BASIC DATA OF ELECTRICAL DISCHARGES

SANBORN C. BROWN
W. P. ALLIS

TECHNICAL REPORT 283

JUNE 9, 1958

FOURTH EDITION

RESEARCH LABORATORY OF ELECTRONICS
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
CAMBRIDGE, MASSACHUSETTS

The Research Laboratory of Electronics is an interdepartmental laboratory of the Department of Electrical Engineering and the Department of Physics.

The research reported in this document was made possible in part by support extended the Massachusetts Institute of Technology, Research Laboratory of Electronics, jointly by the U. S. Army (Signal Corps), the U. S. Navy (Office of Naval Research), and the U. S. Air Force (Office of Scientific Research, Air Research and Development Command), under Signal Corps Contract DA36-039-sc-64637, Department of the Army Task 3-99-06-108 and Project 3-99-00-100.

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Fourth Edition

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I. POTENTIAL ENERGIES

I(a). Table of excitation and ionization energies of atoms in electron volts obtained from spectra by means of the conversion factor, $V\lambda = hc/e = 1.2398 \times 10^{-4}$ volt-cm.

Atomic Number	Element	V_m	V_{res}	V_{i1}	V_{i2}	V_{i3}
1	H		10.198	13.595		
2	He	19.80	21.21	24.580	54.400	
3	Li		1.85	5.390	75.62	122.42
4	Be		5.28	9.320	18.21	153.85
5	B		4.96	8.296	25.15	37.92
6	C	1.26	7.48	11.264	24.376	47.86
7	N	2.38	10.3	14.54	29.60	47.426
8	O	1.97	9.15	13.614	35.15	54.93
9	F		12.7	17.418	34.98	62.65
10	Ne	16.62	16.85	21.559	41.07	63.5 ±0.1
11	Na		2.1	5.138	47.29	71.8 ±0.1
12	Mg	2.709	2.712	7.644	15.03	78.2 ±0.1
13	Al		3.14	5.984	18.82	28.44
14	Si	0.78	4.93	8.149	16.34	33.46
15	P	0.91	6.95	10.55	19.65	30.16
16	S		6.52	10.357	23.4	34.8
17	Cl		8.92	13.01	23.80	39.9
18	A	11.55	11.61	15.755	27.6	40.90
19	K		1.61	4.339	31.81	45.9
20	Ca	1.880	1.886	6.111	11.87	51.21
21	Sc	1.43	1.98	6.56	12.89	24.75
22	Ti	0.81	1.97	6.83	13.57	28.14
23	V	0.26	2.03	6.74	14.2	29.7
24	Cr	0.94	2.89	6.764	16.49	31
25	Mn	2.11	2.28	7.432	15.64	33.69
26	Fe	0.85	2.40	7.90	16.18	30.64
27	Co	0.43	2.92	7.86	17.05	33.49
28	Ni	0.42	3.31	7.633	18.15	36.16
29	Cu	1.38	3.78	7.724	20.29	36.83
30	Zn	4.00	4.03	9.391	17.96	39.70
31	Ga		3.07	6.00	20.51	30.70
32	Ge	0.88	4.65	7.88	15.93	34.21
33	As	1.31	6.28	9.81	18.7 ±0.1	28.3
34	Se		6.10	9.75	21.5	32.0
35	Br		7.86	11.84	21.6	35.9
36	Kr	9.91	10.02	13.996	24.56	36.9
37	Rb		1.56	4.176	27.56	40
38	Sr	1.775	1.798	5.692	11.026	43.6
39	Y		1.305	6.38	12.23	20.5
40	Zr	0.52	1.83	6.835	12.92	24.8
41	Nb		2.97	6.88	13.90	28.1
42	Mo	1.34	3.18	7.131	15.72	29.6

(continued on next page)

Atomic Number	Element	V_m	V_{res}	V_{i1}	V_{i2}	V_{i3}
43	Tc			7.23	14.87	31.9
44	Ru	0.81	3.16	7.36	16.60	30.3
45	Rh	0.41	3.36	7.46	15.92	32.8
46	Pd	0.81	4.48	8.33	19.42	
47	Ag		3.57	7.574	21.48	36.10
48	Cd	3.73	3.80	8.991	16.904	44.5
49	In		3.02	5.785	18.86	28.0
50	Sn	1.07	4.33	7.332	14.6	30.7
51	Sb	1.05	5.35	8.64	16.7 ±0.5	24.8
52	Te	1.31	5.49	9.01	18.8 ±0.5	31
53	I			10.44	19.0	33
54	Xe	8.32	8.45	12.127	21.2	32.1
55	Cs		1.39	3.893	25.1	34.6 ±0.7
56	Ba	1.13	1.57	5.810	10.00	37 ±1
57	La	0.37	1.84	5.61	11.43	19.17
58	Ce			(6.91)	12.3	19.5
59	Pr			(5.76)		
60	Nd			(6.31)		
61	Pm					
62	Sm			5.6	(11.2)	
63	Eu			5.67	11.24	
64	Gd			6.16	(12)	
65	Tb			(6.74)		
66	Dy			(6.82)		
67	Ho					
68	Er					
69	Tm					
70	Yb			6.2	12.10	
71	Lu			6.15	14.7	
72	Hf		2.19	5.5	14.9	
73	Ta			7.7	16.2 ±0.5	
74	W	0.37	2.3	7.98	17.7 ±0.5	
75	Re		2.35	7.87	16.6 ±0.5	
76	Os			8.7	17 ±1	
77	Ir			9.2	17.0 ±0.3	
78	Pt	0.102	3.74	8.96	18.54	
79	Au	1.14	4.63	9.223	20.5	
80	Hg	4.667	4.886	10.434	18.751	34.2
81	Tl		3.28	6.106	20.42	29.8
82	Pb	2.66	4.38	7.415	15.03	31.93
83	Bi	1.42	4.04	7.287	19.3	25.6
84	Po			8.2 ±0.4	19.4 ±1.7	27.3 ±0.8
85	At			9.2 ±0.4	20.1 ±1.7	29.3 ±0.9

(continued on next page)

Atomic Number	Element	V_m	V_{res}	V_{i1}	V_{i2}	V_{i3}
86	Rn	6.77	8.41	10.745	21.4 ±1.8	29.4 ±1.0
87	Fr			3.98 ±0.10	22.5 ±1.8	33.5 ±1.5
88	Ra			5.277	10.144	
89	Ac			6.89 ±0.6	11.5 ±0.4	
90	Th				11.5 ±1.0	20.0
91	Pa					
92	U			4		

The resonant level V_r is the lowest excited level from which electric dipole radiation can take place. If there is an excited level, not part of the ground state multiplet, which is lower than V_r, it is a metastable level V_m.

[The data from columns 5, 6, and 7 are taken from W. Finkelnburg, W. Humbach, Naturwiss. 42, hft. 2, 36-37 (1955).]

I(b). Excitation and Ionization for Molecules

Molecule	V_r	V_{il}	Molecule	V_r	V_{il}
Br_2		12.8	Cl_2		13.2
BrCl		12.9	F_2		17.8
CH_2O		11.3	H_2	11.5	15.6
CH_3Br		10.0	HBr		13.2
CH_3Cl		10.7	HCN		14.8
CH_3I		9.1	HCl		13.8
CH_4		14.5	HF		17.7
CN		14	HI		12.8
CO	6.0	14.1	H_2O	7.6	12.6
CO_2	10.0	14.4	H_2S		10.4
CS		10.6	I_2	2.3	9.7
CS_2		10.4	IBr		11.6
C_2H_2		11.6	ICl		11.9
C_2H_4		12.2	N_2	6.1	15.5
C_2H_6		12.8	NH_3		11.2
C_6H_6		9.6	NO	5.4	9.5
C_7H_8		8.5	NO_2		11.0
CH_3I		10.1	N_2O		12.9
C_2H_5Br		10.2	O_2	7.9	12.5
C_2H_5N		9.8	S_2		10.7
C_2H_5OH		11.3	SO_2		13.1
CH_3COCH_3		10.1			

I(c). Electron Affinities

Atom	Electron Volts
H	0.76
He	-0.53
Li	0.34
C	1.37
N	0.04
O	3.80
F	3.94
Ne	-1.20
Na	0.08
Mg	-0.87
Al	-0.16
S	2.06
Cl	3.70
A	-1.0
Br	3.54
I	3.22
Hg	1.79

From L. B. Loeb, "Fundamental Processes of Electrical Discharges in Gases" (John Wiley & Sons, Inc., New York, 1939), p. 297.

II. COLLISION PROBABILITIES

The probability of collision P_c is defined as the fraction of particles scattered out of a collimated beam per centimeter path per millimeter pressure at 0°C. Similarly the "probability" of any event occurring on collision, such as excitation P_x or ionization P_i, is the fraction of particles suffering that event per centimeter path and millimeter pressure. The probability P is related to the cross section q by

$$P = L\,q/760 \text{ cm}^{-1} (\text{mm Hg})^{-1}$$

where L is Loschmidt's number, or

$$P = 3.5357\,q$$

where q is in square angstrom units. The mean free path ℓ is given by

$$\ell = 1/p_o\,P \text{ cm}$$

and the mean free time τ by

$$1/\tau = v/\ell = 5.93107 \times 10^7\, u^{1/2}\, p_o\, P \text{ sec}^{-1}$$

Here $u = mv^2/2e$ is the energy in electron volts, and $p_o = 273.16\, p/T$ is the "reduced" pressure in millimeters of mercury. p_o does not express a pressure, but a concentration

$$N/V = 3.5357 \times 10^{16}\, p_o \text{ molecules/cm}^3$$

Cross sections are sometimes given in units of $\pi a_o^2 = 0.87981$ A^2, and energies in Hartree units, $k^2 = V/13.605$.

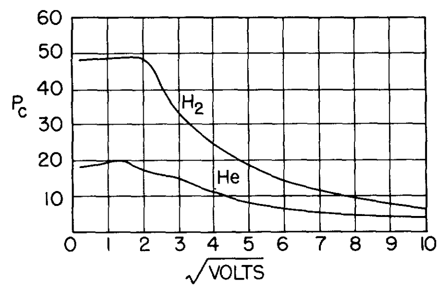
If $q(\theta)$ is the differential cross section for elastic scattering into unit solid angle at an angle θ to the incident direction,

$$q_c = \int q(\theta)\, 2\pi \sin\theta\, d\theta$$

A more important quantity is the cross section for momentum transfer.

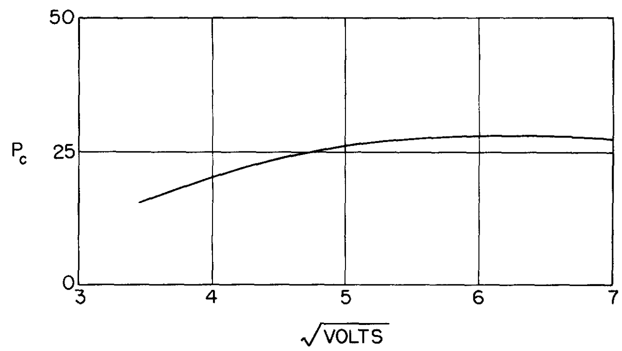
$$q_m = \int q(\theta)\,(1 - \cos\theta)\, 2\pi \sin\theta\, d\theta$$

In general, $q_m \leq q_c$; experimental values of P_c should be "corrected" to P_m in all gas discharge applications.



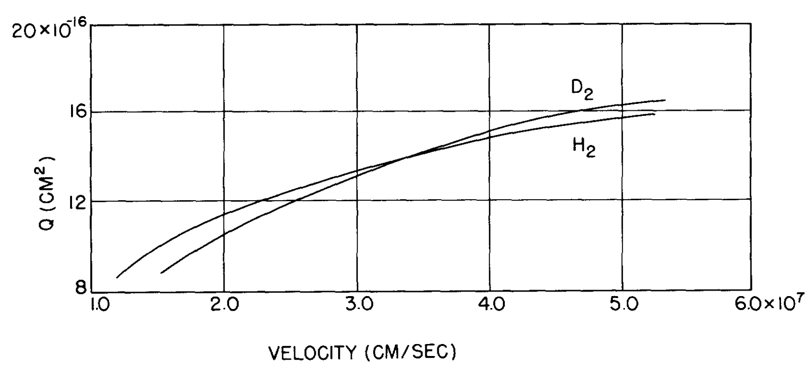
II a1. "Probability" of collision in H_2, He.

*R. B. Brode, Revs. Modern Phys. 5, 257 (1933)
A. V. Phelps, O. T. Fundingsland, S. C. Brown, Phys. Rev. 84, 559 (1951)
L. J. Varnerin, Jr., Phys. Rev. 84, 563 (1951)
L. Gould, S. C. Brown, Phys. Rev. 95, 897 (1954)



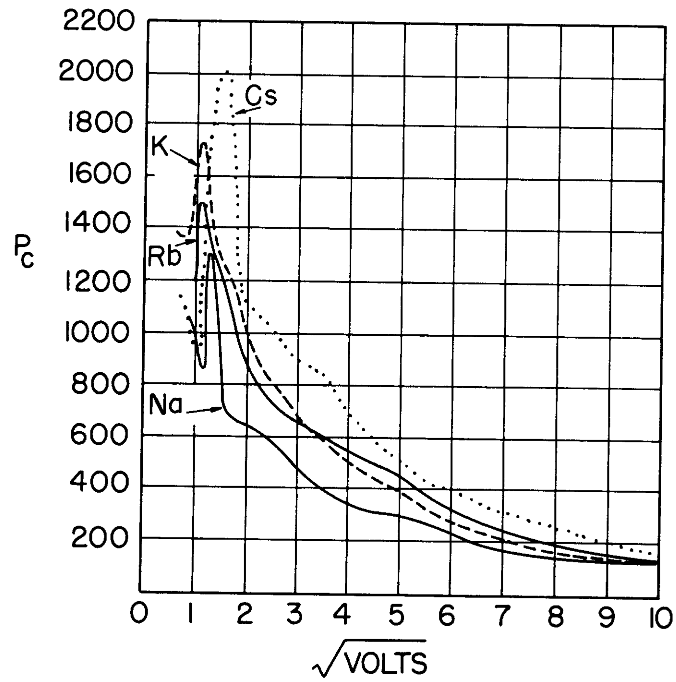
II a2. "Probability" of collision in atomic hydrogen.

A. A. Kruithof, L. S. Ornstein, Physica 2, 611 (1935)

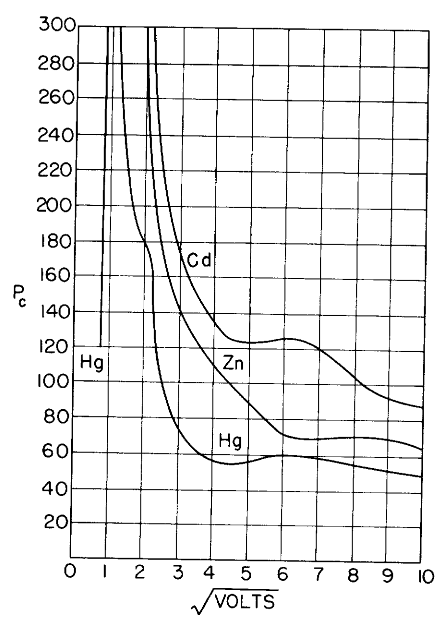


II a2. Collision cross section for electrons in deuterium and hydrogen.

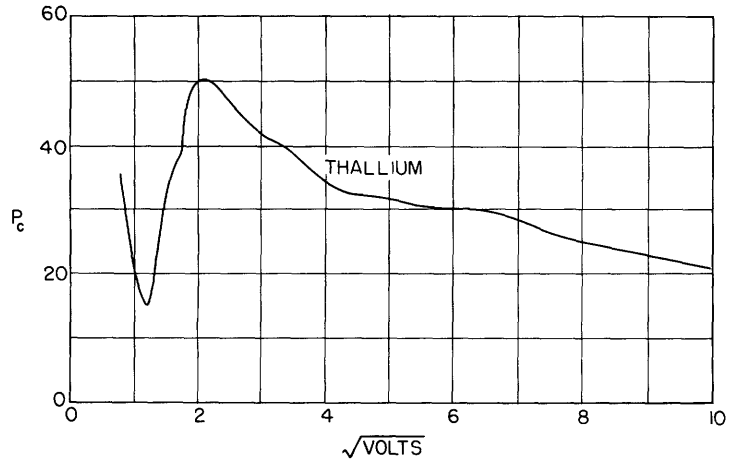
*All references under figures indicate the sources of the experimental data.



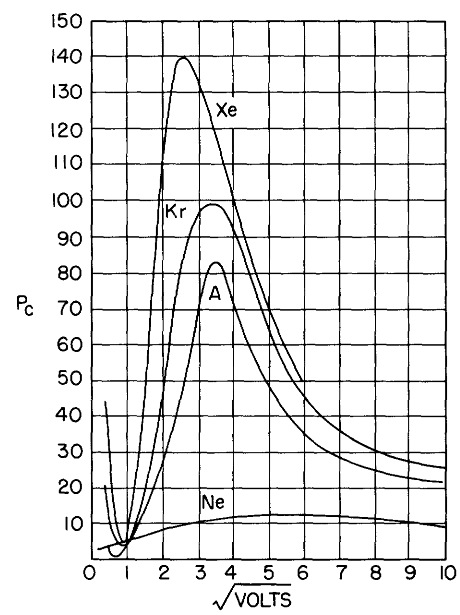
II a3. "Probability" of collision in the alkali metals.
R. B. Brode, Revs. Modern Phys. 5, 257 (1933)



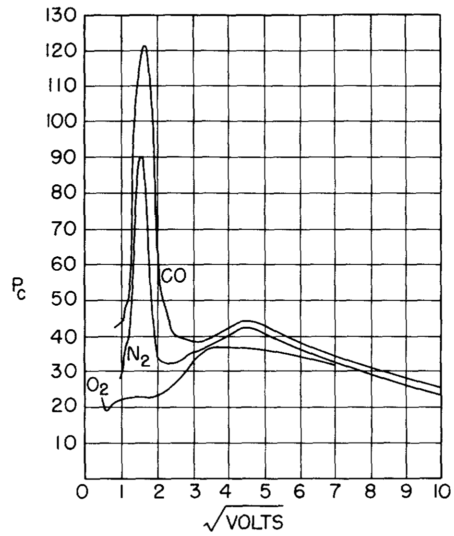
II a4. "Probability" of collision in Hg, Zn, Cd.
R. B. Brode, Revs. Modern Phys. 5, 257 (1933)
H. Margenau, F. P. Adler, Phys. Rev. 79, 970 (1950)



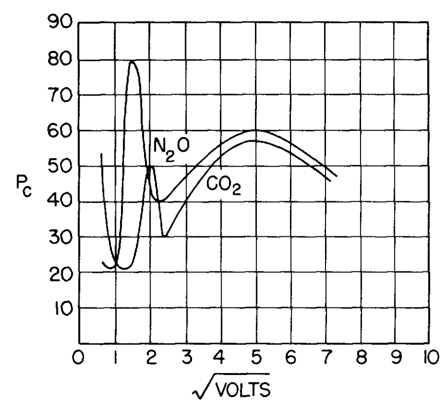
II a5. "Probability" of collision in thallium.
R. B. Brode, Phys. Rev. 37, 570 (1931)



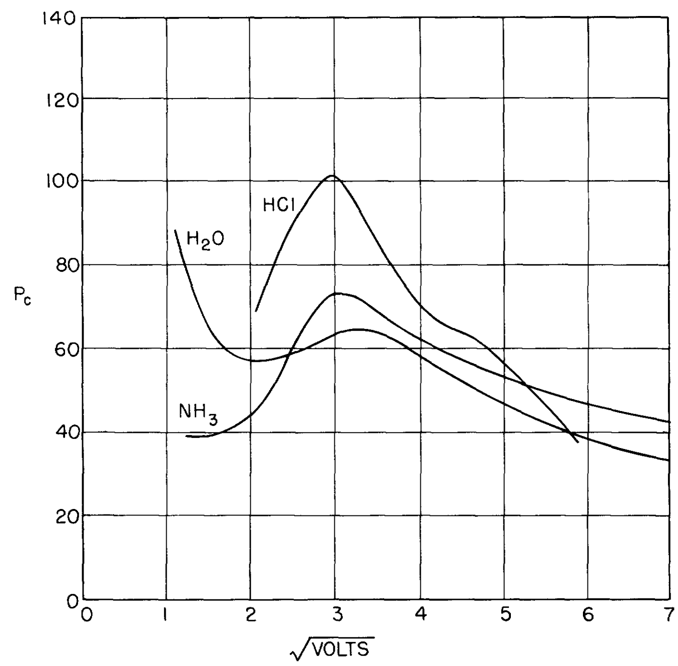
II a6. "Probability" of collision in Ne, A, Kr, Xe.
R. B. Brode, Revs. Modern Phys. 5, 257 (1933)



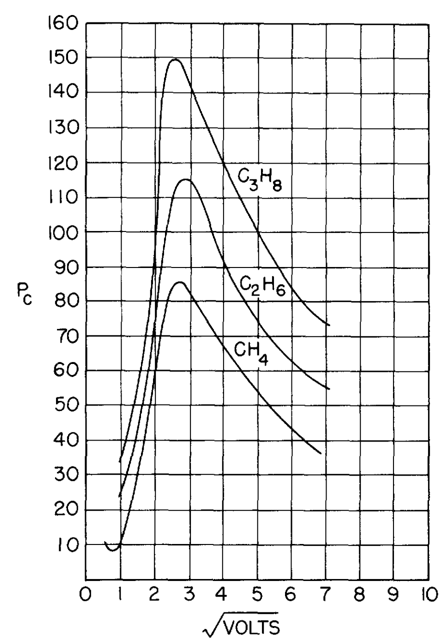
II a7. "Probability" of collision in O_2, N_2, CO.
R. B. Brode, Revs. Modern Phys. 5, 257 (1933)



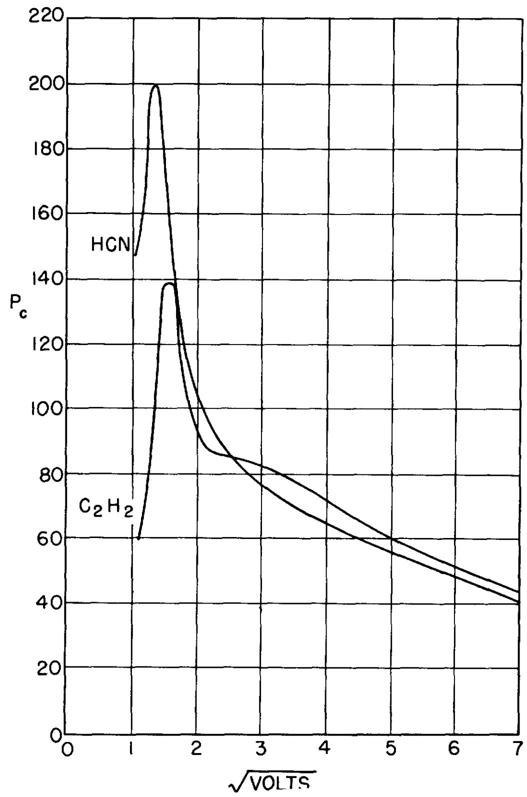
II a8. "Probability" of collision in CO_2, N_2O.
R. B. Brode, Revs. Modern Phys. 5, 257 (1933)



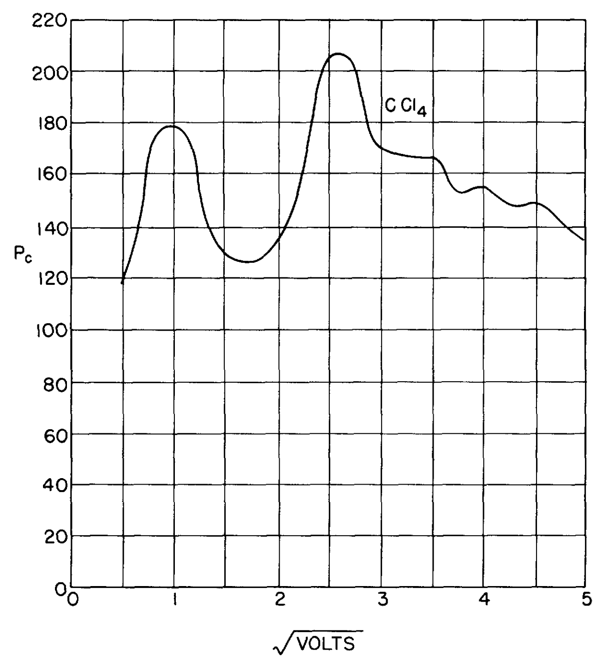
II a9. "Probability" of collision in NH_3, H_2O, HCl.
E. Brüche, Ann. Physik 1, 93 (1929); 83, 1065 (1927)



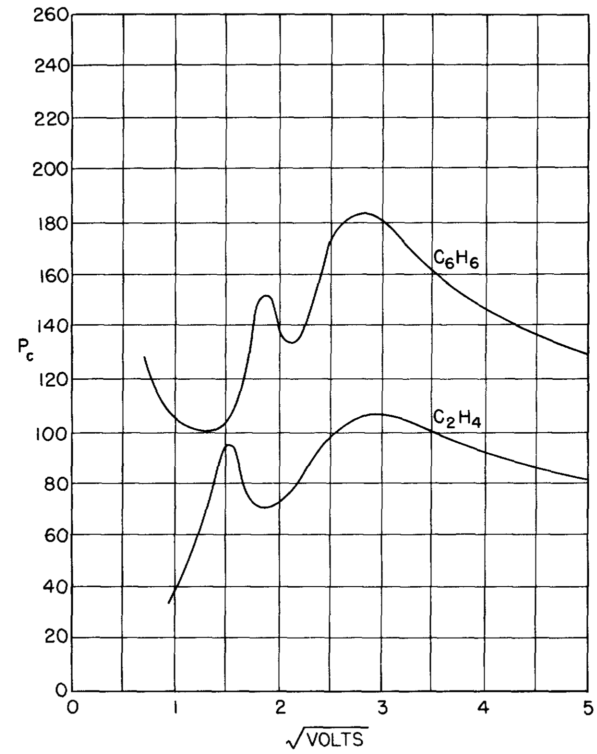
II a10. "Probability" of collision in CH_4, C_2H_6, C_3H_8.
R. B. Brode, Revs. Modern Phys. 5, 257 (1933)



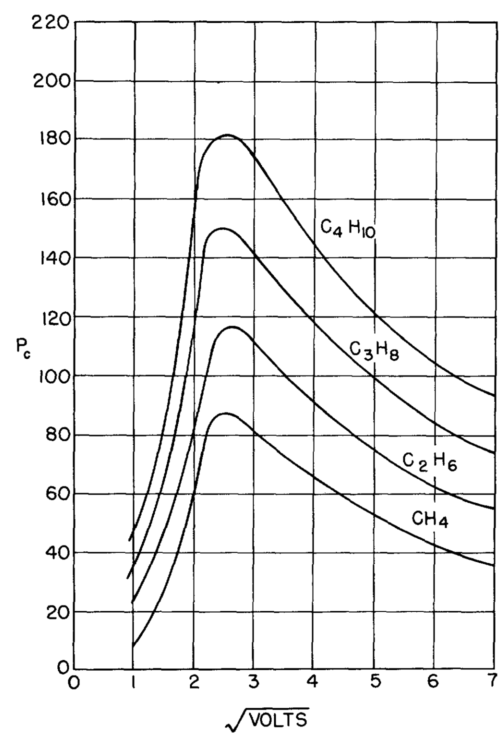
II a11. "Probability" of collision in HCN, C_2H_2.
F. Schmieder, Z. Elektrochem. 36, 700 (1930)



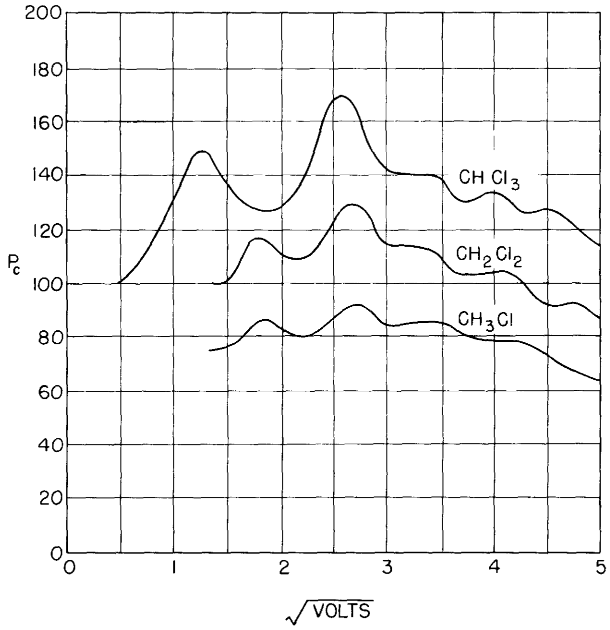
II a12. "Probability" of collision in CCl_4.
W. Holst, J. Holtsmark, Kgl. Norske Videnskab. Selskab. 4, 89 (1931)



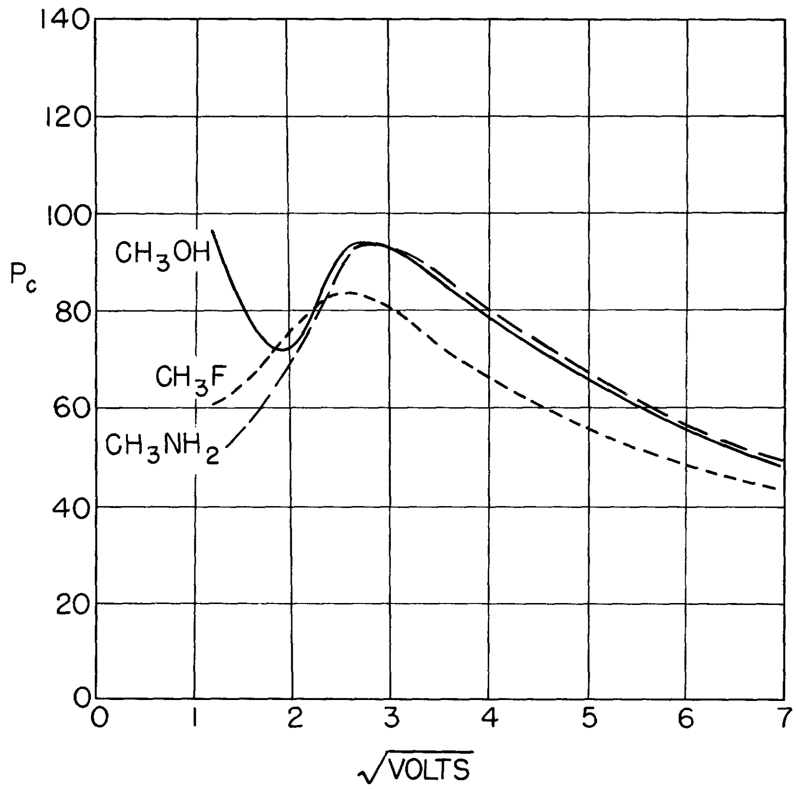
II a13. "Probability" of collisions in C_6H_6, C_2H_4.
W. Holst, J. Holtsmark, Kgl. Norske Videnskab. Selskab. 4, 89 (1931)



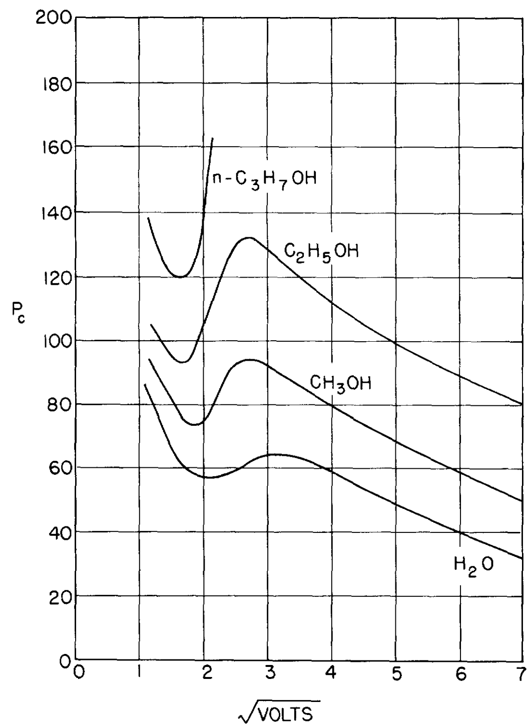
II a14. "Probability" of collision in CH_4, C_2H_6, C_3H_8, C_4H_{10}.
E. Brüche, Ann. Physik 4, 387 (1930)



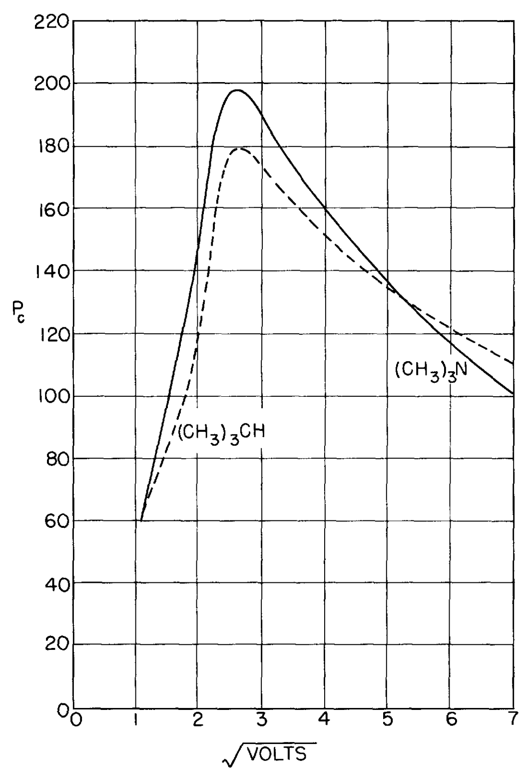
II a15. "Probability" of collision in $CHCl_3$, CH_2Cl_2, CH_3Cl.
W. Holst, J. Holtsmark, Kgl. Norske Videnskab. Selskab. 4, 89 (1931)



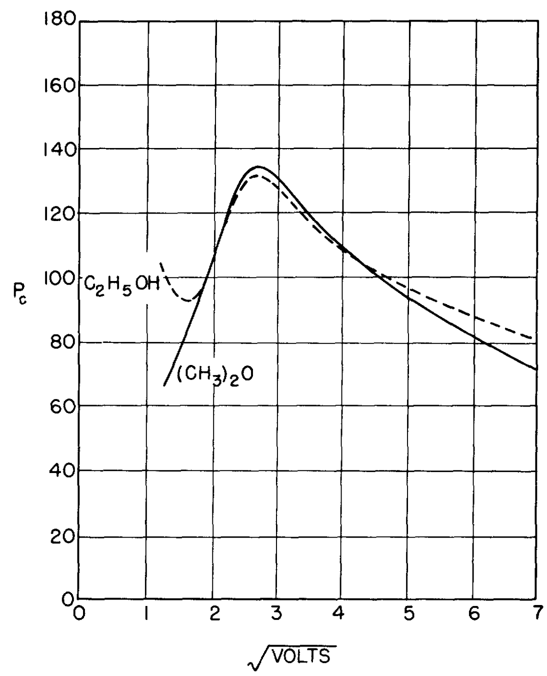
II a16. "Probability" of collision in CH_3OH, CH_3F, CH_3NH_2.
F. Schmieder, Z. Elektrochem. 36, 700 (1930)



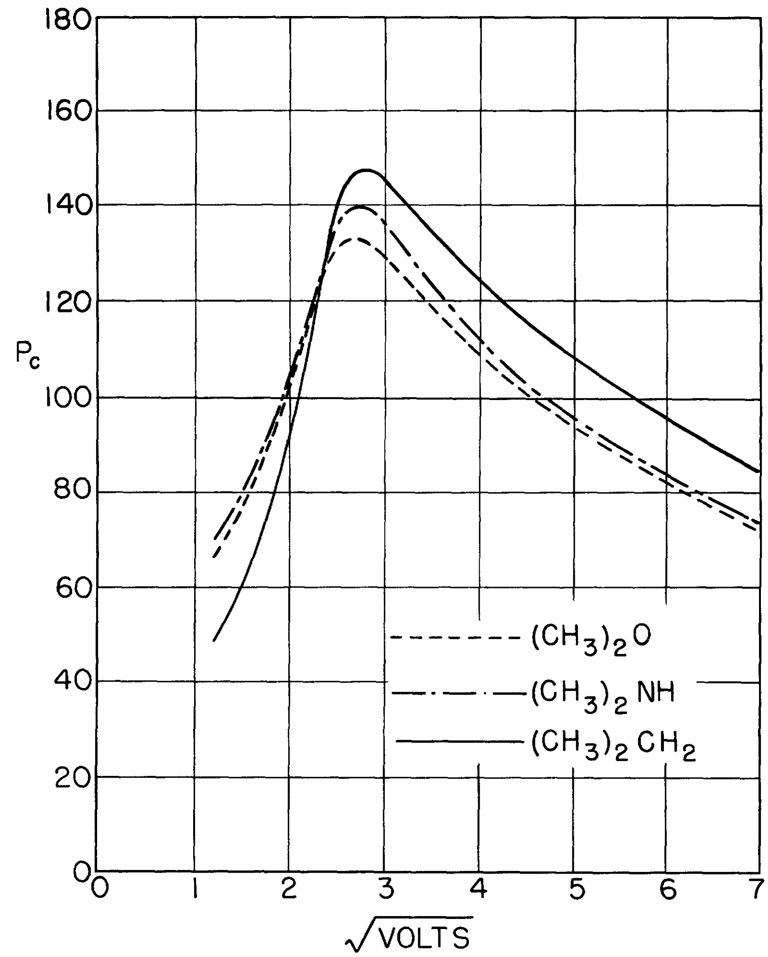
II a17. "Probability" of collision in n - C_3H_7OH, C_2H_5OH, CH_3OH, H_2O. F. Schmieder, Z. Elektrochem. 36, 700 (1930)



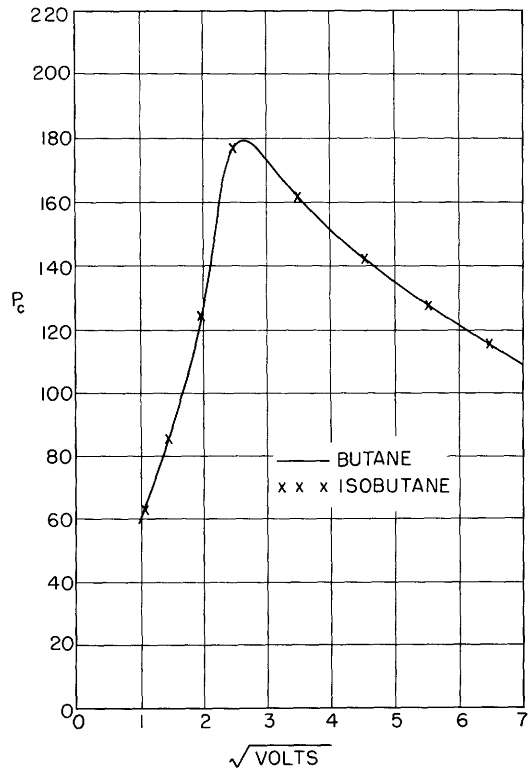
II a18. "Probability" of collision in $(CH_3)_3CH$, $(CH_3)_3N$. F. Schmieder, Z. Elektrochem. 36, 700 (1930)



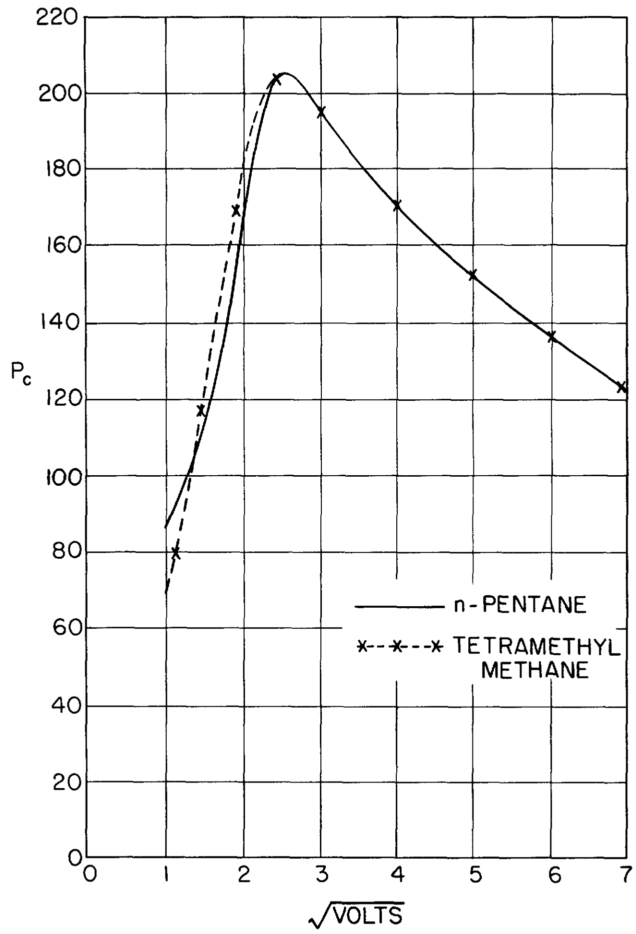
II a19. "Probability" of collision in C_2H_5OH, $(CH_3)_2O$.
F. Schmieder, Z. Elektrochem. 36, 700 (1930)



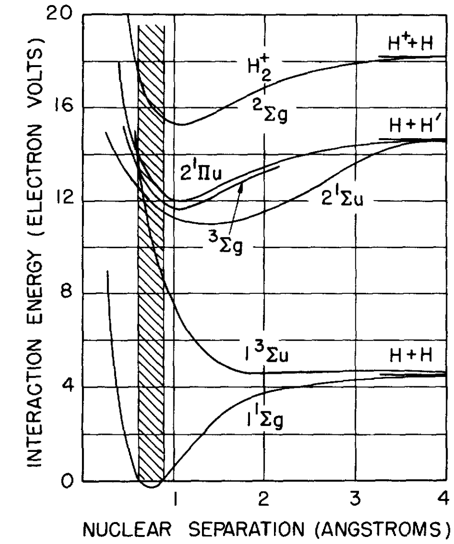
II a20. "Probability" of collision in $(CH_3)_2O$, $(CH_3)_2NH$, $(CH_3)_2CH_2$.
F. Schmieder, Z. Elektrochem. 36, 700 (1930)



II a21. "Probability" of collision in butane, isobutane.
F. Schmieder, Z. Elektrochem. 36, 700 (1930)

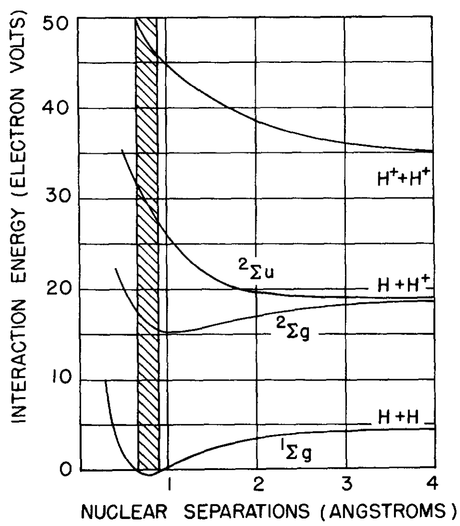


II a22. "Probability" of collision in n-pentane, tetramethyl methane. F. Schmieder, Z. Elektrochem. 36, 700 (1930)



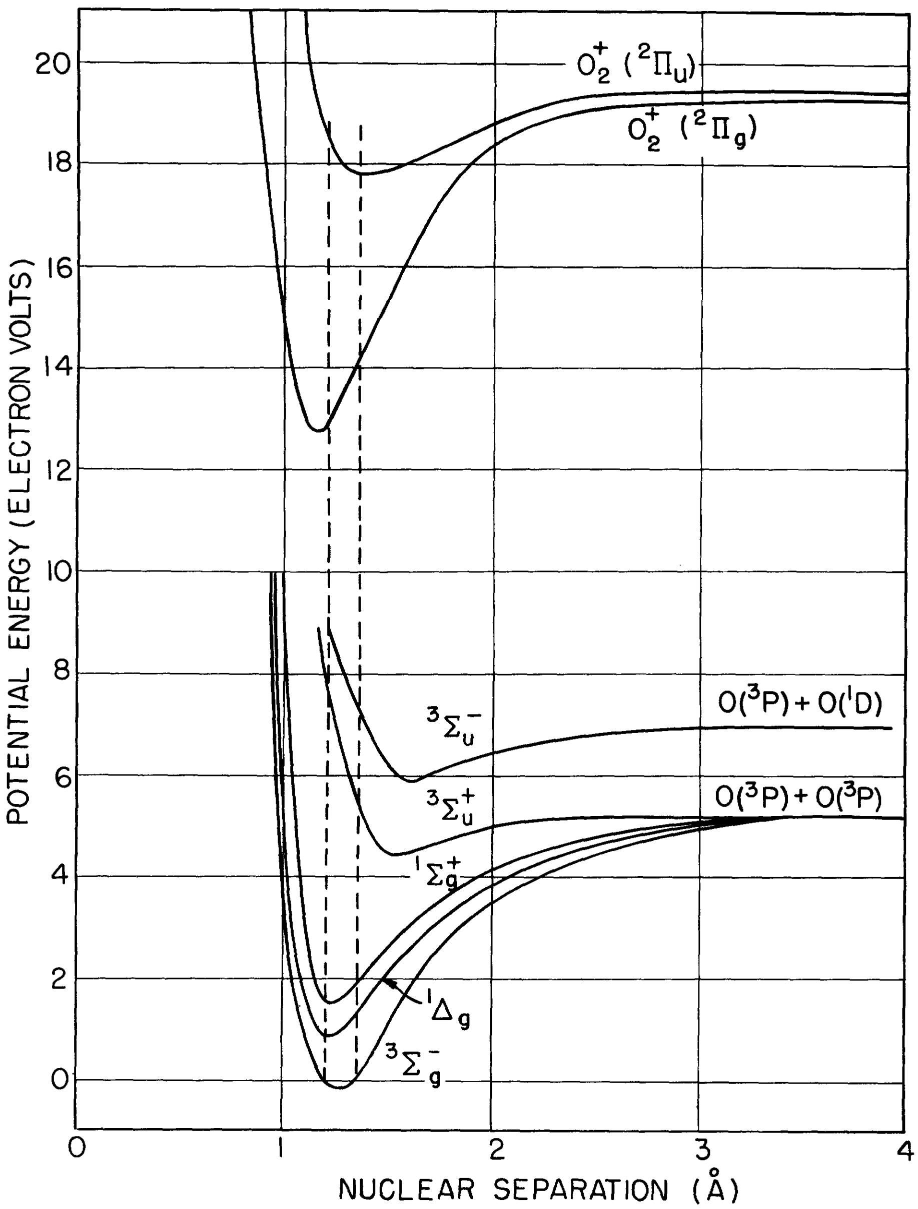
II b1. Potential energy curves for electronic states of H_2 and H_2^+ lying within 20 ev of the ground state.

H. S. W. Massey, E. H. S. Burhop, Electronic and Ionic Impact Phenomena (Clarendon Press, Oxford, 1952), p. 230



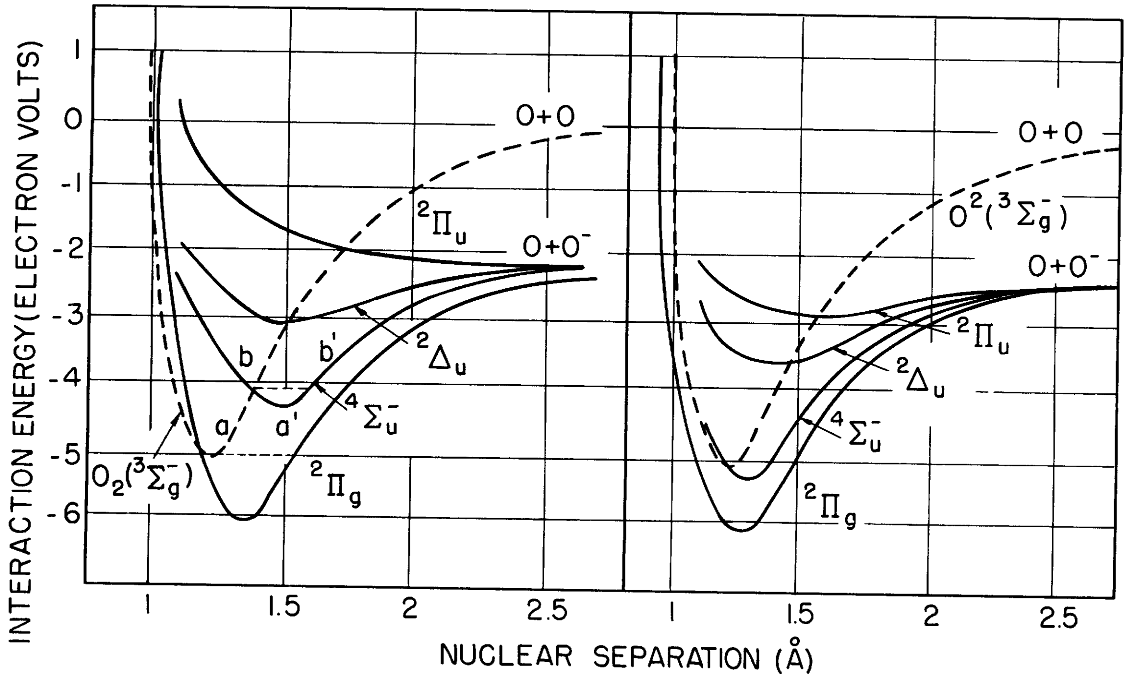
II b1. Potential energy curves for higher energy states of H_2^+.

H. S. W. Massey, E. H. S. Burhop, Electronic and Ionic Impact Phenomena (Clarendon Press, Oxford, 1952), p. 231

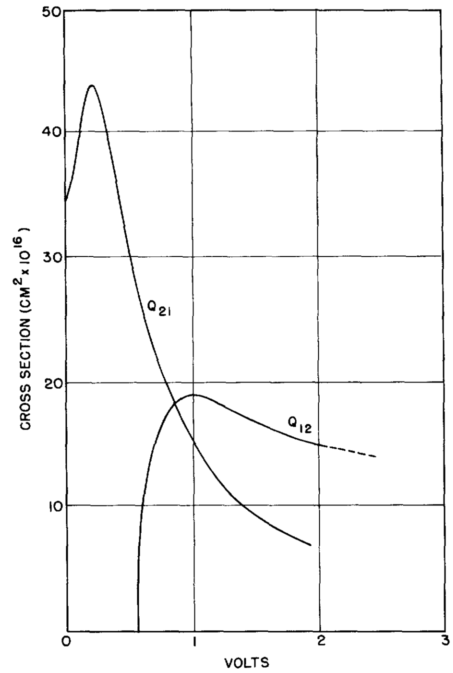


II b2. Potential energy curves for the O_2 molecule.

H. S. W. Massey, E. H. S. Burhop, Electronic and Ionic Impact Phenomena (Clarendon Press, Oxford, 1952), p. 257

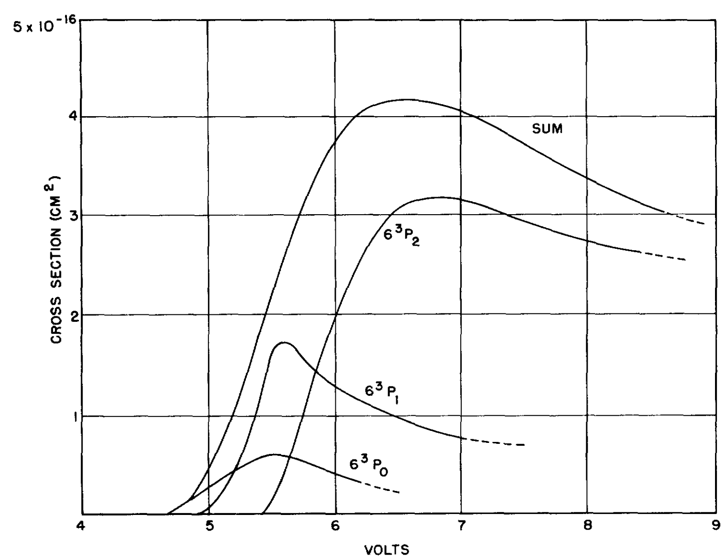


II b2. Two possible sets of potential energy curves for O_2^-.
H. S. W. Massey, E. H. S. Burhop, Electronic and Ionic Impact Phenomena (Clarendon Press, Oxford, 1952), p. 263



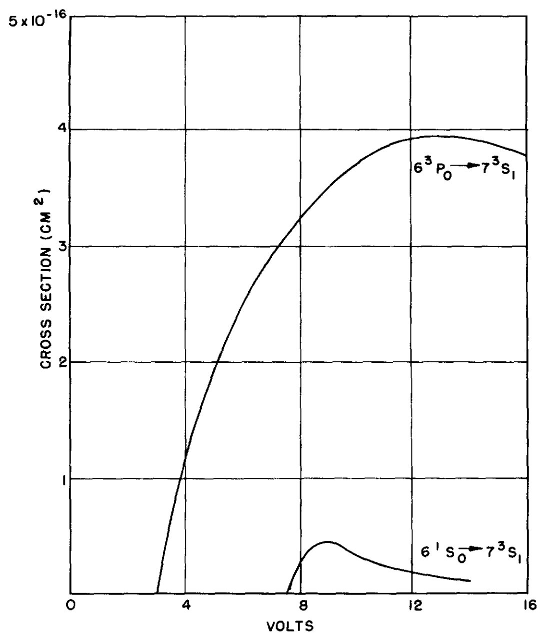
II c1. Q_{12} — cross section for electron collision exciting $6\,^3P_2$ from $6\,^3P_1$ in mercury; Q_{21} — cross section for collision of second kind with electrons returning $6\,^3P_2$ to $6\,^3P_1$ in mercury.

C. Kenty, J. Appl. Phys. 21, 1309 (1950)

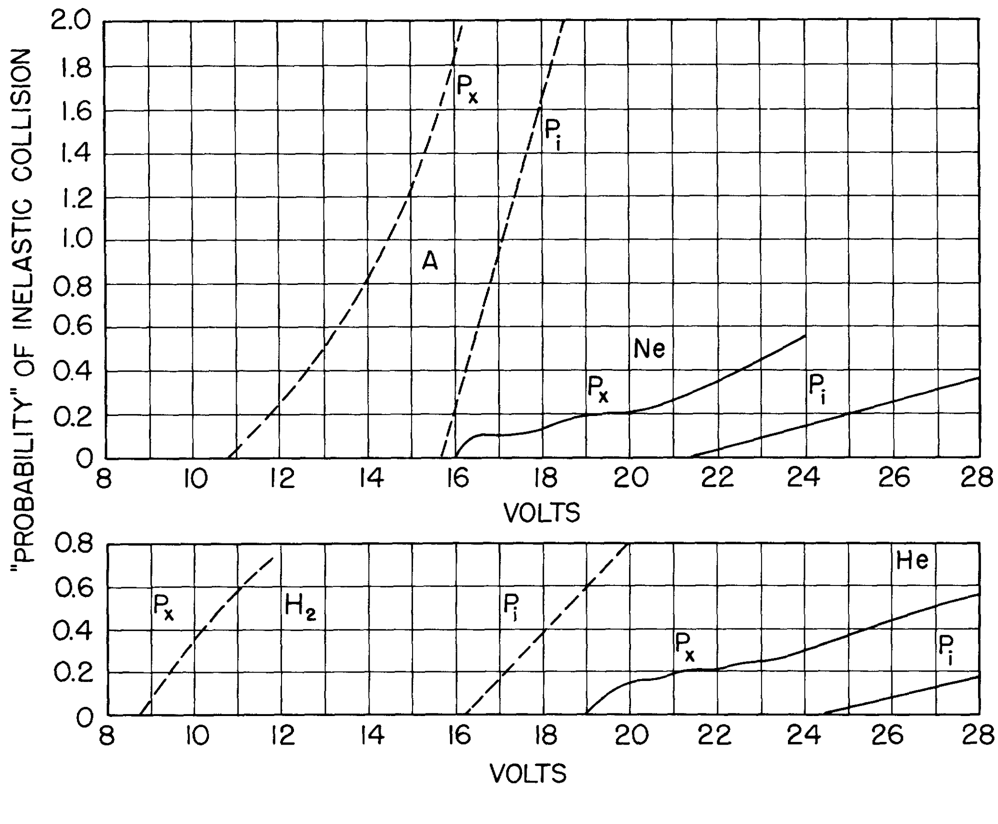


II c1. Calculated cross sections for excitations of $7\,^3S_1$ from $6\,^1S_o$ level in mercury.

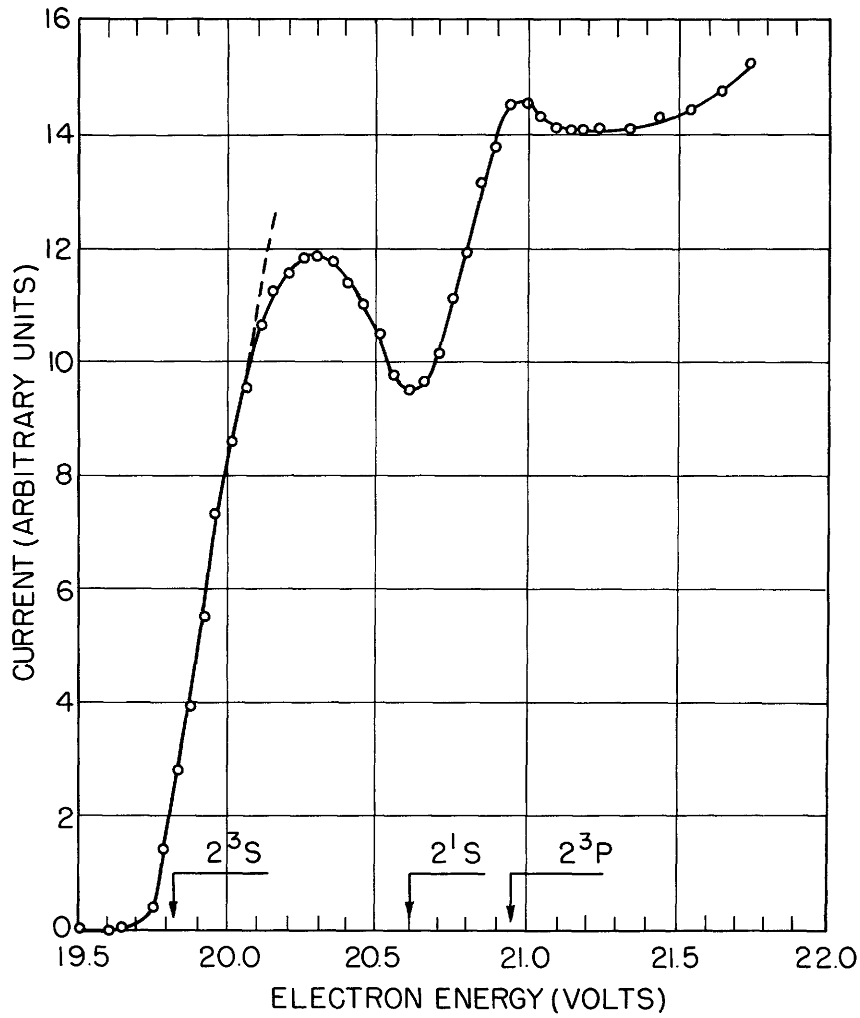
C. Kenty, J. Appl. Phys. 21, 1309 (1950)



II c1. Excitation function for 6^3P states of mercury.
C. Kenty, J. Appl. Phys. 21, 1309 (1950)

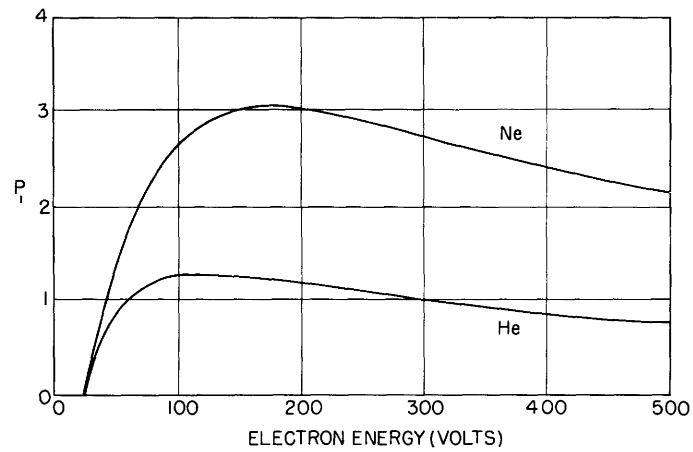


II c2. "Probability" of excitation and ionization in He, H_2, Ne, A.
M. J. Druyvesteyn, F. M Penning, Revs. Modern Phys. 12, 87 (1940)

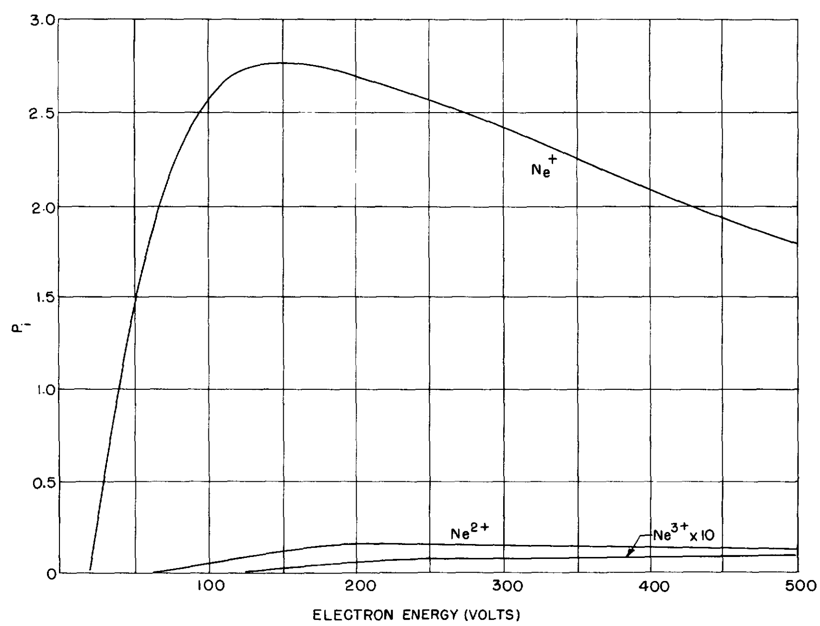


II c2. Excitation of metastable levels in He.

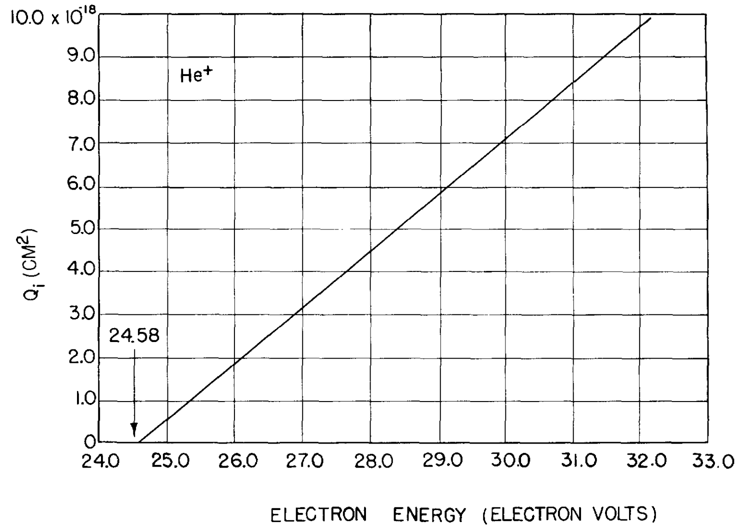
G. J. Schulz, R. E. Fox, Phys. Rev. 106, 1179 (1957)



II c2. "Probability" of ionization in He, Ne.
P. T. Smith, Phys. Rev. 36, 1293 (1930)

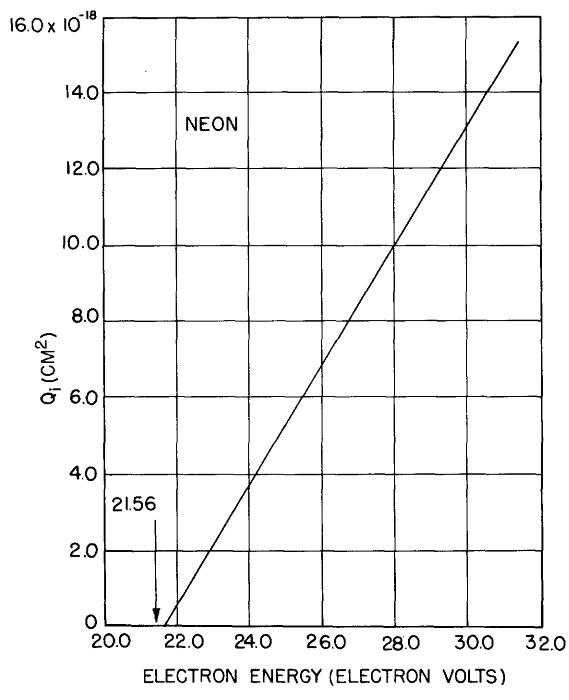


II c2. "Probability" of ionization in neon.
W. Bleakney, Phys. Rev. 36, 1303 (1930)



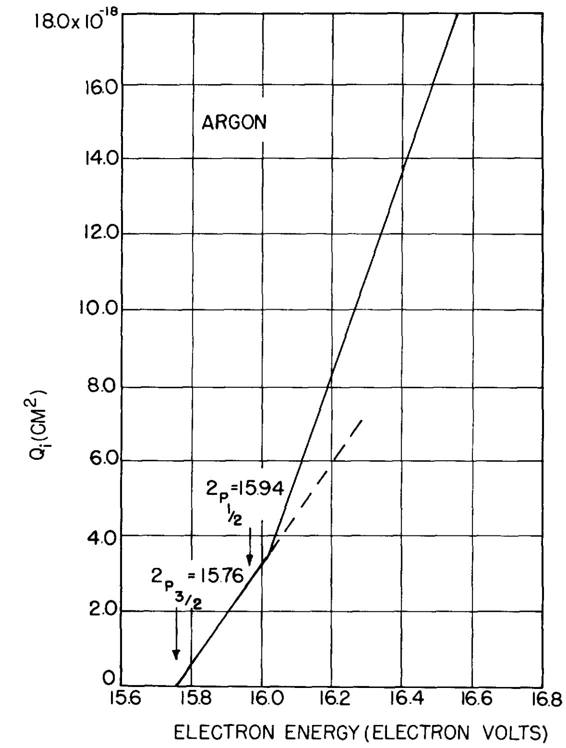
II c3. Ionization cross section in He by electron impact.

R. E. Fox, Research Report 60-94439-4-R2, Westinghouse Electric Corporation, Aug. 15, 1956



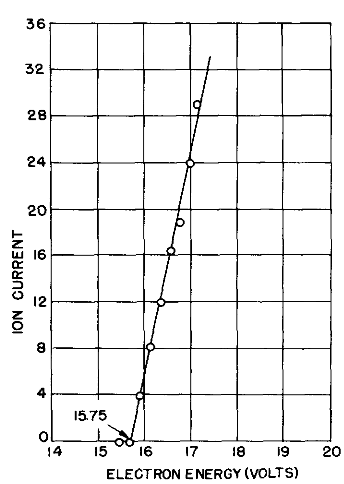
II c4. Ionization cross section for neon.

R. E. Fox, Research Report 60-94439-4-R2, Westinghouse Electric Corporation, Aug. 15, 1956



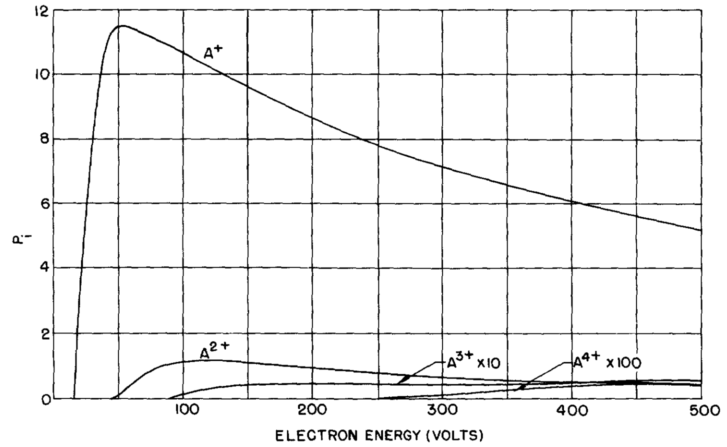
II c5. Ionization cross section for argon.

R. E. Fox, Research Report 60-94439-4-R2, Westinghouse Electric Corporation, Aug. 15, 1956

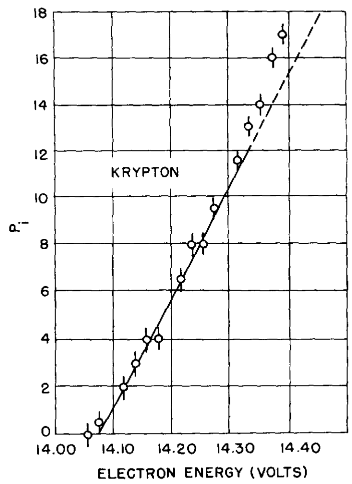


II c5. "Probability" of ionization in argon.

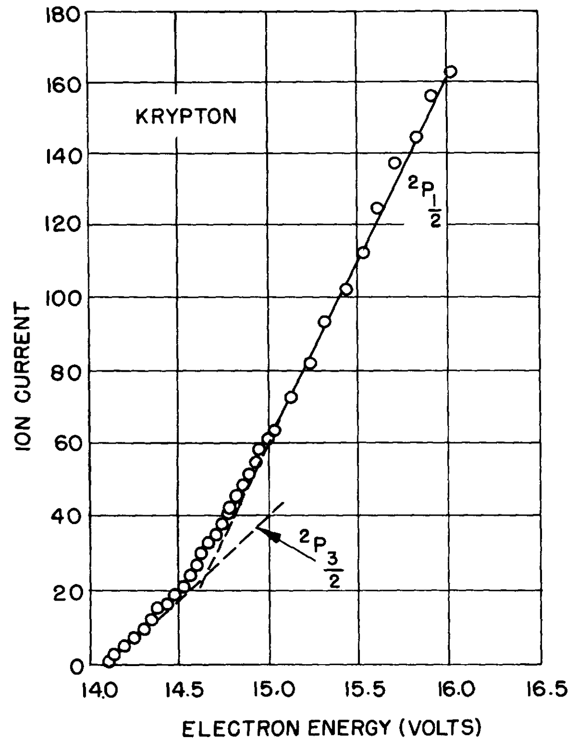
R. E. Fox, W. M. Hickam, T. Kjeldaas, D. J. Grove, Phys. Rev. 84, 859 (1951)



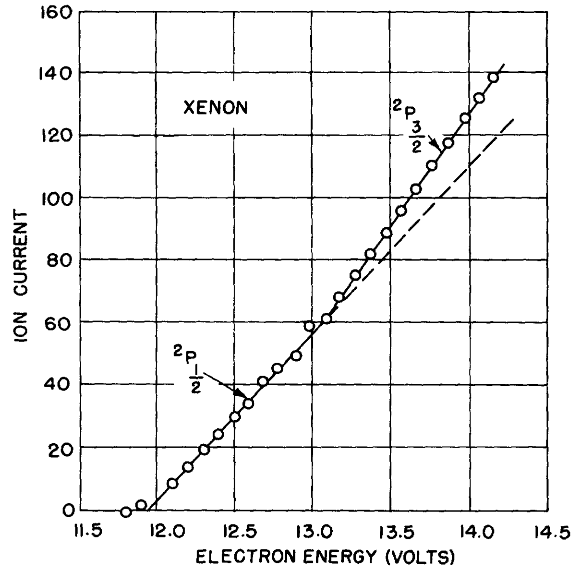
II c5. "Probability" of ionization in argon.
W. Bleakney, Phys. Rev. 36, 1303 (1930)



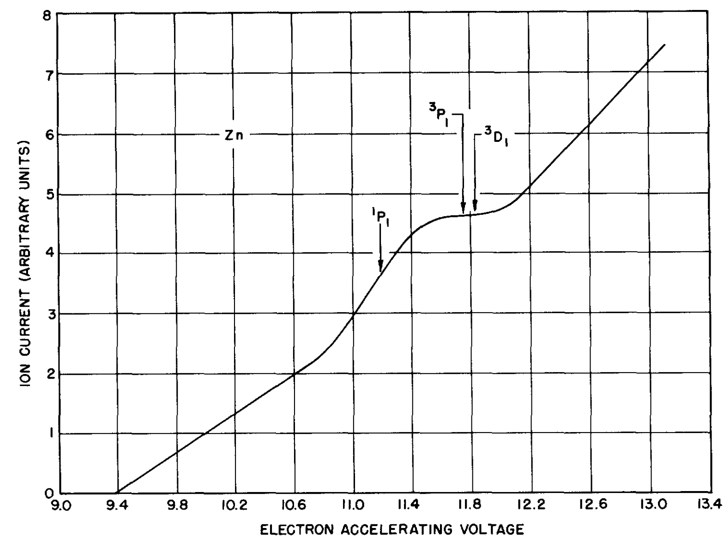
II c6. Relative ionization probability for ionization to the $^2P_{3/2}$ state in krypton.
R. E. Fox, W. M. Hickam, T. Kjeldaas, Phys. Rev. 89, 555 (1953)



II c6. Relative ionization probability for ionization to the $^2P_{1/2}$ state in krypton. R. E. Fox, W. M. Hickam, T. Kjeldaas, Phys. Rev. 89, 555 (1953)

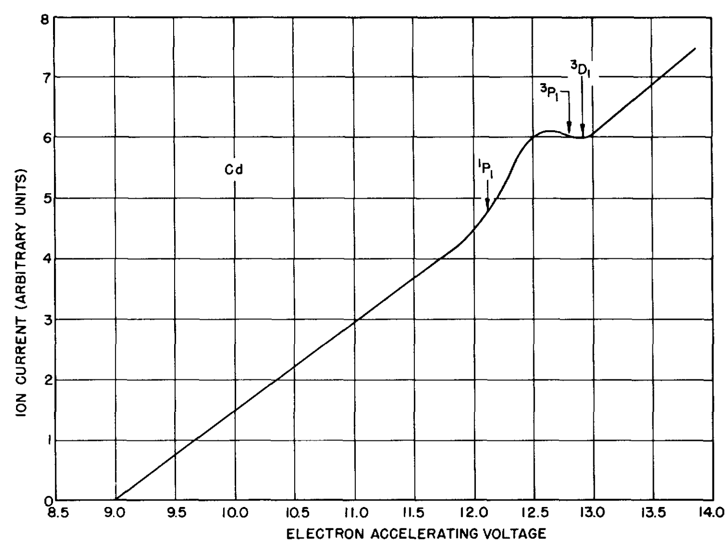


II c7. Relative ionization probability for ionization by electron impact in xenon. R. E. Fox, W. M. Hickam, T. Kjeldaas, Phys. Rev. 89, 555 (1953)



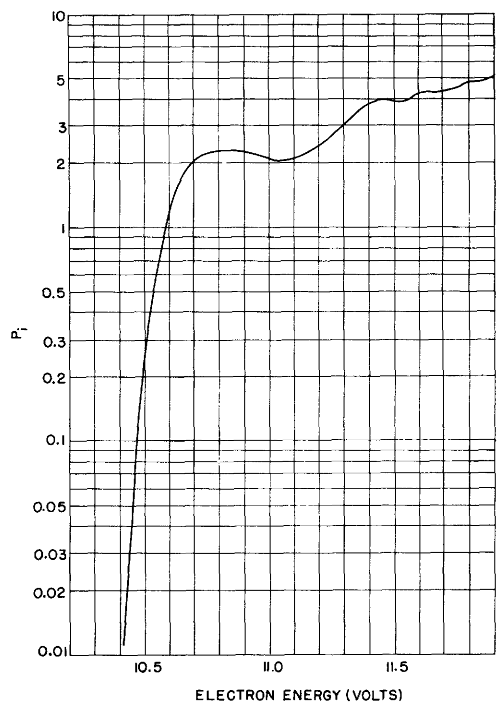
II c8. "Probability" of ionization in zinc.

W. M. Hickam, Scientific Report 1819, Westinghouse Research Laboratory, March 31, 1954

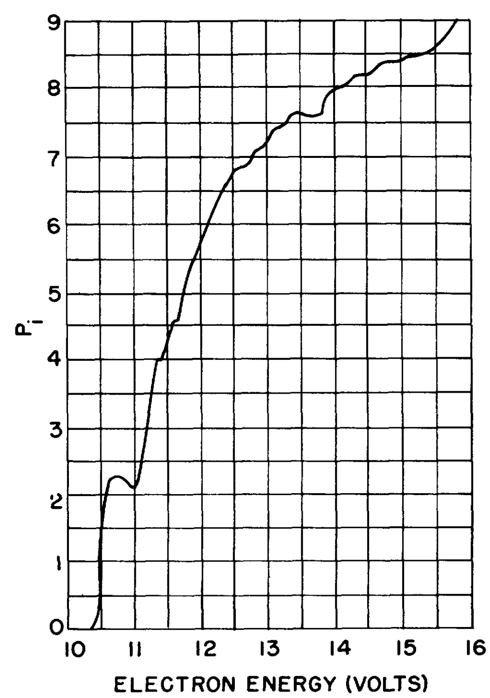


II c9. "Probability" of ionization in cadmium.

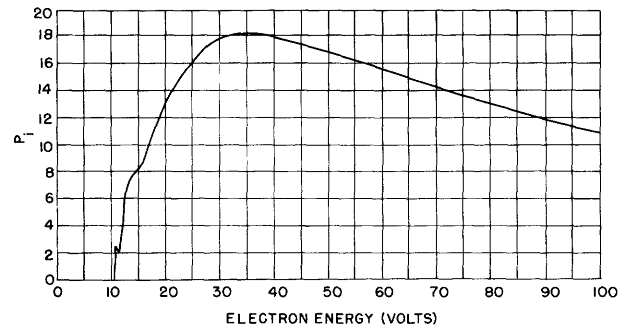
W. M. Hickam, Scientific Report 1819, Westinghouse Research Laboratory, March 31, 1954



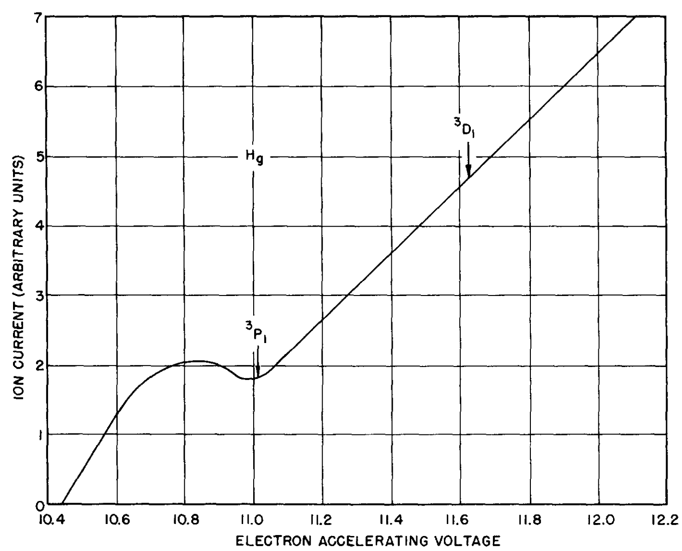
II c10. "Probability" of ionization in mercury.
W. B. Nottingham, Phys. Rev. 55, 203 (1939)



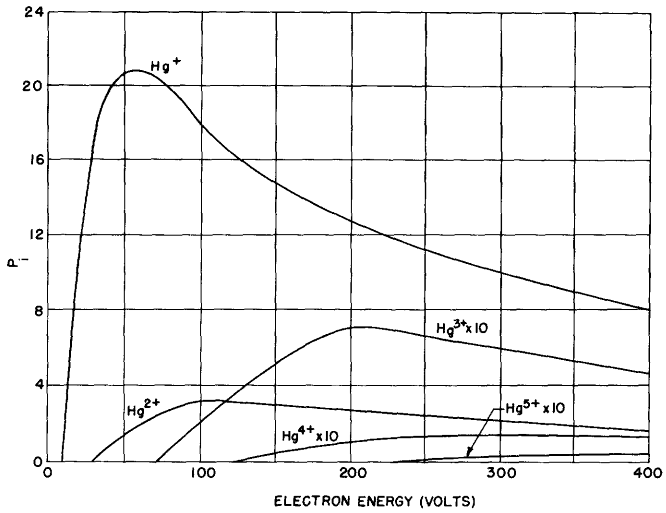
II c10. "Probability" of ionization in mercury.
W. B. Nottingham, Phys. Rev. 55, 203 (1939)



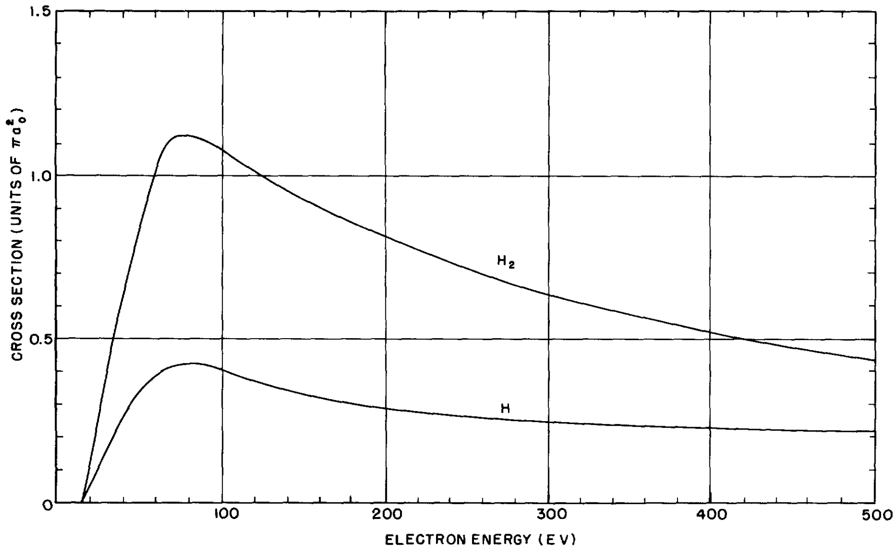
II c10. "Probability" of ionization in mercury.
W. B. Nottingham, Phys. Rev. 55, 203 (1939)



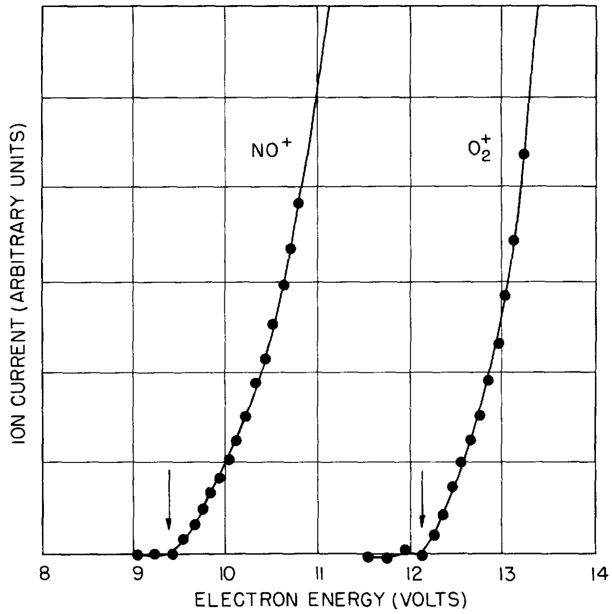
II c10. "Probability" of ionization in mercury.
W. M. Hickam, Scientific Report 1819, Westinghouse Research Laboratory, March 31, 1954



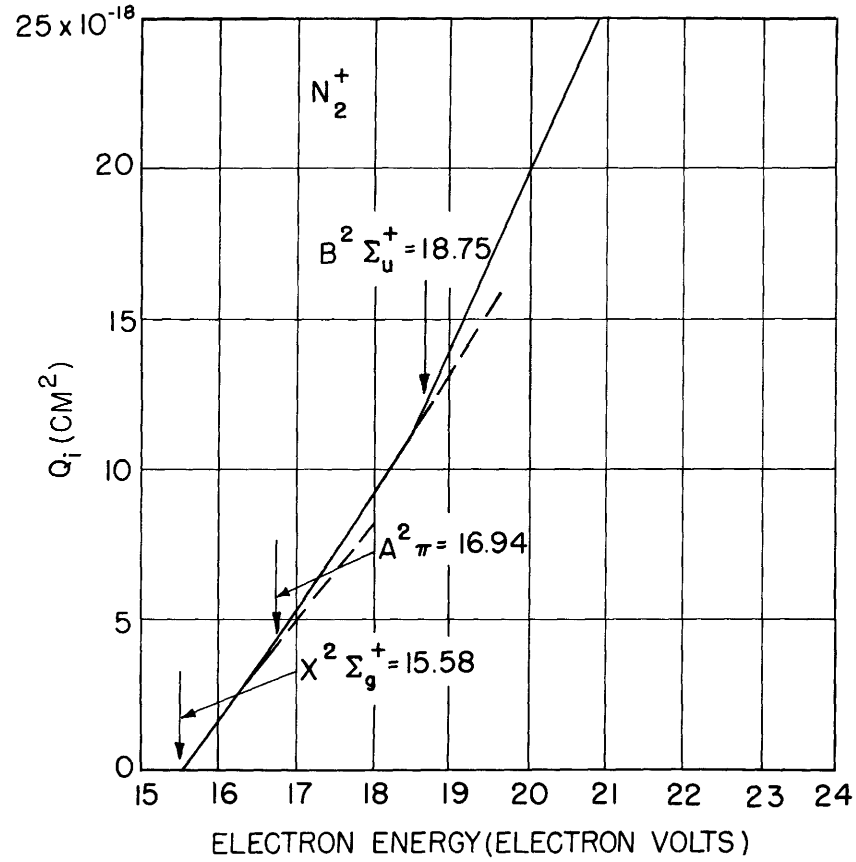
II c10. "Probability" of ionization in mercury.
W. Bleakney, Phys. Rev. 35, 139 (1930)



II c11. Ionization cross sections of hydrogen on electron impact.

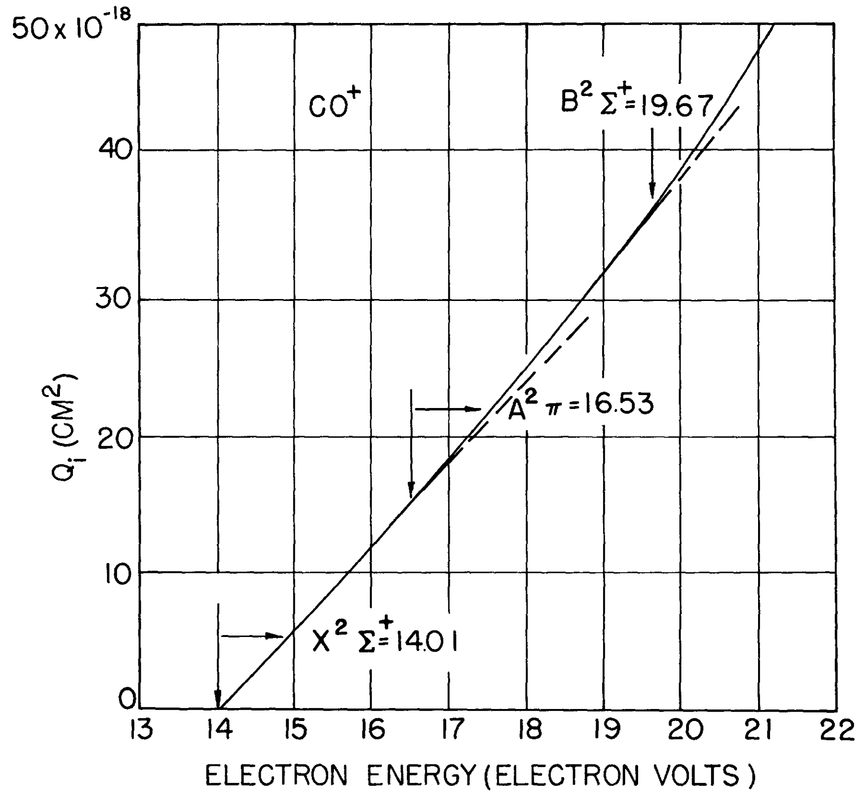


II c12. "Probability" of ionization for electrons in NO, O_2.
H. D. Hagstrum, Revs. Modern Phys. 23, 185 (1951)



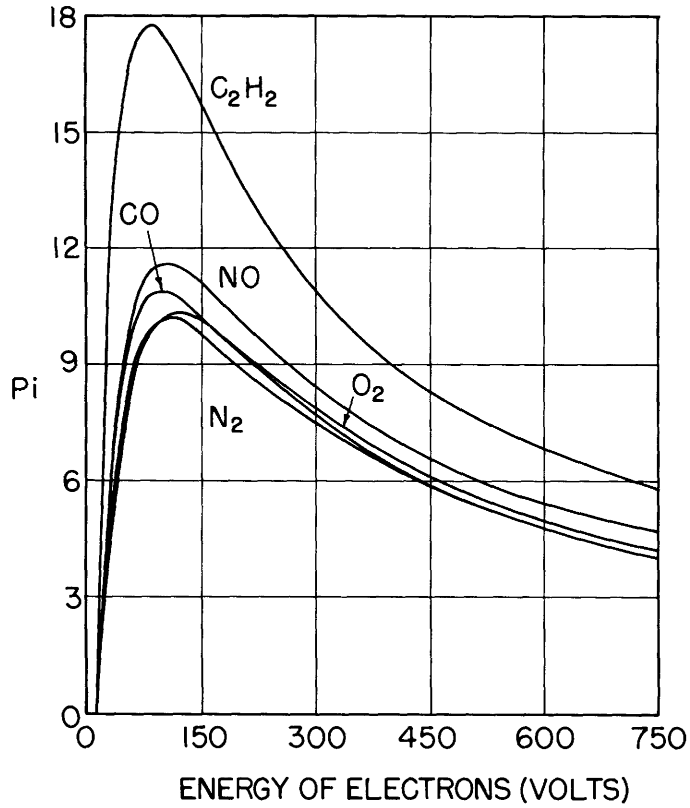
II c12. Ionization cross section for nitrogen.

R. E. Fox, Research Report 60-94439-4-R2, Westinghouse Electric Corporation, Aug. 15, 1956

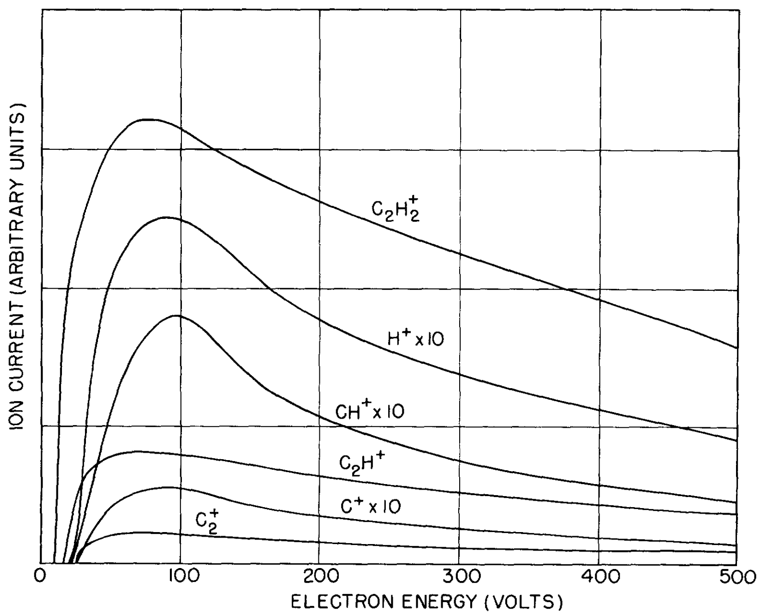


II c12. Ionization cross section for carbon monoxide.

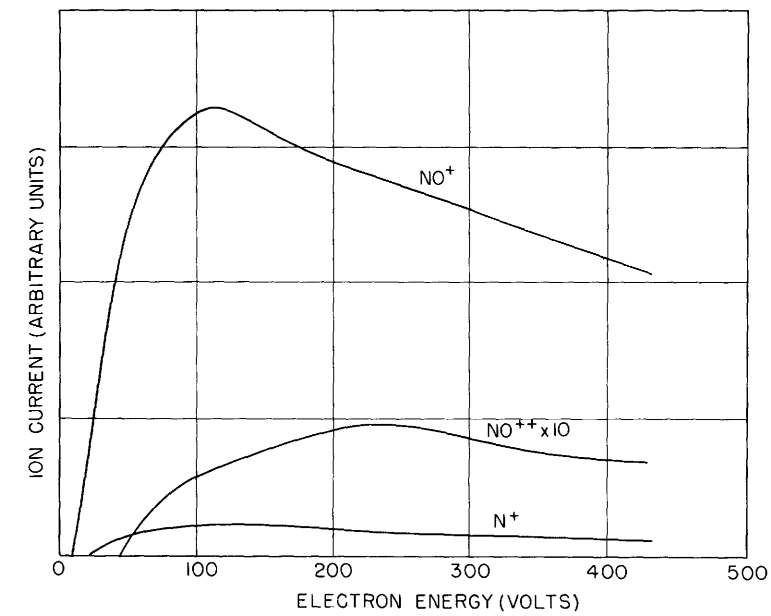
R. E. Fox, Research Report 60-94439-4-R2, Westinghouse Electric Corporation, Aug. 15, 1956



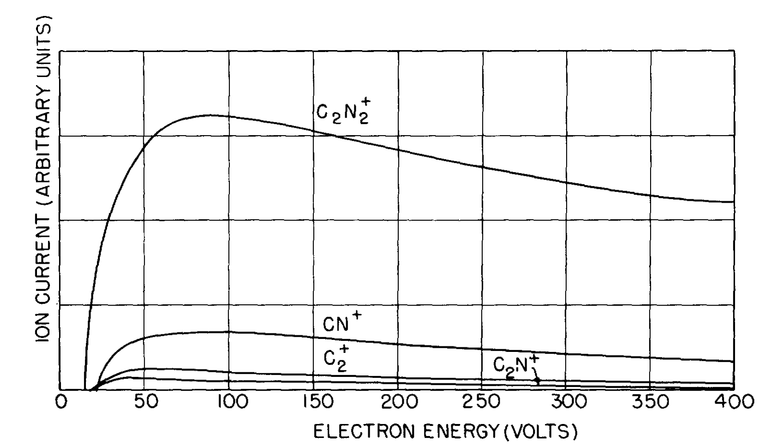
II c13. "Probability" of ionization in N_2, O_2, CO, NO, C_2H_2.
J. T. Tate, P. T. Smith, Phys. Rev. 39, 270 (1932)



II c14. "Probability" of ionization in acetylene.
J. T. Tate, P. T. Smith, A. L. Vaughan, Phys. Rev. 48, 525 (1935)



II c15. "Probability" of ionization in nitric oxide, NO.
J. T. Tate, P. T. Smith, A. L. Vaughan, Phys. Rev. 48, 525 (1935)



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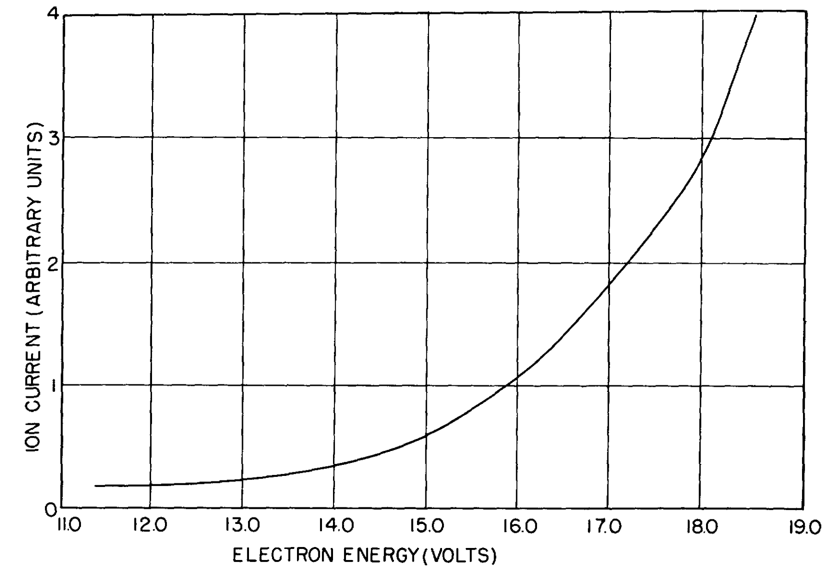

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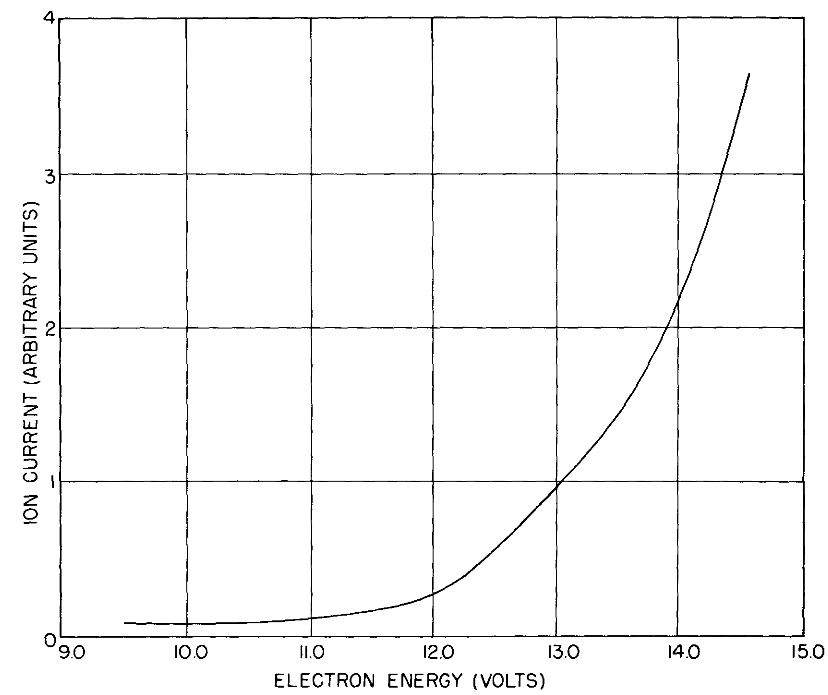

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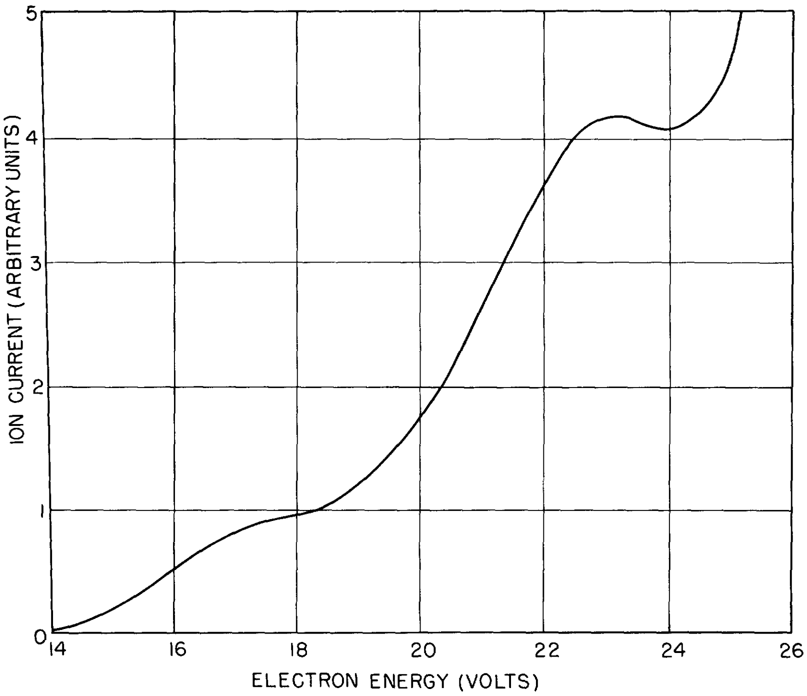

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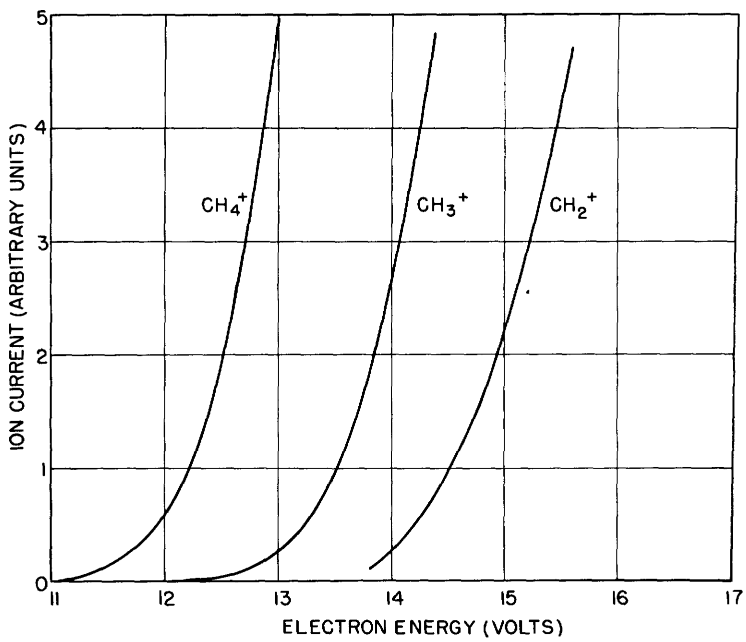

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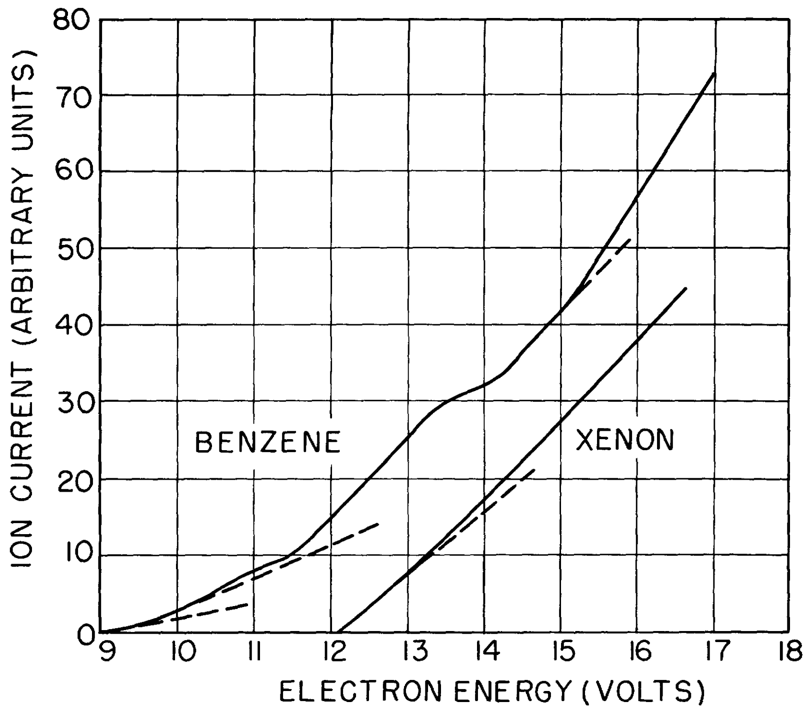

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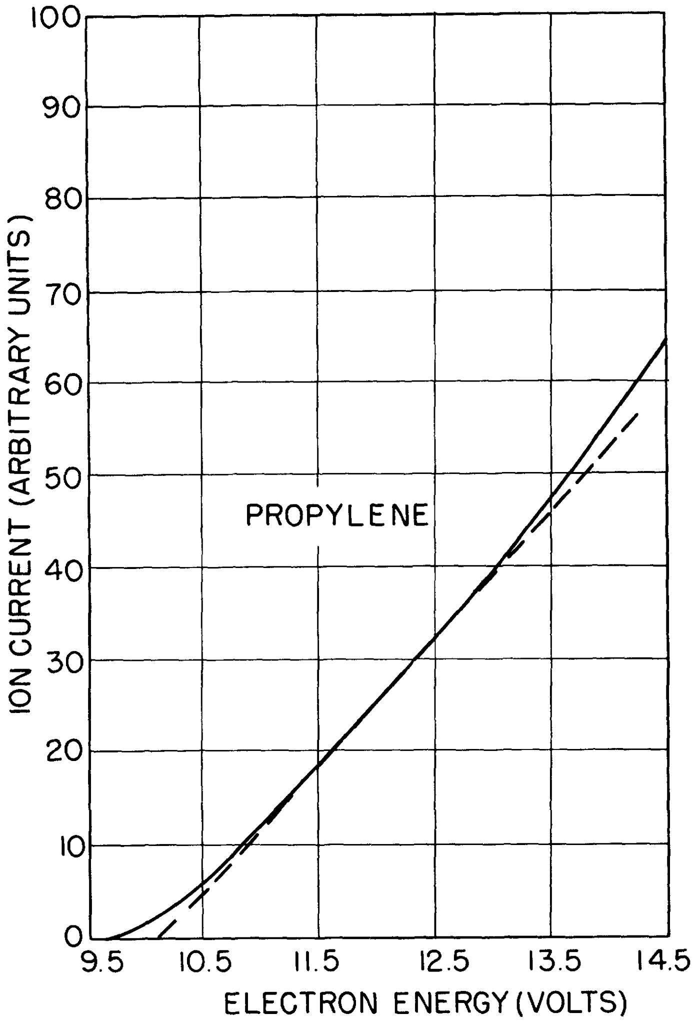

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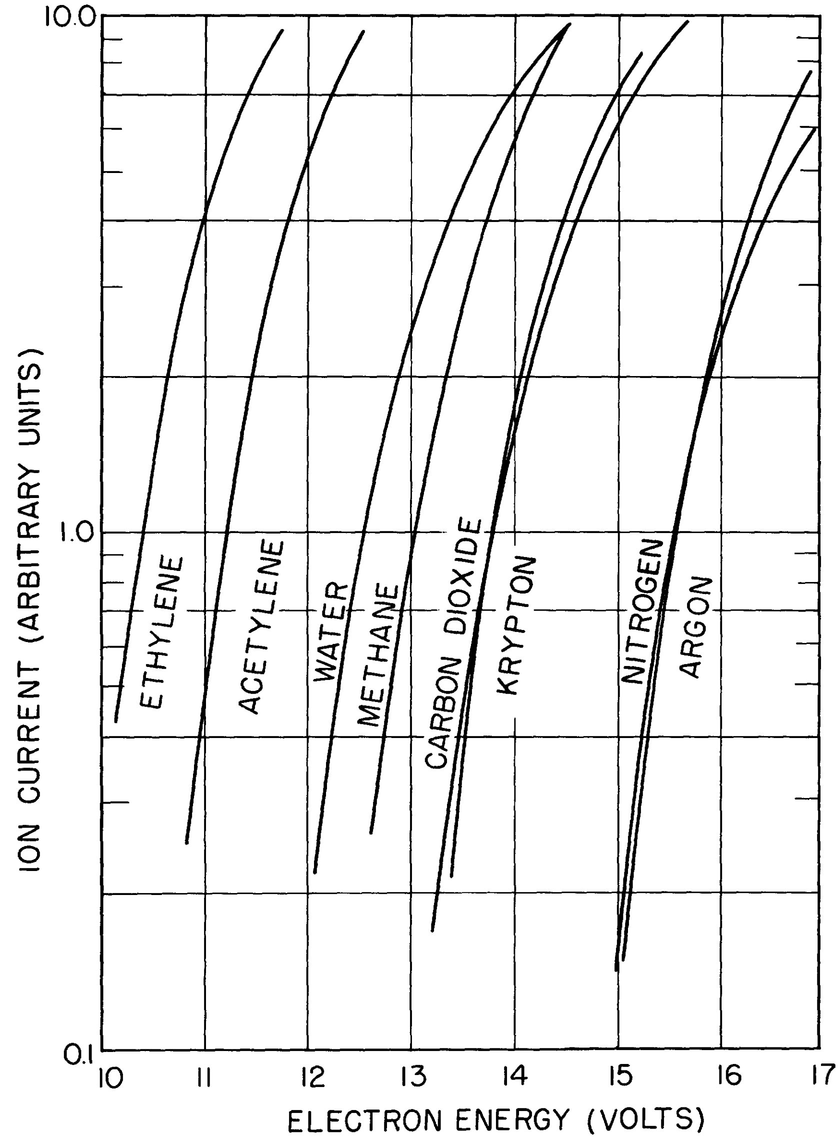

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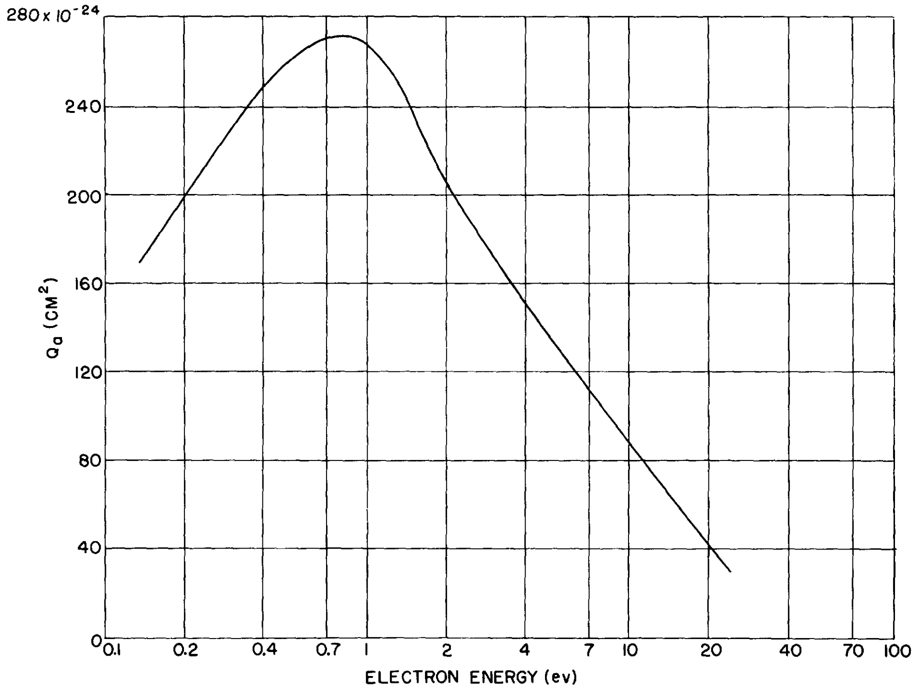

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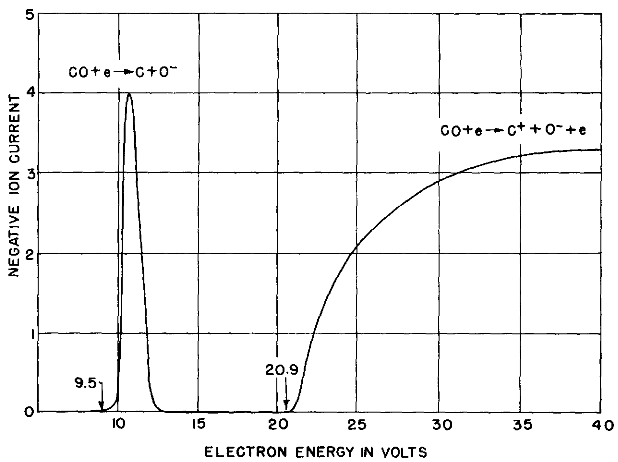
H. S. W. Massey, E. H. S. Burhop, Electronic and Ionic Impact Phenomena (Clarendon Press, Oxford, 1952), p. 335



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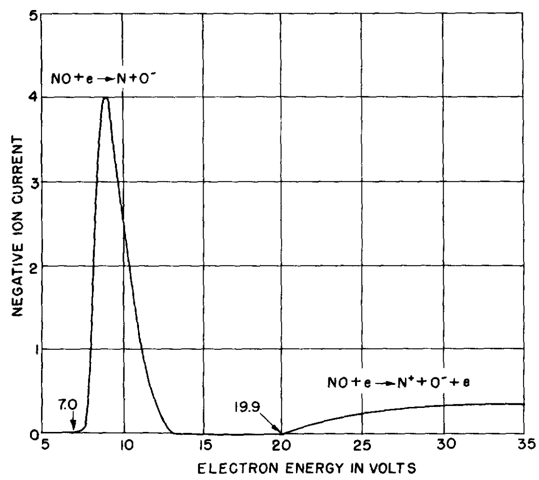

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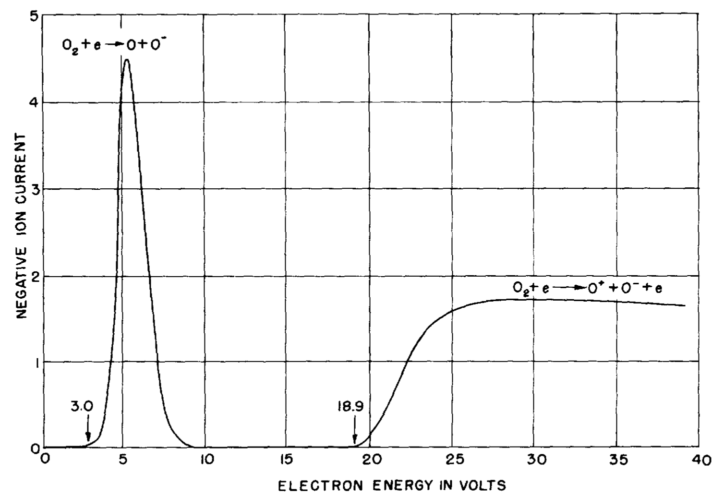

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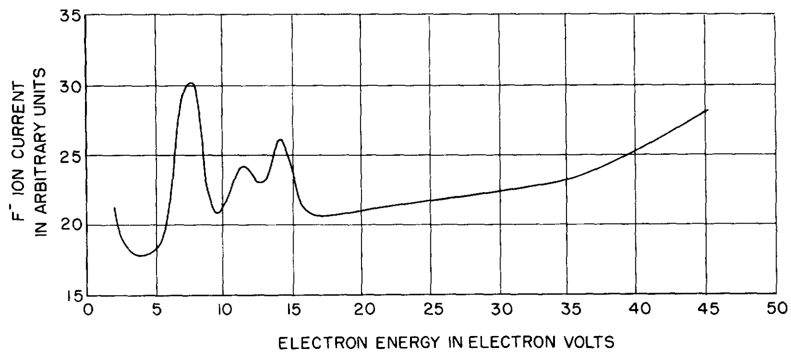

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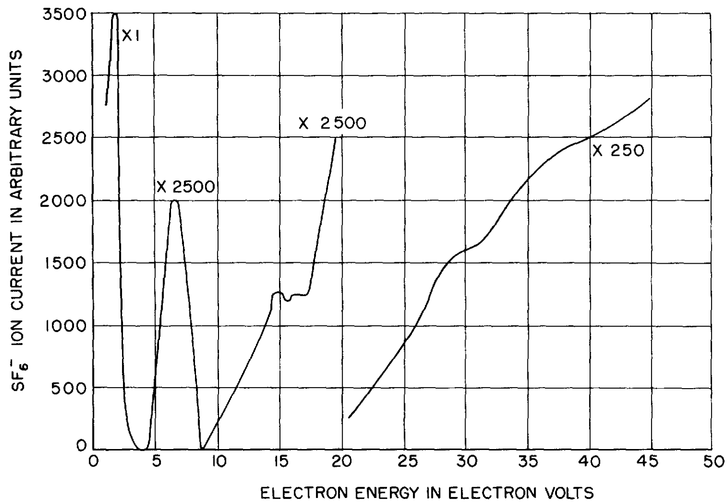

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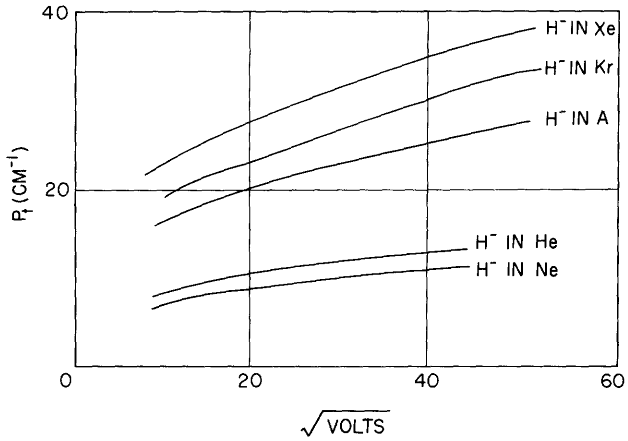

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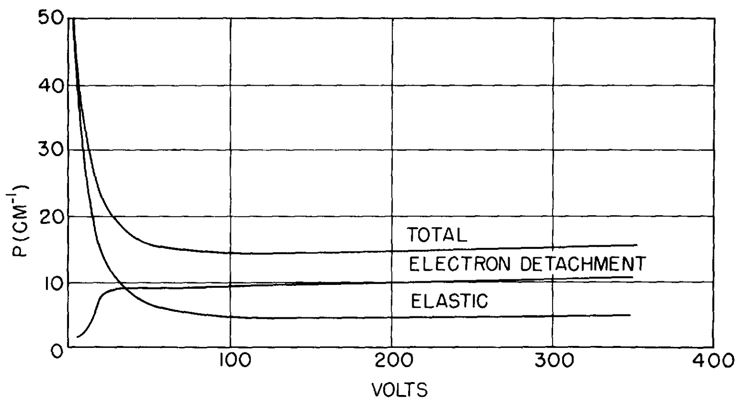
J. B. Hasted, Proc. Roy. Soc. (London) A212, 235 (1952)



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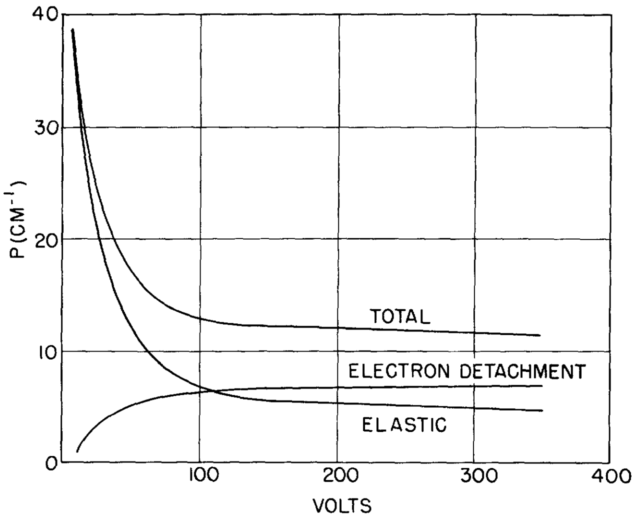

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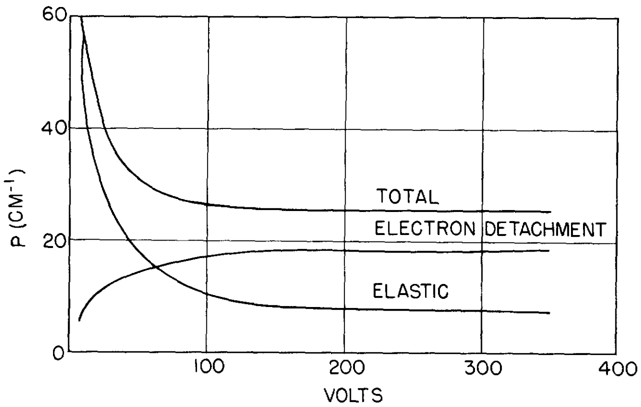

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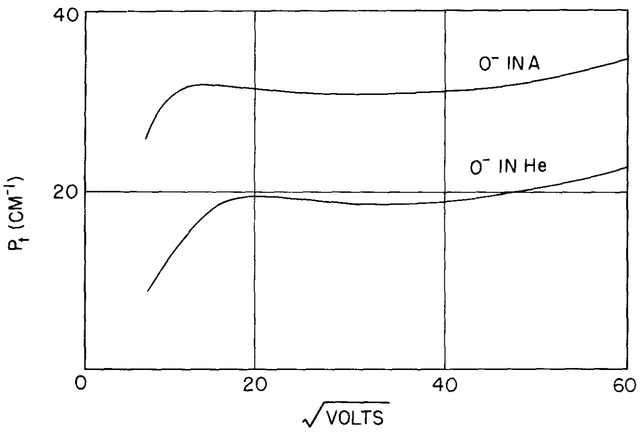

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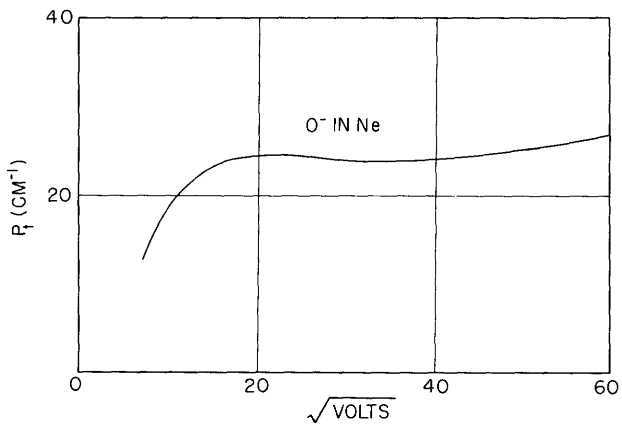

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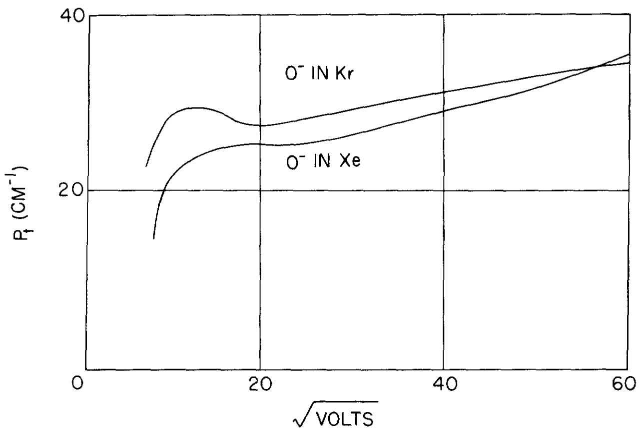

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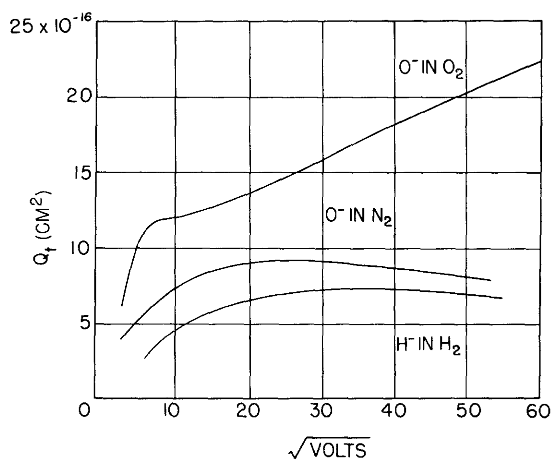

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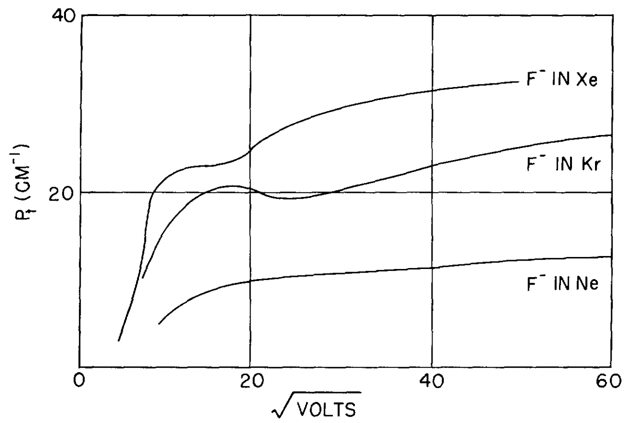

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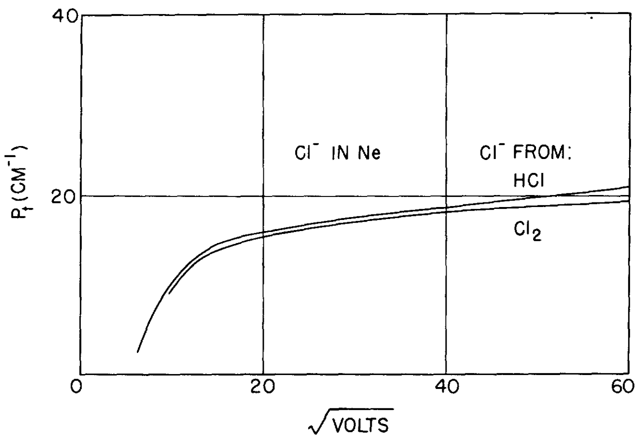

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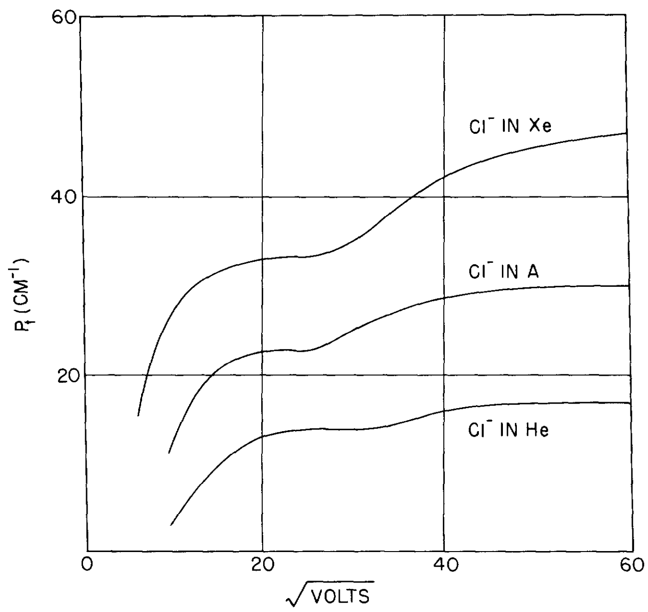

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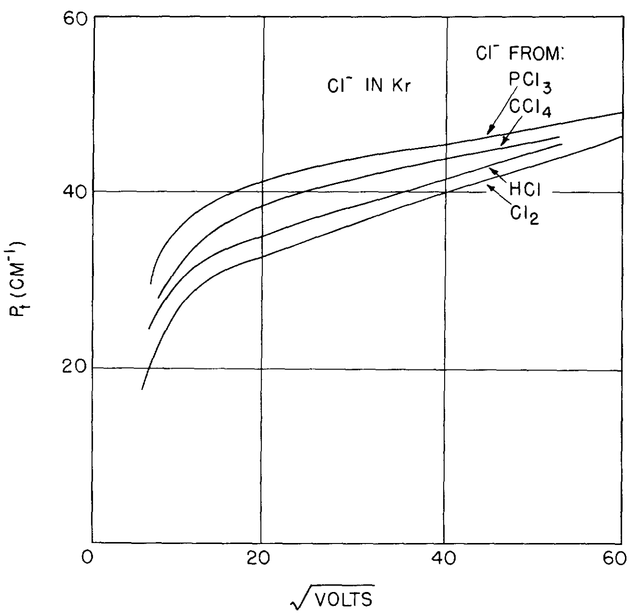

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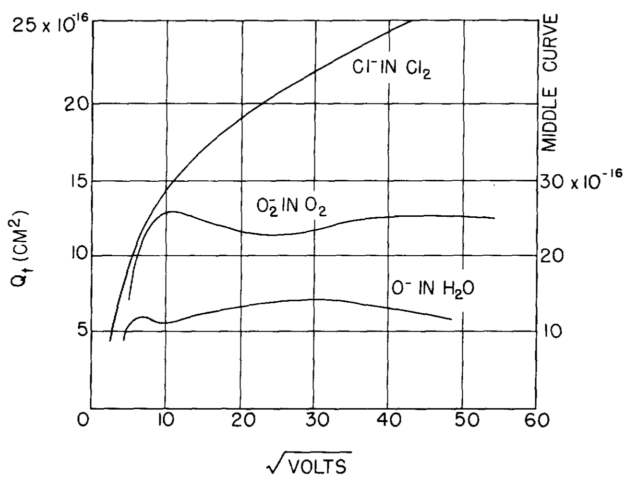

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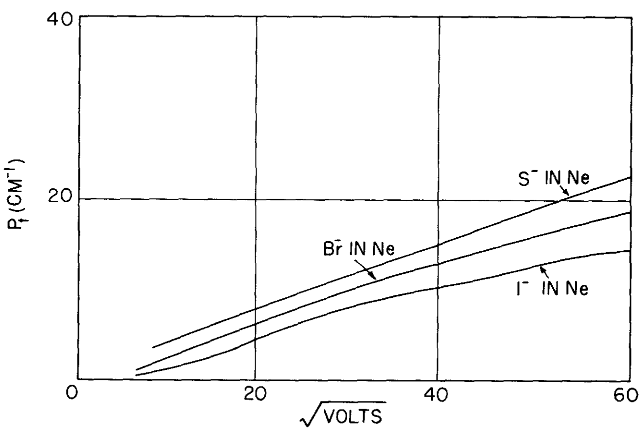

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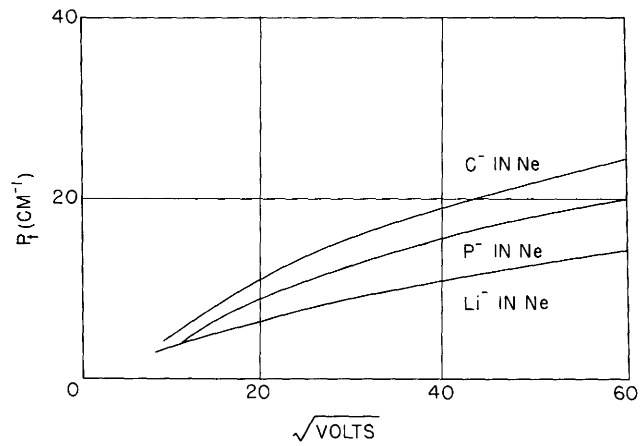

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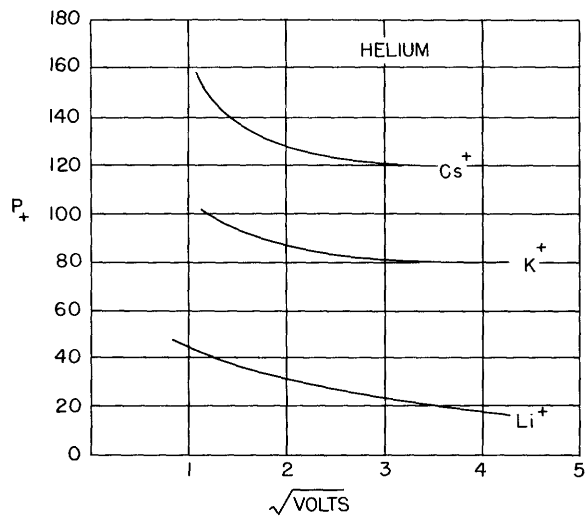

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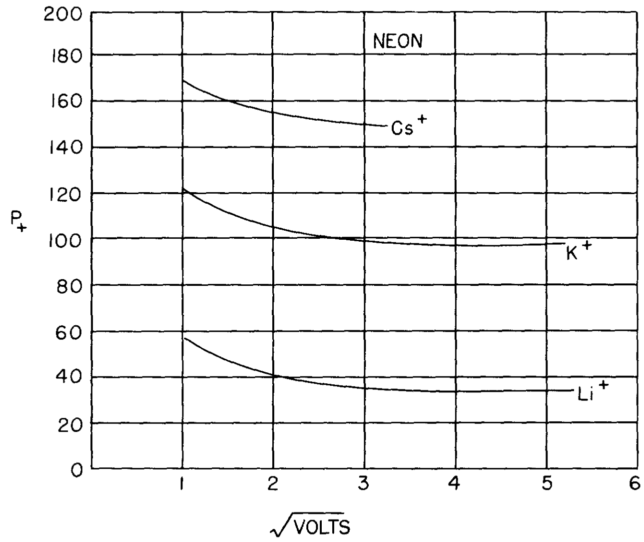
C. Ramsauer, O. Beeck, Ann. Physik 87, 1 (1928)



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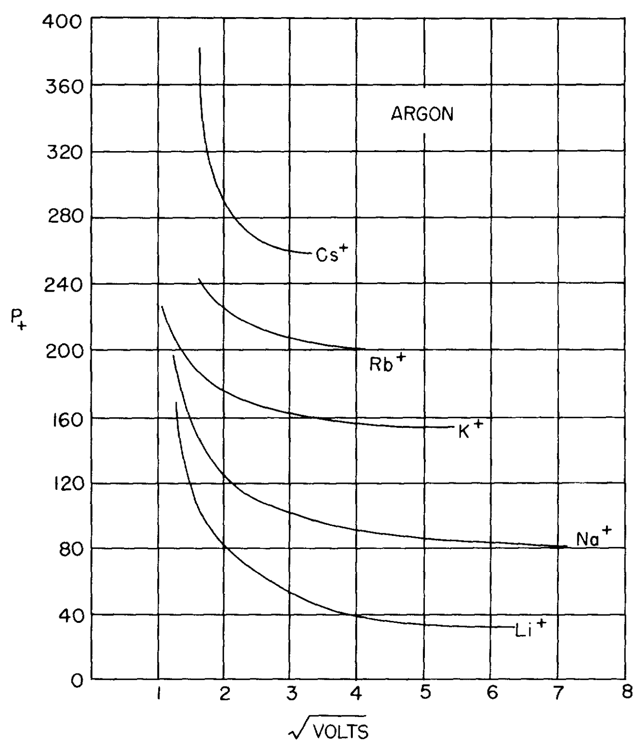

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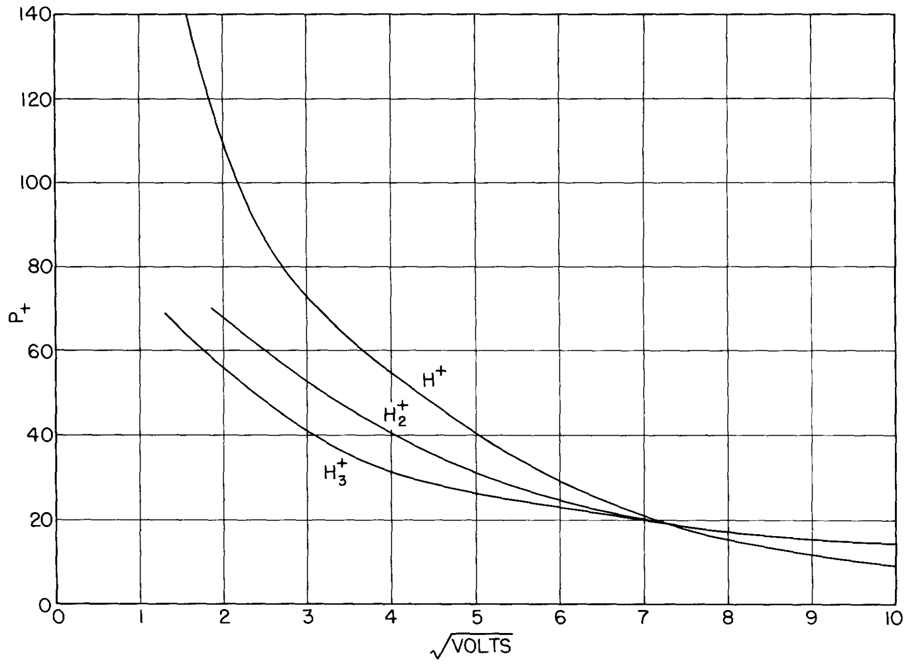

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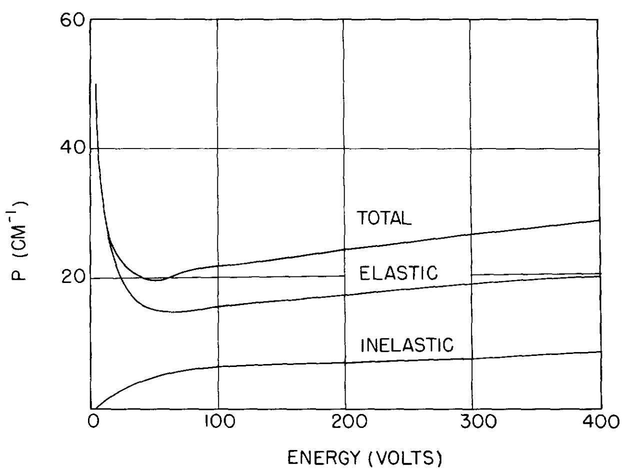
J. H. Simons, C. M. Fontana, E. E. Muschlitz, Jr., S. R. Jackson, J. Chem. Phys. 11, 307 and 316 (1943)



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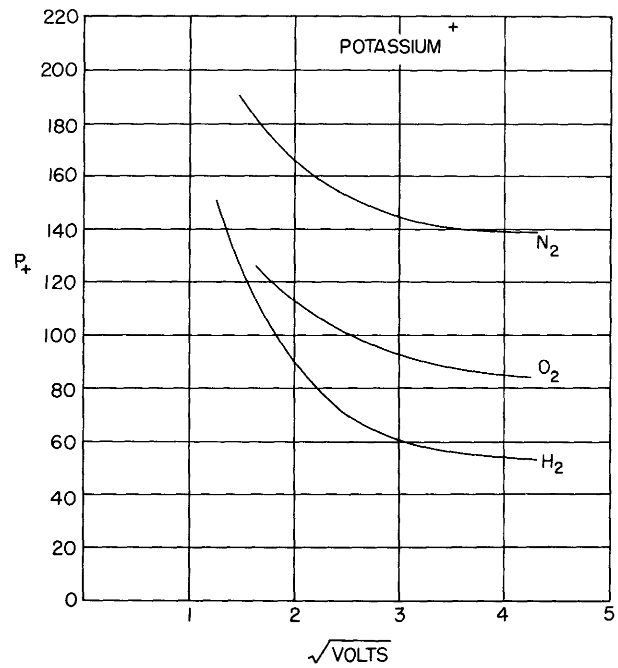

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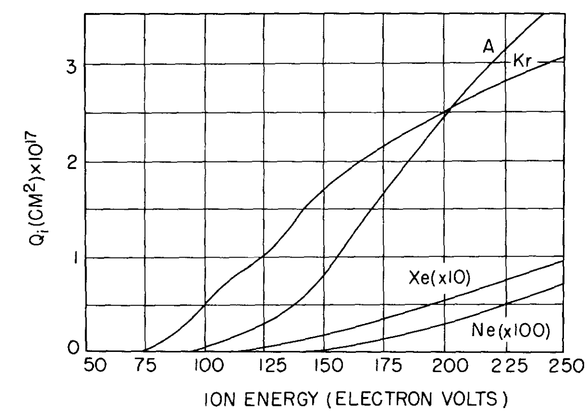

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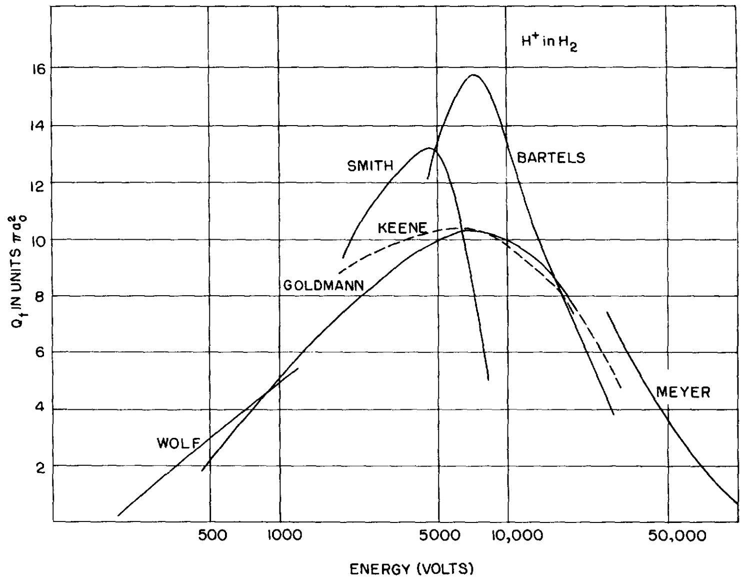
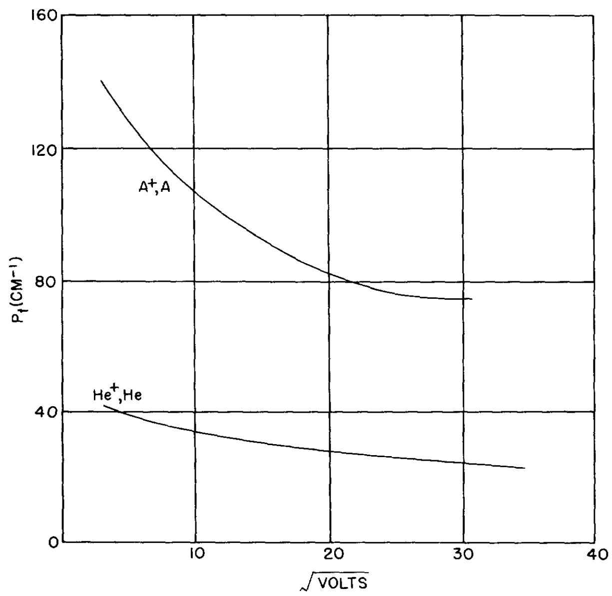


II h1. Charge-transfer cross section of H^+ in H_2.
H. S. W. Massey, E. H. S. Burhop, Electronic and Ionic Impact Phenomena (Clarendon Press, Oxford, 1952), p. 526



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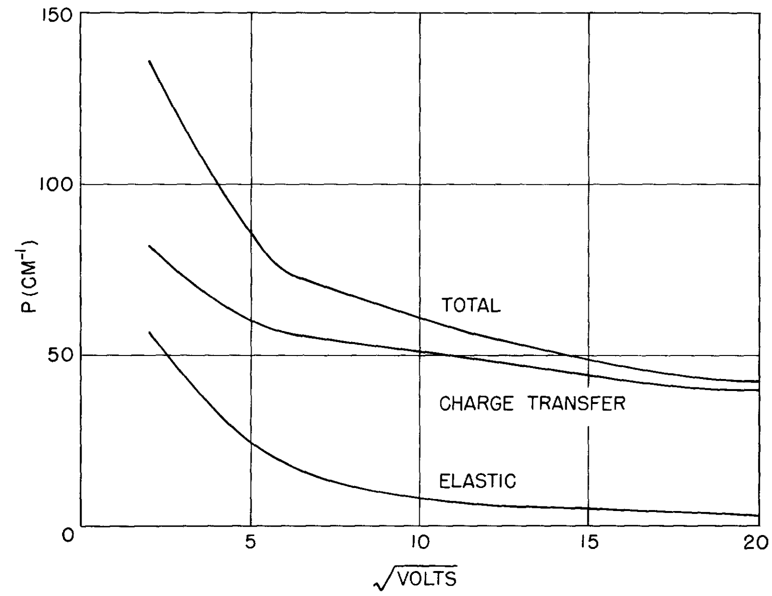

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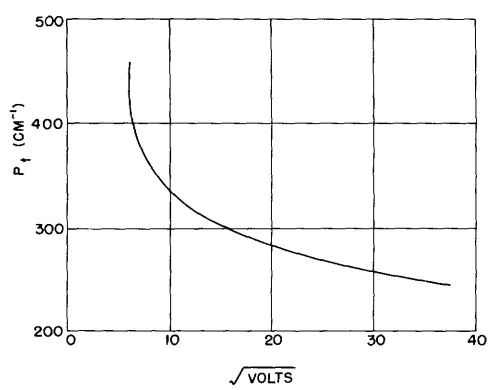
W. H. Cramer, J. H. Simone, J. Chem. Phys. 26, 1272 (1957)



II h3. Charge-transfer cross sections of ions and atoms of mercury.
B. M. Palyukh, L. A. Sena, J. Exp. Theor. Phys. (U.S.S.R.) 20, 481 (1950)

II (h4). Typical Inelastic Collisions Involving Helium and/or Hydrogen Atoms or Ions

Reaction	Description	ΔE (eV)	$E_a^\dagger$ (eV)	References to experimental work
(a) $He^+ + He \rightarrow He + He^+$	Charge exchange	0	0	Rudnick (2), Smith (5), Rostagni (6), Wolf (10), Meyer (12), Keene (14)
(b) $H^+ + He \rightarrow He^+ + H$	Charge exchange	10.9	500	Goldmann (1), Smith (5), Meyer (11), Keene (14)
(c) $H^+ + He \rightarrow H^+ + He'$	Excitation	21.1	1,700	Döpel (4)
(d) $H + He \rightarrow H + He'$	Excitation	21.1	1,700	Döpel (4), Hanle and Junkelmann (9)
(e) $H + He \rightarrow H' + He$	Excitation	10.2	400	Döpel (4), Hanle and Junkelmann (9)
(f) $He + He \rightarrow He' + He$	Excitation	21.1	10,000	Maurer (7)
(g) $He^+ + He \rightarrow He^+ + He'$	Excitation	21.1	10,000	Hanle and Larche (4)
(h) $He^+ + He \rightarrow He'^+ + He$	Excitation	40.8	40,000	Hanle and Larche (4)
(i) $H^+ + He \rightarrow He^+ + H^+ + e$	Ionization	24.5	2,500	Goldmann (1), Keene (14)
(j) $H + He \rightarrow H^+ + He + e$	Ionization	13.5	700	
(k) $He^+ + He \rightarrow He^+ + He^+ + e$	Ionization	24.5	15,000	Brasefield (3), Rostagni (8), Wolf (10), Keene (14)
(l) $He + He \rightarrow He^+ + He + e$	Ionization	24.5	15,000	Brasefield (3), Meyer (12), Berry (13)
(m) $He^+ + He \rightarrow He^{++} + He + e$	Ionization	29.6	22,000	Rudnick (2), Rostagni (8), Meyer (12)

$^\dagger E_a$ is the energy of the incident particle that makes a $\Delta E/hv = 1$.

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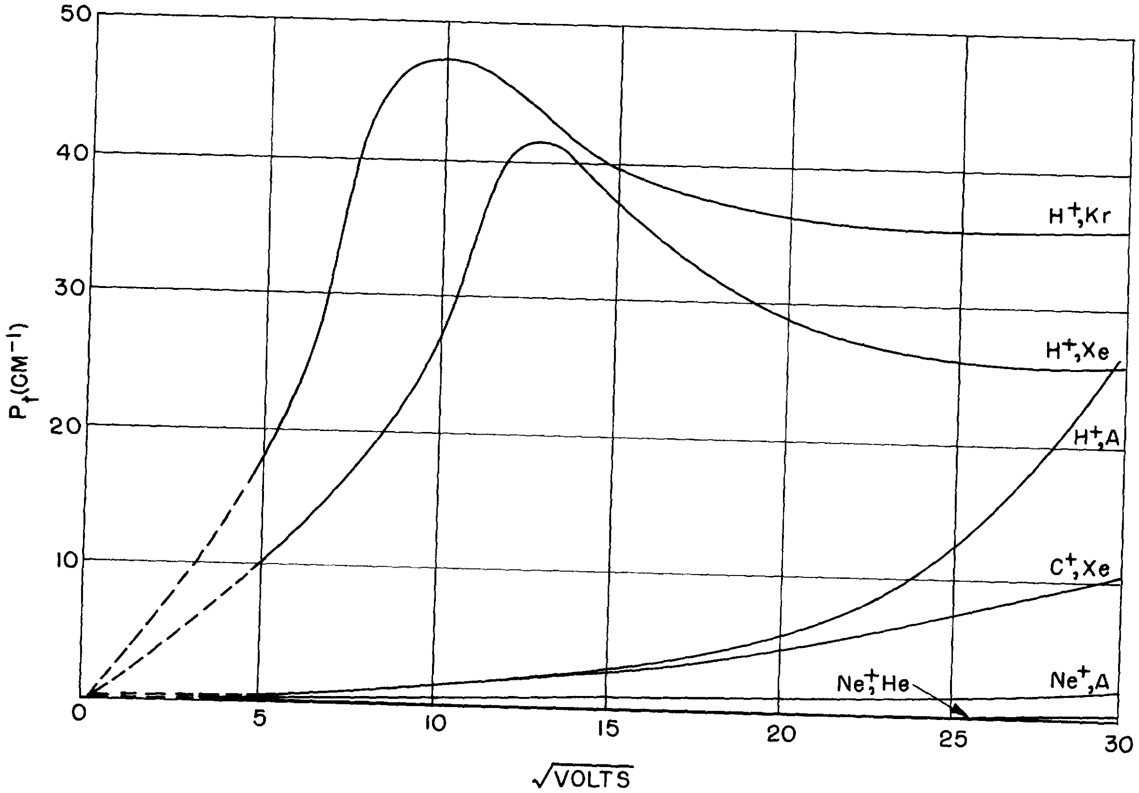
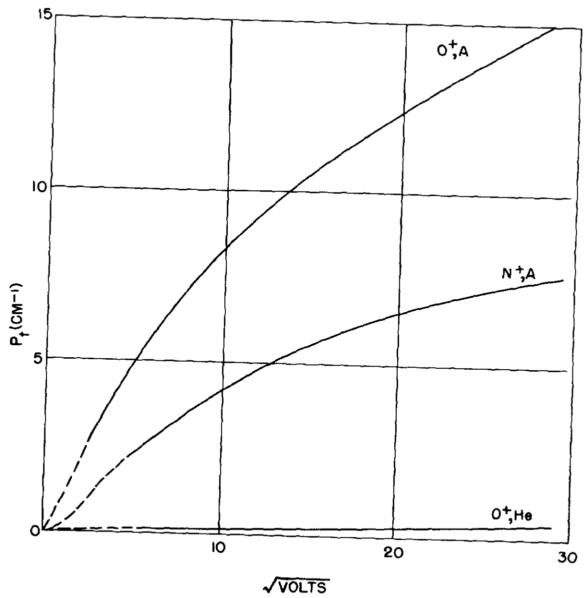


II h5. Normal charge-transfer cross sections.
J. B. Hasted, Proc. Roy. Soc. (London) A205, 421 (1951)



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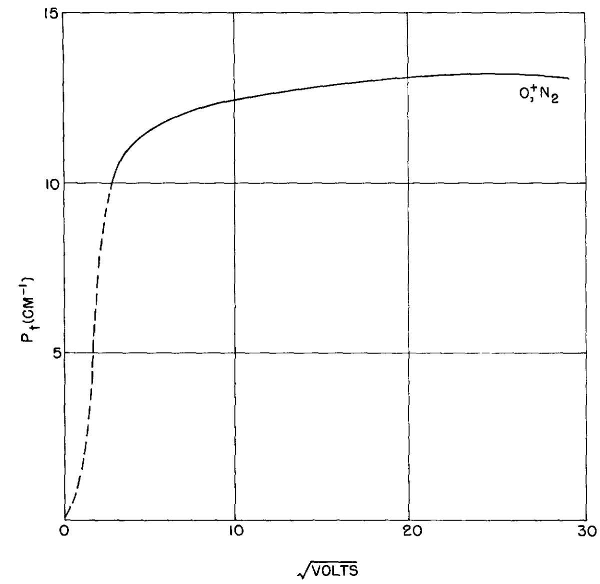

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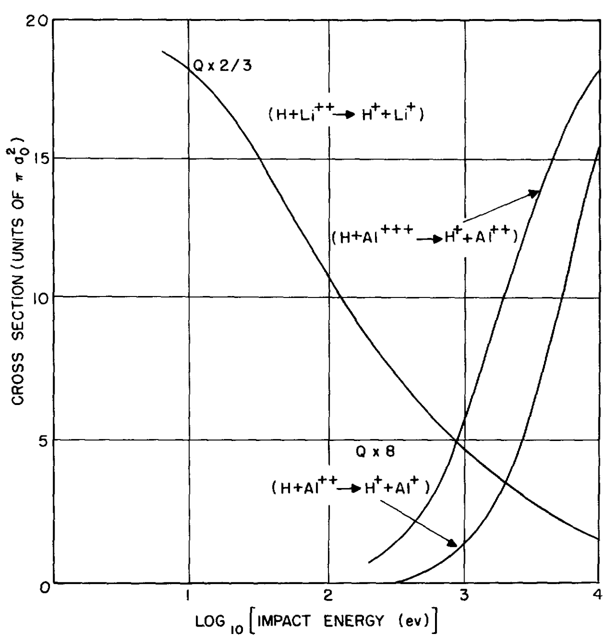

II h8. Cross sections for the reactions $(H, Al^{3+}; H^+, Al^{2+})$, $(H, Li^{2+}; H^+ + Li^+)$, $(H, Al^{2+}; H^+ + Al^+)$ as a function of the impact energy of the colliding ion.

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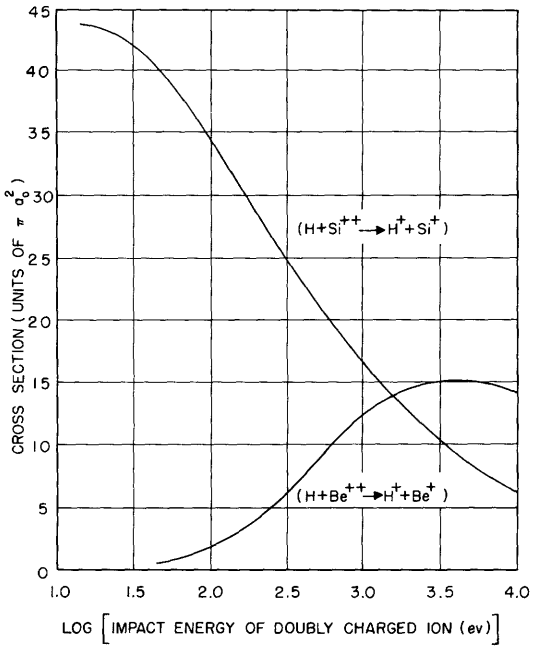

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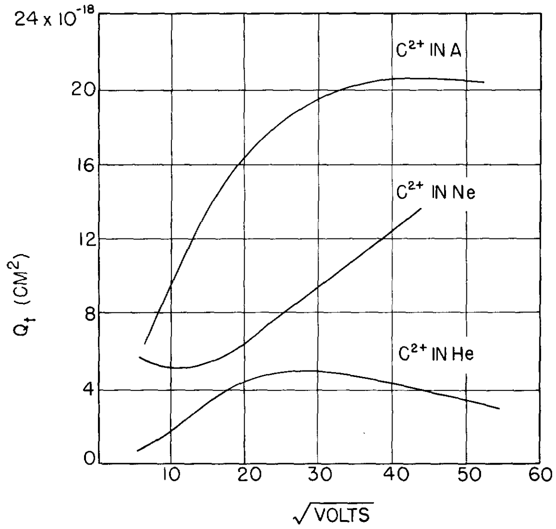
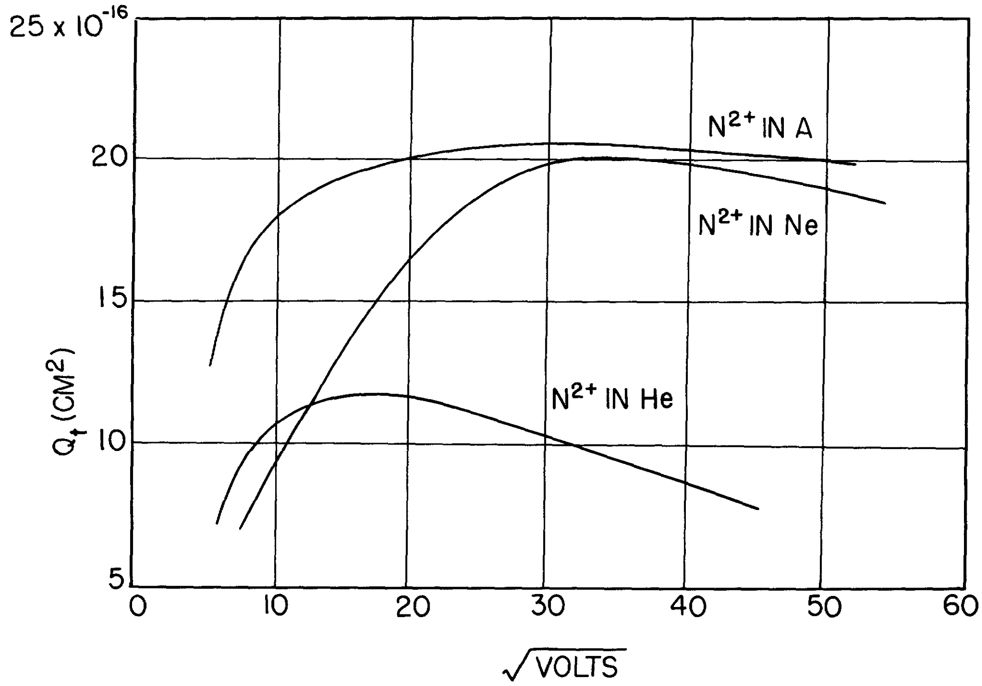
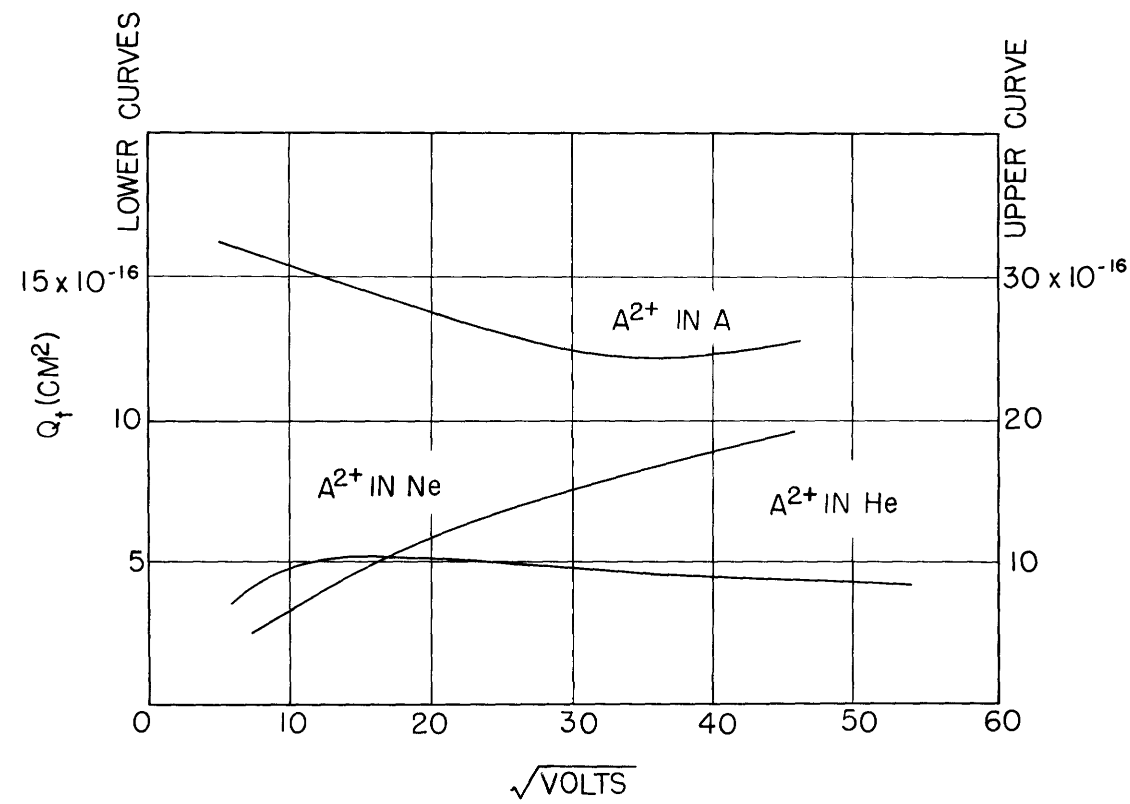


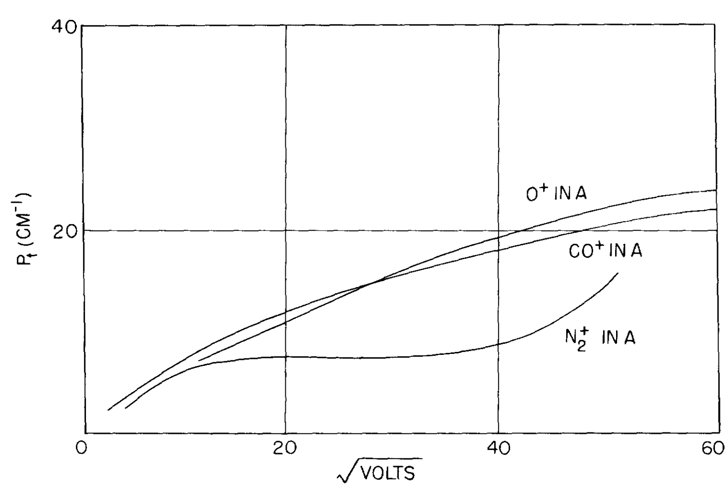
II h10. Charge-transfer cross sections of C^{2+} in argon, neon, and helium.
J. B. Hasted, R. A. Smith, Proc. Roy. Soc. (London) A235, 354 (1956)



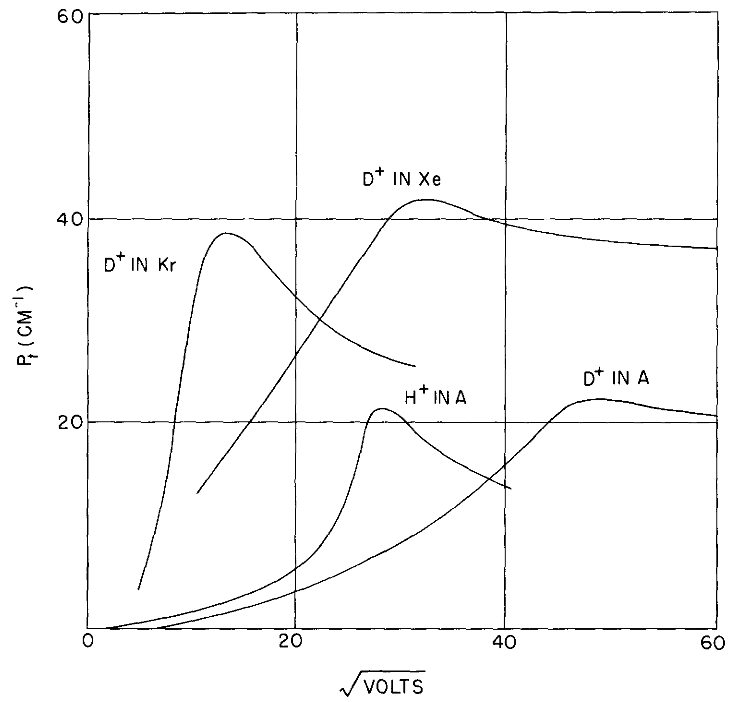
II h11. Charge-transfer cross sections of N^{2+} in argon, neon and helium.
J. B. Hasted, R. A. Smith, Proc. Roy. Soc. (London) A235, 354 (1956)



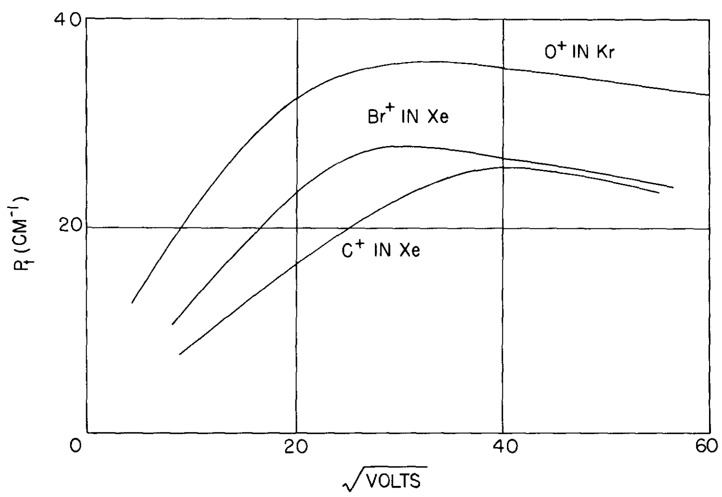
II h12. Charge-transfer cross sections of A^{2+} in A, Ne, and He.
J. B. Hasted, R. A. Smith, Proc. Roy. Soc. (London) A235, 354 (1956)



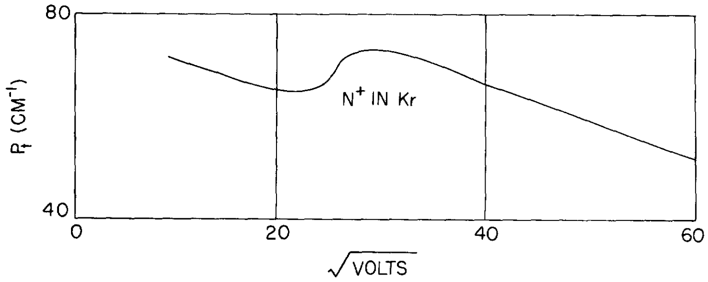
II h13. Charge-transfer cross sections of O^+, CO^+, and N_2^+ in A.
J. B. Hasted, Proc. Roy. Soc. (London) A212, 235 (1952)



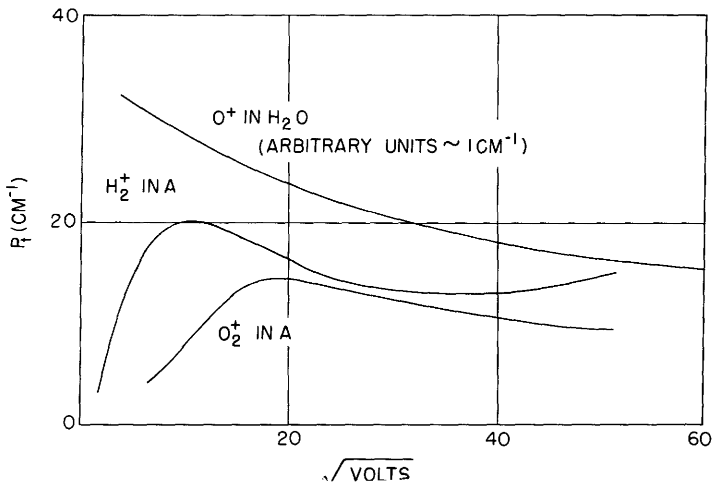
II h14. Charge-transfer cross sections of H^+ in A; D^+ in A, Kr, Xe.
J. B. Hasted, Proc. Roy. Soc. (London) A212, 235 (1952)



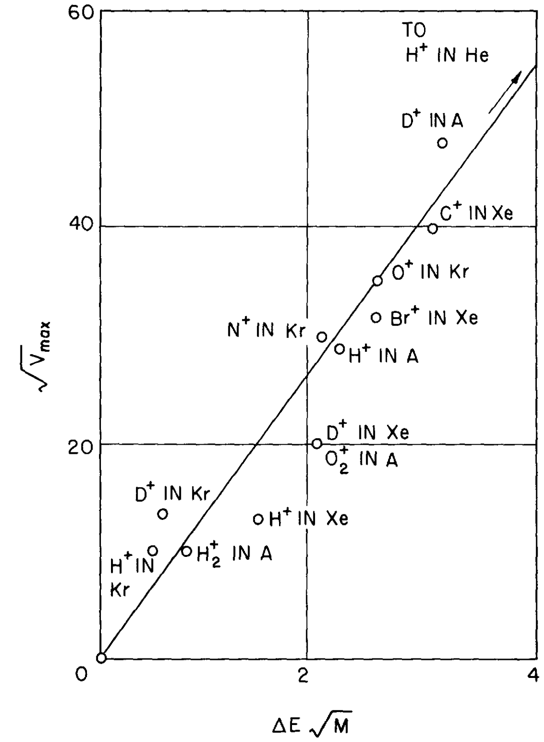
II h15. Charge-transfer cross sections of O^+ in Kr, and Br^+ and C^+ in Xe.
J. B. Hasted, Proc. Roy. Soc. (London) A212, 235 (1952)



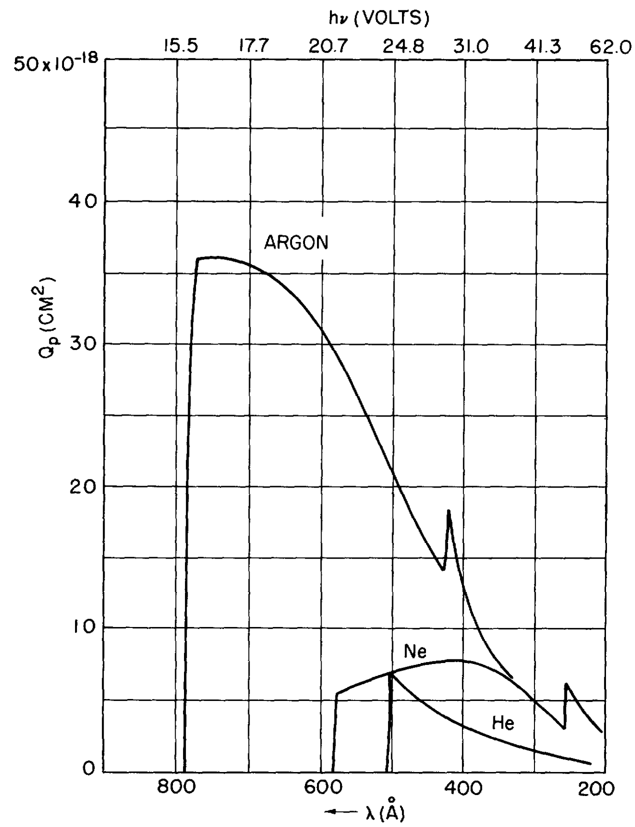
II h16. Charge-transfer cross section of N^+ in Kr.
J. B. Hasted, Proc. Roy. Soc. (London) A212, 235 (1952)



II h17. Charge-transfer cross sections of O^+ in H_2O; O_2^+ and H_2^+ in A.
J. B. Hasted, Proc. Roy. Soc. (London) A212, 235 (1952)

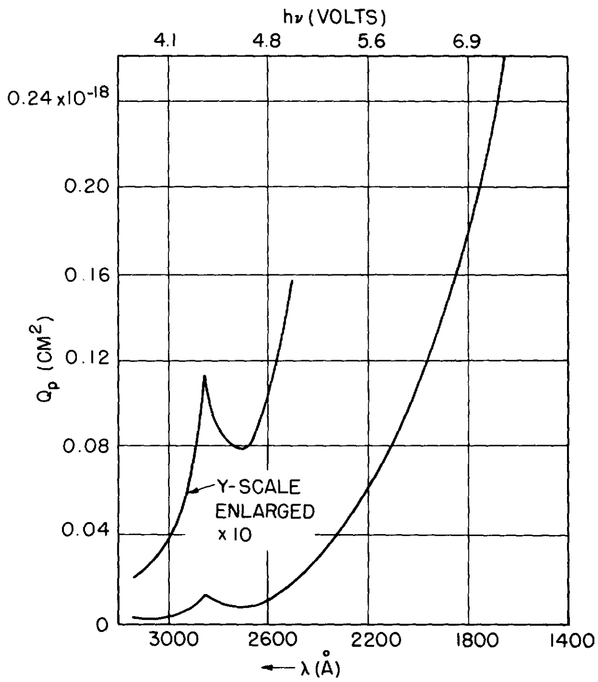


II h18. Maximum voltages of charge-transfer cross sections.
J. B. Hasted, Proc. Roy. Soc. (London) A212, 235 (1952)



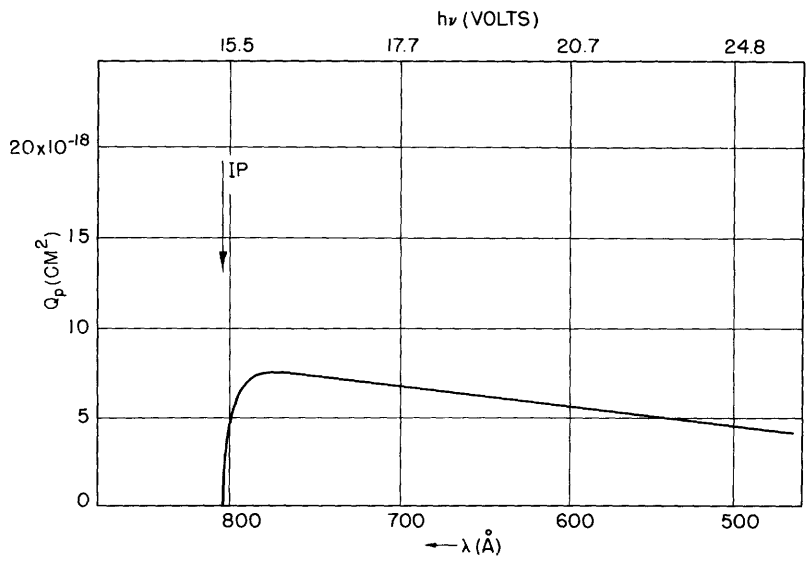
II i1. Photoabsorption cross section in A, Ne, and He.

G. L. Weissler, Handbuch der Physik (Springer Verlag, Berlin, 1956), Vol. 21, p. 304



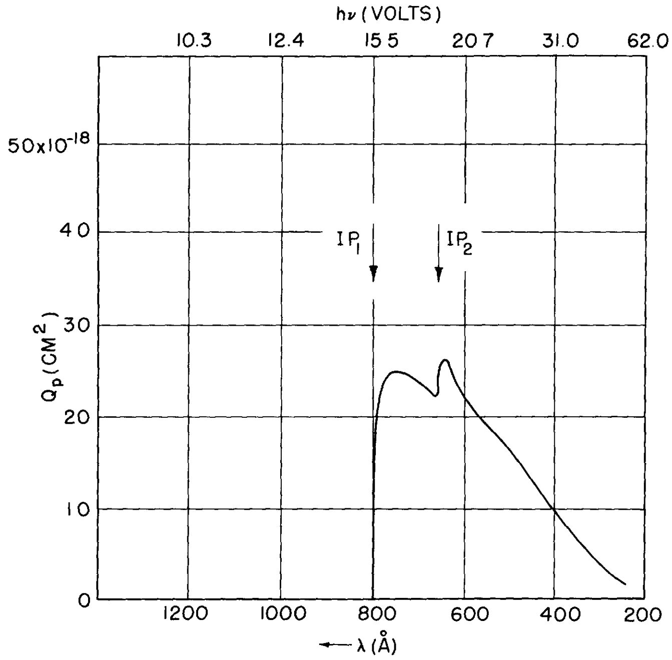
II i2. Photoabsorption cross sections in K.

G. L. Weissler, Handbuch der Physik (Springer Verlag, Berlin, 1956), Vol. 21, p. 304

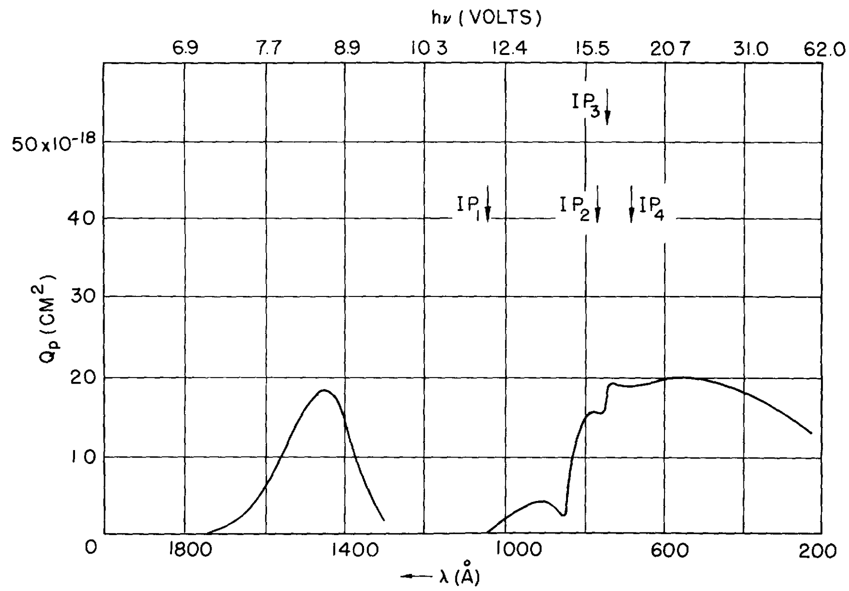


II i3. Photoabsorption cross sections in H_2.

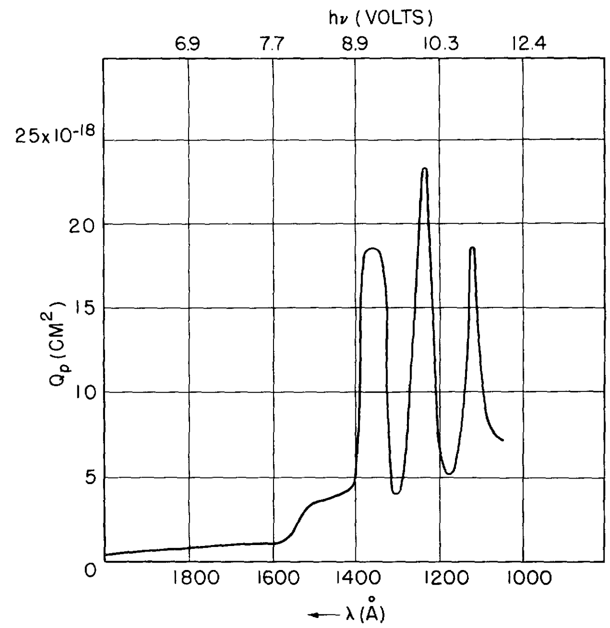
G. L. Weissler, Handbuch der Physik (Springer Verlag, Berlin, 1956), Vol. 21, p. 304



II i4. Photoabsorption cross sections in N_2.
G. L. Weissler, Handbuch der Physik (Springer Verlag, Berlin, 1956), Vol. 21, p. 304

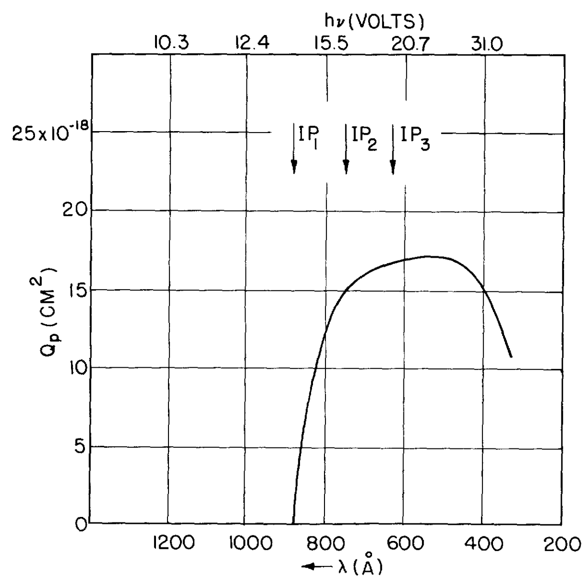


II i5. Photoabsorption cross sections in O_2.
G. L. Weissler, Handbuch der Physik (Springer Verlag, Berlin, 1956), Vol. 21, p. 304



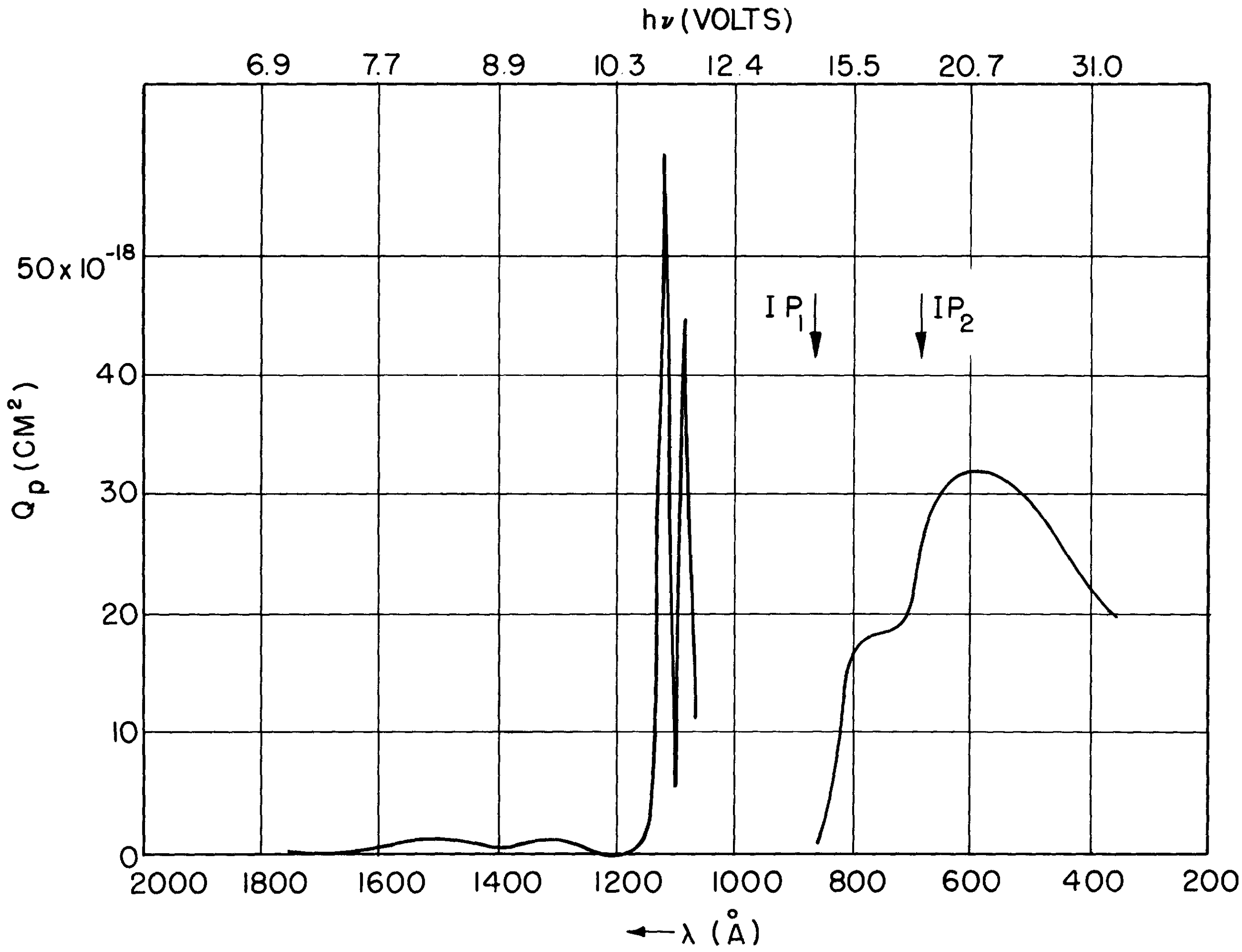
II i6. Photoabsorption cross section in O_3.

G. L. Weissler, Handbuch der Physik (Springer Verlag, Berlin, 1956), Vol. 21, p. 304



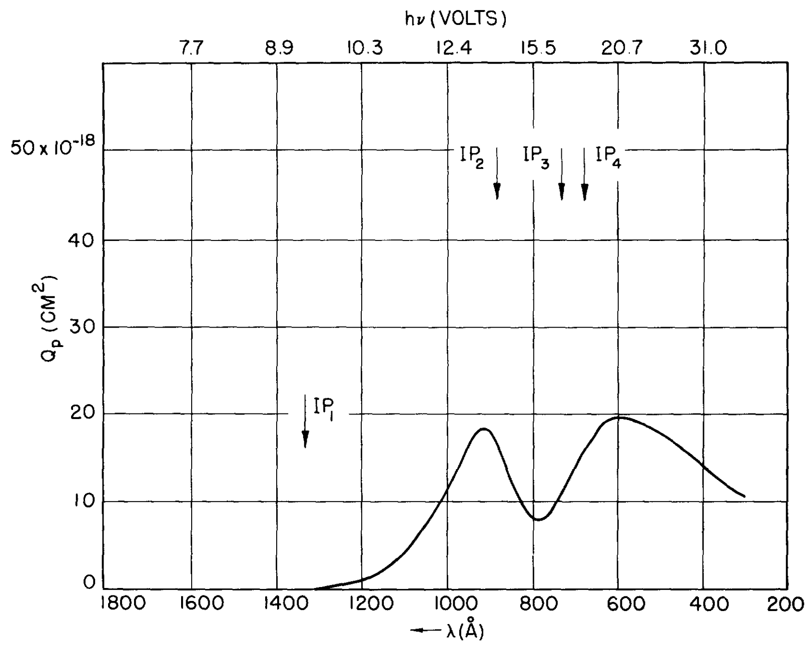
II i7. Photoabsorption cross sections in CO.

G. L. Weissler, Handbuch der Physik (Springer Verlag, Berlin, 1956), Vol. 21, p. 304



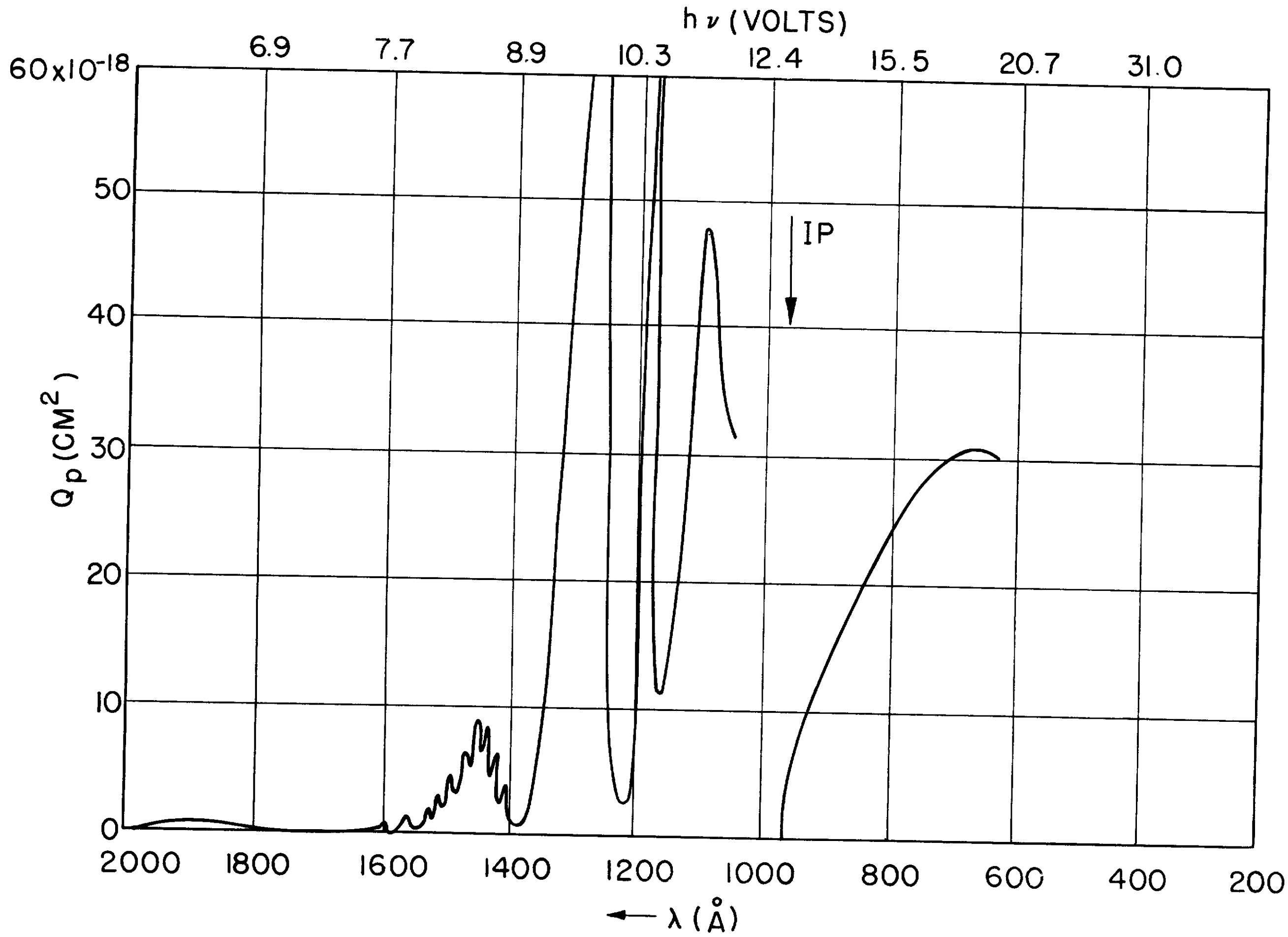
II i8. Photoabsorption cross sections in CO_2.

G. L. Weissler, Handbuch der Physik (Springer Verlag, Berlin, 1956), Vol. 21, p. 304



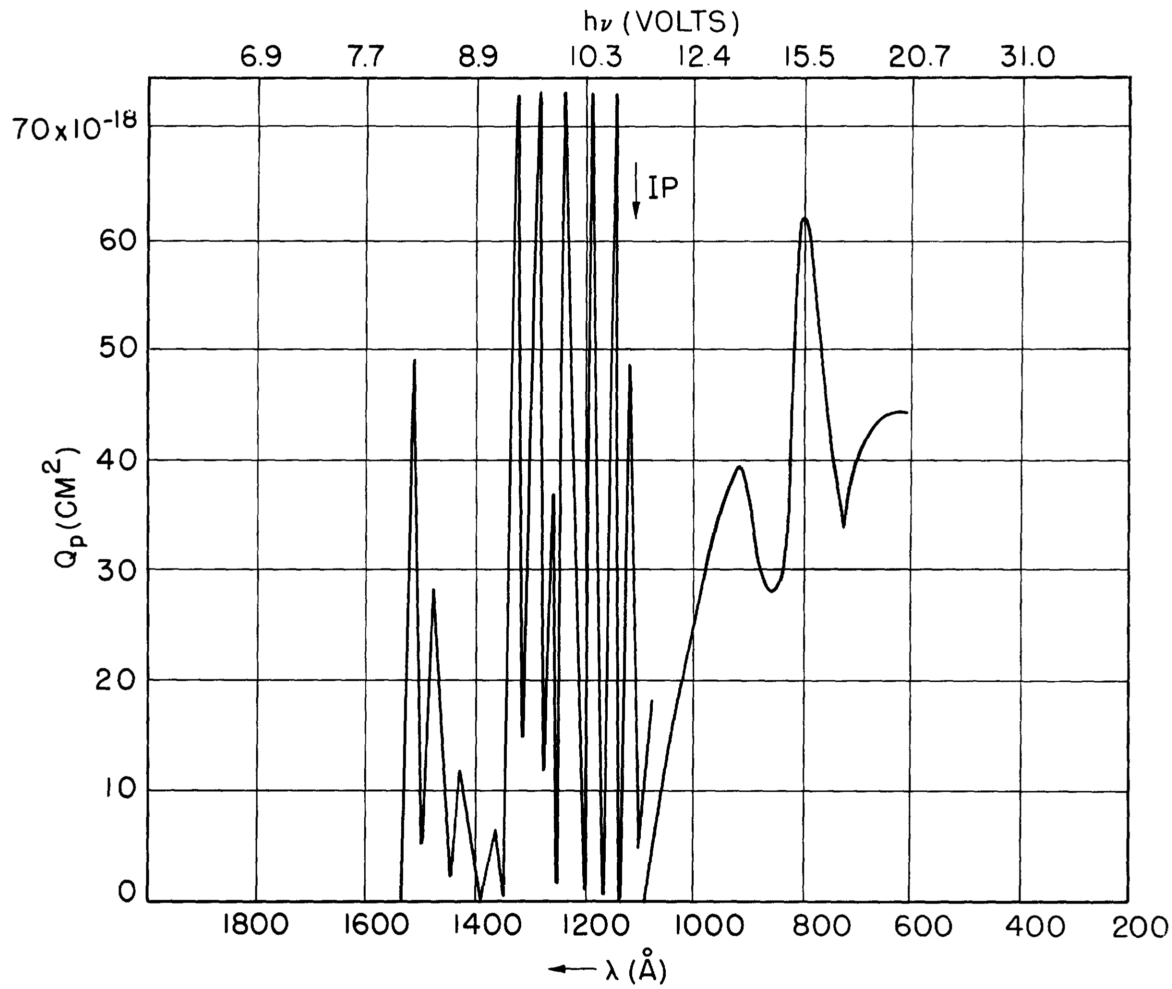
II i9. Photoabsorption cross section in NO.

G. L. Weissler, Handbuch der Physik (Springer Verlag, Berlin, 1956), Vol. 21, p. 304



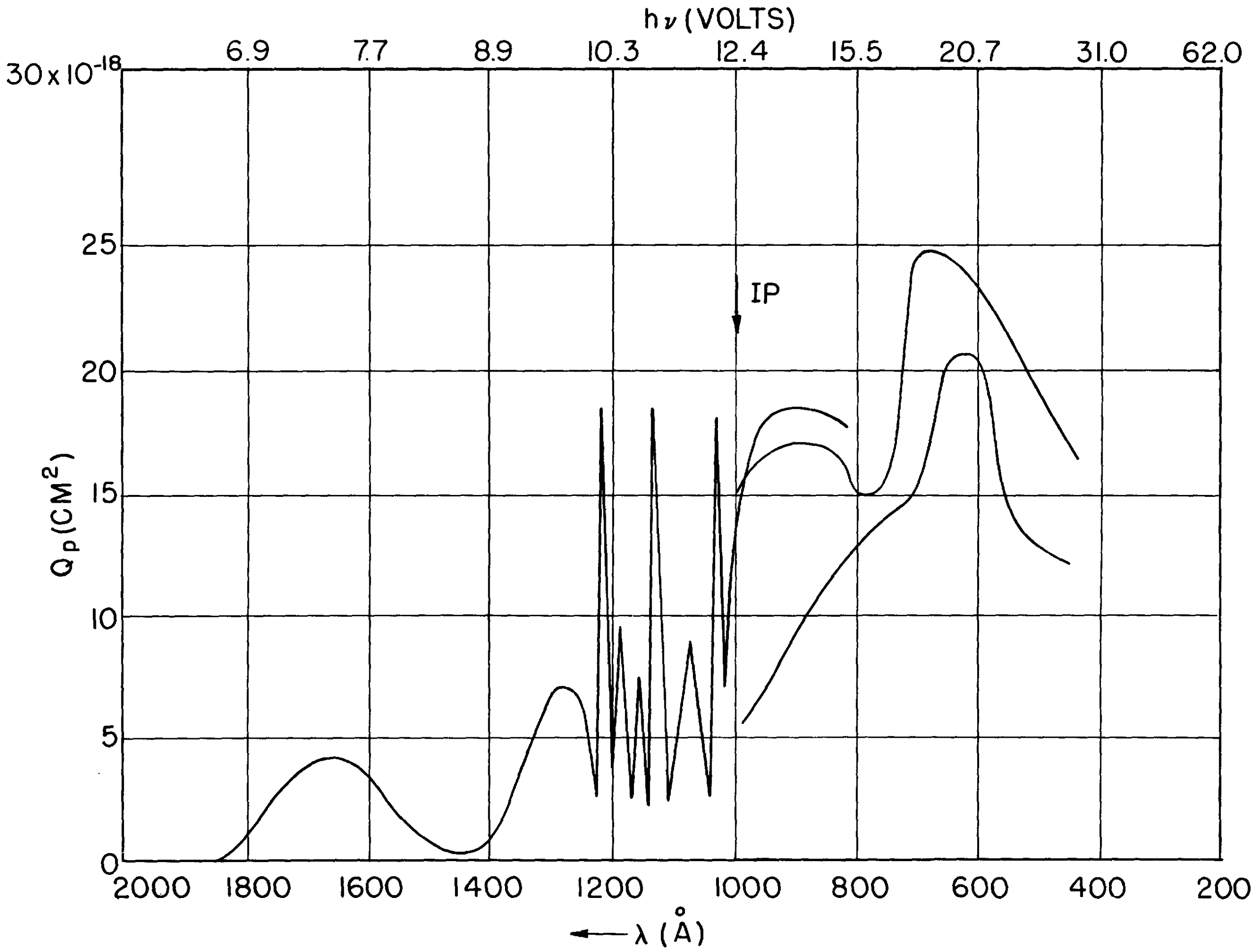
II i10. Photoabsorption cross sections in N_2O.

G. L. Weissler, Handbuch der Physik (Springer Verlag, Berlin, 1956), Vol. 21, p. 304



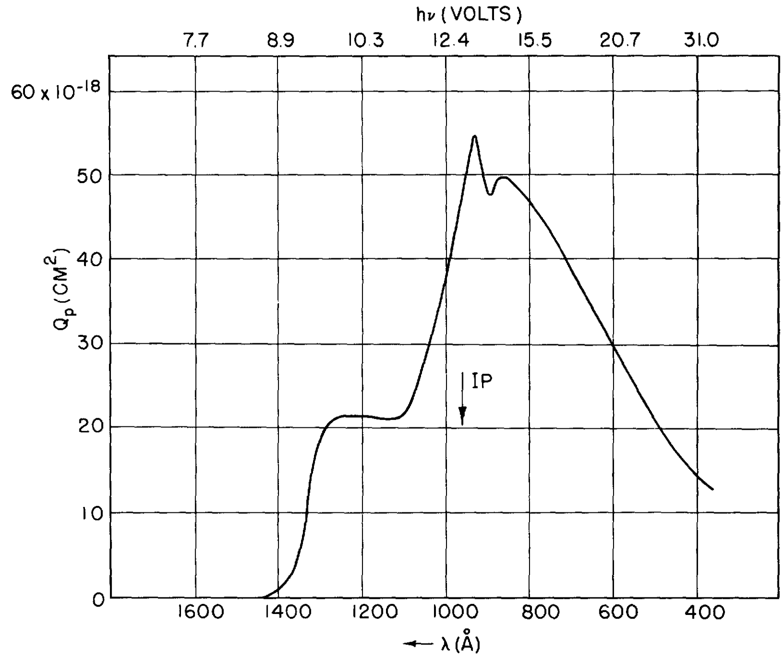
II ill. Photoabsorption cross sections in C_2H_2.

G. L. Weissler, Handbuch der Physik (Springer Verlag, Berlin, 1956), Vol. 21, p. 304



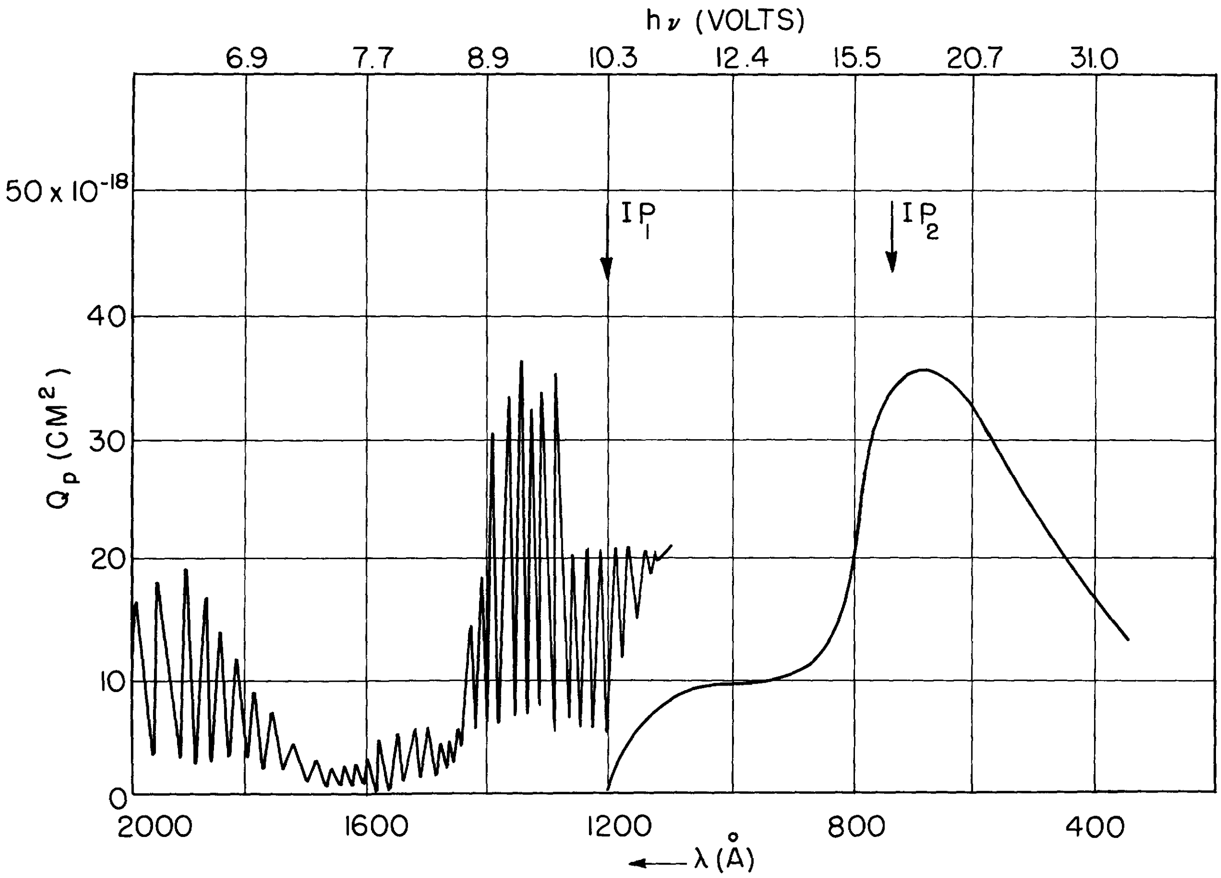
II i12. Photoabsorption cross section in H_2O.

G. L. Weissler, Handbuch der Physik (Springer Verlag, Berlin, 1956), Vol. 21, p. 304



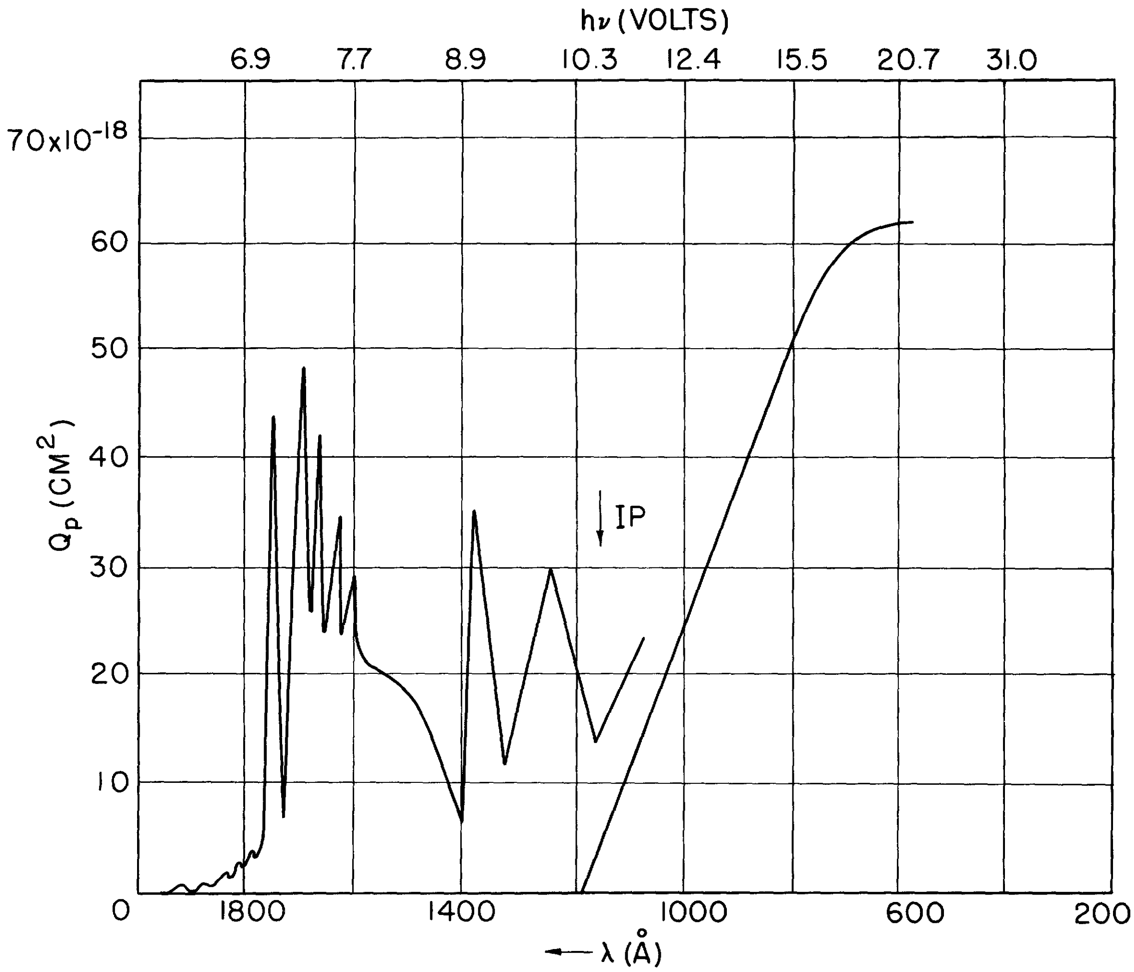
II i13. . Photoabsorption cross sections in CH_4.

G. L. Weissler, Handbuch der Physik (Springer Verlag, Berlin, 1956), Vol. 21, p. 304



II i14. Photoabsorption cross sections in NH_3.

G. L. Weissler, Handbuch der Physik (Springer Verlag, Berlin, 1956), Vol. 21, p. 304



II i15. Photoabsorption cross sections in C_2H_4.

G. L. Weissler, Handbuch der Physik (Springer Verlag, Berlin, 1956), Vol. 21, p. 304

III. SURFACE PHENOMENA

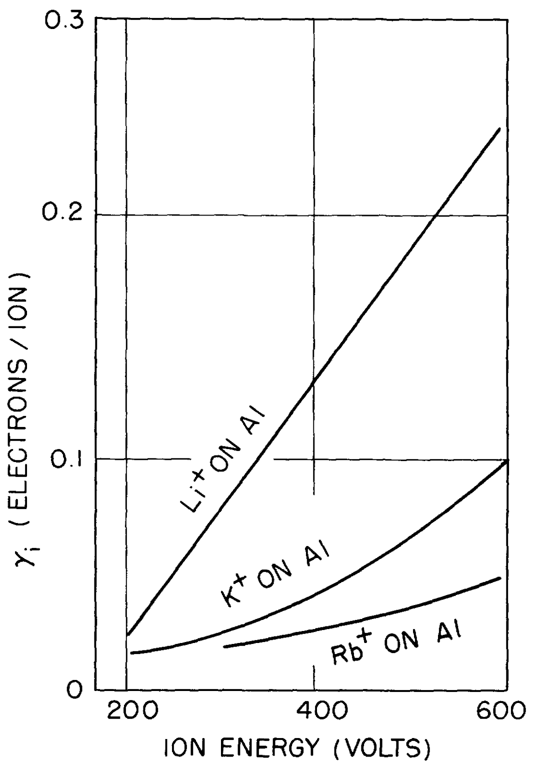
(a) Secondary Emission γ_i

The secondary emission coefficient γ_i is the number of free electrons released from a surface by the impact of a positive ion, over and above any electrons taken from the surface to neutralize the ion. If ϕ is the work function of the surface, and V_i is the ionization potential of the ion, secondary emission requires that $V_i > 2\phi$.

The secondary emission coefficient is in general greatly altered by the presence of adsorbed gas on the surface.

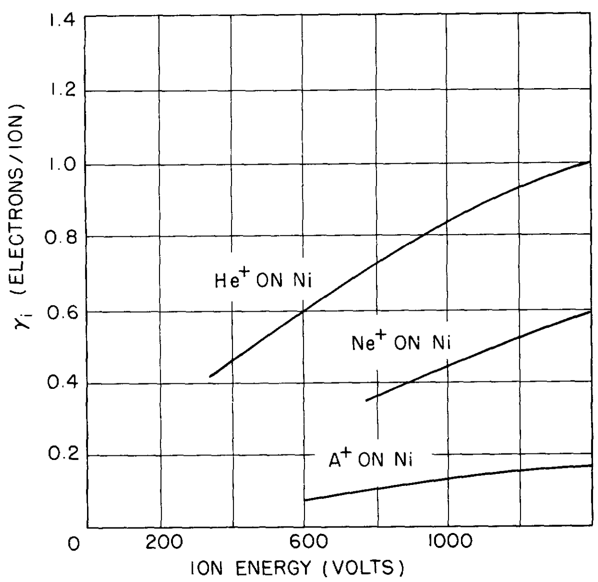
(b) Effective Secondary Emission γ

The second Townsend coefficient γ is defined as the number of secondary electrons escaping from the cathode per positive ion produced in the gas. It is a function of E/p in the gas and is, in general, the resultant effect of photons, ions, and metastables reaching the cathode, and of back diffusion.



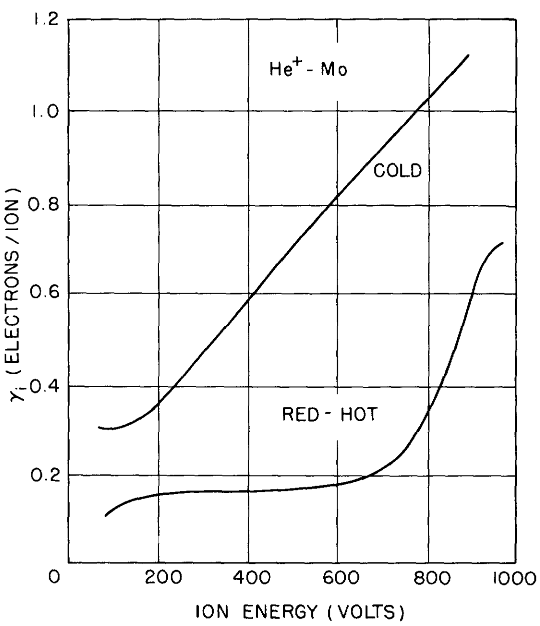
IIIa1. Ejected electron yield of Li^+, K^+, and Rb^+ on aluminum.

H. S. W. Massey, E. H. S. Burhop, Electronic and Ionic Impact Phenomena (Clarendon Press, Oxford, 1952), p. 549



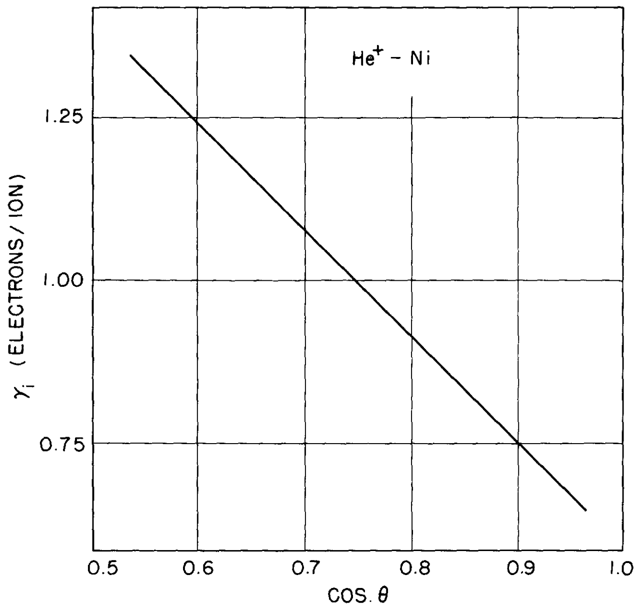
IIIa2. Ejected electron yield of He^+, Ne^+, and A^+ on nickel.

H. S. W. Massey, E. H. S. Burhop, Electronic and Ionic Impact Phenomena (Clarendon Press, Oxford, 1952), p. 549



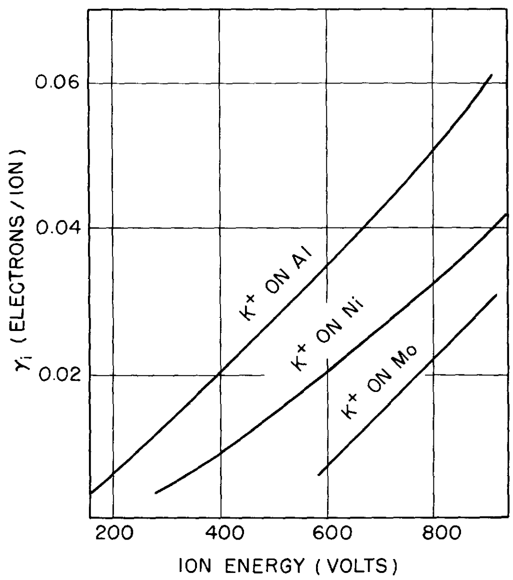
IIIa2. Electron yield of helium ions on hot and cold molybdenum.

P. F. Little, Handbuch der Physik (Springer Verlag, Berlin, 1956), Vol. 21, p. 574



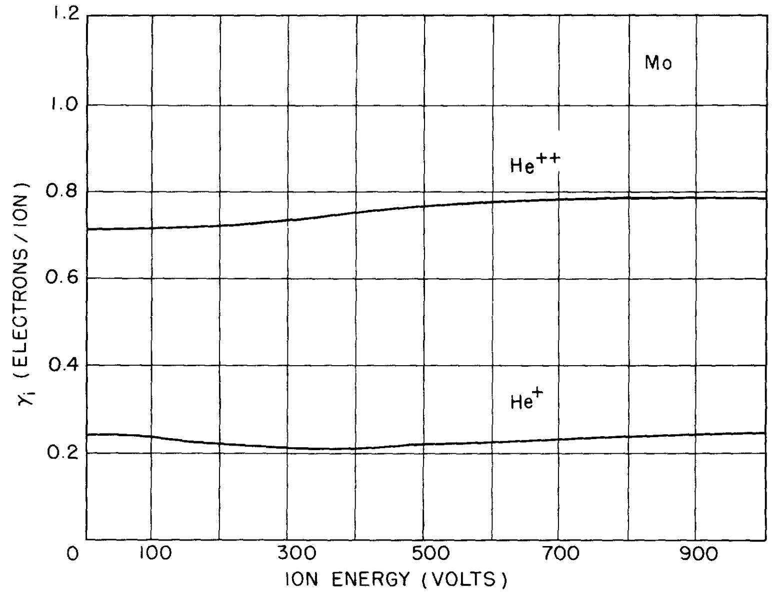
III a3. Electron yield as function of the angle of incidence for helium ions on nickel.

P. F. Little, Handbuch der Physik (Springer Verlag, Berlin, 1956), Vol. 21, p. 574

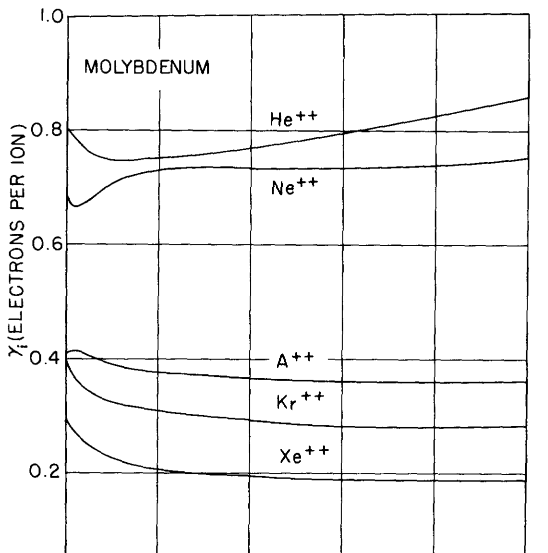


III a4. Ejected electron yield of K^+ on Al, Ni, and Mo.

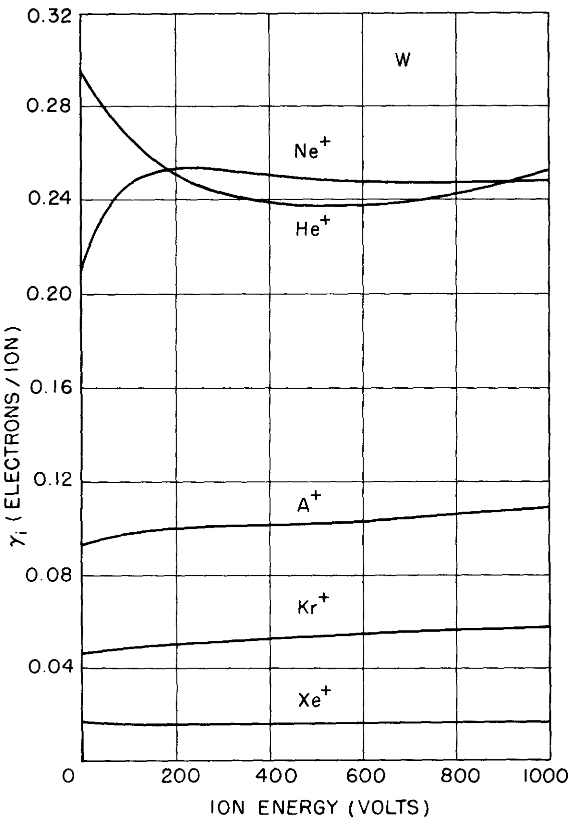
H. S. W. Massey, E. H. S. Burhop, Electronic and Ionic Impact Phenomena (Clarendon Press, Oxford, 1952), p. 549



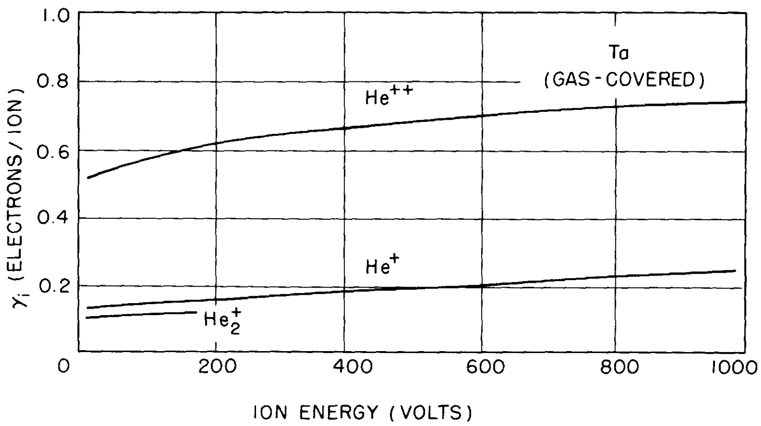
IIIa5. Total electron yield on atomically clean molybdenum.
H. D. Hagstrum, Phys. Rev. 89, 244 (1953)



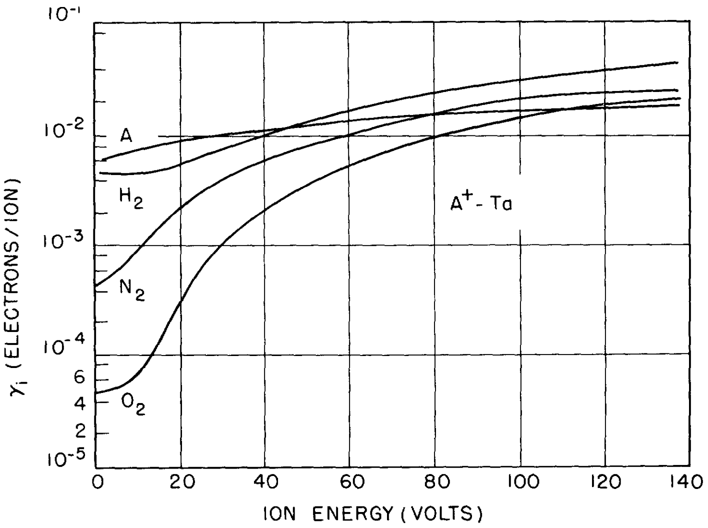
III a5. γ for doubly charged ions of noble gases incident on atomically clean molybdenum.
H. D. Hagstrum, Phys. Rev. 104, 672 (1956)



III a6. γ data for atomically clean tungsten.
H. D. Hagstrum, Phys. Rev. 104, 672 (1956)

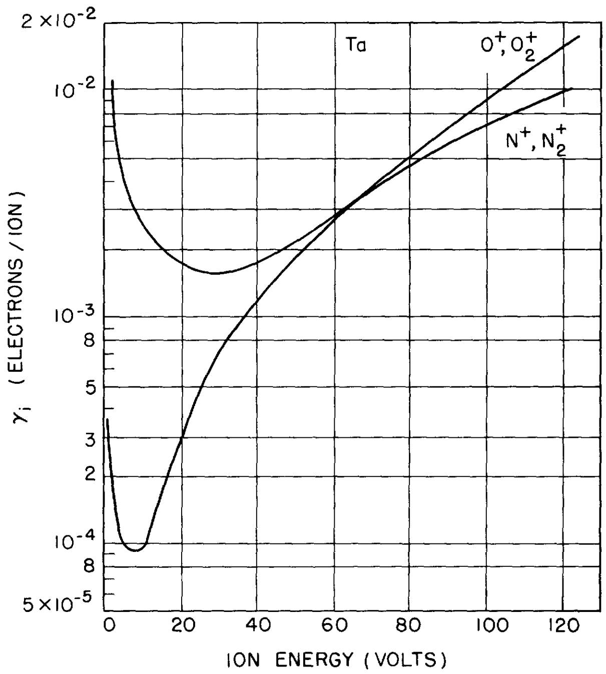


III a7. Total electron yield for He^+, He^{++}, and He_2^+ for gas-covered tantalum.
H. D. Hagstrum, Phys. Rev. 91, 543 (1953)



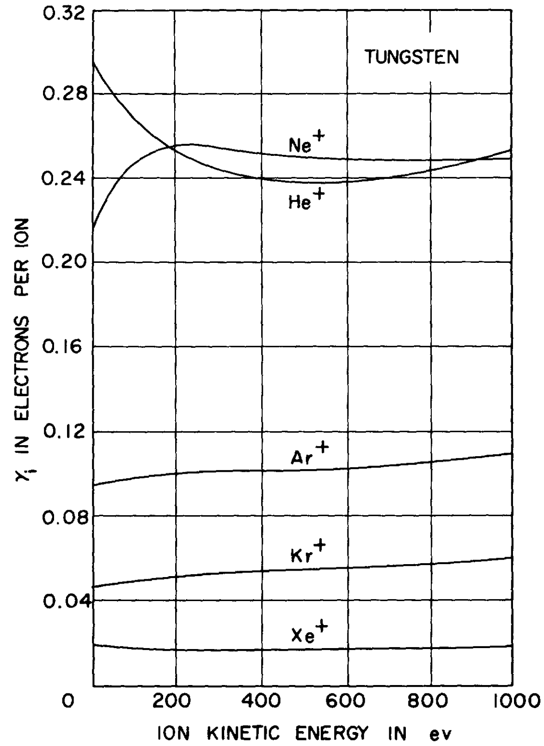
III a8. Ejected electron yield of A^+ ions on outgassed tantalum, H_2, N_2 and O_2–treated tantulum.

J. A. Parker, Jr., Phys. Rev. 93, 1148 (1954)

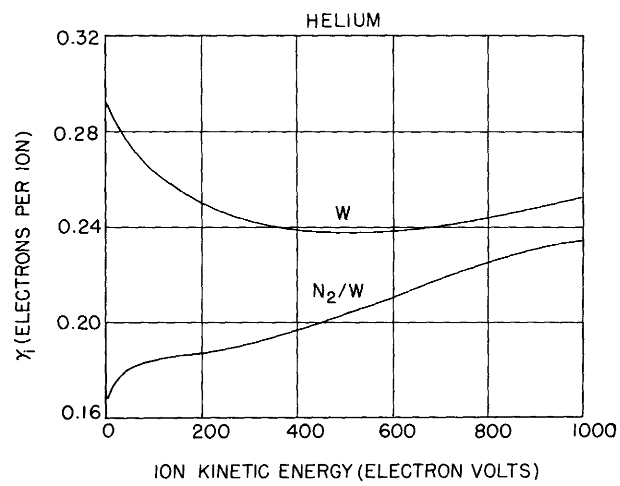


III a9. Electron yield on gas-covered tantalum from molecular gas ions.

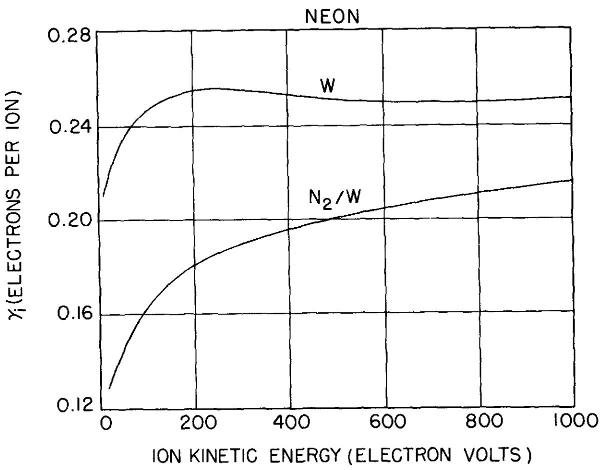
P. F. Little, Handbuch der Physik (Springer Verlag, Berlin, 1956), Vol. 21, p. 574



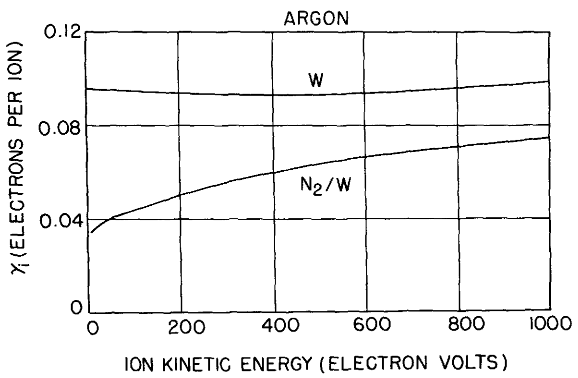
III a10. Total electron yield for singly charged ions on atomically clean tungsten.
H. D. Hagstrum, Phys. Rev. 96, 325 (1954)



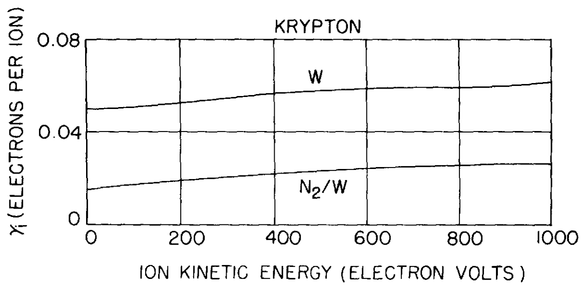
III a10. γ_i in helium for clean tungsten (W) and covered with a nitrogen monolayer (N_2/W).
H. D. Hagstrum, Phys. Rev. 104, 1516 (1956)



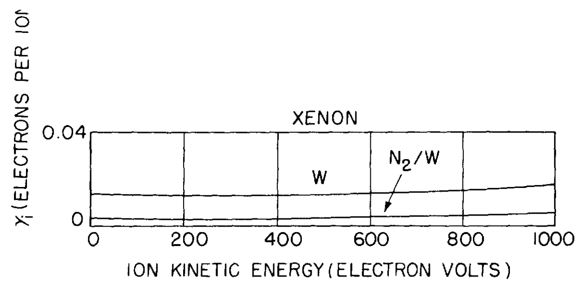
III a10. γ_i in neon for clean tungsten (W) and covered with a nitrogen monolayer (N_2/W).
H. D. Hagstrum, Phys. Rev. 104, 1516 (1956)



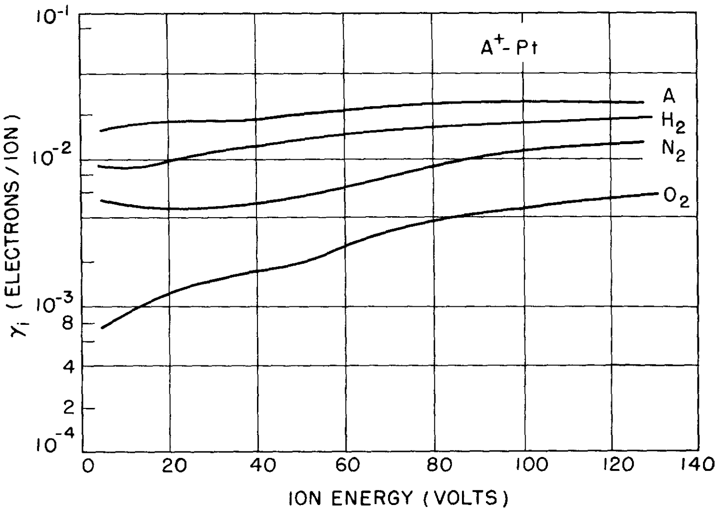
III a10. γ_i in argon for clean tungsten (W) and covered with a N_2 monolayer (N_2/W).
H. D. Hagstrum, Phys. Rev. 104, 1516 (1956)



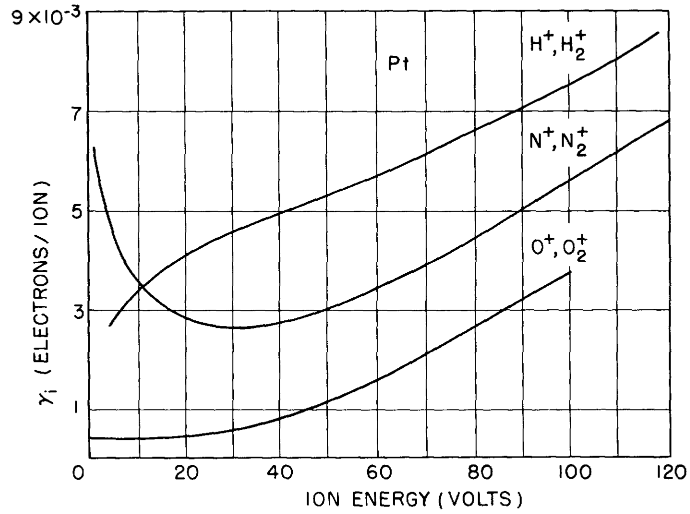
III a10. γ_i in krypton for clean tungsten (W) and covered with a nitrogen monolayer (N_2/W).
H. D. Hagstrum, Phys. Rev. 104, 1516 (1956)



III a10. γ_i in xenon for clean tungsten (W) and covered with a nitrogen monolayer (N_2/W).
H. D. Hagstrum, Phys. Rev. 104, 1516 (1956)

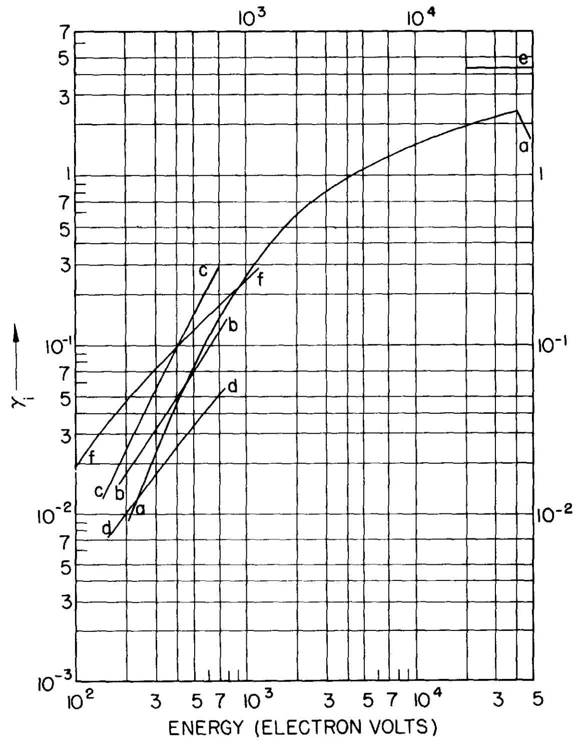


III a11. Electron yield on gas-covered platinum.
P. F. Little, Handbuch der Physik (Springer Verlag, Berlin, 1956), Vol. 21, p. 514



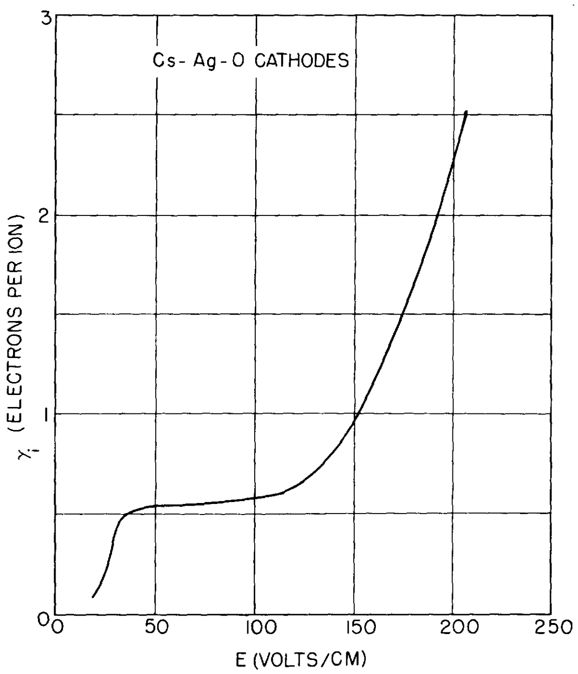
III a12. Electron yield as a function of ion energy for hydrogen, nitrogen, and oxygen ions on platinum.

P. F. Little, Handbuch der Physik (Springer Verlag, Berlin, 1956), Vol. 21, p. 574

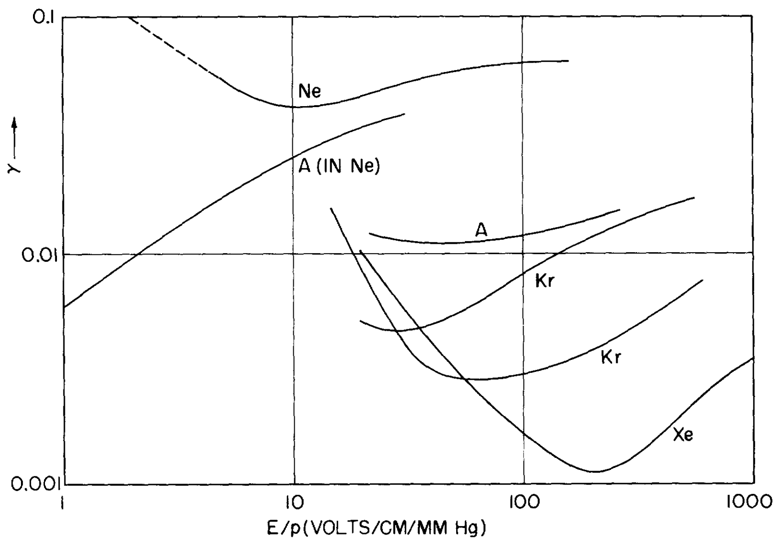


III a13. Ejected electron yields of (a) H and Na ions on Cu; (b) K ions on Al; (c) Li ions on Al; (d) Rb ions on Al; (e) H ions on Cu, Al, and Au; (f) H ions on Ni.

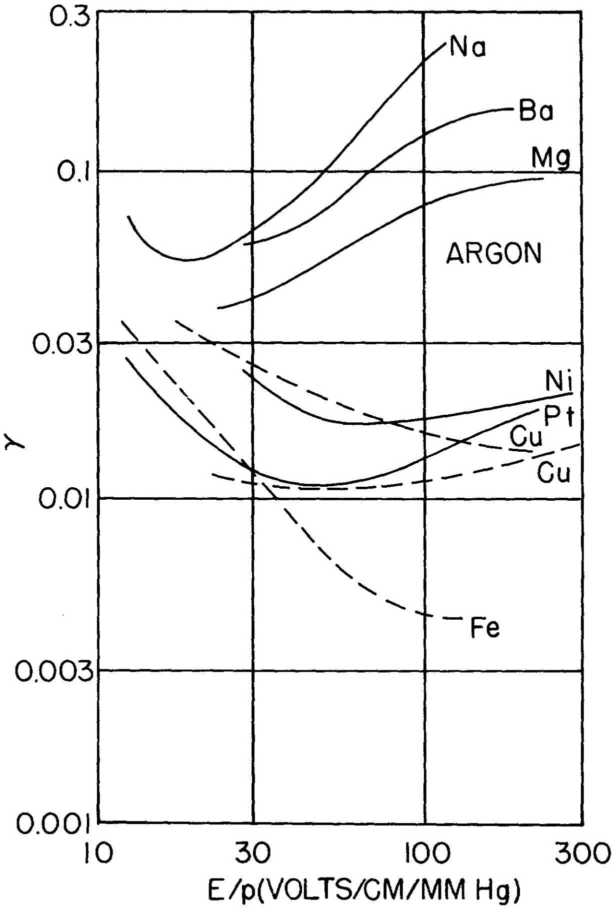
A. von Engel, M. Steenbeck, Elektrische Gasentladungen (Springer Verlag, Berlin, 1932), Vol. 1, p. 116



III a14. Second Townsend coefficient of argon ions on Cs-Ag-O surface.
W. S. Huxford, Phys. Rev. 55, 754 (1939)

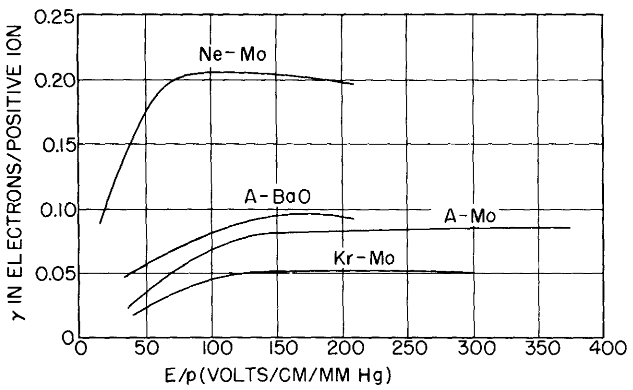


IIIb1. Second Townsend coefficient for copper in the rare gases.
M. J. Druyvesteyn, F. M. Penning, Revs. Modern Phys. 12, 87 (1940)

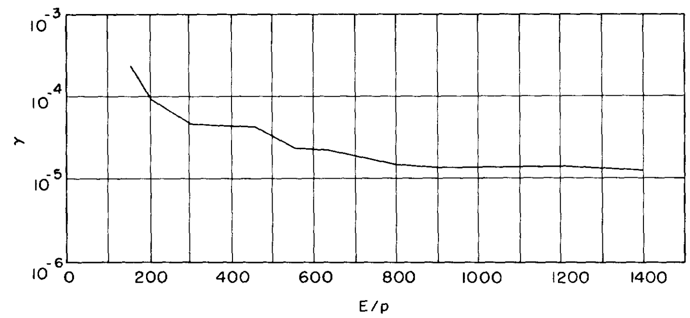


IIIb2. Second Townsend coefficient for argon with different cathode materials.

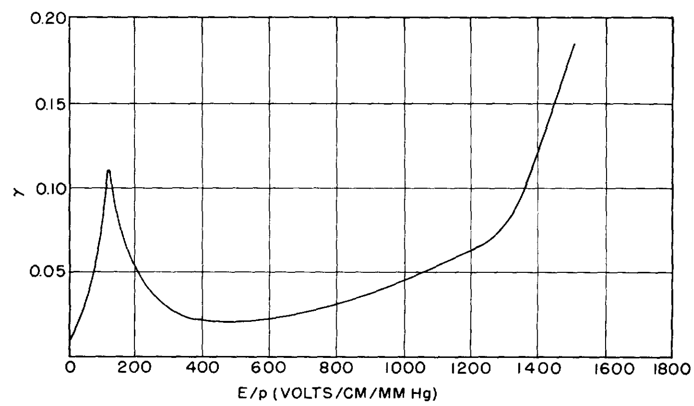
M. J. Druyvesteyn, F. M. Penning, Revs. Modern Phys. 12, 87 (1940)
R. Schöfer, Z. Physik 110, 21 (1938)



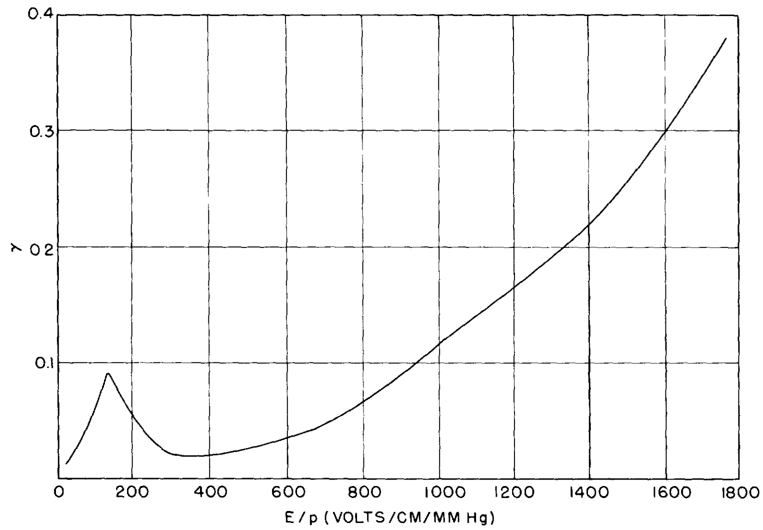
IIIb3. Second Townsend coefficient of Ne^+, A^+, and Kr^+, incident on a clean molybdenum cathode, and of A^+ on a partially activated coated cathode. R. N. Varney, Phys. Rev. 93, 1156 (1954)



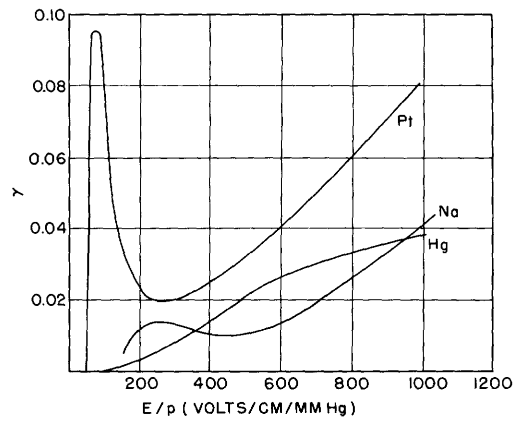
IIIb4. Values of γ as a function of E/p for mercury gas with iron electrodes. E. Badareu, G. G. Bratescu, Bull. Soc. Roumaine Phys. 45, 9 (1944)



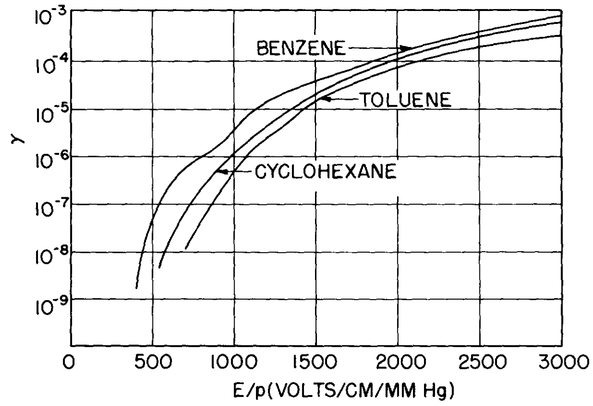
IIIb5. Values of γ as a function of E/p for H_2 gas with Al electrodes. D. H. Hale, Phys. Rev. 56, 1199 (1939)



IIIb6. Values of γ as a function of E/p for H_2 gas with Ni electrodes.
D. H. Hale, Phys. Rev. 56, 1199 (1939)



IIIb7. Values of γ as a function of E/p in nitrogen.
W. E. Bowls, Phys. Rev. 53, 293 (1938)



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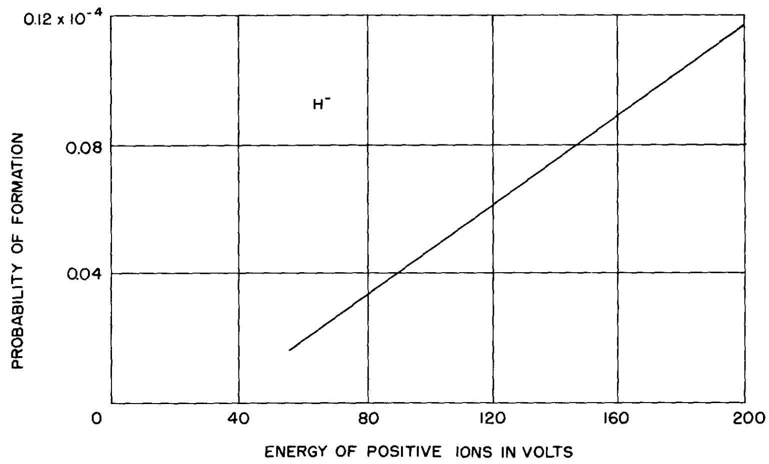
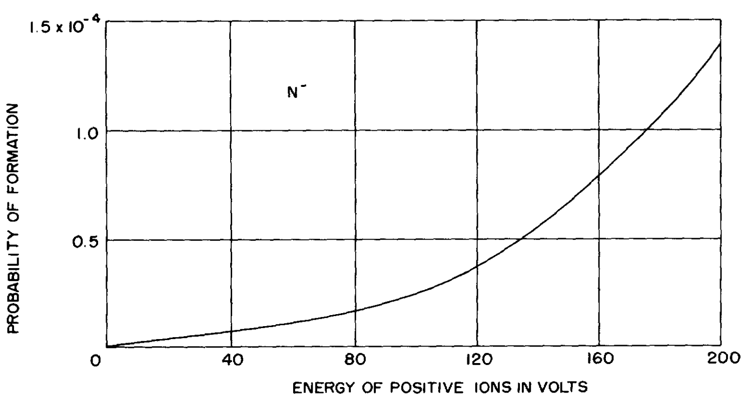


IIIc1. Probability of conversion of positive hydrogen ions into negative hydrogen ions on nickel.

F. L. Arnot, Proc. Roy. Soc. (London) A158, 137 (1937)



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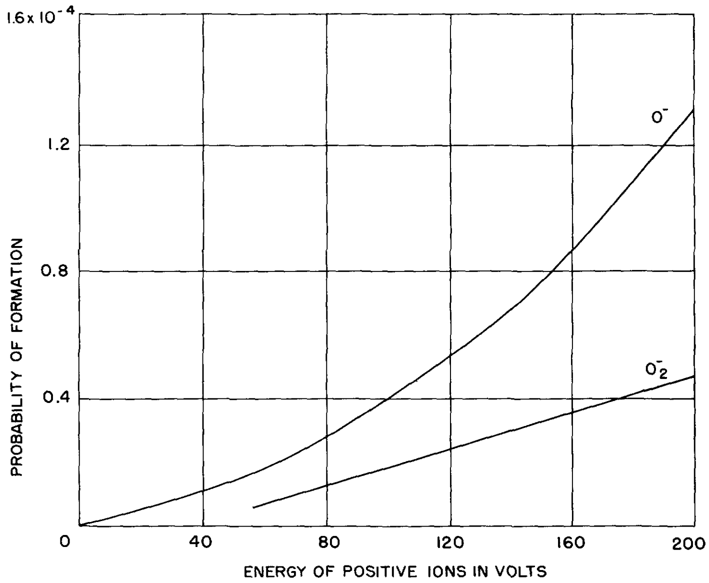
F. L. Arnot, Proc. Roy. Soc. (London) A158, 137 (1937)



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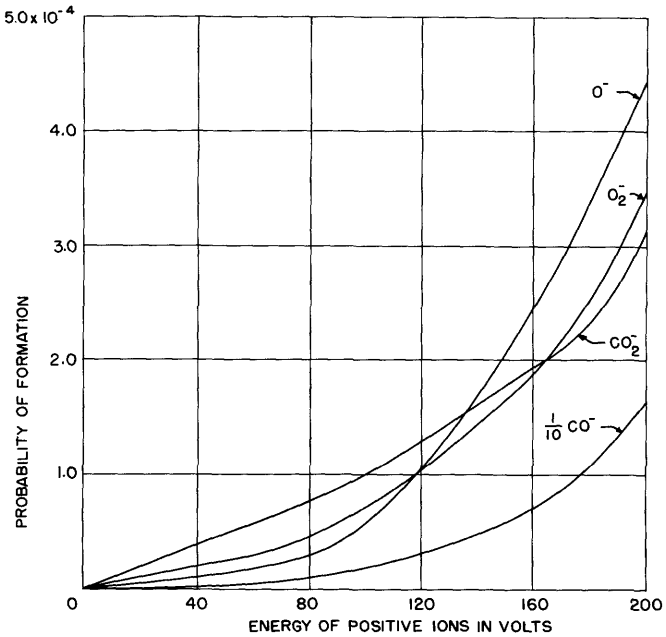
F. L. Arnot, Proc. Roy. Soc. (London) A158, 137 (1937)



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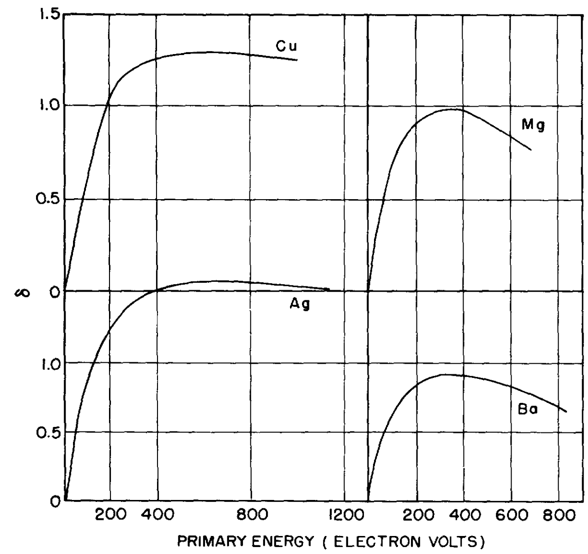
F. L. Arnot, Proc. Roy. Soc. (London) A158, 137 (1937)



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H. S. W. Massey, E. H. S. Burhop, Electronic and Ionic Impact Phenomena (Clarendon Press, Oxford, 1952), p. 306

III(el). Photoelectric Work Functions of Elements

Element	Work Function (volts)	Reference
Ag	4.74	1
Al	4.36	2
As	4.79	3
Au	4.92	4
Ba	2.49	5
Be	3.92	6
Bi	4.26	7
C	4.81	8
Ca	2.42	9
Cd	3.68	10
Co	4.55	11
Cr	3.76	12
Cs	1.38	13
Cu	4.8	14
Fe	4.7	15
Ga	4.12	16
Ge	4.73	17
Hg	4.50	18
K	2.20	19
Li	2.42	20
Mg	2.74	21
Mn	3.76	22
Mo	4.15	23
Na	2.29	24
Ni	5.06	25
Pb	3.97	26
Pd	4.97	27
Pt	6.35	28
Rb	2.09	29
Rh	4.57	30
Sb	4.56	31
Se	5.11	32
Sn	3.62	33
Sr	2.24	34
Ta	4.12	35
Te	4.76	36
Th	3.47	37
Ti	4.17	38

III(e1). Photoelectric Work Functions of Elements

Element	Work Function (volts)	Reference
U	3.63	39
V	3.77	40
W	4.49	41
Zn	4.307	42
Zr	3.73	43

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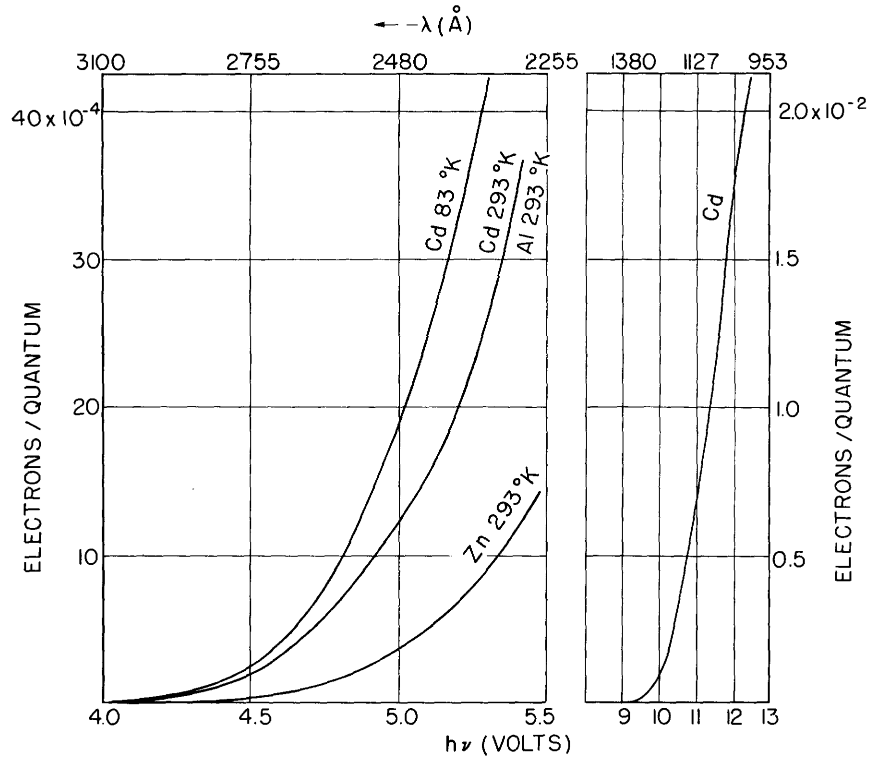
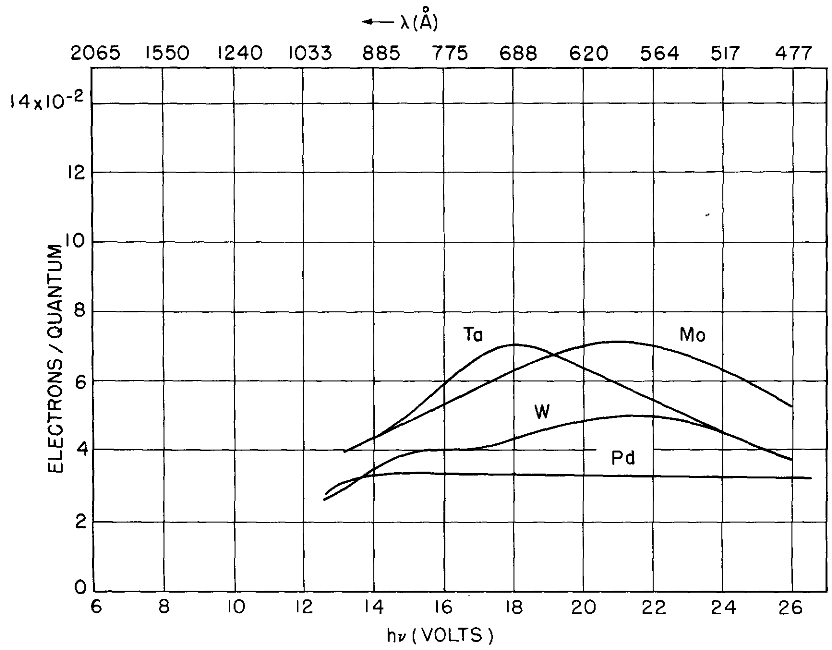


III e2. Photoelectric yields from Al, Cd, and Zn.

G. L. Weissler, Handbuch der Physik (Springer Verlag, Berlin, 1956), Vol. 21, p. 304



III e3. Photoelectric yields from Ta, Mo, W, and Pd.

G. L. Weissler, Handbuch der Physik (Springer Verlag, Berlin, 1956), Vol. 21, p. 304

IV. MOTIONS OF ELECTRONS AND IONS

The drift velocity $\vec{v_d}$ of a charged particle of mass m and charge e in a gas of molecules of mass M, under an electric field $\vec{E}$, is given by

$$\vec{v_d} = e\vec{E}\,\frac{M+m}{Mm}\int \ell\,\frac{\partial f}{\partial v}\,\frac{4\pi}{3}\,v^2\,dv \tag{1}$$

where f(v) is the velocity distribution function.

For particles with a constant mean free time τ_c this yields, for all E/p,

$$\vec{v_d} = \frac{M+m}{Mm}\,e\vec{E}\,\tau_c \tag{2}$$

If collisions are caused by a polarization force

$$\tau_c = \frac{1.8096\,\epsilon_o}{e\,n_g}\left(\frac{Mm/\alpha}{M+m}\right)^{1/2} \tag{3}$$

where the polarizability $\alpha = (\epsilon - \epsilon_o)/n_g$.

For particles with a constant mean free path ℓ_c (rigid spheres) there are two limiting forms:

(a) near thermal equilibrium

$$\vec{v_d} = \frac{3\,e\vec{E}\,\ell_c}{8}\left(\frac{\pi}{2\,kT}\,\frac{M+m}{Mm}\right)^{1/2} \tag{4}$$

(b) for high E/p

$$\vec{v_d} = a\left(\frac{M+m}{m}\right)^{1/4}\left(\frac{eE\ell_c}{M}\right)^{1/2} \qquad a = \begin{cases} 0.8973 & \text{for } m \ll M \\ 0.9643 & \text{for } m = M \\ 1 & \text{for } m \gg M \end{cases} \tag{5}$$

The mobility μ in a mixture of gases a, b, c, ... is given by Blanc's law

$$\frac{1}{\mu} = \frac{1}{\mu_a} + \frac{1}{\mu_b} + \frac{1}{\mu_c}\ \cdots \tag{6}$$

where μ_a, μ_b, μ_c, ... are the mobilities in the pure gases a, b, c, ... at their partial pressures p_a, p_b, p_c, ... provided the mobilities are sensibly independent of field strength.

Because of charge transfer when moving in the parent gas and clustering in the presence of an attaching gas, ions may move considerably slower than indicated by these equations.

In the case of a constant mean free time τ_c, the mobility in an ac electric field of circular frequency ω and in the presence of a magnetic field whose component perpendicular to the electric field is $B_\perp$, is given by

$$\mu = \frac{e/2m}{\nu_c + j(\omega + \omega_b)} + \frac{e/2m}{\nu_c + j(\omega - \omega_b)} \tag{7}$$

where $\omega_b = B_\perp \; e/m$ is the cyclotron frequency.

The complex conductivity of a plasma is given by

$$\sigma = n_+ e \; \mu_+ + n_- e \; \mu_- + j\omega \epsilon_o \tag{8}$$

For a completely ionized plasma

$$\sigma = \frac{1.1632 \; m}{z \; \ln(q-1)} \left(\frac{4\pi \epsilon_o}{e}\right)^2 \left(\frac{2 \; kT}{\pi \; m}\right)^{3/2} = \frac{19141}{z \; \ln(q-1)} \left(\frac{kT}{e}\right)^{3/2} \text{ mho/meter} \tag{9}$$

where $q = 12\pi \, n \, \lambda_D^3$, $\lambda_D^2 = \epsilon_o \, kT/ne^2$ is the Debye length, and $n \, \lambda_D^2 = 3.134 \times 10^4 T$ meters^{-1}. z is the charge on the ions.

If λ is the mean fraction of the energy difference which is transferred in a collision, the mean energy of an electron or ion is given by

$$\frac{1}{2} m \overline{v^2} = \frac{3}{2} kT + e E \tau_c \, v_d/\lambda \tag{10}$$

For elastic collisions

$$\lambda = 2 \; Mm/(M+m)^2$$

For the mean free time case

$$\frac{v_d^2}{\overline{v^2}} = \frac{M + m}{2 \; M} \lambda \left(1 - \frac{3 \; kT}{m \overline{v^2}}\right) \tag{11}$$

Mean energies are usually determined by the approximate relation

$$\frac{D}{\mu} = \frac{m\left(\overline{v^2} - v_d^2\right)}{3 \; e} \tag{12}$$

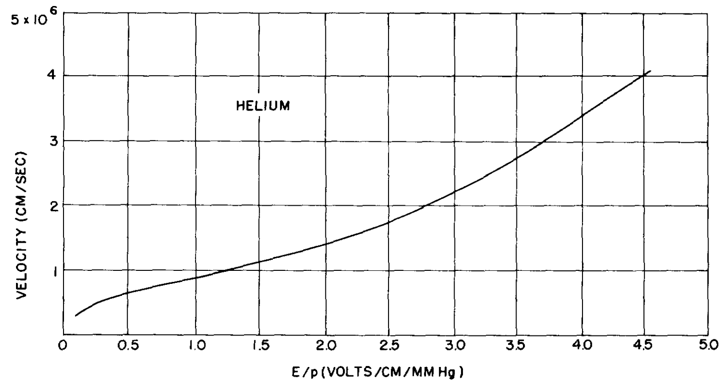
which is exact when the distribution function is Maxwellian.

The diffusion coefficient is given by

$$D = \int \frac{\ell v}{3} f \; 4\pi \, v^2 \, dv \tag{13}$$

When the Debye length λ_D is less than the diffusion length Λ, oppositely charged particles will be constrained by the space-charge field to diffuse at the same rate. This is termed ambipolar diffusion, and the common diffusion coefficient is

$$D_a = \frac{\mu_+ D_- + \mu_- D_+}{\mu_+ + \mu_-} = D_+ \frac{1 + T_-/T_+}{1 + \mu_+/\mu_-}$$



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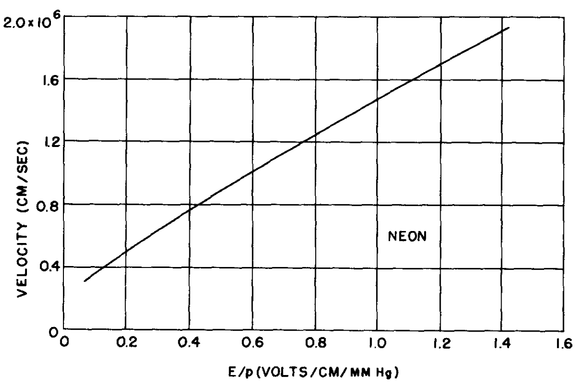
J. A. Hornbeck, Phys. Rev. 83, 374 (1951)



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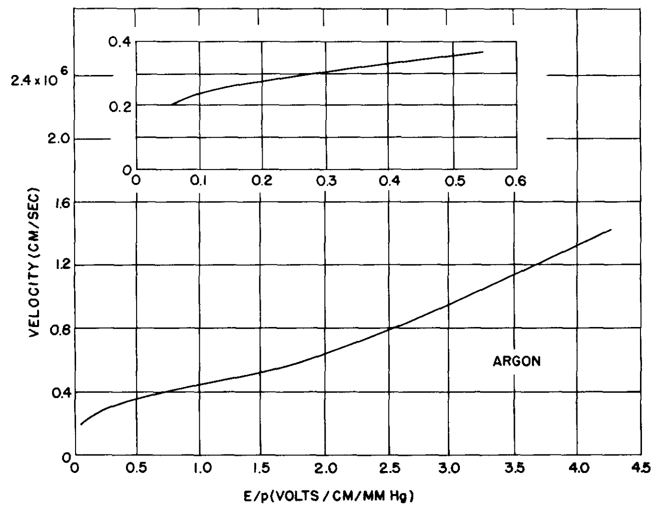
R. A. Nielsen, Phys. Rev. 50, 950 (1936)



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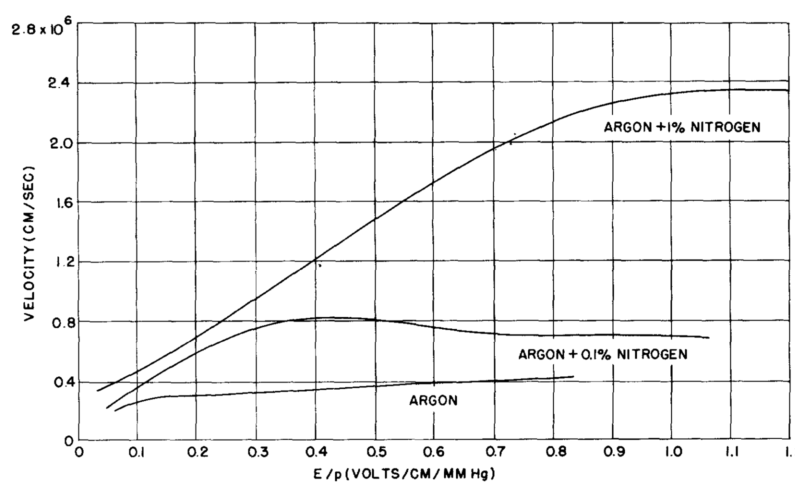

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L. Colli, U. Facchini, Rev. Sci. Instr. 23, 39 (1952)
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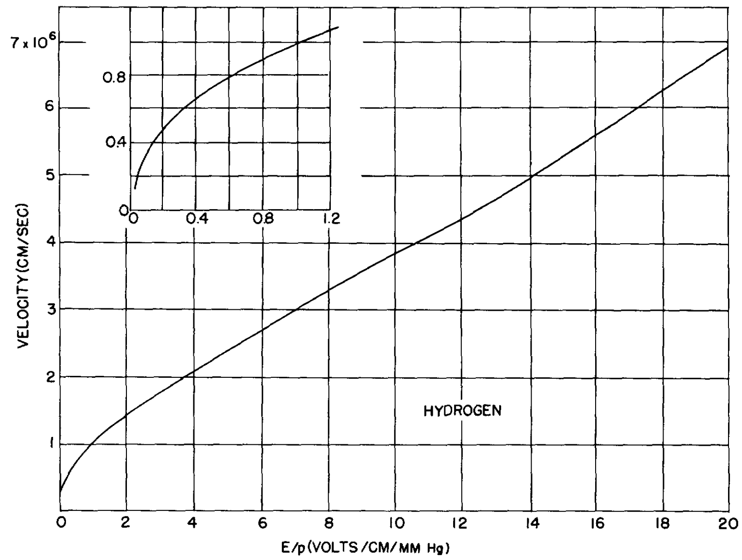

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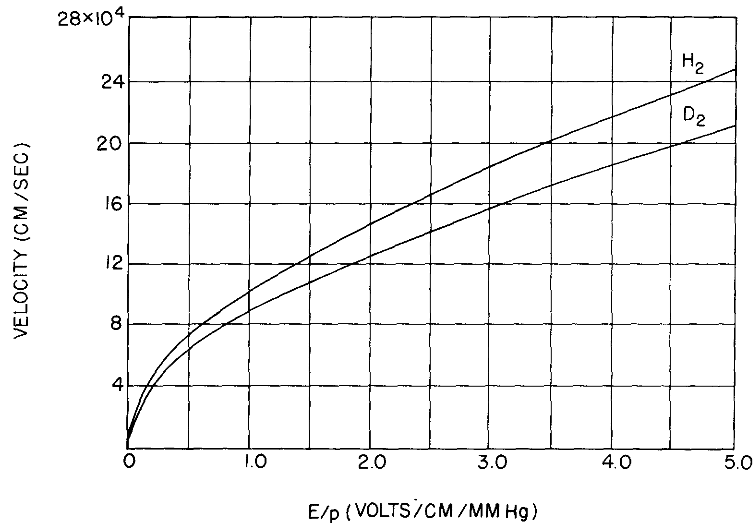
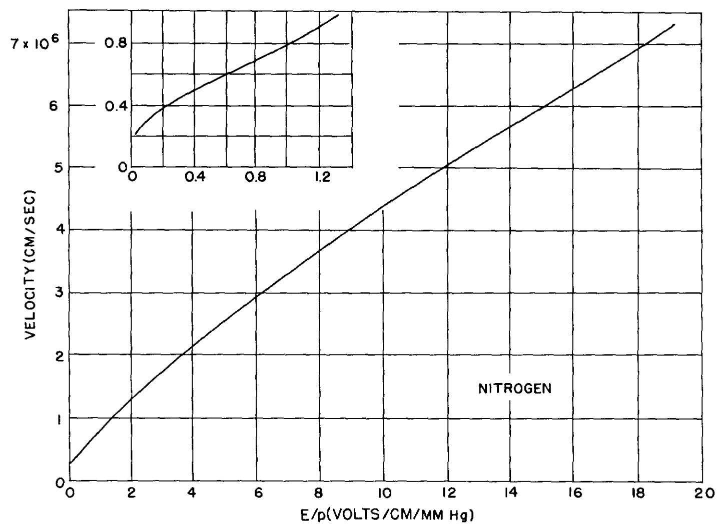


IV a6. Drift velocity of electrons in hydrogen and deuterium.
B. I. H. Hall, Australian J. Phys. 8, 468 (1955)



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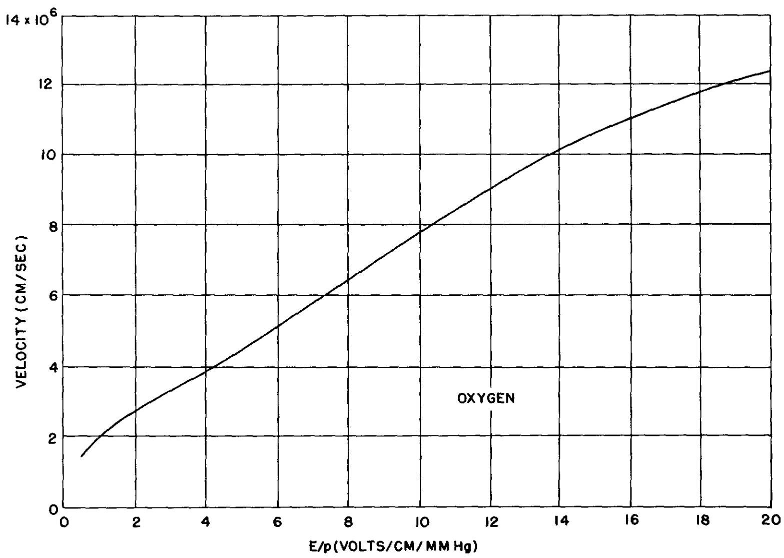

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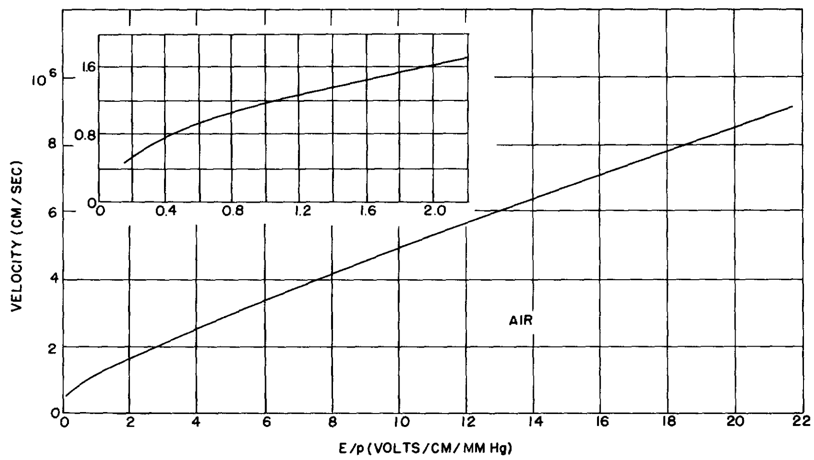

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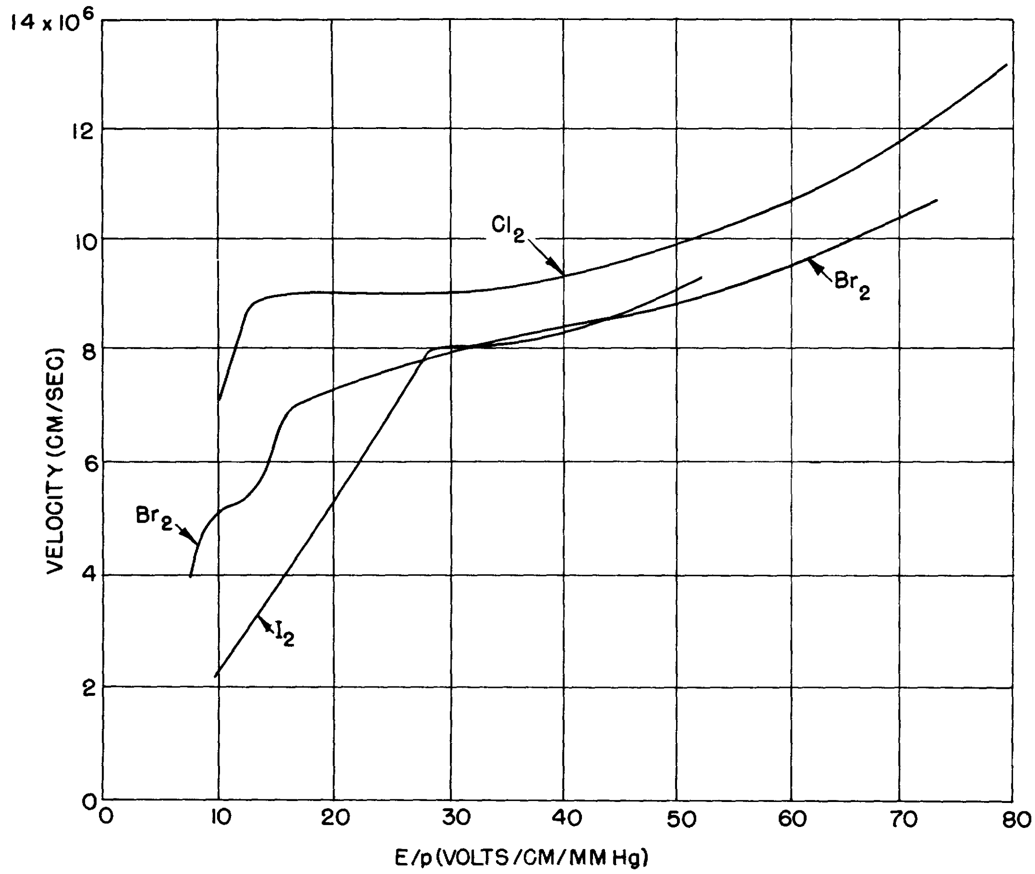

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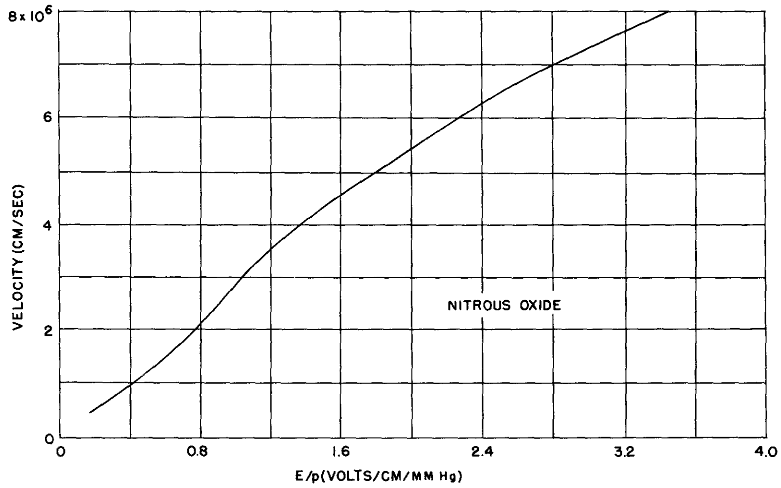
R. H. Healey, J. W. Reed, The Behavior of Slow Electrons in Gases, Amalgamated Wireless, Ltd., Sydney, 1941, p. 53



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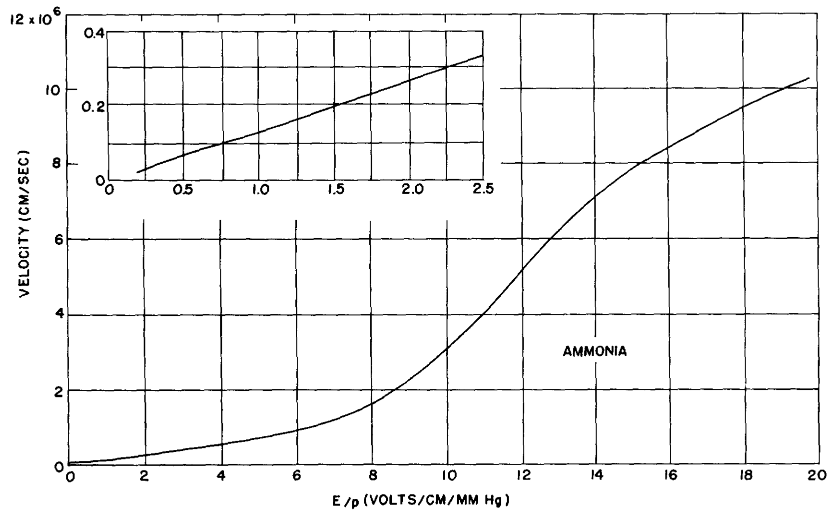

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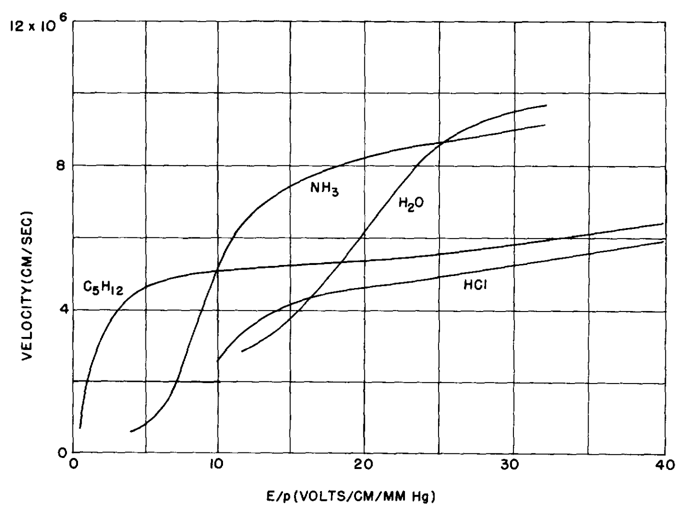

IV a13. Drift velocity of electrons in C_5H_{12}, NH_3, H_2O, and HCl.
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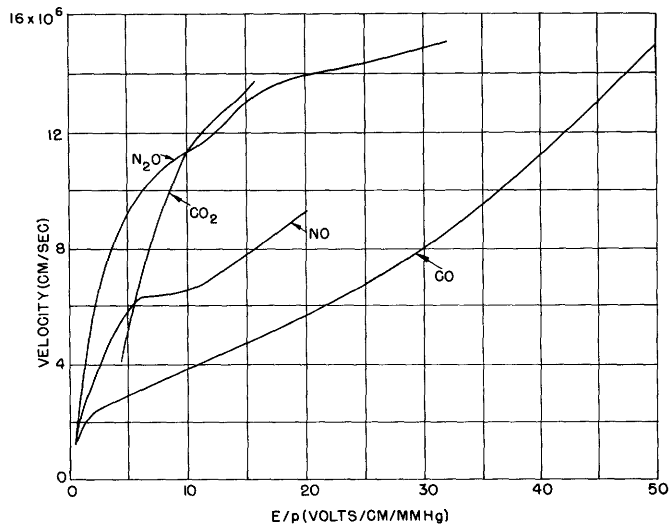

IV a14. Drift velocity of electrons in N_2O, CO_2, NO, and CO.
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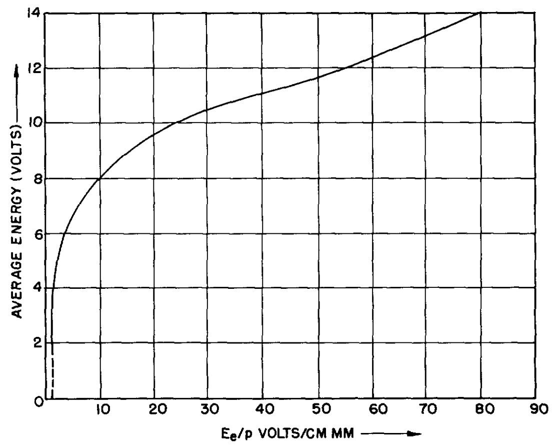

IV b1. Average energy of electrons in helium.
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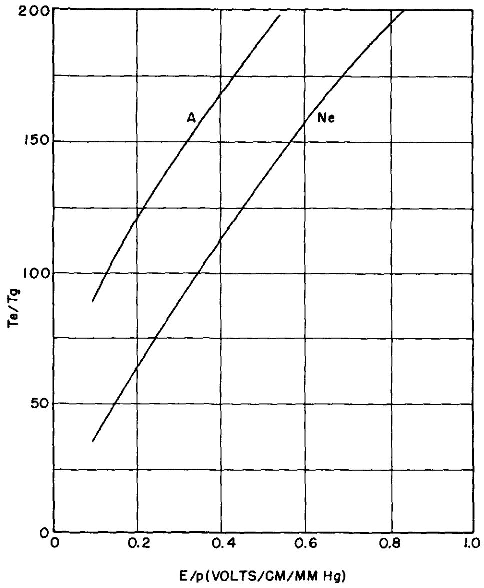

IV b2. Ratio of electron to gas temperature.

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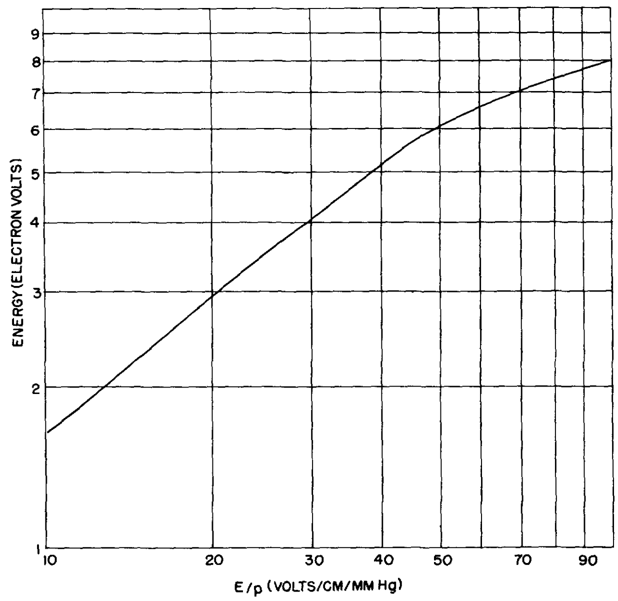

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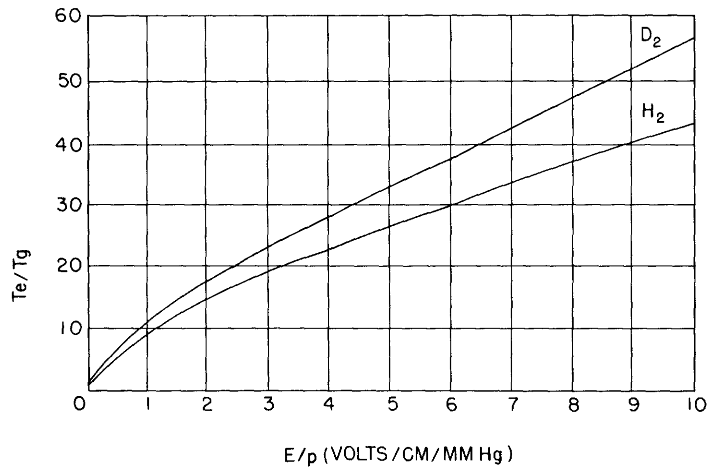
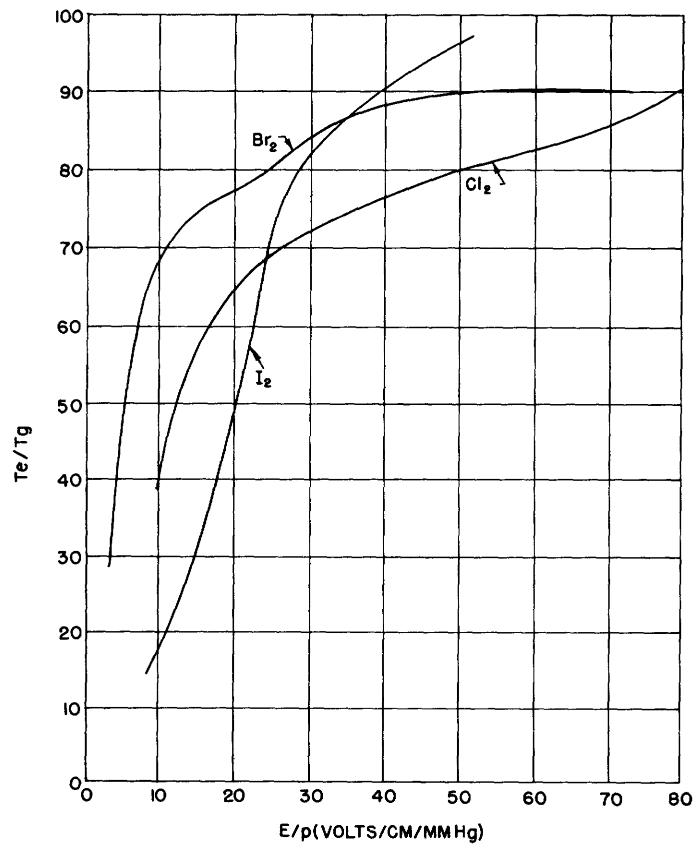


IV b4. Ratio of electron to gas temperature in deuterium and hydrogen.

B. I. H. Hall, Australian J. Phys. 8, 468 (1955)



IV b5. Ratio of electron to gas temperature.

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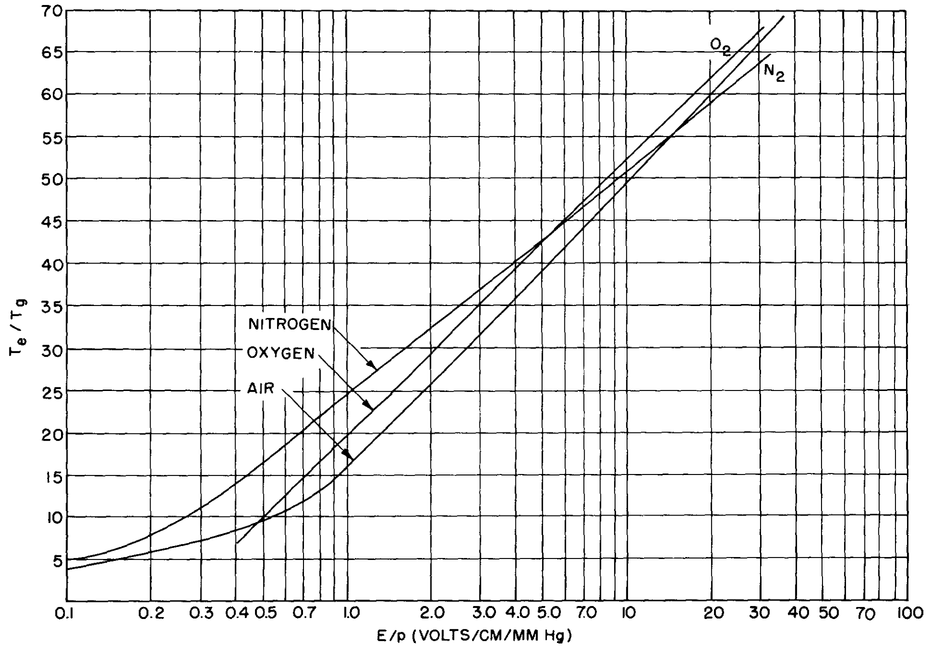

IV b6. Ratio of electron to gas temperature.

Air: R. W. Crompton, L. G. H. Huxley, D. J. Sutton, Proc. Roy. Soc. (London) A218, 507 (1953)

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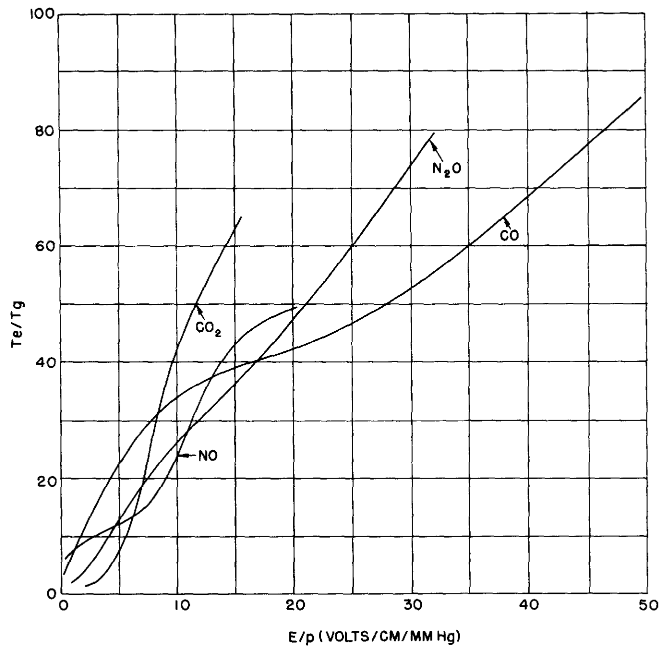
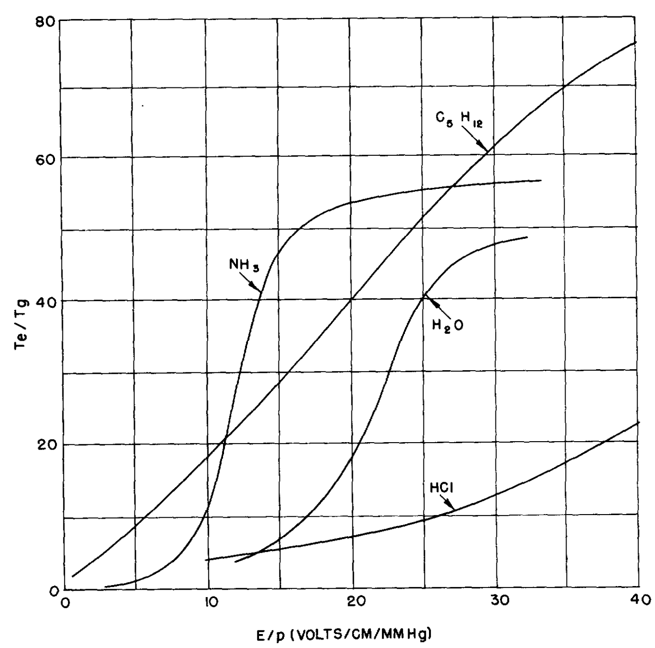
O_2: R. H. Healey, J. W. Reed, The Behavior of Slow Electrons in Gases, Amalgamated Wireless, Ltd., Sydney, 1941, p. 79



IV b7. Ratio of electron to gas temperature.

R. H. Healey, J. W. Reed, The Behavior of Slow Electrons in Gases, Amalgamated Wireless, Ltd., Sydney, 1941, p. 80



IV b8. Ratio of electron to gas temperature.

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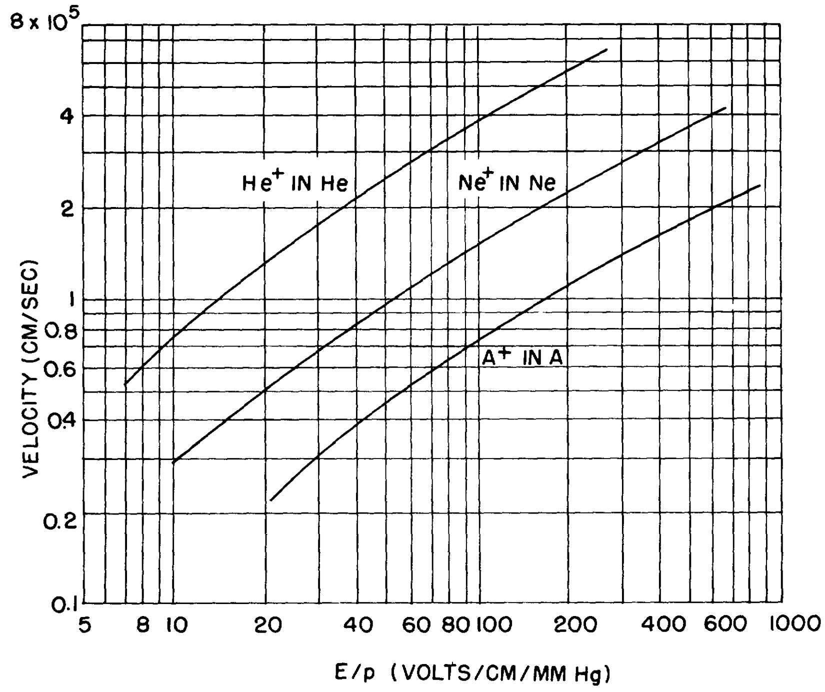

IV c1. Drift velocity of atomic ions in helium, neon, and argon.
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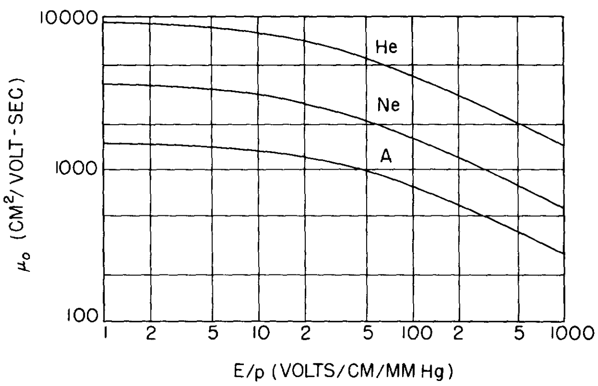

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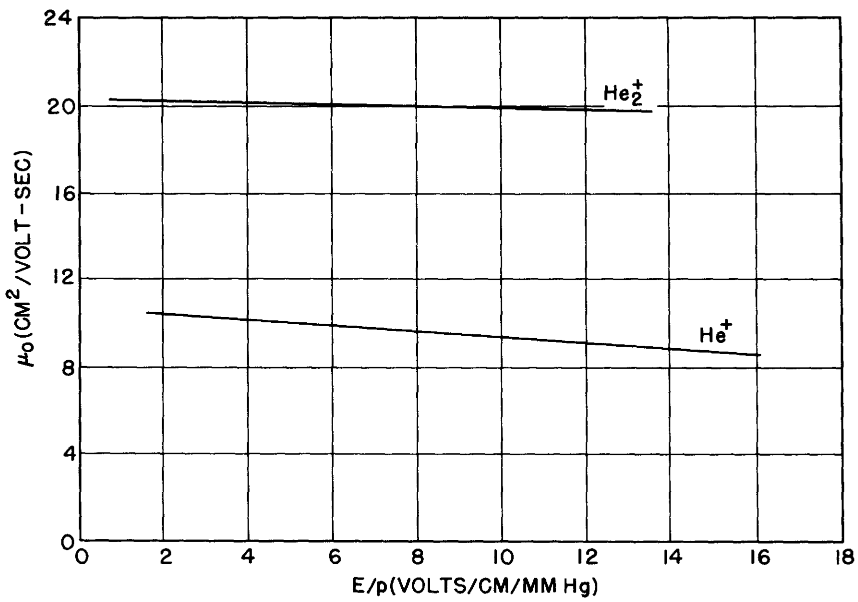

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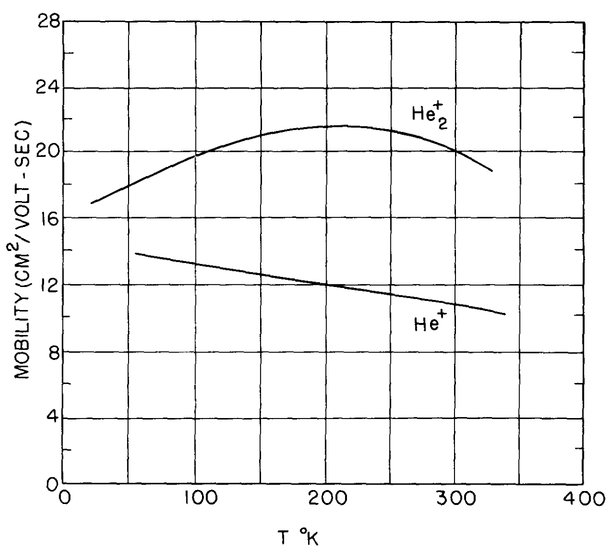
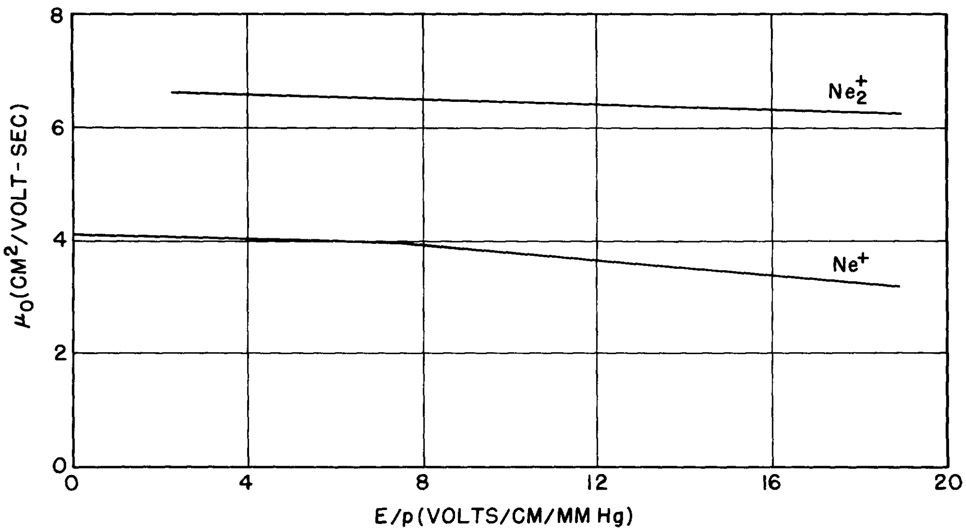
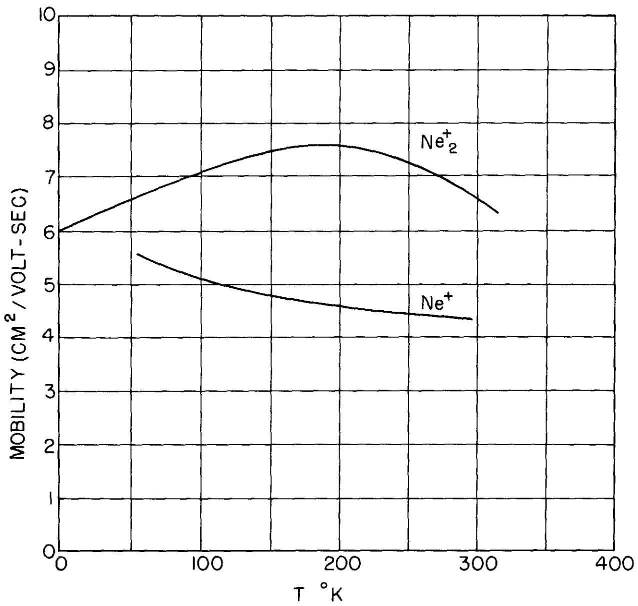


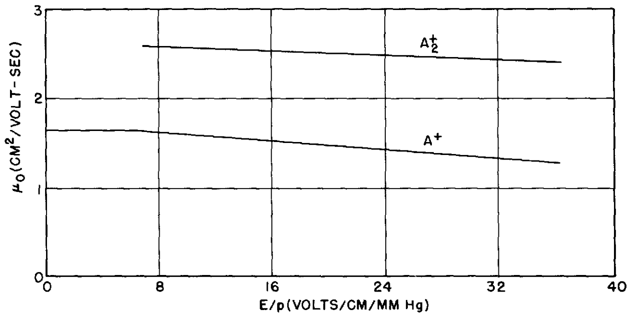
IV c2. Helium ion mobility as a function of temperature.
L. M. Chanin, M. A. Biondi, Phys. Rev. 106, 473 (1957)



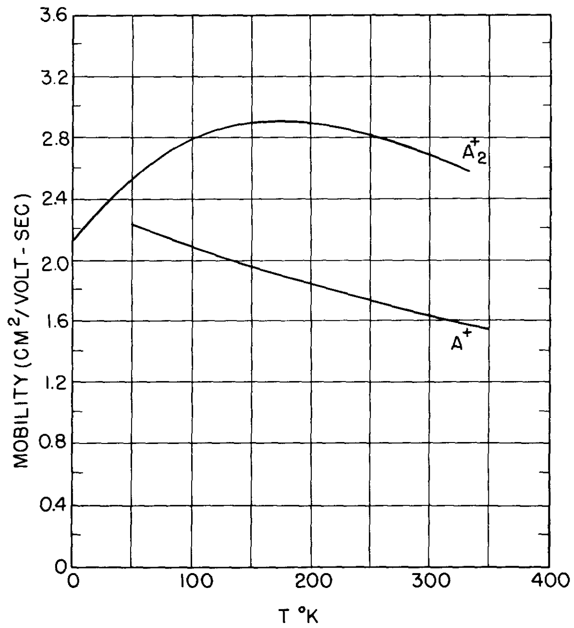
IV c3. Mobility of Ne^+ and Ne_2^+ in neon.
M. A. Biondi, L. M. Chanin, Phys. Rev. 94, 910 (1954)



IV c3. Neon ion mobilities as a function of temperature.
L. M. Chanin, M. A. Biondi, Phys. Rev. 106, 473 (1957)



IV c4. Mobility of A^+ and A_2^+ in argon.
M. A. Biondi, L. M. Chanin, Phys. Rev. 94, 910 (1954)



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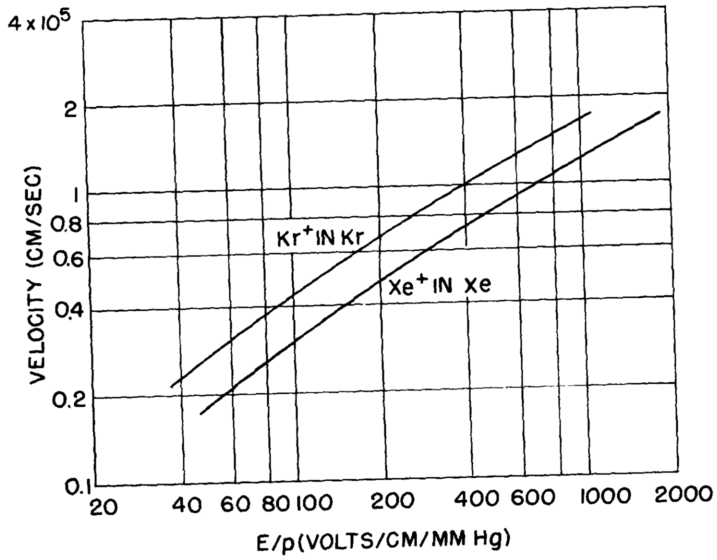
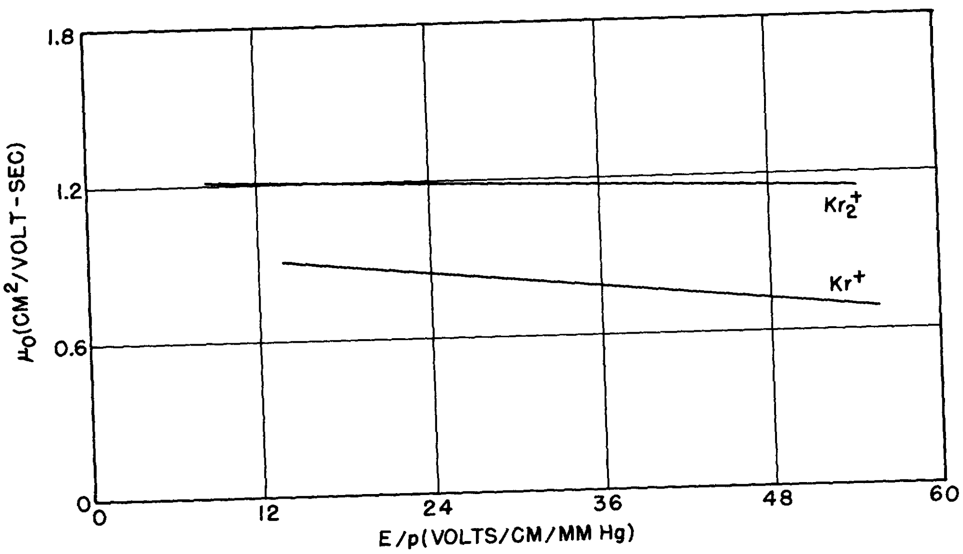


IV c5. Drift velocity of atomic ions in krypton and xenon.
R. N. Varney, Phys. Rev. 88, 362 (1952)



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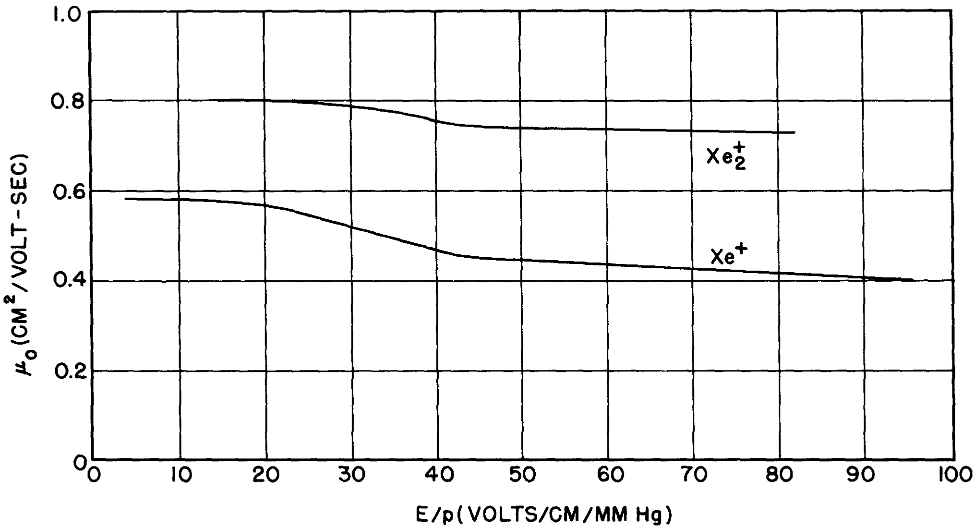

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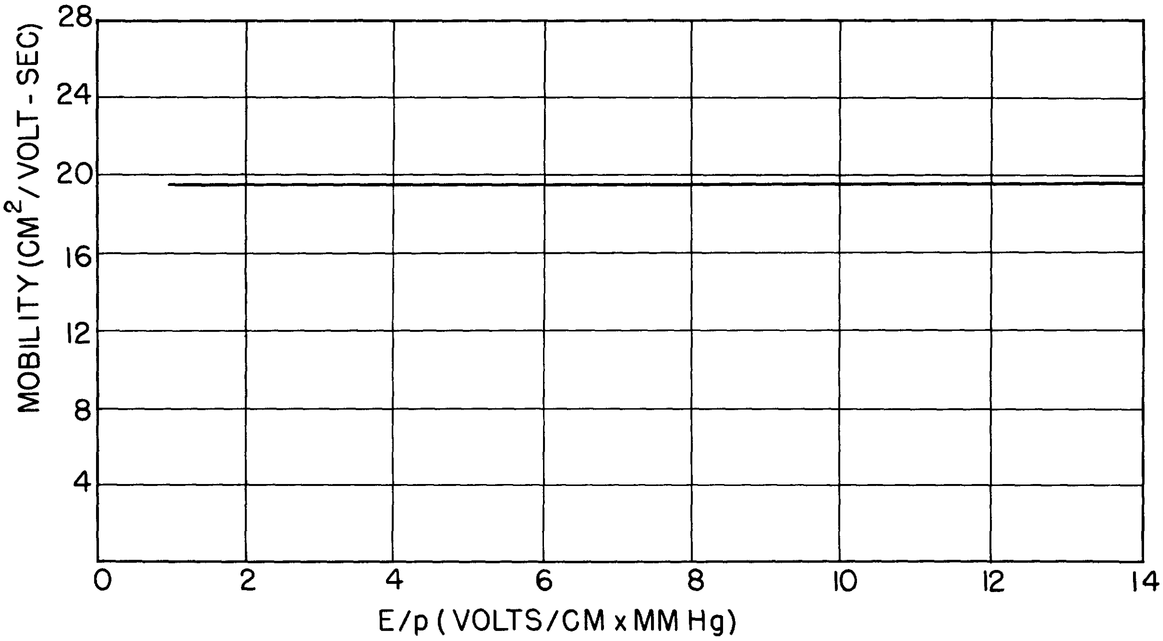
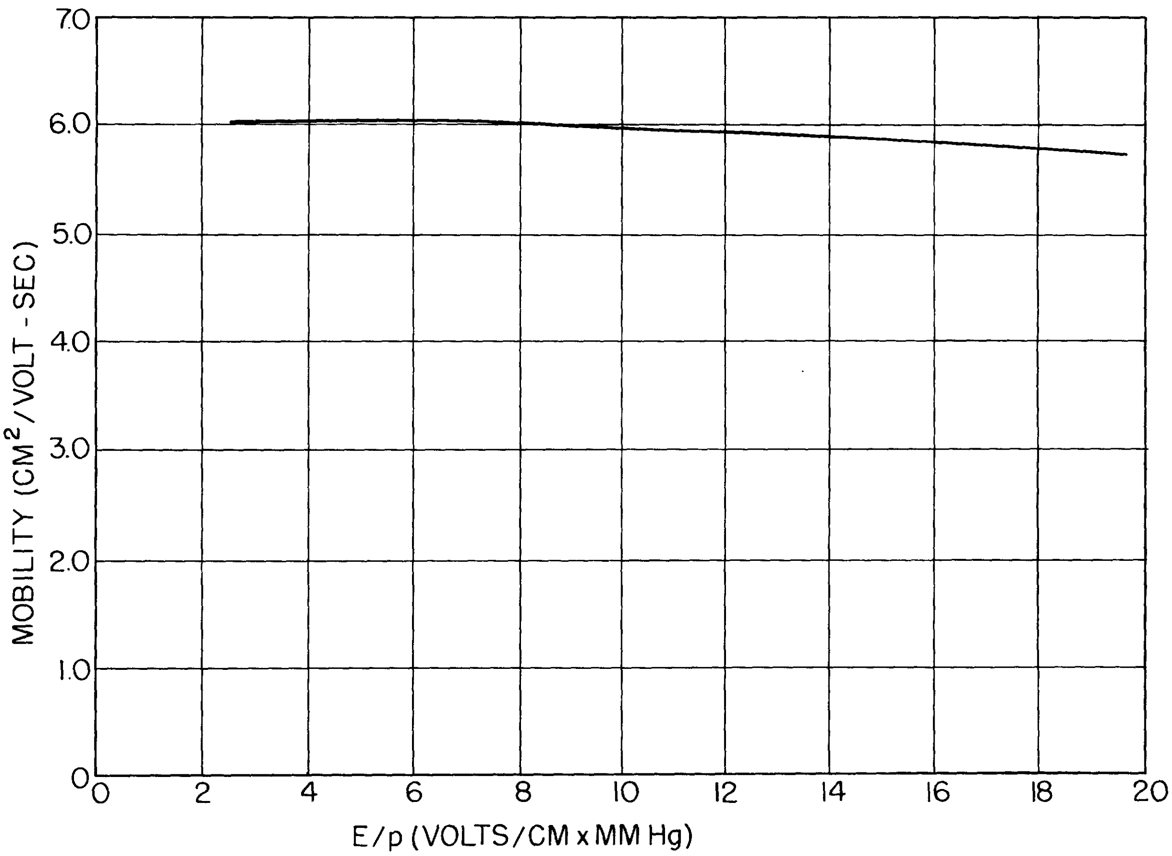
M. A. Biondi, L. M. Chanin, Phys. Rev. 94, 910 (1954)



IV c8. Mobility of mercury ions in helium at 300° K.
L. M. Chanin, M. A. Biondi, Phys. Rev. 107, 1219 (1957)



IV c9. Mobility of mercury ions in neon at 300° K.
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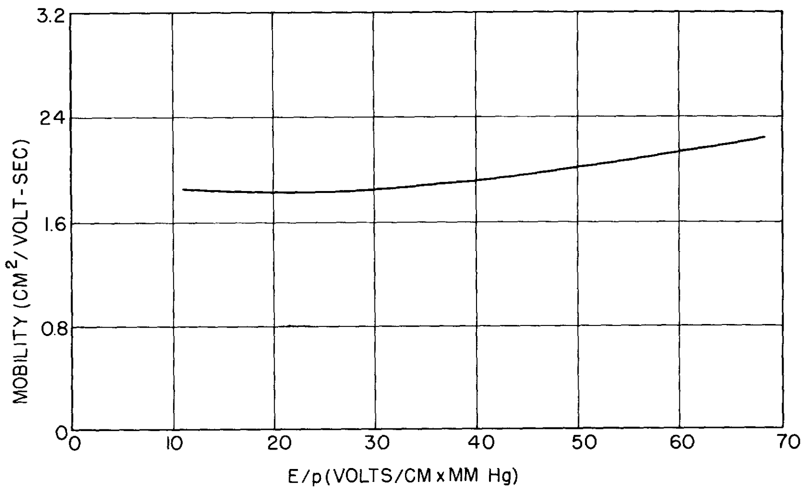

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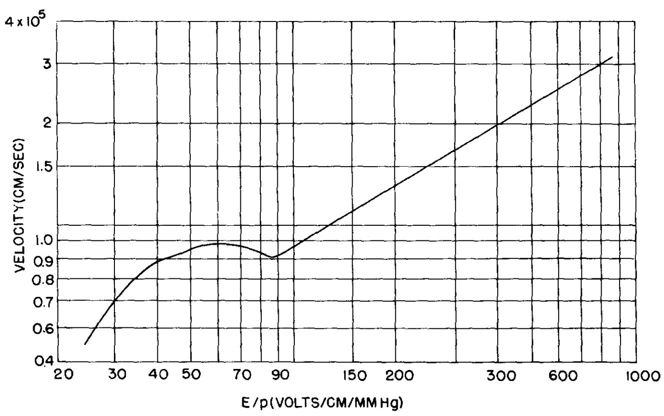
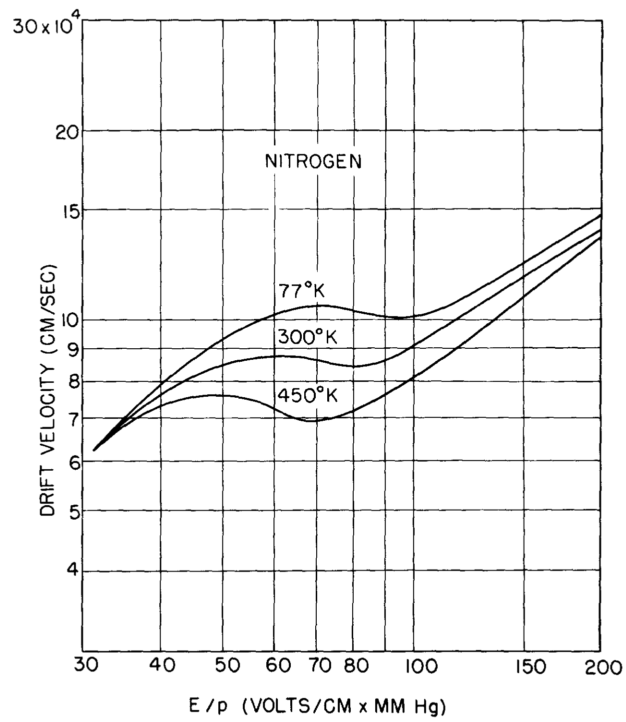
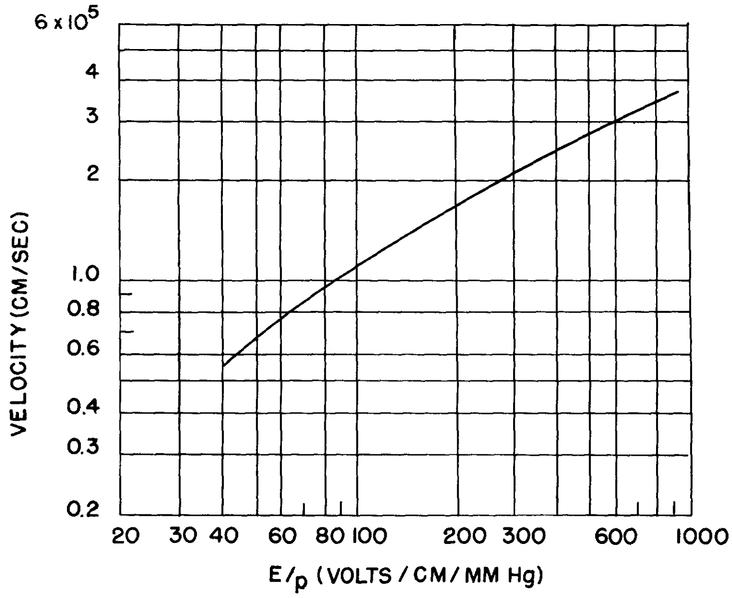
L. M. Chanin, M. A. Biondi, Phys. Rev. 107, 1219 (1957)



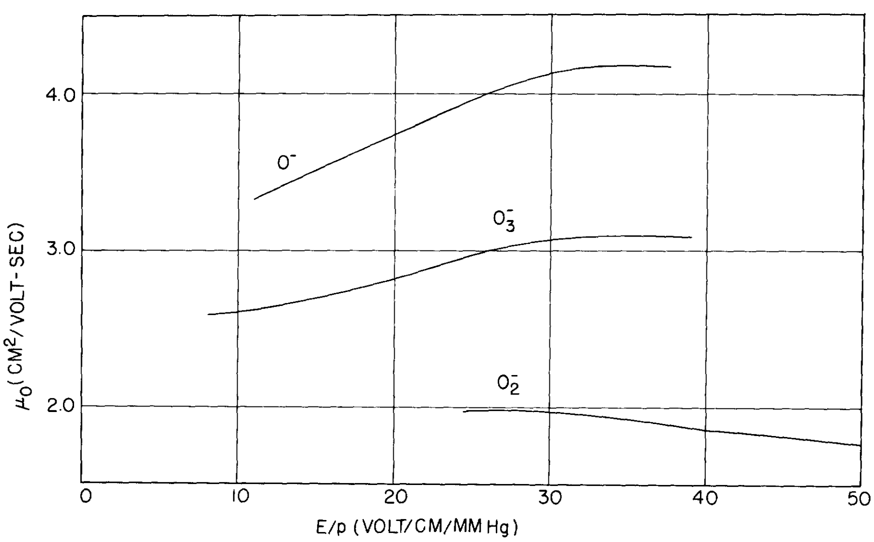
IV c11. Drift velocity of ions in nitrogen. Low (E/p) N_4^+, high (E/p) N_2^+.
R. N. Varney, Phys. Rev. 89, 708 (1953)



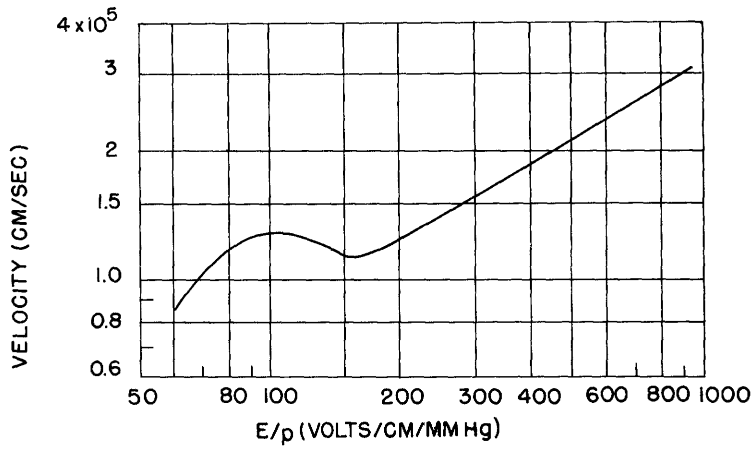
IV c11. Drift velocities of ions in N_2 at various temperatures, N_4^+ ions at low E/p, N_2^+ ions at high E/p.
F. R. Kovar, E. C. Beatty, R. N. Varney, Phys. Rev. 107, 1490 (1957)



IV c12. Drift velocity of ions in oxygen.
R. N. Varney, Phys. Rev. 89, 708 (1953)

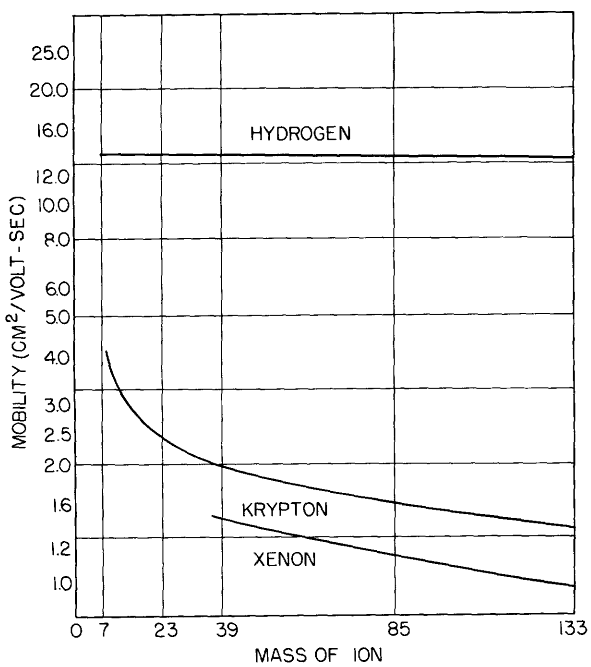


IV c13. Mobility of O^-, O_2^-, O_3^- in oxygen.
D. S. Burch, R. Geballe, Phys. Rev. 106, 183 (1957)



IV c14. Drift velocity of ions in carbon monoxide. Low (E/p) and high (E/p) CO^+, intermediate (E/p) may be CO_2^+.

R. N. Varney, Phys. Rev. 89, 708 (1953)



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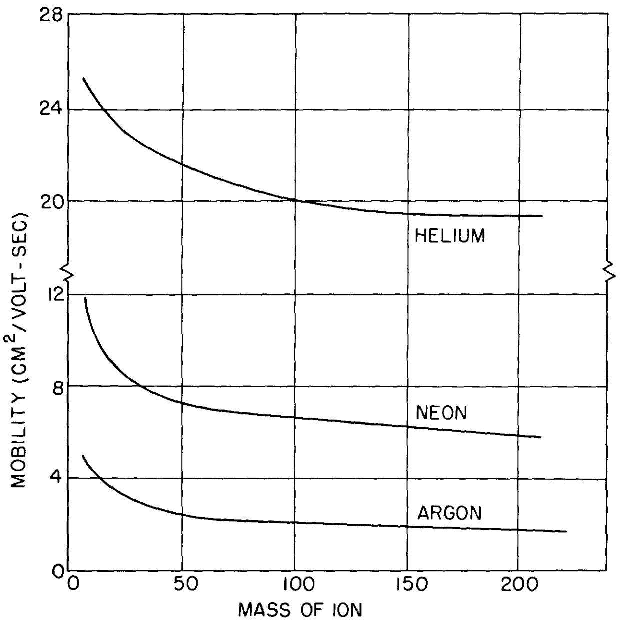
C. F. Powell, L. Brada, Proc. Roy. Soc. (London) A138, 117 (1932)



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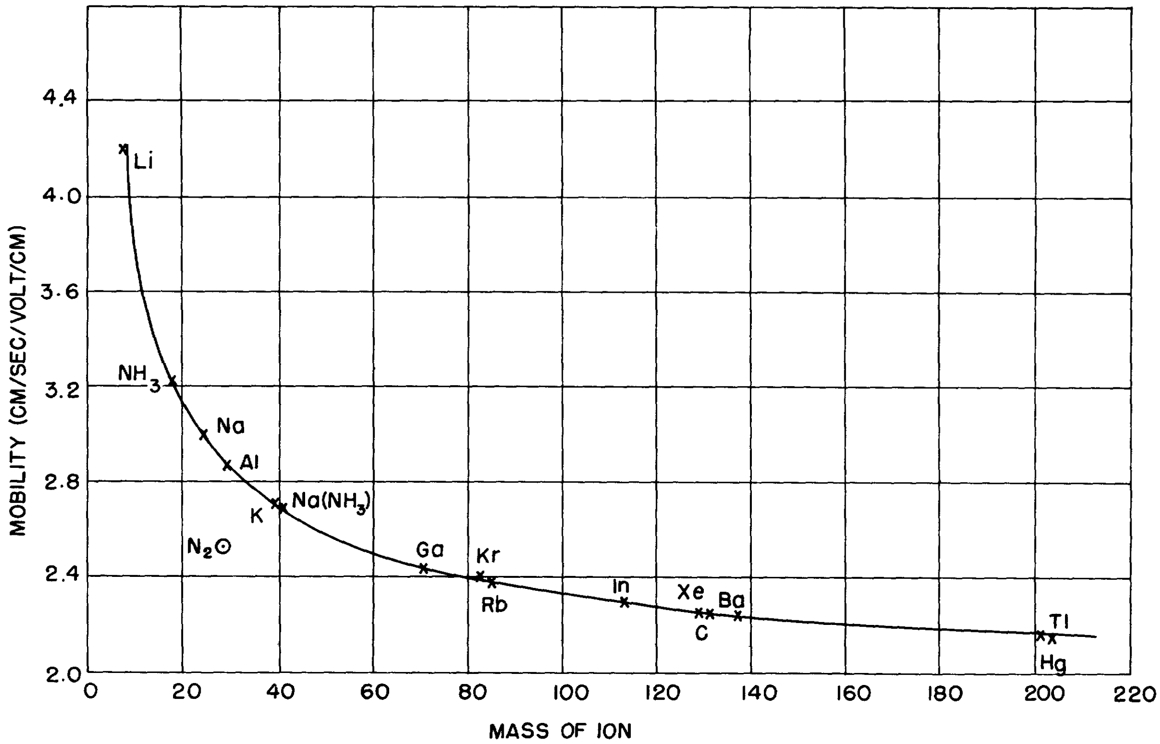

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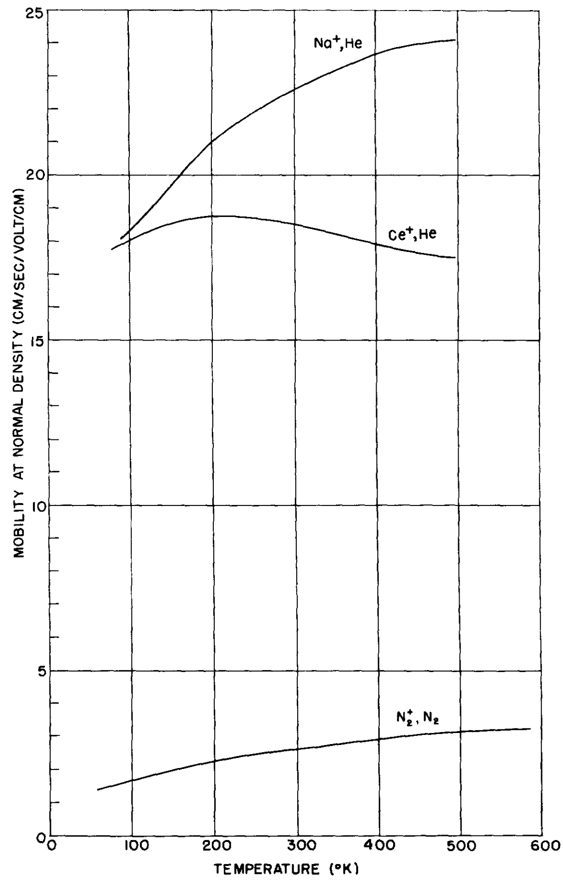

IV c17. Variation of mobility of ions with temperature.

A. M Tyndall, A. F. Pearce, Proc. Roy. Soc. A, 149, 426 (1935)
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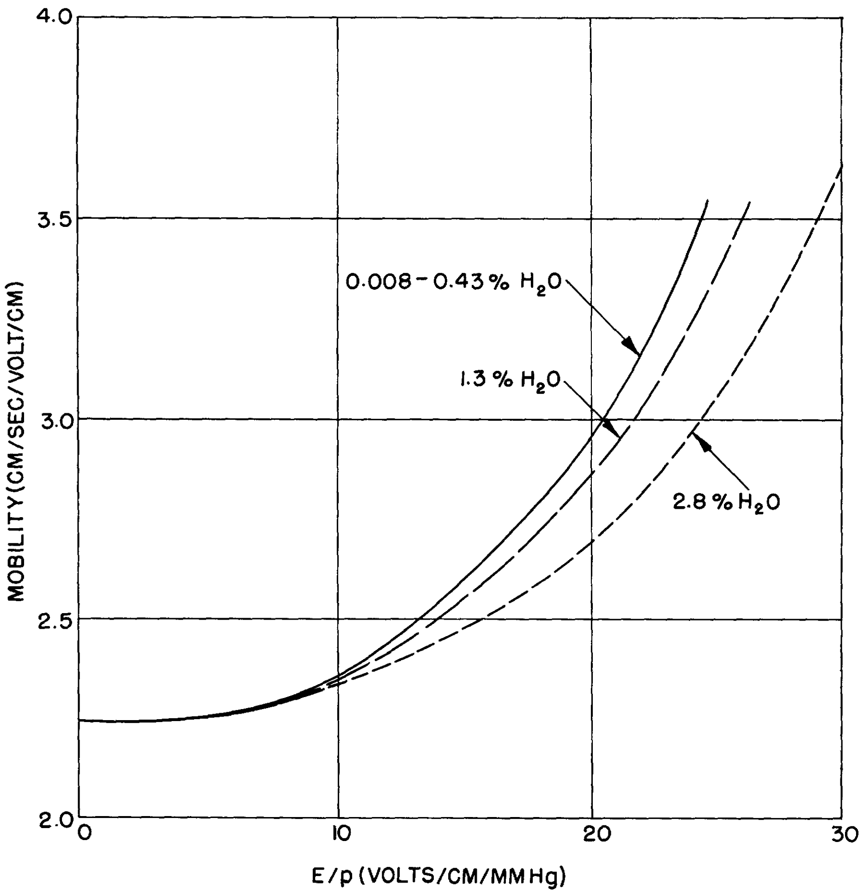

IV c18. Mobility of Li^+ ions in argon in the presence of water vapor, to show effect of clustering.

H. S. W. Massey, E. H. S. Burhop, Electronic and Ionic Impact Phenomena (Clarendon Press, Oxford, 1952), p. 414

IV(d1). Table of Ambipolar Diffusion Coefficients (room temperature)

Element	$D_a p_o$ ($cm^2 sec^{-1}$)	Reference
H_2	700	1
He	540	2
Ne	115	3
A	900	4
O^+	225	5
O_2^+	87	5

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V. PRODUCTION AND DECAY OF IONIZATION

(a) The rate of ionization by electrons in a gas is defined as $dn/dt = n\,\overline{\nu_i}$. It is related to the "probability" of ionization P_i by

$$\frac{1}{n}\frac{dn}{dt} = \overline{\nu_i} = \int p_o\, P_i\, f\, 4\pi\, v^3\, dv \tag{1}$$

The first Townsend coefficient α_i, the number of ionizations per electron per centimeter path, is

$$\alpha_i = \frac{1}{n}\frac{dn}{dx} = \frac{\overline{\nu_i}}{v_d} = \frac{\overline{\nu_i}}{\mu E} \tag{2}$$

The number of ionizations per electron per volt is

$$\eta = \frac{\alpha_i}{E} = \frac{\overline{\nu_i}}{\mu E^2} \tag{3}$$

This quantity is a function of E/p only. When there are non-ionizing inelastic collisions (no Penning effect), α_i can be represented by the function

$$\frac{\alpha_i}{p} = Ae^{-Bp/E} \tag{4}$$

where A is a slowly decreasing function of E/p.

(b) The attachment coefficient β is similar to α_i and measures the rate of attachment of electrons to neutral atoms.

$$\beta = -\frac{1}{n}\frac{dn}{dx} = \frac{\overline{\nu_a}}{\mu E} \tag{5}$$

The attachment efficiency h is the number of attachments per collision

$$h = \frac{\overline{\nu_a}}{\overline{\nu_c}} = \frac{\beta \mu E}{\overline{\nu_c}} \approx \frac{4}{3}\frac{mE}{e}\beta \mu^2 \tag{6}$$

The last expression is generally used to compute h from experimental data but is correct only if P_c is independent of electron velocity.

(c) The ion recombination coefficient α_r is defined by

$$\alpha_r = -\frac{1}{n^2}\frac{dn}{dt} \tag{7}$$

Its dependence on pressure and temperature may be represented by

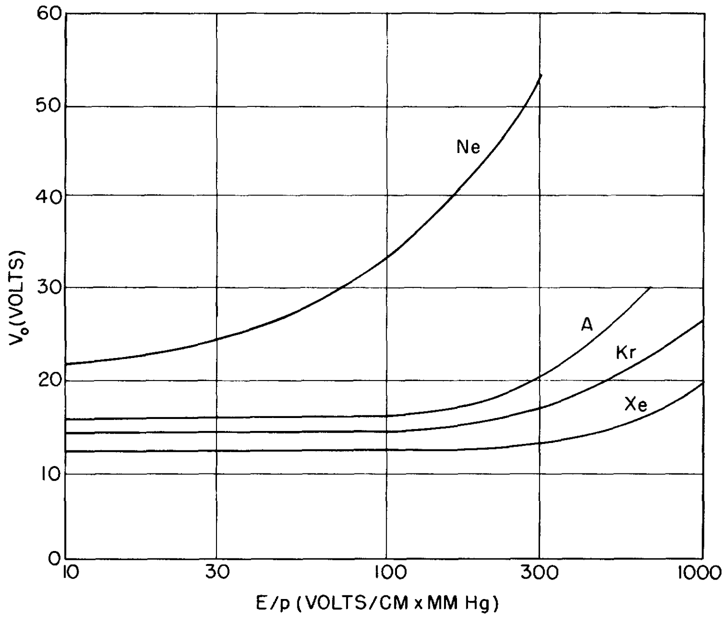
$$\frac{1}{\alpha_r} = a\frac{T^4}{p} + b\frac{p}{T} \tag{8}$$

where the first term was proposed by Thomson; the second, by Langevin.

V(a1). Table 1. Constants A and B in Eq. 4.

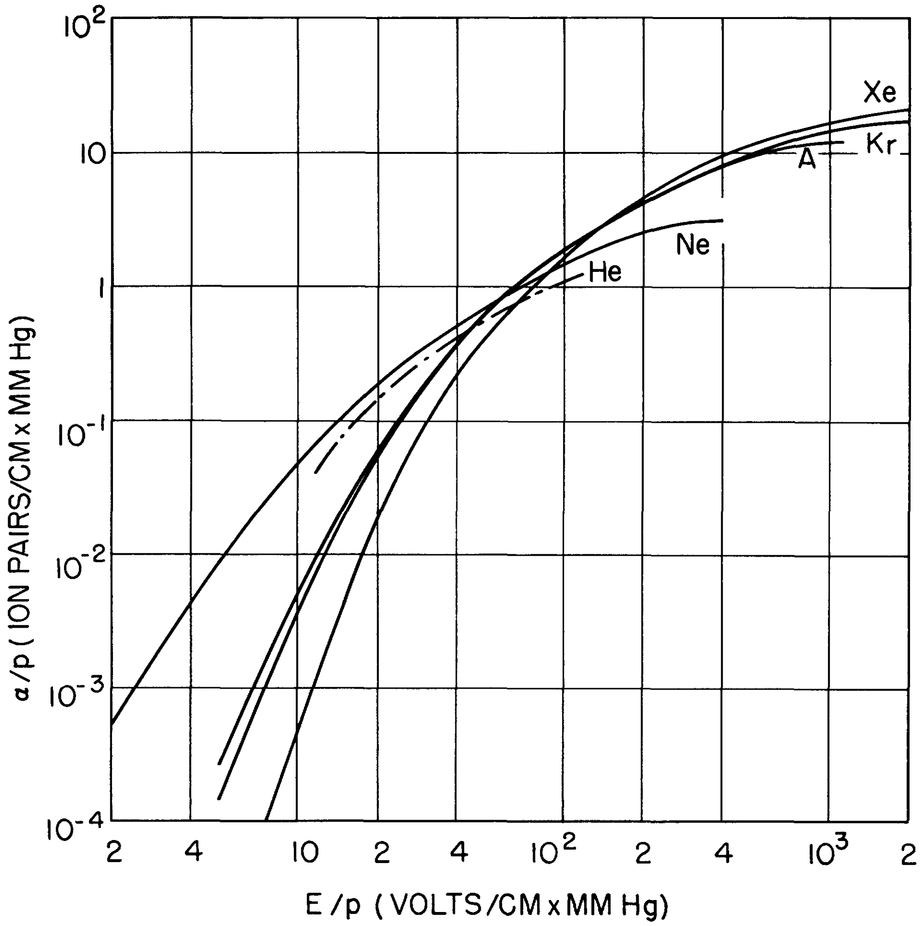
Gas	A ion pairs / cm. × mm. Hg	B V / cm. × mm. Hg	Range of validity E/p V / cm. × mm. Hg	V_i in V
H_2	5	130	150– 600	15.4
N_2	12	342	100– 600	15.5
O_2	–	–	–	12.2
CO_2	20	466	500–1000	13.7
air	15	365	100– 800	–
H_2O	13	290	150–1000	12.6
HCl	25	380	200–1000	–
He	3	34 (25)	20– 150 (3–10)	24.5
Ne	4	100	100– 400	21.5
A	14	180	100– 600	15.7
Kr	17	240	100–1000	14
Xe	26	350	200– 800	12.1
Hg	20	370	200– 600	10.4

From A. von Engel, Handbuch der Physik (Springer Verlag, Berlin, 1956), Vol. 21, p. 504.



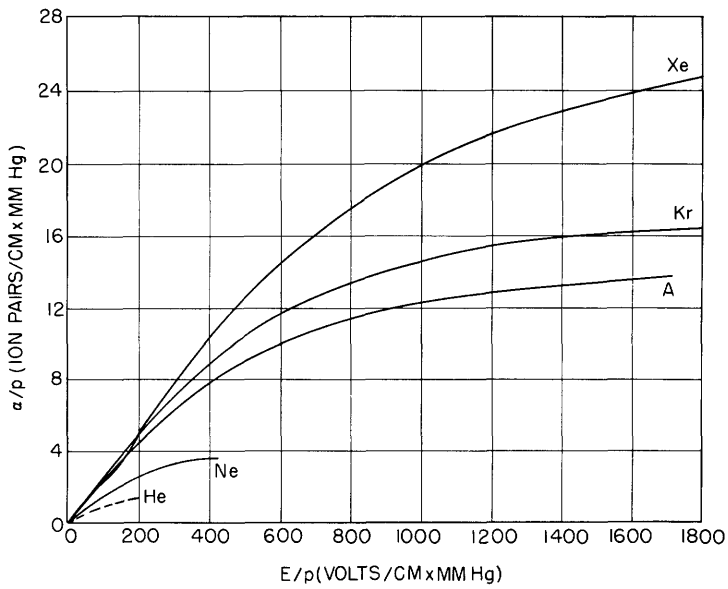
V a2. V_o in $i = i_o \exp\left[h(V - V_o)\right]$.

M. J. Druyvesteyn, F. M. Penning, Revs. Modern Phys. 12, 87 (1940)



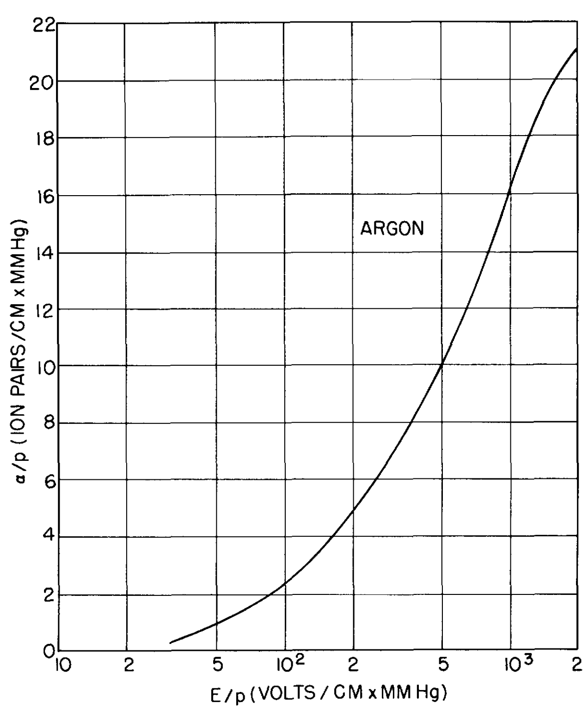
V a3. First Townsend ionization coefficients in noble gases.

A. von Engel, Handbuch der Physik (Springer Verlag, Berlin, 1956) Vol. 21, p. 504



V a3. First Townsend ionization coefficient in Xe, Kr, A.

A. von Engel, Handbuch der Physik (Springer Verlag, Berlin, 1956), Vol. 21, p. 504



V a3. First Townsend ionization coefficient in argon.

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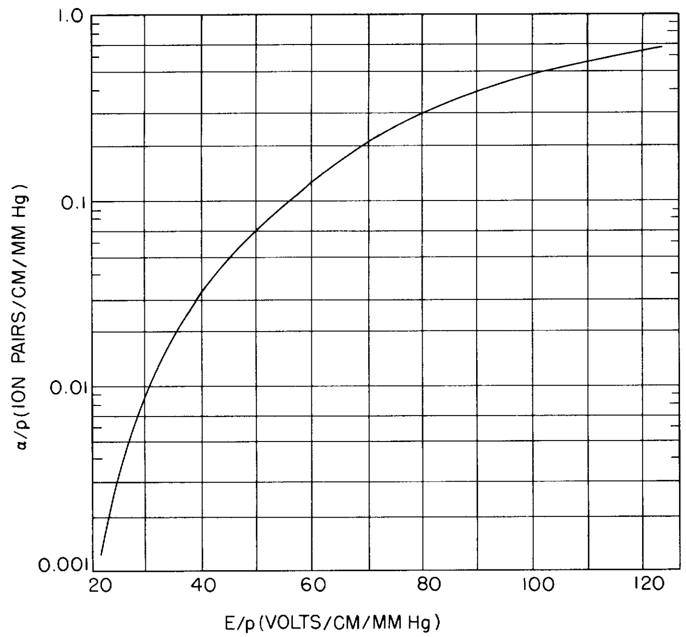

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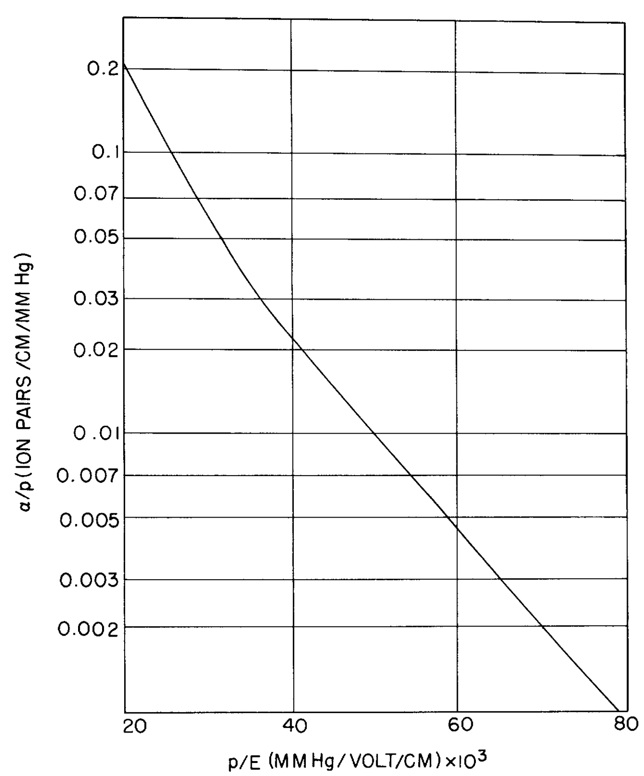
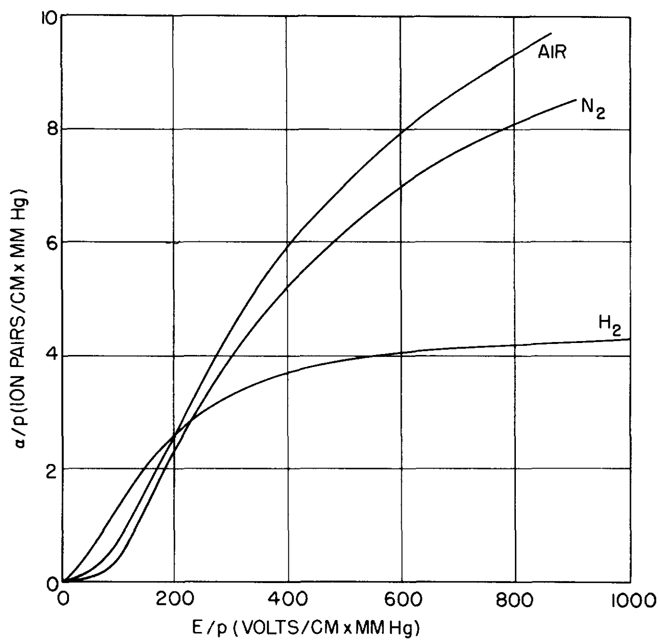
M. A. Harrison, Phys. Rev. 105, 366 (1957)

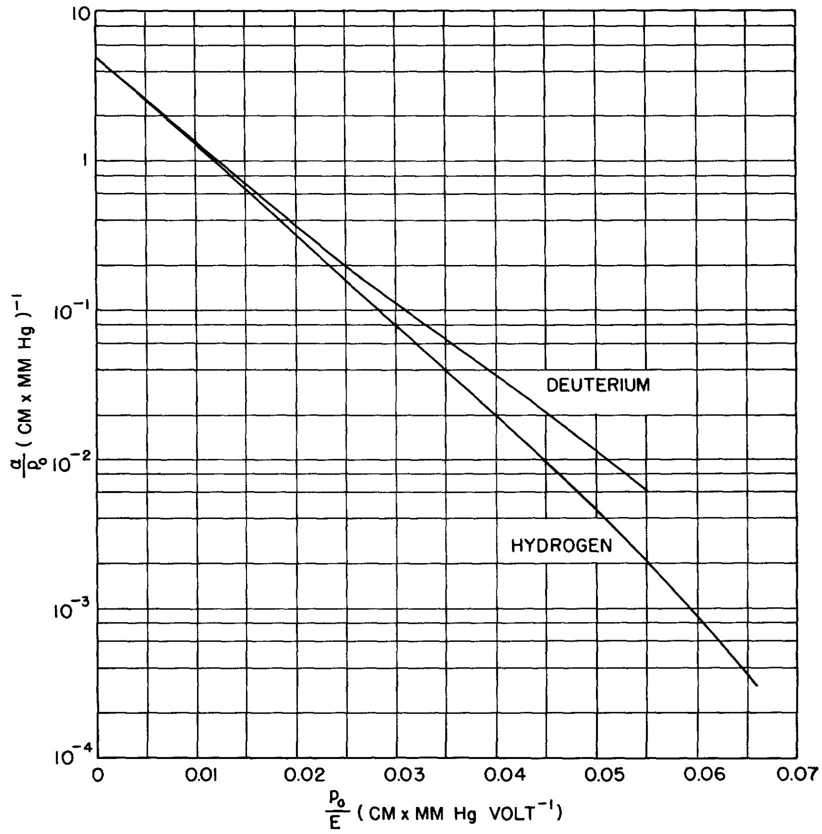


V a5. First Townsend ionization coefficient for oxygen.
D. S. Burch, R. Geballe, Technical Report 4, Department of Physics, University of Washington, Aug. 24, 1956

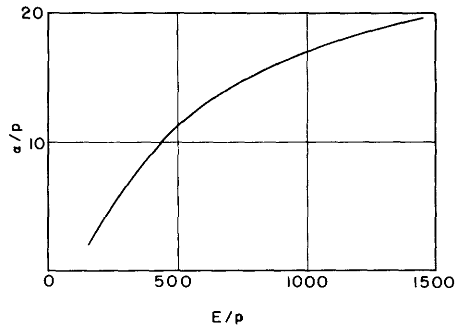


V a6. First Townsend ionization coefficients of air, N_2, H_2.

A. von Engel, Handbuch der Physik (Springer Verlag, Berlin, 1956), Vol. 21, p. 504



V a7. First Townsend ionization coefficients.
D. J. Rose (unpublished)



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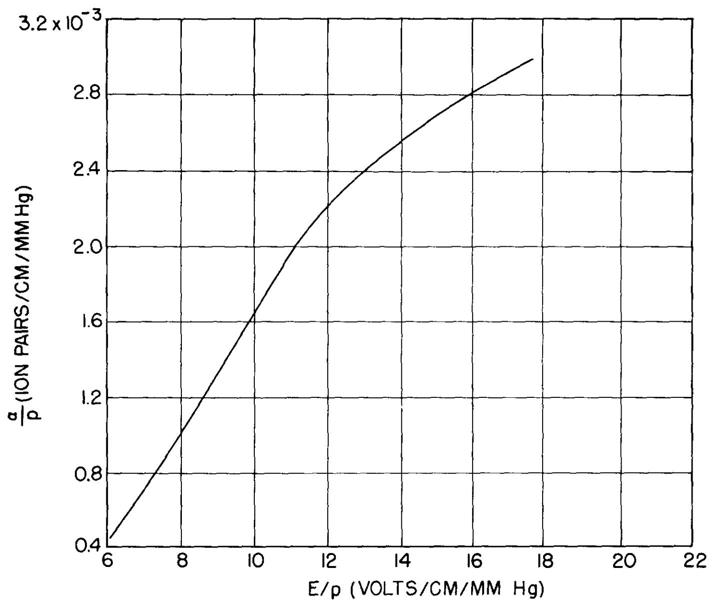

V a9. First Townsend coefficient in CO_2.

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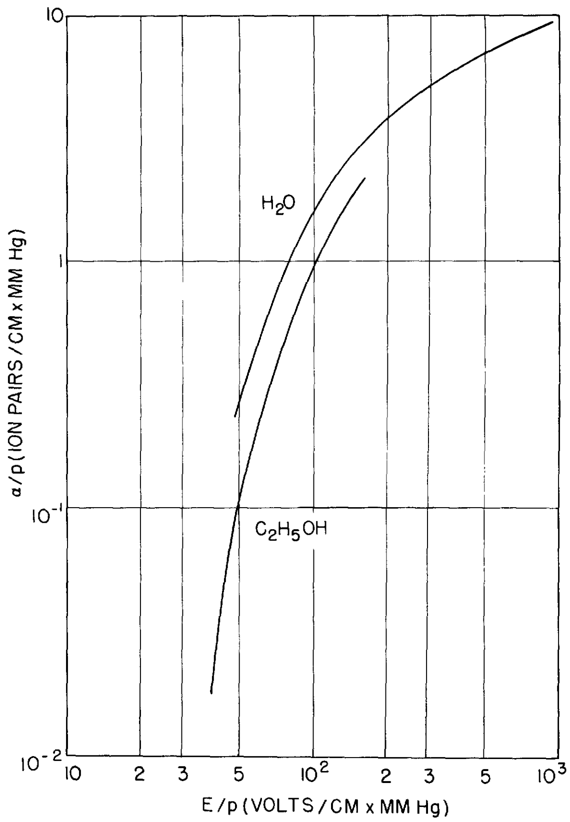
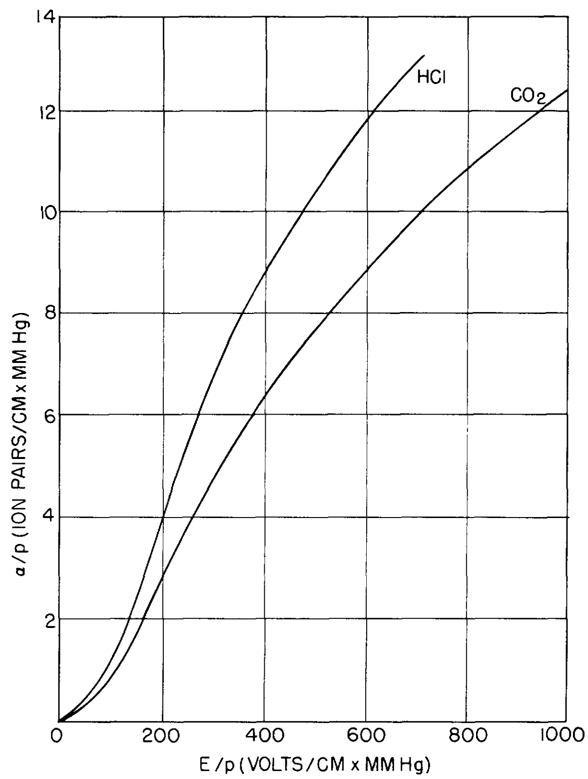


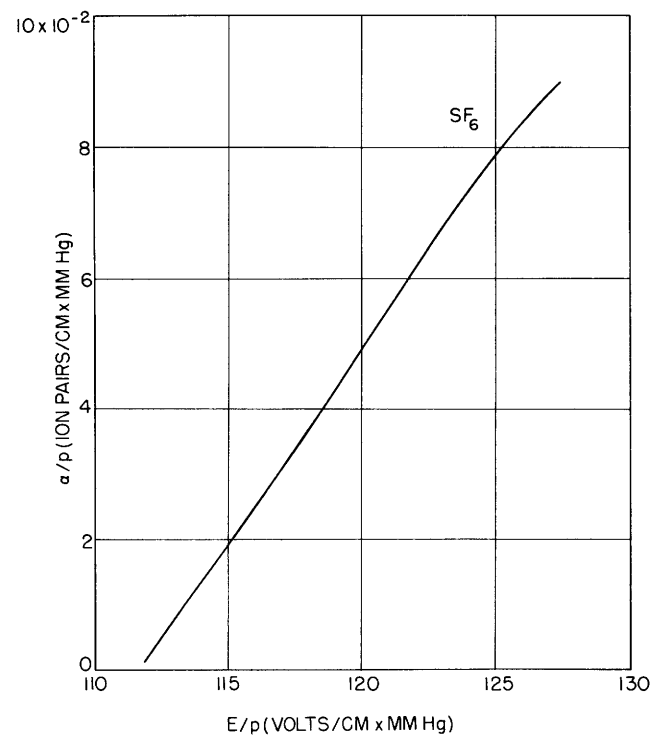
V a10. First Townsend ionization coefficient for H_2O, C_2H_5OH.

A. von Engel, Handbuch der Physik (Springer Verlag, Berlin, 1956), Vol. 21, p. 504



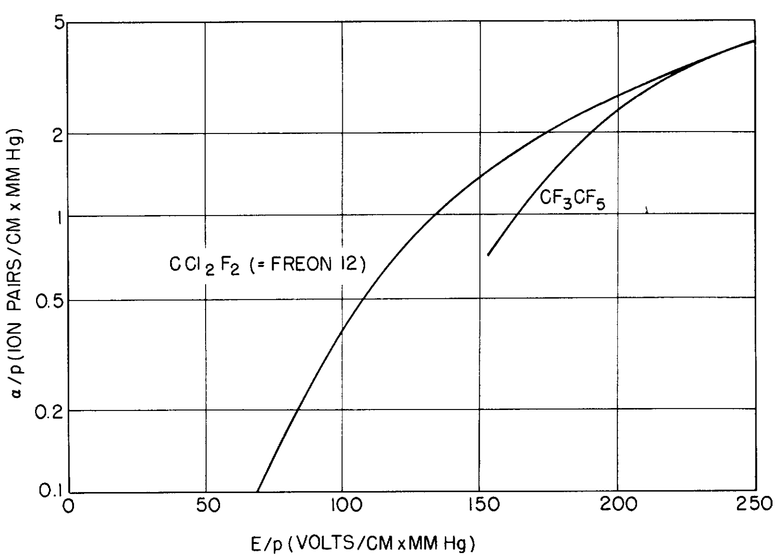
V a11. First Townsend ionization coefficient in HCl, CO_2.

A. von Engel, Handbuch der Physik (Springer Verlag, Berlin, 1956), Vol. 21, p. 504



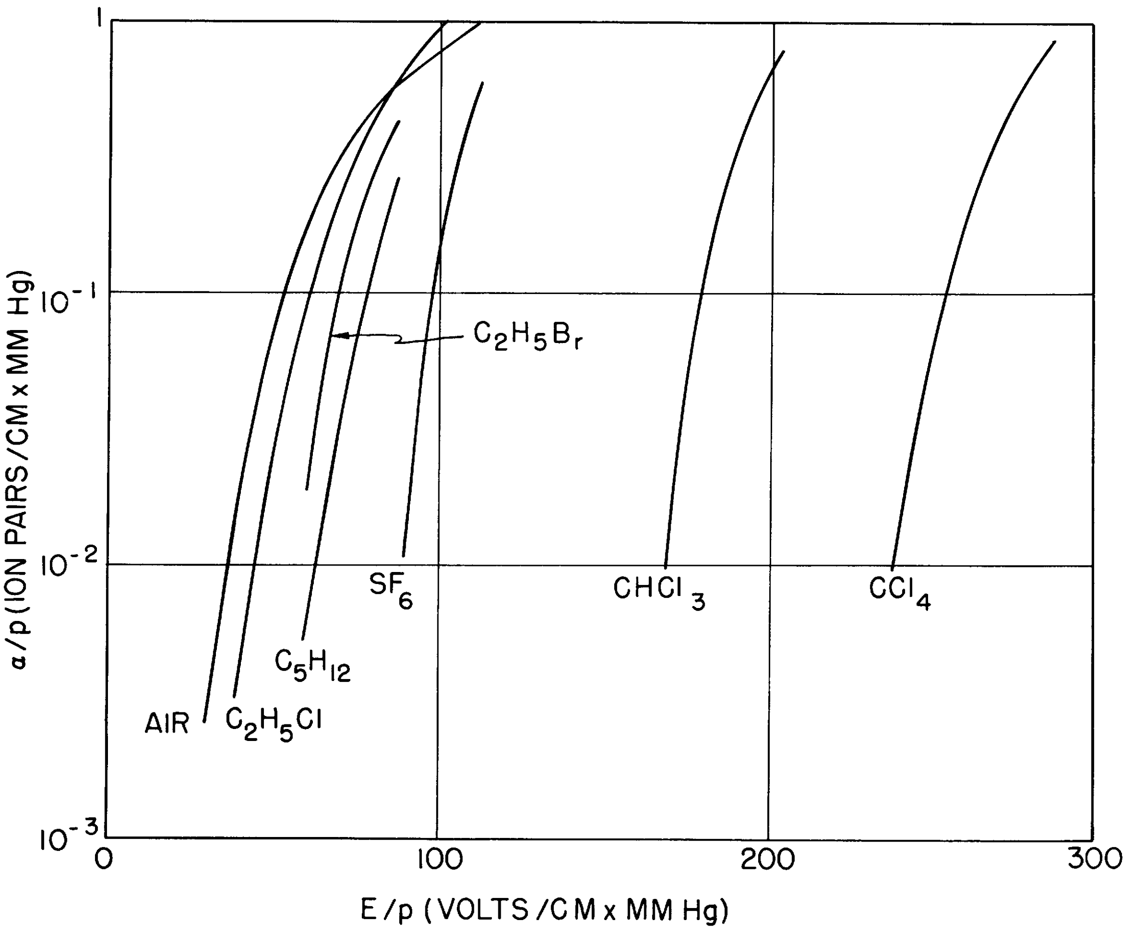
V a12. First Townsend ionization coefficients in SF_6.

A. von Engel, Handbuch der Physik (Springer Verlag, Berlin, 1956), Vol. 21, p. 504

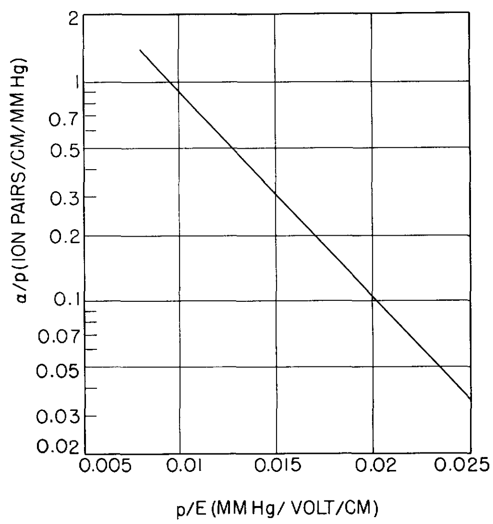


V a13. First Townsend ionization coefficients in CCl_2F_2, CF_3CF_5.

A. von Engel, Handbuch der Physik (Springer Verlag, Berlin, 1956), Vol. 21, p. 504



V a14. First ionization coefficients in air, C_2H_5Cl, C_5H_{12}, C_2H_5Br, SF_6, $CHCl_3$, CCl_4. A. von Engel, Handbuch der Physik (Springer Verlag, Berlin, 1956), Vol. 21, p. 504



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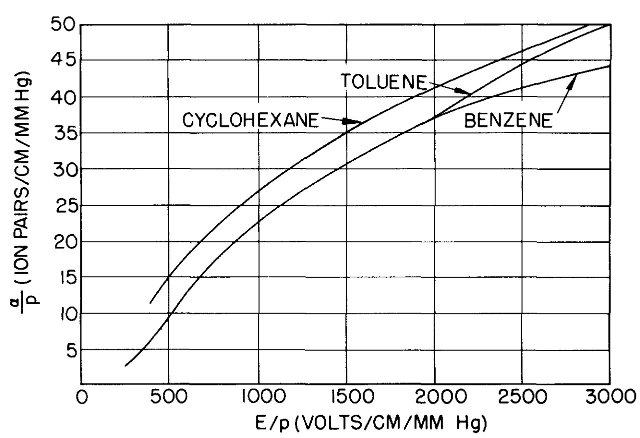

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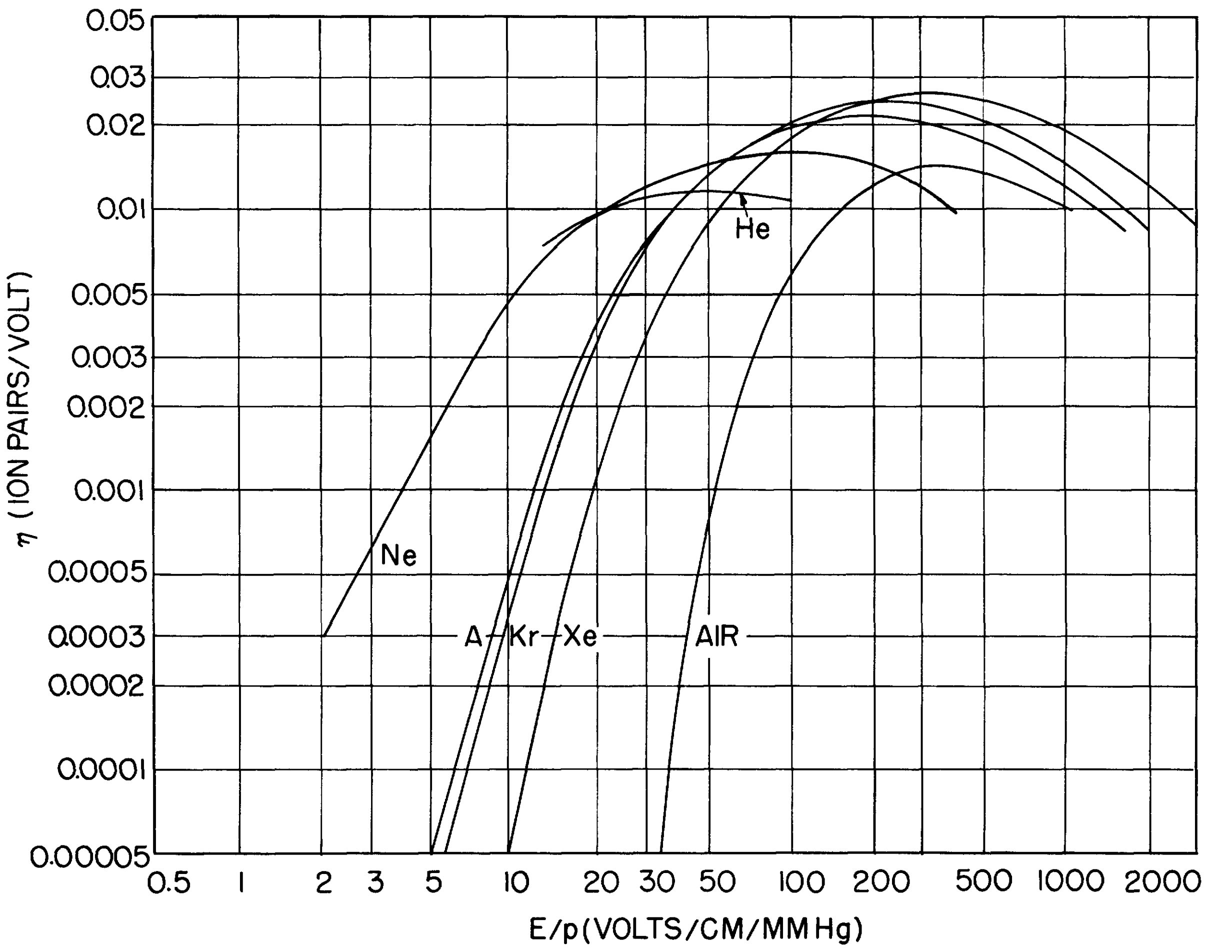
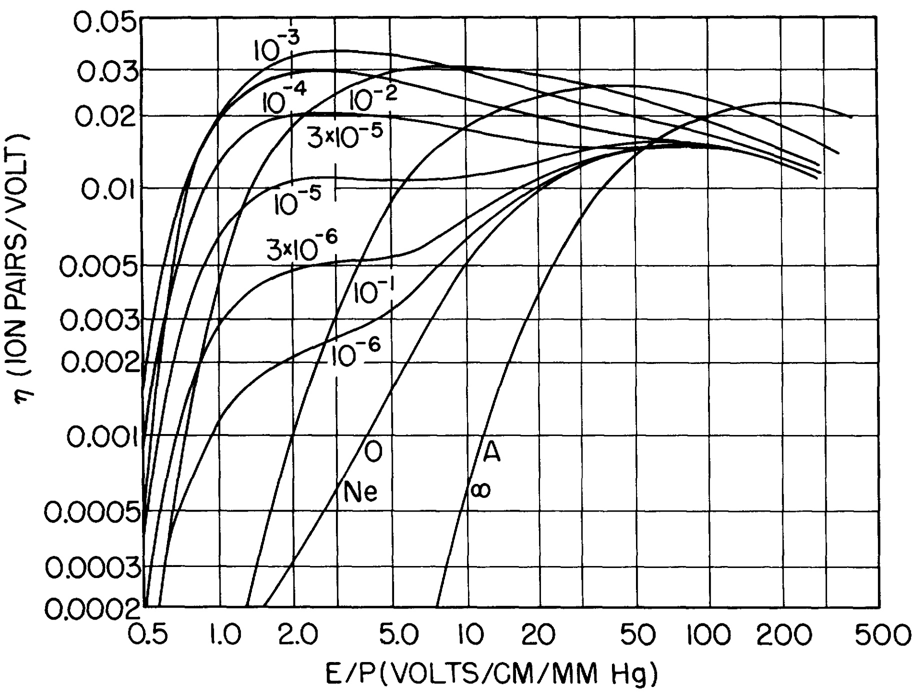
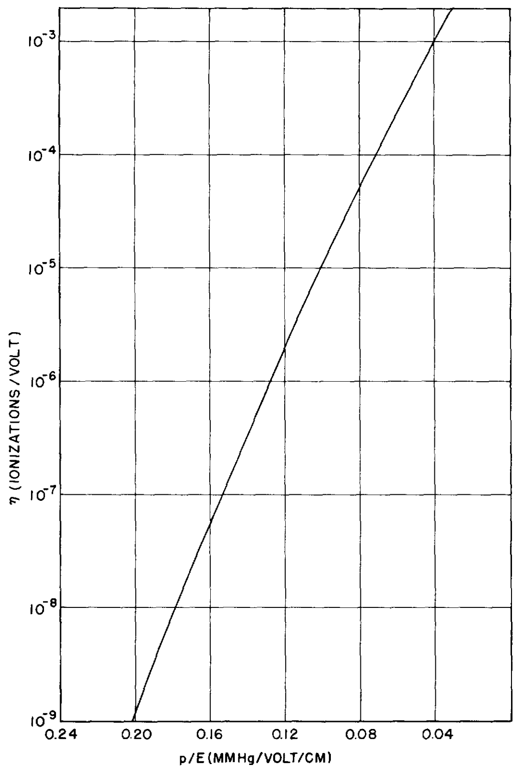


V a17. Ionizations per volt per mm Hg at 0° C for the rare gases and air.
M. J. Druyvesteyn, F. M. Penning, Revs. Modern Phys. 12, 87 (1940)



V a18. Ionizations per volt per mm Hg at 0° C for neon-argon mixtures. The numbers on each curve give the ratio of the argon pressure to the total pressure of the mixture.

A. A. Kruithof, F. M. Penning, Physica 4, 450 (1937)



V a19. Variation of η with p/E for high pressure H_2.

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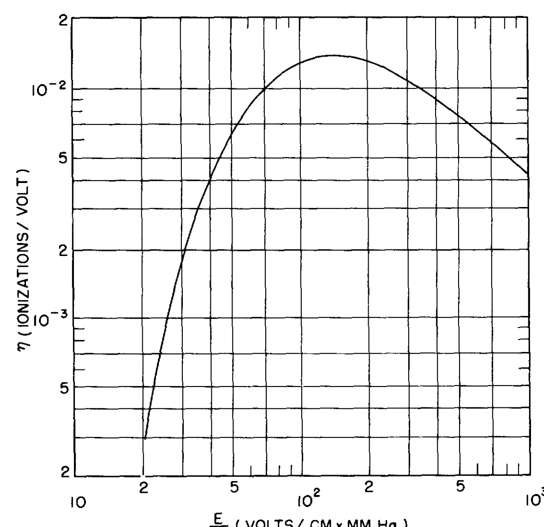
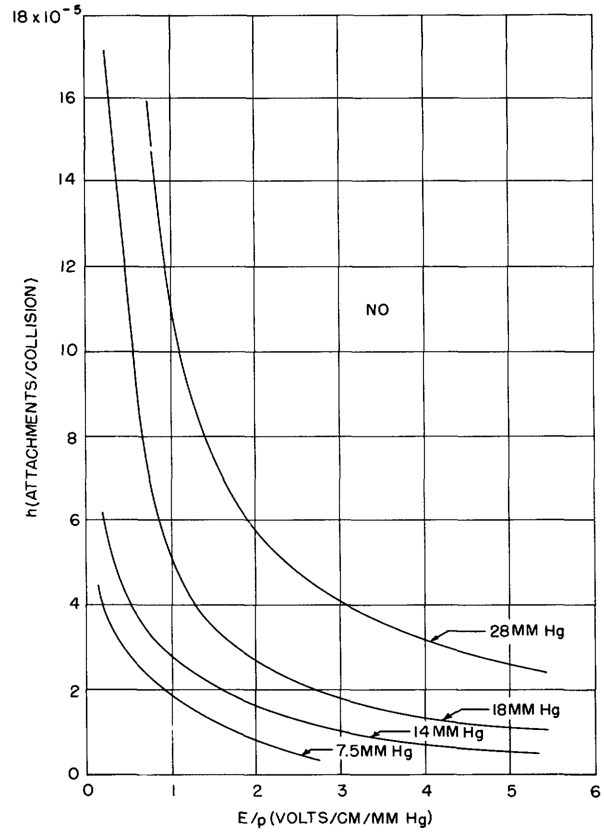
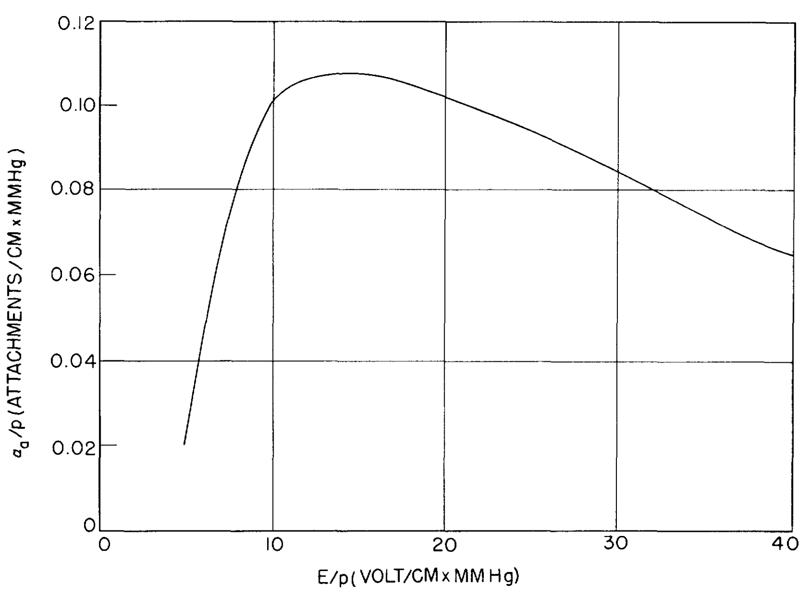


V a19. Ionizations per volt per mm Hg at 0°C in hydrogen.

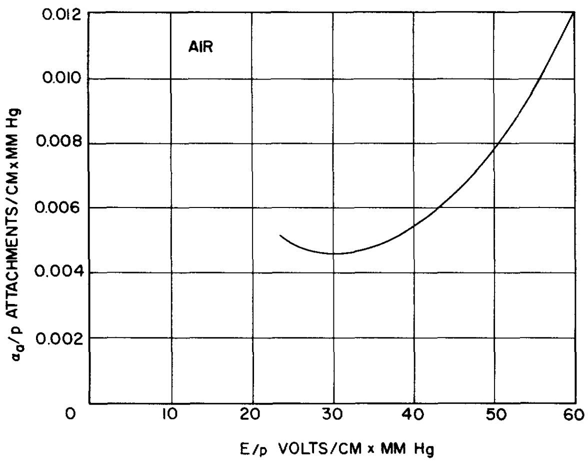
D. J. Rose (unpublished)



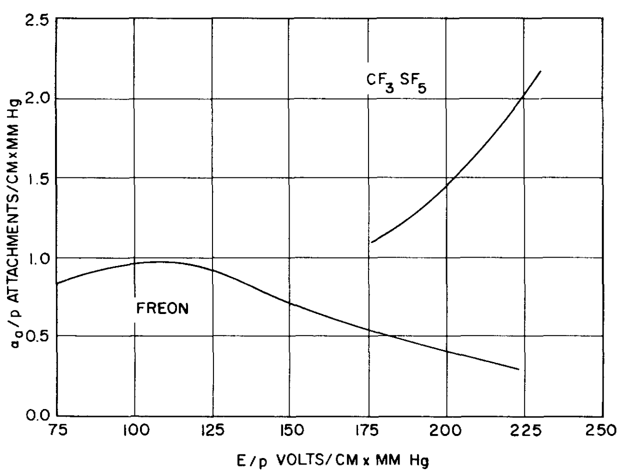
V b1. Efficiency of electron attachment in nitric oxide.
N. E. Bradbury, J. Chem. Phys. 2, 827 (1934)



V b2. Attachment coefficient for oxygen.
D. S. Burch, R. Geballe, Phys. Rev. 106, 183 (1957)



Vb3. Electron attachment coefficient for air.
M. A. Harrison, R. Geballe, Phys. Rev. 91, 1 (1953)



Vb4. Electron attachment coefficients for Freon-12 and CF_3SF_5.
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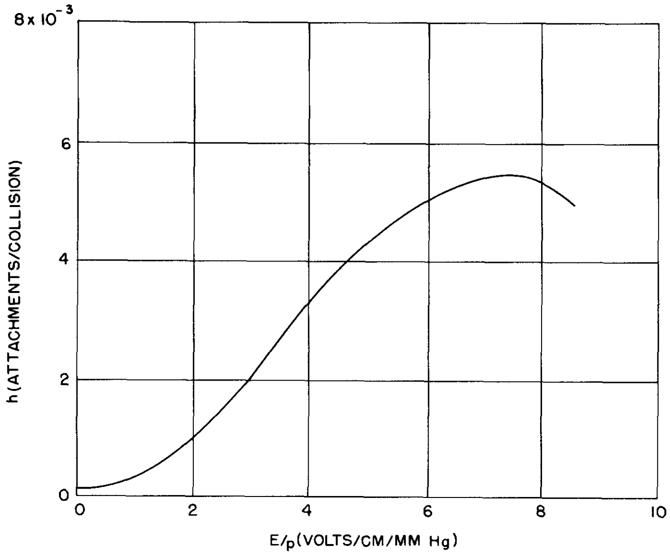
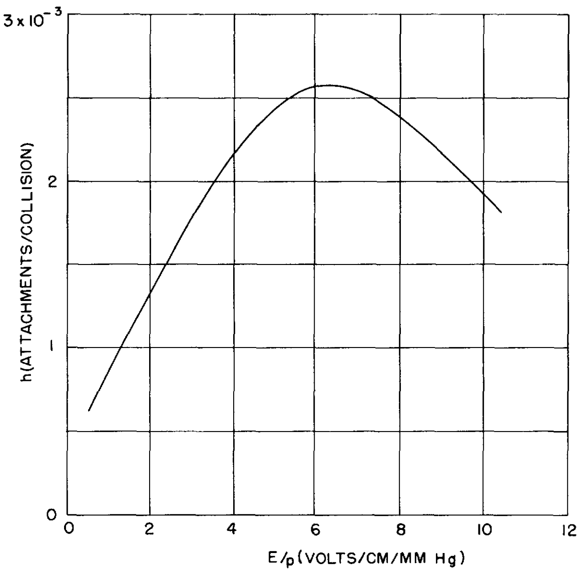
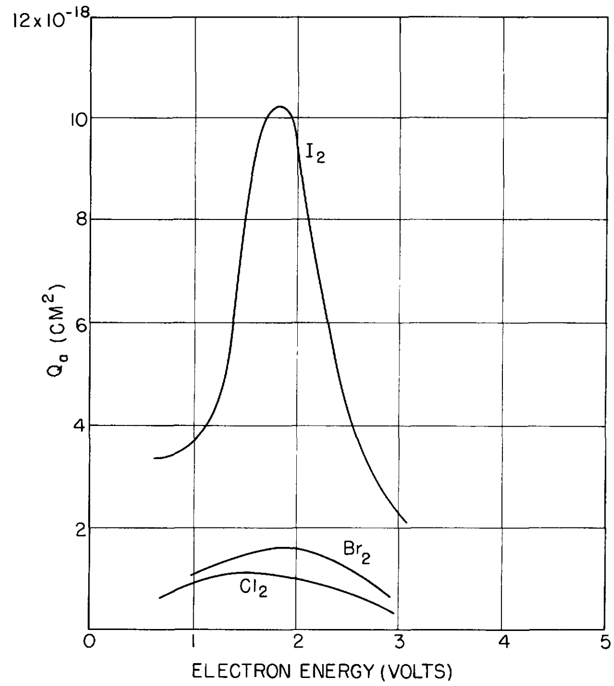


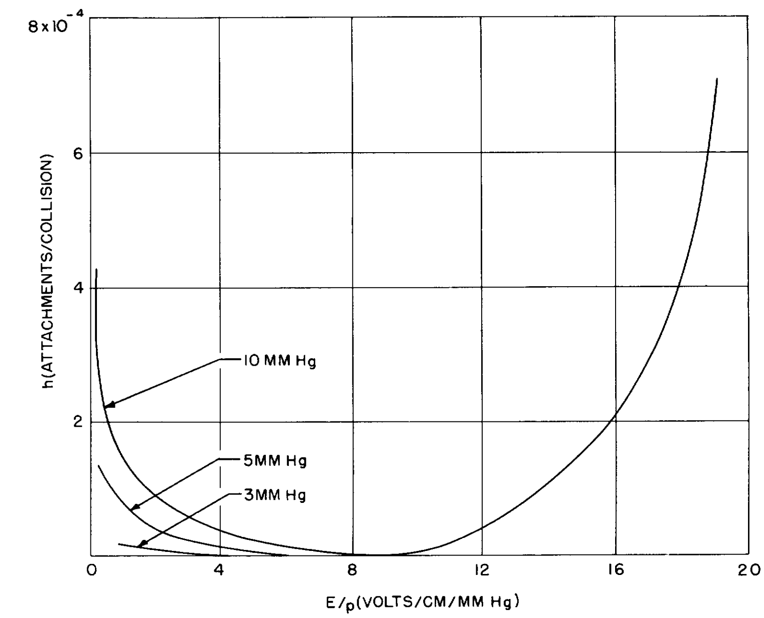
V b5: Efficiency of electron attachment in HCl in argon.
N. E. Bradbury, J. Chem. Phys. 2, 827 (1934)



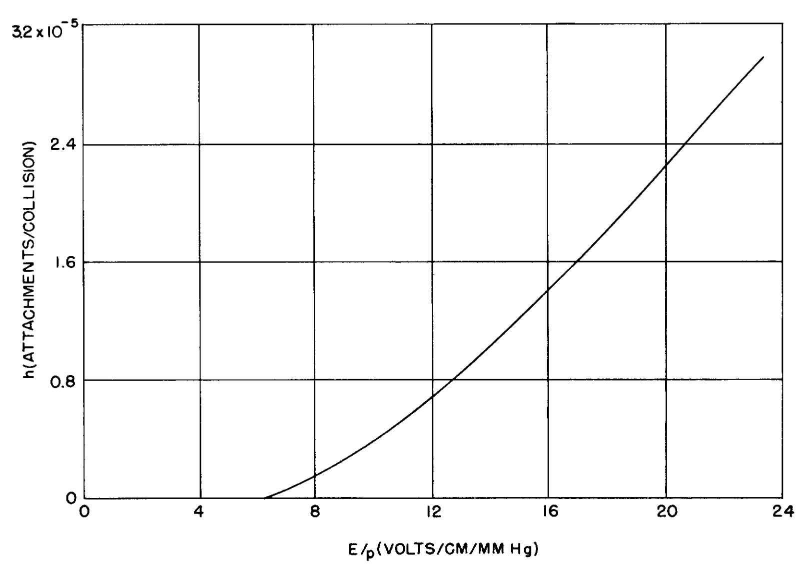
V b6. Efficiency of electron attachment in Cl_2 in argon.
N. E. Bradbury, J. Chem. Phys. 2, 827 (1934)



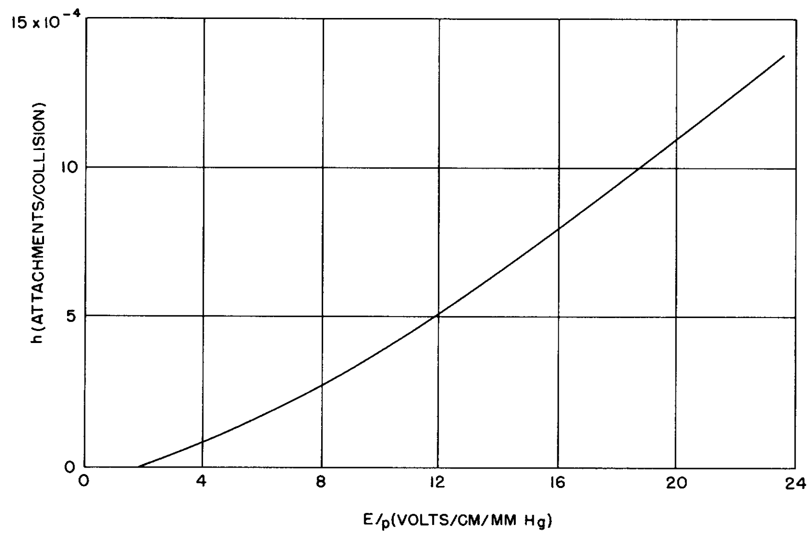
Vb6. Cross sections for attachment of electrons to halogen molecules. R. H. Healey, Phil. Mag. 26, 940 (1938)



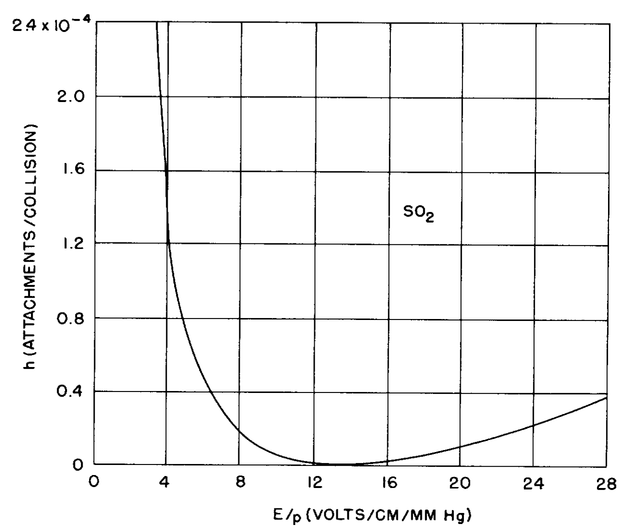
V b7. Efficiency of electron attachment in H_2O at different pressures.
N. E. Bradbury, H. E. Tatel, J. Chem. Phys. 2, 835 (1934)



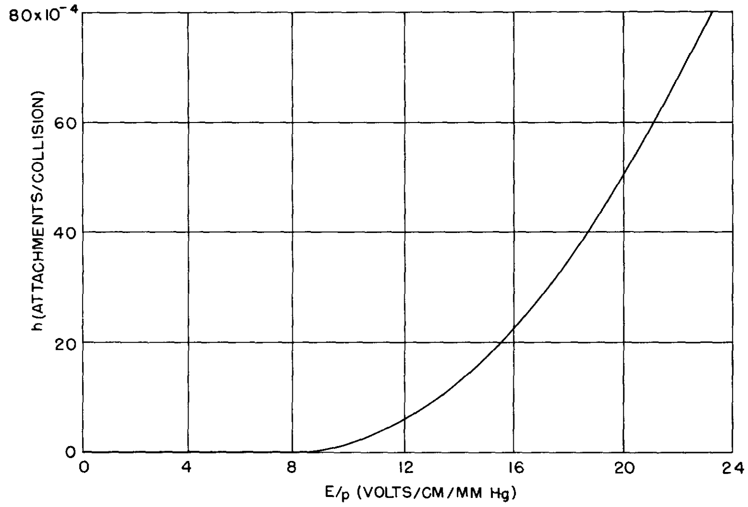
V b8. Efficiency of electron attachment in H_2S.
N. E. Bradbury, H. E. Tatel, J. Chem. Phys. 2, 835 (1934)



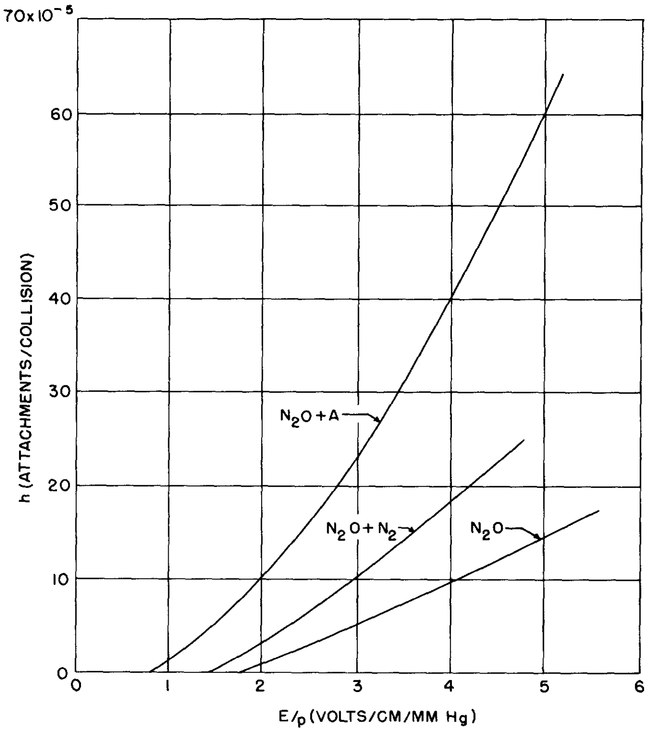
V b9. Efficiency of electron attachment in N_2O.
N. E. Bradbury, H. E. Tatel, J. Chem. Phys. 2, 835 (1934)



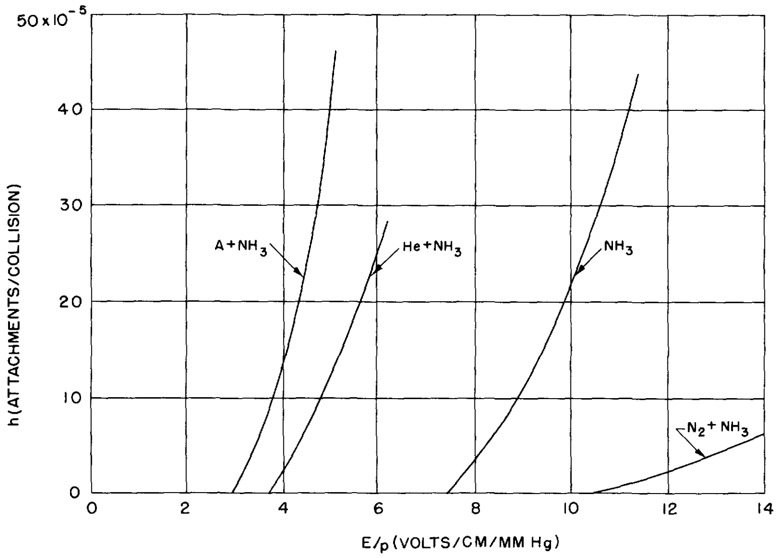
V b10. Efficiency of electron attachment in SO_2.
N. E. Bradbury, H. E. Tatel, J. Chem. Phys. 2, 835 (1934)



V b11. Efficiency of electron attachment in NH_3.
N. E. Bradbury, J. Chem. Phys. 2, 827 (1934)



V b12. Efficiency of electron attachment in mixtures of N_2O in equal parts of N_2 or A.
N. E. Bradbury, H. E. Tatel, J. Chem. Phys. 2, 835 (1934)



V b13. Efficiency of electron attachment in NH_3 and equal parts of He, A, or N_2.

N. E. Bradbury, J. Chem. Phys. 2, 827 (1934)

V(c1). Cross Sections for Radiative Capture of an Electron to Various States of a Hydrogen Atom

Electron Energy (eV)	0.28	0.13	0.069	0.034
Total quantum number of atomic state into which electron is captured	Cross section in 10^{-21} cm^2			
1	8.10	16.63	32.80	66.95
2	4.24	8.93	17.70	36.52
3	2.70	5.91	12.04	24.88
4	1.88	4.24	8.84	18.59
5	1.36	3.20	6.89	14.85
6	0.99	2.49	5.51	12.25
7	0.73	2.00	4.52	10.31
8	..	1.62	3.81	8.75
9	..	1.31	3.23	7.55
10	..	1.04	2.74	6.50
11	..	..	2.33	5.72
12	..	..	2.00	4.52
13	..	..	1.72	4.03
14	0.15	..	1.47	3.62
15	..	..	..	3.25
16	..	..	..	2.91
17	..	..	..	2.62
18	..	..	..	2.35
19	..	..	..	2.09
20	..	0.215	..	..
⋮				
28	..	..	0.302	..
⋮				
40	..	..	..	0.432
Sum for all final states	23.0	53.7	119	272

From H. S. W. Massey and E. H. S. Burhop, Electronic and Ionic Impact Phenomena (Clarendon Press, Oxford, 1952), p. 333.

V (c1). Radiative Recombination Coefficients

Element	$\alpha(\text{cm}^3\ \text{sec}^{-1})$	T_{ok}
H (1)	10^{-11}	
A (2)	2×10^{-10}	3100
Cs (2)	3.4×10^{-10}	2000
Hg (3)	2.3×10^{-10}	2000

References:

(1) J. D. Craggs, W. Hopwood, Proc. Phys. Soc. (London) 59, 771 (1947)

(2) C. Kenty, Phys. Rev. 32, 624 (1928)

(3) F. L. Mohler, Bur. Standards J. Research 19, 447, 559 (1937)

V (c2). Dissociative Recombination

Gas	$\alpha\left(\frac{\text{ions}}{\text{cc}} - \text{sec}\right)^{-1}$
He	1.7×10^{-8}
Ne	2.1×10^{-7}
A	3×10^{-7}
Kr	6×10^{-7}
Xe	2×10^{-6}
N_2	1.4×10^{-6}
O_2	2.8×10^{-7}

References:

M. A. Biondi, S. C. Brown, Phys. Rev. 76, 1697 (1949)

R. B. Holt, J. M. Richardson, B. Howland, B. T. McClure, Phys. Rev. 77, 239 (1950)

R. A. Johnson, B. T. McClure, R. B. Holt, Phys. Rev. 80, 376 (1950)

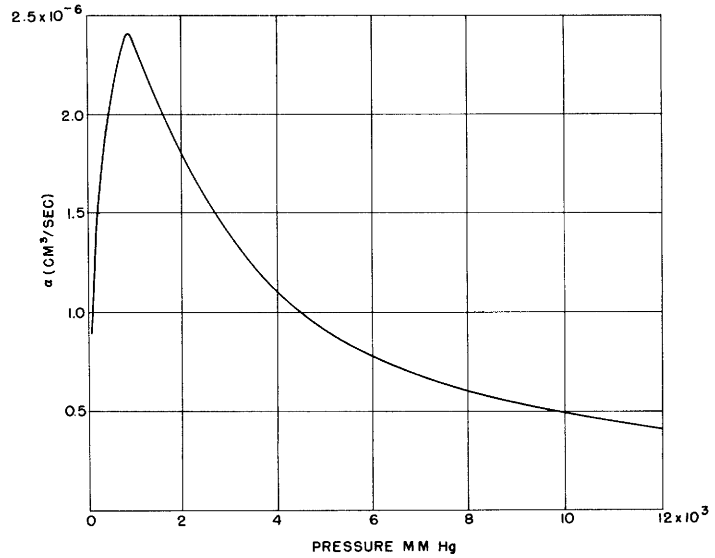
A. Redfield, R. B. Holt, Phys. Rev. 82, 874 (1951)

J. M. Richardson, Phys. Rev. 88, 895 (1952)

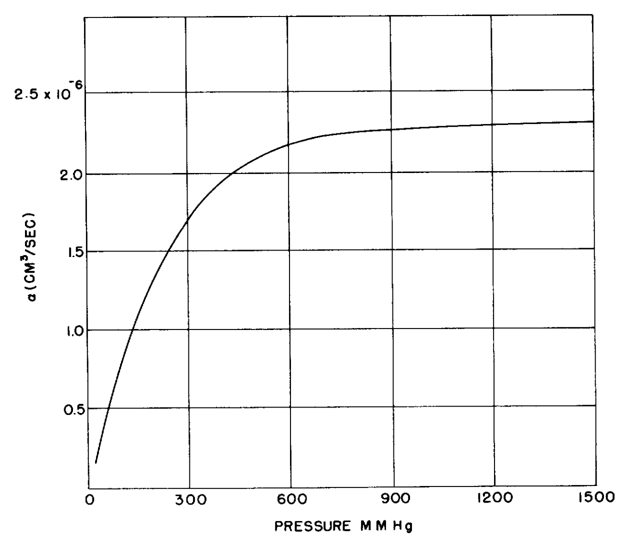
V (c3). Three-Body Recombination Coefficients for Electrons

Gas	α at N.T.P. (cm^3/sec)	Estimated saturation pressure (mm Hg)
Helium	6.8×10^{-9}	2.8×10^{4}
Argon	6.8×10^{-11}	2.8×10^{-5}
Air	1.7×10^{-7}	10^{4}
Hydrogen	1.6×10^{-7}	10^{4}

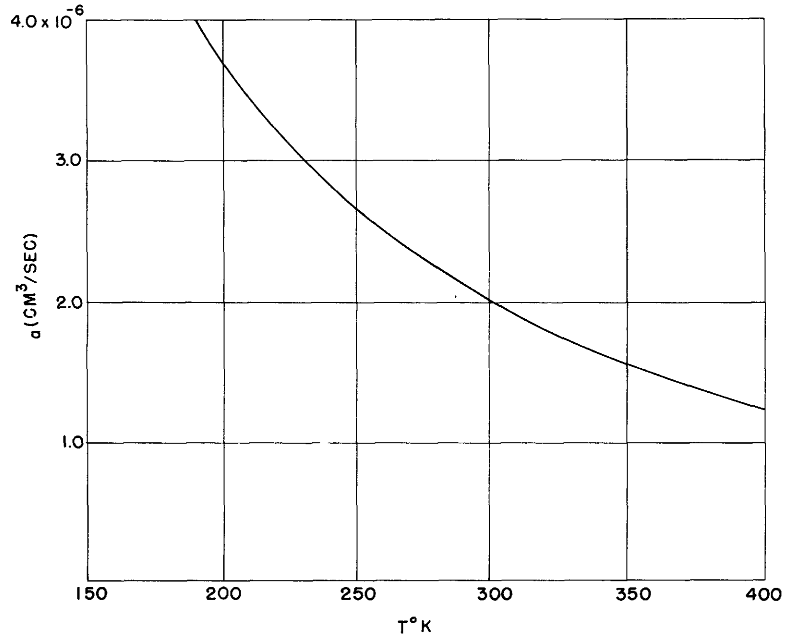
From H. S. W. Massey and E. H. S. Burhop, Electronic and Ionic Impact Phenomena (Clarendon Press, Oxford, 1952), p. 635.



Vd1. Recombination coefficient in air.
J. Sayers, Proc. Roy. Soc. (London) A169, 83 (1938)



Vd1. Recombination coefficient in air.
J. Sayers, Proc. Roy. Soc. (London) A169, 83 (1938)



Vd2. Temperature variation of the recombination coefficient in oxygen at constant pressure.

M. E. Gardner, Phys. Rev. 53, 75 (1938)

VI. BREAKDOWN

(a) High-Frequency Breakdown

In microwave breakdown the rate of production of electrons, $n\nu_i$, is balanced by the rate of diffusion, nD/Λ^2, out of the tube whose diffusion length is Λ. The ionization frequency ν_i is a function of the effective electric field:

$$E_e^2 = \frac{E_p^2}{2} \frac{\nu_c^2}{\nu_c^2 + \omega^2} \qquad (1)$$

The proper variables in which to express breakdown are the voltage $E_e\Lambda$ and the parameter $p\Lambda$.

At lower frequencies the amplitude of oscillation of the electrons brings them in contact with the walls, leading either to their capture by the walls or to secondary emission. These phenomena lead to discontinuities in breakdown fields.

(b) Direct-Current Breakdown

Direct-current breakdown occurs by avalanche multiplication, renewed by secondary electrons from the cathode. The breakdown voltage V_B is given by

$$\eta(V_B - V_A) = \ln(1 - 1/\gamma) \qquad (2)$$

where V_A is an initial voltage necessary to give the electrons their mean energy. The breakdown voltage is a function of the product pd.

At high pressures and nonplanar geometry, space charge will intensify the fields; and secondary electrons may originate from photo-emission in the gas. Breakdown then occurs by streamer formation (spark) and is given by

$$N_c = e^{\alpha d} = 38\pi\, \epsilon_o \frac{Dd}{\mu e} \qquad (3)$$

(c) Time Lags

The formative time lag t_f is the time necessary for the initial current I_o that exists before breakdown to build up to an observable current I_1.

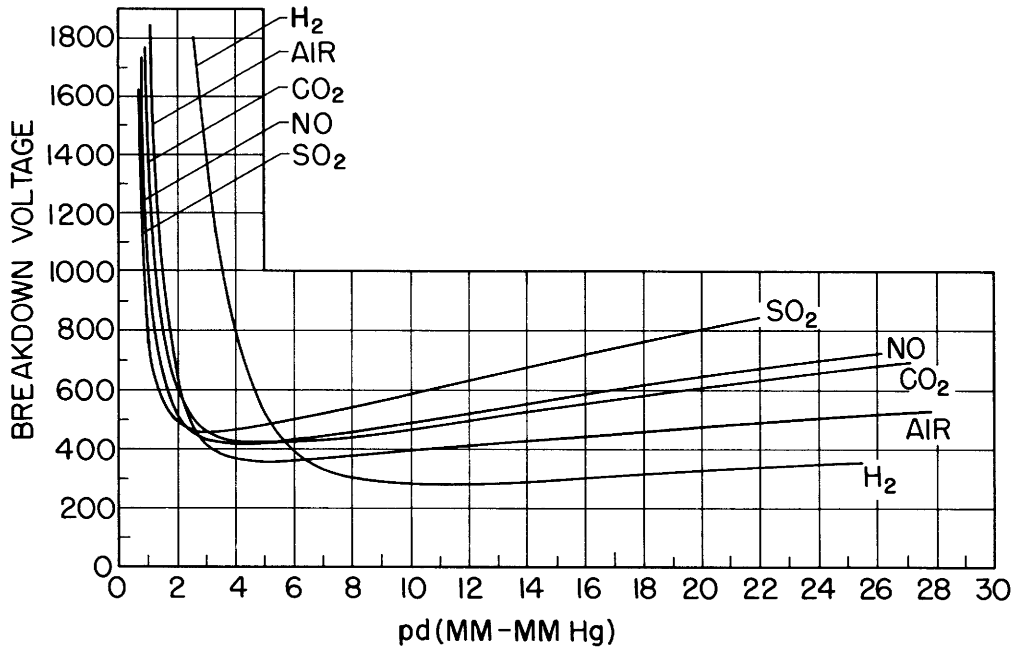
For the Townsend mechanism:

$$t_f = t_i \frac{\log [(m-1)\, I_1/I_o]}{\log M} \geqslant t_{\pm} \qquad (4)$$

where $t_{\pm}$ is the transit time for the slowest particle (ion or electron) and the multiplication factor M has the value $M = \gamma(e^{\eta V} - 1)$.

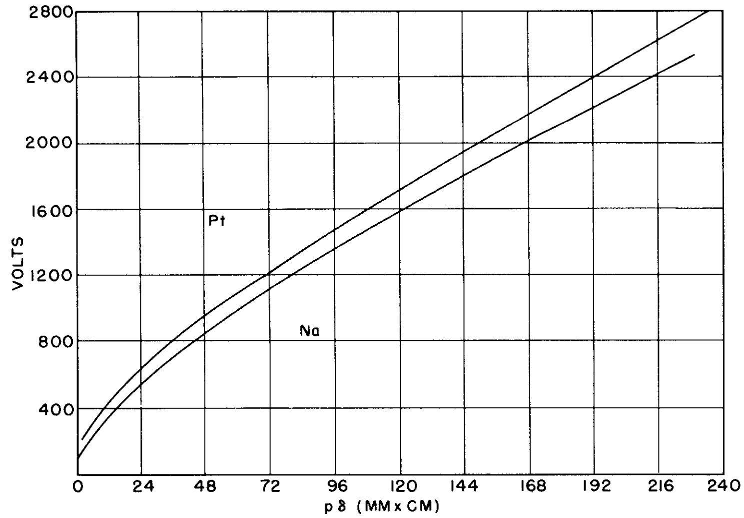
For spark breakdown:

$$t_f = \frac{\log N_c}{\alpha\, \mu\, E} \leqslant t_- \qquad (5)$$

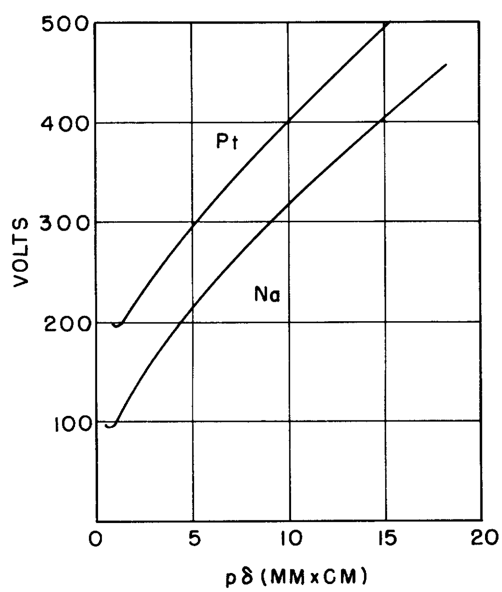


VI a1. Paschen curves for various gases.

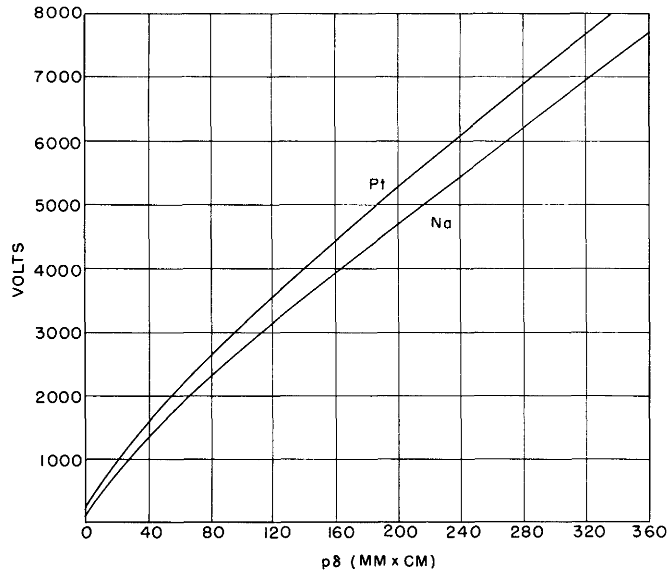
M. Knoll, F. Ollendorff, R. Rompe, Gasentladungstabellen (Springer Verlag, Berlin, 1935), p. 84



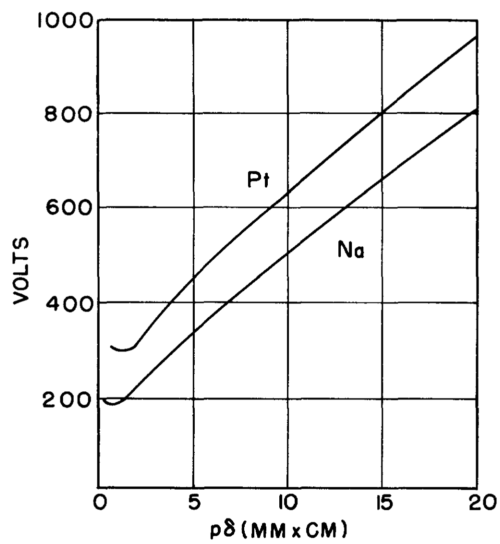
VIa2. Breakdown potential for argon as a function of pδ for Pt and Na electrodes. F. Ehrenkranz, Phys. Rev. 55, 219 (1939)



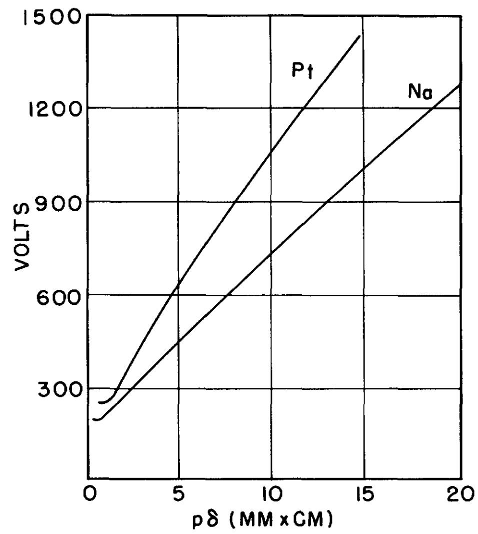
VIa2. Breakdown potential for argon as a function of pδ for Pt and Na electrodes. F. Ehrenkranz, Phys. Rev. 55, 219 (1939)



VIa3. Breakdown potential for hydrogen as a function of pδ for Pt and Na electrodes.
F. Ehrenkranz, Phys. Rev. 55, 219 (1939)

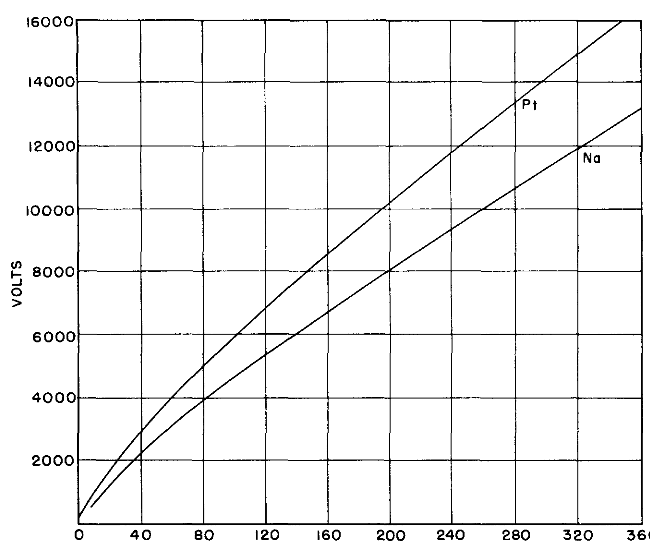


VIa3. Breakdown potential for hydrogen as a function of pδ for Pt and Na electrodes.
F. Ehrenkranz, Phys. Rev. 55, 219 (1939)



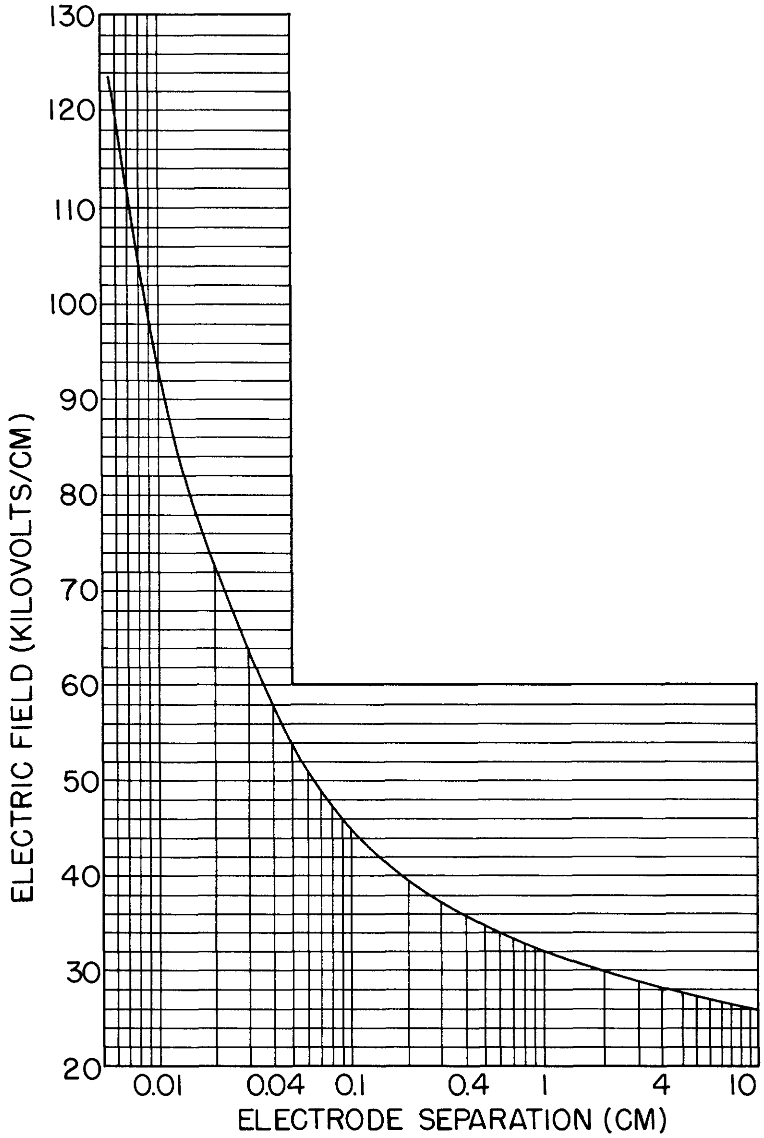
VIa4. Breakdown potential in nitrogen as a function of pδ for Pt and Na electrodes.

F. Ehrenkranz, Phys. Rev. 55, 219 (1939)



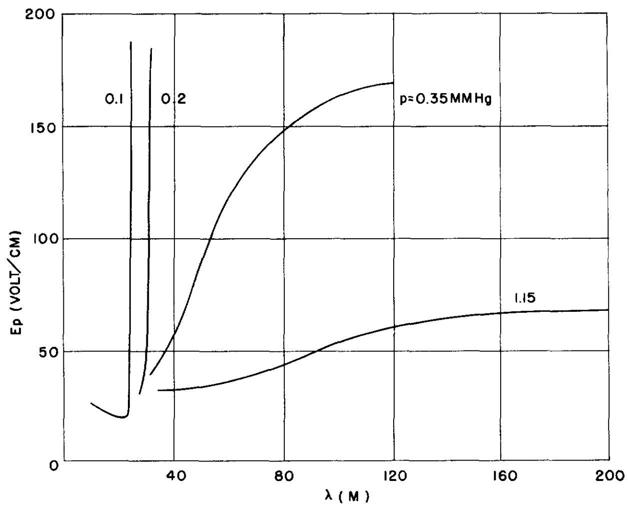
VIa4. Breakdown potential in nitrogen as a function of pδ for Pt and Na electrodes.

F. Ehrenkranz, Phys. Rev. 55, 219 (1939)

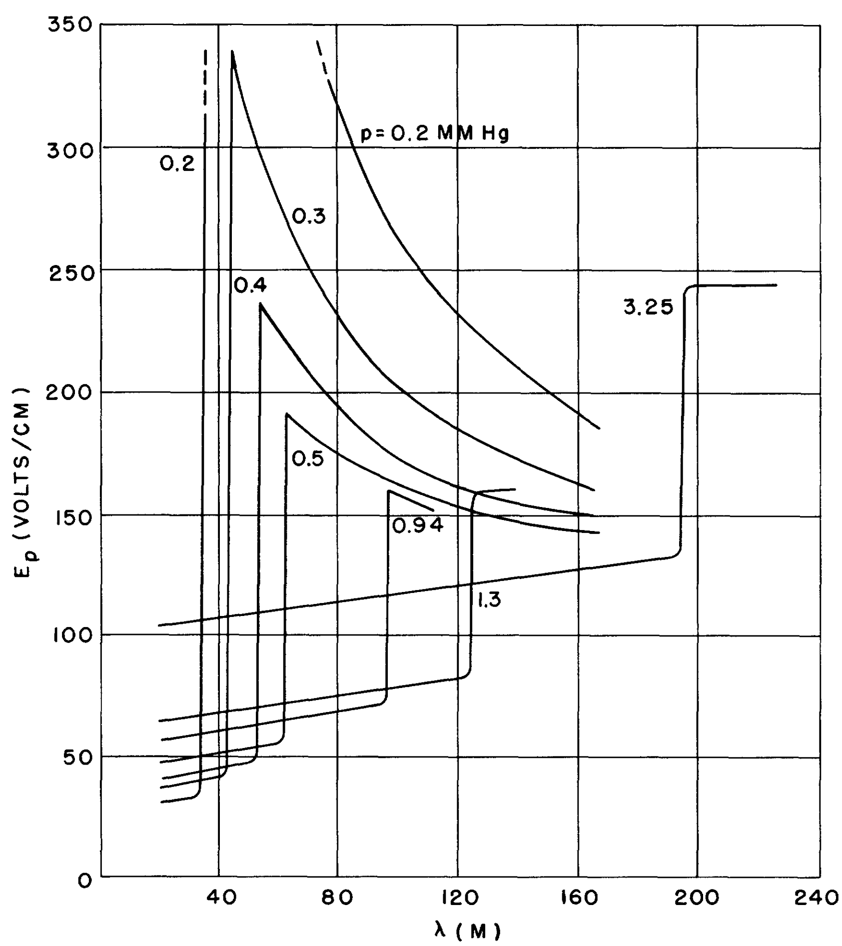


VIa5. Breakdown voltage in air at atmospheric pressure.

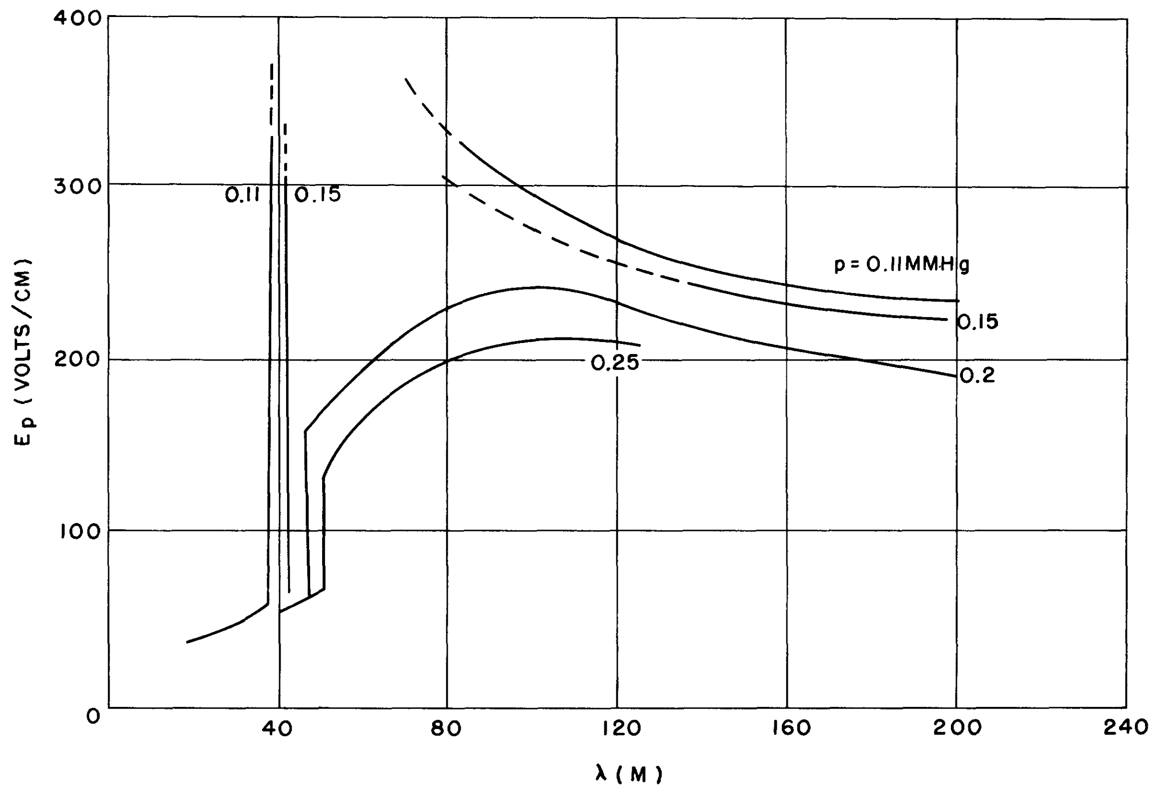
M. Knoll, F. Ollendorff, R. Rompe, Gasentladungstabellen (Springer Verlag, Berlin, 1935), p. 83



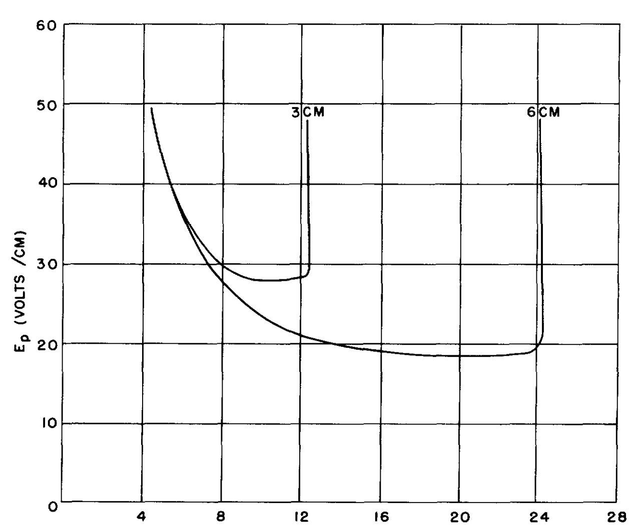
VIb1. High-frequency breakdown in neon.
E. W. B. Gill, A. von Engel, Proc. Roy. Soc. (London) A197, 107 (1949)



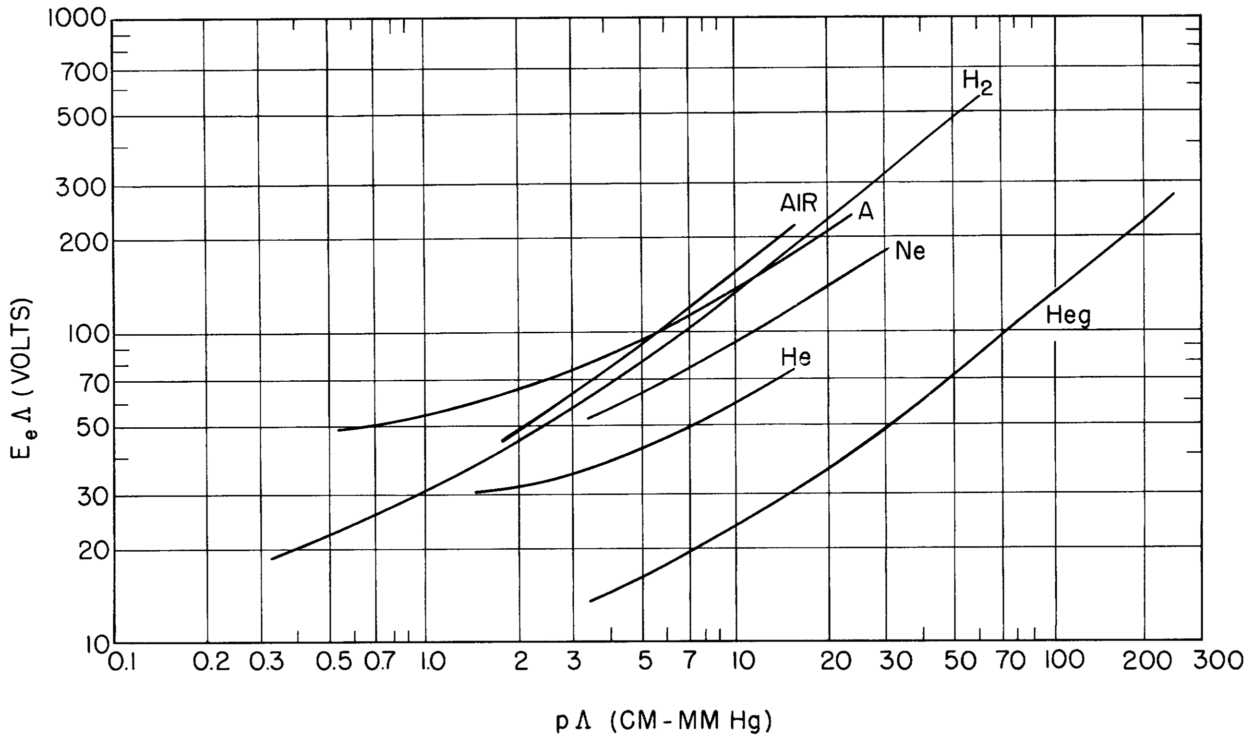
VIb2. High-frequency breakdown in hydrogen.
E. W. B. Gill, A. von Engel, Proc. Roy. Soc. (London) A197, 107 (1949)



VIb3. High-frequency breakdown in nitrogen.
E. W. B. Gill, A. von Engel, Proc. Roy. Soc. (London) A197, 107 (1949)

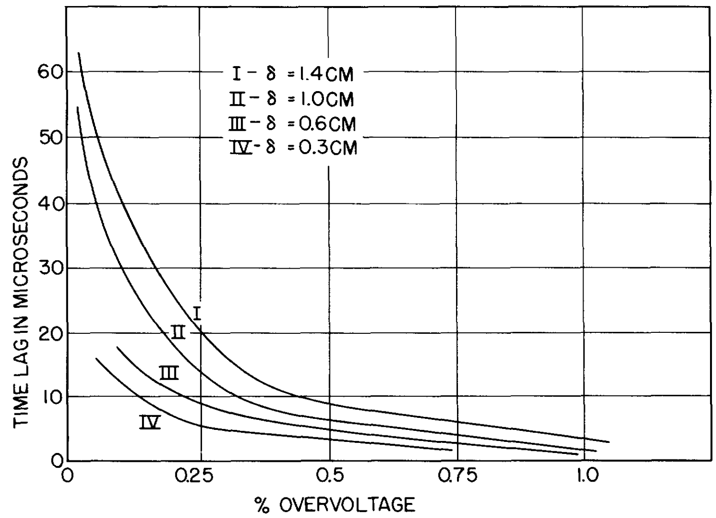


VIb4. Low-pressure, high-frequency breakdown in hydrogen.
E. W. B. Gill, A. von Engel, Proc. Roy. Soc. (London) A192, 446 (1948)

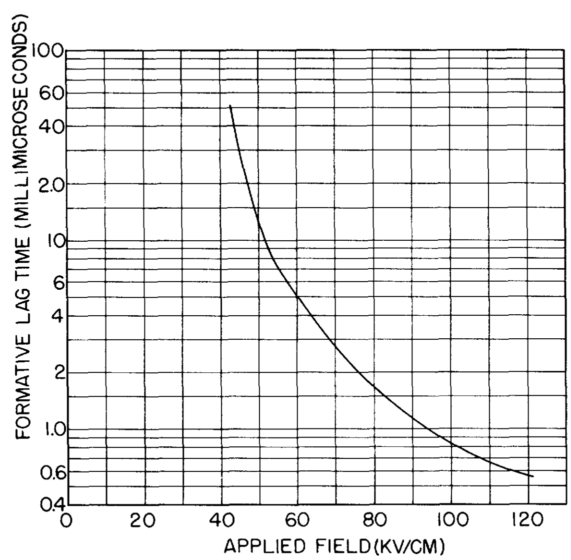


VIb5. Microwave breakdown in gases.

S. C. Brown, Handbuch der Physik (Springer Verlag, Berlin, 1956), Vol. 22, p. 535

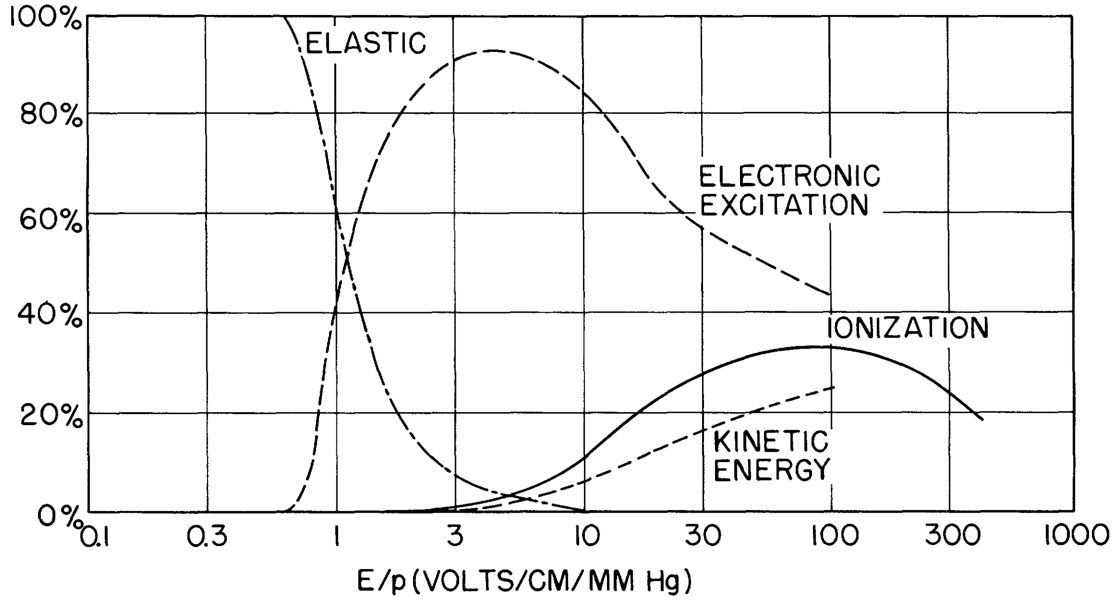


VIc1. Formative time lag for breakdown in air at low overvoltages. L. H. Fisher, B. Bederson, Phys. Rev. 81, 109 (1951)

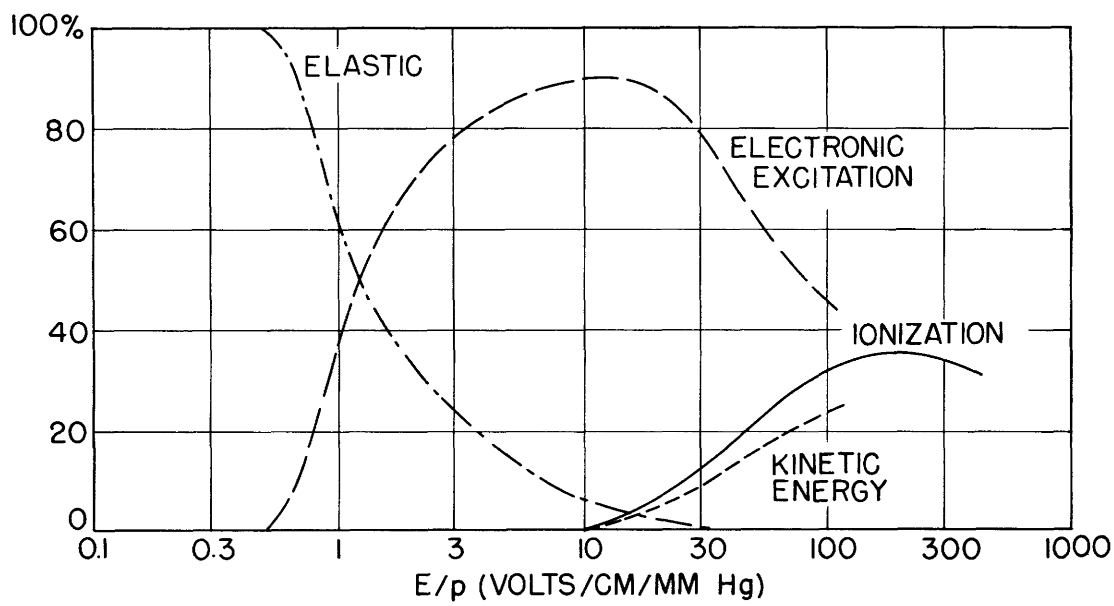


VIc2. Formative time lag for breakdown in air at high overvoltages. R. C. Fletcher, Phys. Rev. 76, 1501 (1949)

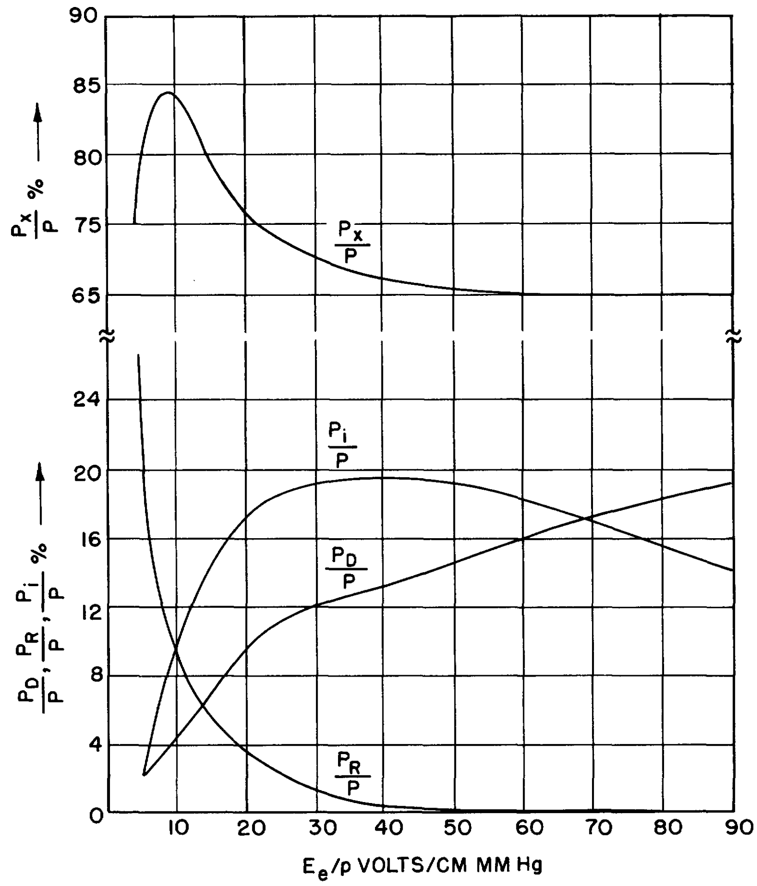
VII ELECTRON ENERGIES



VIIa1. Distribution of electron energy losses in neon.
F. M. Penning, Physica 4, 286 (1938)

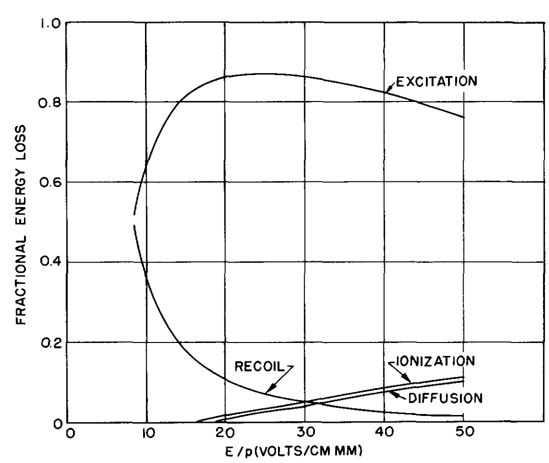


VIIa2. Distribution of electron energy losses in argon.
F. M. Penning, Physica 4, 286 (1938)

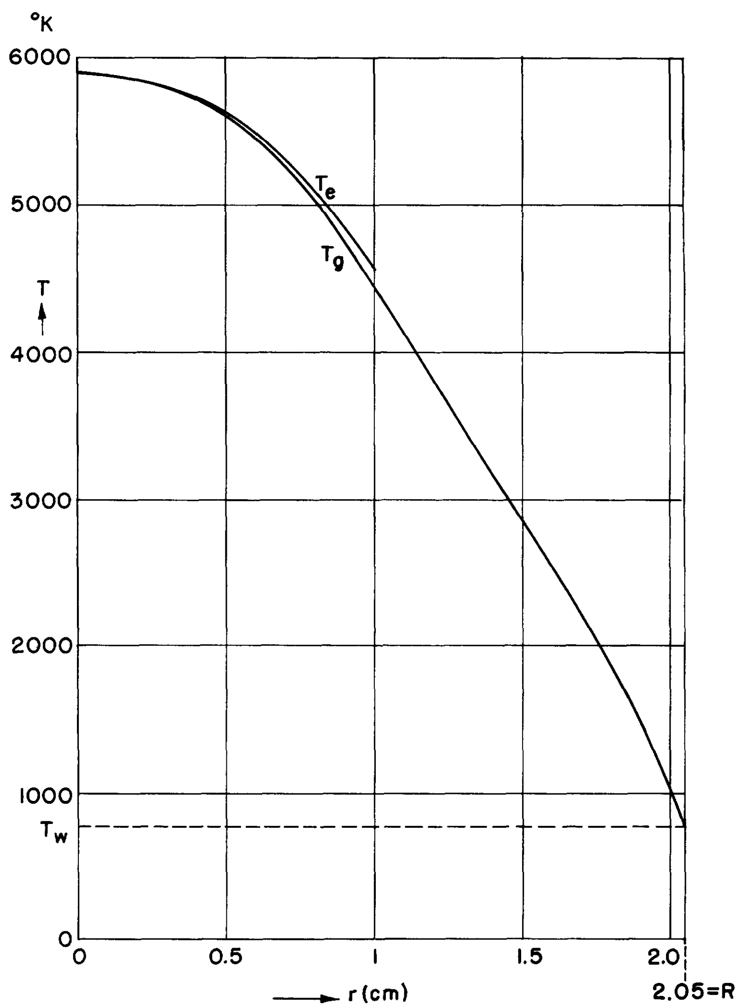


VIIa3. Various power losses of an electron in a microwave discharge in helium, in percentage of input power.

F. H. Reder, S. C. Brown, Phys. Rev. 95, 885 (1954)



VIIa4. Fractional energy loss in H_2.



VIIb1. Electron temperature and gas temperature of a discharge as a function of tube radius.

W. Elenbaas, The High Pressure Mercury Vapour Discharge (North Holland Publishing Company, Amsterdam, 1951), p. 40

VIII CATHODE PHENOMENA

Sputtering yield = $S/(1+\gamma)$ atoms per ion

$S = 10^5\, W/(AI^+t)$

W = loss of weight in grams

A = atomic weight

I^+ = ion current in amperes

t = time of bombardment in seconds

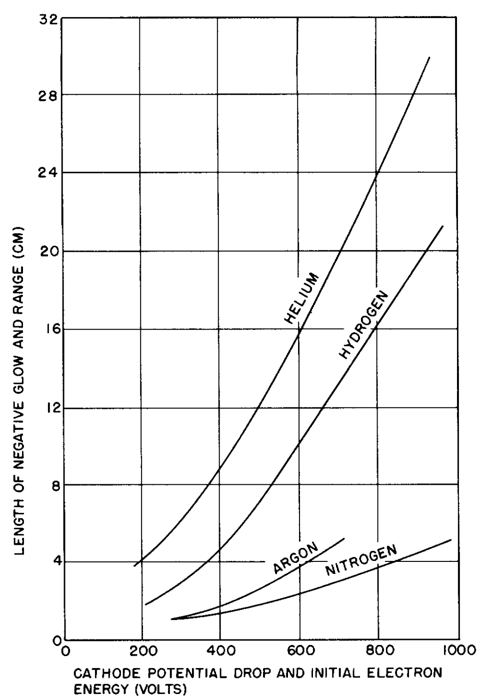
γ = second Townsend coefficient

VIII (a 1). Normal Cathode Fall in Volts

Cathode	Air	A	He	H_2	Hg	Ne	N_2	O_2	CO	CO_2	Cl
Al	229	100	140	170	245	120	180	311			
Ag	280	130	162	216	318	150	233				
Au	285	130	165	247		158	233				
Ba		93	86				157				
Bi	272	136	137	240			210				
C				240	475				525		
Ca		93	86			86	157				
Cd	266	119	167	200		160	213				
Co	380										
Cu	370	130	177	214	447	220	208		484	460	
Fe	269	165	150	250	298	150	215	290			
Hg			142		340		226				
Ir	380										
K	180	64	59	94		68	170		484	460	
Mo					353	115					
Mg	224	119	125	153		94	188	310			
Na	200		80	185		75	178				
Ni	226	131	158	211	275	140	197				
Pb	207	124	177	223		172	210				
Pd	421										
Pt	277	131	165	276	340	152	216	364	490	475	275
Sb	269	136		252			225				
Sn	266	124		226			216				
Sr		93	86				157				
Th						125					
W					305	125					
Zn	277	119	143	184			216	354	480	410	

VIII (a2). Normal Cathode Fall Thickness
($d_n p$ in cm-mm Hg at room temperature)

Cathode	Air	A	H_2	He	Hg	N_2	Ne	O_2
Al	0.25	0.29	0.72	1.32	0.33	0.31	0.64	0.24
C			0.9		0.69			
Cd			0.87					
Cu	0.23		0.8		0.6			
Fe	0.52	0.33	0.9	1.30	0.34	0.42	0.72	0.31
Mg			0.61	1.45		0.35		0.25
Hg			0.9					
Ni			0.9		0.4			
Pb			0.84					
Pt			1.0					
Zn			0.8					

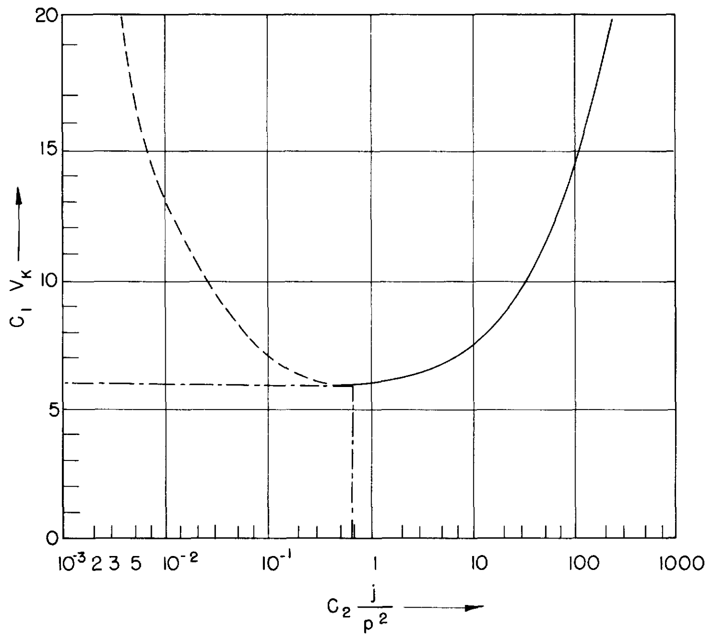


VIIIa3. Length of negative glow and range of electrons.

J. D. Cobine, Gaseous Conductors (McGraw-Hill, N. Y., 1941), p. 220

VIII (a4). Normal Cathode Current Density in a Glow Discharge (μamp/cm^2 × mm^2 of Hg at room temperature)

Cathode	Air	A	H_2	He	Hg	N_2	O_2	Ne
Al	330		90		4			
Au	570		110					
Cu	240		64		15			
Fe		160	72	2.2	8	400		6
Mg		20		3				5
Pt		150	90	5		380	550	18

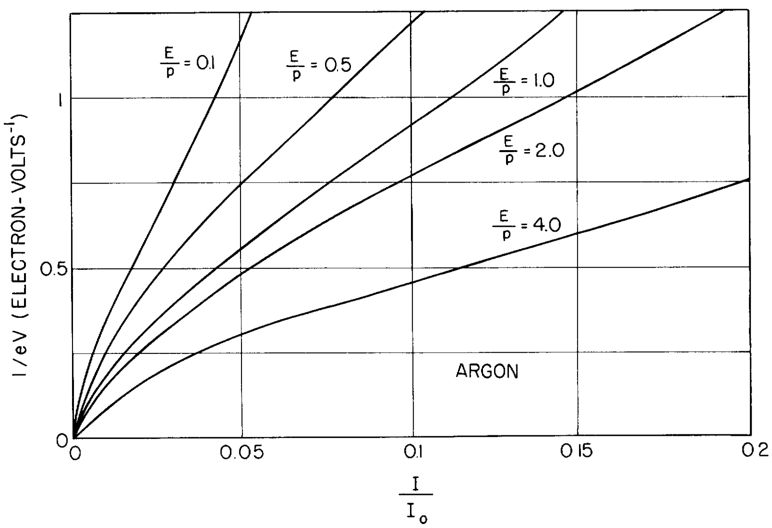


VIIIa4. Anomalous cathode fall.

A. von Engel, M. Steenbeck, Elektrische Gasentladungen (Springer Verlag, Berlin, 1932), Vol. II, p. 73

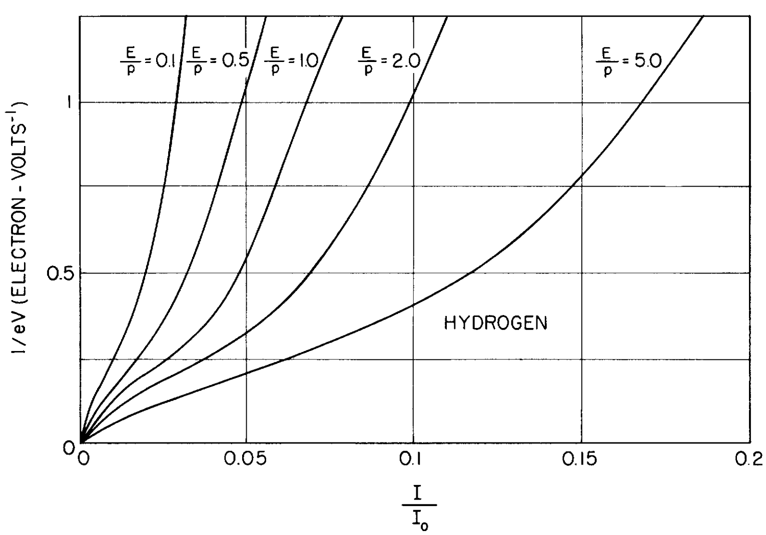
VIII(b1). Sputtered Mass in Micrograms Per Ampere-Second For Metals in Hydrogen

Mg	2.5	Mo	16	C	73
Ta	4.5	Co	16	Cu	84
Cr	7.5	W	16	Zn	95
Al	8	Ni	18	Pb	110
Cd	8.9	Fe	19	Au	130
Mn	11	Sn	55	Ag	205



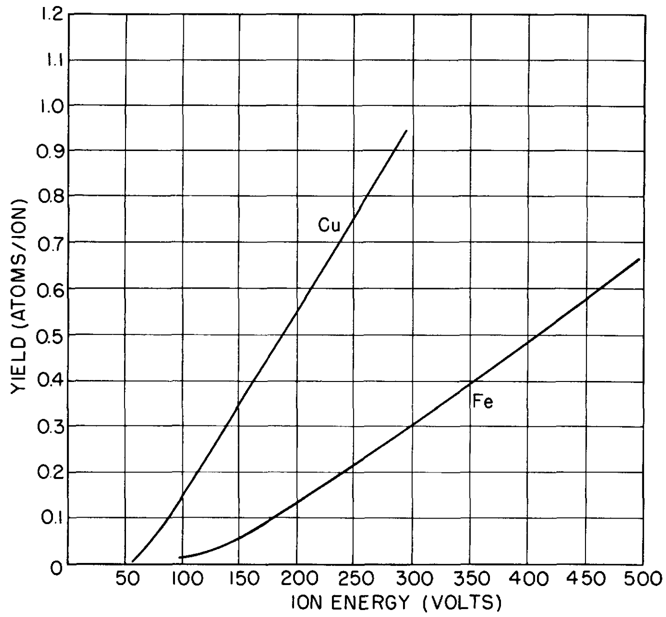
VIIIb1. Current ratio curves versus reciprocal of emissive energy. Curves permit correction for back diffusion for inert gases.

J. K. Theobald, J. Appl. Phys. 24, 123 (1953)



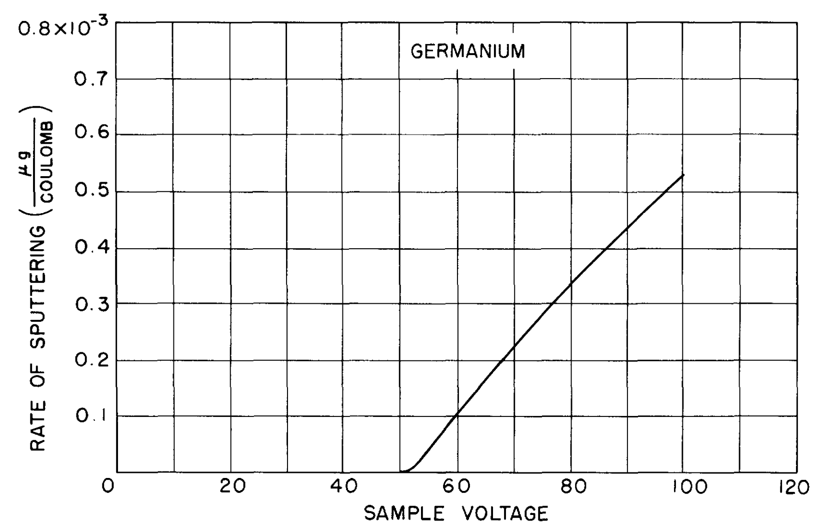
VIIIb2. Current ratio curves versus reciprocal of emissive energy. Curves permit correction for back diffusion for molecular gases.

J. K. Theobald, J. Appl. Phys. 24, 123 (1953)



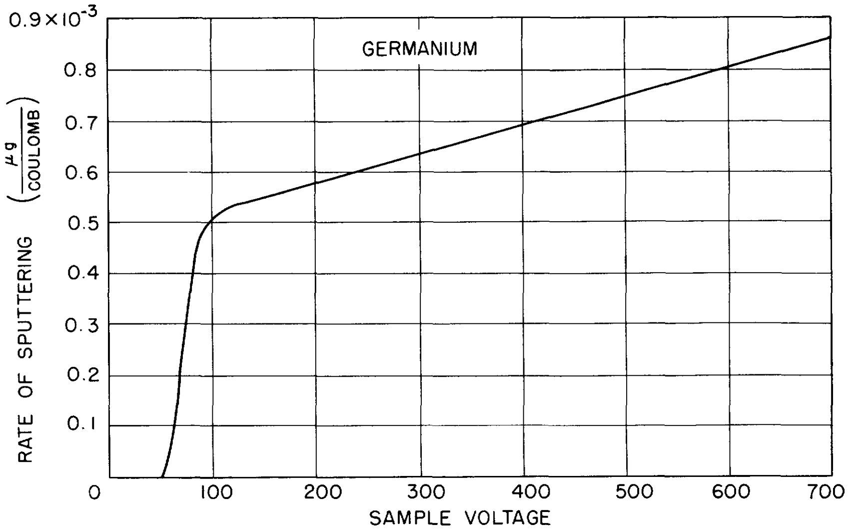
VIIIc1. Sputtering yields of Cu and Fe.

G. K. Wehner, Phys. Rev. 108, 35 (1957)



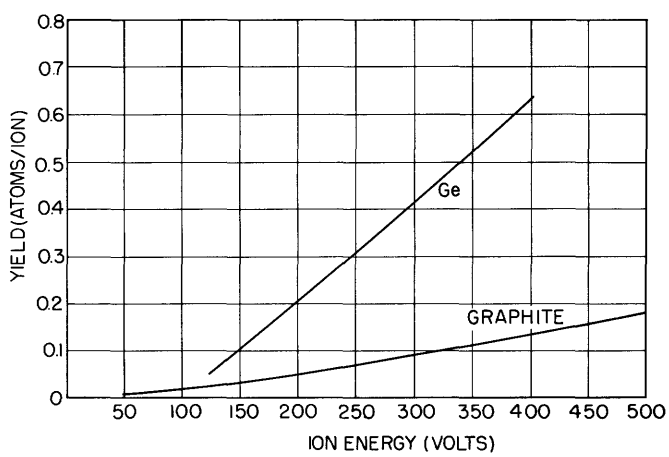
VIIIc2. Rate of sputtering from argon positive ion bombardment versus voltage for germanium.

S. P. Wolsky, Phys. Rev. 108, 1131 (1957)



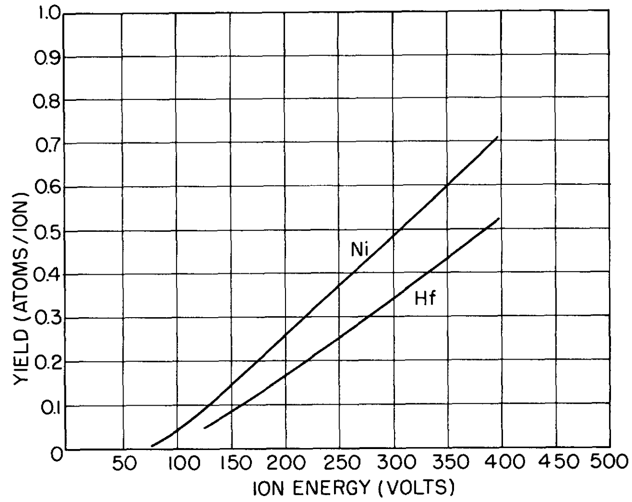
VIIIc2. Rate of sputtering from argon positive ion bombardment versus voltage for germanium.

S. P. Wolsky, Phys. Rev. 108, 1131 (1957)

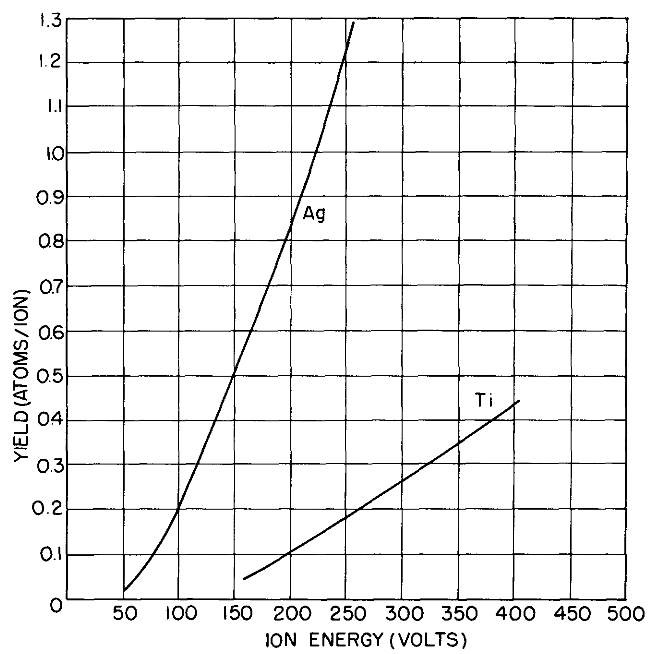


VIIIc2. Sputtering yields of Ge and graphite.

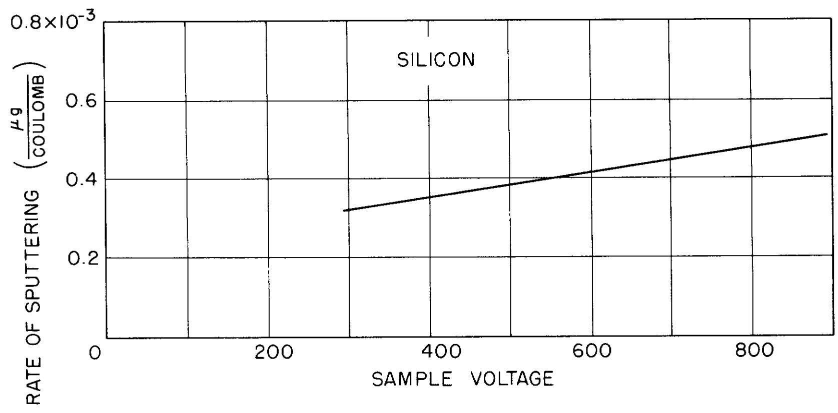
G. K. Wehner, Phys. Rev. 108, 35 (1957)



VIIIc3. Sputtering yields of Ni and Hf.
G. K. Wehner, Phys. Rev. 108, 35 (1957)

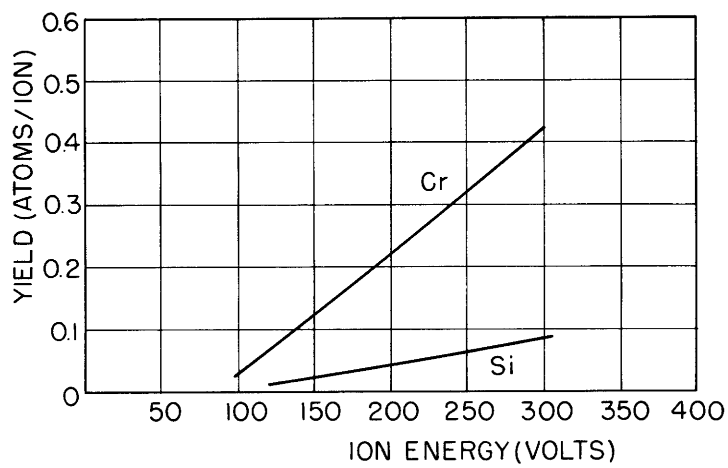


VIIIc4. Sputtering yields of Ag and Ti.
G. K. Wehner, Phys. Rev. 108, 35 (1957)



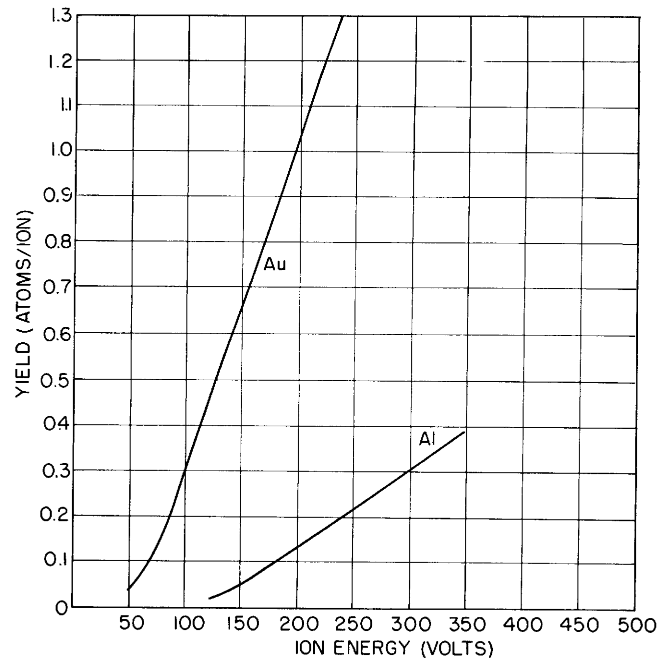
VIIIc5. Rate of sputtering from argon positive ion bombardment versus voltage for silicon.

S. P. Wolsky, Phys. Rev. 108, 1131 (1957)

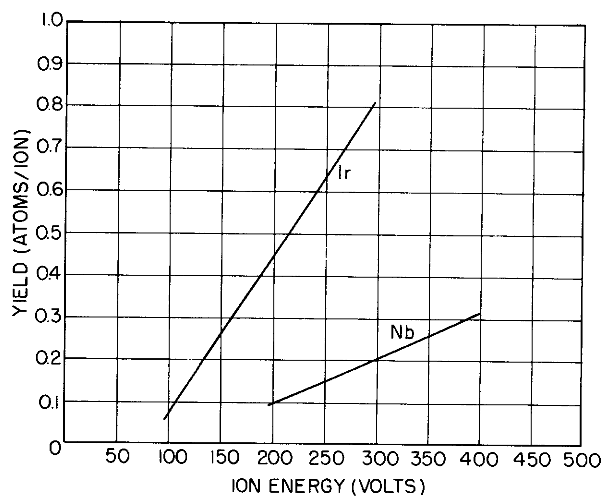


VIIIc5. Sputtering yields of Si and Cr.

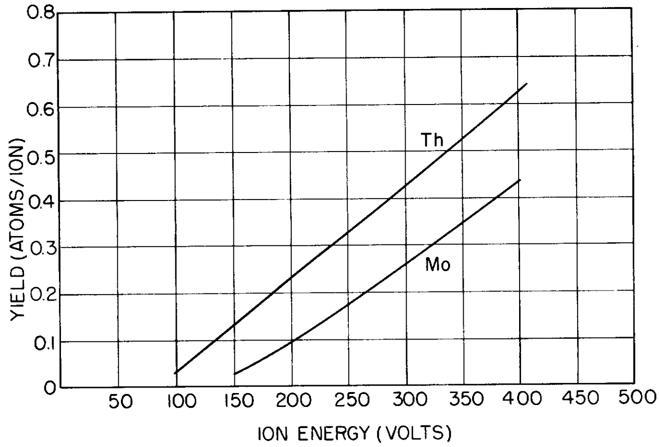
G. K. Wehner, Phys. Rev. 108, 35 (1957)



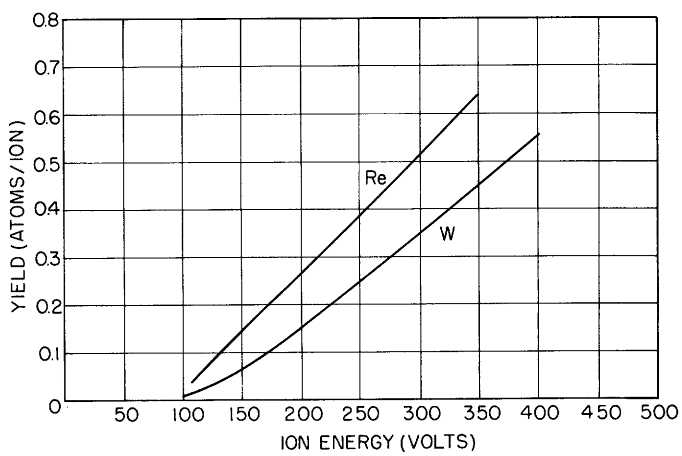
VIIIc6. Sputtering yields of Au and Al.
G. K. Wehner, Phys. Rev. 108, 35 (1957)



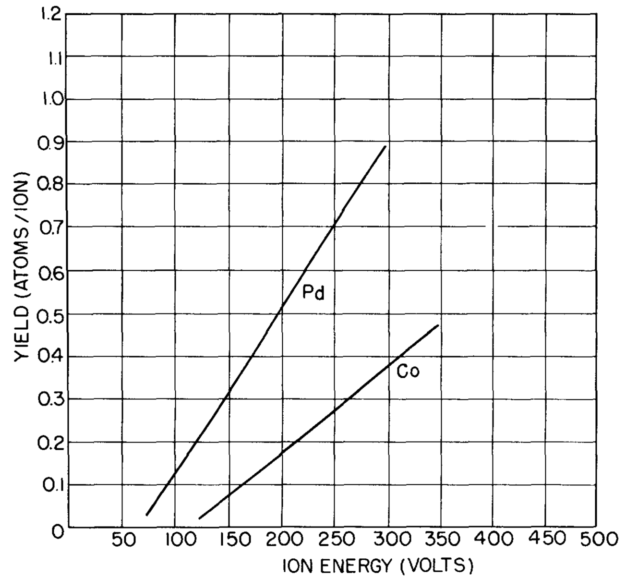
VIIIc7. Sputtering yields of Ir and Nb.
G. K. Wehner, Phys. Rev. 108, 35 (1957)



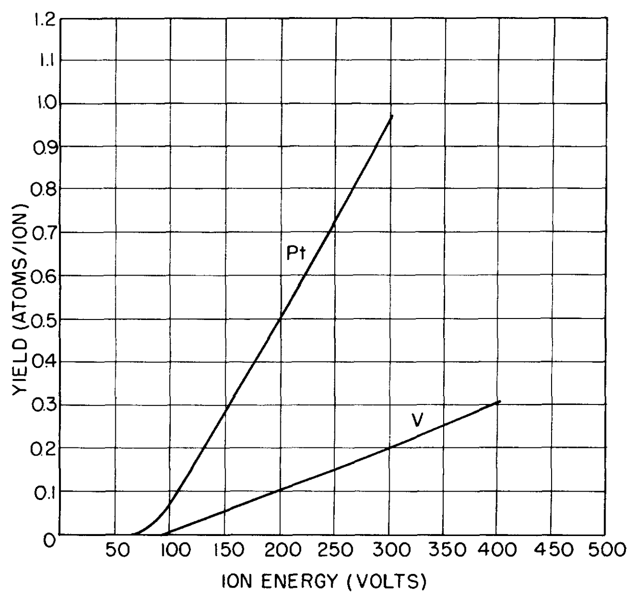
VIIIc8. Sputtering yields of Th and Mo.
G. K. Wehner, Phys. Rev. 108, 35 (1957)



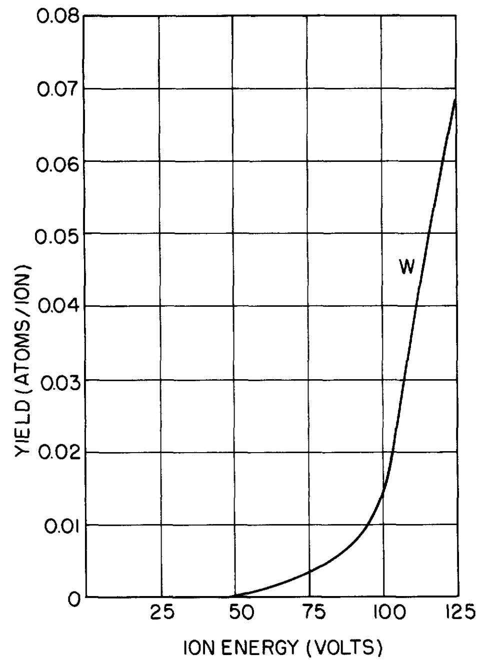
VIIIc9. Sputtering yields of Re and W.
G. K. Wehner, Phys. Rev. 108, 35 (1957)



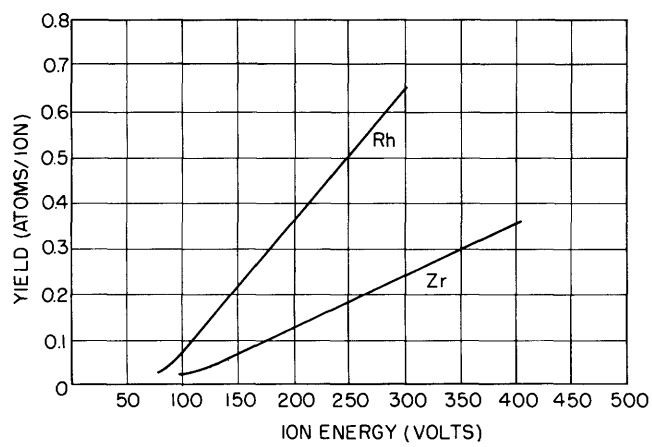
VIIIc10. Sputtering yields of Co and Pd.
G. K. Wehner, Phys. Rev. 108, 35 (1957)



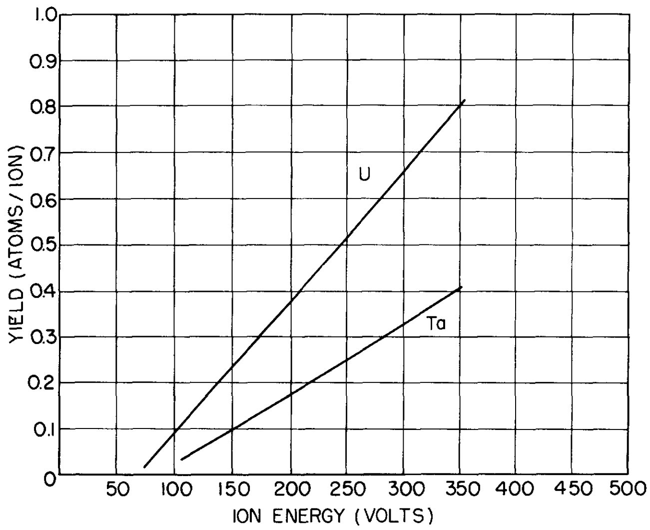
VIIIc11. Sputtering yields of Pt and V.
G. K. Wehner, Phys. Rev. 108, 35 (1957)



VIIIc12. Sputtering yields of W in region of low energy.
G. K. Wehner, Phys. Rev. 108, 35 (1957)



VIIIc13. Sputtering yields of Rh and Zr.
G. K. Wehner, Phys. Rev. 108, 35 (1957)



VIIIc14. Sputtering yields of U and Ta.
G. K. Wehner, Phys. Rev. 108, 35 (1957)