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MASTER

Atomic Data for Controlled Fusion Research

C. F. Barnett
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PHYSICS DIVISION

ATOMIC DATA FOR CONTROLLED FUSION RESEARCH

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ABSTRACT

Presented is an evaluated graphical and tabular compilation of atomic and molecular cross sections of interest to controlled thermonuclear research. The cross sections are tabulated and graphed as a function of energy for collision processes involving heavy particles, electrons, and photons with atoms and ions. Also included are sections on data for particle penetration through macroscopic matter, particle transport properties, particle interactions with surfaces, and pertinent charged particle nuclear cross sections and reaction rates. In most cases estimates have been made of the data accuracy.

FOREWORD

The work described in this report was sponsored by the Energy Research and Development Administration and is part of a series of ORNL reports on atomic and molecular processes of interest in fusion energy technology. The reports in this series are: ORNL-3113, May 1961; ORNL-3113, Revised, August 1964; ORNL-5206, First Volume, February 1977; and ORNL-5207, Second Volume of ORNL-5206, February 1977.

INTRODUCTION

This report is an expanded revision of a previous compilation of atomic and molecular cross sections issued in 1964 as ORNL-3113R. One difficulty encountered in using the previous edition was the problem of obtaining the data from graphs covering several orders of magnitude. This problem has been solved by presenting the data in both tabular and graphical form. For each set of data, references are given from which the data were obtained. All data were plotted and a best-fit to the data was made resulting in a single curve. Estimates have been made of the accuracy or confidence level of the data.

The cross section notation used is that in current use. The cross section σ_{if} represents the cross section of an energetic particle of initial charge state i and final charge state f. All cross sections are plotted in terms of cm^2/molecule or cm^2/atom for a montonic gas. Particular attention should be given to the explanatory notes found in each section.

A diligent effort has been made to ensure the accuracy of the publication process. However, in an effort of this magnitude errors will exist. The authors would greatly appreciate the users bringing these to our attention. An annual up-dating of the data is planned.

C. Electron Collisions

C.1 Electron Scattering

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Total Scattering of Electrons

(Inelastic and Elastic) in Gases

(H, H_2, and He)

$e + H \rightarrow e + H$

$e + H_2 \rightarrow e + H_2$

$e + He \rightarrow e + He$

Energy (eV)	Cross Section (cm^2)		
	H	H_2	He
1.0 E 00		1.31 E-15	5.93 E-16
2.0 E 00		1.51 E-15	5.93 E-16
3.0 E 00		1.58 E-15	5.80 E-16
4.0 E 00	1.04 E-15	1.49 E-15	5.48 E-16
6.0 E 00	8.19 E-16	1.29 E-15	4.87 E-16
8.0 E 00	6.58 E-16	1.09 E-15	4.32 E-16
1.0 E 01	5.41 E-16	9.40 E-16	3.92 E-16
1.5 E 01		7.04 E-16	3.11 E-16
2.0 E 01		5.66 E-16	2.62 E-16
2.5 E 01		4.90 E-16	2.27 E-16
3.0 E 01		4.40 E-16	2.03 E-16
4.0 E 01		3.70 E-16	1.90 E-16
6.0 E 01		2.65 E-16	1.69 E-16
8.0 E 01		1.84 E-16	1.42 E-16
1.0 E 02		1.47 E-16	1.19 E-16
2.0 E 02		1.18 E-16	8.27 E-17
3.0 E 02		6.90 E-17	4.78 E-17
4.0 E 02		5.00 E-17	3.70 E-17

References:

e + H, Experimental: Best fit to experimental data as deduced by L.J. Kieffer, Atomic Data 2, 293 (1971).

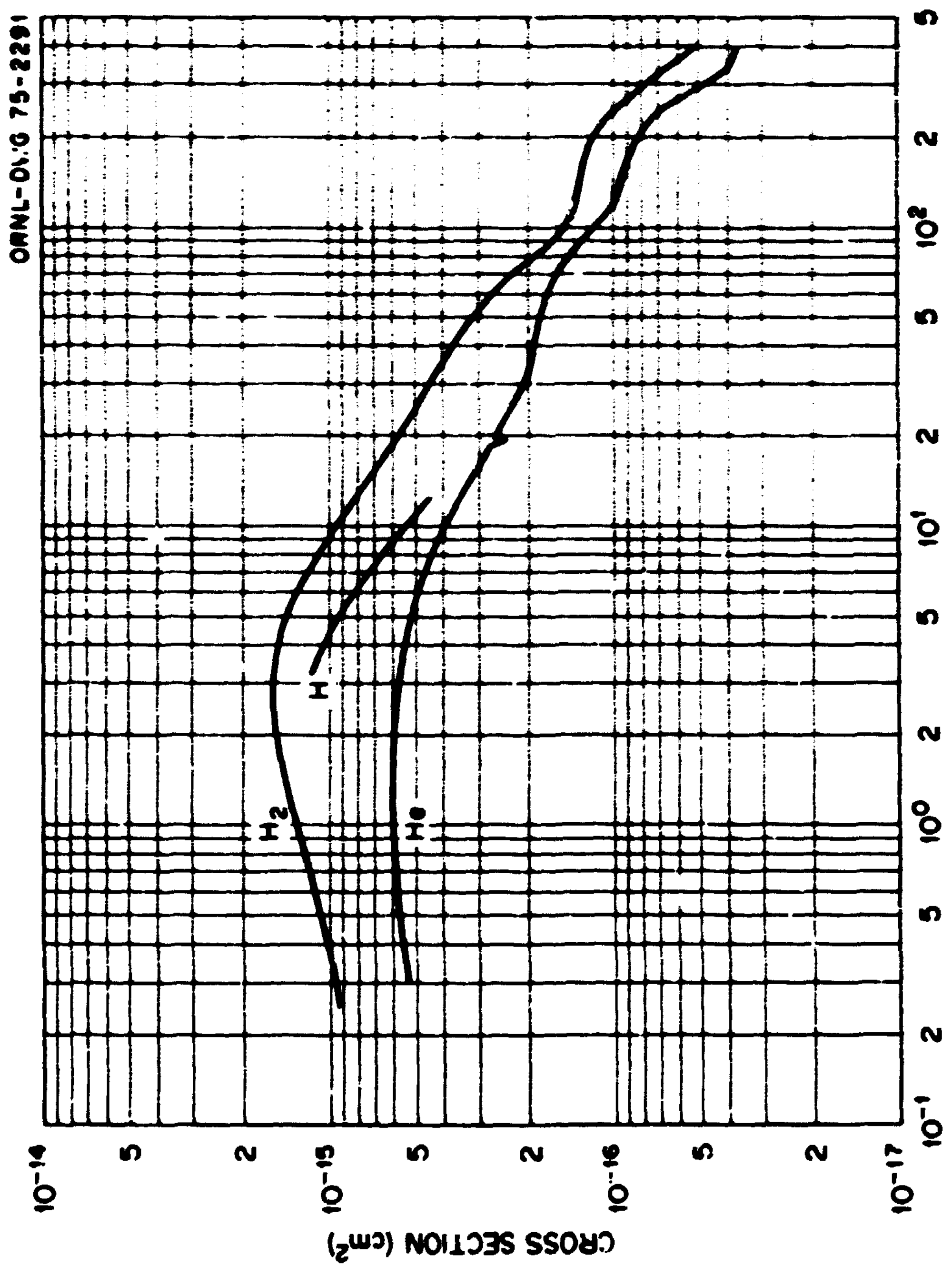
e + H_2, Experimental: D.E. Golden, H.W. Bandel, and J.A. Salerno, Phys. Rev. 146, 40 (1966). C.E. Normand, Phys. Rev. 35, 1217 (1930).

e + He, Experimental: D.E. Golden and H.W. Bandel, Phys. Rev. 138, A14 (1965). C.E. Normand, Phys. Rev. 35, 1217 (1930).

Accuracy: e + H - not specific. e + H_2 - random and systematic errors < $\pm$ 3%. e + He - random and systematic errors < $\pm$ 3%.

Note:

See Note (1) at end of chapter.


ORNL-DWG 75-2291
CROSS SECTION (cm²)
ENERGY (eV)
10^{-14}
5
2
10^{-15}
5
2
10^{-16}
5
2
10^{-17}
10^{-1}
2
5
10^{0}
2
5
10^{1}
2
5
10^{2}
2
5
H_2
H
He

Elastic Differential (In Angle)

Scattering of Electrons on H

$e + H \rightarrow e + H$

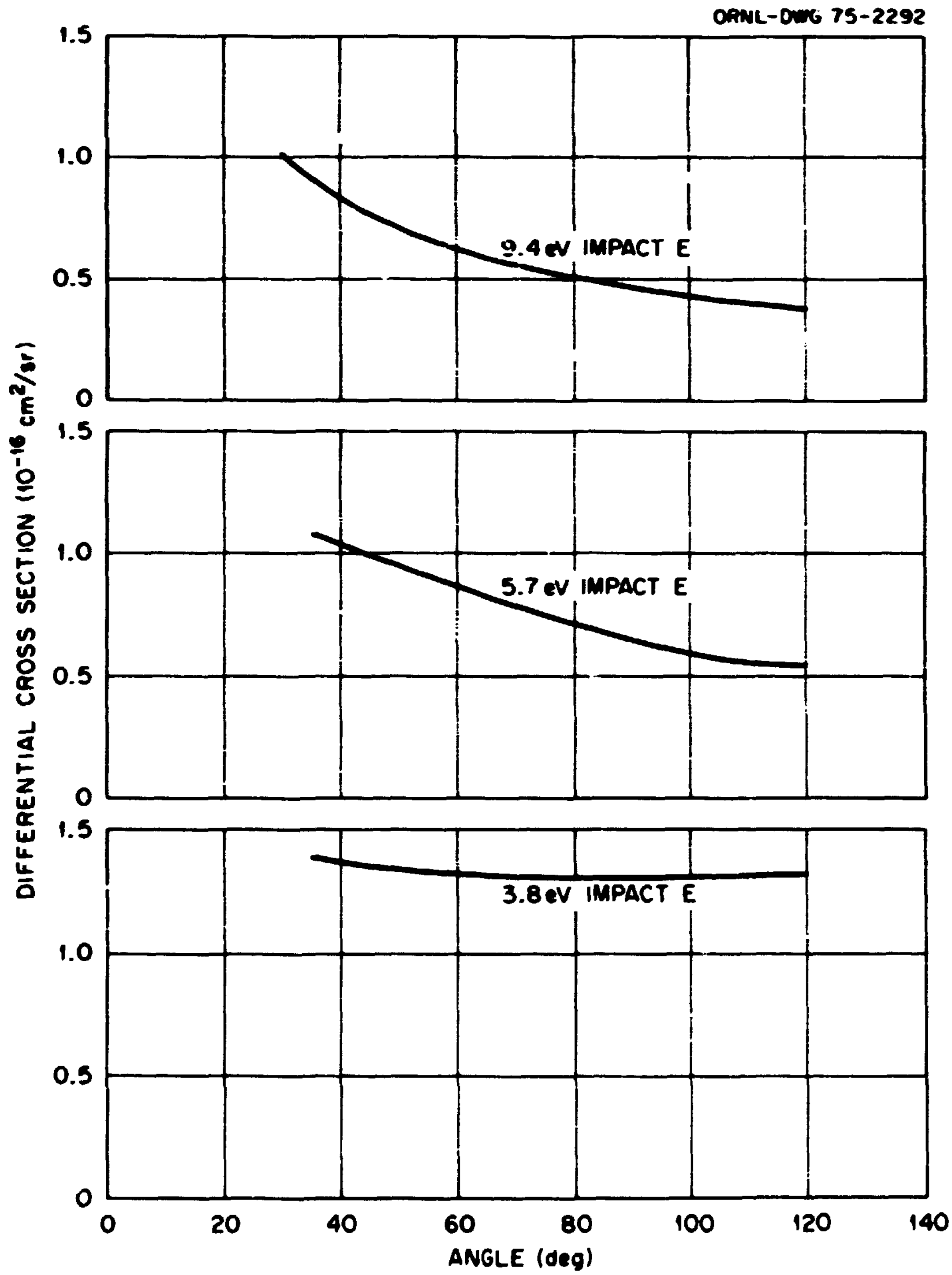
Angle (deg)	Differential Cross Section (cm^2/sr)		
	Impact Energy		
	3.8 eV	5.7 eV	9.4 eV
3.0 E 01			1.02 E-16
3.5 E 01	1.39 E-16	1.08 E-16	9.10 E-15
4.0 E 01	1.37 E-16	1.04 E-16	8.30 E-15
6.0 E 01	1.32 E-16	8.60 E-15	6.10 E-15
8.0 E 01	1.30 E-16	7.10 E-15	5.00 E-15
1.0 E 02	1.30 E-16	6.00 E-15	4.30 E-15
1.2 E 02	1.31 E-16	5.50 E-15	3.80 E-15

Reference:

e + H, Experimental: H.B. Gilbody, R.F. Stebbings, and W.L. Fite, Phys. Rev. 121, 794 (1961).

Accuracy:

Systematic error $< \pm 20\%$.


ORNL-DWG 75-2292
DIFFERENTIAL CROSS SECTION (10^{-16} cm^2/sr)
9.4 eV IMPACT E
5.7 eV IMPACT E
3.8 eV IMPACT E
1.5
1.0
0.5
0
0
20
40
60
80
100
120
140
ANGLE (deg)

Elastic Differential (In Angle) Scattering of Electrons in H_2

$$e + H_2 \rightarrow e + H_2$$

Angle (deg)	Differential Cross Section (cm^2/sr)		
	Impact Energy		
	1.0 eV	30 eV	200 eV
2.0 E 01	5.80 E-17	7.84 E-17	3.75 E-18
3.0 E 01	5.80 E-17	4.45 E-17	1.25 E-18
4.0 E 01	6.00 E-17	2.59 E-17	5.12 E-19
5.0 E 01	6.38 E-17	1.56 E-17	2.50 E-19
6.0 E 01	6.88 E-17	9.88 E-18	1.49 E-19
7.0 E 01	7.77 E-17	6.53 E-18	1.00 E-19
8.0 E 01	8.97 E-17	4.58 E-18	7.11 E-20
9.0 E 01	1.08 E-16	3.38 E-18	5.20 E-20
1.0 E 02	1.11 E-16	2.63 E-18	3.81 E-20
1.1 E 02	1.22 E-16	2.22 E-18	2.85 E-20
1.2 E 02	1.31 E-16	2.08 E-18	2.16 E-20
1.3 E 02	1.39 E-16		
1 4 E 02	1.45 E-16		
1.5 E 02	1.52 E-16		
1.6 E 02	1.62 E-16		
1.7 E 02	1.64 E-16		

References:

$e + H_2$(at 1.0 eV): H. Ehrhardt and F. Linder as quoted by N.F. Lane and S. Geltman, Phys. Rev. 184, 46 (1969). C. Ramsauer and R. Kollath, Ann. Physik 4, 91 (1929).

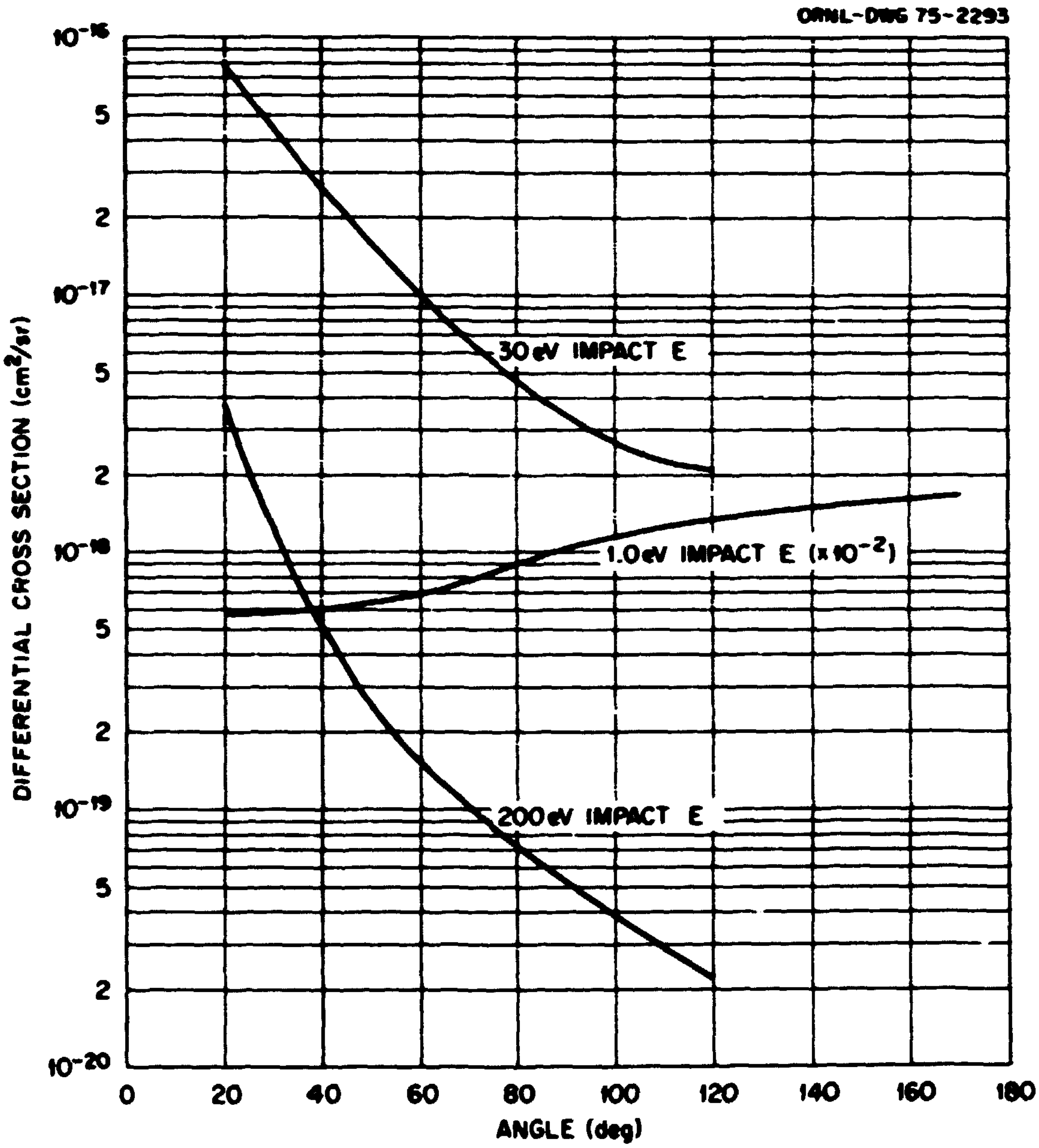
$e + H_2$(at 30 and 200 eV): K.G. Williams. Abstracts of Papers, 6th Intl. Conf. on the Physics of Electronic Collisions (MIT Press, Cambridge, 1969) page 735.

Accuracy:

Random error < ± 2%.

Notes:

See Note (2) at end of chapter.


ORNL-DWG 75-2293
30 eV IMPACT E
1.0 eV IMPACT E (×10⁻²)
200 eV IMPACT E
DIFFERENTIAL CROSS SECTION (cm²/sr)
ANGLE (deg)
10⁻¹⁶
10⁻¹⁷
10⁻¹⁸
10⁻¹⁹
10⁻²⁰
0
20
40
60
80
100
120
140
160
180

Elastic Differential (In Angle) Scattering of Electrons in He

e + He → e + He

Angle (deg)	Differential Cross Section (cm^2/sr)			
	Impact Energy			
	3.1 eV	25 eV	200 eV	700 eV
5.0 E 00			5.42 E-17	
1.0 E 01			3.61 E-17	1.28 E-17
2.0 E 01		1.62 E-17	1.40 E-17	3.50 E-18
3.0 E 01	2.24 E-17	1.10 E-17	6.30 E-18	1.31 E-18
4.0 E 01	2.48 E-17	8.60 E-18	3.14 E-18	5.10 E-19
5.0 E 01	2.69 E-17	7.20 E-18	1.75 E-18	2.50 E-19
6.0 E 01	2.92 E-17	6.20 E-18	1.16 E-19	1.36 E-19
7.0 E 01	3.15 E-17	5.68 E-18	8.07 E-19	8.80 E-20
8.0 E 01	3.39 E-17	5.30 E-18	6.04 E-19	6.06 E-20
9.0 E 01	3.61 E-17	5.10 E-18	4.85 E-19	4.68 E-20
1.0 E 02	3.89 E-17	5.00 E-18	3.82 E-19	3.92 E-20
1.1 E 02	4.17 E-17	5.07 E-18	3.28 E-19	3.55 E-20
1.2 E 02	4.46 E-17	5.36 E-18	2.90 E-19	3.32 E-20
1.3 E 02	4.79 E-17	5.82 E-18	2.70 E-19	3.30 E-20
1.4 E 02	5.21 E-17		2.68 E-19	2.56 E-20
1.5 E 02			2.68 E-19	
1.6				

References:

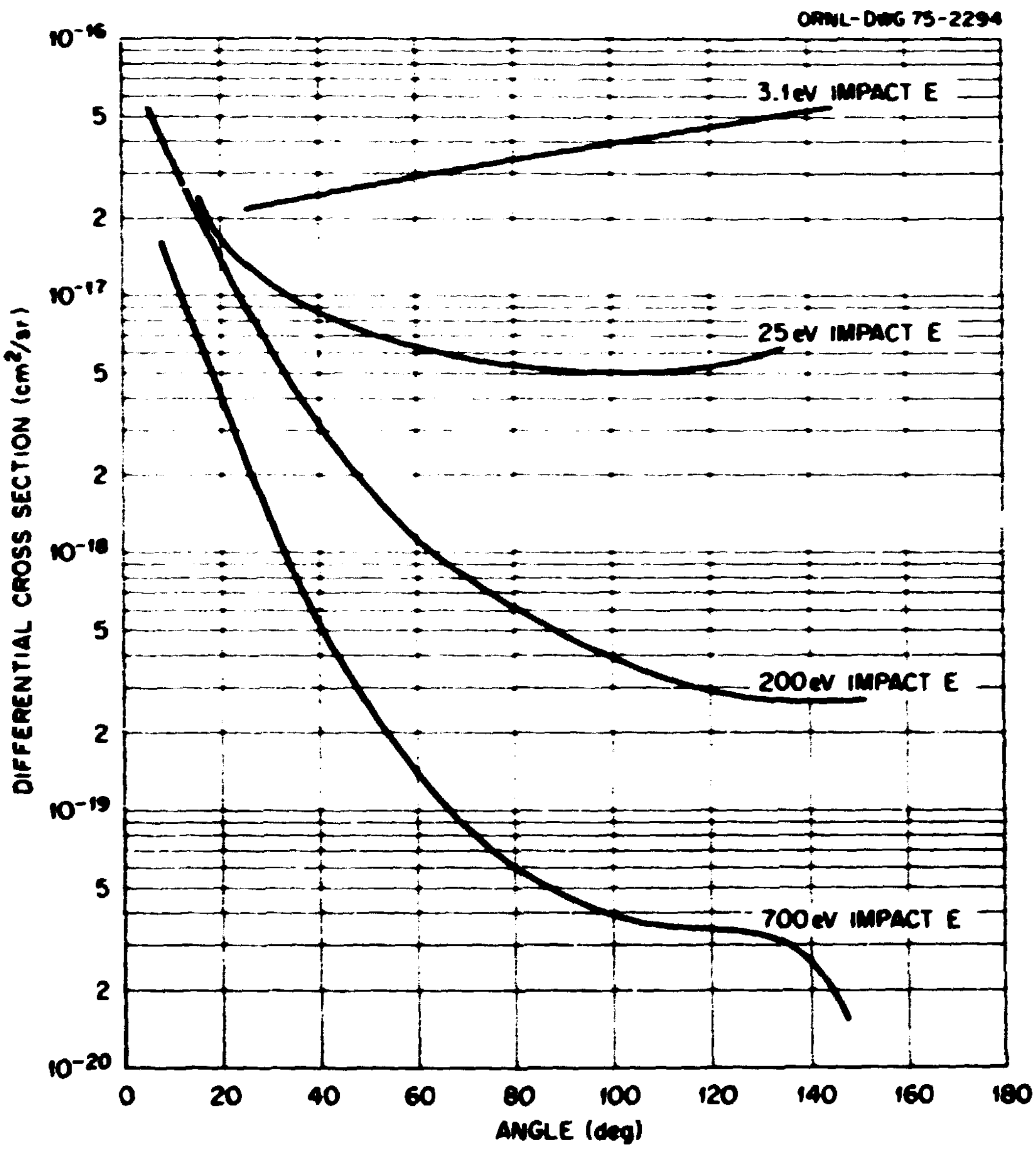
e + He, Experimental: These data are all taken from the review by L.J. Kieffer, Atomic Data 2, 293 (1971). The individual sources are: - at 3.1 eV J.R. Gibson, K.T. Dolder, J. Phys. B 2, 1180 (1969); at 25, 200, and 700 eV A.L. Hughes, J.H. McMillen, G.M. Webb, Phys. Rev. 41, 154 (1932); also at 200 eV, L. Vriens, C.E. Kuyatt, S.R. Mielczarek, Phys. Rev. 170, 163 (1968).

Accuracy:

Random error < ± 15% at 3.1 eV. Random error < ± 3% at all other energies.

Notes:

See Note (3) at end of chapter.


ORNL-DWG 75-2294
DIFFERENTIAL CROSS SECTION (cm²/sr)
ANGLE (deg)
3.1eV IMPACT E
25eV IMPACT E
200eV IMPACT E
700eV IMPACT E
10⁻¹⁶
10⁻¹⁷
10⁻¹⁸
10⁻¹⁹
10⁻²⁰
5
2
0
20
40
60
80
100
120
140
160
180

Differential (In Angle) Cross Sections for Inelastic and Elastic Scattering of Electrons in He at 25 keV Impact Energy

e + He → e + He

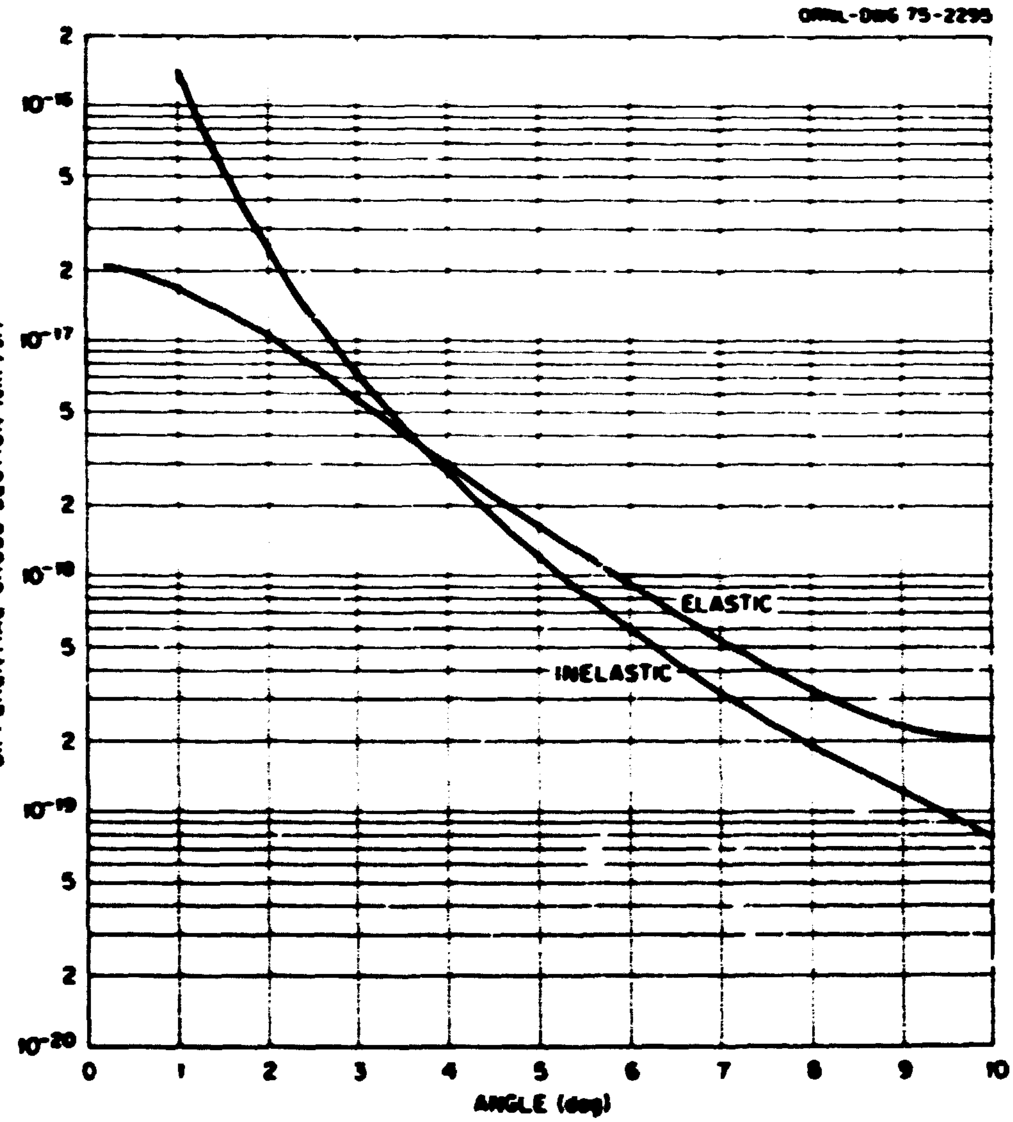
Angle (deg)	Differential Cross Sections (cm^2/sr) Elastic	Inelastic
2.0 E-01	2.04 E-17	
5.0 E-01	1.94 E-17	
1.0 E 00	1.65 E-17	1.42 E-16
2.0 E 00	1.03 E-17	2.40 E-17
3.0 E 00	5.60 E-18	7.24 E-18
4.0 E 00	2.90 E-18	2.70 E-18
5.0 E 00	1.61 E-18	1.17 E-18
6.0 E 00	9.09 E-19	5.78 E-19
7.0 E 00	5.21 E-19	3.10 E-19
8.0 E 00	3.20 E-19	1.85 E-19
9.0 E 00	2.25 E-19	1.18 E-19
1.0 E 01	2.00 E-19	7.52 E-20

Reference:

e + He, Experimental: H.F. Wellenstein, R.A. Bonham, R.C. Ulsh, Phys. Rev. A 8, 304 (1973).

Accuracy:

Systematic error < ± 2%. Random error < ± 2%.


ORNL-DWG 75-2295
DIFFERENTIAL CROSS SECTION (cm²/sr)
10^{-16}
10^{-17}
10^{-18}
10^{-19}
10^{-20}
2
5
ELASTIC
INELASTIC
0 1 2 3 4 5 6 7 8 9 10
ANGLE (deg)

Notes

(1) According to D.E. Golden, H. W. Bandel, and J.A. Salerno, Phys. Rev. 146, 40 (1966), the cross section for D_2 is identical to that for H_2.

(2) References cited include data for other energies between 1.0 and 200 eV. Also relative values to 912 eV are given by Webb, Phys. Rev. 47, 384 (1935).

(3) The review by Kieffer cited here contains data for many other energies between 3.1 and 700 eV.

C.2 Excitations by Electrons

Collisional Excitation of H by Electron Impact:

$$e + H(n'\ell') \rightarrow e + H(n,\ell)$$

At sufficiently high impact energies the excitation cross section is given by the Bethe formula:

$$Q_{n'\ell',\, n\ell} = 8.806 \times 10^{-17}(C_{n'\ell',\, n\ell}/E)\ln(D_{n'\ell',n\ell}\, E)$$

Here E is the electron impact energy; $C_{n'\ell',n\ell}$ and $D_{n'\ell',n\ell}$ are constants depend only on the quantum states involved. This equation is valid only for "optically allowed" transitions (i.e., $\ell-\ell' = 1$).

Given in the tables on the facing page are tabular values of the two constants for excitation events where the principal quantum number increases by one or two (i.e., $n-n' = 1$ or 2) and the angular momentum quantum number increases by one (i.e., $\ell-\ell' = 1$). When these constants are inserted in the above equation with the energy E in electron volts, then the cross section Q is given in units of cm^2. The cross sections should be quite accurate at impact energies above 100 ev for $1s \rightarrow n\ell$ transitions and above 50 eV for all other transitions.

These theoretical values are by G. G. McCoyd and S. N. Milford, Phys. Rev. 130, 206 (1963). Note that the number in parenthesis denotes power of 10.

Collision Excitation of H by Electron Impact $e + H(n'\ell') \rightarrow e + H(n,\ell)$

$C_{n'\ell',n\ell}$ for $n-n' = 1$

ℓ'/n'	1	2	3	4	5	6	7
0	3.0(1)	1.70(2)	5.4(2)	1.32(3)	2.7(3)	5.0(3)	8.4(3)
1		2.7(2)	6.9(2)	1.47(3)	2.8(3)	4.8(3)	7.8(3)
2			1.14(3)	2.2(3)	3.8(3)	6.2(3)	9.5(3)
3				3.3(3)	5.3(3)	8.2(3)	1.22(4)
4					7.5(3)	1.10(4)	1.58(4)
5						1.48(4)	2.1(4)
6							2.7(4)
7							
8							
9							

$C_{n'\ell',n\ell}$ for $n-n' = 2$

ℓ'/n'	1	2	3	4	5	6	7
0	4.8	3.0(1)	9.3(1)	2.2(2)	4.3(2)	7.7(2)	1.27(3)
1		3.5(1)	1.07(2)	2.3(2)	4.4(2)	7.4(2)	1.18(3)
2			1.20(2)	2.9(2)	5.5(2)	9.1(2)	1.42(3)
3				2.9(2)	6.4(2)	1.10(3)	1.71(3)
4					5.6(2)	1.19(3)	1.96(3)
5						9.7(2)	2.0(3)
6							1.54(3)
7							
8							
9							

$D_{n'\ell',n\ell}$ for $n-n' = 1$

ℓ'/n'	1	2	3	4	5	6	7
0	1.03(-1)	2.7(-1)	5.0(-1)	8.0(-1)	1.14	1.6	2
1		5.8(-1)	7.6(-1)	1.08	1.44	1.9	3
2			1.39	1.50	1.77	2	3
3				2.6	2.6	2	4
4					4.2	5	4
5						5	5
6							1.2(1)
7							
8							
9							

$D_{n'\ell',n\ell}$ for $n-n' = 2$

ℓ'/n'	1	2	3	4	5	6	7
0	1.41(-1)	3(-1)	5.2(-1)	8.1(-1)	1.2	1.8	1.8
1		8(-1)	9.7(-1)	1.2	2	1.8	1.8
2			2.7	2	3	3	4
3				5.9	4	5	4
4					1.1(1)	8	7
5						2(1)	1.3(1)
6							3(1)
7							
8							
9							

Collisional Excitation of Hydrogenic Ions by Electron Impact:

(General Formulation)

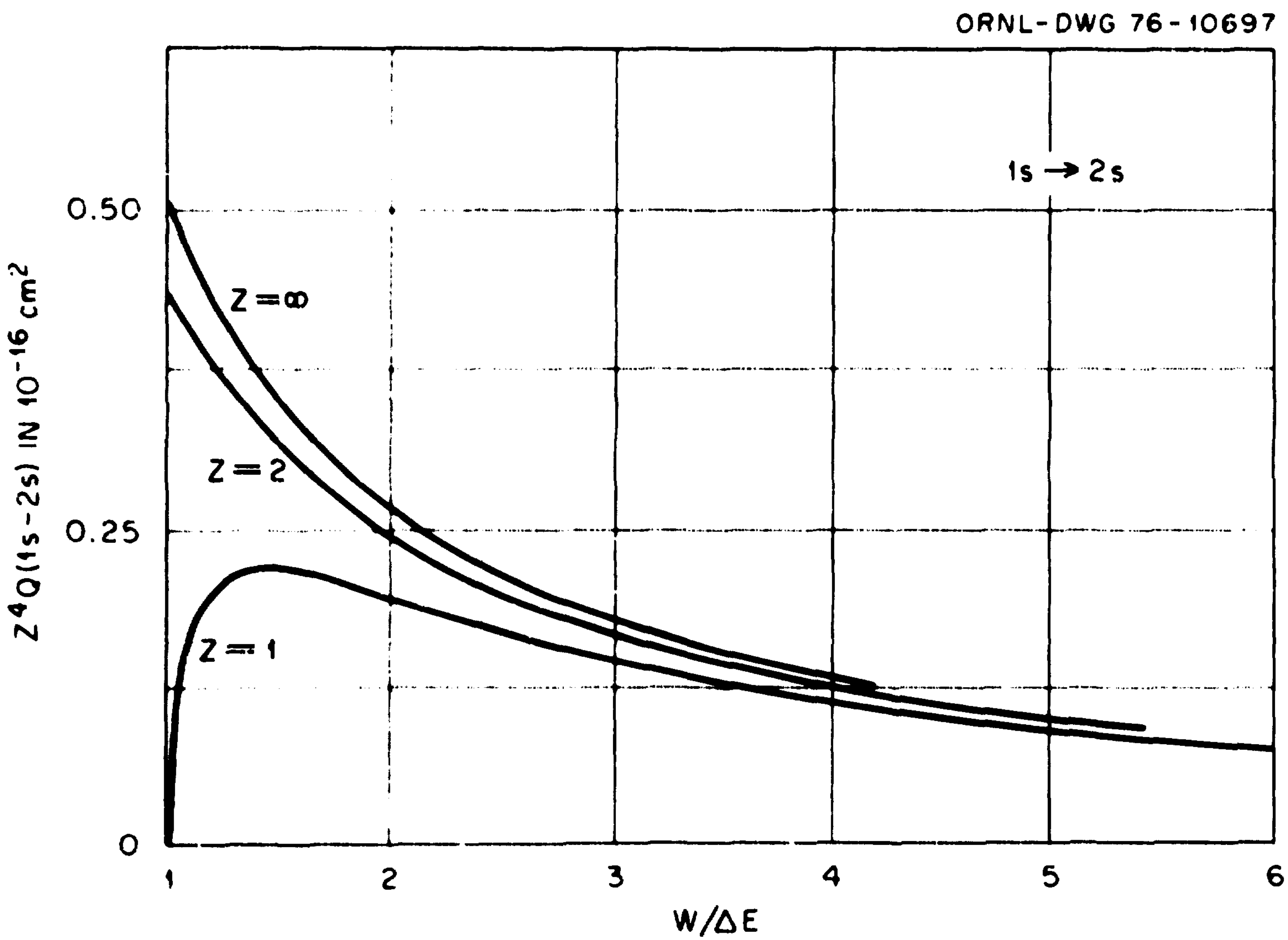
Seaton (in Atomic and Molecular Processes, Ed. D.R. Bates, Academic Press, N.Y. 1962 p. 339) presents curves showing 1s → 2s and 1s → 2p excitation cross sections as a function of target nuclear charge for hydrogenic ions. Here Z is nuclear charge, Q is cross section in cm^2, W is incident energy, and ΔE is the transition energy for the excitation process.

The results as presented here are of qualitative interest only, as the basic theoretical method (Born approximation) is inaccurate at the energy range covered here.

In general one may estimate a cross section for excitation of any hydrogenic ion at projectile impact energies five or more times threshold energy by the following procedure. Taking the cross section for excitation of the required state in H from either of the two preceding data tables:

(i) Increase cross section values by a factor of Z^4 (where Z is the target nuclear charge.

(ii) Increase energy scale by a factor of Z^2.


ORNL-DWG 76-10697
1s → 2s
Z = ∞
Z = 2
Z = 1
0.50
0.25
0
1
2
3
4
5
6
W/ΔE
Z⁴Q(1s - 2s) IN 10⁻¹⁶ cm²

Collisional Excitation of H by Electrons:

$e + H \rightarrow e + H(2s, 2p, n=3, 3s, 4s)$

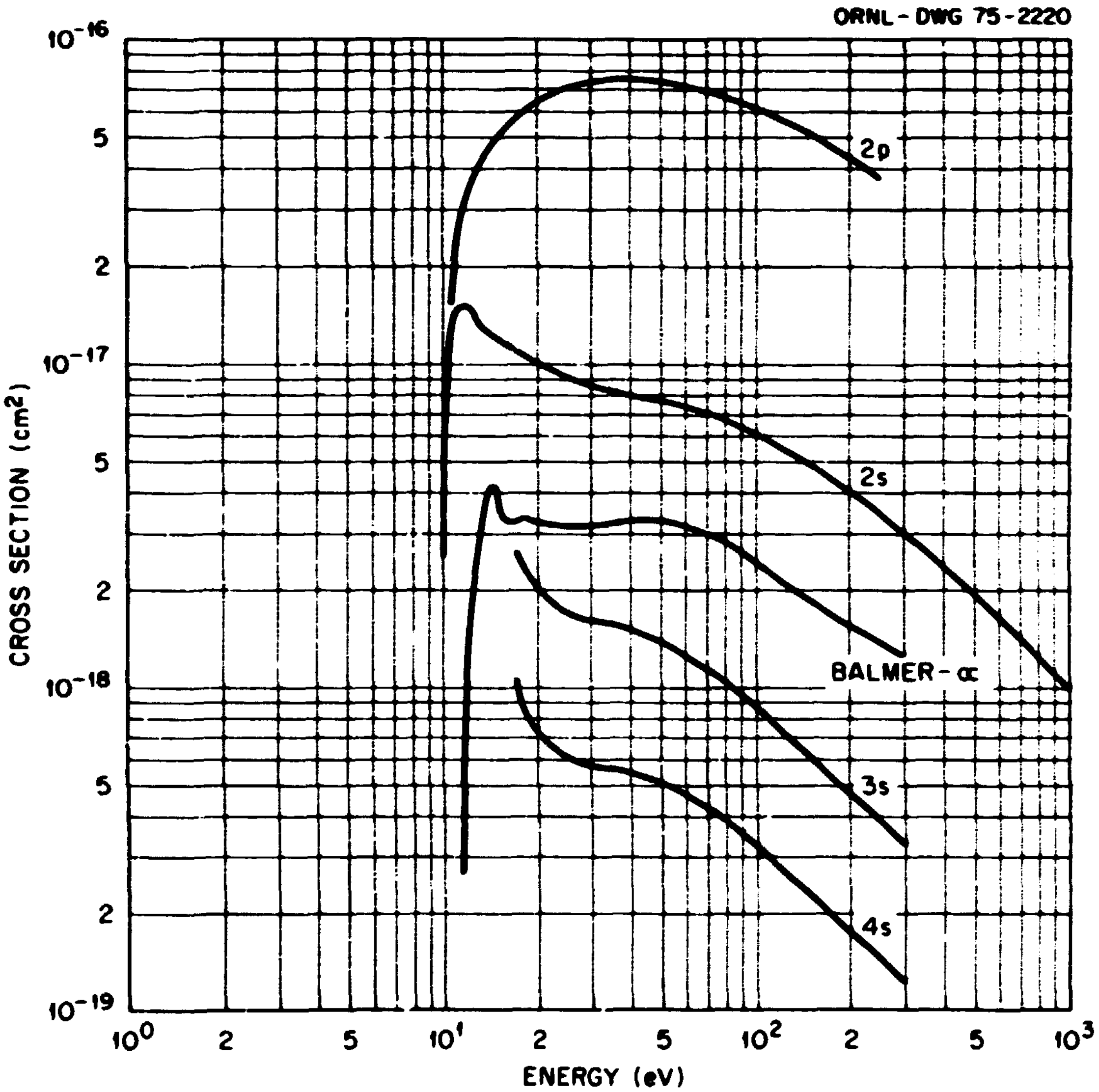
Energy (eV)	Cross Sections for State nℓ (cm²)				
	Experimental		Theoretical		Experimental
	2s	2p	3s	4s	Balmer α
1.0 E 01	2.5 E-18	7.9 E-18			
1.1 E 01	1.44 E-17	2.20 E-17			
1.2 E 01	1.50 E-17	3.38 E-17			1.20 E-18
1.3 E 01	1.34 E-17	4.00 E-17			2.75 E-18
1.4 E 01	1.26 E-17	4.51 E-17			4.01 E-18
1.5 E 01	1.20 E-17	4.95 E-17			3.60 E-18
1.6 E 01	1.14 E-17	5.33 E-17			3.30 E-18
1.7 E 01	1.10 E-17	5.65 E-17	2.70 E-18	1.09 E-18	3.30 E-18
1.8 E 01	1.05 E-17	5.95 E-17	2.40 E-18	8.7 E-19	3.37 E-18
1.9 E 01	1.03 E-17	6.15 E-17	2.20 E-18	7.8 E-19	3.35 E-18
2.0 E 01	1.00 E-17	6.40 E-17	2.04 E-18	7.3 E-19	3.27 E-18
3.0 E 01	8.60 E-18	7.30 E-17	1.61 E-18	5.75 E-19	3.20 E-18
4.0 E 01	8.01 E-18	7.50 E-17	1.50 E-18	5.42 E-19	3.30 E-18
5.0 E 01	7.70 E-18	7.40 E-17	1.37 E-18	5.02 E-19	3.30 E-18
6.0 E 01	7.40 E-18	7.10 E-17	1.25 E-18	4.63 E-19	3.18 E-18
8.0 E 01	6.70 E-18	6.60 E-17	1.02 E-18	3.84 E-19	2.81 E-18
1.0 E 02	6.10 E-18	6.15 E-17	8.6 E-19	3.24 E-19	2.45 E-18
1.5 E 02	4.90 E-18	5.05 E-17	6.0 E-19	2.24 E-19	1.84 E-18
2.0 E 02	4.02 E-18	4.23 E-17	4.7 E-19	1.75 E-19	1.56 E-18
3.0 E 02	3.00 E-18		3.3 E-19	1.22 E-19	1.24 E-18
4.0 E 02	2.34 E-18				
5.0 E 02	1.94 E-18				
6.0 E 02	1.62 E-18				
8.0 E 02	1.23 E-18				
1.0 E 03	9.9 E-19				

References:

$e + H \rightarrow e + H(2s)$ Exp.: W.E. Kauppila, W.R. Ott, W.L. Fite, Phys. Rev. A 1, 1099 (1970). See Notes (1), (3), and (4) at end of chapter.

$e + H \rightarrow e + H(2p)$ Exp.: W.L. Fite and R.T. Brackmann, Phys. Rev. 112, 1151 (1958); W.L. Fite, R.F. Stebbings and R.T. Brackmann, Phys. Rev. 116, 356 (1959); R.L. Long, D.M. Case, S.J. Smith, J. Res. NBS, A 72, 521 (1968). See Notes (2), (3), and (4) at end of chapter.

[To be continued at end of chapter.]


ORNL-DWG 75-2220
CROSS SECTION (cm^2)
10^{-16}
5
2
10^{-17}
5
2
10^{-18}
5
2
10^{-19}
10^0
2
5
10^1
2
5
10^2
2
5
10^3
ENERGY (eV)
2p
2s
BALMER-α
3s
4s

Cross Sections for Excitation of H_2^+ by Electrons:

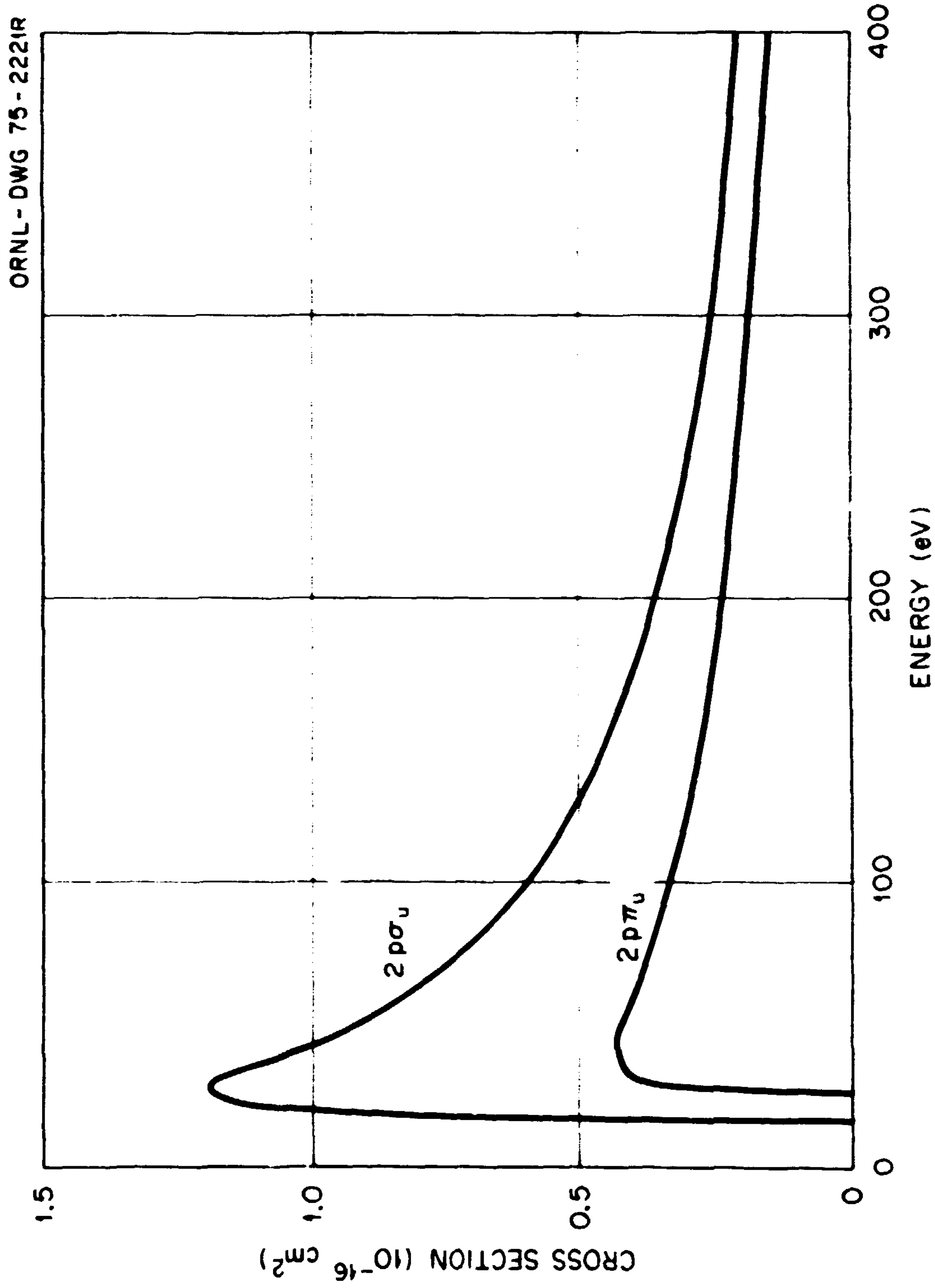
$$e + H_2^+(v=0) \rightarrow e + H_2^+(2p\sigma_u, 2p\pi_u)$$

Energy (eV)	Theoretical Cross Sections (cm^2)	
	$2p\sigma_u$	$2p\pi_u$
2.0 E 01	1.00 E-16	
2.5 E 01	1.81 E-16	
3.0 E 01	1.87 E-16	3.87 E-17
4.0 E 01	1.02 E-16	4.28 E-17
6.0 E 01	8.25 E-17	4.00 E-17
8.0 E 01	6.90 E-17	3.66 E-17
1.0 E 02	5.95 E-17	3.38 E-17
1.5 E 02	4.50 E-17	2.25 E-17
2.0 E 02	3.62 E-17	2.39 E-17
2.5 E 02	2.98 E-17	2.10 E-17
3.0 E 02	2.60 E-17	1.89 E-17
3.5 E 02	2.28 E-17	1.70 E-17
4.0 E 02	2.10 E-17	1.48 E-17

References:

$e + H_2^+(v=0) \rightarrow e + H_2^+(2p\sigma_u)$, Theoretical: B.F. Rozsnyai, J. Chem. Phys. 47, 4102 (1967). See Note[u](5) at end of chapter.

$e + H_2^+(v=0) \rightarrow e + H_2^+(2p\pi_u)$, Theoretical: B.F. Rozsnyai, J. Chem. Phys. 47, 4102 (1967). See Note[u](6) at end of chapter.


ORNL-DWG 75-2221R
2pσu
2pπu
CROSS SECTION (10⁻¹⁶ cm²)
ENERGY (eV)
0
0.5
1.0
1.5
0
100
200
300
400

Cross Sections for Dissociation of H_2 into Excited Fragments by Electron Impact:

$e + H_2 \rightarrow e + H + H(2p, n=3, n=4)$

Energy (eV)	Experimental Cross Sections (cm^2)		
	H(2p) Lyman Alpha Emission (1216 Å)	H(n=3) Balmer Alpha Emission (6563 Å)	H(n=4) Balmer Beta Emission (4431 Å)
1.0 E 01		3.4 E-19	
1.5 E 01	2.8 E-18	6.60 E-19	
2.0 E 01	9.1 E-18	6.70 E-19	
2.5 E 01	1.08 E-17	6.70 E-19	
3.0 E 01	1.17 E-17	8.70 E-19	
4.0 E 01	1.28 E-17	9.20 E-19	
6.0 E 01	1.32 E-17	9.60 E-19	1.88 E-19
8.0 E 01	1.30 E-17	9.30 E-19	1.82 E-19
1.0 E 02	1.22 E-17	8.80 E-19	1.70 E-19
1.5 E 02	1.03 E-17	7.20 E-19	1.38 E-19
2.0 E 02	8.80 E 18	6.00 E-19	1.12 E-19
4.0 E 02	5.08 E-18	3.50 E-19	6.10 E-20
6.0 E 02	3.63 E-18	2.48 E-19	4.10 E-20
8.0 E 02	2.90 E-18	1.90 E-19	3.10 E-20
1.0 E 03	2.45 E-18	1.56 E-19	2.50 E-20
2.0 E 03	1.42 E-18	8.50 E-20	1.25 E-20
4.0 E 03	8.00 E-19	4.65 E020	6.5 E-21
6.0 E 03	5.64 E-19	3.35 E-20	4.5 E-21

References:

$e + H_2 \rightarrow e + H + H$(2p, Lyman alpha), Exp.: J.W. McConkey and F.G. Donalson, Can. J. Phys. 50, 221 (1972).

$e + H_2 \rightarrow e + H + H$(n=3, Balmer alpha), Exp.: D.A. Vroom and F.J. de Heer, J. Chem. Phys. 50, 580 (1969).

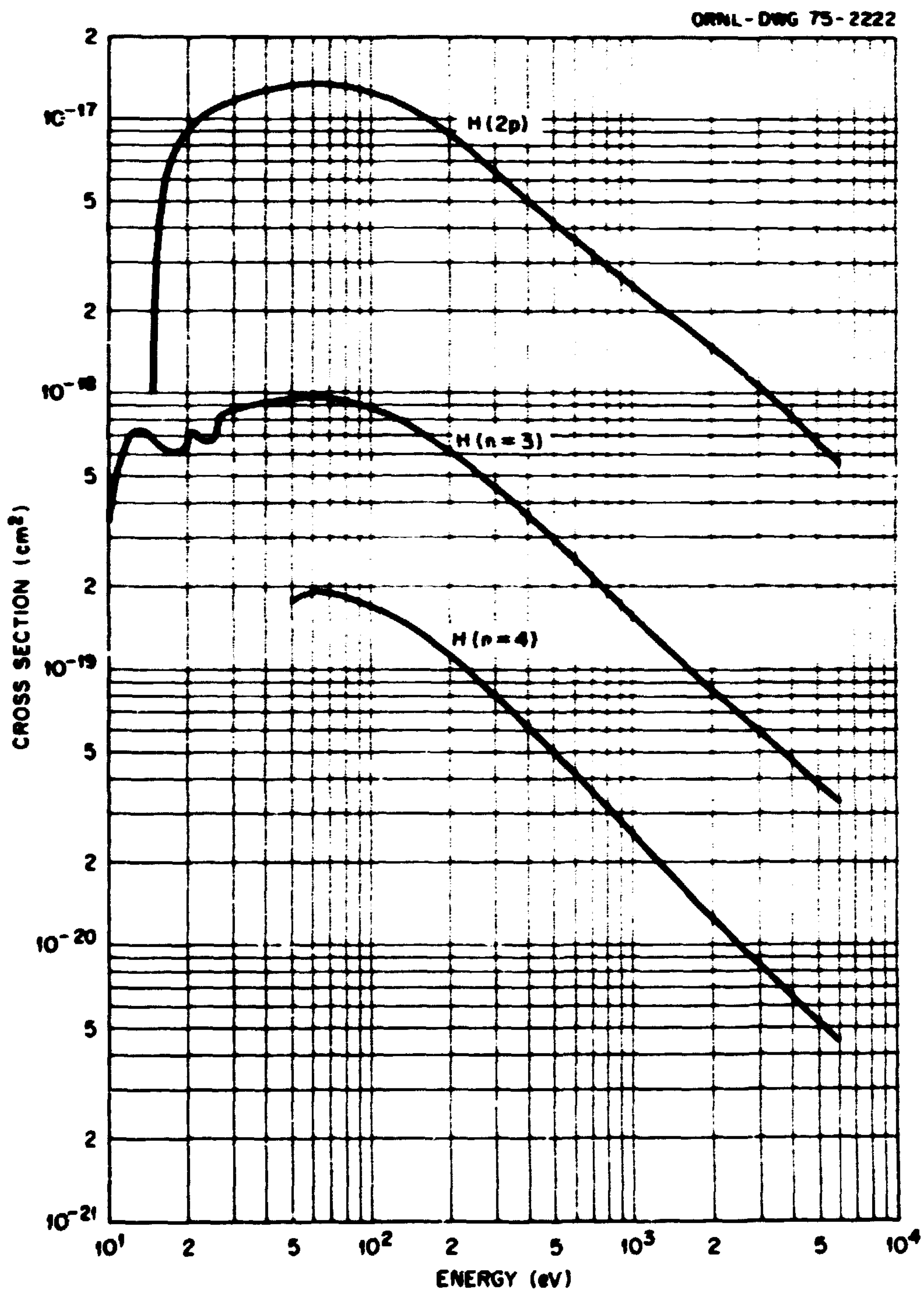
$e + H_2 \rightarrow e + H + H$(n=4, Balmer beta): D.A. Vroom and F.J. de Heer, J. Chem. Phys. 50, 580 (1969) [Note that this reference includes data through n = 6].

Accuracy:

2p state - systematic error < ± 10%; random error < ± 2%.

n = 3 - systematic error < ± 12%; random error < ± 4%.

n = 4 - systematic error < ± 7%; random error < ± 4%.


ORNL-DWG 75-2222
H(2p)
H(n=3)
H(n=4)
CROSS SECTION (cm²)
ENERGY (eV)
2
10⁻¹⁷
5
2
10⁻¹⁸
5
2
10⁻¹⁹
5
2
10⁻²⁰
5
2
10⁻²¹
10¹
2
5
10²
2
5
10³
2
5
10⁴

Cross Sections for Dissociation of D_2

Into Excited Fragments by Electrons:

$e + D_2 \rightarrow e + D + D(2s, 2p, n=3, n=4)$

Energy (eV)	Experimental Cross Sections (cm^2)			
	D(2s) Formation	D(2p) Lyman Alpha Emission(1216 Å)	D(n=3) Balmer Alpha Emission(6563 Å)	D(n=4) Balmer Beta Emission(4431 Å)
1.4 E 01	9.0 E-21			
1.5 E 01	2.41 E-19		2.00 E-19	
2.0 E 01	2.70 E-18		4.20 E-19	
2.5 E 01	3.00 E-18		5.50 E-19	
3.0 E 01	3.10 E-18		5.82 E-19	
4.0 E 01	3.42 E-18		7.11 E-19	
6.0 E 01	3.45 E-18	9.60 E-18	7.90 E-19	1.51 E-19
8.0 E 01	3.42 E-18	9.00 E-18	7.90 E-19	1.54 E-19
1.0 E 02	3.24 E-18	8.30 E-18	7.52 E-19	1.46 E-19
1.5 E 02	2.85 E-18	6.90 E-18	6.47 E-19	1.18 E-19
2.0 E 02	2.52 E-18	5.80 E-18	5.40 E-19	9.60 E-20
4.0 E 02	1.70 E-18	3.57 E-18	3.03 E-19	5.16 E-20
6.0 E 02		2.55 E-18	2.10 E-19	3.37 E-20
8.0 E 02		2.00 E-18	1.55 E-19	2.48 E-20
1.0 E 03		1.67 E-18	1.25 E-19	1.95 E-20
1.5 E 03		1.19 E-18	8.52 E-20	1.29 E-20
2.0 E 03		9.20 E-19	6.55 E-20	9.80 E-21
4.0 E 03		5.20 E-19	3.30 E-20	5.10 E-21
6.0 E 03		3.74 E-19	2.42 E-20	3.49 E-21

References:

$e + D_2 \rightarrow e + D + D(2s)$ Exp.: D.M. Cox and S.J. Smith, Phys. Rev. A 5, 2428 (1972).

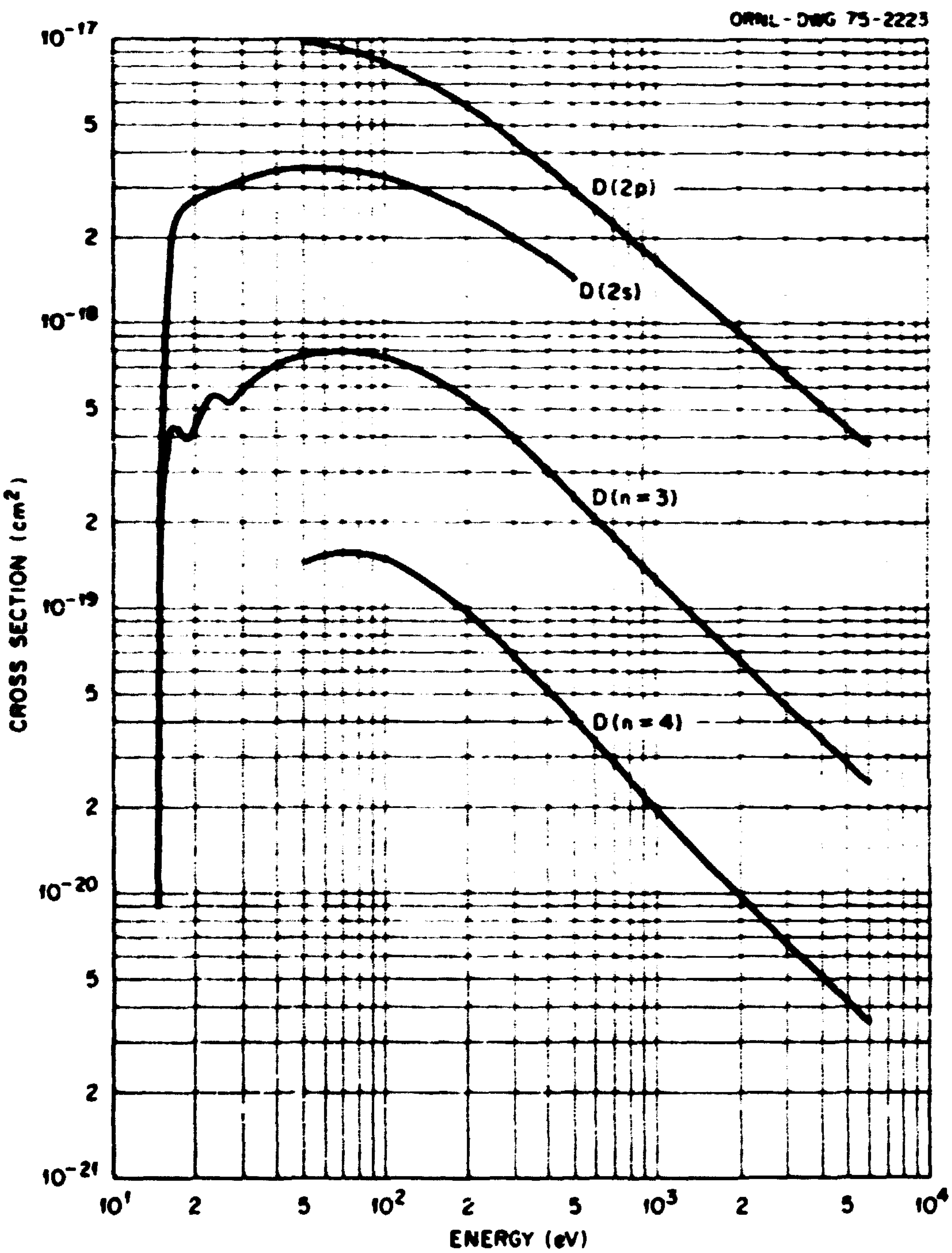
$e + D_2 \rightarrow e + D + D(2p$, Lyman Alpha) Exp.: D.A. Vroom and F.J. de Heer, J. Chem. Phys. 50, 580 (1969) [these data have been normalized]

$e + D_2 \rightarrow e + D + D(n=3$, Balmer Alpha): D.A. Vroom and F.J. de Heer, J. Chem. Phys. 50, 580 (1969).

$e + D_2 \rightarrow e + D + D(n=4$ Balmer Beta): D.A. Vroom and F.J. de Heer, J. Chem. Phys. 50, 580 (1969) [note that this reference includes data through n=6].

Accuracy:

2s state - systematic error < ± 14%; random error < ± 5%. 2p state - systematic error < ± 15%; random error < ± 5%. n=3 - systematic error < ± 12%; random error < ± 4%. n=6 - systematic error < ± 7%; random error < ± 4%.


ORNL-DWG 75-2223
CROSS SECTION (cm²)
ENERGY (eV)
D(2p)
D(2s)
D(n = 3)
D(n = 4)
10⁻¹⁷
5
2
10⁻¹⁸
10⁻¹⁹
10⁻²⁰
10⁻²¹
10¹
10²
10³
10⁴

Cross Sections for Excitation of H_2 by Electrons:

$e + H_2 \rightarrow e + H_2$(1230 Å,B,C,D)

Energy (eV)	Cross Sections (cm^2)			
	Emission of 1230 Å Werner Band C→X(3,7)	B State	C State	D State
1.5 E 01	5.10 E-19			
2.0 E 01	9.92 E-19	3.36 E-17	2.50 E-17	8.58 E-19
3.0 E 01	1.42 E-18	4.26 E-17	3.23 E-17	2.01 E-18
4.0 E 01	1.52 E-18	4.79 E-17	3.08 E-17	2.61 E-18
5.0 E 01	1.52 E-18	4.75 E-17	3.01 E-17	2.89 E-18
6.0 E 01	1.51 E-18	4.55 E-17	3.43 E-17	2.99 E-18
8.0 E 01	1.43 E-18	4.12 E-17	3.13 E-17	2.95 E-18
1.0 E 02	1.36 E-18	3.75 E-17	2.90 E-17	2.87 E-18
1.5 E 02	1.15 E-18	3.00 E-17	2.35 E-17	2.54 E-18
2.0 E 02	1.01 E-18	2.51 E-17	2.01 E-17	2.25 E-18
3.0 E 02	7.97 E-19	2.00 E-17	1.53 E-17	1.80 E-18
5.0 E 02	5.67 E-19			
1.0 E 03	3.42 E-19			

References:

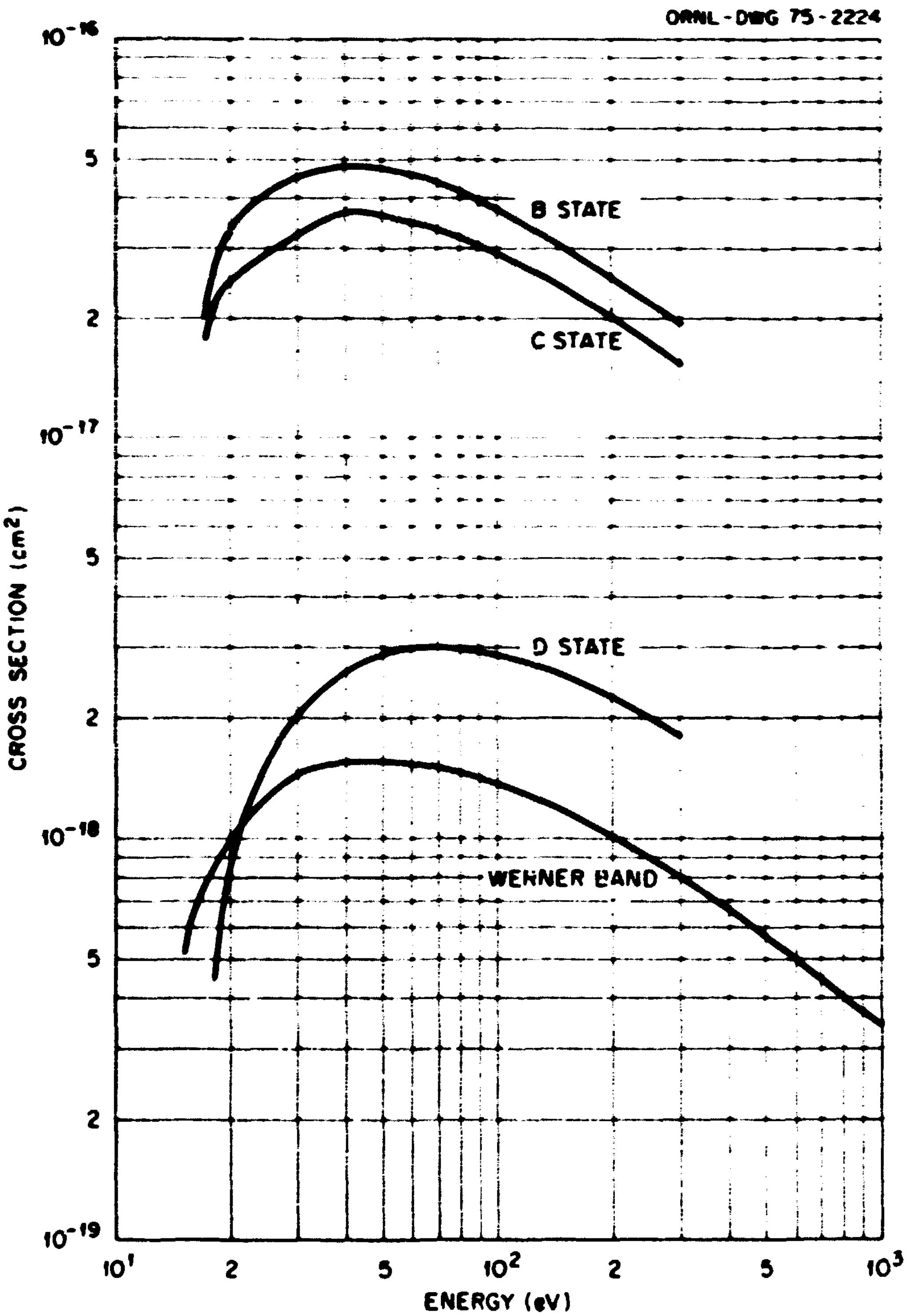
$e + H_2 \rightarrow e + H_2$(1230 Å Werner Band) Exp.: F.J. de Heer and J.D. Carriere, J. Chem. Phys. 55, 3829 (1971).[This reference also includes data for the 1161 Å Werner Band. Further information on relative intensities in these bands are to be found in E.J. Stone and E.C. Zipf, J. Chem. Phys. 56, 4646 (1972)].

$e + H_2 \rightarrow e + H_2$(B,C) Theoretical: S.P. Khare, Phys. Rev. 149, 33 (1966).

$e + H_2 \rightarrow e + H_2$(D) Theoretical: S.P. Khare, Phys. Rev. 152, 74 (1966).

Accuracy:

Experimental data - systematic error - not stated; random error < ± 5%.


ORNL-DWG 75-2224
B STATE
C STATE
D STATE
WERNER BAND
CROSS SECTION (cm²)
ENERGY (eV)
10⁻¹⁶
10⁻¹⁷
10⁻¹⁸
10⁻¹⁹
5
2
10¹
10²
10³

Cross Sections for Vibrational Excitation of H_2 by Electrons:

$e + H_2(v=0) \rightarrow e + H_2(v=1,...,3)$

Energy (eV)	Experimental Cross Sections (cm^2)		
	v=1	v=2	v=3
1.5 E 00	2.50 E-17		
2.0 E 00	3.90 E-17	1.20 E-18	1.22 E-19
3.0 E 00	5.06 E-17	3.24 E-18	3.55 E-19
4.0 E 00	4.68 E-17	4.04 E-18	4.30 E-19
5.0 E 00	3.75 E-17	3.91 E-18	3.51 E-19
6.0 E 00	2.80 E-17	3.32 E-18	2.80 E-19
7.0 E 00	1.55 E-17	1.75 E-18	
1.0 E 01	5.60 E-18	8.50 E-19	
1.5 E 01	1.71 E-18	1.13 E-19	
2.0 E 01	1.24 E-18	4.24 E-20	
4.0 E 01	1.12 E-18	4.54 E-20	
6.0 E 01	8.99 E-19		
8.0 E 01	8.20 E-19		
1.0 E 02	7.10 E-19		

References:

$e + H_2 \rightarrow e + H_2(v=1)$ Exp.: S. Trajmar, D.G. Truhlar, J.K. Rice, A. Kuppermann, J. Chem. Phys. 52, 4516 (1970). H. Ehrhardt, L. Langhans, F. Linder, H.S. Taylor, Phys. Rev. 173, 222 (1968).

$e + H_2 \rightarrow e + H_2(v=2)$ Exp.: S. Trajmar, D.G. Truhlar, J.K. Rice, A. Kuppermann, J. Chem. Phys. 52, 4516 (1970). H. Ehrhardt, L. Langhans, F. Linder, H.S. Taylor, Phys. Rev. 173, 222 (1968).

$e + H_2 \rightarrow e + H_2(v=3)$ Exp.: S. Trajmar, D.G. Truhlar, J.K. Rice, A. Kuppermann, J. Chem. Phys. 52, 4516 (1970). H. Ehrhardt, L. Langhans, F. Linder, H.S. Taylor, Phys. Rev. 173, 222 (1968).

[To be continued at end of chapter.]

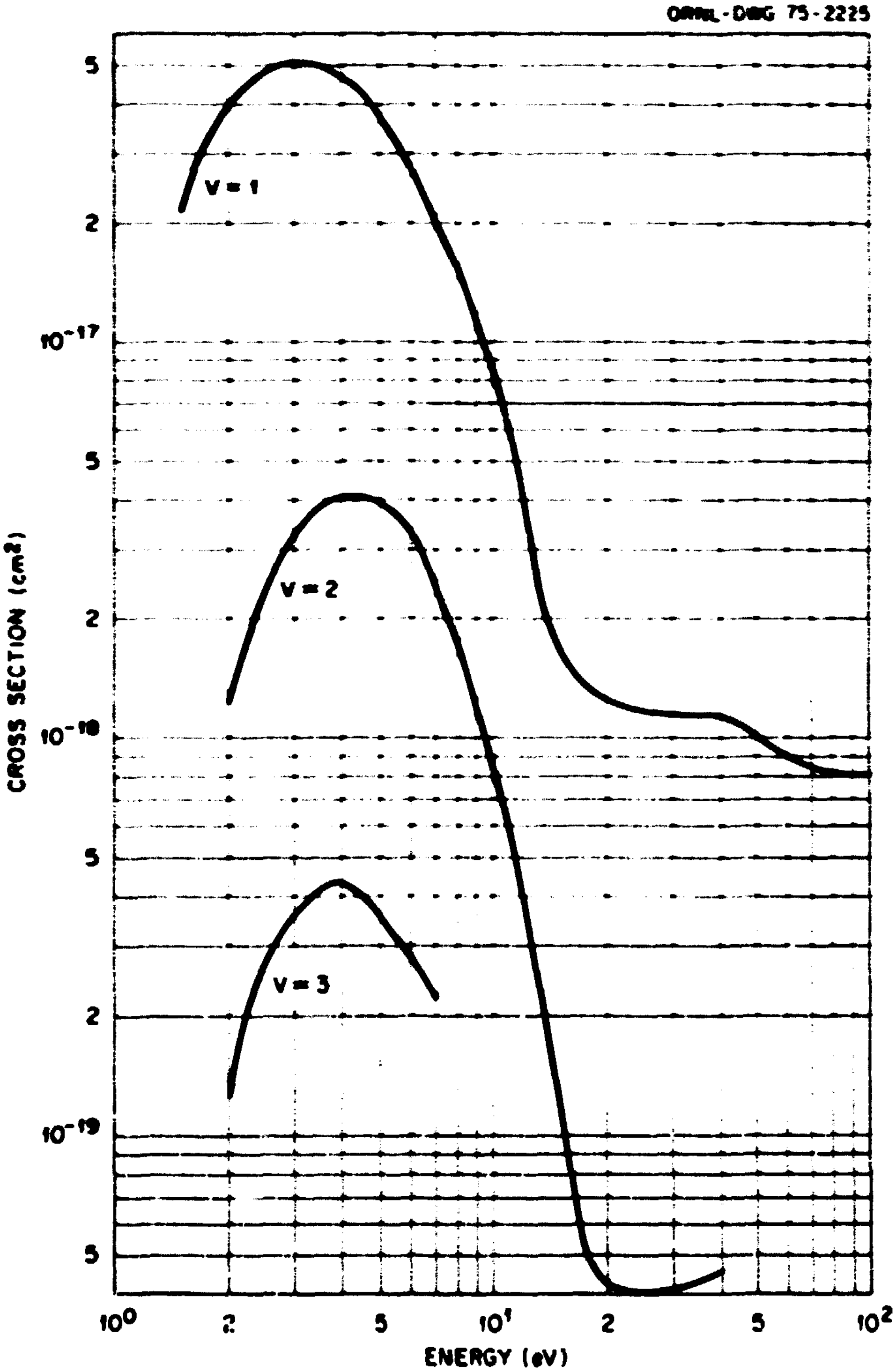
Accuracy: Total error limits (principally systematic).

v = 1 - < ± 45%.

v = 2 - < ± 55%.

v = 3 - < ± 65%.

ORNL-DWG 75-2225



Cross Sections for Excitation of Helium by Electrons:

$e + He \rightarrow e + He(4^1S, 3^1P, 4^1D, 4^3S, 3^3P)$

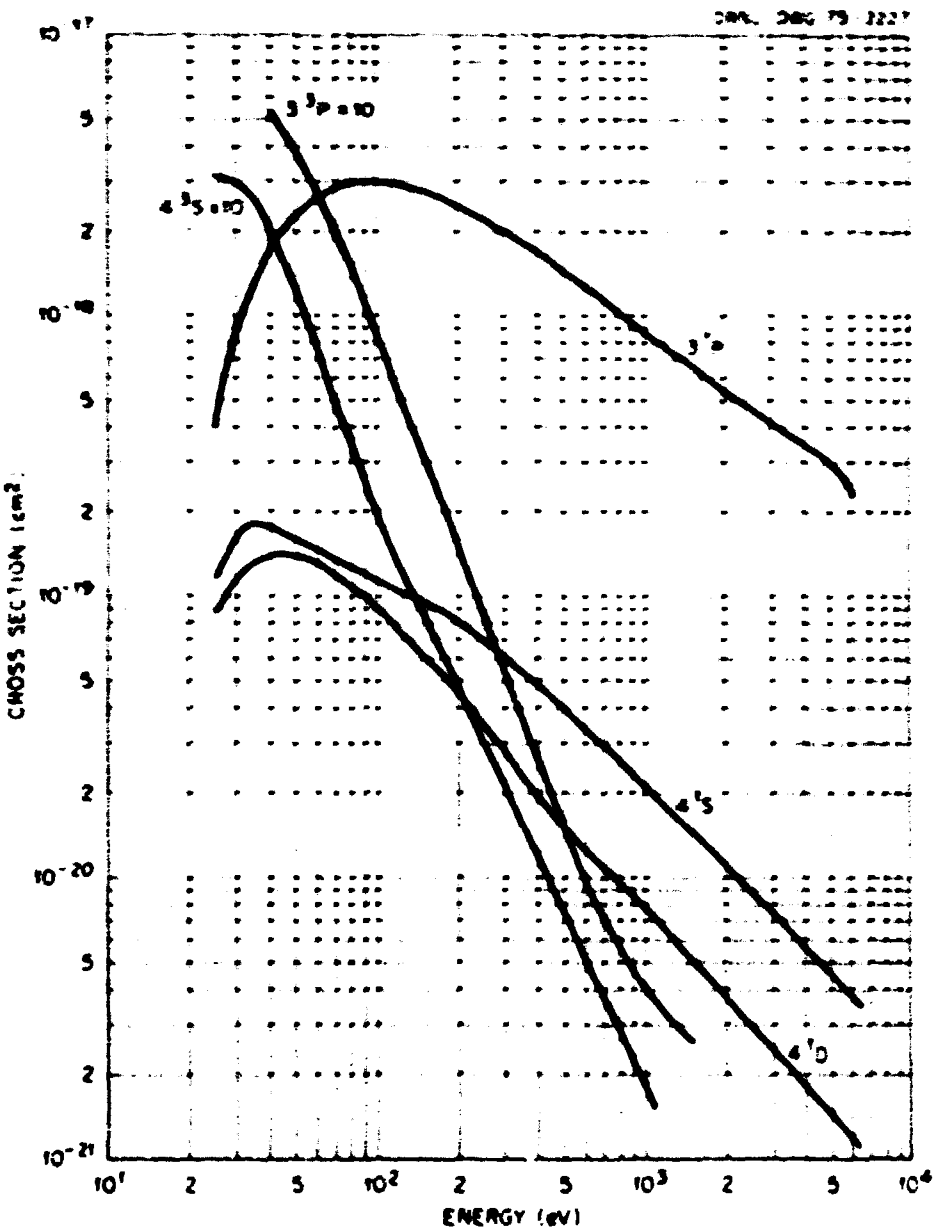
Energy (eV)	Experimental Cross Sections (cm^2)				
	4^1S	3^1P	4^1D	4^3S	3^3P
2.5 E 01	1.14 E-19	4.03 E-19	8.65 E-20	3.15 E-19	
3.0 E 01	1.63 E-19	8.90 E-19	1.13 E-19	2.96 E-19	
3.5 E 01	1.80 E-19	1.32 E-18	1.32 E-19	2.55 E-19	
4.0 E 01	1.76 E-19	1.67 E-18	1.38 E-19	2.01 E-19	5.17 E-19
5.0 E 01	1.58 E-19	2.23 E-18	1.39 E-19	1.20 E-19	3.80 E-19
6.0 E 01	1.46 E-19	2.60 E-18	1.31 E-19	7.45 E-20	2.71 E-19
7.0 E 01	1.35 E-19	2.81 E-18	1.20 E-19	4.94 E-20	2.00 E-19
8.0 E 01	1.26 E-19	2.94 E-18	1.09 E-19	3.40 E-20	1.48 E-19
1.0 E 02	1.12 E-19	2.99 E-18	9.00 E-20	1.90 E-20	8.20 E-20
1.5 E 02	9.40 E-20	2.75 E-18	6.10 E-20	5.40 E-21	3.01 E-20
2.0 E 02	8.10 E-20	2.44 E-18	4.45 E-20	4.70 E-21	1.49 E-20
4.0 E 02	4.75 E-20	1.67 E-18	1.95 E-20	1.13 E-21	2.60 E-21
6.0 E 02	3.38 E-20	1.27 E-18	1.26 E-20	5.15 E-22	1.08 E-21
8.0 E 02	2.58 E-20	1.03 E-18	9.60 E-21	2.80 E-22	5.70 E-22
1.0 E 03	2.08 E-20	8.70 E-19	7.80 E-21	1.78 E-22	4.00 E-22
1.5 E 03	1.44 E-20	6.60 E-19	4.95 E-21		2.62 E-22
2.0 E 03	1.10 E-20	5.40 E-19	3.75 E-21		
3.0 E 03	7.40 E-21	4.15 E-19	2.40 E-21		
4.0 E 03	5.60 E-21	3.48 E-19	1.81 E-21		
5.0 E 03	4.50 E-21	3.05 E-19	1.44 E-21		
6.0 E 03	3.78 E-21	2.40 E-19	1.17 E-21		

References:

A.F.J. Van Raan, J.D. de Jongh, J. Van Eck, and H.G. Heideman, Physica 53, 45 (1971). H.M. Moustafa Moussa, F.J. de Heer, and J. Schutten, Physica 40, 517 (1969). [These data normalized to Van Raan at 2000 eV and used only above that energy for the 4^1S, 3^1P, and 4^1D states.] For information on other states see these two references.

Accuracy:

Systematic error < ± 10%. Random error < ± 7%.


3 3P × 10
4 3S × 10
3 1P
4 1S
4 1D
CROSS SECTION (cm2)
ENERGY (eV)

Cross Sections for Emission of He II Spectral Lines Induced by Electron Impact on He:

$$e + He \rightarrow e + He^{+*} + e$$

$$He^{+*} \rightarrow He^{+} + h\nu$$

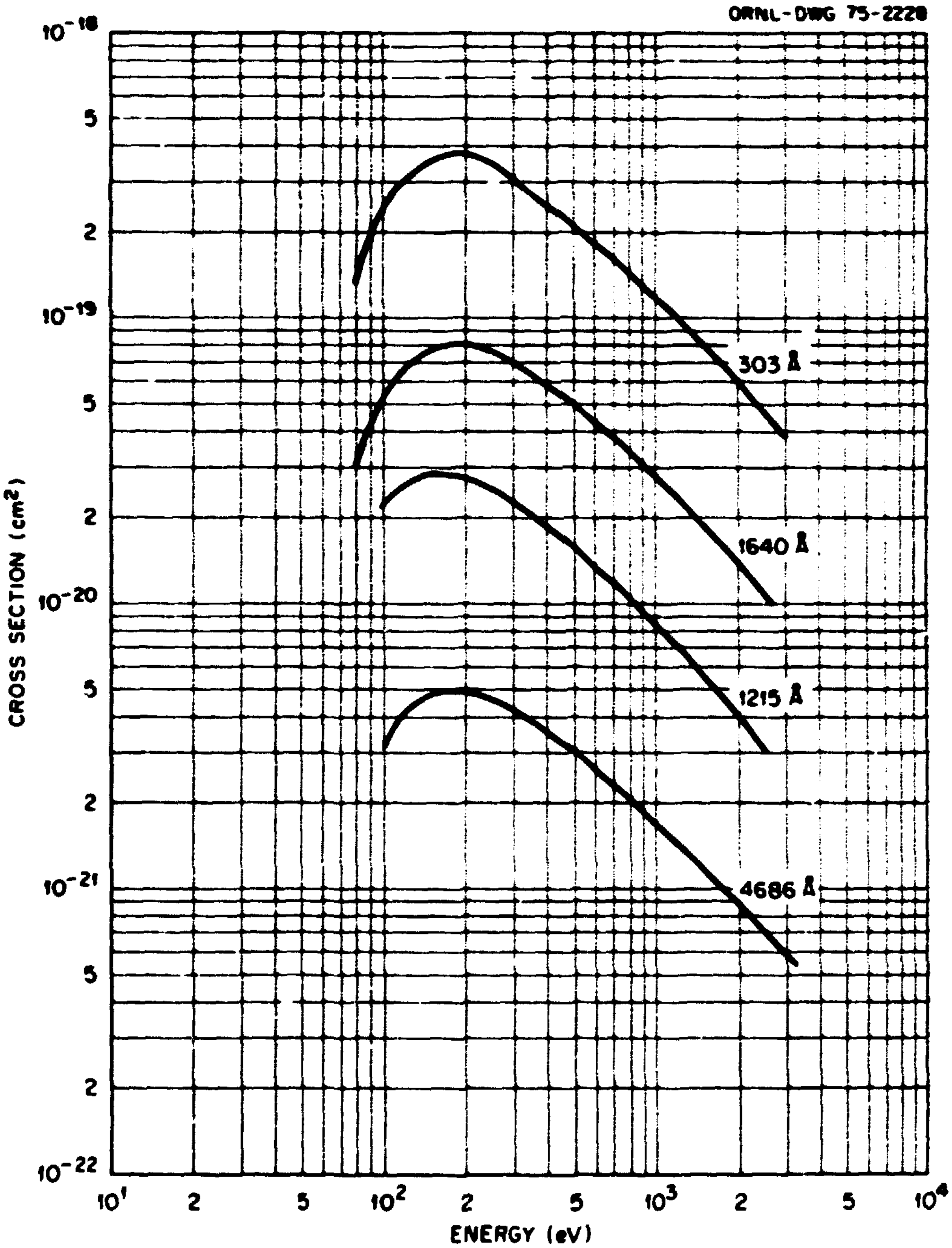
Energy (eV)	Experimental Emission Cross Sections (cm^2)			
	(3→2) (1640 Å)	(4→2) (1251 Å)	($2^2P \rightarrow 1^2S$) (303 Å)	(4→3) (4686 Å)
8.0 E 01	2.98 E-20		1.36 E-19	
1.0 E 02	5.18 E-20	2.21 E-20	2.33 E-19	3.15 E-21
1.5 E 02	7.75 E-20	2.85 E-20	3.55 E-19	4.78 E-21
2.0 E 02	8.00 E-20	2.73 E-20	3.75 E-19	4.85 E-21
3.0 E 02	6.90 E-20	2.27 E-20	3.05 E-19	4.20 E-21
4.0 E 02	5.80 E-20	1.85 E-20	2.48 E-19	3.55 E-21
6.0 E 02	4.30 E-20	1.34 E-20	1.82 E-19	2.60 E-21
8.0 E 02	3.38 E-20	1.03 E-20	1.43 E-19	2.05 E-21
1.0 E 03	2.78 E-20	8.40 E-21	1.18 E-19	1.68 E-21
1.5 E 03	1.87 E-20	5.50 E-21	7.98 E-20	1.14 E-21
2.0 E 03	1.38 E-20	4.00 E-21	5.95 E-20	8.70 E-22
3.0 E 03			3.75 E-20	5.80 E-22

Reference:

H.R. Moustafa Moussa and F.J. de Heer, Physica 36, 646 (1967).

Accuracy:

Systematic error < ± 30%. Random error < ± 5%.


ORNL-DWG 75-2228
CROSS SECTION (cm^2)
ENERGY (eV)
303 Å
1640 Å
1215 Å
4686 Å
10^{-18}
10^{-19}
10^{-20}
10^{-21}
10^{-22}
10^1
10^2
10^3
10^4

Collisional Excitation of He^+ by Electron Impact:

$e + He^+ \rightarrow e + He^+(2s,3s,4s)$

Energy (eV)	Cross Sections (cm^2)		
	Experimental	Theoretical	
	2s	3s	4s
4.0 E 01	2.60 E-19		
4.2 E 01	6.35 E-19		
4.4 E 01	6.45 E-19		
4.6 E 01	6.50 E-19		
4.8 E 01	6.52 E-19		
5.0 E 01	6.50 E-19	1.15 E-19	3.60 E-20
5.5 E 01	6.40 E-19	1.32 E-19	4.29 E-20
6.0 E 01	6.15 E-19	1.42 E-19	4.70 E-20
8.0 E 01	5.18 E-19	1.59 E-19	5.66 E-20
1.0 E 02	4.65 E-19	1.57 E-19	5.70 E-20
2.0 E 02	3.55 E-19	1.04 E-19	3.83 E-20
4.0 E 02	2.66 E-19		
6.0 E 02	2.02 E-19		
8.0 E 02	1.46 E-19		
1.0 E 03	1.24 E-19		

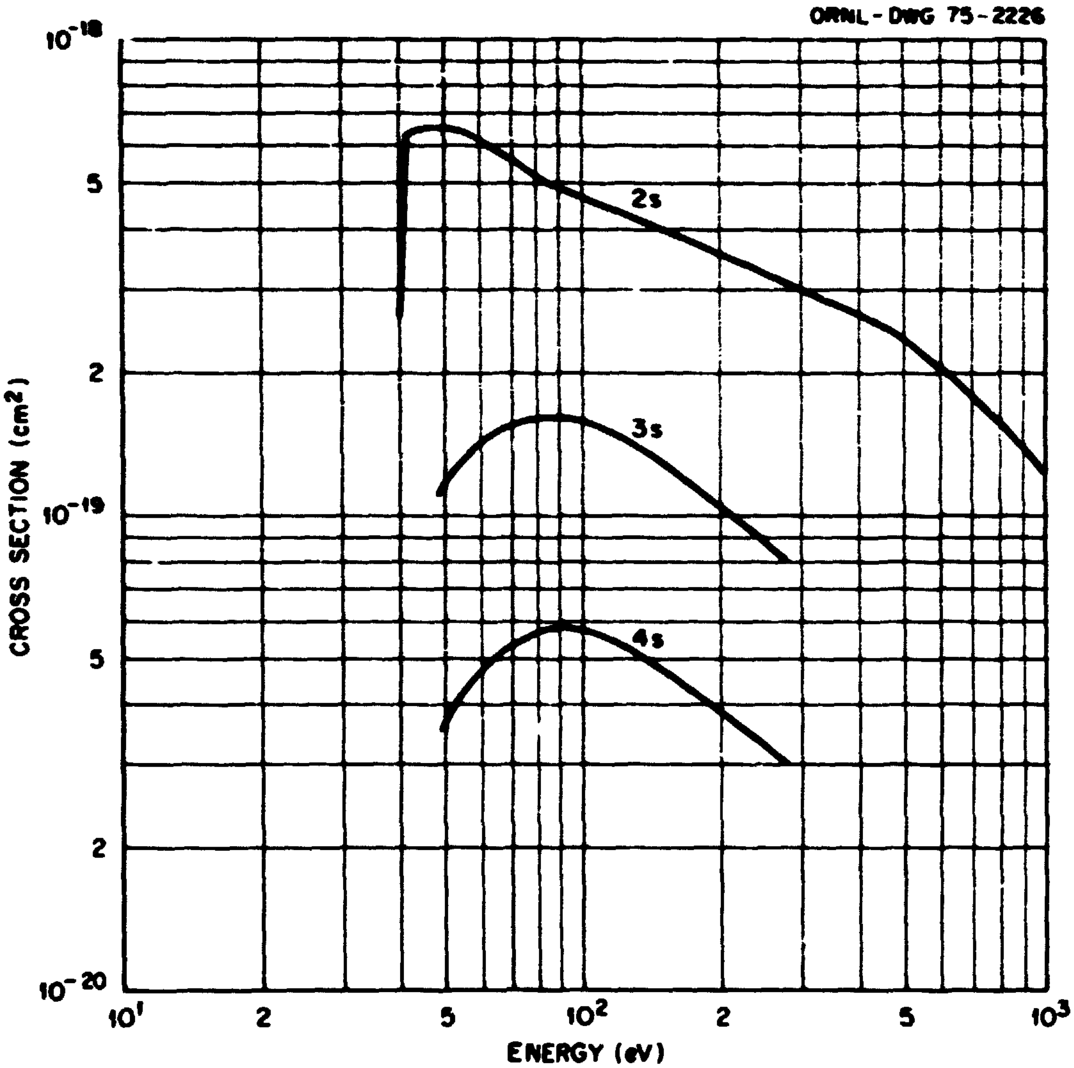
References:

$e + He^+ \rightarrow e + He^+(2s)$ Exp.: K.T. Dolder, B. Peart, J. Phys. B 6, 2415 (1973). See Notes (1) and (3) at end of chapter.

$e + He^+ \rightarrow e + He^+(3s,4s)$ Theoretical: M.R.C. McDowell, L.A. Morgan, V.P. Myerscough, J. Phys. B 6, 1435 (1973).

Accuracy:

Random error < ± 10%.


ORNL-DWG 75-2226
10^{-18}
5
2
10^{-19}
5
2
10^{-20}
CROSS SECTION (cm^2)
10^1
2
5
10^2
2
5
10^3
ENERGY (eV)
2s
3s
4s

Excitation of Carbon by Electrons:

$$e + C(2p^2\ ^3P) \rightarrow e + C(2p^2\ ^1D, 2p^2\ ^1S)$$

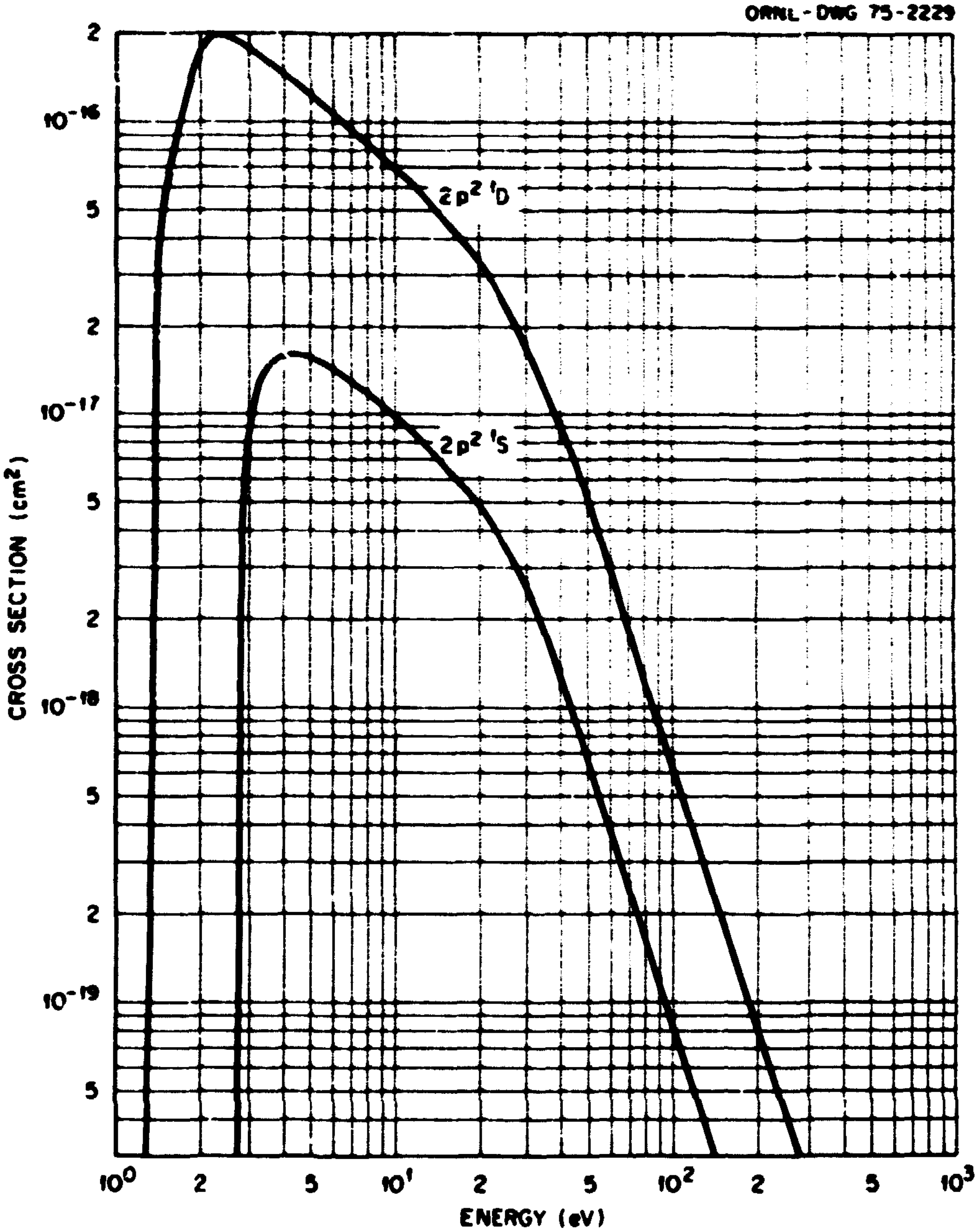
Energy (eV)	Theoretical Cross Sections (cm^2)	
	$2p^2\ ^1D$	$2p^2\ ^1S$
1.0 E 00		
2.0 E 00	1.70 E-16	
3.0 E 00	1.75 E-16	8.00 E-[illegible]9
4.0 E 00	1.46 E-16	1.58 E-17
6.0 E 00	1.06 E-16	1.42 E-17
8.0 E 00	8.40 E-17	1.18 E-17
1.0 E 01	7.00 E-17	1.00 E-17
2.0 E 01	3.38 E-17	4.90 E-18
3.0 E 01	1.70 E-17	2.55 E-18
4.0 E 01	9.20 E-18	1.25 E-18
6.0 E 01	2.75 E-18	3.39 E-19
8.0 E 01	1.16 E-18	1.43 E-19
1.0 E 0[illegible]	6.00 E-19	7.32 E-20
2.0 E 02	7.40 E-20	9.15 E-21
4.0 E 02	9.29 E-21	1.14 E-21
6.0 E 02	2.75 E-21	3.39 E-22
8.0 E 02	1.16 E-21	1.43 E-22
1.0 E 03	5.95 E-22	7.33 E-23

References:

$e + C \rightarrow e + C(2p^2\ ^1D,\ 2p^2\ ^1S)$ Theoretical: R.J.W. Henry, P.G. Burke, and A.L. Sinfailam, Phys. Rev. 178, 218 (1969).

Accuracy:

See Note (7) at end of chapter.


ORNL-DWG 75-2229
CROSS SECTION (cm^2)
ENERGY (eV)
2p^2 ^{1}D
2p^2 ^{1}S
2
10^{-16}
5
2
10^{-17}
5
2
10^{-18}
5
2
10^{-19}
5
10^0
2
5
10^1
2
5
10^2
2
5
10^3

Excitation of Carbon Ions by Electrons:

$e + C^{+}(2p\ ^2P^o) \rightarrow$ See Reference Below

$e + C^{2+}(2s^2\ ^1S) \rightarrow e + C^{2+}(2p\ ^3P)$

$e + C^{3+}(2s\ ^2S) \rightarrow e + C^{3+}(2p\ ^2P^o)$

$e + C^{4+}(1s^2\ ^1S) \rightarrow e + C^{4+}(2s\ ^3S)$

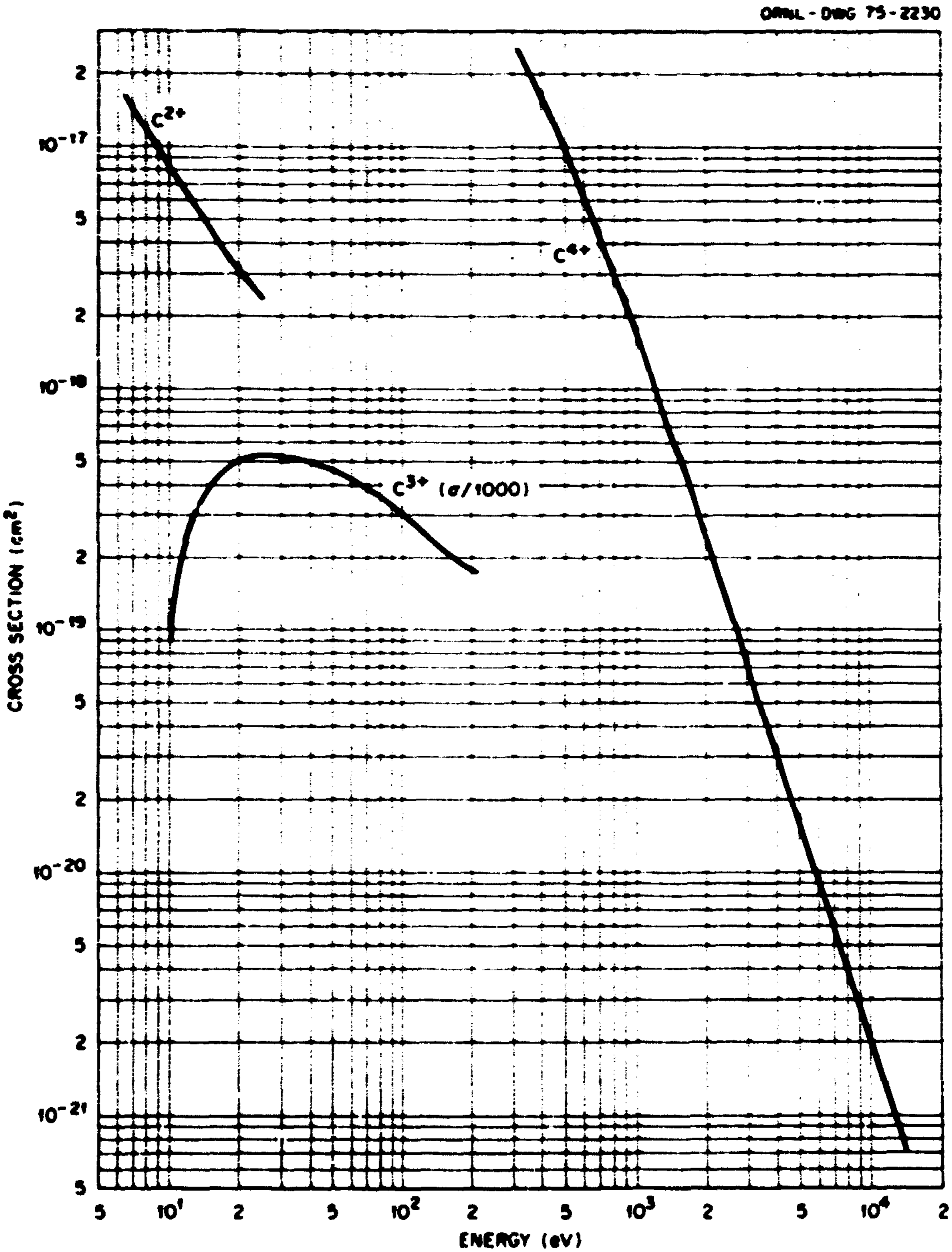
$e + C^{5+} \rightarrow$ See Reference Below

Energy (eV)	Theoretical Cross Sections (cm^2)		
	$C^{2+}(2p\ ^3P)$	$C^{3+}(2p\ ^2P^o)$	$C^{4+}(2s\ ^3S)$
1.0 E 01	8.30 E-18	8.50 E-17	
1.5 E 01	4.6 E-18	3.99 E-16	
2.0 E 01	3.1 E-18	5.00 E-16	
3.0 E 01		5.20 E-16	
4.0 E 01		4.90 E-16	
6.0 E 01		4.19 E-16	
8.0 E 01		4.55 E-16	
1.0 E 02		3.01 E-16	
1.5 E 02		2.20 E-16	
2.0 E 02		1.76 E-16	
4.0 E 02			1.51 E-17
6.0 E 02			6.08 E-18
8.0 E 02			2.96 E-18
1.0 E 03			1.64 E-18
1.5 E 03			5.42 E-19
2.0 E 03			2.30 E-19
3.0 E 03			6.93 E-20
4.0 E 03			3.00 E-20
6.0 E 03			9.10 E-21
8.0 E 03			3.87 E-21
1.0 E 04			1.98 E-21

References:

$e + C^{+}$: There is no cross section information but some theoretical collision strengths are given by D.R. Flower and J.M. Launay, J. Phys. B 5, 2207 (1972).

[Continued at end of chapter.]



ORNL-DWG 75-2230
C^{2+}
C^{4+}
C^{3+} (σ/1000)
CROSS SECTION (cm²)
ENERGY (eV)
10⁻¹⁷
10⁻¹⁸
10⁻¹⁹
10⁻²⁰
10⁻²¹
10¹
10²
10³
10⁴

Excitation of O by Electrons:

$e + O(2p^4\ ^3P) \rightarrow e + O(2p^4\ ^1D,\ 2p^4\ ^1S,$ and 1340 Å Emission)

Energy (eV)	Cross Sections (cm^2)		
	Theoretical		Experimental
	$2p^4\ ^1D$	$2p^4\ ^1S$	1304 Å Emission $[3s\ ^3S \rightarrow 2p^4\ ^3P]$
2.0 E 00			
3.0 E 00	1.57 E-17		
4.0 E 00	2.55 E-17		
5.0 E 00	2.80 E-17	1.00 E-18	
6.0 E 00	2.80 E-17	1.50 E-18	
8.0 E 00	2.75 E-17	2.20 E-18	
1.0 E 01	2.33 E-17	2.42 E-18	5.80 E-18
1.5 E 01	1.85 E-17	2.08 E-18	4.50 E-17
2.0 E 01	1.50 E-17	1.87 E-18	5.20 E-17
3.0 E 01	1.10 E-17	1.44 E-18	4.75 E-17
4.0 E 01	7.50 E-18	1.10 E-18	4.21 E-17
6.0 E 01	3.50 E-18	5.40 E-19	3.44 E-17
8.0 E 01	1.63 E-18	2.15 E-19	3.00 E-17
1.0 E 02	7.50 E-19	1.00 E-19	2.70 E-17
1.5 E 02	2.25 E-19	2.75 E-20	2.28 E-17
2.0 E 02	9.70 E-20	1.12 E-20	
3.0 E 02	2.77 E-20	3.33 E-21	
4.0 E 02	1.17 E-20	1.40 E-21	
6.0 E 02	3.47 E-20	4.16 E-22	
8.0 E 02	1.46 E-21	1.75 E-22	
1.0 E 03	7.50 E-22	9.00 E-23	

References:

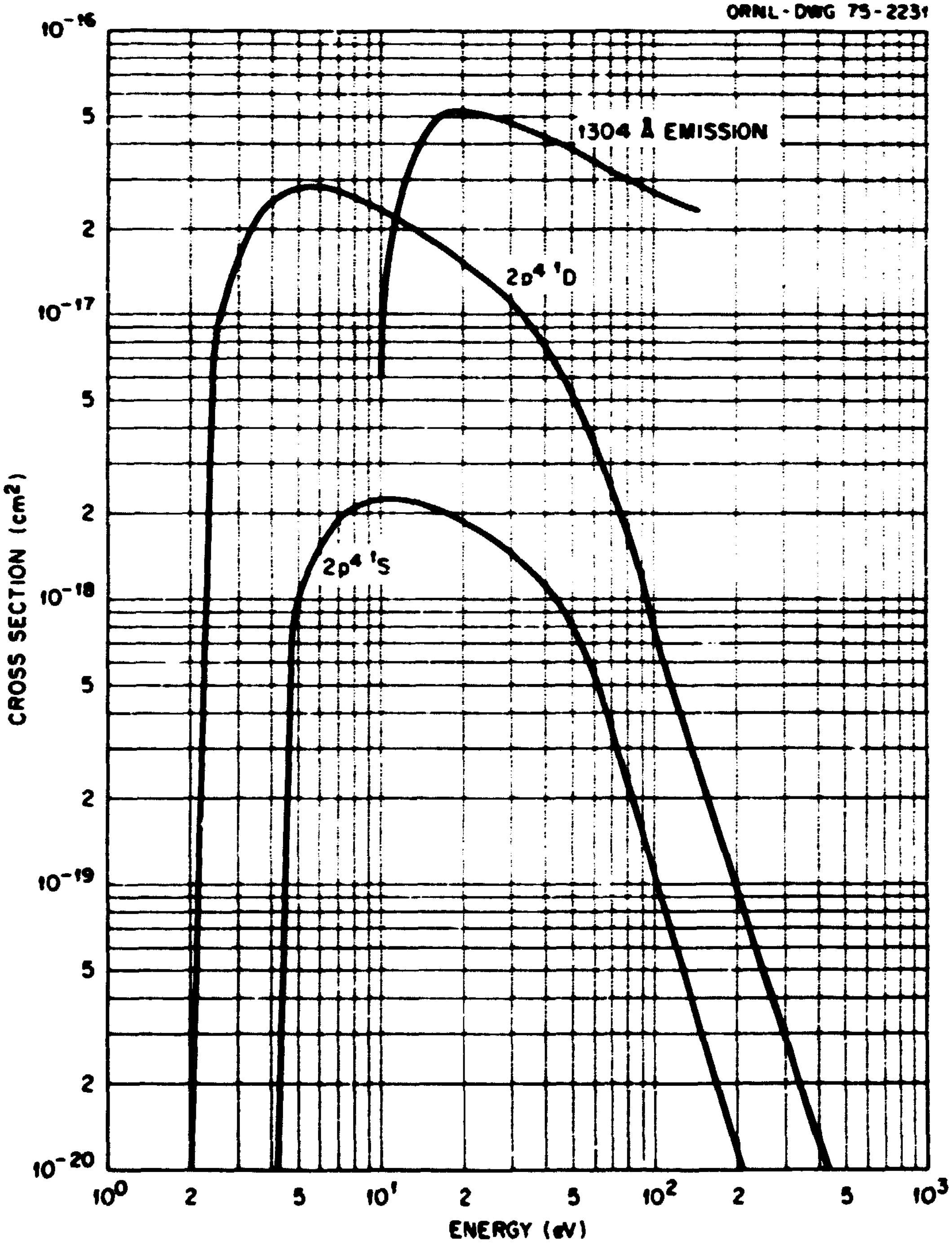
$e + O \rightarrow e + O(2p^4\ 1sp\ ^1D)$ Theoretical: R.J.W. Henry, P.G. Burke, and A.L. Sinfailam, Phys. Rev. 178, 218 (1969).

$e + O \rightarrow e + O(2p^4\ 1sp\ ^1S)$ Theoretical: R.J.W. Henry, P.G. Burke, and A.L. Sinfailam, Phys. Rev. 178, 218 (1969).

$e + O \rightarrow e + O$(1304 Å emission) Exp.: E.C. Zipf - as quoted by T. Sawada and P.S. Garas, Phys. Rev. A 7, 617 (1973).

Notes:

See Notes (7) (accuracy of theory), (8) (accuracy of experiment, and (9) (additional theoretical data).


ORNL-DWG 75-2231
1304 Å EMISSION
$2p^4\ ^1D$
$2p^4\ ^1S$
CROSS SECTION (cm²)
10^{-16}
5
2
10^{-17}
5
2
10^{-18}
5
2
10^{-19}
5
2
10^{-20}
10^0
2
5
10^1
2
5
10^2
2
5
10^3
ENERGY (eV)

Excitation of Oxygen Ions by Electrons:

$e + O^{+}(2p^{3}\ {}^{4}S^{o}) \rightarrow e + O^{+}(2p^{4}\ {}^{4}P)$

$e + O^{2+}$ See Reference Below

$e + O^{5+}(2s\ {}^{2}S) \rightarrow e + O^{5+}(2p\ {}^{2}P)$

$e + O^{6+}$ See Reference Below

$e + O^{7+}$ See Reference Below

Energy (eV)	Theoretical Cross Sections (cm^2)	
	$O^{+}(2p^{4}\ {}^{4}P)$	$O^{5+}(2p\ {}^{2}P)$
1.40 E 01		4.31 E-17
1.50 E 01		6.80 E-17
1.75 E 01	3.90 E-17	1.21 E-16
2.00 E 01	4.49 E-17	1.65 E-16
2.25 E 01	4.84 E-17	2.00 E-16
2.50 E 01	5.06 E-17	2.30 E-16
2.75 E 01	5.30 E-17	2.52 E-16
3.00 E 01	5.41 E-17	2.66 E-16
3.25 E 01	5.45 E-17	2.75 E-16
3.50 E 01	5.43 E-17	2.80 E-16
4.00 E 01		2.83 E-16
6.00 E 01		2.63 E-16
8.00 E 01		2.34 E-16
1.00 E 02		2.10 E-16
1.50 E 02		1.75 E-16
2.00 E 02		1.55 E-16
2.50 E 02		1.41 E-16

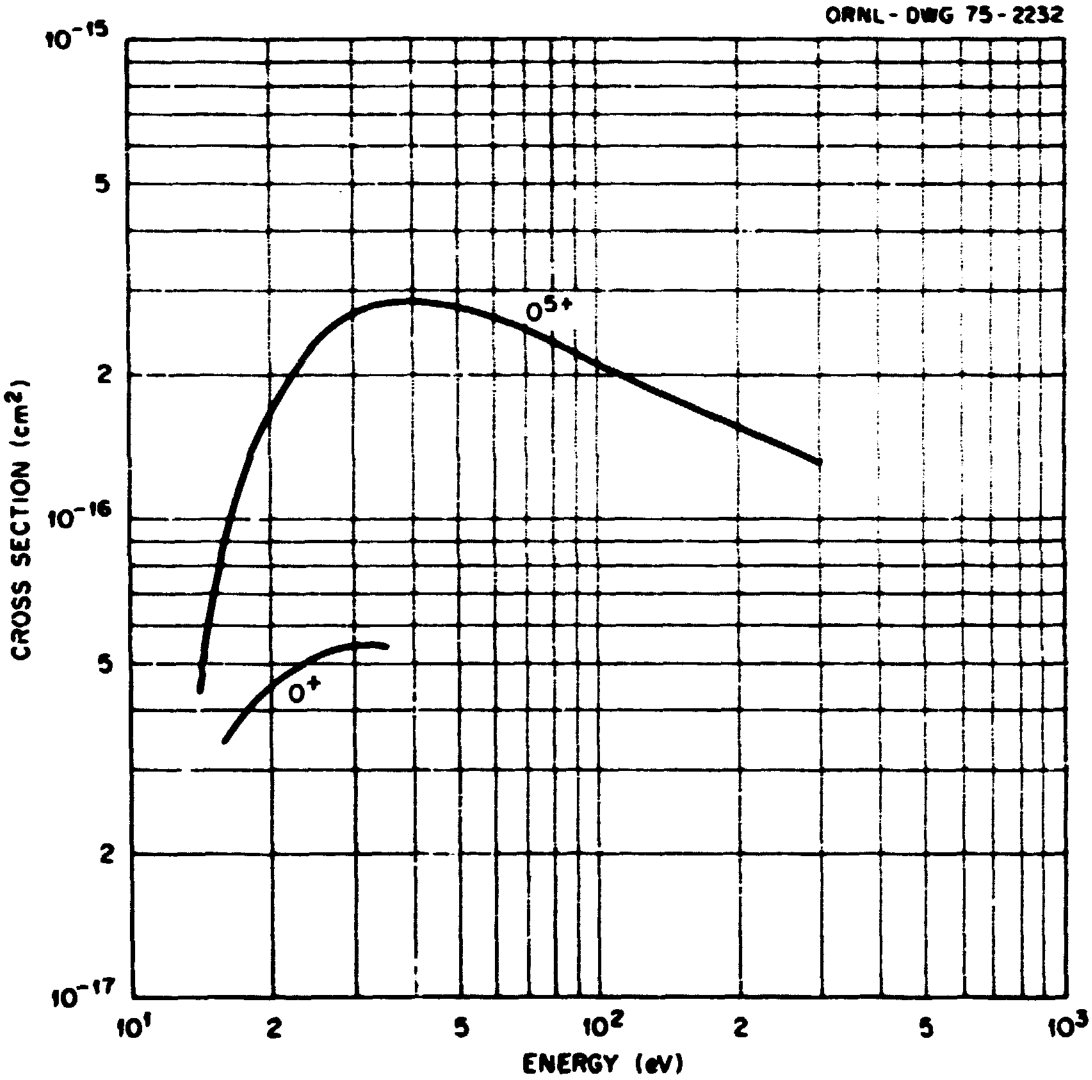
References:

$e + O^{+} \rightarrow e + O^{+}(2p^{4}\ {}^{4}P)$ Theoretical: S. Ormonde, K. Smith, B.W. Torres, A.R. Davis, Phys. Rev. A 8, 262 (1973).

$e + O^{2+}$: Data on excitation of a 2s electron is provided by J.P. Poshyunaute, A.V. Lyash, A.B. Bolokin, Optics and Specy. 29, 424 (1970). Unfortunately this paper is not specific as to the precise final state.

$e + O^{5+} \rightarrow e + O^{5+}(2p\ {}^{2}P)$ Theoretical: K.C. Mathur, A.N. Tripathi, S.K. Joshi, Intl. J. Mass Spectro. Ion Phys. 7, 167 (1971). [This reference also contains data for other levels.]

[Continued at end of chapter.]


ORNL-DWG 75-2232
CROSS SECTION (cm²)
10⁻¹⁵
5
2
10⁻¹⁶
5
2
10⁻¹⁷
O⁵⁺
O⁺
10¹
2
5
10²
2
5
10³
ENERGY (eV)

Excitation of O_2 by Electrons:

$$e + O_2 \rightarrow e + O_2(a\ ^1\Delta_g)$$

$$e + O_2 \rightarrow e + O_2^+(b\ ^4\Sigma_g^-) + e$$

$$e + O_2 \rightarrow e + O_2^+(5632\ \text{Å Band Emission}) + e$$

Energy (eV)	Experimental Cross Sections (cm^2)		
	$O_2(a\ ^1\Delta_g)$	$O_2^+(b\ ^4\Sigma_g^-)$	5632 Å Band Emission
2.0 E 01	2.00 E-18	3.20 E-18	1.70 E-19
3.0 E 01	3.61 E-18	8.51 E-18	1.46 E-18
4.0 E 01	3.96 E-18	1.41 E-17	2.57 E-18
5.0 E 01	3.41 E-18	1.90 E-17	3.32 E-18
6.0 E 01	2.72 E-18	2.30 E-17	3.75 E-18
8.0 E 01		2.98 E-17	4.19 E-18
1.0 E 02		3.18 E-17	4.33 E-18
1.5 E 02		2.82 E-17	4.19 E-18
2.0 E 02		2.53 E-17	3.90 E-18
3.0 E 02		2.11 E-17	3.22 E-18
4.0 E 02		1.82 E-17	2.80 E-18
5.0 E 02		1.62 E-17	2.48 E-18
6.0 E 02		1.47 E-17	2.22 E-18
8.0 E 02		1.21 E-17	1.85 E-18
1.0 E 03		1.04 E-17	1.59 E-18
1.5 E 03		7.99 E-18	
2.0 E 03		6.50 E-18	
3.0 E 03		4.86 E-18	
4.0 E 03		3.96 E-18	
5.0 E 03		3.30 E-18	

References:

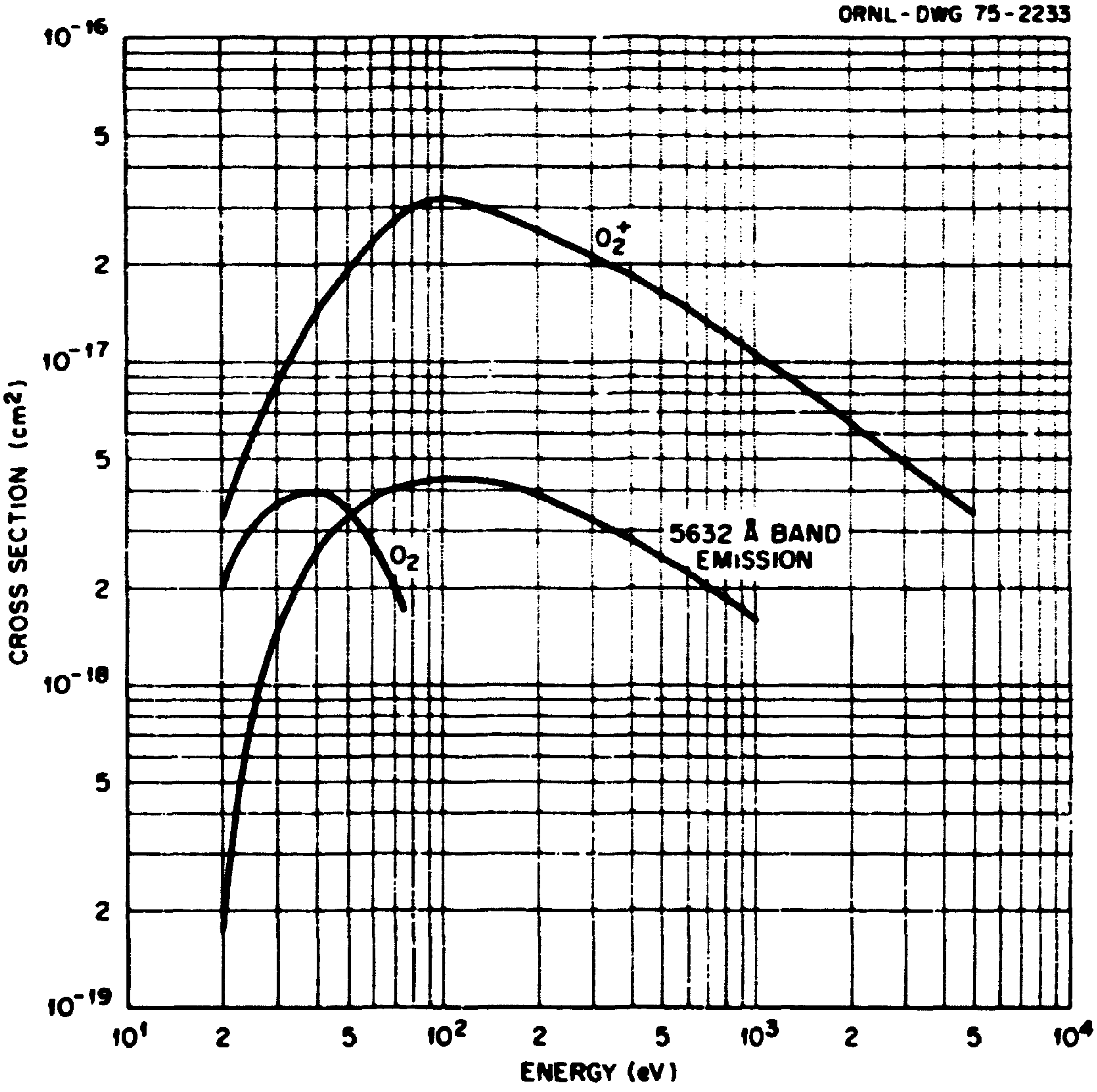
$e + O_2 \rightarrow e + O_2(a\ ^1\Delta_g)$ Exp.: A. Konishi, K. Wakiya, M. Yamamoto, H. Suzuki, J. Phys. Soc. Japan 29, 526 (1970).

$e + O_2 \rightarrow e + O_2^+(b\ ^4\Sigma_g^-) + e$, Exp.: J.W. McConkey and J.M. Woolsey, J. Phys. B 2, 529 (1969).

$e + O_2 \rightarrow e + O_2^+$ (5632 Å bank emission) + e, Exp.: W. L. Borst and E. C. Zipf, Phys. Rev. A 1, 1410 (1970).

Accuracy:

$O_2(a\ ^1\Delta_g)$ – total error < ± 50%. $O_2^+(b\ ^4\Sigma_g^-)$ – random error < ± 5%; systematic error < ±25%. O_2^+(5632 Å band) – random error < ± 10%; systematic error < ± 10%.


ORNL-DWG 75-2233
10^{-16}
5
2
10^{-17}
5
2
10^{-18}
5
2
10^{-19}
CROSS SECTION (cm^2)
10^1
2
5
10^2
2
5
10^3
2
5
10^4
ENERGY (eV)
O_2^+
O_2
5632 Å BAND
EMISSION

Dissociation of O_2 into Excited Fragments by Electrons:

$e + O_2 \rightarrow e + O + O(^5S^o)$

$e + O_2 \rightarrow e + O + O$(1300 Å Multiplet, $3s^2\ ^3S^o \rightarrow 2p^4\ ^3P$)

Energy (eV)	Experimental Cross Sections (cm^2)	
	$O(^5S^o)$	1300 Å Emission
1.5 E 01		7.65 E-19
2.0 E 01	2.53 E-18	1.42 E-18
3.0 E 01	4.57 E-18	2.37 E-18
4.0 E 01	6.59 E-18	2.95 E-18
5.0 E 01	8.36 E-18	3.34 E-18
6.0 E 01	9.89 E-18	3.60 E-18
8.0 E 01	1.12 E-17	3.80 E-18
1.0 E 02	1.17 E-17	3.74 E-18
1.5 E 02	1.12 E-17	3.18 E-18
2.0 E 02	1.02 E-17	2.68 E-18
3.0 E 02	8.00 E-18	2.09 E-18

References:

$e + O_2 \rightarrow e + O + O(^5S^o)$ Exp.: W.C. Wells, W.L. Borst, and E.C. Zipf, Chem. Phys. Letts. 12, 288 (1971).

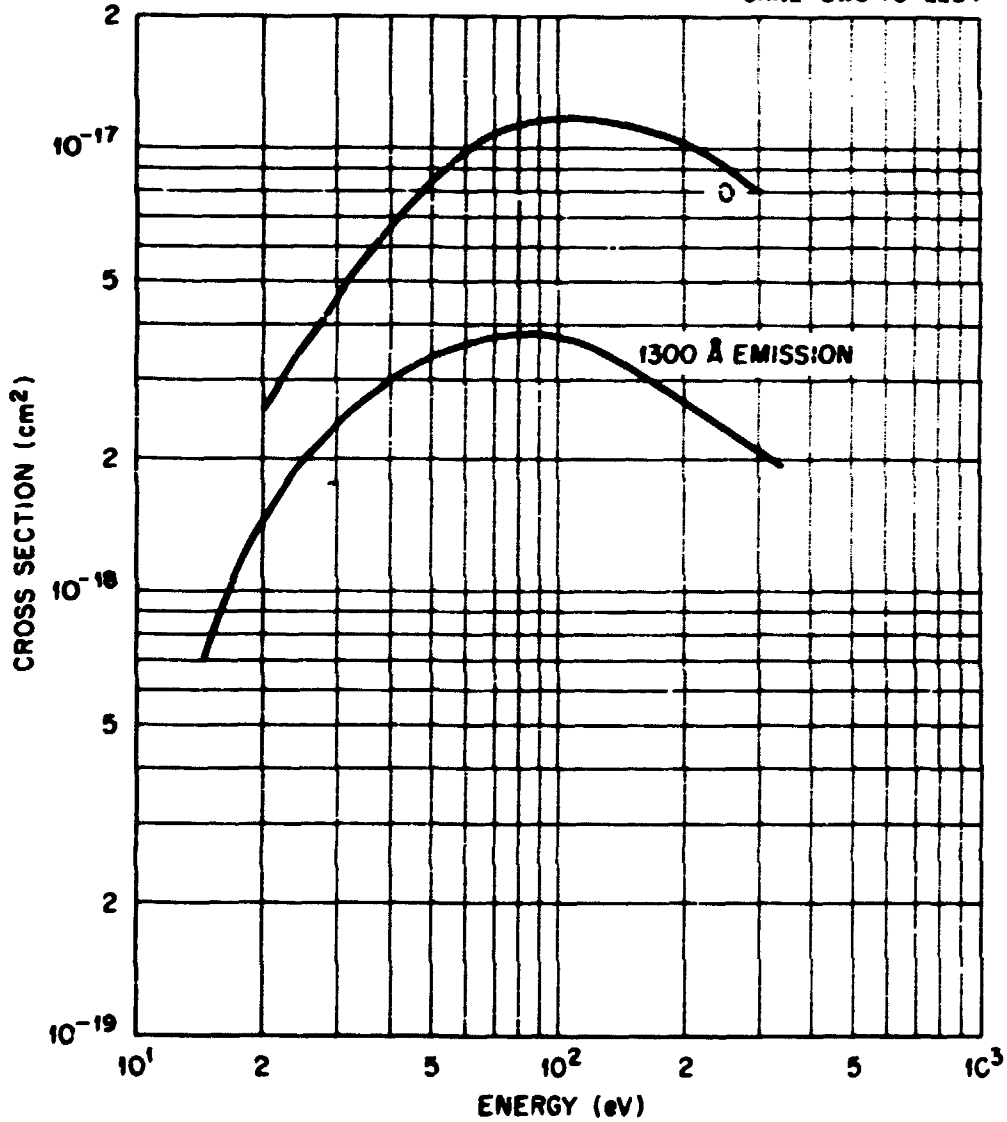
$e + O_2 \rightarrow e + O + O$(1300 Å) Exp.: M.J. Mumma and E.C. Zipf, J. Chem. Phys. 55, 1661 (1971).

Accuracy:

$O(^5S^o)$ - Systematic error < ± 50%. Random error < ± 5%.

1300 Å Emission - Systematic error < ± 17%. Random error < ± 10%.

ORNL-DWG 75-2234



Excitation of Neon by Electrons.

Selected Excitation and Emission Cross Sections:

e + Ne → e + Ne [$^2P_1$, 5852 Å Emission]

e + Ne → e + Ne^+ [3378 Å Emission] + e

e + Ne → e + Ne^{2+} [2677 Å Emission] + 2e

Energy (eV)	Experimental Cross Sections (cm^2)			
	$^2P_1$ State	5852 Å Emission ($^2P_1 \to {}^1S_2$)	3378 Å Emission ($3p\,^2P_{1/2} \to 3s\,^2P_{1/2}$)	2677 Å Emission ($3p\,^3P \to 3s\,^3S^o$)
2.2 E 01	8.50 E-19	8.10 E-19		
2.8 E 01	1.53 E-18	1.62 E-18		
3.0 E 01	1.70 E-18	1.78 E-18		
4.0 E 01	2.30 E-18	2.20 E-18		
5.0 E 01	2.19 E-18	2.31 E-18		
6.0 E 01	2.10 E-18	2.23 E-18	2.30 E-20	
8.0 E 01	1.80 E-18	1.94 E-18	4.90 E-20	
1.0 E 02	1.56 E-18	1.70 E-18	6.29 E-20	
1.4 E 02	1.20 E-18	1.34 E-18	7.20 E-20	3.50 E-21
1.6 E 02	1.08 E-18	1.21 E-18	7.15 E-20	1.36 E-20
2.0 E 02	8.96 E-19	1.00 E-18	6.78 E-20	2.13 E-20
2.5 E 02			6.09 E-20	2.74 E-20
3.0 E 02			5.50 E-20	2.83 E-20
4.0 E 02				2.79 E-20
5.0 E 02				2.64 E-20

References:

e + Ne → e + Ne($^2P_1$) Exp.: F.A. Sharpton, R.M. St. John, C.C. Lin, F.E. Fajen, Phys. Rev. A 2, 1305 (1970).

e + Ne → e + Ne(5852 Å Emission) Exp.: F.A. Sharpton et al. (see above).

e + Ne → e + Ne^+(3378 Å Emission) Exp.: K.G. Walker and R.M. St. John, Phys. Rev. A 6, 240 (1972).

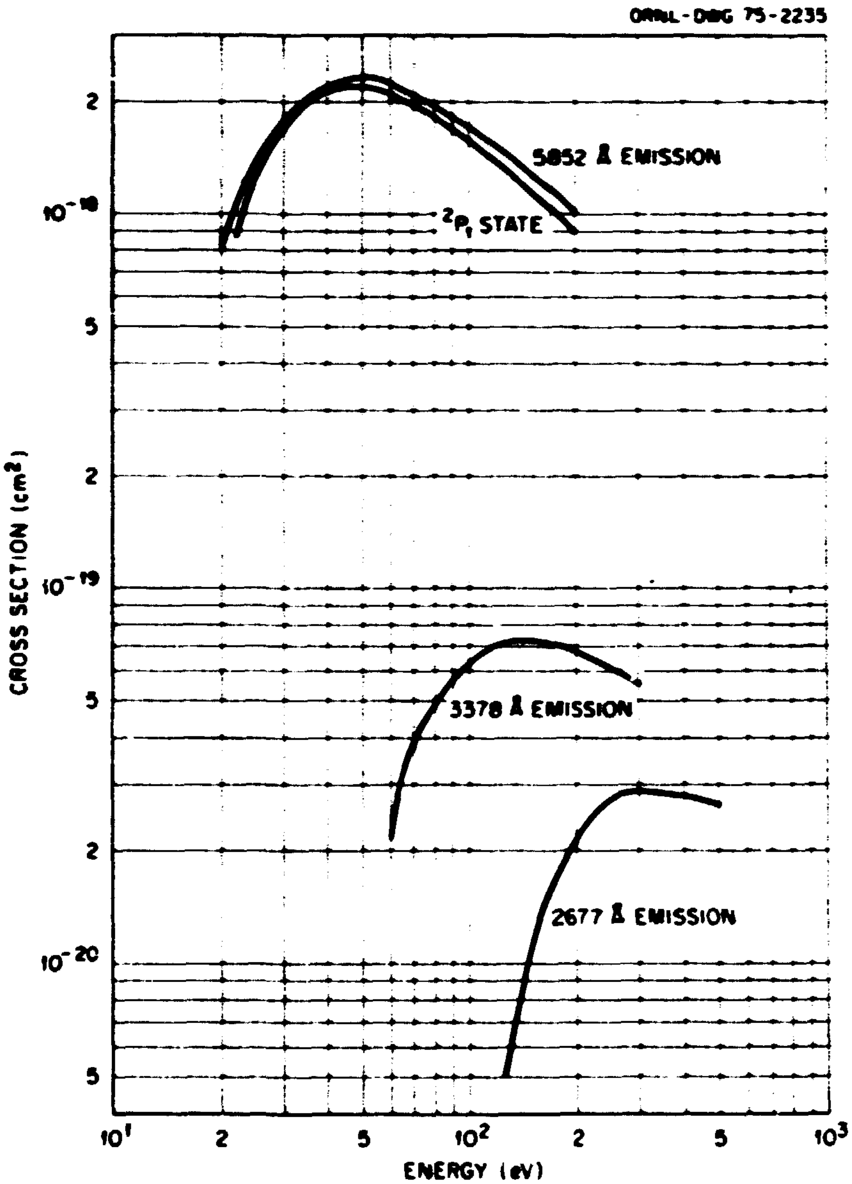
e + Ne → e + Ne^{2+}(2677 Å Emission) Exp.: Yu.M. Smirnov and Yu. D. Sharonov, Optics and Specty. 32, 333 (1972).

Accuracy:

2677 Å Line - no accuracy limits specified. All others - systematic error < ± 10%; random error < ± 5%.

Notes:

See Notes (10), (11), and (12) at end of chapter.


ORNL-DWG 75-2235
5852 Å EMISSION
$^2P_1$ STATE
3378 Å EMISSION
2677 Å EMISSION
CROSS SECTION (cm²)
ENERGY (eV)
10^{-18}
10^{-19}
10^{-20}
10^1
10^2
10^3

Excitation of Neon Ions by Electrons:

$e + Ne^{5+}$ See References Below

$e + Ne^{6+}$ See References Below

$e + Ne^{7+}(2s) \rightarrow e + Ne^{7+}(2p)$

$e + Ne^{8+}$ See References Below

$e + Ne^{9+}$ See References Below

Energy (eV)	Theoretical Cross Section (cm^2)
	Ne^{7+} (2p)
2.0 E 01	4.50 E-17
2.5 E 01	1.16 E-16
3.0 E 01	1.47 E-16
4.0 E 01	1.76 E-16
5.0 E 01	1.80 E-16
6.0 E 01	1.77 E-16
8.0 E 01	1.64 E-16
1.0 E 02	1.51 E-16
1.5 E 02	1.26 E-16
2.0 E 02	1.10 E-16
2.5 E 02	9.80 E-17
3.0 E 02	8.98 E-17

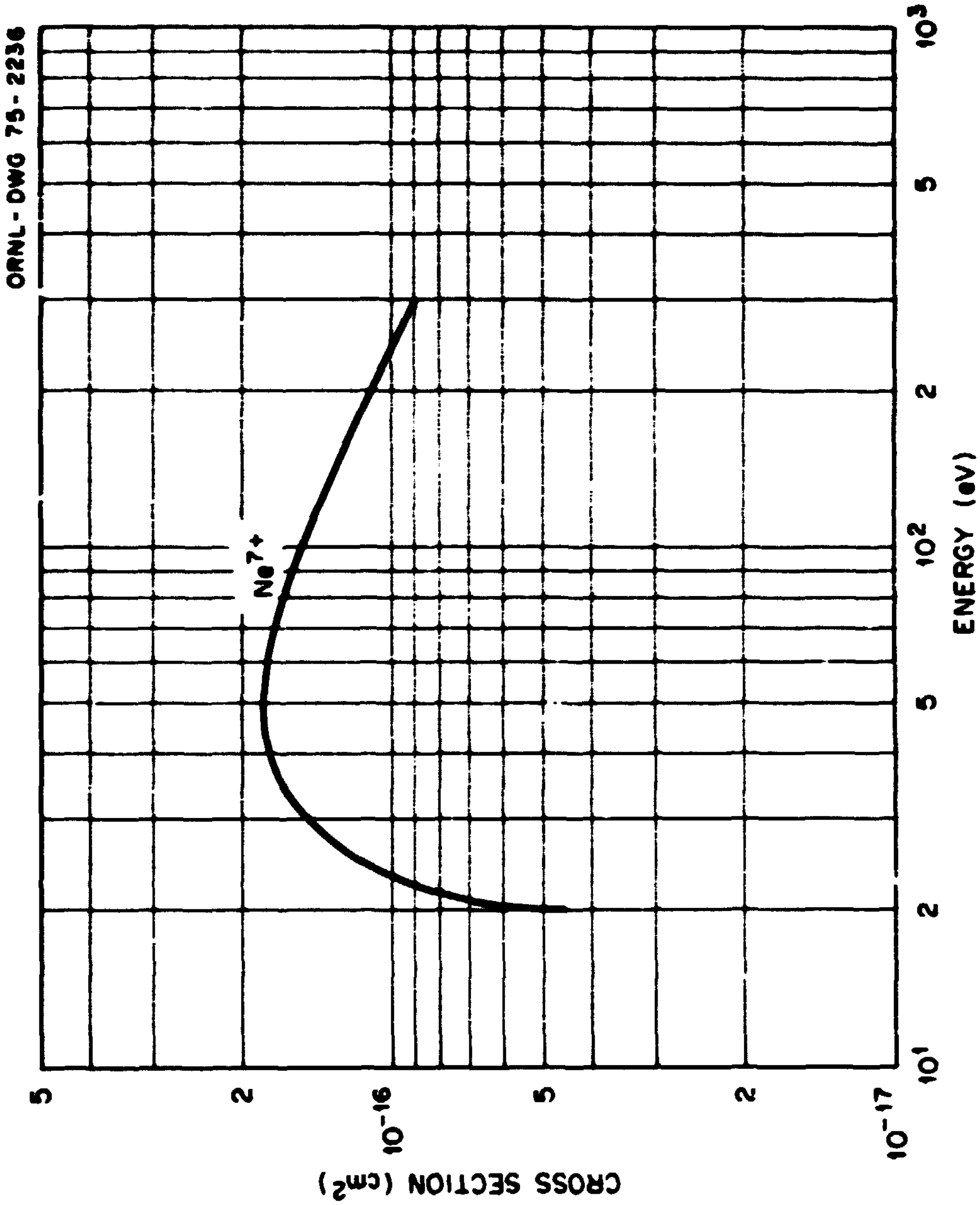
References:

$e + Ne^{5+}$: There are no cross section data for this ion, but there are theoretical calculations of collision strengths given by D.E. Osterboch, J. Phys. B 3, 149 (1970).

$e + Ne^{6+}$: There are no cross section data but experimental rate coefficients are given by: H.J. Kunze, Phys. Rev. A 4, 111 (1971); G. Rondello and R.W.P. McWhirter, J. Phys. B. 4, 715 (1971).

$e + Ne^{7+}(2s) \rightarrow e + Ne^{7+}(2p)$ Theoretical: K.C. Mathur, A.N. Tripathi, and S.K. Joshi, Intl. J. Mass Spectrom. Ion Phys. 7, 167 (1971). [See also W.D. Johnston and H.J. Kunze, Phys. Rev. A 4, 962 (1971) for experimental rate coefficients. Also O. Bely, Proc. Phys. Soc. 88, 587 (1966) for a prescription whereby these cross sections may be calculated.]

[Continued at end of chapter.]


ORNL-DWG 75-2236
Ne^{7+}
CROSS SECTION (cm^2)
ENERGY (eV)
5
2
10^{-16}
5
2
10^{-17}
10^1
2
5
10^2
2
5
10^3

Excitation of Argon by Electrons:

$e + Ar \rightarrow e + Ar(1s_2 + 1s_4$, 1067 Å Emission, 7503 Å Emission)

$e + Ar \rightarrow e + Ar^{+}$(4765 Å Emission) + e

Energy (eV)	Experimental Cross Sections (cm^2)			
	$1s_2$ & $1s_4$ States (Sum of Two States)	1067 Å Emission ($1s_4 \rightarrow 1p_0$)	7503 Å Emission ($2p_1 \rightarrow 1s_2$)	4765 Å Emission ($4p\,^2P_{\frac{3}{2}} \rightarrow 4s\,^2P_{\frac{1}{2}}$)
1.5 E 01	2.50 E-17	9.20 E-18	9.38 E-18	
2.0 E 01	3.67 E-17	1.68 E-17	8.62 E-18	
2.5 E 01	4.20 E-17	2.09 E-17	7.38 E-18	
3.0 E 01	4.44 E-17	2.17 E-17	6.95 E-18	
4.0 E 01	4.40 E-17	1.44 E-17	6.88 E-18	1.70 E-19
5.0 E 01	4.21 E-17	1.23 E-17	7.22 E-18	4.46 E-19
6.0 E 01	4.00 E-17	1.11 E-17	7.22 E-18	4.87 E-19
8.0 E 01	3.61 E-17	9.99 E-18	6.82 E-18	5.04 E-19
1.0 E 02	3.27 E-17	9.04 E-18	6.30 E-18	5.00 E-19
1.5 E 02	2.65 E-17	7.39 E-18	5.30 E-18	3.88 E-19
2.0 E 02	2.24 E-17	6.20 E-18	4.60 E-18	3.28 E-19
2.5 E 02	1.93 E-17	5.35 E-18		
3.0 E 02	1.71 E-17	4.72 E-18		
4.0 E 02	1.40 E-17	3.86 E-18		
5.0 E 02	1.19 E-17	3.28 E-18		
6.0 E 02	1.03 E-17	2.86 E-18		
8.0 E 02	8.46 E-18	2.30 E-18		
1.0 E 03	7.10 E-18	1.92 E-18		

References:

$e + Ar \rightarrow e + Ar(1s_2 + 1s_4$ states together) Exp.: J.W. McConkey and F.G. Donaldson, Can. J. Phys. 51, 867 (1973).

$e + Ar \rightarrow e + Ar$(1067 Å emission) Exp.: J.W. McConkey and F.G. Donaldson, Can. J. Phys. 51, 867 (1973).

$e + Ar \rightarrow e + Ar$(7503 Å emission) Exp.: J.K. Ballou, C.C. Lin, and F.E. Fajen, Phys. Rev. A 8, 1797 (1973).

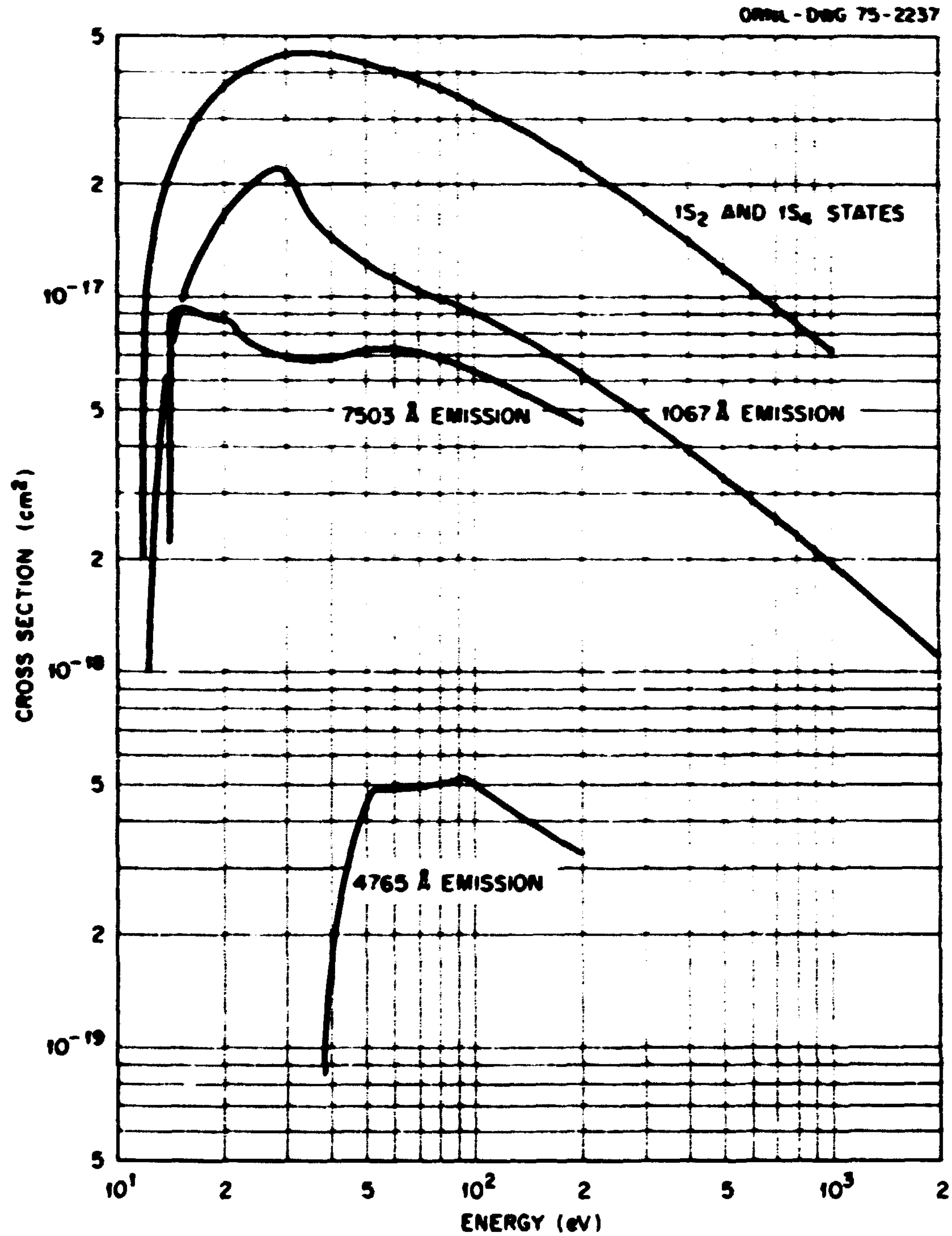
$e + Ar \rightarrow e + Ar^{+}$(4765 Å emission) Exp.: I.D. Latimer and R.M. St. John, Phys. Rev. A 1, 1612 (1970).

Accuracy:

Systematic error < ± 10%. Random error < ± 5%.

Notes:

See Notes (10) and (12) at end of chapter.


ORNL-DWG 75-2237
1S2 AND 1S4 STATES
7503 Å EMISSION
1067 Å EMISSION
4765 Å EMISSION
CROSS SECTION (cm²)
ENERGY (eV)
5
2
10⁻¹⁷
5
2
10⁻¹⁸
5
2
10⁻¹⁹
5
10¹
2
5
10²
2
5
10³
2

Excitation of Argon Ions by Electrons:

$e + Ar^{+} \rightarrow e + Ar^{+}$(4658 Å and 4880 Å Emissions)

$e + Ar^{7+} \rightarrow$ See Reference Below

$e + Ar^{17+} \rightarrow$ See Reference Below

Energy (eV)	Experimental Cross Sections (cm^2)	
	4658 Å Emission (4p $^2P^0_{1/2} \rightarrow$ 4s $^2P_{3/2}$)	4880 Å Emission (4p $^2D^0_{5/2} \rightarrow$ 4s $^2P_{3/2}$)
1.7 E 01	2.00 E-19	6.50 E-19
1.8 E 01	9.60 E-19	2.39 E-18
1.9 E 01	1.75 E-18	5.30 E-18
2.0 E 01	2.54 E-18	7.80 E-18
2.1 E 01	3.25 E-18	1.00 E-17
2.2 E 01	3.60 E-18	1.13 E-17
2.3 E 01	2.81 E-18	8.67 E-18
2.4 E 01	2.24 E-18	7.79 E-18
2.5 E 01	2.64 E-18	8.10 E-18
2.6 E 01	3.21 E-18	9.30 E-18
2.7 E 01	3.41 E-18	1.19 E-17
2.8 E 01	3.58 E-18	1.28 E-17
2.9 E 01	3.62 E-18	1.30 E-17
3.0 E 01	3.58 E-18	1.27 E-17
3.1 E 01	3.41 E-18	1.23 E-17
3.2 E 01	3.20 E-18	1.19 E-17
3.3 E 01	2.95 E-18	1.13 E-17
3.4 E 01	2.68 E-18	1.08 E-17
3.5 E 01		1.02 E-17

References:

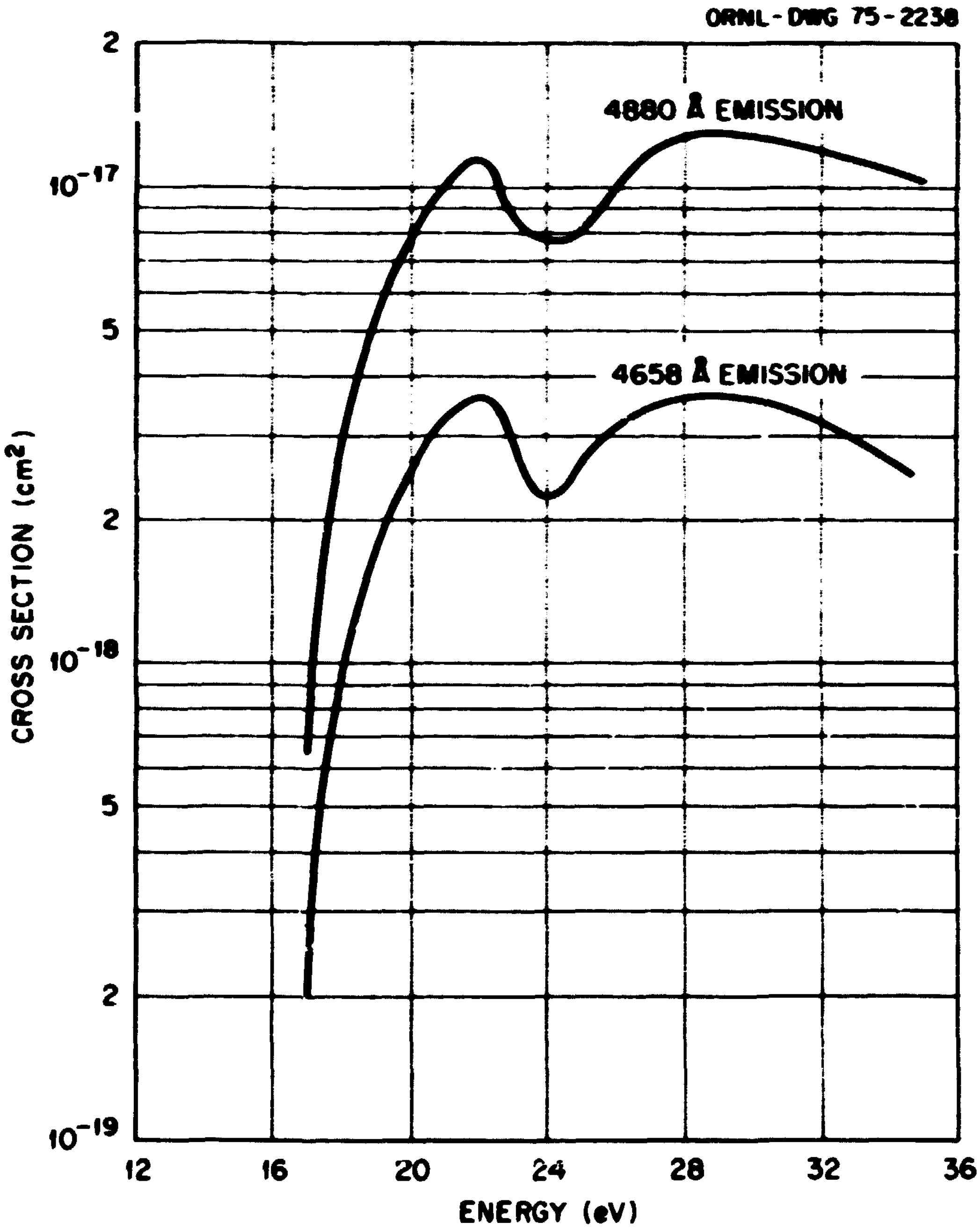
$e + Ar^{+} \rightarrow e + Ar^{+}$(4658 and 4880 Å Emission) Exp.: A.M. Imre, A.I. Dashchenko, I.P. Zapesochnyi, and V.A. Kel'man, Zh. Eks. i Teor. Fiz. Pis. Red. 15, 712 (1972) [JETP Letters 15, 503 (1972)].

$e + Ar^{7+}$: There are no cross section data, but rate coefficients have been measured in a plasma ($kT_e \sim 250$ eV). See R.V. Datla, H.J. Kunze, and D. Petrini, Phys. Rev. A 6, 38 (1972).

$e + Ar^{17+}$: The excitation of the hydrogenic ion is covered in the general formulation at the beginning of this chapter.

Accuracy:

Systematic error < ± 40%. Random error < ± 15%.


ORNL-DWG 75-2238
4880 Å EMISSION
4658 Å EMISSION
CROSS SECTION (cm²)
2
10⁻¹⁷
5
2
10⁻¹⁸
5
2
10⁻¹⁹
12
16
20
24
28
32
36
ENERGY (eV)

Excitation of Lithium Ions by Electrons:

$e + Li^{+}(1^{1}S) \rightarrow e + Li^{+}(2^{1}S, 2^{1}P, 2^{3}S)$

Energy (eV)	Theoretical Cross Sections (cm^2)		
	$2^{1}S$	$2^{1}P$	$2^{3}S$
6.0 E 01			2.30 E-17
8.0 E 01			1.40 E-17
1.0 E 02			8.20 E-18
1.5 E 02			2.99 E-18
2.0 E 02			1.40 E-18
3.0 E 02			4.61 E-19
4.0 E 02			2.00 E-19
5.0 E 02	2.14 E-19	1.99 E-18	1.01 E-19
6.0 E 02	1.79 E-19	1.81 E-18	5.90 E-20
8.0 E 02	1.34 E-19	1.55 E-18	2.30 E-20
1.0 E 03	1.07 E-19	1.32 E-18	1.13 E-20
1.5 E 03	7.15 E-20	9.92 E-19	3.05 E-21
2.0 E 03	5.36 E-20	8.10 E-19	
3.0 E 03	3.57 E-20	6.06 E-19	
4.0 E 03	2.68 E-20	4.90 E-19	
5.0 E 03	2.14 E-20	4.16 E-19	
6.0 E 03	1.79 E-20	3.60 E-19	
8.0 E 03	1.34 E-20	2.87 E-19	
1.0 E 04	1.07 E-20	2.41 E-19	
1.5 E 04	7.15 E-21	1.74 E-19	
2.0 E 04	5.36 E-21	1.38 E-19	
3.0 E 04	3.57 E-21	1.00 E-19	

References:

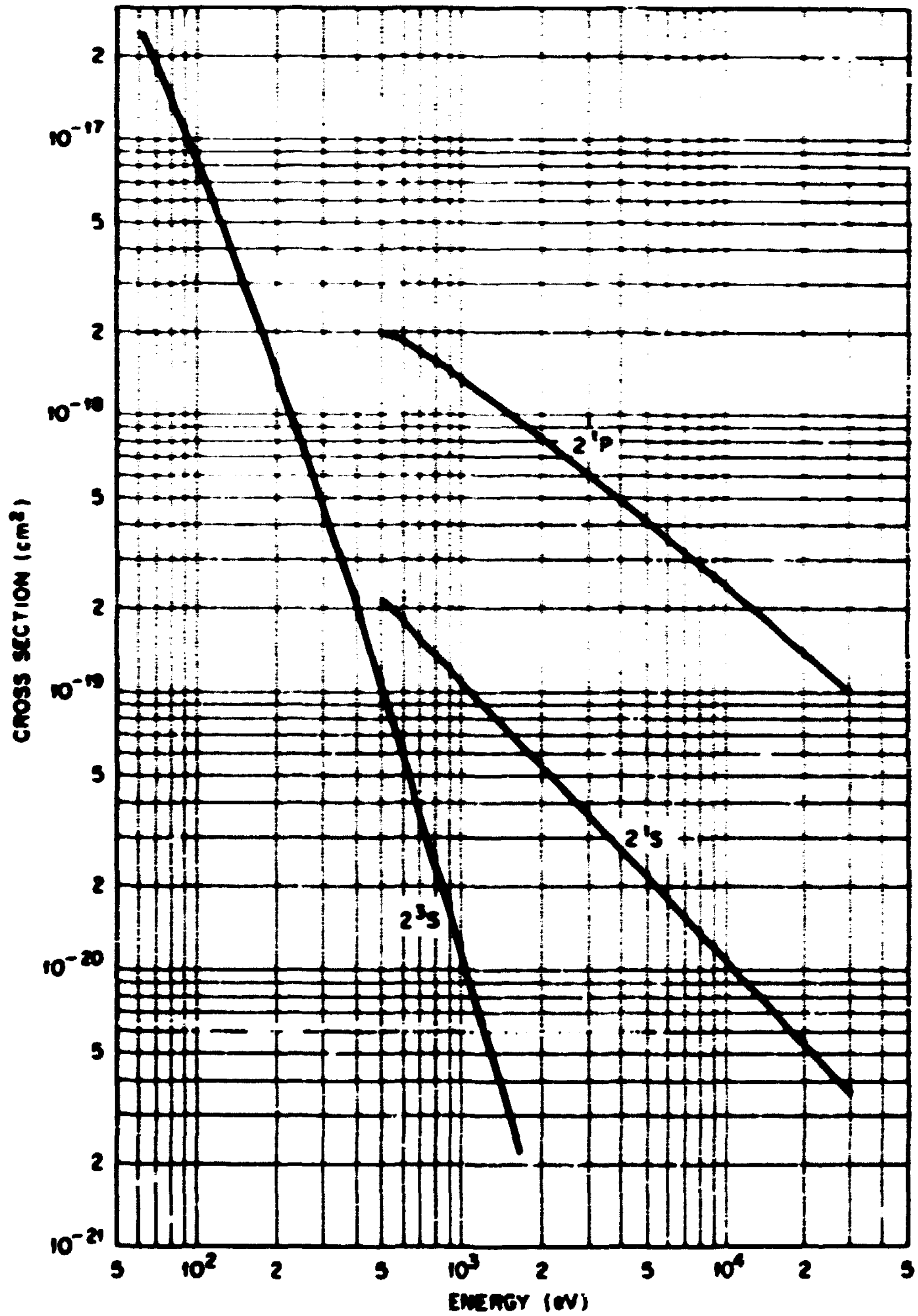
$e + Li^{+} \rightarrow e + Li^{+}(2^{1}S, 2^{1}P)$ Theoretical: Y.-K. Kim and M. Inokuti, Phys. Rev. A 1, 1132 (1970). [This reference also provides a prescription for estimating cross sections to higher singlet states.]

$e + Li^{+} \rightarrow e + Li^{+}(2^{3}S)$ Theoretical: I.L. Beigman and L.A. Vainshtein, Zh. Eks. i Teor. Fiz. 52, 185 (1967) [Soviet Phys. JETP 25, 119 (1967)].

Accuracy:

See Note (7) at end of chapter.

ORNL-DWG 75-2239



Excitation of Nickel by Electrons:

$e + Ni^{12+}$ See References Below

$e + Ni^{17+}(3s) \rightarrow e + Ni^{17+}(3p)$

$e + Ni^{17+}(3p) \rightarrow e + Ni^{17+}(3d)$

Energy (eV)	Theoretical Cross Sections (cm^2)	
	3s → 3p	3p → 3d
1.0 E 03	7.[illegible]4 E-19	
1.5 E 03	7.09 E-19	2.25 E-19
2.0 E 03	6.52 E-19	2.12 E-19
2.5 E 03	5.80 E-19	1.97 E-19
3.0 E 03	5.25 E-19	1.83 E-19
3.5 E 03	4.66 E-19	1.63 E-19
4.0 E 03	4.20 E-19	1.40 E-19
4.5 E 03	3.75 E-19	1.23 E-19
5.0 E 03		1.10 E-19
5.5 E 03		9.70 E-20
6.0 E 03		8.70 E-20
6.5 E 03		7.90 E-20

References:

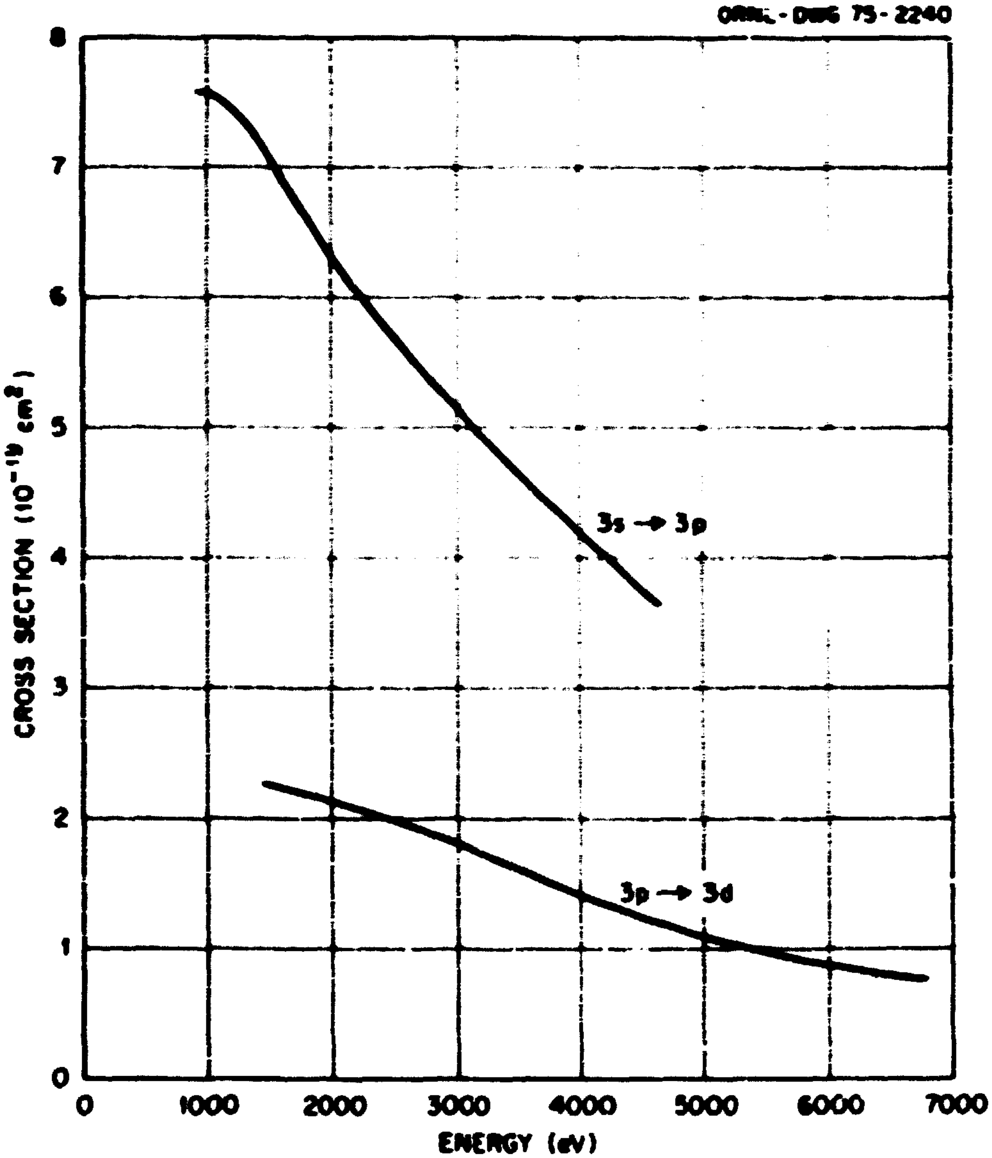
$e + Ni^{12+}$: There are no cross section data, but collision strengths at, and very close to, threshold have been calculated by S.J. Czyzak et al., Proc. Phys. Soc. (London) 92, 1146 (1967).

$e + Ni^{17+}(3s) \rightarrow e + Ni^{17+}(3p)$ Theoretical: M. Golshani, Phys. Rev. A 2, 2340 (1970).

$e + Ni^{17+}(3p) \rightarrow e + Ni^{17+}(3d)$ Theoretical: M. Golshani, Phys. Rev. A 2, 2340 (1970).

Accuracy:

See Note (7) at end of chapter.


ORNL-DWG 75-2240
CROSS SECTION (10^{-19} cm^2)
ENERGY (eV)
3s → 3p
3p → 3d
0
1
2
3
4
5
6
7
8
0
1000
2000
3000
4000
5000
6000
7000

Excitation of Iron by Electrons:

$e + Fe^{15+}(3s) \rightarrow e + Fe^{15+}(3p)$

For All Other States of Ionization See Reference List Below

Energy (eV)	Theoretical Cross Section (cm^2)
	3s → 3p
3.5 E 01	8.50 E-18
4.0 E 01	2.10 E-18
4.5 E 01	3.10 E-18
5.0 E 01	3.58 E-18
5.5 E 01	3.85 E-18
6.0 E 01	4.01 E-18
8.0 E 01	4.17 E-18
1.0 E 02	4.00 E-18
1.5 E 02	3.40 E-18
2.0 E 02	2.83 E-18
3.0 E 02	2.60 E-18

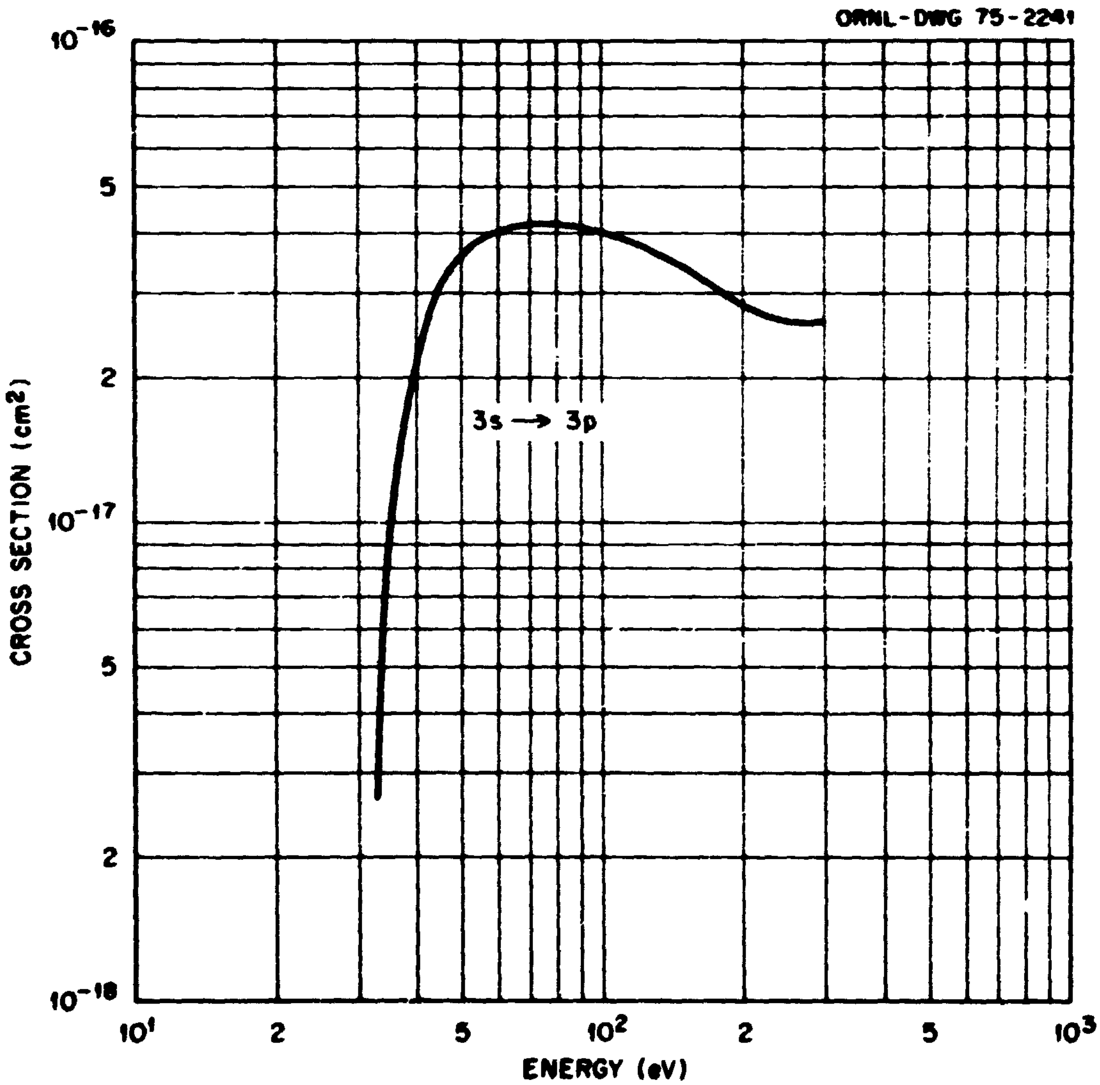
References:

$e + Fe^{15+} \rightarrow e + Fe^{15+}(3p)$: Theoretical: K.C. Mathur, A.N. Tripathi, and S.K. Joshi, Intl. J. Mass Spectrom. Ion Phys. 7, 167 (1971).

For other states of ionization there are no cross section information. However theoretical collision strengths close to threshold are to be found in the following references: D.R. Flower, J. Phys. B 4, 697 (1970) [Fe^{12+}, Fe^{13+}, Fe^{14+}, Fe^{16+}]; S.J. Czyzak, et al., Mon. Not. R. Astr. Soc. 148, 361 (1970) [Fe^{11+}]; M. Blaha, Astrophys. J. 157, 473 (1969) [Fe^{12+}, Fe^{13+}]; D. Petrini, Astron. & Astrophys. 1, 139 (1969) [Fe^{14+}]; F. Bely, et al., Ann. d'Astrophys. 29, 343 (1966) [Fe^{12+}]; S.J. Szyzak, Proc. Phys. Soc. 90, 619 (1967) [Fe^{11+}]; S.J. Szyzak, et al., Proc. Phys. Soc. 92, 1146 (1967) [Fe^{10+}, Fe^{12+}].

Accuracy:

See Note (7) at end of chapter.


ORNL-DWG 75-2241
CROSS SECTION (cm²)
ENERGY (eV)
3s → 3p
10⁻¹⁶
5
2
10⁻¹⁷
5
2
10⁻¹⁸
10¹
2
5
10²
2
5
10³

Collisional Excitation of H by Electrons:

$e + H \rightarrow e + H(2s, 2p, n=3, 3s, 4s)$

(Continued)

$e + H \rightarrow H(3s, 4s)$ Theoretical: M.R.C. McDowell, L.A. Morgan, V.P. Myerscough, J. Phys. B 6, 1435 (1973).

$e + H \rightarrow$ Balmer alpha, Experimental data for emission of the Balmer alpha line. H. Kleinpoppen, E. Kraiss, Phys. Rev. Letts 20, 361 (1968). See Note (3) at end of chapter.

Accuracy:

Random error: $< \pm 15\%$ for 2s and 2p, $< \pm 30\%$ for Balmer alpha.

Higher Energies:

For higher (non-relativistic) impact energies the cross sections given here for the 2s, 3s, and 4s states may be extrapolated by the formula $\sigma = A/E$. For extrapolation of the 2p cross section see graph.

Cross Sections for Vibrational Excitation of H_2 by Electrons

(Continued)

$e + C^{2+} \rightarrow e + C^{2+}(2p\,^2P)$ Theoretical: I.L. Beigman and L.A. Vainstein, J. Eks. i Teor. Fiz. 52, 185 (1967) [Soviet Physics JETP 25, 119 (1967)]. Corrected by a factor of 10^3 [See D.E. Osterbrock, J. Phys. B 3, 149 (1970). This reference also has some collision strength calculations.]

$e + C^{3+} \rightarrow e + C^{3+}(2p\,^2P^0)$ Theoretical: K.C. Mathur, A.N. Tripathi, and S.K. Joshi, Intl. J. Mass Spectrom. Ion Phys. 7, 167 (1971). [This reference also has data for other levels.] Petrini also gives collision strengths at low energies; Astron. & Astrophys. 17, 410 (1972).

$e + C^{4+} \rightarrow e + C^{4+}(2s\,^3S)$ Theoretical: I.L. Beigman and L.A. Vainshtein, Zh. Eks. i Teor. Fiz. 52, 185 (1967). [Soviet Physics JETP 25, 119 (1967).] Rate coefficients have been measured in a plasma ($kT_e \sim 250$ eV). See H.J. Kunze et al., Phys. Rev. 165, 267 (1968).

$e + C^{5+}$: The excitation of the hydrogenic C^{5+} ion is covered in the general formulation at the beginning of this chapter.

Notes:

See Note (7) (accuracy) at end of chapter.

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Excitation of Carbon Ions by Electrons

(Continued)

$e + C^{2+} \rightarrow e + C^{2+}(2p\,^2P)$ Theoretical: I.L. Beigman and L.A. Vainstein, J. Eks. i Teor. Fiz. 52, 185 (1967) [Soviet Physics JETP 25, 119 (1967)]. Corrected by a factor of 10^3 [See D.E. Osterbrock, J. Phys. B 3, 149 (1970). This reference also has some collision strength calculations.]

$e + C^{3+} \rightarrow e + C^{3+}(2p\,^2P^o)$ Theoretical: K.C. Mathur, A.N. Tripathi, and S.K. Joshi, Intl. J. Mass Spectrom. Ion Phys. 7, 167 (1971). [This reference also has data for other levels.] Petrini also gives collision strengths at low energies; Astron. & Astrophys. 17, 410 (1972).

$e + C^{4+} \rightarrow e + C^{4+}(2s\,^3S)$ Theoretical: I.L. Beigman and L.A. Vainshtein, Zh. Eks. i Teor. Fiz 52, 185 (1967). [Soviet Physics JETP 25, 119 (1967).] Rate coefficients have been measured in a plasma ($kT_e \sim 250$ eV). See H.J. Kunze et al., Phys. Rev. 165, 267 (1968).

$e + C^{5+}$: The excitation of the hydrogenic C^{5+} ion is covered in the general formulation at the beginning of this chapter.

Notes:

See Note (7) (accuracy) at end of chapter.

Excitation of Oxygen Ions by Electrons

(Continued)

$e + O^{6+}$: There are no cross section data, but rate coefficients have been measured in a plasma ($kT_e \sim 250$ eV). See R.C. Eldon and W.W. Koppendorfer, Phys. Rev. 160, 194 (1967); also H.J. Kunze, A.H. Gabriel, and H. Griem, Phys. Rev. 165, 267 (1968); see also theoretical data of O. Bely Phys. Letts. A 26, 408 (1968).

$e + O^{7+}$: The excitation of the hydrogenic O^{7+} ion is covered in the general formulation at the beginning of this chapter.

Notes:

See Note (7) (accuracy).

Excitation of Neon on Ions by Electrons

(Continued)

$e + Ne^{8+}$: There are no cross section data, but experimental values of collisional rate coefficients are to be found in W. Engelhardt et al., Phys. Rev. A 6, 1908 (1972).

$e + Ne^{9+}$: the excitation of the hydrogenic Ne^{9+} ion is covered in the general formulation at the beginning of this chapter.

Accuracy:

See Note (7) at end of chapter.

Notes

(1) These data are the cross section for formation of the excited state by all mechanisms including direct excitation and also cascade from higher states. In this case cascade is believed to be an appreciable contribution to the total cross section.

(2) These data are the cross section for formation of the excited state by all mechanisms including direct excitation and also cascade from higher states. In this case cascade is believed to be a small contribution to the total cross section.

(3) The experimental magnitudes of these experimental data were established by normalising to theory at high energies. This is believed to be quite reliable.

(4) At impact energies just above threshold these cross sections exhibit considerable resonant type structure. This can be observed only when using electron beams of very fine energy resolution (100 meV or better); it cannot be displayed on the scale used in the present graphical presentations. For details see for example: H. Koschmieder, V. Raible, and H. Kleinpoppen, Phys. Rev. A 8, 1365 (1973); A. Oed, Phys. Letts. A 34, 435 (1971); B.L. Moiseiwitsch, and S. J. Smith, Rev. Mod. Phys. 40, 238 (1968).

(5) The $2p\sigma_u$ state of H_2^+ is repulsive and dissociates to form $H^+ + H(1s)$. Cross sections for excitation from excited vibrational states of H_2^+ (i.e. for $v \neq 0$) are to be found in J.M. Peek, Phys. Rev. 140, A11 (1965).

(6) The $2p\pi_u$ state of H_2^+ is repulsive and dissociates to form $H^+ + H(2p)$.

(7) These data are theoretical cross sections. There has been no test of the theory's validity at all; the data are likely to be very inaccurate at energies close to threshold.

(8) There is some evidence that these experimental data are to high in absolute magnitude by a factor of two. Furthermore there is certainly an appreciable contribution from cascade transitions into the excited state.

(9) A useful set of cross sections for excitation of O is given by P.A. Kazaks et al., Phys. Rev. A 6, 2169 (1972). Though not of as high accuracy as the data we quote here, they can be of great practical utility.

(10) Notation used here for excited neutral rare gas atoms is the Paschen form. For identification in other notations see "Atomic Energy Levels" Volume 1, NBS Circular 467 (1949) by C.E. Moore.

(11) The emission data shown here have been arbitrarily chosen from the very large number of cross sections shown in the cited references. Laser action has been identified for each of the lines tabulated here.

(12) Each reference cited includes data for a number of other excited states.

C.3 Dissociation by Electron Impact

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Cross Sections for the Dissociation of O_2^+ Ions and H_2 Molecules by Electron Impact

Energy (eV)	Cross Sections for Dissociation (cm^2)	
	$e + O_2^+$	$e + H_2$
9.0 E 00		7.0 E-18
1.0 E 01		2.5 E-17
1.2 E 01		6.5 E-17
1.5 E 01		8.8 E-17
1.7 E 01	2.20 E-16	8.8 E-17
2.0 E 01	2.30 E-16	8.0 E-17
3.0 E 01	2.80 E-16	3.8 E-17
4.0 E 01	3.20 E-16	2.0 E-17
5.0 E 01	3.43 E-16	1.1 E-17
6.0 E 01	3.58 E-16	5.0 E-18
7.5 E 01	3.64 E-16	1.0 E-18
1.0 E 02	3.52 E-16	
1.5 E 02	3.30 E-16	
2.0 E 02	2.99 E-16	
2.5 E 02	2.73 E-16	
4.0 E 02	2.11 E-16	
5.0 E 02	1.88 E-16	

References:

O_2^+: B. Van Zyl and G.H. Dunn, Phys. Rev. 163, 43 (1967).

H_2: S.J.B. Corrigan, J. Chem. Phys. 43, 4381 (1965).

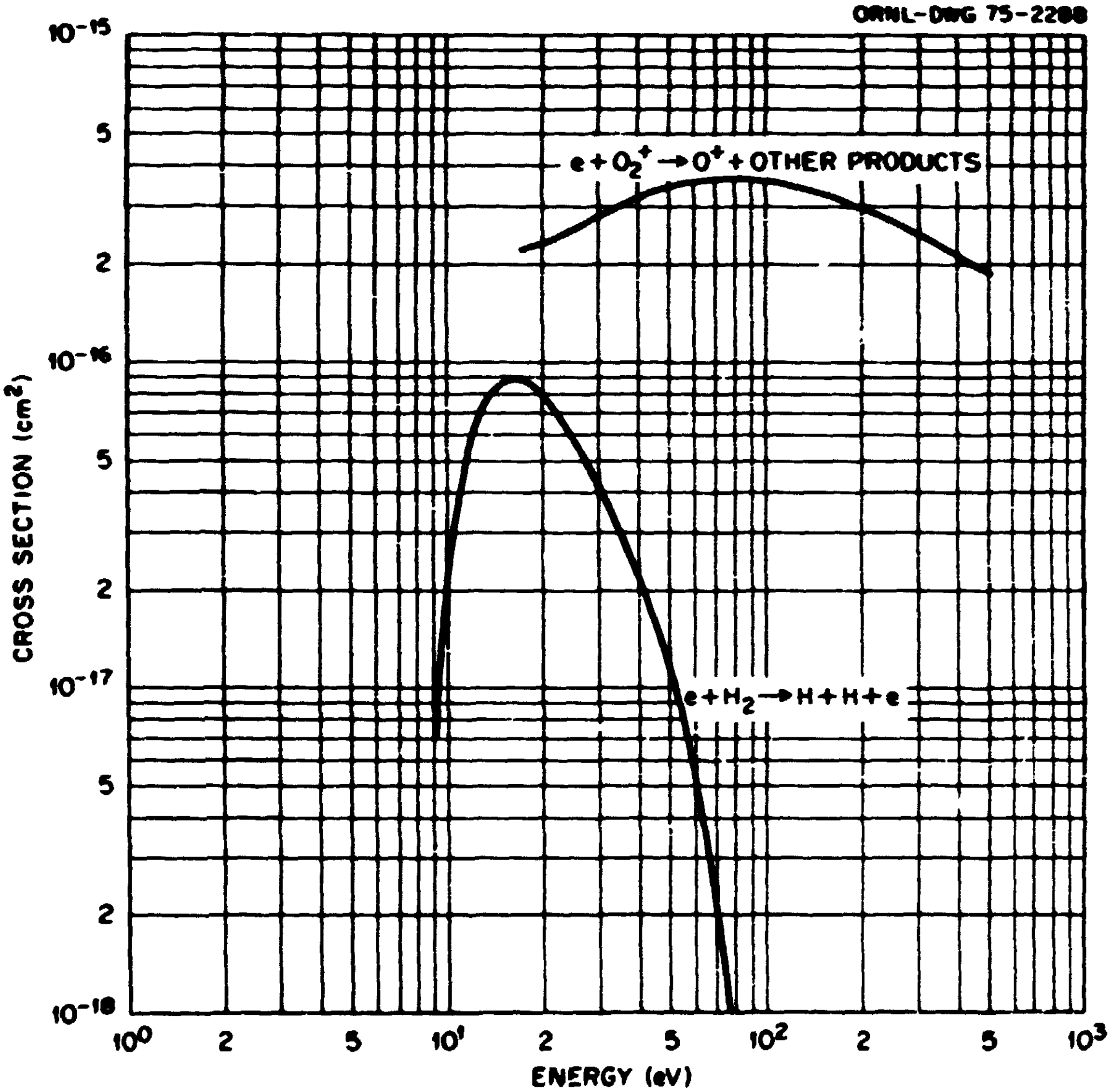
Accuracy:

O_2^+: The total error is believed not to exceed ± 20% over most of the energy scale.

H_2: The total error is believed not to exceed ± 50%.

Note:

O_2^+: The target O_2^+ ions are typical of those formed by bombardment of O_2 by high (150 eV) energy electrons in a low-pressure (10^{-3} torr) ion source, and may thus be a mixture of ground- and excited-state molecular ions.


ORNL-DWG 75-2208
CROSS SECTION (cm^2)
ENERGY (eV)
10^{-15}
5
2
10^{-16}
5
2
10^{-17}
5
2
10^{-18}
10^0
2
5
10^1
2
5
10^2
2
5
10^3
$e + O_2^+ \rightarrow O^+ +$ OTHER PRODUCTS
$e + H_2 \rightarrow H + H + e$

Cross Sections for the Dissociation Reactions $e + H_2^+ \rightarrow H^+ + H + e$ and $e + N_2^+ \rightarrow N^+ + $ Other Products

Energy (eV)	Cross Sections for Dissociation (cm^2)	
	$e + N_2^+$	$e + H_2^+$
1.0 E 01	3.6 E-17	
1.5 E 01	1.2 E-16	
2.0 E 01	2.0 E-16	
2.5 E 01	2.6 E-16	4.3 E-16
3.0 E 01	3.0 E-16	3.8 E-16
5.0 E 01	3.7 E-16	2.8 E-16
8.0 E 01	3.9 E-16	2.1 E-16
1.0 E 02	3.7 E-16	1.8 E-16
1.5 E 02	3.5 E-16	1.4 E-16
2.5 E 02	2.8 E-16	9.3 E-17
3.5 E 02	2.3 E-16	7.0 E-17
5.0 E 02	1.8 E-16	5.2 E-17
7.0 E 02		4.2 E-17

References:

H_2^+: B. Peart and K.T. Dolder, J. Phys. B 5, 860 (1972).

N_2^+: B. Van Zyl and G.H. Dunn, Phys. Rev. 163, 43 (1967).

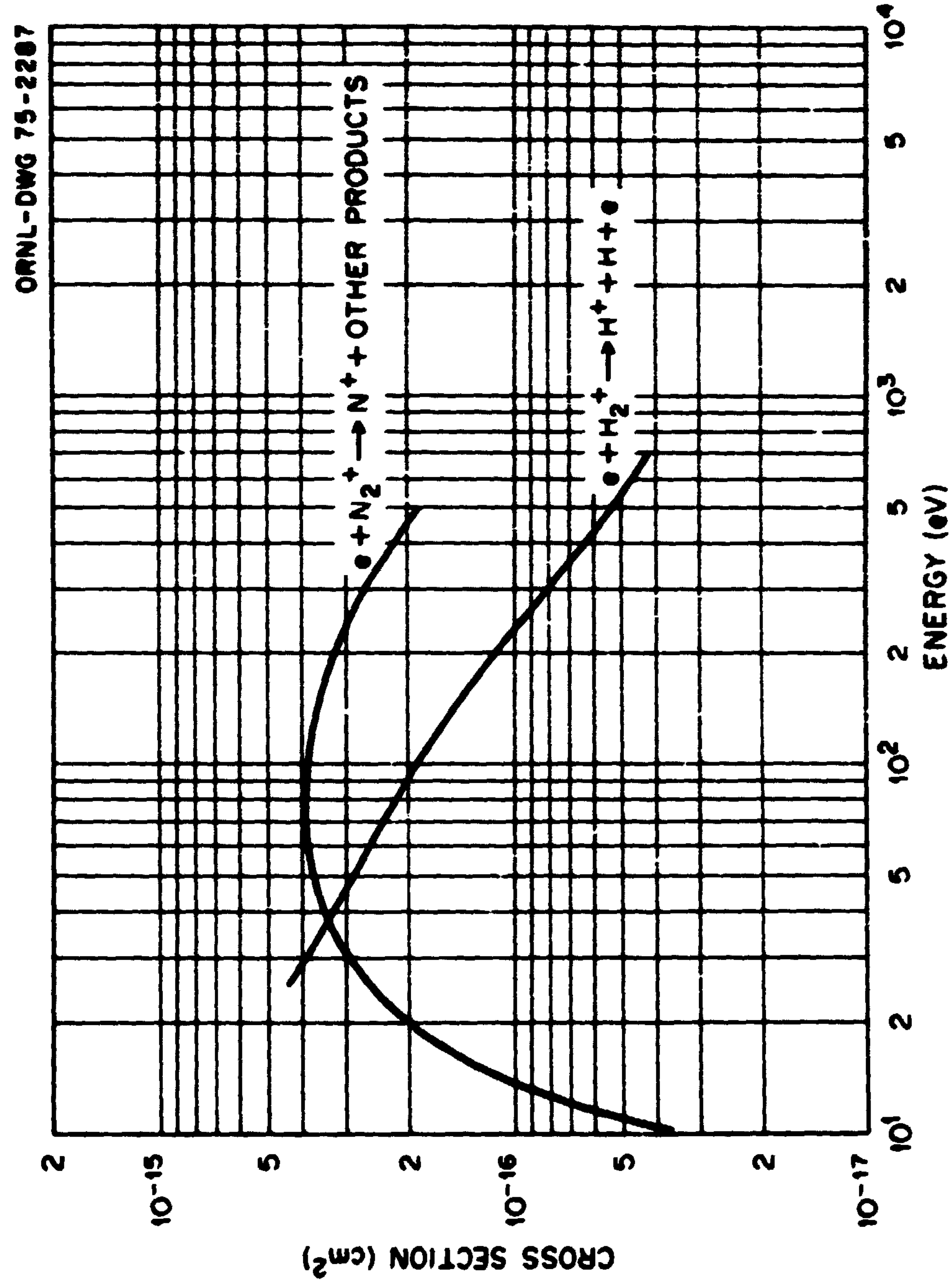
Accuracy:

H_2^+: systematic error $\leq \pm$ 8%, random error $\leq \pm$ 8%. N_2^+: The Total error is believed not to exceed ± 20% over most of the energy scale.

Notes:

H_2^+: The H_2^+ ions are in the $1s\sigma_g$ state; they have a vibrational distribution corresponding to the ionization of cold hydrogen gas by fast electrons. The H atoms formed may be in excited states.

N_2^+: The target N_2^+ ions are typical of those formed by bombardment of N_2 by high (150 eV) energy electrons in a low-pressure (10^{-3} torr) ion source, and may thus be a mixture of ground- and excited-state molecular ions.


ORNL-DWG 75-2287
e + N2+ → N+ + OTHER PRODUCTS
e + H2+ → H+ + H + e
CROSS SECTION (cm2)
10-15
10-16
10-17
ENERGY (eV)
10¹
10²
10³
10⁴

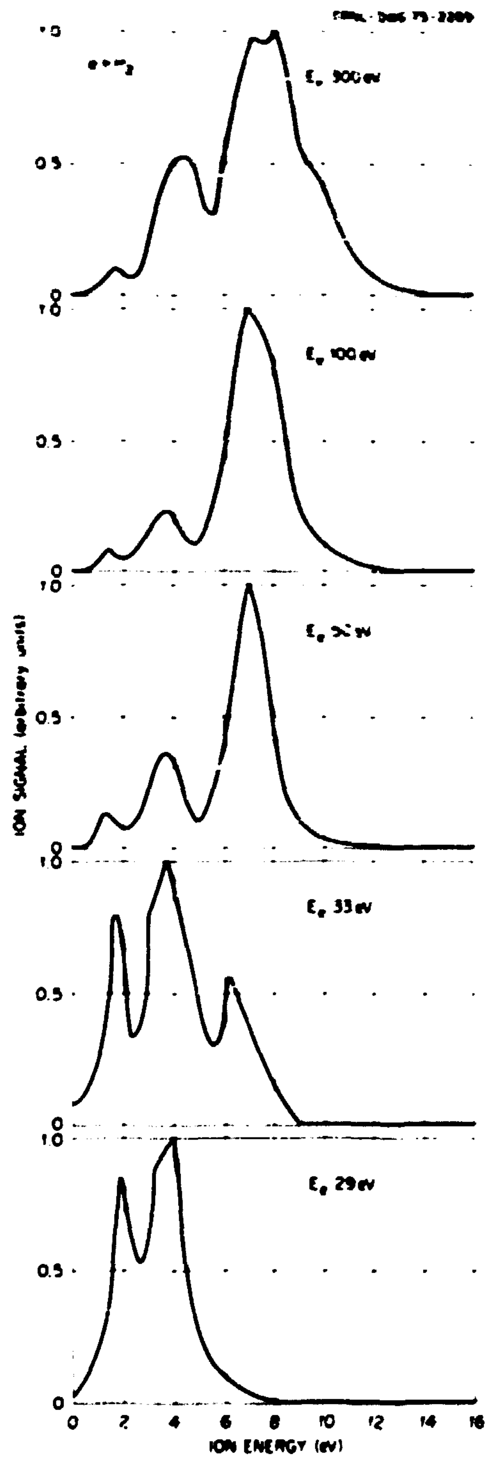
C.3.6

Energy Spectra of Protons Obtained in Dissociative Ionization of H_2 Molecules by Electron Impact (The incident electron energies are indicated alongside the graphs. Data were taken at an angle of 27° to the electron beam direction.)

Tabular data not presented because the data are not cross sections, and the curves have a lot of structure.

Reference:

A. Crowe and J.W. McConkey, Phys. Rev. Letts. 31, 192 (1973).


ORNL-DWG 75-2209
$e + H_2$
E_e 300 eV
E_e 100 eV
E_e 50 eV
E_e 33 eV
E_e 29 eV
ION SIGNAL (arbitrary units)
ION ENERGY (eV)
0
0.5
1.0
0
2
4
6
8
10
12
14
16

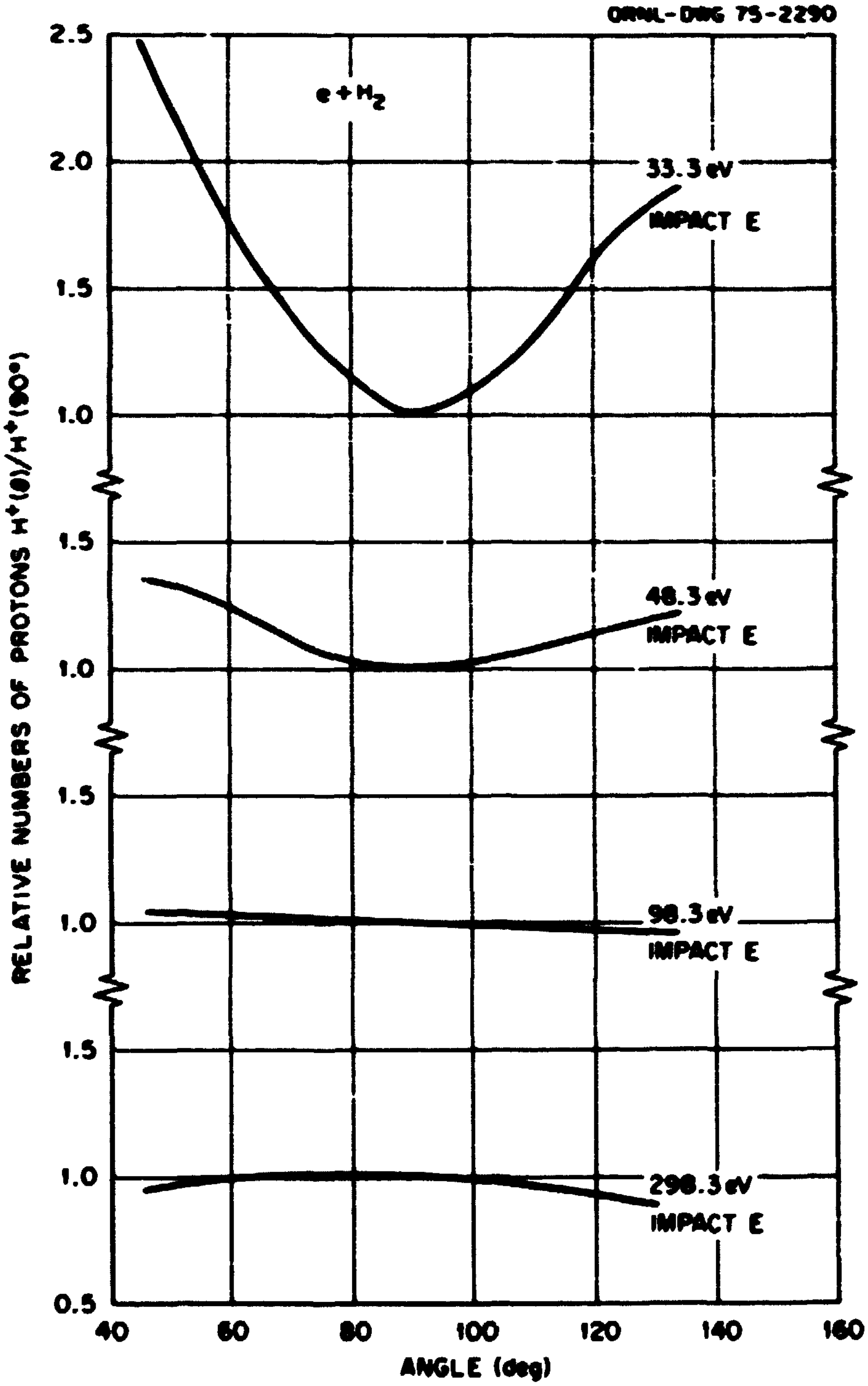
Angular Distributions of Protons Produced in Dissociative Ionization of H_2 Molecules by Electron Impact

(the protons come from the $^2\Sigma_u^+ / H_2^+$.
The incident electron energies are shown by the graphs.)

Angle (deg)	Relative Numbers of Protons $[H^+(\theta)/H^+(90°)]$			
	33.3 eV	48.3 eV	98.3 eV	298.3 eV
5.0 E 01	2.22 E 00	1.33 E 00	1.03 E 00	9.70 E-01
5.5 E 01	1.98 E 00	1.28 E 00	1.02 E 00	9.80 E-01
6.0 E 01	1.76 E 00	1.23 E 00	1.02 E 00	9.93 E-01
6.5 E 01	1.57 E 00	1.18 E 00	1.02 E 00	1.00 E 00
7.0 E 01	1.40 E 00	1.11 E 00	1.02 E 00	1.01 E 00
7.5 E 01	1.26 E 00	1.06 E 00	1.01 E 00	1.01 E 00
8.0 E 01	1.15 E 00	1.03 E 00	1.00 E 00	1.01 E 00
8.5 E 01	1.06 E 00	1.01 E 00	1.00 E 00	1.00 E 00
9.0 E 01	1.00 E 00	1.00 E 00	1.00 E 00	1.00 E 00
9.5 E 01	1.03 E 00	1.01 E 00	1.00 E 00	9.90 E-01
1.0 E 02	1.10 E 00	1.02 E 00	9.90 E-01	9.80 E-01
1.1 E 02	1.30 E 00	1.07 E 00	9.80 E-01	9.60 E-01
1.2 E 02	1.62 E 00	1.13 E 00	9.76 E-01	9.26 E-01
1.3 E 02	1.84 E 00	1.20 E 00	9.64 E-01	8.80 E-01

Reference:

A. Crowe and J.W. McConkey, J. Phys. B 6, 2088 (1973).


ORNL-DWG 75-2290
e + H_2
33.3 eV
IMPACT E
48.3 eV
IMPACT E
98.3 eV
IMPACT E
298.3 eV
IMPACT E
RELATIVE NUMBERS OF PROTONS $H^+(\theta)/H^+(90°)$
ANGLE (deg)
2.5
2.0
1.5
1.0
1.5
1.0
1.5
1.0
1.5
1.0
0.5
40
60
80
100
120
140
160

C.4 Electron Ionization of Atoms, Molecules, and Ions

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Cross Sections σ for Single Ionization of Hydrogen and Oxygen Atoms by Electron Impact

Energy (keV)	Cross Sections (cm^2) $e+H \rightarrow H^+ + 2e$	$e+O \rightarrow O^+ + 2e$
	Experimental	**Experimental**
2.0 E-02	3.00 E-17	5.60 E-17
2.5 E-02	4.37 E-17	8.70 E-17
3.0 E-02	5.27 E-17	1.08 E-16
4.0 E-02	6.24 E-17	1.32 E-16
6.0 E-02	7.66 E-17	1.52 E-16
8.0 E-02	6.59 E-17	1.58 E-16
1.0 E-01	6.08 E-17	1.55 E-16
1.5 E-01	4.80 E-17	1.42 E-16
2.0 E-01	4.13 E-17	1.31 E-16
2.5 E-01	3.57 E-17	1.22 E-16
3.0 E-01	3.19 E-17	1.10 E-16
4.0 E-01	2.51 E-17	9.26 E-17
6.0 E-01	1.80 E-17	
8.0 E-01	1.41 E-17	
	Theoretical	
1.0 E 00	1.2 E-17	
5.0 E 00	2.8 E-18	
1.0 E 01	1.5 E-18	
5.0 E 01	3.9 E-19	
1.0 E 02	2.3 E-19	
5.0 E 02	1.0 E-19	
1.0 E 03	9.3 E-20	
5.0 E 03	9.7 E-20	
1.0 E 04	1.0 E-19	
5.0 E 04	1.2 E-19	
1.0 E 05	1.3 E-19	

References:

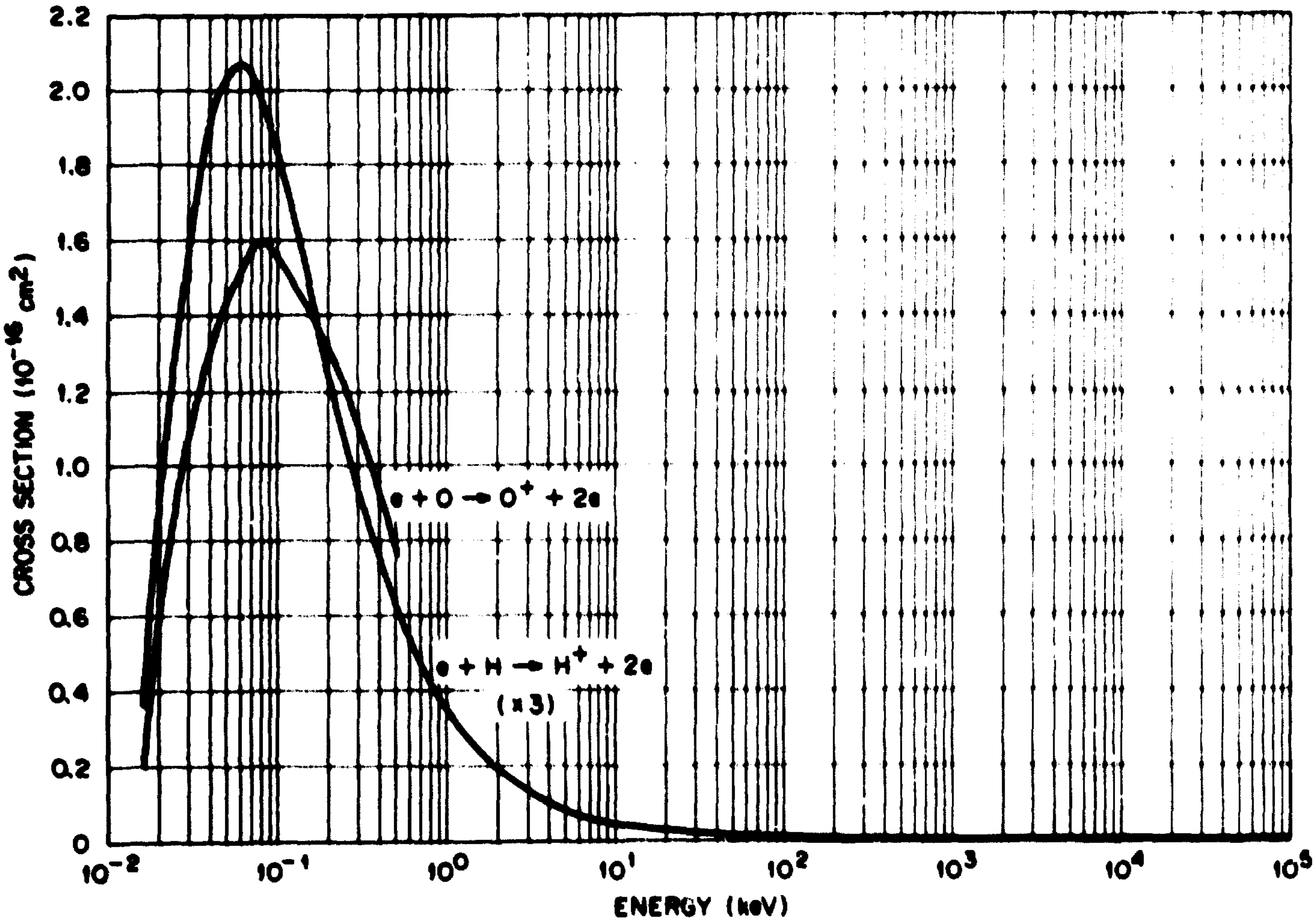
e + H: W.L. Fite and R.T. Brackmann, Phys. Rev. 112, 1141 (1958). A. Boksenberg, Thesis, Univ. of London (1961). E.W. Rothe, L.L. Marino, R.H. Neynaber, and S.M. Trujillo, Phys. Rev. 125, 582 (1962). M. Inokuti, Argonne Natl. Lab. Report ANL-6769 (1963).

e + O: W.L. Fite and R.T. Brackmann, Phys. Rev. 113, 815 (1959). A. Boksenberg, Thesis, Univ. of London (1961).

Accuracy:

The total error is believed not to exceed ± 15% for H and ± 30% for O.

ORNL-DWG 75-2242



Electron Impact Ionization Cross Section of Atomic Hydrogen in the Metastable 2s State

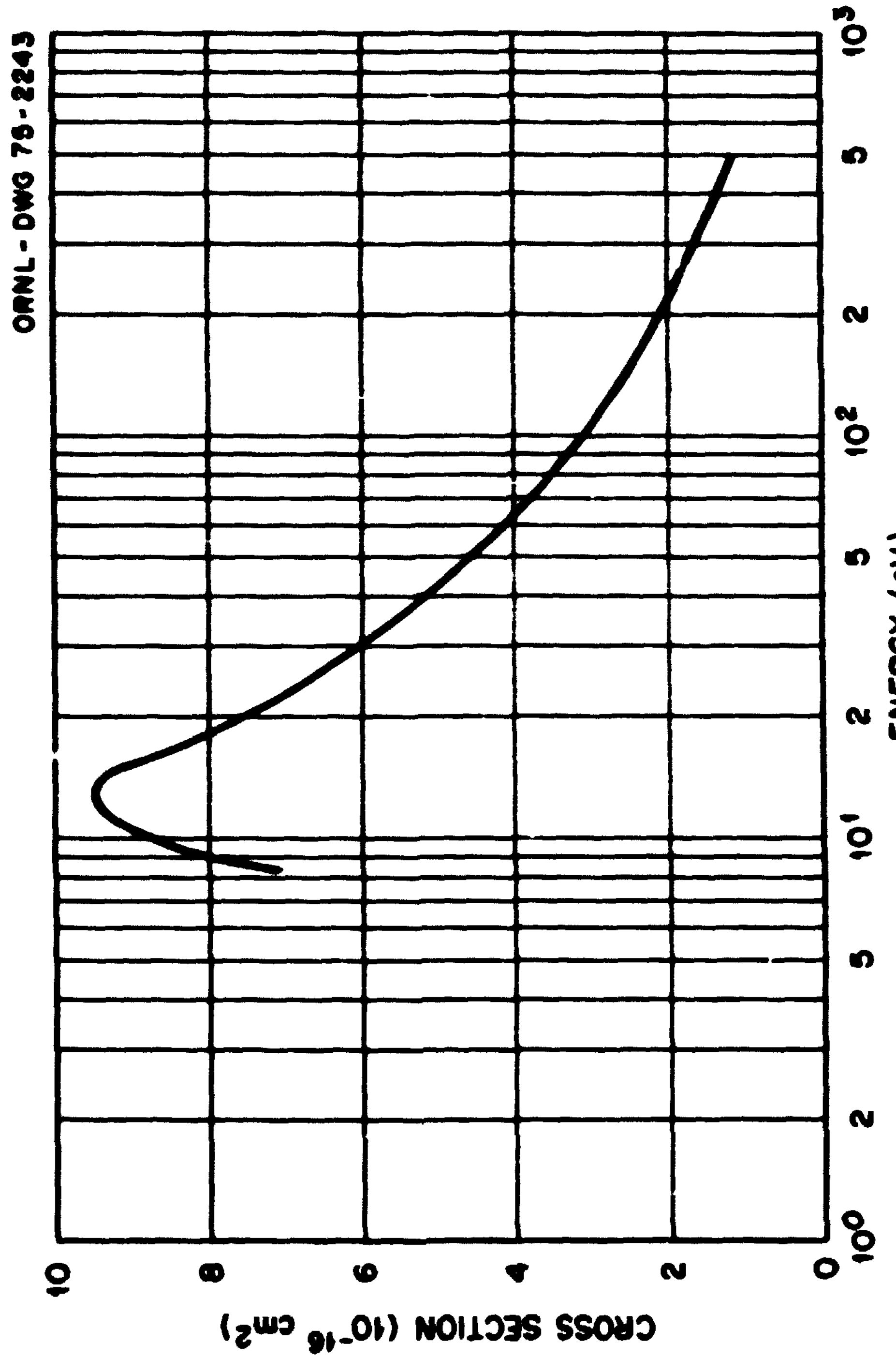
Energy (eV)	Electron Impact Ionization Cross Section (cm^2)
8.3 E 00	7.12 E-16
1.0 E 01	8.72 E-16
1.3 E 01	9.45 E-16
2.0 E 01	7.58 E-16
3.0 E 01	6.06 E-16
4.0 E 01	5.20 E-16
5.0 E 01	4.62 E-16
7.0 E 01	3.80 E-16
1.0 E 02	3.11 E-16
1.5 E 02	2.50 E-16
2.0 E 02	2.11 E-16
3.0 E 02	1.65 E-16
4.0 E 02	1.38 E-16
5.0 E 02	1.18 E-16

Reference:

A.J. Dixon, A. Von Engel, and M.F.A. Harrison, Proc. Roy. Soc. A-343, 333 (1975).

Accuracy:

The total error is believed not to exceed ± 25%.


ORNL-DWG 75-2243
ENERGY (eV)
CROSS SECTION (10^{-16} cm^2)
10^0
2
5
10^1
2
5
10^2
2
5
10^3
0
2
4
6
8
10

Cross Sections for Ionization of Atomic and Molecular Hydrogen by Electron Impact Near Threshold

$e + H \rightarrow H^+ + 2e$		$e + H_2 \rightarrow H_2^+ + 2e$	
Energy (eV)	Cross Section (cm^2)	Energy (eV)	Cross Section (cm^2)
1.355 E 01	1.2 E-20	1.545 E 01	1.1 E-20
1.360 E 01	6.0 E-20	1.550 E 01	2.2 E-20
1.365 E 01	2.0 E-19	1.555 E 01	4.0 E-20
1.370 E 01	4.0 E-19	1.560 E 01	6.3 E-20
1.375 E 01	6.2 E-19	1.570 E 01	1.2 E-19
1.380 E 01	9.0 E-19	1.580 E 01	1.9 E-19
1.385 E 01	1.2 E-18	1.590 E 01	2.6 E-19
1.390 E 01	1.5 E-18	1.600 E 01	3.2 E-19
1.395 E 01	1.8 E-18	1.610 E 01	3.9 E-19
		1.620 E 01	4.5 E-19

References:

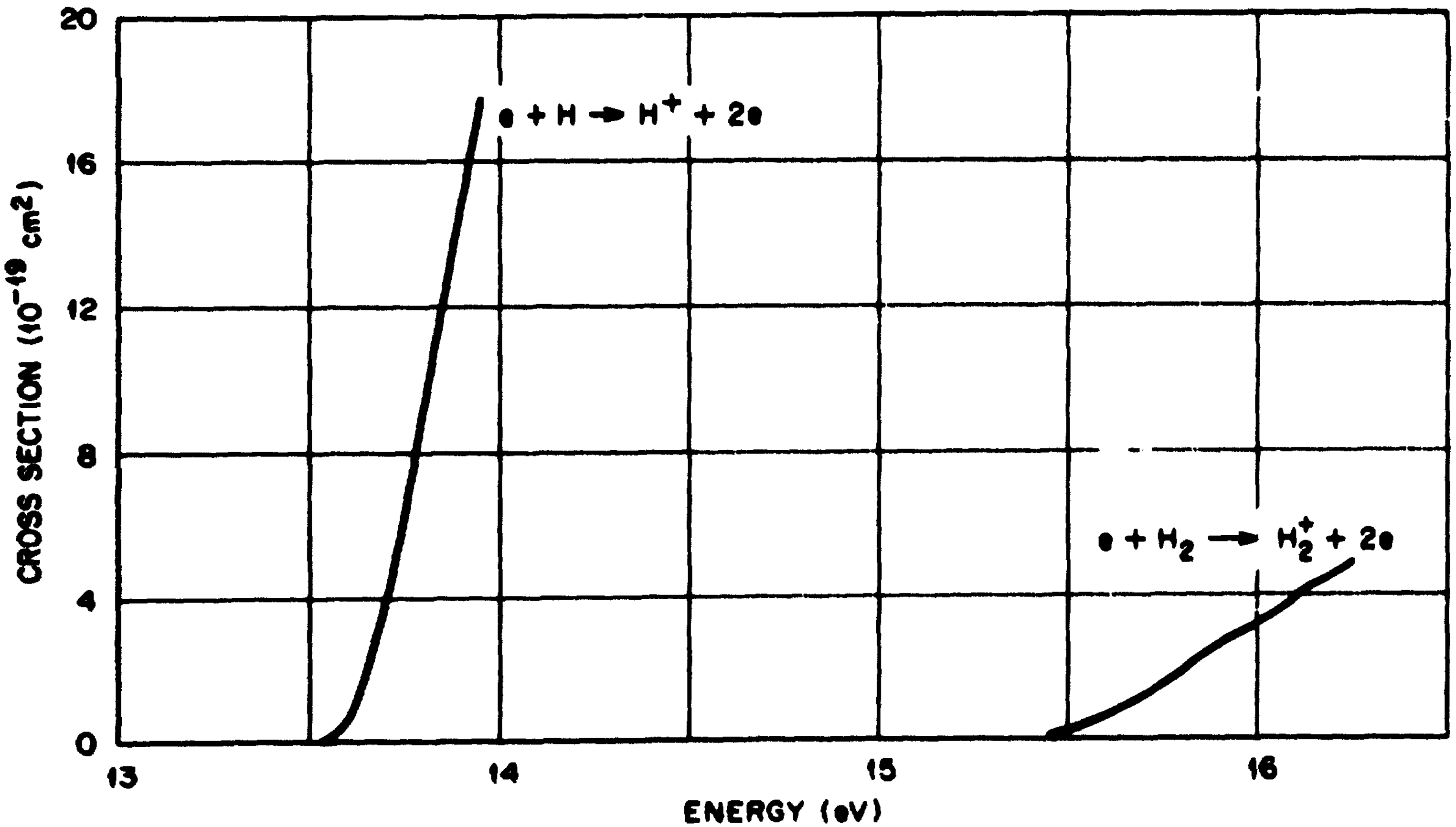
$e + H$: J.W. McGowan and E.M. Clarke, Phys. Rev. 167, 43 (1968).

$e + H_2$: J.W. McGowan, M.A. Fineman, E.M. Clarke, and H.P. Hanson, Phys. Rev. 167, 52 (1968).

Accuracy:

The total error is believed not to exceed ± 30%.

ORNL-DWG 75-2244



Total Cross Sections σ_i for Ionization of Hydrogen and Deuterium Molecules by Electron Impact

Energy (keV)	Cross Sections (cm^2)	
	$e + H_2$	$e + D_2$
	Experimental	Experimental
2.0 E-02	2.70 E-17	[illegible] E-17
3.0 E-02	6.91 E-17	[illegible] E-17
4.0 E-02	8.59 E-17	[illegible] E-17
8.0 E-02	9.70 E-17	9.75 E-17
1.0 E-01	9.23 E-17	[illegible] E-17
2.0 E-01	7.21 E-17	[illegible] E-17
3.0 E-01	5.72 E-17	[illegible] E-17
4.0 E-01	4.71 E-17	[illegible] E-17
8.0 E-01	2.74 E-17	[illegible] E-17
1.0 E 00	2.24 E-17	[illegible] E-17
2.0 E 00	1.18 E-17	1.35 E-17
4.0 E 00	6.26 E-18	6.95 E-18
6.0 E 00	4.32 E-18	[illegible] E-18
1.0 E 01	2.82 E-18	2.35 E-18
2.0 E 01	1.60 E-18	[illegible] E-18
	Theoretical	
5.0 E 01	7.6 E-19	
1.0 E 02	4.6 E-19	
5.0 E 02	2.1 E-19	
1.0 E 03	1.9 E-19	
5.0 E 03	2.0 E-19	
1.0 E 04	2.2 E-19	
5.0 E 04	2.6 E-19	
1.0 E 05	2.8 E-19	

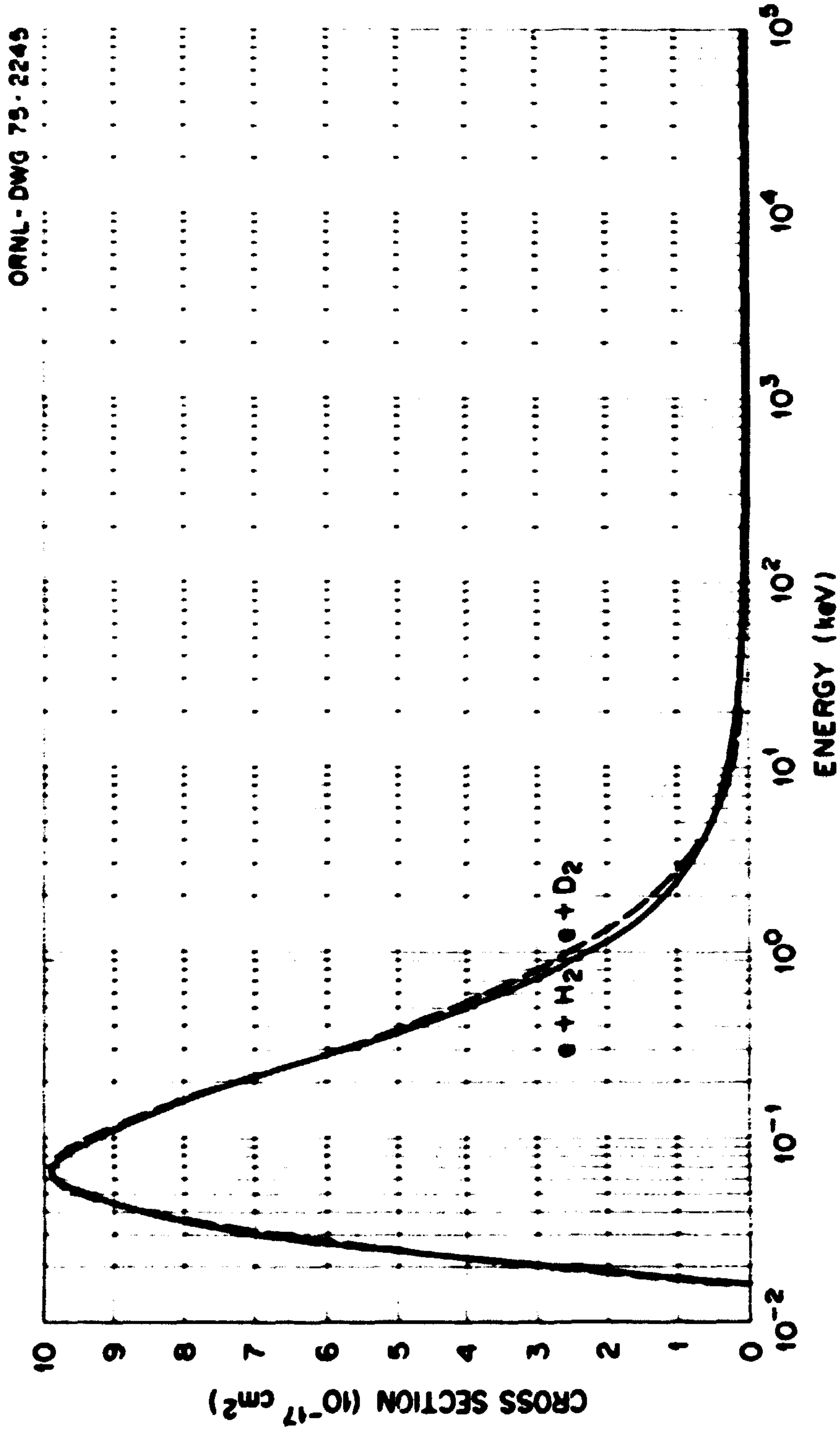
References:

$e + H_2$: J.T. Tate and P.T. Smith, Phys. Rev. 39, 270 (1932). B.L. Schram, F.J. de Heer, M.J. van der Wiel, and J. Kistemaker, Physica 31, 94 (1964). D. Rapp and P. Englander-Golden, J. Chem. Phys. 43, 1464 (1965). F.F. Rieke and W. Prepejchal, Phys. Rev. A 6, 1507 (1972).

$e + D_2$: B.L. Schram, F.J. de Heer, M.J. van der Wiel, and J. Kistemaker, Physica 31, 94 (1964). D. Rapp and P. Englander-Golden, J. Chem. Phys. 43, 1464 (1965).

Accuracy:

The total error is believed not to exceed ± 12% for H_2 and D_2.


ORNL-DWG 75-2245
CROSS SECTION (10^{-17} cm^2)
ENERGY (keV)
$e + H_2$
$e + D_2$
0
1
2
3
4
5
6
7
8
9
10
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
10^{4}
10^{5}

Cross Sections for the Dissociative Ionization of H_2 and N_2 Molecules by Electron Impact Yielding Product H^+ and N^+ Ions with Kinetic Energies Greater than 2.5 and 0.25 eV, Respectively

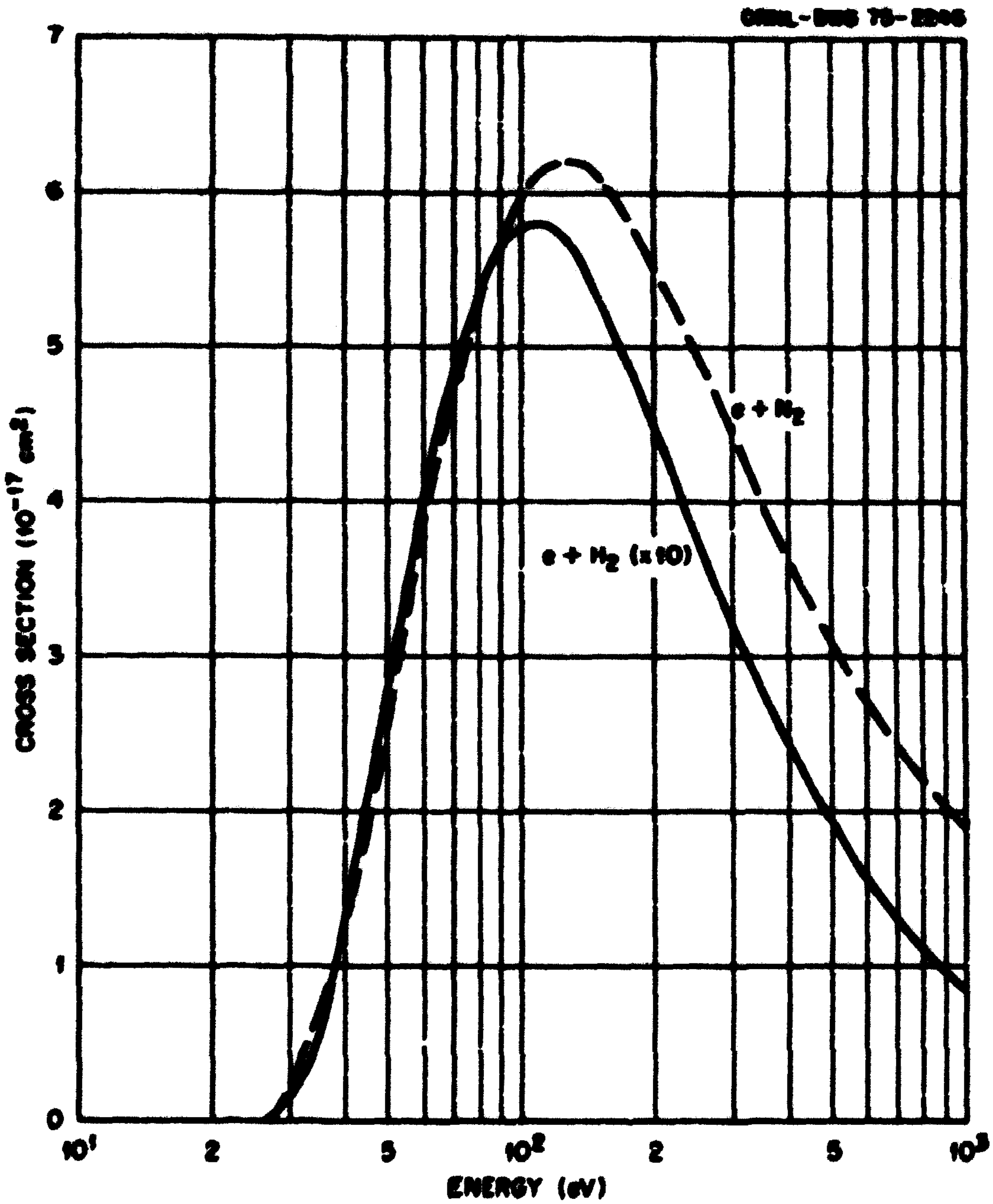
Energy (eV)	Cross Section (cm^2)	
	$e + H_2$	$e + N_2$
2.5 E 01		
3.0 E 01	1.52 E-19	2.30 E-18
4.0 E 01	1.35 E-18	1.30 E-17
6.0 E 01	4.02 E-18	3.81 E-17
8.0 E 01	5.37 E-18	5.30 E-17
1.0 E 02	5.75 E-18	5.95 E-17
1.5 E 02	5.32 E-18	6.12 E-17
2.0 E 02	4.48 E-18	5.50 E-17
2.5 E 02	3.75 E-18	4.97 E-17
3.0 E 02	3.21 E-18	4.45 E-17
4.0 E 02	2.46 E-18	3.63 E-17
6.0 E 02	1.57 E-18	2.71 E-17
8.0 E 02	1.12 E-18	2.20 E-17
1.0 E 03	8.40 E-19	1.91 E-17

References:

$e + (H_2, N_2)$: F. Englander-Golden and D. Rapp, Lockheed Missiles and Space Co. Report LMSC-6-74-64-12 (1964), Palo Alto, California. D. Rapp, P. Englander-Golden, and D.D. Briglia, J. Chem. Phys. 42, 4081 (1965).

Accuracy:

The total error is believed not to exceed ± 30%.



7
6
5
4
3
2
1
0
CROSS SECTION (10^{-17} cm^2)
10^1
2
5
10^2
2
5
10^3
ENERGY (eV)
e + H_2
e + H_2 (x10)

Ratios of Cross Sections σ^{2+}/σ_T in Ionization of Atomic Helium and σ^{n+}/σ_T in Ionization of Atomic Neon by Electron Impact

e + He: Energy (eV)	e + He: σ^{2+}/σ_T	e + Ne: Energy (eV)	e + Ne: σ^{2+}/σ_T
		8.0 E 01	7.0 E-03
1.0 E 02	7.0 E-04	1.0 E 02	1.4 E-02
1.5 E 02	2.4 E-03	1.5 E 02	3.2 E-02
2.0 E 02	3.8 E-03	2.0 E 02	4.5 E-02
4.0 E 02	6.3 E-03	4.0 E 02	5.4 E-02
6.0 E 02	6.6 E-03	6.0 E 02	4.8 E-02
8.0 E 02	6.2 E-03	8.0 E 02	4.4 E-02
1.0 E 03	5.9 E-03	1.0 E 03	4.1 E-02
2.0 E 03	4.7 E-03	2.0 E 03	3.4 E-02
4.0 E 03	3.7 E-03	4.0 E 03	2.8 E-02
6.0 E 03	3.3 E-03	6.0 E 03	2.6 E-02
8.0 E 03	3.1 E-03	8.0 E 03	2.4 E-02
1.0 E 04	2.9 E-03	1.0 E 04	2.3 E-02
1.5 E 04	2.7 E-03	1.5 E 04	2.2 E-02

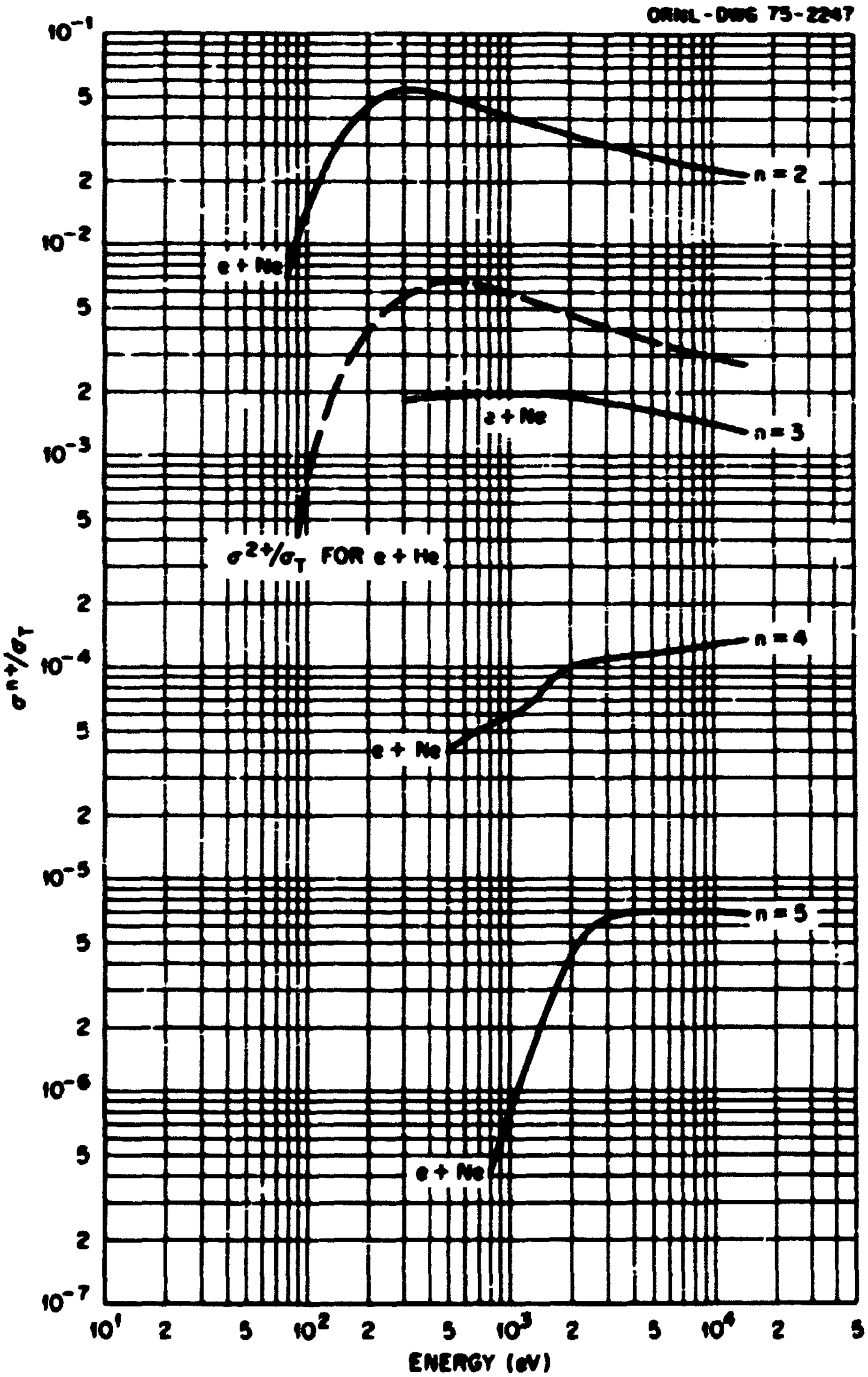
Energy (eV)	e + Ne σ^{n+}/σ_T: n = 3	n = 4	n = 5
3.0 E 02	1.8 E-03		
4.0 E 02	1.9 E-03		
5.0 E 02	1.9 E-03	4.0 E-05	
7.0 E 02	1.9 E-03	5.0 E-05	
8.0 E 02	1.9 E-03	5.3 E-05	4.0 E-07
1.0 E 03	1.9 E-03	5.9 E-05	7.9 E-07
2.0 E 03	1.9 E-03	9.9 E-05	4.5 E-06
4.0 E 03	1.7 E-03	1.1 E-04	6.9 E-06
6.0 E 03	1.6 E-03	1.2 E-04	7.0 E-06
8.0 E 03	1.5 E-03	1.2 E-04	7.0 E-06
1.0 E 04	1.4 E-03	1.3 E-04	7.0 E-06
1.5 E 04	1.3 E-03	1.3 E-04	6.8 E-06

Reference:

L.J. Kieffer, Atomic Data 1, 19 (1969).

Accuracy:

The total error is believed not to exceed ± 20%.


ORNL-DWG 75-2247
e + Ne
n = 2
σ^{2+}/σ_T FOR e + He
e + Ne
n = 3
n = 4
e + Ne
n = 5
e + Ne
σ^{n+}/σ_T
ENERGY (eV)

Cross Sections for Single Ionization of Helium Atoms and Molecular Nitrogen by Electron Impact Near Threshold

$e + He \rightarrow He^+ + 2e$		$e + N_2 \rightarrow N_2^+ + 2e$	
Energy (eV)	Cross Section (cm^2)	Energy (eV)	Cross Section (cm^2)
2.5 E 01	6.0 E-19	1.60 E 01	1.5 E-18
2.6 E 01	1.9 E-18	1.65 E 01	3.2 E-18
2.7 E 01	3.2 E-18	1.70 E 01	5.0 E-18
2.8 E 01	4.5 E-18	1.75 E 01	7.1 E-18
2.9 E 01	5.8 E-18	1.80 E 01	9.2 E-18
3.0 E 01	7.1 E-18	1.85 E 01	1.1 E-17
3.1 E 01	8.4 E-18	1.90 E 01	1.4 E-17
3.2 E 01	9.7 E-18	1.95 E 01	1.7 E-17
		2.00 E 01	2.0 E-17
		2.05 E 01	2.3 E-17
		2.10 E 01	2.6 E-17

References:

$e + He$: R.E. Fox, J. Chem. Phys. 35, 1379 (1961).

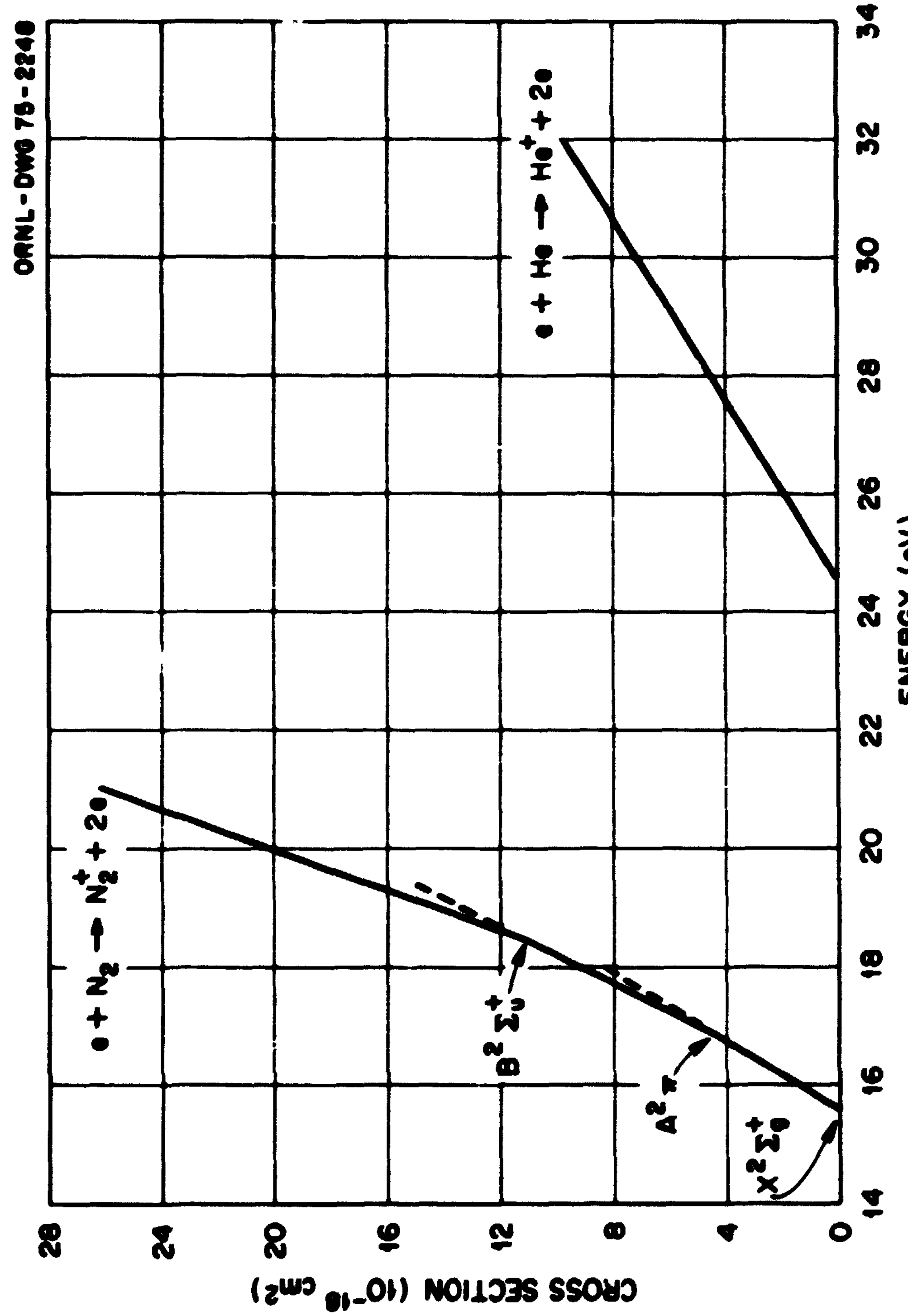
$e + N_2$: R.E. Fox, J. Chem. Phys. 35, 1379 (1961).

Accuracy:

The total error is believed not to exceed ± 25%.

Note:

On the curve for N_2, the arrows indicate the onset of production of the designated states of the N_2^+ ion.


ORNL-DWG 75-2248
e + He → He⁺ + 2e
e + N₂ → N₂⁺ + 2e
B²Σᵤ⁺
A²π
X²Σg⁺
ENERGY (eV)
CROSS SECTION (10⁻¹⁸ cm²)
14
16
18
20
22
24
26
28
30
32
34
0
4
8
12
16
20
24
28

Total Cross Sections σ_T for Ionization of Helium, Neon, and Argon Atoms by Electron Impact

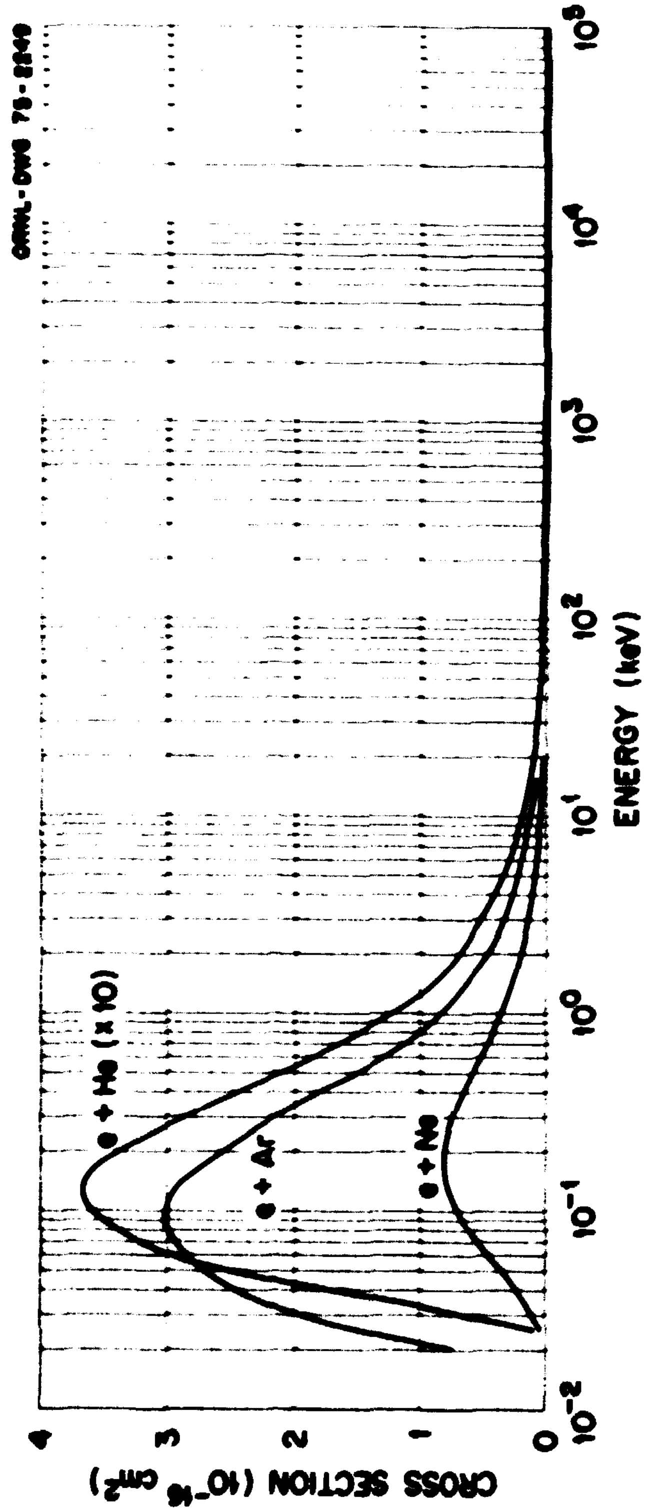
Energy (keV)	Cross Sections (cm^2)		
	e + He	e + Ne	e + Ar
2.0 E-02			7.40 E-17
2.5 E-02	8.80 E-19	4.10 E-18	1.50 E-16
4.0 E-02	1.71 E-17	2.30 E-17	2.48 E-16
6.0 E-02	2.99 E-17	4.65 E-17	2.85 E-16
8.0 E-02	3.41 E-17	6.12 E-17	3.00 E-16
1.0 E-01	3.60 E-17	7.00 E-17	3.01 E-16
2.0 E-01	3.38 E-17	8.10 E-17	2.50 E-16
4.0 E-01	2.44 E-17	6.48 E-17	1.80 E-16
8.0 E-01	1.48 E-17	4.27 E-17	1.01 E-16
1.0 E 00	1.22 E-17	3.60 E-17	8.50 E-17
2.0 E 00	6.92 E-18	2.00 E-17	4.70 E-17
3.0 E 00	5.20 E-18	1.41 E-17	3.38 E-17
4.0 E 00	4.19 E-18	1.08 E-17	2.68 E-17
6.0 E 00	3.00 E-18	7.80 E-18	1.98 E-17
8.0 E 00	2.31 E-18	5.90 E-18	1.58 E-17
	Theoretical		
1.0 E 01	1.9 E-18	5.20 E-18	1.20 E-17
1.5 E 01		3.60 E-18	8.20 E-18
2.0 E 01		2.70 E-18	
5.0 E 01	5.1 E-19		
1.0 E 02	3.1 E-19		
5.0 E 02	1.4 E-19		
1.0 E 03	1.3 E-19		
5.0 E 03	1.4 E-19		
1.0 E 04	1.5 E-19		
5.0 E 04	1.8 E-19		
1.0 E 05	1.9 E-19		

References:

L.J. Kieffer, Atomic Data 1, 19 (1969); M. Inokuti and Yong-Ki Kim, Phys. Rev. 186, 100 (1969); J. Fletcher and I.R. Cowling, J. Phys. B 6, L-258 (1973).

Accuracy:

e + He: The total error is believed not to exeed ± 12%. e + Ne: The total error is believed not to exceed ± 15%. e + Ar: The total error is believed not to exceed ± 25%.


CROSS SECTION (10^{-16} cm^2)
ENERGY (keV)
e + He (x 10)
e + Ar
e + Ne
0
1
2
3
4
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
10^{4}
10^{5}

Total Cross Sections σ_T for Ionization of Nitrogen Atoms and Carbon Monoxide Molecules by Electron Impact

Energy (eV)	Cross Sections (cm^2)	
	e + N	e + CO
2.0 E 01		4.29 E-17
2.5 E 01	4.79 E-17	8.79 E-17
3.0 E 01	6.50 E-17	1.27 E-16
4.0 E 01	9.40 E-17	1.83 E-16
6.0 E 01	1.36 E-16	2.47 E-16
8.0 E 01	1.50 E-16	2.81 E-16
1.0 E 02	1.53 E-16	2.89 E-16
1.5 E 02	1.40 E-16	2.72 E-16
2.0 E 02	1.30 E-16	2.49 E-16
2.5 E 02	1.18 E-16	2.26 E-16
3.0 E 02	1.08 E-16	2.05 E-16
4.0 E 02	8.93 E-17	1.72 E-16
6.0 E 02	6.10 E-17	1.33 E-16
8.0 E 02	4.21 E-17	1.10 E-16
1.0 E 03		9.40 E-17

References:

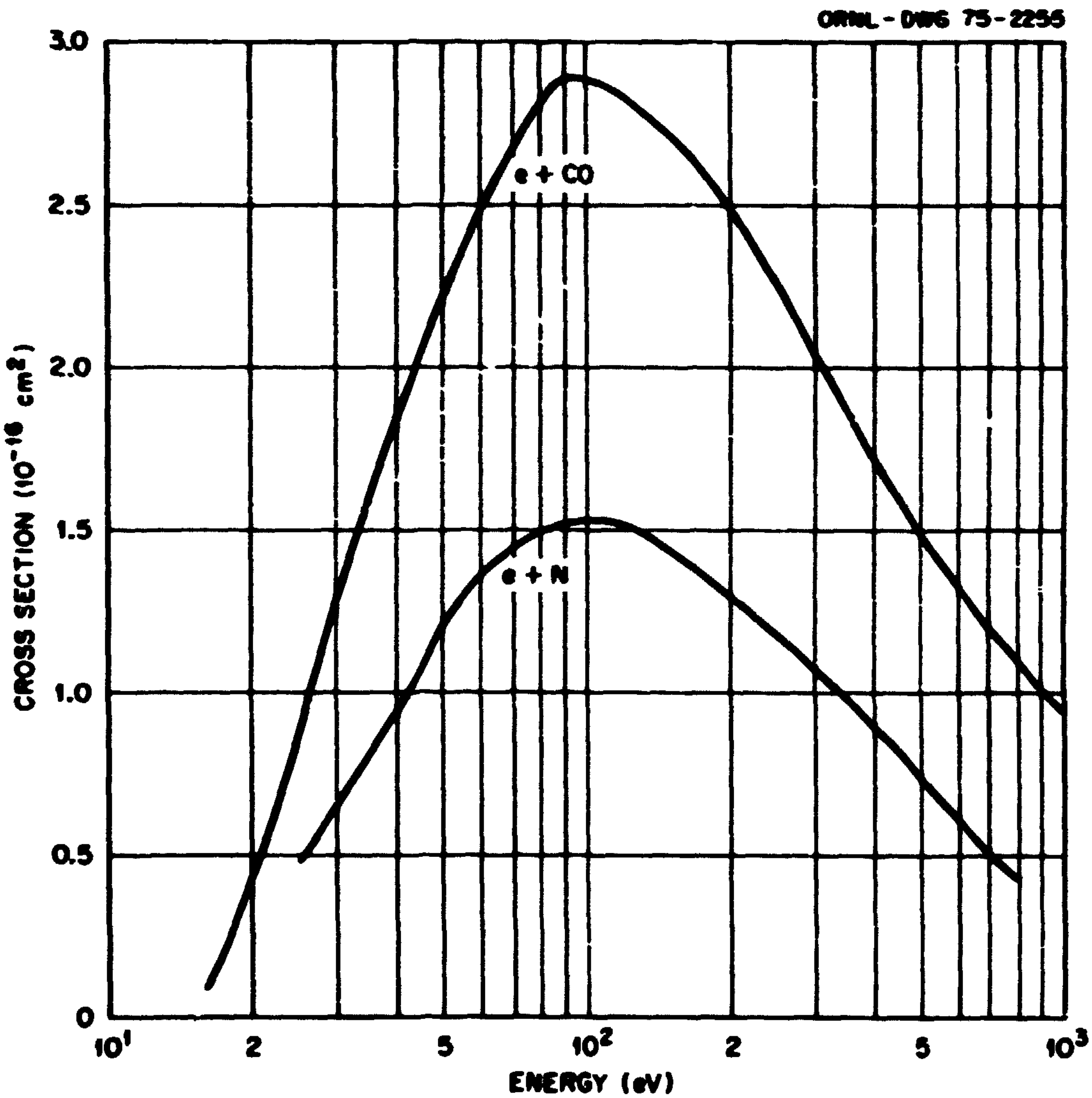
e + N: A.C.H. Smith, E. Caplinger, R.H. Neynaber, E.W. Rothe, and S.M. Trujillo, Phys. Rev. 127, 1647 (1962).

e + CO: J.T. Tate and P.T. Smith, Phys. Rev. 39, 270 (1932). R.K. Asundi, J.D. Craggs, and M.V. Kurepa, Proc. Phys. Soc. 82, 967 (1963). D. Rapp and P. Englander-Golden, J. Chem. Phys. 43, 1464 (1965).

Accuracy:

e + N: The total error is believed not to exceed ± 30%.

e + CO: The total error is believed not to exceed ± 18%.



ORNL-DWG 75-2256
e + CO
e + N
CROSS SECTION (10^{-16} cm^2)
3.0
2.5
2.0
1.5
1.0
0.5
0
10^1
2
5
10^2
2
5
10^3
ENERGY (eV)

Total Cross Sections σ_T for Ionization of

Nitrogen and Oxygen Molecules by Electron Impact

Energy (eV)	Cross Sections (cm^2)	
	$e + N_2$	$e + O_2$
2.0 E 01	3.19 E-17	3.12 E-17
2.5 E 01	6.36 E-17	5.92 E-17
3.0 E 01	9.38 E-17	8.82 E-17
4.0 E 01	1.55 E-16	1.50 E-16
6.0 E 01	2.34 E-16	2.32 E-16
8.0 E 01	2.61 E-16	2.62 E-16
1.0 E 02	2.69 E-16	2.77 E-16
1.5 E 02	2.62 E-16	2.74 E-16
2.0 E 02	2.40 E-16	2.59 E-16
2.5 E 02	2.19 E-16	2.38 E-16
3.0 E 02	2.01 E-16	2.17 E-16
4.0 E 02	1.72 E-16	1.85 E-16
6.0 E 02	1.34 E-16	1.42 E-16
8.0 E 02	1.10 E-16	1.16 E-16
1.0 E 03	9.36 E-17	9.76 E-17
2.0 E 03	5.30 E-17	5.42 E-17
4.0 E 03	2.92 E-17	3.00 E-17
6.0 E 03	1.96 E-17	2.19 E-17
8.0 E 03	1.50 E-17	1.69 E-17
1.0 E 04	1.23 E-17	1.40 E-17
1.5 E 04	8.80 E-18	9.92 E-18

References:

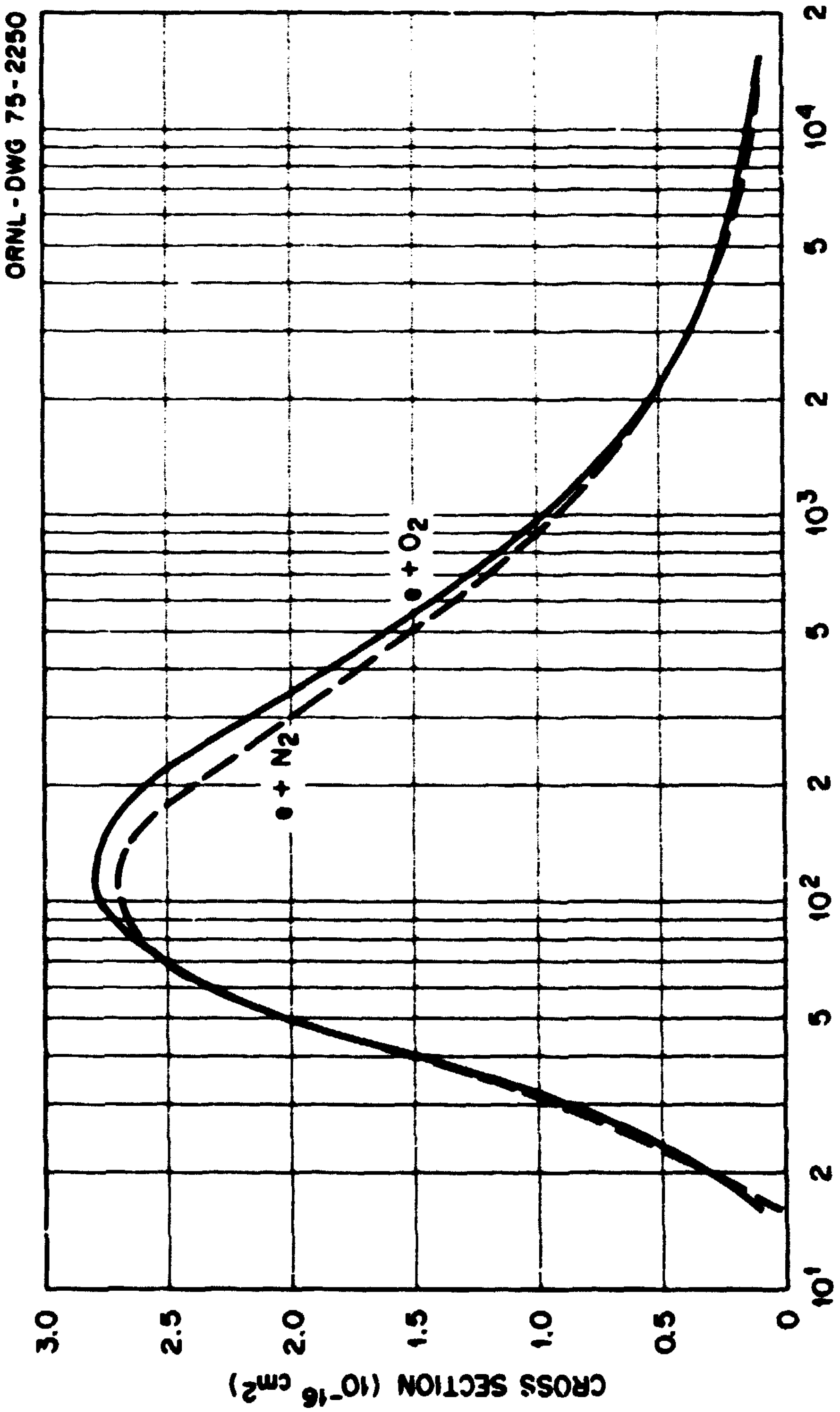
$e + N_2$: J.T. Tate and P.T. Smith, Phys. Rev. 39, 270 (1932). B.L. Schram, F.J. de Heer, M.J. van der Wiel, and J. Kistemaker, Physica 31, 94 (1964). D. Rapp and P. Englander-Golden, J. Chem. Phys. 43, 1464 (1965).

$e + O_2$: J.T. Tate and P.T. Smith, Phys. Rev. 39, 270 (1932). R.K. Asundi, J.D. Craggs, and M.V. Kurepa, Proc. Phys. Soc. 82, 967 (1963). B.L. Schram, F.J. de Heer, M.J. van der Wiel, and J. Kistemaker, Physica 31, 94 (1964). D. Rapp and P. Englander-Golden, J. Chem. Phys. 43, 1464 (1965).

Accuracy:

The total error is believed not to exceed ± 15% for $e + N_2$.

The total error is believed not to exceed ± 15% for $e + O_2$.


ORNL-DWG 75-2250
e + O_2
e + N_2
ENERGY (eV)
CROSS SECTION (10^{-16} cm^2)
0
0.5
1.0
1.5
2.0
2.5
3.0
10^1
2
5
10^2
2
5
10^3
2
5
10^4
2

Ratios of Cross Sections σ^{n+}/σ_T in Ionization of Atomic Argon by Electron Impact

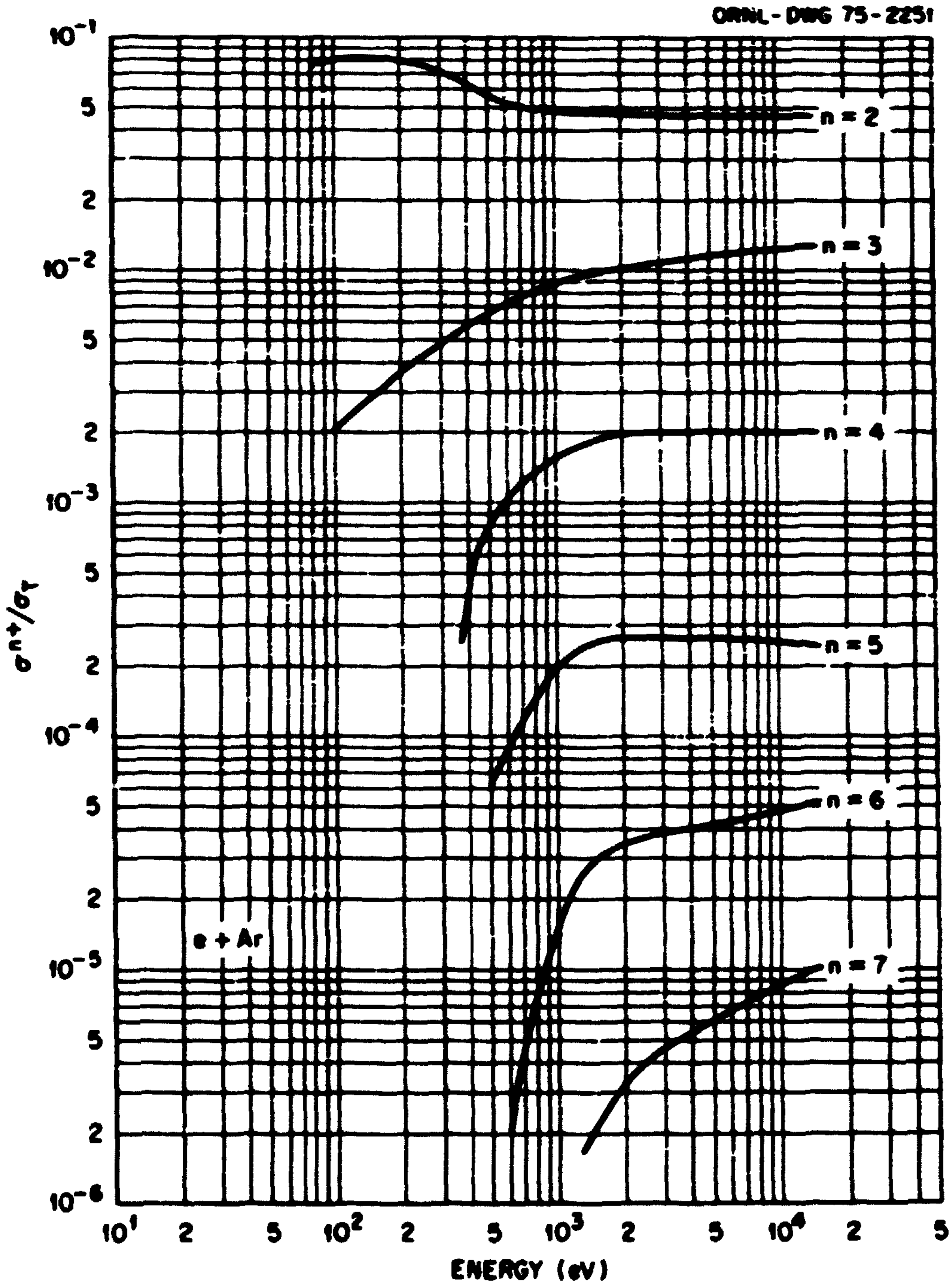
Energy (eV)	e + Ar	σ^{n+}/σ_T	
	n = 2	n = 3	n = 4
8.0 E 01	7.6 E-02		
1.0 E 02	7.9 E-02	2.0 E-03	
2.0 E 02	8.0 E-02	3.6 E-03	
3.0 E 02	7.1 E-02	4.8 E-03	
4.0 E 02	6.4 E-02	5.7 E-03	4.0 E-04
5.0 E 02	5.7 E-02	6.5 E-03	7.9 E-04
7.0 E 02	5.0 E-02	7.6 E-03	1.2 E-03
8.0 E 02	4.9 E-02	8.0 E-03	1.3 E-03
1.0 E 03	4.8 E-02	8.7 E-03	1.5 E-03
2.0 E C3	4.6 E-02	1.0 E-02	2.0 E-03
4.0 E 03	4.6 E-02	1.1 E-02	2.0 E-03
6.0 E 03	4.6 E-02	1.2 E-02	2.0 E-03
8.0 E 03	4.6 E-02	1.2 E-02	2.0 E-03
1.0 E 04	4.6 E-02	1.2 E-02	2.0 E-03
1.5 E 04	4.6 E-02	1.3 E-02	2.0 E-03
	n = 5	n = 6	n = 7
5.0 E 02	6.1 E-05		
6.0 E 02	8.8 E-05	2.1 E-06	
7.0 E 02	1.2 E-04	4.7 E-06	
8.0 E 02	1.4 E-04	7.8 E-06	
9.0 E 02	1.7 E-04	1.2 E-05	
1.0 E 03	1.9 E-04	1.5 E-05	
1.5 E 03	2.5 E-04	2.9 E-05	2.2 E-06
2.0 E 03	2.6 E-04	3.4 E-05	3.2 E-06
4.0 E 03	2.6 E-04	4.0 E-05	5.4 E-06
6.0 E 03	2.6 E-04	4.3 E-05	6.7 E-06
8.0 E 03	2.6 E-04	4.6 E-05	7.7 E-06
9.0 E 03	2.5 E-04	4.7 E-05	8.1 E-06
1.0 E 04	2.5 E-04	4.8 E-05	8.6 E-06
1.5 E 04	2.4 E-04	5.2 E-05	1.0 E-05

References:

W. Bleakney, Phys. Rev. 36, 1303 (1930); B.L. Schram, F.J. de Heer, M.J. Van der Wiel, and J. Kistemaker, Physica 31, 94 (1965).

Accuracy:

The total error is believed not to exceed ± 20%.


ORNL-DWG 75-2251
10^{-1}
5
2
10^{-2}
5
2
10^{-3}
5
2
10^{-4}
5
2
10^{-5}
5
2
10^{-6}
σ^{n+}/σ_T
n = 2
n = 3
n = 4
n = 5
n = 6
n = 7
e + Ar
10^1 2 5 10^2 2 5 10^3 2 5 10^4 2 5
ENERGY (eV)

Cross Section for Single Ionization of Atomic Carbon and Total Cross Section, σ_T, for Ionization of Water Molecules and Gold Atoms by Electron Impact

Energy (eV)	e + C (cm^2)	e + H_2O (cm^2)	e + Au (cm^2)
1.5 E 01	4.4 E-17		
3.0 E 01	3.5 E-16		
5.0 E 01	4.32 E-16		1.00 E-15
8.0 E 01	4.03 E-16	1.98 E-16	1.50 E-15
1.0 E 02	3.77 E-16	2.0 E-16	1.52 E-15
1.5 E 02	3.32 E-16	1.86 E-16	1.38 E-15
2.0 E 02	2.72 E-16	1.7 E-16	
4.0 E 02	1.7 E-16	1.25 E-16	
7.0 E 02	1.02 E-16	9.0 E-17	
1.0 E 03	7.5 E-17	6.8 E-17	
1.5 E 03	5.5 E-17	5.2 E-17	
2.0 E 03		3.9 E-17	
4.0 E 03		2.2 E-17	
6.0 E 03		1.6 E-17	
1.0 E 04		1.0 E-17	
1.5 E 04		8.0 E-18	
2.0 E 04		7.0 E-18	

References:

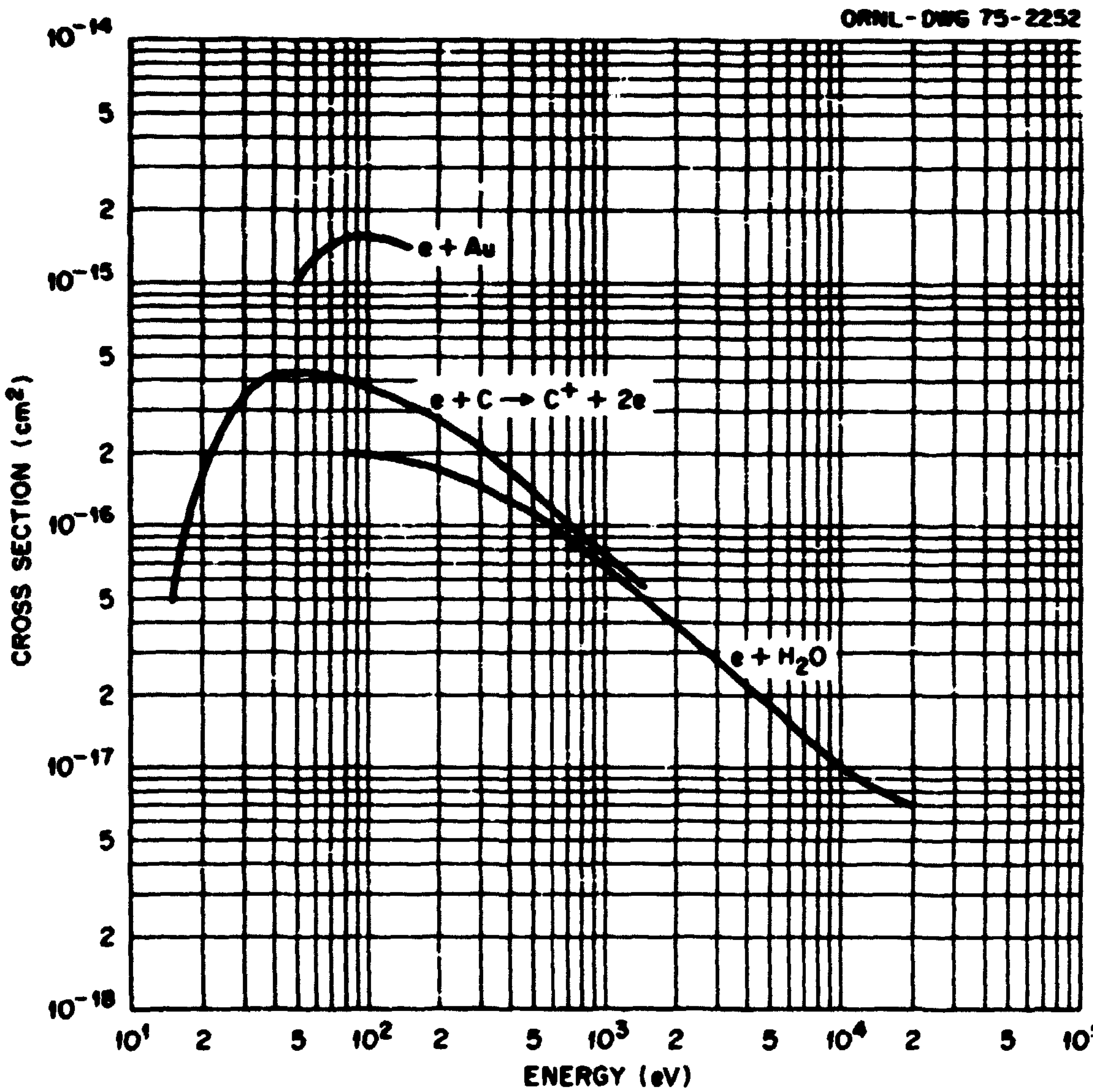
Gold: J.M. Schroeer, D.H. Gündüz, and S. Livingston, J. Chem. Phys. 58, 5135 (1973).

Carbon: K.L. Wang and C.K. Crawford, "Electron Impact Ionization Cross Sections," Tech. Rept. No. 6, Particle Optics Lab., MIT, Cambridge, Mass., 1971, AFML-TR-70-289.

Water Vapor: J. Schutten, F.J. de Heer, H.R. Moustafa, A.J. Boerboom, and J. Kistemaker, J. Chem. Phys. 44, 3924 (1966).

Accuracy:

Gold: The total error is believed not to exceed ± 50%. Carbon: The total error is believed not to exceed ± 30%. Water Vapor: The total error is believed not to exceed ± 30%.


ORNL-DWG 75-2252
CROSS SECTION (cm²)
ENERGY (eV)
e + Au
e + C → C⁺ + 2e
e + H₂O
10⁻¹⁴
5
2
10⁻¹⁵
5
2
10⁻¹⁶
5
2
10⁻¹⁷
5
2
10⁻¹⁸
10¹
2
5
10²
2
5
10³
2
5
10⁴
2
5

Cross Sections for Ionization of Copper Atoms by Electron Impact

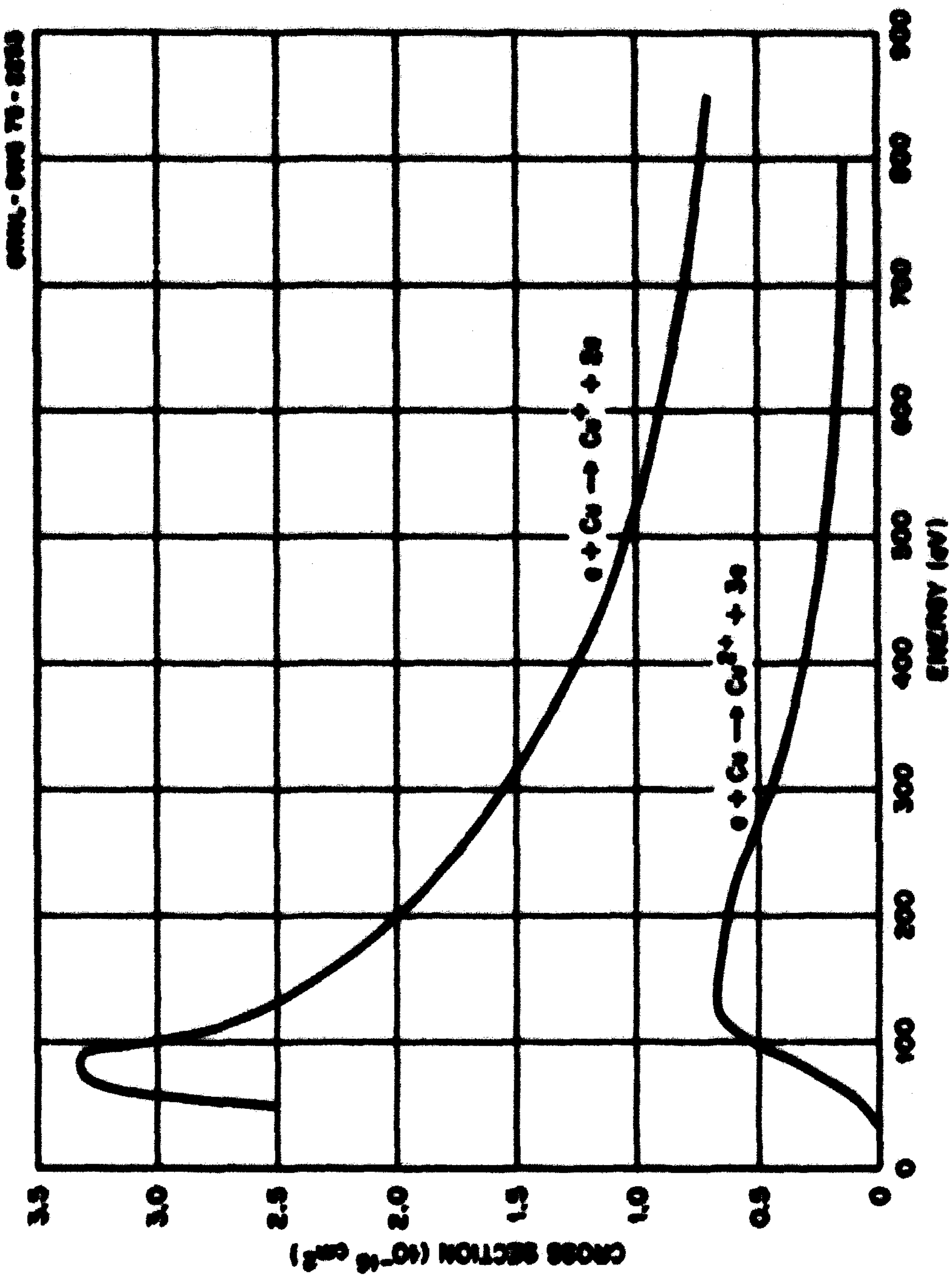
Energy (eV)	Cross Section (cm^2)	Cross Section (cm^2)
	Cu^+	Cu^{++}
5.0 E 01	2.5 E-16	8.3 E-18
6.0 E 01	3.1 E-16	1.4 E-17
8.0 E 01	3.3 E-16	3.1 E-17
1.0 E 02	3.1 E-16	5.2 E-17
1.5 E 02	2.3 E-16	6.6 E-17
2.0 E 02	2.0 E-16	6.2 E-17
3.0 E 02	1.6 E-16	4.5 E-17
4.0 E 02	1.3 E-16	3.1 E-17
5.0 E 02	1.0 E-16	2.3 E-17
6.0 E 02	9.0 E-17	1.8 E-17
8.0 E 02	7.3 E-17	1.4 E-17
8.5 E 02	7.0 E-17	

Reference:

C.K. Crawford, AFML-TR-67-376, A.F. Materials Laboratory, Wright-Patterson A.F.B., Ohio 1967.

Accuracy:

The total error is believed not to exceed ± 30%.



e + Cu → Cu⁺ + 2e
e + Cu → Cu²⁺ + 3e
CROSS SECTION (10⁻¹⁶ cm²)
ENERGY (eV)
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
100
200
300
400
500
600
700
800
900

Total Cross Sections σ_T for Ionization of Atomic Rubidium and Atomic Potassium by Electron Impact

Energy (eV)	σ_T e + Rb (cm^2)	Energy (eV)	σ_T e + K (cm^2)
6.0 E 00	6.6 E-16	5.0 E 00	2.5 E-16
1.0 E 01	8.2 E-16	6.0 E 00	5.9 E-16
1.2 E 01	8.2 E-16	8.0 E 00	7.7 E-16
1.6 E 01	8.2 E-16	1.0 E 01	7.6 E-16
1.8 E 01	8.4 E-16	1.4 E 01	6.8 E-16
2.0 E 01	8.9 E-16	1.8 E 01	6.4 E-16
2.4 E 01	9.9 E-16	2.2 E 01	6.9 E-16
2.8 E 01	1.0 E-15	2.5 E 01	7.3 E-16
3.6 E 01	1.0 E-15	3.0 E 01	7.8 E-16
4.0 E 01	1.0 E-15	4.0 E 01	6.7 E-16
6.0 E 01	1.0 E-15	6.0 E 01	5.8 E-16
8.0 E 01	9.6 E-16	8.0 E 01	5.7 E-16
1.0 E 02	9.2 E-16	1.0 E 02	5.5 E-16
1.2 E 02	8.7 E-16	1.5 E 02	4.9 E-16
1.6 E 02	7.9 E-16	2.0 E 02	4.3 E-16
2.0 E 02	7.2 E-16	3.0 E 02	3.4 E-16
2.4 E 02	6.5 E-16	4.0 E 02	2.8 E-16
		5.0 E 02	2.5 E-16

<u>References</u>:

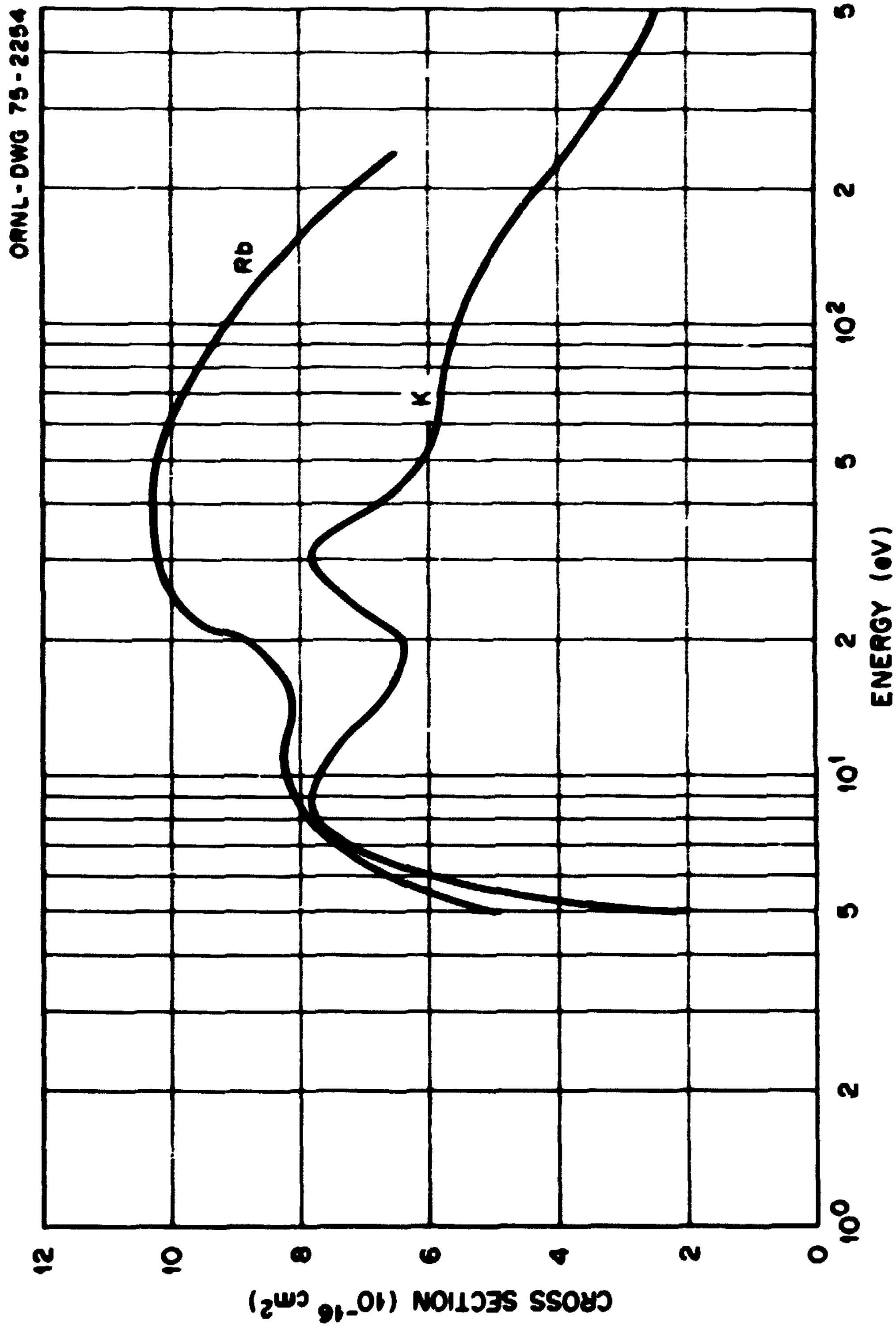
e + Rb: K.J. Nygaard and Y.B. Hahn, J. Chem. Phys. <u>58</u>, 3493 (1973).

e + K: R.H. McFarland and J.D. Kinney, Phys. Rev. <u>137</u>, A-1058 (1965).
Yu. P. Korchevoi and A.M. Przhonskii, Sov. Phys. JETP <u>24</u>, 1089 (1967).
K.T. Nygaard, to be published.

<u>Accuracy</u>:

e + Rb: The total error is believed not to exceed ± 18%.

e + K: The total error is believed not to exceed ± 20%.


ORNL-DWG 75-2254
Rb
K
CROSS SECTION (10^-16 cm^2)
ENERGY (eV)
12
10
8
6
4
2
0
10^0
2
5
10^1
2
5
10^2
2
5

Total Cross Section σ_T for Ionization of Atomic Sodium and Cesium, and Cross Section for Double Ionization of Atomic Sodium by Electron Impact

Energy (eV)	σ_T e + Cs (cm^2)	Energy (eV)	σ_T e + Na (cm^2)	Energy (eV)	σ^{2+} $e+Na \rightarrow Na^{2+}+3e$ (cm^2)
6.0 E 00	4.8 E-16	6.0 E 00	2.0 E-16	8.0 E 01	2.3 E-18
8.0 E 00	7.0 E-16	7.0 E 00	3.9 E-16	9.0 E 01	2.8 E-18
1.0 E 01	7.3 E-16	8.0 E 00	5.2 E-16	1.0 E 02	3.4 E-18
1.2 E 01	7.2 E-16	1.0 E 01	6.3 E-16	1.2 E 02	4.4 E-18
1.4 E 01	8.6 E-16	1.2 E 01	6.7 E-16	1.4 E 02	5.3 E-18
1.6 E 01	9.5 E-16	1.6 E 01	6.7 E-16	1.6 E 02	6.2 E-18
2.0 E 01	8.3 E-16	2.0 E 01	6.5 E-16	1.8 E 02	6.9 E-18
2.4 E 01	9.3 E-16	3.0 E 01	5.8 E-16	2.0 E 02	7.7 E-18
2.8 E 01	1.0 E-15	4.0 E 01	5.2 E-16	2.5 E 02	9.1 E-18
3.2 E 01	1.0 E-15	6.0 E 01	4.3 E-16	3.0 E 02	1.0 E-17
3.6 E 01	1.0 E-15	1.0 E 02	3.4 E-16	3.5 E 02	1.1 E-17
4.0 E 01	9.9 E-16	1.2 E 02	3.1 E-16	4.0 E 02	1.1 E-17
5.0 E 01	9.6 E-16	1.6 E 02	2.7 E-16		
6.0 E 01	9.4 E-16	2.0 E 02	2.5 E-16		
7.0 E 01	9.1 E-16	3.0 E 02	2.0 E-16		
9.0 E 01	8.8 E-16	4.0 E 02	1.7 E-16		

References:

e + Cs: K.J. Nygaard, J. Chem. Phys. 49, 1995 (1968). I.P. Zapesochnyi and I.S. Aleksakhin, Sov. Phys. JETP 28, 41 (1969).

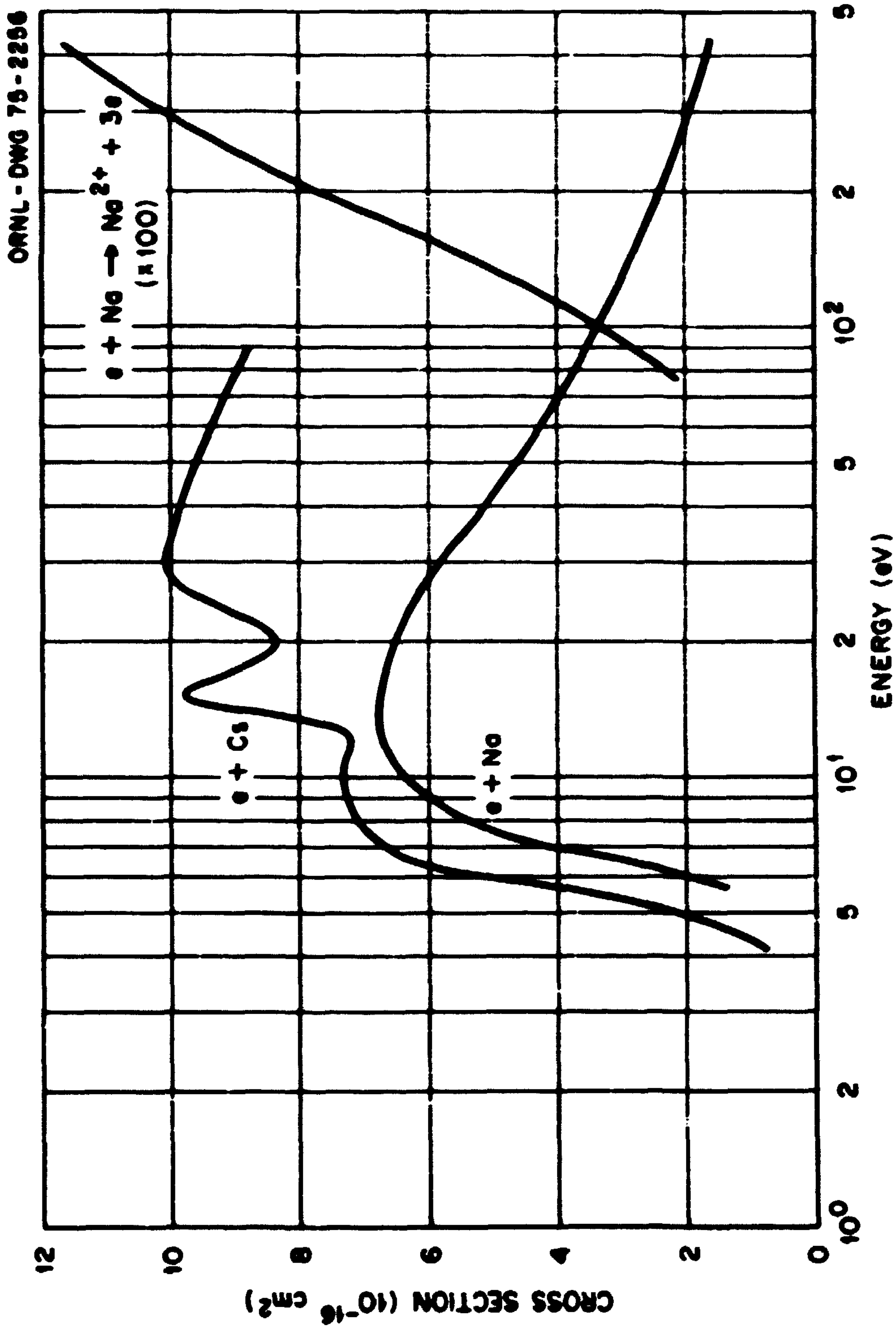
σ_T, e+Na: R.H. McFarland and J.D. Kinney, Phys. Rev. 137, A-1058 (1965). I.P. Zapesochnyi and I.S. Aleksakhin, Sov. Phys. JETP 28, 41 (1969).

σ^{2+}, e+Na: J.T. Tate and P.T. Smith, Phys. Rev. 46, 773 (1934).

Accuracy:

The total error is believed not to exceed ± 30% for e + Cs.

The total error is believed not to exceed ± 18% in σ_T for e + Na.


ORNL-DWG 75-2256
e + Na → Na2+ + 3e
(x100)
e + Cs
e + Na
CROSS SECTION (10-16 cm2)
ENERGY (eV)
0
2
4
6
8
10
12
10^0
2
5
10^1
2
5
10^2
2
5

Total Cross Section σ_T for Ionization of Carbon Dioxide

by Electron Impact, and Cross Section for Single

Ionization of He^+ Ions by Electron Impact

Energy (eV)	σ_T $e + CO_2$ (cm^2)	Energy (eV)	σ $e + He^+ \rightarrow He^{2+} + 2e$ (cm^2)
1.5 E 01	6.6 E-18	5.0 E 01	4.3 E-18
2.0 E 01	5.0 E-17	7.5 E 01	1.5 E-17
3.0 E 01	1.5 E-16	1.0 E 02	2.4 E-17
4.0 E 01	2.2 E-16	1.5 E 02	3.0 E-17
6.0 E 01	2.9 E-16	2.0 E 02	3.1 E-17
8.0 E 01	3.4 E-16	2.5 E 02	3.0 E-17
1.0 E 02	3.5 E-16	3.0 E 02	2.9 E-17
1.4 E 02	3.5 E-16	4.0 E 02	2.6 E-17
1.8 E 02	3.4 E-16	5.0 E 02	2.3 E-17
2.2 E 02	3.1 E-16	6.0 E 02	2.2 E-17
2.6 E 02	3.0 E-16	7.0 E 02	2.0 E-17
3.0 E 02	2.8 E-16	8.0 E 02	1.9 E-17
4.0 E 02	2.4 E-16	9.0 E 02	1.8 E-17
5.0 E 02	2.1 E-16	1.0 E 03	1.6 E-17
6.0 E 02	1.9 E-16		
8.0 E 02	1.6 E-16		
1.0 E 03	1.4 E-16		

References:

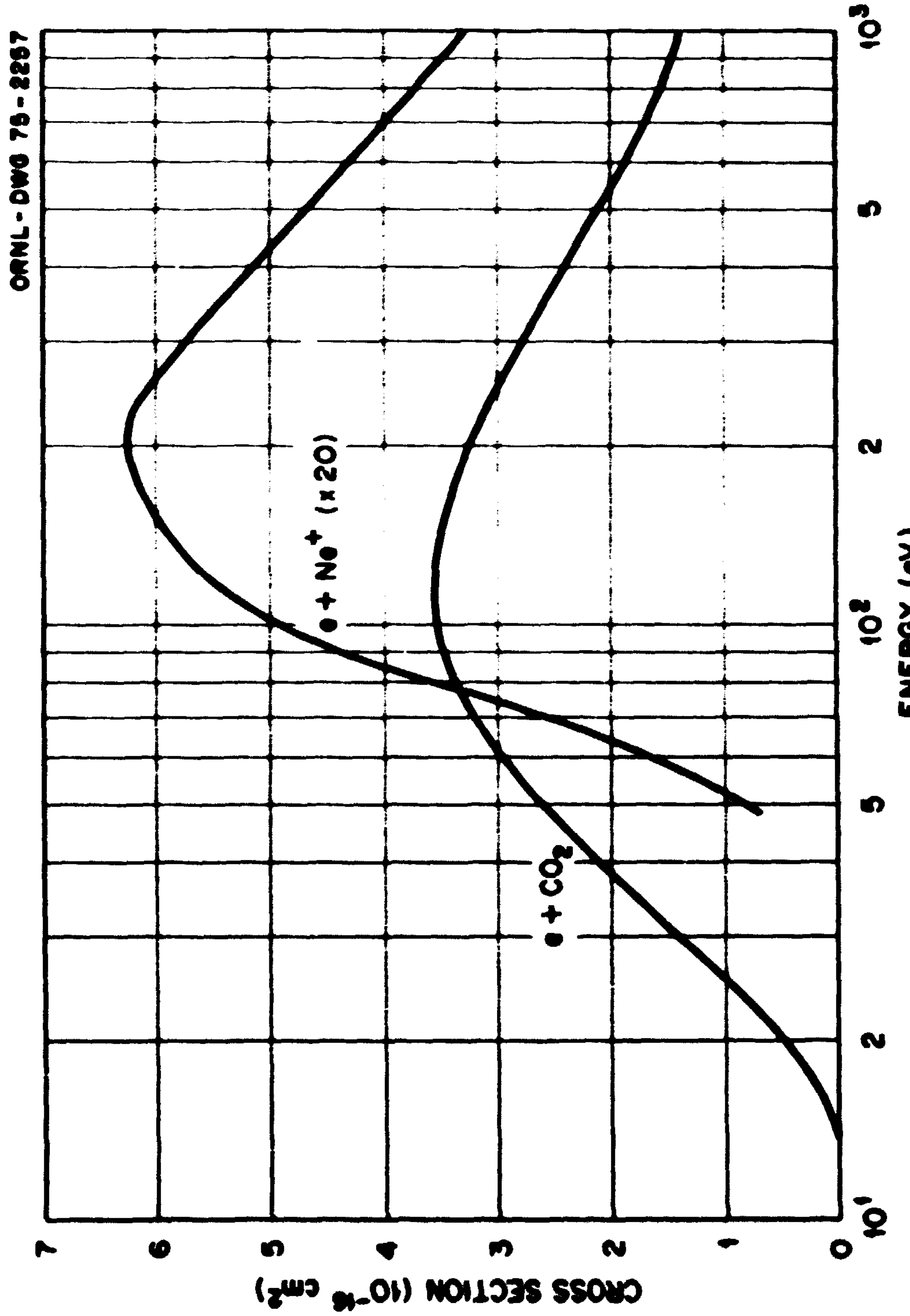
$e + CO_2$: D. Rapp and P. Englander-Golden, J. Chem. Phys. 43, 1464 (1965).

$e + He^+$: K.T. Dolder, M.F.A. Harrison, and P.C. Thonemann, Proc. Roy. Soc. A-274, 546 (1963).

Accuracy:

$e + CO_2$: The total error is believed not to exceed ± 30%.

$e + He^+$: Maximum total error ≤ ± 10%.



ORNL-DWG 75-2257
e + Ne+ (x 20)
e + CO2
CROSS SECTION (10-16 cm2)
ENERGY (eV)
0
1
2
3
4
5
6
7
10^1
2
5
10^2
2
5
10^3

Cross Section for the Production of $H^+(D^+)$ Ions in Electron Impacts on $H_2^+(D_2^+)$ Ions

Energy (eV)	Cross Sections (cm^2)	
	$e + H_2^+$	$e + D_2^+$
1.5 E 01	4.75 E-16	
2.0 E 01	4.31 E-16	
2.5 E 01	3.99 E-16	
3.0 E 01	3.72 E-16	
4.0 E 01	3.32 E-16	
6.0 E 01	2.78 E-16	2.77 E-16
8.0 E 01	2.43 E-16	[illegible]
1.0 E 02	2.17 E-16	[illegible]
1.5 E 02	1.71 E-16	1.71 E-16
2.0 E 02	1.41 E-16	1.41 E-16
2.5 E 02	1.20 E-16	[illegible]
3.0 E 02	1.03 E-16	1.03 E-16
4.0 E 02	8.00 E-17	8.00 E-17
6.0 E 02	5.40 E-17	
8.0 E 02	4.20 E-17	
1.0 E 03	3.50 E-17	
1.5 E 03	2.47 E-17	

References:

$e + (H_2^+, D_2^+)$: G. H. Dunn and B. Van Zyl, Phys. Rev. 154, 40 (1967).

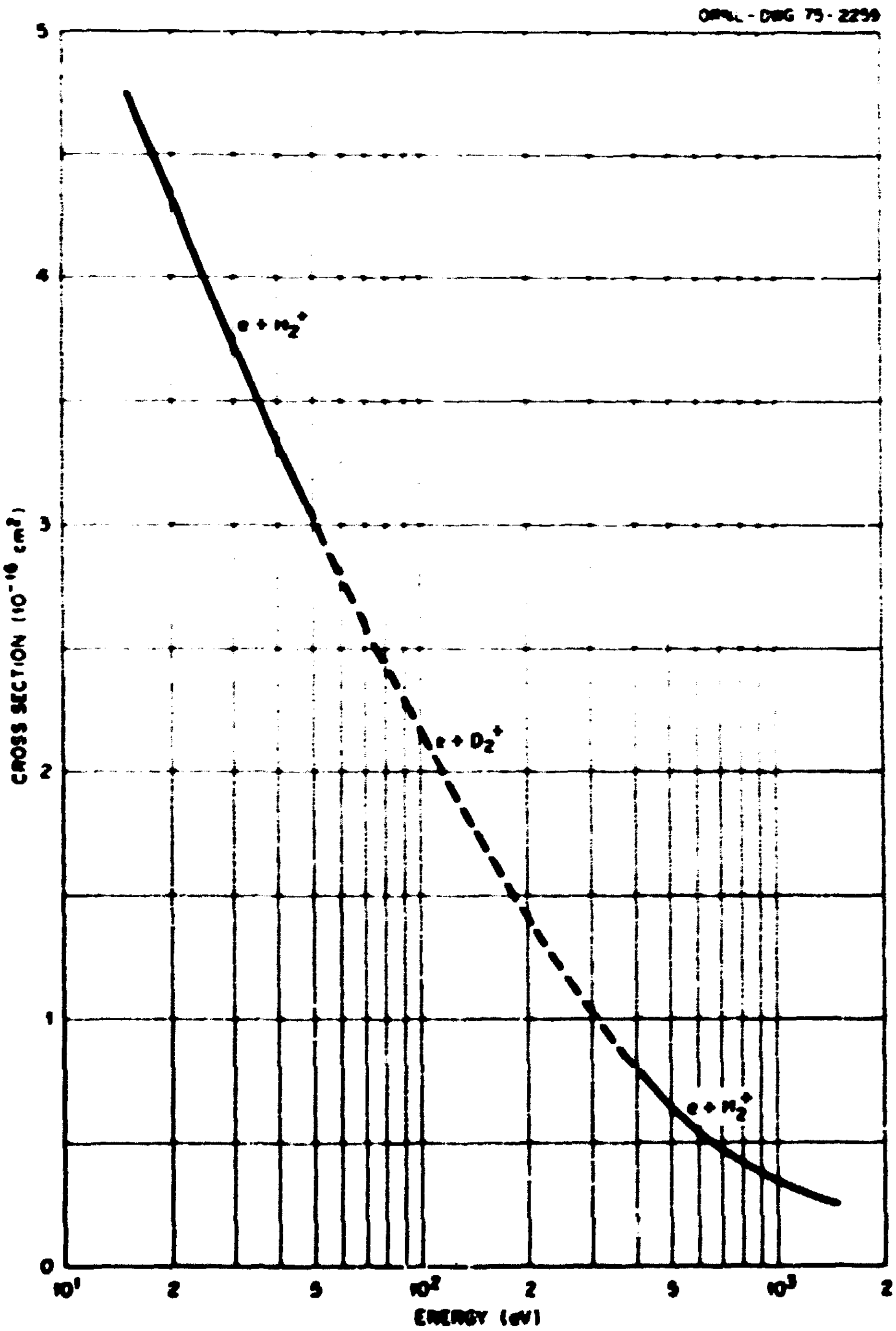
Accuracy:

$e + (H_2^+, D_2^+)$: Maximum systematic error < 10%. Random error < 5%.

Notes:

$e + H_2^+$: The quantity plotted is the sum of the cross section for the reaction $e + H_2^+ \rightarrow H^+ + H + e$ and twice the cross section for the reaction $e + H_2^+ \rightarrow H^+ + H^+ + 2e$. The H_2^+ ions are in the $1s\sigma_g$ state. They have a vibrational distribution corresponding to the ionization of cold hydrogen gas by fast electrons. The H atoms formed in the first reaction may be in excited states.

$e + D_2^+$: The quantity plotted is the sum of the cross section for the reaction $e + D_2^+ \rightarrow D^+ + D + e$ and twice the cross section for the reaction $e + D_2^+ \rightarrow D^+ + D^+ + 2e$. The D_2^+ ions are in the $1s\sigma_g$ state. They have a vibrational distribution corresponding to the ionization of cold deuterium gas by fast electrons. The D atoms formed in the first reaction may be in excited states.


ORNL-DWG 75-2259
5
4
3
2
1
0
CROSS SECTION (10^{-16} cm^2)
$e + H_2^+$
$e + D_2^+$
$e + H_2^+$
10^1
2
5
10^2
2
5
10^3
2
ENERGY (eV)

Cross Section for the Production of Protons in Electron Impacts on H_2^+ Ions and Cross Section for the Dissociative Ionization Reaction $e + H_2^+ \rightarrow H^+ + H^+ + 2e$

Energy (eV)	Cross Section (cm^2) $e + H_2^+$ Proton Production	$e + H_2^+$ Dissociative Ionization
4.0 E 00	9.90 E-16	
8.0 E 00	7.98 E-16	
1.0 E 01	6.87 E-16	
2.0 E 01	4.73 E-16	1.06 E-18
4.0 E 01	3.46 E-16	6.90 E-18
6.0 E 01	2.81 E-16	1.30 E-17
8.0 E 01	2.40 E-16	1.62 E-17
1.0 E 02	2.09 E-16	1.75 E-17
2.0 E 02	1.24 E-16	1.33 E-17
3.0 E 02	9.20 E-17	9.71 E-18
4.0 E 02	7.50 E-17	7.60 E-18
8.0 E 02	4.20 E-17	4.57 E-18
1.0 E 03	3.40 E-17	4.00 E-18

References:

$e + H_2^+$ (proton production): B. Peart and K. T. Dolder, J. Phys. B 4, 1496 (1971); 5, 1554 (1972).

$e + H_2^+$ (dissociative ionization): B. Peart and K.T. Dolder, J. Phys. B 6, 2409 (1973).

Accuracy:

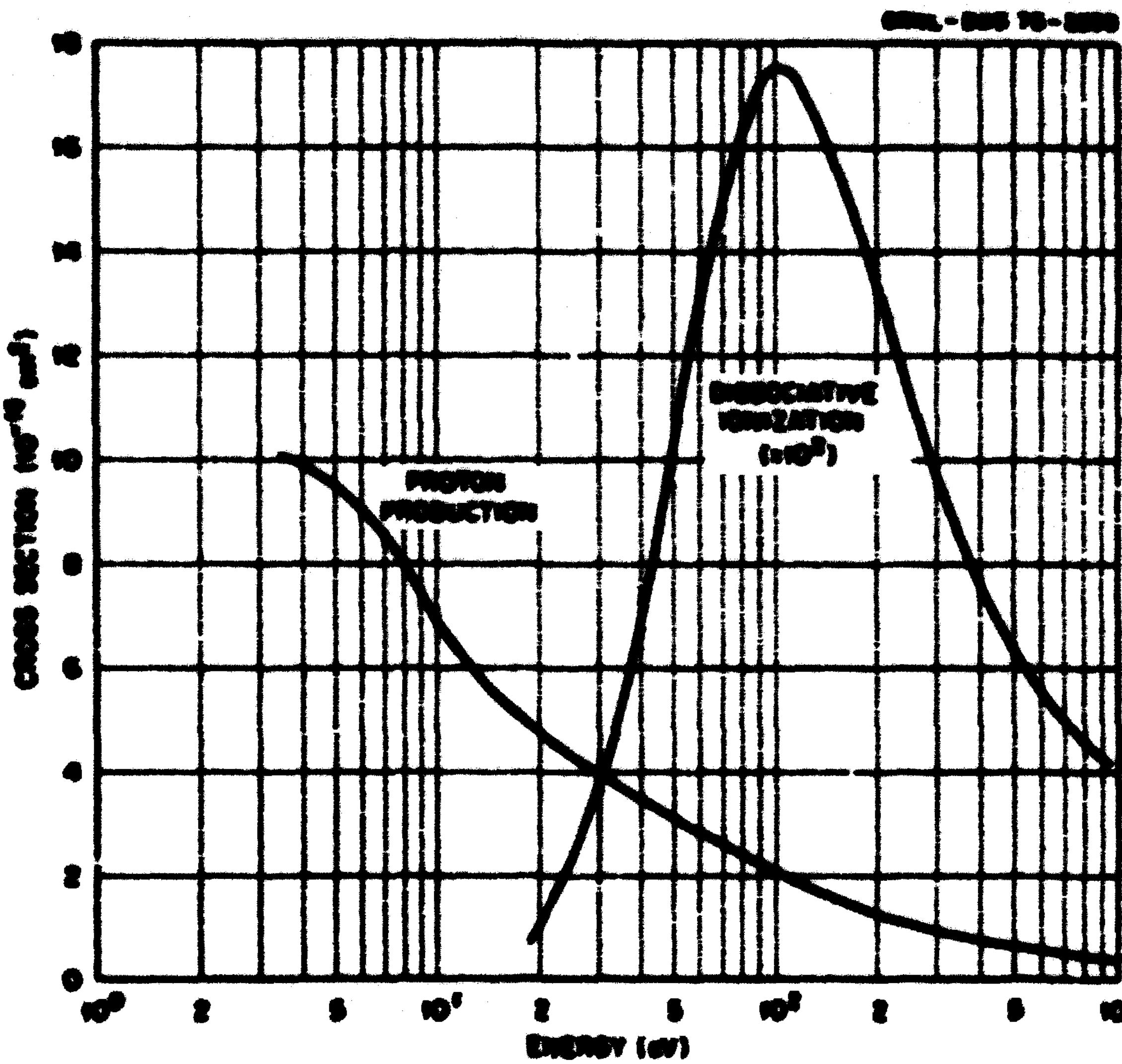
$e + H_2^+$ (proton production): Systematic error $\leq \pm$ 10%. Random error $\pm$ 10%.

$e + H_2^+$ (dissociative ionization): Systematic error < $\pm$ 6%. Random error $\leq \pm$ 11% over most of energy range.

Notes:

$e + H_2^+$ (proton production): The quantity plotted is the sum of the cross sections for the reactions $e + H_2^+ \rightarrow H^+ + H + e$ and $e + H_2^+ \rightarrow H^+ + H^+ + 2e$. The H_2^+ ions are in the $1s\sigma_g$ state; they have a vibrational distribution corresponding to the ionization of cold hydrogen gas by fast electrons. The H atoms formed in the first reaction may be in excited states.

$e + H_2^+$ (dissociative ionization): The H_2^+ ions are in the $1s\sigma_g$ state; they have a vibrational distribution corresponding to the ionization of cold hydrogen gas by fast electrons.


PROTON
PRODUCTION
DISSOCIATIVE
IONIZATION
CROSS SECTION
ENERGY (eV)
2
5
2
5
2
5
0
2
4
6
8
10
12
14
16
18

Total Cross Section, σ_T, for Ionization of Atomic Lithium by Electron Impact, and Cross Section for Production of He^{2+} from He^+ by Electron Impact

Energy (eV)	σ_T e + Li (cm^2)	Energy (eV)	σ $e+He^+ \to He^{2+}+2e$ (cm^2)
1.0 E 02	1.0 E-16	5.5 E 01	1.0 E-19
2.0 E 02	7.4 E-17	6.8 E 01	1.5 E-18
3.0 E 02	5.5 E-17	9.8 E 01	3.6 E-18
4.0 E 02	4.5 E-17	1.2 E 02	4.0 E-18
5.0 E 02	3.6 E-17	1.7 E 02	4.8 E-18
6.0 E 02	3.0 E-17	2.0 E 02	4.5 E-18
7.0 E 02	2.5 E-17	3.0 E 02	4.2 E-18
8.0 E 02	2.2 E-17	4.0 E 02	3.9 E-18
9.0 E 02	2.0 E-17	6.0 E 02	3.1 E-18
1.0 E 03	1.8 E-17	8.0 E 02	2.6 E-18
1.2 E 03	1.5 E-17	1.0 E 03	2.2 E-18
1.4 E 03	1.3 E-17	1.2 E 03	2.1 E-18
1.6 E 03	1.2 E-17	1.6 E 03	1.6 E-18
1.8 E 03	1.2 E-17	2.0 E 03	1.3 E-18
2.0 E 03	1.1 E-17	3.0 E 03	9.7 E-19
		4.0 E 03	7.6 E-19
		6.0 E 03	5.0 E-19
		8.0 E 03	3.9 E-19
		1.0 E 04	3.2 E-19

References:

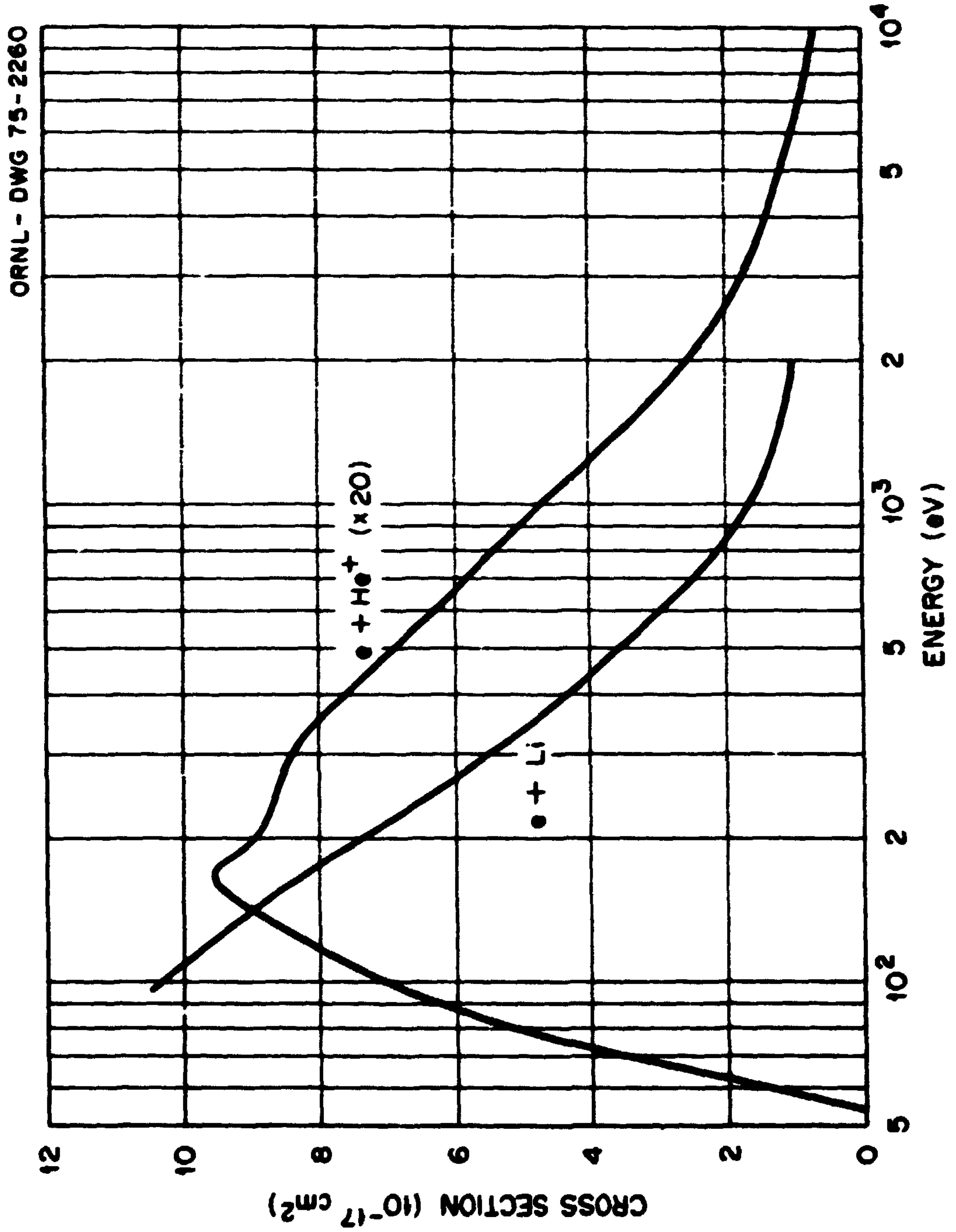
e + Li: R. Jalin, R. Hagemann, and R. Botter, J. Chem. Phys. 59, 952 (1973).

e + He^+: B. Peart, D.S. Walton, and K.T. Dolder, J. Phys. B 2, 1347 (1969).

Accuracy:

e + Li: The total error is believed not to exceed ± 15%.

e + He^+: Systematic error < 8%. Random error < 9% over most of the energy range.


ORNL-DWG 75-2260
CROSS SECTION (10^{-17} cm^2)
0
2
4
6
8
10
12
ENERGY (eV)
5
10^2
2
5
10^3
2
5
10^4
e + He^+ (x20)
e + Li

Cross Sections for Single and Double Ionization of Li^+ Ions and Cross Sections for Single Ionization of Na^+ and K^+ Ions by Electron Impact

Energy (eV)	Cross Sections (cm^2)			
	$e+Li^+ \rightarrow Li^{2+}+2e$	$e+Li^+ \rightarrow Li^{3+}+3e$	$e+Na^+ \rightarrow Na^{2+}+2e$	$e+K^+ \rightarrow K^{2+}+2e$
4.0 E 01				3.80 E-17
6.0 E 01			3.30 E-18	8.54 E-17
8.0 E 01			9.10 E-18	9.80 E-17
1.0 E 02	1.52 E-18		1.50 E-17	9.83 E-17
1.5 E 02	3.45 E-18		2.32 E-17	9.17 E-17
2.5 E 02	4.08 E-18	2.04 E-21	2.67 E-17	7.39 E-17
3.0 E 02	4.13 E-18	3.80 E-21	2.64 E-17	6.55 E-17
4.0 E 02	4.09 E-18	6.82 E-21	2.50 E-17	5.55 E-17
6.0 E 02	3.71 E-18	1.00 E-20	2.18 E-17	4.30 E-17
1.0 E 03	2.85 E-18	9.56 E-21	1.68 E-17	3.00 E-17
1.5 E 03	2.13 E-18	7.11 E-21	1.28 E-17	2.18 E-17
2.0 E 03	1.86 E-18	5.21 E-21	1.06 E-17	1.80 E-17
2.5 E 03	1.62 E-18	4.40 E-21	8.90 E-18	1.56 E-17
3.0 E 03	1.42 E-18		7.50 E-18	1.39 E-17
6.0 E 03	7.91 E-19			
1.0 E 04	5.29 E-19			
2.0 E 04	2.91 E-19			
2.5 E 04	2.38 E-19			

References:

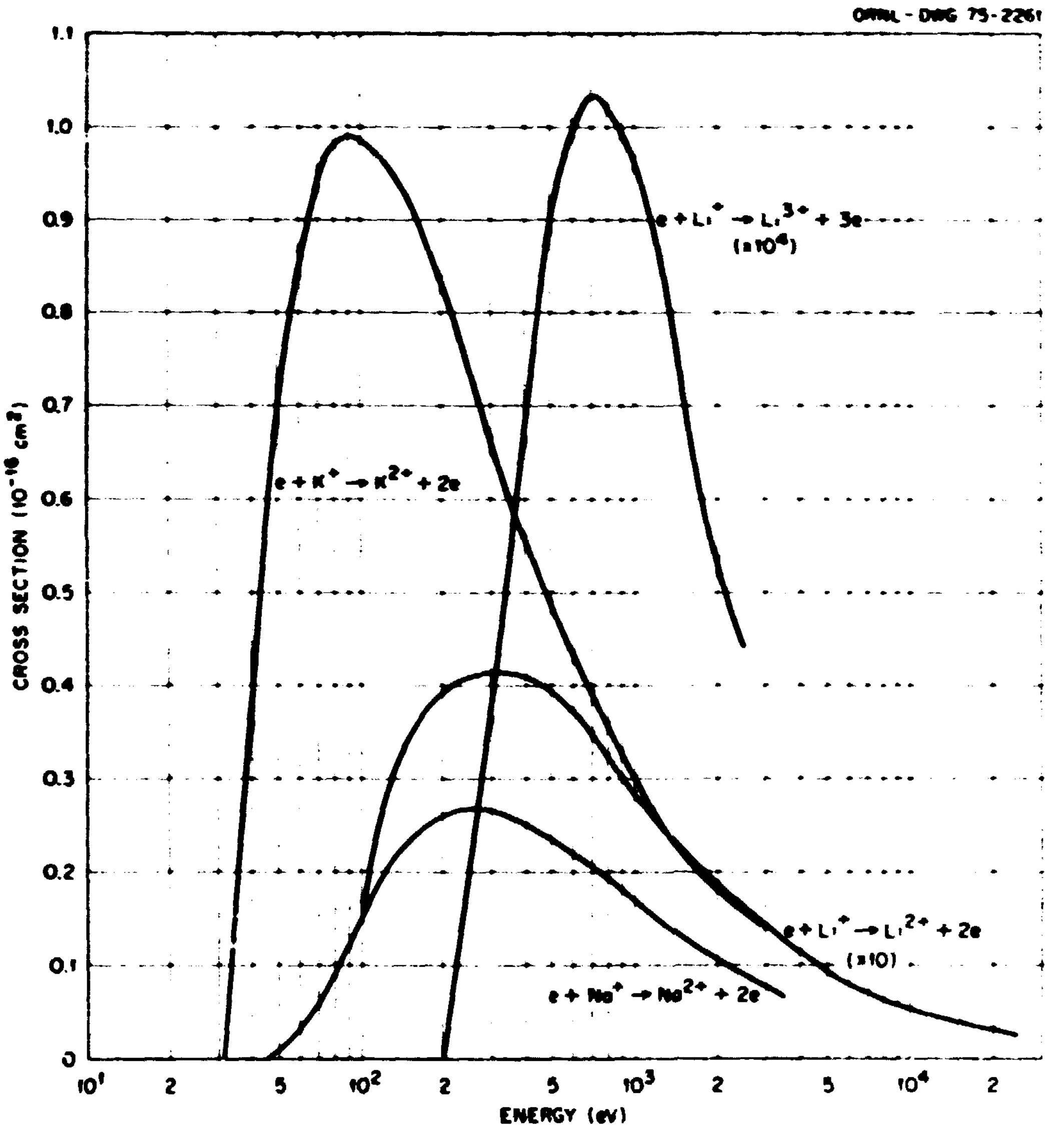
$e + Li^+$ (single ionization): W.C. Lineberger, J.W. Hooper, and E.W. McDaniel, Phys. Rev. 141, 151 (1966). B. Peart and K.T. Dolder, J. Phys. B 1, 872 (1968). B. Peart, D.S. Walton, and K.T. Dolder, J. Phys. B 2, 1347 (1969).

$e + Li^+$ (double ionization): B. Peart and K.T. Dolder, J. Phys. B 2, 1169 (1969).

$e + (Na^+, K^+)$: B. Peart and K.T. Dolder, J. Phys. B 1, 240 (1968). J.W. Hooper, W.C. Lineberger, and F.M. Bacon, Phys. Rev. 141, 165 (1966).

Accuracy:

$e + Li^+$ (single ionization): systematic error < ± 8%, random error < ± 6% over most of energy range. $e + Li^+$ (double ionization): systematic error < ± 9%, random error < ± 9%. $e + Na^+$: maximum total error = ± 6% for $E \leq 2000$ eV; ± 10% at E = 3500 eV. $e + K^+$: maximum total error = ± 6% at $E \leq 1250$ eV; ± 9% at E = 3000 eV.


ORNL-DWG 75-2261
CROSS SECTION (10^{-16} cm^2)
ENERGY (eV)
e + K⁺ → K²⁺ + 2e
e + Li⁺ → Li³⁺ + 3e
(×10⁴)
e + Li⁺ → Li²⁺ + 2e
(×10)
e + Na⁺ → Na²⁺ + 2e
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
10¹
2
5
10²
2
5
10³
2
5
10⁴
2

Cross Sections for Single Ionization of N^{+} and N^{2+} Ions by Electron Impact

Energy (eV)	Cross Sections (cm^2)	
	$e + N^{+}$	$e + N^{2+}$
3.0 E 01	1.00 E-18	
4.0 E 01	1.91 E-17	
6.0 E 01	3.65 E-17	7.80 E-18
8.0 E 01	4.56 E-17	1.41 E-17
1.0 E 02	4.99 E-17	1.67 E-17
1.5 E 02	4.85 E-17	1.76 E-17
2.0 E 02	4.50 E-17	1.69 E-17
2.5 E 02	4.13 E-17	1.56 E-17
3.0 E 02	3.79 E-17	1.45 E-17
4.0 E 02	3.16 E-17	1.26 E-17
6.0 E 02		9.70 E-18
8.0 E 02		7.80 E-18

References:

$e + N^{+}$: M.F.A. Harrison, K.T. Dolder, and P.C. Thonemann, Proc. Phys. Soc. 82, 368 (1963).

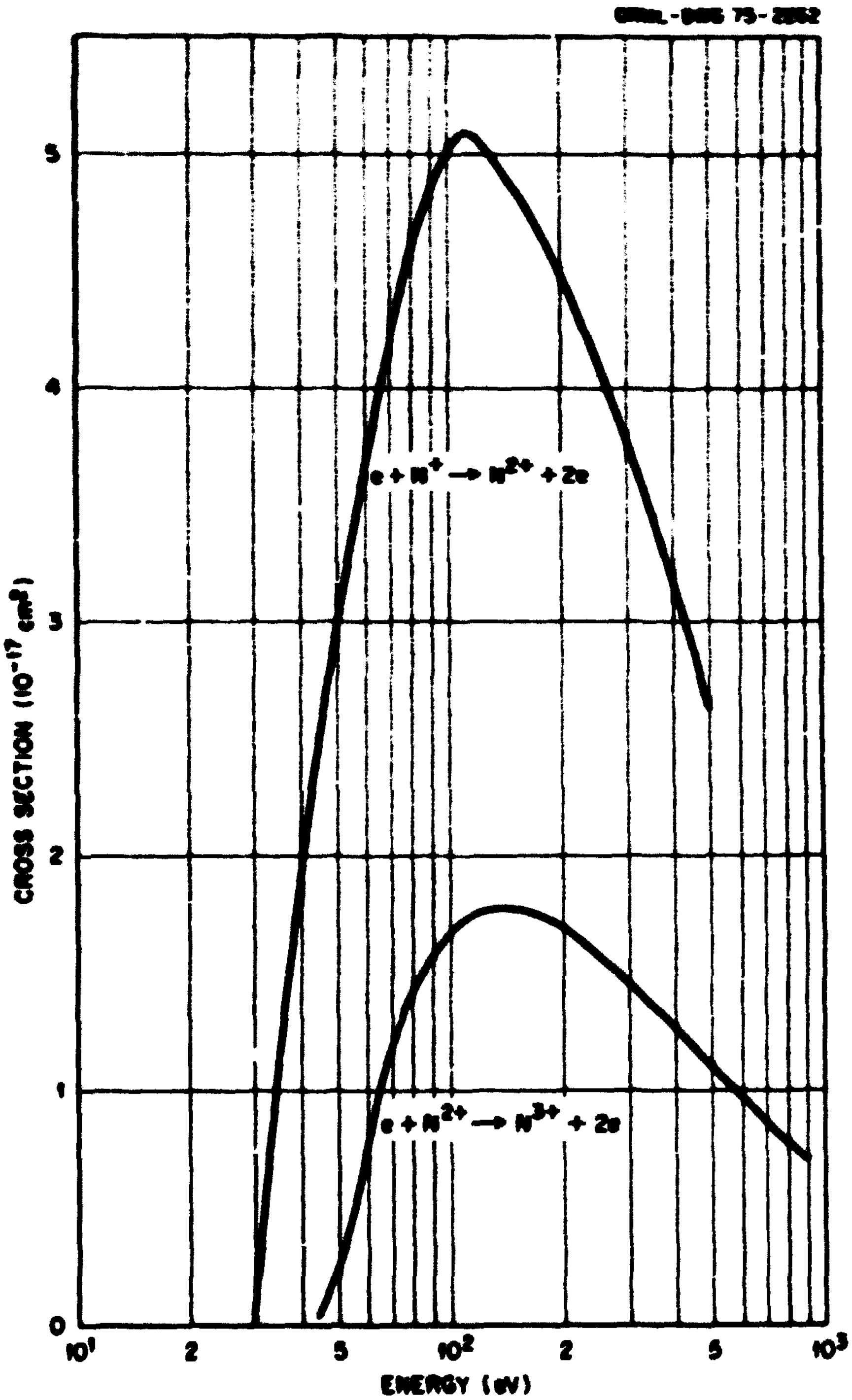
$e + N^{2+}$: K.L. Aitken, M.F.A. Harrison, and R.D. Rundel, J. Phys. B 4, 1189 (1971).

Accuracy:

$e + N^{+}$: The total error is believed not to exceed ± 15%.

$e + N^{2+}$: Systematic error < 10%. Random error < 5%.

C.4.43


CROSS SECTION (10^{-17} cm^2)
0
1
2
3
4
5
$e + N^+ \rightarrow N^{2+} + 2e$
$e + N^{2+} \rightarrow N^{3+} + 2e$
10^1
2
5
10^2
2
5
10^3
ENERGY (eV)

Cross Sections for Single Ionization of O^+ and O^{2+} Ions by Electron Impact

Energy (eV)	Cross Sections (cm^2)	
	$e + O^+$	$e + O^{2+}$
2.5 E 01	5.00 E-20	
3.0 E 01	2.50 E-19	
4.0 E 01	6.89 E-18	
6.0 E 01	2.64 E-17	5.20 E-18
8.0 E 01	3.68 E-17	1.27 E-17
1.0 E 02	4.19 E-17	1.65 E-17
1.5 E 02	4.38 E-17	1.82 E-17
2.0 E 02	4.19 E-17	1.76 E-17
2.5 E 02	3.93 E-17	1.66 E-17
3.0 E 02	3.70 E-17	1.56 E-17
4.0 E 03	3.29 E-17	1.36 E-17
6.0 E 02	2.66 E-17	
8.0 E 02	2.21 E-17	
1.0 E 03	1.85 E-17	

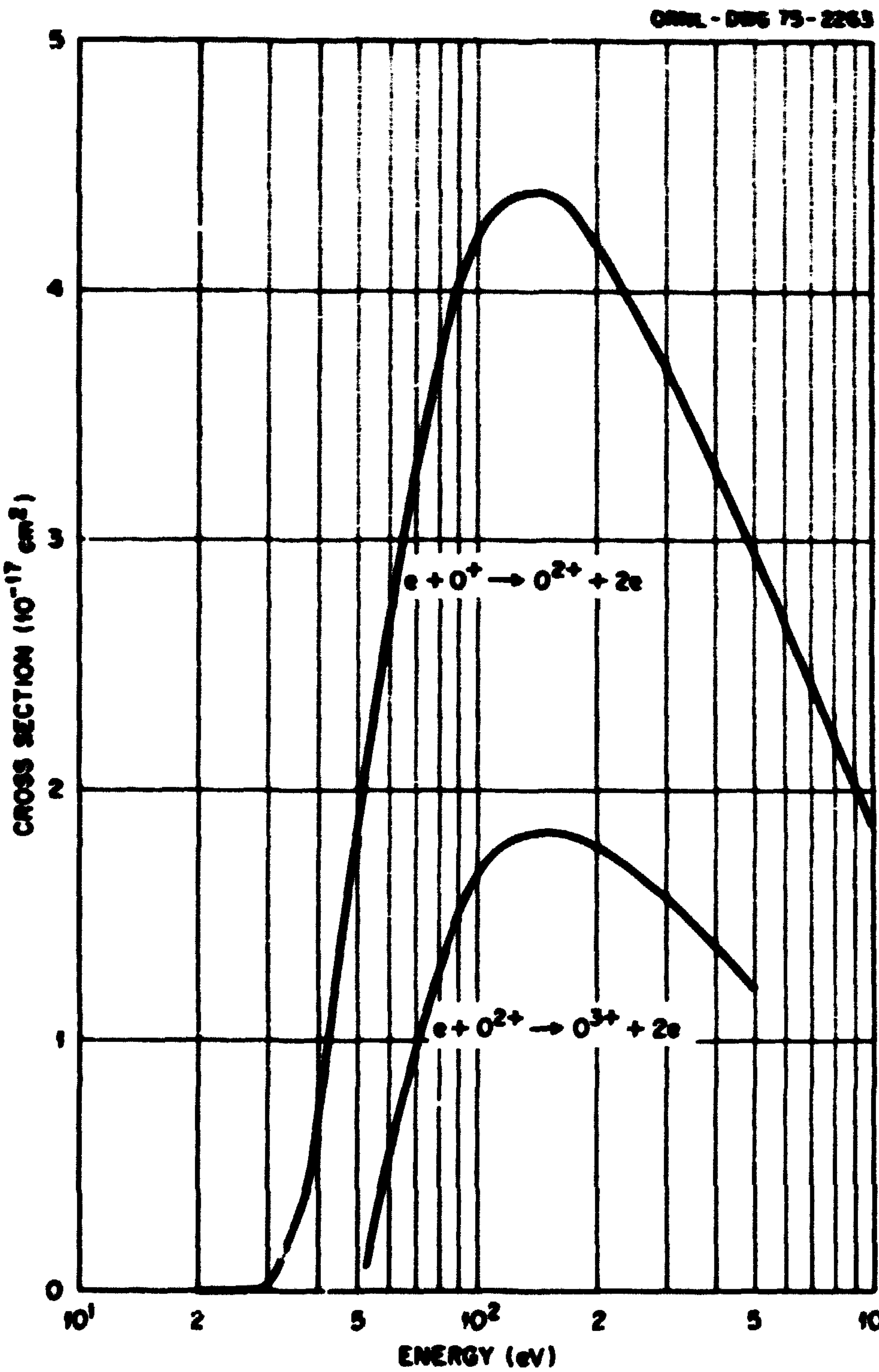
Reference:

$e + (O^+, O^{2+})$: K.L. Aitken and M.F.A. Harrison, J. Phys. B 4, 1176 (1971).

Accuracy:

$e + O^+$: Systematic error < 10%. Random error < 5%.

$e + O^{2+}$: Systematic error ≤ 15% at E < 63 eV. Random error ≤ 15% at E < 63 eV.


ORNL-DWG 75-2263
CROSS SECTION (10^{-17} cm^2)
ENERGY (eV)
0
1
2
3
4
5
10^1
2
5
10^2
2
5
10^3
$e + O^{+} \rightarrow O^{2+} + 2e$
$e + O^{2+} \rightarrow O^{3+} + 2e$

Cross Sections for Ionization of Ca^{+} and Sr^{+} by Electron Impact

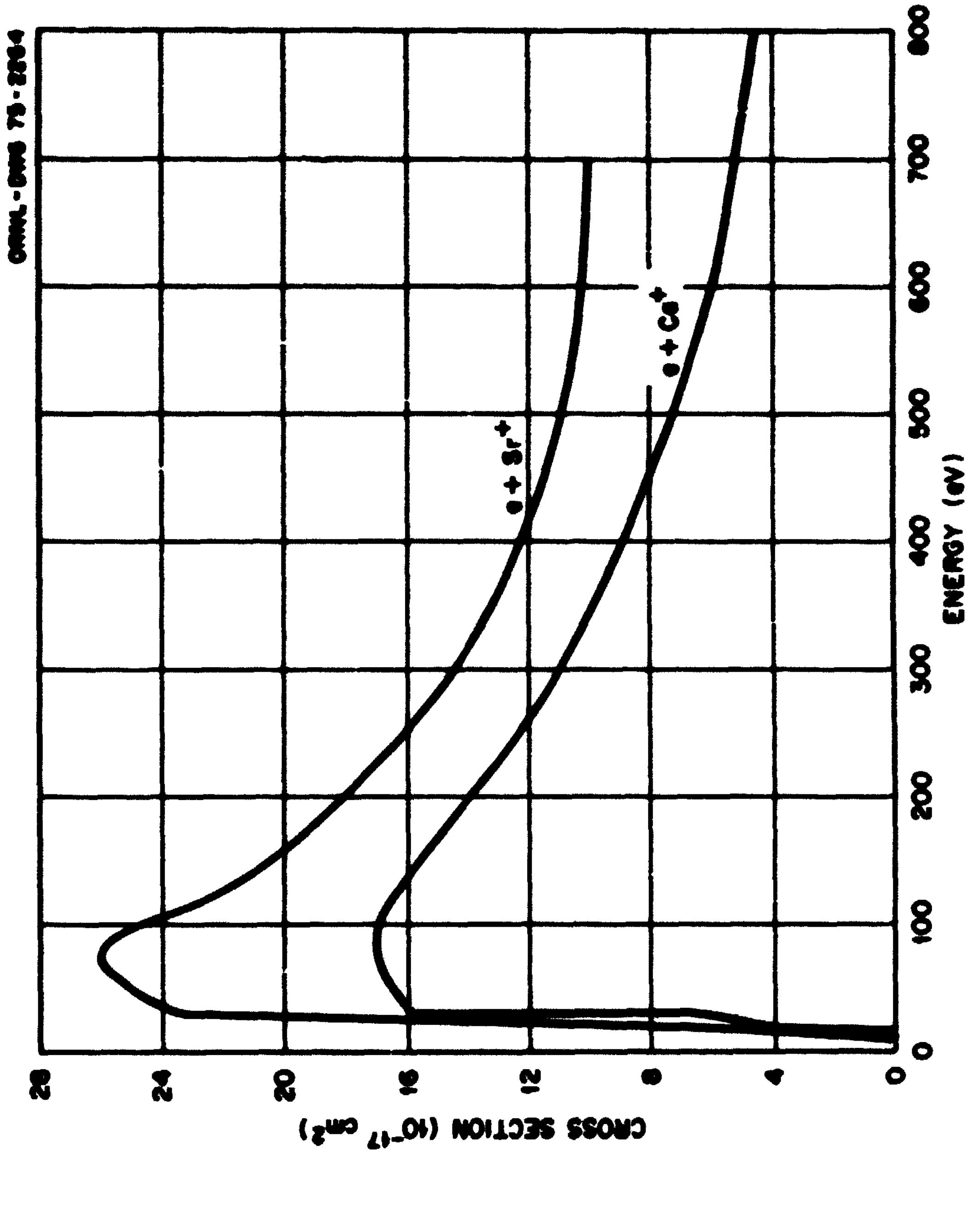
Energy (eV)	Cross Sections (cm^2)	
	$e + Ca^{+}$	$e + Sr^{+}$
1.7 E 01		5.20 E-17
2.0 E 01	4.00 E-17	9.00 E-17
3.0 E 01	1.59 E-16	2.20 E-16
5.0 E 01	1.65 E-16	2.50 E-16
7.5 E 01	1.70 E-16	2.60 E-16
8.0 E 01	1.70 E-16	2.59 E-16
1.1 E 02	1.68 E-16	2.36 E-16
1.5 E 02	1.56 E-16	2.04 E-16
2.0 E 02	1.40 E-16	1.82 E-16
3.0 E 02	1.10 E-16	1.45 E-16
4.0 E 02	9.00 E-17	1.23 E-16
5.0 E 02	7.20 E-17	1.09 E-16
6.0 E 02	6.00 E-17	1.03 E-16
7.0 E 02	5.20 E-17	1.00 E-16
8.0 E 02	4.50 E-17	

Reference:

B. Peart and K.T. Dolder, J. Phys. B 8, 56 (1975).

Accuracy:

The total error is believed not to exceed ± 12%.


ORNL-DWG 75-2264
CROSS SECTION (10^{-17} cm^2)
0
4
8
12
16
20
24
28
ENERGY (eV)
0
100
200
300
400
500
600
700
800
e + Sr^+
e + Ca^+

Cross Sections for Single Ionization of Ba^+ and Tl^+ Ions by Electron Impact

Energy (eV)	Cross Sections (cm^2)	
	$e+Ba^+ \rightarrow Ba^{2+}+2e$	$e+Tl^+ \rightarrow Tl^{2+}+2e$
1.0 E 01		
1.5 E 01	1.31 E-16	
2.0 E 01	4.10 E-16	4.20 E-17
2.5 E 01	4.31 E-16	6.75 E-17
3.0 E 01	4.37 E-16	1.05 E-16
4.0 E 01	4.33 E-16	1.45 E-16
6.0 E 01	4.14 E-16	1.68 E-16
8.0 E 01	3.92 E-16	1.74 E-16
1.0 E 02	3.72 E-16	1.75 E-16
1.5 E 02	3.26 E-16	1.16 E-16
2.0 E 02	2.85 E-16	1.50 E-16
2.5 E 02	2.50 E-16	1.35 E-16
3.0 E 02	2.20 E-16	1.25 E-16
4.0 E 02	1.85 E-16	1.08 E-16
6.0 E 02	1.44 E-16	8.90 E-17
8.0 E 02	1.21 E-16	7.70 E-17
1.0 E 03	1.05 E-16	6.75 E-17
1.5 E 03	7.80 E-17	5.20 E-17
2.0 E 03	6.10 E-17	4.10 E-17

References:

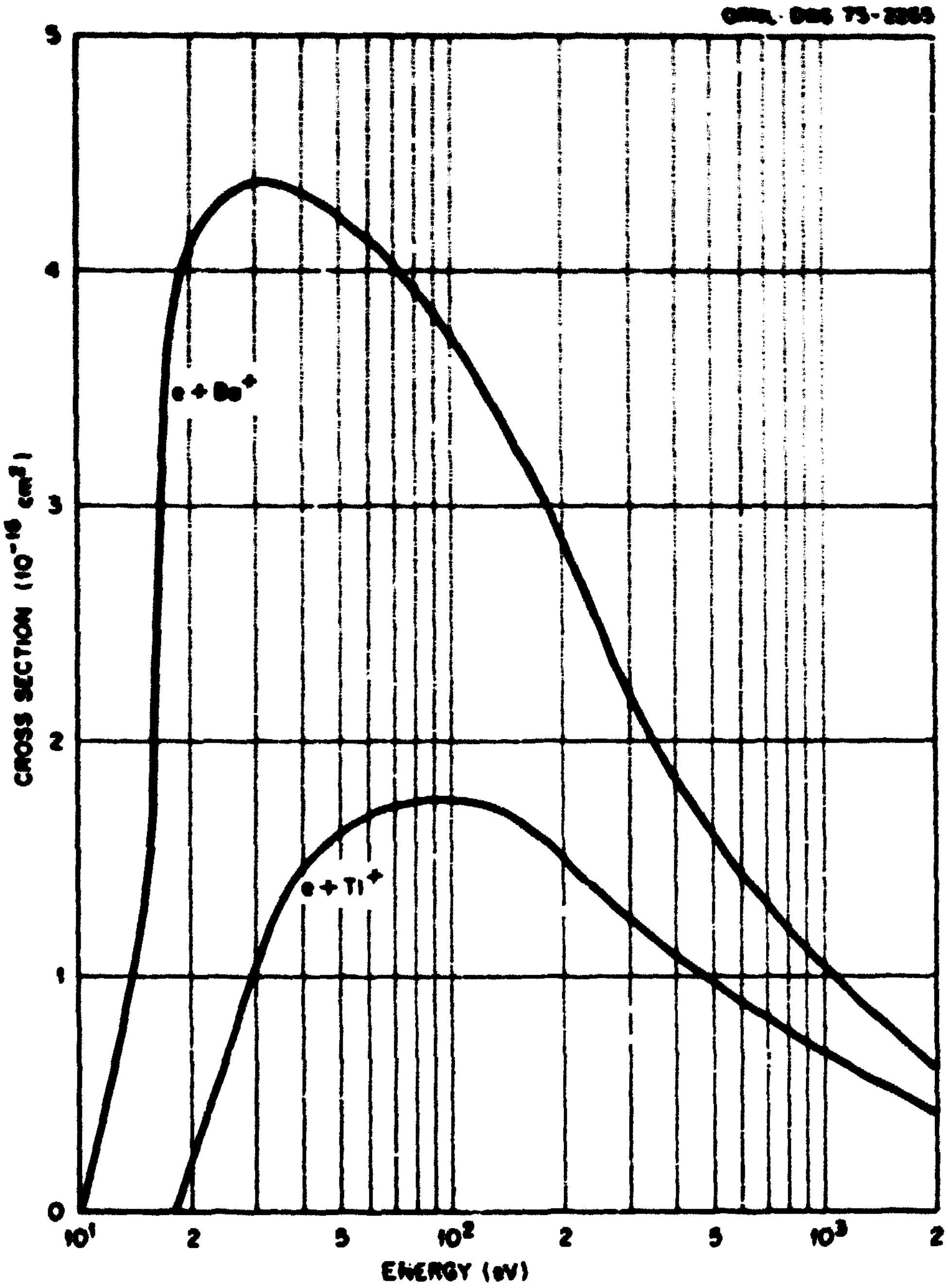
$e + Ba^+$: B. Peart, J. G. Stevenson, and K. T. Dolder, J. Phys. B 6, 146 (1973). R.K. Feeney, J.W. Hooper, and M.T. Elford, Phys. Rev. A 6, 1469 (1972); B. Peart and K.T. Dolder, J. Phys. B 1, 872 (1968).

$e + Tl^+$: T.F. Divine, R.K. Feeney, W.E. Sayle, II, and J.W. Hooper, Phys. Rev. A 13, 54 (1976).

Accuracy:

$e + Ba^+$: Maximum total error $\leq \pm$ 10% at E $\geq$ 20 eV; $\pm$ 25% at E = 15 eV.

$e + Tl^+$: The total error is believed not to exceed $\pm$ 15%.


CROSS SECTION (10^{-16} cm^2)
ENERGY (eV)
e + Ba⁺
e + Tl⁺
0
1
2
3
4
5
10^1
2
5
10^2
2
5
10^3
2

Cross Sections for Single Ionization of Mg^{+} and Mg^{2+} Ions by Electron Impact

Energy (eV)	Cross Sections (cm^2) $e + Mg^{+}$	$e + Mg^{2+}$
2.0 E 01	3.30 E-17	
2.5 E 01	4.45 E-17	
3.0 E 01	4.70 E-17	
4.0 E 01	4.81 E-17	
6.0 E 01	4.54 E-17	
8.0 E 01	4.28 E-17	
1.0 E 02	4.08 E-17	2.70 E-18
1.5 E 02	3.70 E-17	9.19 E-18
2.0 E 02	3.41 E-17	1.15 E-17
2.5 E 02	3.18 E-17	1.25 E-17
3.0 E 02	3.00 E-17	1.30 E-17
4.0 E 02	2.69 E-17	1.30 E-17
6.0 E 02	2.25 E-17	1.21 E-17
8.0 E 02	1.94 E-17	1.19 E-17
1.0 E 03	1.69 E-17	9.70 E-18
1.5 E 03	1.22 E-17	7.50 E-18
2.0 E 03		6.20 E-18
2.5 E 03		5.40 E-18
3.0 E 03		4.90 E-18

References:

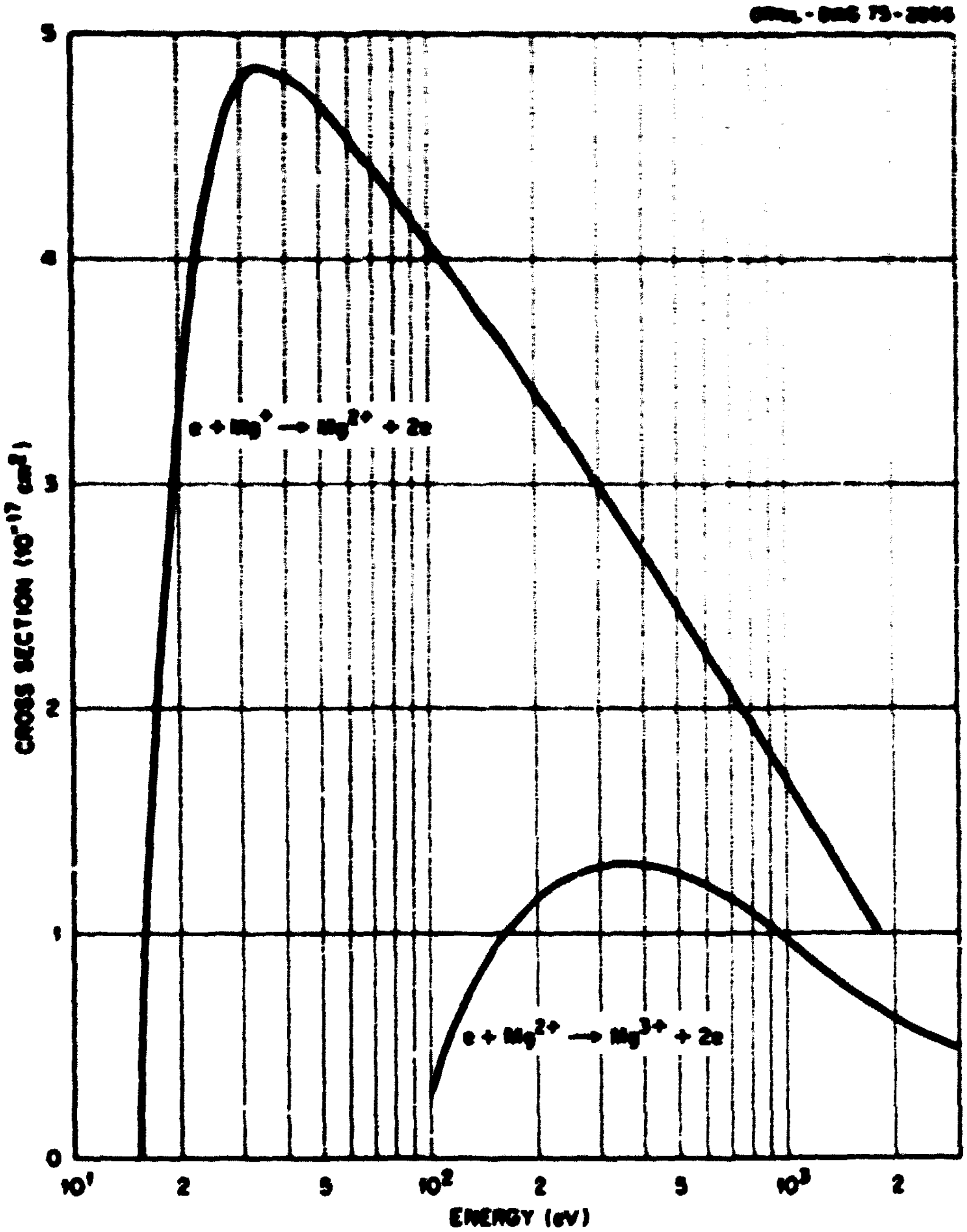
$e + Mg^{+}$: S.O. Martin, B. Peart, and K.T. Dolder, J. Phys. B 1, 537 (1968).

$e + Mg^{2+}$: B. Peart, S.O. Martin, and K.T. Dolder, J. Phys. B 2, 1176 (1969).

Accuracy:

$e + Mg^{+}$: Maximum total error $\leq \pm$ 10% at E $\geq$ 50 eV; $\pm$ 20% at E = 20 eV.

$e + Mg^{2+}$: Systematic error < $\pm$ 8%. Random error < $\pm$ 5%.


ORNL-DWG 75-2866
CROSS SECTION (10^{-17} cm^2)
0
1
2
3
4
5
10^1
2
5
10^2
2
5
10^3
2
ENERGY (eV)
$e + Mg^+ \rightarrow Mg^{2+} + 2e$
$e + Mg^{2+} \rightarrow Mg^{3+} + 2e$

Cross Sections for Ionization of Rb^+ and Cs^+ Ions by Electron Impact

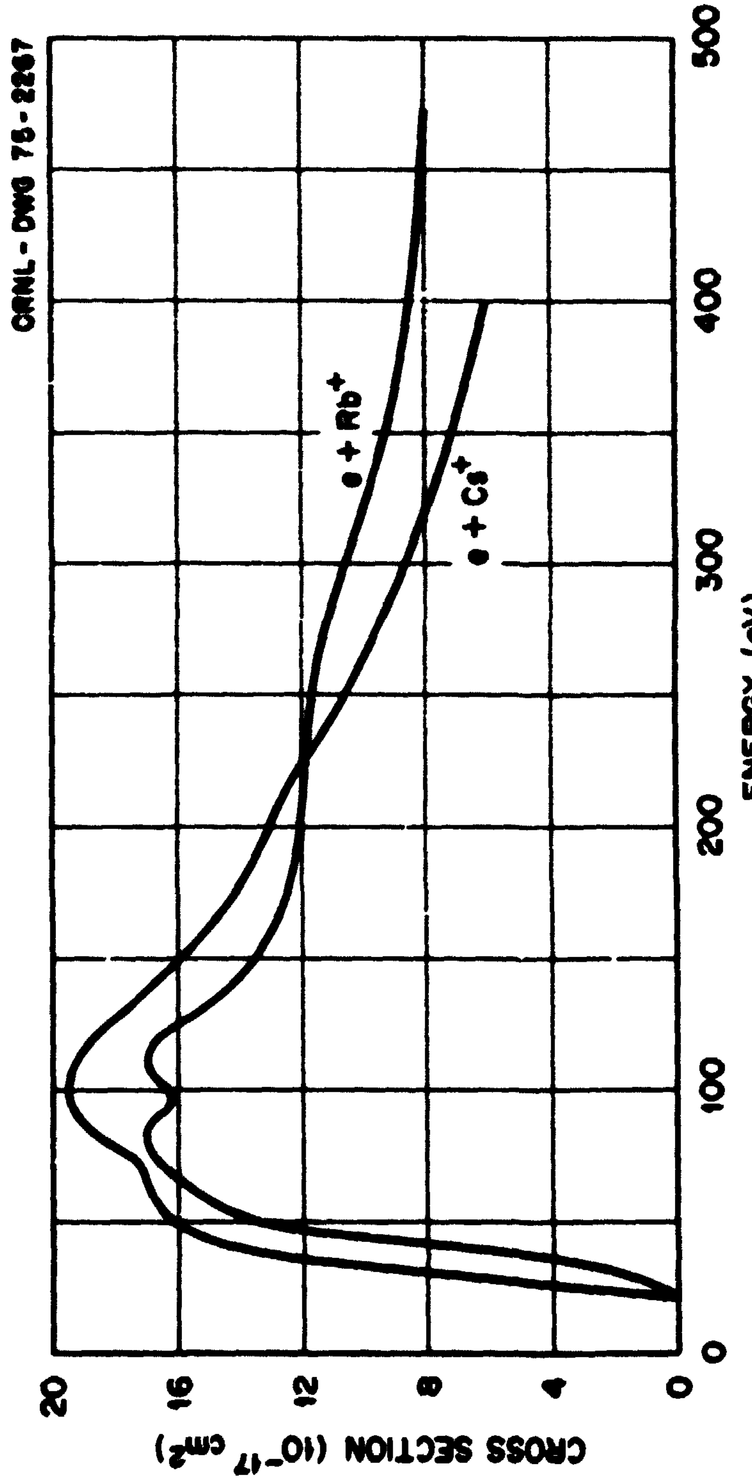
Energy (eV)	Cross Sections (cm^2)	
	$e + Rb^+$	$e + Cs^+$
3.0 E 01	1.60 E-17	7.00 E-17
4.0 E 01	6.60 E-17	1.40 E-16
5.0 E 01	1.32 E-16	1.62 E-16
6.0 E 01	1.52 E-16	1.68 E-16
7.0 E 01	1.64 E-16	1.72 E-16
7.5 E 01	1.68 E-16	1.76 E-16
8.0 E 01	1.70 E-16	1.82 E-16
9.0 E 01	1.66 E-16	1.92 E-16
1.0 E 02	1.63 E-16	1.95 E-16
1.1 E 02	1.69 E-16	1.92 E-16
1.2 E 02	1.66 E-16	1.86 E-16
1.3 E 02	1.53 E-16	1.78 E-16
1.5 E 02	1.36 E-16	1.60 E-16
2.0 E 02	1.21 E-16	1.30 E-16
2.25 E 02	1.19 E-16	1.20 E-16
2.5 E 02	1.16 E-16	1.06 E-16
3.5 E 02	9.20 E-17	7.10 E-17
4.0 E 02	8.50 E-17	6.00 E-17
4.75 E 02	8.00 E-17	

Reference:

B. Peart and K.T. Dolder, J. Phys. B 8, 56 (1975).

Accuracy:

The total error is believed not to exceed ± 12%.



ORNL-DWG 75-2267
e + Rb+
e + Cs+
ENERGY (eV)
CROSS SECTION (10-17 cm2)
0
100
200
300
400
500
20
16
12
8
4
0

Differential Cross Sections for Ejection of Electrons from Helium Atoms by Electron Impact

(The cross sections are differential in the ejected electron energy. The incident electron energy is indicated alongside the curves.)

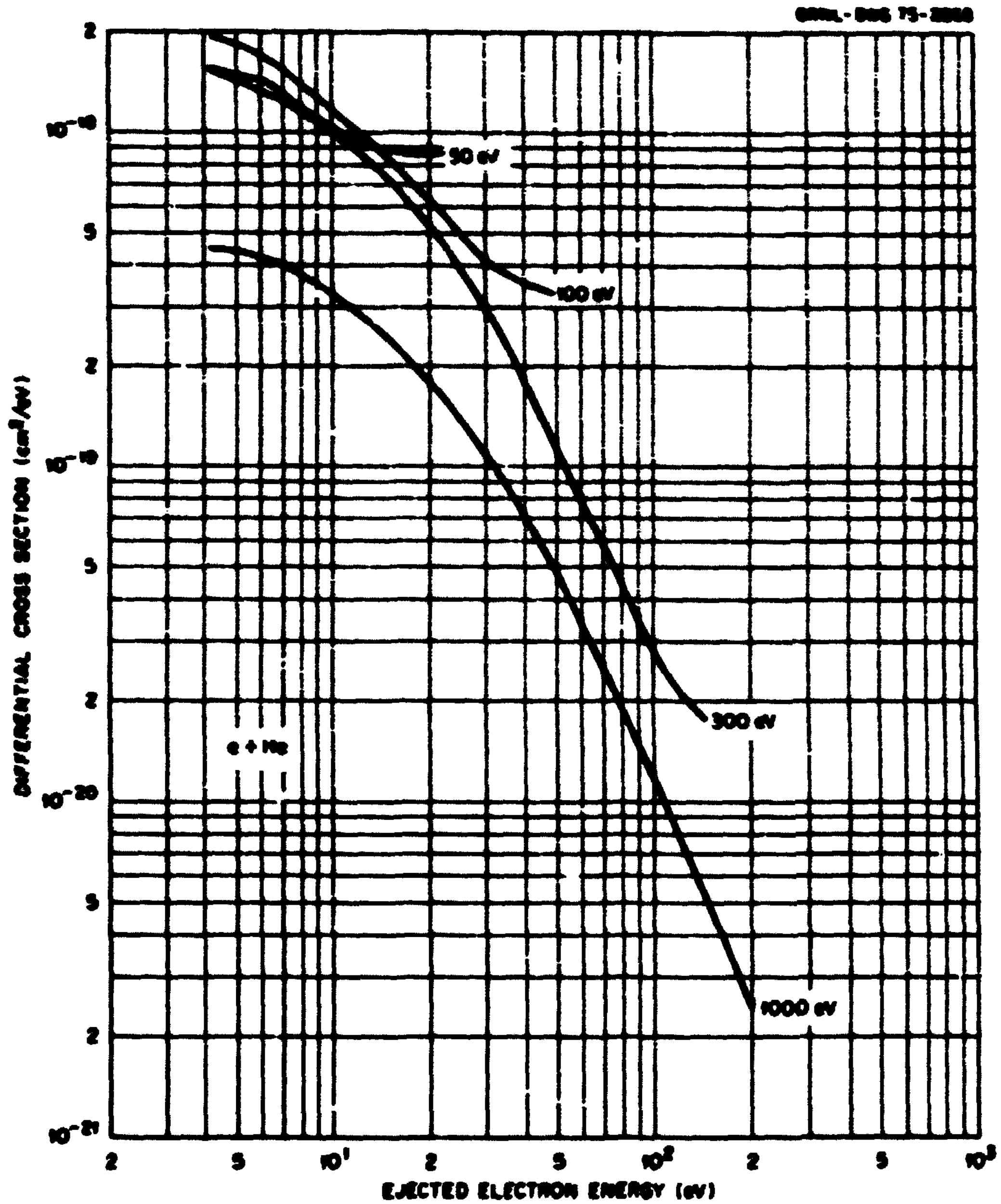
Energy (eV)	Differential Cross Sections (cm^2/eV)			
	50 eV	100 eV	300 eV	1000 eV
5.0 E 00	1.49 E-18	1.82 E-18	1.42 E-18	4.40 E-19
6.0 E 00	1.44 E-18	1.71 E-18	1.32 E-18	4.42 E-19
8.0 E 00	1.20 E-18	1.40 E-18	1.15 E-18	3.78 E-19
1.0 E 01	1.04 E-18	1.18 E-18	1.00 E-18	3.30 E-19
1.5 E 01	8.80 E-19	8.20 E-19	7.17 E-19	2.39 E-19
2.0 E 01	8.59 E-19	6.26 E-19	5.20 E-19	1.79 E-19
2.5 E 01		5.00 E-19	3.89 E-19	1.39 E-19
3.0 E 01		4.17 E-19	3.00 E-19	1.09 E-19
4.0 E 01		3.57 E-19	1.80 E-19	7.00 E-20
6.0 E 01			7.88 E-20	3.39 E-20
8.0 E 01			4.43 E-20	1.90 E-20
1.0 E 02			2.82 E-20	1.18 E-20
1.5 E 02				4.76 E-21
2.0 E 02				2.46 E-21

References:

e + He: C.B. Opal, E.C. Beaty, and W.K. Peterson, Atomic Data 4, 209 (1972); JILA Report No. 108, Univ. of Colorado, Boulder, Colorado (1971).

Accuracy:

The total error is believed not to exceed ± 30%.


ORNL-DWG 75-2888
30 eV
100 eV
300 eV
1000 eV
e + Ne
DIFFERENTIAL CROSS SECTION (cm²/eV)
EJECTED ELECTRON ENERGY (eV)

Differential Cross Sections for Ejection of Electrons from H_2, N_2, and O_2 Molecules by Impact of Incident Electrons with 500 eV Energy

(The cross sections are differential in the ejected electron energy.)

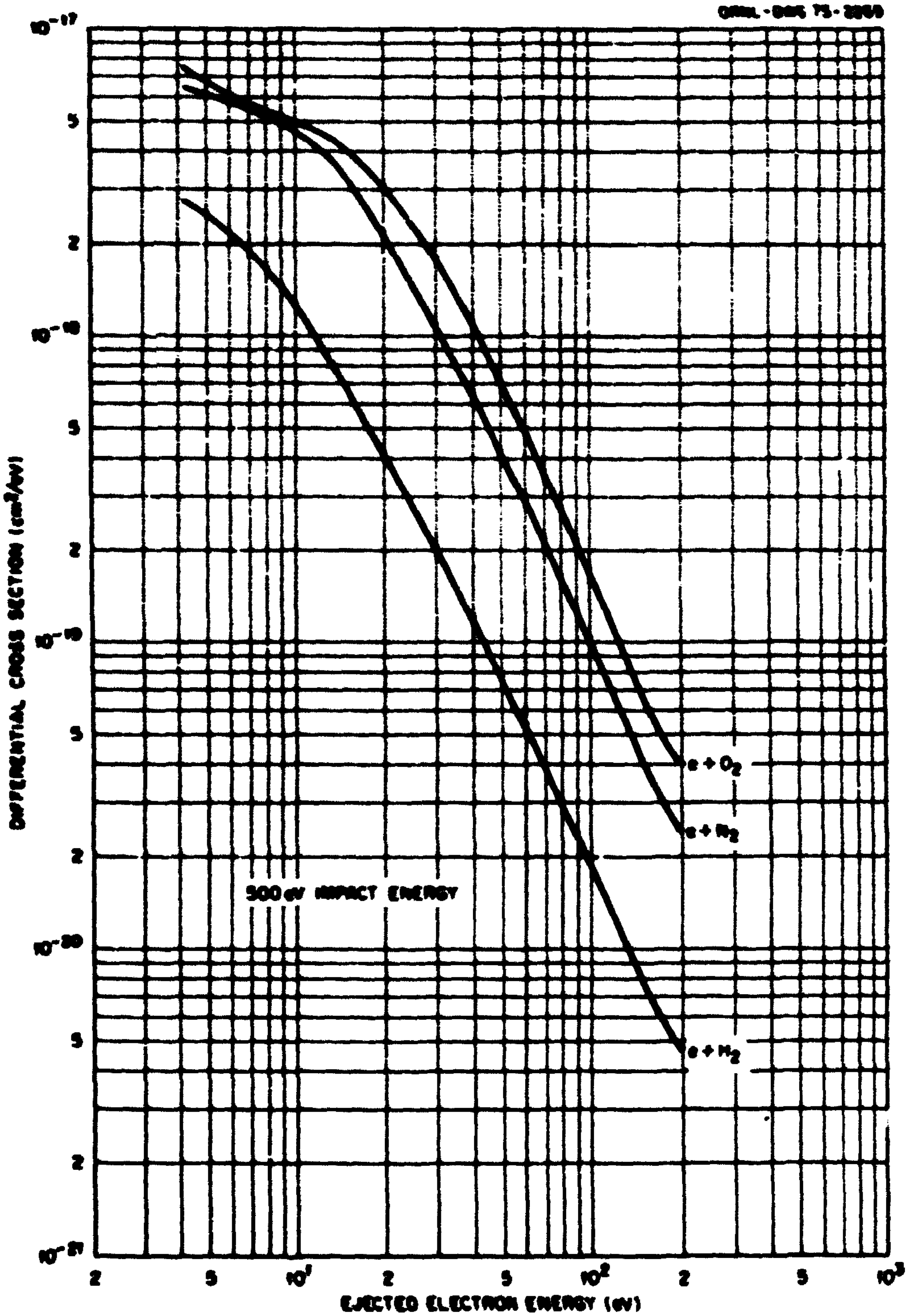
Energy (eV)	Differential Cross Section (cm^2/eV)		
	e + H_2	e + N_2	e + O_2
5.0 E 00	2.49 E-18	6.11 E-18	6.79 E-18
6.0 E 00	2.17 E-18	5.77 E-18	6.16 E-18
8.0 E 00	1.64 E-18	5.19 E-18	5.42 E-18
1.0 E 01	1.23 E-18	4.63 E-18	5.00 E-18
1.5 E 01	6.60 E-19	3.21 E-18	4.00 E-18
2.0 E 01	4.04 E-19	2.10 E-18	3.02 E-18
2.5 E 01	2.74 E-19	1.44 E-18	2.30 E-18
3.0 E 01	1.98 E-19	1.06 E-18	1.75 E-18
4.0 E 01	1.13 E-19	6.30 E-19	1.08 E-18
6.0 E 01	5.18 E-20	2.88 E-19	4.90 E-19
8.0 E 01	2.89 E-20	1.60 E-19	2.70 E-19
1.0 E 02	1.80 E-20	9.83 E-20	1.64 E-19
1.5 E 02	7.48 E-21	3.98 E-20	6.53 E-20
2.0 E 02	4.60 E-21	2.38 E-20	4.00 E-20

References:

e+(H_2,N_2,O_2): C.B. Opal, E.C. Beaty, and W.K. Peterson, Atomic Data 4, 209 (1972); JILA Report No. 108, Univ. of Colorado, Boulder, Colorado (1971).

Accuracy:

e+(H_2,N_2,O_2): The total error is believed not to exceed ± 30%.


ORNL-DWG 75-3869
10^{-17}
5
2
10^{-18}
5
2
10^{-19}
5
2
10^{-20}
5
2
10^{-21}
DIFFERENTIAL CROSS SECTION (cm²/eV)
2
5
10^1
2
5
10^2
2
5
10^3
EJECTED ELECTRON ENERGY (eV)
e + O_2
e + N_2
e + H_2
500 eV IMPACT ENERGY

C.5 Electron Attachment

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Cross Section for Radiative Attachment of Electrons to Ground-State Hydrogen Atoms (Theoretical)

$e + H \rightarrow H^- + h\nu$

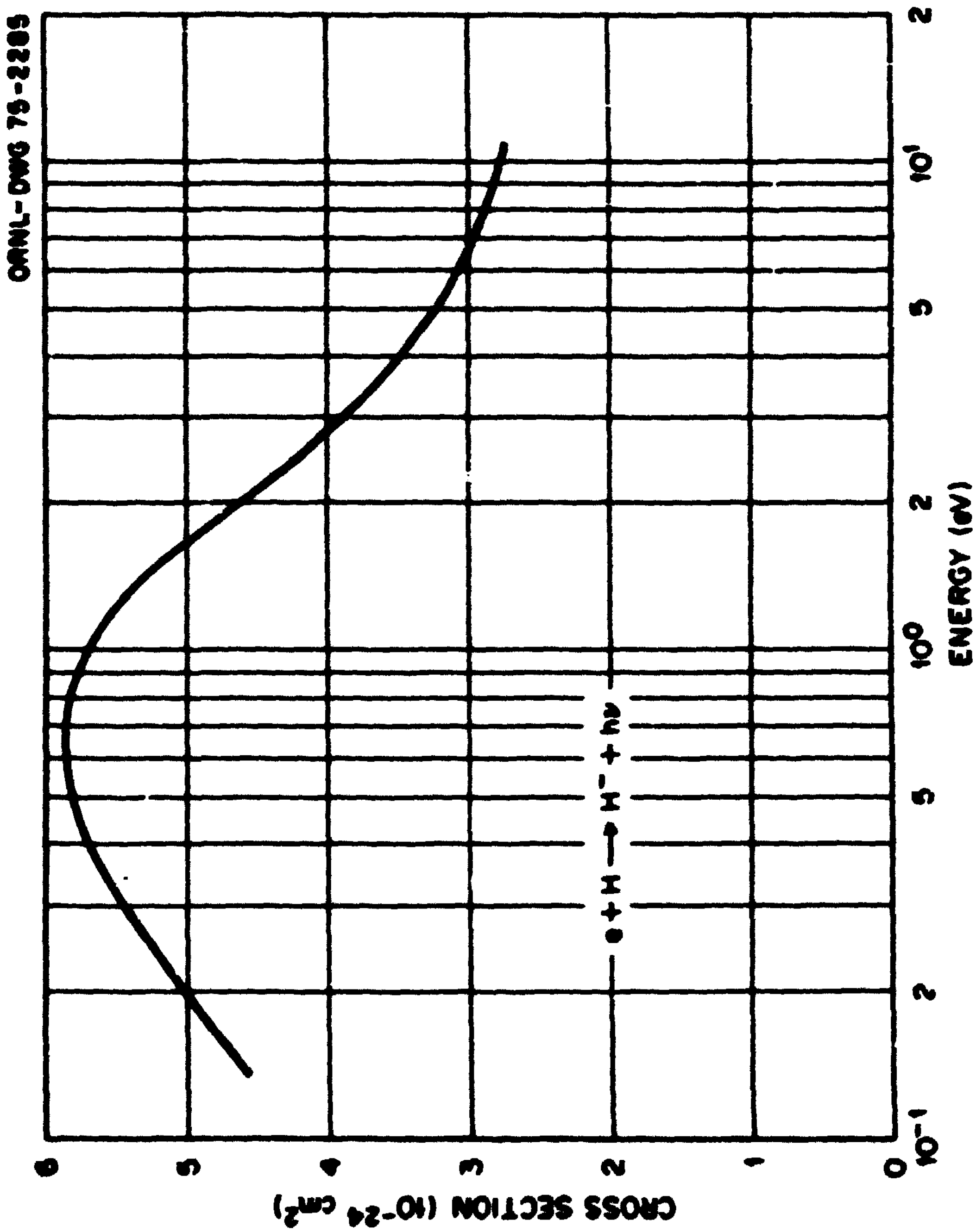
Electron Energy (eV)	Cross Section (cm^2)
1.35 E-01	4.56 E-24
2.00 E-01	5.02 E-24
3.00 E-01	5.45 E-24
4.00 E-01	5.70 E-24
5.00 E-01	5.82 E-24
6.00 E-01	5.86 E-24
7.00 E-01	5.86 E-24
8.00 E-01	5.83 E-24
1.00 E 00	5.70 E-24
1.50 E 00	5.20 E-24
2.00 E 00	4.62 E-24
3.00 E 00	3.91 E-24
4.00 E 00	3.50 E-24
6.00 E 00	3.08 E-24
8.00 E 00	2.87 E-24
1.00 E 01	2.77 E-24
1.08 E 01	2.73 E-24

Reference:

H.S.W. Massey, E.H.S. Burhop, and H.B. Gilbody, "Electronic and Ionic Impact Phenomena," Vol. II, Oxford Univ. Press (1969), page 1260.

Accuracy:

The total error is believed not to exceed ± 5%.


ORNL-DWG 75-2285
e + H → H⁻ + hν
ENERGY (eV)
CROSS SECTION (10⁻²⁴ cm²)
0
1
2
3
4
5
6
10⁻¹
2
5
10⁰
2
5
10¹
2

Cross Section for the Production of H^- Ions by Dissociative Attachment of Electrons in Hydrogen Gas

$$e + H_2 \rightarrow H^- + \text{products}$$

Electron Energy (eV)	Cross Section (cm^2)
6.00 E 00	
7.00 E 00	5.00 E-22
8.00 E 00	1.20 E-21
9.00 E 00	4.50 E-21
1.00 E 01	1.10 E-20
1.10 E 01	1.20 E-20
1.20 E 01	1.22 E-20
1.24 E 01	1.26 E-20
1.30 E 01	1.03 E-20
1.34 E 01	9.70 E-21
1.38 E 01	2.10 E-20
1.40 E 01	3.10 E-20
1.42 E 01	3.37 E-20
1.46 E 01	3.46 E-20
1.48 E 01	2.00 E-20
1.50 E 01	2.10 E-20
1.54 E 01	1.62 E-20
1.60 E 01	1.75 E-20
1.70 E 01	1.83 E-20
1.80 E 01	1.96 E-20
1.90 E 01	2.12 E-20
2.00 E 01	2.20 E-20
2.20 E 01	2.34 E-20
2.30 E 01	2.41 E-20

Reference:

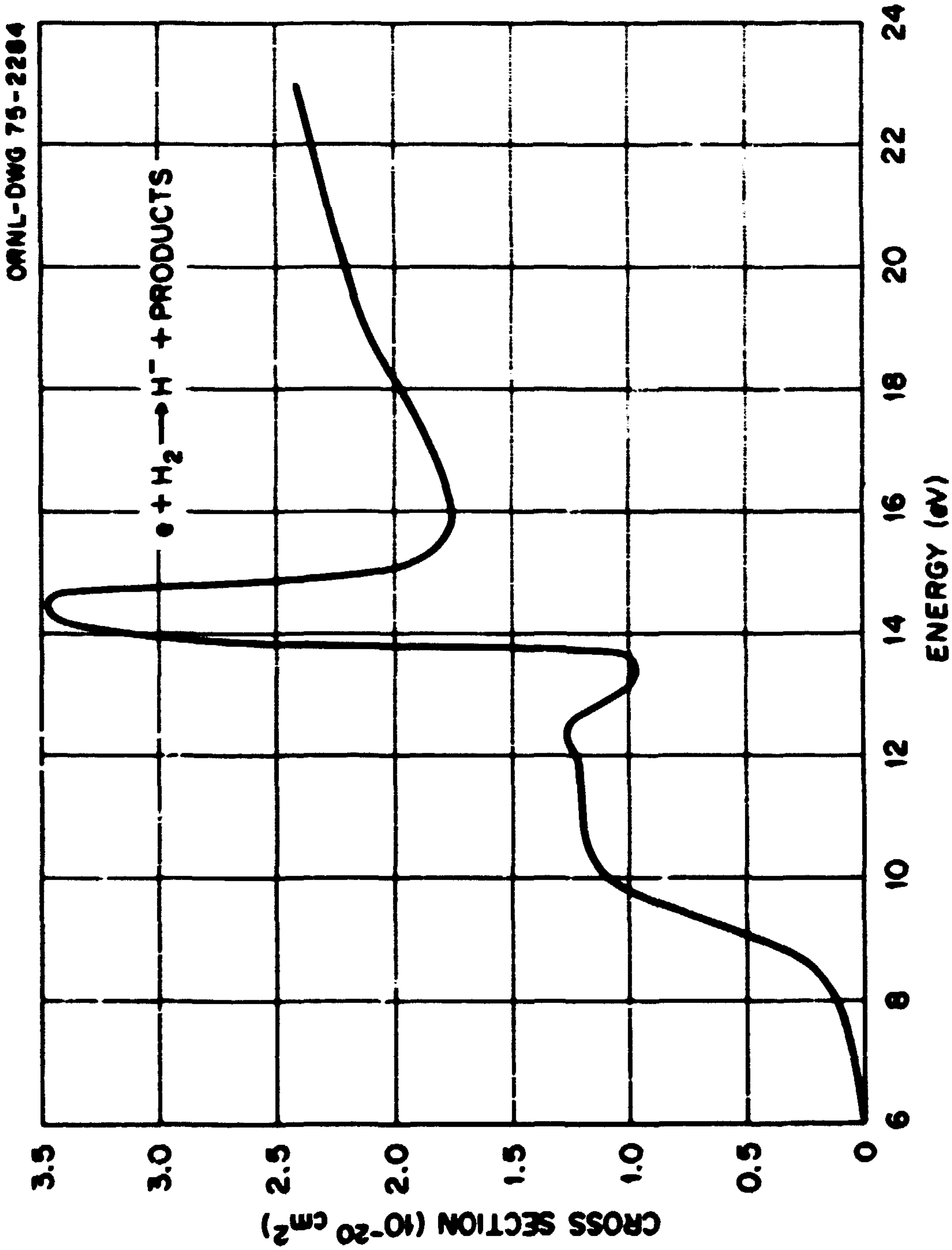
G.J. Schulz, Phys. Rev. **113**, 816 (1959).

Accuracy:

The total error is believed not to exceed ± 35%.

Note:

Below 13.6 eV, the reaction is $e + H_2 \rightarrow H^- + H$. Above 13.6 eV, the reaction $e + H_2 \rightarrow H^- + H^*$ can occur. Above 17.2 eV, H^- and H^+ can be produced simultaneously in an "ion-pair production" process.


ORNL-DWG 75-2284
e + H2 ⟶ H⁻ + PRODUCTS
CROSS SECTION (10⁻²⁰ cm²)
ENERGY (eV)
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
6
8
10
12
14
16
18
20
22
24

Cross Sections for Negative Ion Formation in H_2, HD, and D_2 by Low Energy Electrons

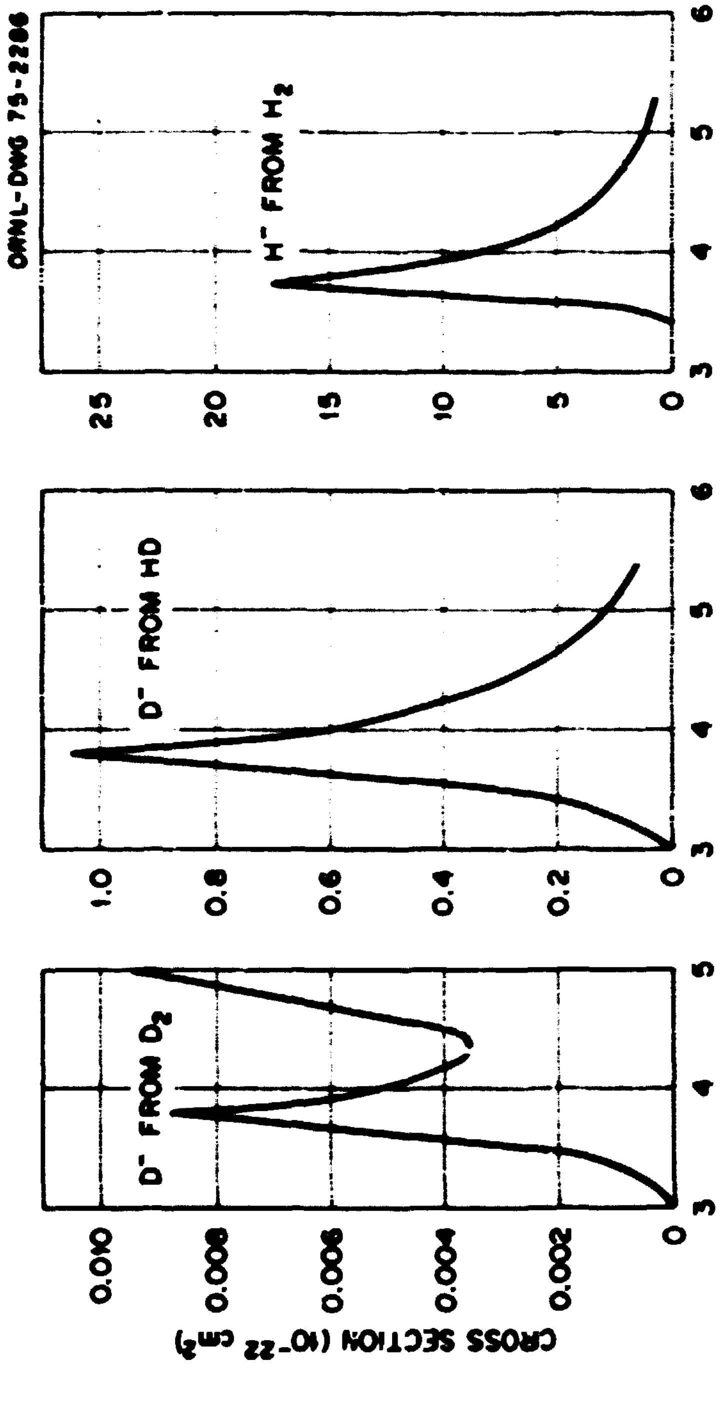
Electron Energy (eV)	Cross Sections (cm^2)		
	H^- from H_2	D^- from HD	D^- from D_2
3.00 E 00			
3.30 E 00		1.10 E-23	7.00 E-26
3.40 E 00		2.00 E-23	1.30 E-25
3.60 E 00	7.50 E-22	5.30 E-23	4.60 E-25
3.75 E 00	1.75 E-21	9.30 E-23	7.00 E-25
3.80 E 00	1.45 E-21	1.05 E-22	8.90 E-25
4.00 E 00	9.50 E-22	6.00 E-23	5.20 E-25
4.30 E 00	4.25 E-22	3.55 E-23	3.55 E-25
4.40 E 00	3.60 E-22	3.00 E-23	3.55 E-25
4.60 E 00	2.50 E-22	2.15 E-23	5.15 E-25
4.80 E 00	1.70 E-22	1.55 E-23	7.40 E-25
5.00 E 00	1.15 E-22	1.10 E-23	9.50 E-25
5.30 E 00	7.00 E-23	7.00 E-24	
5.40 E 00		6.00 E-24	

References:

G.J. Schulz and R.K. Asundi, Phys. Rev. Letts. 15, 946 (1965); G.J. Schulz and R.K. Asundi, Phys. Rev. 158, 25 (1967).

Accuracy:

The total error is believed not to exceed ± 30%.


ORNL-DWG 75-2286
D⁻ FROM D2
D⁻ FROM HD
H⁻ FROM H2
ENERGY (eV)
CROSS SECTION (10⁻²² cm²)
0.010
0.008
0.006
0.004
0.002
0
1.0
0.8
0.6
0.4
0.2
25
20
15
10
5
3
4
5
6

Calculated Recombination Coefficient $\alpha_{n,\ell}$ for the Radiative Recombination of Electrons to H^+ Ions in Different Final Quantum States n,ℓ at Temperatures T of 10,000°K and 20,000°K

$$e + H^+ \rightarrow H(n,\ell) + h\nu$$

Recombination Coefficient $\alpha_{n,\ell}$ (10^{-16} cm^3/sec)

T = 10,000 °K

n\ℓ	0	1	2	3	4	5	6	7	8	9	10	11
1	1582											
2	234	536										
3	78.2	204	173									
4	36.3	96.5	109	55.5								
5	19.9	52.8	66.9	49.4	17.9							
6	12.2	31.6	42.9	37.5	20.5	5.85						
7	7.94	20.3	28.8	28.2	18.7	8.22	2.00					
8	5.48	13.7	20.0	20.9	15.8	8.59	3.25	0.706				
9	3.94	9.73	14.4	15.6	12.8	7.97	3.75	1.28	0.259			
10	2.93	7.09	10.6	12.0	10.5	7.12	3.83	1.61	0.502	0.100		
11	2.23	5.34	7.94	9.15	8.45	6.20	3.67	1.77	0.688	0.203	0.039	
12	1.74	3.99	6.08	7.22	6.85	5.38	3.41	1.83	0.825	0.304	0.084	0.016

T = 20,000°K

n\ℓ	0	1	2	3	4	5	6	7	8	9	10	11
1	1079											
2	160	324										
3	52.9	123	90.9									
4	24.3	58.1	56.7	25.7								
5	13.2	31.3	34.9	22.3	7.54							
6	7.95	18.6	22.3	16.9	8.10	2.35						
7	5.14	11.7	15.1	12.7	7.38	2.96	0.766					
8	3.52	7.81	10.5	9.78	6.43	3.11	1.10	0.267				
9	2.50	5.45	7.51	7.45	5.45	3.00	1.28	0.424	0.096			
10	1.86	3.94	5.50	5.74	4.53	2.74	1.32	0.526	0.164	0.036		
11	1.40	2.93	4.13	4.49	3.75	2.46	1.29	0.572	0.215	0.064	0.014	
12	1.09	2.23	3.16	3.51	3.08	2.17	1.24	0.598	0.252	0.091	0.026	0.006

Reference:

D.R. Bates, Case Studies in Atomic Physics 4, 57 (1974).

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Total Recombination Coefficient α for the Radiative Electon-Ion Recombination of Various Ions at 250°K

System	Recombination Coefficient α (cm^3/sec)
$H^+ + e$	4.8 E-12
$He^+ + e$	4.8 E-12
$C^+ + e$	4.2 E-12
$N^+ + e$	3.6 E-12
$O^+ + e$	3.7 E-12

Reference:

D.R. Bates and A. Dalgarno, Atomic and Molecular Processes, ed. by D.R. Bates, Academic Press, New York, 1962, p.252.

Recombination Coefficient α for the Radiative Recombination of Electrons with He^+ and H^+ Ions at 10,000°K and 20,000°K

Level Formed / Temp. (°K)	He Ground State	Excited He Singlets	Excited He Triplets	He Any Level	H Any Level
	Recombination Coefficient α (cm^3/sec)				
10,000	1.59 E-13	6.30 E-14	2.10 E-13	4.31 E-13	4.17 E-13
20,000	1.15 E-13	3.50 E-14	1.20 E-13	2.69 E-13	2.51 E-13

Reference:

A. Burgess and M.F. Seaton, Monthly Notices of the Royal Astronomical Society 121, 471 (1960).

Calculated Radiative Recombination Coefficient α for the Recombination of Electrons with O^+ Ions

$$e + O^+ \rightarrow O + h\nu$$

Electron Temp. (°K)	Recombination Coefficient α (cm^3/sec)
2.5 E 02	3.4 E-12
5.0 E 02	2.2 E-12
1.0 E 03	1.3 E-12
2.0 E 03	8.0 E-13

Reference:

A. Dalgarno, Ann. Geophys. 17, 16 (1961).

Calculated Recombination Coefficient $\alpha_{n,\ell}$ for the Radiative Recombination of Electrons to H^+ Ions in Several Final Quantum States at Various Temperatures T

$$e + H^+ \rightarrow H(n,\ell) + h\nu$$

Quantum Numbers of Final States		Recombination Coefficient $\alpha_{n,\ell}$ (cm^3/sec)				
n	ℓ	T=312.5° K	T=1250° K	T=10^{4}° K	T =$8x10^{4}$° K	T=$6.4x10^{5}$° K
2	0	1.36 E-12	6.8 E-13	2.3 E-13	6.7 E-14	1.1 E-14
	1	3.72 E-12	1.82 E-12	5.4 E-13	9.4 E-14	8.0 E-15
3	0	4.60 E-13	2.3 E-13	8.0 E-14	2.1 E-14	3.0 E-15
	1	1.41 E-12	6.9 E-13	2.0 E-13	3.5 E-14	3.0 E-15
	2	1.61 E-12	7.5 E-13	1.7 E-13	1.9 E-14	1.0 E-15

Reference:

H.S.W. Massey, Electronic and Ionic Impact Phenomena, Vol. II, Electron Collisions with Molecules and Photo-Ionization, p. 1070 (Clarendon Press, Oxford, 1969).

Calculated Cross Sections for the Radiative Recombination of Electrons to H^+ Ions in Various Final Quantum States for Four Different Electron Energies

$$e + H^+ \rightarrow H(n,\ell) + h\nu$$

Quantum Numbers of Final States		Cross Sections (cm^2)			
n	ℓ	0.28 eV	0.13 eV	0.069 eV	0.034 eV
2	0	1.20 E-21	2.45 E-21	4.80 E-21	9.81 E-21
	1	3.04 E-21	6.48 E-21	1.29 E-20	2.67 h-20
3	0	4.02 E-22	8.26 E-22	1.62 E-21	3.30 E-21
	1	1.15 E-21	2.46 E-21	4.95 E-21	1.01 E-20
	2	1.15 E-21	2.62 E-21	5.47 E-21	1.15 E-20

Reference:

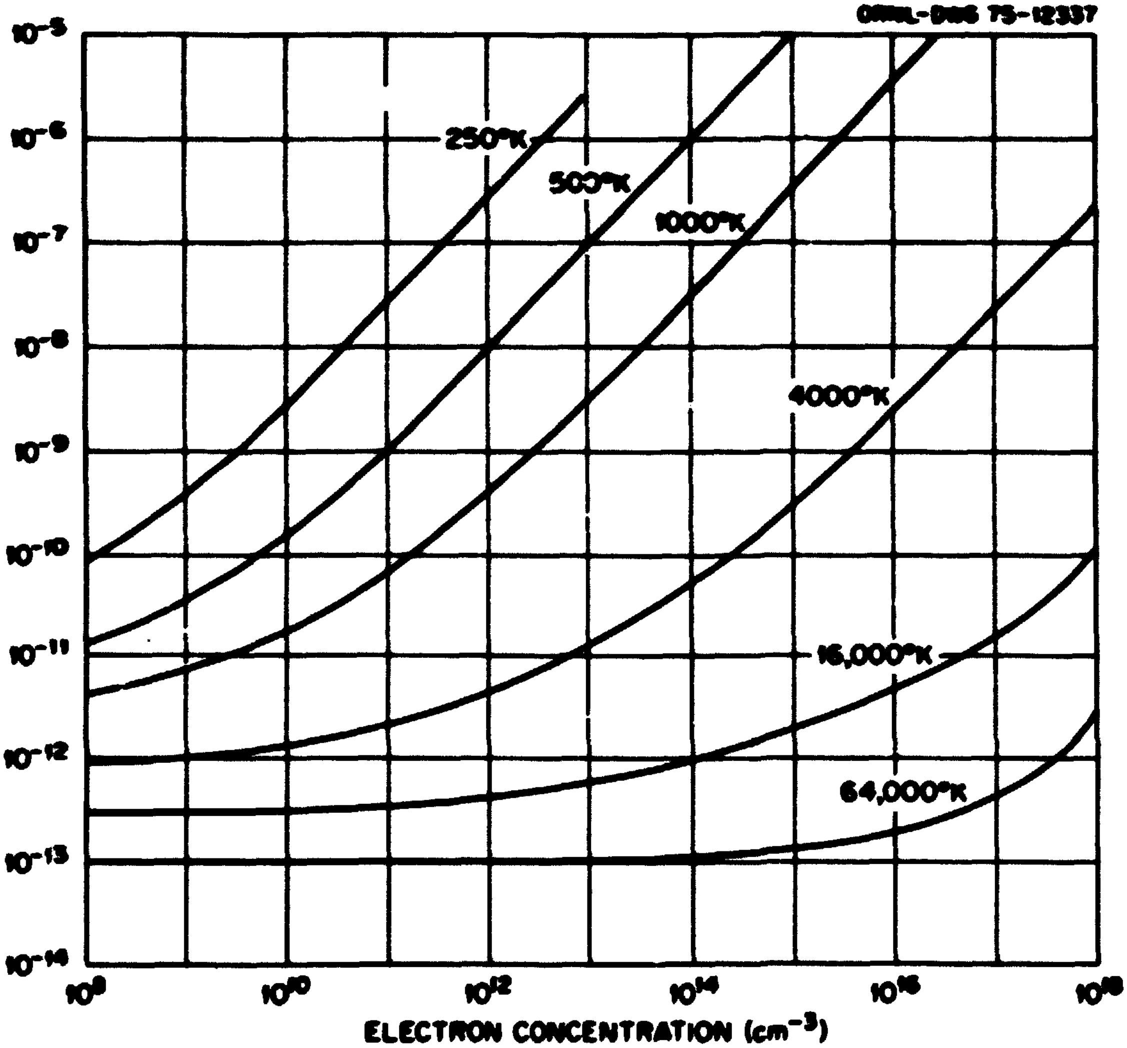
H.S.W. Massey, Electronic and Ionic Impact Phenomena, Vol. II, Electron Collisions with Molecules and Photo-Ionization, Clarendon Press, Oxford (1969), p. 1070.

Calculated Recombination Coefficient α for the Collisional-Radiative Recombination of Electrons with H^+ Ions in an Optically Thin H^+ Plasma, for Various Electron Temperatures T_e

Electron Concentration n_e (cm^{-3})	Recombination Coefficient α (cm^3/sec)					
	T_e = 250° K	T_e = 500° K	T_e = 1000° K	T_e = 4000° K	T_e = 16,000° K	T_e = 64,000° K
Limit $n_e \to 0$	4.8 E-12	3.1 E-12	2.0 E-12	7.9 E-13	2.9 E-13	1.0 E-13
1.0 E 08	8.8 E-11	1.4 E-11	4.1 E-12	9.2 E-13	3.0 E-13	1.0 E-13
1.0 E 09	4.0 E-10	3.8 E-11	7.5 E-12	1.0 E-12	3.0 E-13	1.0 E-13
1.0 E 10	2.8 E-09	1.6 E-10	1.9 E-11	1.4 E-12	3.2 E-13	1.0 E-13
1.0 E 11	2.7 E-08	1.0 E-09	6.9 E-11	2.2 E-12	3.4 E-13	1.0 E-13
1.0 E 12	2.6 E-07	9.0 E-09	3.9 E-10	4.4 E-12	4.3 E-13	1.0 E-13
1.0 E 13	2.6 E-06	8.9 E-08	3.1 E-09	1.2 E-11	6.2 E-13	1.1 E-13
1.0 E 14	2.6 E-05	8.8 E-07	2.9 E-09	5.1 E-11	1.0 E-12	1.2 E-13
1.0 E 15		8.8 E-06	2.9 E-07	2.7 E-10	2.3 E-12	1.6 E-13
1.0 E 16			2.9 E-06	2.3 E-09	5.0 E-12	1.9 E-13
1.0 E 17				2.1 E-08	1.4 E-11	4.4 E-13
1.0 E 18				2.0 E-07	9.6 E-11	2.8 E-12
Limit $n_e \to \infty$	2.6 E-19 n_e	8.8 E-21 n_e	2.9 E-22 n_e	1.9 E-25 n_e	9.1 E-29 n_e	2.7 E-30 n_e

Reference:

D.R. Bates, A.E. Kingston, and R.W.P. McWhirter, Proc. Roy. Soc. (London) A267, 297 (1962).


ORNL-DWG 75-12337
250°K
500°K
1000°K
4000°K
16,000°K
64,000°K
α, RECOMBINATION COEFFICIENT (cm³/sec)
ELECTRON CONCENTRATION (cm⁻³)

Calculated Recombination Coefficient α_n for the Radiative Recombination of Electrons to Different Final States of H^+ Ions at Various Electron Temperatures T_e

$$e + H^+ \rightarrow H(n) + h\nu$$

Recombination Coefficient α_n (cm^3/sec)

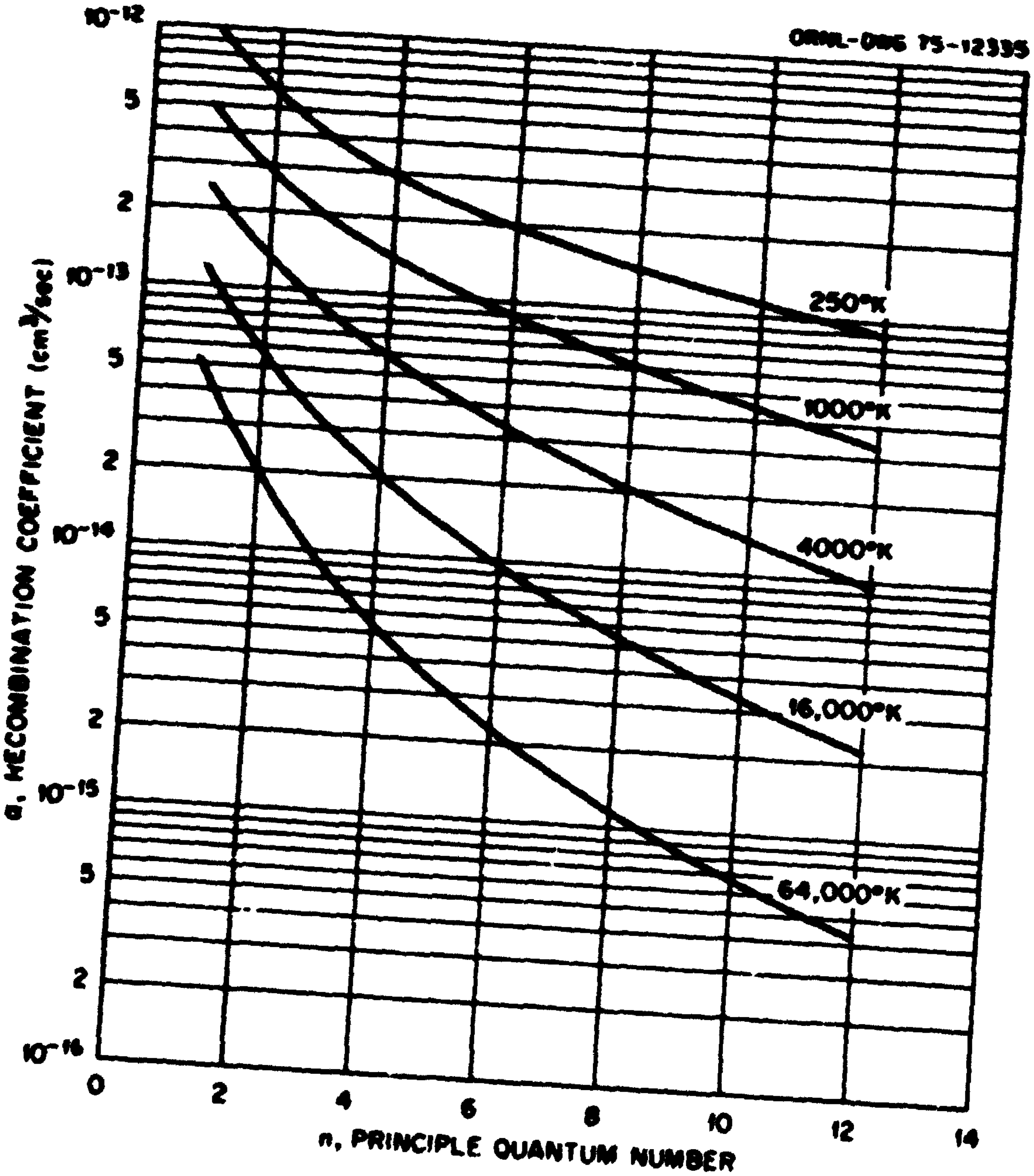
Principal Quantum Number n	T_e=250° K	T_e=500° K	T_e=1000° K	T_e=2000° K	T_e=4000° K	T_e=8000° K
1	1.02 E-12	7.17 E-13	5.07 E-13	3.56 E-13	2.50 E-13	1.74 E-13
2	5.66 E-13	3.98 E-13	2.79 E-13	1.94 E-13	1.32 E-13	8.80 E-14
3	3.90 E-13	2.72 E-13	1.88 E-13	1.28 E-13	8.44 E-14	5.33 E-14
4	2.95 E-13	2.04 E-13	1.40 E-13	9.23 E-14	5.86 E-14	3.53 E-14
5	2.36 E-13	1.62 E-13	1.08 E-13	6.99 E-14	4.29 E-14	2.48 E-14
6	1.96 E-13	1.33 E-13	8.70 E-14	5.48 E-14	3.26 E-14	1.82 E-14
7	1.66 E-13	1.11 E-13	7.16 E-14	4.39 E-14	2.54 E-14	1.38 E-14
8	1.43 E-13	9.46 E-14	5.99 E-14	3.59 E-14	2.02 E-14	1.07 E-14
9	1.25 E-13	8.17 E-14	5.08 E-14	2.98 E-14	1.64 E-14	8.51 E-15
10	1.11 E-13	7.13 E-14	4.36 E-14	2.51 E-14	1.35 E-14	6.88 E-15
11	9.88 E-14	6.27 E-14	3.77 E-14	2.13 E-14	1.13 E-14	5.65 E-15
12	8.87 E-14	5.56 E-14	3.29 E-14	1.83 E-14	9.53 E-15	4.71 E-15
Total*	4.84 E-12	3.12 E-12	1.99 E-12	1.26 E-12	7.85 E-13	4.83 E-13

Principal Quantum Number n	T_e=16000° K	T_e=32000° K	T_e=64000° K
1	1.20 E-13	8.02 E-14	5.19 E-14
2	5.63 E-14	3.42 E-14	1.95 E-14
3	3.19 E-14	1.80 E-14	9.46 E-15
4	2.00 E-14	1.06 E-14	5.33 E-15
5	1.35 E-14	6.87 E-15	3.32 E-15
6	9.53 E-15	4.71 E-15	2.22 E-15
7	7.02 E-15	3.39 E-15	1.56 E-15
8	5.34 E-15	2.53 E-15	1.14 E-15
9	4.16 E-15	1.93 E-15	8.66 E-16
10	3.31 E-15	1.52 E-15	6.72 E-16
11	2.68 E-15	1.22 E-15	5.33 E-16
12	2.21 E-15	9.89 E-16	4.30 E-16
Total*	2.93 E-13	1.73 E-13	1.00 E-13

Reference:

D.R. Bates and A. Dalgarno, Atomic and Molecular Processes, Ed. by D.R. Bates, Ch. 7, Electronic Recombination, Academic Press, New York (1962), p. 249.

*Summed over all final states.


ORNL-DWG 75-12335
250°K
1000°K
4000°K
16,000°K
64,000°K
α, RECOMBINATION COEFFICIENT (cm³/sec)
n, PRINCIPLE QUANTUM NUMBER
10⁻¹²
10⁻¹³
10⁻¹⁴
10⁻¹⁵
10⁻¹⁶
0
2
4
6
8
10
12
14

Calculated Cross Sections for the Radiative Capture of Electrons to Various States of a Hydrogen Atom at Four Different Electron Energies

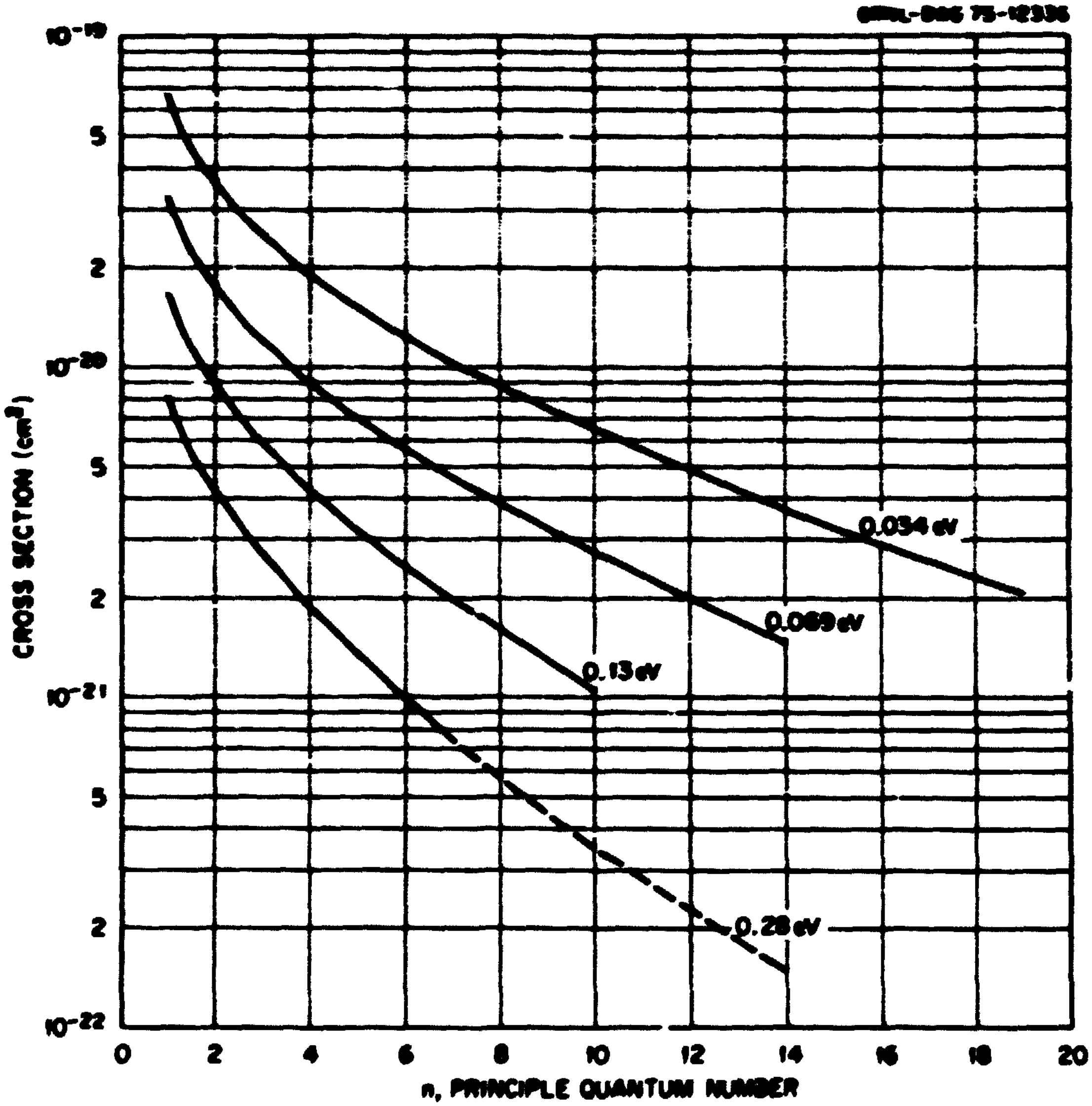
$$e + H^+ \rightarrow H(n) + h\nu$$

Total*	Cross Sections (cm^2)			
	0.28 eV	0.13 eV	0.069 eV	0.034 eV
1	8.10 E-21	1.66 E-20	3.28 E-20	6.70 E-20
2	4.24 E-21	8.93 E-21	1.77 E-20	3.65 E-20
3	2.70 E-21	5.91 E-21	1.20 E-20	2.49 E-20
4	1.88 E-21	4.24 E-21	8.84 E-21	1.96 E-20
5	1.36 E-21	3.20 E-21	6.89 E-21	1.49 E-20
6	9.90 E-22	2.49 E-21	5.51 E-21	1.23 E-20
7	7.30 E-22	2.00 E-21	4.52 E-21	1.03 E-20
8		1.62 E-21	3.81 E-21	8.75 E-21
9		1.31 E-21	3.23 E-21	7.55 E-21
10		1.04 E-21	2.74 E-21	6.50 E-21
11			2.33 E-21	5.72 E-21
12			2.00 E-21	4.52 E-21
13			1.72 E-21	4.03 E-21
14	1.50 E-22		1.47 E-21	3.62 E-21
15				3.25 E-21
16				2.91 E-21
17				2.62 E-21
18				2.35 E-21
19				2.09 E-21
20		2.15 E-22		
28			3.02 E-22	
40				4.32 E-22
Total	2.30 E-20	5.37 E-20	1.19 E-19	2.72 E-19

Reference:

H.S.W. Massey, Electronic and Ionic Impact Phenomena, Vol. II, Electron Collisions with Molecules and Photo-Ionization, Clarendon Press, Oxford (1969), p. 1071.

*Total Quantum Number of Atomic State into which Electron is Captured.


ORNL-DWG 75-12336
10^{-19}
5
2
10^{-20}
5
2
10^{-21}
5
2
10^{-22}
CROSS SECTION (cm^2)
0
2
4
6
8
10
12
14
16
18
20
n, PRINCIPLE QUANTUM NUMBER
0.034 eV
0.069 eV
0.13 eV
0.28 eV

Calculated Recombination Coefficient α for the Collisional-Radiative Recombination of Electrons with H^+ Ions in Three Different H^+ Plasmas (Optically Thin, Optically Thick Towards Lines of the Lyman Series, and Optically Thick Towards Lines of all Series) for Several Electron Temperatures T_e

Electron Density n_e (cm^{-3})	Recombination Coefficient α (cm^3/sec)			
	T_e=500° K*	T_e=500° K†	T_e=500° K‡	T_e=4000° K*
1.0 E 08	1.4 E-11	1.1 E-11	2.6 E-12	9.2 E-13
1.0 E 09	3.8 E-11	3.3 E-11	1.1 E-11	1.0 E-12
1.0 E 10	1.6 E-10	1.6 E-10	1.0 E-10	1.4 E-12
1.0 E 11	1.0 E-09	1.0 E-09	1.0 E-09	2.2 E-12
1.0 E 12	9.0 E-09	9.0 E-09	9.0 E-09	4.4 E-12
1.0 E 13				1.2 E-11
1.0 E 14				5.1 E-11
1.0 E 15				2.7 E-10
1.0 E 16				2.3 E-09

Electron Density n_e (cm^{-3})	T_e=4000° K†	T_e=4000° K‡	T_e=32,000° K*	T_e=32,000° K†	T_e=32,000° K‡
1.0 E 08	9.2 E-13	3.9 E-13	1.8 E-13	9.5 E-14	7.6 E-14
1.0 E 09	1.0 E-12	3.9 E-13	1.8 E-13	9.0 E-14	7.6 E-14
1.0 E 10	1.2 E-12	3.9 E-13	1.8 E-13	8.8 E-14	7.6 E-14
1.0 E 11	2.0 E-12	3.9 E-13	1.8 E-13	8.5 E-14	7.6 E-14
1.0 E 12	3.3 E-12	5.4 E-13	2.0 E-13	8.2 E-14	7.6 E-14
1.0 E 13	9.0 E-12	2.4 E-12	2.4 E-13	8.0 E-14	7.6 E-14
1.0 E 14	3.5 E-11	2.0 E-11	3.1 E-13	7.6 E-14	7.6 E-14
1.0 E 15	1.9 E-10	1.9 E-10	4.9 E-13	9.0 E-14	9.0 E-14
1.0 E 16	1.7 E-09	1.7 E-09	7.3 E-13	1.8 E-13	1.8 E-13

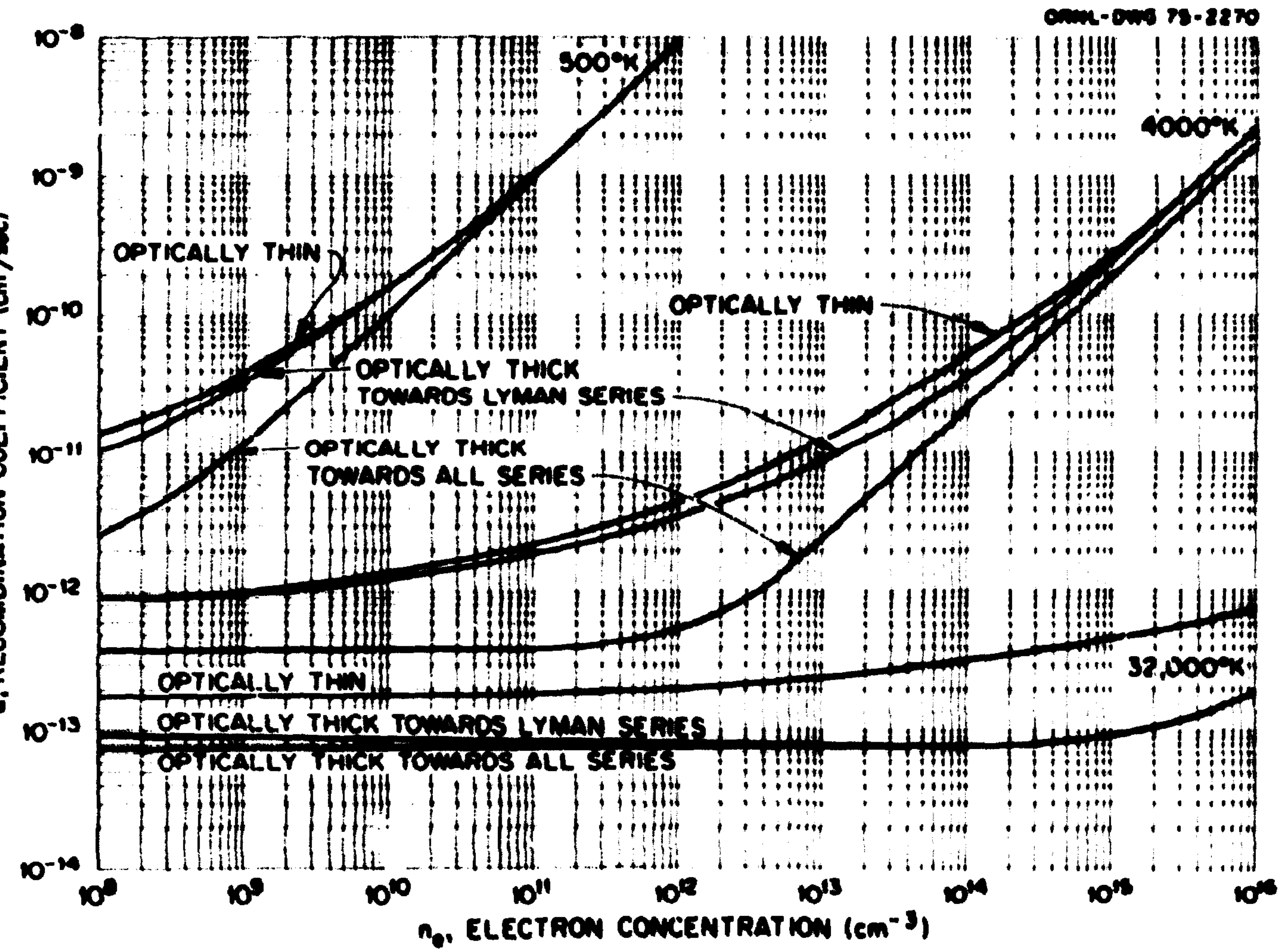
Reference:

H.S.W. Massey and H.B. Gilbody, Electronic and Ionic Impact Phenomena, Vol. IV, Recombination and Fast Collisions of Heavy Particles, p. 2135 (Clarendon Press, Oxford, 1974).

*Optically thin.

†Optically thick towards lines of Lyman series.

‡Optically thick towards lines of all series.

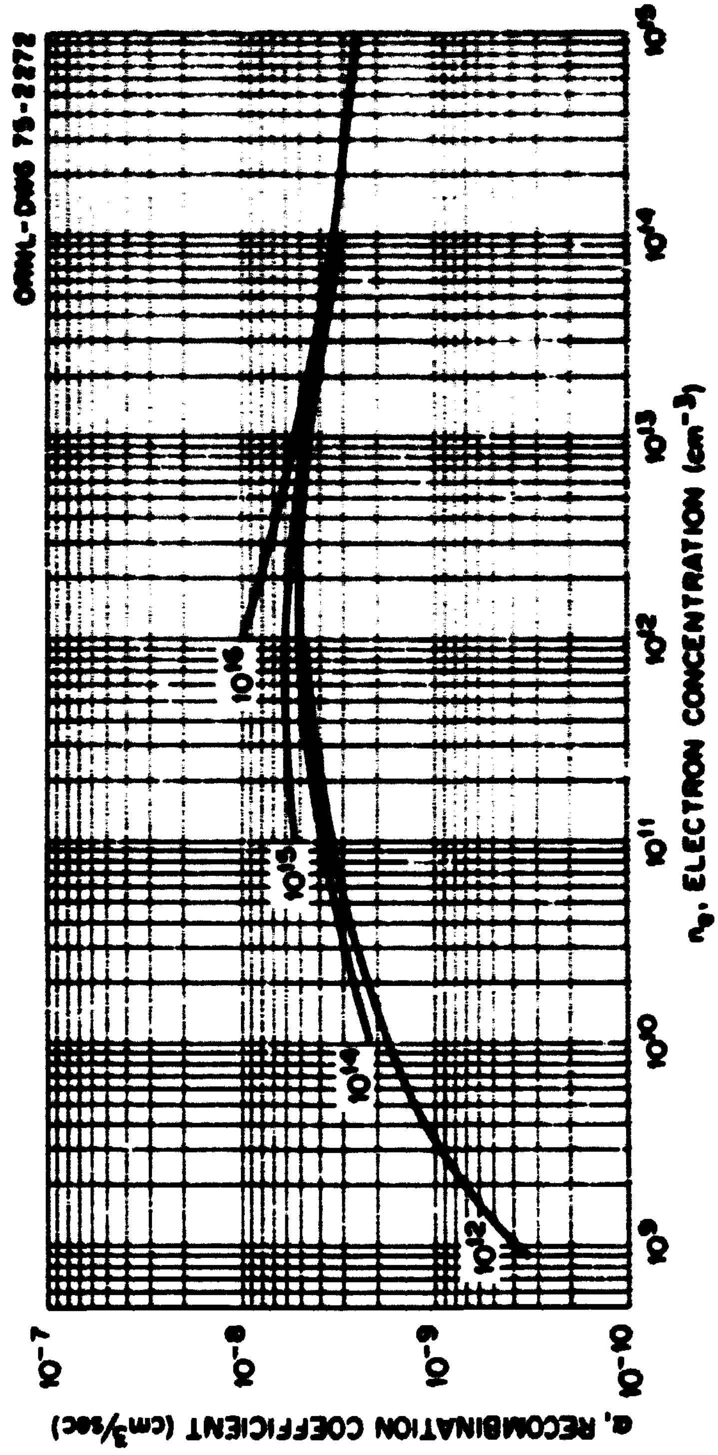

ORNL-DWG 75-2270
α, RECOMBINATION COEFFICIENT (cm³/sec)
n_e, ELECTRON CONCENTRATION (cm⁻³)
500°K
4000°K
32,000°K
OPTICALLY THIN
OPTICALLY THICK TOWARDS LYMAN SERIES
OPTICALLY THICK TOWARDS ALL SERIES
OPTICALLY THIN
OPTICALLY THICK TOWARDS LYMAN SERIES
OPTICALLY THICK TOWARDS ALL SERIES
OPTICALLY THIN
OPTICALLY THICK TOWARDS LYMAN SERIES
OPTICALLY THICK TOWARDS ALL SERIES

Calculated Recombination Coefficient α for the Collisional-Radiative Recombination of Electrons with H^+ Ions in an H^+ Plasma in Which Both the Neutral Gas Temperature T_g and the Ion Temperature T_I are Maintained at 250° K, for Various Concentrations N of Neutral Atoms in the Ground State

Electron Concentration n_e (cm^{-3})	Recombination Coefficient α (cm^3/sec)			
	$N=10^{12}cm^{-3}$	$N=10^{14}cm^{-3}$	$N=10^{15}cm^{-3}$	$N=10^{16}cm^{-3}$
8.6 E 08	3.34 E-10			
1.0 E 09	3.80 E-10			
3.0 E 09	9.71 E-10			
1.0 E 10	1.78 E-09	2.24 E-09		
3.0 E 10	2.50 E-09	2.97 E-09		
1.0 E 11	3.53 E-09	3.83 E-09	5.33 E-09	
5.1 E 11	4.50 E-09	4.85 E-09	6.10 E-09	
1.0 E 12	4.81 E-09	4.89 E-09	6.00 E-09	1.00 E-08
1.3 E 12		5.04 E-09	5.95 E-09	9.20 E-09
3.0 E 12		4.90 E-09	5.45 E-09	7.30 E-09
1.0 E 13		4.49 E-09	4.55 E-09	5.33 E-09
3.0 E 13		3.65 E-09	3.65 E-09	4.15 E-09
1.0 E 14		3.02 E-09	3.11 E-09	3.27 E-09
3.0 E 14				2.88 E-09
1.0 E 15				2.50 E-09

Reference:

H.S.W. Massey and H.B. Gilbody, Electronic and Ionic Impact Phenomena, Vol. IV, Recombination and Fast Collisions of Heavy Particles, p. 2145 (Clarendon Press, Oxford, 1974).

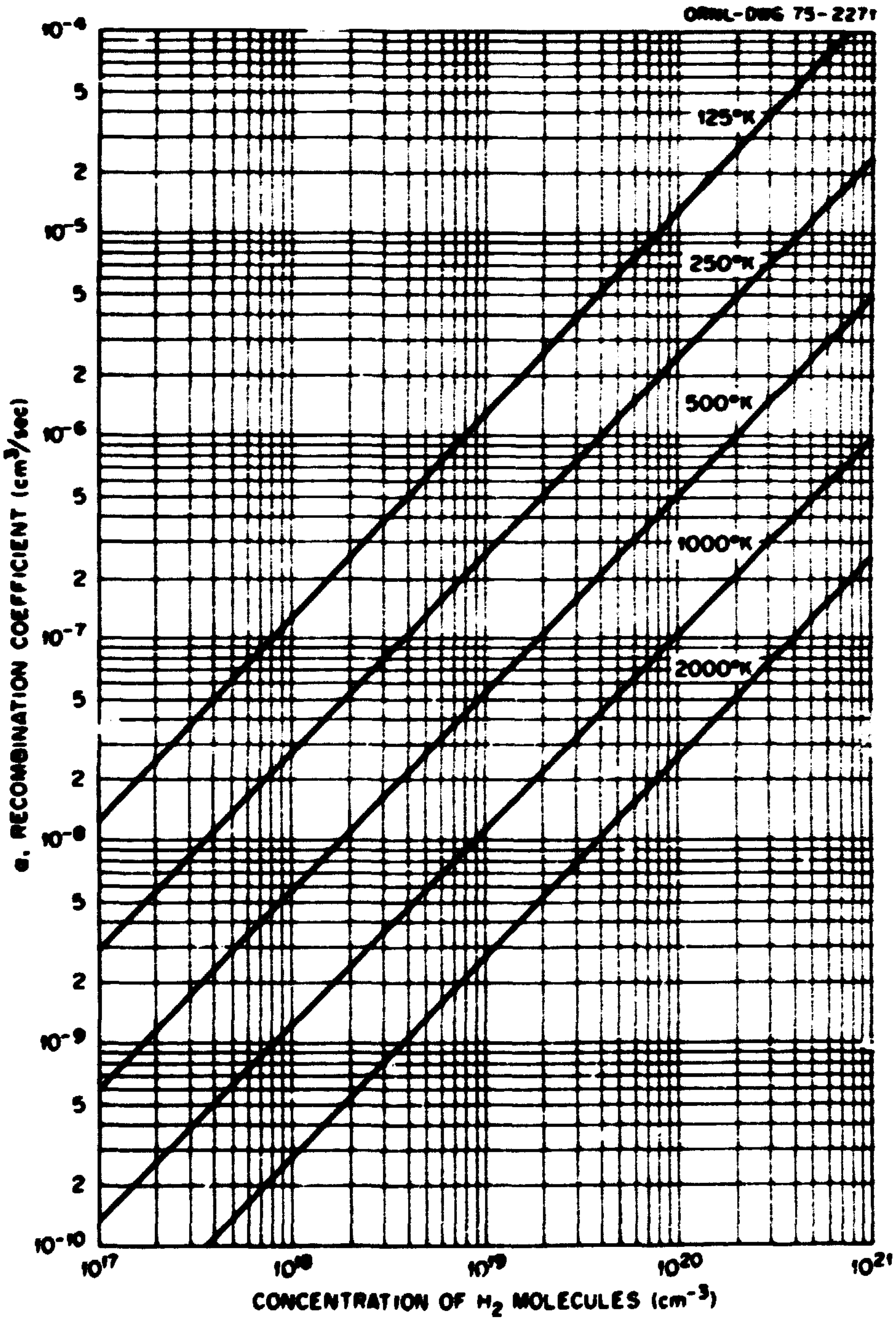

ORNL-DWG 75-2272
n_e, ELECTRON CONCENTRATION (cm^{-3})
α, RECOMBINATION COEFFICIENT (cm^3/sec)
10^9
10^{10}
10^{11}
10^{12}
10^{13}
10^{14}
10^{15}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{12}
10^{14}
10^{15}
10^{16}

Calculated Recombination Coefficient α for the Collisional-Radiative Recombination of Electrons with H_2^+ Ions in H_2 at Various Temperatures T

Concentration of H_2 Molecules (cm^{-3})	Recombination Coefficient α (cm^3/sec)				
	T = 125 °K	T = 250 °K	T = 500 °K	T = 1000° K	T = 2000 °K
1.0 E 17	1.27 E-08	2.91 E-09	5.97 E-10	1.37 E-10	
3.6 E 17	4.20 E-08	1.00 E-08	2.10 E-09	4.60 E-10	1.00 E-10
1.0 E 18	1.30 E-07	2.76 E-08	5.52 E-09	1.21 E-09	2.73 E-10
3.0 E 18	3.80 E-07	8.10 E-08	1.65 E-08	3.70 E-09	8.10 E-10
1.0 E 19	1.30 E-06	2.57 E-07	5.22 E-08	1.14 E-08	2.61 E-09
3.0 E 19	3.90 E-06	7.70 E-07	1.58 E-07	3.25 E-08	7.90 E-09
1.0 E 20	1.27 E-05	2.37 E-06	5.05 E-07	1.06 E-07	2.48 E-08
7.1 E 20	1.00 E-04	1.75 E-05	3.50 E-06	7.10 E-07	1.82 E-07
1.0 E 21		2.51 E-05	5.00 E-06	1.00 E-06	2.57 E-07

Reference:

H.S.W. Massey and H.B. Gilbody, Electronic and Ionic Impact Phenomena, Vol. IV, Recombination and Fast Collisions of Heavy Particles, p. 2153 (Clarendon Press, Oxford, 1974).

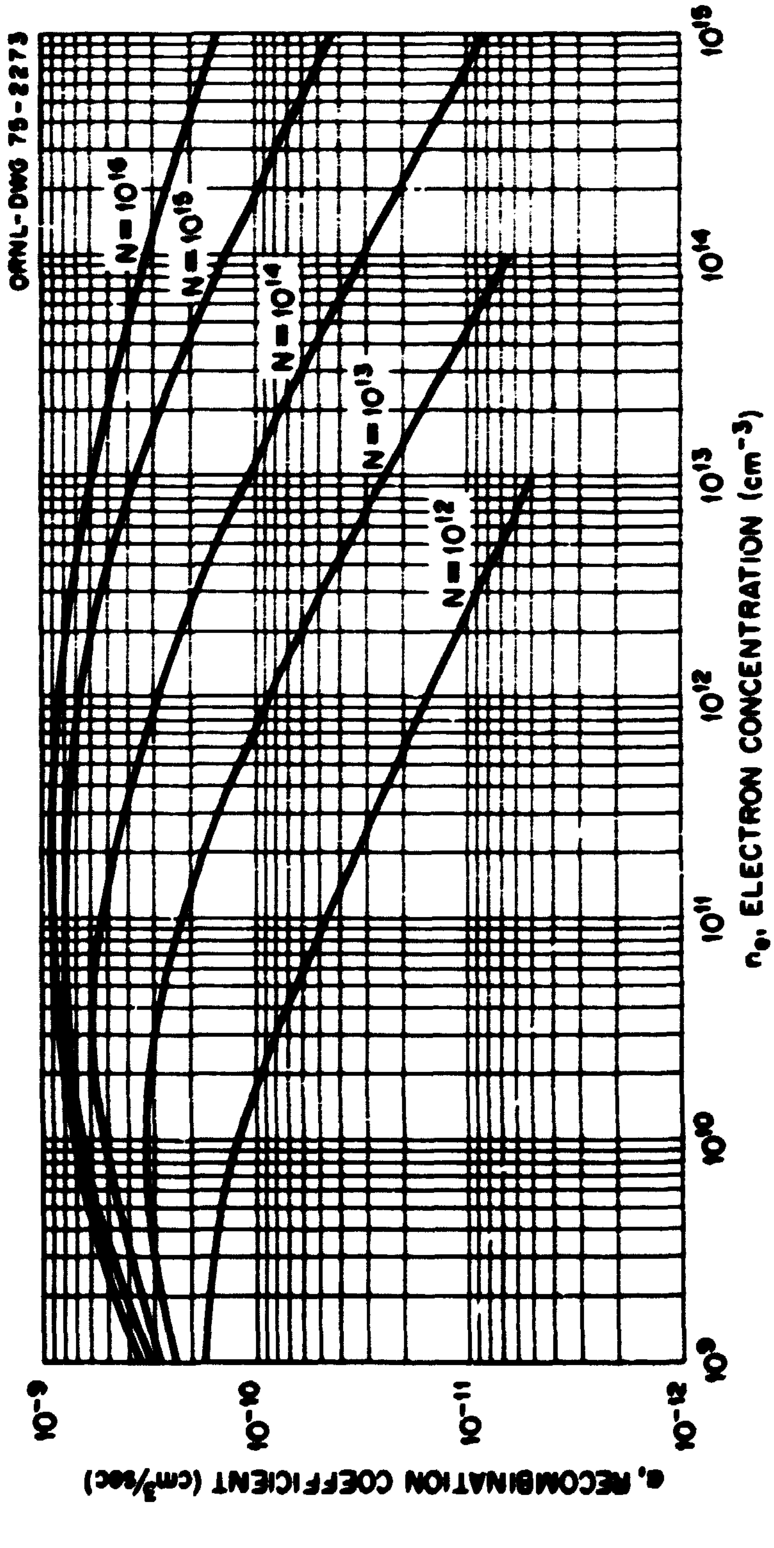

ORNL-DWG 75-2271
125°K
250°K
500°K
1000°K
2000°K
α, RECOMBINATION COEFFICIENT (cm³/sec)
CONCENTRATION OF H₂ MOLECULES (cm⁻³)
10⁻⁴
10⁻⁵
10⁻⁶
10⁻⁷
10⁻⁸
10⁻⁹
10⁻¹⁰
10¹⁷
10¹⁸
10¹⁹
10²⁰
10²¹

Calculated Recombination Coefficient α for the Collisional-Radiative Recombination of Electrons with He^+ Ions in an Optically Thick Decaying He^+ Plasma with Atom Temperatures Maintained at 250° K for Various Concentrations N of Neutral Atoms in the Ground State

Electron Concentration n_e (cm^{-3})	Recombination Coefficient α (cm^3/sec)				
	$N=10^{12} cm^{-3}$	$N=10^{13} cm^{-3}$	$N=10^{14} cm^{-3}$	$N=10^{15} cm^{-3}$	$N=10^{16} cm^{-3}$
1.0 E 09	1.73 E-10	2.36 E-10	2.89 E-10	3.21 E-10	3.64 E-10
3.0 E 09	1.55 E-10	3.00 E-10	3.85 E-10	4.90 E-10	5.40 E-10
1.0 E 10	1.23 E-10	3.33 E-10	5.32 E-10	6.60 E-10	7.36 E-10
3.6 E 10	7.40 E-11	2.90 E-10	5.86 E-10	7.70 E-10	8.50 E-10
1.0 E 11	4.61 E-11	2.25 E-10	5.32 E-10	7.80 E-10	8.90 E-10
2.3 E 11	3.10 E-11	1.65 E-10	4.45 E-10	7.60 E-10	9.12 E-10
1.0 E 12	1.53 E-11	8.61 E-11	2.89 E-10	6.60 E-10	8.40 E-10
3.0 E 12	8.95 E-12	4.80 E-11	1.85 E-10	5.20 E-10	7.20 E-10
1.0 E 13	4.88 E-12	2.44 E-11	1.06 E-10	3.64 E-10	5.86 E-10
3.0 E 13		1.30 E-11	5.90 E-11	2.27 E-10	4.45 E-10
1.0 E 14		6.03 E-12	3.16 E-11	1.33 E-10	3.21 E-10
3.0 E 14			1.65 E-11	7.90 E-11	2.23 E-10
1.0 E 15			8.07 E-12	4.24 E-11	1.50 E-10

Reference:

H.S.W. Massey and H.B. Gilbody, Electronic and Ionic Impact Phenomena, Vol. IV, Recombination and Fast Collisions of Heavy Particles, p. 2147 (Clarendon Press, Oxford, 1974).

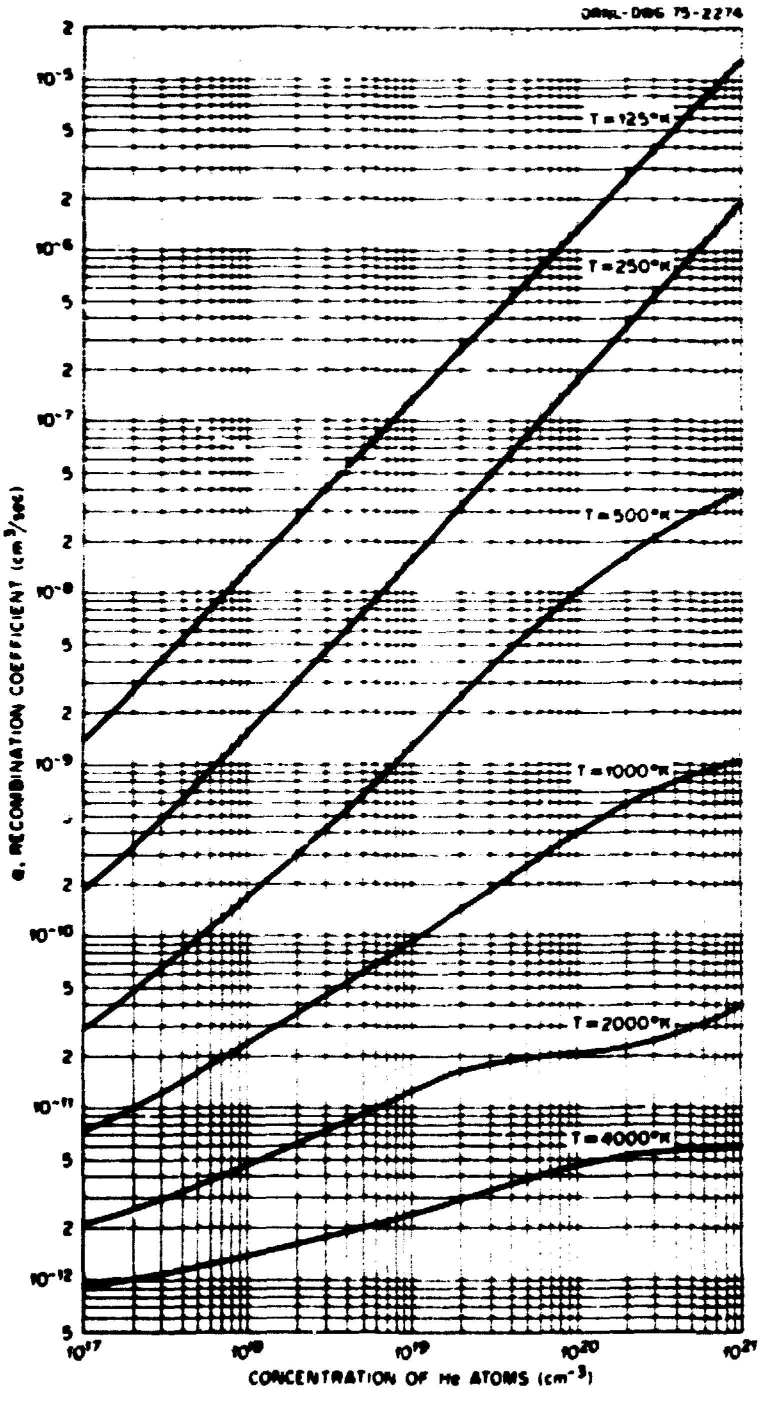

ORNL-DWG 75-2273
N = 10^16
N = 10^15
N = 10^14
N = 10^13
N = 10^12
10^-9
10^-10
10^-11
10^-12
α, RECOMBINATION COEFFICIENT (cm^3/sec)
10^9
10^10
10^11
10^12
10^13
10^14
10^15
n_e, ELECTRON CONCENTRATION (cm^-3)

Electronic Recombination Coefficient α for the 3-Body Electron-Ion Recombination Reaction $He^{+} + e + He \rightarrow 2He$

He Atom Density (cm^{-3})	Recombination Coefficient α (cm^3/sec)					
	T=125° K	T=250° K	T=500° K	T=1000° K	T=2000° K	T=4000° K
1.0 E 17	1.41 E-09	1.82 E-10	2.88 E-11	7.30 E-12	2.09 E-12	[illegible]
3.0 E 17	4.15 E-09	4.93 E-10	6.52 E-11	1.22 E-11	2.94 E-12	1.10 E-12
1.0 E 18	1.34 E-08	1.52 E-09	1.67 E-10	2.37 E-11	4.63 E-12	1.40 E-12
3.0 E 18	4.00 E-08	4.59 E-09	4.26 E-10	4.54 E-11	7.16 E-12	1.77 E-12
1.0 E 19	1.33 E-07	1.52 E-08	1.30 E-09	9.44 E-11	1.27 E-11	2.43 E-12
3.0 E 19	4.00 E-07	4.86 E-08	3.40 E-09	1.95 E-10	1.77 E-11	3.24 E-12
1.0 E 20	1.33 E-06	1.79 E-07	1.00 E-08	4.13 E-10	2.04 E-11	[illegible]
3.0 E 20	4.11 E-06	5.45 E-07	2.09 E-08	7.11 E-10	2.50 E-11	5.45 E-12
1.0 E 21	1.30 E-05	1.90 E-06	3.88 E-08	1.08 E-09	3.88 E-11	5.78 E-12

Reference:

D.R. Bates and S.P. Khare, Proc. Phys. Soc. (London) 85, 231 (1965).


ORNL-DWG 75-2274
T = 125°K
T = 250°K
T = 500°K
T = 1000°K
T = 2000°K
T = 4000°K
α, RECOMBINATION COEFFICIENT (cm³/sec)
CONCENTRATION OF He ATOMS (cm⁻³)
10⁻⁵
10⁻⁶
10⁻⁷
10⁻⁸
10⁻⁹
10⁻¹⁰
10⁻¹¹
10⁻¹²
10¹⁷
10¹⁸
10¹⁹
10²⁰
10²¹

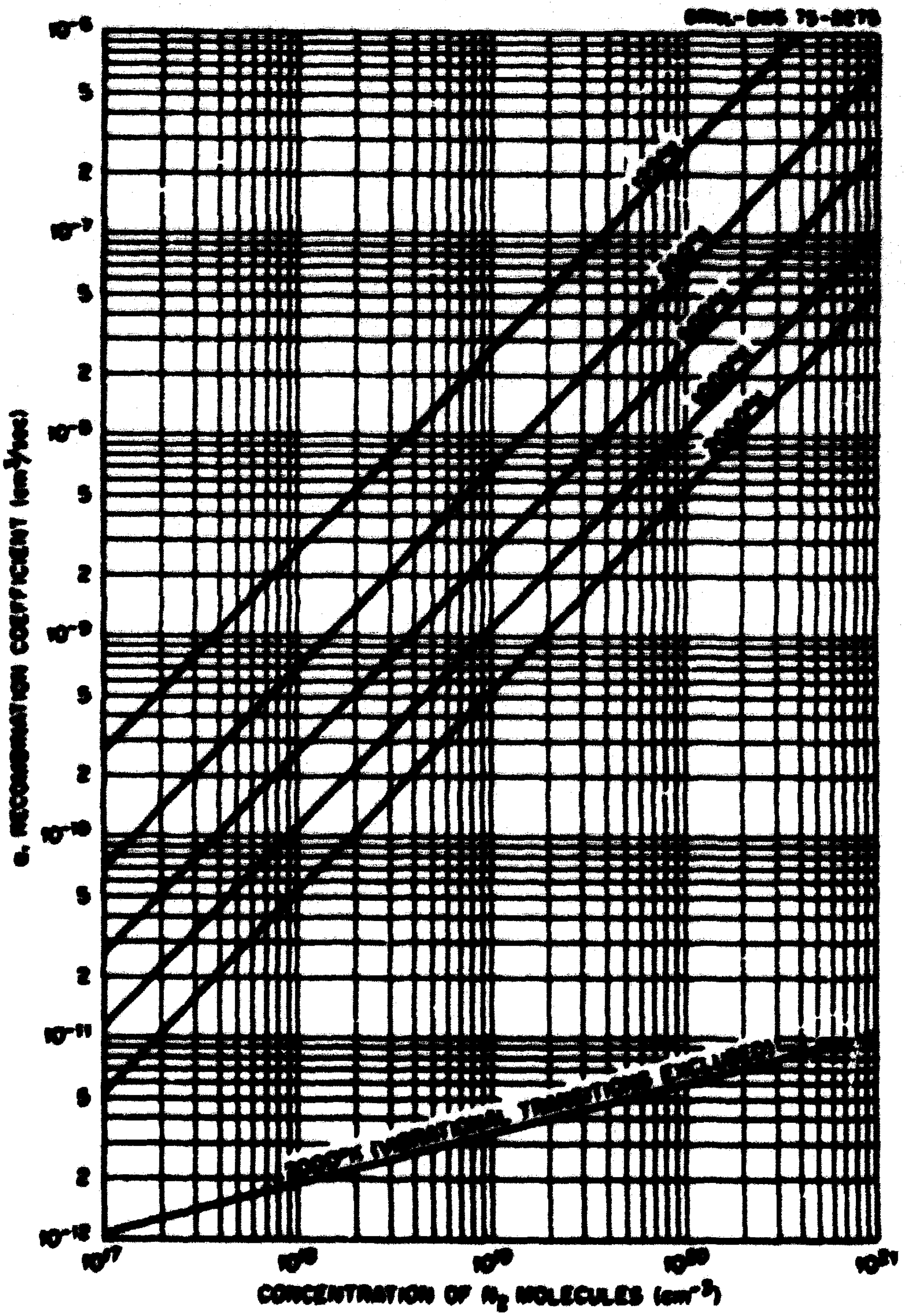
Collisional-Radiative Recombination Coefficient α for Electrons with N_2^+ Ions in N_2*

Concentration of N_2 Molecules (cm^{-3})	Recombination Coefficient α (cm^3/sec)					
	T=125° K	T=250° K	T=500° K	T=1000° K	T=2000° K	T=2000° K*
1.0 E 17	2.72 E-10	6.95 E-11	2.61 E-11	1.15 E-11	5.46 E-12	1.07 E-12
3.0 E 17	7.90 E-10	2.05 E-10	7.80 E-11	3.35 E-11	1.60 E-11	1.40 E-12
1.0 E 18	2.65 E-09	6.90 E-10	2.60 E-10	1.10 E-10	5.30 E-11	1.90 E-12
3.0 E 18	8.00 E-09	2.05 E-09	7.70 E-10	3.25 E-10	1.60 E-10	2.50 E-12
1.0 E 19	2.65 E-08	6.90 E-09	2.60 E-09	1.09 E-09	5.30 E-10	3.35 E-12
3.0 E 19	7.90 E-08	2.00 E-08	7.80 E-09	3.25 E-09	1.60 E-09	4.40 E-12
1.0 E 20	2.65 E-07	6.85 E-08	2.60 E-08	1.07 E-08	5.40 E-09	5.90 E-12
3.0 E 20	7.95 E-07	2.00 E-07	7.80 E-08	3.20 E-08	1.60 E-08	7.80 E-12
1.0 E 21		6.78 E-07	2.61 E-07	1.04 E-07	5.41 E-08	1.02 E-11

Reference:

H.S.W. Massey and H.B. Gilbody, Electronic and Ionic Impact Phenomena, Vol. IV, Clarendon Press, Oxford (1974), p. 2153-2154.

*Vibrational transitions excluded.


ORNL-DWG 75-2879
α, RECOMBINATION COEFFICIENT (cm³/sec)
10⁻⁶
5
2
10⁻⁷
5
2
10⁻⁸
5
2
10⁻⁹
5
2
10⁻¹⁰
5
2
10⁻¹¹
5
2
10⁻¹²
10¹⁷
10¹⁸
10¹⁹
10²⁰
10²¹
CONCENTRATION OF H₂ MOLECULES (cm⁻³)

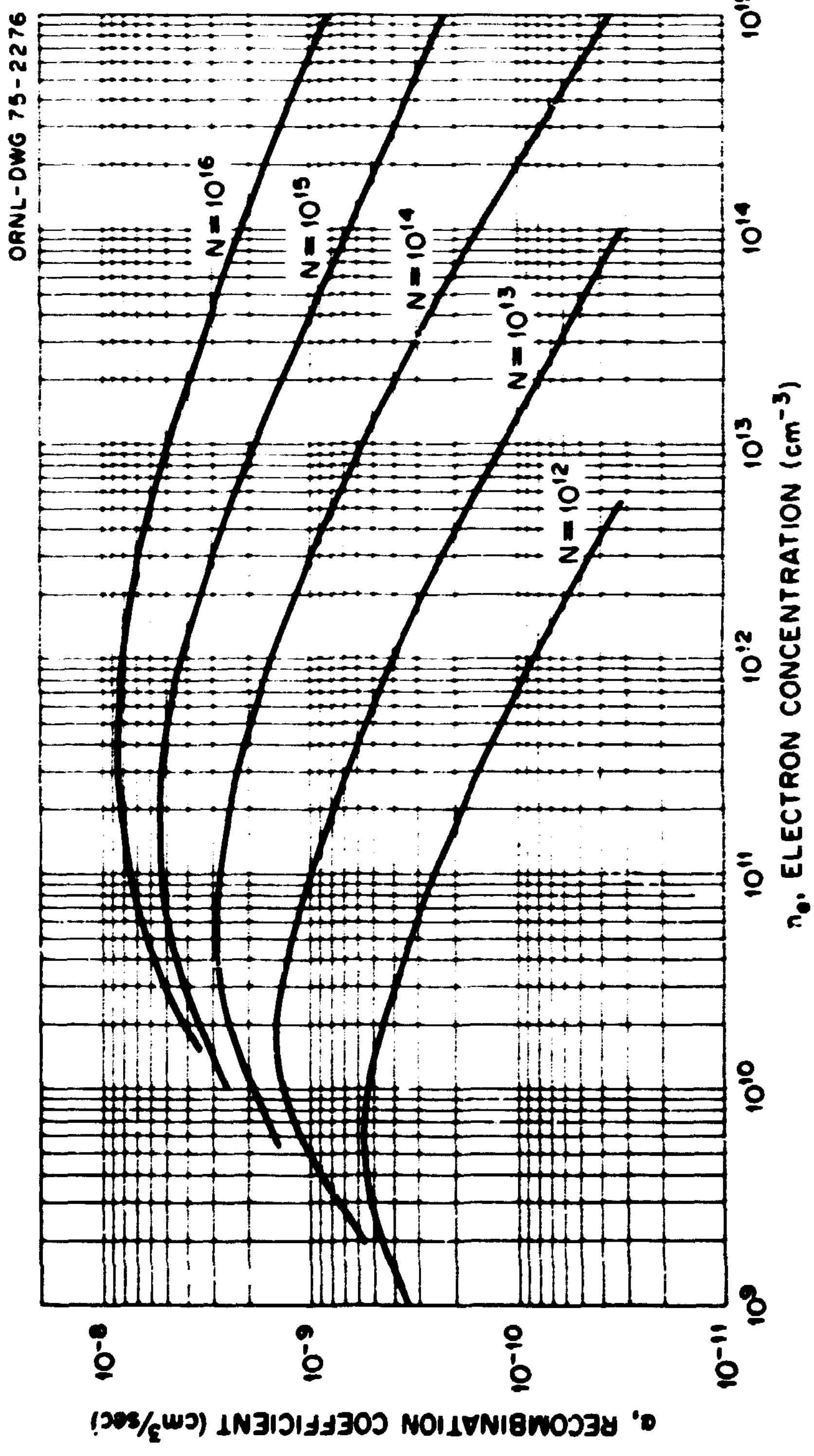
Collisional-Radiative Recombination Coefficient α for Electrons with H^+ Ions in a Magnetically Confined Optically Thick H^+ Plasma at Various Concentrations N of Neutral Atoms. The Atom Temperature is Held at 250° K.

Electron Concentration n_e (cm^{-3})	Recombination Coefficient α (cm^3/sec)				
	$N=10^{12}$ cm^{-3}	$N=10^{13}$ cm^{-3}	$N=10^{14}$ cm^{-3}	$N=10^{15}$ cm^{-3}	$N=10^{16}$ cm^{-3}
1.0 E 09	3.45 E-10				
1.9 E 09	4.50 E-10	5.15 E-10			
3.0 E 09	5.20 E-10	7.60 E-10			
5.4 E 09	5.66 E-10	1.08 E-09	1.42 E-09		
1.0 E 10	5.46 E-10	1.36 E-09	1.91 E-09	2.52 E-09	
1.5 E 10	4.90 E-10	1.48 E-09	2.25 E-09	3.10 E-09	3.43 E-09
3.0 E 10	3.76 E-10	1.38 E-09	2.73 E-09	4.12 E-09	5.08 E-09
4.8 E 10	3.30 E-10	1.25 E-09	2.86 E-09	4.60 E-09	6.20 E-09
1.0 E 11	2.54 E-10	9.84 E-10	2.65 E-09	4.98 E-09	6.89 E-09
1.7 E 11	2.00 E-10	8.20 E-10	2.42 E-09	5.29 E-09	8.00 E-09
3.0 E 11	1.42 E-10	6.55 E-10	2.19 E-09	5.10 E-09	8.30 E-09
4.3 E 11	1.28 E-10	5.60 E-10	2.00 E-09	4.90 E-09	8.43 E-09
1.0 E 12	7.71 E-11	3.58 E-10	1.57 E-09	4.12 E-09	7.98 E-09
3.0 E 12	4.50 E-11	2.29 E-10	9.75 E-10	2.89 E-09	6.89 E-09
5.5 E 12	3.17 E-11	1.67 E-10	7.30 E-10	2.35 E-09	5.90 E-09
1.0 E 13		1.11 E-10	5.56 E-10	1.86 E-09	4.89 E-09
3.0 E 13		6.12 E-11	3.11 E-10	1.15 E-09	3.43 E-09
1.0 E 14		3.33 E-11	1.56 E-10	6.55 E-10	2.19 E-09
3.0 E 14			7.80 E-11	3.72 E-10	1.42 E-09
1.0 E 15			3.44 E-11	2.29 E-10	8.22 E-10

References:

D.R. Bates and A.E. Kingston, Proc. Roy. Soc. A-279, 10 (1964).

H.S.W. Massey and H.B. Gilbody, Electronic and Ionic Impact Phenomena, Vol. IV, Clarendon Press, Oxford (1974), p. 2144.

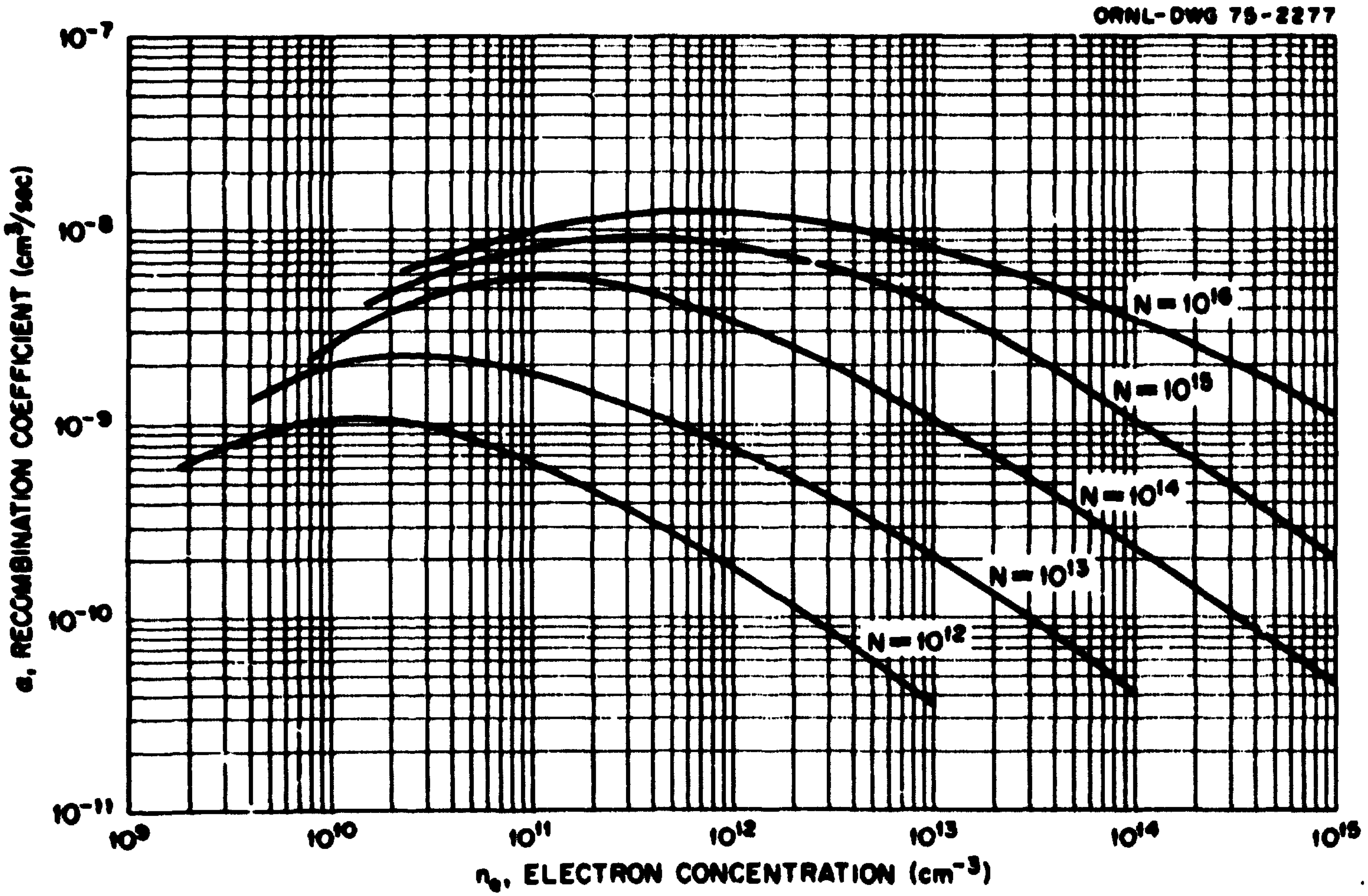

ORNL-DWG 75-2276
N = 10^16
N = 10^15
N = 10^14
N = 10^13
N = 10^12
10^-8
10^-9
10^-10
10^-11
10^9
10^10
10^11
10^12
10^13
10^14
10^15
α, RECOMBINATION COEFFICIENT (cm^3/sec)
n_e, ELECTRON CONCENTRATION (cm^-3)

Recombination Coefficient α for the Collisional-Radiative Recombination of Electrons with He^+ Ions in an Optically Thin Decaying He^+ Plasma Maintained at an Atom Temperature of 250° K At Various Concentrations N of Neutral Atoms

Electron Concentration n_e (cm^{-3})	Recombination Coefficient α (cm^3/sec)				
	$N = 10^{12}$	$N = 10^{13}$	$N = 10^{14}$	$N = 10^{15}$	$N = 10^{16}$
1.8 E 09	6.19 E-10				
4.0 E 09	8.80 E-10	1.39 E-09			
7.9 E 09	1.05 E-09	1.85 E-09	2.17 E-09		
1.0 E 10	1.09 E-09	2.00 E-09	2.60 E-09		
1.5 E 10	1.11 E-09	2.20 E-09	3.80 E-09	4.20 E-09	
2.2 E 10	1.06 E-09	2.30 E-09	4.10 E-09	5.10 E-09	6.11 E-09
2.6 E 10	1.03 E-09	2.33 E-09	4.40 E-09	5.40 E-09	6.60 E-09
1.0 E 11	6.49 E-10	1.84 E-09	5.78 E-09	8.51 E-09	1.00 E-08
3.5 E 11	3.35 E-10	1.20 E-09	4.90 E-09	9.55 E-09	1.21 E-08
5.8 E 11	2.50 E-10	9.60 E-10	4.25 E-09	8.90 E-09	1.27 E-08
1.0 E 12	1.80 E-10	7.48 E-10	3.45 E-09	8.51 E-09	1.22 E-08
3.0 E 12	8.70 E-11	4.20 E-10	2.05 E-09	6.40 E-09	1.10 E-08
1.0 E 13	3.44 E-11	2.07 E-10	1.06 E-09	4.20 E-09	8.32 E-09
3.0 E 13		1.00 E-10	5.20 E-10	2.25 E-09	5.60 E-09
1.0 E 14		4.00 E-11	2.28 E-10	1.04 E-09	3.45 E-09
3.0 E 14			1.05 E-10	4.90 E-10	2.05 E-09
1.0 E 15			4.46 E-11	1.98 E-10	1.11 E-09

Reference:

D.R. Bates and A.E. Kingston, Proc. Roy. Soc. A 279, 32 (1964).


ORNL-DWG 75-2277
α, RECOMBINATION COEFFICIENT (cm³/sec)
10⁻⁷
10⁻⁸
10⁻⁹
10⁻¹⁰
10⁻¹¹
10⁹
10¹⁰
10¹¹
10¹²
10¹³
10¹⁴
10¹⁵
nₑ, ELECTRON CONCENTRATION (cm⁻³)
N = 10¹⁶
N = 10¹⁵
N = 10¹⁴
N = 10¹³
N = 10¹²

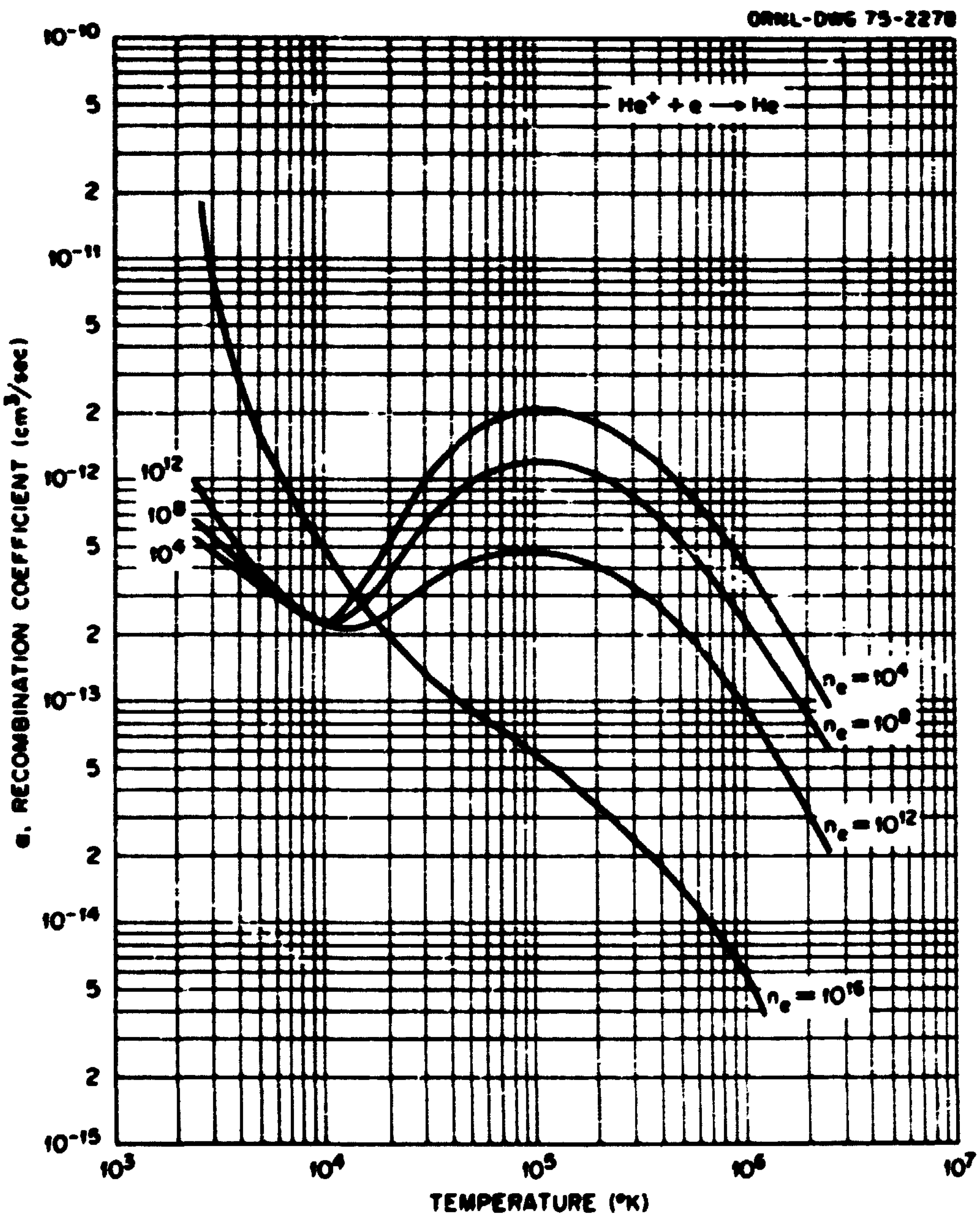
Calculated Collisional-Dielectronic Recombination Coefficient α for Electrons in an He^+ Plasma for Four Different Electron Concentrations n_e

Temperature (°K)	Recombination Coefficient α (cm^3/sec)			
	$n_e = 10^{16}$	$n_e = 10^{12}$	$n_e = 10^{8}$	$n_e = 10^{4}$
2.4 E 03		1.00 E-12	6.49 E-13	5.53 E-13
2.6 E 03	1.76 E-11	8.80 E-13	6.00 E-13	5.20 E-13
3.0 E 03	7.45 E-12	6.87 E-13	5.31 E-13	4.66 E-13
1.0 E 04	4.55 E-13	2.18 E-13	2.18 E-13	2.18 E-13
2.0 E 04	1.88 E-13	2.51 E-13	3.76 E-13	5.08 E-13
3.0 E 04	1.37 E-13	3.26 E-13	6.49 E-13	1.05 E-12
5.0 E 04	8.95 E-14	4.26 E-13	1.00 E-12	1.64 E-12
1.0 E 05	5.93 E-14	4.75 E-13	1.25 E-12	2.17 E-12
3.0 E 05	2.31 E-14	3.26 E-13	8.32 E-13	1.49 E-12
5.0 E 05	1.28 E-14	2.18 E-13	5.31 E-13	9.18 E-13
1.0 E 06	5.92 E-15	9.16 E-14	2.30 E-13	3.77 E-13
1.2 E 06	3.83 E-15	7.00 E-14	1.75 E-13	3.00 E-13
2.5 E 06		2.07 E-14	5.93 E-14	9.16 E-14

Reference:

A. Burgess and H.P. Summers, Astrophys. J. 157, 1007 (1969).

D.R. Bates, Case Studies in Atomic Physics 4, 57 (1974).


ORNL-DWG 75-2278
He⁺ + e → He
α, RECOMBINATION COEFFICIENT (cm³/sec)
TEMPERATURE (°K)
10¹²
10⁸
10⁴
nₑ = 10⁴
nₑ = 10⁸
nₑ = 10¹²
nₑ = 10¹⁶
10⁻¹⁰
5
2
10⁻¹¹
10⁻¹²
10⁻¹³
10⁻¹⁴
10⁻¹⁵
10³
10⁴
10⁵
10⁶
10⁷

Total Recombination Coefficients α for the Radiative

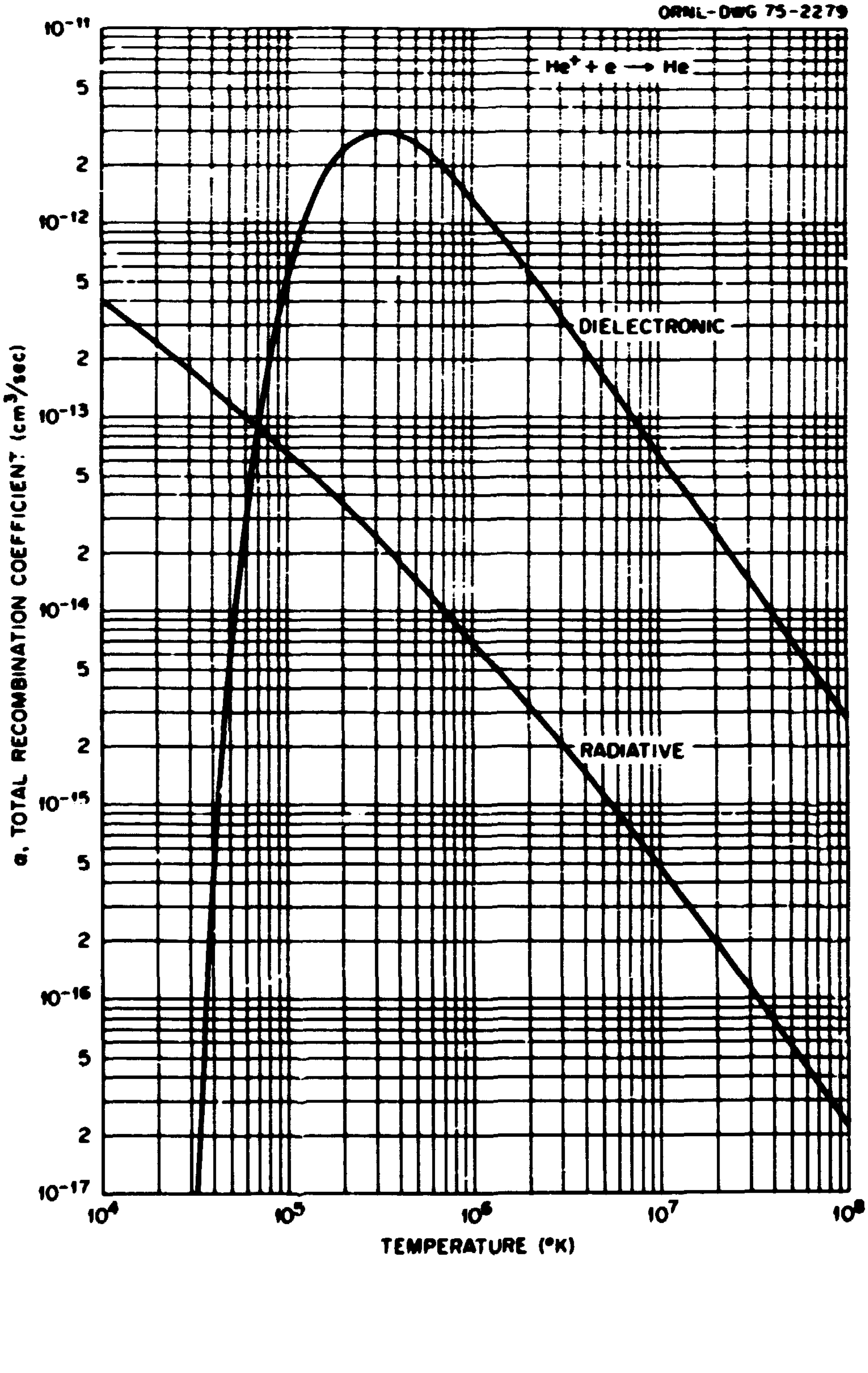
and Dielectronic Recombination of He^+ Ions with Electrons

Temperature (°K)	Total Recombination Coefficient α (cm³/sec)	
	Radiative $He^+ + e \rightarrow He$	Dielectronic $He^+ + e \rightarrow He$
1.0 E 04	4.19 E-13	
3.0 E 04	1.88 E-13	
3.2 E 04	1.68 E-13	1.00 E-17
4.0 E 04	1.41 E-13	7.05 E-16
5.0 E 04	1.18 E-13	5.96 E-15
8.0 E 04	7.80 E-14	2.17 E-13
1.0 E 05	6.81 E-14	5.43 E-13
1.2 E 05	5.60 E-14	8.97 E-13
1.5 E 05	4.55 E-14	1.59 E-12
2.0 E 05	3.45 E-14	2.35 E-12
3.0 E 05	2.30 E-14	2.95 E-12
3.3 E 05	2.15 E-14	2.95 E-12
5.0 E 05	1.42 E-14	2.64 E-12
8.0 E 05	8.50 E-15	1.71 E-12
1.0 E 06	7.08 E-15	1.38 E-12
3.0 E 06	2.02 E-15	3.29 E-13
1.0 E 07	4.70 E-16	6.28 E-14
3.0 E 07	1.05 E-16	1.48 E-14
1.0 E 08	2.11 E-17	2.68 E-15

Reference:

A. Burgess, Astrophys. J. 139, 776 (1964).

D.R. Bates, Case Studies in Atomic Physics 4, 57 (1974).


ORNL-DWG 75-2279
He⁺ + e → He
DIELECTRONIC
RADIATIVE
α, TOTAL RECOMBINATION COEFFICIENT (cm³/sec)
TEMPERATURE (°K)
10⁻¹¹
5
2
10⁻¹²
5
2
10⁻¹³
5
2
10⁻¹⁴
5
2
10⁻¹⁵
5
2
10⁻¹⁶
5
2
10⁻¹⁷
10⁴
10⁵
10⁶
10⁷
10⁸

C.7 Dissociative Recombination

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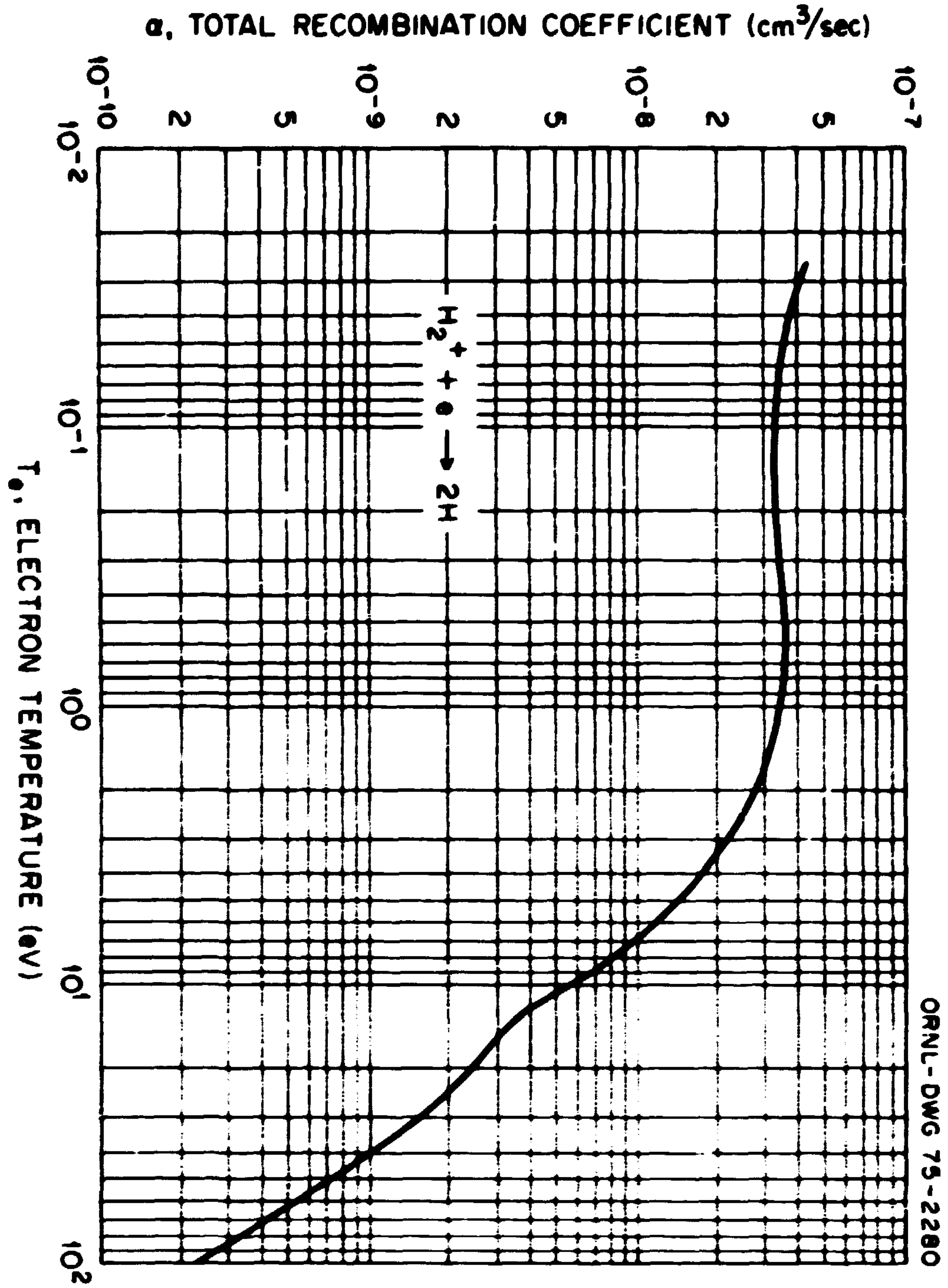
Total Recombination Coefficient α for Dissociative Recombination

of H_2^+ Ions with Electrons

Electron Temperature T_e (eV)	Total Recombination Coefficient α (cm^3/sec)
	Theoretical $H_2^+ + e \rightarrow 2H$
2.5 E-02	4.27 E-08
5.0 E-02	3.70 E-08
9.0 E-02	3.36 E-08
1.5 E-01	3.21 E-08
2.0 E-01	3.33 E-08
5.0 E-01	3.63 E-08
1.5 E 00	3.12 E-08
3.0 E 00	2.15 E-08
5.0 E 00	1.30 E-08
9.0 E 00	6.80 E-09
1.0 E 01	5.37 E-09
1.5 E 01	2.95 E-09
2.0 E 01	2.44 E-09
3.0 E 01	1.45 E-09
5.0 E 01	7.21 E-10
1.0 E 02	2.18 E-10

Reference:

H.W. Drawin, Collision and Transport Cross-Sections, Report No. EUR-CEA-FC-383, January 1967, Association EURATOM-C.E.A., Fontenay-aux-Roses (France).


α, TOTAL RECOMBINATION COEFFICIENT (cm³/sec)
10-10
2
5
10-9
2
5
10-8
2
5
10-7
10-2
10-1
10⁰
10¹
10²
$H_2^+ + e \rightarrow 2H$
Tₑ, ELECTRON TEMPERATURE (eV)
ORNL-DWG 75-2280

Cross Sections for Dissociative Recombination of Electrons with H_2^+ and D_2^+ Ions

Energy (eV)	Cross Sections (cm^2) $e + H_2^+ \rightarrow$ Neutrals	$e + D_2^+ \rightarrow$ Neutrals
3.0 E-01	2.33 E-15	1.79 E-15
4.0 E-01	1.99 E-15	1.66 E-15
5.0 E-01	1.75 E-15	1.53 E-15
6.0 E-01	1.47 E-15	1.41 E-15
8.0 E-01	8.90 E-16	1.14 E-15
1.0 E 00	6.30 E-16	9.00 E-16
1.5 E 00	4.67 E-16	6.48 E-16
2.0 E 00	3.49 E-16	5.13 E-16
2.5 E 00	2.71 E-16	4.10 E-16
3.0 E 00	2.20 E-16	3.35 E-16
4.0 E 00		2.36 E-16

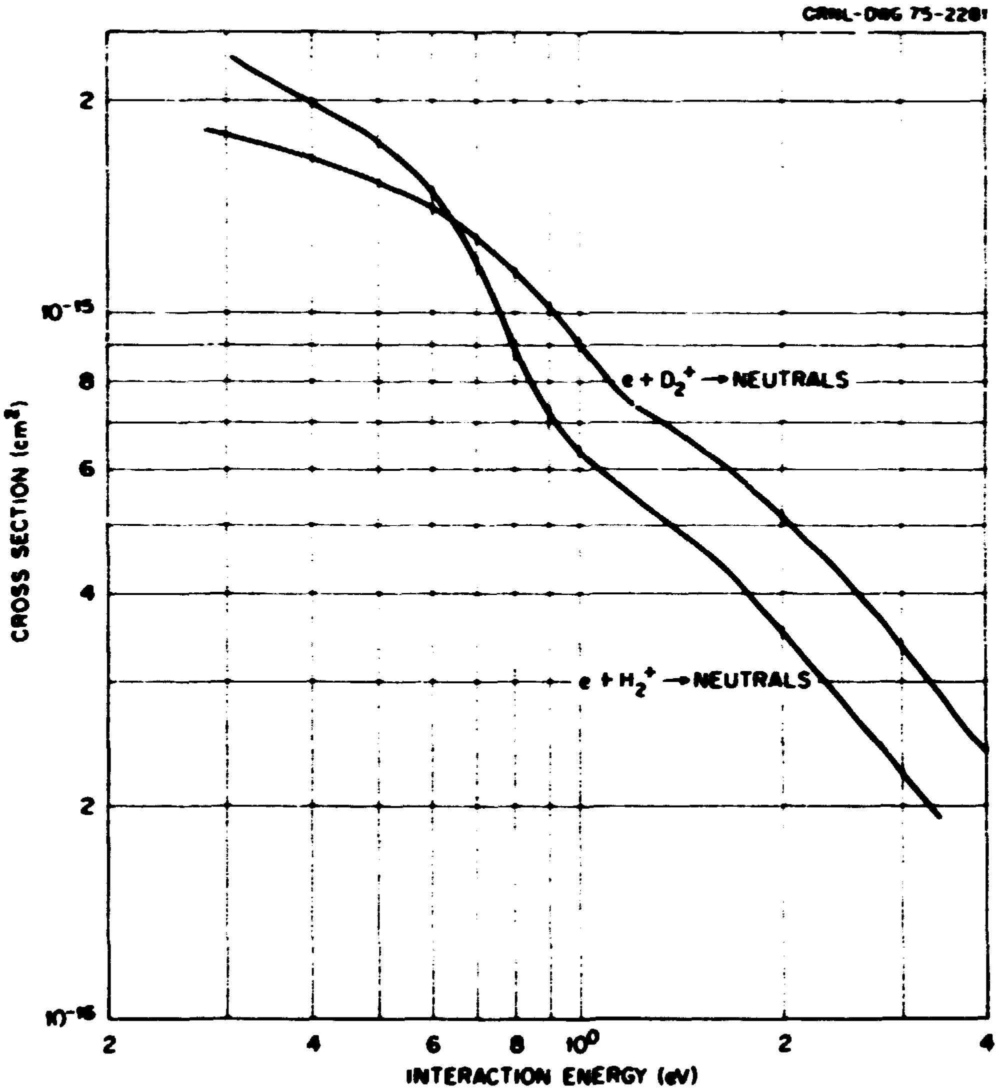
References:

H_2^+: B. Peart and K.T. Dolder, J. Phys. B 7, 236 (1974).

D_2^+: B. Peart and K.T. Dolder, J. Phys. B 6, L-359 (1973).

Accuracy:

The total error is believed not to exceed ± 10%.


ORNL-DWG 75-2281
CROSS SECTION (cm²)
2
10⁻¹⁵
8
6
4
2
10⁻¹⁶
e + D₂⁺ → NEUTRALS
e + H₂⁺ → NEUTRALS
2
4
6
8
10⁰
2
4
INTERACTION ENERGY (eV)

Cross Section for Dissociative Recombination of Electrons with H_3^+ Ions

Energy (eV)	Cross Section (cm^2)
	$e + H_3^+ \rightarrow$ Neutral Products
2.5 E-02	2.73 E-14
3.0 E-02	2.3[illegible] E-14
4.0 E-02	1.79 E-14
6.0 E-02	1.23 E-14
8.0 E-02	9.50 E-15
1.0 E-01	7.50 E-15
2.0 E-01	4.17 E-15
2.5 E-01	3.40 E-15
3.0 E-01	2.90 E-15
4.0 E-01	2.2[illegible] E-15
6.0 E-01	1.53 E-15
8.0 E-01	1.19 E-15
1.0 E 00	9.65 E-16
2.0 E 00	5.19 E-16
2.5 E 00	4.20 E-16
3.0 E 00	3.59 E-16
4.0 E 00	2.76 E-16

References:

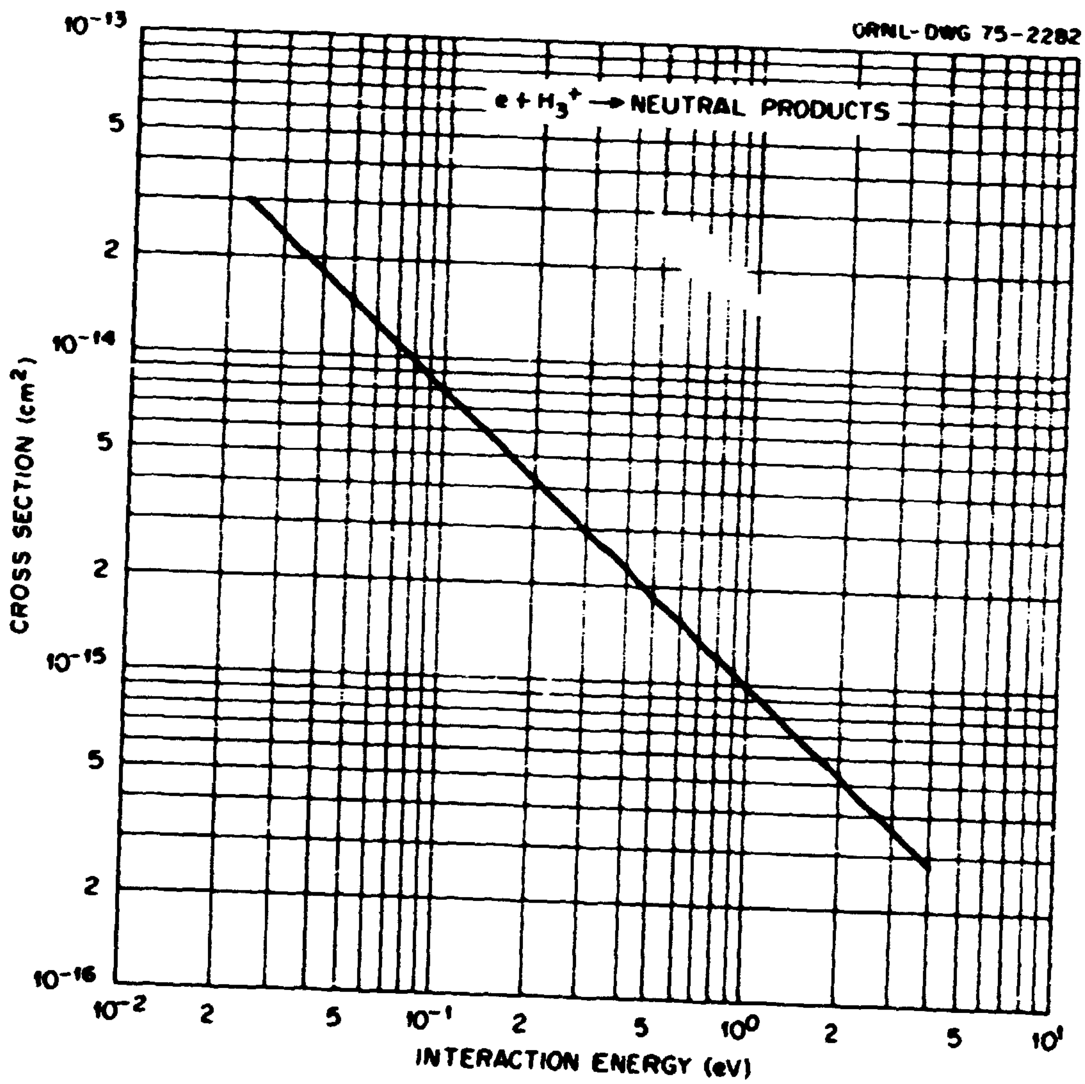
M.T. Leu, M.A. Biondi, and R. Johnsen, Phys. Rev. A 8, 413 (1973); B. Peart and K.T. Dolder, J. Phys. B. 7, 1948 (1974).

Accuracy:

The total error is believed not to exceed ± 15%.

Note:

The cross sections at energies between 0.05 and 0.4 eV are obtained by interpolating between the low energy microwave afterglow data of Leu, et al., and the higher-energy inclined beam data of Peart and Dolder.


ORNL-DWG 75-2282
e + H_3^+ → NEUTRAL PRODUCTS
CROSS SECTION (cm^2)
10^{-13}
5
2
10^{-14}
5
2
10^{-15}
5
2
10^{-16}
10^{-2}
2
5
10^{-1}
2
5
10^{0}
2
5
10^{1}
INTERACTION ENERGY (eV)

Cross Sections for Dissociative Recombination of Electrons with O_2^+ and NO^+ Ions

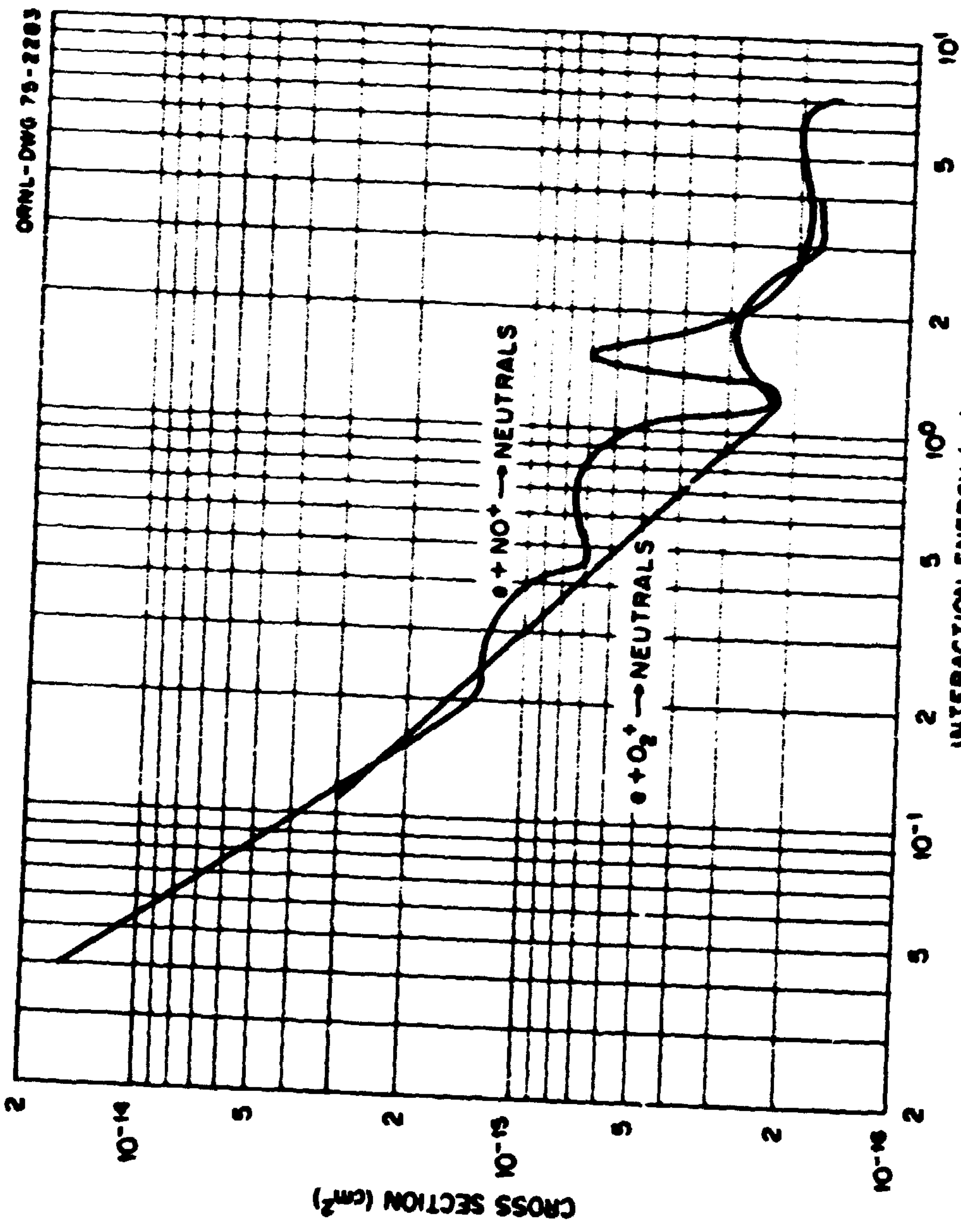
Energy (eV)	Cross Sections (cm^2)	
	$e + O_2^+ \rightarrow$ Neutrals	$e + NO^+ \rightarrow$ Neutrals
4.0 E-02		1.57 E-14
6.0 E-02		8.40 E-15
8.0 E-02		5.39 E-15
1.0 E-01		3.91 E-15
1.5 E-01	2.13 E-15	2.05 E-15
2.0 E-01	1.55 E-15	1.35 E-15
3.0 E-01	1.00 E-15	1.22 E-15
4.0 E-01	7.27 E-16	9.66 E-16
6.0 E-01	4.68 E-16	7.42 E-16
8.0 E-01	3.40 E-16	7.08 E-16
1.0 E 00	2.69 E-16	5.39 E-16
1.5 E 00	6.90 E-16	2.77 E-16
2.0 E 00	2.85 E-16	2.92 E-16
3.0 E 00	1.91 E-16	1.76 E-16
4.0 E 00	1.87 E-16	1.77 E-16
6.0 E 00	2.00 E-16	

References:

F.L. Walls and G.H. Dunn, J. Geophys. Research 79, 1911 (1974); Physics Today, August 1974, p. 30.

Accuracy:

The total error is believed not to exceed ± 30%.


ORNL-DWG 75-2283
e + NO+ → NEUTRALS
e + O2+ → NEUTRALS
INTERACTION ENERGY (eV)
CROSS SECTION (cm2)

Two-Body Electron-Ion Dissociative Recombination Rate Coefficients α at 300° K

Ion	α (cm³/sec)	References
H_3^+	2.3×10^{-7}	M. T. Leu, M. A. Biondi, and R. Johnsen, Phys. Rev. A 8, 413 (1973).
H_5^+	$\sim 3 \times 10^{-6}$	M. T. Leu, M. A. Biondi, and R. Johnsen, Phys. Rev. A 8, 413 (1973).
He_2^+	1×10^{-8}	A. W. Johnson and J. B. Gerardo, Phys. Rev. A 5, 1410 (1972).
N_2^+	2.2×10^{-7}	W. H. Kasner and M. A. Biondi, Phys. Rev. 137, A 317 (1965); F. J. Mehr and M. A. Biondi, Phys. Rev. 181, 264 (1969).
N_4^+	$\sim 2 \times 10^{-6}$	W. H. Kasner and M. A. Biondi, Phys. Rev. 137, A 317 (1965).
O_2^+	2.1×10^{-7}	F. J. Mehr and M. A. Biondi, Phys. Rev. 181, 264 (1969); W. H. Kasner and M. A. Biondi, Phys. Rev. 174, 139 (1968).
O_4^+	$\sim 2 \times 10^{-6}$	W. H. Kasner and M. A. Biondi, Phys. Rev. 174, 139 (1968).

Accuracy:

Where two significant digits are given, the total error probably does not exceed ± 20%.
Where only one significant digit is given, the total error probably exceeds ± 30%.

D. Surface Collisions

D.1 Sputtering

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Sputtering Yields for H^+ on C, Graphite, SiC, Al, and Cu (normal incidence)

Energy (keV)	Sputtering Coefficients, S (atoms/ion)		
	Cu	SiC	Graphite
1.0 E 00	3.8 E-02		
2.0 E 00	3.8 E-02		
2.5 E 00	3.5 E-02		
3.0 E 00	3.3 E-02		2.4 E-02
5.0 E 00		9.0 E-03	1.8 E-02
7.5 E 00		7.0 E-03	1.5 E-02
3.3 E 01	5.3 E-03		
5.0 E 01	3.4 E-03		
7.0 E 01	2.4 E-03		
1.0 E 02	1.6 E-03		
1.5 E 02	1.1 E-03		

Reference:

H^+ + Cu: C. E. KenKnight and G. K. Wehner, J. Appl. Phys. 35, 322 (1964); G. K. Wehner, G. S. Anderson, and C. E. KenKnight, Report #3031 Applied Science Division, Litton Systems; R. Weissmann and R. Behrisch, Rad. Effects 19, 69 (1973); O. C. Yonts, C. E. Normand and D. E. Harrison, Jr., J. Appl. Phys. 31, 447 (1960).

H^+ + SiC: R. Behrisch, et al., Max-Planck Institute Für Plasmaphysik, Report #IPPAR-1974.

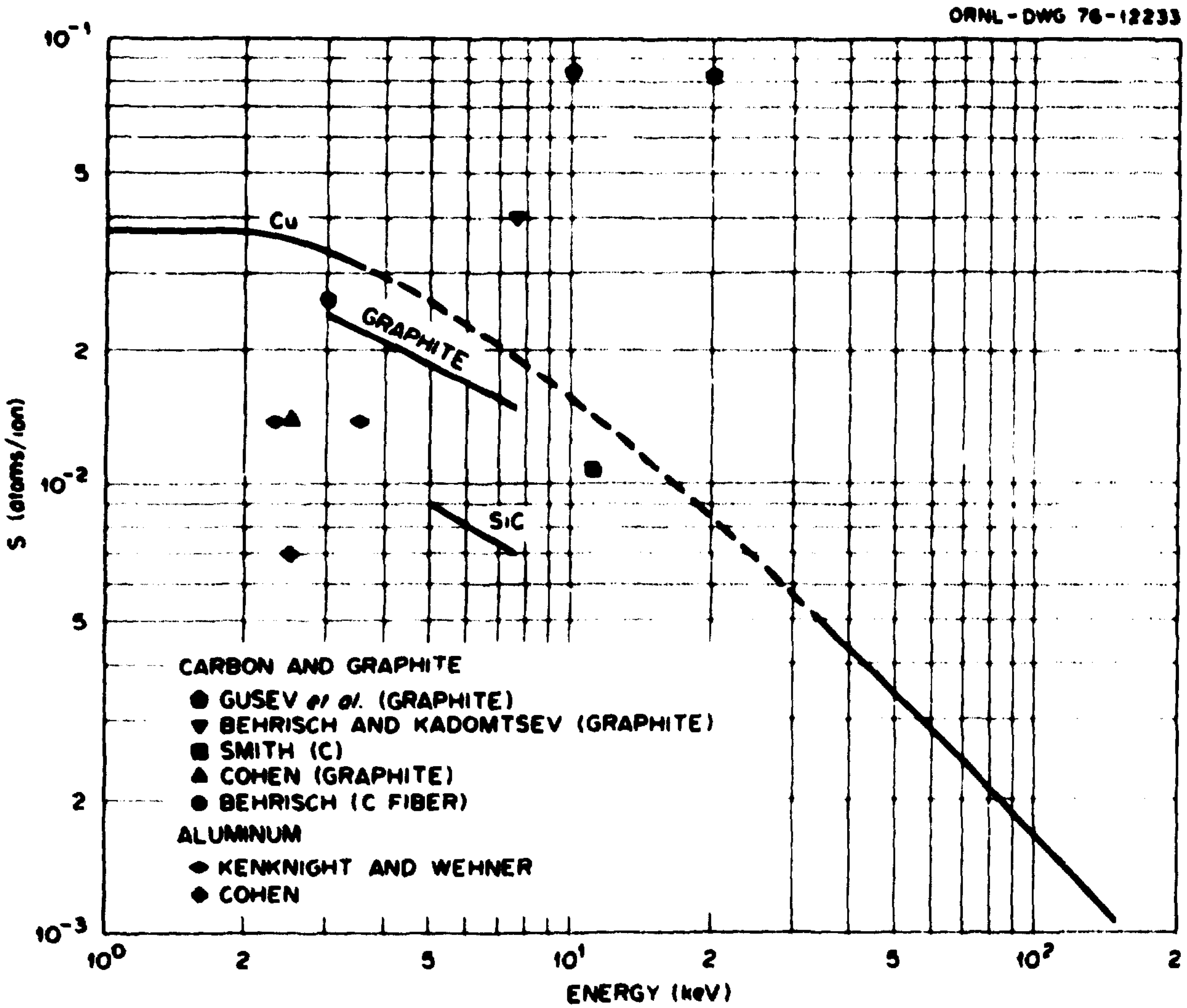
See Notes (1), (2), and (3) at end of chapter.

Accuracy:

Unknown

Notes:

See Note (4) at end of chapter.


ORNL-DWG 76-12233
S (atoms/ion)
ENERGY (keV)
Cu
GRAPHITE
SiC
CARBON AND GRAPHITE
GUSEV et al. (GRAPHITE)
BEHRISCH AND KADOMTSEV (GRAPHITE)
SMITH (C)
COHEN (GRAPHITE)
BEHRISCH (C FIBER)
ALUMINUM
KENKNIGHT AND WEHNER
COHEN

Sputtering of Fe, Stainless Steel, Nb, and Ta by Protons (normal incidence)

Energy (keV)	Sputtering Coefficients, S (atoms/ion)			
	Fe	SS	Nb	Ta
5.0 E-01		3.2 E-03		
7.0 E-01		3.7 E-03		
1.0 E 00		4.4 E-03		
2.0 E 00	1.0 E-02	6.0 E-03		6.3 E-03
3.0 E 00	1.1 E-02	7.1 E-03		7.7 E-03
5.0 E 00	1.2 E-02	7.3 E-03		9.5 E-03
7.0 E 00		6.2 E-03		1.1 E-02
1.0 E 01				1.2 E-02
1.2 E 01			2.2 E-03	
2.0 E 01			2.0 E-03	
4.0 E 01			1.8 E-03	
7.0 E 01			1.7 E-03	
1.0 E 02			1.6 E-03	2.0 E-02

References:

H^+ + Fe: G. K. Wehner, G. S. Anderson, and C. E. KenKnight, Report #3031, Applied Science Division, Litton Systems.

H^+ + SS: R. Behrisch, et al., Max-Planck Institute Für Plasmaphysik, Report #IPPAR-1974

V. M. Gusev, M. I. Guseva, E. S. Ionova, Yu. L. Krasulin, S. V. Mirnov, and A. V. Nedospasov, Report #OLS-7-75.

H^+ + Nb: R. Behrisch and R. Weissman, Phys. Letters 30A, 506 (1969); A. J. Summers, N. J. Freeman and N. R. Daly, J. Appl. Phys. 42, 4774 (1971)

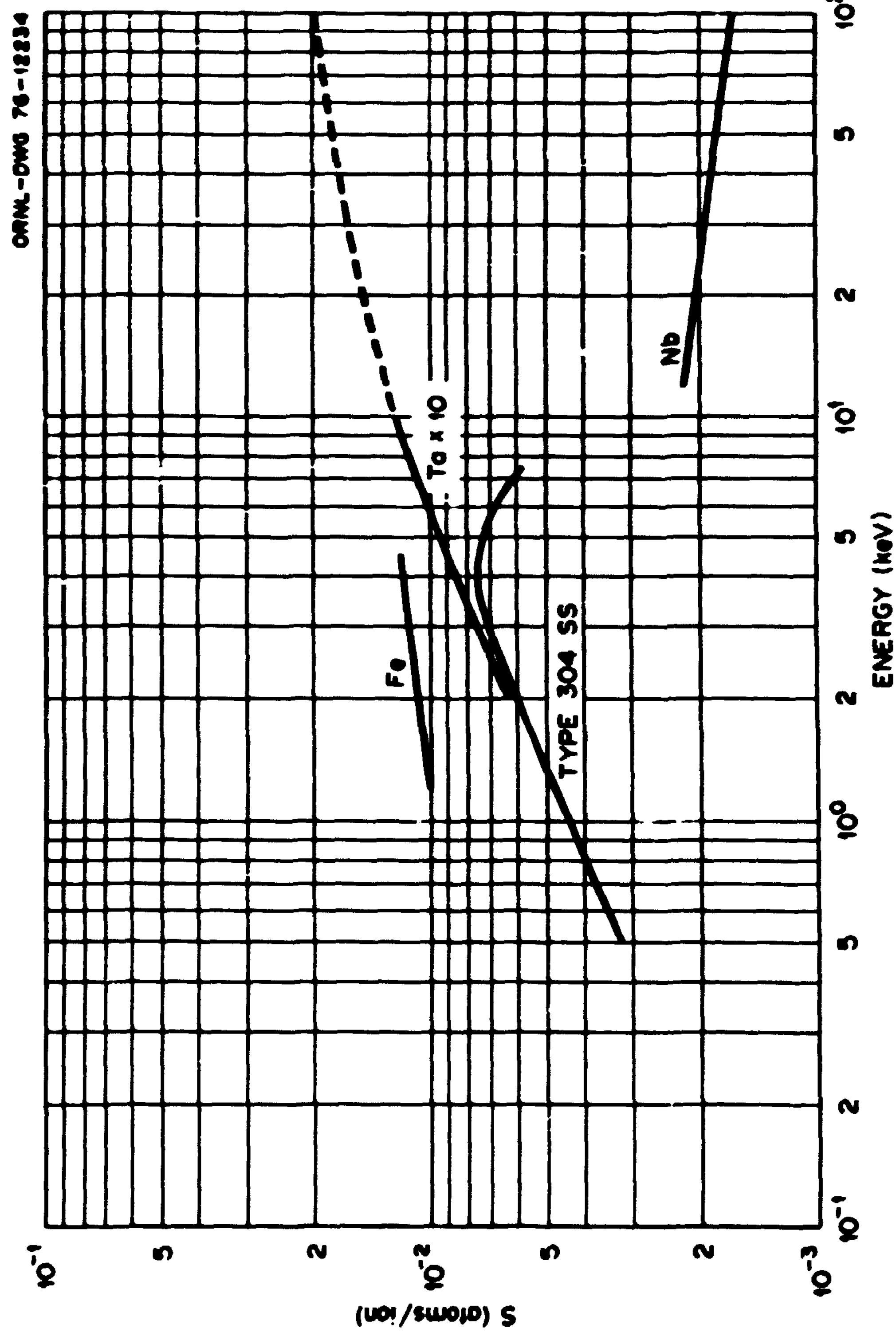
See Note (5) at end of chapter.

Accuracy:

Unknown

Notes:

See Note (6) at end of chapter.


ORNL-DWG 76-12234
Ta x 10
Fe
TYPE 304 SS
Nb
ENERGY (keV)
S (atoms/ion)
10^{-1}
2
5
10^{0}
2
5
10^{1}
2
5
10^{2}
10^{-3}
2
5
10^{-2}
2
5
10^{-1}

Sputtering of Ti, Mo and W

by Protons (normal incidence)

Energy (keV)	Sputtering Coefficients, S (atoms/ion)			
	Mo	Ti	W	W'
1.0 E 00	1.7 E-03		2.3 E-04	
2.0 E 00	2.1 E-03		2.6 E-04	2.8 E-04
3.0 E 00	2.4 E-03	5.6 E-03	2.9 E-04	5.2 E-04
4.0 E 00	2.7 E-03		3.1 E-04	8.2 E-04
7.0 E 00	3.2 E-03		3.5 E-04	
9.0 E 00				
1.1 E 01				4.0 E-03
1.0 E 02		1.4 E-03		

<u>References</u>:

H^+ + Mo: C. R. Finfgeld, Report #ORO-3557-15; C. E. KenKnight, and G. K. Wehner, J. Appl. Phys. 35, 322 (1964); G. K. Wehner, G. S. Anderson, and C. E. KenKnight, Report #3031, Applied Science Division, Litton Systems.

H^+ + Ti: R. Behrisch and R. Weissman, Phys. Letters 30A, 506 (1966); C. E. KenKnight and G. K. Wehner, J. Appl. Phys. 35, 322 (1964); G. K. Wehner, G. S. Anderson, and C. E. KenKnight, Report #3031, Applied Science Division, Litton Systems.

H^+ + W: C. R. Finfgeld, Report #ORO-3557-15.

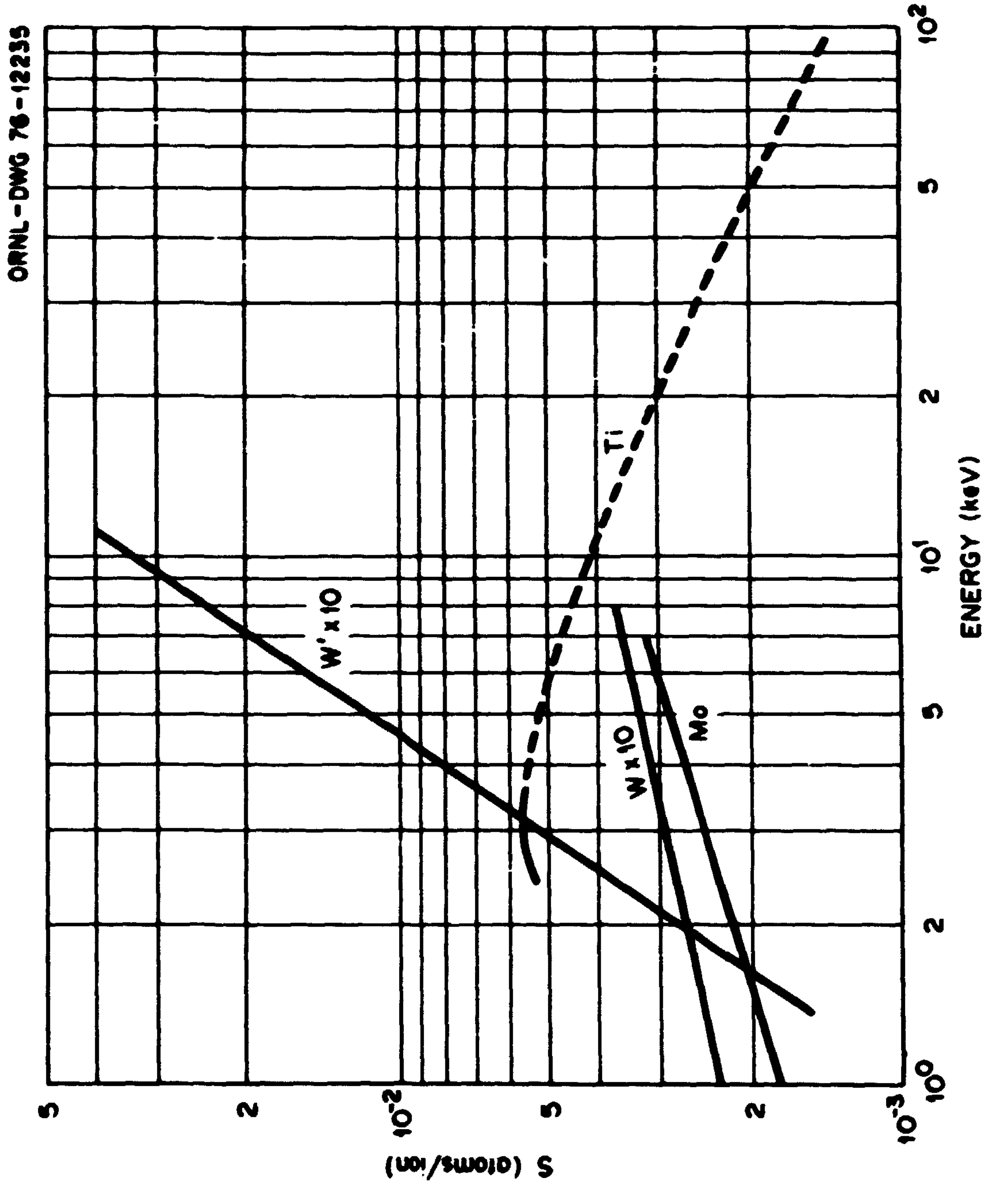
H^+ + W': C. E. KenKnight and G. K. Wehner, J. Appl. Physics 35, 322 (1964); J. N. Smith, Jr., C. H. Meyer, Jr., and J. K. Layton, Report #GA-A13665; G. K. Wehner, G. S. Anderson, and C. E. KenKnight, Report #3031, Applied Systems Division, Litton Systems.

<u>Accuracy</u>:

Unknown

<u>Notes</u>:

See Notes (7) and (8) at end of chapter.


ORNL-DWG 76-12235
W' x 10
Ti
W x 10
Mo
S (atoms/ion)
ENERGY (keV)
5
2
10^{-2}
5
2
10^{-3}
10^0
2
5
10^1
2
5
10^2

Sputtering Yields for H^+ on Au, Ag, and Zr (normal incidence)

Energy (keV)	Sputtering Coefficients, S (atoms/ion)		
	Au	Ag	Zr
4.0 E-01		2.4 E-03	
6.0 E-01		4.6 E-03	
1.0 E 00	3.0 E-02	9.5 E-03	
1.5 E 00	3.1 E-02	1.4 E-02	
2.0 E 00	3.1 E-02	1.7 E-02	
2.5 E 00	3.1 E-02	1.8 E-02	3.2 E-03
3.0 E 00	3.2 E-02	1.9 E-02	3.4 E-03
5.0 E 00	3.2 E-02	2.1 E-02	
8.0 E 00	3.1 E-02	2.2 E-02	
1.0 E 01	3.1 E-02		
1.3 E 01	3.1 E-02		

References:

H^+ + Ag: F. Grønlund and W. J. Moore, J. Chem. Phys. 32, 1540 (1960); C. D. O'Briain, A. Linder, and W. J. Moore, J. Chem. Phys. 29, 3 (1958); C. E. KenKnight and G. K. Wehner, J. Appl. Phys. 35, 322 (1964); J. N. Smith, Jr., C. H. Meyer, Jr., and J. K. Layton, Report #GA-A13665; G. K. Wehner, G. S. Anderson, and C. E. KenKnight, Report #3031, Applied Science Division, Litton Systems.

H^+ + Au: C. R. Finfgeld, Report #ORO-3557-15; A. K. Furr and C. R. Finfgeld, J. Appl. Phys. 41, 1739 (1970); C. E. KenKnight and G. K. Wehner, J. Appl. Phys. 35, 322 (1964); G. K. Wehner, G. S. Anderson, and C. E. KenKnight, Report #3031, Applied Science Division, Litton Systems.

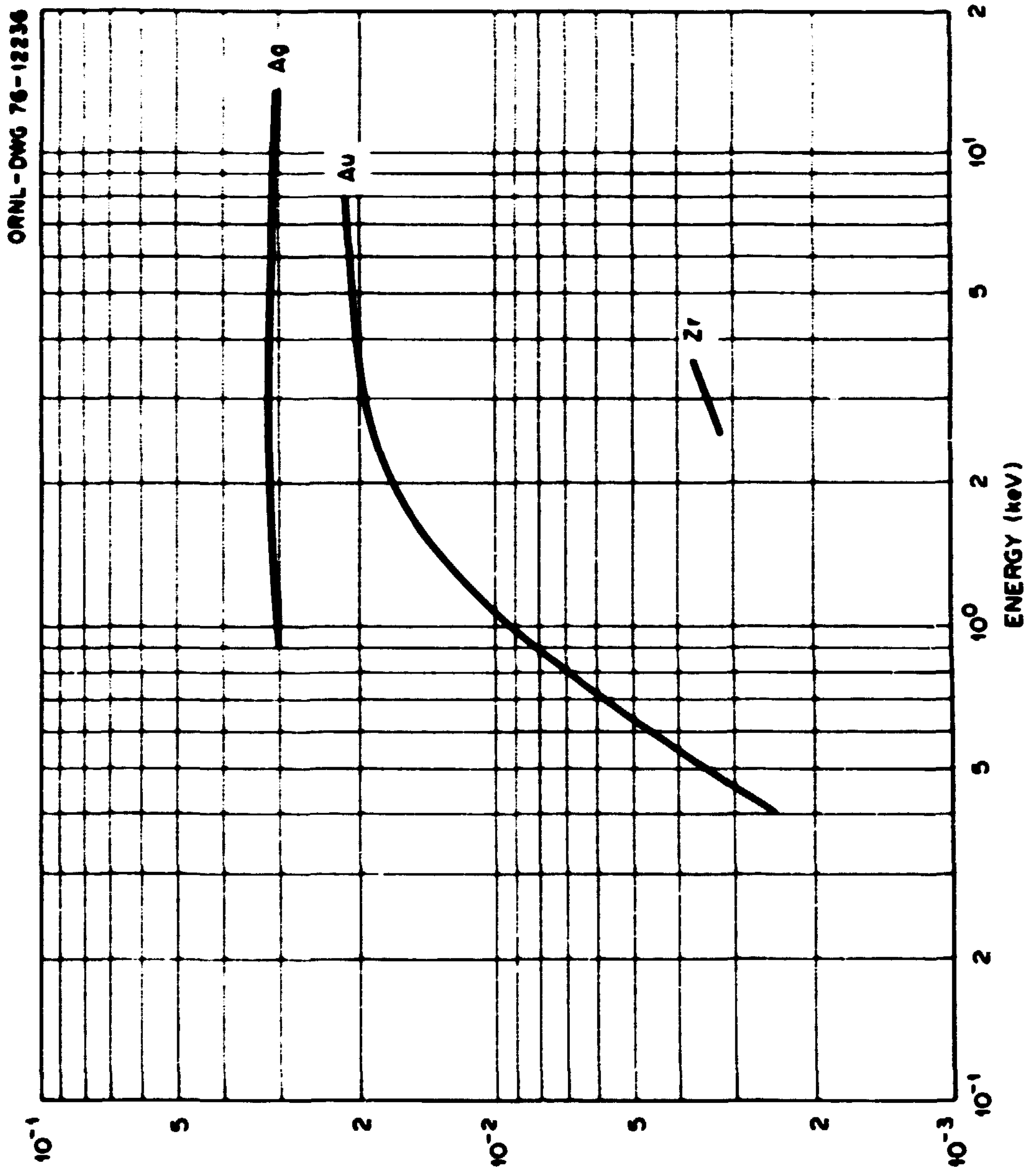
H^+ + Zr: C. E. KenKnight and G. K. Wehner, J. Appl. Phys. 35, 322 (1964).

Accuracy:

Unknown

Notes:

See Note (9) at end of chapter.


ORNL-DWG 76-12236
Ag
Au
Zr
S (atoms/ion)
ENERGY (keV)
10^{-1}
5
2
10^{-2}
5
2
10^{-3}
10^{-1}
2
5
10^{0}
2
5
10^{1}
2

Sputtering Coefficients for D^+ on Cu, Al, Ni, and Fe

(normal incidence)

Energy (keV)	Sputtering Coefficients, S (atoms/ion)	
	Cu	Al
3.0 E 00		3.3 E-02
7.0 E 00	7.2 E-02	
1.0 E 01	6.5 E-02	1.3 E-02
1.5 E 01	4.4 E-02	
2.0 E 01	3.8 E-02	8.0 E-03
3.0 E 01	2.9 E-02	
4.0 E 01	2.3 E-02	
5.0 E 01	1.9 E-02	
1.0 E 02	8.0 E-03	
1.5 E 02	4.5 E-03	
2.0 E 02	3.1 E-03	
3.0 E 02	1.9 E-03	
5.0 E 02	1.1 E-03	
7.0 E 02	7.5 E-04	
1.0 E 03	4.6 E-04	
1.2 E 03	3.5 E-04	

References:

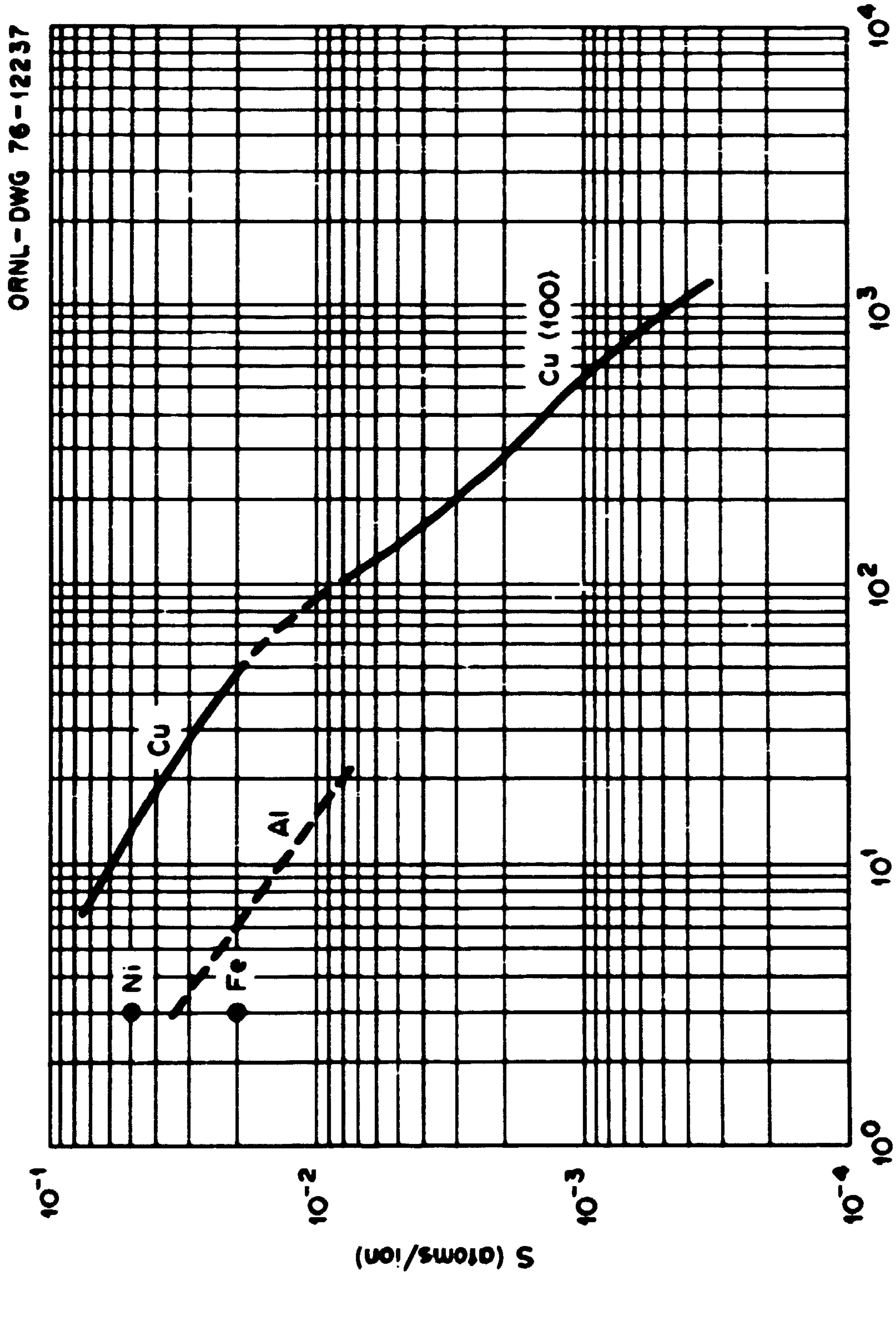
$D^+ \rightarrow$ Cu: G. K. Wehner, Final Rpt. to USAEC, No. 3031 (1966); O. C. Yonts, et al., J. Appl. Phys. 31, 447 (1960); O. C. Yonts, ORNL-TM-2692 (1969); M. Kaminsky, Advances Mass Spec. 3, 69 (1966), single crystal (100); V. M. Gusev, M. I. Guseva, V. P. Vlasenko, L. P. Elistratov, Bull. Acad. Sci. USSR, Phys. Sec. 24. 696 (1960).

$D^+ \rightarrow$ Al: O. C. Yonts, ORNL-TM-2692 (1969); G. K. Wehner, Final Rpt. tc USAEC, No. 3031 (1966).

$D^+ \rightarrow$ Fe, $D^+ \rightarrow$ Ni: G. K. Wehner, Final Rpt. to USAEC, No. 3031 (1966).

Accuracy:

Unknown


ORNL-DWG 76-12237
S (atoms/ion)
10^-1
10^-2
10^-3
10^-4
10^0
10^1
10^2
10^3
10^4
Cu (100)
Cu
Al
Ni
Fe

D.1.14

Sputtering Coefficients for D^+ on Stainless Steel, Be, Mo, and Ag (normal incidence)

Energy (keV)	Sputtering Coefficients, S (atoms/ion)		
	SS	Mo	Ag
1.0 E 00		2.9 E-03	
2.0 E 00		3.3 E-03	9.0 E-02
3.0 E 00		3.7 E-03	9.2 E-02
5.0 E 00	5.0 E-02	4.4 E-03	9.2 E-02
7.5 E 00	5.8 E-02	5.3 E-03	8.8 E-02
1.0 E 01	5.3 E-02	6.2 E-03	7.5 E-02
1.2 E 01	4.6 E-02		6.2 E-02
1.5 E 01	3.7 E-02	7.9 E-03	
2.0 E 01	2.9 E-02	1.0 E-02	
3.0 E 01	2.0 E-02		
1.0 E 02			5.1 E-03
1.5 E 02			4.0 E-03
3.0 E 02			2.6 E-03
5.0 E 02			1.9 E-03
7.5 E 02			1.5 E-03
9.0 E 02			1.3 E-03

References:

$D^+ \rightarrow$ SS: M. I. Guseva, Radio Eng. & Electronic Phys. No. 7, 1563 (1962).

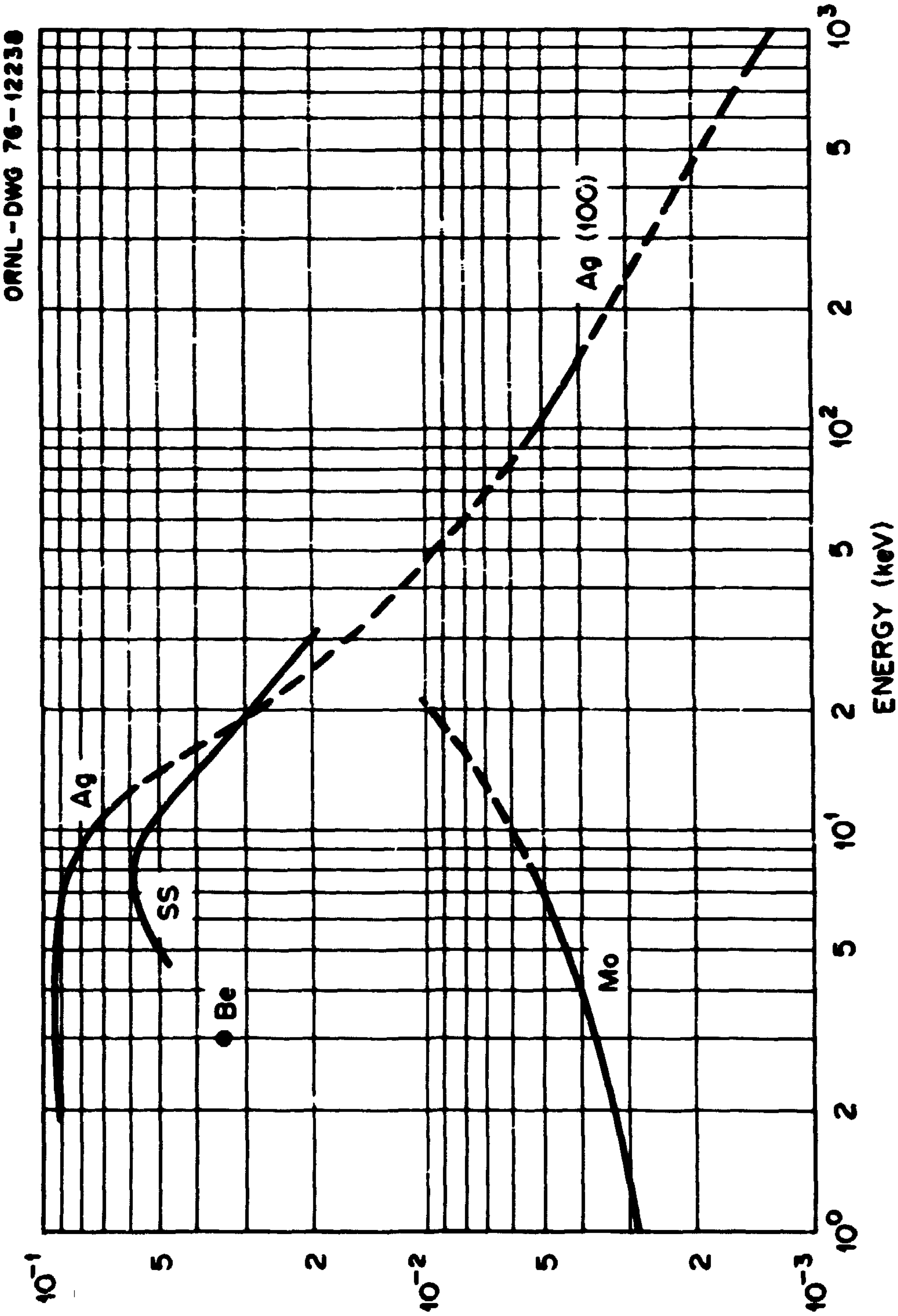
$D^+ \rightarrow$ Mo: C. R. Finfgeld, Final Report to USAEC, No. ORO-3557-15 (1967); O. C. Yonts, ORNL-TM-2692 (1969); G. K. Wehner, Final Rpt. to USAEC, No. 3031 (1966).

$D^+ \rightarrow$ Ag: F. Grønlund, W. J. Moore, J. Chem. Phys. 32, 1540 (1960); M. Kaminsky, Advances Mass. Spec. 3, 69 (1966), single crystal (100); G. K. Wehner, Final Rpt. to USAEC, No. 3031 (1966).

$D^+ \rightarrow$ Be: G. K. Wehner, Final Rpt. to USAEC, No. 3031 (1966).

Accuracy:

Unknown


ORNL-DWG 76-12238
S (atoms/ion)
ENERGY (keV)
Ag
SS
Be
Mo
Ag (100)

Sputtering Coefficients for D^+ on Nb, Nb-Zr, Ta, W, and Au (normal incidence)

Energy (keV)	Sputtering Coefficients, S (atoms/ion)				
	Nb	Nb-Zr	Ta	W	Au
5.0 E-01			1.4 E-03		1.7 E-02
7.0 E-01			1.5 E-03		2.2 E-02
1.0 E 00			1.6 E-03	7.2 E-04	2.8 E-02
1.5 E 00			1.8 E-03		3.3 E-02
2.0 E 00			2.0 E-03	9.0 E-04	3.6 E-02
3.0 E 00			2.3 E-03	9.5 E-04	4.1 E-02
5.0 E 00			2.9 E-03	9.3 E-04	4.6 E-02
7.0 E 00			3.4 E-03	9.2 E-04	5.0 E-02
1.0 E 01			4.2 E-03	8.9 E-04	5.3 E-02
1.2 E 01	8.0 E-03				
1.5 E 01	5.4 E-03		4.9 E-03		
2.0 E 01	4.4 E-03	1.3 E-03	5.1 E-03	7.9 E-04	
3.0 E 01	3.4 E-03		5.3 E-03		
4.0 E 01	2.6 E-03				
5.5 E 01	1.5 E-03				

References:

$D^+ \rightarrow$ Nb and $D^+ \rightarrow$ Nb-Zr: A. J. Summers, et al., J. Appl. Phys. 42, 4774 (1971); O. C. Yonts, ORNL-TM-2692 (1969).

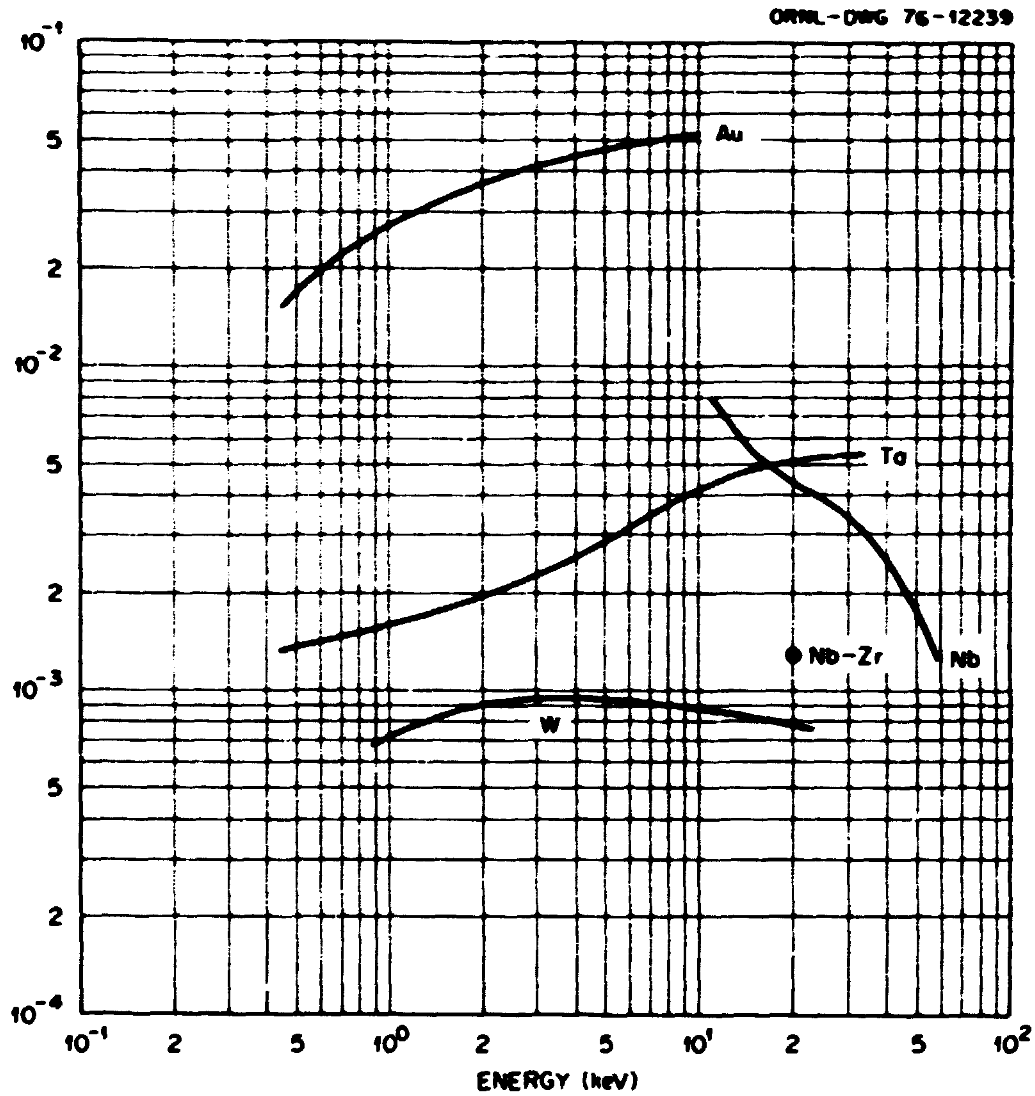
$D^+ \rightarrow$ Ta: C. R. Finfgeld, Final Rpt. to USAEC, No. ORO-3557-15 (1976); M. I. Guseva, Radio Eng. & Electronic Physics No. 7, 1563 (1962); G. K. Wehner, Final Rpt. to USAEC, No. 3031 (1966).

$D^+ \rightarrow$ W: C. R. Finfgeld, Final Rpt. to USAEC, No. ORO-3557-15 (1976); O. C. Yonts, ORNL-TM-2692 (1969).

$D^+ \rightarrow$ Au: C. R. Finfgeld, Final Rpt. to USAEC, No. ORO-3557-15 (1976); G. K. Wehner, Final Rpt. to USAEC, No. 3031 (1966).

Accuracy:

Unknown


ORNL-DWG 76-12239
S (atoms/ion)
ENERGY (keV)
Au
Ta
Nb
Nb-Zr
W
10^{-1}
5
2
10^{-2}
5
2
10^{-3}
5
2
10^{-4}
10^{-1}
2
5
10^{0}
2
5
10^{1}
2
5
10^{2}

Sputtering Coefficients for D_2^+ on Be, Al, Fe, SS, Ni, Cu, Mo, Ag, Ta, and Au (normal incidence)

Energy (keV)	Sputtering Coefficients, S (atoms/ion)					
	Be	**Fe**	**Nb**	**Cu**	**Ag**	**Isolated Points**
2.0 E 00					2.1 E-01	
3.0 E 00					2.1 E-01	
4.0 E 00					2.1 E-01	
5.0 E 00					2.1 E-01	
6.0 E 00			8.0 E-03		2.1 E-01	
6.5 E 00				1.7 E-01		
7.0 E 00				1.8 E-01	2.0 E-01	9.5 E-02 ($D_2^+ \rightarrow$ Ni)
7.5 E 00	3.7 E-02	3.7 E-02				5.9 E-02 ($D_2^+ \rightarrow$ Al)
7.5 E 00						7.5 E-02 ($D_2^+ \rightarrow$ SS)
7.5 E 00						9.1 E-02 ($D_2^+ \rightarrow$ Au)
8.0 E 00			8.0 E-03	2.0 E-01	1.8 E-01	
9.0 E 00	3.9 E-02	3.7 E-02		2.0 E-01	1.7 E-01	
1.0 E 01	4.0 E-02	3.8 E-02	8.0 E-03	1.8 E-01	1.6 E-01	1.5 E-02 ($D_2^+ \rightarrow$ Mo)
1.0 E 01						1.1 E-02 ($D_2^+ \rightarrow$ Ta)
1.6 E 01			6.0 E-03			

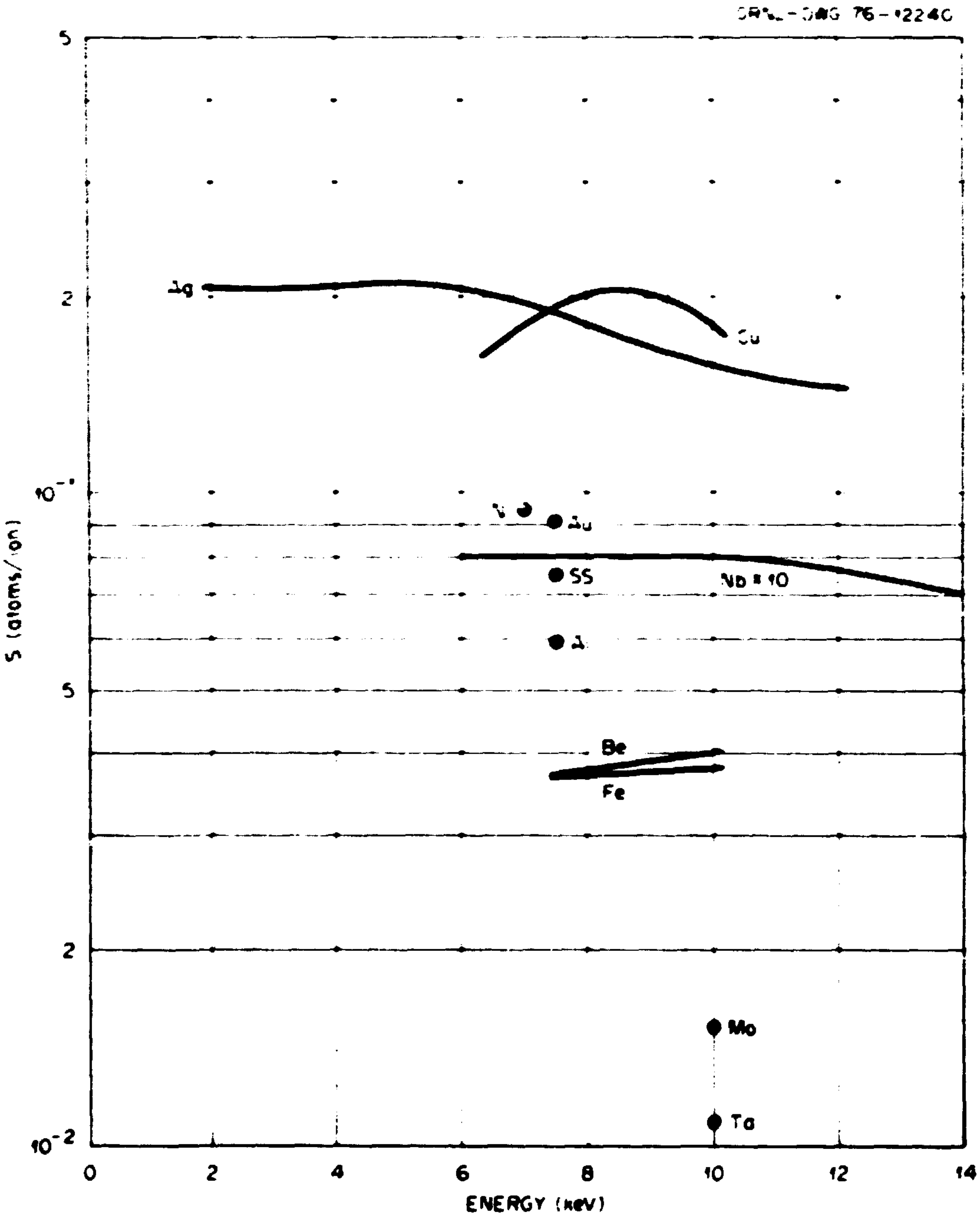
References:

$D_2^+ \rightarrow$ Ag: F. Grønlund, W. J. Moore, J. Chem. Phys. 32, 1540 (1960); G. K. Wehner, Final Rpt. to USAEC, No. 3031 (1966).

$D_2^+ \rightarrow$ Be, $D_2^+ \rightarrow$ Fe, $D_2^+ \rightarrow$ Cu, $D_2^+ \rightarrow$ Ni, $D_2^+ \rightarrow$ Al, $D_2^+ \rightarrow$ SS, $D_2^+ \rightarrow$ Au, $D_2^+ \rightarrow$ Mo, $D_2^+ \rightarrow$ Ta: G. K. Wehner, Final Rpt. to USAEC, No. 3031, (1966).

Accuracy:

Unknown


ORNL-DWG 76-12240
5
2
10^{-1}
5
2
10^{-2}
S (atoms/ion)
Ag
Cu
Au
SS
Nb x 10
Be
Fe
Mo
Ta
0
2
4
6
8
10
12
14
ENERGY (keV)

Sputtering Coefficients of D_3^+ on Be, Al, Fe, SS, Ni, Cu, Mo, Ag, Ta, and Au (normal incidence)

Energy (keV)	Sputtering Coefficients, S (atoms/ion)				
	Be	Fe	Cu	Ag	Isolated Points
2.0 E 00				2.8 E-01	
3.0 E 00				3.1 E-01	
4.0 E 00				3.2 E-01	
5.0 E 00				3.2 E-01	
6.0 E 00				3.2 E-01	
6.5 E 00			2.6 E-01		
7.0 E 00			2.7 E-01	3.2 E-01	1.5 E-01 ($D_3^+ \rightarrow$ Ni)
7.5 E 00	1.1 E-01	5.7 E-02			1.0 E-01 ($D_3^+ \rightarrow$ Al)
7.5 E 00					1.2 E-01 ($D_3^+ \rightarrow$ SS)
7.5 E 00					1.3 E-01 ($D_3^+ \rightarrow$ Au)
8.0 E 00			2.9 E-01	3.1 E-01	
9.0 E 00	8.7 E-02	5.9 E-02	2.9 E-01	2.9 E-01	
1.0 E 01	7.4 E-02	6.1 E-02	2.7 E-01	2.7 E-01	2.5 E-02 ($D_3^+ \rightarrow$ Mo)
1.0 E 01					1.0 E-02 ($D_3^+ \rightarrow$ Ta)
1.1 E 01				2.6 E-01	
1.2 E 01				2.7 E-01	

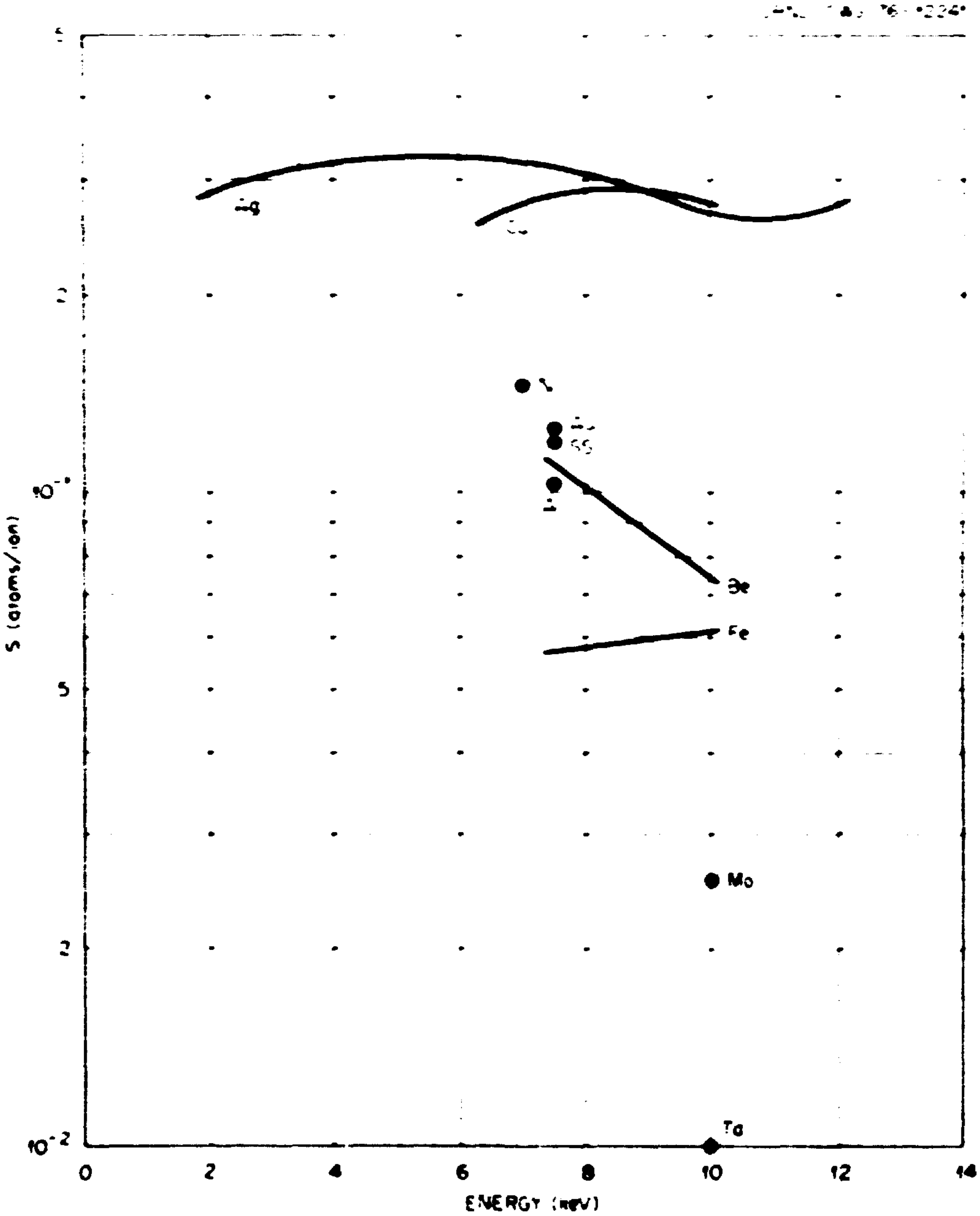
References:

$D_3^+ \rightarrow$ Ag: F. Grøndlund, W. J. Moore, J. Chem. Phys. 32, 1540 (1960); G. K. Wehner, Final Rpt. to USAEC, No. 3031, (1966).

All other data: G. K. Wehner, Final Rpt. to USAEC, No. 3031 (1966).

Accuracy:

Unknown


S (atoms/ion)
ENERGY (keV)
0
2
4
6
8
10
12
14
10^{-2}
2
5
10^{-1}
2
Be
Fe
Mo
Ta
SS

Sputtering Coefficients of He^+ on

C, Be, Al, Si, and Ti

Energy (keV)	Sputtering Coefficients, S (atoms/ion)				
	C	Be	Al	Si	Ti
1.0 E-01	8.0 E-03	4.0 E-02		1.8 E-02	1.0 E-02
2.0 E-01	2.0 E-02	9.3 E-02	5.0 E-03	4.9 E-02	3.7 E-02
3.0 E-01	3.5 E-02	1.4 E-01	8.0 E-03	8.0 E-02	5.2 E-02
6.0 E-01	8.5 E-02	2.5 E-01	2.1 E-02	1.6 E-01	8.0 E-02
1.0 E 00	1.1 E-01	3.5 E-01		2.0 E-01	9.2 E-02
2.0 E 00	1.3 E-01	3.1 E-01		1.6 E-01	9.0 E-02
5.0 E 00	1.2 E-01	1.1 E-01		8.6 E-02	8.2 E-02
7.0 E 00		7.6 E-02		6.4 E-02	9.2 E-02
9.0 E 00	1.0 E-01	5.7 E-02		5.1 E-02	1.0 E-01
2.0 E 01	7.3 E-02		1.7 E-02	2.9 E-02	1.4 E-02
3.0 E 01				2.2 E-02	
5.0 E 01				1.7 E-02	
9.0 E 01				1.6 E-02	

References:

$He^+ \rightarrow$ C: D. Rosenberg, G. K. Wehner, J. Appl. Phys. 33, 1842 (1962); V. M. Gusev, et al., IAE RR Kurchatov, Moscow, Rpt. No. OLS-7-75.

$He^+ \rightarrow$ Be: H. Fetz, H. Oechsner, 6th Int. Conf. Ionization Phenomena Gases, Paris (1963), II, 39; D. Rosenberg, G. K. Wehner, J. Appl. Phys. 33, 1842 (1962); G. K. Wehner, G. S. Anderson, C. E. KenKnight, Surface Bobmardment Studies, Final Rpt. to USAEC, No. 3031 (1966).

$He^+ \rightarrow$ Al: D. Rosenberg, G. K. Wehner, J. Appl. Phys. 33, 1842 (1962); O. C. Yonts, ORNL-TM-2692 (1969); G. K. Wehner, G. S. Anderson, C. E. KenKnight, Final Rpt. to USAEC, No. 3031 (1966).

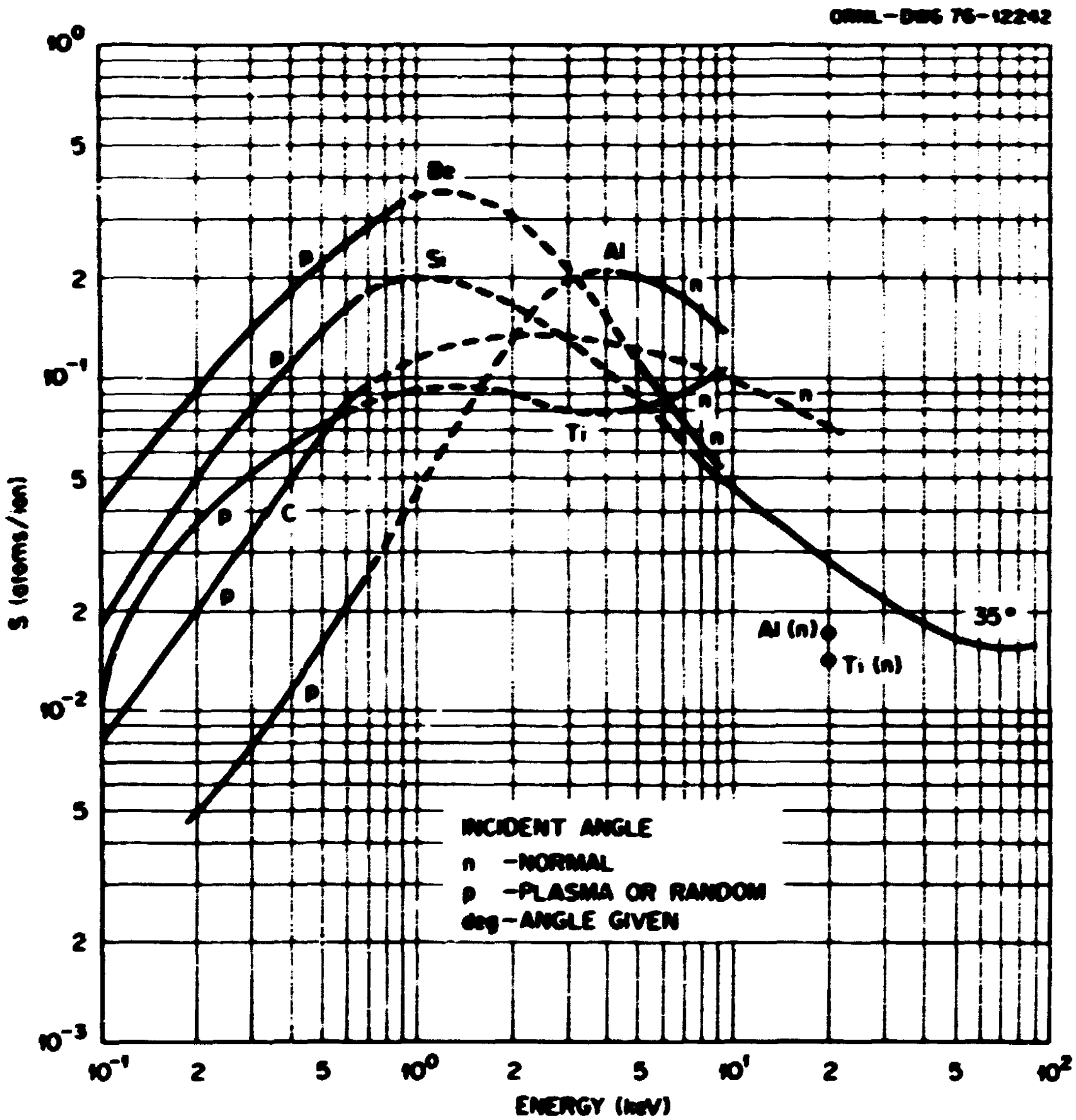
See Notes (10) and (11) at end of chapter.

Accuracy:

Unknown

Notes:

See Notes (12) and (13) at end of chapter.


ORNL-DWG 76-12242
S (atoms/ion)
ENERGY (keV)
Be
Si
Al
Ti
C
35°
Al (n)
Ti (n)
INCIDENT ANGLE
n -NORMAL
p -PLASMA OR RANDOM
deg-ANGLE GIVEN

Sputtering Coefficients of He^+ on

Zr, Nb, Ag, Pt, and Au

Energy (keV)	Sputtering Coefficients, S (atoms/ion)				
	Zr	Nb	Ag	Pt	Au
1.0 E-01			5.0 E-02		
2.0 E-01		5.0 E-03	1.4 E-01	4.0 E-03	2.0 E-02
4.0 E-01	1.9 E-02	1.7 E-02	2.5 E-01	1.8 E-02	5.0 E-02
6.0 E-01	2.5 E-02	3.0 E-02	3.3 E-01	3.5 E-02	8.0 E-02
1.0 E 00	2.9 E-02		3.9 E-01		1.3 E-01
2.0 E 00		5.6 E-02	4.0 E-01		2.2 E-01
3.0 E 00	3.9 E-02		4.0 E-01		
4.0 E 00					3.6 E-01
5.0 E 00	4.3 E-02	6.5 E-02	3.8 E-01		
7.0 E 00	4.6 E-02		3.7 E-01		5.1 E-01
1.0 E 01	4.8 E-02	6.5 E-02	3.5 E-01		5.9 E-01
1.2 E 01	4.9 E-02		3.4 E-01		
2.0 E 01	5.1 E-02	6.0 E-02			7.0 E-01
2.5 E 01	5.2 E-02				
3.0 E 01		5.6 E-02			7.1 E-01
4.0 E 01		5.3 E-02			6.9 E-01
6.0 E 01		4.8 E-02			6.0 E-01

References:

$He^+ \rightarrow Zr$: B. V. Panin, Soviet Phys. JETP 14, 1 (1962); D. Rosenberg, G. K. Wehner, J. Appl. Phys. 33, 1842 (1962).

$He^+ \rightarrow Nb$: D. Rosenberg, G. K. Wehner, J. Appl. Phys. 33, 1842 (1962); A. J. Summers, N. J. Freeman, N. R. Daly, J. Appl. Phys. 42, 4774 (1971); O. C. Yonts, ORNL-TM-2692 (1969) - Also $He^+ \rightarrow$ Nb-Zr.

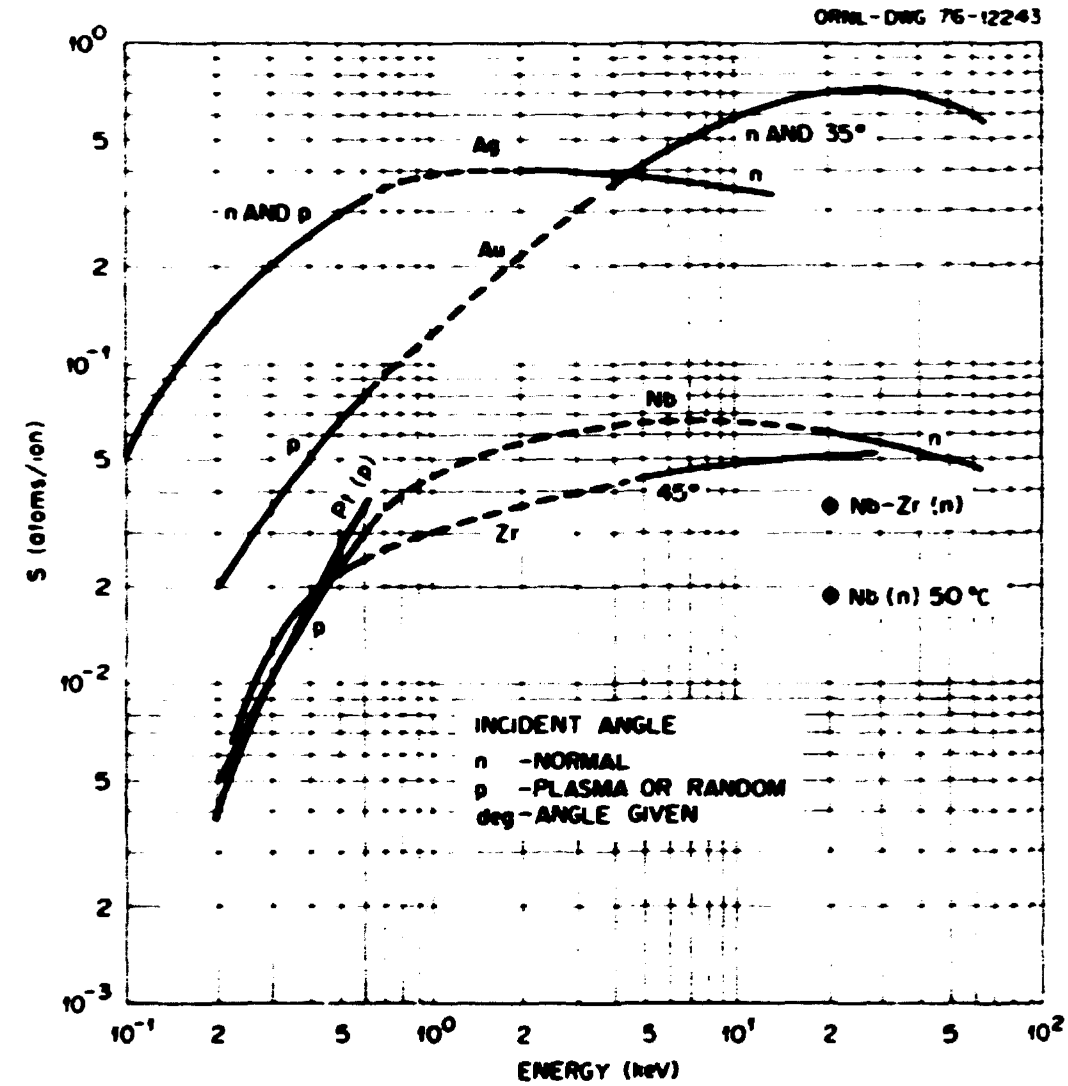
See Notes (14), (15), and (16) at end of chapter.

Accuracy:

Unknown

Notes:

See Notes (17) and (18) at end of chapter.


ORNL-DWG 76-12243
S (atoms/ion)
ENERGY (keV)
Ag
n AND 35°
n
n AND p
Au
p
Nb
n
Pt (p)
45°
Zr
● Nb-Zr (n)
● Nb (n) 50 °C
p
INCIDENT ANGLE
n -NORMAL
p -PLASMA OR RANDOM
deg-ANGLE GIVEN

Sputtering Coefficients of He^{+} on V, Cr, Fe, Ni, Cu, Mo, Ta, and W

Energy (keV)	Sputtering Coefficients, S (atoms/ion)							
	V	Cr	Fe	Ni	Cu	Mo	Ta	W
1.0 E-01	3.0 E-03	3.0 E-02	3.0 E-02		4.5 E-02	1.0 E-03		
2.0 E-01	2.1 E-02	7.0 E-02	6.3 E-02	5.3 E-02	1.1 E-01	5.0 E-03	2.0 E-03	1.0 E-03
3.0 E-01	3.9 E-02	1.1 E-01	9.2 E-02	8.3 E-02	1.6 E-01	1.4 E-02	3.0 E-0[illegible]	4.0 E-03
4.0 E-01	5.7 E-02	1.4 E-01	1.2 E-01	1.1 E-01	2.0 E-01	2.4 E-02	4.5 E-03	5.6 E-03
6.0 E-01	9.0 E-02	2.0 E-01	1.6 E-01	1.6 E-01	2.7 E-01	4.0 E-02	1.2 E-02	8.0 E-03
9.0 E-01			2.1 E-01	2.3 E-01	3.3 E-01			
2.0 E 00			2.1 E-01	2.7 E-01	3.8 E-01			
5.0 E 00			1.5 E-01	2.0 E-01	3.3 E-01			
7.0 E 00			1.2 E-01	1.7 E-01	2.9 E-01			
9.0 E 00			9.6 E-02	1.4 E-01	2.6 E-01			
2.0 E 01			1.7 E-02		1.5 E-01			
3.9 E 01					8.0 E-02			

References:

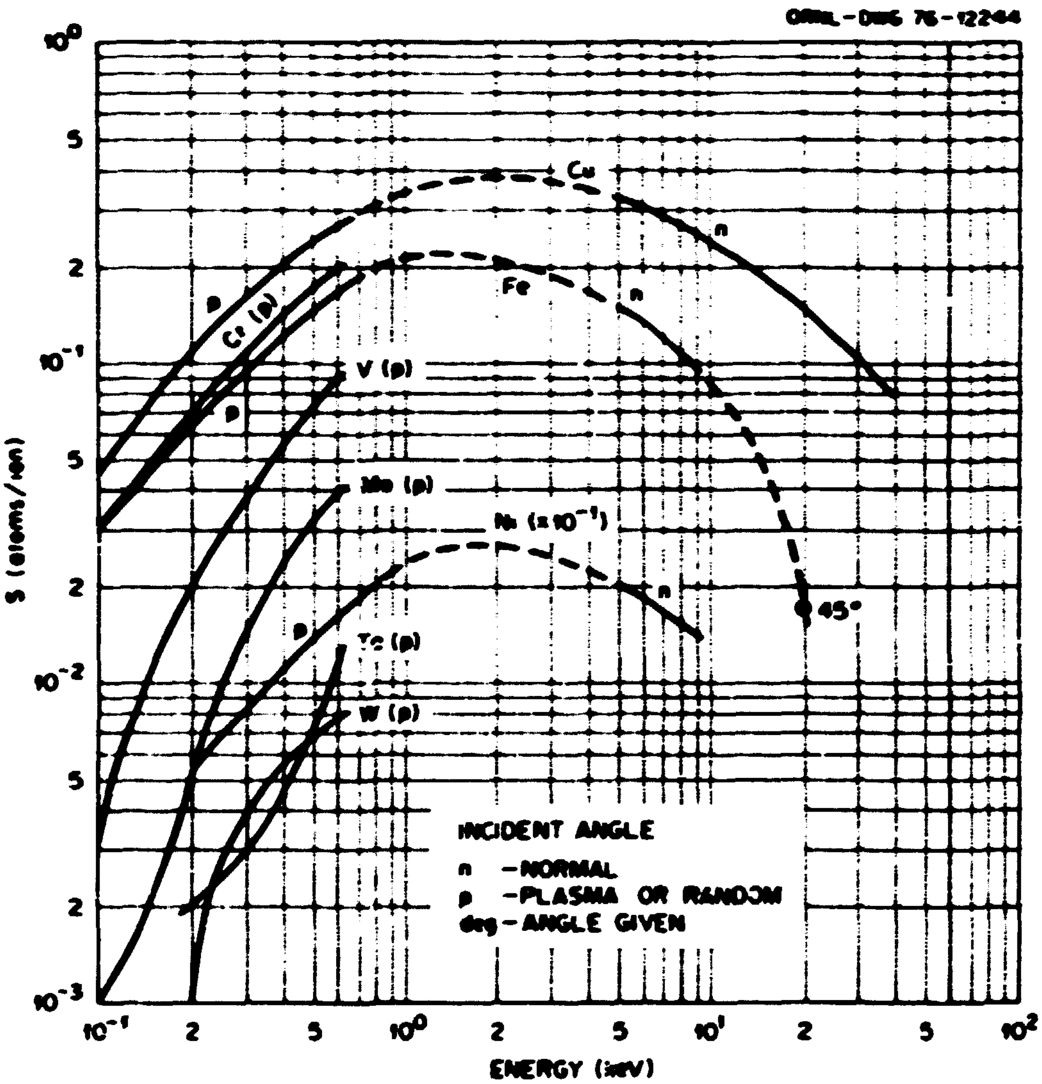
See Notes (19), (20), (21), and (22) at end of chapter.

Accuracy:

Unknown

Notes:

Plasma incidence data (p) are not corrected for secondary electron emission (Ref. Rosenberg, *et al*.).


ORNL-DWG 76-12244
Cu
n
Fe
n
Cr (p)
p
p
V (p)
Mo (p)
Nb (x10^-1)
n
45°
p
Ta (p)
W (p)
INCIDENT ANGLE
n -NORMAL
p -PLASMA OR RANDOM
deg-ANGLE GIVEN
S (atoms/ion)
ENERGY (keV)

Sputtering Coefficients for Nitrogen Ions on Copper, Silver and Gold

Energy (keV)	Sputtering Coefficients, S (atoms/ion)					
	N^+ + Ag	N^+ + Cu Normal	N^+ + Cu 45°-50°	N_2^+ + Cu Normal	N_2^+ + Cu 45°-50°	N_2^+ + Au
4.0 E-01						6.8 E-01
5.0 E-01				1.1 E 00	1.8 E 00	
6.0 E-01						8.3 E-01
1.0 E 00				1.9 E 00	2.8 E 00	
1.5 E 00				2.5 E 00	3.6 E 00	
2.5 E 00				3.4 E 00	4.8 E 00	
4.0 E 00				4.3 E 00	5.7 E 00	
5.0 E 00	4.0 E 00	1.8 E 00	3.0 E 00	4.6 E 00		
7.0 E 00		1.9 E 00	3.3 E 00	4.6 E 00	6.2 E 00	
1.0 E 01	3.2 E 00	2.0 E 00	3.4 E 00	4.1 E 00	6.4 E 00	
1.5 E 01		2.0 E 00	3.4 E 00	3.6 E 00	6.6 E 00	
2.0 E 01	2.8 E 00	2.0 E 00	3.4 E 00	3.6 E 00	6.7 E 00	
2.5 E 01		1.9 E 00		3.7 E 00	6.7 E 00	
3.0 E 01	2.7 E 00	1.8 E 00				
4.0 E 01	2.7 E 00	1.6 E 00				
5.0 E 01	2.7 E 00	1.3 E 00				

References:

$N^+ \rightarrow$ Ag: O. Almén, G. Bruce, Nucl. Instr. & Meth. 11, 257 (1961); F. Grønlund, W. J. Moore, J. Chem. Phys. 32, 1540 (1960).

$N^+ \rightarrow$ Cu: P. K. Rol, J. M. Fluit, J. Kistemaker, Physica 26, 1000 (1960); O. Almén, G. Bruce, Nucl. Instr. & Meth. 11, 257 (1961).

$N_2^+ \rightarrow$ Cu: P. K. Rol, J. M. Fluit, J. Kistemaker, Physica 26, 1000 (1960); T. W. Snouse, Rpt. NASA TN D-2235 (1964).

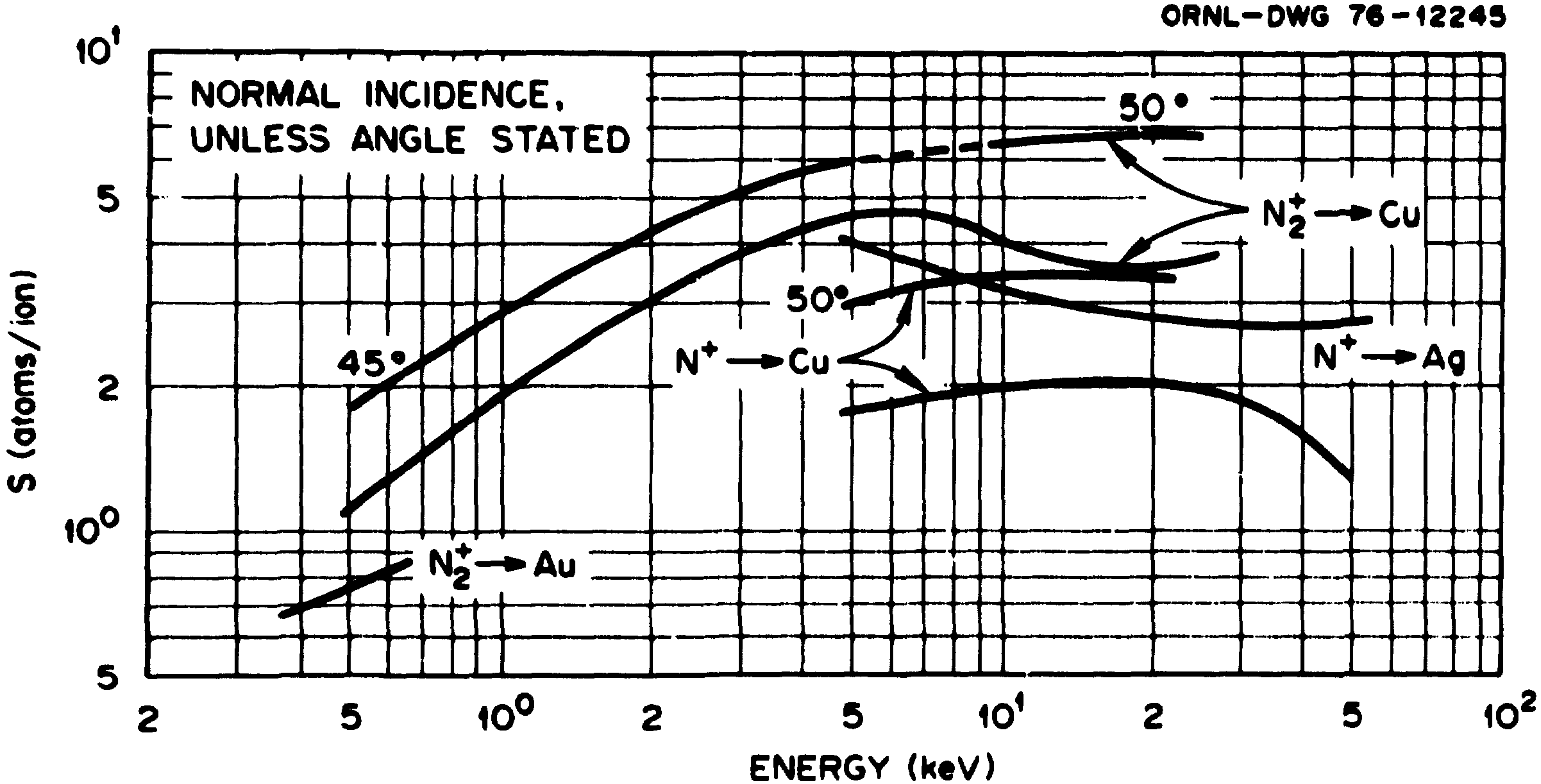
$N_2^+ \rightarrow$ Au: J. S. Colligon, C. M. Hicks, A. P. Neokleous, Rad. Eff. 18, 119 (1973).

Accuracy:

Unknown

Notes:

N_2^+ + Au data are not corrected for secondary electron emission.


ORNL-DWG 76-12245
NORMAL INCIDENCE,
UNLESS ANGLE STATED
50°
$N_2^+ \rightarrow Cu$
50°
45°
$N^+ \rightarrow Cu$
$N^+ \rightarrow Ag$
$N_2^+ \rightarrow Au$
S (atoms/ion)
ENERGY (keV)
10^1
5
2
10^0
5
2
5
10^0
2
5
10^1
2
5
10^2

D.1.30

Self-Sputtering Coefficients for

Al, Ni, Cu, Ag, and Au

(normal incidence)

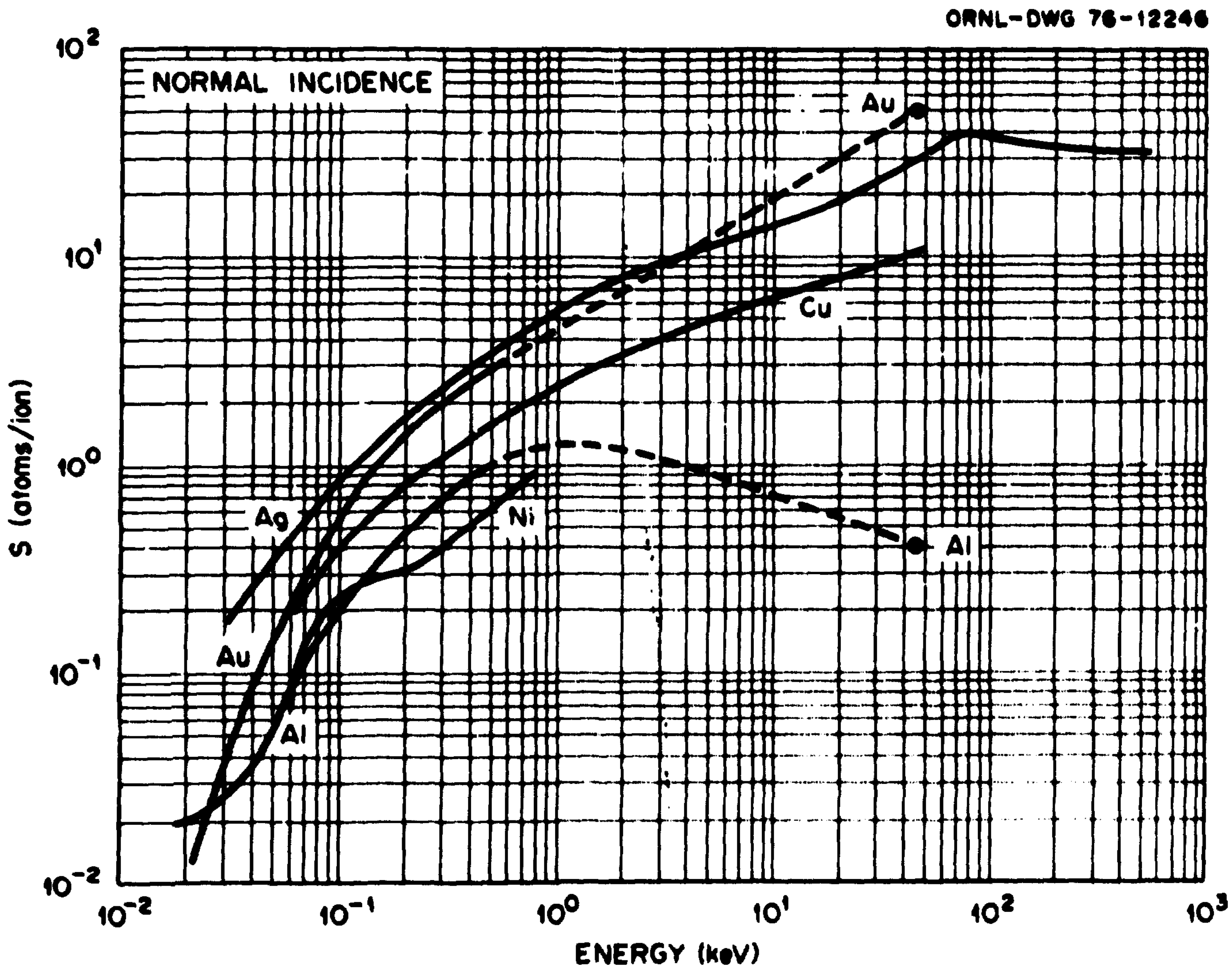
Energy (keV)	Self-Sputtering Coefficients, S (atoms/ion)				
	Al	Ni	Cu	Ag	Au
2.0 E-02	2.0 E-02				
2.2 E-02					1.4 E-02
3.0 E-02	2.5 E-02				3.9 E-02
3.5 E-02				2.2 E-01	
4.0 E-02	3.5 E-02				8.3 E-02
5.0 E-02	5.6 E-02			3.6 E-01	1.4 E-01
6.0 E-02		8.0 E-02			2.2 E-01
6.5 E-02	1.0 E-01	1.1 E-01	2.2 E-01	5.1 E-01	
8.0 E-02	1.4 E-01	1.8 E-01	3.1 E-01	6.7 E-01	3.9 E-01
1.0 E-01	2.0 E-01	2.3 E-01	4.0 E-01	8.7 E-01	5.9 E-01
2.0 E-01	4.7 E-01	3.1 E-01	8.1 E-01	1.7 E 00	1.4 E 00
5.0 E-01	1.0 E 00	6.4 E-01	1.6 E 00	3.6 E 00	2.9 E 00
8.0 E-01		9.1 E-01	2.2 E 00	5.0 E 00	
1.0 E 00	1.3 E 00		2.5 E 00	5.7 E 00	4.6 E 00
2.0 E 00	1.2 E 00		3.5 E 00	8.3 E 00	7.0 E 00
3.0 E 00			4.2 E 00	9.8 E 00	
5.0 E 00	9.0 E-01		5.2 E 00	1.1 E-01	1.3 E-01
1.0 E 01	7.0 E-01		6.7 E 00	1.5 E-01	2.0 E-01
2.0 E 01	5.5 E-01		8.3 E 00	2.0 E-01	3.1 E-01
3.0 E 01			9.3 E 00	2.4 E-01	
4.5 E 01	4.2 E-01				5.2 E-01
5.0 E 01			1.1 E 01	3.2 E-01	
7.0 E 01				4.0 E-01	
1.0 E 02				3.9 E-01	
2.0 E 02				3.6 E-01	
3.0 E 02				3.5 E-01	
5.0 E 02				3.4 E-01	

<u>**References**</u>:

See Notes (23), (24), (25), (26), and (27) at end of chapter.

<u>**Accuracy**</u>:

Unknown


ORNL-DWG 76-12246
NORMAL INCIDENCE
Au
Cu
Ag
Ni
Al
Au
Al
S (atoms/ion)
10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-2}
10^{-1}
10^0
10^1
10^2
10^3
ENERGY (keV)

Self-Sputtering Coefficients for Si, Cr, and Zn (normal incidence)

Energy (keV)	Self-Sputtering Coefficients, S (atoms/ion)		
	$Si^+ \rightarrow Si$	$Cr^+ \rightarrow Cr$	$Zn^+ \rightarrow Zn$
3.3 E-02			1.5 E-01
4.0 E-02			3.1 E-01
6.0 E-02			5.0 E-01
8.0 E-02			5.8 E-01
1.0 E-01			6.2 E-01
1.5 E-01			7.0 E-01
2.0 E-01		4.5 E-01	
2.1 E-01			7.4 E-01
3.0 E-01		7.7 E-01	
5.0 E-01		1.1 E 00	
5.0 E 00			
1.0 E 01			
1.5 E 01			
2.0 E 01			
2.1 E 01			
4.5 E 01	4.0 E-02		

References:

$Si^+ \rightarrow Si$: O. Almén, G. Bruce, Nucl. Instr. & Meth. 11, 279 (1961).

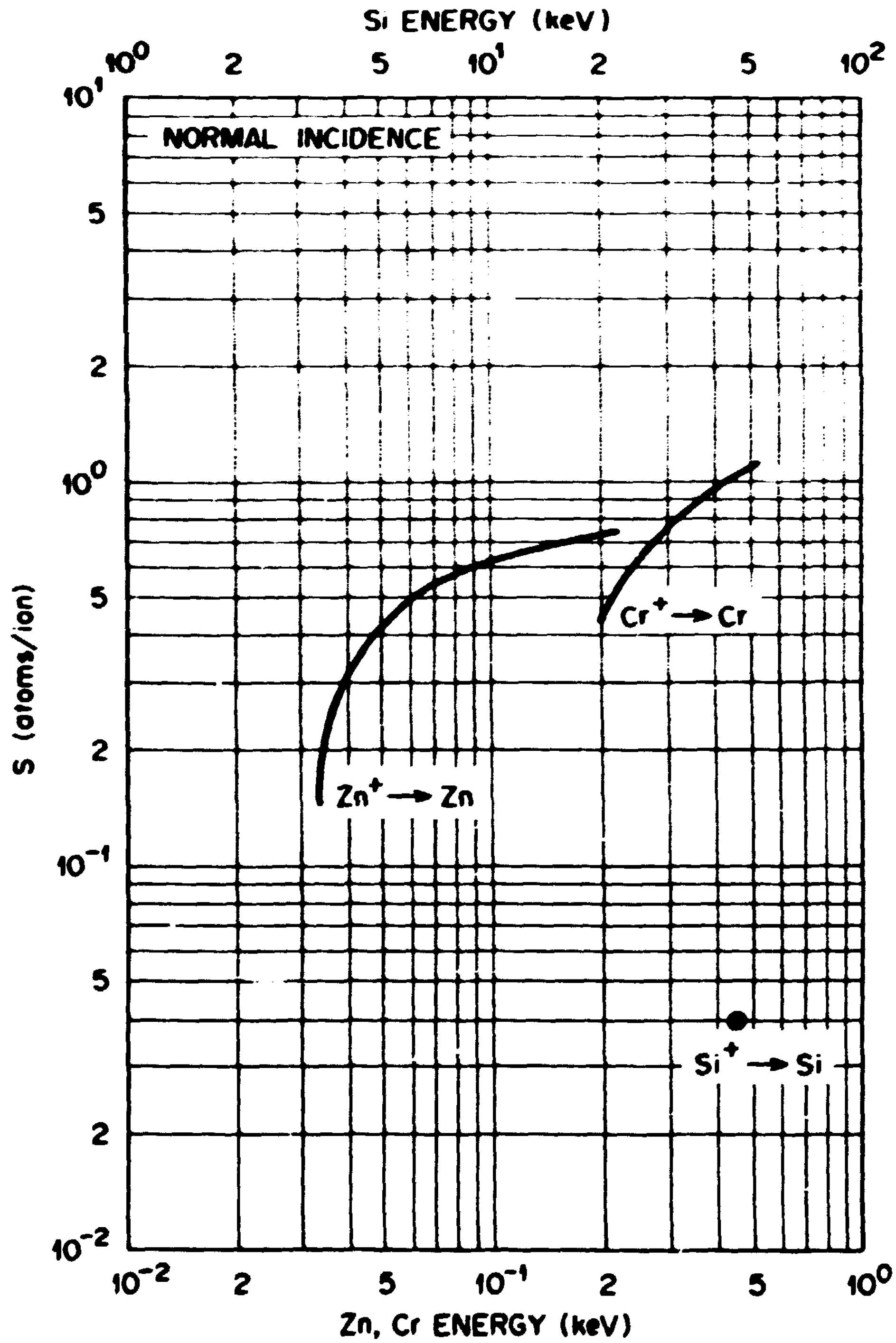
$Cr^+ \rightarrow Cr$: W. H. Hayward, A. R. Wolter, J. Appl. Phys. 40, 2911 (1969).

$Zn^+ \rightarrow Zn$: A Fontell, E. Arminen, Can. J. Phys. 47, 2405 (1969).

Accuracy:

Unknown

ORNL-DWG 76-12247



Sputtering Coefficients for Oxygen Particles on Copper,

Silver, Gold and Tantalum (normal incidence)

Particle	Target	Energy (keV)	S (atoms/ion)	Ref.	Year
O^+	Cu	4.5 E 01	1.0 E 00	1	1961
O^+	Ag	5.0 E 00	4.4 E 00	2	1960
O^+	Ag	4.5 E 01	4.8 E 00	1	1961
O^+	Ta	4.5 E 01	2.0 E-01	1	1961
O^o	Ag	9.0 E 00	2.6 E 00	3	1969
O^o	Au	9.0 E 00	1.7 E 00	3	1969
O_2^o	Ag	9.0 E 00	6.0 E 00	3	1969
O_2^o	Au	9.0 E 00	2.8 E 00	3	1969
O_3^o	Ag	9.0 E 00	7.6 E 00	3	1969

References:

1. O. Almén, G. Bruce, Nucl. Instr. & Meth. 11, 279 (1961).
2. F. Grønlund, W. J. Moore, J. Chem. Phys. 32, 1540 (1960).
3. F. M. Devienne, A. Roustan, Compt. Rend. 268B, 1362 (1969).

Accuracy:

Unknown

Self-Sputtering of V, Fe, Zr, Nb, Mo, Ta,

and W^+ at 45 keV (normal incidence)

Element	Self-Sputtering Coefficient, s (atoms/ion)
V	7.6 E-01
Fe	2.8 E 00
Zr	1.2 E 00
Nb	1.3 E 00
Mo	2.1 E 00
Ta	3.1 E 00
W	4.8 E 00

Reference:

O. Almén, G. Bruce, Nucl, Instr. & Meth. 11, 279 (1961).

Accuracy:

Unknown

Sputtering Coefficients for Neutrons

on Fe, Nb, and Au

Material (Treatment)	Energy (MeV)	Dose (n/cm^2)	Sputtering Coefficient (atoms/ion)	Ref	Year
Fe (foil)	>0.1(av.)	1.2 E 19(av.)	6.3 E-03(av.)	1	1974
Cu (foil)	14.1	2.4 E 13	≤3.9 E-02	2	1968
Nb (crystal)	16(av.)	3.5 E 16	≤3.0 E-05	3	1975
Nb (worked)	16(av.)	3.3 E 16	≤3.0 E-05[f]	3	1975
Nb (worked)	16(av.)	3.3 E 16	≤3.0 E-05[b]	3	1975
Nb (cold worked)	14	1.1 E 16	≤1.5 E-05[f,b]	4	1975
Nb (cold worked)	14	4.6 E 15	2.5 E-01	5	1974
In (foil	14	1.5 E 13	≤3.6 E-03	2	1968
W (foil)	14	1.5 E 13	≤1.1 E-02	2	1968
Au (foil)	14	1.9 E 14	3.3 E-04[f]	6	1974
Au (foil)	14	1.9 E 14	2.6 E-04[b]	6	1974
Au (crystal)	14	2.3 E 13	3.0 E-03	7	1974
Au (annealed crystal)	>0.1	3.3 E 17(av.)	3.3 E-03(av.)	8	1974
Au (foil)	>0.1		1.1 E-04	9	1969
Au (foil)	>0.1	4.4 E 17	1.0 E-04	10	1966
Au (foil)	14	2.4 E 13	≤6.0 E-04	2	1968

[f]Forward sputtering; [b]Backward sputtering.

References:

1. T. S. Baer, J. N. Anno, J. Nucl. Mater. 54, 79 (1974).
2. K. Keller, Plasma Phys. 10, 195 (1968).
3. L. H. Jenkins, T. S. Noggle, R. E. Reed, M. J. Saltmarsh, Appl. Phys. Lett. 26, 426 (1975).
4. O. K. Harling, M. T. Thomas, R. L. Brodzinski, L. A. Rancitelli, Phys. Rev. Lett. 34, 1340 (1975).
5. M. Kaminsky, J. H. Peavey, S. K. Das, Phys. Rev. Lett. 32, 599 (1974).
6. R. Behrisch, R. Gähler, J. Kalus, J. Nucl. Mater. 53, 183 (1974).
7. R. I. Garber. G. P. Dolya, V. M. Kolyada, A. A. Modlin, A. I. Fedorenko, JETP Lett. (Sov. Phys.) 7, 296 (1968).
8. M. A. Kirk, T. H. Blewitt, A. C. Klank, T. L. Scott, R. Malewicki, J. Nucl. Mater. 53, 179 (1974).
9. B. P. Fairand, Thesis, Ohio State Univ., Columbus, Ohio (1969).
10. D. W. Norcross, B. P. Fairand, J. N. Anno, J. Appl. Phys. 37, 621 (1966).

Notes

(1) H^+ + Pyrolytic graphite: R. Behrisch, et al., Max-Planck Institute Für Plasmaphysik, Report #IPPAR-1974. Other data plotted for graphite include; (1) V. M. Gusev, M. I. Guseva, E. S. Ionova, Yu. L. Krasulin, S. V. Mirov, and A. V. Nedospasov, Report #OLS-7-75 (1975); R. Behrisch and B. B. Kadomtsev, IAEA International Conference on Nuclear Fusion (1974) Paper #IAEA-CN-33/52; S. A. Cohen, Report #Matt-Q-32 (1974).

(2) H^+ + C: R. Behrisch, et al., Max-Planck Institute Für Plasmaphysik, Report #IPPAR-1974; J. N. Smith, Jr., C. H. Meyer, Jr. and J. K. Layton, Report #GA-A13665.

(3) H^+ + Al: S. A. Cohen, Report #Matt-Q-32 (1974); C. E. KenKnight and G. K. Wehner, J. Appl. Phys. 35, 322 (1964).

(4) The sputtering yields reported by Behrisch, et al., Behrisch and Kadomtsev, KenKnight, et al. and Wehner are for incident H_2^+ and H_3^+ ions. The energy and yield has been divided by 2 and 3 for H_2^+ and H_3^+ respectively to determine the yield for incident protons.

(5) H^+ + Ta: R. Behrisch and R. Weissman, Phys. Letters 30A, 506 (1969); C. R. Finfgled, Report #ORO-3557-15.

(6) Yields determined for Fe by Wehner, et al. and for SS 304 by Behrisch were for H_2^+ and H_3^+ incident ions. The values for proton impact were obtained by dividing the measured energy and yield by 2 and 3 for H_2^+ and H_3^+ respectively.

(7) Yields determined by KenKnight, et al. and Wehner, et al., were for H_2^+ and H_3^+ incident ions. The values for proton impact were obtained by dividing the measured energy and yield by 2 and 3 for H_2^+ and H_3^+ respectively.

(8) Yields for W are small and difficult to measure accurately. Curve labeled W is taken from Finfgeld's paper. Curve labeled W' is for tungsten and is taken from work of Smith, et al., Kenknight, et al., and Wehner, et al. We are unable to determine the correct yields for protons on tungsten.

(9) The sputtering yields reported by KenKnight, et al. and Wehner, et al. are for incident H_2^+ and H_3^+ ions. The energy and yield has been divided by 2 and 3 for H_2^+ and H_3^+ respectively to determine the yield for incident protons.

(10) He^+ → Si: D. Rosenberg, G. K. Wehner, J. Appl. Phys. 33, 1842 (1962); G. K. Wehner, C. KenKnight, D. L. Rosenberg, Planet. Space Sci. 11, 885 (1963); A. van Wijngaarden, B. Miremadi, N. M. A. Finney, Phys. Rev. 185, 490 (1969).

(11) $He^+ \rightarrow Ti$: D. Rosenberg, G. K. Wehner, J. Appl. Phys. 33, 1842 (1962); G. K. Wehner, G. S. Anderson, C. E. KenKnight, Final Rpt. to USAEC No. 3031 (1966); O. C. Yonts, ORNL-TM-2692 (1969).

(12) C(45°), Si(35°) data are not corrected for contribution of reflected He^+ to sputtered ion current (Ref.-Panin; van Wijngaarden, et al.).

(13) Plasma incident data are not corrected for electron emission (Ref.-Rosenberg, et al.).

(14) $He^+ \rightarrow Ag$: D. Rosenberg, G. K. Wehner, J. Appl. Phys. 33, 1842 (1962); F. Grønlund, W. J. Moore, J. Chem. Phys. 32, 1540 (1960); M. Koedam, Physica 25, 742 (1959); G. K. Wehner, G. S. Anderson, C. E. KenKnight, Surface Bombardment Studies, Final Rpt. to USAEC, No. 3031 (1966); D. McKeown, H. R. Poppa, M. G. Fox, Molecular Impact Studies, Ann. Rpt. AD-445823 (O.N.R., GDA-DBE64-048), 1964.

(15) $He^+ \rightarrow Pt$: D. Rosenberg, G. K. Wehner, J. Appl. Phys. 33, 1842 (1962).

(16) $He^+ \rightarrow Au$: D. Rosenberg, G. K. Wehner, J. Appl. Phys. 33, 1842 (1962); G. K. Wehner, G. S. Anderson, C. E. KenKnight, Final Rpt. to USAEC, No. 3031 (1966); A. van Wijngaarden, E. Reuther, J. N. Bradford, Can. J. Phys 47, 411 (1969).

(17) Plasma incident data are not corrected for secondary electron emission (Ref.-Rosenberg, et al.).

(18) Zr (35°) and Au (45°) data not corrected for contribution of reflected He^+ to sputtered ion current (Ref.-Panin; Wijngaarden, et al.).

(19) $He^+ \rightarrow V$, $He^+ \rightarrow Cr$, $He^+ \rightarrow Mo$, $He^+ \rightarrow Ta$, $He^+ \rightarrow W$: D. Rosenberg, G. K. Wehner, J. Appl. Phys. 33, 1842 (1962).

(20) $He^+ \rightarrow Fe$: D. Rosenberg, G. K. Wehner, J. Appl. Phys. 33, 1842 (1962); G. K. Wehner, G. S. Anderson, C. E. KenKnight, Surface Bombardment Studies, Final Rpt. to USAEC, No. 3031 (1966); D. Heymann, J. Geophys. Res. 69, 1941 (1964).

(21) $He^+ \rightarrow Ni$: D. Rosenberg, G. K. Wehner, J. Appl. Phys. 33, 1842 (1962); H. Fetz, H. Oechsner, 6th Int. Conf. Ionization Phenomena Gases, p. 39, Paris (1963); G. K. Wehner, G. S. Anderson, C. E. KenKnight, Final Rpt. to USAEC, No. 3031 (1966).

(22) $He^+ \rightarrow Cu$: D. Rosenberg, G. K. Wehner, J. Appl. Phys. 33, 1842 (1962); G. K. Wehner, G. S. Anderson, C. E. KenKnight, Final Rpt. to USAEC, No. 3031 (1966); O. C. Yonts, C. E. Normand, D. E. Harrison, J. Appl. Phys. 31, 447 (1960); O. C. Yonts, ORNL-TM-2692 (1969).

(23) $Al^+ \rightarrow Al$: W. H. Hayward, A. R. Wolter, J. Appl. Phys. 40, 2911 (1969); O. Almén, G. Bruce, Nucl. Instr. & Meth. 11, 279 (1961).

(24) $Ni^+ \rightarrow Ni$: A. Fontell, E. Arminen, Can. J. Phys. 47, 2405 (1969).

(25) $Cu^+ \rightarrow Cu$: W. H. Hayward, A. R. Wolter, J. Appl. Phys. 40, 2911 (1969); O. Almén, G. Bruce, Nucl. Instr. & Meth. 11, 279 (1961); M. I. Guseva, Soviet Phys.-Solid State Phys. 1, 1410 (1959); A. Fontell, E. Arminen, Can. J. Phys. 47, 2405 (1969); P. K. Rol, J. M. Fluit, J. Kistemaker, Physica 26, 1000 (1960); D. Onderlinden, Can. J. Phys. 46, 739 (1968) - Cu crystal; O. C. Yonts, C. E. Normand, D. E. Harrison, J. Appl. Phys. 31, 447 (1960); H. H. Andersen, H. Bay, Rad. Eff. 13, 67 (1972).

(26) $Ag^+ \rightarrow Ag$: W. H. Hayward, A. R. Wolter, J. Appl. Phys. 40, 2911 (1969); O. Almén, G. Bruce, Nucl. Instr. & Meth. 11, 279 (1961); M. I. Guseva, Soviet Phys.-Solid State Phys. 1, 1410 (1959); H. H. Andersen, H. L. Bay, Rad. Eff. 19, 139 (1973).

(27) $Au^+ \rightarrow Au$: W. H. Hayward, A. R. Wolter, J. Appl. Phys. 40, 2911 (1969); O. Almén, G. Bruce, Nucl. Instr. & Meth. 11, 279 (1961).

D.2 Secondary Electron Emission from Electron Impact

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Emission of Secondary Electrons by Electron Impact on a Graphite Surface

(Electrons Incident Normally on Surface)

e on C

Energy Impact (keV)	Secondary Electron Emission Coefficient δ Electrons/Electron
1.5 E-01	7.80 E-01
2.0 E-01	9.03 E-01
4.0 E-01	9.20 E-01
6.0 E-01	7.97 E-01
8.0 E-01	6.90 E-01
1.0 E 00	6.00 E-01
1.5 E 00	4.53 E-01
2.0 E 00	3.74 E-01
3.0 E 00	2.78 E-01
4.0 E 00	2.23 E-01
5.0 E 00	1.86 E-01

References:

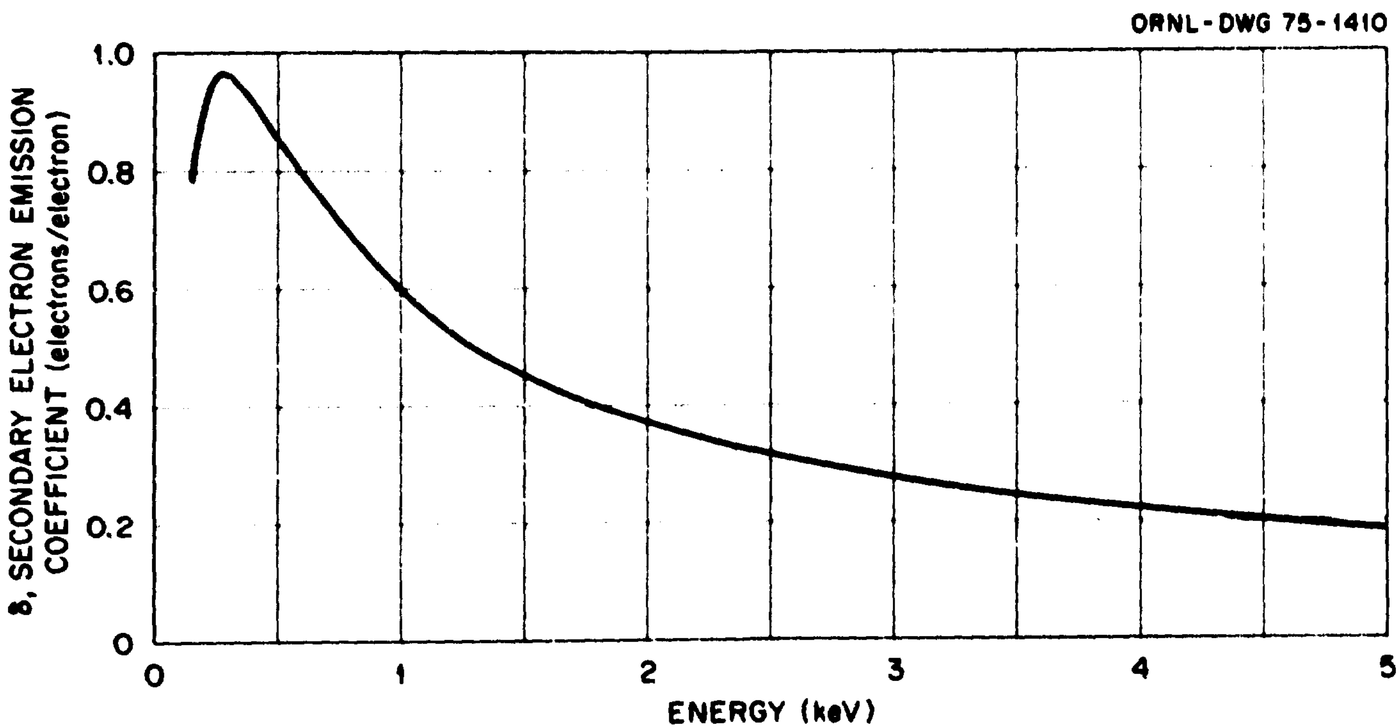
J. Hölzl and K. Jacobi, Surface Sci. 14, 351 (1969). H. Bruining, Philips. Tech. Rev. 3, 80 (1938).

Accuracy:

Systematic error < ± 5%. Random error < ± 2%.

Notes:

See Notes (1) and (2) at end of chapter.


ORNL-DWG 75-1410
δ, SECONDARY ELECTRON EMISSION COEFFICIENT (electrons/electron)
1.0
0.8
0.6
0.4
0.2
0
0
1
2
3
4
5
ENERGY (keV)

Emission of Secondary Electrons by Electron Impact on a Steel Surface

(Electrons Incident Normally on Surface)

e on Steel

Energy Impact (keV)	Secondary Electron Emission Coefficient δ Electrons/Electron
4.0 E 01	3.08 E-01
6.0 E 01	2.14 E-01
8.0 E 01	1.60 E-01
1.0 E 02	1.34 E-01
1.5 E 02	1.04 E-01
2.0 E 02	8.80 E-02

Reference:

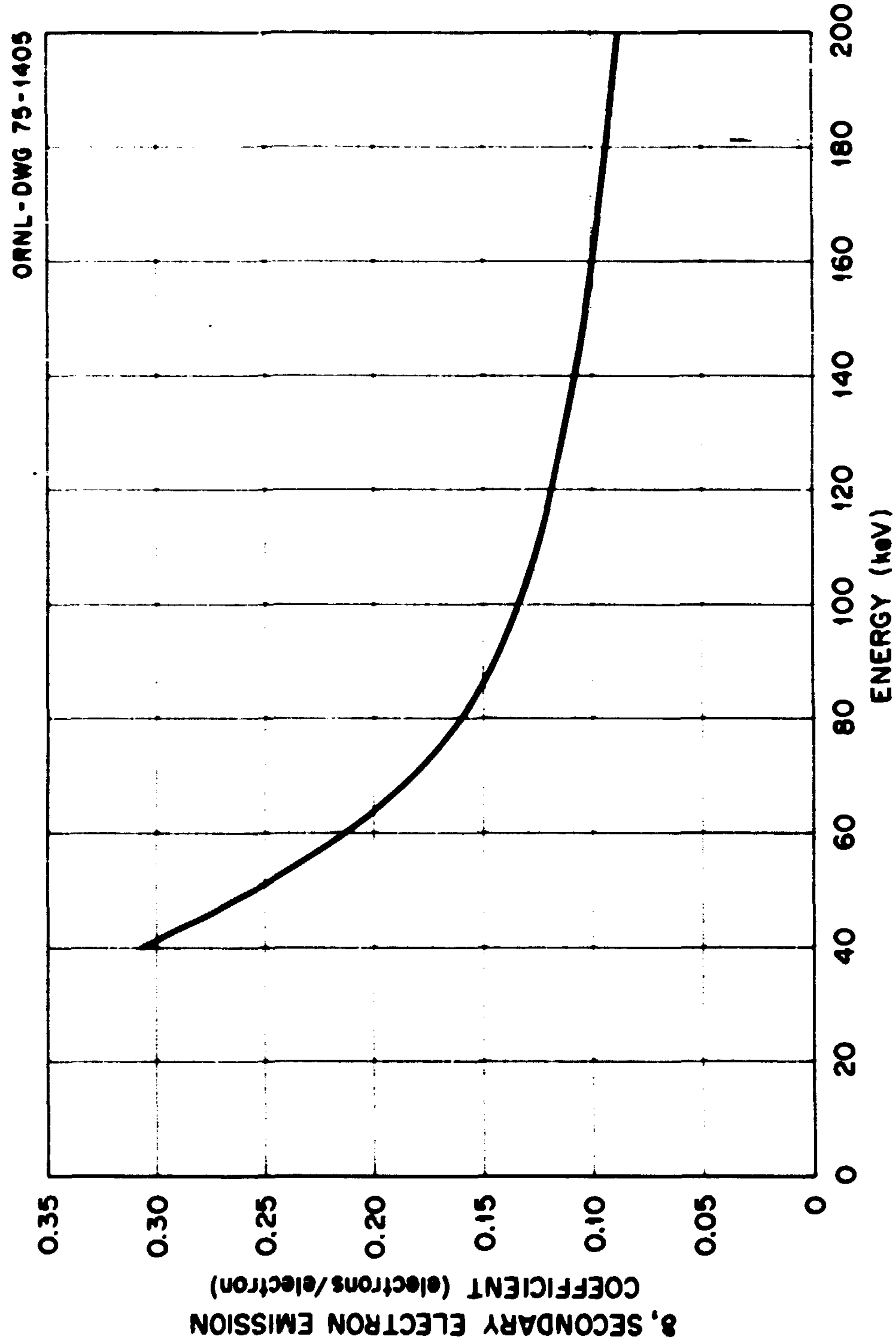
J.G. Trump and R.J. Van de Graaff, Phys. Rev. 75, 44 (1948).

Accuracy:

Unknown

Notes:

See Notes (11) and (12) at end of chapter.


ORNL-DWG 75-1405
δ, SECONDARY ELECTRON EMISSION
COEFFICIENT (electrons/electron)
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0
ENERGY (keV)
0
20
40
60
80
100
120
140
160
180
200

Emission of Secondary Electrons by Electron Impact

on a Polycrystaline Nickel Surface

(Electrons Incident Normally on Surface)

e on Ni

Energy Impact (keV)	Secondary Electron Emission Coefficient δ Electrons/Electron
2.0 E-01	8.32 E-01
4.0 E-01	9.93 E-01
6.0 E-01	1.00 E 00
8.0 E-01	9.60 E-01
1.0 E 00	9.10 E-01
1.5 E 00	7.80 E-01
2.0 E 00	6.86 E-01
3.0 E 00	5.52 E-01
4.0 E 00	4.60 E-01

References:

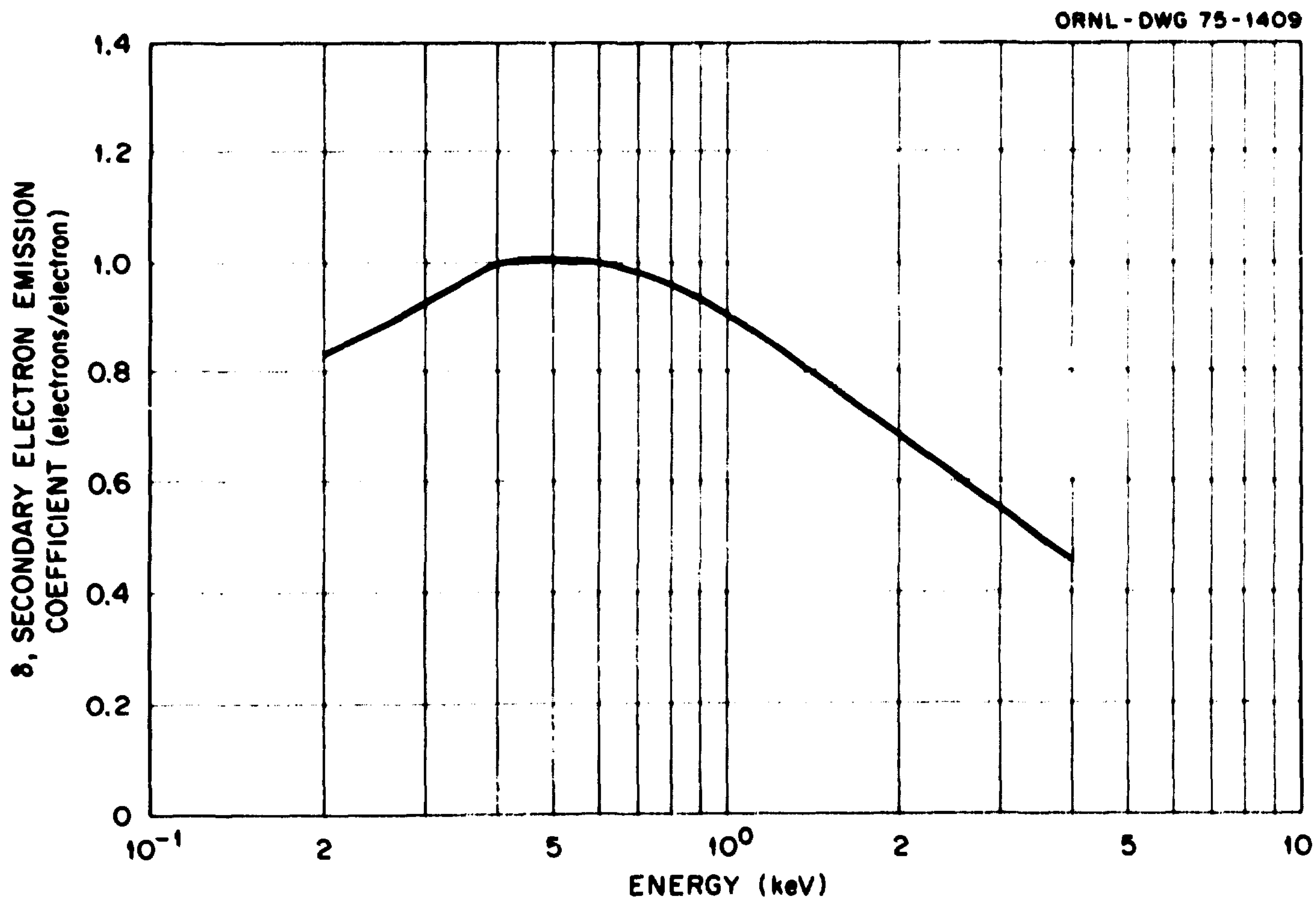
A.R. Shul'man, I.R. Zakiyova, Iu. A. Morozov, and S.A. Freidman, Soviet Phys. Tech. Phys. 3, 79 (1958). I.M. Bronshtein, and S.S. Denisov, Soviet Phys., Solid State 9, 731 (1967).

Accuracy:

Systematic error < ± 5%. Random error < ± 2%.

Notes:

See Notes (2) and (3) at end of chapter.


ORNL-DWG 75-1409
δ, SECONDARY ELECTRON EMISSION COEFFICIENT (electrons/electron)
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
10^{-1}
2
5
10^{0}
2
5
10^{1}
ENERGY (keV)

Emission of Secondary Electrons by Electron Impact on a Polycrystaline Gold Surface

(Electrons Incident Normally on Surface)

e on Au

Energy Impact (keV)	Secondary Electron Emission Coefficient δ Electrons/Electron
4.0 E-03	1.20 E-02
8.0 E-03	6.30 E-02
1.0 E-02	9.60 E-02
1.5 E-02	1.95 E-01
2.0 E-02	2.63 E-01
3.0 E-02	3.66 E-01
4.0 E-02	4.25 E-01
8.0 E-02	4.98 E-01
1.0 E-01	5.97 E-01
2.0 E-01	7.22 E-01
4.0 E-01	8.23 E 01
8.0 E-01	8.83 E-01
1.0 E 00	8.24 E-01
1.5 E 00	7.12 E-01
2.0 E 00	6.27 E-01
4.0 E 00	4.00 E-01
6.0 E 00	2.62 E-01
8.0 E 00	2.16 E-01
2.0 E 01	4.50 E-01
4.0 E 01	3.60 E-01
8.0 E 01	2.50 E-01
1.0 E 02	2.12 E-01
1.5 E 02	1.43 E-01
2.0 E 02	1.00 E-01

References:

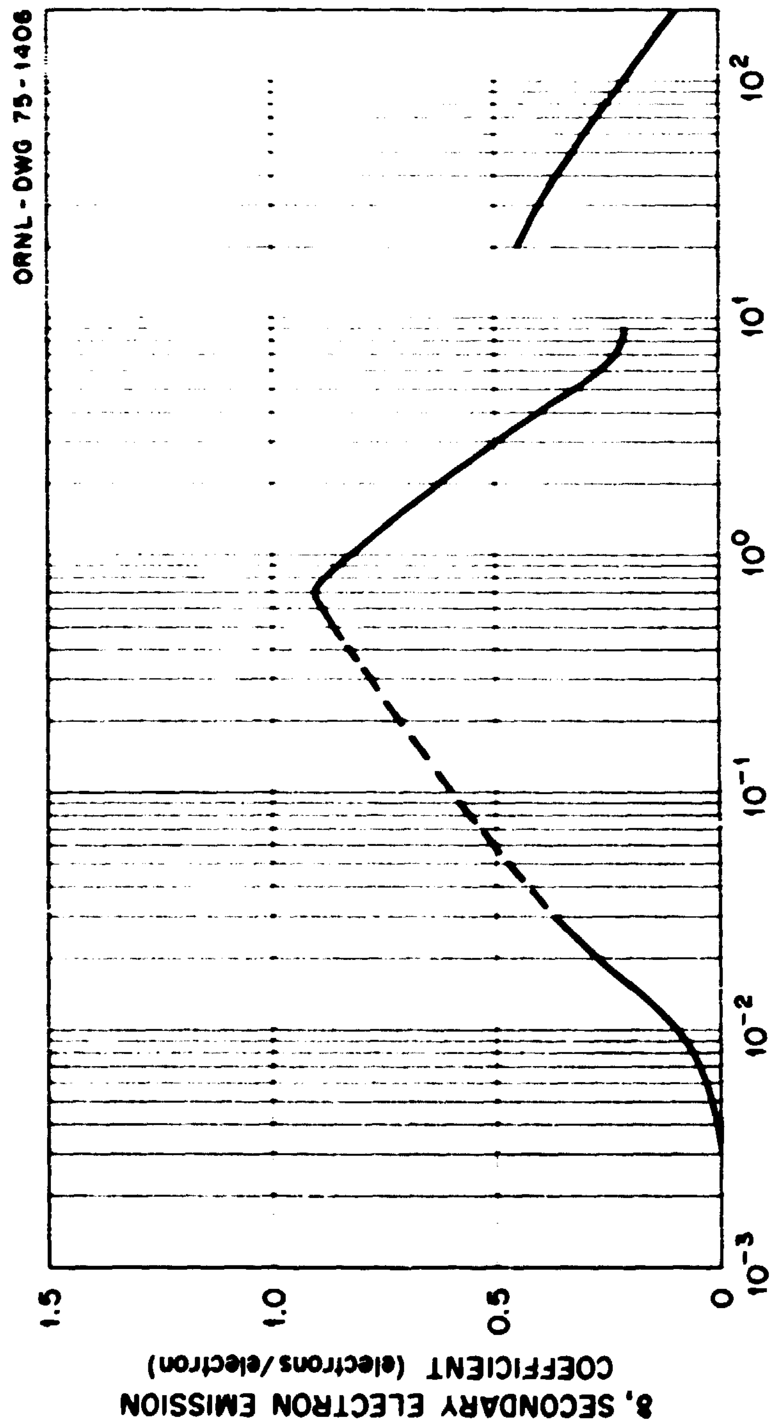
I.M. Bronstein and V.V. Roshchin, Soviet Phys. Tech. Phys. 3, 2271 (1958). J. Kadlec and L. Eckertova, Z. Angew. Phys. 30, 141 (1970). B.L. Miller and W.C. Porter, J. Franklin Institute 260, 31 (1955).

Accuracy:

Systematic error < ± 10% for E < 9 keV. Systematic error unknown for E > 20 keV. Random error < ± 5%.

Notes:

See Notes (2), (7), (8), (9), (10), and (13) at end of chapter.


ORNL-DWG 75-1406
δ, SECONDARY ELECTRON EMISSION
COEFFICIENT (electrons/electron)
0
0.5
1.0
1.5
ENERGY (keV)
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}

Emission of Secondary Electrons by Electron Impact

on a Polycrystaline Molybdenum Surface

(Electrons Incident Normally on Surface)

e on Mo

Energy Impact (keV)	Secondary Electron Emission Coefficient δ Electrons/Electron
4.0 E-03	1.90 E-02
8.0 E-03	1.00 E-01
1.0 E-02	1.38 E-01
2.0 E-02	2.93 E-01
2.5 E-02	3.60 E-01
3.0 E-02	4.15 E-01
4.0 E-02	4.98 E-01
1.0 E-01	7.72 E-01
2.0 E-01	9.81 E-01
4.0 E-01	1.27 E 00
6.0 E-01	1.23 E 00
8.0 E-01	1.16 E 00
1.0 E 00	1.09 E 00
2.0 E 00	7.55 E-01
4.0 E 00	4.52 E-01
6.0 E 00	3.36 E-01
8.0 E 00	2.99 E-01

References:

Von G. Blankenfeld, Ann. der Physik 9, 48 (1951). I.M. Bronshtein, Bull. Acad. Sci. USSR 22, 442 (1958).

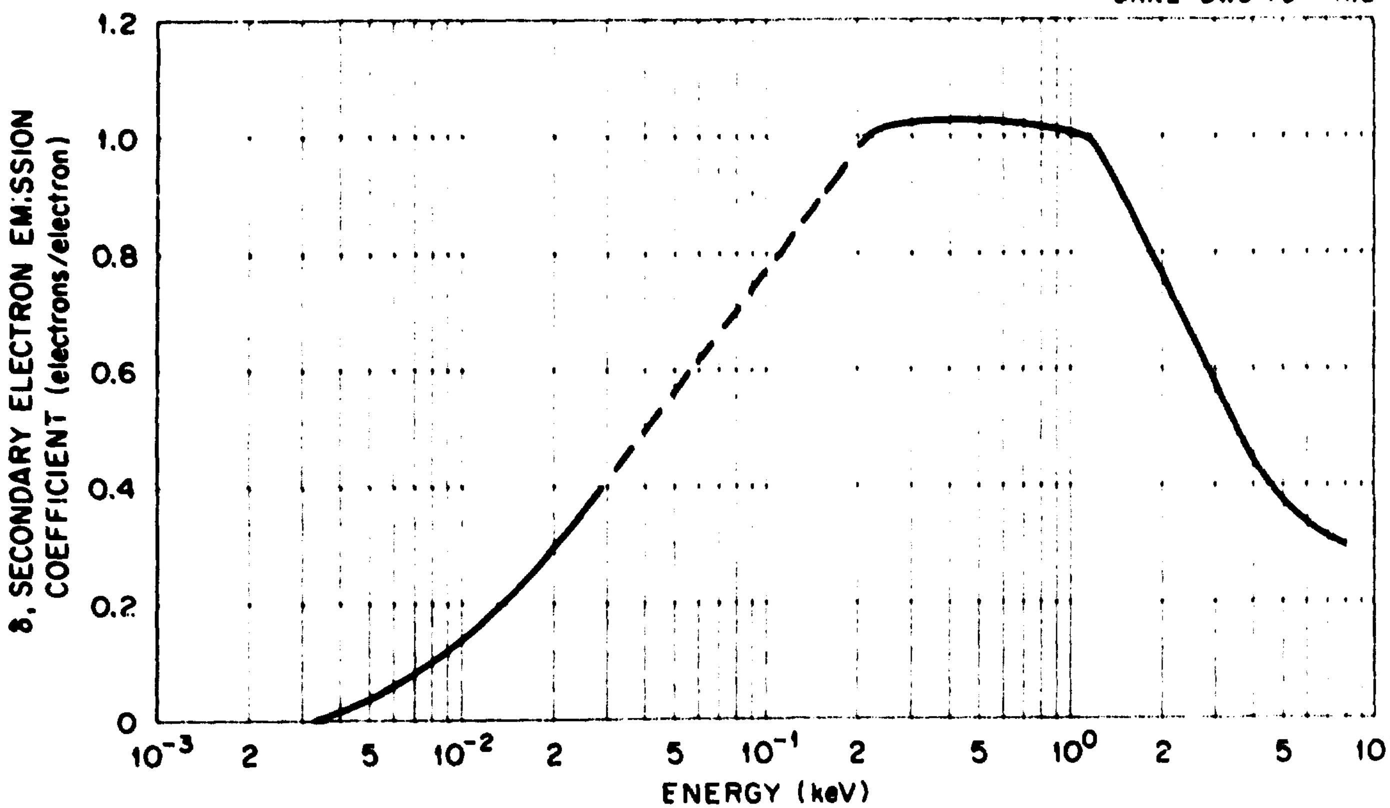
Accuracy:

Systematic error < ± 5%. Random error < ± 2%.

Notes:

See Notes (2), (4), and (13) at end of chapter.

ORNL-DWG 75-1408



Emission of Secondary Electrons by Electron Impact on a Polycrystaline Tungsten Surface

(Electrons Incident Normally on Surface)

e on W

Energy Impact (keV)	Secondary Electron Emission Coefficient δ Electrons/Electron
4.0 E-03	1.00 E-02
8.0 E-03	8.10 E-02
1.0 E-02	1.20 E-01
1.5 E-02	2.00 E-01
3.0 E-02	2.70 E-01
2.5 E-02	4.19 E-01
4.0 E-02	5.31 E-01
8.0 E-02	7.03 E-01
1.0 E-01	7.98 E-01
2.0 E-01	1.12 E 00
4.0 E-01	1.44 E 00
8.0 E-01	1.55 E 00
1.0 E 00	1.50 E 00
1.5 E 00	1.36 E 00
2.0 E 00	1.21 E 00
3.0 E 00	9.34 E-01
4.0 E 00	7.80 E-01
8.0 E 00	5.64 E-01
1.0 E 01	5.19 E-01
2.0 E 01	4.00 E-01
4.0 E 01	3.00 E-01
8.0 E 01	2.07 E-01
1.0 E 02	1.79 E-01
1.5 E 02	1.30 E-01
2.0 E 02	9.50 E-02

References:

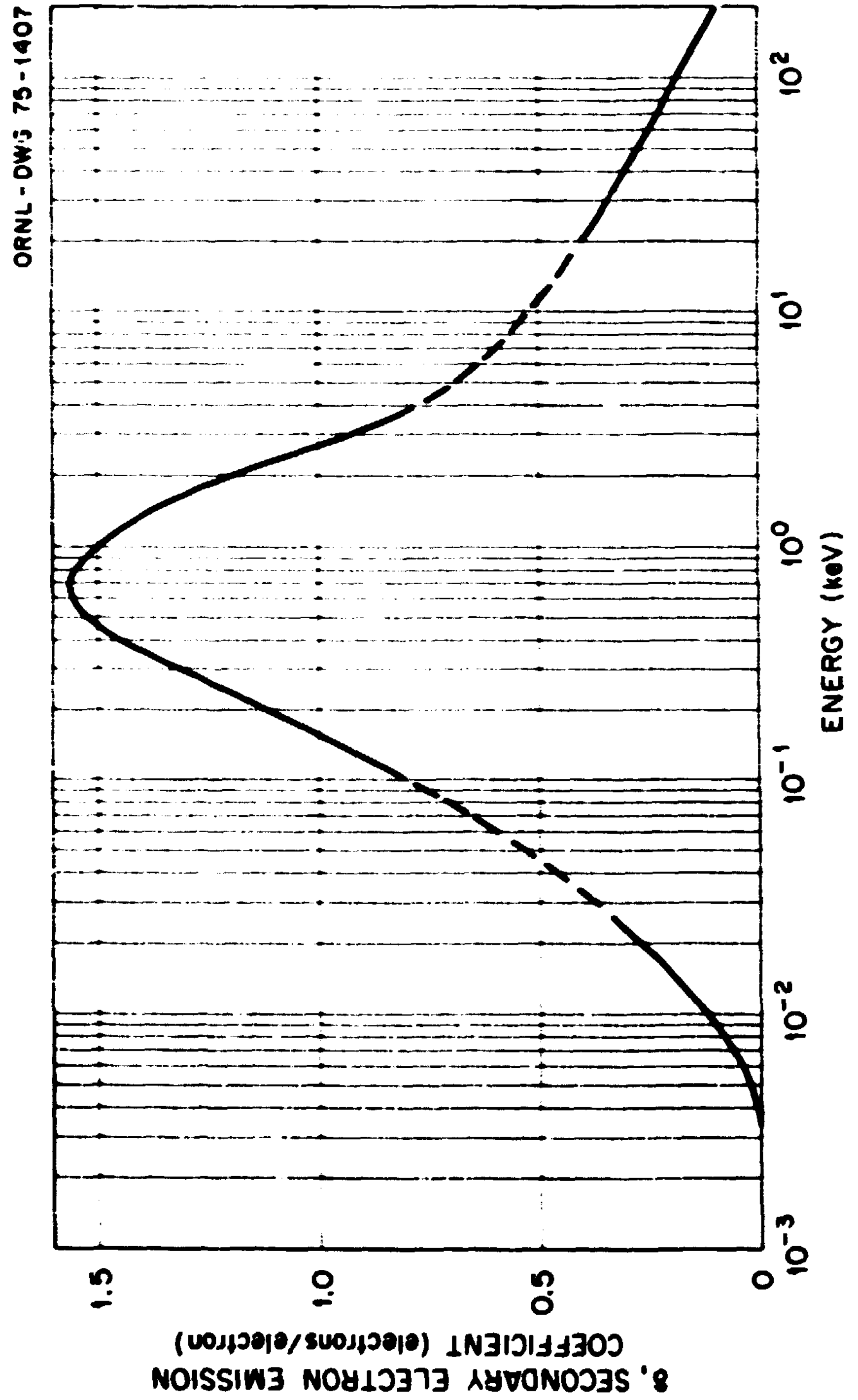
I.M. Bronstein, Bull. Acad. Sci. USSR **22**, 442 (1958). I.M. Bronstein and R.B. Segal, Soviet Phys. Solid State **1**, 1142 (1959). B.L. Miller and W.C. Porter, J. Franklin Institute **260**, 31 (1955).

Accuracy:

Systematic error < ± 10% for E < 4 keV. Systematic error unknown for E > 4 keV. Random error < ± 5%.

Notes:

See Notes (2), (5), (6), (7), and (13) at end of chapter.


ORNL-DWG 75-1407
δ, SECONDARY ELECTRON EMISSION
COEFFICIENT (electrons/electron)
1.5
1.0
0.5
0
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
ENERGY (keV)

Notes

(1) Data given here are appropriate to a pyrolitic graphite sample whose basal plane is parallel to the surface. For a basal plane perpendicular to the surface the yield is somewhat less, being 0.75 electrons/electron at the maximum. See R.H. Whetten, J. Appl. Phys. 34, 771 (1963).

(2) The measurement here is the ratio of the secondary emission electron flux (integrated over all final outgoing directions) to the incident electron flux; it is given the symbol δ. This is related to the coefficient for all emerging electrons, σ, (which includes true secondaries and backscattered electrons) and to the coefficient for reflection (or backscattering) η; the relationship is $\sigma = \delta + \eta$. The coefficient η is discussed elsewhere, and the coefficient σ can obviously be generated by this equation.

(3) For data on how the coefficient varies with incidence angle, see I.M. Bronshtein and S.S. Denisov, Soviet Phys. Solid State 9, 731 (1967).

(4) The data presented here at energies above 100 eV represent the total flux of electrons emerging from the target surface and therefore is the sum of the true secondary emission and the backscattered electron flux. There appear to be no reliable measurements of the true secondary emission alone.

(5) The data between 0.1 and 3.6 keV were obtained by taking the difference between total electron flux (σ) and backscattered flux (η) in the work of Bronshtein and Segal (see cited reference).

(6) The dependence of δ on incidence angle may be obtained from Bronshtein and Segal [Soviet Phys. Solid State 1, 1142 (1959)] by taking the difference between the coefficients they call σ and η [see also Note (5) above].

(7) The data between 20 and 200 keV were obtained by taking the difference between total electron flux and the backscattered electron flux from the work of Miller and Porter (see reference cited).

(8) For information on how the secondary emission coefficient varies with incidence angle see J. Keller, Z. Physik 227, 427 (1969).

(9) For information on the angular distribution of secondary electrons see J. Kadlec and L. Eckertova, Z. Angew. Phys. 30, 141 (1970).

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(10) In this case there is a serious apparent discrepancy between the work of Kadlec (up to 9 keV) and that of Miller (from 20 keV upwards). The discrepancy is probably because Kadlec used thin films and Miller used a thick target. It is to be expected that δ for a thin film will be less than that for a thick target; the difference may be small at one keV but maybe 30% or more at 10 keV.

(11) The data of Trump and Van de Graaf are for total flux of electrons (true secondaries plus backscattered electrons) and for the flux with energies over 800 eV (presumably representing backscattered electrons). We present here the difference between the two which should represent the true secondary emission alone.

(12) The type of steel used in this work was not specified.

(13) On the graph, regions where we have interpolated between data sets are shown by broken lines.

D.3 Secondary Electron Emission by Ion Impact

Secondary Electron Emission by Impact of Ions

on a Carbon (Graphite) Target:

H^+, H_2^+, H_3^+ on C

(Projectiles Incident Normally on Target)

Impact Energy (keV)	Secondary Emission Coefficient γ Electrons/Ion		
	H^+	H_2^+	H_3^+
2.0 E 01	1.68 E 00	2.40 E 00	3.10 E 00
4.0 E 01	2.15 E 00	3.12 E 00	3.97 E 00
6.0 E 01	2.45 E 00	3.70 E 00	4.77 E 00
8.0 E 01	2.53 E 00	4.20 E 00	5.55 E 00

Reference:

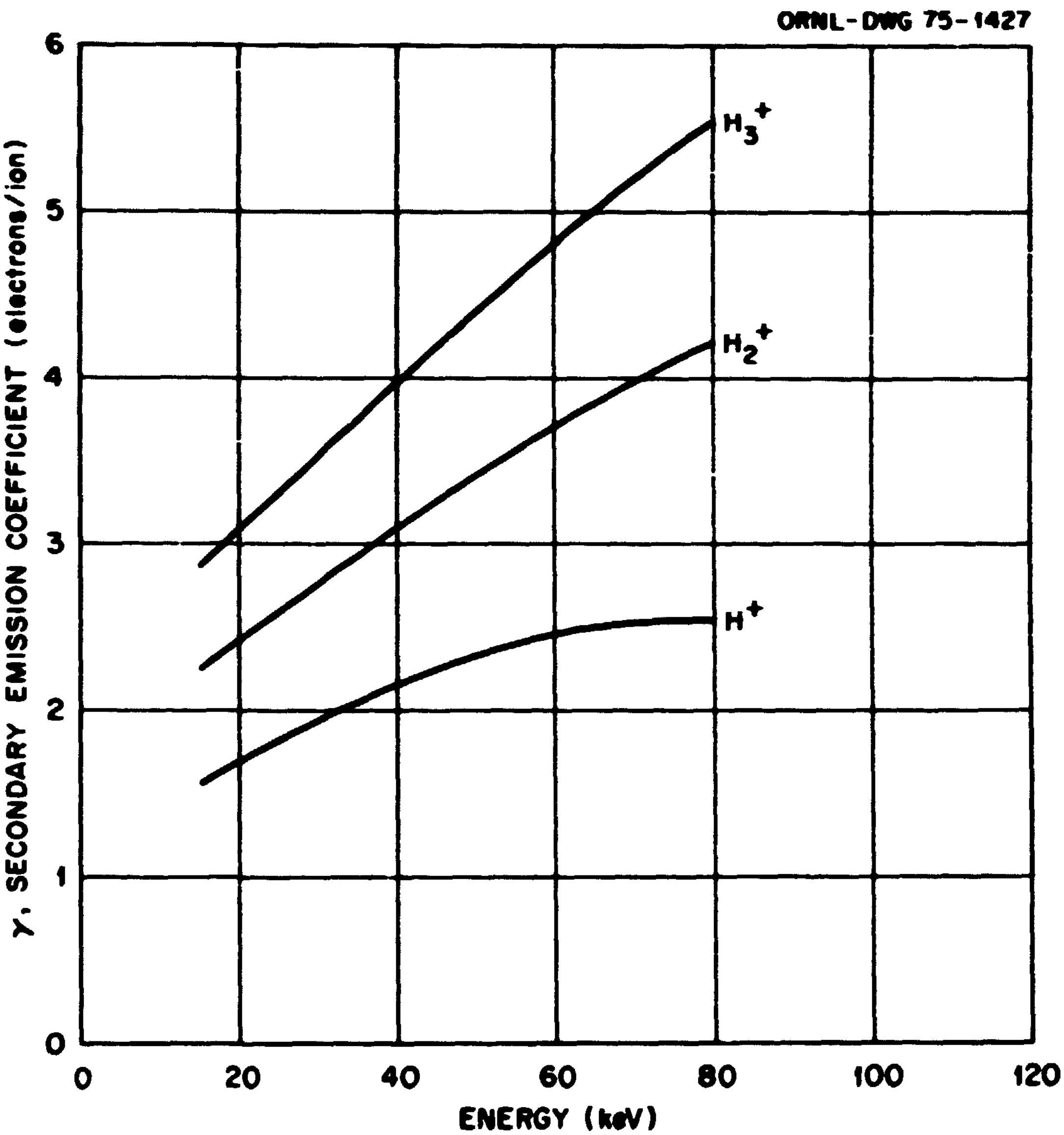
H^+, H_2^+, H_3^+ on C: L.N. Large, W.S. Whitlock, Proc. Phys. Soc. 79, 148 (1962).

Accuracy:

Systematic error < ± 5%. Random error < ± 5%.

Notes:

See Notes (1) and (2) at end of chapter.


ORNL-DWG 75-1427
γ, SECONDARY EMISSION COEFFICIENT (electrons/ion)
ENERGY (keV)
H_3^+
H_2^+
H^+
0
1
2
3
4
5
6
0
20
40
60
80
100
120

Secondary Electron Emission by Impact of Ions on a Polycrystaline Nickel Target: H^+, H_2^+, H_3^+, He^+ on Ni

(Projectiles Incident Normally on Target)

Impact Energy (keV)	Secondary Emission Coefficient γ Electrons/Ion			
	H^+	H_2^+	H_3^+	He^+
1.0 E 00				1.70 E-01
2.0 E 00				2.30 E-01
4.0 E 00				3.50 E-01
6.0 E 00				4.40 E-01
8.0 E 00				5.50 E-01
1.0 E 01				6.50 E-01
1.5 E 01				8.15 E-01
2.0 E 01	9.60 E-01	1.20 E 00	1.38 E 00	9.60 E-01
4.0 E 01	1.25 E 00	1.60 E 00	1.81 E 00	1.30 E 00
6.0 E 01	1.45 E 00	1.97 E 00	2.25 E 00	
8.0 E 01	1.52 E 00	2.32 E 00	2.68 E 00	
1.0 E 02	1.58 E 00	2.65 E 00	2.97 E 00	
1.2 E 02	1.60 E 00	2.83 E 00	3.24 E 00	
1.3 E 02	1.60 E 00	2.95 E 00	3.30 E 00	

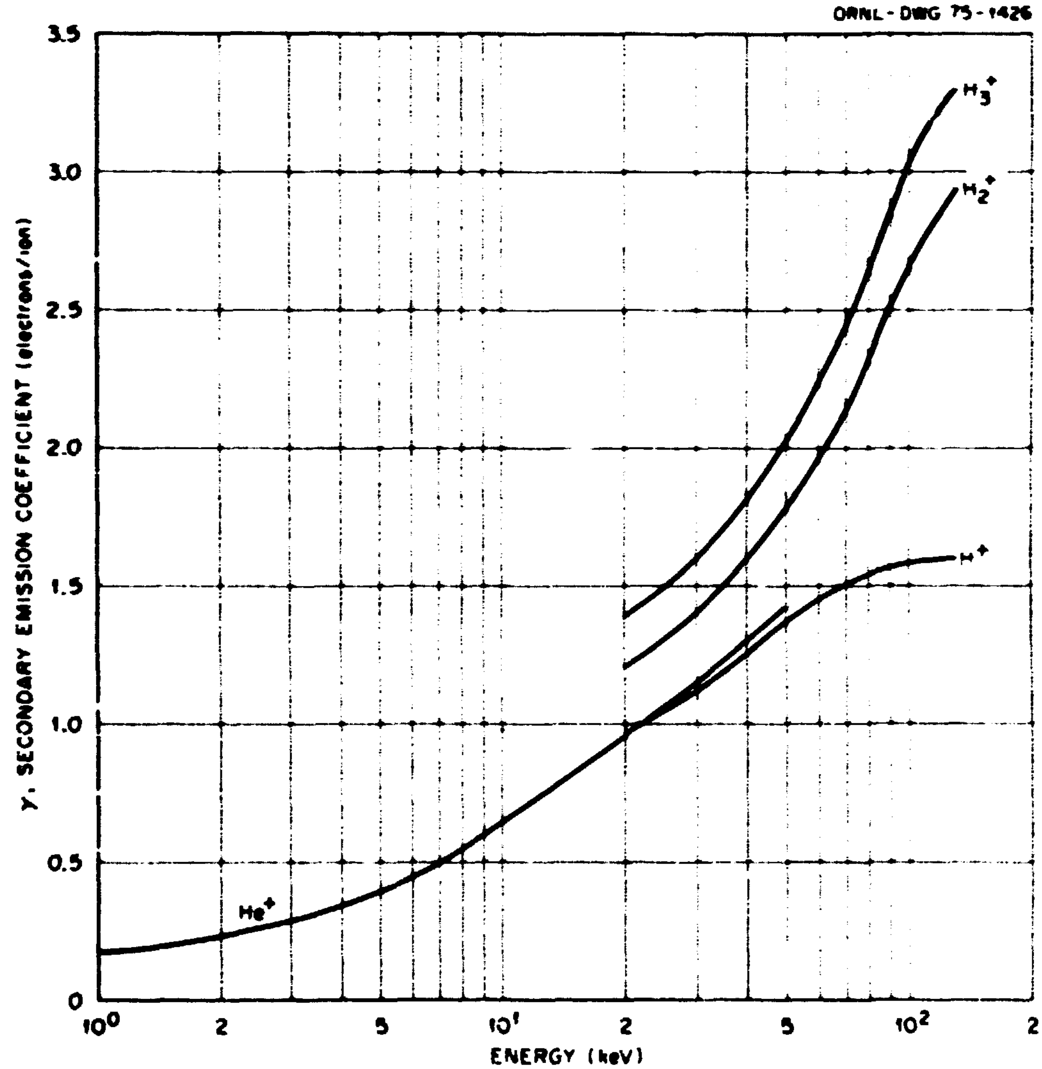
References:

H^+, H_2^+, H_3^+ on Ni: L.H. Large, W.S. Whitlock, Proc. Phys. Soc. 79, 148 (1962).

He^+ on Ni: V.A. Arifov, R.R. Rakhimov, and O.V. Khozinskii, Bull. Acad. Sci. USSR, Phys. Ser. 26, 1422 (1962) [Izv. Akad. Nauk SSR, Ser. Fiz. 26, 1398 (1962)].

Accuracy:

Systematic error < ± 5%. Random error < ± 2%.


ORNL-DWG 75-1426
γ, SECONDARY EMISSION COEFFICIENT (electrons/ion)
ENERGY (keV)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
10⁰
2
5
10¹
2
5
10²
2
He⁺
H₃⁺
H₂⁺
H⁺

Secondary Electron Emission by Impact of Ions on a Polycrystaline Gold Target: H^+, H_2^+, H_3^+ on Au

(Projectiles Incident Normally on Target)

Impact Energy (keV)	Secondary Emission Coefficient γ Electrons/Ion		
	H^+	H_2^+	H_3^+
1.5 E 01	1.49 E 00	2.40 E 00	2.58 E 00
2.0 E 01	1.57 E 00	2.55 E 00	2.75 E 00
4.0 E 01	1.82 E 00	2.93 E 00	3.33 E 00
6.0 E 01	1.94 E 00	3.20 E 00	3.81 E 00
8.0 E 01	1.99 E 00	3.37 E 00	4.17 E 00
1.0 E 02	2.00 E 00	3.45 E 00	4.37 E 00
1.2 E 02	1.98 E 00	3.49 E 00	4.48 E 00

Reference:

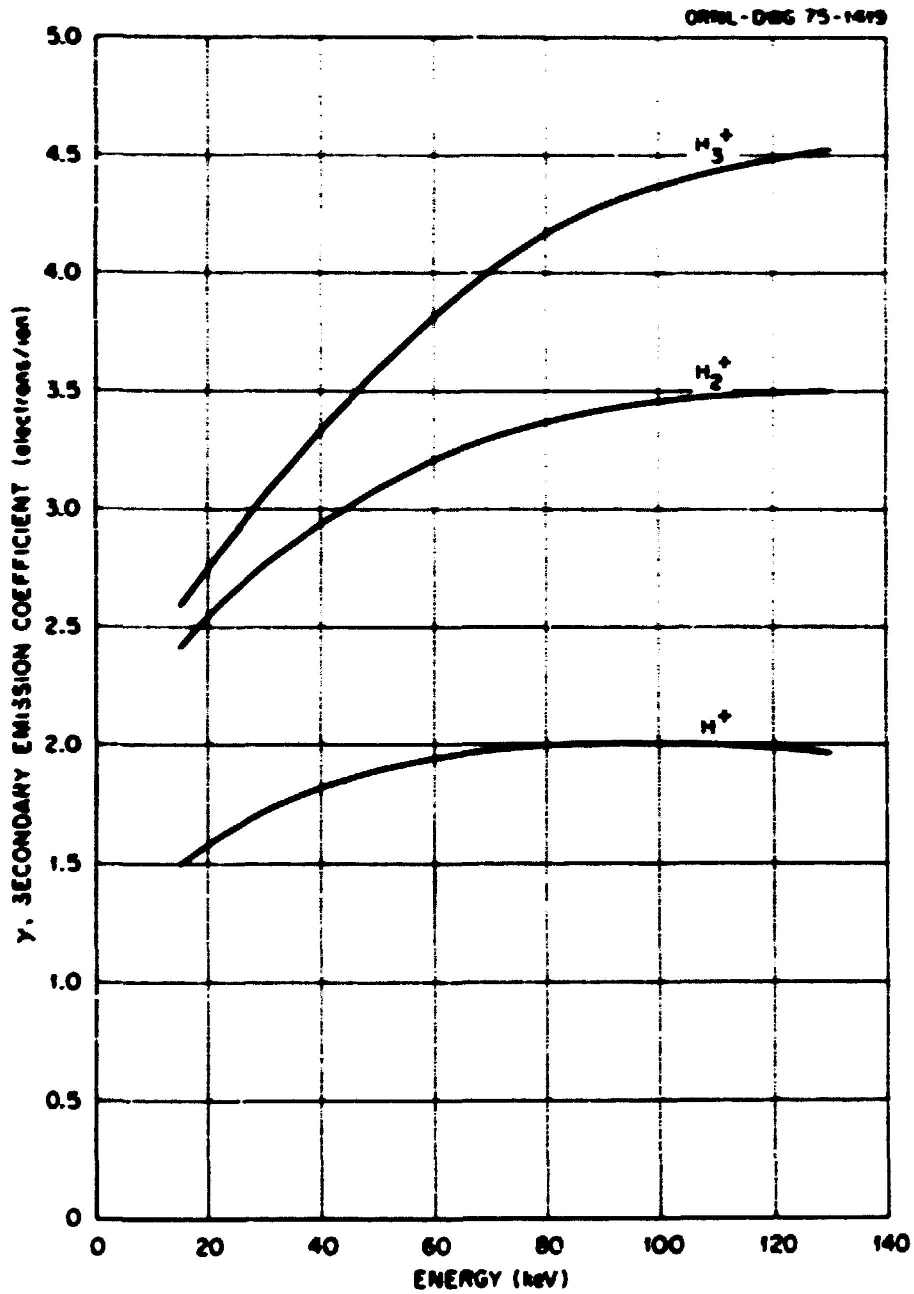
H^+, H_2^+, H_3^+ on Au: L.N. Large, W.S. Whitlock, Proc. Phys. Soc. 79, 148 (1962).

Accuracy:

Systematic error < ± 5%. Random error < ± 5%.

Notes:

See Notes (1) and (2) at end of chapter.


ORNL-DWG 75-1419
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
H_3^+
H_2^+
H^+
γ, SECONDARY EMISSION COEFFICIENT (electrons/ion)
0
20
40
60
80
100
120
140
ENERGY (keV)

Secondary Electron Emission by Impact of Ions on a Polycrystaline Zirconium Target:

H^+, H_2^+, H_3^+ on Zr

(Projectiles Incident Normally on Target)

Impact Energy (keV)	Secondary Emission Coefficient γ Electrons/Ion		
	H^+	H_2^+	H_3^+
1.0 E 01	9.20 E-01	1.30 E 00	1.49 E 00
2.0 E 01	1.08 E 00	1.50 E 00	1.73 E 00
4.0 E 01	1.30 E 00	1.90 E 00	2.20 E 00
6.0 E 01	1.46 E 00	2.25 E 00	2.63 E 00
8.0 E 01	1.57 E 00	2.53 E 00	3.05 E 00
1.0 E 02	1.63 E 00	2.75 E 00	3.41 E 00
1.2 E 02	1.70 E 00	2.84 E 00	3.80 E 00

Reference:

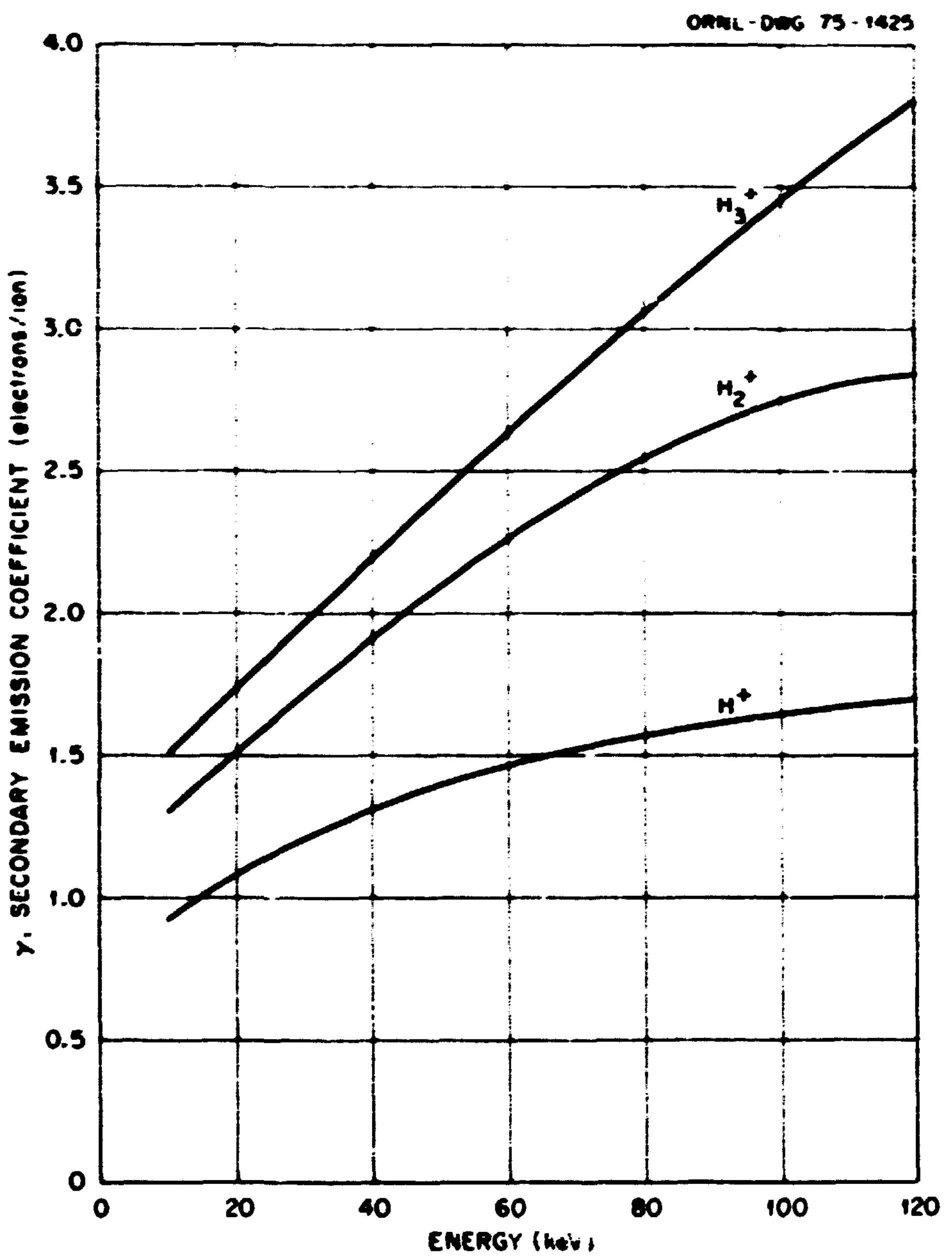
H^+, H_2^+, H_3^+ on Zr: L.N. Large, W.S. Whitlock, Proc. Phys. Soc. 79, 148 (1962).

Accuracy:

Systematic error < ± 5%. Random error < ± 10%.

Notes:

See Notes (1), (2), and (3) at end of chapter.


ORNL-DWG 75-1425
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
γ, SECONDARY EMISSION COEFFICIENT (electrons/ion)
H_3^+
H_2^+
H^+
0
20
40
60
80
100
120
ENERGY (keV)

Secondary Electron Emission by Impact of Hydrogenic

Ions on a Polycrystaline Molybdenum Target:

H^-, H^+, H_2^+, H_3^+ on Mo

(Projectiles Incident Normally on Target)

Impact Energy (keV)	Secondary Emission Coefficient γ Electrons/Ion			
	H^-	H^+	H_2^+	H_3^+
1.0 E-01		8.00 E-02	3.70 E-02	
2.0 E-01		9.60 E-02	5.40 E-02	3.35 E-02
4.0 E-01	4.90 E-02	1.40 E-01	1.00 E-01	4.60 E-02
5.0 E-01	8.20 E-02	1.80 E-01	1.40 E-01	7.00 E-02
6.0 E-01	1.11 E-01	2.19 E-01	1.84 E-01	9.65 E-02
1.0 E 00	1.39 E-01	2.50 E-01	2.24 E-01	1.25 E-01
1.5 E 00	2.25 E-01	3.29 E-01	3.16 E-01	2.05 E-01
2.0 E 00	3.18 E-01	3.99 E-01	4.00 E-01	2.87 E-01
4.0 E 00	5.99 E-01	5.98 E-01	6.00 E-01	5.70 E-01
6.0 E 00	8.10 E-01	7.24 E-01	9.06 E-01	8.10 E-01
1.0 E 01	1.10 E 00	8.82 E-01	1.21 E 00	1.22 E 00
1.5 E 01	1.35 E 00	1.02 E 00	1.48 E 00	1.61 E 00
2.0 E 01	1.53 E 00	1.12 E 00	1.69 E 00	
4.0 E 01		1.36 E 00	1.34 E 00	
6.0 E 01		1.50 E 00	1.82 E 00	
1.0 E 02		1.58 E 00	2.01 E 00	
1.2 E 02		1.48 E 00	1.91 E 00	

Reference:

H^- on Mo: P. Mahadevan, G.D. Magnuson, J.K. Layton, and C.E. Carlson, Phys. Rev. 140, A1407 (1965). M. Perdrix, S. Paletto, R. Goutte, and C. Guillaud, J. Phys. D 2, 441 (1969).

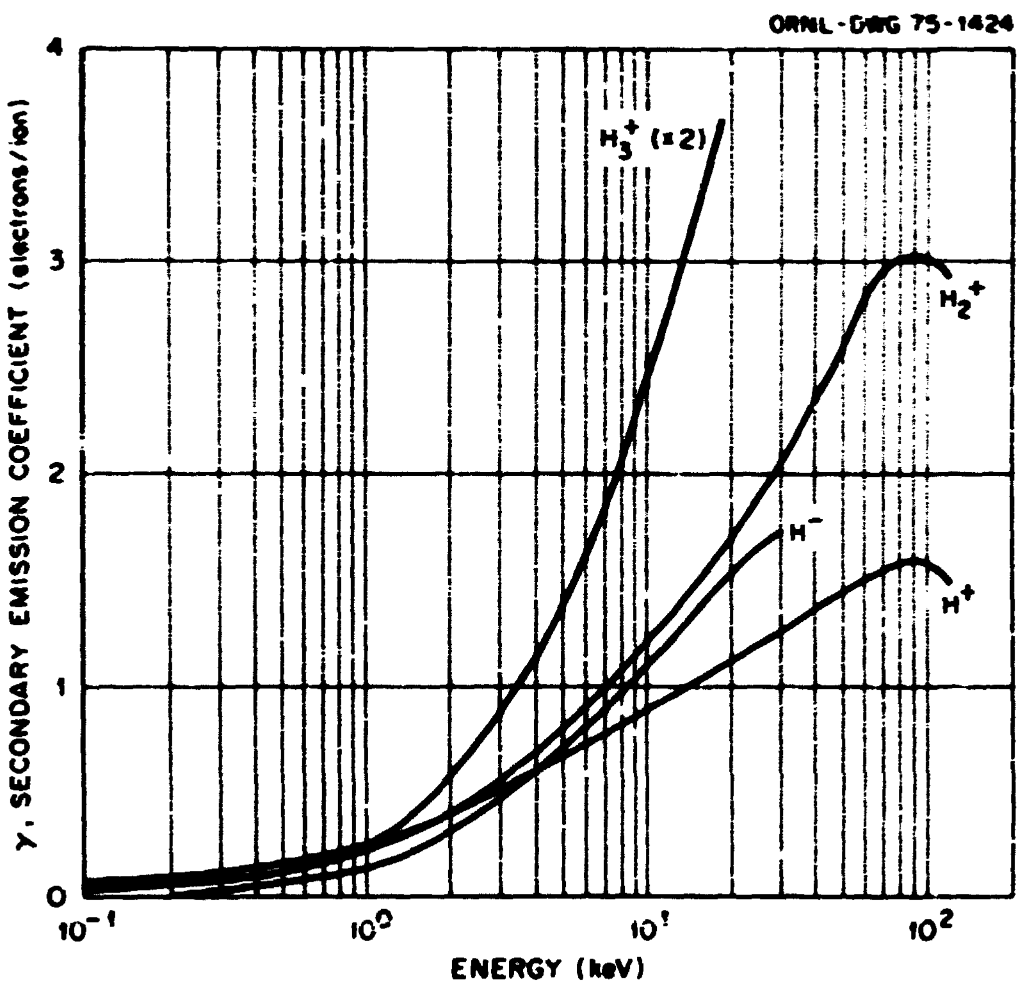
H^+, H_2^+, H_3^+ on Mo: P. Mahadevan, G.D. Magnuson, J.K. Layton, and C.E. Carlson, Phys. Rev. 140, A1407 (1965). W.H.P. Losch, Physica Status Solidi A 2, 123 (1970). M. Perdrix, S. Paletto, R. Goutte, and C. Guillaud, J. Phys. D 2, 441 (1969). L.N. Large, W.S. Whitlock, Proc. Phys. Soc. 79, 148 (1962). A.A. Doroshkin and N.N. Petrov, Sov. Phys. Tech. Phys. 8, 257 (1963). [Zh. Tekh. Fiz. 33, 350 (1963).]

Accuracy:

Systematic error < ± 5%. Random error < ± 5%.

Notes:

See Notes (1), (2), and (4) at end of chapter.


ORNL-DWG 75-1424
Y, SECONDARY EMISSION COEFFICIENT (electrons/ion)
ENERGY (keV)
H3+ (x2)
H2+
H-
H+
0
1
2
3
4
10-1
100
101
102

Secondary Electron Emission by Impact of Hydrogenic Ions on a Polycrystaline Tungsten Target:

H^+, H_2^+ on W

(Projectile incident Normally on Target)

Impact Energy (keV)	Secondary Emission Coefficient γ Electrons/Ion	
	H^+	H_2^+
5.0 E-02		2.47 E-02
1.0 E-01		2.90 E-02
1.5 E-01		3.39 E-02
2.0 E-01		3.90 E-02
4.0 E-01		5.50 E-02
6.0 E-01		7.20 E-02
8.0 E-01		9.20 E-02
1.0 E 00		1.11 E-01
2.0 E 00		2.10 E-01
4.0 E 00		4.03 E-01
6.0 E 00		6.20 E-01
8.0 E 00		8.31 E-01
1.0 E 01		1.00 E 00
2.0 E 01		1.57 E 00
4.0 E 01		2.15 E 00
6.0 E 01	1.57 E 00	2.50 E 00
8.0 E 01	1.62 E 00	2.78 E 00
1.0 E 02	1.64 E 00	3.02 E 00
1.2 E 02	1.64 E 00	3.21 E 00
1.4 E 02	1.64 E 00	3.26 E 00
2.0 E 02	1.56 E 00	

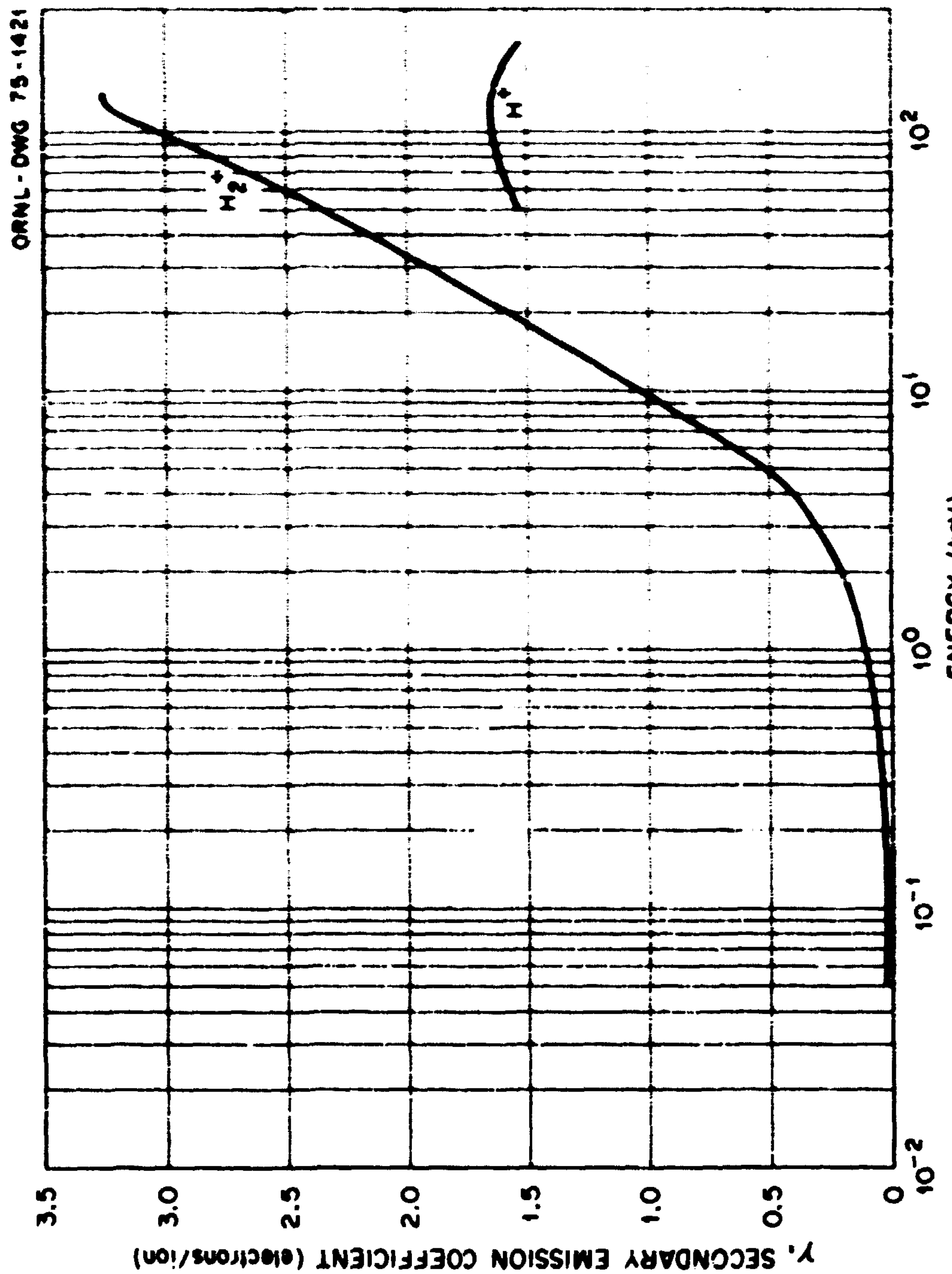
References:

H^+ + W: R.J. Ewing, Phys. Rev. 139, A 1840 (1965).

H_2^+ + W: F.M. Propst and E. Lüscher, Phys. Rev. 132, 1037 (1963). A.A. Dorozhkin and N.N. Petrov, Soviet Phys. Tech. Phys. 8, 257 (1963). [Zh. Tekh. Fiz. 33, 350 (1963).] L.N. Large, Proc. Phys. Soc. 81, 1101 (1963).

Accuracy:

Systematic error < ± 5%. Random error < ± 5%.


ORNL-DWG 75-1421
γ, SECONDARY EMISSION COEFFICIENT (electrons/ion)
ENERGY (keV)
H_2^+
H^+
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}

Secondary Electron Emission by Impact of Helium Ions on a Polycrystaline Molybdenum Target:

He^{+}, He^{2+} on Mo

(Projectiles Incident Normally on Target)

Impact Energy (keV)	Secondary Emission Coefficient γ Electrons/Ion	
	He^{2+}	He^{+}
1.0 E-02	7.13 E-01	3.00 E-01
5.0 E-02	7.11 E-01	2.88 E-01
1.0 E-01	7.17 E-01	2.78 E-01
2.0 E-01	7.25 E-01	2.64 E-01
4.0 E-01	7.56 E-01	2.49 E-01
6.0 E-01	7.77 E-01	2.50 E-01
8.0 E-01	7.18 E-01	2.60 E-01
1.0 E 00	7.85 E-01	2.76 E-01
2.0 E 00		3.66 E-01
4.0 E 00		5.22 E-01
6.0 E 00		6.82 E-01
8.0 E 00		8.30 E-01
1.0 E 01		9.66 E-01
2.0 E 01		1.54 E 00
4.0 E 01		2.22 E 00

References:

He^{2+} on Mo: H.D. Hagstrum, Phys. Rev. 89, 244 (1953).

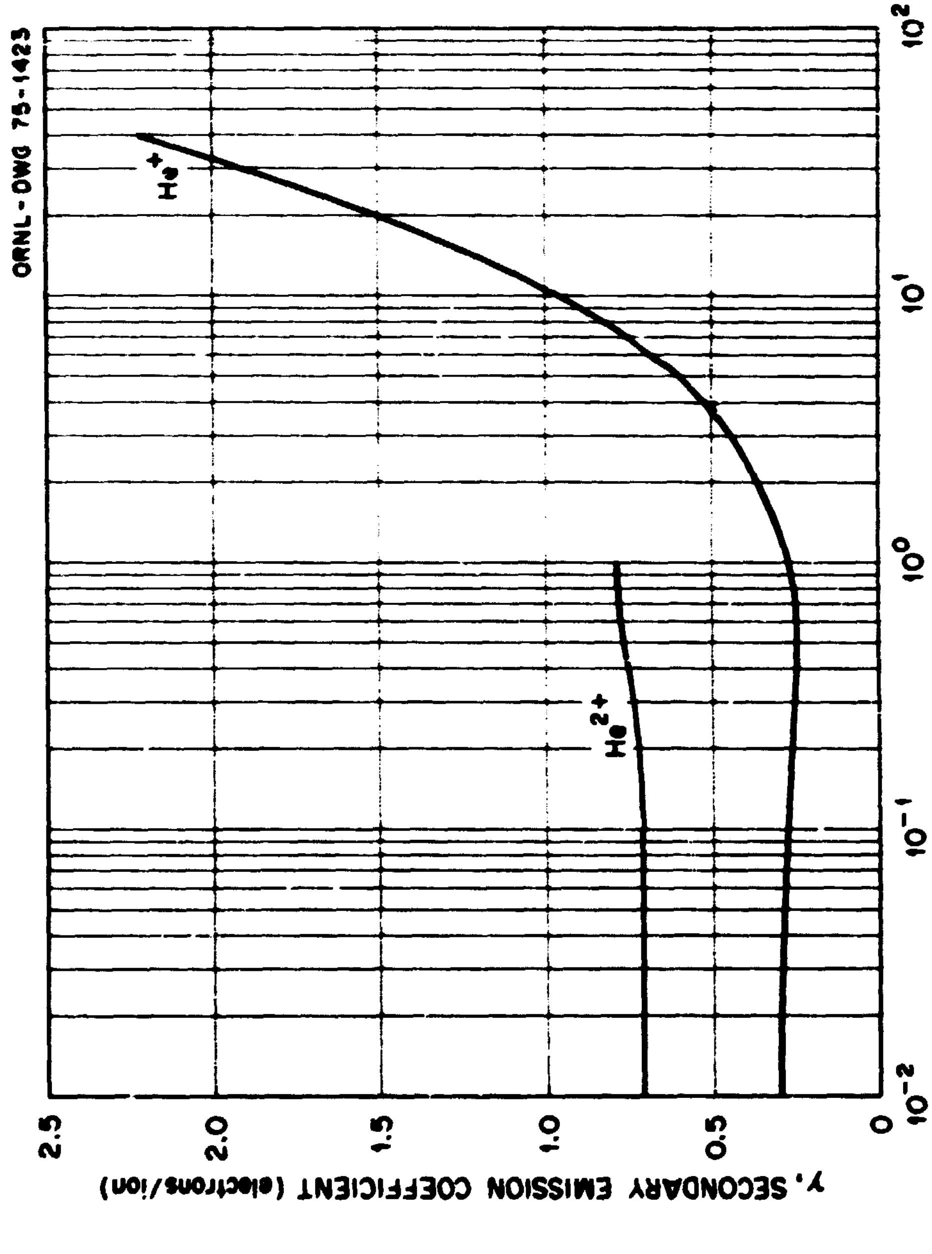
He^{+} on Mo: H.D. Hagstrum, Phys. Rev. 104, 672 (1953). P. Mahadevan, J.K. Layton, D.B. Medved, Phys. Rev. 129, 79 (1963). D.W. Vance, Phys. Rev. 169, 252 (1967). V.A. Arifov, R.R. Rakhinov, O.V. Khozinskii, Bull. Acad. Sci. USSR 26, 1422 (1962) [Zh. Akad. Nauk. SSSR, Ser. Fiz. 26, 1398 (1962)]. V.G. Tel'kovskii, Soviet Phys., Doklady 1, 334 (1956).

Accuracy:

Systematic error < ± 2%. Random error < ± 2%.

Notes:

See Notes (3) and (5) at end of chapter.


ORNL-DWG 75-1423
He^{+}
He^{2+}
ENERGY (keV)
γ, SECONDARY EMISSION COEFFICIENT (electrons/ion)
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
0
0.5
1.0
1.5
2.0
2.5

Secondary Electron Emission by Impact of Ions and Atoms on a Polycrystaline Tungsten Target: He^+, He, O^+, O_2^+ on W

(Projectile Incident Normally on Target)

Impact Energy (keV)	Secondary Emission Coefficient γ Electrons/Ion			
	He^+	He^0	O^+	O_2^+
1.0 E-02	2.92 E-01			
5.0 E-02	2.73 E-01			
1.0 E-01	2.63 E-01			
1.5 E-01	2.57 E-01			
2.0 E-01	2.50 E-01			
3.0 E-01	2.41 E-01	4.00 E-03		
4.0 E-01	2.39 E-01	2.00 E-02		
6.0 E-01	2.39 E-01	5.00 E-02		
8.0 E-01	2.44 E-01	7.40 E-02		
1.0 E 00	2.52 E-01	1.00 E-01		
2.0 E 00	3.40 E-01	2.26 E-01		
4.0 E 00	5.18 E-01			
6.0 E 00	6.80 E-01			
8.0 E 00	8.17 E-01			
1.0 E 01	9.32 E-01			
2.0 E 01	1.42 E 00			
4.0 E 01	2.36 E 00		2.76 E 00	3.38 E 00
6.0 E 01	2.44 E 00		3.42 E 00	4.47 E 00
8.0 E 01	2.74 E 00		4.05 E 00	5.42 E 00
1.0 E 02	2.98 E 00		4.60 E 00	6.21 E 00
1.2 E 02	3.11 E 00		5.14 E 00	6.81 E 00
1.4 E 02	3.16 E 00		5.57 E 00	

References:

He^+ + W: H.D. Hagstrum, Phys. Rev. 104, 317 (1956). V.A. Arifov, R.R. Rakhimov, and O.V. Khozinskii, Bull. Acad. Sci. USSR, Phys. Ser. 26, 1422 (1962). [Izv. Akad. Nauk SSSR, Ser. Fiz. 26, 1398 (1962)]. L.N. Large, Proc. Phys. Soc. 81, 1101 (1963).

He^0 + W: H.W. Berry, J. Appl. Phys. 29, 1219 (1958).

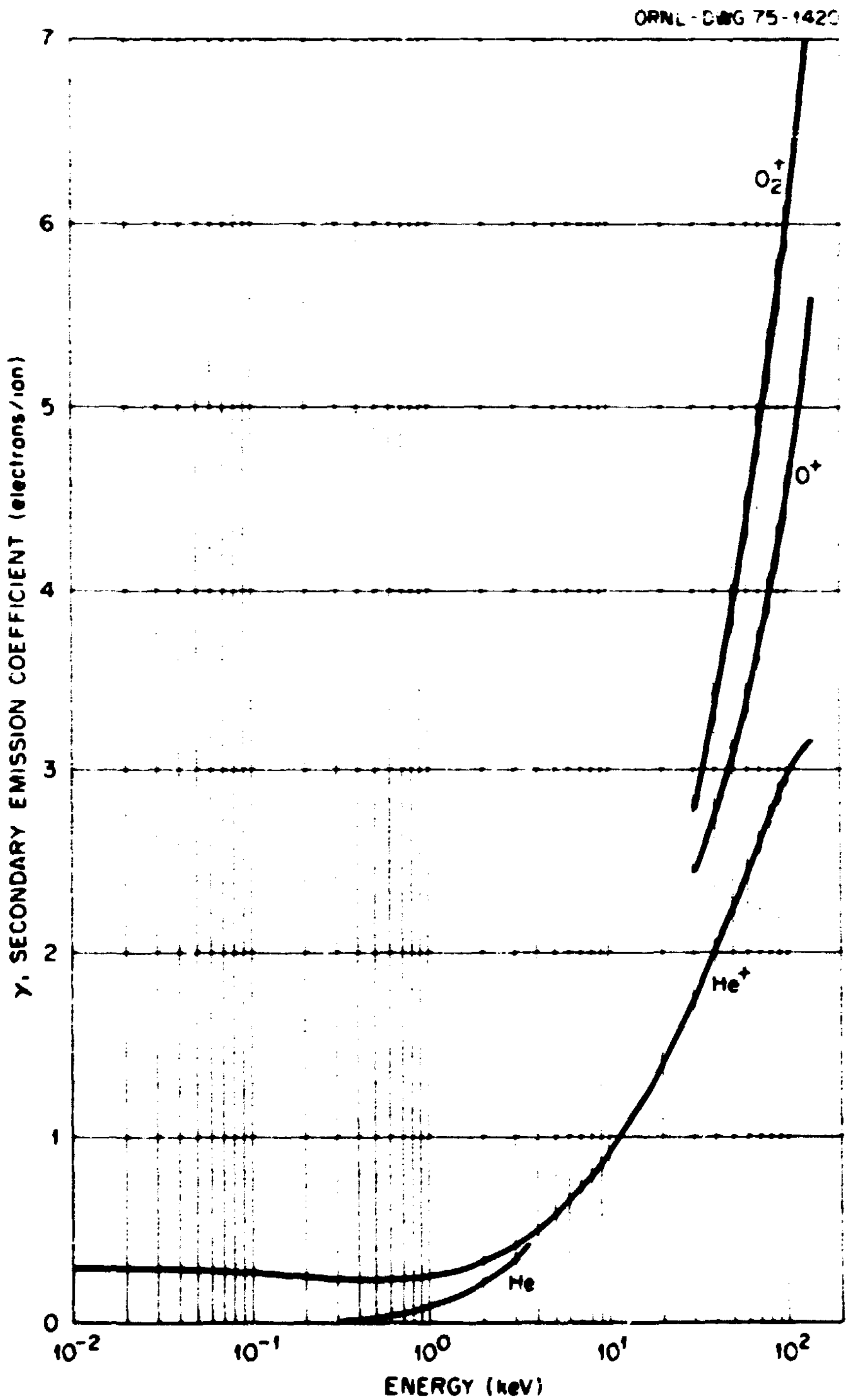
O^+ and O_2^+ + W: L.N. Large, Proc. Phys. Soc. 81, 1101 (1963).

Accuracy:

Systematic error < ± 5%. Random error < ± 2%.

Notes:

See Note (6) at end of chapter.


ORNL-DWG 75-1420
γ, SECONDARY EMISSION COEFFICIENT (electrons/ion)
ENERGY (keV)
0
1
2
3
4
5
6
7
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
O_2^+
O^+
He^+
He

Secondary Electron Emission by Impact of Oxygen Ions on a Polycrystaline Molybdenum Target: O^-, O^+, O_2^-, O_2^+ on Mo

(Projectiles Incident Normally on Target)

Impact Energy (keV)	Secondary Emission Coefficient γ Electrons/Ion			
	O^-	O^+	O_2^+	O_2^-
5.0 E-02		4.10 E-02	2.74 E-02	
1.0 E-01		4.20 E-02	2.75 E-02	
2.0 E-01		5.30 E-02	2.80 E-02	
4.0 E-01	9.00 E-03	8.10 E-02	3.06 E-02	1.40 E-03
6.0 E-01	2.00 E-02	1.20 E-01	3.40 E-02	1.08 E-02
8.0 E-01	3.50 E-02	1.42 E-01	4.38 E-02	2.03 E-02
1.0 E 00	5.74 E-02	1.78 E-01	6.00 E-02	3.25 E-02
1.4 E 00	1.05 E-01	2.41 E-01	1.05 E-01	6.10 E-02
1.8 E 00	1.58 E-01	3.20 E-01	1.58 E-01	8.80 E-02
2.0 E 00	1.82 E-01	3.32 E-01		
4.0 E 00	4.08 E-02	5.71 E-01		
8.0 E 00	7.61 E-01	9.20 E-01		
1.0 E 01	9.06 E-01	1.08 E 00		
1.5 E 01	1.24 E 00	1.40 E 00		
2.0 E 01	1.50 E 00	1.67 E 00		
2.5 E 01	1.72 E 00	1.90 E 00		
3.0 E 01	1.89 E 00	2.08 E 00		

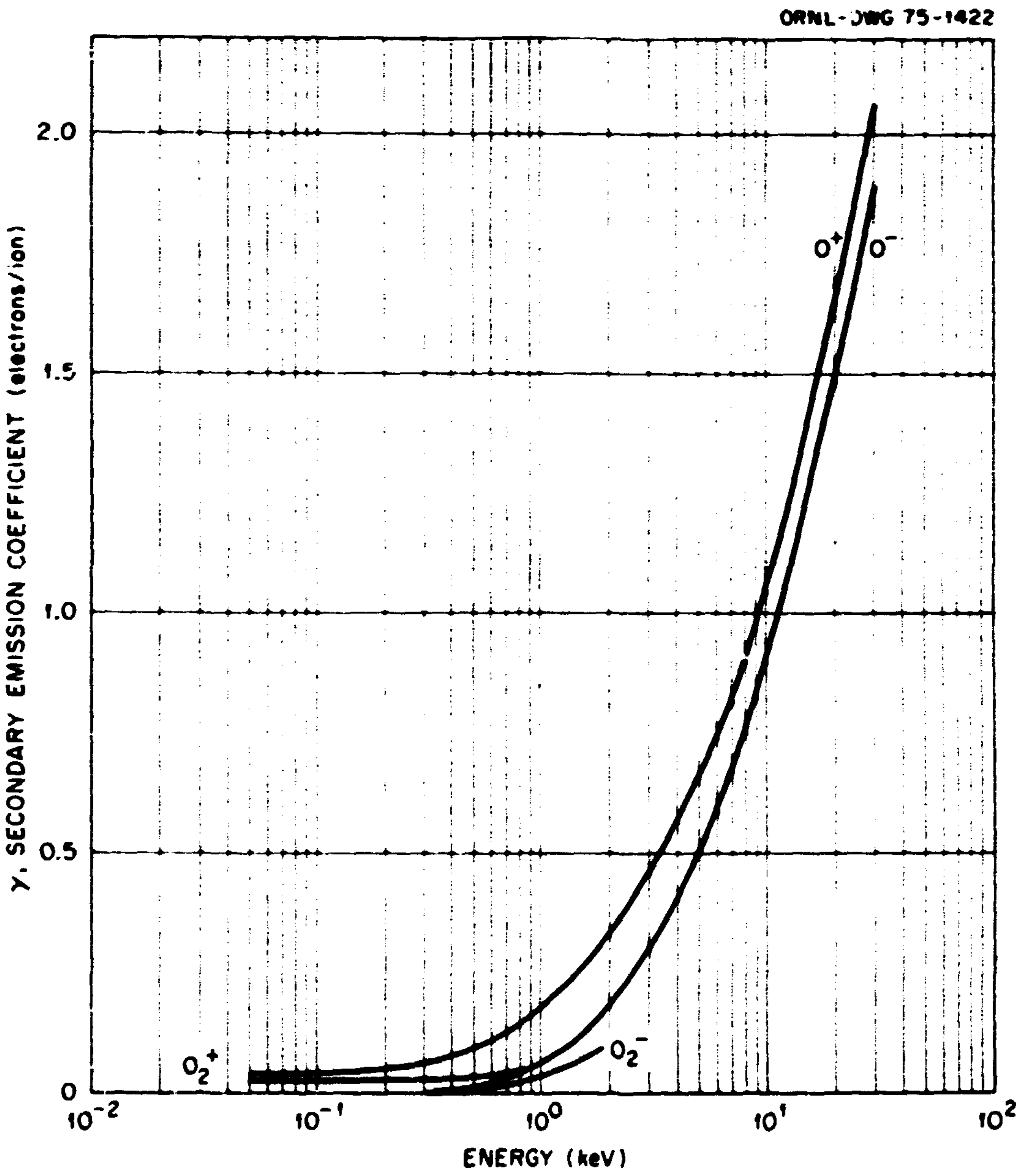
References:

O^+ and O^- on Mo: P. Mahadevan, G.D. Magnuson, J. K. Layton and C.E. Carlson, Phys. Rev. 140, A1407 (1965). M. Perdrix, S. Paletto, R. Goutte, and C. Guillaud, J. Phys. D 2, 441 (1969).

O_2^+ and O_2^- on Mo: P. Mahadevan, G.D. Magnuson, J.K. Layton, and C.E. Carlson, Phys. Rev. 140, A1407 (1965).

Accuracy:

Systematic error < ± 5%. Random error < ± 2%.


ORNL-DWG 75-1422
γ, SECONDARY EMISSION COEFFICIENT (electrons/ion)
2.0
1.5
1.0
0.5
0
O^+
O^-
O_2^+
O_2^-
10^{-2}
10^{-1}
10^0
10^1
10^2
ENERGY (keV)

Notes

(1) All reported studies indicate D^+ ions behave the same as H^+ ions of the same velocity. See for example L.N. Large and W. S. Whitlock, Proc. Phys. Soc. 79, 148 (1962).

(2) There is evidence that secondary emission coefficients for H_2^+ impact are approximately twice that for H^+ of the same velocity; similarly the coefficient for H_3^+ is approximately three times that for H^+ of the same velocity [see for example L.N. Large and W.S. Whitlock, Proc. Phys. Soc. 79, 148 (1962)]. In the absence of direct measurements for H_2^+ and H_3^+ it is possible to estimate coefficients by scaling from H^+ data by this rule.

(3) For information on the secondary electron emission coefficient as a function of incidence angle, see I.W. Evdokimov et al., Physica Status, Solidi 19, 407 (1967).

(4) For information on angular distributions of electrons, see for example W.H.P. Losch, Physica Status Solidi (a) 2, 123 (1970).

(5) For further information on the dependence of γ with incidence angle, see D.W. Vance, Phys. Rev. 169, 252 (1967).

(6) For information on the dependence of secondary emission flux with angle, see H.J. Klein, Zeits, für Physik, 188, 78 (1965).

D.4 Electron Reflection

Backscattering of Electrons Resulting from Electron Impact on a Graphite Surface

(Electrons Incident Normally on Surface)

e on C

Energy of Impact (keV)	Backscattering Coefficient η Electrons/Electron
1.0 E-01	1.25 E-01
2.0 E-01	1.25 E-01
4.0 E-01	1.25 E-01
8.0 E-01	1.24 E-01
1.0 E 00	1.24 E-01
1.5 E 00	1.19 E-01
2.0 E 00	1.16 E-01
4.0 E 00	1.05 E-01
8.0 E 00	9.40 E-02
1.0 E 01	9.00 E-02
1.5 E 01	7.00 E-02
2.0 E 01	7.20 E-02
4.0 E 01	7.80 E-02
8.0 E 01	8.20 E-02
1.0 E 02	8.00 E-02
1.5 E 02	7.50 E-02
2.0 E 02	7.00 E-02

<u>References:</u>

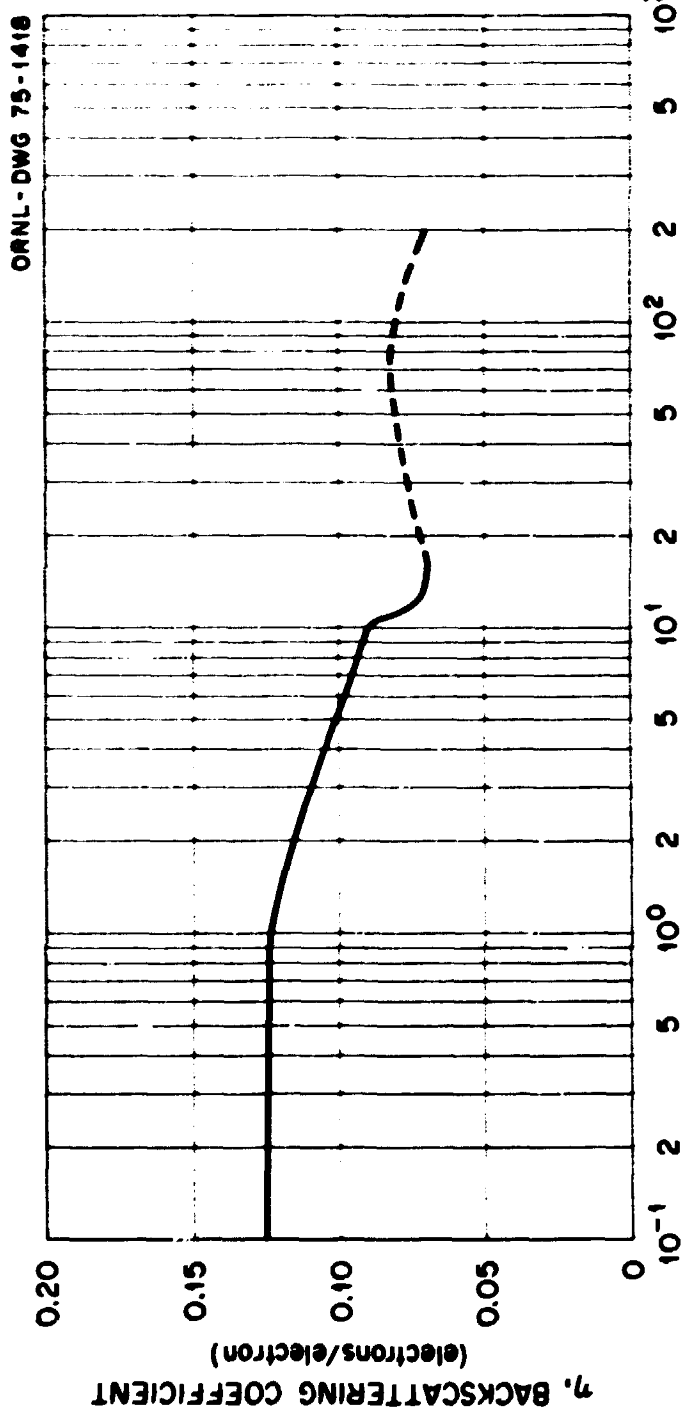
J. Hölzl and K. Jacobi, Surface Sci. <u>14</u>, 351 (1969). P. Palluel, Comptes Rendus <u>254</u>, 1492 (1947). R.W. Dressel, Phys. Rev. <u>144</u>, 332 (1966).

<u>Accuracy:</u>

Systematic error < ± 5%. Random error < ± 5%.

<u>Notes:</u>

See Notes (1), (2), and (4) at end of chapter.


ORNL-DWG 75-1418
ENERGY (keV)
η, BACKSCATTERING COEFFICIENT
(electrons/electron)
0.20
0.15
0.10
0.05
0
10^-1
2
5
10^0
2
5
10^1
2
5
10^2
2
5
10^3

Backscattering of Electrons Resulting from Electron Impact on a Steel Surface

(Electrons Incident Normally to Surface)

e on Steel

Energy of Impact (keV)	Backscattering Coefficient η Electrons/Electron
4.0 E 01	9.20 E-02
8.0 E 01	1.58 E-01
1.0 E 02	1.66 E-01
1.5 E 02	1.85 E-01
2.0 E 02	1.92 E-01
3.0 E 02	1.96 E-01

Reference:

J.G. Trump and R.J. Van de Graaff, Phys. Rev. 75, 44 (1949).

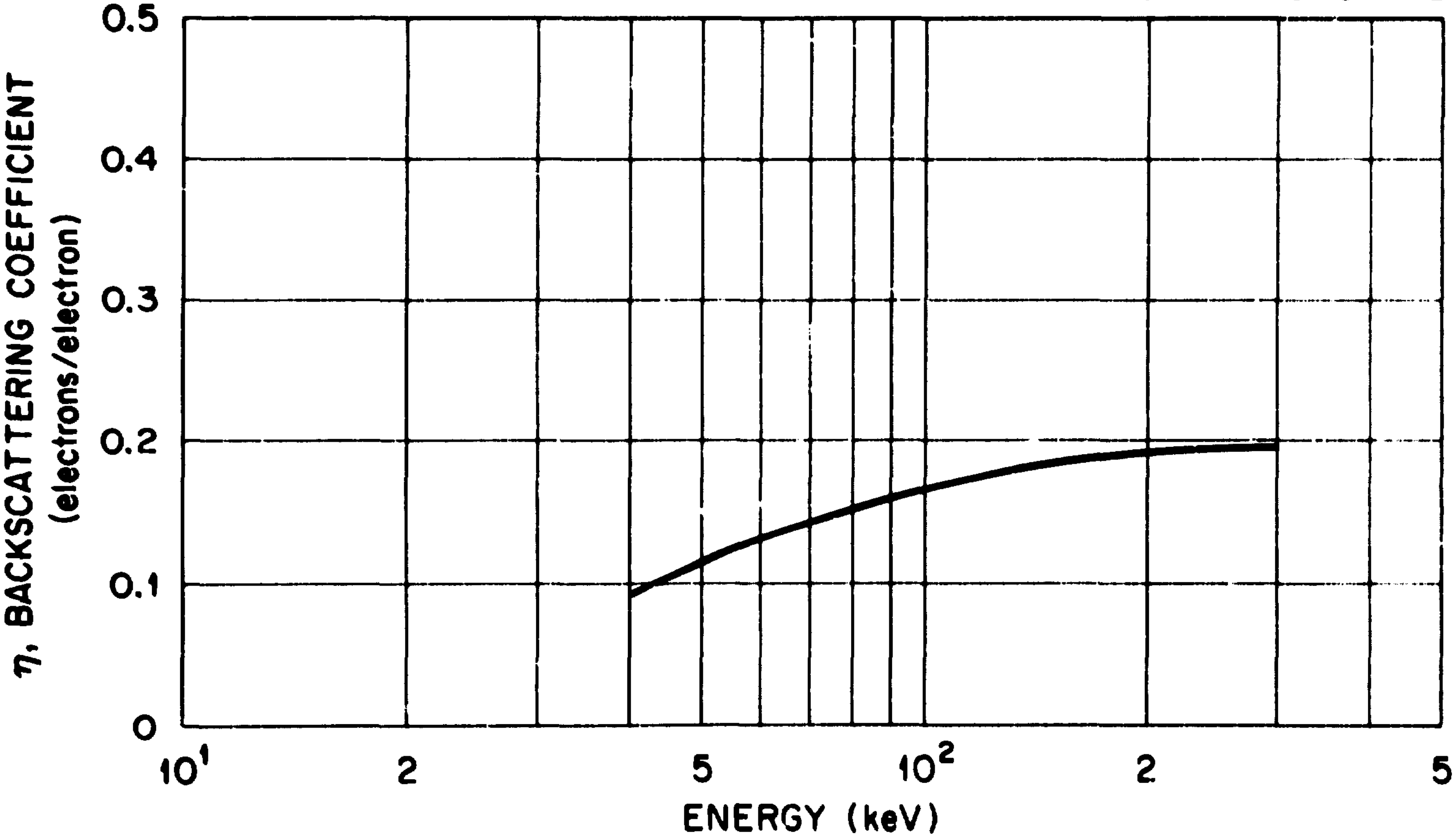
Accuracy:

Unknown

Notes:

See Notes (1) and (6) at end of chapter.

ORNL-DWG 75-1412



Backscattering of Electrons Resulting from Electron Impact on a Polycrystaline Iron Surface

(Electrons Incident Normally to Surface)

e on Fe

Energy of Impact (keV)	Backscattering Coefficient η Electrons/Electron
3.0 E-01	2.22 E-01
4.0 E-01	2.20 E-01
8.0 E-01	2.20 E-01
1.0 E 00	2.20 E-01
2.0 E 00	2.30 E-01
4.0 E 00	2.76 E-01
8.0 E 00	2.98 E-01
1.0 E 00	2.99 E-01
1.5 E 00	2.93 E-01
2.0 E 00	2.76 E-01
3.0 E 00	2.49 E-01

References:

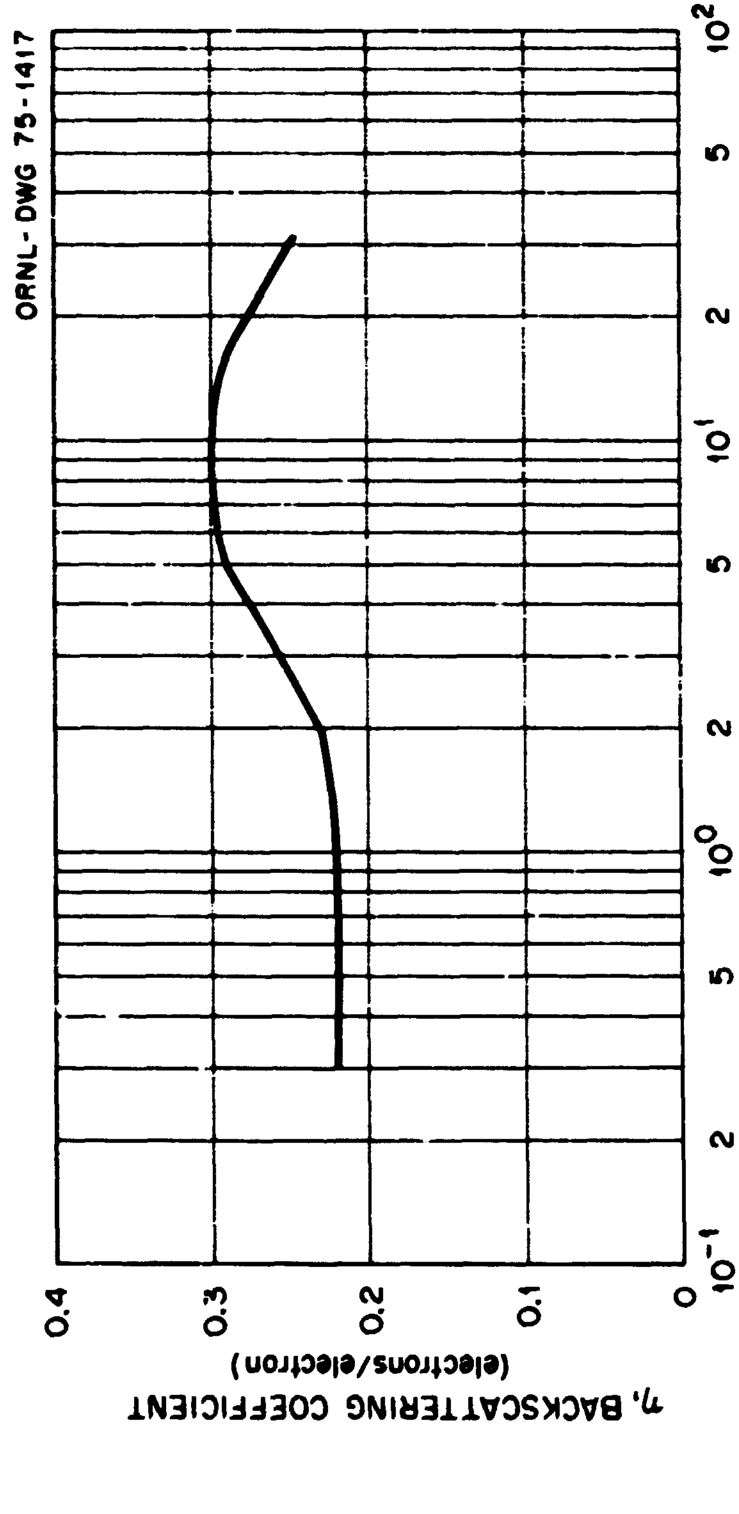
E.J. Sternglass, Phys. Rev. 95, 345 (1954). P. Palluel, Comptes Rendus 245, 1492 (1947). E. Weinryb and J. Philibert, Comptes Rendus 258, 4535 (1964).

Accuracy:

Systematic error < ± 5%. Random error < ± 5%.

Notes:

See Notes (1) and (4) at end of chapter.


ORNL-DWG 75-1417
η, BACKSCATTERING COEFFICIENT
(electrons/electron)
ENERGY (keV)
0
0.1
0.2
0.3
0.4
10^{-1}
2
5
10^{0}
2
5
10^{1}
2
5
10^{2}

Backscattering of Electrons Resulting from Electron Impact on a Polycrystaline Nickel Surface

(Electrons Incident Normally to Surface)

e on Ni

Energy of Impact (keV)	Backscattering Coefficient η Electrons/Electron
2.0 E-01	2.50 E-01
4.0 E-01	3.35 E-01
8.0 E-01	3.50 E-01
1.0 E 00	3.23 E-01
1.5 E 00	2.97 E-01
2.0 E 00	2.95 E-01
4.0 E 00	2.99 E-01
8.0 E 00	3.06 E-01
1.0 E 01	3.07 E-01
1.5 E 01	3.04 E-01
2.0 E 01	2.97 E-01
3.0 E 01	2.74 E-01

References:

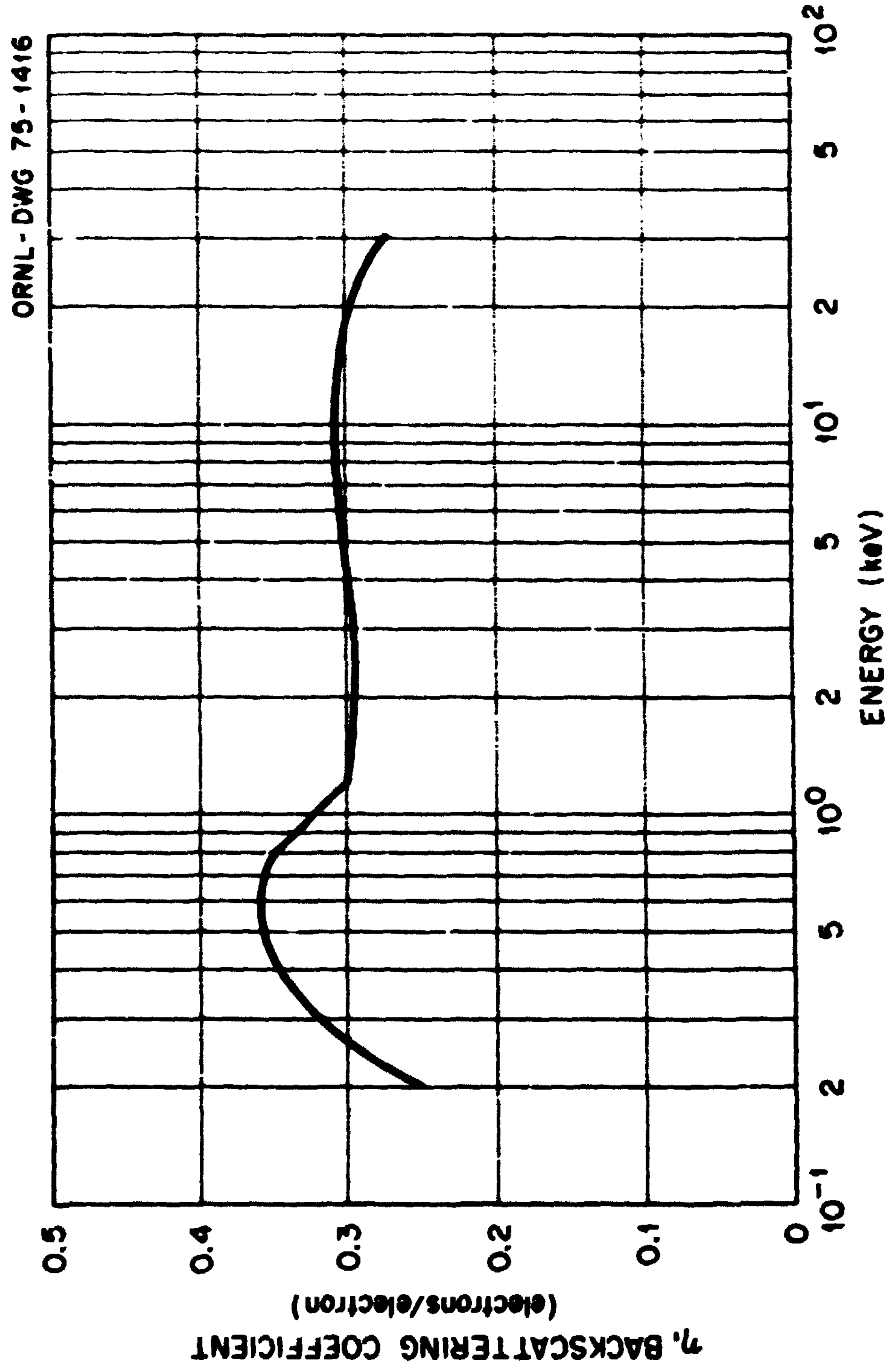
A.R. Shul'man, I.R. Zakiyova, Iu. A. Morozov, and S.A. Fridrikhov, Soviet Phys., Tech. Phys. 3, 79 (1958). P. Palluel, Comptes Rendus 245, 1492 (1947). E. Weinryb and J. Philibert, Comptes Rendus 258, 4535 (1964).

Accuracy:

Systematic error < ± 5%. Random error < ± 5%.

Notes:

See Notes (1), (3), and (4) at end of chapter.


ORNL-DWG 75-1416
η, BACKSCATTERING COEFFICIENT
(electrons/electron)
0.5
0.4
0.3
0.2
0.1
0
10⁻¹
2
5
10⁰
2
5
10¹
2
5
10²
ENERGY (keV)

Backscattering of Electrons Resulting from Electron Impact on a Polycrystaline Gold Surface

(Electrons Incident Normally to Surface)

e on Au

Energy of Impact (keV)	Backscattering Coefficient η Electrons/Electron
0.0 E-03	7.15 E-02
2.0 E-03	8.40 E-02
4.0 E-03	8.80 E-02
8.0 E-03	1.41 E-01
1.0 E-02	2.00 E-01
1.5 E-02	1.48 E-01
2.0 E-02	9.40 E-02
4.0 E-02	6.80 E-02
8.0 E-02	1.15 E-01
1.0 E-01	1.30 E-01
1.5 E-01	1.56 E-01
2.0 E-01	1.75 E-01
4.0 E-01	2.21 E-01
8.0 E-01	2.67 E-01
1.0 E 00	2.80 E-01
1.9 E 00	3.10 E-01
2.0 E 00	3.33 E-01
4.0 E 00	3.83 E-01
8.0 E 00	4.40 E-01
1.0 E 01	4.56 E-01
1.5 E 01	4.83 E-01
2.0 E 01	4.95 E-01
4.0 E 01	5.08 E-01
8.0 E 01	5.14 E-01
1.0 E 02	5.12 E-01
2.0 E 02	4.73 E-01
4.0 E 02	4.51 E-01

References:

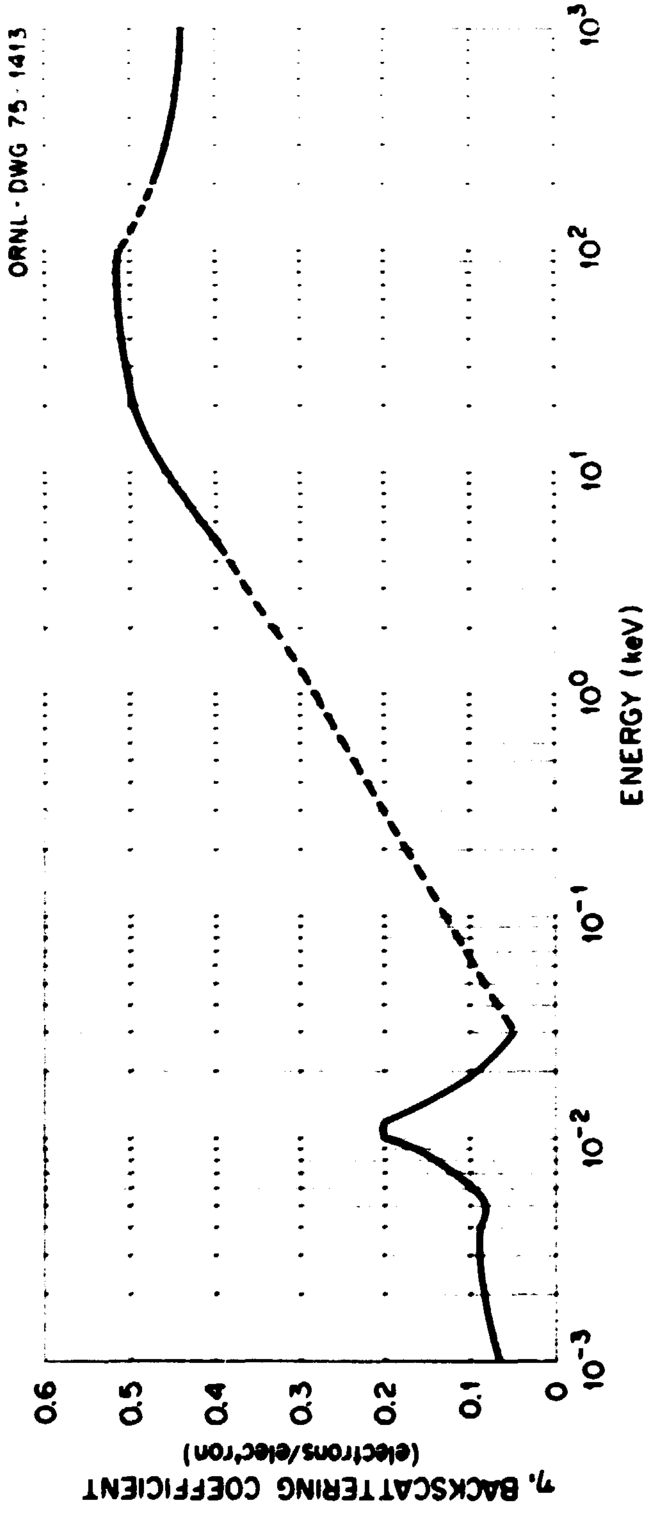
I.M. Bronshtein and V.V. Roshchin, Soviet Phys. Tech. Phys. 3, 2271 (1958). K.H. Stehberger, Ann. Physik, 86, 825 (1928) [as quoted by E.J. Sternglass, Phys. Rev. 95, 345 (1954)]. J.E. Holliday and E.J. Sternglass J. Appl. Phys. 28, 1189 (1957). H. Drescher, L. Reimer, H. Seidel, Z. Angew. Phys. 29, 331 (1970). B.L. Miller and W.C. Porter, J. Franklin Inst. 260, 31 (1955).

Accuracy:

Systematic error < ± 10%. Random error < ± 5%.

Notes:

See Notes (1) and (4) at end of chapter.



ORNL-DWG 75-1413
η, BACKSCATTERING COEFFICIENT
(electrons/electron)
0
0.1
0.2
0.3
0.4
0.5
0.6
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
ENERGY (keV)

Backscattering of Electrons Resulting from

Electron Impact on a Polycrystaline Molybdenum Surface

(Electrons Incident Normally to Surface)

e on Mo

Energy of Impact (keV)	Backscattering Coefficient η Electrons/Electron
1.0 E-03	7.00 E-02
2.0 E-03	1.17 E-01
4.0 E-03	1.33 E-01
8.0 E-03	1.33 E-01
1.0 E-02	1.33 E-01
1.5 E-02	9.20 E-02
2.0 E-02	6.50 E-02
4.0 E-02	6.00 E-02
8.0 E-02	9.20 E-02
1.0 E-01	1.05 E-01
2.0 E-01	1.50 E-01
4.0 E-01	1.67 E-01
8.0 E-01	2.00 E-01
1.0 E 00	2.16 E-01
1.5 E 00	2.50 E-01
2.0 E 00	2.75 E-01
4.0 E 00	3.45 E-01
8.0 E 00	3.66 E-01
1.0 E 01	3.70 E-01
1.5 E 01	3.75 E-01
2.0 E 01	3.75 E-01

References:

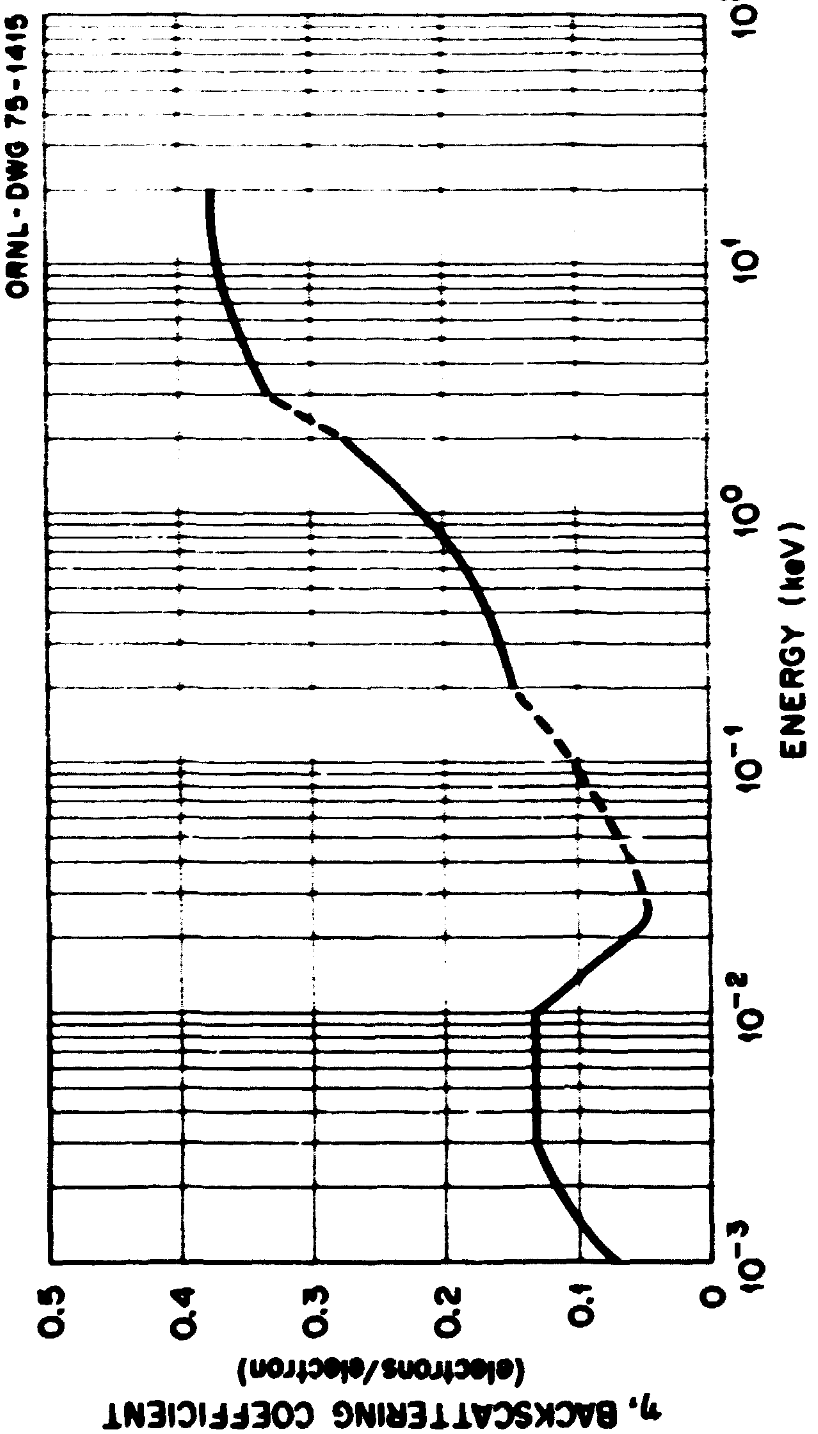
I.M. Bronshtein, Bull. Acad. Sci. USSR. 22, 442 (1958). E.J. Sternglass, Phys. Rev. 95, 345 (1954). P. Palluel, Comptes Rendus 245, 1492 (1947).

Accuracy:

Systematic error < ± 10%. Random error < ± 5%.

Notes:

See Notes (1) and (4) at end of chapter.


ORNL-DWG 75-1415
η, BACKSCATTERING COEFFICIENT
(electrons/electron)
0
0.1
0.2
0.3
0.4
0.5
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
ENERGY (keV)

Backscattering of Electrons Resulting from Electron Impact on a Polycrystaline Tungsten Surface

(Electrons Incident Normally to Surface)

e on W

Energy of Impact (keV)	Backscattering Coefficient η Electrons/Electron
1.0 E-03	5.20 E-02
2.0 E-03	6.80 E-02
4.0 E-03	1.20 E-01
8.0 E-03	1.65 E-01
1.0 E-02	1.66 E-01
1.5 E-02	1.56 E-01
2.0 E-02	1.42 E-01
3.0 E-02	1.15 E-01
4.0 E-02	1.17 E-01
8.0 E-02	1.22 E-01
1.0 E-01	1.25 E-01
2.0 E-01	1.47 E-01
4.0 E-01	2.85 E-01
8.0 E-01	4.03 E-01
1.0 E 00	4.32 E-01
1.5 E 00	4.64 E-01
2.0 E 00	4.81 E-01
4.0 E 00	4.85 E-01
8.0 E 00	4.45 E-01
1.0 E 01	4.40 E-01
2.0 E 01	4.36 E-01
3.0 E 01	4.40 E-01
4.0 E 01	4.42 E-01
8.0 E 01	4.47 E-01
1.0 E 02	4.50 E-01
2.0 E 02	4.83 E-01
3.0 E 02	5.00 E-01

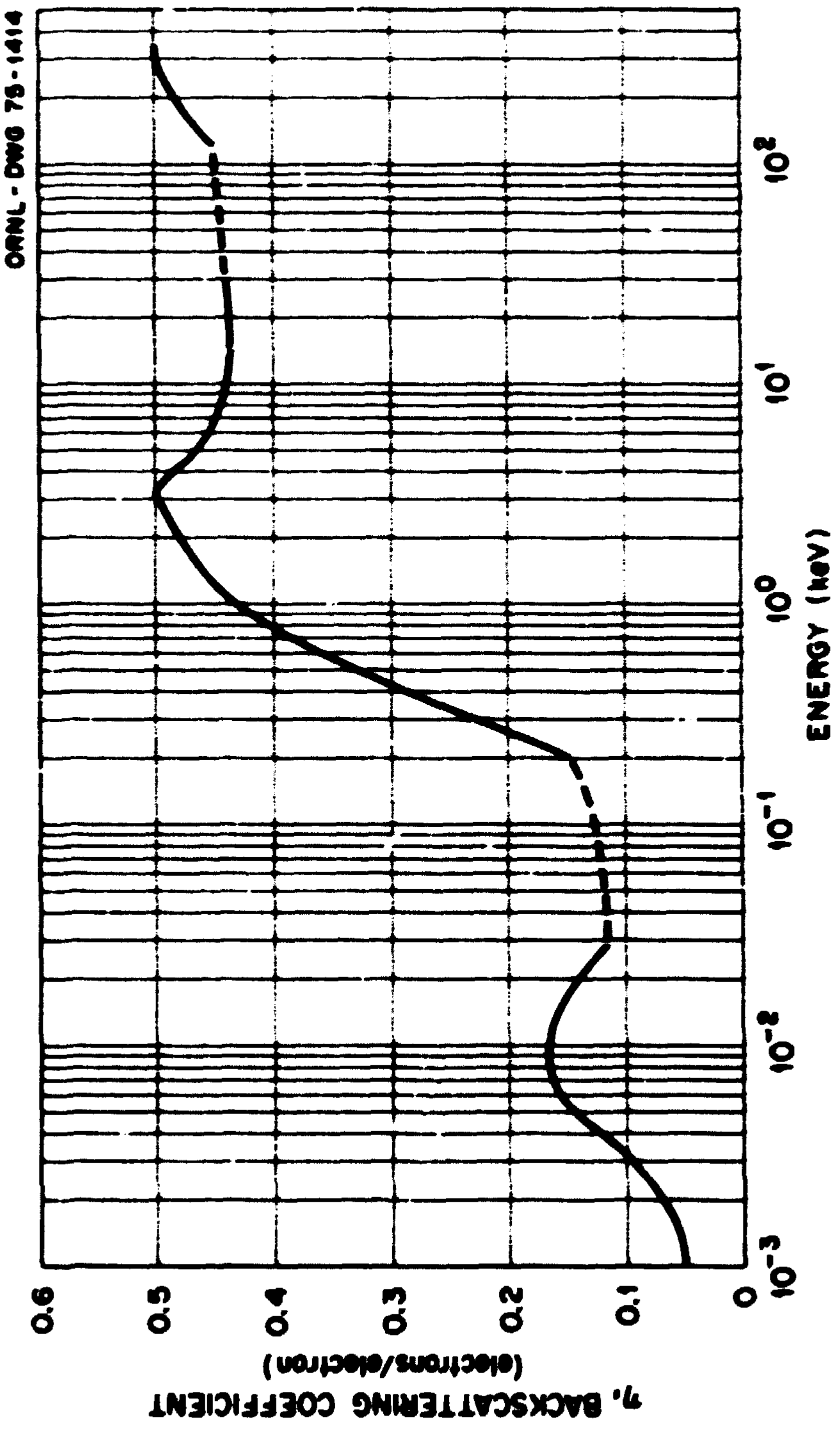
References:

I.M. Bronshtein, Bull. Acad. Sci. USSR, 22, 442 (1958). I.M. Bronshtein and R.B. Segal, Soviet Phys. Solid State 1, 1142 (1959). E. Weinryb and J. Philibert, Comptes Rendus 258, 4535 (1964). J.G. Trump and R.J. Van de Graaff, Phys. Rev. 75, 44 (1949).

Accuracy:

Systematic error < ± 10%. Random error < ± 5%.

Notes:


ORNL-DWG 75-1414
η, BACKSCATTERING COEFFICIENT
(electrons/electron)
0
0.1
0.2
0.3
0.4
0.5
0.6
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
ENERGY (keV)

Notes

(1) The measurement here is the ratio of the reflected or backscattered electron flux (integrated over all final outgoing directions) to the incident electron flux; it is given the symbol η. This is related to the coefficient for all emerging electrons, σ, (which includes true secondaries and backscattered electrons) and to the coefficient for true secondary electron emission δ; the relationship is $\sigma = \delta + \eta$. The coefficient δ is discussed elsewhere and the coefficient σ can obviously be generated by this equation.

(2) At energies between 20 and 200 keV we have used the work of Dressel [Phys. Rev. 144, 332 (1966)]; this is in fact an interpolation between Palluel's work ($E < 20$ keV) and Dressel's measurements at high energies ($E > 700$ keV). However, based on the apparently slow variation of η with E indicated in Dressel's paper, one would expect this to be reasonably accurate.

(3) For information on how η varies with angle of incidence, see I.M. Bronshtein and S.S. Denisov, Soviet Phys. Tech. Phys. 9, 731 (1967). It should be noted that the values of η given for normal incidence are not consistent with those adopted in the tabular data we present. There is no obvious explanation for this discrepancy. One can, however, use the relative variation with angle in complete confidence.

(4) On the graph, regions where we have interpolated between data sets are shown by broken lines.

(5) For an indication of how η varies with incidence angle, see the work of I.M. Bronstein and R.B. Segal', Soviet Phys. Solid State 1, 1142 (1959).

(6) The type of steel used here is unspecified. There seems some possibility that the data are inaccurate towards lower energies.

D.5 Ion Reflection from Surfaces

D.5.2

Scattering of H^0, H^+, H_2^+, and H_3^+ from Solid Copper

Flux of scattered H^+ and H^0 integrated over all scattered particle energies.

Primary Ion Energy: Various
Angle of Incidence α: 80°
Angle of Emergence β: 55°

(Data are for H^+ impact - for H^0, H_2^+, and H_3^+ see note below.)

Energy of Incident H^+, (keV)	Particle Flux (Arbitrary Units) Scattered H^+	Scattered $H^0 + H^+$
5.0 E 00		1.7 E-3
1.0 E 01	2.9 E-4	1.9 E-3
1.5 E 01	4.2 E-4	2.1 E-3
2.0 E 01	5.1 E-4	2.2 E-3
2.5 E 01	5.7 E-4	2.2 E-3
3.0 E 01	5.9 E-4	2.0 E-3
3.5 E 01	6.1 E-4	1.8 E-3
4.0 E 01	6.2 E-4	1.6 E-3
4.5 E 01		1.3 E-3

Reference:

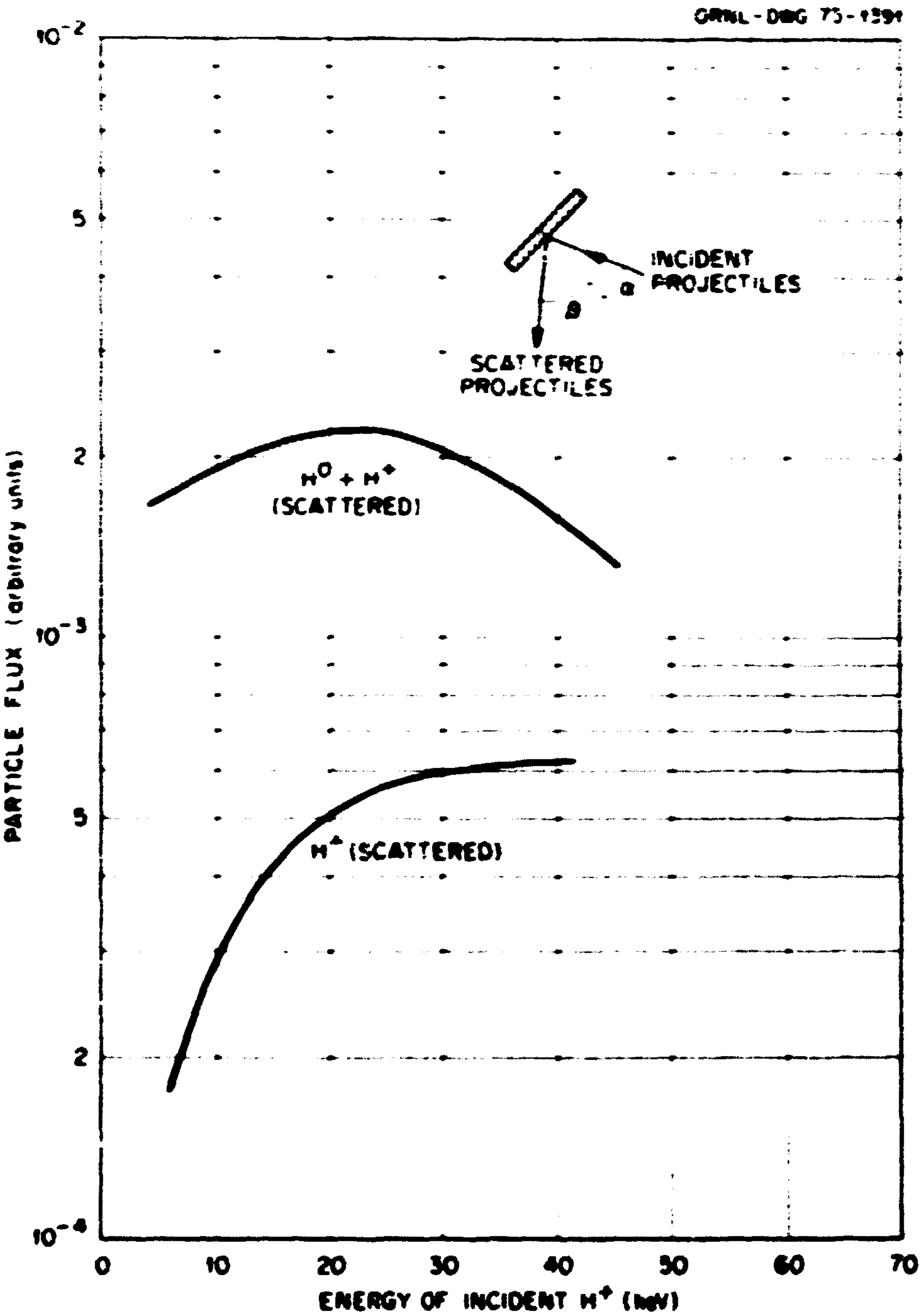
H^+ + Au, Experimental: K. Morita, H. Akimune, T. Suita, Japanese J. Appl. Phys. 7, 916 (1968).

Accuracy:

Random error < ± 5%.

Note:

H^0, H_2^+, and H_3^+ impact. Yields of both H^+ and $H^0 + H^+$ are found to be the same as for H^+ impact at the corresponding velocity.


ORNL-DWG 73-1394
INCIDENT
PROJECTILES
α
β
SCATTERED
PROJECTILES
$H^0 + H^+$
(SCATTERED)
H^+ (SCATTERED)
PARTICLE FLUX (arbitrary units)
ENERGY OF INCIDENT H^+ (keV)
10^{-2}
5
2
10^{-3}
5
2
10^{-4}
0
10
20
30
40
50
60
70

Scattering of H^+ from Solid Copper

Flux of scattered H^+ (integrated over all scattered energies) as a function of emergence angle for various incident angles.

Primary Ion Energy: 21.6 keV
Angle of Incidence α: 80°, 75°, 70°, 65°
Angle of Emergence β: Various

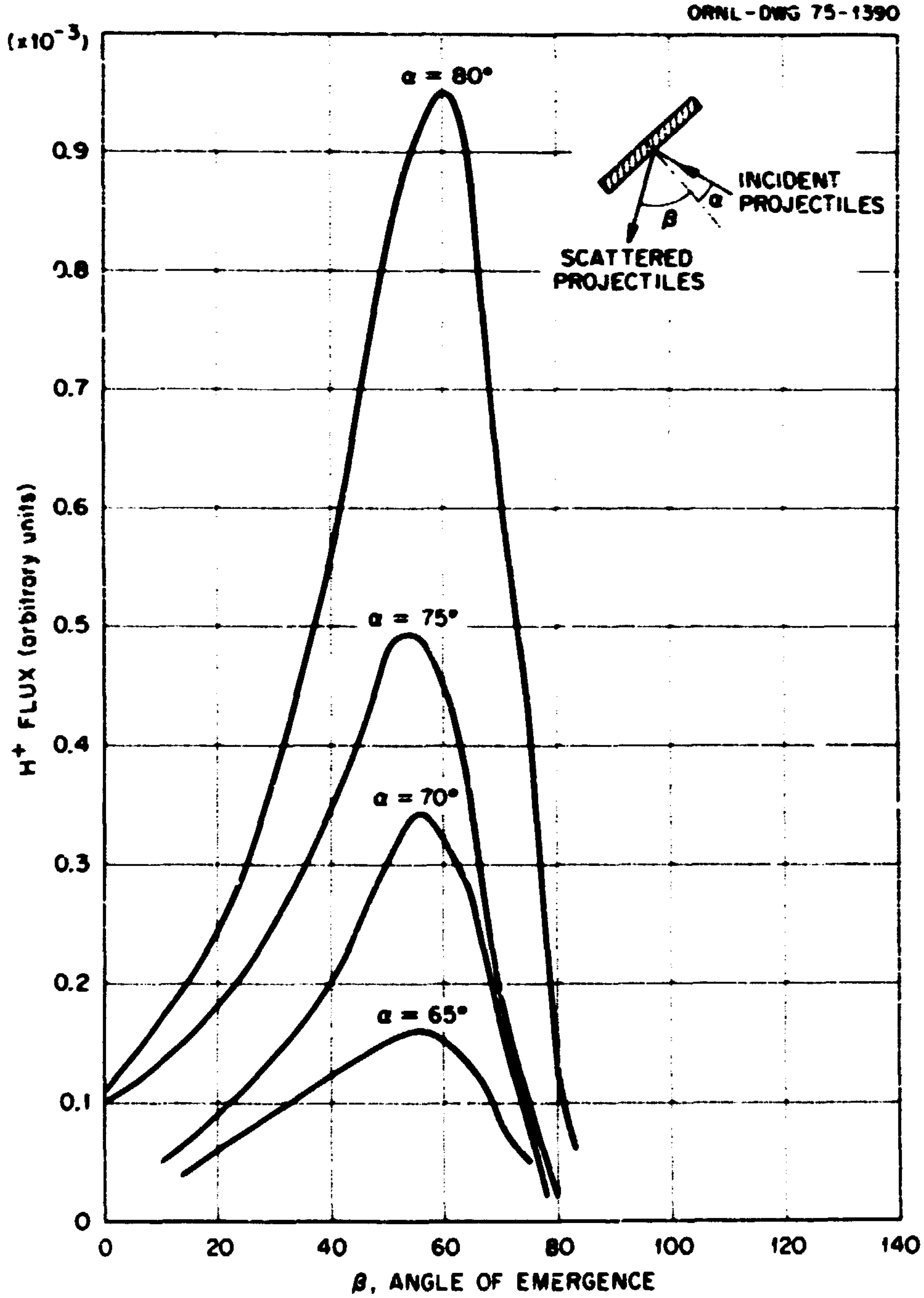
Angle of Emergence β (degrees)	H^+ Flux (Arbitrary Units) Incidence Angle (Degrees) α			
	80°	75°	70°	65°
1.0 E 01	1.7 E-1	1.3 E-1	5.0 E-2	
2.0 E 01	2.4 E-1	1.8 E-1	9.0 E-2	6.0 E-2
3.0 E 01	3.8 E-1	2.5 E-1	1.4 E-1	9.0 E-2
4.0 E 01	5.5 E-1	3.5 E-1	2.0 E-1	1.2 E-1
5.0 E 01	8.2 E-1	4.8 E-1	3.0 E-1	1.5 E-1
6.0 E 01	9.5 E-1	4.5 E-1	3.2 E-1	1.5 E-1
7.0 E 01	6.2 E-1	1.9 E-1	1.6 E-1	8.0 E-2
8.0 E 01	1.3 E-1	2.0 E-2		

Reference:

H^+ + Cu, Experimental: K. Morita, H. Akimune, T. Suita, Japanese J. Appl. Phys. 7, 916 (1968).

Accuracy:

Random error < ± 5%.


ORNL-DWG 75-1390
(x10⁻³)
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
H⁺ FLUX (arbitrary units)
α = 80°
α = 75°
α = 70°
α = 65°
INCIDENT PROJECTILES
SCATTERED PROJECTILES
α
β
0
20
40
60
80
100
120
140
β, ANGLE OF EMERGENCE

Scattering of H^+ from Solid Beryllium, Niobium, and Tantalum

Energy Distribution of Neutrals Plus Ions

Primary Ion Energy: 9.25 keV
Angle of Incidence α: 0°
Angle of Emergence β: 45°

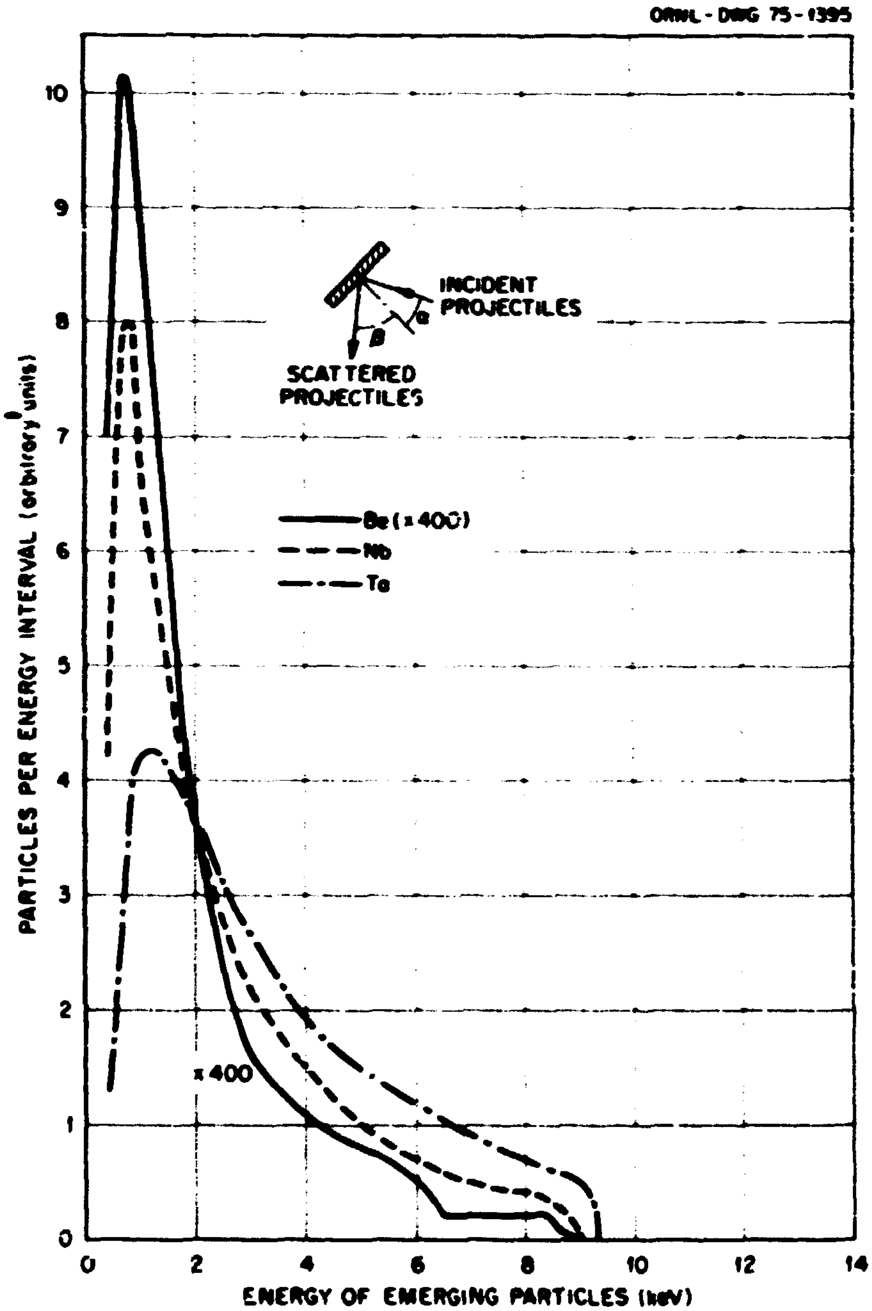
Energy of Emerging Particle (keV)	Particle Flux (Arbitrary Units)		
	Be	Nb	Ta
1.0 E 00	2.2 E-2	6.8 E 0	4.2 E 0
2.0 E 00	9.2 E-3	3.6 E 0	3.7 E 0
3.0 E 00	4.0 E-3	1.6 E 0	2.7 E 0
4.0 E 00	2.9 E-3	1.1 E 0	1.9 E 0
5.0 E 00	2.0 E-3	1.0 E 0	1.5 E 0
6.0 E 00	1.2 E-3	7.0 E-1	1.2 E 0
7.0 E 00	5.0 E-4	5.0 E-1	9.0 E-1
8.0 E 00	5.0 E-4	4.0 E-1	7.0 E-1
9.0 E 00			5.0 E-1

Reference:

H^+ + Be, Nb, Ta, Experimental: P. Meischner, H. Verbeek, Proceedings of Conference on "Surface Effects in Controlled Thermonuclear Devices and Reactors," Argonne, Illinois, January 1974 (Unpublished).

Accuracy:

Random error < ± 10%.


ORNL-DWG 75-1395
INCIDENT PROJECTILES
SCATTERED PROJECTILES
α
β
Be (×400)
Nb
Ta
×400
PARTICLES PER ENERGY INTERVAL (arbitrary units)
ENERGY OF EMERGING PARTICLES (keV)
0
1
2
3
4
5
6
7
8
9
10
0
2
4
6
8
10
12
14

Scattering of D^+ from Solid Niobium–

Energy Distribution of Scattered D^+

Primary Ion Energy: 60, 40, and 20 keV
Angle of Incidence α: 0°
Angle of Emergence β: Integrated Over All Emergence Angles

Energy of Emerging Particles (keV)	Particle Flux (Arbitrary Units) Impact Energy		
	20 keV	40 keV	60 keV
1.0 E 00			
2.0 E 00	2.1 E 5	8.0 E 4	4.5 E 4
4.0 E 00	2.1 E 5	8.5 E 4	5.4 E 4
6.0 E 00	1.7 E 5	8.2 E 4	5.4 E 4
8.0 E 00	1.3 E 5	7.0 E 4	4.8 E 4
1.0 E 01	9.6 E 4	5.5 E 4	4.0 E 4
1.5 E 01	4.0 E 4	3.2 E 4	2.7 E 4
2.0 E 01		2.0 E 4	1.8 E 4
2.5 E 01		1.4 E 4	1.3 E 4
3.0 E 01		1.0 E 4	1.0 E 4
3.5 E 01		8.0 E 3	8.0 E 3
4.0 E 01			6.8 E 3
4.5 E 01			6.0 E 3
5.0 E 01			5.4 E 3
5.5 E 01			5.1 E 3
6.0 E 01			

Reference:

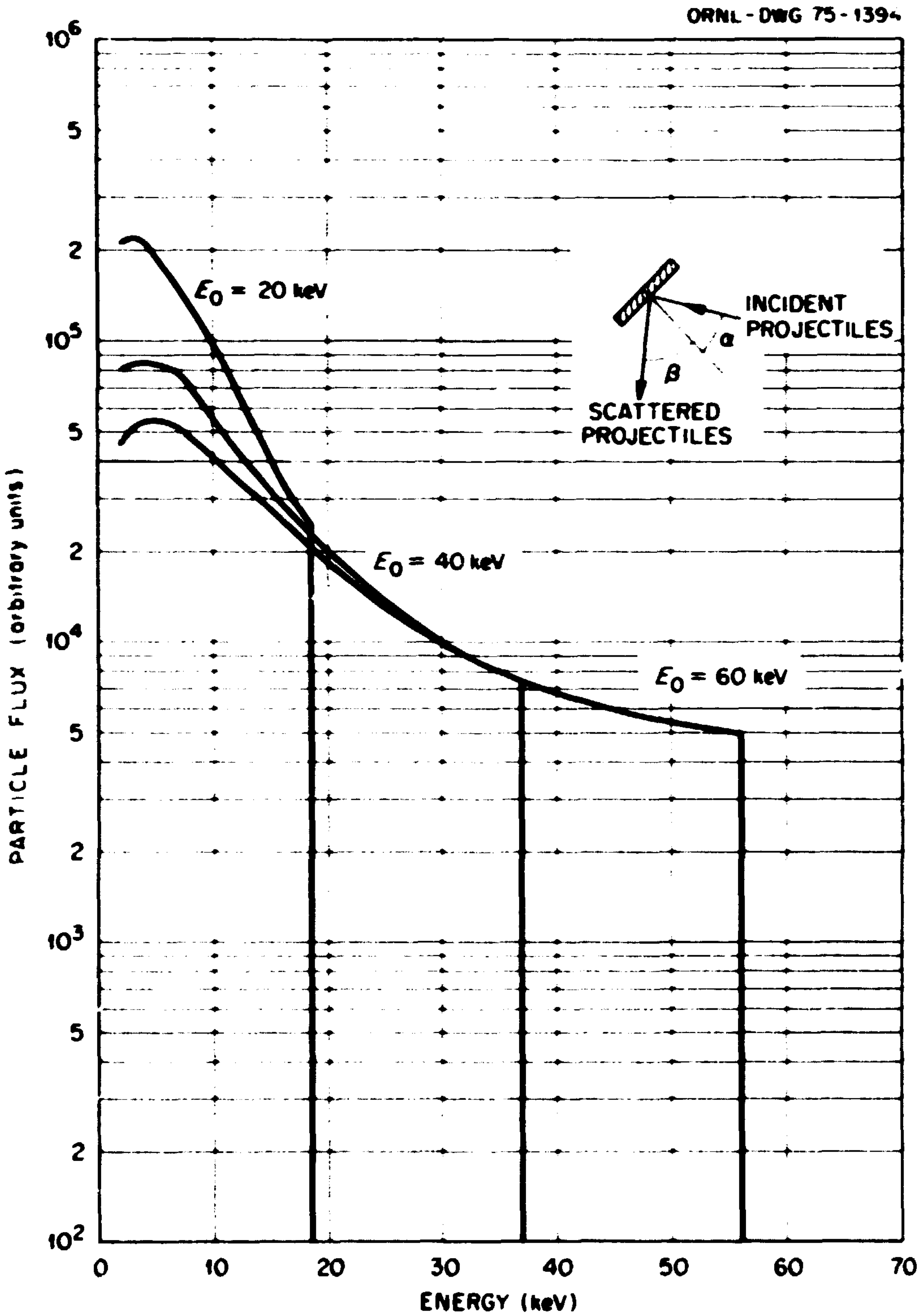
D^+ + Mo, Experimental: G.M. McCracken, N.J. Freeman, J. Phys. B. 2, 661 (1969).

Accuracy:

Unspecified

Notes:

The reference cited provides a computational procedure for estimating energy distributions for any target.


ORNL-DWG 75-1394
E_0 = 20 keV
E_0 = 40 keV
E_0 = 60 keV
INCIDENT PROJECTILES
SCATTERED PROJECTILES
α
β
PARTICLE FLUX (arbitrary units)
ENERGY (keV)
10^6
5
2
10^5
5
2
10^4
5
2
10^3
5
2
10^2
0
10
20
30
40
50
60
70

Scattering of H^+ from Solid Molybdenum-

Energy Distributions of Charged and Neutral Particles

Primary Ion Energy: 18.5 keV
Angle of Incidence α: 25°
Angle of Emergence β: 20°

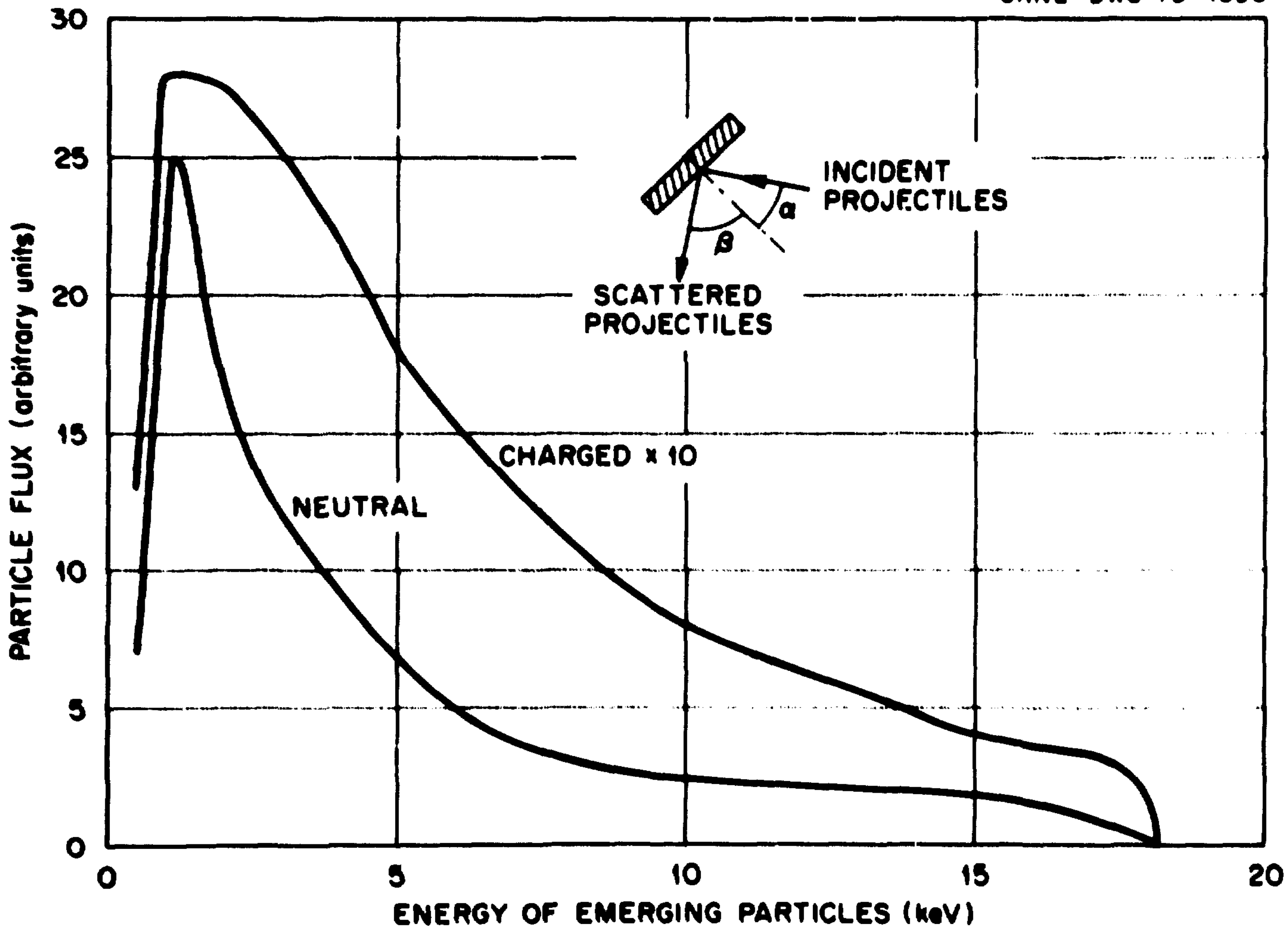
Energy of Emerging Particle (keV)	Particle Flux (Arbitrary Units)	
	Neutrals	Ions
	H^0	H^+
1.0 E 00	2.3 E 1	2.8 E 0
2.0 E 00	1.7 E 1	2.7 E 0
3.0 E 00	1.2 E 1	2.5 E 0
4.0 E 00	9.3 E 0	2.2 E 0
5.0 E 00	6.9 E 0	1.8 E 0
7.5 E 00	3.4 E 0	1.2 E 0
1.0 E 01	2.4 E 0	8.0 E-1
1.2 E 01	2.2 E 0	6.0 E-1
1.5 E 01	1.8 E 0	4.0 E-1
1.7 E 01	6.0 E-1	3.0 E-1
1.8 E 01	2.0 E-1	2.0 E-1

H^+ + Mo, Experimental: P. Meischner, H. Verbeek, "Proceedings of Conference on Surface Effects in Controlled Thermonuclear Devices and Reactors," Argonne, Illinois, January 1974 (Unpublished).

Accuracy:

Random error < ± 10%.

ORNL-DWG 75-1396



Scattering of H^+ from Solid Aluminum, Molybdenum, and Gold-

Percentage of Ions Backscattered (as H^+ and H^0) with Energy Greater than 1 keV.

Primary Ion Energy: Various
Angle of Incidence α: 0°
Angle of Emergence β: Integrated Over All Emergence Angles

Energy of Incident Particle (keV)	Percentage of Projectiles Reflected with E > 1 keV		
	Al	Mo	Au
5.0 E 00	4.5 E 0	4.0 E 1	
1.0 E 01	2.5 E 0	2.3 E 1	7.0 E 1
1.5 E 01	1.5 E 0	1.4 E 1	4.9 E 1
2.0 E 01	1.0 E 0	9.5 E 0	3.4 E 1
2.5 E 01	7.0 E-1	6.6 E 0	2.5 E 1
3.0 E 01	5.2 E-1	4.9 E 0	1.8 E 1
3.5 E 01	4.2 E-1	4.0 E 0	1.4 E 1
4.0 E 01	3.5 E-1	3.4 E 0	1.2 E 1
5.0 E 01	2.7 E-1	2.6 E 0	8.8 E 0
6.0 E 01	2.2 E-1	2.0 E 0	6.8 E 0
7.0 E 01	1.9 E-1	1.6 E 0	5.5 E 0
8.0 E 01	1.7 E-1	1.3 E 0	4.7 E 0
9.0 E 01	1.5 E-1	1.1 E 0	4.0 E 0
1.0 E 02	1.3 E-1	9.0 E-1	3.5 E 0

Reference:

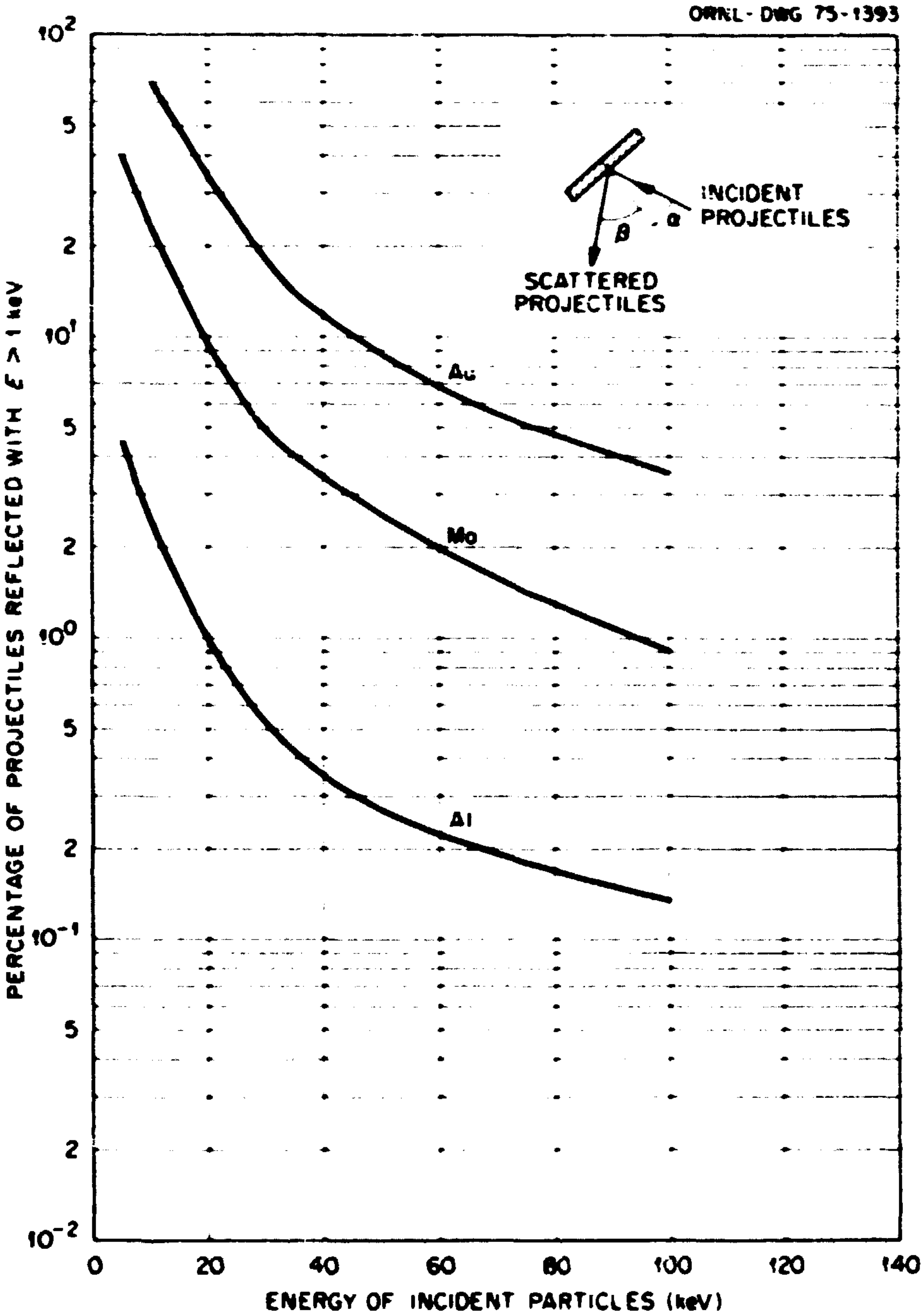
H^+ + Mo, Theoretical: G.M. McCracken and N.J. Freeman, J. Phys. B 2, 661 (1969).

Accuracy:

Unspecified.

Notes:

The reference cited provides a computational procedure for estimating backscattering flux for any target.


ORNL-DWG 75-1393
INCIDENT
PROJECTILES
SCATTERED
PROJECTILES
α
β
Au
Mo
Al
PERCENTAGE OF PROJECTILES REFLECTED WITH E > 1 keV
ENERGY OF INCIDENT PARTICLES (keV)
0
20
40
60
80
100
120
140

Scattering of H^0, H^+, H_2^+, and H_3^+ from Solid Gold-

Flux of Scattered H^+ and H^0 Integrated
Over All Scattered Particle Energies.

Primary Ion Energy: Various
Angle of Incidence α: 80°
Angle of Emergence β: 55°

(Data are for H^+ impact - for H^0, H_2^+, and H_3^+ see note below.)

Energy of Incident H^+, (keV)	Particle Flux (Arbitrary Units) Scattered H^+	Scattered $H^0 + H^+$
5.0 E 00		2.3 E-3
1.0 E 01	3.6 E-4	2.7 E-3
1.5 E 01	5.0 E-4	2.9 E-3
2.0 E 01	6.0 E-4	2.8 E-3
2.5 E 01	6.4 E-4	2.6 E-3
3.0 E 01	6.8 E-4	2.3 E-3
3.5 E 01	7.0 E-4	2.0 E-3
4.0 E 01	7.1 E-4	1.7 E-3
4.5 E 01		1.4 E-3

Reference:

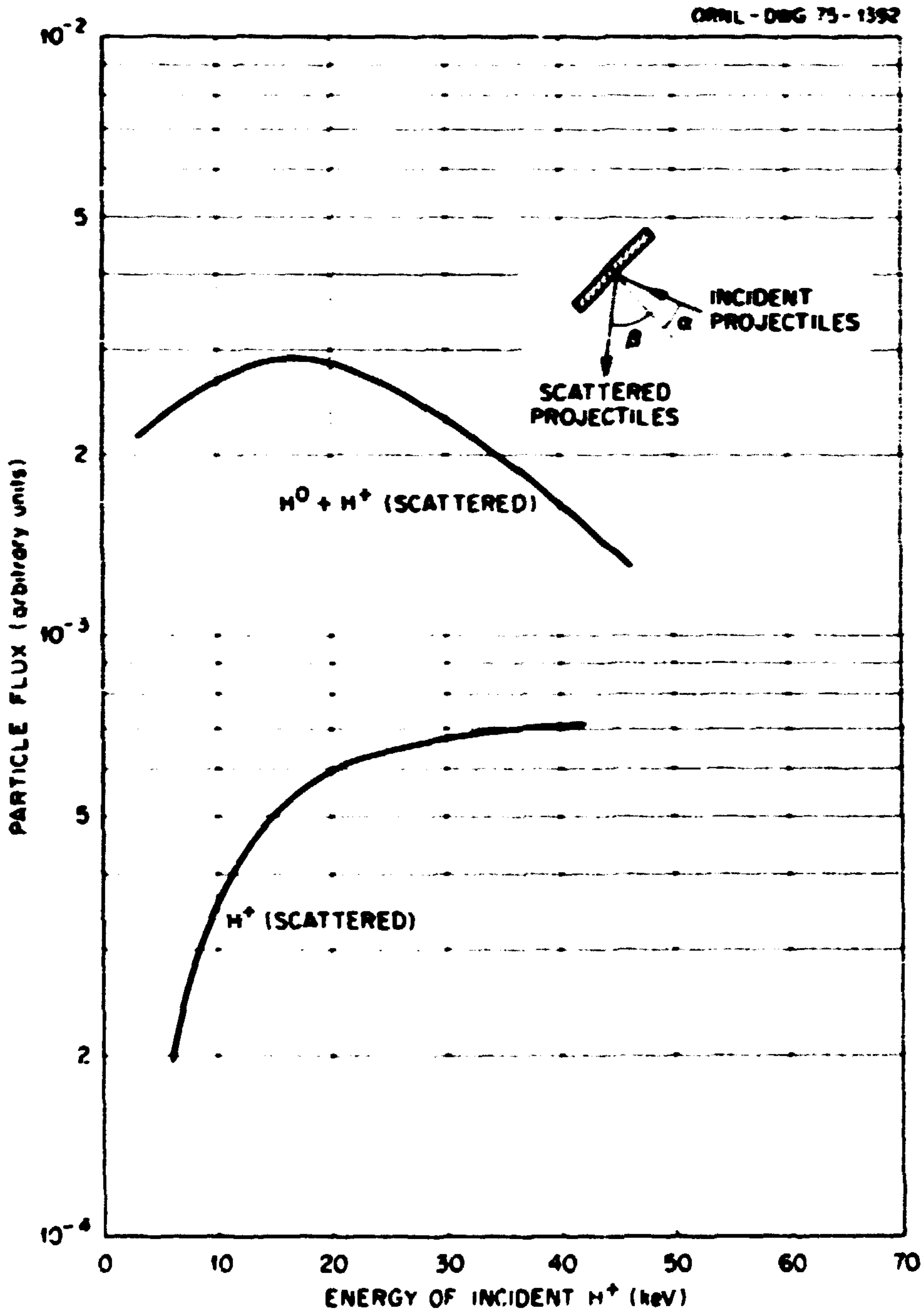
H^+ + Au, Experimental: K. Morita, H. Akimune, T. Suita, Japanese J. Appl. Phys. 7, 916 (1968).

Accuracy:

Random error < ± 5%.

Note:

H^0, H_2^+, and H_3^+ impact. Yields of both H^+ and $H^0 + H^+$ are found to be the same as for H^+ impact at the corresponding velocity.


ORNL-DWG 75-1392
INCIDENT PROJECTILES
SCATTERED PROJECTILES
α
β
$H^0 + H^+$ (SCATTERED)
H^+ (SCATTERED)
PARTICLE FLUX (arbitrary units)
ENERGY OF INCIDENT H^+ (keV)
10^{-2}
5
2
10^{-3}
5
2
10^{-4}
0
10
20
30
40
50
60
70

Scattering of He^+ and O^+ Ions from Solid Molybdenum-

Reflection Coefficient of the Scattered Ions.

These data represent the ratio of the reflected ion flux to the incident ion flux.

Primary Ion Energy: Various
Angle of Incidence α: 90°
Angle of Emergence β: Integrated Over All Angles

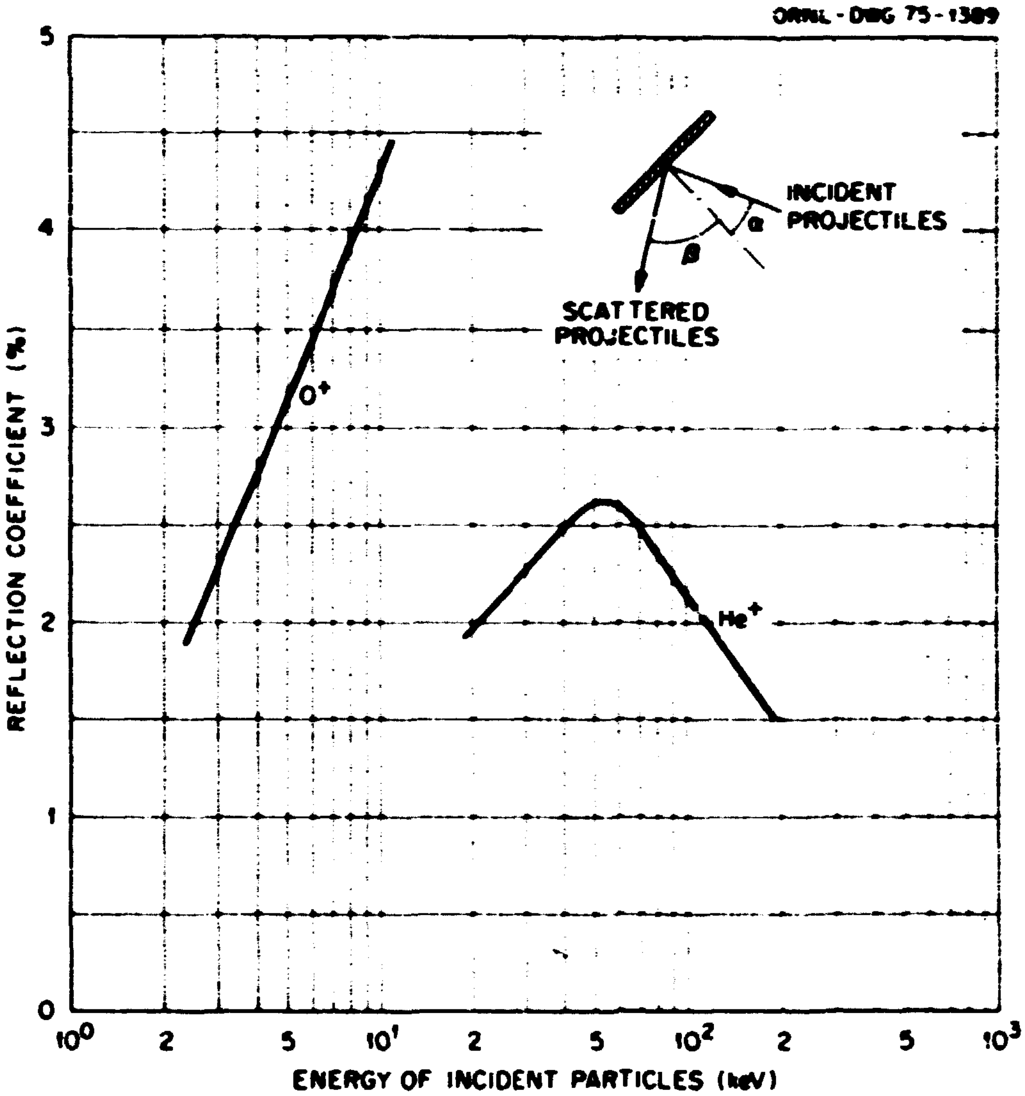
Energy of Incident Particles (keV)	Reflection Coefficient (%) Incident He^+	Incident O^+
5.0 E 00		3.2 E 0
1.0 E 01		4.3 E 0
1.5 E 01		
2.0 E 01	2.0 E 0	
2.5 E 01	2.2 E 0	
3.0 E 01	2.3 E 0	
3.5 E 01	2.4 E 0	
4.0 E 01	2.5 E 0	
4.5 E 01	2.6 E 0	
5.0 E 01	2.7 E 0	
6.0 E 01	2.7 E 0	
7.0 E 01	2.5 E 0	
8.0 E 01	2.4 E 0	
9.0 E 01	2.3 E 0	
1.0 E 02	2.2 E 0	
1.1 E 02	2.1 E 0	
1.2 E 02	2.0 E 0	
1.3 E 02	1.9 E 0	
1.4 E 02	1.8 E 0	
1.5 E 02	1.7 E 0	
1.6 E 02	1.6 E 0	
1.7 E 02	1.6 E 0	
1.8 E 02	1.5 E 0	
1.9 E 02	1.5 E 0	

Reference:

He^+ and O^+ + Mo, Experimental: Ya. M. Fogel', R.P. Slabospitskii, and A.B. Rastrepin, Soviet Phys. Tech. Phys. 5, 58 (1960).

Accuracy:

Unspecified. The validity of the technique used for this measurement has not been independently confirmed and the accuracy of the data is therefore suspect.


ORNL-DWG 75-1389
INCIDENT
PROJECTILES
SCATTERED
PROJECTILES
α
β
O+
He+
REFLECTION COEFFICIENT (%)
ENERGY OF INCIDENT PARTICLES (keV)

Scattering of He^{+} from Solid Tungsten-

Reflection Coefficient of the Scattered Ions.

These data represent the ratio of the reflected ion flux to the incident ion flux.

Primary Ion Energy: Various
Angle of Incidence α: 90°
Angle of Emergence β: Integrated Over All Angles

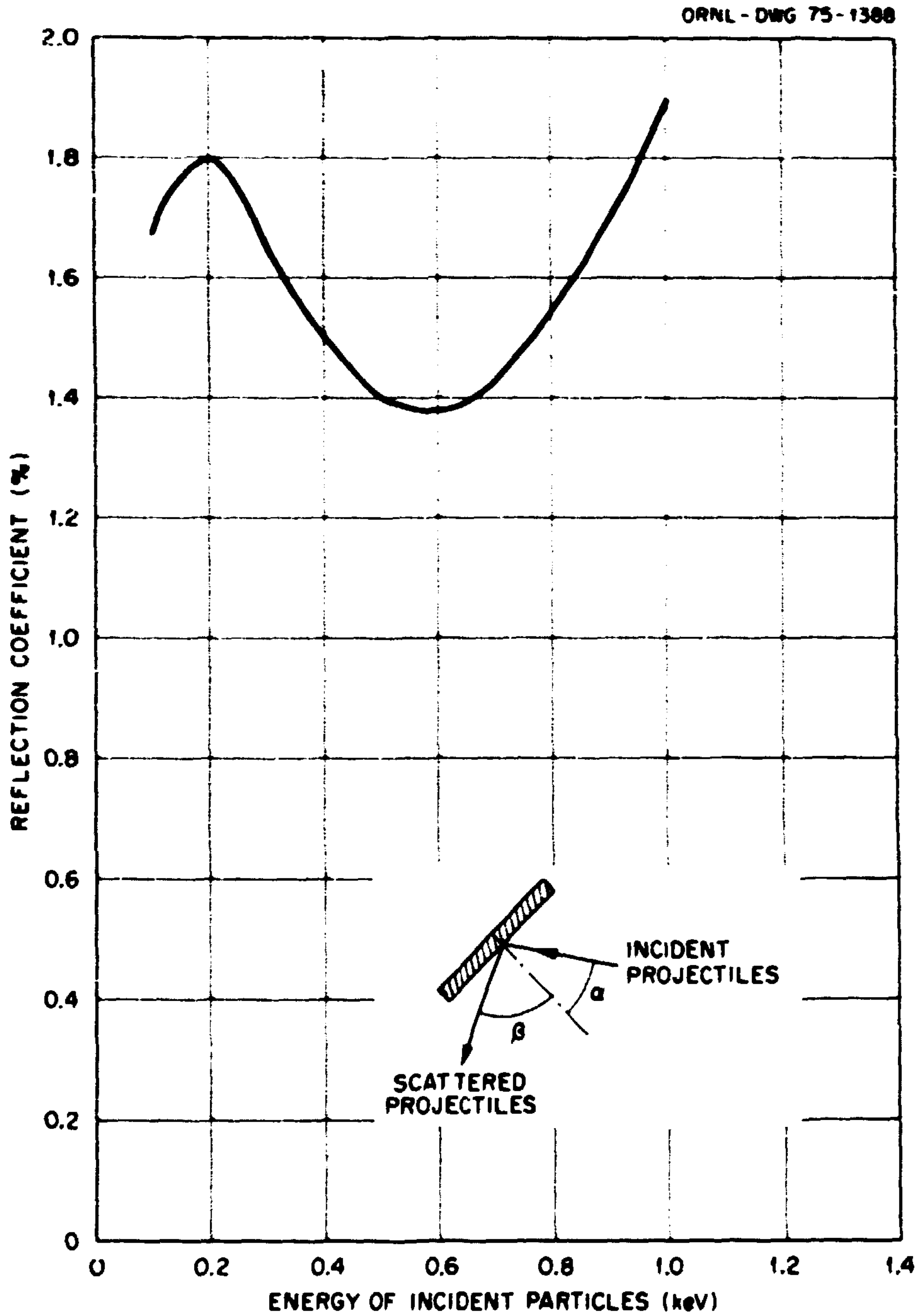
Energy of Incident Particle (keV)	Reflection Coefficient (%)
1.0 E-01	1.67 E 0
2.0 E-01	1.80 E 0
3.0 E-01	1.65 E 0
4.0 E-01	1.50 E 0
5.0 E-01	1.40 E 0
6.0 E-01	1.38 E 0
7.0 E-01	1.43 E 0
8.0 E-01	1.55 E 0
9.0 E-01	1.70 E 0
1.0 E 00	1.90 E 0

Reference:

He^{+} + W, Experimental, H.D. Hagstrum, Phys. Rev. 123, 758 (1961).

Accuracy:

Unspecified.


ORNL-DWG 75-1388
REFLECTION COEFFICIENT (%)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
ENERGY OF INCIDENT PARTICLES (keV)
INCIDENT PROJECTILES
SCATTERED PROJECTILES
α
β

E. Transport Properties of Electrons, Ions, and Neutrals

E.1 Electron Drift Velocities and Diffusion

Definitions, Relationships, and References

$\vec{v}_d$ = drift velocity of electron = average velocity of drift along field lines in a gas exposed to a constant, uniform electric field, $\vec{E}$. v_d is usually expressed in cm/sec.

K = mobility of electron, defined by the equation $\vec{v}_d = K\vec{E}$. K is usually expressed in cm^2/V-sec.

E/N = electron energy parameter = ratio of electric field intensity to gas number density. E/N is usually expressed in units of (volts/cm)/(1/cm^3) = V-cm^2.

Td = unit of E/N, the "Townsend" = 10^{-17} V-cm^2.

$$D = \begin{vmatrix} D_T & 0 & 0 \\ 0 & D_T & 0 \\ 0 & 0 & D_L \end{vmatrix} = \text{electron diffusion tensor.}$$

D_L = (scalar) longitudinal diffusion coefficient = coefficient of diffusion along electric field.

D_T = (scalar) transverse diffusion coefficient = coefficient of diffusion transverse to electric field.

D_L/K and D_T/K are measures of the average electron energy at a given E/N.

In the limit $E/N \to 0$, $D_L = D_T = D$, the scalar diffusion coefficient.

For electrons in a given gas at a given temperature, the drift velocity, mobility, diffusion coefficients, and average energy are functions of E/N alone.

$q_{m_{el}}$ = electron momentum transfer cross section (considering only elastic impacts), defined by the equation

$$q_{m_{el}} = \int (1 - \cos \Theta)\, I_s(\Theta)\, d\Omega_{CM}$$

where Θ is the scattering angle in the center-of-mass system and $I_s(\Theta)d\Omega_{CM}$ is the differential scattering cross section.

General references which contain much data not presented here are: "The Diffusion and Drift of Electrons in Gases," by L. G. H. Huxley and R. W. Crompton, Wiley, New York (1974) and "Low Energy Electron Collisions in Gases" by A. Gilardini, Wiley, New York (1972).

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The Momentum Transfer Cross Section for

Elastic Collisions of Electrons in H_2

Energy (eV)	$q_{m_{el}}$ (cm^2)
1.0 E-02	7.30 E-16
2.0 E-02	8.00 E-16
4.0 E-02	8.96 E-16
7.0 E-02	9.85 E-16
1.0 E-01	1.05 E-15
2.0 E-01	1.20 E-15
4.0 E-01	1.39 E-15
7.0 E-01	1.63 E-15
1.1 E 00	1.77 E-15
1.6 E 00	1.83 E-15
2.0 E 00	1.80 E-15
4.0 E 00	1.62 E-15
7.0 E 00	1.10 E-15
1.0 E 01	9.15 E-16
2.0 E 01	5.84 E-16
4.0 E 01	3.45 E-16
7.0 E 01	2.34 E-16
1.0 E 02	1.83 E-16

References:

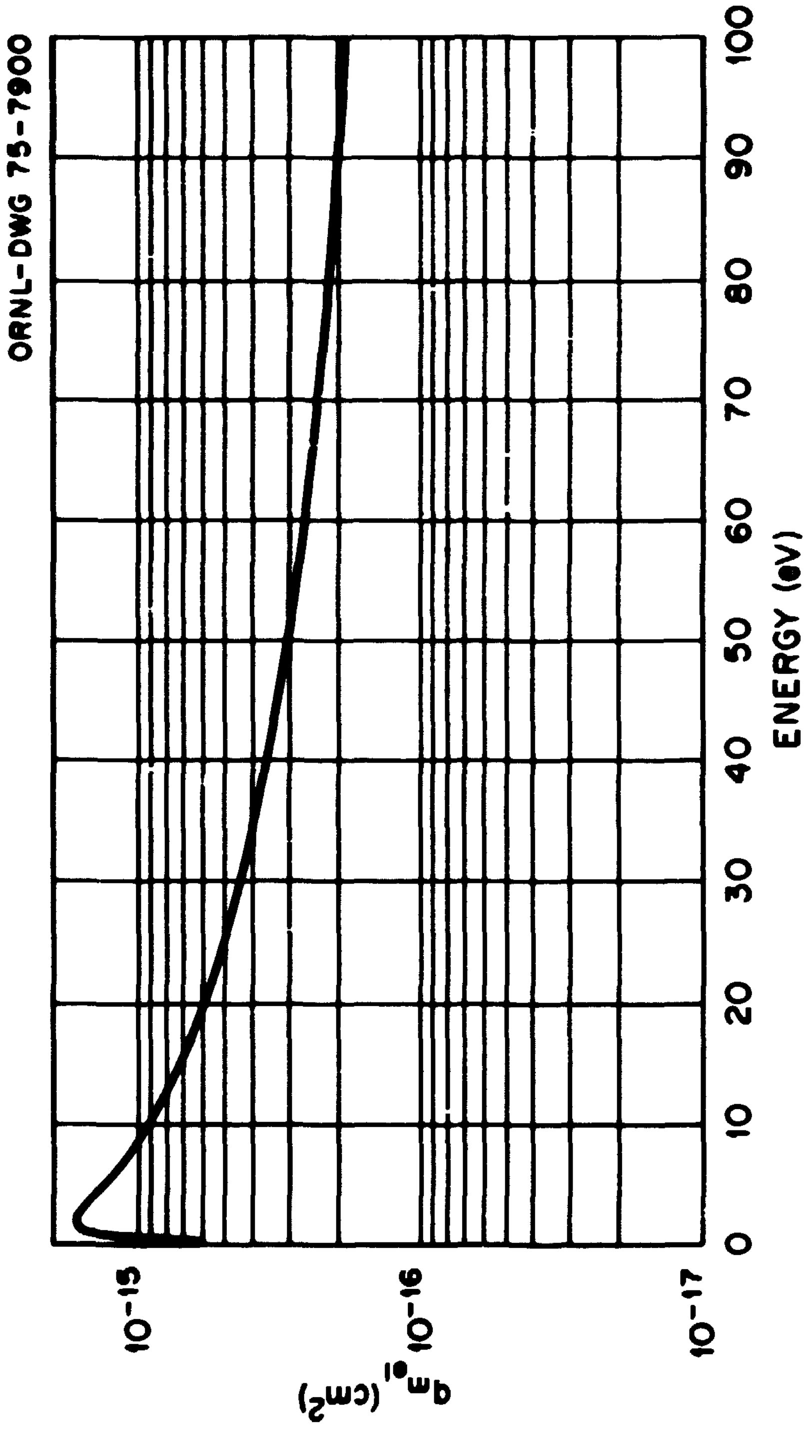
R.W. Crompton, D.K. Gibson, and A.I. McIntosh, Aust. J. Phys. 22, 715 (1969).

A. Engelhardt and A.V. Phelps, Phys. Rev. 131, 2115 (1963).

L.G.H. Huxley and R.W. Crompton, The Diffusion and Drift of Electrons in Gases, John Wiley and Sons, New York, 1974, p. 623, 625.

Accuracy:

The total error is believed not to exceed ± 5%.


ORNL-DWG 75-7900
10^{-15}
10^{-16}
10^{-17}
$q_{m_{el}}$ (cm^2)
0
10
20
30
40
50
60
70
80
90
100
ENERGY (eV)

The Drift Velocity v_d and the Ratio D_T/K for Electrons in H_2 as a Function of E/N at Two Temperatures

E/N (Td)	v_d T=77°K (cm/sec)	D_T/K T=77°K (volts)	E/N (Td)	v_d T=293°K (cm/sec)	D_T/K T=293°K (cm/sec)
2.0 E-03		6.76 E-03	2.0 E-02	3.11 E 04	2.59 E-02
5.0 E-03		7.09 E-03	4.0 E-02	6.00 E 04	2.71 E-02
8.0 E-03	2.74 E 04	7.55 E-03	7.0 E-02	9.98 E 04	2.92 E-02
1.4 E-02	4.35 E 04	8.67 E-03	1.0 E-01	1.37 E 05	3.25 E-02
2.0 E-02	5.67 E 04	9.86 E-03	2.0 E-01	2.35 E 05	3.87 E-02
3.5 E-02	8.42 E 04	1.27 E-02	4.0 E-01	3.79 E 05	5.24 E-02
5.0 E-02	1.07 E 05	1.51 E-02	7.0 E-01	5.24 E 05	7.35 E-02
1.0 E-01	1.73 E 05	2.10 E-02	1.0 E 00	6.23 E 05	9.58 E-02
1.4 E-01	2.18 E 05	2.47 E-02	2.0 E 00	8.37 E 05	1.09 E-01
2.0 E-01	2.78 E 05	2.94 E-02	4.0 E 00	1.15 E 06	2.55 E-01
4.0 E-01	4.29 E 05	4.33 E-02	6.0 E 00	1.42 E 06	3.71 E-01
7.0 E-01	5.75 E 05	6.42 E-02	1.0 E 01	1.87 E 06	5.11 E-01
1.0 E 00	6.71 E 05	8.60 E-02	2.0 E 01	2.81 E 06	7.87 E-01
1.4 E 00	7.50 E 05	1.16 E-01	4.0 E 01	4.54 E 06	1.33 E 00
2.0 E 00	8.70 E 05	1.60 E-01	6.0 E 01	6.95 E 06	1.98 E 00
3.5 E 00	1.10 E 06	2.52 E-01	8.0 E 01	9.80 E 06	2.37 E 00
5.0 E 00	1.29 E 06	3.25 E-01	1.0 E 02	1.28 E 07	2.67 E 00
8.0 E 00	1.66 E 06	4.40 E-01	1.4 E 02	1.94 E 07	3.19 E 00
1.2 E 01	2.09 E 06	5.65 E-01	2.0 E 02		3.82 E 00
2.0 E 01	2.81 E 06				

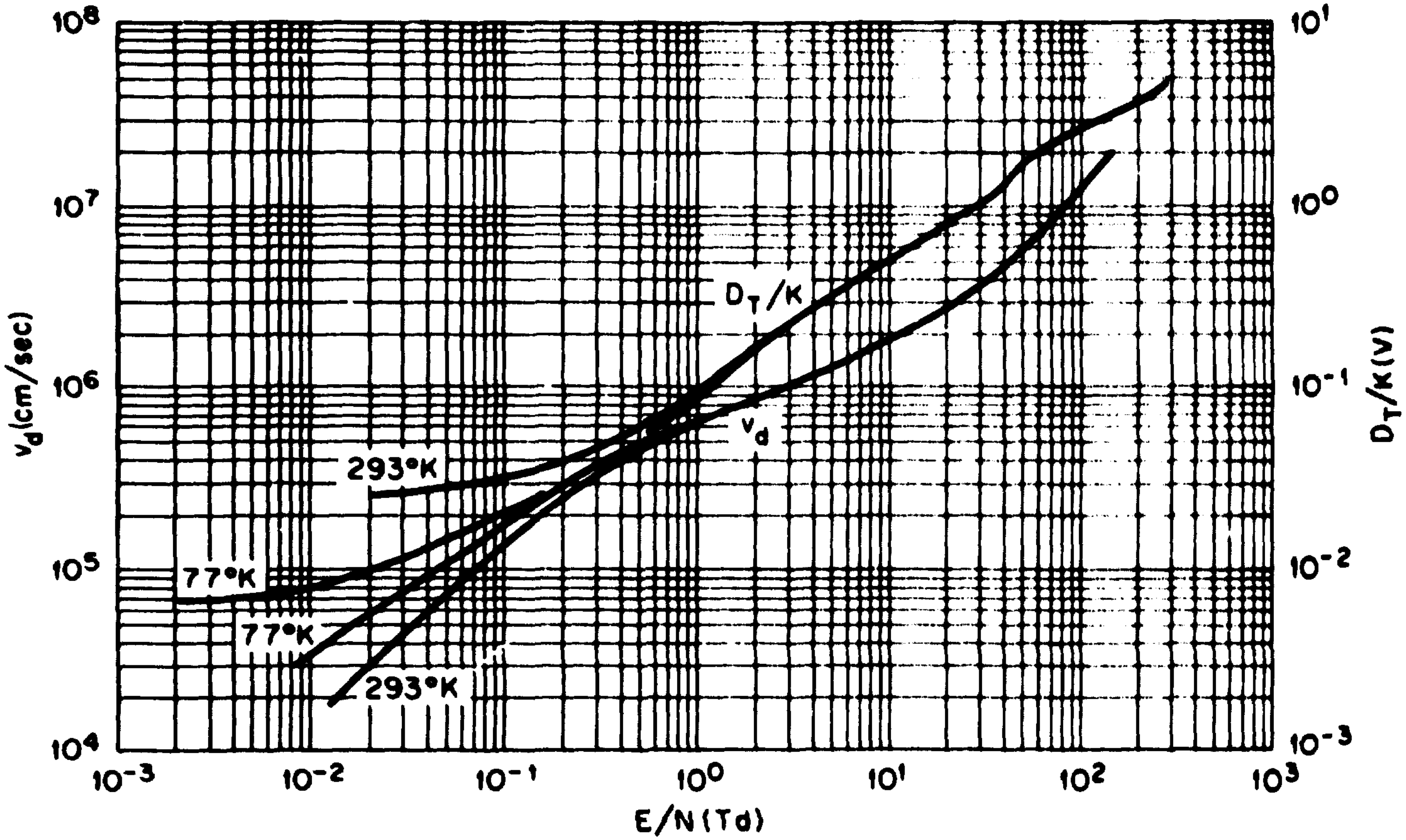
Reference:

L.G.H. Huxley and R.W. Crompton, The Diffusion and Drift of Electrons in Gases, John Wiley and Sons, New York, 1974, p. 615-617.

Accuracy:

The total error is believed not to exceed ± 3% for v_d, ± 2% for D_T/K at T = 77° K, and ± 5% for D_T/K at T = 293° K.

ORNL-DWG 75-7899



The Product ND_T at Two Temperatures and the Ratio D_L/K at T = 300° K

for Electrons in H_2 as a Function of E/N

E/N (Td)	ND_T T=77° K ($cm^{-1}sec^{-1}$)	E/N (Td)	ND_T T=293° K ($cm^{-1}sec^{-1}$)	D_L/K* T=300° K (volts)
8.0 E-03	2.59 E 21	0.0 E 00	3.96 E 21	
1.4 E-02	2.69 E 21	2.0 E-02	4.03 E 21	
2.0 E-02	2.80 E 21	4.0 E-02	4.07 E 21	
3.5 E-02	3.05 E 21	7.0 E-02	4.17 E 21	
5.0 E-02	3.23 E 21	1.0 E-01	4.31 E 21	
1.0 E-01	3.62 E 21	2.0 E-01	4.54 E 21	2.91 E-02
1.4 E-01	3.84 E 21	4.0 E-01	4.96 E 21	3.42 E-02
2.0 E-01	4.08 E 21	7.0 E-01	5.50 E 21	4.19 E-02
4.0 E-01	4.64 E 21	1.0 E 00	5.94 E 21	5.07 E-02
7.0 E-01	5.27 E 21	2.0 E 00	7.01 E 21	8.00 E-02
1.0 E 00	5.77 E 21	4.0 E 00	8.16 E 21	1.43 E-01
1.4 E 00	6.20 E 21	6.0 E 00	8.76 E 21	1.89 E-01
2.0 E 00	6.94 E 21	1.0 E 01	9.56 E 21	
3.5 E 00	7.89 E 21	2.0 E 01	1.11 E 22	
5.0 E 00	8.40 E 21	4.0 E 01	1.51 E 22	
8.0 E 00	9.13 E 21	6.0 E 01	2.30 E 22	
1.2 E 01	9.84 E 21	8.0 E 01	2.91 E 22	
		1.0 E 02	3.42 E 22	
		1.4 E 02	4.43 E 22	

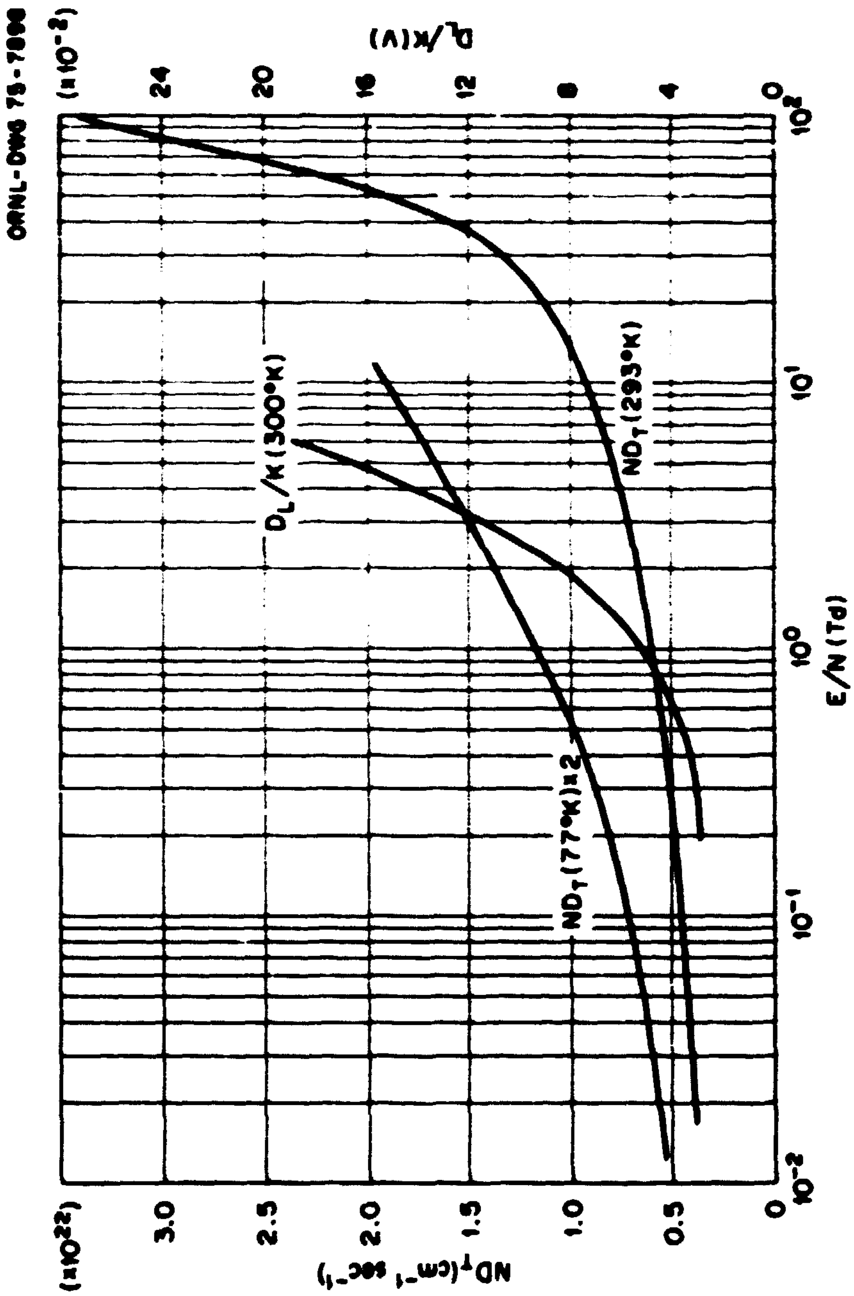
Reference:

L.G.H. Huxley and R.W. Crompton, The Diffusion and Drift of Electrons in Gases, John Wiley and Sons, New York, 1974, p. 615-17, p. 622.

Accuracy:

The total error is believed not to exceed ± 3% for ND_T and ± 5% for D_L/K.

*Measured at T = 300° K.


ORNL-DWG 75-7898
D_L/K(V)
(x10^-2)
24
20
16
12
8
4
0
ND_T(cm^-1 sec^-1)
(x10^22)
3.0
2.5
2.0
1.5
1.0
0.5
0
E/N (Td)
10^-2
10^-1
10^0
10^1
10^2
D_L/K(300°K)
ND_T(293°K)
ND_T(77°K)x2

The Drift Velocity v_d and the Ratio D_T/K for Electrons in D_2 as a Function of E/N at Two Temperatures

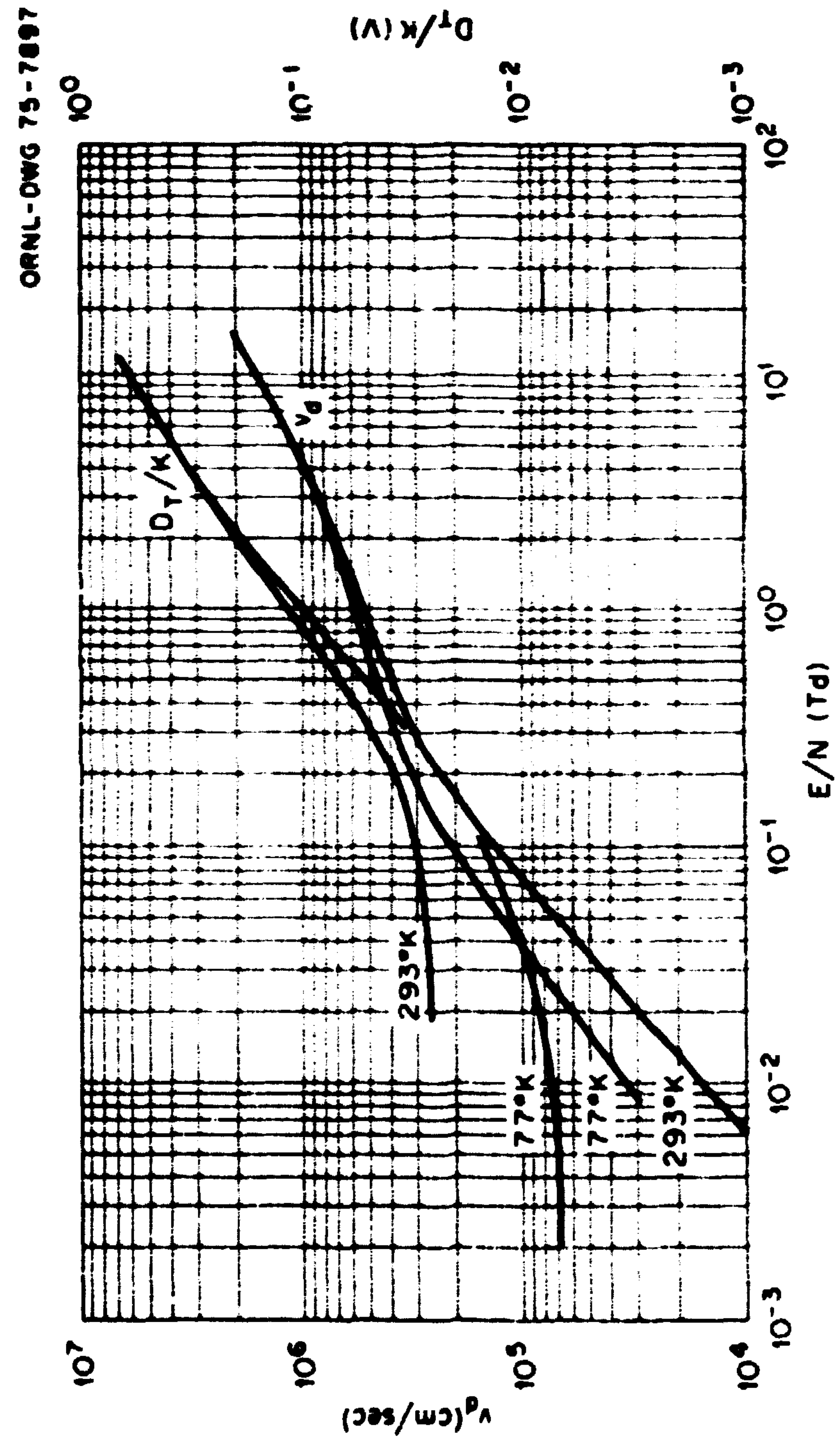
E/N (Td)	v_d T=77° K (cm/sec)	D_T/K T=77° K (volts)	E/N (Td)	v_d T=293° K (cm/sec)	D_T/K T=293° K (volts)
2.0 E-03		6.80 E-03	2.0 E-02	3.08 E 04	2.58 E-02
4.0 E-03		6.92 E-03	3.0 E-02	4.57 E 04	2.63 E-02
8.0 E-03	2.80 E 04	7.33 E-03	5.0 E-02	7.40 E 04	2.74 E-02
1.2 E-02	4.01 E 04	7.78 E-03	7.0 E-02	1.00 E 05	2.87 E-02
2.0 E-02	6.18 E 04	8.66 E-03	1.0 E-01	1.36 E 05	3.09 E-02
4.0 E-02	1.09 E 05	1.05 E-02	1.4 E-01	1.78 E 05	3.40 E-02
7.0 E-02	1.67 E 05	1.29 E-02	2.0 E-01	2.32 E 05	3.90 E-02
1.0 E-01	2.14 E 05	1.52 E-02	3.0 E-01	3.03 E 05	4.80 E-02
2.0 E-01	3.25 E 05	2.34 E-02	5.0 E-01	4.00 E 05	6.74 E-02
3.0 E-01	3.95 E 05	3.23 E-02	7.0 E-01	4.65 E 05	8.81 E-02
5.0 E-01	4.80 E 05	5.21 E-02	1.0 E 00	5.38 E 05	1.19 E-01
7.0 E-01	5.30 E 05	7.37 E-02	1.4 E 00	6.19 E 05	1.57 E-01
1.0 E 00	5.86 E 05	1.07 E-01	2.0 E 00	7.27 E 05	2.07 E-01
2.0 E 00	7.50 E 05	2.00 E-01	3.0 E 00	8.88 E 05	2.75 E-01
3.0 E 00	9.05 E 05	2.70 E-01	5.0 E 00	1.12 E 06	3.88 E-01
5.0 E 00	1.16 E 06	3.85 E-01	7.0 E 00	1.38 E 06	
7.0 E 00	1.39 E 06	4.84 E-01	1.0 E 01	1.67 E 06	
1.0 E 01	1.68 E 06	6.12 E-01	1.4 E 01	2.02 E 06	
1.2 E 01		6.94 E-01			

Reference:

L.G.H. Huxley and R.W. Crompton, The Diffusion and Drift of Electrons in Gases, John Wiley and Sons, New York, 1974, p. 619-21.

Accuracy:

The total error is believed not to exceed ± 2% for v_d and ± 2% for D_T/K.


ORNL-DWG 75-7897
D_T/K (V)
v_d(cm/sec)
E/N (Td)
D_T/K
v_d
293°K
77°K
77°K
293°K
10^0
10^{-1}
10^{-2}
10^{-3}
10^7
10^6
10^5
10^4
10^{-3}
10^{-2}
10^{-1}
10^0
10^1
10^2

The Product ND_T for Electrons in D_2 as a Function of E/N at Two Temperatures

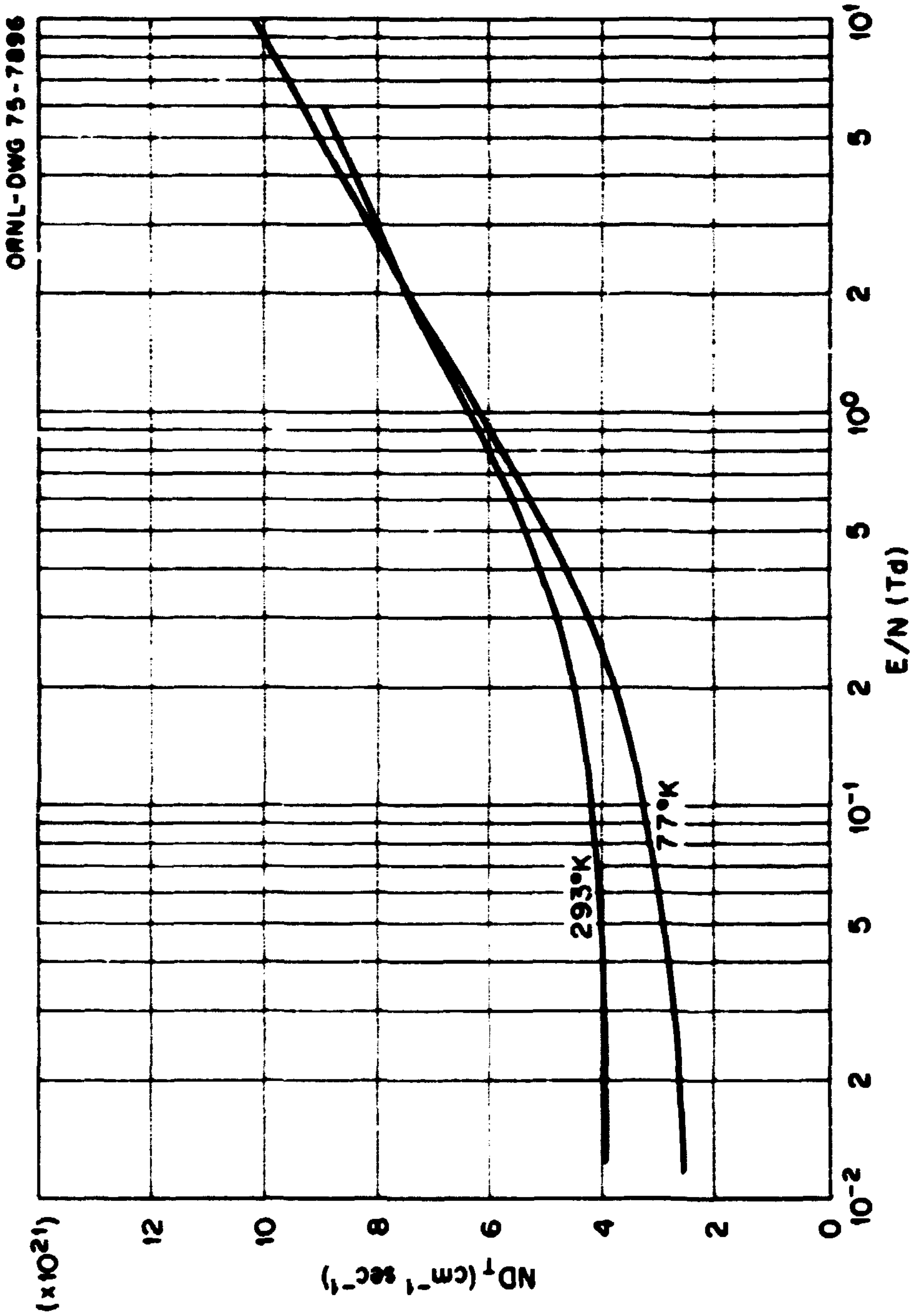
E/N (Td)	ND_T T=77° K ($cm^{-1}sec^{-1}$)	E/N (Td)	ND_T T=293° K ($cm^{-1}sec^{-1}$)
8.0 E-03	2.57 E 21	2.0 E-02	3.98 E 21
1.2 E-02	2.60 E 21	3.0 E-02	4.01 E 21
2.0 E-02	2.68 E 21	5.0 E-02	4.06 E 21
4.0 E-02	2.85 E 21	7.0 E-02	4.11 E 21
7.0 E-02	3.07 E 21	1.0 E-01	4.20 E 21
1.0 E-01	3.26 E 21	1.4 E-01	4.33 E 21
2.0 E-01	3.80 E 21	2.0 E-01	4.52 E 21
3.0 E-01	4.25 E 21	3.0 E-01	4.84 E 21
5.0 E-01	5.00 E 21	5.0 E-01	5.39 E 21
7.0 E-01	5.58 E 21	7.0 E-01	5.86 E 21
1.0 E 00	6.25 E 21	1.0 E 00	6.40 E 21
2.0 E 00	7.49 E 21	1.4 E 00	6.96 E 21
3.0 E 00	8.15 E 21	2.0 E 00	7.50 E 21
5.0 E 00	8.93 E 21	3.0 E 00	8.14 E 21
7.0 E 00	9.61 E 21	5.0 E 00	8.71 E 21
1.0 E 01	1.03 E 22		

Reference:

L.G.H. Huxley and R.W. Crompton, The Diffusion and Drift of Electrons in Gases, John Wiley and Sons, New York, 1974, p. 619-20.

Accuracy:

The total error is believed not to exceed ± 3%.



ORNL-DWG 75-7896
(x10^21)
ND_T (cm^-1 sec^-1)
0
2
4
6
8
10
12
10^-2
2
5
10^-1
2
5
10^0
2
5
10^1
E/N (Td)
293°K
77°K

The Momentum Transfer Cross Section for Elastic Collisions of Electrons in He, and the Electron Energy Distribution Function for Two Values of E/N at a Temperature of 77° K

		E/N = 0.008 Td		E/N = 2.0 Td	
Energy (eV)	$q_{m_{el}}$ (cm^2)	Energy (eV)	$[(eV)^{-1}]$*	Energy (eV)	$[(eV)^{-1}]$*
1.0 E-02	5.21 E-16	1.0 E-03	3.26 E 01	4.0 E-02	1.92 E 01
2.0 E-02	5.35 E-16	1.5 E-03	3.78 E 01	5.0 E-02	2.15 E 01
3.0 E-02	5.46 E-16	2.0 E-03	4.22 E 01	6.0 E-02	2.35 E 01
5.0 E-02	5.62 E-16	3.0 E-03	4.58 E 01	8.0 E-02	2.66 E 01
7.0 E-02	5.74 E-16	4.0 E-03	5.25 E 01	1.0 E-01	2.99 E 01
1.0 E-01	5.86 E-16	5.0 E-03	5.39 E 01	1.5 E-01	3.57 E 01
1.5 E-01	6.04 E-16	6.0 E-03	5.41 E 01	2.0 E-01	4.39 E 01
2.0 E-01	6.16 E-16	8.0 E-03	5.20 E 01	3.0 E-01	4.88 E 01
3.0 E-01	6.35 E-16	1.0 E-02	4.77 E 01	4.0 E-01	5.42 E 01
4.0 E-01	6.49 E-16	1.5 E-02	3.38 E 01	6.0 E-01	6.13 E 01
6.0 E-01	6.66 E-16	2.0 E-02	2.04 E 01	8.0 E-01	6.15 E 01
8.0 E-01	6.77 E-16	3.0 E-02	8.58 E 00	1.0 E 00	5.79 E 01
1.0 E 00	6.85 E-16	4.0 E-02	3.43 E 00	1.5 E 00	3.79 E 01
1.5 E 00	6.96 E-16	5.0 E-02	1.20 E 00	2.0 E 00	1.89 E 01
2.0 E 00	6.99 E-16			3.0 E 00	2.75 E 00
3.0 E 00	6.89 E-16				
4.0 E 00	6.26 E-16				
6.0 E 00	6.01 E-16				

References:

R.W. Crompton, M.T. Elford, and A.G. Robertson, Aust. J. Phys. 23, 667 (1970).

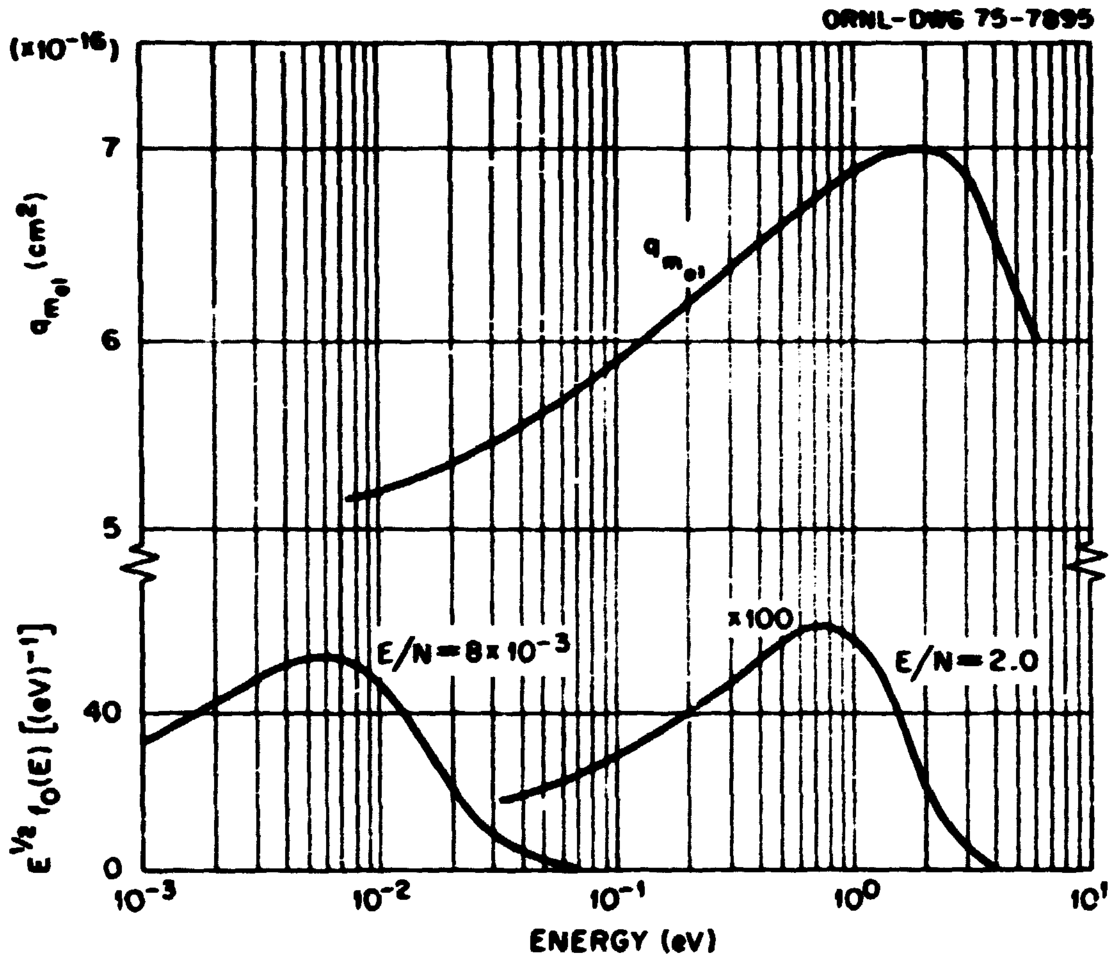
M.T. Elford, Case Studies in Atomic Collision Physics, E.W. McDaniel and M.R.C. McDowell, eds., North Holland, Chap. 2 (1972).

L.G.H. Huxley and R.W. Crompton, The Diffusion and Drift of Electrons in Gases, John Wiley and Sons, New York, 1974, p. 603.

Accuracy:

The total error in the elastic cross section is believed not to exceed ± 5%.

*$E^{1/2} f_o(E)\, dE$ is the fraction of electrons in the swarm with energies between E and E + dE.


ORNL-DWG 75-7895
(×10⁻¹⁶)
7
6
5
40
0
$q_{m_{el}}$ (cm²)
$E^{1/2} f_0(E)$ [(eV)⁻¹]
$q_{m_{el}}$
E/N = 8 × 10⁻³
×100
E/N = 2.0
10⁻³
10⁻²
10⁻¹
10⁰
10¹
ENERGY (eV)

The Drift Velocity v_d and the Ratio D_T/K for Electrons in He as a Function of E/N at Two Temperatures

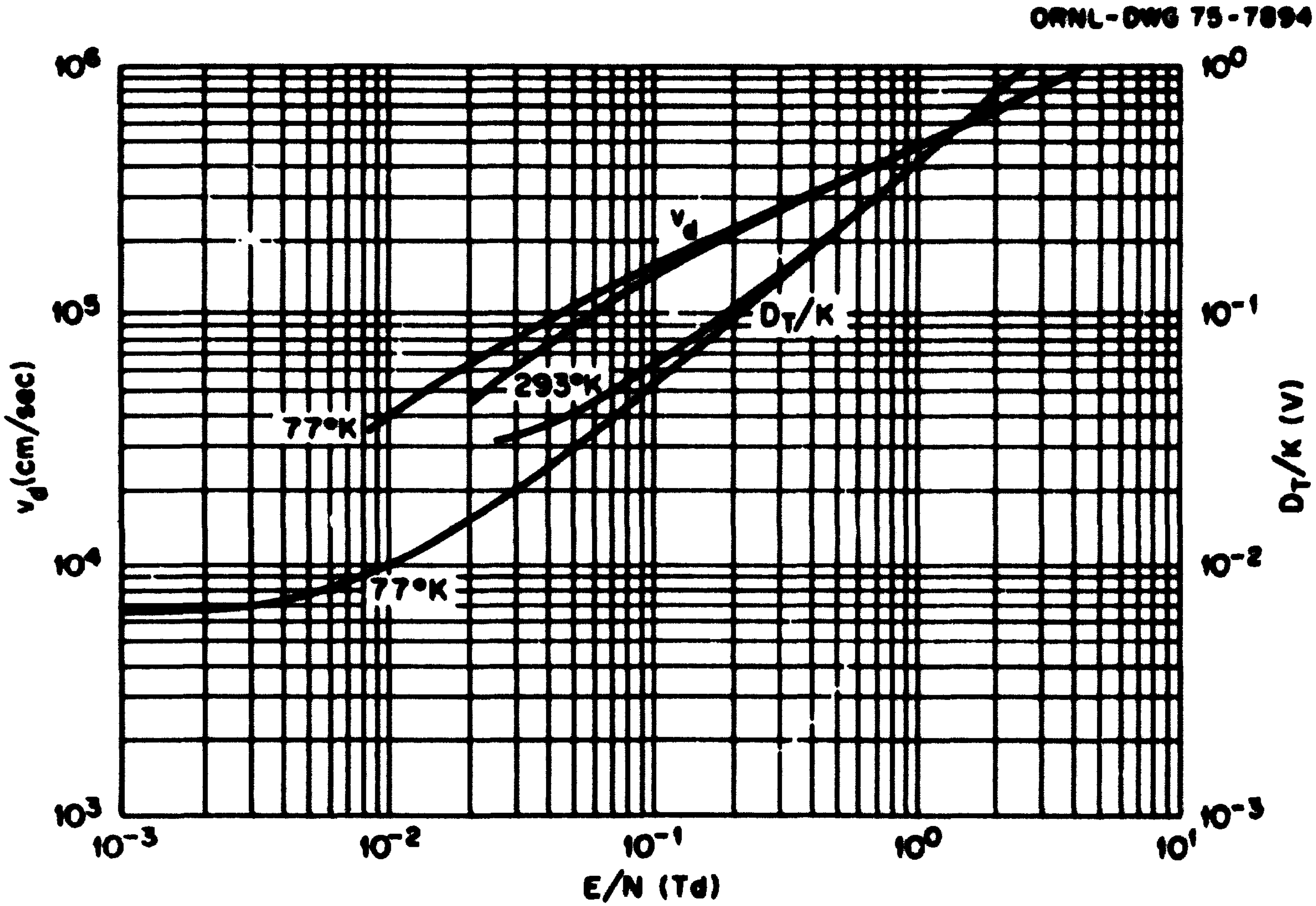
E/N (Td)	v_d T=77° K (cm/sec)	D_T/K T=293° K (volts)	E/N (Td)	v_d T=293° K (cm/sec)	D_T/K T=77° K (volts)
1.0 E-03		6.69 E-03	2.5 E-02	5.46 E 04	3.16 E-02
2.0 E-03		6.80 E-03	3.5 E-02	7.11 E 04	3.56 E-02
4.0 E-03		7.42 E-03	5.0 E-02	9.22 E 04	4.20 E-02
7.0 E-03		8.83 E-03	1.0 E-01	1.45 E 05	6.45 E-02
1.0 E-02		1.04 E-02	2.0 E-01	2.14 E 05	1.09 E-01
1.5 E-02		1.31 E-02	3.0 E-01	2.65 E 05	1.52 E-01
2.5 E-02	7.58 E 04	1.84 E-02	4.0 E-01	3.08 E 05	1.94 E-01
3.5 E-02	9.23 E 04	2.33 E-02	6.0 E-01	3.77 E 05	2.76 E-01
5.0 E-02	1.12 E 05	3.06 E-02	8.0 E-01	4.35 E 05	3.56 E-01
1.0 E-01	1.61 E 05	5.50 E-02	1.0 E 00	4.85 E 05	4.35 E-01
2.0 E-01	2.27 E 05	1.03 E-01	1.7 E 00	6.33 E 05	7.09 E-01
3.0 E-01	2.76 E 05	1.50 E-01	2.5 E 00	7.69 E 05	1.03 E 00
4.0 E-01	3.17 E 05	1.95 E-01	3.5 E 00	9.28 E 05	
6.0 E-01	3.85 E 05	2.78 E-01			
8.0 E-01	4.41 E 05	3.64 E-01			
1.0 E 00	4.91 E 05	4.48 E-01			
1.7 E 00	6.36 E 05	7.22 E-01			

Reference:

L.G.H. Huxley and R.W. Crompton, The Diffusion and Drift of Electrons in Gases, John Wiley and Sons, New York, 1974, p. 600-602.

Accuracy:

The total error is believed not to exceed ± 1% for v_d, ± 3% for D_T/K at T = 77° K, and ± 1% for D_T at T = 293° K.


ORNL-DWG 75-7894
v_d (cm/sec)
10^3
10^4
10^5
10^6
D_T/K (V)
10^{-3}
10^{-2}
10^{-1}
10^0
E/N (Td)
10^{-3}
10^{-2}
10^{-1}
10^0
10^1
v_d
D_T/K
293°K
77°K
77°K

The Product ND_T and the Ratio D_L/K for Electrons

In He as a Function of E/N at a Temperature T = 293° K

E/N (Td)	ND_T T=293° K ($cm^{-1} sec^{-1}$)	D_L/K T=293° K (volts)
0.0 E 00	6.35 E 21	
2.5 E-02	6.90 E 21	2.68 E-02
3.5 E-02	7.24 E 21	2.84 E-02
5.0 E-02	7.75 E 21	2.97 E-02
1.0 E-01	9.33 E 21	3.90 E-02
2.0 E-01	1.17 E 22	6.08 E-02
3.0 E-01	1.35 E 22	7.95 E-02
4.0 E-01	1.49 E 22	1.07 E-01
6.0 E-01	1.74 E 22	1.36 E-01
8.0 E-01	1.94 E 22	
1.0 E 00	2.11 E 22	
1.7 E 00	2.64 E 22	
2.5 E 00	3.15 E 22	
3.5 E 00	3.66 E 22*	
5.0 E 00	4.55 E 22*	
6.0 E 00	5.21 E 22	
8.0 E 00	6.67 E 22	

References:

R.W. Crompton, M.T. Elford, and R.L. Jory, Aust. J. Phys. 20, 369 (1967).

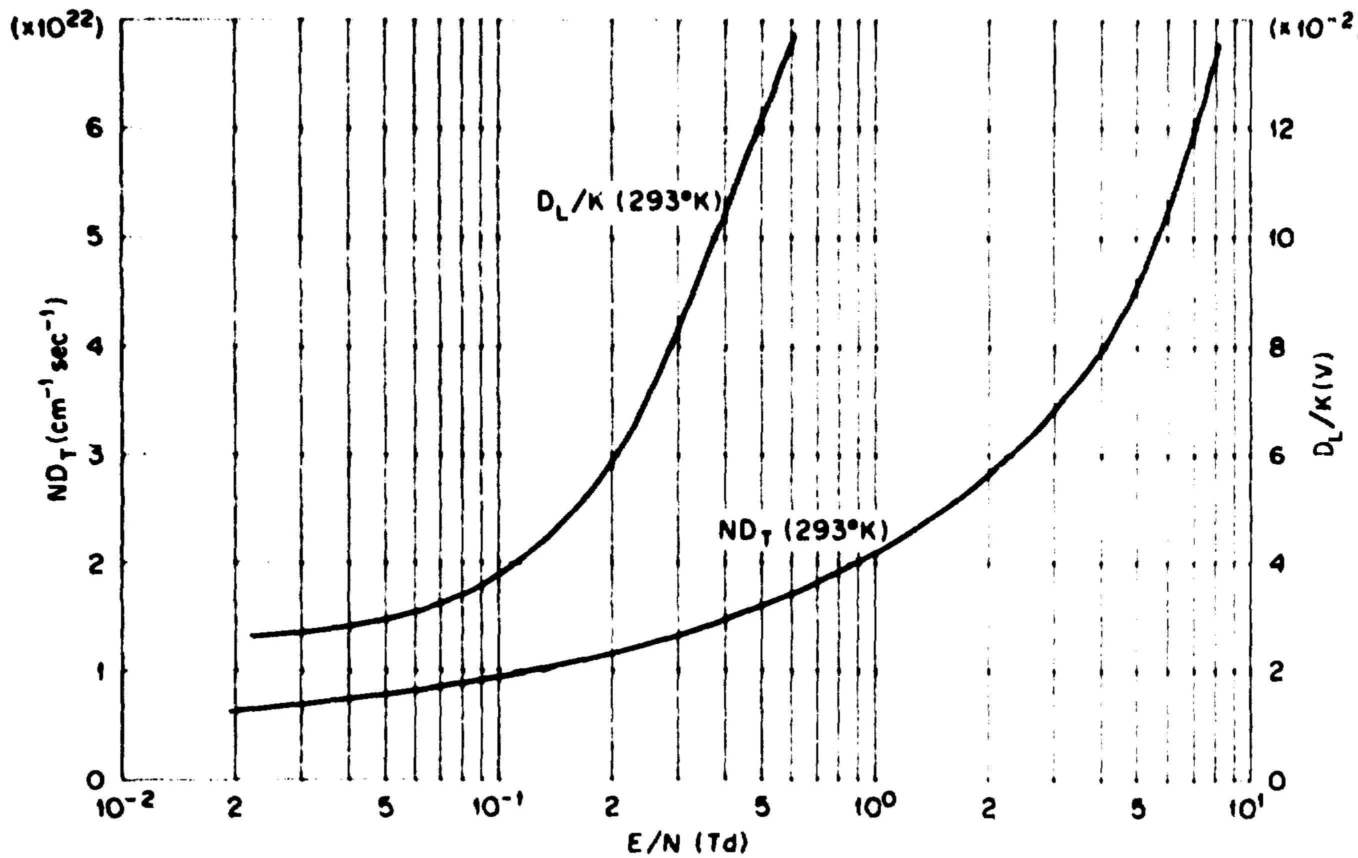
L.G.H. Huxley and R.W. Crompton, The Diffusion and Drift of Electrons in Gases, John Wiley and Sons, New York, 1974, p. 600-01.

Accuracy:

The total error is believed not to exceed ± 2% for ND_T and ± 3% for D_L/K.

*Values measured at T = 300° K.

ORNL-DWG 75-7893



E.2 Ion Drift Velocities, Mobility, and Diffusion

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Definitions, Relationships, and Reference

$\vec{v}_d$ = drift velocity of ion = average velocity of drift of ion along field lines in a gas exposed to a constant, uniform electric field $\vec{E}$. v_d is usually expressed in cm/sec.

K = mobility of ion, defined by the equation $\vec{v}_d = K\,\vec{E}$. K is usually expressed in cm^2/V-sec.

K_o = reduced mobility of ion = mobility of ion reduced to S.T.P., defined by the equation

$$K_o = \frac{p}{760}\,\frac{273.16}{T}\,K,$$

where p is the gas pressure in torr and T is the gas temperature in degrees Kelvin at which K was measured.

E/N = ionic energy parameter = ratio of electric field intensity to gas number density. E/N is usually expressed in units of $(volts/cm)/(1/cm^3) = V - cm^2$.

$K_o(0)$ = zero-field reduced mobility = K_o in the limit $E/N \to 0$.

Td = unit of E/N, the "Townsend" = 10^{-17} V - cm^2.

v_d = $0.0269 \times (E/N) \times K_o$, where v_d is in 10^4 cm/sec, E/N is in Td, and K_o is in cm^2/V - sec.

$$\overleftrightarrow{D} = \begin{vmatrix} D_T & 0 & 0 \\ 0 & D_T & 0 \\ 0 & 0 & D_L \end{vmatrix} = \text{ionic diffusion tensor.}$$

D_L = (scaler) longitudinal diffusion coefficient = coefficient of diffusion along electric field.

D_T = (scalar) transverse diffusion coefficient = coefficient of diffusion transverse to electric field.

In the limit $E/N \to 0$, $D_L = D_T = D$, the scalar diffusion coefficient.

For a particular ionic species in a given gas at a given temperature, the drift velocity, mobility, diffusion coefficients, and average ionic energy are functions of E/N alone.

General reference which contains much data not presented here: "The Mobility and Diffusion of Ions in Gases," by E.W. McDaniel and E.A. Mason, Wiley, New York (1973).

Zero-Field Reduced Mobility K_o in cm^2/V-sec of Ions in He Gas at 300° K

Ion	K_o	Reference
He^+	10.40 ± 0.10	E.C. Beaty and P.L. Patterson, Phys. Rev. **137**, A-346 (1965).
He_2^+	16.70 ± 0.17	E.C. Beaty and P.L. Patterson, Phys. Rev. **137**, A-346 (1965).
He_2^{+m} ($^4\Sigma_u^+$) (metastable)	19.6 ± 0.3	E.C. Beaty and P.L. Patterson, Phys. Rev. **137**, A-346 (1965).
H^+	31.8 ± 1.3	O.J. Orient, J. Phys. B **4**, 1257 (1971).
D^+	24.9 ± 1.0	O.J. Orient, J. Phys. B **5**, 1056 (1972).

Drift Velocity of H^+, H_3^+, and H^- Ions in H_2 Gas at 300° K as a Function of E/N

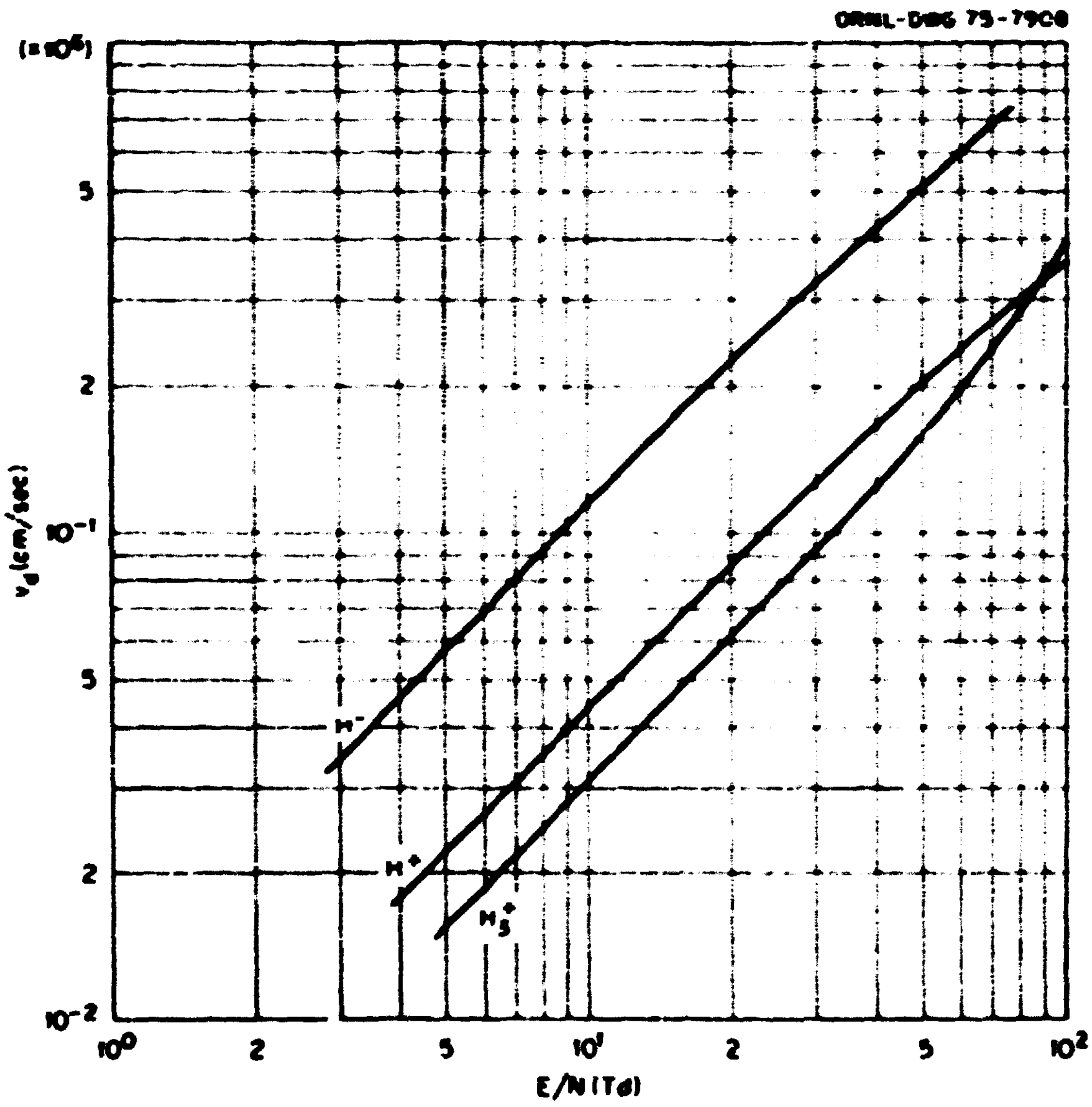
E/N (Td)	H^+ Ions in H_2 v_d (cm/sec)	H_3^+ Ions in H_2 v_d (cm/sec)	H^- Ions in H_2 v_d (cm/sec)
3.0 E 00			3.4 E 04
4.0 E 00	1.9 E 04		4.7 E 04
6.0 E 00	[illegible]	1.8 E 04	7.3 E 04
8.0 E 00	3.5 E 04	2.4 E 04	9.2 E 04
1.0 E 01	4.3 E 04	3.1 E 04	1.2 E 05
1.2 E 01	5.2 E 04	3.6 E 04	1.4 E 05
1.6 E 01	6.9 E 04	4.9 E 04	1.8 E 05
2.0 E 01	8.6 E 04	6.1 E 04	[illegible]
2.5 E 01	1.1 E 05	7.6 E 04	2.4 E 05
3.0 E 01	1.3 E 05	9.2 E 04	[illegible]
4.0 E 01	1.7 E 05	1.2 E 05	4.2 E 05
6.0 E 01	2.3 E 05	1.9 E 05	[illegible]
8.0 E 01	3.0 E 05	2.9 E 05	
1.0 E 02	3.6 E 05		

Reference:

E. Graham, D.R. James, W.C. Keever, D.L. Albritton, and E.W. McDaniel, J. Chem. Phys. 59, 3477 (1973).

Accuracy:

The total error is believed not to exceed ± [illegible].


ORNL-DWG 75-7908
(×10^6)
5
2
10^-1
5
2
10^-2
v_d (cm/sec)
H^-
H^+
H_3^+
10^0
2
5
10^1
2
5
10^2
E/N (Td)

The Product of the Longitudinal Diffusion Coefficient (D_L) and the Gas Number Density (N) for H^+, H_3^+, and H^- Ions in H_2 Gas at 300° K as a Function of E/N

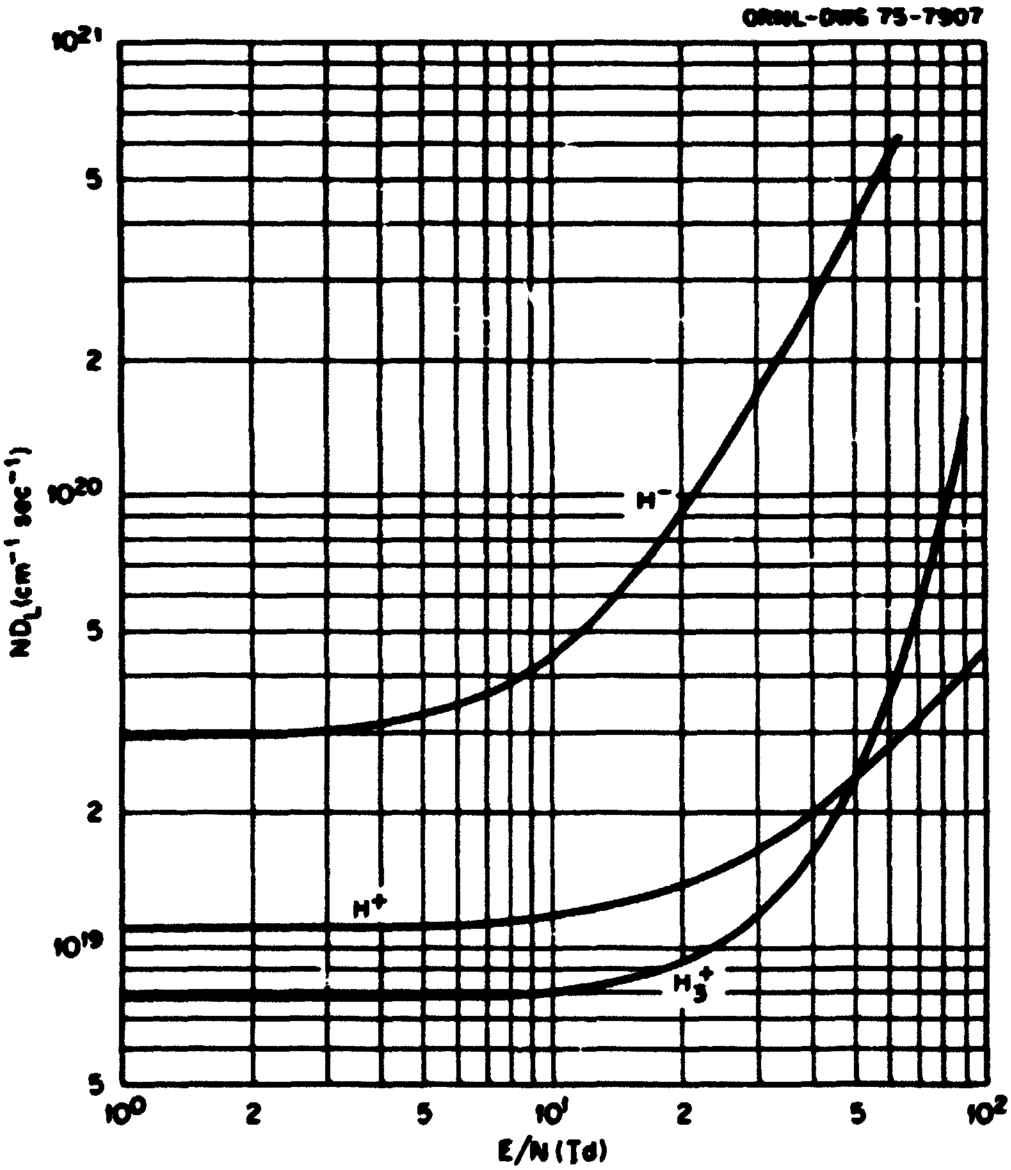
E/N (Td)	H^+ Ions in H_2 ND_L ($cm^{-1}sec^{-1}$)	H_3^+ Ions in H_2 ND_L ($cm^{-1}sec^{-1}$)	H^- Ions in H_2 ND_L ($cm^{-1}sec^{-1}$)
1.0 E 00	1.1 E 19	7.9 E 18	3.0 E 19
2.0 E 00	1.1 E 19	7.9 E 18	3.0 E 19
4.0 E 00	1.1 E 19	7.9 E 18	3.1 E 19
6.0 E 00	1.1 E 19	7.9 E 18	3.4 E 19
8.0 E 00	1.2 E 19	8.0 E 18	3.9 E 19
1.0 E 01	1.2 E 19	8.0 E 18	4.4 E 19
1.2 E 01	1.2 E 19	8.2 E 18	5.1 E 19
1.6 E 01	1.3 E 19	8.8 E 18	6.9 E 19
2.0 E 01	1.4 E 19	9.4 E 18	9.1 E 19
2.5 E 01	1.5 E 19	1.1 E 19	1.2 E 20
3.0 E 01	1.6 E 19	1.2 E 19	1.6 E 20
4.0 E 01	2.0 E 19	1.6 E 19	2.7 E 20
5.0 E 01	2.4 E 19	2.5 E 19	4.0 E 20
6.0 E 01	2.8 E 19	3.8 E 19	5.6 E 20
7.0 E 01	3.2 E 19	5.6 E 19	
8.0 E 01	3.7 E 19	9.2 E 19	
1.0 E 02	4.5 E 19		

Reference:

E. Graham, D.R. James, W.C. Keever, D.L. Albritton, and E.W. McDaniel, J. Chem. Phys. 59, 3477 (1973).

Accuracy:

The total error is believed not to exceed ± 10%.


ORNL-DWG 75-7907
10^{21}
5
2
10^{20}
5
2
10^{19}
5
$ND_L (cm^{-1} sec^{-1})$
H^-
H^+
H_3^+
10^0
2
5
10^1
2
5
10^2
E/N (Td)

The Reduced Mobilities of H^+ and H_3^+ Ions in H_2 at 302° K as a Function of E/N

E/N (Td)	H^+ Ions in H_2 K_o (cm_2/v-sec)	H_3^+ Ions in H_2 K_o (cm_2/v-sec)
4.0 E 00	1.57 E 01	1.11 E 01
6.0 E 00	1.57 E 01	1.11 E 01
1.0 E 01	1.58 E 01	1.12 E 01
2.0 E 01	1.57 E 01	1.12 E 01
2.5 E 01	1.55 E 01	1.12 E 01
3.0 E 01	1.54 E 01	1.12 E 01
4.0 E 01	1.51 E 01	1.12 E 01
6.0 E 01	1.44 E 01	1.22 E 01
8.0 E 01	1.38 E 01	1.35 E 01
1.0 E 02	1.34 E 01	1.49 E 01
1.5 E 02	1.30 E 01	1.60 E 01
2.0 E 02	1.28 E 01	1.54 E 01
2.5 E 02		1.43 E 01
3.0 E 02		1.38 E 01

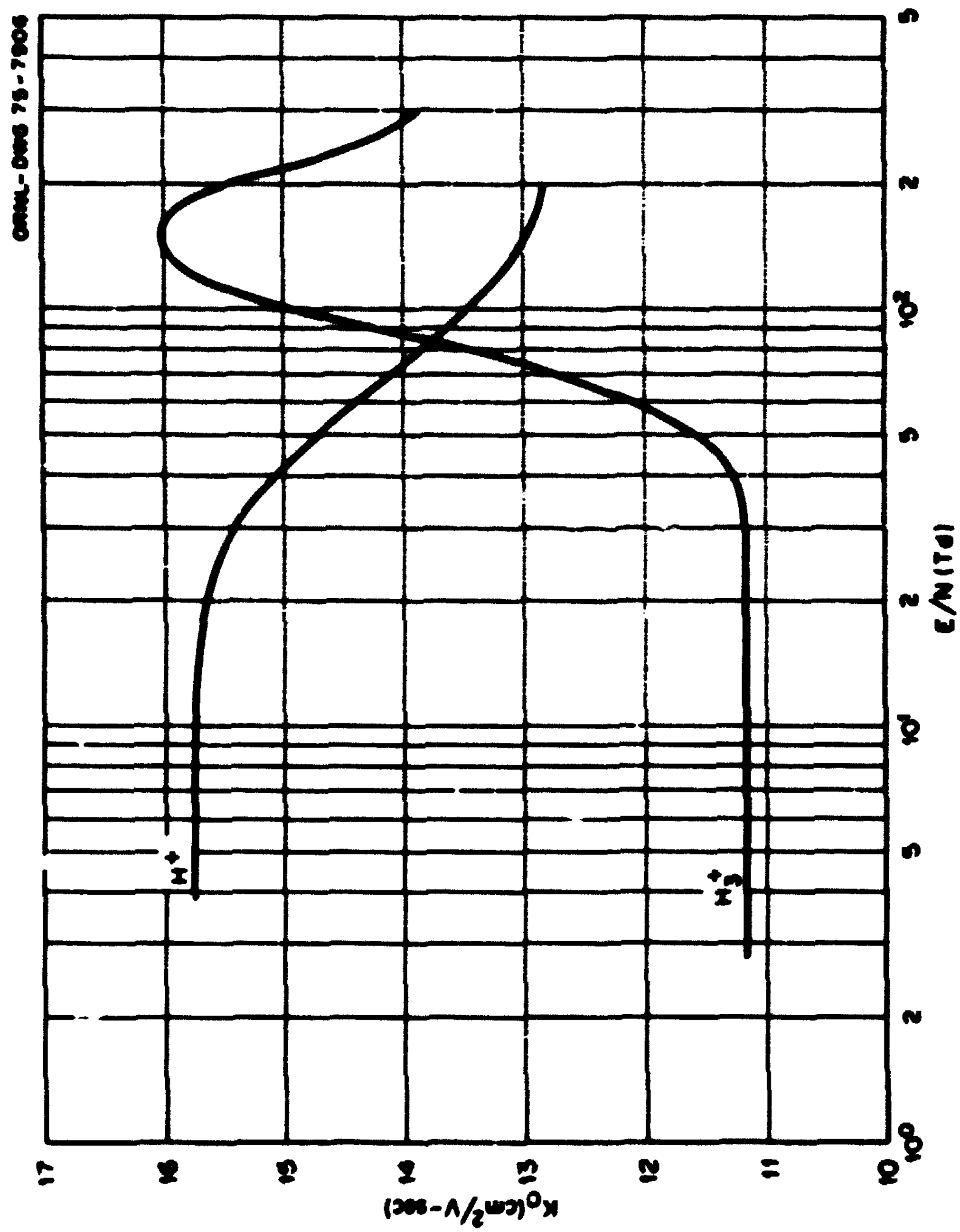
Reference:

T.M. Miller, J.T. Moseley, D.W. Martin, and E.W. McDaniel, Phys. Rev. 173, 115 (1968).

Accuracy:

The total error is believed not to exceed ± 4%.

E.2.9


ORNL-DWG 75-7906
E/N (Td)
K0 (cm2/V-sec)
H+
H3+
10
11
12
13
14
15
16
17
10^0
2
5
10^1
2
5
10^2
2
5

The Product of the Transverse Diffusion Coefficient (D_T) and the Gas Number Density (N) for H_3^+ and K^+ Ions in H_2 Gas at Room Temperature, Plotted as a Function of E/N

E/N (Td)	K^+ Ions in H_2 ND_T ($cm^{-1}sec^{-1}$)	H_3^+ Ions in H_2 ND_T ($cm^{-1}sev^{-1}$)
2.0 E 00	8.8 E 18	7.7 E 18
4.0 E 00	8.8 E 18	7.7 E 18
8.0 E 00	8.8 E 18	7.8 E 18
1.0 E 01	8.8 E 18	8.0 E 18
1.6 E 01	9.1 E 18	8.2 E 18
2.0 E 01	9.3 E 18	8.5 E 18
3.0 E 01	1.0 E 19	9.2 E 18
4.0 E 01	1.2 E 19	1.0 E 19
6.0 E 01	2.0 E 19	1.3 E 19
8.0 E 01	3.4 E 19	2.0 E 19
1.0 E 02	4.7 E 19	3.2 E 19
1.2 E 02	6.2 E 19	5.2 E 19
1.4 E 02	7.2 E 19	8.4 E 19
1.6 E 02	8.0 E 19	
2.0 E 02	9.2 E 19	

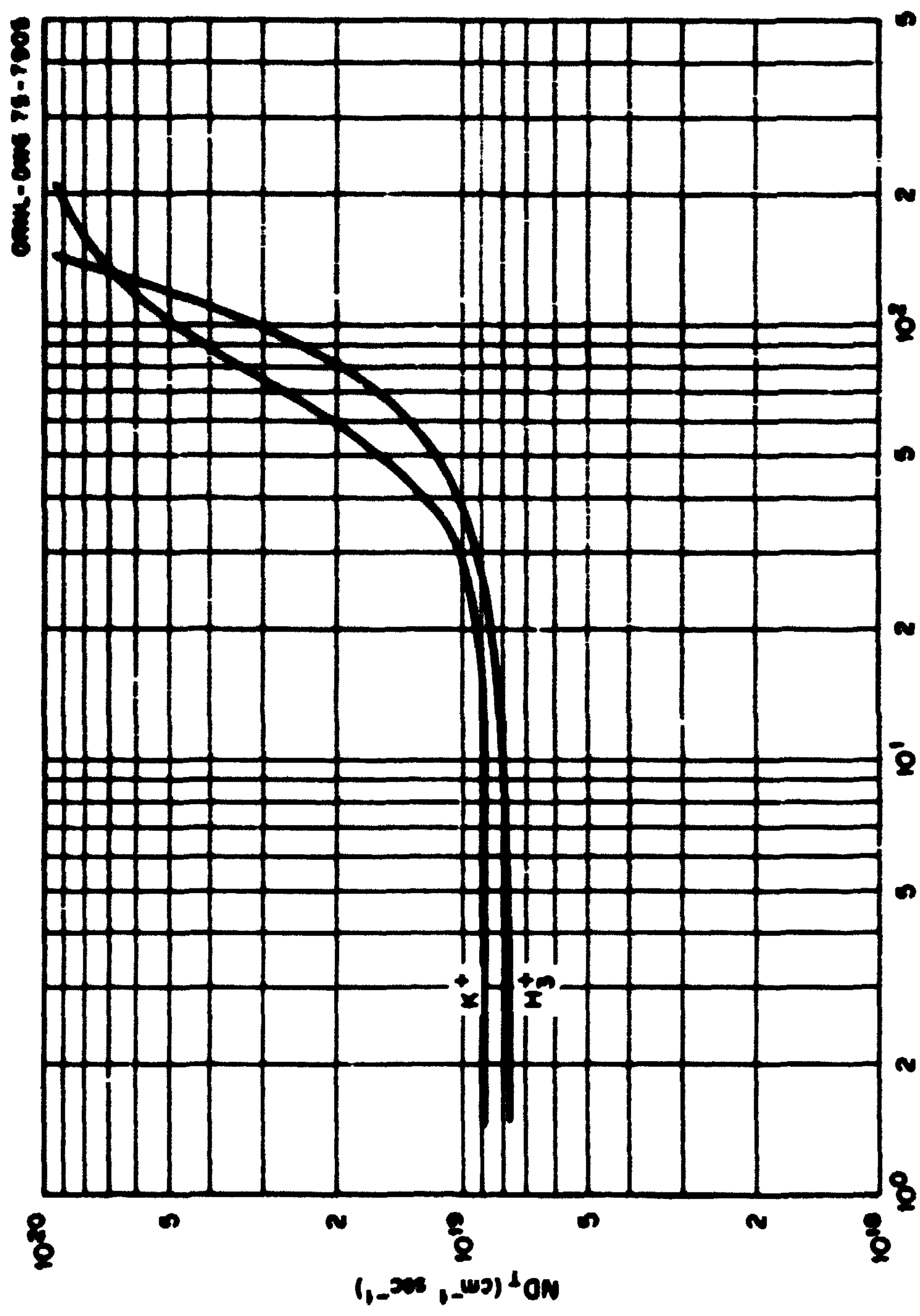
References:

H_3^+ in H_2: T.M. Miller, J.T. Moseley, D.W. Martin, and E.W. McDaniel, Phys. Rev. 173, 115 (1968).

K^+ in H_2: I.A. Fleming, R.J. Tunnicliffe, and J.A. Rees, J. Phys. B 2, 780 (1969).

Accuracy:

The total error is believed not to exceed ± 10%.


E/N (Td)
K^+
H_3^+

The Product of the Longitudinal Diffusion Coefficient (D_L) and the Gas Number Density (N) for D^+, D_3^+, and D^- Ions in D_2 Gas at 300° K as a Function of E/N

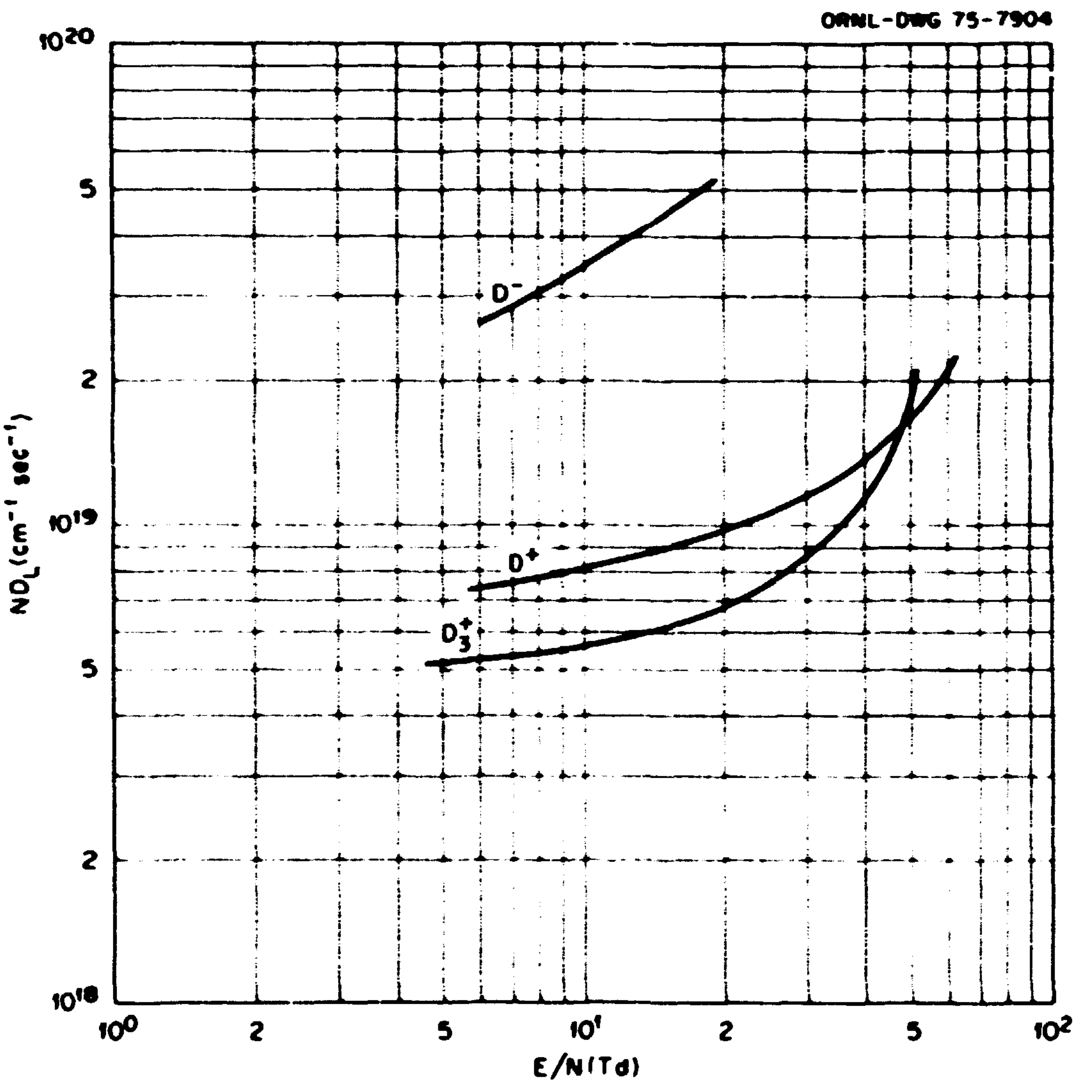
E/N (Td)	D^+ Ions in D_2 ND_L ($cm^{-1}sec^{-1}$)	D_3^+ Ions in D_2 ND_L ($cm^{-1}sec^{-1}$)	D^- Ions in D_2 ND_L ($cm^{-1}sec^{-1}$)
6.0 E 00	7.4 E 18	5.2 E 18	2.6 E 19
7.0 E 00	7.55 E 18	5.3 E 18	2.9 E 19
8.0 E 00	7.7 E 18	5.4 E 18	3.1 E 19
1.0 E 01	8.1 E 18	5.6 E 18	3.5 E 19
1.2 E 01	8.4 E 18	5.8 E 18	3.9 E 19
1.6 E 01	9.1 E 18	6.2 E 18	4.6 E 19
2.0 E 01	9.8 E 18	6.8 E 18	
2.5 E 01	1.1 E 19	7.6 E 18	
3.0 E 01	1.2 E 19	8.6 E 18	
3.5 E 01	1.3 E 19	9.8 E 18	
4.0 E 01	1.4 E 19	1.2 E 19	
5.0 E 01	1.7 E 19	1.8 E 19	

<u>Reference</u>:

E. Graham, D.R. James, W.C. Keever, D.L. Albritton, and E.W. McDaniel, J. Chem. Phys. <u>59</u>, 3477 (1973).

<u>Accuracy</u>:

The total error is believed not to exceed ± 10%.


ORNL-DWG 75-7904
$ND_L(cm^{-1} sec^{-1})$
10^{20}
5
2
10^{19}
5
2
10^{18}
10^0
2
5
10^1
2
5
10^2
E/N(Td)
D^-
D^+
D_3^+

Drift Velocity of D^+, D_3^+, and D^- Ions in D_2 Gas at 300° K as a Function of E/N

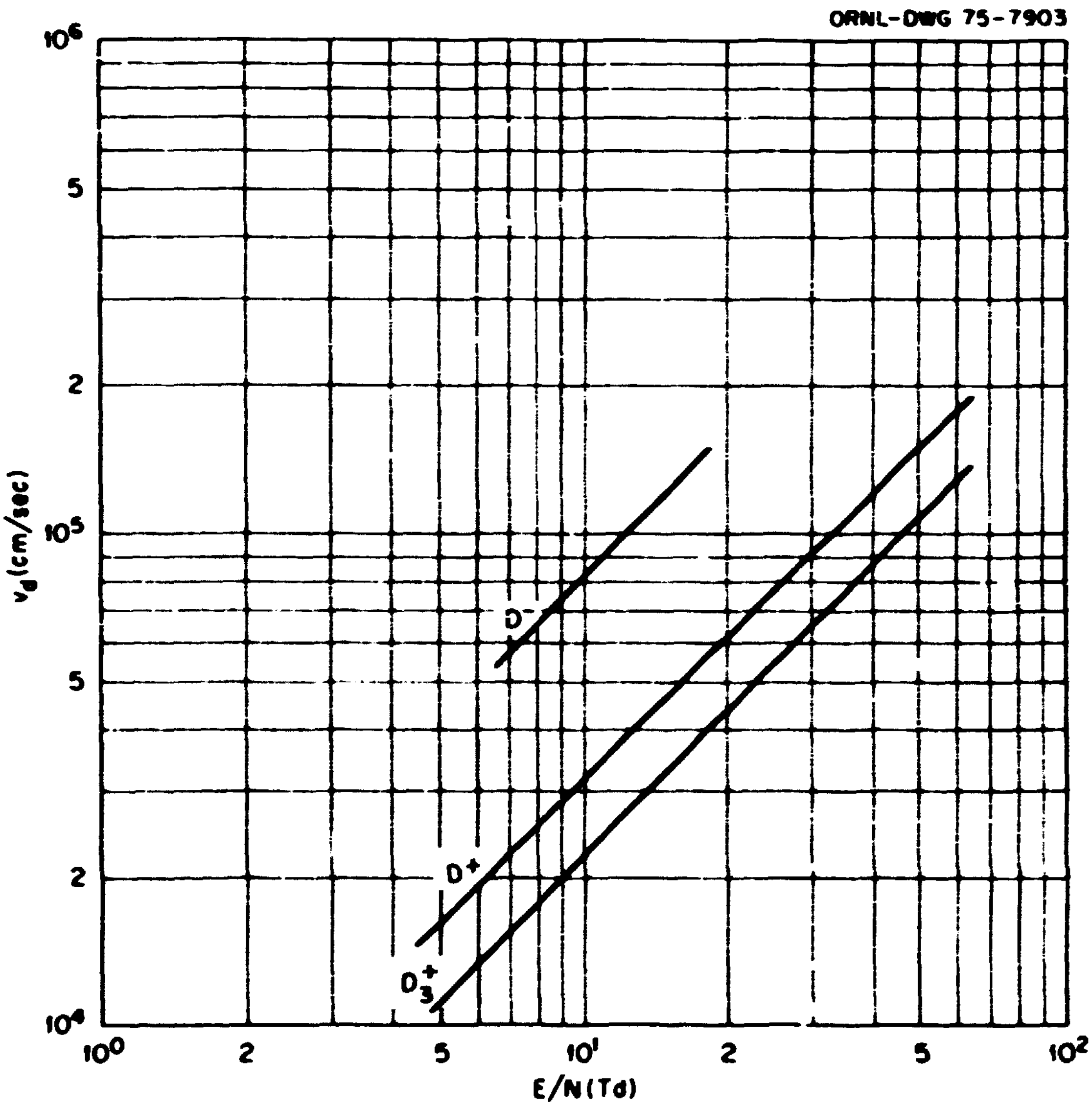
E/N (Td)	D^+ Ions in D_2 v_d (cm/sec)	D_3^+ Ions in D_2 v_d (cm/sec)	D^- Ions in D_2 v_d (cm/sec)
5.0 E 00	1.6 E 04	1.1 E 04	
6.0 E 00	1.9 E 04	1.3 E 04	
8.0 E 00	2.5 E 04	1.8 E 04	6.5 E 04
1.0 E 01	3.1 E 04	2.2 E 04	8.1 E 04
1.2 E 01	3.7 E 04	2.6 E 04	9.7 E 04
1.6 E 01	4.9 E 04	3.5 E 04	1.3 E 05
2.0 E 01	6.2 E 04	4.3 E 04	
2.5 E 01	7.6 E 04	5.4 E 04	
3.0 E 01	9.1 E 04	6.5 E 04	
4.0 E 01	1.2 E 05	8.6 E 04	
5.0 E 01	1.5 E 05	1.1 E 05	
6.0 E 01	1.8 E 05	1.3 E 05	

Reference:

E. Graham, I.R. James, W.C. Keever, D.L. Albritton, and E.W. McDaniel, J. Chem. Phys. 59, 3477 (1973).

Accuracy:

The total error is believed not to exceed ± 2%.


ORNL-DWG 75-7903
10^6
5
2
10^5
5
2
10^4
v_d(cm/sec)
D^-
D^+
D_3^+
10^0
2
5
10^1
2
5
10^2
E/N(Td)

The Reduced Mobilities of D^+ and D_3^+ Ions

in D_2 at 302° K as a Function of E/N

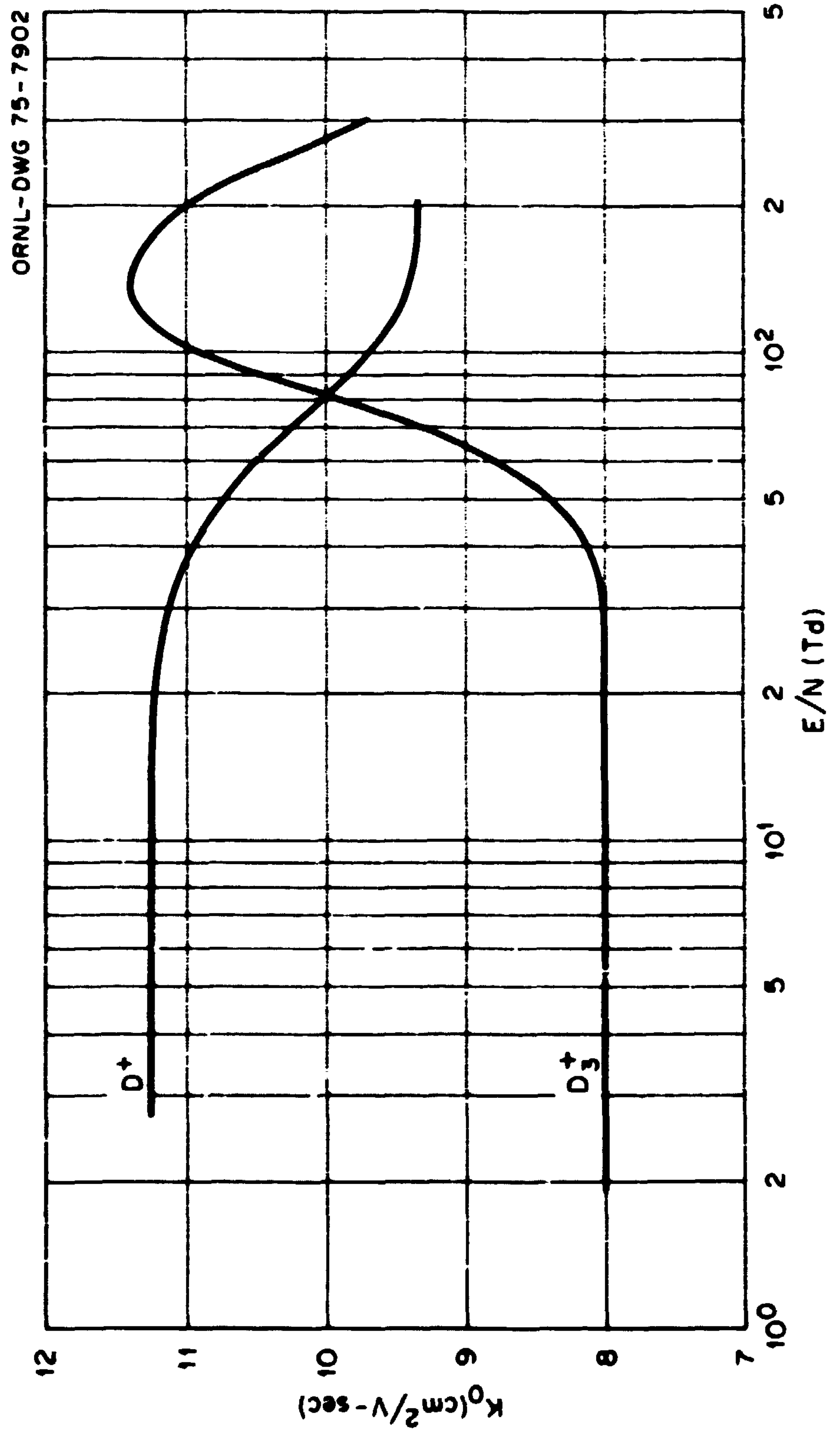
E/N (Td)	D^+ Ions in D_2 K_0 (cm²/v-sec)	D_3^+ Ions in D_2 K_0 (cm²/v-sec)
2.0 E 00		8.00 E 00
4.0 E 00	1.12 E 01	8.00 E 00
6.0 E 00	1.13 E 01	8.00 E 00
1.0 E 01	1.13 E 01	8.00 E 00
2.0 E 01	1.12 E 01	8.00 E 00
3.0 E 01	1.11 E 01	8.00 E 00
4.0 E 01	1.09 E 01	8.14 E 00
6.0 E 01	1.05 E 01	8.77 E 00
8.0 E 01	1.00 E 01	9.86 E 00
1.0 E 02	9.66 E 00	1.09 E 01
1.5 E 02	9.37 E 00	1.14 E 01
2.0 E 02	9.37 E 00	1.10 E 01
2.5 E 02		1.04 E 01
3.0 E 02		9.69 E 00

<u>Reference</u>:

T.M. Miller, J.T. Moseley, D.W. Martin, and E.W. McDaniel, Phys. Rev. <u>173</u>, 115 (1968).

<u>Accuracy</u>:

The total error is believed not to exceed ± 4%.


ORNL-DWG 75-7902
$K_0(cm^2/V\text{-}sec)$
12
11
10
9
8
7
10^0
2
5
10^1
2
5
10^2
2
5
E/N (Td)
D^+
D_3^+

Drift Velocities of He^+ Ions in He, Ne^+ Ions in Ne, and Ar^+ Ions in Ar at 300° K as a Function of E/N

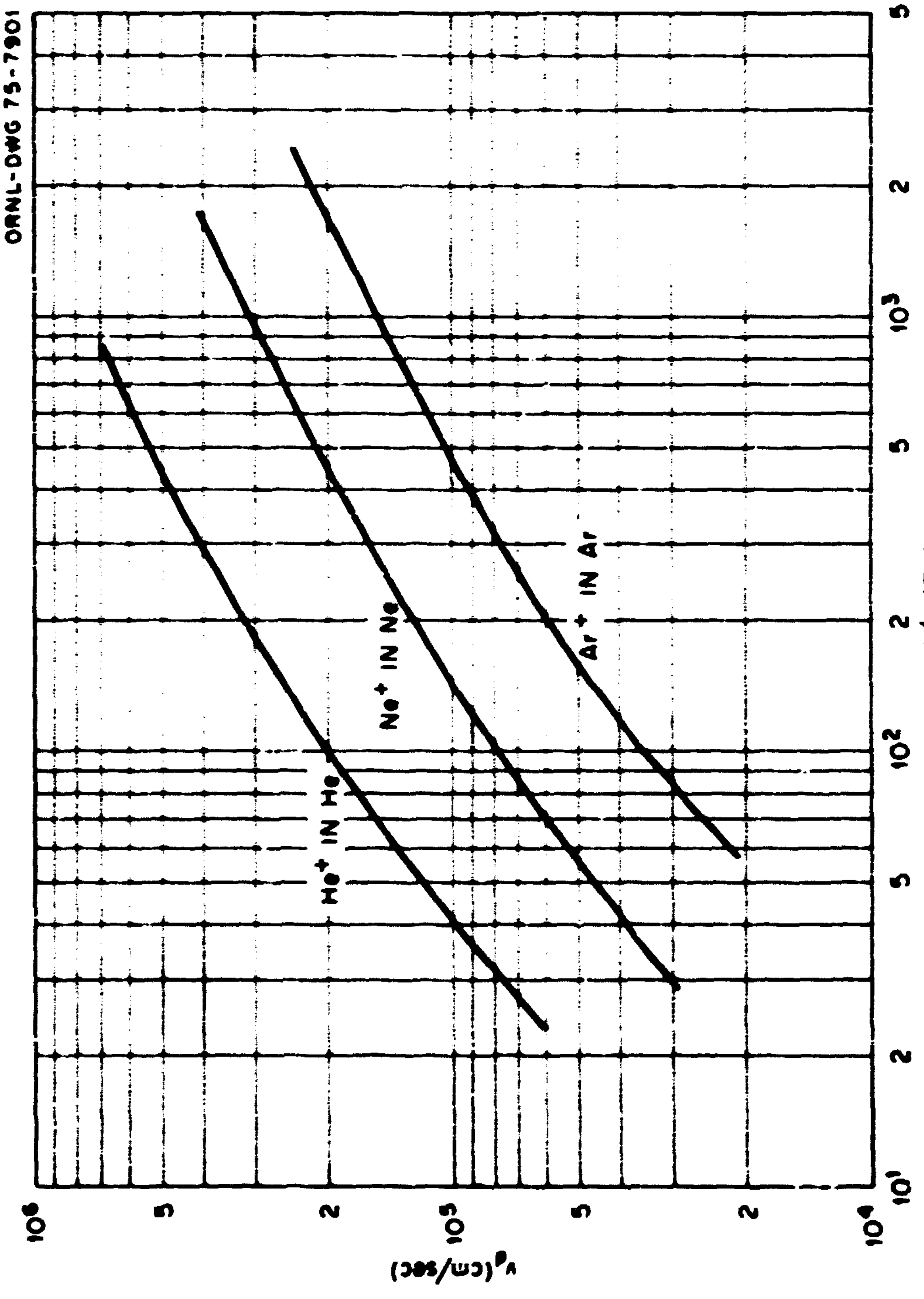
E/N (Td)	He^+ Ions in He v_d (cm/sec)	Ne^+ Ions in Ne v_d (cm/sec)	Ar^+ Ions in Ar v_d (cm/sec)
2.5 E 01	6.6 E 04		
3.0 E 01	7.6 E 04	3.0 E 04	
4.0 E 01	9.8 E 04	3.8 E 04	
5.0 E 01	1.2 E 05	4.6 E 04	
6.0 E 01	1.4 E 05	5.3 E 04	2.2 E 04
8.0 E 01	1.7 E 05	6.6 E 04	2.9 E 04
1.0 E 02	2.0 E 05	7.7 E 04	3.6 E 04
1.5 E 02	2.6 E 05	1.0 E 05	4.7 E 04
2.0 E 02	3.2 E 05	1.3 E 05	5.9 E 04
3.0 E 02	4.1 E 05	1.6 E 05	7.9 E 04
4.0 E 02	4.8 E 05	1.9 E 05	9.4 E 04
6.0 E 02	5.9 E 05	2.4 E 05	1.2 E 05
8.0 E 02	6.7 E 05	2.8 E 05	1.4 E 05
1.0 E 03		3.1 E 05	1.5 E 05
1.5 E 03		3.8 E 05	1.9 E 05
2.0 E 03			2.2 E 05

Reference:

J.A. Hornbeck, Phys. Rev. 84, 615 (1951).

Accuracy:

The total error is believed not to exceed ± 5%.



ORNL-DWG 75-7901
He+ IN He
Ne+ IN Ne
Ar+ IN Ar
E/N (Td)
v_d (cm/sec)
10^1
2
5
10^2
2
5
10^3
2
5
10^4
2
5
10^5
2
5
10^6

E.3 Diffusion Coefficient of Neutral Particles

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Maxwellian Averaged Quantal Diffusion Cross Section $\bar{\sigma}_D$ for H Atoms Diffusing in an Atomic Hydrogen Medium

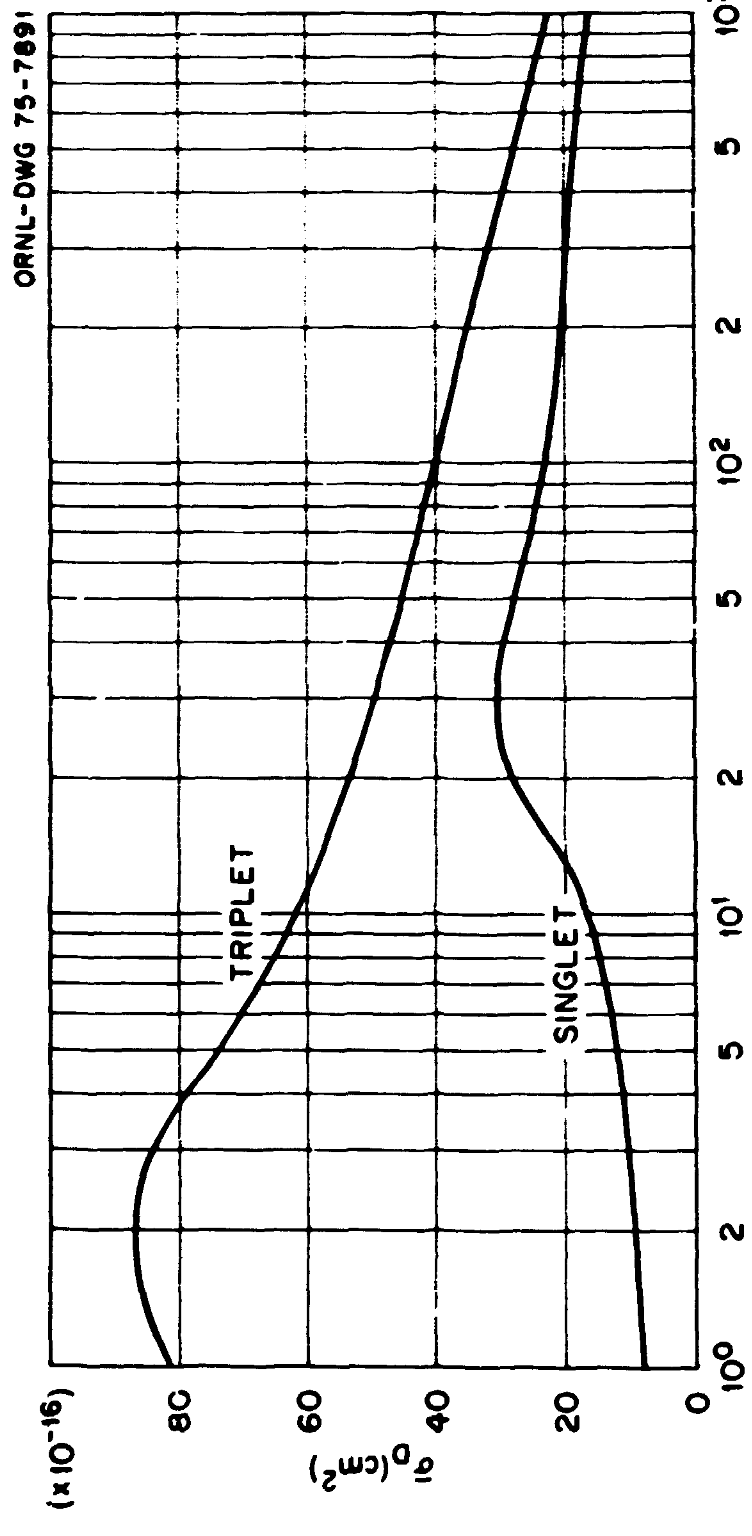
T (°K)	$\bar{\sigma}_D$ Singlet (cm^2)	$\bar{\sigma}$ Triplet (cm^2)
1.0 E 00	8.0 E-16	8.2 E-15
2.0 E 00	9.5 E-16	8.7 E-15
4.0 E 00	1.1 E-15	7.9 E-15
6.0 E 00	1.3 E-15	7.0 E-15
1.0 E 01	1.7 E-15	6.2 E-15
2.0 E 01	2.8 E-15	5.4 E-15
3.0 E 01	3.1 E 15	4.9 E-15
5.0 E 01	2.8 E-15	4.5 E-15
8.0 E 01	2.5 E-15	4.2 E-15
1.0 E 02	2.3 E-15	4.0 E-15
2.0 E 02	2.1 E-15	3.5 E-15
3.0 E 02	2.0 E-15	3.1 E-15
4.0 E 02	1.9 E-15	2.9 E-15
5.0 E 02	1.9 E-15	2.8 E-15
6.0 E 02	1.8 E-15	2.6 E-15
7.0 E 02	1.8 E-15	2.5 E-15
8.0 E 02	1.7 E-15	2.4 E-15
9.0 E 02	1.7 E-15	2.3 E-15
1.0 E 03	1.6 E-15	2.2 E-15

<u>Reference</u>:

A.C. Allison and F.J. Smith, Atomic Data <u>3</u>, 317 (1971).

<u>Accuracy</u>:

The total error is believed not to exceed ± 5%.


ORNL-DWG 75-7891
TRIPLET
SINGLET
$\sigma_D(cm^2)$
$(\times 10^{-16})$
0
20
40
60
80
10^0
2
5
10^1
2
5
10^2
2
5
10^3
T(°K)

Product of Total Gas Pressure and Diffusion Coefficient

for Various Neutral Gas Pairs

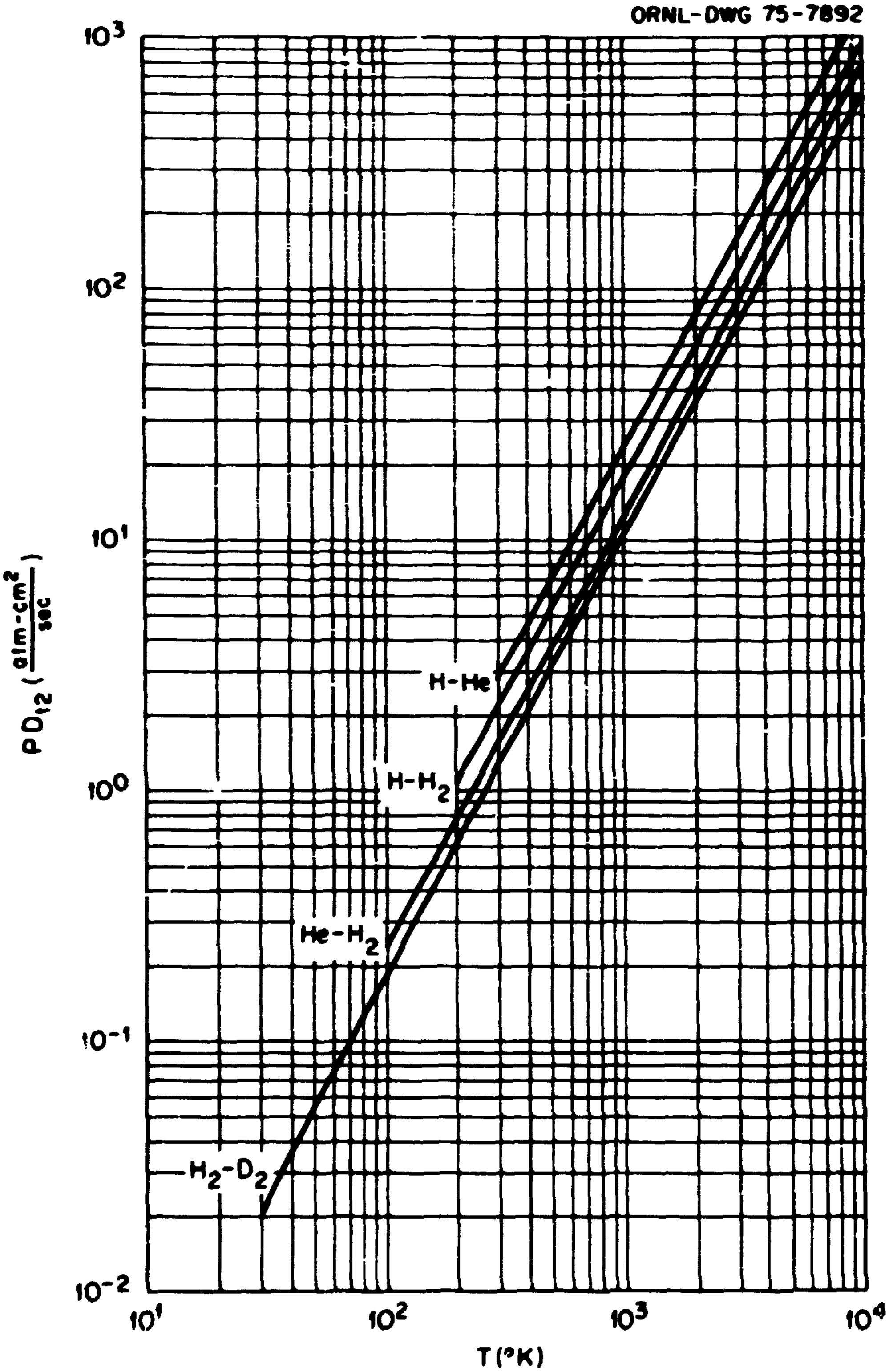
	pD_{12} (Atm-cm^2/sec)			
T(°K)	H_2 - D_2	H_2 - He	H - H_2	H - He
3.0 E 01	2.1 E-02			
5.0 E 01	5.6 E-02			
1.0 E 02	1.9 E-01	2.4 E-01		
2.0 E 02	6.3 E-01	7.7 E-01	1.1 E 00	
3.0 E 02	1.3 E 00	1.5 E 00	2.2 E 00	2.8 E 00
5.0 E 02	3.1 E 00	3.7 E 00	5.2 E 00	6.8 E 00
1.0 E 03	1.0 E 01	1.2 E 01	1.7 E 01	2.2 E 01
5.0 E 03	1.7 E 02	2.1 E 02	2.8 E 02	3.6 E 02
1.0 E 04	5.8 E 02	7.5 E 02	9.3 E 02	1.2 E 03

References:

E.A. Mason and T.R. Marrero, "The Diffusion of Atoms and Molecules," in "Advances in Atomic and Molecular Physics" (edited by D.R. Bates and I. Esterman), Academic Press, New York, Vol. 6, pages 155-232 (1970).
T.R. Marrero and E.A. Mason, J. Phys. Chem. Ref. Data 1, pages 3-118 (1972).

Accuracy:

The total error is believed not to exceed ± 15% for the H_2 - He and H_2 - D_2 data, and ± 30% for the H - H_2 and H - He data.


ORNL-DWG 75-7892
10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
PD_{12} (atm-cm²/sec)
H-He
H-H₂
He-H₂
H₂-D₂
10^1
10^2
10^3
10^4
T(°K)

F. Nuclear Reactions

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Cross Sections and Reaction Rates

for the D(d,n) ^{3}He Reaction

Energy (keV)	Cross Section (cm^2)	Reaction Rate (cm^3/sec)
1.0 E 00	3.3 E-43	8.5 E-23
2.0 E 00	2.0 E-37	2.8 E-21
3.0 E 00	6.7 E-34	1.5 E-20
4.0 E 00	2.0 E-33	4.3 E-20
5.0 E 00	2.0 E-32	8.8 E-20
6.0 E 00	1.1 E-31	1.6 E-19
7.0 E 00	4.0 E-31	2.4 E-19
8.0 E 00	1.1 E-30	3.4 E-19
9.0 E 00	2.7 E-30	4.5 E-19
1.0 E 01	5.4 E-30	6.0 E-19
1.5 E 01	6.4 E-29	1.5 E-18
2.0 E 01	2.5 E-29	2.6 E-18
4.0 E 01	2.5 E-27	8.0 E-18
7.0 E 01	9.6 E-27	1.7 E-17
1.0 E 02	1.7 E-26	2.3 E-17
2.0 E 02	3.7 E-26	4.8 E-17
4.0 E 02	6.0 E-26	9.5 E-17
7.0 E 02	8.0 E-26	1.1 E-16
1.0 E 03	8.9 E-26	1.3 E-16
2.0 E 03	1.0 E-25	1.2 E-16
4.0 E 03	9.6 E-26	7.8 E-17
7.0 E 03	4.5 E-26	4.8 E-17
1.0 E 04	1.7 E-26	3.3 E-17
2.0 E 04	2.3 E-27	1.5 E-17
4.0 E 04	3.6 E-27	5.7 E-17
7.0 E 04	8.2 E-29	2.7 E-18
1.0 E 05	3.6 E-29	1.6 E-18

<u>References</u>:

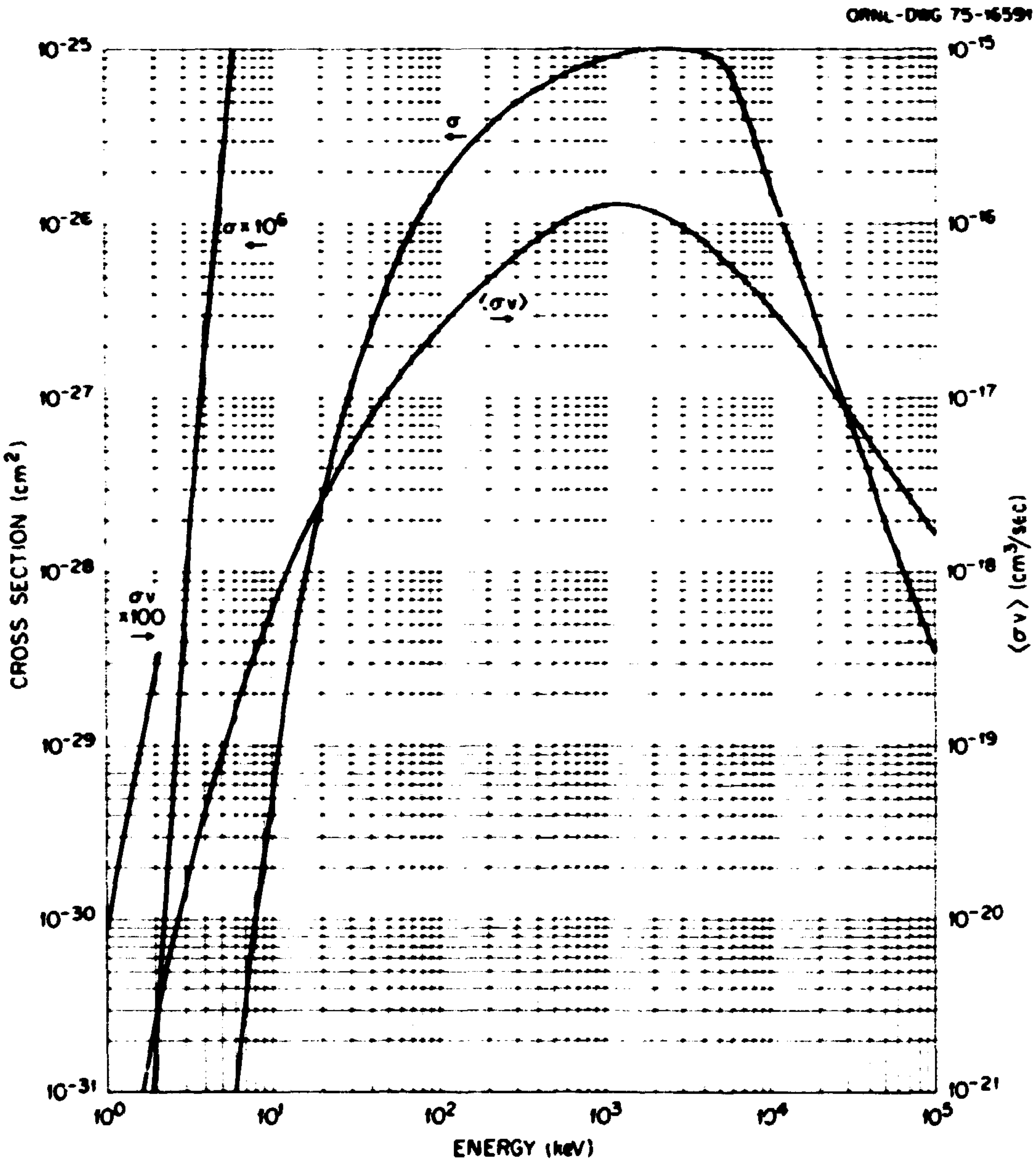
G. H. Miley, H. Towner, and N. Ivich, "Fusion Cross Sections and Reactivities," COO-2218-17 (1974); Battelle Pacific Northwest Laboratories Annual Report, edited by W. C. Wolkenhauer, BNWL-1685 (1972); S. L. Green, Jr. Report #UCRL-70522 (1967).

<u>Accuracy</u>:

± 10%.

<u>Notes</u>:

Reaction rate is the reaction rate averaged over both Maxwellian distributions. Measurements have not been made below 7.5 keV. Data below this energy represent an extrapolation using analytical expressions.


ORNL-DWG 75-16591
CROSS SECTION (cm²)
⟨σv⟩ (cm³/sec)
ENERGY (keV)
σ
σ × 10⁶
⟨σv⟩
σv ×100
10⁻²⁵
10⁻²⁶
10⁻²⁷
10⁻²⁸
10⁻²⁹
10⁻³⁰
10⁻³¹
10⁻¹⁵
10⁻¹⁶
10⁻¹⁷
10⁻¹⁸
10⁻¹⁹
10⁻²⁰
10⁻²¹
10⁰
10¹
10²
10³
10⁴
10⁵

F.1.4.

Cross Sections and Reaction Rates

for the D(d,p)T Reaction

Energy (keV)	Cross Section (cm^2)	Reaction Rate (cm^3/sec)
1.0 E 00	1.4 E-42	8.3 E-23
2.0 E 00	5.2 E-37	2.9 E-21
3.0 E 00	1.4 E-33	1.5 E-20
4.0 E 00	3.7 E-33	4.3 E-20
5.0 E 00	3.3 E-32	8.9 E-20
6.0 E 00	1.7 E-31	1.6 E-19
7.0 E 00	5.8 E-31	2.4 E-19
8.0 E 00	1.6 E-30	3.3 E-19
9.0 E 00	3.5 E-30	4.5 E-19
1.0 E 01	7.0 E-30	5.8 E-19
1.5 E 01	7.0 E-29	1.4 E-18
2.0 E 01	2.6 E-28	2.4 E-18
4.0 E 01	2.5 E-27	7.3 E-18
7.0 E 01	8.8 E-27	1.4 E-17
1.0 E 02	1.5 E-26	2.2 E-17
2.0 E 02	3.0 E-26	4.2 E-17
4.0 E 02	5.2 E-26	6.2 E-17
7.0 E 02	7.0 E-26	9.2 E-17
1.0 E 03	8.0 E-26	9.5 E-17
2.0 E 03	9.2 E-26	7.4 E-17
4.0 E 03	8.5 E-26	4.5 E-17
7.0 E 03	1.6 E-26	2.6 E-17
1.0 E 04	5.7 E-27	1.7 E-17
2.0 E 04	8.4 E-28	7.2 E-18
4.0 E 04	1.4 E-28	2.8 E-18
7.0 E 04	3.2 E-29	1.3 E-18
1.0 E 05	1.4 E-29	7.8 E-19

References:

G. H. Miley, H. Towner, and N. Ivich, "Fusion Cross Sections and Reactivities," COO-2218-17 (1974); Battelle Pacific Northwest Laboratories Annual Report, edited by W. C. Wolkenhauer, BNWL-1685, p. 80 and 92 (1972); S. L. Green, Jr., Report #UCRL-70522 (1967).

Accuracy:

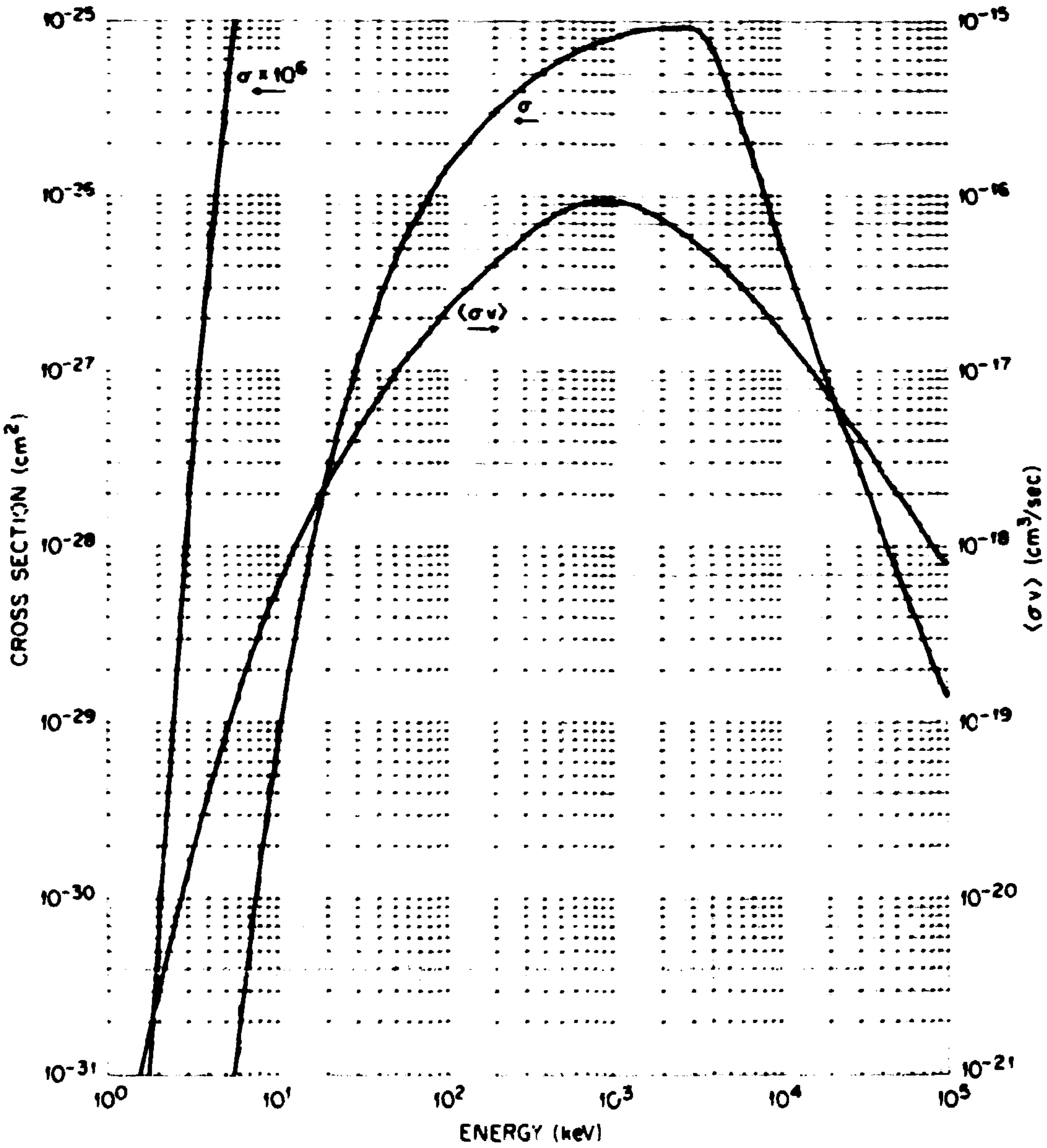
± 10%.

Notes:

Reaction rate is the reaction rate averaged over both Maxwellian distributions. Measurements have not been made below 12 keV. Data below this region represent an extrapolation using analytical expressions.

F.1.5

ORNL-DWG 75-16602



Cross Sections and Reaction Rates

for the Reaction T(t,2n) ^{4}He

Energy (keV)	Cross Section (cm^2)	Reaction Rate (cm^3/sec)
6.0 E 00	2.1 E-30	
8.0 E 00	1.4 E-29	
1.0 E 01	4.5 E-29	6.8 E-19
2.0 E 01	8.0 E-28	2.4 E-18
4.0 E 01	5.0 E-27	6.6 E-18
7.0 E 01	1.3 E-26	1.3 E-17
1.0 E 02	1.9 E-26	2.0 E-17
2.0 E 02	3.2 E-26	4.1 E-17
4.0 E 02	5.0 E-26	7.4 E-17
7.0 E 02	6.6 E-26	8.5 E-17
1.0 E 03	9.7 E-26	8.0 E-17
2.0 E 03	1.7 E-25	5.1 E-17
3.0 E 03	7.4 E-26	3.5 E-17
4.0 E 03	2.8 E-26	2.5 E-17
7.0 E 03	4.1 E-27	1.3 E-17
1.0 E 04	1.4 E-27	8.4 E-18
2.0 E 04	2.1 E-28	3.3 E-18
4.0 E 04	3.5 E-29	1.3 E-18
7.0 E 04	8.5 E-30	5.7 E-19
1.0 E 05	3.8 E-30	3.4 E-19

References:

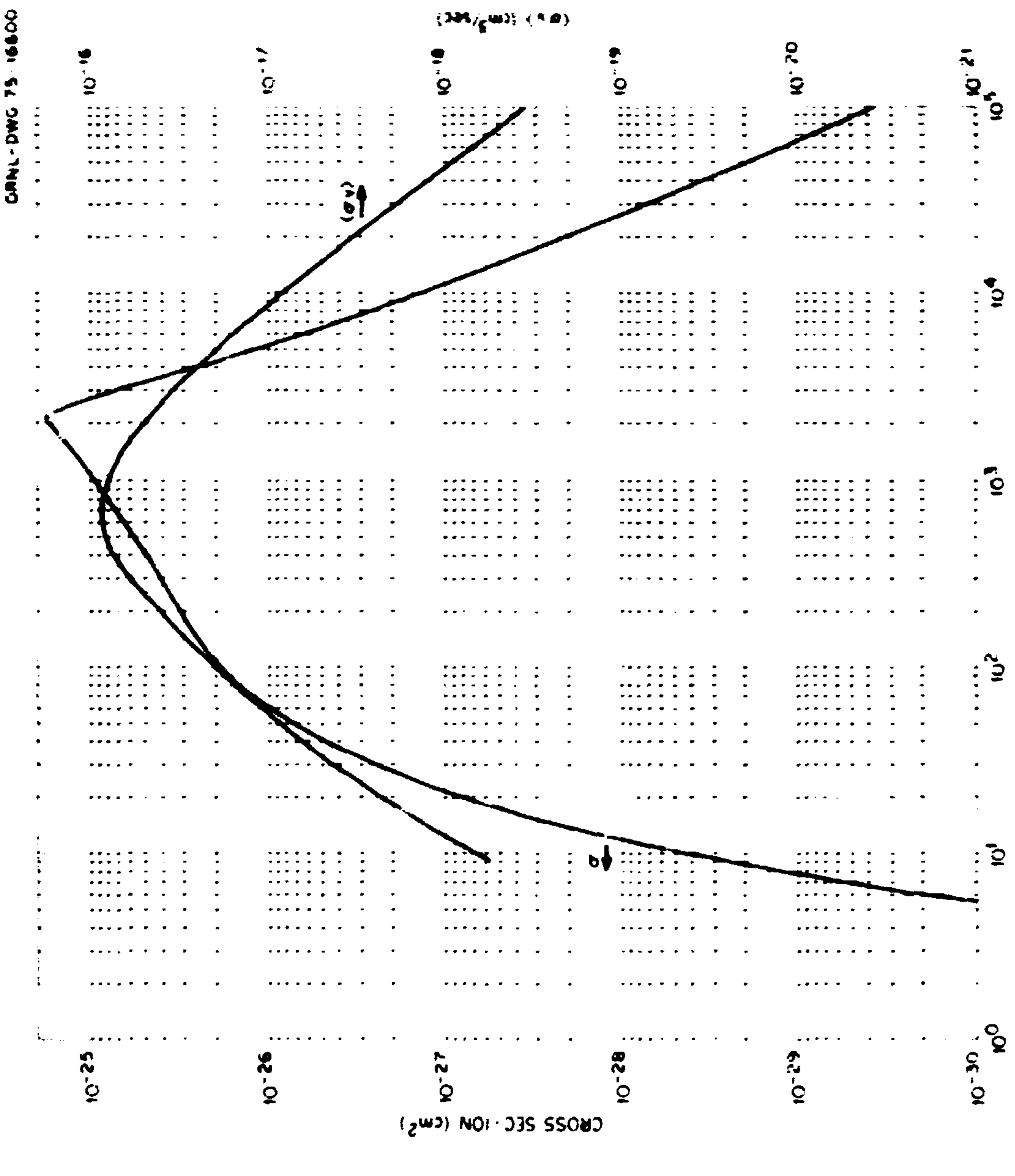
G. H. Miley, H. Towner, and N. Ivich, "Fusion Cross Sections and Reactivities," COO-2218-17 (1974); Battelle Pacific Northwest Laboratories Annual Report, edited by W. C. Wolkenhauer, BNWL-1685 (1972); S. L. Green, Jr., Report #UCRL-70522 (1967).

Accuracy:

See Notes.

Notes:

Reaction rate is the reaction rate averaged over both Maxwellian distributions. Measurements have been made for energies between 60 keV and 2 MeV. Both Green and Miley, et al., gave reaction rate values down to energies of 1 keV. They are not plotted here due to large discrepancies. For an evaluation of this cross section, consult L. Stewart and G. M. Hale, Report #LA-5828-MS or USNDC-CTR-2. Use extreme caution in using these results.


ORNL-DWG 75-16800
⟨σv⟩ (cm³/sec)
CROSS SECTION (cm²)
ENERGY (keV)
⟨σv⟩
σ
10⁻¹⁶
10⁻¹⁷
10⁻¹⁸
10⁻¹⁹
10⁻²⁰
10⁻²¹
10⁻²⁵
10⁻²⁶
10⁻²⁷
10⁻²⁸
10⁻²⁹
10⁻³⁰
10⁰
10¹
10²
10³
10⁴
10⁵

Cross Sections and Reaction Rates for the T(d,n) ^{4}He Reaction

Energy (keV)	Deuterium Cross Section (cm^2)	Tritium Cross Section (cm^2)	Reaction Rate (cm^3/sec)
1.0 E 00	2.7 E-40	1.4 E-44	5.7 E-21
2.0 E 00	9.4 E-35	9.8 E-38	2.7 E-19
3.0 E 00	2.5 E-32	9.7 E-35	1.7 E-18
4.0 E 00	6.6 E-31	5.7 E-33	5.6 E-18
5.0 E 00	6.0 E-30	8.9 E-32	1.3 E-17
6.0 E 00	3.1 E-29	6.7 E-31	2.4 E-17
7.0 E 00	1.1 E-28	3.2 E-30	4.0 E-17
8.0 E 00	3.0 E-28	1.1 E-29	5.9 E-17
1.0 E 01	1.4 E-27	7.4 E-29	1.1 E-16
2.0 E 01	5.2 E-26	7.4 E-27	4.3 E-16
3.0 E 01	2.7 E-26	5.4 E-26	6.6 E-16
4.0 E 01	6.9 E-25	1.7 E-25	8.1 E-16
7.0 E 01	2.9 E-24	1.1 E-24	9.0 E-16
1.0 E 02	4.8 E-24	2.7 E-24	8.4 E-16
1.5 E 02	4.0 E-24	4.8 E-24	7.0 E-16
2.0 E 02	2.7 E-24	4.7 E-24	6.2 E-16
4.0 E 02	8.1 E-25	1.7 E-24	4.2 E-16
7.0 E 02	3.4 E-25	6.2 E-25	3.1 E-16
1.0 E 03	2.2 E-25	3.6 E-25	2.7 E-16
2.0 E 03	1.3 E-25	1.7 E-25	2.3 E-16
4.0 E 03	1.0 E-25	1.2 E-25	2.2 E-16
7.0 E 03	8.1 E-26	9.4 E-26	2.3 E-16
1.0 E 04	7.1 E-26	8.2 E-26	2.3 E-16
4.0 E 04	3.9 E-26	4.7 E-26	2.5 E-16
7.0 E 04	3.1 E-26	3.7 E-26	2.6 E-16
1.0 E 05	2.7 E-26	3.3 E-26	2.6 E-16

References:

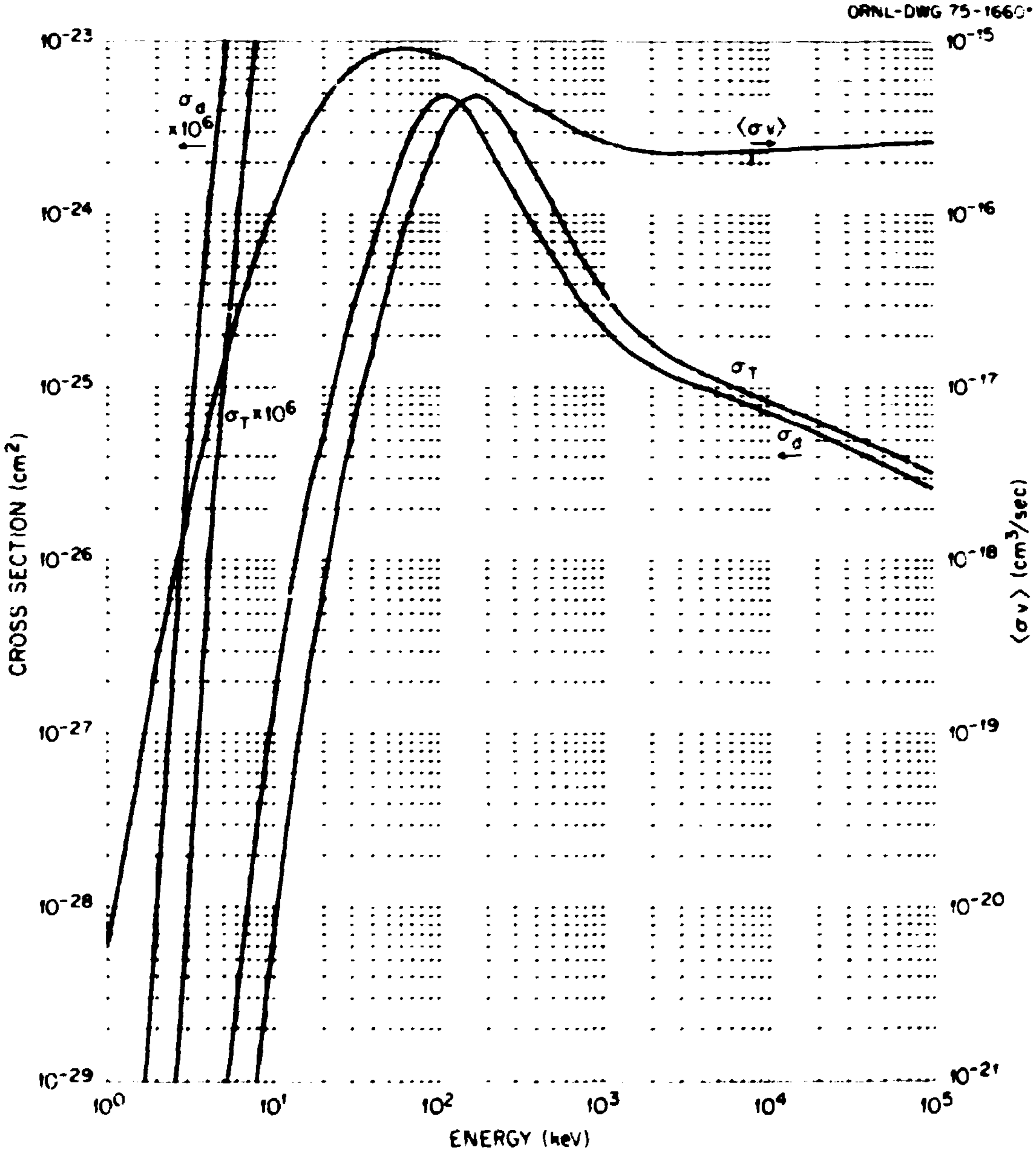
G. H. Miley, H. Towner, and N. Ivich, "Fusion Cross Sections and Reactivities," COO-2218-17 (1974); Battelle Pacific Northwest Laboratories Annual Report, edited by W. C. Wolkenhauer, BNWL-1685, p. 78 and 92 (1972); S. L. Green, Jr., Report #UCRL-70522 (1967).

Accuracy:

± 10%.

Notes:

Reaction rate is the reaction rate averaged over both Maxwellian distributions. Deuterium cross section is cross section for incident deuteron; tritium cross section is cross section for incident triton. Measurements have not been made below deuteron energies of 8 keV. Below this region represents an extrapolation.


ORNL-DWG 75-1660
CROSS SECTION (cm²)
⟨σv⟩ (cm³/sec)
ENERGY (keV)
σd ×10⁶
σT ×10⁶
⟨σv⟩
σT
σd
10⁻²³
10⁻²⁴
10⁻²⁵
10⁻²⁶
10⁻²⁷
10⁻²⁸
10⁻²⁹
10⁻¹⁵
10⁻¹⁶
10⁻¹⁷
10⁻¹⁸
10⁻¹⁹
10⁻²⁰
10⁻²¹
10⁰
10¹
10²
10³
10⁴
10⁵