality." In Perspectives on the Emergence of Scientific Disciplines, edited by Gerard Lemaine, Roy Macleod, Michael Mulkay, and Peter Weingart. Chicago: Aldine, 1976.

_____. "Treatments for Pneumonia in Britain, 1910-1940." In Medicine and Change: Historical and Sociological Studies of Medical Innovation, edited by Illana Lowy. London: John Libby, 1993.

Yankauer, Alfred. "The American Journal of Public Health, 1911-1985." American Journal of Public Health 76 (1986): 809-15.

Young, Harold N. The Virginia Agricultural Experiment Station, 1886-1966. Charlottesville: University Press of Virginia, 1975.

Ziporyn, Terra. "Typhoid Fever: A Disease of the Indifferent." In Disease in the Popular American Press, 71-111. Westport, CT: Greenwood Press, 1988.

Zirkle, C. "The Role of Liberty Hyde Bailey and Hugo de Vries in the Rediscovery of Mendelism." Journal of the History of Biology 2 (1969): 205-18.