NEWTON AND THE ORIGIN OF SPECTROANALYSIS

by

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PREFACE

The author wishes to extend thanks to Professor William H. Dennen, of the M.I.T. Department of Geology, and Professor Giorgio deSantillana, of the Department of Humanities, for their guidance in the experimental and historical aspects of this paper; to the staff of the Geology Shop, for their patient assistance in finding and constructing equipment; and to Miss Jean B. Luena, who was an unbiased witness for the existence of spectral lines in a place where Sir Isaac Newton never mentioned having seen them.

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ABSTRACT

It has been assumed that the first observer of the absorption lines on the solar spectrum was Wollaston, who, in 1802, made the observations which marked the birth of spectroanalysis. However, Sir Isaac Newton apparently had similar apparatus when he worked with the nature of light, yet he said nothing of the lines.

In an effort to determine whether Newton could have seen the lines, his experiments were duplicated at M. I. T., in the spring of 1960, and it was demonstrated that the lines were visible.

To account for his silence in the matter, the theory is advanced that he confused them with other phenomena , and/or, lacking a plausible explanation for them, dismissed them as unimportant, perhaps motivated by his desire to avoid arguments about observations which he could not explain.

CHAPTER I

The development of modern scientific practices is largely dependent upon highly complex equipment and sophisticated derivative methods. It is easy to forget, sometimes, that the most imposing of sciences is usually erected upon simple foundations, and that sometimes a whole new field may be opened as the result of some fortuitous accident involving a wholly unrelated field of investigation. A case in point is the field of spectroanalysis, which is not only a free-standing part of chemistry, but one of the most important contributors to a host of other sciences, including physics, medicine, and geology. Refinements of technique tend to bely the humble origins of an art; surely the operator of a spectrograph need not know when the principle of its operation was discovered.

Historically, though, "When was it discovered ?" is an important question. In the case of spectroanalysis, there is evidence that it might have been discovered earlier; in fact, possibly as much as one hundred years. Had this been the case, it is likely that our present knowledge of the universe would be advanced---although it would be difficult indeed to say by how much. To the historian, the contemporary effects of this "might have been" are of relatively minor importance. What is important is the possibility itself; that somewhere in the past, certain factors combined, and a science was almost born, "before its time".

In reality the first stirrings of the new science came in 1802, when W. H. Wollaston noted a number of dark lines crossing a solar spectrum which he produced by shining sunlight from a narrow slit upon a glass prism, focussing the image with a lens placed between the slit and prism. However, he dismissed them as being natural boundaries for the various colors.[1] In 1816 a German optician named Fraunhofer actually was responsible for precipitating the new field of study upon the scientific world:

> "...seeking to improve the method of defining the color of light used in measuring the index of refraction of glasses, he made a detailed examination of the spectrum of sunlight...Placing a 60° flint glass prism 24 feet from a slit in his window shutter, he viewed the light through his theodolite telescope, and found the spectrum crossed

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[1]Ralph A. Sawyer, Experimental Spectroscopy (New York: Prentice Hall, Inc.; 1951), P. 4.

> with an almost countless number of strong and weak vertical lines.
> Experiments with different prisms and slits and other variations of the conditions showed the lines to be really in the sunlight. Fraunhofer could not explain the lines, but he made a map of about 700 of them, and assigned to eight of the more prominent ones the letters A to H, by which they are still known. (See Figure 1.) These lines gave him and optical science the first definite standards for the comparison of the dispersion of different glasses, and an exact science of spectrography was founded."[2]

There remained one step before spectrography could become a useful science. The fact that each atom and molecule had its own characteristic spectra was yet to be recognized. Fraunhofer contributed, himself, to this recognition by observing that the yellow lines in a flame were also lines which appeared in the solar spectrum.[3]

There is some confusion as to who actually made the crucial connection of spectrum and element. J.F.W. Herschel performed studies of the flame spectra of salts, and said:

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[2] Ibid, P.5.

[3] Ibid, P.7.

> "The colours thus communicated by the different bases to flames afford, in many cases, a ready and neat way of detecting extremely minute quantities of them."[4]

On the surface, this statement seems unequivocal, but he qualified it by observing:

> "When the combustion is violent, as in the case of an oil lamp urged by a blow pipe, or in the upper part of the flame of a spirit lamp, or when sulphur is thrown into a white-hot crucible, a very large quantity of a definite and purely homogeneous light is produced."[5]

Apparently, he here confused three definite and distinct forms of radiation. Nevertheless, he seems to have been on the right track, in recognizing that certain substances give definite spectra. His error was in not realizing that one spectrum is uniquely associated with only one substance.

W. H. Fox-Talbot was also near the truth; in 1825, he observed flame spectra and concluded that the peculiar orange ray which he found there was probably due to the presence of strontium. Acting on this supposition, he stated:

> "...a glance at the prismatic spectrum of a flame may show it to contain substances which it would otherwise require a laborious chemical analy-

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[4]<u>Ibid</u>

[5]<u>Ibid</u>

sis to detect."[6]

Later, he reiterated that lithium and strontium were distinguishable through the use of the spectrograph, but he remained unclear about the significance of characteristic spectra.

Other names deserve mention as having contributed to the mass of knowledge surrounding the unique connection of spectra with various substances, including Wheatstone, Crookes, Ångstrom, Alter, and Foucault; all of these men seem to have understood some of the facts of characteristic emission and absorption. However, it remained for G. R. Kirchhoff, of Heidelberg, to generalize the data and formulate it as a mathematical law stating that a gas which radiates a line spectrum must absorb the lines which it radiates at the same temperature. Through it, he explained the dark lines in the solar spectrum, and applied it practically to the first chemical analyses of the sun. With Bunsen, he assaulted the problems of chemical analysis with the spectrometer, and in 1861 they used the instrument to discover two new elements, caesium and rubidium.

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[6] Ibid

Thus, the science of spectroscopy was born; many men later claimed post hoc distinction for the discovery, but there seems to be no doubt that Kirchhoff was the first to assemble the complete picture.

However, the thread of discovery did not originate with Fraunhofer and Wollaston, important though their observations were. It may be followed back through Thomas Young, who in 1802 explained the phenomenon of interference with his undulatory theory of light; through J. W. Ritter, and Herschel the elder, who discovered the ultra-violet and infra-red ends of the spectrum, respectively. Even farther back in time stands Thomas Melvill, who observed the sodium flame with a prism, and in 1752 published the first account of an emission spectrum.

Ultimately, the thread of history must have a spinning-point, from which it emerges as an organic strand, and before which it exists merely as disassociated filaments. In the case of spectroscopy, this point came in 1704, when Sir Isaac Newton, Lucasian Professor at Trinity College, published his volume on the nature of light, Opticks. In this single work, Newton had assembled the products of years of observation and precise thought, and in it were carefully delineated the essential factors which were present in Wollaston's experiments some 98 years later.

According to the Opticks Newton used a prism, an opening in his shutter, and a lens to focus the image of the opening on the prism, and onto a screen on the wall. He experimented with various shapes for the opening; at first, he used a round 1/4 inch hole. However, the spectrum produced by this method was too narrow, and he says, in Opticks:

> "Yet, instead of the Circular Hole F., 'tis better to substitute an Oblong Hole shaped like a Long Paralleogram, with its Length parallel to the Prism ABC. For if this Hole be an Inch or two long, and but a tenth or a twentieth Part of an Inch broad, or narrower; the Light of the Image ...will be as simple as before, or simpler, and the Image will become much broader, and therefore more fit to have Experiments tried on its light than before."[7] (See Figure 4)

He used a variety of prisms, including ones made both of solid glass and of glass plate, filled with rain-water, which he saturated with "Saccharum Saturni" (Lead Acetate) to increase the refractive index.[8] Although he complained

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[7]Newton, Isaac, Opticks (New York: Dover Publications Inc., 1952) P. 70.

[8]Ibid, P.72.

in a number of instances about the poor quality of the glass in his solid prisms, he seemed to have found a few fairly good specimens, whose defects were sufficiently localized that he could cover them up with black paper, and eliminate their effects:

> "I took another Prism of clear white Glass; but the Spectrum of Colours which this Prism made had long white Streams of faint Light shooting out from both ends of the Colours, which made me conclude that something was amiss; and viewing the Prism I found two or three little Bubbles in the glass, which refracted the Light irregularly. Wherefore I covered that part of the glass with black Paper, and letting the Light pass through another Part of it which was free from such Bubbles, the Spectrum of Colours became free from those irregular Streams of Light, and was now such as I desired."[9]

He used lenses of focal length six, eight, ten, or twelve feet, and of sufficiently high quality:

> "...as may serve for optical uses."[10]

He thus had a spectroscope in nearly modern form, and with it, he generated solar spectra, nearly ten inches in length.

Newton was in reality the grandfather of spectroscopy. It was with virtually identical

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[9]*Ibid*, P. 88.

[10]*Ibid*, P.72.

equipment that Wollaston first saw the absorption lines, and Fraunhofer made only a few improvements in order to quantify what he saw.

Thus, there arise certain critical questions. If Newton had the equipment, why didn't he see the lines? Or if he did see them, why didn't he speak of them? Was his vision too poor? Was his optical apparatus of such poor quality, as claimed by Sawyer[11], that the lines failed to appear?

At M. I. T., during the spring of 1960, an attempt was made to reconstruct Sir Issac Newton's apparatus, and duplicate, as nearly as possible, his experiments with the spectrum. In this way, it was hoped, conclusive answers to the query "Were the lines visible?" could be provided. Simultaneously, research was done into the literature, both Newton's own works, and those of his colleagues, interpreters, and critics, in an effort to understand his attitudes and provide some insight into his reasoning.

This thesis contains the results of these studies; its purpose is to provide what the author hopes are reasonable answers to the questions posed, and add some small amount to what has been

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[11] Sawyer, op. cit. P. 3

learned about a man who stands as a legendary figure in the annals of science.

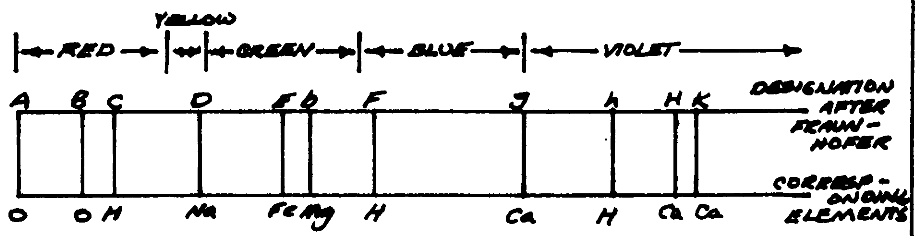

FIG. 1. THE STRONGEST FRAUNHOFER LINES IN THE SOLAR SPECTRUM.

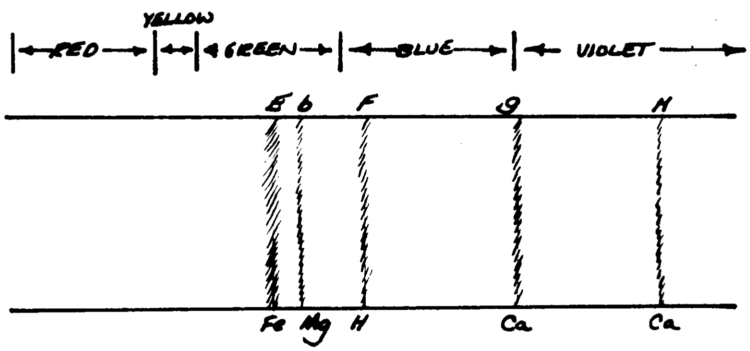

FIG. 2. SOLAR SPECTRUM PRODUCED WITH SOLID GLASS PRISM. SLIT OPENING 1 MM.

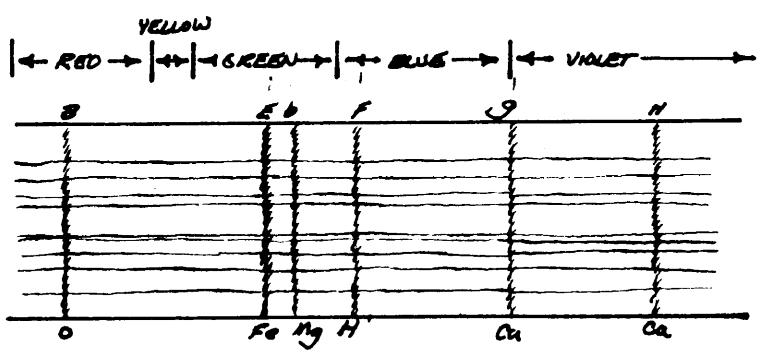

FIG. 3. SOLAR SPECTRUM PRODUCED WITH LIQUID-FILLED PRISM. SLIT OPENING .8 MM. NOTE HORIZONTAL LINEATIONS PRODUCED BY DIRT AND IRREGULAR CLOSURE OF SLIT.

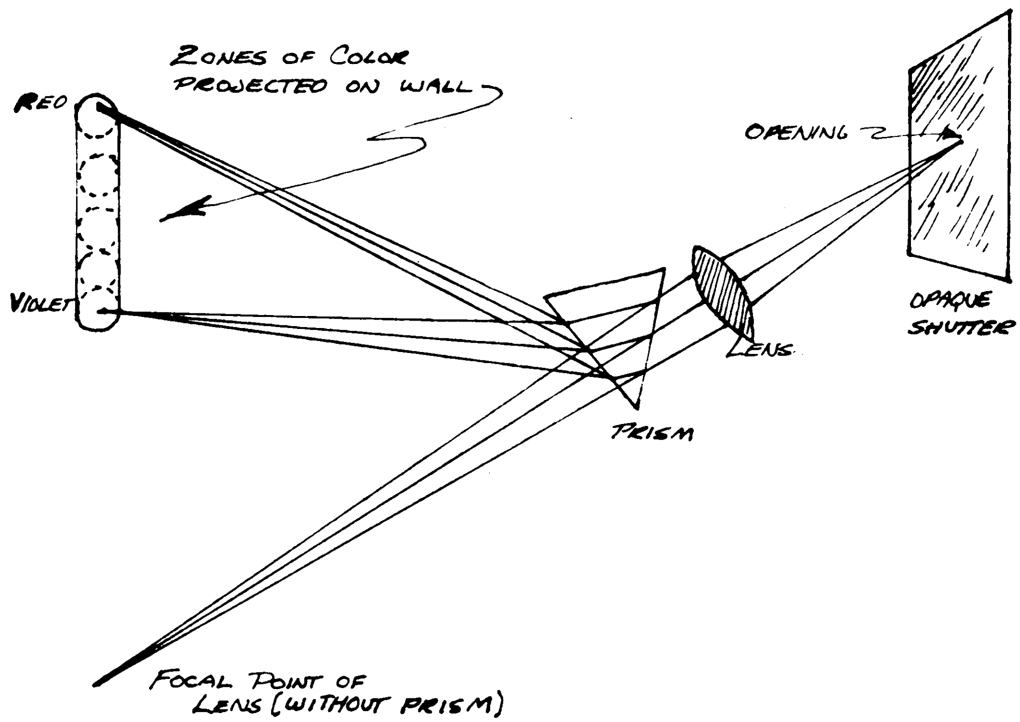

Fig. 4. NEWTON'S APPARATUS FOR VIEWING THE SOLAR SPECTRUM. NOT TO SCALE.

CHAPTER II

The absorption lines are a "secondary" phenomenon (for all of their importance), yet it seems strange that such a careful observer as Newton should overlook them, and not mention them at all, even in passing. He apparently did overlook them, however, for he did not mention them even when he spoke of experiments where he used an assistant whose:

> "Eyes for distinguishing Colours were better than..(his)"[12]

to help fix the boundaries of the colored zones. (It should be mentioned that, in this particular experiment, Newton is believed to have used a round hole; at least, his illustrations so indicate. However, his descriptions of the use of a slit for a source implied that he considered it to be superior to a round hole, and it is equally likely that he used a slit, but illustrated it as a circle, for simplicity .)

Thus, on the one hand, Newton presumably had the equipment with which to observe the spectral lines; on the other, there is the un-

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[11]Sawyer, op. cit. P. 3

questionably authoritative word of the man himself, which mentions nothing about them.

As has been stated, in an attempt to resolve the problem, it was decided to duplicate the essentials of Newton's apparatus and attempt to repeat his experiments. If the results were positive, they would justify asking "Why did he not mention the lines?"; if they were negative, his silence would be explained, as merely non-reporting of a phenomenon which had not been observed.

In the original experiments, Dr. Newton had the advantagesof a room which he could darken totally, and in which he could work undisturbed, of pieces of optical equipment which often were made exactly to his fancy, as he himself designed and built them, and a period of six years in which to experiment, plus an additional thirty-two years in which to ready his manuscript for publishing. Obviously, for the modern experimenter and would-be duplicator of Newton's experiments, it would be impractical to spend six years, even six months, attempting to copy his trials in meticulous detail; if for no other reason than lack of space at M. I. T.

Accordingly, it was decided to dispense with trivial duplications, and concentrate upon the important things, i.e. the lens, slit, and prism.

Various prisms were procured: one 60° flint-glass model, a 45°-45°-90° war-surplus tank-periscope prism, and a number of liquid-filled prisms, or "prismatick Vessels", as Newton termed them, constructed by the author. (See Figure 9.)
A simple adjustable slit was procured, and a double-convex lens of 36 centimeters focal-length. (See Figure 10.) The exact specifications of lens and prism were somewhat arbitrary--Newton apparently used lenses with focal-lengths of between six and twelve feet, and prisms with angles of between 60° and 70°.[13]
The optical components were mounted upon a plywood board which was in turn fastened to a clock-driven telescope mount. The original intent was to point the device at the sun, and allow it to "track" or follow it; however, this arrangement proved to be impractical, for the spectrum was inevitably cast into a sunlit spot, and obliterated, or it would fall onto the nearby

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[13] _Ibid_, P. 67

floor or wall, where the light path was so short as to render the spectrum too small to be useful. Finally, a suitable arrangement was made by mounting the instrument horizontally and using a mirror to reflect sunlight into it. With this method light paths of up to 18 feet were available, and the most consistent experimental results were obtained, out of all attempts made.

A word must be said about the liquid-filled prisms, for they proved to be the greatest obstacle to the experimental work. Initially, the author intended that only solid prisms be used, believing that Newton had had optical glass prisms of reasonably good quality. Mr. Walter Pitts, however, suggested that a liquid-filled model be tried, in case the suppositions about Sir Isaac's glass prisms proved to be wrong.

Accordingly, the author spent a number of weeks building and testing various types of prisms; in all, seven were built or begun. Two types of glass were used; 1/16" and 1/8" in thickness. The latter type proved to be more practical because of its durability and was used in the final model. The edges on all models were fastened together with "Scotch" No.'s 33 and 27 electrical tape, and attempts to seal the ends were made with a variety of compounds including paraffin, vacuum-putty ("Apiezon Q"), flourosilicon rubber ("Silastic"), and epoxy resin. The epoxy proved to be the only sealant which would retain its strength under the action of solution in the prism (Lead Acetate), and the top and bottom of the test prism were fastened on with it. In addition, a screw-cap vial with the bottom removed was sealed into a hole in the top-plate of the prism, thus providing a convenient means of filling and emptying it. (See Figure 9)

The prism thus produced had angles of 55°-55°-70°, and its optical qualities proved to be quite good. It was filled, as mentioned, with lead acetate solution, which had been boiled and filtered to remove gases and dust. The water used had been previously distilled and demineralized, to duplicate the rain-water which Newton used.[14]

Before the prisms and lenses were actually tested in the sunlight, a series of preliminary experiments were carried out at the Cabot Spectrographic

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[14] Ibid, P.72

Laboratory, at M. I. T.. The laboratory's Wadsworth Spectrograph, a diffraction-grating type,(consisting of a room with an adjustable slit, in one wall, and optical components mounted within the room,) was modified slightly in order to use the prism and lens . (See Figures 6 and 7)

The light-source used was a d.c. carbon arc, and the spectrum produced was viewed from within the spectrograph by observing a white screen placed where the plate normally went. This spectrum was clearly defined, and spectral lines were present. The slit widths were from .25 to 1 millimeter; during one trial, a width of 2 millimeters was used, but with the grating, rather than the prism. (This seemingly irrevelant experiment was conducted to determine if under <u>any</u> circumstances, a slit width of the order of a millimeter or more would produce lines.)

A carbon arc, however, is not the sun, and although the results with the arc were encouraging, there yet remained the unanswered questions about the solar spectrum.

The first answers came on the second of April, 1960, in Laconia, N.H.. The apparatus had been constructed in that city, at the author's home, and inasmuch as the sun had put in one of it's rare late winter appearances, it was decided to test the equipment. The equatorial mount had not at that time been attached, so the device was propped against a kitchen chair, and the spectrum produced was directed through the open door into the living-room. This spectrum, which measured about 6" long, showed blurred but definite lines or bands at the positions of the E (iron), b (magnesium), F (hydrogen), g, and possibly H (calcium) lines. (See Figures 1 and 2) The slit-opening was approximately 1 millimeter or a little less than Newton's 1/20 of an inch. (1.287 millimeters) The prism used was the 60° solid-glass model, since the liquid-filled one had not yet been constructed. The total light path from prism to screen was about 10 feet.

The problem of finding room for further experimentation was finally solved by Dr. Dennen, who permitted the back doors of the Cabot Laboratory at M. I. T., Room 24-018, to be unsealed. Through the use of drop cloths, all but a small beam of light from the setting sun was shut out, and the spectrograph was operated on two occasions in this manner, with both prisms.

Further experimentation revealed that reflected sunlight produced spectral results identical to those obtained directly, so a shaving-mirror was placed outside the laboratory, and beams of sunlight directed at the spectroscope within. This permitted experiments at any time of the day, rather than the previous sunset - only scheduling, and for the first time, careful study was made of the spectra produced by using the lead-acetate-prism. In the laboratory the light path was about 15 feet long, and the spectrum produced, about 10 inches long. Using slits of between .5 and .8 millimeter, well within Newton's nebulous "1/20" of an inch "or less", lines were visible, probably the E, F, and g lines and, on one occasion, a line in the red, perhaps the B (oxygen) or C (hydrogen) lines (See Figure 3). They were blurred, but definitely present. The slit, however, was dirty, and suffered from some misalignment; the result was the appearance of a definite lineation which ran at right angles to the spectral lines. (See Figure 3) It was determined that this lineation could, however, be eliminated by cleaning the slit.

In summary then, the experiments proved that, using apparatus similar to Sir Isaac Newton's the lines in the solar spectrum are certainly visible, even to an untrained observer. (The author's mother, and a young lady of his acquaintance both saw the lines on several occasions.) In some cases, the lines might be confused with other phenomena, but a careful observer would note, almost immediately, their intrinsic place on the spectrum, In general, results from the solid prism were slightly better than from the liquid one, (i.e. the slit could be opened wider and still produce lines) except when the solution in the latter was fresh, at which point they were of nearly equal optical excellence. (The liquid prism's refractive index was slightly less than the glass.)

Thus Sawyer's assumption:

> "He apparently failed to see the Fraunhofer lines because of the poor optical qualities of his glass.."[15]

proves to be erroneous, and one must turn elsewhere for explanations of Newton's failure to mention the phenomenon.

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[15]Sawyer, op. cit., P. 3

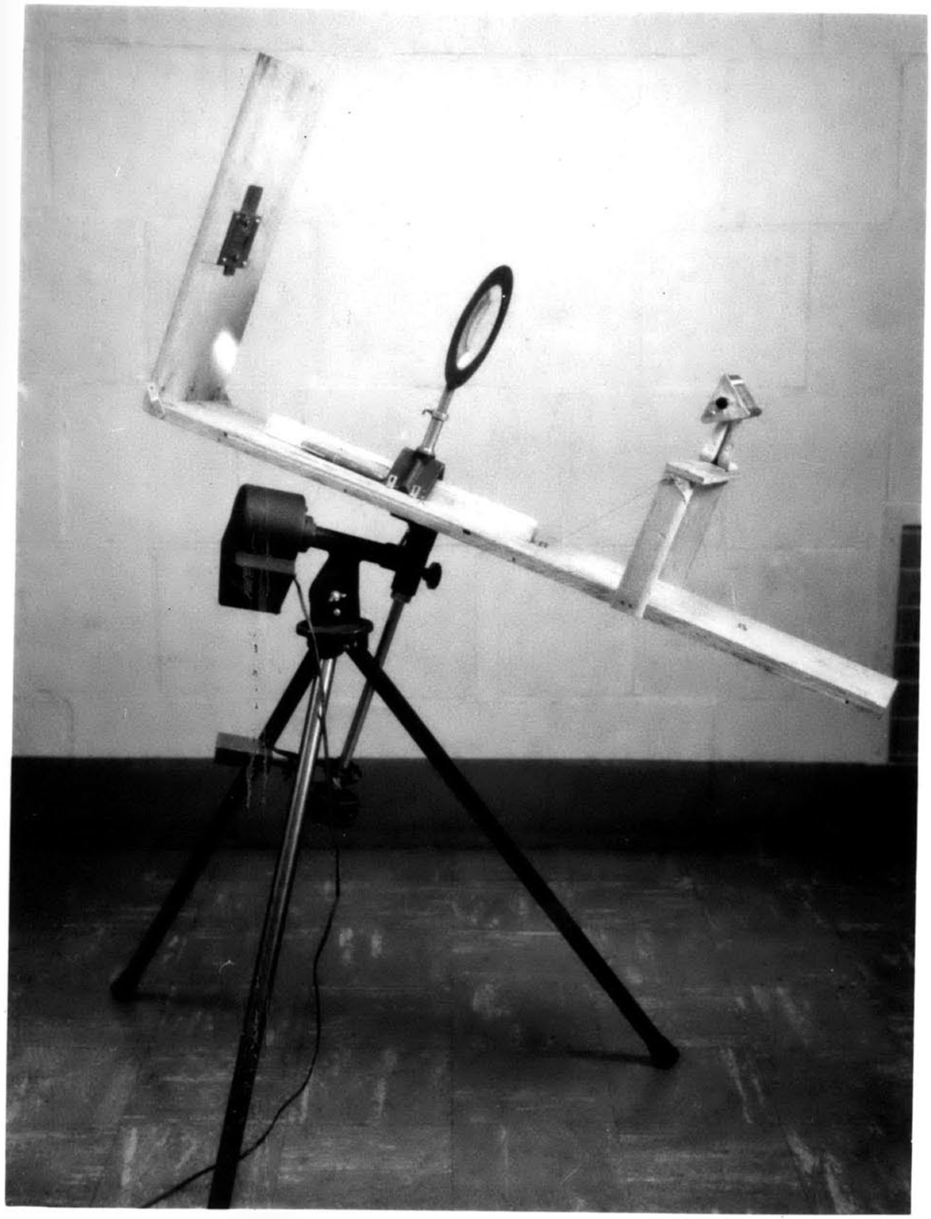

Fig. 5. APPARATUS FOR DUPLICATING NEWTON'S EXPERIMENT. SHOWN WITH LIQUID-FILLED PRISM ATTACHED. APPARATUS APPROX 3' LONG.

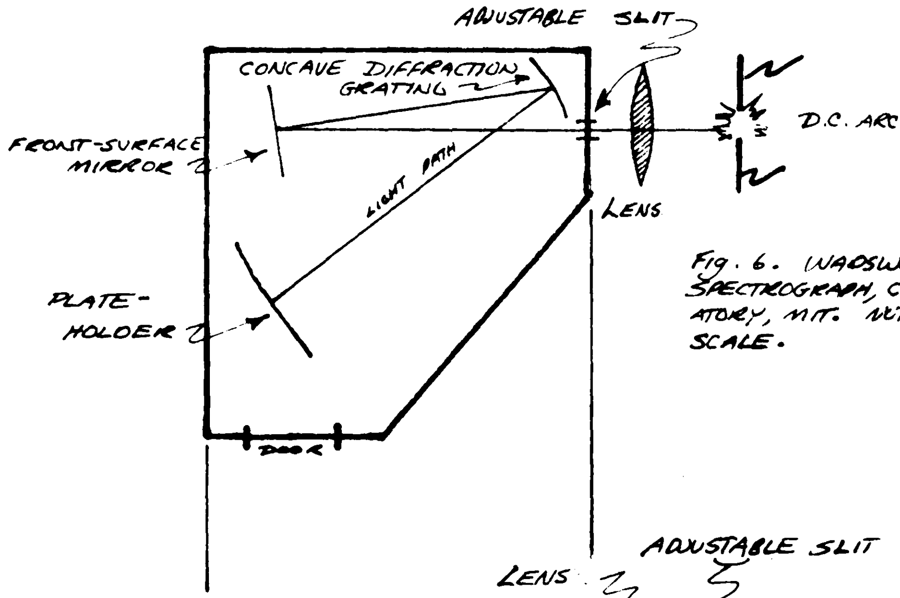

Fig. 6. WADSWORTH SPECTROGRAPH, CABOT LABORATORY, M.I.T. NOT TO SCALE.

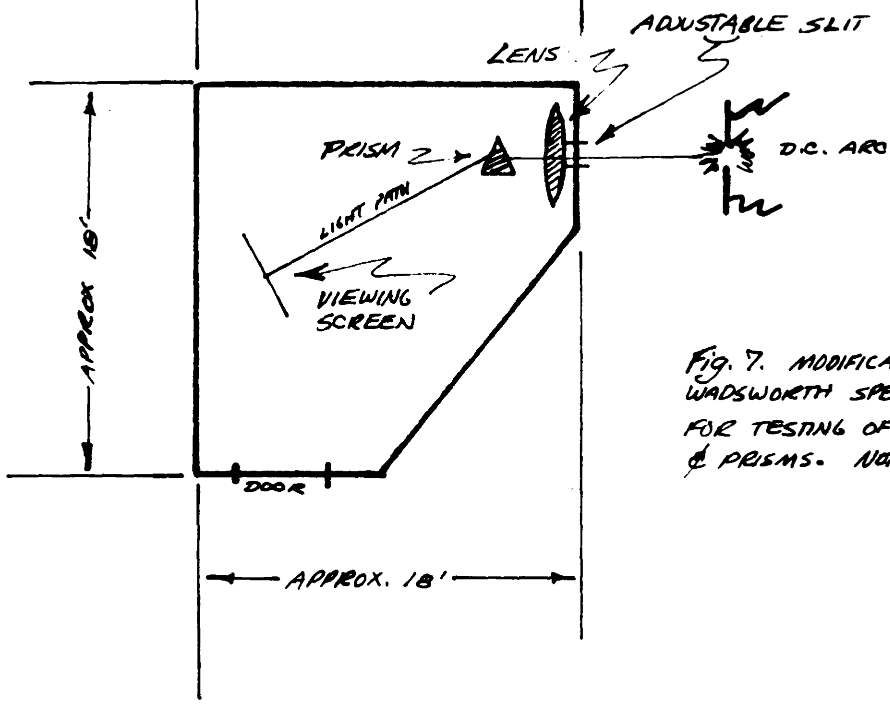

Fig. 7. MODIFICATIONS OF WADSWORTH SPECTROGRAPH FOR TESTING OF LENSES & PRISMS. NOT TO SCALE

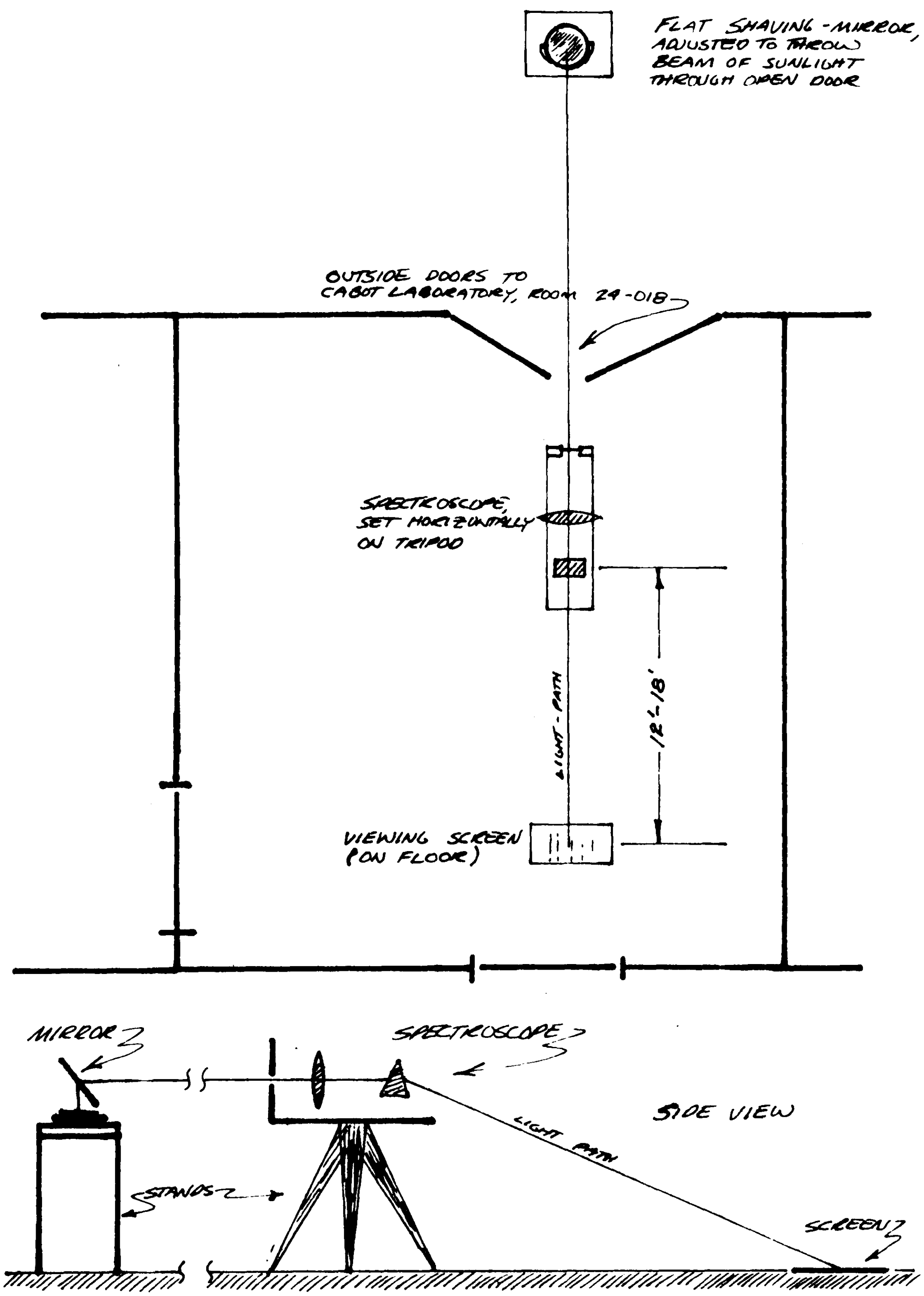

Fig.8 EVENTUAL OPTICAL ARRANGEMENT BY WHICH LINES WERE SEEN. VARIATIONS INCLUDED PRISM INVERTED FROM PRESENT POSITION SCREEN ABOVE SPECTROSCOPE, & POINTING SPECTROSCOPE DIRECTLY AT SUN. NOT TO SCALE.

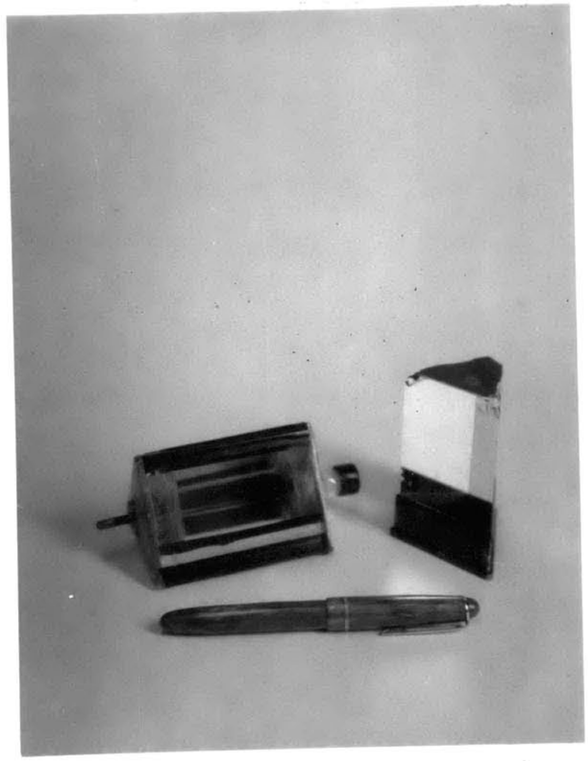

Fig. 9. WATER-FILLED AND GLASS PRISMS USED IN DUPLICATING NEWTON'S EXPERIMENTS. SCALE IS SHOWN BY FOUNTAIN PEN. LIQUID PRISM IS SEVENTH MODEL MADE, AND ONE ULTIMATELY USED SUCCESSFULLY.

FIG. 10. ADJUSTABLE SLIT. APPROX 3" X 3". NOT CALIBRATED; SLIT-WIDTHS WERE MEASURED WITH GRADUATED RETICULE.

CHAPTER III

Newton <u>should</u> have seen the lines. Now arise the queries; "Did he?" and "Why didn't he mention them?" A number of possible answers spring to mind, and it will be the purpose of this chapter to explore them in detail. Briefly stated they are:

1) He saw the lines but confused them with the effects of dirt or other defects in his optical system, or

2) He was engrossed with only one aspect of the problem - the nature of color - and simply paid no attention to the existence of such nebulous entities as lines, or

3) He was unwilling to embroil himself in controversy with his critics, over something which he could not adequately explain himself.

The most obvious, and in many ways, most attractive thesis to be advanced is that Newton confused lines with defects in his optical system. That is to imply, there is no doubt that there <u>were</u> lines visible when he observed the spectrum, but he either failed to recognize them as inherent spectral characteristics, or acknowledged their existence as simply being one more of the phenomena which he saw when he assembled his apparatus, but which changed characteristics each time he changed his optical arrangement - e.g. they disappeared when he used a round hole. (On the other hand, they should have persisted, no matter which prism he tried, as long as he used the slit.) This hypothesis is supported by the experimental work done, inasmuch as only a small amount of dirt on the slit caused criss-cross lines in the spectrum.

Conceivably, Newton could have dismissed the striations in both directions as being caused by dirt in his slit; this would have been supported if he opened the slit, slightly, for all lines disappear when it is more than about one millimeter wide. However, it is questionable that Newton's slit was easily adjustable - he probably made it by making a knife cut in some opaque material. It is more than possible, though, that he made attempts to remove the striations by cleaning the slit, probably with alcohol or water. This process of course, would have altered the horizontal line pattern markedly, without changing the appearance of the spectral lines - something which Newton would have been almost certain to notice, had he done the cleaning. It is left to conclude, therefore, that he either did not clean the slit, and wrote all the lines off as dirt-produced, or he did clean it, and concluded that the remaining (spectral) lines were the product of some other phenomenon, perhaps related to interference fringes,[16] which he produced by a number of methods, including a narrow slit:

> "I placed another Knife by this so that their edges might be parallel, and look towards one another, and that the beam of Light might fall upon both the Knives, and some part of it pass between their edges."[17]

> "...as the Knives approached one another...Fringes began to appear on ...either side of the direct Light."[18]

Newton theorized that the fringes were caused by differential bending of the light as it came nearer to the edges of the knives, and it is conceivable that he considered the spectral lines as merely another manifestation of the effects of a narrow slit upon a beam of light, with the prism serving to spread them throughout the spectrum. The argument against this is essentially the same as against the dirty-slit hypothesis - the fringes

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[16] Newton, op. cit., pp. 317 - 340

[17] Ibid, P. 327

[18] Ibid, P. 328

change position and shape as the slit is moved or altered in width, whereas the spectral lines merely change intensity, becoming more obvious as the slit narrows, but never changing position within the spectrum. (Although it is not known whether Newton changed the width of his first slit, he definitely did move the knife blades.)

This leaves the possibilities that Newton overlooked the lines entirely in his single-minded effort to determine the nature of color, or seeing them, was at a loss to explain them, and since they seemed rather a minor phenomenen, neglected to mention them. Perhaps, also, he sought to avoid the attacks of his contemporaries (e.g. Hooke) upon any observation which he may have been unable to defend, (or even consistently reproduce) and therefore refused to mention having seen them. This last supposition deserves some consideration, for a number of reasons.

First, Newton was by nature suspicious, introverted, and sensitive. He waited for thirty-two years to publish Opticks, until Hooke was dead. (Hooke died in 1703, Opticks appeared in 1704, although it contained information gathered between 1668 to 1672.)

> "Newton was a man of passions... and...of the most fearful, cautious

> and suspicious temper that I ever knew."[19]
>
> "...is not Newton convicted of an irrationally motivated lie in his reply to Huygens' remarks about the composition of the color white?"[20]

He was reticent in the extreme about releasing information about his studies, and, in his writings, showed a tendency to simply deny that he had written anything earlier that might contradict his later work, rather than admit he might have been mistaken. There were exceptions, however; on grounds where he was certain of his correctness, he, although reluctant to argue, felt compelled to counter his assailants. (There were many, especially after the publication of his first optical theories.) However, when he had a choice, he supressed his theories until the opposition was inactive, as in the case of Hooke and the Opticks.

He was also determined that his scientific works should include nothing but observations; he tried to avoid mention of "hypotheses", or theories. Opticks contains a great deal that is

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[19] I. Bernard Cohen, Isaac Newton's Papers and Letters on Natural Philosophy (Cambridge: Harvard University Press, 1958) P. 39

[20] Ibid, P. 40

theoretical; still, it remains first a book of observations. At the onset of his experiments, Newton was primarily interested in color phenomena as produced by a prism. Although his interests shifted as he became involved in optical studies, it is conceivable that his concentration upon colors was so intensive that he simply ignored any and all secondary phenomenae which he could not immediately explain. Since he was often adamant against changing what he had written, preferring to deny it if he later changed his mind, he may never have returned to consider the secondary effects, particularly if they were a product of the studies which he refused to re-examine. Thus, he may have avoided mention of the lines out of sheer stubbornness.

A great deal of material has been written about Newton. Much of it is accurate, factually, but none can completely avoid being speculative about certain aspects of his life and work. In particular, there is disagreement about the exact meanings of some of his writings, especially with regard to the specifications of his instruments; for example, in _Newton and the Origin of Colours_, it is stated:

> "He added to the water a little sugar of lead to raise its mean refractive index sufficiently to make it equal to that of glass. This addition...also increases the dispersive power and Newton therefore detected no difference in the lengths of spectra produced by water and by glass."[22]

However, in the course of the experimental reproduction of his work it was determined that even a saturated solution of lead acetate <u>never</u> produced a spectrum as long as a glass prism of approximately the same angle, i.e. the 70° water-prism, produced a spectrum much shorter than the 60° glass prism; it more nearly approximated that of the 45° prism.

Certainly, Newton was unclear about his instruments, his ideas, and some of his techniques. It is difficult today to decipher all of his meanings, particularly since they were frequently colored by his own peculiar way of thinking. It is difficult enough to reproduce his meanings, and it is well-nigh impossible to duplicate the mental attitudes of the man. .

This perhaps justifies the lack of precision in analyses of Newton's life and labors; it makes it no easier, though, to unearth relevant

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[22]Michael Roberts and E. R. Thomas, <u>Newton and the Origin of Colours</u>, (London: G. Bell and Sons Ltd., 1934) P. 108

data about him. However, certain consistencies remain. Throughout the welter of conflicting information and speculation, it is these facts which must be considered in order to answer the questions asked in this paper:

1) It is highly likely that the lines were visible with Newton's apparatus.

2) He makes no mention of the lines at any place in the <u>Opticks</u>.

3) There were a number of optical effects which might have been confused with the lines.

4) Newton recorded meticulously nearly everything he observed, and, practically everything he recorded (at least in his account of the color experiments), he managed to explain; e.g. the spurious radiation caused by bubbles in the prism.

5) He was extremely sensitive to criticism.

From these, it is possible to effect a synthesis of what might have been his reasons for failing to mention the lines. Obviously, there is no positive way of justifying this synthesis; rather, its purpose is to provide a reasonable, and in the opinion of the author, plausible, answer to the questions, to wit:

Newton probably observed the lines; it is highly likely that they were faint, and easily confused with other effects. Since they were faint, Newton regarded them as secondary phenomena , and didn't bother to mention them, inasmuch as he lacked a good explanation for their existence, and was engrossed in a much more important issue, the nature of color. If he had any second thoughts about them, and attempted to differentiate them from other secondary effects, he obviously failed to arrive at any conclusions, and the possibility of ridicule from his opponents deterred him from ever mentioning them.

Thus, a science which was "ready" 100 years before its time was not born. It would be difficult to blame Sir Isaac Newton for failing to be its midwife. All that may be asked is "What if...?" It is the hope of the author that this paper will provide information which someday may lead to a positive solution to this question.

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APPENDIX

LIST OF IMPORTANT EXPERIMENTS IN SERIES

DATE AND PLACE	COMMENTS
25 March 1960, Cabot Laboratory, M. I. T.	Used unmodified Wadsworth Spectrograph with 2 mm slit and carbon arc. Diffuse, but visible, lines.
28 March 1960, Cabot Laboratory, M. I. T.	Used modified Wadsworth Spectrograph. (See Figure 7) Tested 60° glass prism with up to 1 mm slit-widths. Lines clearly visible, in all cases, as long as arc was "visible" to slit. (the carbons themselves provide a continuous spectrum; if the slit "sees" both arc and carbons, a continuous spectrum crossed by dark lines is caused)
2 April 1960, Laconia, N.H.	Used 36 cm. F.L. DCX lense with slit and 60° prism, mounted on board, and pointed at sun. Two lines visible in green, one between green and blue, at widths up to 1 mm.

DATE AND PLACE	COMMENTS
24 April 1960, Cabot Laboratory	New liquid prism built (seventh in series) using epoxy and rubber seals. Changed to all-epoxy. Tested in Wadsworth. Lines plainly visible with widths up to 1 mm when slit "sees" both arc and carbons, up to 2 mm when arc alone focussed on slit.
26 April 1960, Cabot Laboratory, M. I. T.	First successful test of liquid prism in solar spectroscope. Slit @ .5 mm, lines clearly visible in red and green; @ 1 mm, visible as bands. Sun went behind cloud before conclusive results were established.
2 May 1960, Cabot Laboratory, M. I. T.	Liquid prism used, and shaving mirror to shine light into instrument, thus achieved continuous viewing. Slit @ .5 mm, E-b doublet resolved. Slit @ .8 - 1.0 mm, numerous lines seen; also, @ .5 mm, dirt on slit produced horizontal lineations.