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**Atomic Data for Controlled
Fusion Research**

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ADAMIC 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 $\text{cm}^2/\text{molecule}$ or cm^2/atom for a monatomic 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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C.1.4

Total Scattering of Electrons
(Inelastic and Elastic) in Gases

(H, H₂, 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)		
	<u>H</u>	<u>H₂</u>	<u>He</u>
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	1.93 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.

C.1.6

Elastic Differential (In Angle)

Scattering of Electrons on H

Angle (deg)	Differential Cross Section (cm ² /sr)		
	Impact Energy		
	<u>3.8 eV</u>	<u>5.7 eV</u>	<u>9.4 eV</u>
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 < ± 20%.

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C.1.8

Elastic Differential (In Angle) Scattering of Electrons in H₂

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.

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C.1.10

Elastic Differential (In Angle) Scattering of Electrons in 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	2.43 E-17	3.60 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-18	1.36 E-19
7.0 E 01	3.15 E-17	5.68 E-18	3.07 E-19	4.80 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	4.95 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		2.63 E-19	2.56 E-20
1.5 E 02			2.68 E-19	
1.6				

References:

$e + \text{He}$, 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. McMiller, G.M. Webb, Phys. Rev. 41, 154 (1932); also at 200 eV, L. Vriens, C.E. Kayatt, S.R. Vielczarek, Phys. Rev. 170, 163 (1968).

Accuracy:

Random error < $\pm 15\%$ at 3.1 eV. Random error < $\pm 3\%$ at all other energies.

Notes:

See Note (3) at end of chapter.

C.1.12

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

Angle (deg)	Differential Cross Sections (cm ² /sr)	
	<u>Elastic</u>	<u>Inelastic</u>
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-19
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:

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

Accuracy:

Systematic error < $\pm 2\%$. Random error < $\pm 2\%$.

C.1.13

C.1.15

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

C.2.2

Collisional Excitation of H by Electron Impact:

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

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

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

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., $l-l' = 1$). 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 $1s \rightarrow nl$ transitions and above 50 eV for all other transitions.

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

C.2.3

Collision Excitation of H by Electron Impact $e + H(n'l') \rightarrow e + H(n,l)$ $C_{n'l',nl}$ 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)	5.2(3)	8.4(3)
1		2.7(2)	6.9(2)	1.47(3)	2.8(3)	4.6(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							

 $C_{n'l',nl}$ for $n-n' = 2$

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							

 $D_{n'l',nl}$ 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							

 $D_{n'l',nl}$ for $n-n' = 2$

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 $1s \rightarrow 2s$ and $1s \rightarrow 2p$ 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 .

C.2.6

Collisional Excitation of H by Electrons:

Energy (eV)	Cross Sections for State n <i>l</i> (cm ²)				
	<u>Experimental</u>		<u>Theoretical</u>		<u>Experimental</u>
	<u>2s</u>	<u>2p</u>	<u>3s</u>	<u>4s</u>	<u>Balmer α</u>
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.]

C.2.7

C.2.8

Cross Sections for Excitation of H_2^+ by Electrons:

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.

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Cross Sections for Dissociation of H_2 into

Excited Fragments by Electron Impact:

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	
5.0 E 01	1.32 E-17	9.60 E-19	1.88 E-19
6.0 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	5.03 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 E-20	6.5 E-21
6.0 E 03	5.64 E-19	3.35 E-20	4.5 E-21

References:

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

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

$e + H_2 \rightarrow e + H + H(n=4, \text{Balmer beta})$: 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 $< \pm 10\%$; random error $< \pm 2\%$.

$n = 3$ - systematic error $< \pm 12\%$; random error $< \pm 4\%$.

$n = 4$ - systematic error $< \pm 7\%$; random error $< \pm 4\%$.

C.2.12

Cross Sections for Dissociation of D_2

Into Excited Fragments by Electrons:

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(4481 Å)
1.4 ± 0.1	9.0 E-21			
1.5 ± 0.1	2.41 E-19		2.00 E-19	
2.0 ± 0.1	2.70 E-18		4.20 E-19	
2.5 ± 0.1	3.00 E-18		5.50 E-19	
3.0 ± 0.1	3.10 E-18		5.82 E-19	
4.0 ± 0.1	3.42 E-18		7.11 E-19	
6.0 ± 0.1	3.45 E-18	9.60 E-18	7.90 E-19	1.51 E-19
8.0 ± 0.1	3.42 E-18	9.00 E-18	7.90 E-19	1.54 E-19
1.0 ± 0.2	3.24 E-18	8.30 E-18	7.52 E-19	1.46 E-19
1.5 ± 0.2	2.85 E-18	6.90 E-18	6.47 E-19	1.18 E-19
2.0 ± 0.2	2.52 E-18	5.80 E-18	5.40 E-19	9.60 E-20
4.0 ± 0.2	1.70 E-18	3.57 E-18	3.03 E-19	5.16 E-20
6.0 ± 0.2		2.55 E-18	2.10 E-19	3.37 E-20
8.0 ± 0.2		2.00 E-18	1.55 E-19	2.48 E-20
1.0 ± 0.3		1.67 E-18	1.25 E-19	1.95 E-20
1.5 ± 0.3		1.19 E-18	8.52 E-20	1.29 E-20
2.0 ± 0.3		9.20 E-19	6.55 E-20	9.80 E-21
4.0 ± 0.3		5.20 E-19	3.30 E-20	5.10 E-21
6.0 ± 0.3		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).

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

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

$e + D_2 \rightarrow e + D + D(n=4 \text{ Balmer Beta})$: 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%.

C.2.13

Cross Sections for Excitation of H_2 by Electrons:

Energy (eV)	Cross Sections (cm^2)			
	Emission of 1230 $\text{\AA}$ Werner Band B-X(3,7)	B State	C State	D State
1.5 $\pm$ 0.1	5.13 E-19			
1.9 $\pm$ 0.1	9.92 E-19	3.36 E-17	2.53 E-17	3.58 E-19
3.0 $\pm$ 0.1	1.42 E-18	4.26 E-17	3.23 E-17	2.31 E-18
4.0 $\pm$ 0.1	1.52 E-18	4.79 E-17	3.68 E-17	2.61 E-18
5.0 $\pm$ 0.1	1.52 E-18	4.75 E-17	3.61 E-17	2.39 E-18
6.0 $\pm$ 0.1	1.51 E-18	4.55 E-17	3.43 E-17	2.99 E-19
8.0 $\pm$ 0.1	1.43 E-18	4.12 E-17	3.13 E-17	2.95 E-18
1.0 $\pm$ 0.2	1.36 E-18	3.75 E-17	2.93 E-17	2.37 E-18
1.5 $\pm$ 0.2	1.15 E-18	3.00 E-17	2.35 E-17	2.54 E-18
2.0 $\pm$ 0.2	1.01 E-18	2.51 E-17	2.01 E-17	2.25 E-18
3.0 $\pm$ 0.2	7.97 E-19	2.00 E-17	1.53 E-17	1.80 E-18
5.0 $\pm$ 0.2	5.67 E-19			
1.0 $\pm$ 0.3	3.42 E-19			

References:

$e + H_2 \rightarrow e + H_2(1230 \text{ \AA}$ 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 $\text{\AA}$ 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 $< \pm 5\%$.

C.2.25

ORNL-DWG 75-2224

Cross Sections for Vibrational Excitation of H_2 by Electrons:

Energy (eV)	Experimental Cross Sections (cm^2)		
	<u>v=1</u>	<u>v=2</u>	<u>v=3</u>
1.5 ± 0.3	2.50 E-17		
2.0 ± 0.3	3.90 E-17	1.20 E-18	1.20 E-19
3.0 ± 0.3	5.06 E-17	3.24 E-18	3.55 E-19
4.0 ± 0.3	4.63 E-17	4.04 E-18	4.30 E-19
5.0 ± 0.3	3.75 E-17	3.91 E-18	3.51 E-19
6.0 ± 0.3	2.80 E-17	3.32 E-18	2.80 E-19
7.0 ± 0.3	1.55 E-17	1.75 E-18	
1.0 ± 0.1	5.60 E-18	5.50 E-19	
1.5 ± 0.1	1.71 E-18	1.12 E-19	
2.0 ± 0.1	1.24 E-18	4.24 E-20	
3.0 ± 0.1	1.12 E-18	4.54 E-20	
6.0 ± 0.1	3.99 E-19		
8.0 ± 0.1	8.20 E-19		
1.0 ± 0.2	5.10 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).

$v = 1 - < \pm 45\%$.

$v = 2 - < \pm 55\%$.

$v = 3 - < \pm 65\%$.

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Cross Sections for Excitation of Helium by Electrons:

Energy (eV)	Experimental Cross Sections (cm ²)				
	<u>4¹S</u>	<u>3¹P</u>	<u>4¹D</u>	<u>4³S</u>	<u>3³P</u>
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	4.84 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	2.90 E-20	8.20 E-20
1.5 E 02	9.40 E-20	2.75 E-18	6.10 E-20	8.40 E-21	3.01 E-20
2.0 E 02	3.10 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	1.00 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		2.60 E-22
2.0 E 03	1.10 E-20	5.40 E-19	3.70 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* 41, 517 (1969). [These data normalized to Van Raan at 2000 eV and used only above that energy for the 4¹S, 3¹P, and 4¹D states.] For information on other states see these two references.

Accuracy:

Systematic error < $\pm 10\%$. Random error < $\pm 7\%$.

C.2.19

C.2.20

Cross Sections for Emission of He II Spectral Lines

Induced by Electron Impact on He:

Energy (eV)	Experimental Emission Cross Sections (cm ²)			
	(3→2) (1640 Å)	(4→2) (1251 Å)	(2 ² P→1 ² S) (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%.

C.2.21

Collisional Excitation of He^+ by Electron Impact:

Energy (eV)	Cross Sections (cm^2)		
	<u>Experimental</u>	<u>Theoretical</u>	
	<u>2s</u>	<u>3s</u>	<u>4s</u>
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:

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

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

Accuracy:

Random error $< \pm 10\%$.

C.2.23

C.2.24

Excitation of Carbon by Electrons:

Energy (eV)	Theoretical Cross Sections (cm ²)	
	<u>2p² ¹D</u>	<u>2p² ¹S</u>
1.0 E 00		
2.0 E 00	1.70 E-16	
3.0 E 00	1.75 E-16	8.00 E-19
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 02	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.

C.2.25

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Excitation of Carbon Ions by Electrons:

Energy (eV)	Theoretical Cross Sections (cm ²)		
	<u>C²⁺(2p ³P)</u>	<u>C³⁺(2p ²P^o)</u>	<u>C⁴⁺(2s ³S)</u>
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			2.90 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.]

C.2.27

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C.2.28

Excitation of O by Electrons:

Energy (eV)	Cross Sections (cm ²)		
	Theoretical	Theoretical	Experimental
	$2p^4 \ ^1D$	$2p^4 \ ^1S$	$1304 \text{ \AA Emission}$ $[3s \ ^3S + 2p^4 \ ^3P]$
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-13	
6.0 E 00	2.80 E-17	1.50 E-13	
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:

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

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

$e + O \rightarrow e + O(1304 \text{ \AA emission})$ 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).

C.2.30

Excitation of Oxygen Ions by Electrons:

Energy (eV)	Theoretical Cross Sections (cm ²)	
	<u>O⁺(2p⁴ ⁴P)</u>	<u>O⁵⁺(2p ²P)</u>
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:

$e + O^+ \rightarrow e + O^+(2p^4 \ ^4P)$ 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. Poshynaute, A.V. Lyash, A.B. Bolokin, Optics and Specy. 29, 424 (1970). Unfortunately this paper is not specific as to the precise final state.

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

[Continued at end of chapter.]

C.2.31

Excitation of O_2 by Electrons:

Energy (eV)	Experimental Cross Sections (cm ²)		
	$O_2(a^1\Delta_g)$	$O_2^+(b^4\Sigma_g^-)$	5632 \AA 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	2.40 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		3.39 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).

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

Accuracy:

$O_2(a^1\Delta_g)$ - total error < $\pm 50\%$. $O_2^+(b^4\Sigma_g^-)$ - random error < $\pm 5\%$; systematic error < $\pm 25\%$. $O_2^+(5632 \text{ \AA} \text{ band})$ - random error < $\pm 10\%$; systematic error < $\pm 10\%$.

C.2.34

Dissociation of O_2 into Excited Fragments by Electrons:

Energy (eV)	Experimental Cross Sections (cm ²)	
	$O(^5S^0)$	1300 Å Emission
1.5 ± 01		7.65 E-19
2.0 ± 01	2.53 E-18	1.42 E-18
3.0 ± 01	4.57 E-18	2.37 E-18
4.0 ± 01	6.59 E-18	2.95 E-18
5.0 ± 01	8.36 E-18	3.34 E-18
6.0 ± 01	9.89 E-18	3.60 E-18
8.0 ± 01	1.12 E-17	3.80 E-18
1.0 ± 02	1.17 E-17	3.74 E-18
1.5 ± 02	1.12 E-17	3.18 E-18
2.0 ± 02	1.02 E-17	2.68 E-18
3.0 ± 02	8.00 E-18	2.09 E-18

References:

$e + O_2 \rightarrow e + O + O(^5S^0)$ Exp.: W.C. Wells, W.L. Borst, and E.C. Zipf, Chem. Phys. Letts. 12, 288 (1971).

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

Accuracy:

$O(^5S^0)$ - Systematic error < ± 50%. Random error < ± 5%.

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

Excitation of Neon by Electrons.

Selected Excitation and Emission Cross Sections:

Energy (eV)	Experimental Cross Sections (cm ²)			
	² P ₁ State	5852 Å Emission (² P ₁ + ¹ S ₂)	3378 Å Emission (3p ² P _{1/2} + 3s ² P _{1/2})	2677 Å Emission (3p ¹ P + 3s ¹ S ⁰)
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:

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

$e + \text{Ne} \rightarrow e + \text{Ne} (5852 \text{ \AA} \text{ Emission})$ Exp.: F.A. Sharpton et al. (see above).

$e + \text{Ne} \rightarrow e + \text{Ne}^+ (3378 \text{ \AA} \text{ Emission})$ Exp.: K.G. Walker and R.M. St. John, Phys. Rev. A 6, 240 (1972).

$e + \text{Ne} \rightarrow e + \text{Ne}^{2+} (2677 \text{ \AA} \text{ Emission})$ Exp.: Yu.M. Smirnov and Yu. D. Sharonov, Optics and Spectry. 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.

C.2.37

Excitation of Neon Ions by Electrons:

 $e + \text{Ne}^{5+}$ See References Below $e + \text{Ne}^{6+}$ See References Below $e + \text{Ne}^{7+}(2s) \rightarrow e + \text{Ne}^{7+}(2p)$ $e + \text{Ne}^{8+}$ See References Below $e + \text{Ne}^{9+}$ See References Below

Energy (eV)	Theoretical Cross Section (cm ²)
	<u>$\text{Ne}^{7+}(2p)$</u>
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:

$e + \text{Ne}^{5+}$: 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).

$e + \text{Ne}^{6+}$: 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).

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

Excitation of Argon by Electrons:

Energy (eV)	Experimental Cross Sections (cm ²)			
	1s ₂ & 1s ₄ States (Sum of Two States)	1067 \AA Emission (1s ₄ →1p ₈)	7503 \AA Emission (2p ₁ →1s ₂)	4765 \AA Emission (4p ² P _{3/2} →4s ² P _{3/2})
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:

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

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

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

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

Accuracy:

Systematic error < $\pm 10\%$. Random error < $\pm 5\%$.

Notes:

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

C.2.41

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Excitation of Argon Ions by Electrons:

Energy (eV)	Experimental Cross Sections (cm ²)	
	4658 Å Emission ($4p^2 \rightarrow 4s^2$)	4880 Å Emission ($4p^2 \rightarrow 4s^2$)
1.7 E 01	2.00 E-19	6.50 E-19
1.8 E 01	9.60 E-19	2.99 E-18
1.9 E 01	1.75 E-18	5.37 E-18
2.0 E 01	2.51 E-18	7.90 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	4.91 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	1.23 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:

$e + \text{Ar}^+ \rightarrow e + \text{Ar}^+(4658 \text{ and } 4880 \text{ \AA} \text{ Emission})$ 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)].

$e + \text{Ar}^{7+}$: There are no cross section data, but rate coefficients have been measured in a plasma ($kT_e \sim 250 \text{ eV}$). See R.V. Datla, H.J. Kunze, and D. Petrini, Phys. Rev. A 6, 33 (1972).

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

Accuracy:

Systematic error $< \pm 40\%$. Random error $< \pm 15\%$.

C.2.43

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Excitation of Lithium Ions by Electrons:

Energy (eV)	Theoretical Cross Sections (cm ²)		
	<u>2¹S</u>	<u>2¹P</u>	<u>3¹S</u>
0.0 E 01			2.30 E-17
0.5 E 01			1.40 E-17
1.0 E 02			8.20 E-18
1.5 E 02			4.99 E-18
2.0 E 02			3.40 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	5.50 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:

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

$e + \text{Li}^+ \rightarrow e + \text{Li}^+(2^3S)$ Theoretical: I.L. Zeigman 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.

C.2.45

Excitation of Nickel by Electrons:

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

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

Energy (eV)	Theoretical Cross Sections (cm^2)	
	<u>3s $\rightarrow$ 3p</u>	<u>3p $\rightarrow$ 3d</u>
1.0 E 03	7.04 E-19	
1.5 E 03	7.09 E-19	2.05 E-19
2.0 E 03	6.32 E-19	2.12 E-19
2.5 E 03	5.81 E-19	1.97 E-19
3.0 E 03	5.15 E-19	1.83 E-19
3.5 E 03	4.66 E-19	1.63 E-19
4.0 E 03	4.23 E-19	1.40 E-19
4.5 E 03	3.79 E-19	1.23 E-19
5.0 E 03		1.11 E-19
5.5 E 03		9.70 E-20
6.0 E 03		8.73 E-20
6.5 E 03		7.93 E-20

References:

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

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

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

Accuracy:

See Note (7) at end of chapter.

0.2.47

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Excitation of Iron by Electrons:

For All Other States of Ionization See Reference List Below

Energy (eV)	Theoretical Cross Section (cm ²)
	<u>3s → 3p</u>
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:

$e + \text{Fe}^{15+} \rightarrow e + \text{Fe}^{15+}(3p)$: Theoretical: K.C. Mathur, A.W. 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^{15+}]; D. Petrini, Astron. & Astrophys. 1, 139 (1969) [Fe^{14+}]; P. 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.

C.2.49

C.2.51

Collisional Excitation of H by Electrons:

(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. Vainshtein, 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.

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C.2.52

Excitation of Carbon Ions by Electrons

(Continued)

$e + C^{2+} \rightarrow e + C^{2+}(2p^2P)$ Theoretical: I.L. Beigman and L.A. Vainshtein, *Zh. 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.] Petrinì 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 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.

C.2.53

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 normalizing 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 $2p\sigma$ 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 $2p\pi$ 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 too 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 0 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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C.3.2

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 $\pm 20\%$ over most of the energy scale.

H_2 : The total error is believed not to exceed $\pm 50\%$.

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.

C.3.4

Cross Sections for the Dissociation Reactions $e + H_2^+ \rightarrow H^+ + H + e$

and $e + N_2^+ \rightarrow N^+ + \text{Other Products}$

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 $\pm 20\%$ 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.

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).

C.3.7

C.3.8

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 [$H^+(0)/H^+(90^\circ)$]			
	<u>33.3 eV</u>	<u>48.3 eV</u>	<u>98.3 eV</u>	<u>298.3 eV</u>
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).

C.3.9

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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)	
	<u>$e+H \rightarrow H^+ + 2e$</u>	<u>$e+O \rightarrow O^+ + 2e$</u>
	<u>Experimental</u>	<u>Experimental</u>
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	
	<u>Theoretical</u>	
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 $\pm 15\%$ for H and $\pm 30\%$ for O.

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C.4.4

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 $\pm 25\%$.

C.4.5

C.4.6

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

<u>$e + H \rightarrow H^+ + 2e$</u>		<u>$e + H_2 \rightarrow H_2^+ + 2e$</u>	
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 $\pm 30\%$.

C.4.8

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

Energy (keV)	Cross Sections (cm ²)	
	<u>e + H₂</u>	<u>e + D₂</u>
	<u>Experimental</u>	<u>Experimental</u>
2.0 E-02	2.70 E-17	2.70 E-17
3.0 E-02	6.91 E-17	7.00 E-17
4.0 E-02	8.59 E-17	8.50 E-17
5.0 E-02	9.70 E-17	9.75 E-17
1.0 E-01	9.23 E-17	9.50 E-17
2.0 E-01	7.21 E-17	7.50 E-17
3.0 E-01	5.72 E-17	5.50 E-17
4.0 E-01	4.71 E-17	4.50 E-17
5.0 E-01	2.74 E-17	3.00 E-17
1.0 E 00	2.24 E-17	2.50 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	4.50 E-18
1.0 E 01	2.82 E-18	2.95 E-18
2.0 E 01	1.60 E-18	1.50 E-18
	<u>Theoretical</u>	
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 + H₂: 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 + D₂: 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 $\pm 12\%$ for H₂ and D₂.

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C.4.9

C.4.10

Cross Sections for the Dissociative Ionization of H_2 and D_2 Molecules
by Electron Impact Yielding Product H^+ and D^+ Ions with Kinetic Energies
Greater than 2.5 and 0.25 eV, Respectively

Energy (eV)	Cross Section (cm ²)	
	$e + H_2$	$e + D_2$
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:

$e + (H_2, D_2)$: P. 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 $\pm 30\%$.

C.4.11

C.4.12

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

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

<u>e + Ne</u>			
Energy (eV)	σ^{n+}/σ_T		
	<u>n = 3</u>	<u>n = 4</u>	<u>n = 5</u>
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 $\pm 20\%$.

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C.4.14

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

<u>$e + \text{He} \rightarrow \text{He}^+ + 2e$</u>		<u>$e + \text{N}_2 \rightarrow \text{N}_2^+ + 2e$</u>	
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:

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

$e + \text{N}_2$: R.E. Fox, J. Chem. Phys. 35, 1379 (1961).

Accuracy:

The total error is believed not to exceed $\pm 25\%$.

Note:

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

C.4.16

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

Energy (keV)	Cross Sections (cm ²)		
	<u>e + He</u>	<u>e + Ne</u>	<u>e + Ar</u>
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
<hr/>			
	<u>Theoretical</u>		
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 exceed $\pm 12\%$. e + Ne: The total error is believed not to exceed $\pm 15\%$. e + Ar: The total error is believed not to exceed $\pm 25\%$.

C.4.17

C.4.18

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

Energy (eV)	Cross Sections (cm ²)	
	<u>e + N</u>	<u>e + CO</u>
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%.

C.4.19

C.4.20

Total Cross Sections σ_T for Ionization of
Nitrogen and Oxygen Molecules by Electron Impact

Energy (eV)	Cross Sections (cm ²)	
	<u>e + N₂</u>	<u>e + O₂</u>
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 + N₂: 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 + O₂: 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 $\pm 15\%$ for e + N₂.

The total error is believed not to exceed $\pm 15\%$ for e + O₂.

C.4.22

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

Energy (eV)	e + Ar		σ^{n+}/σ_T	
	<u>n = 2</u>		<u>n = 3</u>	<u>n = 4</u>
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 03	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
	<u>n = 5</u>		<u>n = 6</u>	<u>n = 7</u>
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 $\pm 20\%$.

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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 ₂ O (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. Schroeder, D.H. Gündüg, 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 $\pm 50\%$. Carbon: The total error is believed not to exceed $\pm 30\%$. Water Vapor: The total error is believed not to exceed $\pm 30\%$.

C.b.25

C.4.26

Cross Sections for Ionization of Copper Atoms by Electron Impact

Energy (eV)	Cross Section (cm ²)	Cross Section (cm ²)
	<u>Cu⁺</u>	<u>Cu⁺⁺</u>
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 $\pm 30\%$.

C.4.27

**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

References:

- e + Rb: K.J. Nygaard and Y.B. Hahn, J. Chem. Phys. 58, 3493 (1973).
 e + K: R.H. McParland and J.D. Kinney, Phys. Rev. 137, A-1058 (1965).
 Yu. P. Korchevoi and A.M. Przhonskii, Sov. Phys. JETP 24, 1089 (1967).
 K.T. Nygaard, to be published.

Accuracy:

- e + Rb: The total error is believed not to exceed $\pm 18\%$.
 e + K: The total error is believed not to exceed $\pm 20\%$.

C.4.29

ORNL-DWG 75-2254

C.4.30

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+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 (1963). 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 $\pm 30\%$ for e + Cs.

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

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 $e + \text{CO}_2$ (cm^2)	Energy (eV)	σ $e + \text{He}^+ \rightarrow \text{He}^{2+} + 2e$ (cm^2)
1.5 E 01	6.6 E-18	5.0 E 01	4.3 E-17
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	3.3 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:

$e + \text{CO}_2$: D. Rapp and P. Englander-Golden, J. Chem. Phys. 43, 1464 (1965).

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

Accuracy:

$e + \text{CO}_2$: The total error is believed not to exceed $\pm 30\%$.

$e + \text{He}^+$: Maximum total error $\leq \pm 10\%$.

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-10	
2.0 E 01	4.31 E-10	
2.5 E 01	3.99 E-10	
3.0 E 01	3.72 E-10	
4.0 E 01	3.32 E-10	
6.0 E 01	2.78 E-10	2.78 E-10
8.0 E 01	2.43 E-10	2.43 E-10
1.0 E 02	2.17 E-10	2.17 E-10
1.5 E 02	1.71 E-10	1.71 E-10
2.0 E 02	1.41 E-10	1.41 E-10
2.5 E 02	1.20 E-10	1.20 E-10
3.0 E 02	1.03 E-10	1.03 E-10
4.0 E 02	8.00 E-11	8.00 E-11
6.0 E 02	5.40 E-11	
8.0 E 02	4.20 E-11	
1.0 E 03	3.50 E-11	
1.5 E 03	2.47 E-11	

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.

C.4.35

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C.4.36

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	
5.0 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	7.30 E-17	7.60 E-18
5.0 E 02	6.20 E-17	6.57 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.

C.4.37

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 ⁺ →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 $\pm 15\%$.

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

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)			
	$e+\text{Li}^+ \rightarrow \text{Li}^{2+} + 2e$	$e+\text{Li}^+ \rightarrow \text{Li}^{3+} + 3e$	$e+\text{Na}^+ \rightarrow \text{Na}^{2+} + 2e$	$e+\text{K}^+ \rightarrow \text{K}^{2+} + 2e$
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:

$e + \text{Li}^+$ (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).

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

$e + (\text{Na}^+, \text{K}^+)$: 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:

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

C.4.41

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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-19	
4.0 E 01	1.91 E-17	
6.0 E 01	3.65 E-17	7.90 E-19
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	1.06 E-17
6.0 E 02		9.70 E-18
8.0 E 02		7.90 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

ORNL-ORNL 75-2862

C.b.44

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

Energy (eV)	Cross Sections (cm ²)	
	<u>$e + O^+$</u>	<u>$e + O^{2+}$</u>
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.

C. L. HS

C.4.46

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

Energy (eV)	Cross Sections (cm^2)	
	$e + \text{Ca}^+$	$e + \text{Sr}^+$
1.7 E 01		5.00 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 $\pm 12\%$.

C.4.47

C.4.46

Cross Sections for Single Ionization of Ba⁺ and Tl⁺

Ions by Electron Impact

Energy (eV)	Cross Sections (cm ²)	
	<u>e+Ba⁺→Ba²⁺+e</u>	<u>e+Tl⁺→Tl²⁺+e</u>
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	1.63 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	9.90 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 ≤ ± 10% at E ≥ 20 eV; ± 25% at E = 15 eV.

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

C.4.49

ORNL-DM-73-2863

C.4.50

Cross Sections for Single Ionization of Mg^+ and Mg^{2+}

Ions by Electron Impact

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

References:

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

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

Accuracy:

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

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

C.6.51

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C.4.52

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

Energy (eV)	Cross Sections (cm^2)	
	$e + \text{Rb}^+$	$e + \text{Cs}^+$
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 $\pm 12\%$.

C.4.53

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)			
	<u>50 eV</u>	<u>100 eV</u>	<u>300 eV</u>	<u>1000 eV</u>
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. Beatty, 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%.

C.4.55

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. Beatty, and W.K. Peterson, Atomic Data 6, 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 $\pm 30\%$.

C.4.57

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C.5 Electron Attachment

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C.5.2

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

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 $\pm 5\%$.

C-5.3

C.5.4

Cross Section for the Production of H^- Ions by Dissociative

Attachment of Electrons in Hydrogen Gas

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 $\pm 35\%$.

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.

C.5.6

Cross Sections for Negative Ion Formation in H₂, HD, and D₂

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
3.50 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	8.80 E-25
4.00 E 00	8.50 E-22	6.00 E-23	9.20 E-25
4.30 E 00	4.25 E-22	3.55 E-23	3.55 E-25
4.40 E 00	3.50 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
4.90 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		5.00 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, 75 (1967).

Accuracy:

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

C.6.3

Calculated Recombination Coefficient $\alpha_{n,l}$ 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

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

$n \backslash l$	$T = 10,000^\circ\text{K}$											
	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	20.3	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

$n \backslash l$	$T = 20,000^\circ\text{K}$											
	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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C.6.4

Total Recombination Coefficient α for the Radiative Electron-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.k. 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

Recombination Coefficient α (cm ³ /sec)					
Level Formed Temp. (°K)	He Ground State	Excited He Singlets	Excited He Triplets	He Any Level	H Any Level
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 $e + O^+ \rightarrow O + \nu$

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).

C.6.5

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

at Various Temperatures T

Quantum Numbers of Final States		Recombination Coefficient $\alpha_{n,l}$ (cm ³ /sec)				
n	l	T=112.5° 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

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 E-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 → 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 → ∞	2.6 E-19 n _e	8.8 E-21 n _e	2.9 E-22 n _e	1.9 E-23 n _e	9.1 E-29 n _e	2.7 E-30 n _e

C.6.6

Reference:

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

C.6.7

C.6.8

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

Principal
Quantum
Number n

Recombination Coefficient α_n
(cm^3/sec)

	$T_e=250^\circ K$	$T_e=500^\circ K$	$T_e=1000^\circ K$	$T_e=2000^\circ K$	$T_e=4000^\circ K$	$T_e=8000^\circ K$
1	1.02 E-12	7.17 E-13	5.07 E-13	3.36 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	9.80 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	6.98 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

	$T_e=16000^\circ K$	$T_e=32000^\circ K$	$T_e=64000^\circ K$
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.

c.6.9

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

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	1.86 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.

c.6.11

C.6.12

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)

	$T_e=500^\circ K^*$	$T_e=500^\circ K^\dagger$	$T_e=500^\circ K^\ddagger$	$T_e=4000^\circ K^*$	
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	
	$T_e=4000^\circ K^\ddagger$	$T_e=4000^\circ K^*$	$T_e=32,000^\circ K^*$	$T_e=32,000^\circ K^\ddagger$	$T_e=32,000^\circ K^*$
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.

C-6.13

C.6.14

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)			
	$N=10^{12} cm^{-3}$	$N=10^{13} cm^{-3}$	$N=10^{14} cm^{-3}$	$N=10^{15} cm^{-3}$
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	
3.1 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).

c.6.15

C.6.16

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).

C.6.17

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 $n_e (\text{cm}^{-3})$	Recombination Coefficient α (cm^3/sec)				
	$N=10^{12} \text{cm}^{-3}$	$N=10^{13} \text{cm}^{-3}$	$N=10^{14} \text{cm}^{-3}$	$N=10^{15} \text{cm}^{-3}$	$N=10^{16} \text{cm}^{-3}$
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).

C.6.19

C.6.20

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

He Atom Density (cm^{-3})	Recombination Coefficient α (cm^3/sec)					
	<u>T=125° K</u>	<u>T=250° K</u>	<u>T=500° K</u>	<u>T=1000° K</u>	<u>T=2000° K</u>	<u>T=4000° K</u>
1.0 E 17	1.41 E-09	1.82 E-10	2.88 E-11	7.30 E-12	2.09 E-12	9.00 E-13
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	3.40 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	4.60 E-12
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).

c.6.21

C.6.22

Collisional-Radiative Recombination Coefficient α
for Electrons with H_2^+ Ions in H_2^+

Concentration
of H_2 Molecules
(cm^{-3})

Recombination Coefficient α
(cm^3/sec)

	$T=125^\circ K$	$T=225^\circ K$	$T=300^\circ K$	$T=1000^\circ K$	$T=2000^\circ K$	$T=2000^\circ K^*$
1.0×10^{17}	2.72×10^{-10}	6.95×10^{-11}	2.61×10^{-11}	1.15×10^{-11}	5.46×10^{-12}	1.07×10^{-12}
3.0×10^{17}	7.90×10^{-10}	2.03×10^{-10}	7.80×10^{-11}	3.35×10^{-11}	1.60×10^{-11}	1.40×10^{-12}
1.0×10^{18}	2.65×10^{-09}	6.90×10^{-10}	2.60×10^{-10}	1.10×10^{-10}	5.30×10^{-11}	1.90×10^{-12}
3.0×10^{18}	8.00×10^{-09}	2.05×10^{-09}	7.70×10^{-10}	3.25×10^{-10}	1.60×10^{-10}	2.50×10^{-12}
1.0×10^{19}	2.65×10^{-08}	6.90×10^{-09}	2.60×10^{-09}	1.09×10^{-09}	5.30×10^{-10}	3.35×10^{-12}
3.0×10^{19}	7.90×10^{-08}	2.00×10^{-08}	7.80×10^{-09}	3.25×10^{-09}	1.60×10^{-09}	4.40×10^{-12}
1.0×10^{20}	2.65×10^{-07}	6.85×10^{-08}	2.60×10^{-08}	1.07×10^{-08}	5.40×10^{-09}	5.90×10^{-12}
3.0×10^{20}	7.95×10^{-07}	2.00×10^{-07}	7.80×10^{-08}	3.20×10^{-08}	1.60×10^{-08}	7.80×10^{-12}
1.0×10^{21}		6.78×10^{-07}	2.61×10^{-07}	1.04×10^{-07}	5.41×10^{-08}	1.02×10^{-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.

C.6.23

C.6.24

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	2.55 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.

C.6.26

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 $n_e (\text{cm}^{-3})$	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).

C.6.29

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).

Total Recombination Coefficients α for the Radiative
and Dielectronic Recombination of He^+ Ions with Electrons

Temperature (°K)	Total Recombination Coefficient α (cm^3/sec)	
	<u>Radiative</u> <u>$\text{He}^+ + e \rightarrow \text{He}$</u>	<u>Dielectronic</u> <u>$\text{He}^+ + e \rightarrow \text{He}$</u>
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).

C.6.31

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-PC-383, January 1967, Association EURATOM-C.E.A., Fontenay-aux-Roses (France).

C.7.4

Cross Sections for Dissociative Recombination of Electrons

with H_2^+ and D_2^+ Ions

Energy (eV)	Cross Sections (cm^2)	
	$e + \text{H}_2^+ \rightarrow$ <u>Neutrals</u>	$e + \text{D}_2^+ \rightarrow$ <u>Neutrals</u>
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 $\pm 10\%$.

C.7.5

C.7.6

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

Energy (eV)	Cross Section (cm ²)
<u>$e + H_3^+ \rightarrow$ Neutral Products</u>	
2.5 E-02	2.73 E-14
3.0 E-02	2.31 E-14
4.0 E-02	1.79 E-14
6.0 E-02	1.23 E-14
8.0 E-02	9.52 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	2.24 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	5.18 E-16
2.5 E 00	4.20 E-16
3.0 E 00	3.58 E-16
4.0 E 00	2.76 E-16

References:

M.T. Leu, M.A. Biondi, and R. Johnsen, Phys. Rev. A 3, 413 (1973); E. Peart and K.T. Dolder, J. Phys. B. 7, 1948 (1974).

Accuracy:

The total error is believed not to exceed $\pm 15\%$.

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.

C.7.8

Cross Sections for Dissociative Recombination of Electrons

with O_2^+ and NO^+ Ions

Energy (eV)	Cross Sections (cm ²)	
	$e + O_2^+ \rightarrow$ <u>Neutrals</u>	$e + NO^+ \rightarrow$ <u>Neutrals</u>
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		3.81 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	5.33 E-16
1.5 E 00	6.90 E-16	2.77 E-16
2.0 E 00	2.85 E-16	2.82 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 $\pm 30\%$.

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

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

Accuracy:

Where two significant digits are given, the total error probably does not exceed $\pm 20\%$.

Where only one significant digit is given, the total error probably exceeds $\pm 30\%$.

D. Surface Collisions

D.1 Sputtering

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D.1.4

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

Energy (keV)	Sputtering Coefficients, S (atoms/ion)		
	<u>Cu</u>	<u>SiC</u>	<u>Graphite</u>
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

D.1.5

D.1.6

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

Energy (keV)	Sputtering Coefficients, S (atoms/ion)			
	<u>Fe</u>	<u>SS</u>	<u>Nb</u>	<u>Ta</u>
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.

D.1.7

D.1.8

Sputtering of Ti, Mo and W by Protons (normal incidence)

Energy (keV)	Sputtering Coefficients, S (atoms/ion)			
	<u>Mo</u>	<u>Ti</u>	<u>W</u>	<u>W[†]</u>
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		

References:

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.

Accuracy:

Unknown

Notes:

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

D.1.9

ORNL-DWG 76-12235

D.1.10

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

Energy (keV)	Sputtering Coefficients, S (atoms/ion)		
	<u>Au</u>	<u>Ag</u>	<u>Zr</u>
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. Grönlund and W. J. Moore, J. Chem. Phys. 32, 1540 (1960); C. D. O'Brian, 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 #ORD-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.

D.1.11

ORNL-DWG 76-12236

D.1.12

Sputtering Coefficients for D^+ on Cu, Al, Ni, and Fe
(normal incidence)

Energy (keV)	Sputtering Coefficients, S (atoms/ion)	
	<u>Cu</u>	<u>Al</u>
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. to 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

D.1.14

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

Energy (keV)	Sputtering Coefficients, S (atoms/ion)		
	<u>SS</u>	<u>Mo</u>	<u>Ag</u>
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. Grönlund, 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

D.1.15

ORNL-DWG 76-12238

D.1.16

Sputtering Coefficients for D^+ on Nb, Nb-Zr,

Ta, W, and Au (normal incidence)

Energy (keV)	Sputtering Coefficients, S (atoms/ion)				
	<u>Nb</u>	<u>Nb-Zr</u>	<u>Ta</u>	<u>W</u>	<u>Au</u>
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

D.1.17

ORNL-DWG 76-12239

D.1.18

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)					
	<u>Be</u>	<u>Fe</u>	<u>Nb</u>	<u>Cu</u>	<u>Ag</u>	<u>Isolated Points</u>
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. Grönlund, 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

D.1.19

D.1.20

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)				
	<u>Be</u>	<u>Fe</u>	<u>Cu</u>	<u>Ag</u>	<u>Isolated Points</u>
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. Gröndlund, 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

D.1.21

D.1.22

Sputtering Coefficients of He⁺ on

C, Be, Al, Si, and Ti

Energy (keV)	Sputtering Coefficients, S (atoms/ion)				
	<u>C</u>	<u>Be</u>	<u>Al</u>	<u>Si</u>	<u>Ti</u>
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⁺ → C: D. Rosenberg, G. K. Wehner, J. Appl. Phys. 33, 1842 (1962); V. M. Gusev, et al., IAE ER Kurchatov, Moscow, Rpt. No. OLS-7-75.

He⁺ → Be: H. Fetz, H. Oechsner, 6th Int. Conf. Ionization Phenomena Gases, Paris (1963), II, 37; 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).

He⁺ → Al: D. Rosenberg, G. K. Wehner, J. Appl. Phys. 33, 1842 (1962); O. C. Younts, 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.

D.1.24

Sputtering Coefficients of He^+ on

Zr, Nb, Ag, Pt, and Au

Energy (keV)	Sputtering Coefficients, S (atoms/ion)				
	<u>Zr</u>	<u>Nb</u>	<u>Ag</u>	<u>Pt</u>	<u>Au</u>
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:

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

$\text{He}^+ \rightarrow \text{Nb}$: 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 $\text{He}^+ \rightarrow \text{Nb-Zr}$.

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

Accuracy:

Unknown

Notes:

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

D.1.25

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

Energy (keV)	Sputtering Coefficients, S (atoms/ion)							
	<u>V</u>	<u>Cr</u>	<u>Fe</u>	<u>Ni</u>	<u>Cu</u>	<u>Mo</u>	<u>Ta</u>	<u>W</u>
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-03	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.).

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Sputtering Coefficients for Nitrogen Ions
on Copper, Silver and Gold

Energy (keV)	Sputtering Coefficients, S (atoms/ion)					
	$N^+ + Ag$	$N^+ + Cu$		$N_2^+ + Cu$		$N_2^+ + Au$
		Normal	45°-50°	Normal	45°-50°	
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. Grönlund, 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.

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D.1.29

D.1.30

Self-Sputtering Coefficients for

Al, Ni, Cu, Ag, and Au

(normal incidence)

Energy (keV)	Self-Sputtering Coefficients, S (atoms/ion)				
	<u>Al</u>	<u>Ni</u>	<u>Cu</u>	<u>Ag</u>	<u>Au</u>
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	

References:

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

Accuracy:

Unknown

D.1.32

Self-Sputtering Coefficients for Si,

Cr, and Zn (normal incidence)

Energy (keV)	Self-Sputtering Coefficients, S (atoms/ion)		
	<u>Si⁺ → Si</u>	<u>Cr⁺ → Cr</u>	<u>Zn⁺ → Zn</u>
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⁺ → Si: O. Almén, G. Bruce, Nucl. Instr. & Meth. 11, 279 (1961).Cr⁺ → Cr: W. H. Hayward, A. R. Wolter, J. Appl. Phys. 40, 2911 (1969).Zn⁺ → Zn: A Fontell, E. Arminen, Can. J. Phys. 47, 2405 (1969).Accuracy:

Unknown

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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^0	Ag	9.0 E 00	2.6 E 00	3	1969
O^0	Au	9.0 E 00	1.7 E 00	3	1969
O_2^0	Ag	9.0 E 00	6.0 E 00	3	1969
O_2^0	Au	9.0 E 00	2.8 E 00	3	1969
O_3^0	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. Grönlund, W. J. Moore, J. Chem. Phys. 32, 1540 (1960).
3. F. M. Devienne, A. Roustan, Compt. Rend. 268B, 1362 (1969).

Accuracy:

Unknown

D.1.35

Self-Sputtering of V, Fe, Zr, Nb, Mo, Ta,
and K^+ 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

^fForward sputtering; ^bBackward 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. Gehler, 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. Miremadí, N. M. A. Finney, Phys. Rev. 185, 490 (1969).

D.1.38

- (11) $\text{He}^+ \rightarrow \text{Ti}$: 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) $\text{He}^+ \rightarrow \text{Ag}$: D. Rosenberg, G. K. Wehner, J. Appl. Phys. 33, 1842 (1962); F. Grönlund, 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) $\text{He}^+ \rightarrow \text{Pt}$: D. Rosenberg, G. K. Wehner, J. Appl. Phys. 33, 1842 (1962).
- (16) $\text{He}^+ \rightarrow \text{Au}$: 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) $\text{He}^+ \rightarrow \text{V}$, $\text{He}^+ \rightarrow \text{Cr}$, $\text{He}^+ \rightarrow \text{Mo}$, $\text{He}^+ \rightarrow \text{Ta}$, $\text{He}^+ \rightarrow \text{W}$: D. Rosenberg, G. K. Wehner, J. Appl. Phys. 33, 1842 (1962).
- (20) $\text{He}^+ \rightarrow \text{Fe}$: 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) $\text{He}^+ \rightarrow \text{Ni}$: 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) $\text{He}^+ \rightarrow \text{Cu}$: 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, U. 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. Younts, 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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D.2.2

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 < $\pm 5\%$. Random error < $\pm 2\%$.

Notes:

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

8, SECONDARY ELECTRON EMISSION
COEFFICIENT (electrons/electron)

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D.2.4

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.

D.2.6

Emission of Secondary Electrons by Electron Impact

on a Polycrystalline 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 < $\pm 5\%$. Random error < $\pm 2\%$.

Notes:

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

D.2.8

Emission of Secondary Electrons by Electron Impact

on a Polycrystalline 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 $< \pm 10\%$ for $E < 9$ keV. Systematic error unknown for
 $E > 20$ keV. Random error $< \pm 5\%$.

Notes:

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

Emission of Secondary Electrons by Electron Impact

on a Polycrystalline 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 < $\pm 5\%$. Random error < $\pm 2\%$.

Notes:

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

D.2.12

Emission of Secondary Electrons by Electron Impact
on a Polycrystalline 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
3.0 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 $< \pm 10\%$ for $E < 4$ keV. Systematic error unknown for $E > 4$ keV. Random error $< \pm 5\%$.

Notes:

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

Notes

- (1) Data given here are appropriate to a pyrolytic 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 δ 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, 781 (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

D.3.2

Secondary Electron Emission by Impact of Ions

on a Carbon (Graphite) Target:

(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:

$\text{H}^+, \text{H}_2^+, \text{H}_3^+$ on C: L.N. Large, W.S. Whitlock, Proc. Phys. Soc. 79, 148 (1962).

Accuracy:

Systematic error $< \pm 5\%$. Random error $< \pm 5\%$.

Notes:

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

D.3.3

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D.3.4

Secondary Electron Emission by Impact of Ions

on a Polycrystalline 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.N. 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 $< \pm 5\%$. Random error $< \pm 2\%$.

D.3.5

D.3.6

Secondary Electron Emission by Impact of Ions

on a Polycrystalline 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.M. Large, W.S. Whitlock, Proc. Phys. Soc. 72, 148 (1962).

Accuracy:

Systematic error < $\pm 5\%$. Random error < $\pm 5\%$.

Notes:

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

D.3.7

D.3.8

Secondary Electron Emission by Impact of Ions

on a Polycrystalline 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	2.94 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 < $\pm$ 5%. Random error < $\pm$ 10%.

Notes:

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

D.3.10

Secondary Electron Emission by Impact of Hydrogenic

Ions on a Polycrystalline Molybdenum Target:

(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 $< \pm 5\%$. Random error $< \pm 5\%$.

Notes:

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

D.3.11

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D.3.12

Secondary Electron Emission by Impact of Hydrogenic

Ions on a Polycrystalline Tungsten Target:

(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
7.0 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 < $\pm 5\%$. Random error < $\pm 5\%$.

D.3.14

Secondary Electron Emission by Impact of Helium

Ions on a Polycrystalline Molybdenum Target:

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

(Projectiles Incident Normally on Target)

Impact Energy (keV)	Secondary Emission Coefficient γ Electrons/Ion	
	<u>He^{2+}</u>	<u>He^+</u>
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	7.35 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 < $\pm 2\%$. Random error < $\pm 2\%$.

Notes:

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

D.3.16

Secondary Electron Emission by Impact of Ions
and Atoms on a Polycrystalline Tungsten Target:

He^+ , He , O^+ , O_2^+ on W

(Projectile Incident Normally on Target)

Impact Energy (keV)	Secondary Emission Coefficient γ Electrons/Ion			
	<u>He^+</u>	<u>He^0</u>	<u>O^+</u>	<u>O_2^+</u>
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:

$\text{He}^+ + \text{W}$: 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.W. Large, Proc. Phys. Soc. 81, 1101 (1963).

$\text{He}^0 + \text{W}$: H.W. Berry, J. Appl. Phys. 29, 1219 (1958).

O^+ and $\text{O}_2^+ + \text{W}$: L.W. Large, Proc. Phys. Soc. 81, 1101 (1963).

Accuracy:

Systematic error < $\pm 5\%$. Random error < $\pm 2\%$.

Notes:

See Note (6) at end of chapter.

D.3.18

Secondary Electron Emission by Impact of Oxygen

Ions on a Polycrystalline 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 $< \pm 5\%$. Random error $< \pm 2\%$.

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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

D.4.2

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

References:

J. Hölzl and K. Jacobi, Surface Sci. 14, 351 (1969). P. Palluel, Comptes Rendus 254, 1492 (1947). R.W. Dressel, Phys. Rev. 144, 332 (1966).

Accuracy:

Systematic error < $\pm 5\%$. Random error < $\pm 5\%$.

Notes:

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

D.4.3

D.4.4

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.

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D.4.5

D.4.6

Backscattering of Electrons Resulting from Electron Impact on a Polycrystalline Iron Surface (Electrons Incident Normally to Surface)

e on Fe

Energy of Impact Backscattering Coefficient η (keV) 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	2.93 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 < $\pm 5\%$. Random error < $\pm 5\%$.

Notes:

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

D.4.8

Backscattering of Electrons Resulting from Electron Impact on a Polycrystalline 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). Z. Weinryb and J. Philibert, Comptes Rendus 258, 4535 (1964).

Accuracy:

Systematic error < $\pm 5\%$. Random error < $\pm 5\%$.

Notes:

See Notes (1), (3), and (4) at end of chapter.

D.4.9

**Backscattering of Electrons Resulting from
Electron Impact on a Polycrystalline 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. 25, 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 < $\pm 10\%$. Random error < $\pm 5\%$.

Notes:

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

D.4.12

D.4.12

Backscattering of Electrons Resulting from Electron Impact on a Polycrystalline 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 $< \pm 10\%$. Random error $< \pm 5\%$.

Notes:

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

D.4.14

Backscattering of Electrons Resulting from Electron Impact on a Polycrystalline 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. Weinsyb 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 $< \pm 10\%$. Random error $< \pm 5\%$.

Notes:

D.4.15

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. 2, 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 $< \pm 5\%$.

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.

D.5.3

D.5.4

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			
	<u>80°</u>	<u>75°</u>	<u>70°</u>	<u>65°</u>
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 < $\pm 5\%$.

D.5.5

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D.5.6

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)		
	<u>Be</u>	<u>Nb</u>	<u>Ta</u>
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 $< \pm 10\%$.

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D.5.8

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.

D.5.10

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 $< \pm 10\%$.

D.5.12

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		
	<u>Al</u>	<u>Mo</u>	<u>Au</u>
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

D.5.14

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 $< \pm 5\%$.

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.

D.5.15

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D.5.16

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	Incident
	He^+	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.

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D.5.18

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.

D.5.19

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E. Transport Properties of Electrons, Ions, and Neutrals

E.1 Electron Drift Velocities and Diffusion

E.1.5

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, $\vec{E}$. $\vec{v}_d$ is usually expressed in cm/sec.

κ = mobility of electron, defined by the equation $\vec{v}_d = \kappa \vec{E}$. κ is usually expressed in $\text{cm}^2/\text{V-sec}$.

E/N = electron energy parameter = ratio of electric field intensity to gas number density. E/N is usually expressed in units of $(\text{volts/cm})/(1/\text{cm}^3) = \text{V-cm}^2$.

T_d = unit of E/N , the "Townsend" = 10^{-17} V-cm^2 .

D = $\begin{vmatrix} D_T & 0 & 0 \\ 0 & D_T & 0 \\ 0 & 0 & D_L \end{vmatrix}$ = 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/κ and D_T/κ are measures of the average electron energy at a given E/N .

In the limit $E/N \rightarrow 0$, $D_L = D_T = D$, 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_{mel} = electron momentum transfer cross section (considering only elastic impacts), defined by the equation

$$q_{\text{mel}} = \int (1 - \cos \theta) I_s(\theta) d\Omega_{\text{CM}}$$

where θ is the scattering angle in the center-of-mass system and $I_s(\theta)d\Omega_{\text{CM}}$ 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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E.1.6

The Momentum Transfer Cross Section for Elastic Collisions of Electrons in H₂

Energy (eV)	q_{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 $\pm 5\%$.

E.1.8

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 $T=77^\circ K$ (cm/sec)	D_T/K $T=77^\circ K$ (volts)	E/N (Td)	v_d $T=293^\circ K$ (cm/sec)	D_T/K $T=293^\circ K$ (cm/sec)
2.0 E-03		6.76 E-03	2.0 E-02	3.11 E 04	2.69 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	3.15 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	9.52 E-02
1.4 E-01	2.18 E 05	2.47 E-02	2.0 E 00	8.37 E 05	1.68 E-01
2.0 E-01	2.79 E 05	2.94 E-02	4.0 E 00	1.15 E 06	2.95 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	1.92 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 $\pm 3\%$ for v_d , $\pm 2\%$ for D_T/K at $T = 77^\circ K$, and $\pm 5\%$ for D_T/K at $T = 293^\circ K$.

E.1.10

The Product ND_T at Two Temperatures and the Ratio D_L/K at $T = 300^\circ \text{K}$
for Electrons in H_2 as a Function of E/N

E/N (Td)	ND_T $T=77^\circ \text{K}$ ($\text{cm}^{-1}\text{sec}^{-1}$)	E/N (Td)	ND_T $T=293^\circ \text{K}$ ($\text{cm}^{-1}\text{sec}^{-1}$)	D_L/K^* $T=300^\circ \text{K}$ (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	6.00 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 $\pm 3\%$ for ND_T and $\pm 5\%$ for D_L/K .

* Measured at $T = 300^\circ \text{K}$.

E.1.12

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 $T=77^\circ \text{ K}$ (cm/sec)	D_T/K $T=77^\circ \text{ K}$ (volts)	E/N (Td)	v_d $T=293^\circ \text{ K}$ (cm/sec)	D_T/K $T=293^\circ \text{ K}$ (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 $\pm 2\%$ for v_d and $\pm 2\%$ for D_T/K .

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E.1.14

The Product ND_T for Electrons in D_2 as a Function
of E/N at Two Temperatures

E/N (Td)	ND_T $T=77^\circ K$ ($cm^{-1}sec^{-1}$)	E/N (Td)	ND_T $T=293^\circ K$ ($cm^{-1}sec^{-1}$)
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 $\pm 3\%$.

E.1.16

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 = 0.005 Tl			E/N = 2.0 Tl		
Energy (eV)	$\frac{dne}{dE}$ (cm ⁻¹)	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	4.88 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	4.09 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%.

* $E^{1/2} \int_0^E f(E) dE$ is the fraction of electrons in the swarm with energies between 0 and $E + dE$.

E.1.18

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 $T=77^\circ \text{ K}$ (cm/sec)	D_T/K $T=293^\circ \text{ K}$ (volts)	E/N (Td)	v_d $T=293^\circ \text{ K}$ (cm/sec)	D_T/K $T=77^\circ \text{ K}$ (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 $\pm 1\%$ for v_d , $\pm 3\%$ for D_T/K at $T = 77^\circ \text{ K}$, and $\pm 1\%$ for D_T at $T = 293^\circ \text{ K}$.

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E.1.19

The Product ND_T and the Ratio D_L/K for Electrons
in He as a Function of E/K at a Temperature $T = 293^\circ \text{K}$

E/K (Ti)	ND_T $T=293^\circ \text{K}$ ($\text{cm}^{-1}\text{sec}^{-1}$)	D_L/K $T=293^\circ \text{K}$ (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	6.03 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	1.35 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 $\pm 2\%$ for ND_T and $\pm 3\%$ for D_L/K .

* Values measured at $T = 300^\circ \text{K}$.

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E.2 Ion Drift Velocities, Mobility, and Diffusion

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E.2.2

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 $\text{cm}^2/\text{V-sec}$.

K_0 = reduced mobility of ion = mobility of ion reduced to S.T.P., defined by the equation

$$K_0 = \frac{p}{760} \frac{273.16}{T} K,$$

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 $(\text{volts/cm})/(\text{l/cm}^3) = \text{V} - \text{cm}^2$.

$K_0(0)$ = zero-field reduced mobility = K_0 in the limit $E/N \rightarrow 0$.

Td = unit of E/N , the "Townsend" = $10^{-17} \text{ V} - \text{cm}^2$.

v_d = $0.0269 \times (E/N) \times K_0$, where v_d is in 10^5 cm/sec , E/N is in Td , and K_0 is in $\text{cm}^2/\text{V}^0 - \text{sec}$.

$$\vec{D} = \begin{vmatrix} D_T & 0 & 0 \\ 0 & D_T & 0 \\ 0 & 0 & D_L \end{vmatrix} = \text{ionic diffusion tensor.}$$

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.

In the limit $E/N \rightarrow 0$, $D_L = D_T = D$, 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_0 in $\text{cm}^2/\text{V}\cdot\text{sec}$ of Ions in He Gas at 300°K

Ion	K_0	Reference
He^+	10.40 ± 0.10	E.C. Beaty and P.L. Patterson, Phys. Rev. <u>137</u> , A-346 (1965).
He_2^+	16.70 ± 0.17	E.C. Beaty and P.L. Patterson, Phys. Rev. <u>137</u> , A-346 (1965).
$\text{He}_2^{+m} (^4\Sigma_u^+)$ (metastable)	19.6 ± 0.3	E.C. Beaty and P.L. Patterson, Phys. Rev. <u>137</u> , A-346 (1965).
H^+	31.8 ± 1.3	O.J. Orient, J. Phys. B <u>4</u> , 1257 (1971).
D^+	24.9 ± 1.0	O.J. Orient, J. Phys. B <u>5</u> , 1056 (1972).

E.2.4

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	1.4 E 04		4.7 E 04
5.0 E 00	1.7 E 04	1.8 E 04	7.0 E 04
6.0 E 00	3.0 E 04	2.4 E 04	9.0 E 04
1.0 E 01	4.3 E 04	3.1 E 04	1.2 E 05
1.5 E 01	5.2 E 04	3.6 E 04	1.4 E 05
2.0 E 01	6.9 E 04	4.9 E 04	1.8 E 05
2.5 E 01	8.6 E 04	6.1 E 04	2.2 E 05
3.0 E 01	1.1 E 05	7.4 E 04	2.8 E 05
4.0 E 01	1.3 E 05	9.2 E 04	3.4 E 05
5.0 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	5.1 E 05
8.0 E 01	3.2 E 05	2.9 E 05	
1.0 E 02	3.8 E 05		

Reference:

A. Granam, D.R. James, W.C. Keever, D.L. Albritton, and E.M. McDaniel,
J. Chem. Phys. 59, 3477 (1973).

Accuracy:

The total error is believed not to exceed $\pm 10\%$.

E.2.6

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 $\pm 10\%$.

E.2.7

E.2.8

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_0 ($cm^2/v\text{-sec}$)	H_3^+ Ions in H_2 K_C ($cm^2/v\text{-sec}$)
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 $\pm 4\%$.

E.2.9

E.2.10

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 ($cm^{-1}sec^{-1}$)
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 $\pm 10\%$.

R.2.11

E.2.12

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 ($\text{cm}^{-1}\text{sec}^{-1}$)	D_3^+ Ions in D_2 ND_L ($\text{cm}^{-1}\text{sec}^{-1}$)	D^- Ions in D_2 ND_L ($\text{cm}^{-1}\text{sec}^{-1}$)
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	

Reference:

Z. 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 $\pm 10\%$.

ORNL-DWG 75-7904

E.2.14

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:

Z. Graham, L.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 $\pm 2\%$.

E.2.16

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 $\bar{\mu}_0$ (cm ² /v-sec)	D_3^+ Ions in D_2 $\bar{\mu}_0$ (cm ² /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	9.36 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

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 $\pm 4\%$.

ORNL-DWG 75-7902

F.2.18

Drift Velocities of He^+ Ions in He, Ne^+ Ions in He, 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. 94, 615 (1951).

Accuracy:

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

E.3 Diffusion Coefficient of Neutral Particles

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E.3.2

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

Reference:A.C. Allison and F.J. Smith, Atomic Data 3, 317 (1971).Accuracy:The total error is believed not to exceed $\pm 5\%$.

E.3.4

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 $\pm 15\%$ for the H₂ - He and H₂ - D₂ data, and $\pm 30\%$ for the H - H₂ and H - He data.

F. Nuclear Reactions

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F.1.2

Cross Sections and Reaction Rates for the $D(d,n) \text{ }^3\text{He}$ 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

References:

G. H. Wiley, E. Towner, and N. Ivich, "Fusion Cross Sections and Reactivities," COO-2218-17 (1974); Battelle Pacific Northwest Laboratories Annual Report, edited by W. C. Welkenhauer, BNWL-1685 (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 7.5 keV. Data below this energy represent an extrapolation using analytical expressions.

F.1.3

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.1.6

Cross Sections and Reaction Rates

for the Reaction $T(t,2n) \text{ }^4\text{He}$

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.

F.1.7

F.1.8

Cross Sections and Reaction Rates for the T(d,n) ⁴He 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.

F.1.9