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ATOMIC DATA for CONTROLLED FUSION RESEARCH

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ATOMIC DATA FOR CONTROLLED FUSION RESEARCH

C. F. Barnett, J. A. Ray, E. Ricci, M. I. Wilker
Oak Ridge National Laboratory

E. W. McDaniel, E. W. Thomas
Georgia Institute of Technology

and

H. B. Gilbody
Queens University, Belfast

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Oak Ridge National Laboratory
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ABSTRACT

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

FOREWORD

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

INTRODUCTION

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

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

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

A. Heavy Particle Collisions

A.1 Heavy Particle Scattering

Elastic Scattering of H^o Induced by H^o Impact on H

$H + H \rightarrow H + H$

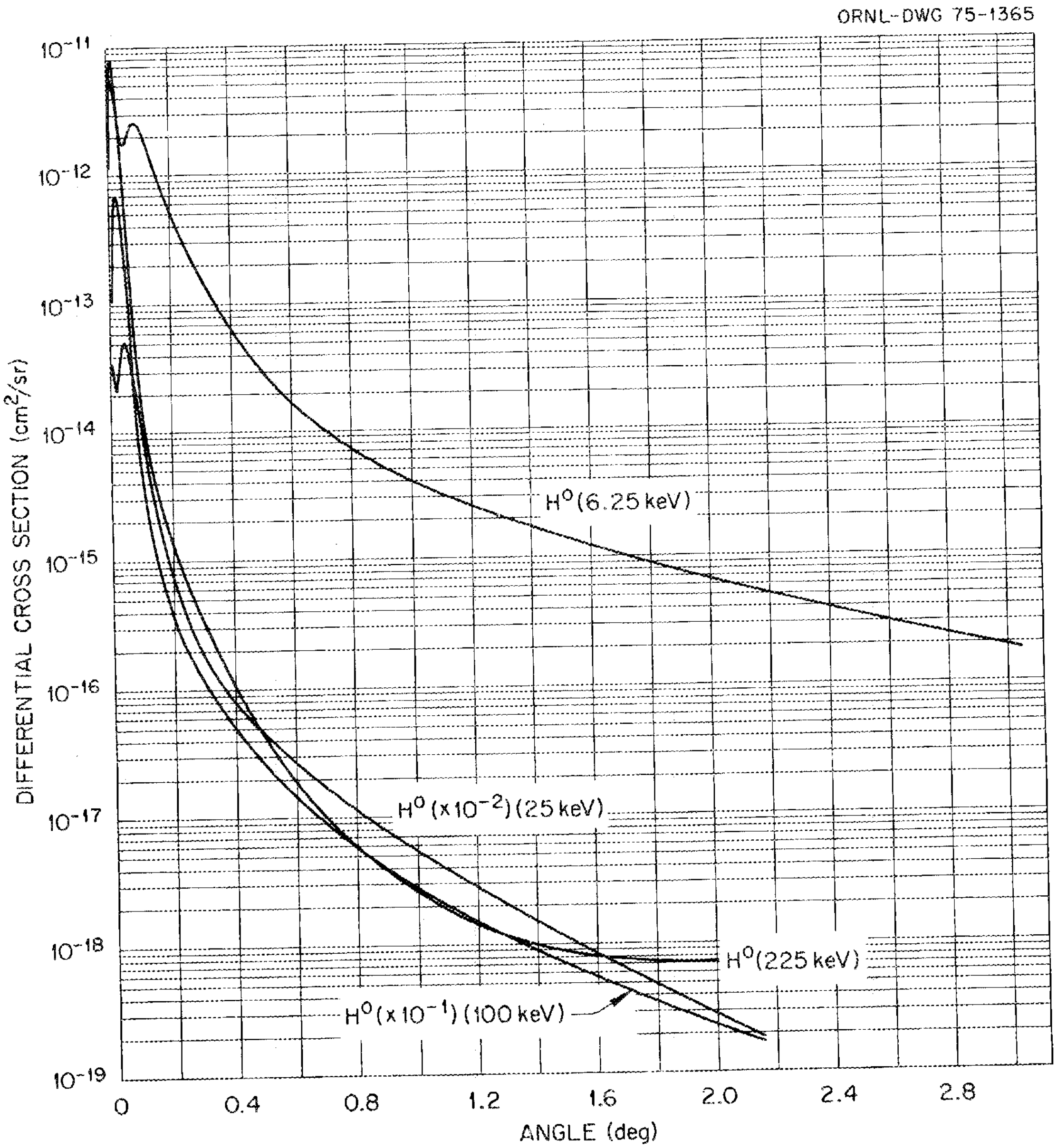
Angle (deg)	Differential Cross Sections (cm^2/sr)			
	6.25 keV Impact	25 keV Impact	100 keV Impact	225 keV Impact
0.0 E-01	6.79 E-12	3.61 E-12	1.31 E-12	6.38 E-13
1.0 E-01	2.50 E-12	1.18 E-12	4.40 E-14	1.54 E-14
2.0 E-01	5.17 E-13	7.68 E-14	3.60 E-15	1.27 E-15
3.0 E-01	1.61 E-13	1.80 E-14	1.10 E-15	3.38 E-16
4.0 E-01	6.50 E-14	8.19 E-15	4.90 E-16	1.09 E-16
5.0 E-01	3.15 E-14	4.48 E-15	2.59 E-16	4.29 E-17
6.0 E-01	1.73 E-14	2.70 E-15	1.46 E-16	1.91 E-17
8.0 E-01	7.00 E-15	1.14 E-15	5.80 E-17	5.60 E-18
1.0 E 00	4.00 E-15	5.52 E-16	2.80 E-17	2.60 E-18
1.5 E 00	1.46 E-15	1.11 E-16	7.18 E-18	8.70 E-19
2.0 E 00	6.60 E-16	2.74 E-17	2.35 E-18	7.10 E-19
2.5 E 00	3.33 E-16			
3.0 E 00	1.86 E-16			

Reference:

H + H, Theoretical: M. R. Flannery and K. J. McCann, Phys. Rev. A **9**, 1947 (1974).

Accuracy:

These theoretical predictions have not been experimentally tested, and their reliability is unknown. The theory neglects excitation of the target, so the cross sections are certainly low; this will be most serious at the higher impact energies.


ORNL-DWG 75-1365
DIFFERENTIAL CROSS SECTION (cm²/sr)
10⁻¹¹
10⁻¹²
10⁻¹³
10⁻¹⁴
10⁻¹⁵
10⁻¹⁶
10⁻¹⁷
10⁻¹⁸
10⁻¹⁹
H⁰(6.25 keV)
H⁰(x10⁻²)(25 keV)
H⁰(225 keV)
H⁰(x10⁻¹)(100 keV)
0
0.4
0.8
1.2
1.6
2.0
2.4
2.8
ANGLE (deg)

Elastic Scattering of H^+ Induced by H^+ Impact on H

$$H^+ + H \rightarrow H^+ + H$$

Angle (deg)	Differential Cross Sections (cm^2/sr)		
	6.25 keV Impact	25 keV Impact	225 keV Impact
0.0 E-01	2.00 E-11	4.71 E-11	8.08 E-11
1.0 E-01	5.40 E-12	1.30 E-12	3.74 E-14
2.0 E-01	7.23 E-13	1.35 E-13	1.74 E-15
3.0 E-01	2.26 E-13	3.26 E-14	2.82 E-16
4.0 E-01	1.01 E-13	1.10 E-15	
5.0 E-01	5.10 E-14	4.84 E-15	
6.0 E-01	2.80 E-14	2.42 E-15	
8.0 E-01	1.12 E-14		
1.0 E 00	5.30 E-15		
1.5 E 00	1.11 E-15		
2.0 E 00	2.71 E-16		

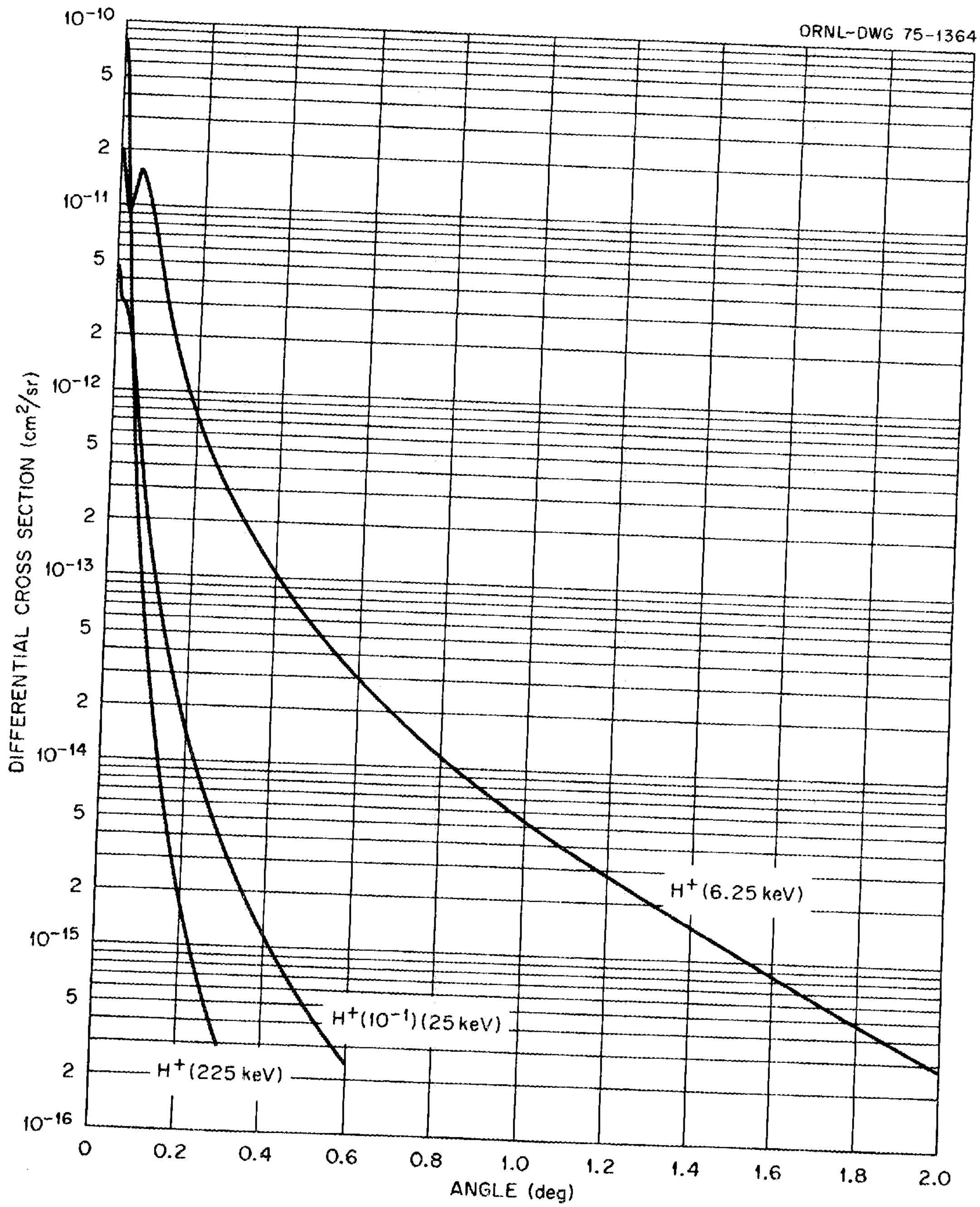
Reference:

H^+ + H: Theoretical data. M.R. Flannery and K.J. McCann, J. Phys. B (to be published). This paper discusses only the basis for the calculation and displays no data; the data presented here were obtained by private communication with the authors.

Accuracy:

These theoretical predictions have not been experimentally tested, and their reliability is unknown. The theory neglects excitation of the target so the cross sections are certainly low; this will be most serious at the higher impact energies.

Note added in proof: For experimental data in the energy range 250 - 2000 eV see J. C. Houver, J. Fayeton, and M. Barat, J. Phys. B 7, 1358 (1974).


ORNL-DWG 75-1364
DIFFERENTIAL CROSS SECTION (cm²/sr)
ANGLE (deg)
10⁻¹⁰
5
2
10⁻¹¹
10⁻¹²
10⁻¹³
10⁻¹⁴
10⁻¹⁵
10⁻¹⁶
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
H⁺(6.25 keV)
H⁺(10⁻¹)(25 keV)
H⁺(225 keV)

Angular Distribution of H^+ Formed as H^O Traverses a Target of H_2

$$H^O + H_2 \rightarrow H^+ + e + H_2$$

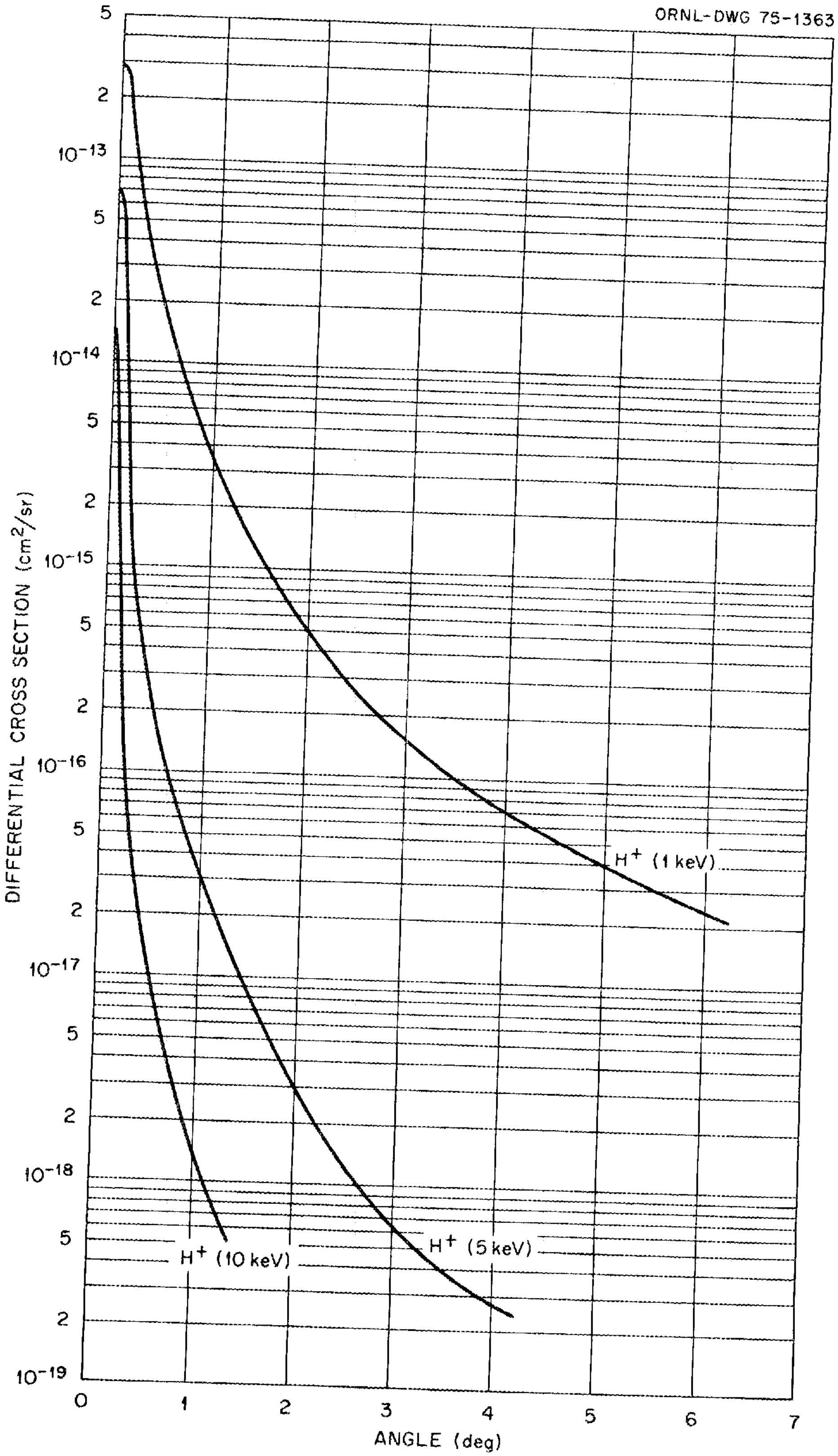
Angle (deg)	Differential Cross Sections (cm^2/sr)		
	1 keV Impact	5 keV Impact	10 keV Impact
	H^+	H^+	H^+
0.0 E-01	2.90 E-13	7.20 E-12	1.44 E-11
1.0 E-01	2.20 E-13	3.20 E-12	1.30 E-12
2.0 E-01	9.00 E-14	2.50 E-13	1.75 E-13
3.0 E-01	4.54 E-14	7.00 E-14	4.60 E-14
4.0 E-01	2.71 E-14	3.20 E-14	1.95 E-14
6.0 E-01	1.26 E-14	1.16 E-14	6.28 E-15
8.0 E-01	6.29 E-15	5.55 E-15	2.80 E-15
1.0 E 00	3.85 E-15	3.30 E-15	1.40 E-15
1.5 E 00	1.20 E-15	7.90 E-16	
2.0 E 00	5.16 E-16	2.80 E-16	
2.5 E 00	2.63 E-16	1.30 E-16	
3.0 E 00	1.50 E-16	6.48 E-17	
3.5 E 00	1.00 E-16	3.85 E-17	
4.0 E 00	6.37 E-17	2.69 E-17	
5.0 E 00	4.10 E-17		
6.0 E 00	2.54 E-17		

Reference:

$H + H_2$, Experimental: H. H. Fleischmann, C. F. Barnett, and J. A. Ray, Phy. Rev. A 10, 569 (1974).

Accuracy:

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


ORNL-DWG 75-1363
DIFFERENTIAL CROSS SECTION (cm²/sr)
ANGLE (deg)
H⁺ (1 keV)
H⁺ (5 keV)
H⁺ (10 keV)
5
2
10⁻¹³
10⁻¹⁴
10⁻¹⁵
10⁻¹⁶
10⁻¹⁷
10⁻¹⁸
10⁻¹⁹
0
1
2
3
4
5
6
7

Scattering of H^o Formed by Charge Transfer Neutralization of H^+ in H_2*

Energy (keV)	Half Angle (deg)
1.0 E 00	2.40 E-02
1.5 E 00	1.90 E-02
2.0 E 00	1.69 E-02
3.0 E 00	1.50 E-02
4.0 E 00	1.43 E-02
5.5 E 00	1.43 E-02

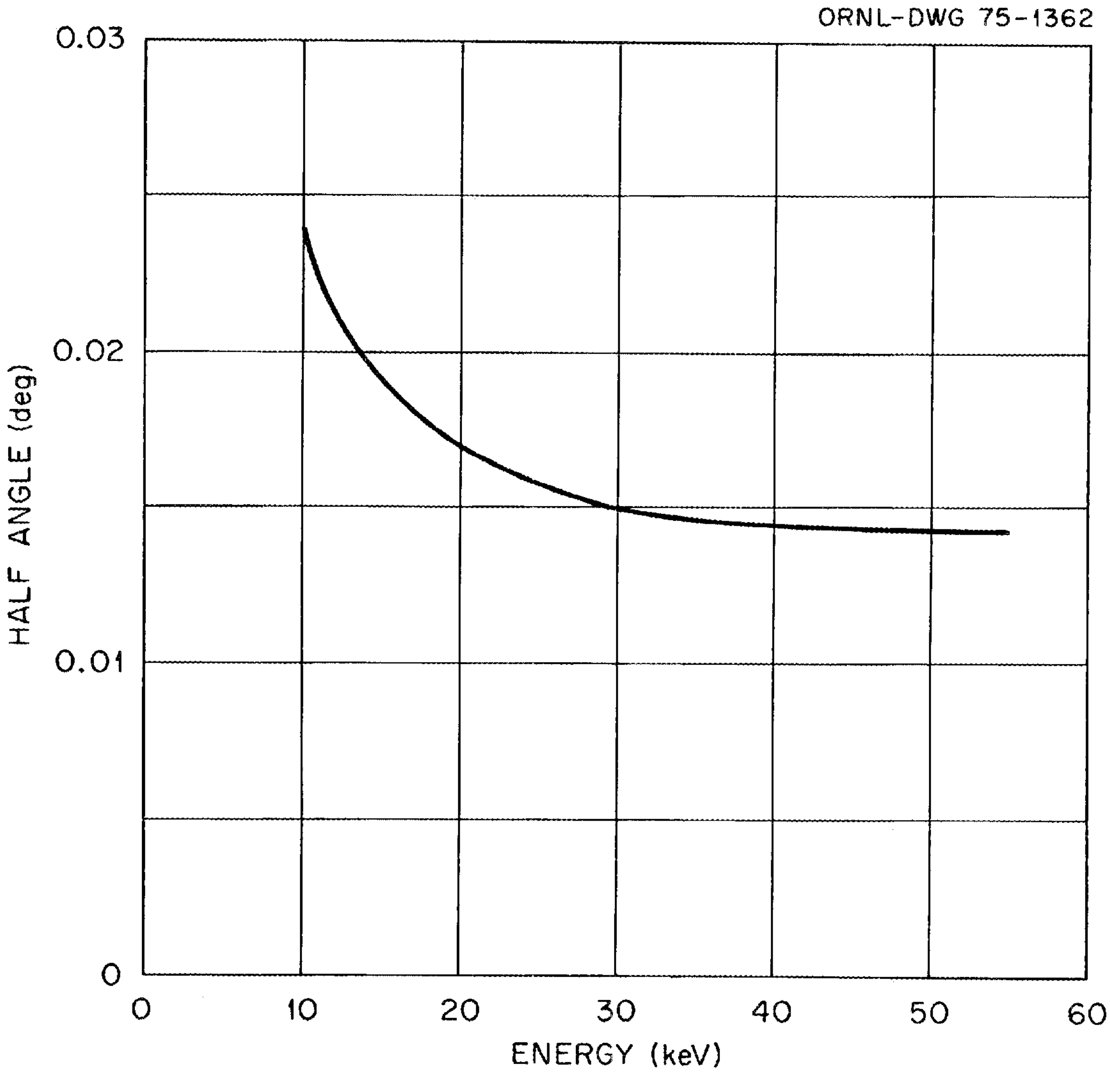
*There are no published cross sections for this process. We present here the half angle of the scattered H^o distribution (i.e. the deviation angle at which the H^o flux is half its maximum value).

Reference:

$H^+ + H_2$, Experimental: A.B. Wittkower, P.H. Rose, R.P. Bastide, and N.B. Brooks, Phys. Rev. 136, A1254 (1964).

Accuracy:

Unspecified.


ORNL-DWG 75-1362
0.03
0.02
0.01
0
HALF ANGLE (deg)
0
10
20
30
40
50
60
ENERGY (keV)

Angular Distribution of H^+ Formed by Dissociation of H_2^+ on an H Target

$$H_2^+ + H \rightarrow H^+ + H^O + H$$

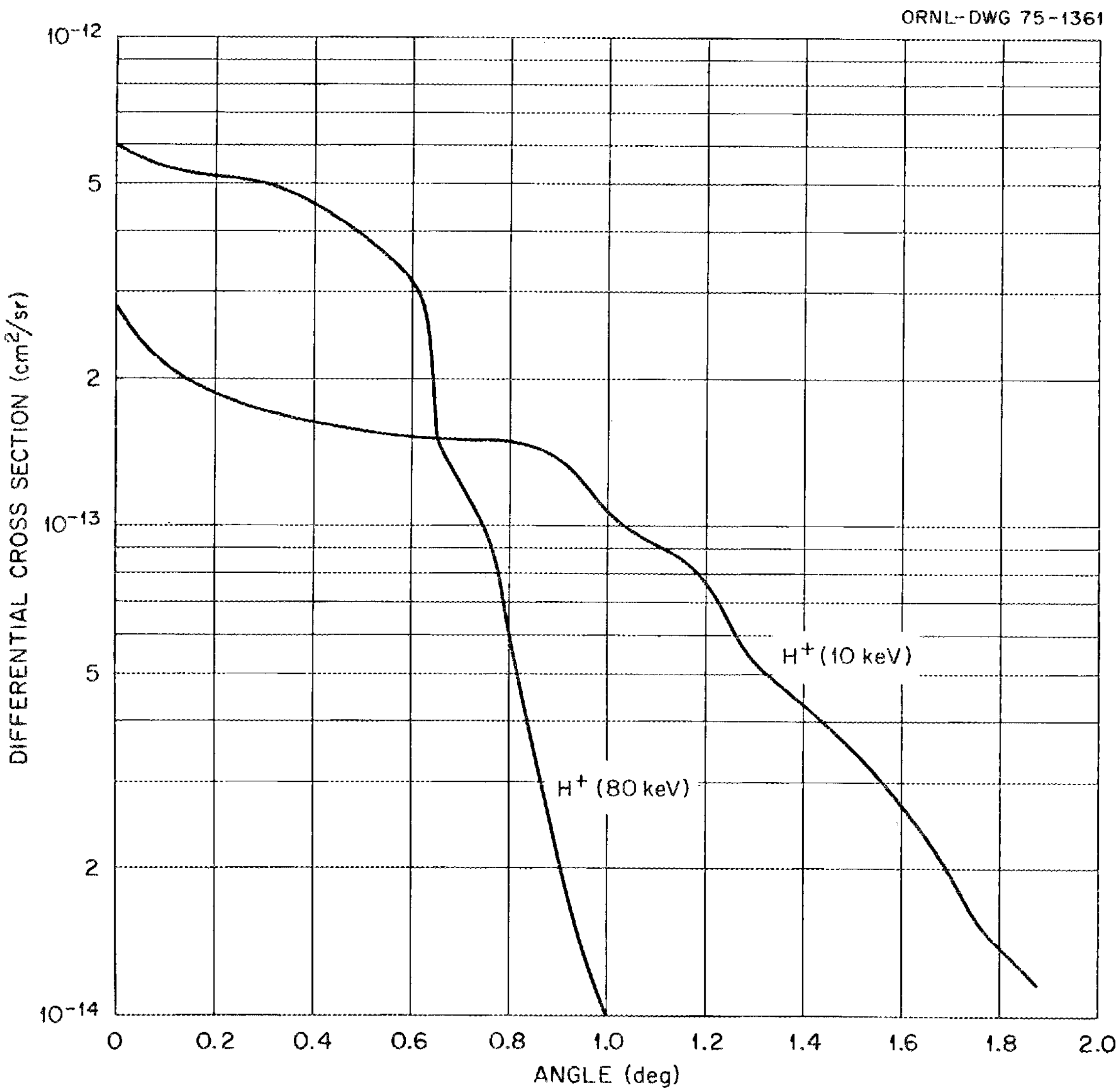
Angle (deg)	Differential Cross Sections (cm^2/sr) 10 keV Impact	80 keV Impact
0.0 E-01	2.80 E-13	6.00 E-13
1.0 E-01	2.14 E-13	5.40 E-13
2.0 E-01	1.87 E-13	5.14 E-13
3.0 E-01	1.74 E-13	4.99 E-13
4.0 E-01	1.64 E-13	4.54 E-13
6.0 E-01	1.54 E-13	3.16 E-13
8.0 E-01	1.49 E-13	5.90 E-14
1.0 E 00	1.06 E-13	1.00 E-14
1.2 E 00	7.63 E-14	
1.4 E 00	4.32 E-14	
1.6 E 00	2.70 E-14	
1.8 E 00	1.37 E-14	

Reference:

Experimental Data: According to G.W. McClure, Phys. Rev. 153, 182 (1967), the cross section for this process is essentially equal to the corresponding cross section for H_2^+ dissociation on H_2 as measured in G.W. McClure, Phys. Rev. 140, A769 (1965). Equality within $\pm$ 10% is indicated and the accuracy of the data is no better than this. The data presented here are actually the cross sections for dissociation in H_2 from McClure's work.

Accuracy:

Systematic error < $\pm$ 8%. Random error < $\pm$ 8%.


ORNL-DWG 75-1361
DIFFERENTIAL CROSS SECTION (cm²/sr)
10⁻¹²
5
2
10⁻¹³
5
2
10⁻¹⁴
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
ANGLE (deg)
H⁺ (10 keV)
H⁺ (80 keV)

Angular Distribution of H^o and H^+ Formed by Dissociation of H_2^+ on H_2 Target

$$H_2^+ + H_2 \rightarrow H^+ + H^o + H_2$$

Angle (deg)	Differential Cross Sections (cm^2/sr)			
	10 keV Impact		80 keV Impact	
	H^o	H^+	H^o	H^+
1.0 E-01	3.50 E-12	2.40 E-13	4.50 E-12	5.89 E-13
2.0 E-01	1.40 E-12	2.02 E-13	2.64 E-12	5.07 E-13
3.0 E-01	8.00 E-13	1.82 E-13	1.40 E-12	4.81 E-13
4.0 E-01	5.62 E-13	1.62 E-13	6.68 E-13	4.45 E-13
6.0 E-01	3.70 E-13	1.26 E-13	1.23 E-13	3.04 E-13
8.0 E-01	2.35 E-13	9.35 E-14		7.50 E-14
1.0 E 00	1.43 E-13	6.62 E-14		9.70 E-15
1.2 E 00	8.45 E-14	4.60 E-14		
1.4 E 00	4.74 E-14	3.10 E-14		
1.6 E 00	2.50 E-14	1.94 E-14		
1.8 E 00	9.70 E-15	9.23 E-15		
2.0 E 00	4.67 E-15	4.95 E-15		
2.2 E 00	1.79 E-15	2.01 E-15		

Reference:

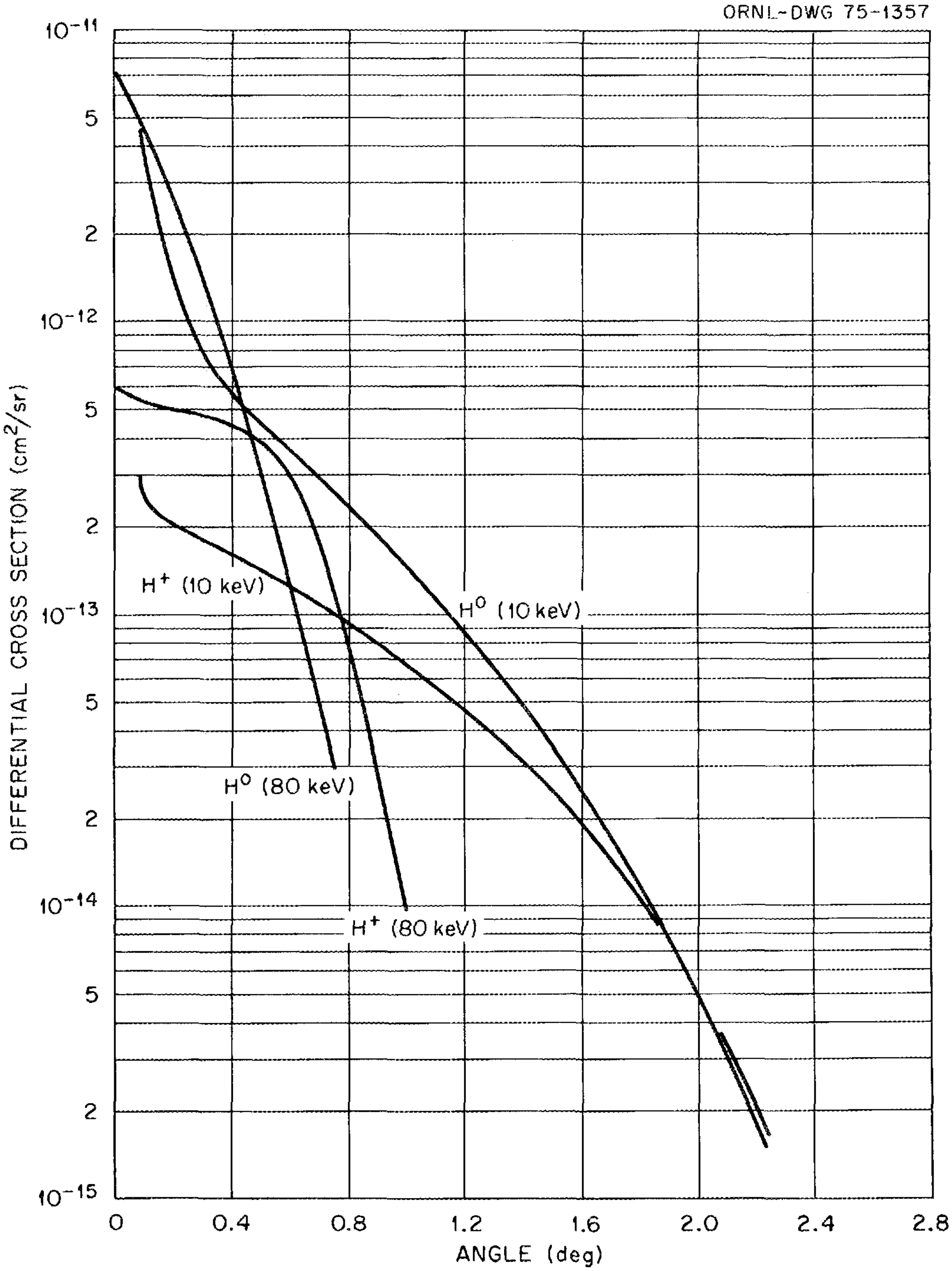
H_2^+ + H_2, Experimental: I. Sauers, R.L. Fitzwilson, J.C. Ford, and E.W. Thomas, Phys. Rev. A 6, 1418 (1972); G.W. McClure, Phys. Rev. 140, A 769 (1965).

Accuracy:

Systematic error < ± 8%. Random error < ± 8%.

Notes:

See Note (1) at end of chapter.


ORNL-DWG 75-1357
DIFFERENTIAL CROSS SECTION (cm²/sr)
ANGLE (deg)
H⁺ (10 keV)
H⁰ (10 keV)
H⁰ (80 keV)
H⁺ (80 keV)
10⁻¹¹
5
2
10⁻¹²
5
2
10⁻¹³
5
2
10⁻¹⁴
5
2
10⁻¹⁵
0
0.4
0.8
1.2
1.6
2.0
2.4
2.8

Scattering of H^+ and H^o Induced by H^+ Impact on He

$$H^+ + He \rightarrow H^o + He^+$$

$$H^+ + He \rightarrow H^+ + He$$

Angle (deg)	Differential Cross Sections (cm^2/sr)			
	5 keV Impact		20 keV Impact	
	H^o	H^+	H^o	H^+
4.0 E-01				1.07 E-14
6.0 E-01	2.55 E-15	2.41 E-14	2.64 E-15	4.68 E-15
8.0 E-01	1.10 E-15	1.10 E-14	1.01 E-15	2.11 E-15
1.0 E 00	5.78 E-16	6.20 E-15	4.25 E-16	1.06 E-15
1.5 E 00			9.40 E-17	2.40 E-16

Reference:

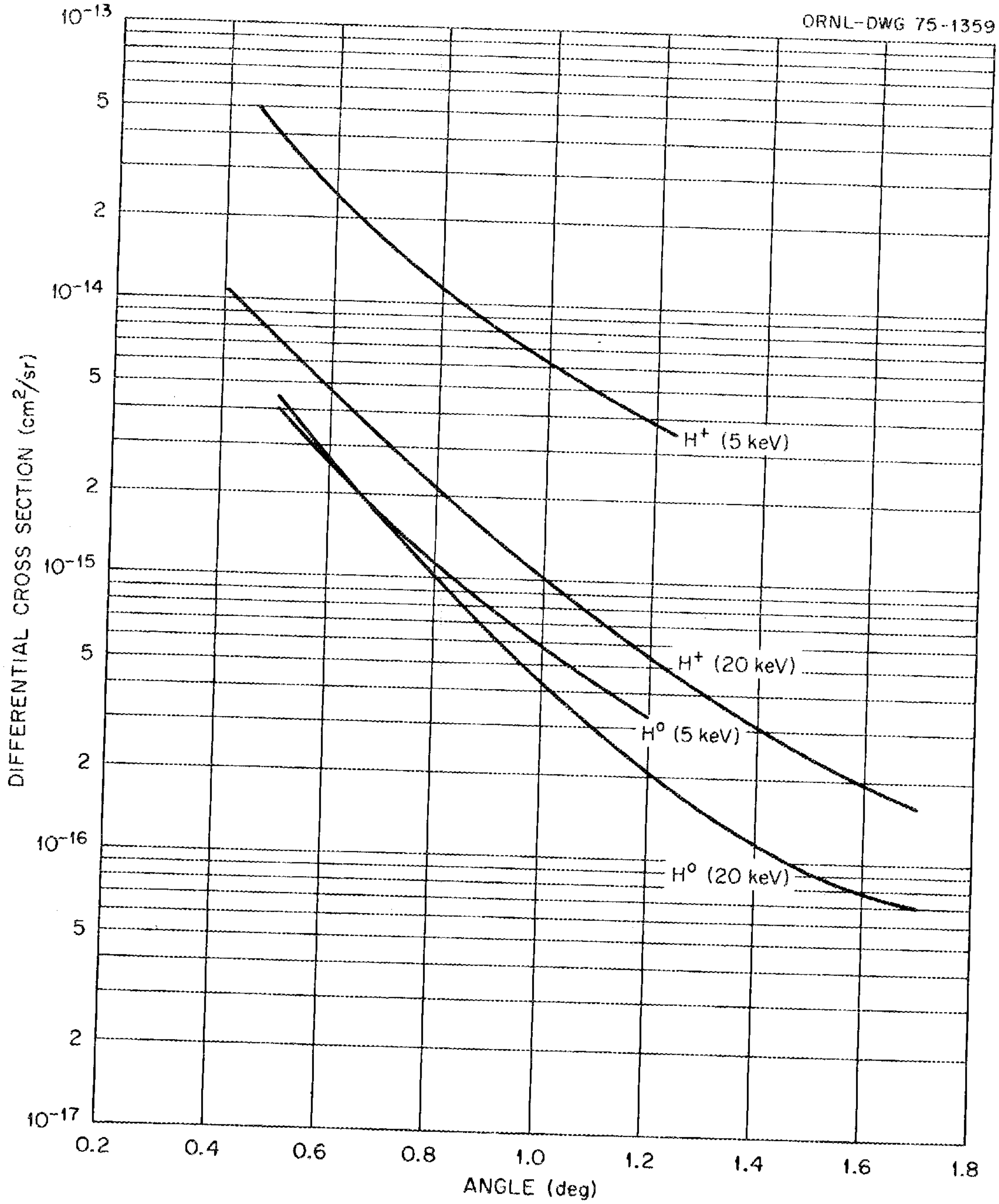
R.L. Fitzwilson and E.W. Thomas, Phys. Rev. A 6, 1054 (1972).

Accuracy:

Systematic error < ± 6%. Random error < ± 7%.

Notes:

See Note (2) at end of chapter.


ORNL-DWG 75-1359
DIFFERENTIAL CROSS SECTION (cm²/sr)
ANGLE (deg)
H⁺ (5 keV)
H⁺ (20 keV)
H⁰ (5 keV)
H⁰ (20 keV)
10⁻¹³
5
2
10⁻¹⁴
10⁻¹⁵
10⁻¹⁶
10⁻¹⁷
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8

Angular Distribution of H^0 and H^+ Formed as H^0 Traverses a Target of He

$$H^0 + He \rightarrow H^0 + He$$

$$H^0 + He \rightarrow H^+ + e + He$$

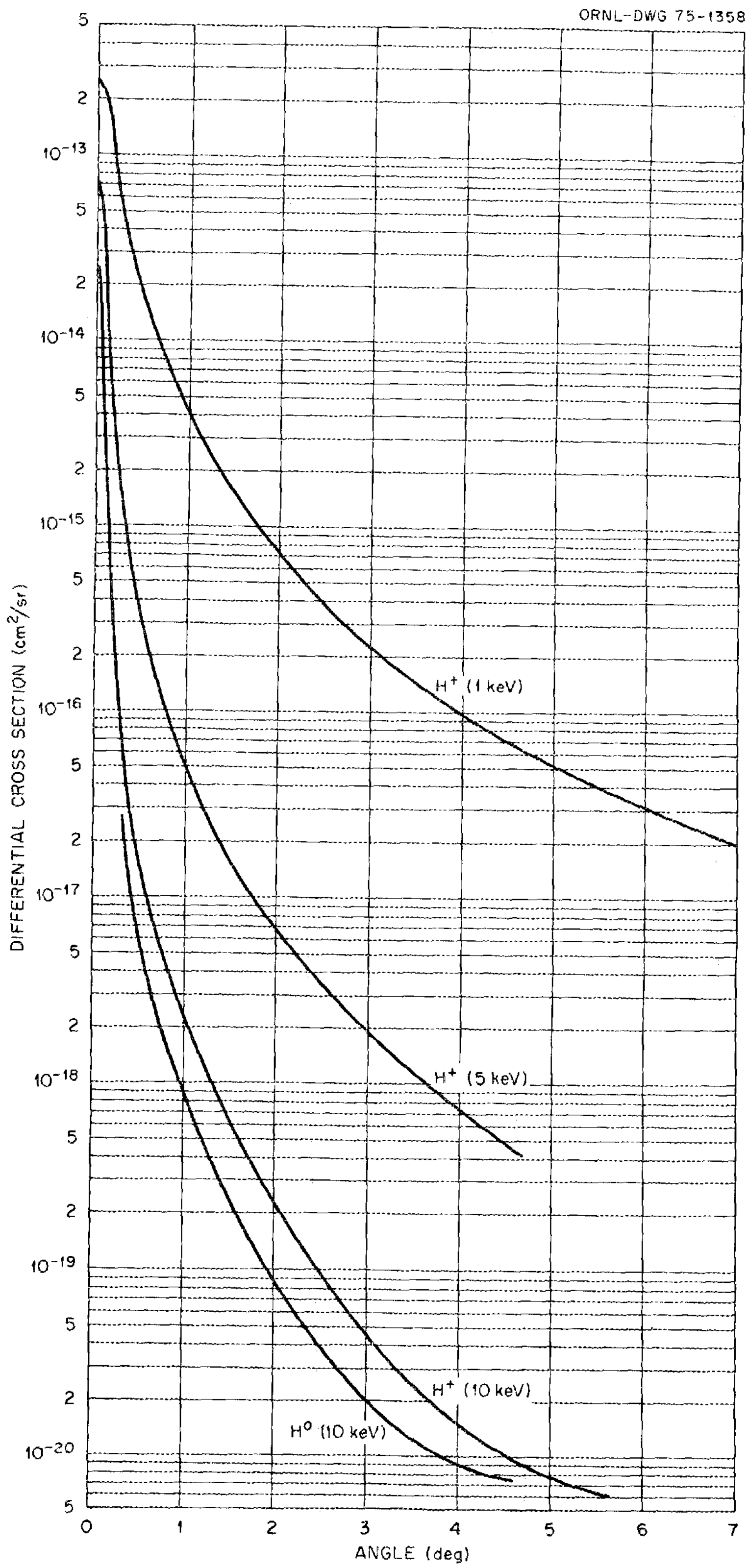
Angle (deg)	Differential Cross Sections (cm^2/sr)			
	1 keV Impact	5 keV Impact	10 keV Impact	
	H^+	H^+	H^0	H^+
0.0 E-01	2.50 E-13	7.00 E-12		2.38 E-11
1.0 E-01	1.95 E-13	2.10 E-12		2.60 E-12
2.0 E-01	7.40 E-14	3.05 E-13		2.30 E-13
3.0 E-01	4.00 E-14	1.10 E-13		6.50 E-14
4.0 E-01	2.59 E-14	5.23 E-14	1.20 E-14	2.80 E-14
6.0 E-01	1.30 E-14	1.99 E-14	3.52 E-15	8.63 E-15
8.0 E-01	7.13 E-15	9.30 E-15	1.58 E-15	4.38 E-15
1.0 E 00	4.20 E-15	5.00 E-15	8.50 E-16	2.37 E-15
1.5 E 00	1.50 E-15	1.57 E-15	2.30 E-16	6.55 E-16
2.0 E 00	7.00 E-16	6.35 E-16	8.30 E-17	2.21 E-16
2.5 E 00	3.90 E-16	3.30 E-16	3.90 E-17	9.70 E-17
3.0 E 00	2.20 E-16	1.82 E-16	2.10 E-17	4.55 E-17
3.5 E 00	1.40 E-16	1.10 E-16	1.20 E-17	2.40 E-17
4.0 E 00	1.00 E-16	7.30 E-17	8.55 E-18	1.50 E-17
5.0 E 00	5.20 E-17			7.34 E-18
6.0 E 00	3.19 E-17			
7.0 E 00	2.00 E-17			

References:

H + He, Experimental: H. H. Fleischmann, C. F. Barnett, and J. A. Ray, Phys. Rev. A 10, 569 (1974). I. Sauers and W. E. Thomas, Phys. Rev. A 10, 822 (1974).

Accuracy:

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



ORNL-DWG 75-1358
DIFFERENTIAL CROSS SECTION (cm^2/sr)
ANGLE (deg)
H$^+$ (1 keV)
H$^+$ (5 keV)
H$^+$ (10 keV)
H^0 (10 keV)
5
2
10^{-13}
10^{-14}
10^{-15}
10^{-16}
10^{-17}
10^{-18}
10^{-19}
10^{-20}
0
1
2
3
4
5
6
7

Angular Distribution of H^o and H^+ Formed by Dissociation of H_2^+ on an He Target

$$H_2^+ + He \rightarrow H^+ + H + He$$

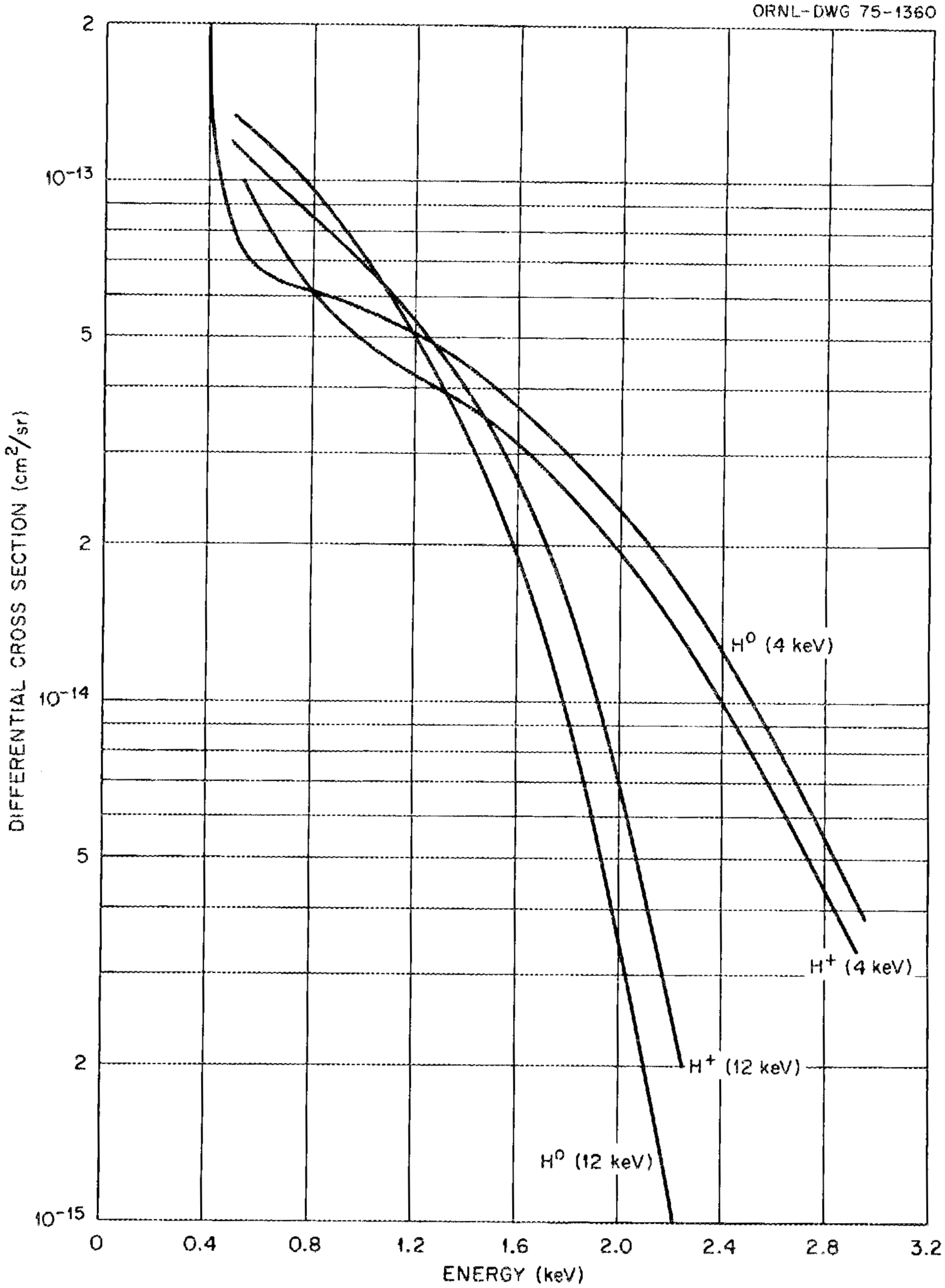
Angle (deg)	Differential Cross Sections (cm^2/sr)			
	4 keV Impact		12 keV Impact	
	H^o	H^+	H^o	H^+
4.0 E-01	1.50 E-13			
6.0 E-01	6.70 E-14	8.55 E-14	1.21 E-13	1.05 E-13
8.0 E-01	6.20 E-14	6.16 E-14	9.64 E-14	8.51 E-14
1.0 E 00	5.65 E-14	4.90 E-14	7.20 E-14	6.88 E-14
1.2 E 00	5.08 E-14	4.20 E-14	5.00 E-14	5.38 E-14
1.4 E 00	4.40 E-14	3.70 E-14	3.21 E-14	3.95 E-14
1.6 E 00	3.67 E-14	3.12 E-14	1.89 E-14	2.64 E-14
1.8 E 00	2.94 E-14	2.50 E-14	9.06 E-15	1.50 E-14
2.0 E 00	2.31 E-14	1.93 E-14	3.45 E-15	6.90 E-15
2.2 E 00	1.76 E-14	1.42 E-14	1.10 E-15	2.60 E-15
2.4 E 00	1.26 E-14	1.00 E-14		
2.6 E 00	8.48 E-15	7.21 E-15		
2.8 E 00	5.42 E-15	4.35 E-15		

Reference:

H_2^+ + He, Experimental: T. Sauers, R.L. Fitzwilson, J.C. Ford, and E.W. Thomas, Phys. Rev. A 6, 1418 (1972).

Accuracy:

Systematic error < ± 8%. Random error < ± 8%.


ORNL-DWG 75-1360
DIFFERENTIAL CROSS SECTION (cm²/sr)
ENERGY (keV)
2
10⁻¹³
5
2
10⁻¹⁴
5
2
10⁻¹⁵
0
0.4
0.8
1.2
1.6
2.0
2.4
2.8
3.2
H⁰ (4 keV)
H⁺ (4 keV)
H⁺ (12 keV)
H⁰ (12 keV)

Notes

(1) References cited provide data for other energies from 4 to 80 keV. The width of the H^+ distribution has been measured to 200 keV by C.F. Barnett and J.A. Ray, Atomic Collision Processes, (North Holland Publ. Co. Amsterdam, 1964) p. 743. Also see D.R. Sweetman, Proc. Roy. Soc. A 256, 416 (1960).

(2) There are some studies of H^o angular distributions induced by H^+ on He where only the half angle (the deviation angle at which the H^o flux is half its maximum value) is given. According to A.B. Wittkower, P.H. Rose, R.P. Bastide, and N.B. Brooks, Phys. Rev. 136, A1254 (1964), the half angle varies from 0.35 milliradians at 20 keV to 0.25 milliradians at 55 keV.

A.2 Excitation by Heavy Particles

Excitation Cross Sections for the Reactions

$H + H \rightarrow H(2s,2p) + H$

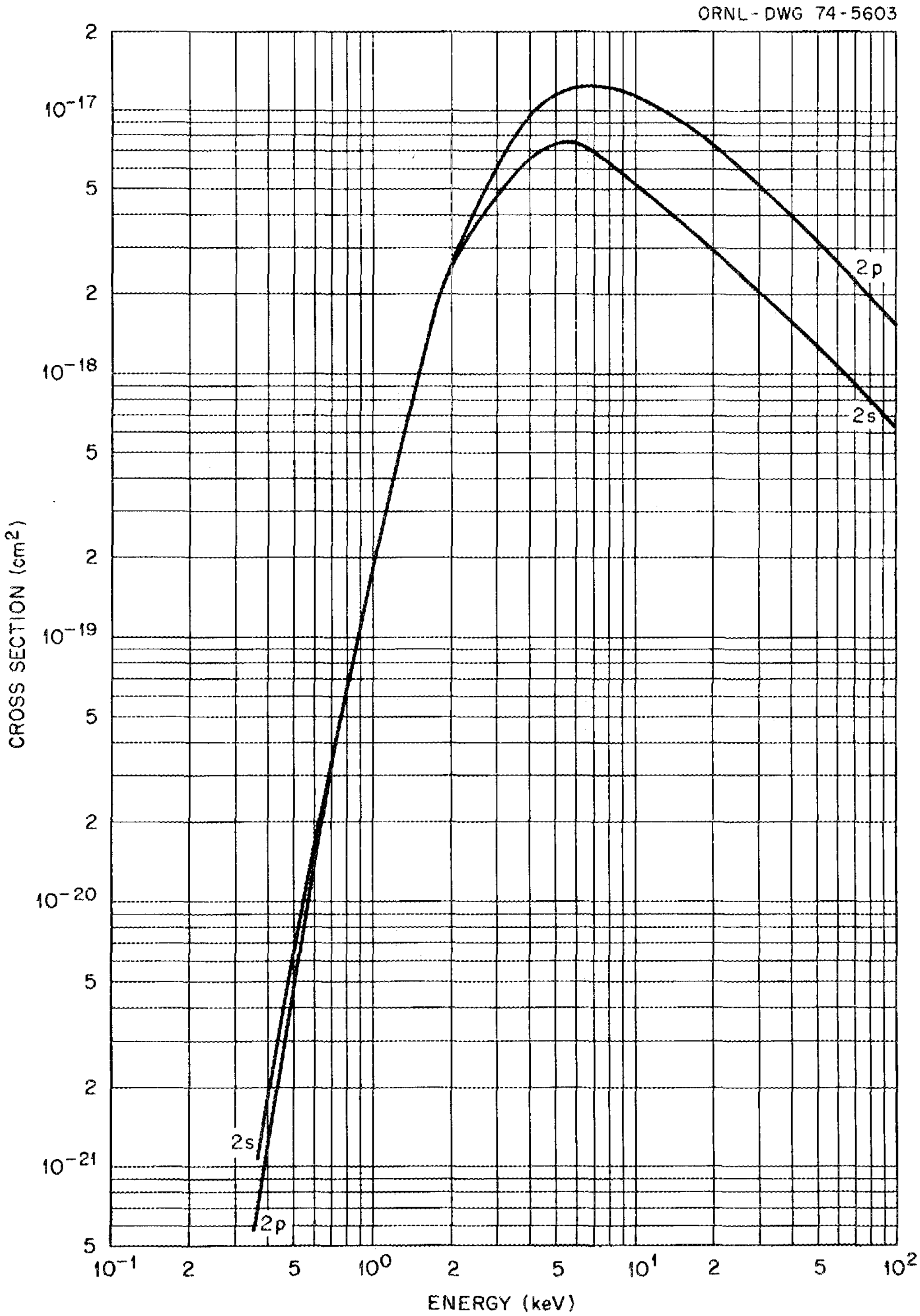
Energy (keV)	Cross Section for State $n\ell$ (cm^2)	
	2s	2p
4.0 E-01	1.7 E-21	1.1 E-21
5.0 E-01	6.6 E-21	4.8 E-21
6.0 E-01	1.7 E-20	1.7 E-20
7.0 E-01	3.1 E-20	3.1 E-20
8.0 E-01	5.5 E-20	5.5 E-20
9.0 E-01	9.0 E-20	9.0 E-20
1.0 E 00	1.8 E-18	1.8 E-18
1.5 E 00	1.0 E-18	1.0 E-18
2.0 E 00	2.6 E-18	2.6 E-18
3.0 E 00	4.8 E-18	6.1 E-18
4.0 E 00	6.4 E-18	9.8 E-18
5.0 E 00	7.5 E-18	1.2 E-17
6.0 E 00	7.6 E-18	1.2 E-17
7.0 E 00	7.0 E-18	1.2 E-17
8.0 E 00	6.2 E-18	1.2 E-17
9.0 E 00	5.7 E-18	1.2 E-17
1.0 E 01	5.2 E-18	1.1 E-17
1.5 E 01	3.8 E-18	9.1 E-18
2.0 E 01	3.0 E-18	8.5 E-18
3.0 E 01	2.0 E-18	5.1 E-18
4.0 E 01	1.6 E-18	3.9 E-18
5.0 E 01	1.3 E-18	3.1 E-18
6.0 E 01	1.1 E-18	2.6 E-18
7.0 E 01	8.8 E-19	2.2 E-18
8.0 E 01	7.8 E-19	2.0 E-18
9.0 E 01	7.1 E-19	1.7 E-18
1.0 E 02	6.3 E-19	1.6 E-18

References:

$H + H \rightarrow H(2s,2p) + H$: M.R. Flannery, Phys. Rev. 183, 241 (1969).

Notes:

See Note (22) at end of chapter.



ORNL-DWG 74-5603
CROSS SECTION (cm^2)
ENERGY (keV)
2p
2s
2s
2p

Excitation Cross Sections for the Reactions

$H + H_2 \rightarrow H(2s,3s,2p,3p,3d) + H_2$

Energy (keV)	Cross Sections for State nℓ (cm^2)				
	2s	3s	2p	3p	3d
5	1.10 E-17		4.05 E-17		
10	1.45 E-17	1.75 E-18	2.50 E-17		1.02 E-18
15	1.60 E-17	2.00 E-18	2.40 E-17	1.48 E-18	9.00 E-19
20	1.50 E-17	2.10 E-18	2.10 E-17	1.38 E-18	8.50 E-19
25	1.20 E-17	2.05 E-18	1.80 E-17	1.50 E-18	8.30 E-19
30		1.95 E-18		1.60 E-18	7.7 E-19
35		1.90 E-18		1.45 E-18	7.1 E-19

References:

$H + H_2 \rightarrow H(2s,2p) + H_2$: J.H. Birely and R.J. McNeal, Phys. Rev. A 5, 692 (1972)

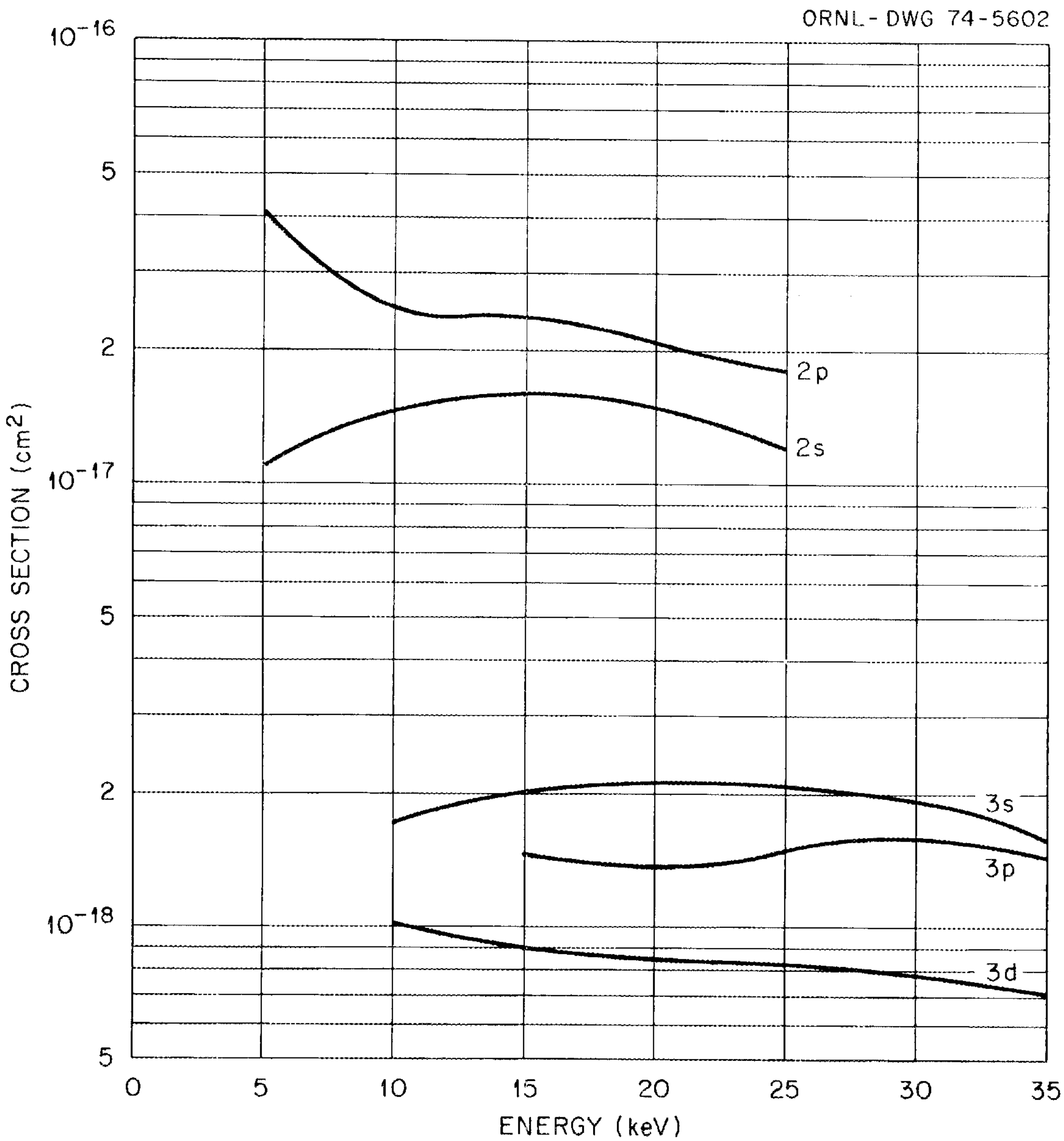
$H + H_2 \rightarrow H(3s,3p,3d) + H_2$: R.H. Hughes, H.M. Petefish, and H. Kisner, Phys. Rev. A 5, 2103 (1972).

Notes:

See Note (23) at end of chapter.

Accuracy:

Systematic error < 50% for 2s, 2p state; systematic error < 20% for 3s, 3p, 3d state. Random error < 10%.



ORNL-DWG 74-5602
10^{-16}
5
2
10^{-17}
5
2
10^{-18}
5
CROSS SECTION (cm^2)
0
5
10
15
20
25
30
35
ENERGY (keV)
2p
2s
3s
3p
3d

Excitation Cross Sections for the Reactions

$$H + H_2 \rightarrow H + H + H(2s,2p)$$

Energy (keV)	Cross Sections for State $n\ell$ (cm^2)	
	2s	2p
5.0 E 00	2.8 E-18	7.0 E-18
6.0 E 00	3.3 E-18	8.1 E-18
7.0 E 00	3.5 E-18	9.2 E-18
8.0 E 00	3.7 E-18	1.1 E-17
9.0 E 00	3.9 E-18	1.2 E-17
1.0 E 01	3.9 E-18	1.4 E-17
1.5 E 01	4.2 E-18	1.5 E-17
2.0 E 01	3.7 E-18	1.2 E-17
2.5 E 01	3.6 E-18	9.2 E-18

Reference:

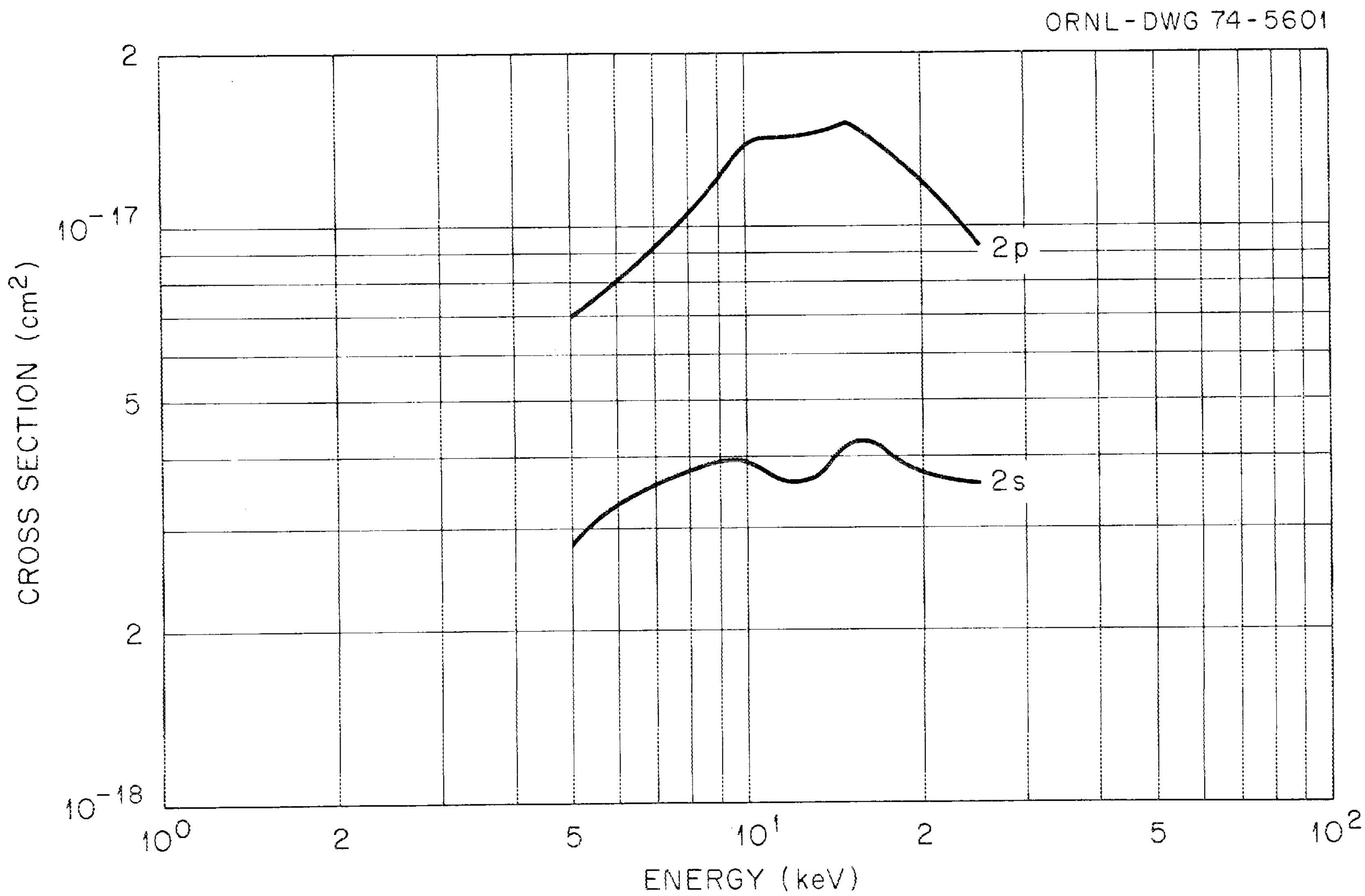
J.H. Birely and R.J. McNeal, Phys. Rev. A 5, 692 (1972).

Notes:

See Note (24) at end of chapter.

Accuracy:

Systematic error < 50%. Random error < 10%.


ORNL-DWG 74-5601
CROSS SECTION (cm^2)
ENERGY (keV)
2p
2s
2
10^{-17}
5
2
10^{-18}
10^0
2
5
10^1
2
5
10^2

Excitation Cross Sections for the Reactions

$H^{o} + He \rightarrow H^{o} + He\ (4^{1}S,\ 4^{1}P,\ 4^{3}S,\ 4^{3}P)$

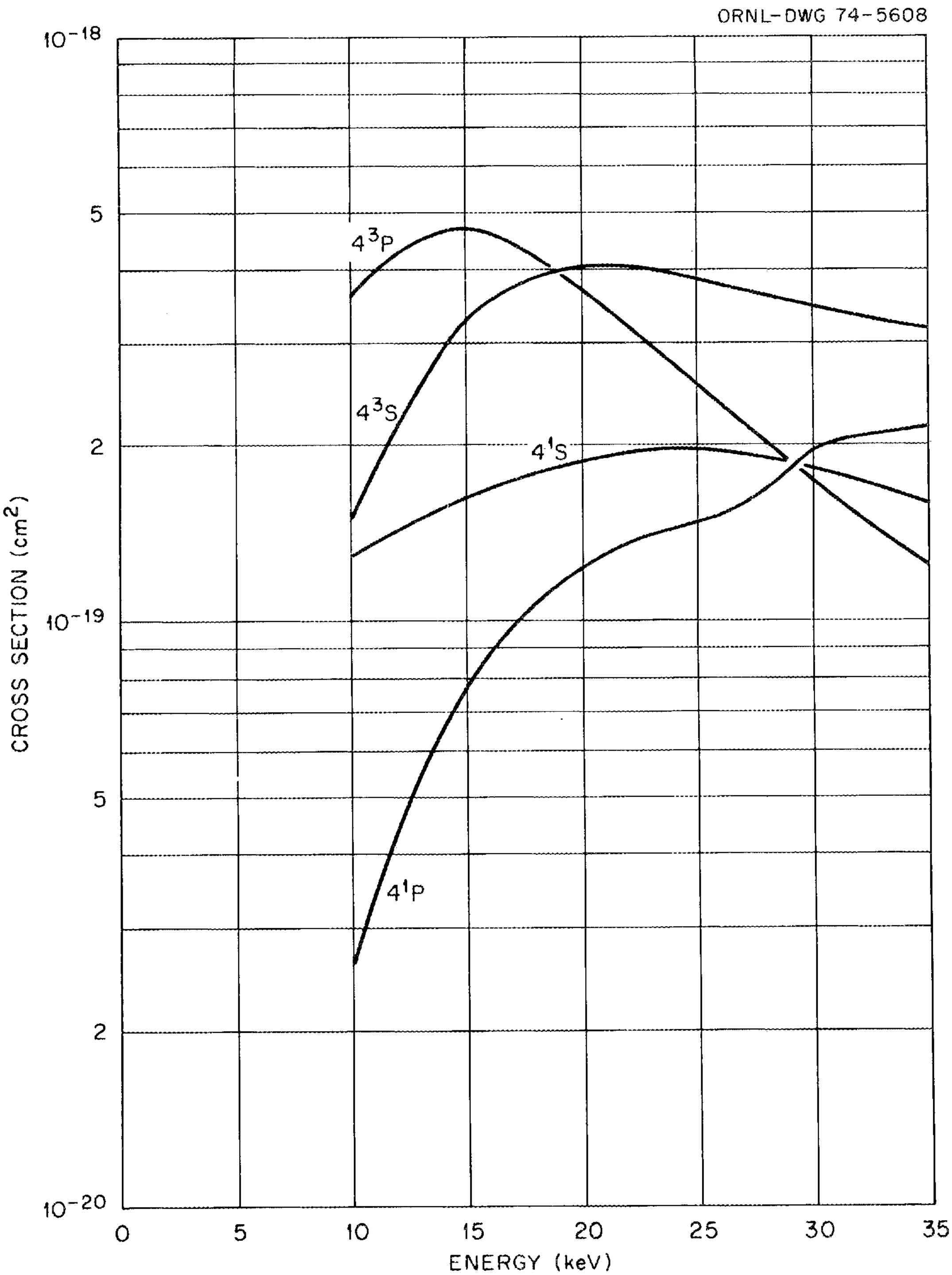
Energy (keV)	Cross Sections for Excited States $n\ell$ (cm^2)			
	$4^{1}S$	$4^{1}P$	$4^{3}S$	$4^{3}P$
1.0 E 01	1.30 E-19	2.60 E-20	1.50 E-19	3.64 E-19
1.5 E 01	1.63 E-19	7.90 E-20	3.32 E-19	4.71 E-19
2.0 E 01	1.85 E-19	1.25 E-19	4.07 E-19	3.68 E-19
2.5 E 01	1.96 E-19	1.47 E-19	3.88 E-19	2.50 E-19
3.0 E 01	1.82 E-19	1.86 E-19	3.43 E-19	1.71 E-19
3.5 E 01	1.58 E-19	2.12 E-19	3.13 E-19	1.25 E-19

References:

J. Van Eck, F. J. de Heer, and J. Kistemaker, Physica 30, 1171 (1964), as revised by J. Van den Bos;(private communication from F. J. de Heer).

Notes:

See Notes (41) and (42) at end of chapter.


ORNL-DWG 74-5608
CROSS SECTION (cm²)
ENERGY (keV)
10⁻¹⁸
5
2
10⁻¹⁹
5
2
10⁻²⁰
0
5
10
15
20
25
30
35
4³P
4³S
4¹S
4¹P

xcitation Cross Sections by Electron Capture for the React

$H^+ + H \rightarrow H(2s,2p) + H^+$

Energy (keV)	Cross Sections for State $n\ell$ (cm^2)			
	Experimental		Theoretical	
	2s	2p	2s	2p
2.3 E 00		2.8 E-17		
3.0 E 00	4.6 E-19	2.9 E-17		
4.0 E 00	1.5 E-18	3.3 E-17		
5.0 E 00	3.6 E-18	3.4 E-17		
6.0 E 00	6.6 E-18	3.3 E-17		
7.0 E 00	1.0 E-17	3.3 E-17		
8.0 E 00	1.5 E-17	3.2 E-17		
9.0 E 00	1.9 E-17	3.1 E-17		
1.0 E 01	2.3 E-17	3.0 E-17		
1.5 E 01	3.2 E-17	2.3 E-17		
2.0 E 01	3.4 E-17	1.5 E-17		
3.0 E 01	2.8 E-17	8.0 E-18	3.2 E-17	8.0 E-18
4.0 E 01	2.0 E-17		2.4 E-17	5.2 E-18
5.0 E 01	1.3 E-17		1.6 E-17	3.1 E-18
6.0 E 01	7.4 E-18		1.1 E-17	2.0 E-18
7.0 E 01	4.2 E-18		7.6 E-18	1.3 E-18
8.0 E 01			5.3 E-18	9.4 E-19
9.0 E 01			3.8 E-18	6.6 E-19
1.0 E 02			2.7 E-18	4.8 E-19
1.5 E 02			5.8 E-19	8.0 E-20
2.0 E 02			1.8 E-19	2.9 E-20
3.0 E 02			3.2 E-20	5.8 E-21
1.0 E 03			7.6 E-23	7.8 E-24

References:

$H^+ + H \rightarrow H(2s) + H^+$ Exp.: T.J. Morgan, J. Geddes, and H.B. Gilbody, J. Phys. B 6, 2118 (1973); J.E. Bayfield, Phys. Rev. 185, 105 (1969).

$H^+ + H \rightarrow H(2p) + H^+$ Exp.: T.J. Morgan, J. Geddes, and H.B. Gilbody, J. Phys. B 6, 2118 (1973).

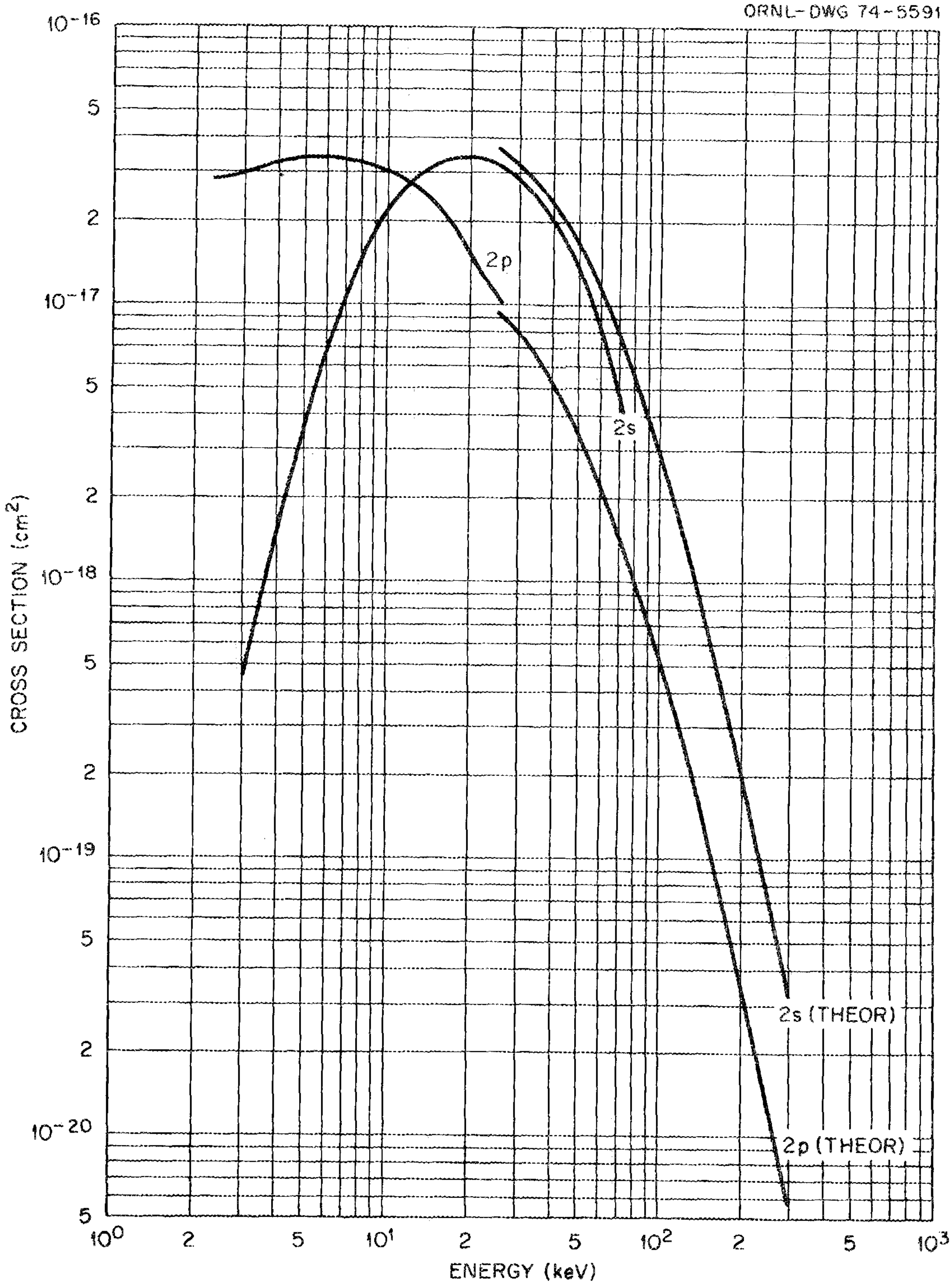
$H^+ + H \rightarrow H(2s,2p)$ Theoretical: I.M. Cheshire, D.F. Gallaher, and A. Joanna Taylor, J. Phys. B 3, 813 (1970).

Notes:

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

Accuracy:

Systematic error < 50%. Random error < 10%.


ORNL-DWG 74-5591
CROSS SECTION (cm^2)
ENERGY (keV)
10^{-16}
5
2
10^{-17}
5
2
10^{-18}
5
2
10^{-19}
5
2
10^{-20}
5
10^0
2
5
10^1
2
5
10^2
2
5
10^3
2p
2s
2s (THEOR)
2p (THEOR)

Excitation Cross Sections for the Reactions

$$H^+ + H \rightarrow H^+ + H\ (2s,2p)$$

Energy (keV)	Cross Sections for State $n\ell$ (cm^2) 2s	2p
2.5 E 00		3.0 E-17
3.0 E 00		3.0 E-17
4.0 E 00		3.0 E-17
5.0 E 00	5.5 E-18	3.3 E-17
6.0 E 00	5.8 E-18	3.4 E-17
8.0 E 00	5.8 E-18	2.7 E-17
1.0 E 01	5.7 E-18	2.4 E-17
1.5 E 01	8.2 E-18	2.9 E-17
2.0 E 01	9.9 E-18	3.6 E-17
2.5 E 01	1.0 E-17	4.4 E-17
3.0 E 01	1.1 E-17	4.7 E-17
4.0 E 01	1.3 E-17	7.0 E-17
5.0 E 01	1.7 E-17	7.8 E-17
6.0 E 01	1.8 E-17	8.2 E-17
8.0 E 01	1.6 E-17	8.6 E-17
1.0 E 02	1.4 E-17	8.6 E-17

References:

Experimental (2 - 26 keV): T.J. Morgan, J. Geddes, and H.B. Gilbody, J. Phys. B 6, 2118 (1973).

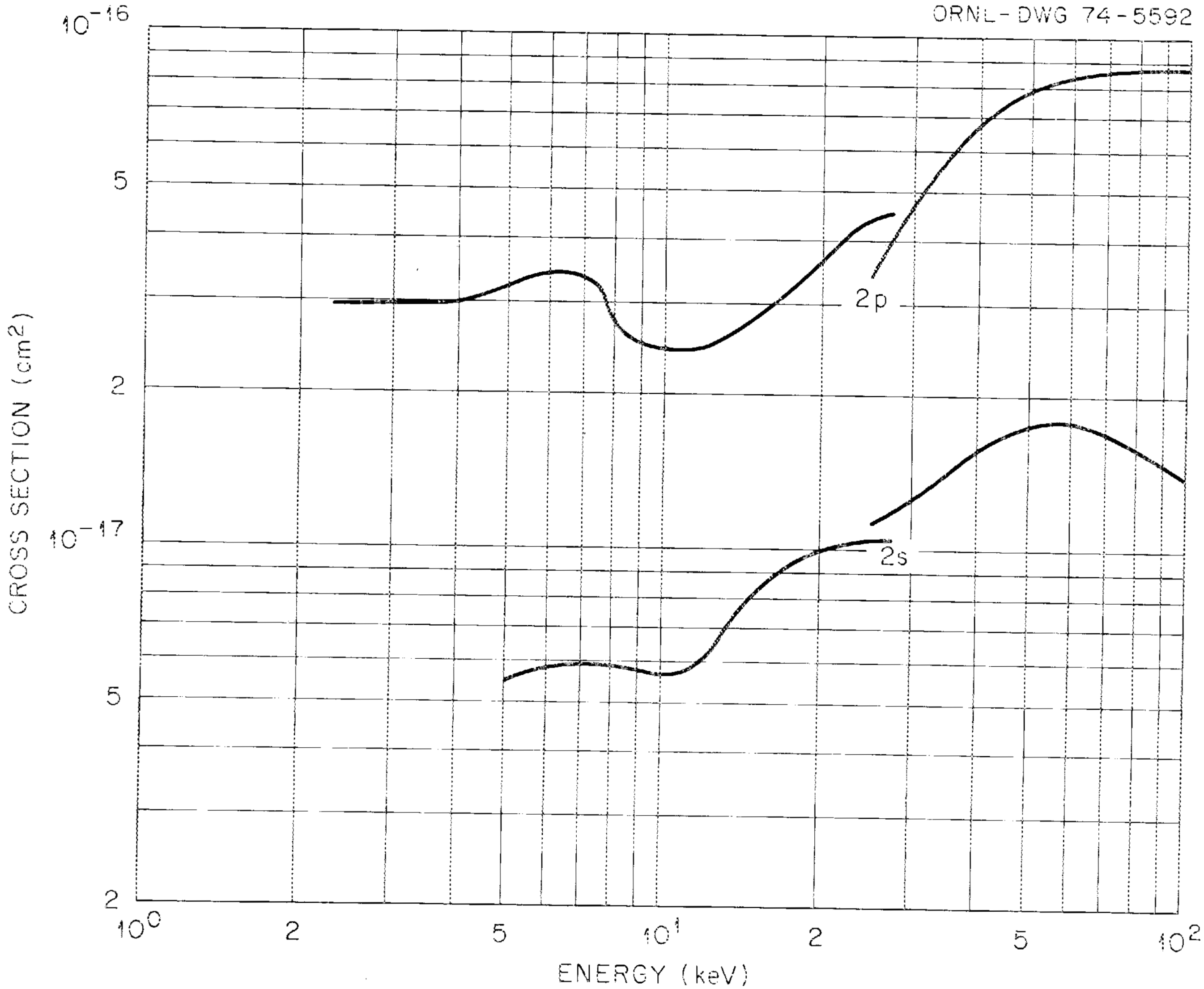
Theoretical (25 - 100 keV): I.M. Cheshire, D.F. Gallaher, and A.J. Taylor, J. Phys. B 3, 813 (1970).

Notes:

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

Accuracy:

Experimental data: Systematic error < 50%. Random error < 10%.


ORNL-DWG 74-5592
CROSS SECTION (cm^2)
ENERGY (keV)
10^{-16}
5
2
10^{-17}
5
2
10^0
2
5
10^1
2
5
10^2
2p
2s

Cross Sections for Excitation by Electron Capture for the Reactions

$$H^+ + H_2 \rightarrow H(2s,3s,4s) + H_2^+$$

Energy (keV)	Cross Sections for Excited State $n\ell$ (cm^2)		
	2s	3s	4s
2.0 E 00	2.1 E-18		
3.0 E 00	2.9 E-18		
4.0 E 00	3.7 E-18		
5.0 E 00	4.3 E-18		2.5 E-19
6.0 E 00	5.0 E-18		2.8 E-19
7.0 E 00	5.5 E-18		3.3 E-19
8.0 E 00	6.1 E-18		3.8 E-19
9.0 E 00	6.7 E-18		4.3 E-19
1.0 E 01	7.4 E-18	1.9 E-18	4.7 E-19
1.5 E 01	1.2 E-17	2.6 E-18	7.5 E-19
2.0 E 01	1.7 E-17	3.6 E-18	1.1 E-18
3.0 E 01	2.0 E-17	5.6 E-18	1.8 E-18
4.0 E 01	1.8 E-17	5.6 E-18	1.8 E-18
5.0 E 01	1.5 E-17	4.5 E-18	1.5 E-18
6.0 E 01	1.2 E-17	3.7 E-18	1.2 E-18
7.0 E 01	9.1 E-18	2.8 E-18	9.3 E-18
8.0 E 01	6.8 E-18	2.2 E-18	7.3 E-18
9.0 E 01	5.4 E-18	1.6 E-18	5.6 E-18
1.0 E 02	4.1 E-18	1.2 E-18	4.4 E-18
1.5 E 02	1.1 E-18	2.7 E-19	
2.0 E 02		7.7 E-20	
3.0 E 02		1.9 E-20	

References:

$H^+ + H_2 \rightarrow H(2s) + H_2^+$: R.H. Hughes, E.D. Stokes, Song-Sik Choe, and T.J. King, Phys. Rev. A 4, 1453 (1971); G. Ryding, A.B. Wittkower, and H.B. Gilbody, Proc. Phys. Soc., London 89, 547 (1966); J. Bayfield, Phys. Rev. 182, 115 (1969).

$H^+ + H_2 \rightarrow H(3s) + H_2^+$: R.H. Hughes, C.A. Stigers, B.M. Doughty, E.D. Stokes, Phys. Rev. A 1, 1424 (1970); J.C. Ford and E.W. Thomas, Phys. Rev. A 5, 1701 (1972).

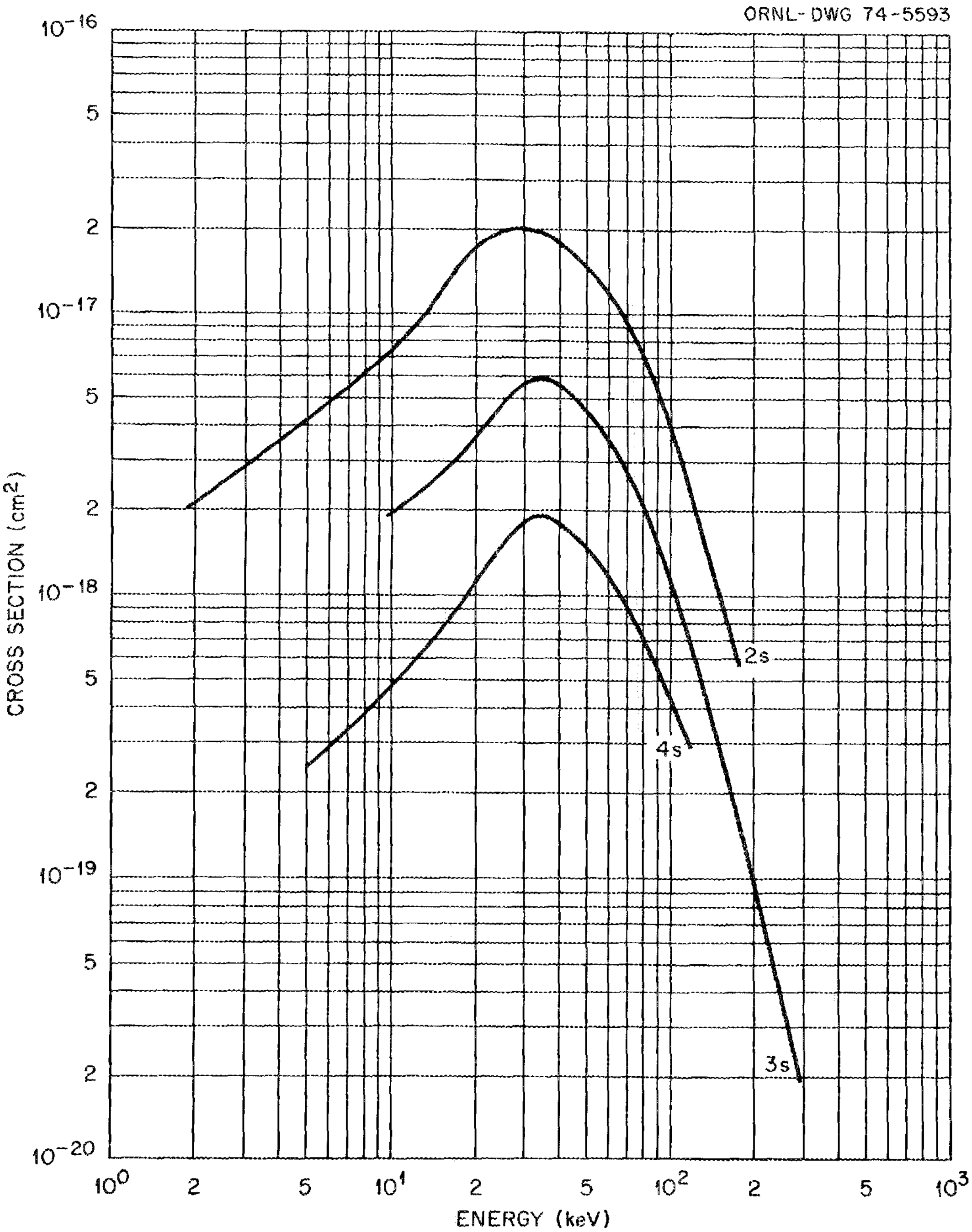
$H^+ + H_2 \rightarrow H(4s) + H_2^+$: R.H. Hughes, H.R. Dawson, and B.M. Doughty, Phys. Rev. 164, 166 (1967).

Notes:

See Notes (6) and (7) at end of chapter.

Accuracy:

Systematic error < 50%. Random error < 15%.


ORNL-DWG 74-5593
CROSS SECTION (cm^2)
10^{-16}
5
2
10^{-17}
5
2
10^{-18}
5
2
10^{-19}
5
2
10^{-20}
10^0
2
5
10^1
2
5
10^2
2
5
10^3
ENERGY (keV)
2s
4s
3s

Cross Sections for Excitation by Electron Capture for the Reactions

$$H^+ + H_2 \rightarrow H(2p,3p,3d) + H_2^+$$

Energy (keV)	Cross Sections for Excited State nℓ (cm^2)		
	2p	3p	3d
4.0 E 00	2.3 E-17		
5.0 E 00	2.6 E-17		
6.0 E 00	2.4 E-17		
7.0 E 00	2.3 E-17		
8.0 E 00	2.3 E-17		
9.0 E 00	2.5 E-17		
1.0 E 01	2.7 E-17	1.2 E-18	1.8 E-18
1.5 E 01	2.9 E-17	2.1 E-18	1.3 E-18
2.0 E 01	2.5 E-17	3.2 E-18	9.7 E-19
3.0 E 01	1.5 E-17	1.7 E-18	6.5 E-19
4.0 E 01	9.0 E-18	9.5 E-19	4.5 E-19
5.0 E 01	6.0 E-18	6.0 E-19	3.0 E-19
6.0 E 01	4.5 E-18	3.5 E-19	2.0 E-19
7.0 E 01	3.9 E-18	2.5 E-19	1.3 E-19
8.0 E 01	2.7 E-18	1.9 E-19	9.8 E-20
9.0 E 01	2.2 E-18	1.6 E-19	7.2 E-20
1.0 E 02	1.9 E-18	1.3 E-19	5.0 E-20
1.2 E 02	1.7 E-18		

References:

$H^+ + H_2 \rightarrow H(2p) + H_2^+$: R.H. Hughes, T.J. King, and Song-Sik Choe, Phys. Rev. A 5, 644 (1972); J.H. Birely and R.J. McNeal, Phys. Rev. A 5, 692 (1972); E.P. Andreev, V.A. Ankudinov, and S.V. Bobashev, Fifth International Conference on the Physics of Electronic & Atomic Collisions: Abstract of Papers, p.309, Publishing House Nauka, Leningrad, USSR (1967).

$H^+ + H_2 \rightarrow H(3p) + H_2^+$: E.P. Andreev, V.A. Ankudinov, and S.V. Bobashev, Fifth International Conference on the Physics of Electronic & Atomic Collisions: Abstract of Papers, p.309, Publishing House Nauka, Leningrad, USSR (1967); R.H. Hughes, C.A. Stigers, B.M. Doughty, and E.D. Stokes, Phys. Rev. A 1, 1424 (1970).

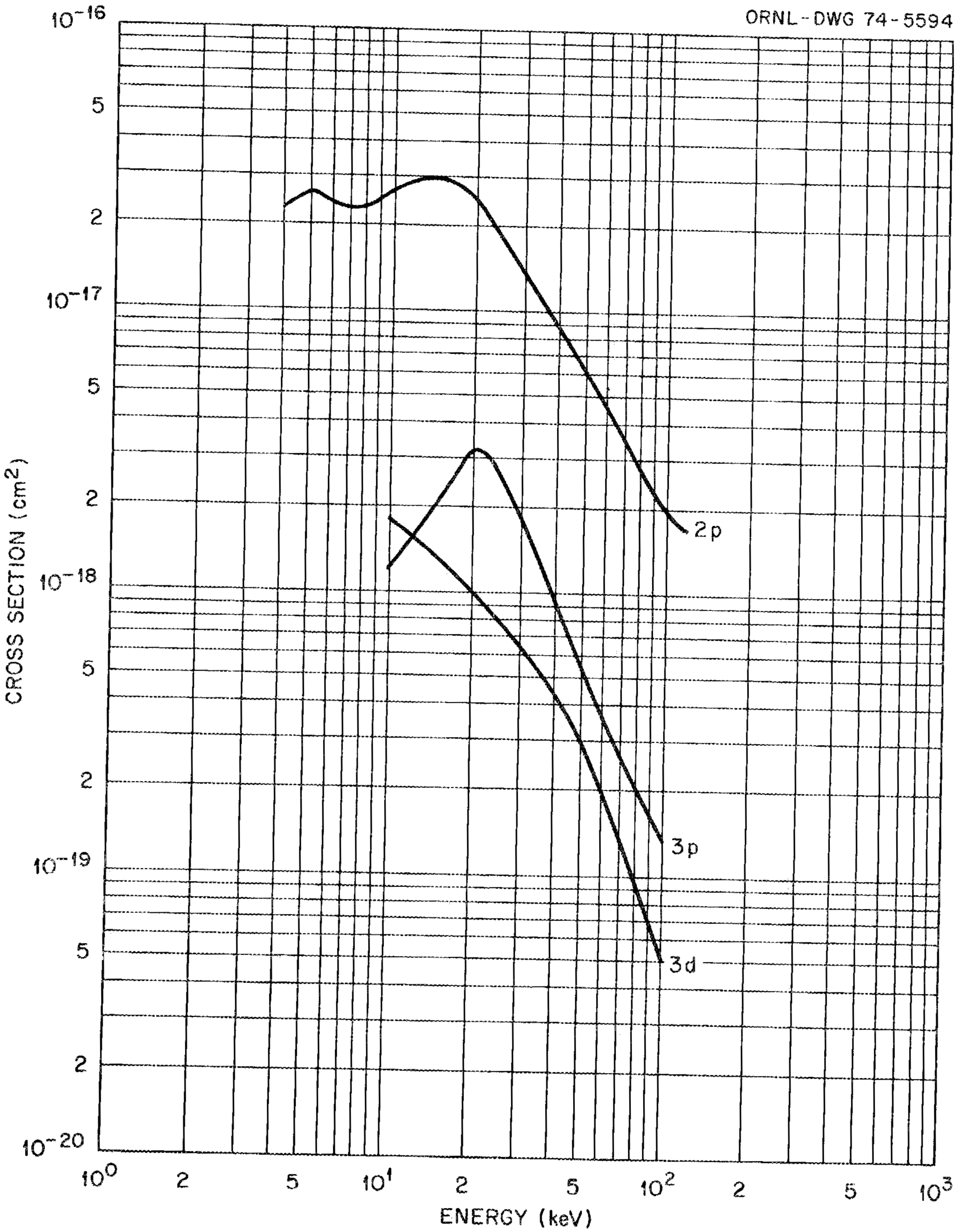
$H^+ + H_2 \rightarrow H(3d) + H_2^+$: R.H. Hughes, C.A. Stigers, B.M. Doughty, and E.D. Stokes, Phys. Rev. A 1, 1424 (1970).

Notes:

See Note (5) at end of chapter.

Accuracy:

Systematic error < 50%. Random error < 15%.


ORNL-DWG 74-5594
CROSS SECTION (cm²)
ENERGY (keV)
2p
3p
3d
10⁻¹⁶
5
2
10⁻¹⁷
10⁻¹⁸
10⁻¹⁹
10⁻²⁰
10⁰
10¹
10²
10³

Excitation Cross Sections for the Reactions

$$H^+ + H_2 \rightarrow H^+ + H + H(2s,2p,3p)$$

Energy (keV)	Cross Sections for Excited State $n\ell$ (cm^2)		
	2s	2p	3p
4.0 E 00		7.0 E-18	
5.0 E 00	1.3 E-18	9.3 E-18	
6.0 E 00	2.6 E-18	1.4 E-17	
7.0 E 00	3.5 E-18	1.8 E-17	
8.0 E 00	4.1 E-18	2.2 E-17	
1.0 E 01	4.7 E-18	2.8 E-17	
1.5 E 01	5.8 E-18	3.2 E-17	2.0 E-18
2.0 E 01	6.4 E-18	3.0 E-17	2.4 E-18
3.0 E 01	7.2 E-18	2.5 E-17	1.2 E-18
4.0 E 01		2.1 E-17	
5.0 E 01		1.8 E-17	
6.0 E 01		1.6 E-17	
7.0 E 01		1.5 E-17	
8.0 E 01		1.4 E-17	
1.0 E 02		1.2 E-17	

References:

$H^+ + H_2 \rightarrow H^+ + H + H(2s)$: J.H. Birely and R.J. McNeal, Phys. Rev. A 5, 692 (1972); E.P. Andreev, V.A. Ankudinov, and S.V. Bobashev, Fifth International Conference on the Physics of Electronic & Atomic Collisions: Abstract of Papers, p.309, Publishing House Nauka, Leningrad, USSR (1967).

$H^+ + H_2 \rightarrow H^+ + H + H(2p)$: J.H. Birely, R.J. McNeal, Phys. Rev. A 5, 692 (1972); R.H. Hughes, T.J. King, and Song-Sik Choe, Phys. Rev. A 5, 644 (1972).

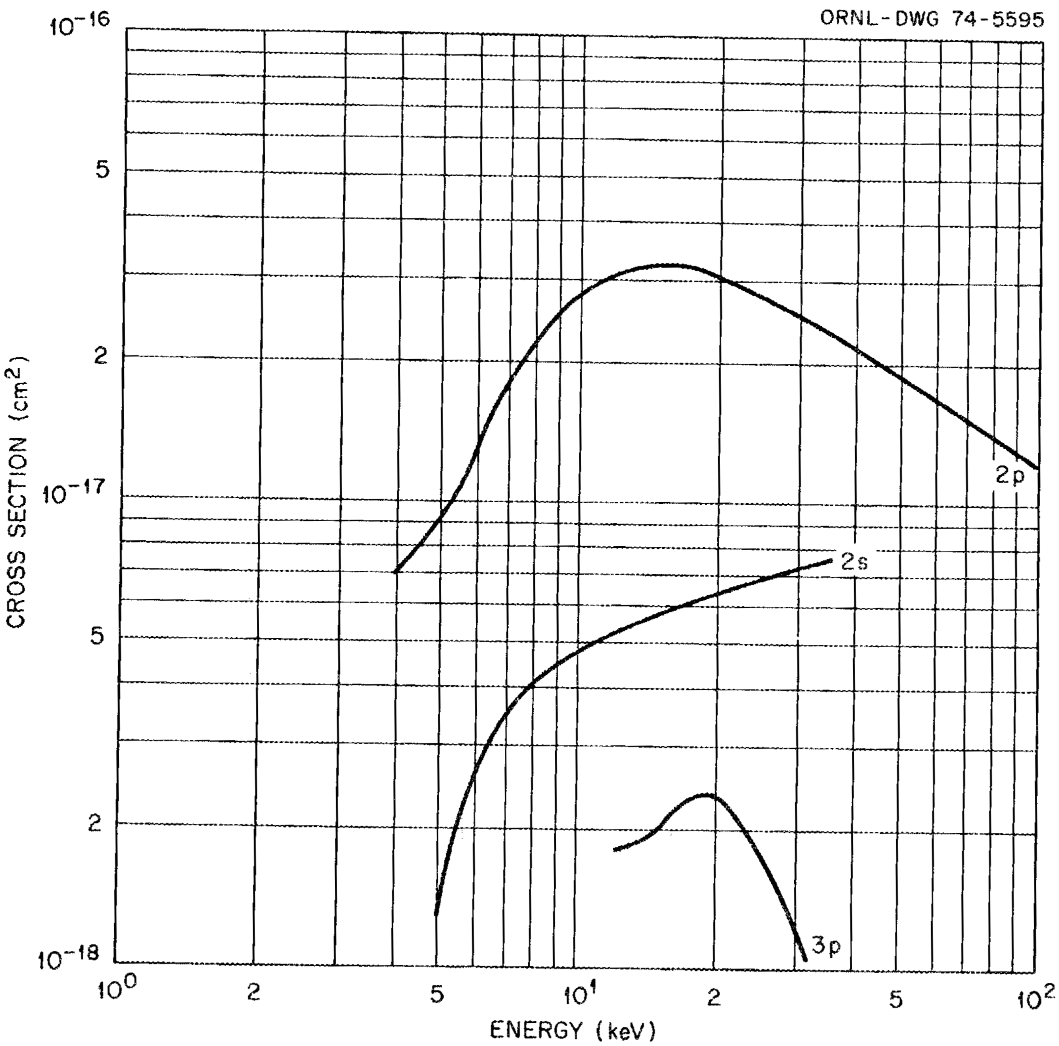
$H^+ + H_2 \rightarrow H^+ + H + H(3p)$: E.P. Andreev, V.A. Ankudinov, and S.V. Bobashev, Fifth International Conference on the Physics of Electronic & Atomic Collisions: Abstract of Papers, p.309, Publishing House Nauka, Leningrad, USSR (1967).

Notes:

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

Accuracy:

Systematic error < 50% for H(2s) and H(2p); systematic error < 20% for H(3p). Random error < 10%.


ORNL-DWG 74-5595
CROSS SECTION (cm^2)
10^{-16}
5
2
10^{-17}
5
2
10^{-18}
10^0
2
5
10^1
2
5
10^2
ENERGY (keV)
2p
2s
3p

Cross Sections for Emission of Balmer-Alpha Radiation for the Reactions

$$H^+ + H_2 \rightarrow H^+ + H + H(n = 3 \rightarrow 2)$$

Energy (keV)	Emission Cross Sections (cm^2)
5.0 E 00	1.1 E-18
6.0 E 00	1.3 E-18
8.0 E 00	1.8 E-18
1.0 E 01	2.2 E-18
1.5 E 01	2.5 E-18
2.0 E 01	2.3 E-18
3.0 E 01	1.7 E-18
4.0 E 01	1.4 E-18
5.0 E 01	1.2 E-18
6.0 E 01	1.0 E-18
8.0 E 01	8.0 E-19
1.0 E 02	6.5 E-19
1.5 E 02	4.4 E-19
2.0 E 02	3.5 E-19
3.0 E 02	2.4 E-19
4.0 E 02	1.9 E-19
5.0 E 02	1.6 E-19
6.0 E 02	1.3 E-19
8.0 E 02	1.1 E-19
9.0 E 02	9.9 E-20

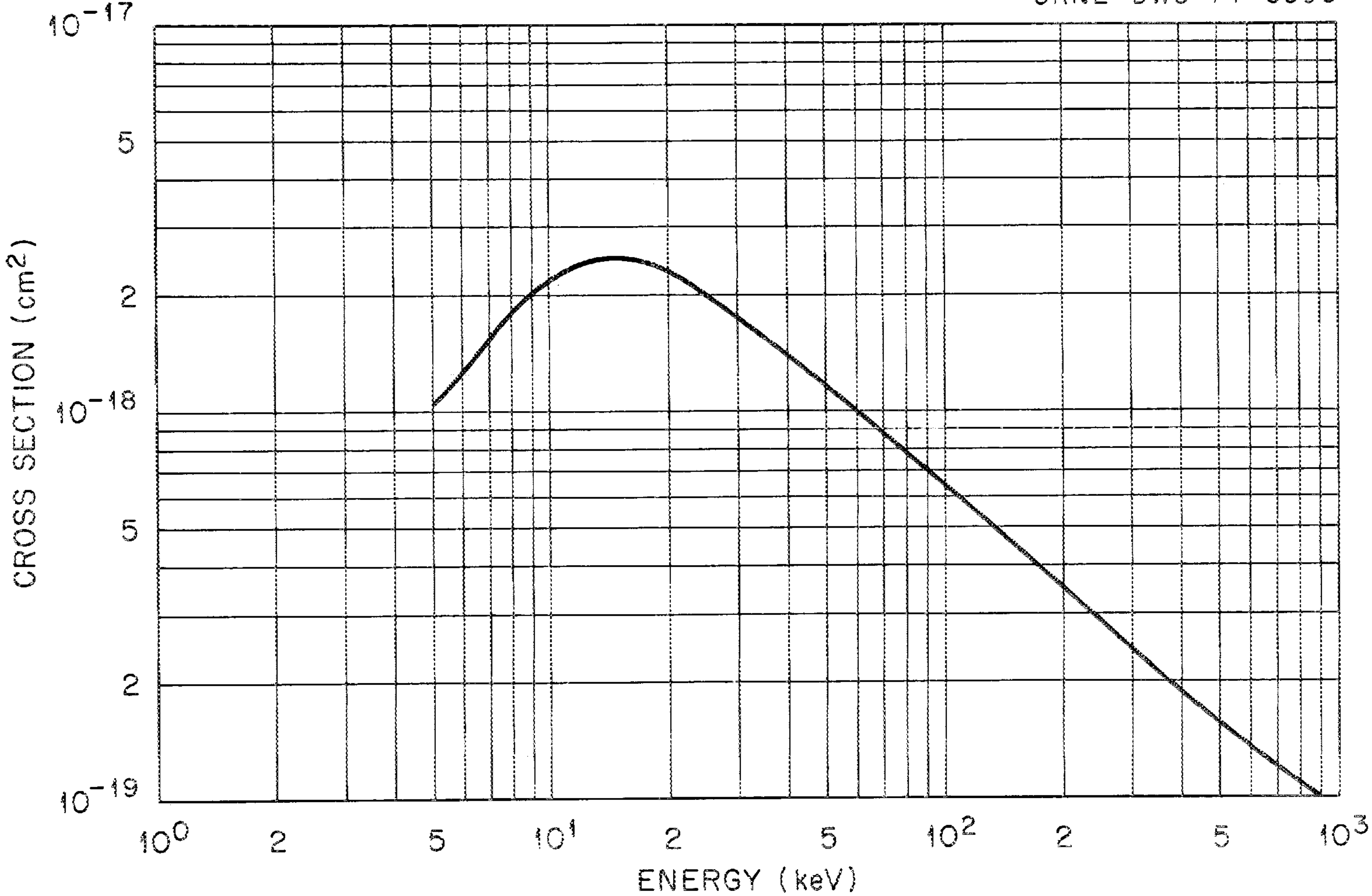
References:

J.L. Edwards, and E.W. Thomas, Phys. Rev. 165, 16 (1968); R.H. Hughes, S. Lin, and L.L. Hatfield, Phys. Rev. 130, 2318 (1963) (normalized to Edwards et al.).

Accuracy:

Systematic error < 20%. Random error < 10%.

ORNL-DWG 74-5596



Cross Sections for Emission of the 1606 Å and 4180 Å H_2 Bands by H^+ Impact

Energy (keV)	Emission Cross Section (cm^2) 1606 Å Band	4180Å Band
2.0 E 01	3.3 E-18	
3.0 E 01	4.5 E-18	
4.0 E 01	5.0 E-18	
5.0 E 01	5.2 E-18	
6.0 E 01	5.2 E-18	
8.0 E 01	5.0 E-18	
1.0 E 02	4.7 E-18	
1.5 E 02		8.0 E-21
2.0 E 02		6.3 E-21
3.0 E 02		4.3 E-21
4.0 E 02		3.2 E-21
5.0 E 02		2.5 E-21
6.0 E 02		2.1 E-21
8.0 E 02		1.6 E-21
9.0 E 02		1.4 E-21

References:

1606 Å Band: D.A. Dahlberg, D.K. Anderson, and I.E. Dayton, Phys. Rev. 170, 127 (1968).

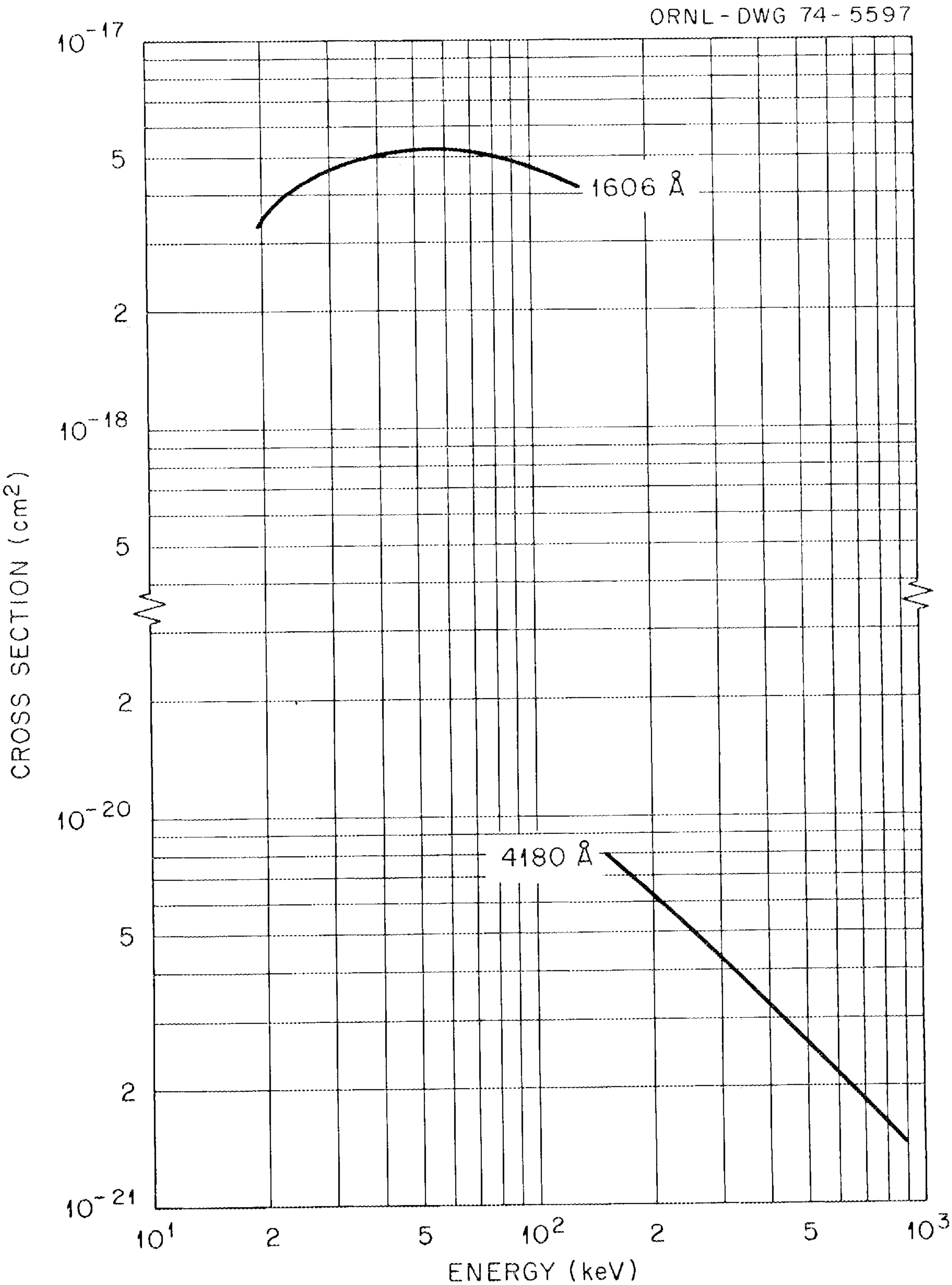
4180 Å Band: J.L. Edwards, and E.W. Thomas, Phys. Rev. 165, 16 (1968).

Notes:

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

Accuracy:

Systematic error < 50% for 1606 Å band; systematic error < 20% for 4180 Å band. Random error < 10%.


ORNL-DWG 74-5597
10^{-17}
5
2
10^{-18}
5
2
10^{-20}
5
2
10^{-21}
1606 Å
4180 Å
CROSS SECTION (cm^2)
10^1
2
5
10^2
2
5
10^3
ENERGY (keV)

Excitation Cross Sections for Reactions

$H^- + He \rightarrow H(2s,2p) + He + e$

Energy (keV)	Cross Sections for State $n\ell$ (cm^2) 2s	2p
5.0 E 00		2.80 E-17
6.0 E 00	5.44 E-17	2.74 E-17
7.0 E 00	5.12 E-17	2.68 E-17
8.0 E 00	4.80 E-17	2.64 E-17
9.0 E 00	4.36 E-17	2.62 E-17
1.0 E 01	4.00 E-17	2.57 E-17
1.5 E 01	3.14 E-17	2.45 E-17
2.0 E 01	2.87 E-17	2.36 E-17
2.5 E 01	2.68 E-17	2.28 E-17
3.0 E 01	2.57 E-17	2.24 E-17
3.5 E 01	2.52 E-17	2.16 E-17
3.8 E 01	2.52 E-17	2.14 E-17

Reference:

A. L. Orbeli, E. P. Andreev, V. A. Ankudinov, and V. M. Dukel'ski, Soviet Phys.-JETP 31, 1044 (1970).

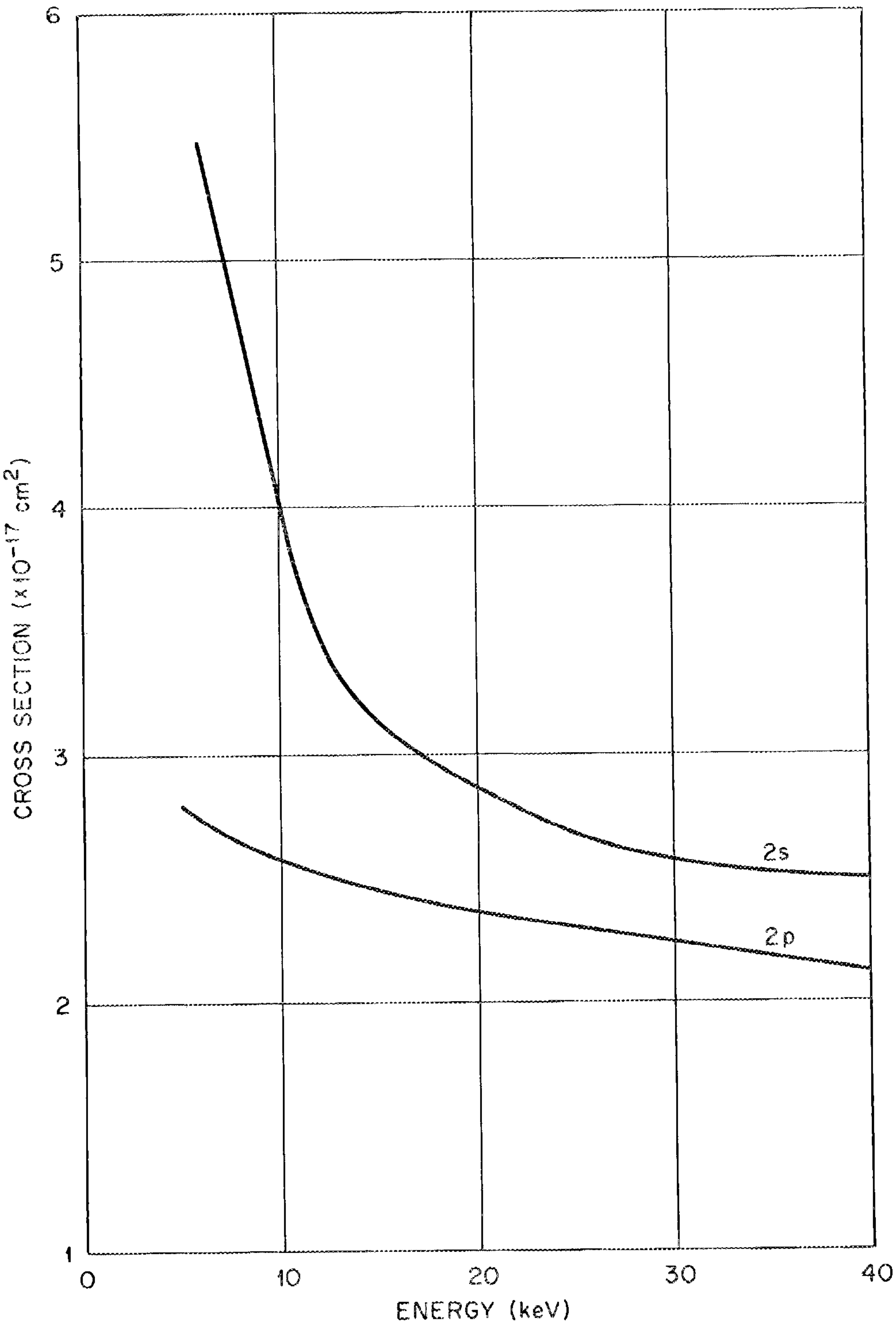
Notes:

See Notes (27), (28), and (29) at end of chapter.

Accuracy:

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

ORNL-DWG 74-5609



Excitation Cross Sections for the Reactions

H + He → H(2s,3s,2p,3p,3d) + He

Energy (keV)	Cross Sections for State nℓ (cm^2)		
	3s	3p	3d
1.0 E 01	1.3 E-18		1.2 E-18
1.5 E 01	1.0 E-18	1.0 E-18	8.8 E-19
2.0 E 01	9.2 E-19	9.7 E-19	5.5 E-19
3.0 E 01	7.8 E-19	7.8 E-19	4.2 E-19
3.5 E 01	8.2 E-19	8.0 E-19	4.6 E-19
	2s	2p	
1.0 E 00	5.2 E-18	5.4 E-17	
2.0 E 00	7.3 E-18	4.6 E-17	
5.0 E 00	7.7 E-18	3.3 E-17	
7.0 E 00	7.0 E-18	2.6 E-17	
1.0 E 01	5.5 E-18	2.0 E-17	
2.0 E 01	4.4 E-18	1.0 E-17	
5.0 E 01	3.5 E-18	4.8 E-18	
7.0 E 01	2.8 E-18	4.5 E-18	
1.0 E 02	2.1 E-18	4.3 E-18	
2.0 E 02	1.4 E-18	3.2 E-18	
5.0 E 02	7.4 E-19	2.1 E-18	
7.0 E 02	5.2 E-19	1.7 E-18	
1.0 E 03	3.7 E-19	1.3 E-18	

References:

H + He → H(2s) + He: E.W. Thomas and I. Sauers, Eighth International Conference on the Physics of Electronic & Atomic Collisions: Abstract of Papers, p.166, Beograde Institute of Physics Publishing Co. Beograd (1973). R.H. Hughes and Song-Sik Choe Phys. Rev. A 5, 1758 (1972). H. Levy, Phys. Rev. 185, 7 (1969).

H + He → H(3s,3p,3d) + He: R.H. Hughes, H.M. Petefish, and H. Kisner, Phys. Rev. A 5, 2103 (1972).

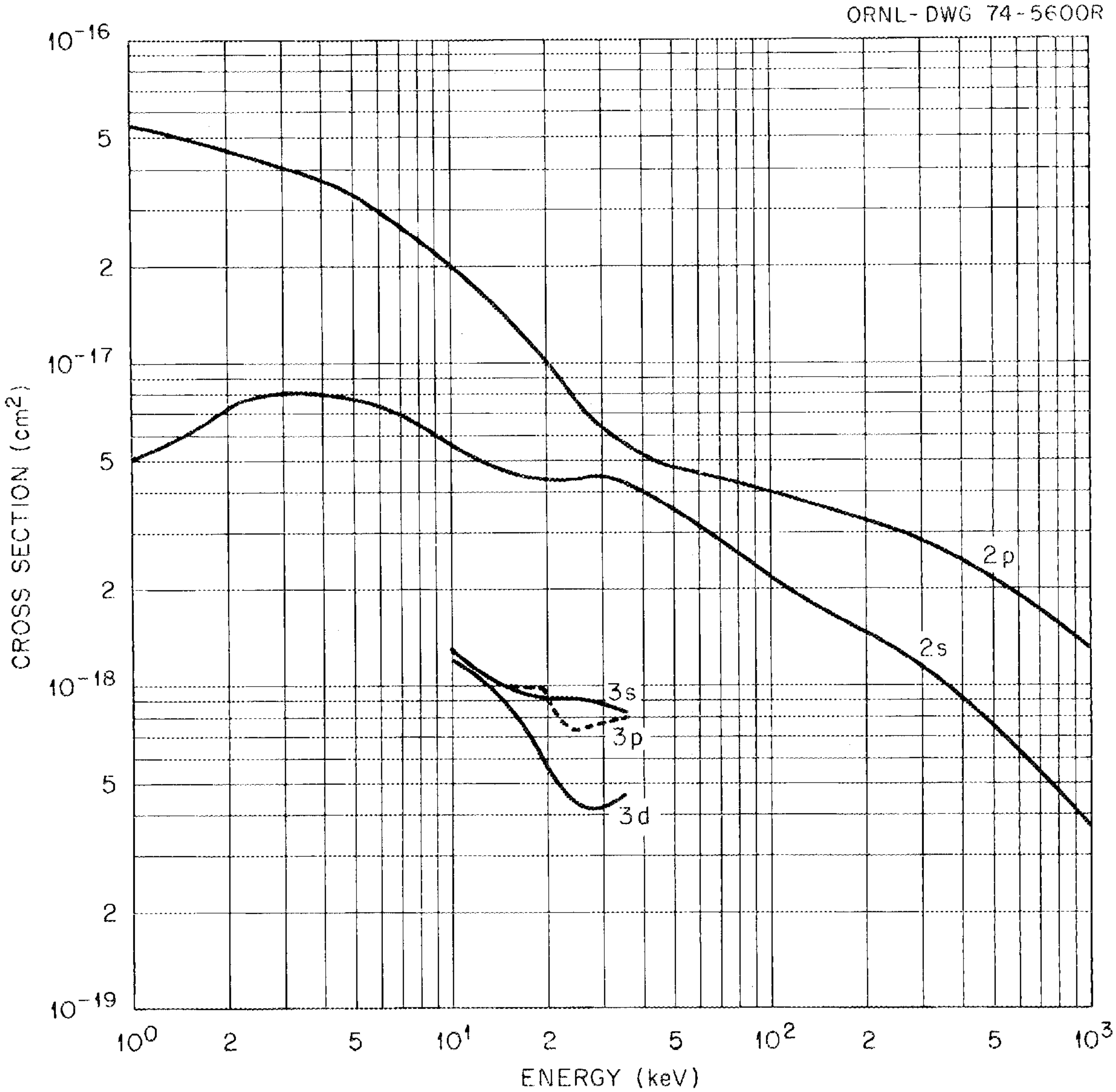
H + He → H(2p) + He: R.H. Hughes and Song-Sik Choe, Phys. Rev. A 5, 656 (1972). J.H. Birely and R.J. McNeal, Phys. Rev. A 5, 257 (1972). H. Levy, Phys. Rev. 185, 7 (1969).

Notes:

See Notes (25) and (26) at end of chapter.

Accuracy:

Systematic error < 50%. Random error < 10%.


ORNL-DWG 74-5600R
CROSS SECTION (cm²)
10^{-16}
5
2
10^{-17}
5
2
10^{-18}
5
2
10^{-19}
10^{0}
2
5
10^{1}
2
5
10^{2}
2
5
10^{3}
ENERGY (keV)
2p
2s
3s
3p
3d

Excitation Cross Sections by Electron Capture for the Reactions

$$H^+ + He \rightarrow H(2p,3p,3d) + He^+$$

Energy (keV)	Cross Sections for Excited State $n\ell$ (cm^2)		
	2p	3p	3d
2.5 E-01	4.7 E-19		
3.0 E-01	4.6 E-19		
5.0 E-01	4.8 E-19		
7.0 E-01	5.2 E-19		
1.0 E 00	6.2 E-19		
1.5 E 00	7.8 E-19		
2.0 E 00	9.3 E-19		
3.0 E 00	1.2 E-18		
4.0 E 00	1.4 E-18		
5.0 E 00	1.6 E-18		
6.0 E 00	1.7 E-18		
7.0 E 00	1.9 E-18		
8.0 E 00	2.1 E-18		
9.0 E 00	2.2 E-18		
1.0 E 01	2.4 E-18	3.6 E-19	1.3 E-19
1.5 E 01	3.2 E-18	4.5 E-19	1.9 E-19
2.0 E 01	3.6 E-18	6.0 E-19	1.9 E-19
3.0 E 01	3.3 E-18	7.0 E-19	1.6 E-19
4.0 E 01	2.5 E-18	4.7 E-19	1.2 E-19
5.0 E 01	1.7 E-18	2.6 E-19	1.0 E-19
6.0 E 01	1.3 E-18	1.7 E-19	8.0 E-20
7.0 E 01	1.0 E-18	1.0 E-19	6.5 E-20
8.0 E 01	7.9 E-19	7.0 E-20	5.2 E-20
9.0 E 01	6.4 E-19	5.0 E-20	4.2 E-20
1.0 E 02	5.4 E-19	3.7 E-20	3.7 E-20
1.5 E 02	2.8 E-19	9.4 E-21	
2.0 E 02		3.0 E-21	
3.0 E 02		3.4 E-22	

References:

$H^+ + He \rightarrow H(2p) + He^+$: D. Pretzer, B. Van Zyl, and R. Geballe, Proceedings of the Third International Conference on the Physics of Electronic and Atomic Collisions: Abstract of Papers, p.618, North Holland Publishing Co., Amsterdam (1963).

$H^+ + He \rightarrow H(3p) + He^+$: R.H. Hughes, C.A. Stigers, B.M. Doughty, and E.D. Stokes, Phys. Rev. A 1, 1424 (1970); J.C. Ford and E.W. Thomas, Phys. Rev. A 5, 1694 (1972) (normalized to work of Hughes et al.).

$H^+ + He \rightarrow H(3d) + He^+$: R.H. Hughes, C.A. Stigers, B.M. Doughty, and E.D. Stokes, Phys. Rev. A 1, 1424 (1970).

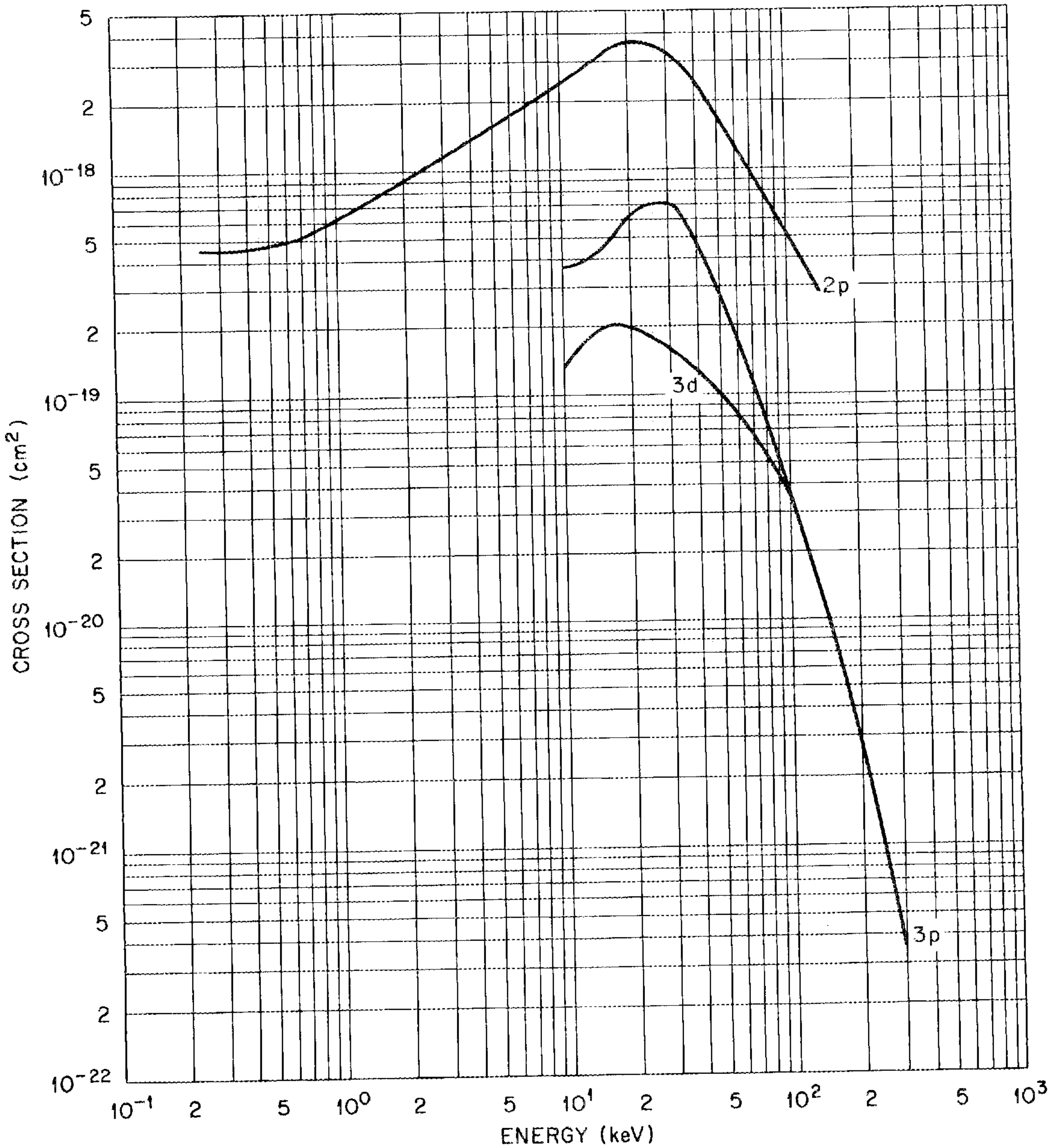
Notes:

See Notes (5), (13), and (14) at end of chapter.

Accuracy:

Systematic error < 50%. Random error < 15%.

ORNL-DWG 74-5598



Excitation Cross Sections by Electron Capture for the Reactions

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

Energy (keV)	Cross Sections for Excited State $n\ell$ (cm^2)		
	2s	3s	4s
4.0 E 00	6.5 E-20		
5.0 E 00	1.5 E-19	1.6 E-19	4.1 E-20
6.0 E 00	2.7 E-19	2.3 E-19	5.0 E-20
7.0 E 00	4.2 E-19	2.8 E-19	6.1 E-20
8.0 E 00	5.4 E-19	3.3 E-19	7.2 E-20
9.0 E 00	6.1 E-19	3.7 E-19	8.3 E-20
1.0 E 01	6.7 E-19	4.0 E-19	9.3 E-20
1.5 E 01	9.2 E-19	6.2 E-19	1.4 E-19
2.0 E 01	1.6 E-18	8.0 E-19	2.0 E-19
3.0 E 01	4.7 E-18	1.4 E-18	3.4 E-19
4.0 E 01	7.4 E-18	1.8 E-18	5.6 E-19
5.0 E 01	8.0 E-18	1.7 E-18	7.0 E-19
6.0 E 01	7.0 E-18	1.4 E-18	6.8 E-19
7.0 E 01	6.0 E-18	1.2 E-18	6.1 E-19
8.0 E 01	4.8 E-18	1.1 E-18	5.0 E-19
9.0 E 01	4.0 E-18	9.0 E-19	3.9 E-19
1.0 E 02	3.2 E-18	8.0 E-19	3.0 E-19
1.5 E 02	1.3 E-18	3.8 E-19	
2.0 E 02	5.6 E-19	1.6 E-19	
3.0 E 02		3.5 E-20	
4.0 E 02		1.0 E-20	
5.0 E 02		5.4 E-21	
6.0 E 02		3.0 E-21	
7.0 E 02		1.9 E-21	

References:

$H^+ + He \rightarrow H(2s) + He^+$: R.H. Hughes, E.D. Stokes, Song-Sik Choe, and T.J. King, Phys. Rev. A 4, 1453 (1971); R.L. Fitzwilson and E.W. Thomas, Phys. Rev. A 3, 1305 (1971) (normalized to Hughes et al.); G. Ryding, A.B. Wittkower, and H.B. Gilbody, Proc. Phys. Soc., London 89, 547 (1966).

$H^+ + He \rightarrow H(3s) + He^+$: R.H. Hughes, C.A. Stigers, B.M. Doughty, and E.D. Stokes, Phys. Rev. A 1, 1424 (1970); R.J. Conrads, T.W. Nichols, J.C. Ford, and E.W. Thomas, Phys. Rev. 7, 1928 (1973).

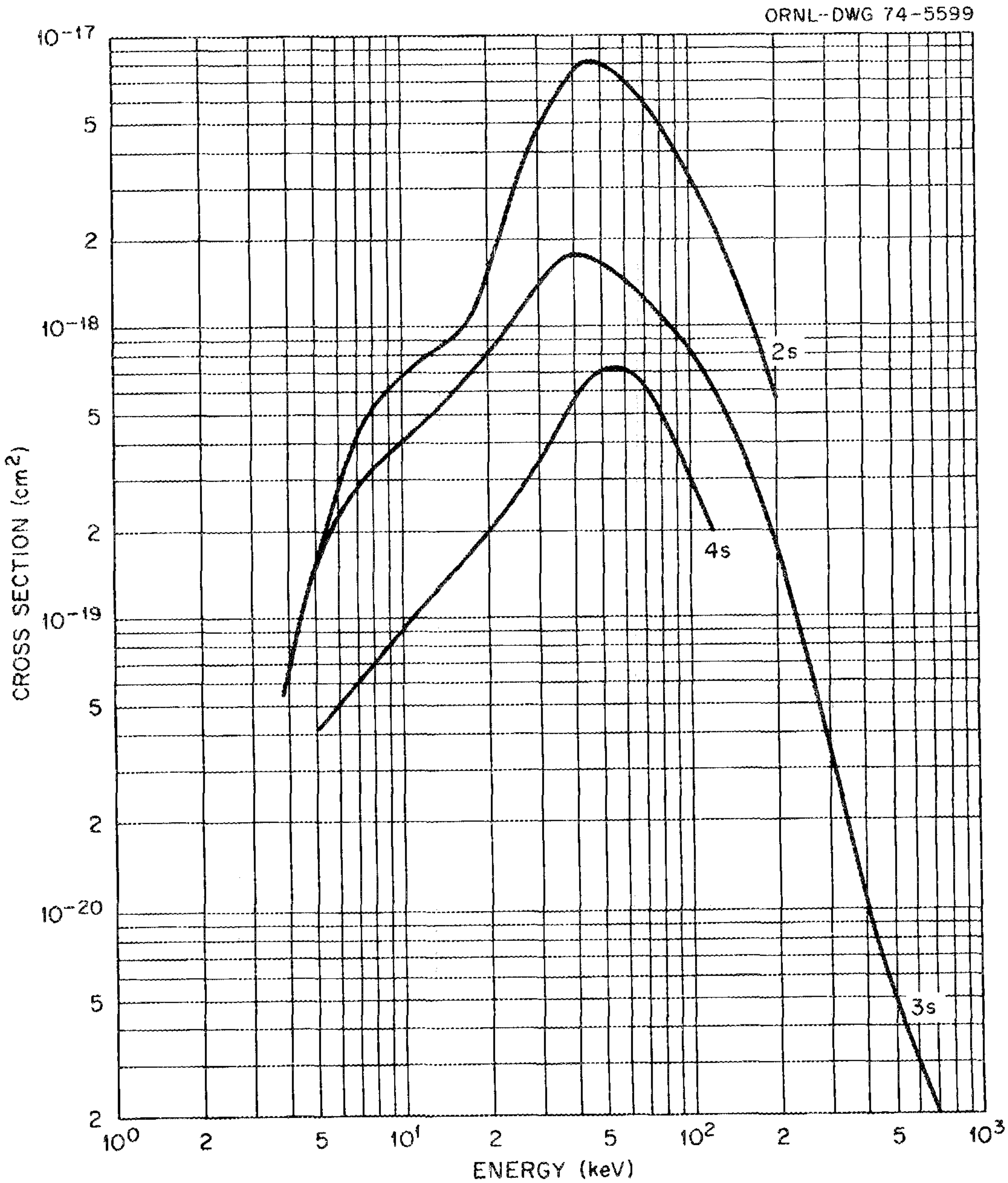
$H^+ + He \rightarrow H(4s) + He^+$: R.H. Hughes, H.R. Dawson, and B.M. Doughty, Phys. Rev. 164, 166 (1967).

Notes:

See Notes (13), (14), (15), and (16) at end of chapter.

Accuracy:

Systematic error < 50%. Random error < 15%.


ORNL-DWG 74-5599
CROSS SECTION (cm²)
ENERGY (keV)
2s
3s
4s
10⁻¹⁷
5
2
10⁻¹⁸
10⁻¹⁹
10⁻²⁰
10⁰
10¹
10²
10³

Excitation Cross Sections for the Reactions

$H^{+} + He \rightarrow H^{+} + He\ (4^{1}S,\ 4^{1}P,\ 4^{1}D)$

Energy (keV)	Cross Sections for Excited States nℓ (cm^2)		
	$4^{1}S$	$4^{1}P$	$4^{1}D$
1.0 E 00	2.8 E-22		
2.0 E 00	1.2 E-21		2.3 E-21
3.0 E 00	2.0 E-21		3.6 E-21
4.0 E 00	2.2 E-21		6.9 E-21
5.0 E 00	4.6 E-21		1.8 E-20
7.0 E 00	3.9 E-20		7.5 E-20
1.0 E 01	8.6 E-20	1.2 E-19	1.4 E-19
2.0 E 01	1.6 E-19	3.2 E-19	1.3 E-19
3.0 E 01	4.1 E-19	3.7 E-19	1.2 E-19
4.0 E 01	4.8 E-19	4.5 E-19	1.4 E-19
5.0 E 01	4.8 E-19	5.8 E-19	1.5 E-19
7.0 E 01	4.4 E-19	8.0 E-19	1.5 E-19
1.0 E 02	3.4 E-19	9.6 E-19	1.3 E-19
2.0 E 02	1.8 E-19	9.2 E-19	6.6 E-20
3.0 E 02	1.2 E-19	7.3 E-19	4.3 E-20
4.0 E 02	8.8 E-20	6.1 E-19	3.1 E-20
5.0 E 02	7.0 E-20	5.3 E-19	2.5 E-20
7.0 E 02	5.0 E-20	4.3 E-19	1.8 E-20
1.0 E 03	3.7 E-120	3.3 E-19	1.3 E-20

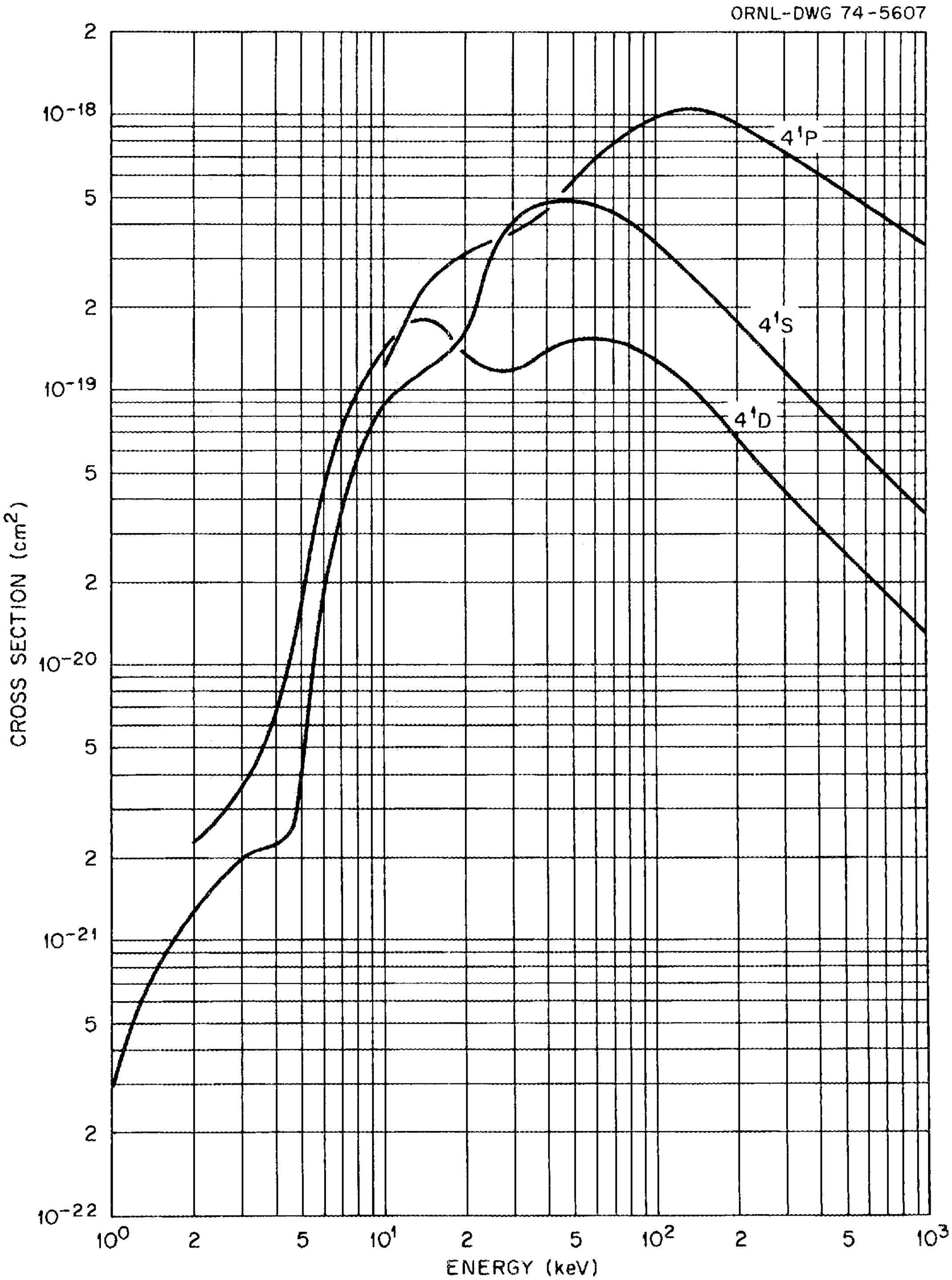
References:

J. Van den Bos, G. J. Winter, and F. J. de Heer, Physica 40, 357 (1968); A. Scharmann and K. H. Schartner, Z. Physik 228, 254 (1969) (these data were published as relative cross sections only; shown here normalized to the works of Van de Bos, *et al.* at 140 keV).

Notes:

See Notes (41), (42), and (43) at end of chapter.

Accuracy: Systematic error < 9%. Random error < 5%.


ORNL-DWG 74-5607
CROSS SECTION (cm²)
ENERGY (keV)
4¹P
4¹S
4¹D
2
10⁻¹⁸
5
2
10⁻¹⁹
5
2
10⁻²⁰
5
2
10⁻²¹
5
2
10⁻²²
10⁰
2
5
10¹
2
5
10²
2
5
10³

Cross Sections for Formation of H Atoms in High Excited States by H^+ Impact on H_2, He, N_2, O_2

Energy (keV)	Coefficients $\sigma(n) \times n^3$ (see note 18) (cm^2)			
	H_2	He	N_2	O_2
1.5 E 01		5.0 E-17		
2.0 E 01	2.4 E-16	8.3 E-17	3.2 E-16	4.2 E-16
3.0 E 01	3.3 E-16	1.2 E-16	3.9 E-16	5.0 E-16
4.0 E 01	3.0 E-16	1.1 E-16	3.9 E-16	4.5 E-16
5.0 E 01	2.1 E-16	8.9 E-17	3.6 E-16	3.7 E-16
6.0 E 01	1.4 E-16	7.3 E-17	3.1 E-16	3.1 E-16
7.0 E 01	9.3 E-17	5.7 E-17	2.4 E-16	2.6 E-16
8.0 E 01	6.7 E-17	4.6 E-17	2.0 E-16	2.3 E-16
1.0 E 02	3.5 E-17	2.9 E-17	1.3 E-16	1.7 E-16
1.5 E 02	9.3 E-18		6.0 E-17	9.7 E-17
1.8 E 02	4.0 E-18			

References:

$H^+ + (H_2,He) \rightarrow H(n) + (H_2^+,He^+)$: R.N. Il'lin, V.A. Oparin, E.S. Solov'ev, and N.V. Fedorenko, Soviet Phys-JETP Lett. 2, 197 (1965).

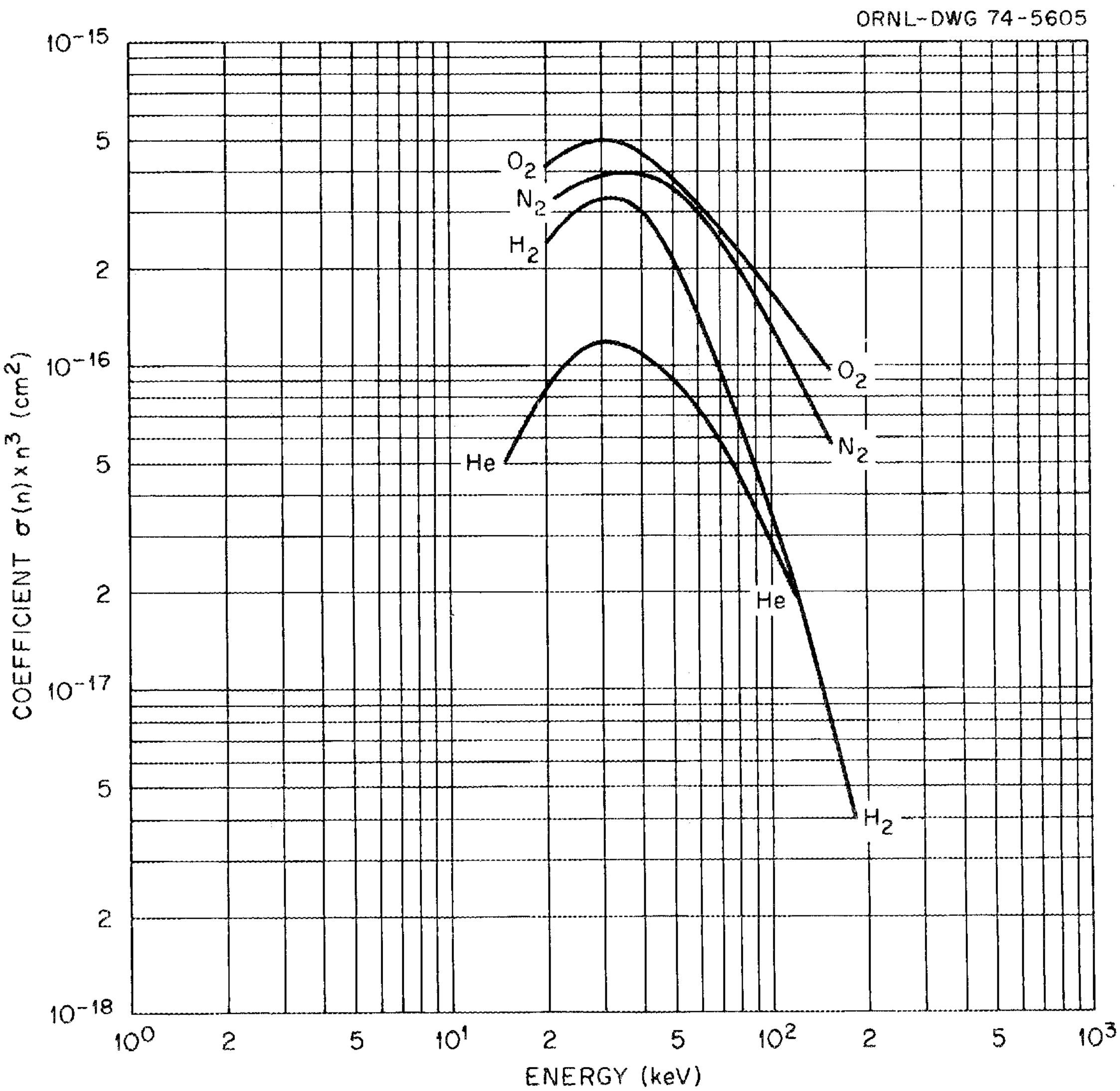
$H^+ + (N_2,O_2) \rightarrow H(n) + (N_2^+,O_2^+)$: R. Le Doucen, and J. Guidini, Le Journal de Phys. 31, 965 (1970).

Notes:

See Notes (18) and (19) at end of chapter.

Accuracy:

Systematic error < 10%. Random error < 10%.


ORNL-DWG 74-5605
COEFFICIENT $\sigma(n) \times n^3$ (cm^2)
ENERGY (keV)
10^{-15}
5
2
10^{-16}
5
2
10^{-17}
5
2
10^{-18}
10^0
2
5
10^1
2
5
10^2
2
5
10^3
O_2
N_2
H_2
He
O_2
N_2
He
H_2

Excitation Cross Sections for the Reactions

$H^+ + (N_2, O_2, CO_2) \rightarrow H(2s) + (N_2^+, O_2^+, CO_2^+)$

Energy (keV)	Cross Sections for Formation H(2s) (cm^2)		
	N_2	O_2	CO_2
1.0 E 00			2.9 E-17
1.5 E 00			4.5 E-17
2.0 E 00			4.9 E-17
3.0 E 00			5.2 E-17
4.0 E 00			5.6 E-17
5.0 E 00	9.0 E-18	1.1 E-17	5.8 E-17
6.0 E 00	1.1 E-17	1.3 E-17	5.9 E-17
8.0 E 00	1.4 E-17	1.7 E-17	5.9 E-17
1.0 E 01	1.5 E-17	2.1 E-17	5.6 E-17
1.5 E 01	1.9 E-17	2.1 E-17	5.0 E-17
2.0 E 01	2.6 E-17	2.1 E-17	4.0 E-17
3.0 E 01	2.9 E-17	2.0 E-17	3.3 E-17
4.0 E 01	2.6 E-17	1.9 E-17	
5.0 E 01	2.3 E-17	1.7 E-17	
6.0 E 01	2.0 E-17	1.6 E-17	
8.0 E 01	1.4 E-17	1.2 E-17	
1.0 E 02	9.2 E-18	8.9 E-18	

References:

$H^+ + (N_2, O_2) \rightarrow H(2s) + (N_2^+, O_2^+)$: R.H. Hughes, E.D. Stokes, Song-Sik Choe, and T.J. King, Phys. Rev. A 4, 1453 (1971); R.L. Fitzwilson, and E.W. Thomas, Phys. Rev. A 3, 1305 (1971) (normalized to Hughes et al.).

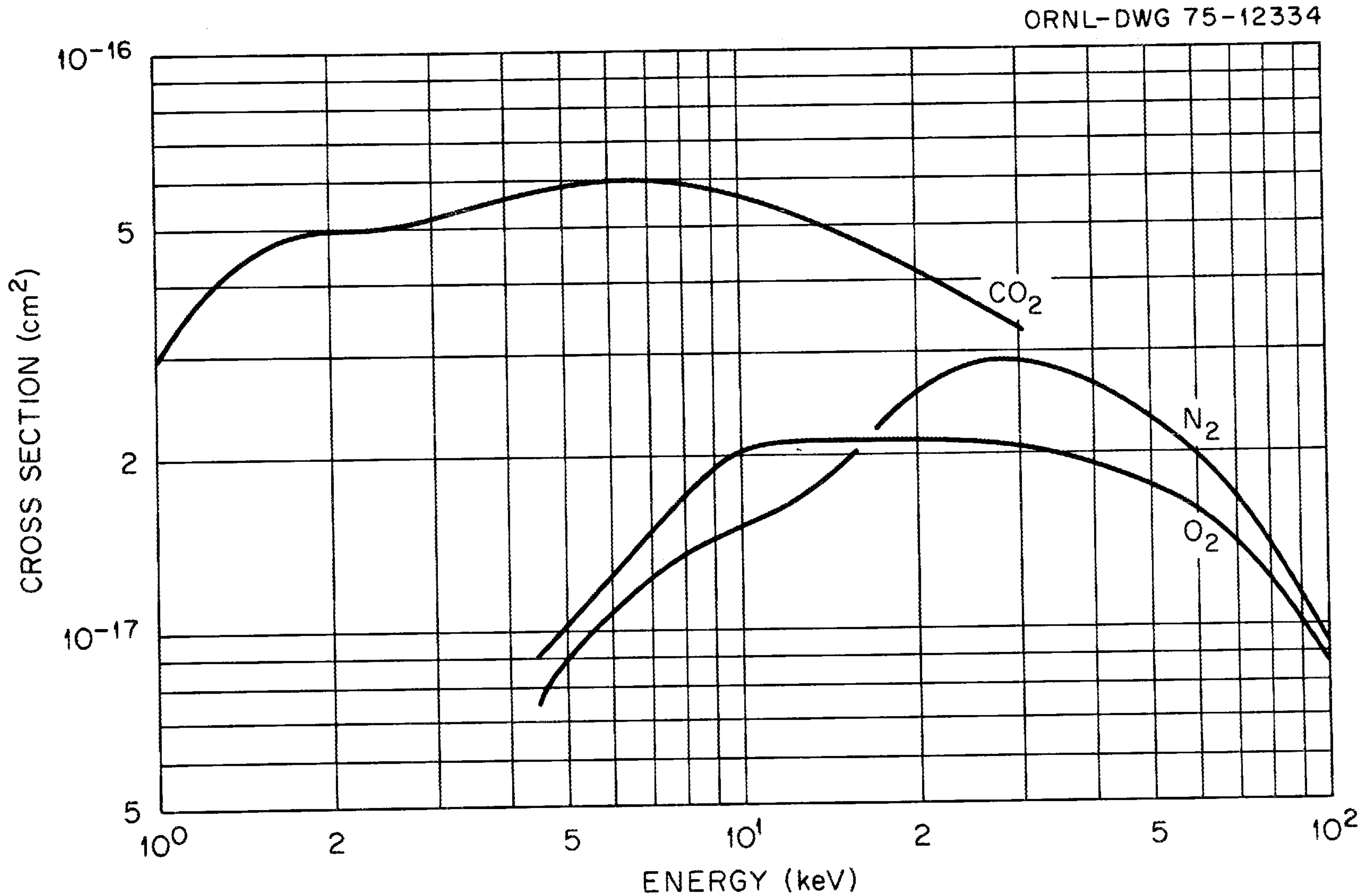
$H^+ + (CO_2) \rightarrow H(2s) + CO_2^+$: J.H. Birely and R.J. McNeal, J. Chem. Phys. 56, 2189 (1972).

Notes:

See Note (17) at end of chapter.

Accuracy:

Systematic error < 50%. Random error < 10%.



ORNL-DWG 75-12334
CROSS SECTION (cm^2)
10^{-16}
5
2
10^{-17}
5
10^0
2
5
10^1
2
5
10^2
ENERGY (keV)
CO_2
N_2
O_2

A.2.37

Excitation Cross Sections for the Reactions

$H^+ + (N_2, O_2, CO_2) \rightarrow H(3s) + (N_2^+, O_2^+, CO_2^+)$

Energy (keV)	Cross Sections for Formation H(3s) (cm^2)		
	N_2	O_2	CO_2
5.0 E 00	3.2 E-18	3.7 E-18	
6.0 E 00	3.5 E-18	4.0 E-18	
8.0 E 00	4.0 E-18	4.9 E-18	
1.0 E 01	4.8 E-18	6.0 E-18	
1.5 E 01	7.0 E-18	7.9 E-18	
2.0 E 01	9.2 E-18	8.1 E-18	
3.0 E 01	9.6 E-18	8.8 E-18	
4.0 E 01	7.8 E-18	7.6 E-18	
5.0 E 01	6.5 E-18	5.7 E-18	
6.0 E 01	5.4 E-18	4.4 E-18	
8.0 E 01	4.0 E-18	3.4 E-18	5.1 E-18
1.0 E 02	3.1 E-18	3.1 E-18	4.0 E-18
1.5 E 02	1.4 E-18	1.7 E-18	2.1 E-18
2.0 E 02	6.0 E-19	7.8 E-19	1.0 E-18
3.0 E 02	1.4 E-19		
4.0 E 02	4.8 E-20		
5.0 E 02	2.0 E-20		
6.0 E 02	1.0 E-20		

References:

$H^+ + (N_2, O_2) \rightarrow H(3s) + (N_2^+, O_2^+)$: R.H. Hughes, H.R. Dawson, B.M. Doughty, D.B. Kay, and C.A. Stigers, Phys. Rev. 146, 53 (1966); J.C. Ford and E.W. Thomas, Phys. Rev. A 5, 1701 (1972).

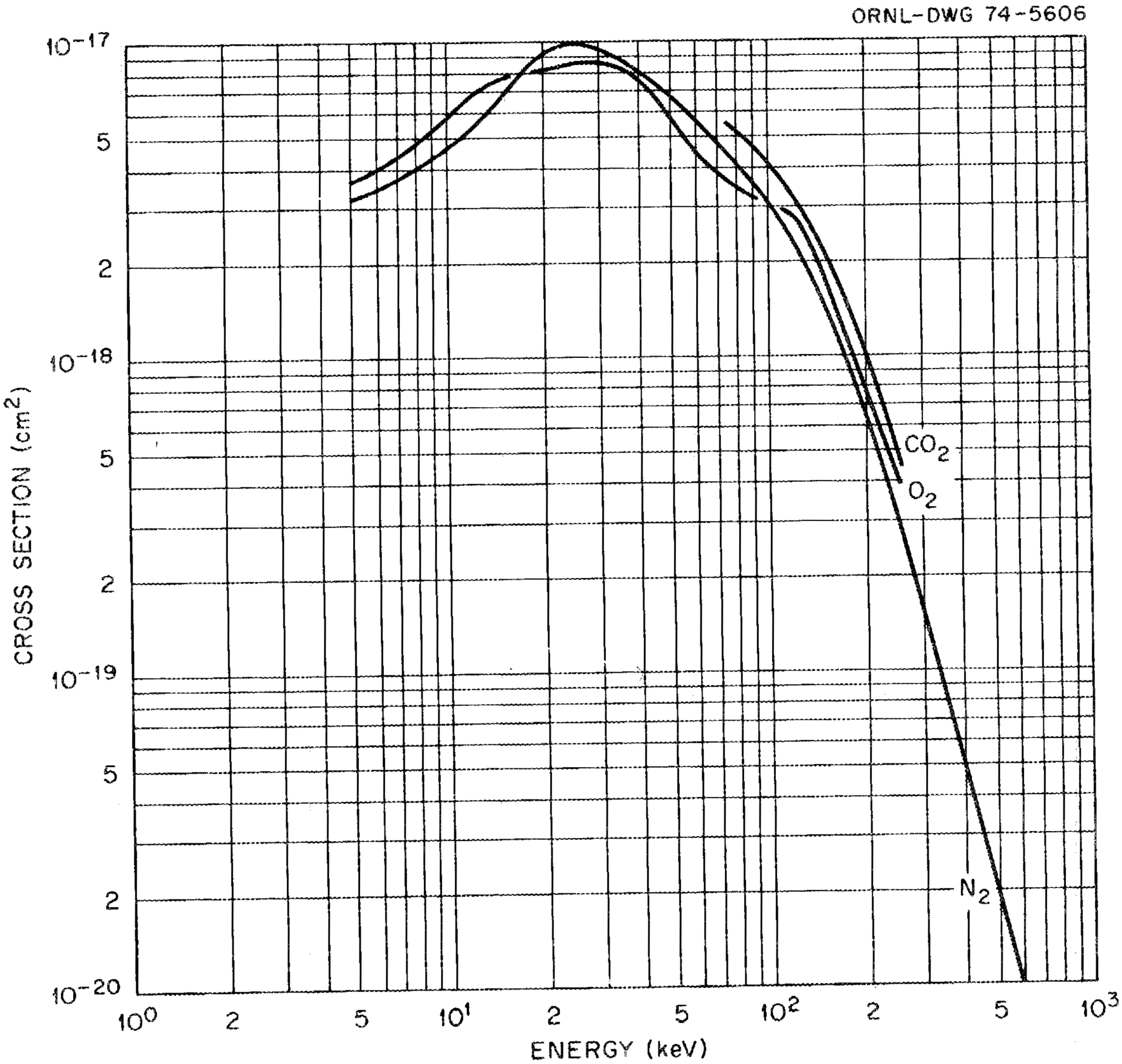
$H^+ + (CO_2) \rightarrow H(3s) + CO_2^+$: J.C. Ford and E.W. Thomas, Phys. Rev. A 5, 1701 (1972).

Notes:

See Note (17) at end of chapter.

Accuracy:

Systematic error < 50%. Random error < 10%.


ORNL-DWG 74-5606
CROSS SECTION (cm^2)
10^{-17}
5
2
10^{-18}
5
2
10^{-19}
5
2
10^{-20}
10^0
2
5
10^1
2
5
10^2
2
5
10^3
ENERGY (keV)
CO_2
O_2
N_2

Excitation Cross Sections for the Reactions

$H^+ + Ar \rightarrow H(2s,3s) + Ar^+$

Energy (keV)	Cross Sections for State $n\ell$ (cm^2)	
	2s	3s
4.0 E 00	4.8 E-18	3.3 E-18
5.0 E 00	3.7 E-18	3.7 E-18
6.0 E 00	4.3 E-18	3.6 E-18
8.0 E 00	6.9 E-18	3.5 E-18
1.0 E 01	1.0 E-17	4.0 E-18
1.5 E 01	2.0 E-17	5.7 E-18
2.0 E 01	2.3 E-17	7.4 E-18
3.0 E 01	2.3 E-17	7.7 E-18
4.0 E 01	2.3 E-17	6.4 E-18
5.0 E 01	2.1 E-17	5.2 E-18
6.0 E 01	1.9 E-17	4.5 E-18
8.0 E 01	1.4 E-17	3.5 E-18
1.0 E 02	9.6 E-18	2.7 E-18
1.5 E 02		1.0 E-18
2.0 E 02		3.5 E-19
3.0 E 02		6.0 E-20
4.0 E 02		1.7 E-20
5.0 E 02		6.0 E-21
6.0 E 02		5.1 E-21
7.0 E 02		4.2 E-21

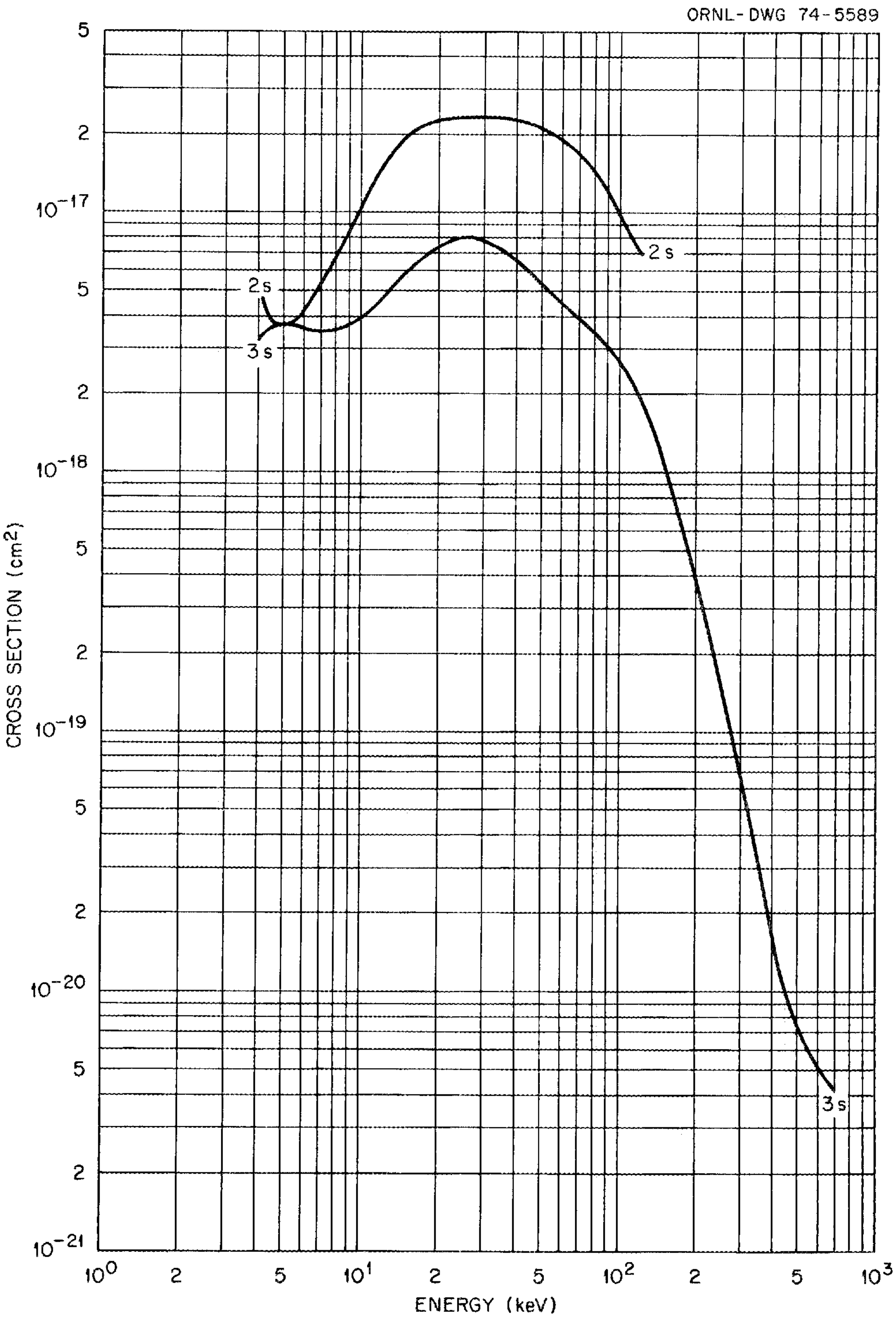
References:

$H^+ + Ar \rightarrow H(3s) + Ar^+$: R.H. Hughes, E.D. Stokes, Song-Sik Choe, and T.J. King Phys. Rev. A 4, 1453 (1971); R.L. Fitzwilson and E.W. Thomas, Phys. Rev. A 3, 1305 (1971) [normalized to Hughes et al.].

$H^+ + Ar \rightarrow H(3s) + Ar^+$: R.H. Hughes, H.R. Dawson, B.M. Doughty, D.B. Kay, and C.A. Stigers, Phys. Rev. 146, 53 (1966); R.J. Conrads, T.W. Nichols, J.C. Ford, and E.W. Thomas, Phys. Rev. A 7, 1928 (1973).

Notes:

See Notes (45) and (46) at end of chapter.


ORNL-DWG 74-5589
CROSS SECTION (cm²)
ENERGY (keV)
2s
3s
2s
3s
5
2
10⁻¹⁷
5
2
10⁻¹⁸
5
2
10⁻¹⁹
5
2
10⁻²⁰
5
2
10⁻²¹
10⁰
2
5
10¹
2
5
10²
2
5
10³

Excitation Cross Sections for the Reactions

$H^+ + (Cs,K) \rightarrow H(2s) + (Cs^+,K^+)$

Energy (keV)	Cross Sections for Formation 2s (cm^2)	
	K	Cs
2.0 E 00		2.3 E-14
3.0 E 00		2.1 E-14
4.0 E 00		1.6 E-14
5.0 E 00		1.1 E-14
6.0 E 00		6.6 E-15
7.0 E 00		4.5 E-15
8.0 E 00		2.8 E-15
9.0 E 00		1.8 E-15
1.0 E 01	7.7 E-16	1.1 E-15
1.5 E 01	3.3 E-16	3.3 E-16
2.0 E 01	2.3 E-16	
3.0 E 01	1.5 E-16	

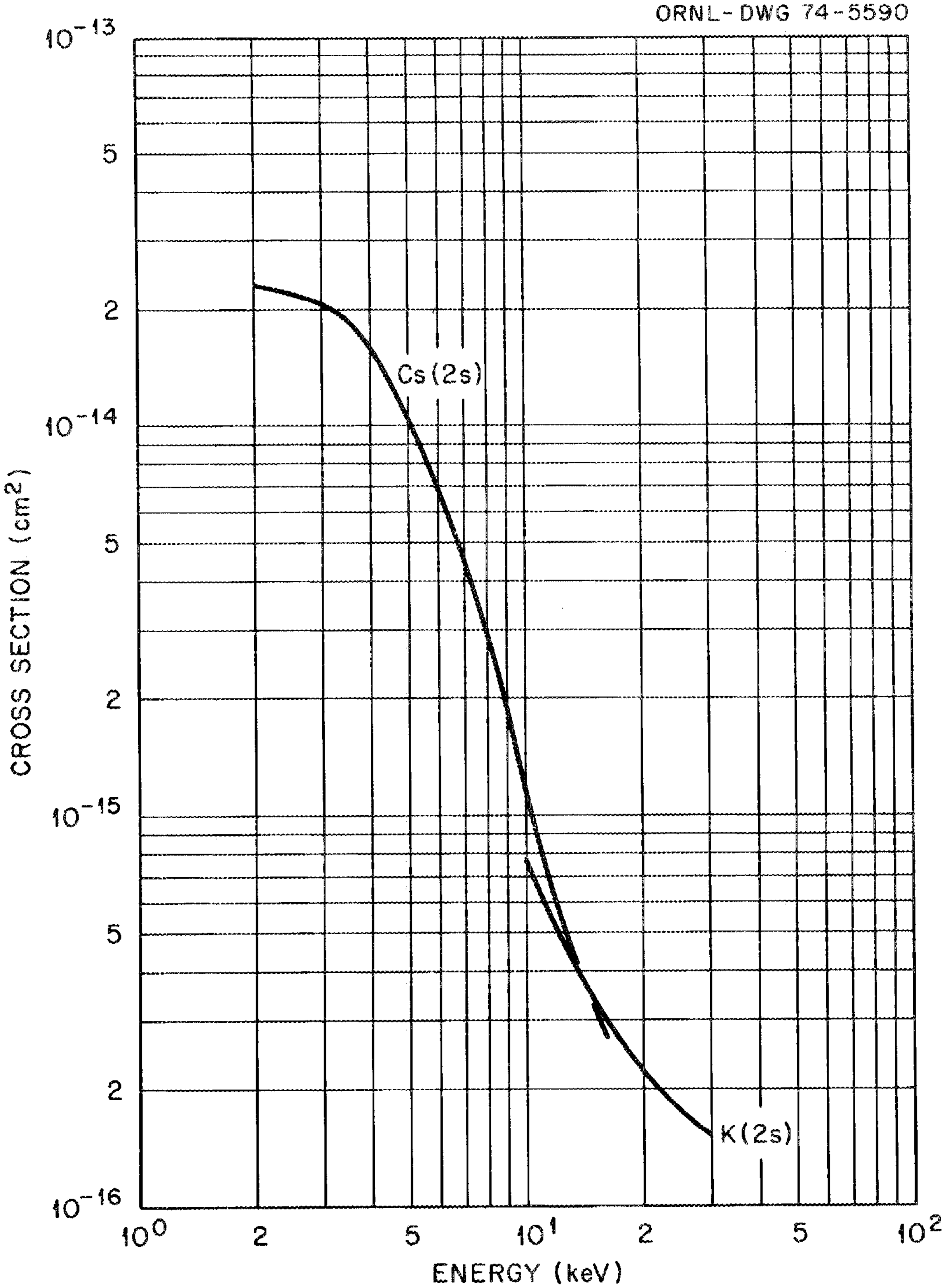
References:

$H^+ + K \rightarrow H(2s) + K^+$: I.A. Sellin and L. Granoff, Phys. Letters 25A, 484 (1967).

$H^+ + Cs \rightarrow H(2s) + Cs^+$: B.L. Donnally, T. Clapp, W. Sawyer, and M. Schultz, Phys. Rev. Letters 12, 502 (1964); I.A. Sellin and L. Granoff, Phys. Letters 25A, 484 (1967).

Notes:

See Notes (45), (46), and (47) at end of chapter.


ORNL-DWG 74-5590
10^{-13}
5
2
10^{-14}
5
2
10^{-15}
5
2
10^{-16}
CROSS SECTION (cm^2)
Cs(2s)
K(2s)
10^0
2
5
10^1
2
5
10^2
ENERGY (keV)

Cross Sections for Formation of H Atoms in High Excited States

by H^+ Impact on Na, Mg, K, and Cs

Energy (keV)	Coefficients $\sigma(n) \times n^3$ (see note 20) (cm^2)			
	Na	Mg	K	Cs
1.0 E 01	7.3 E-15	2.4 E-15	1.0 E-14	1.5 E-14
1.5 E 01	4.0 E-15	3.3 E-15	5.1 E-15	6.4 E-15
2.0 E 01	2.0 E-15	2.4 E-15	1.5 E-15	2.2 E-15
3.0 E 01	4.3 E-16	8.5 E-16	3.2 E-16	7.0 E-16
4.0 E 01	7.7 E-17	2.6 E-16	2.8 E-16	5.1 E-16
5.0 E 01	4.0 E-17	1.0 E-16	2.4 E-16	4.8 E-16
6.0 E 01	3.2 E-17	3.6 E-17	2.0 E-16	4.5 E-16
8.0 E 01	2.9 E-17	1.8 E-17	1.4 E-16	3.4 E-16
1.0 E 02	2.8 E-17	1.3 E-17	1.0 E-16	2.2 E-16
1.5 E 02	2.1 E-17	9.8 E-18	5.0 E-17	7.8 E-17
1.8 E 02	1.7 E-17	8.4 E-18	3.2 E-17	4.0 E-17

References:

$H^+ + (Na, Mg, K, Cs) \rightarrow H(n) + (Na^+, Mg^+, K^+, Cs^+)$: R.N. Il'lin, V.A. Oparin, E.S. Solov'ev, and N.V. Fedorenko, Soviet Phys-JETP Lett. 2, 197 (1965).

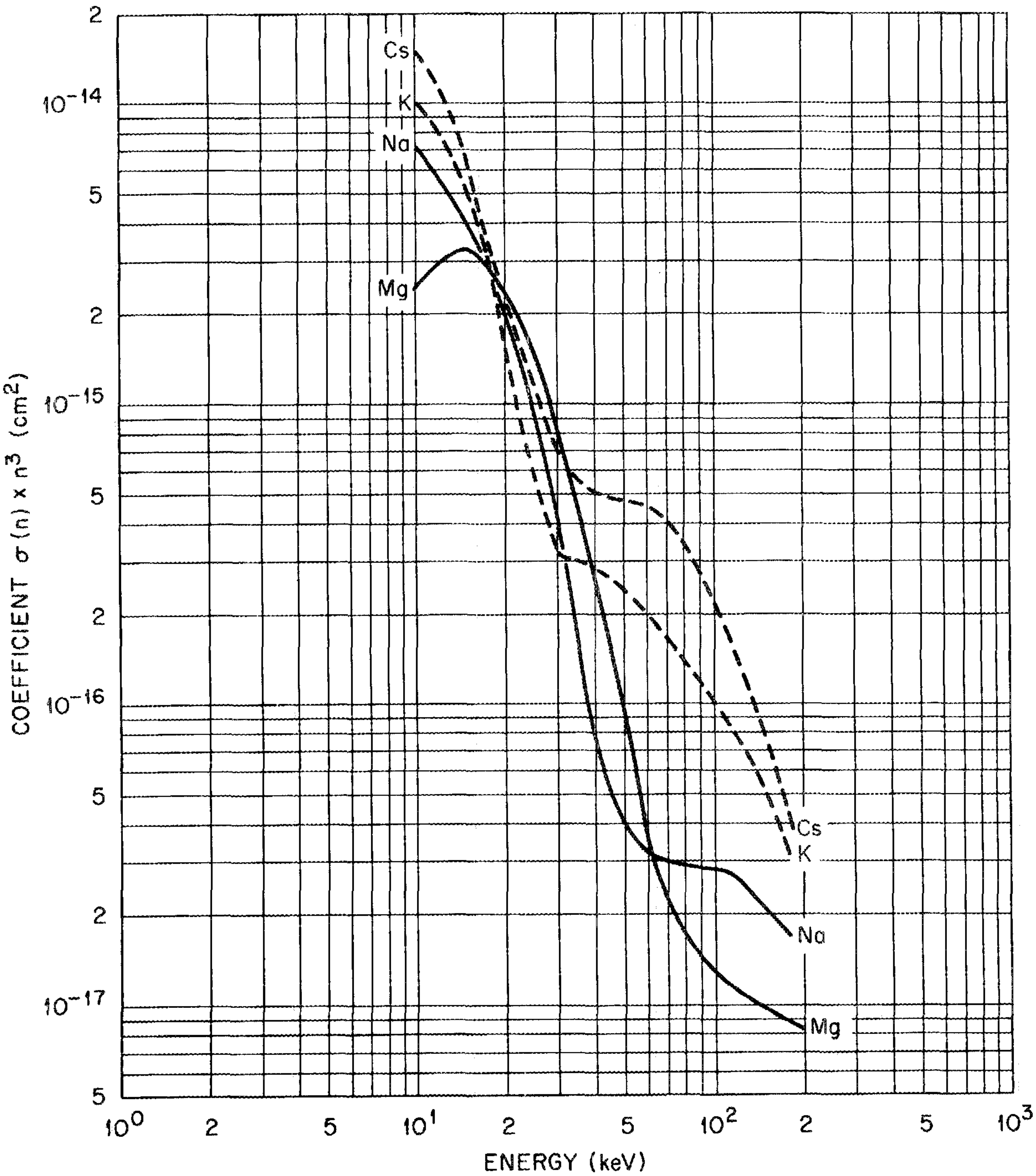
Notes:

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

Accuracy:

Systematic error < 10%. Random error < 10%.

ORNL-DWG 74-5604



Excitation Cross Sections for the Reactions

$H_2^+ + H_2 \rightarrow H(2s,3s,2p,3p,3d) + H^+ + H_2$

Energy (keV)	Cross Sections for State nℓ (cm^2)		
	2s	2p	3p
1.2 E 01	1.70 E-17	4.40 E-17	3.00 E-18
1.4 E 01	1.85 E-17	4.40 E-17	3.05 E-18
1.6 E 01	1.95 E-17	4.60 E-17	3.25 E-18
1.8 E 01	2.05 E-17	4.85 E-17	3.30 E-18
2.0 E 01	2.15 E-17	5.15 E-17	3.45 E-18
2.2 E 01	2.35 E-17	5.60 E-17	3.55 E-18
2.4 E 01	2.55 E-17	5.70 E-17	3.55 E-18
2.6 E 01	2.60 E-17	5.40 E-17	3.40 E-18
2.8 E 01	2.60 E-17	4.60 E-17	3.15 E-18

Energy (keV)	Cross Sections for State nℓ (cm^2)	
	3s	3d
1.0 E 02	3.60 E-18	5.60 E-18
1.5 E 02	2.85 E-18	3.60 E-18
2.0 E 02	2.43 E-18	2.85 E-18
3.0 E 02	2.10 E-18	2.50 E-18
4.0 E 02	2.00 E-18	2.50 E-18
5.0 E 02	1.97 E-18	2.50 E-18
6.0 E 02	1.70 E-18	2.23 E-18
7.0 E 02	1.40 E-18	2.00 E-18

References:

$H_2^+ + H_2 \rightarrow H(2s,2p,3p) + H^+ + H_2$. E.P. Andreev, V.A. Ankudinov, and S.V. Bobashev, Fifth International Conference on the Physics of Electronic & Atomic Collisions: Abstract of Papers, p.309, Publishing House Nauka, Leningrad, USSR (1967).

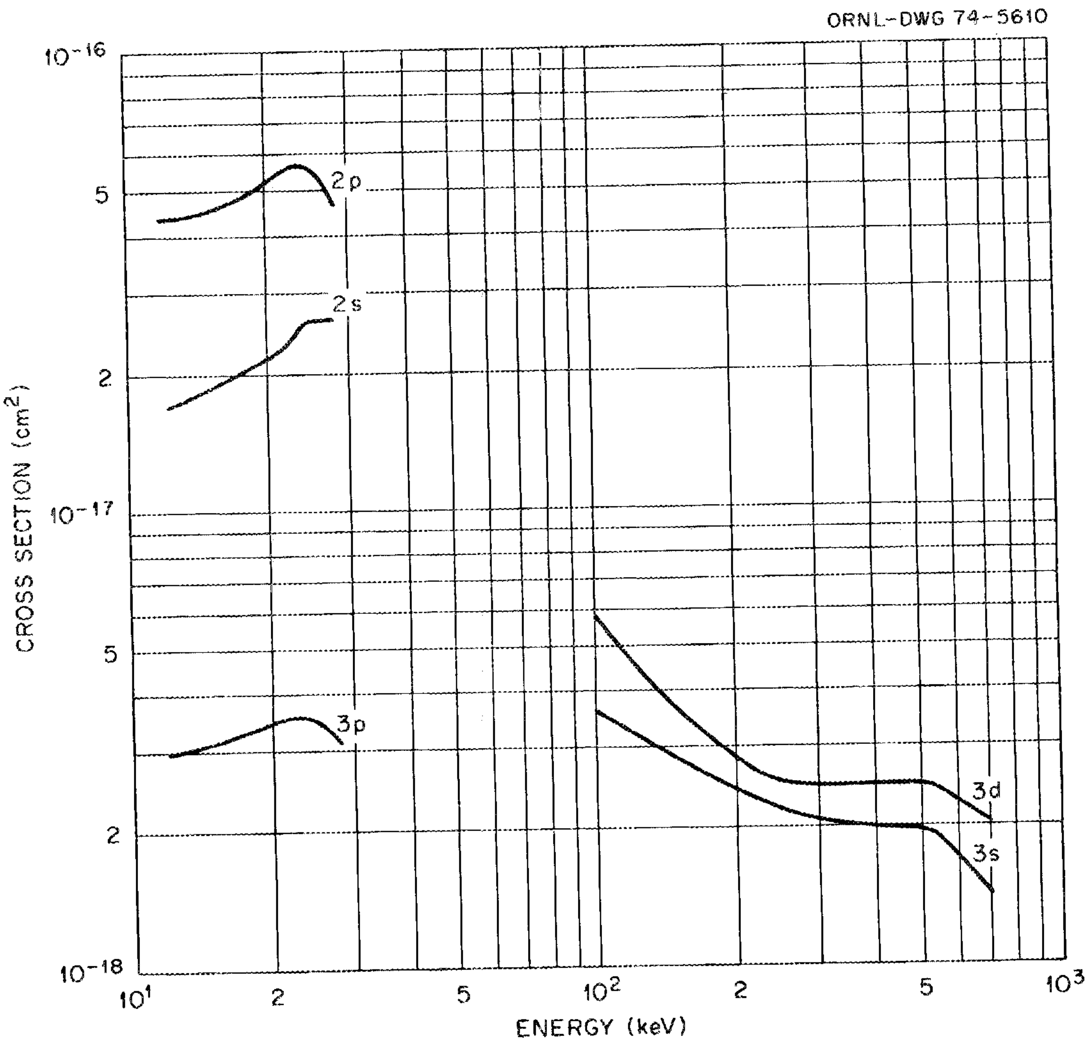
$H_2^+ + H_2 \rightarrow H(3s,3d) + H^+ + H_2$. R.J. Conrads, T.W. Nichols, J.C. Ford, and E.W. Thomas, Phys. Rev. A 7, 1928 (1973).

Notes:

See Notes (30) and (31) at end of chapter.

Accuracy:

Systematic error < 50%. Random error < 10%.


ORNL-DWG 74-5610
CROSS SECTION (cm²)
ENERGY (keV)
10⁻¹⁶
5
2
10⁻¹⁷
5
2
10⁻¹⁸
10¹
2
5
10²
2
5
10³
2p
2s
3p
3d
3s

Excitation Cross Sections for the Reactions

$$H_2^+ + H_2 \rightarrow H_2^+ + H + H(2s,2p,3p)$$

$$H_2^+ + H_2 \rightarrow H_2^+ + H + H(n = 3 \rightarrow 2)$$

Energy (keV)	Cross Sections for State $n\ell$ (cm^2)			
	2s	2p	3p	$n = 3 \rightarrow 2$
1.2 E 01	4.0 E-18	1.4 E-17	1.5 E-18	
1.5 E 01	7.6 E-18	2.3 E-17	1.9 E-18	3.8 E-18
2.0 E 01	6.8 E-18	3.0 E-17	2.6 E-18	5.0 E-18
2.5 E 01	7.4 E-18	3.9 E-17	2.4 E-18	5.9 E-18
3.0 E 01	7.7 E-18	3.6 E-17	2.1 E-18	6.3 E-18
4.0 E 01				6.4 E-18
5.0 E 01				6.0 E-18
6.0 E 01				5.5 E-18
8.0 E 01				4.6 E-18
1.0 E 02				3.8 E-18
1.3 E 02				3.2 E-18

References:

$H_2^+ + H_2 \rightarrow H_2^+ + H + H(2s,2p,3p)$: E.P. Andreev, V.A. Ankudinov, and S.V. Bobashev, Fifth International Conference on the Physics of Electronic & Atomic Collisions: Abstract of Papers, p.309, Publishing House Nauka, Leningrad, USSR (1967).

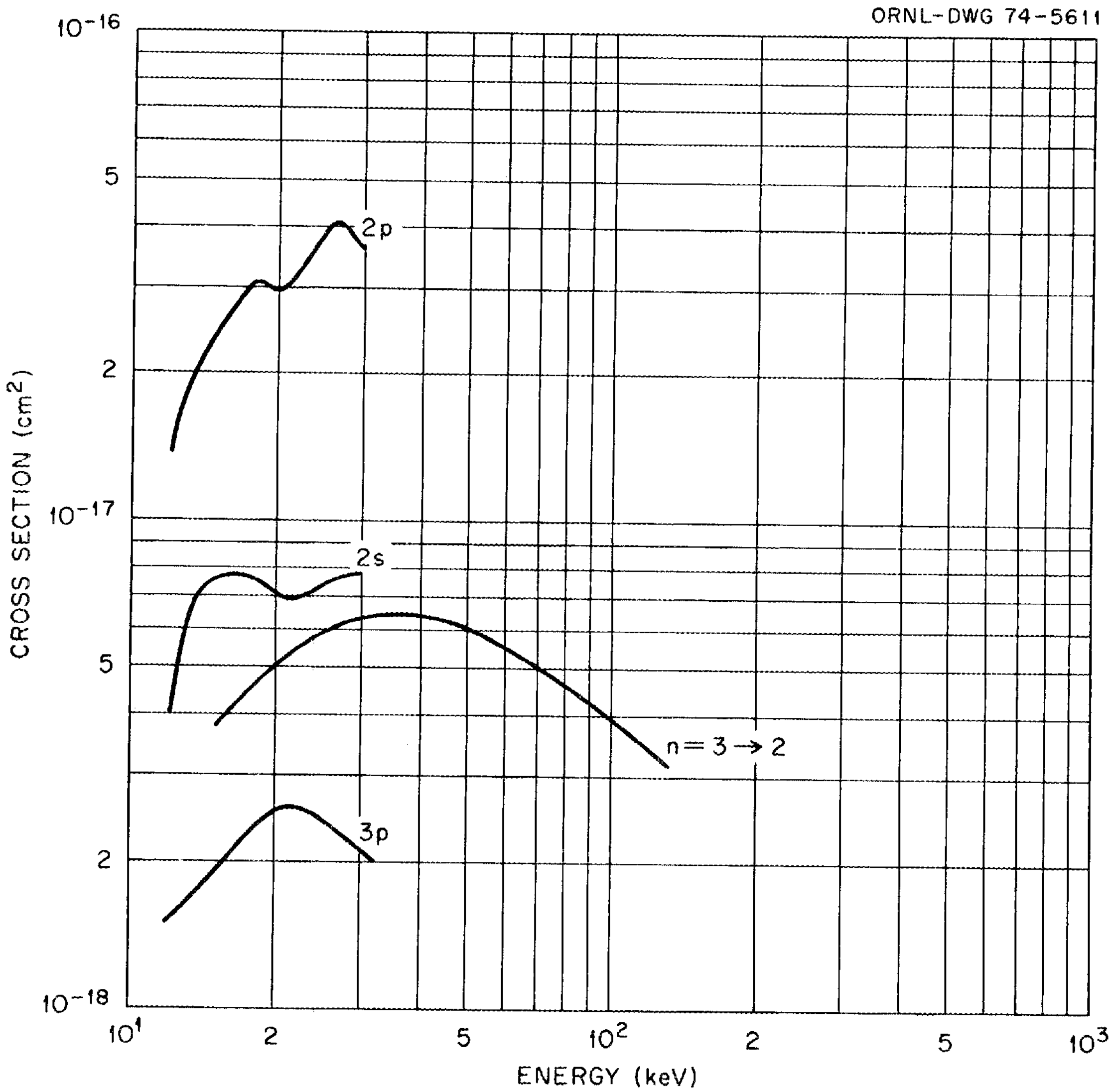
$H_2^+ + H_2 \rightarrow H_2^+ + H + H(n = 3 \rightarrow 2)$: L.L. Hatfield and R.H. Hughes, Phys. Rev. 131, 2556 (1963).

Notes:

See Notes (32), (33), (34), and (35) at end of chapter.

Accuracy:

Systematic error < 50% for H(2s,2p,3p); systematic error < 20% for H(n = 3 → 2). Random error < 10%.


ORNL-DWG 74-5611
CROSS SECTION (cm^2)
ENERGY (keV)
10^{-16}
5
2
10^{-17}
5
2
10^{-18}
10^1
2
5
10^2
2
5
10^3
2p
2s
n = 3 → 2
3p

A.2.50

Excitation Cross Sections for the Reactions

$H_2^+ + He \rightarrow H(2s,3s,3p,3d)$

Energy (keV)	Cross Sections for State $n\ell$ (cm^2)			
	2s	3s	2p	3d
5.0 E-01			2.6 E-17	
7.0 E-01			3.0 E-17	
1.0 E 00			3.4 E-17	
1.5 E 00			4.0 E-17	
2.0 E 00	6.0 E-18		4.3 E-17	
4.0 E 00	6.0 E-18		4.3 E-17	
6.0 E 00	5.9 E-18		4.0 E-17	
8.0 E 00	5.8 E-18		3.8 E-17	
1.0 E 01	5.8 E-18		3.6 E-17	
1.5 E 01	5.5 E-18		3.2 E-17	
2.0 E 01	5.2 E-18		2.9 E-17	
4.0 E 01		2.1 E-18		
6.0 E 01		2.2 E-18		
8.0 E 01		2.1 E-18		2.6 E-18
1.0 E 02		2.0 E-18		2.4 E-18
1.5 E 02		1.8 E-18		2.3 E-18
2.0 E 02		1.6 E-18		2.0 E-18
4.0 E 02		1.1 E-18		1.4 E-18
6.0 E 02		9.0 E-19		1.1 E-18
7.0 E 02		8.2 E-19		1.0 E-18

References:

$H_2^+ + He \rightarrow H(2s) + He + H^+$: D. Jaecks and E. Tynan, Fourth International Conference on the Physics of Electronic & Atomic Collisions: Abstract of Papers, p.315, Science Bookcrafters New York (1965).

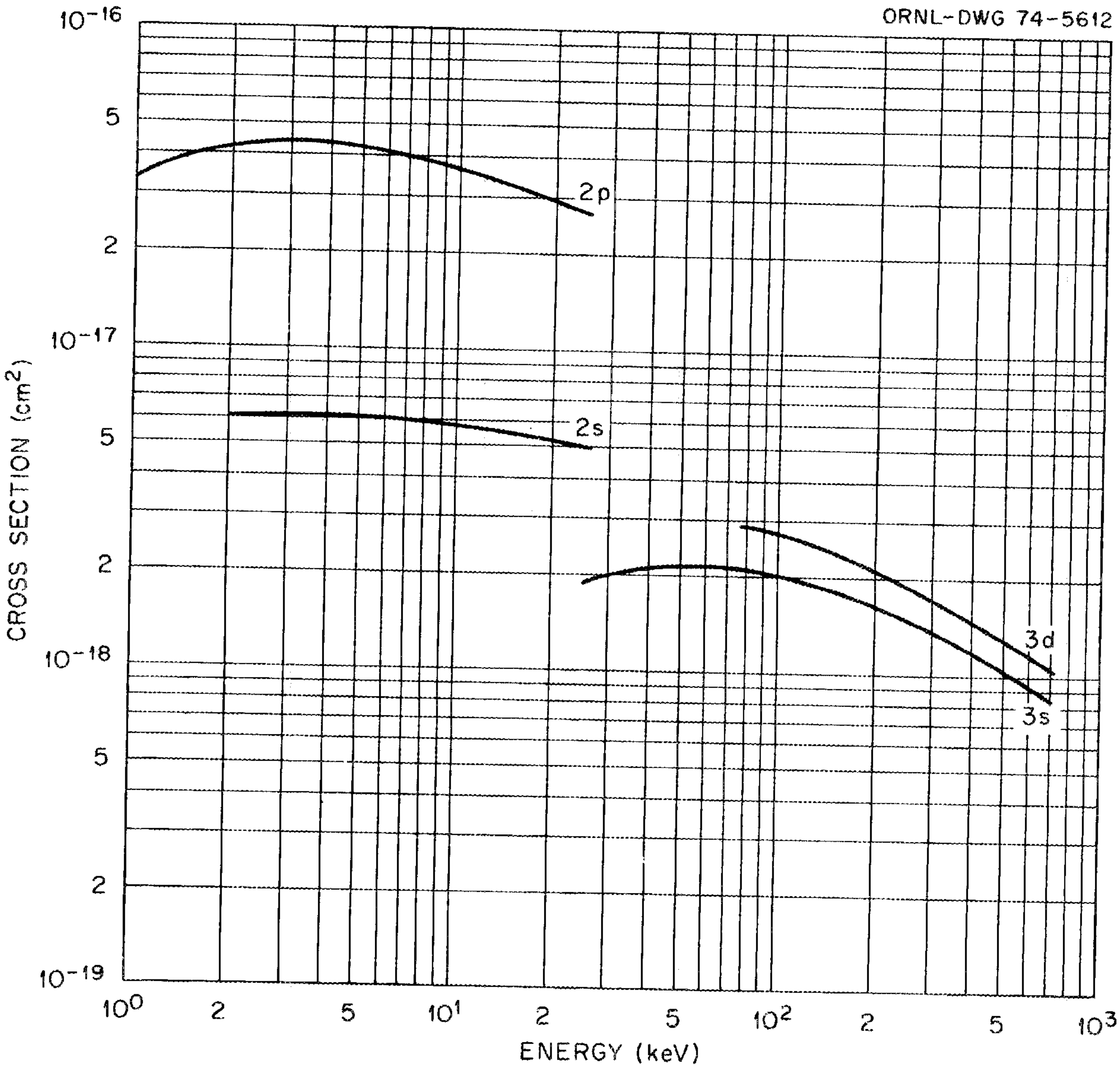
$H_2^+ + He \rightarrow H(3s) + He + H^+$: R.H. Hughes, D.B. Kay, C.A. Stigers, and E.D. Stokes, Phys. Rev. 167, 26 (1968); J.C. Ford, F.M. McCoy, R. Conrads, and E.W. Thomas, Phys. Rev. A 5, 1705 (1972).

$H_2^+ + He \rightarrow H(3p) + He + H^+$: B. Van Zyl, D. Jaecks, D. Pretzer, and R. Geballe, Phys. Rev. A 136, 1561 (1969).

$H^+ + He \rightarrow H(3d) + He + H^+$: J.C. Ford, R. Conrads, F.M. McCoy, and E.W. Thomas, Phys. Rev. A 5, 1705 (1972).

Notes:

See Notes (31), (36), and (37) at end of chapter.


ORNL-DWG 74-5612
CROSS SECTION (cm^2)
ENERGY (keV)
2p
2s
3d
3s
10^{-16}
5
2
10^{-17}
5
2
10^{-18}
5
2
10^{-19}
10^0
2
5
10^1
2
5
10^2
2
5
10^3

Excitation Cross Section for the Reaction

$$H_2^+ + He \rightarrow H_2^+ + He^*(n\ell)$$

Energy (keV)	Cross Sections for States $n\ell$ (cm^2)			
	4^1S	4^1P	4^3S	4^3P
1.00 E 00	1.60 E-21		5.00 E-22	
2.00 E 00	4.60 E-21		5.90 E-21	6.60 E-21
3.00 E 00	6.80 E-21		1.21 E-20	1.07 E-20
4.00 E 00	6.10 E-21	1.70 E-20	9.60 E-21	5.03 E-20
5.00 E 00	9.90 E-21	2.60 E-20	2.33 E-20	4.96 E-20
6.00 E 00	1.20 E-20	3.70 E-20	2.98 E-20	5.05 E-20
7.00 E 00	1.35 E-20	6.00 E-20	3.11 E-20	6.47 E-20
8.00 E 00	1.53 E-20	7.70 E-20	3.19 E-20	9.48 E-20
9.00 E 00	1.80 E-20	9.30 E-20	4.29 E-20	1.17 E-19
1.00 E 01	2.32 E-20	1.10 E-19	5.38 E-20	1.44 E-19
1.50 E 01	8.80 E-20	1.59 E-19	1.71 E-19	1.41 E-19
2.00 E 01	1.40 E-19	2.29 E-19	2.35 E-19	1.34 E-19
3.00 E 01	1.60 E-19	3.66 E-19	4.31 E-19	4.22 E-19
4.00 E 01	2.07 E-19	4.61 E-19	6.32 E-19	5.81 E-19
5.00 E 01	2.78 E-19	4.92 E-19	7.10 E-19	6.19 E-19
6.00 E 01	3.35 E-19	5.12 E-19	6.66 E-19	5.86 E-19
7.00 E 01	4.22 E-19	5.70 E-19	5.95 E-19	5.34 E-19
8.00 E 01	4.85 E-19	6.35 E-19	5.04 E-19	4.31 E-19
9.00 E 01	5.10 E-19	6.38 E-19	4.66 E-19	3.49 E-19
1.00 E 02	5.31 E-19	6.20 E-19	4.19 E-19	3.06 E-19
1.20 E 02	5.68 E-19	7.60 E-19	2.93 E-19	1.78 E-19
1.50 E 02	4.84 E-19	8.02 E-19	1.72 E-19	1.09 E-19
2.00 E 02	3.00 E-19			
3.00 E 02	2.03 E-19			
4.00 E 02	1.41 E-19			
5.00 E 02	1.21 E-19			
6.00 E 02	1.02 E-19			
8.00 E 02	8.10 E-20			

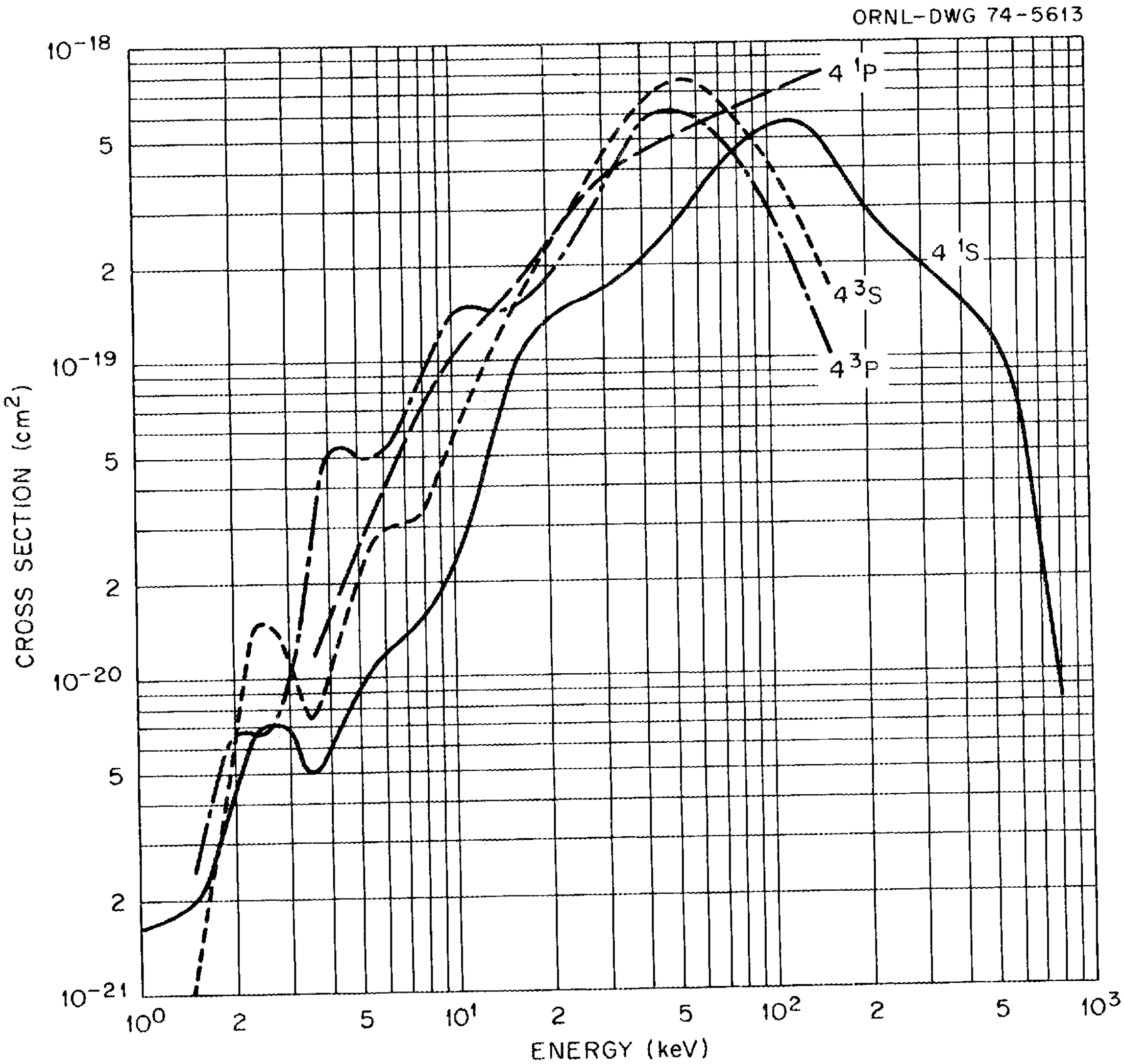
References:

J. Van den Bos, G. Winter, and F. J. De Heer, Physica 44, 143 (1969).
E. W. Thomas and G. D. Bent, J. Opt. Soc. Am. 58, 138 (1968).

Notes:

See Note (44) at end of chapter.

Accuracy: Systematic error < 10%. Random error < 5%.


ORNL-DWG 74-5613
CROSS SECTION (cm^2)
ENERGY (keV)
10^{-18}
5
2
10^{-19}
5
2
10^{-20}
5
2
10^{-21}
10^0
2
5
10^1
2
5
10^2
2
5
10^3
4 ^{1}P
4 ^{1}S
4 ^{3}S
4 ^{3}P

Excitation Cross Sections for the Reactions

$H_3^+ + He \rightarrow H(3s,3d) + H_2^+ + He$ and $H_3^+ + H_2 \rightarrow H(3s) + H_2^+ + H_2$

Energy (keV)	Cross Sections for States nℓ (cm^2)		
	H_3^+ + He		$H_3^+ + H_2$
	3s	3d	3s
2.0 E 01	2.4 E-18		3.0 E-18
3.0 E 01	2.6 E-18		3.6 E-18
4.0 E 01	2.8 E-18		4.4 E-18
5.0 E 01	2.9 E-18		4.9 E-18
6.0 E 01	3.0 E-18		5.4 E-18
7.0 E 01	3.0 E-18		5.5 E-18
8.0 E 01	3.0 E-18		5.4 E-18
9.0 E 01	3.0 E-18		5.3 E-18
1.0 E 02	2.9 E-18	6.7 E-18	5.2 E-18
1.5 E 02	2.8 E-18	3.8 E-18	
2.0 E 02	2.7 E-18	3.2 E-18	
3.0 E 02	2.4 E-18	2.8 E-18	
4.0 E 02	2.1 E-18	2.4 E-18	
5.0 E 02	1.8 E-18	1.9 E-18	
6.0 E 02	1.6 E-18	1.6 E-18	
7.0 E 02	1.4 E-18	1.4 E-18	

References:

$H_3^+ + He \rightarrow H(3s) + H_2^+ + He$: R.H. Hughes, D.B. Kay, C.A. Stigers, and E.D. Stokes, Phys. Rev. 167, 26 (1968); J.C. Ford, F.M. McCoy, R. Conrads, and E.W. Thomas, Phys. Rev. A 5, 1705 (1972).

$H_3^+ + He \rightarrow H(3d) + H_2^+ + He$: J.C. Ford, F.M. McCoy, R. Conrads, and E.W. Thomas, Phys. Rev. A 5, 1705 (1972).

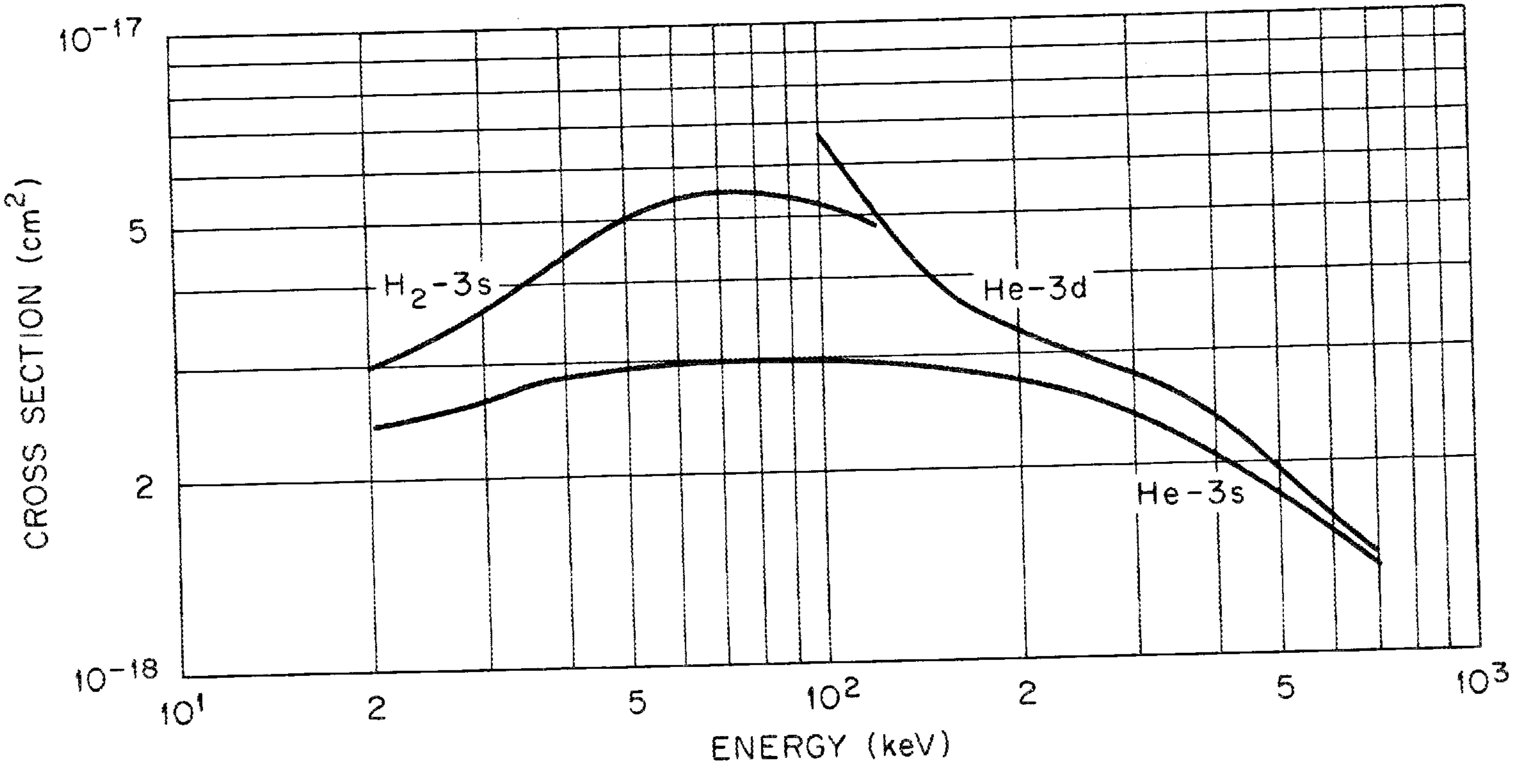
$H_3^+ + H_2 \rightarrow H(3s) + H_2^+ + He$: R.H. Hughes, D.B. Kay, C.A. Stigers, and E.D. Stokes, Phys. Rev. 167, 26 (1968).

Notes:

Accuracy:

Systematic error < 50%. Random error < 10%.

ORNL-DWG 74-5615



Excitation Cross Sections for the Reaction

$$H_3^+ + He \rightarrow H_3^+ + He^*(n\ell)$$

Energy (keV)	Cross Sections for States $n\ell$ (cm^2)			
	4^1S	4^1P	4^3S	4^3P
1.00 E 00	6.00 E-21		2.00 E-21	8.60 E-21
2.00 E 00	1.85 E-20	1.06 E-19	5.80 E-21	2.37 E-20
3.00 E 00	3.05 E-20	1.14 E-19	1.71 E-20	3.96 E-20
4.00 E 00	3.34 E-20	9.00 E-20	3.52 E-20	3.77 E-20
5.00 E 00	2.89 E-20	8.80 E-20	2.82 E-20	6.17 E-20
6.00 E 00	3.11 E-20	9.70 E-20	2.78 E-20	9.95 E-20
7.00 E 00	3.34 E-20	1.08 E-19	3.71 E-20	9.60 E-20
8.00 E 00	3.37 E-20	1.33 E-19	4.63 E-20	9.26 E-20
9.00 E 00	3.60 E-20	1.49 E-19	4.83 E-20	9.23 E-20
1.00 E 01	3.69 E-20	1.61 E-19	4.88 E-20	9.65 E-20
1.50 E 01	8.60 E-20	1.85 E-19	1.10 E-19	1.23 E-19
2.00 E 01	1.36 E-19	1.88 E-19	2.25 E-19	1.45 E-19
3.00 E 01	2.13 E-19	2.62 E-19	3.65 E-19	1.58 E-19
4.00 E 01	2.81 E-19	3.82 E-19	4.31 E-19	3.73 E-19
5.00 E 01	3.21 E-19	4.51 E-19	4.88 E-19	4.81 E-19
6.00 E 01	3.39 E-19	5.40 E-19	5.84 E-19	5.67 E-19
7.00 E 01	3.52 E-19	5.82 E-19	6.27 E-19	6.78 E-19
8.00 E 01	3.28 E-19	6.41 E-19	7.69 E-19	7.08 E-19
9.00 E 01	3.72 E-19	6.36 E-19	7.30 E-19	7.86 E-19
1.00 E 02	4.18 E-19	7.33 E-19	7.11 E-19	7.76 E-19
1.20 E 02	4.82 E-19	8.78 E-19	6.50 E-19	6.23 E-19
1.50 E 02	5.48 E-19	9.01 E-19	5.42 E-19	4.56 E-19

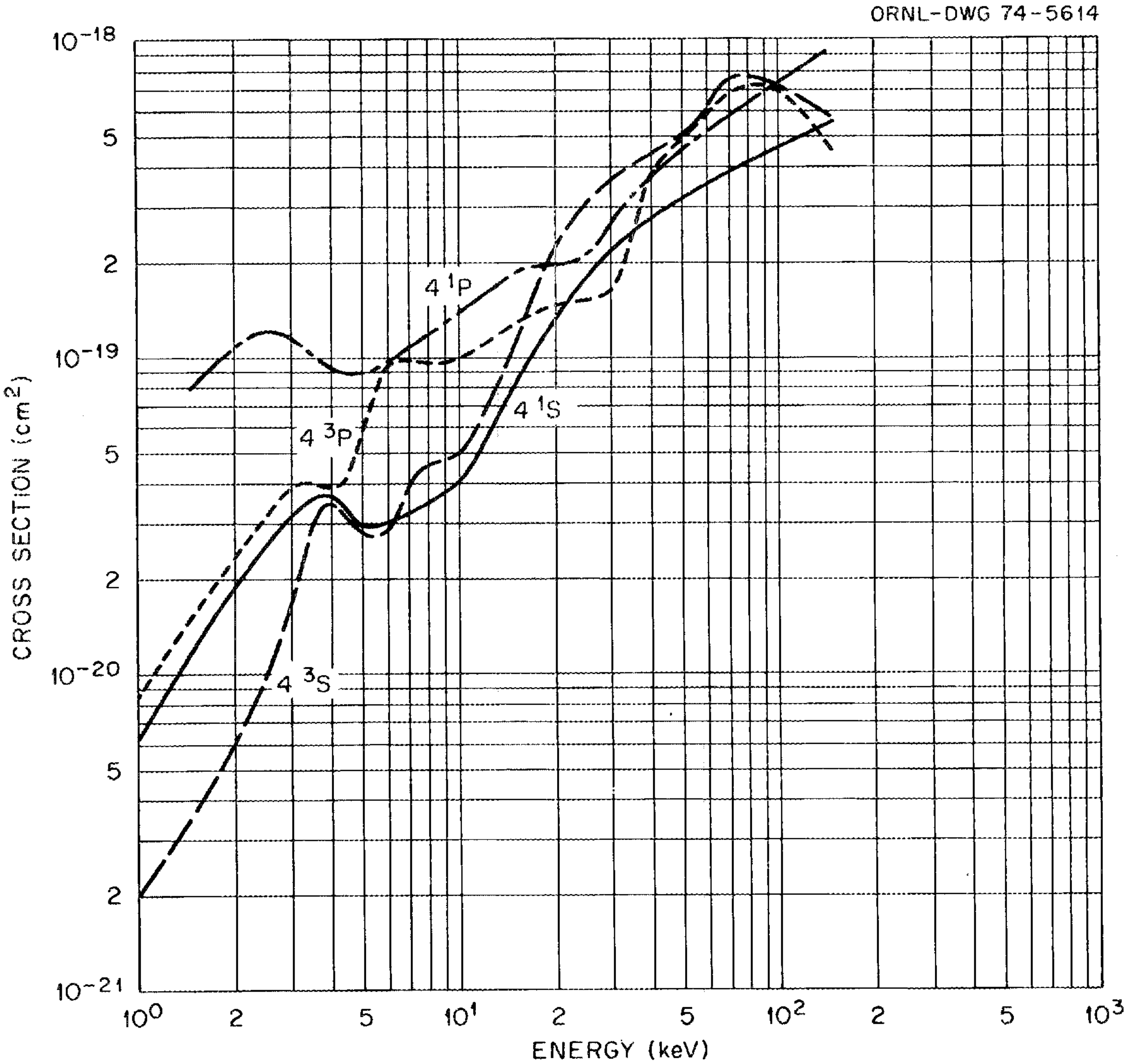
References:

J. Van den Bos, G. Winter, and F. J. DeHeer, Physica 44, 143 (1969).
E. W. Thomas and G. D. Bent, J. Opt. Soc. Am. 58, 138 (1968).

Notes:

See Note (44) at end of chapter.

Accuracy: Systematic error < 10%. Random error < 5%.


ORNL-DWG 74-5614
CROSS SECTION (cm^2)
ENERGY (keV)
10^{-18}
5
2
10^{-19}
5
2
10^{-20}
5
2
10^{-21}
10^0
2
5
10^1
2
5
10^2
2
5
10^3
4 ^{1}P
4 ^{1}S
4 ^{3}P
4 ^{3}S

Excitation Cross Sections for the Reaction

$$He^{+} + H \rightarrow He^{+} + H(2p)$$

Energy (keV)	Cross Section (cm^2)
5.0 E-01	9.0 E-18
1.0 E 00	2.0 E-17
2.0 E 00	3.0 E-17
3.0 E 00	3.3 E-17
4.0 E 00	3.5 E-17
5.0 E 00	3.6 E-17
6.0 E 00	3.7 E-17
7.0 E 00	3.8 E-17
8.0 E 00	3.8 E-17
9.0 E 00	3.9 E-17
1.0 E 01	4.0 E-17
1.5 E 01	4.3 E-17
2.0 E 01	4.7 E-17
2.5 E 01	4.8 E-17
3.0 E 01	4.0 E-17

References:

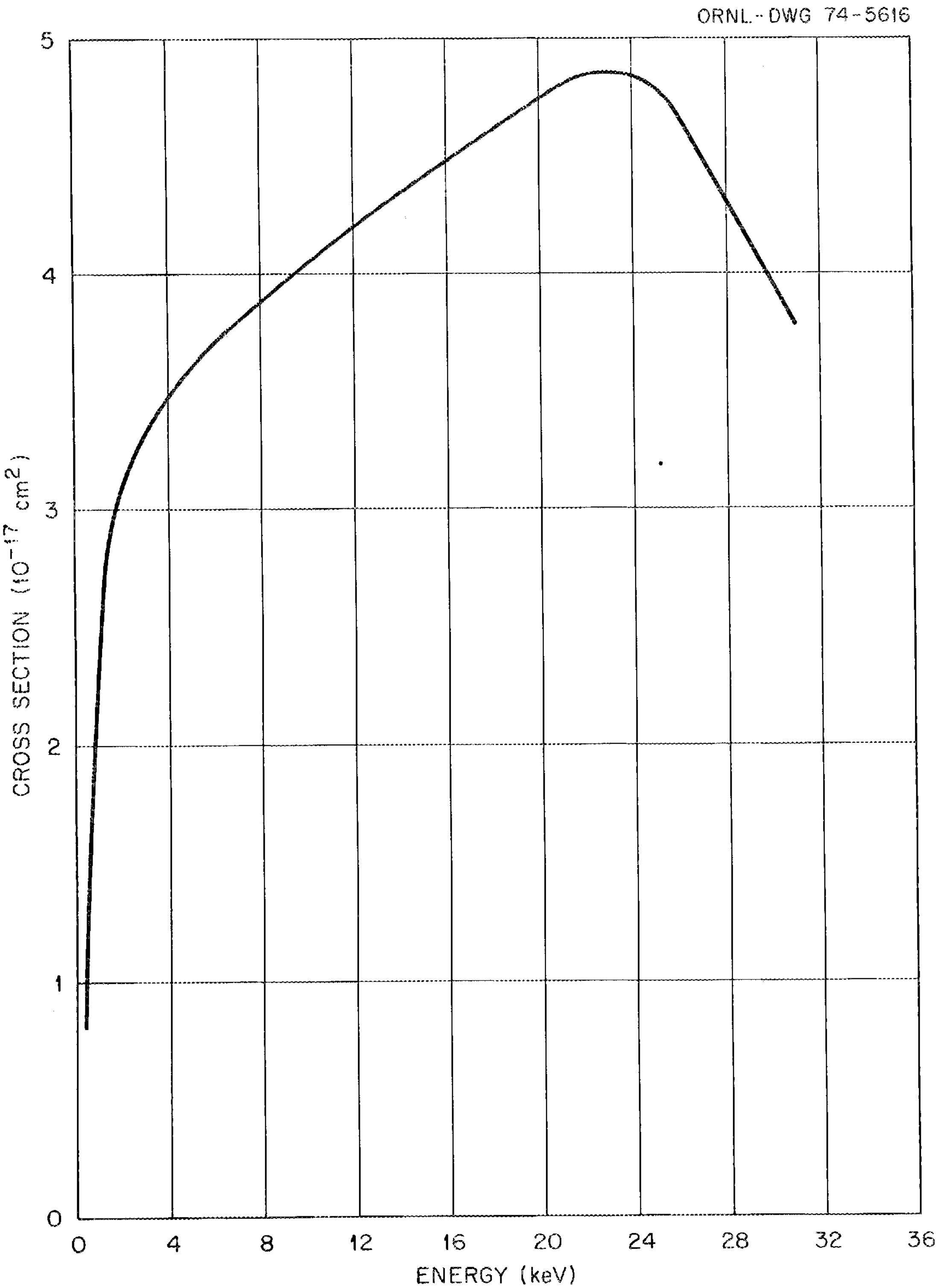
S.J. Young, J.S. Murray, and J.R. Sheridan, Phys. Rev. 178, 40 (1969).

Notes:

See Note (38) at end of chapter.

Accuracy:

Systematic error - < 50%. Random error < 10%.


ORNL-DWG 74-5616
5
4
3
2
1
0
0
4
8
12
16
20
24
28
32
36
CROSS SECTION (10^{-17} cm^2)
ENERGY (keV)

Cross Sections for Balmer-Alpha Emission from the Impact of He^+ and He^o on H_2 Gas

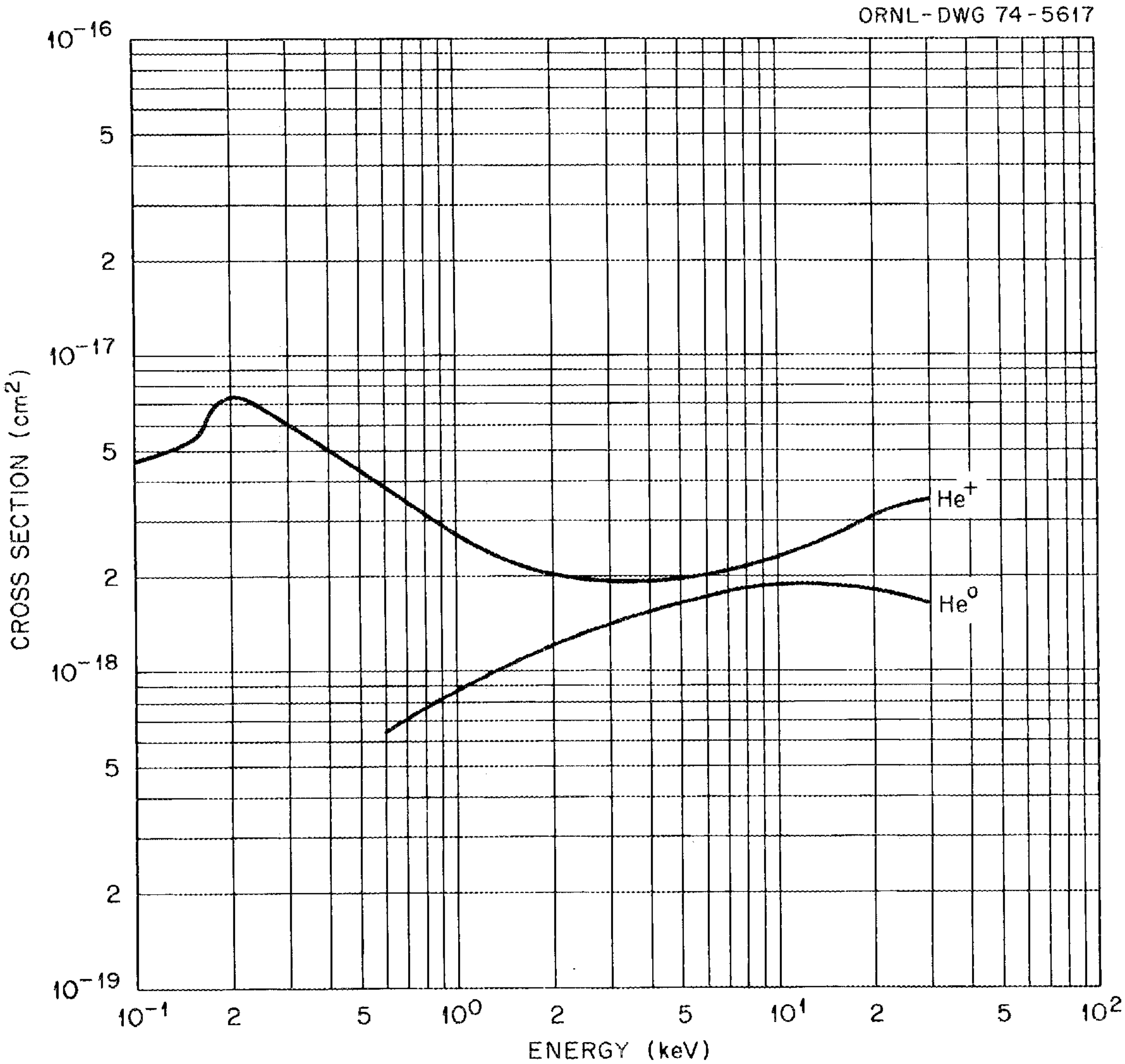
Energy (keV)	Cross Section (cm^2)	
	$He^+ + H_2$	$He^o + H_2$
1.0 E-01	4.6 E-18	
1.5 E-01	5.4 E-18	
2.0 E-01	7.4 E-18	
3.0 E-01	6.0 E-18	
4.0 E-01	5.0 E-18	
6.0 E-01	3.8 E-18	6.4 E-19
8.0 E-01	3.1 E-18	7.8 E-19
1.0 E 00	2.7 E-18	8.7 E-19
1.5 E 00	2.2 E-18	1.0 E-18
2.0 E 00	2.1 E-18	1.2 E-18
3.0 E 00	2.0 E-18	1.4 E-18
4.0 E 00	1.9 E-18	1.5 E-18
6.0 E 00	2.1 E-18	1.7 E-18
8.0 E 00	2.2 E-18	1.8 E-18
1.0 E 01	2.3 E-18	1.9 E-18
1.5 E 01	2.7 E-18	1.9 E-18
2.0 E 01	3.1 E-18	1.8 E-18
3.0 E 01	3.5 E-18	1.6 E-18

Reference:

V.A. Gusev, G.N. Polyakova, V.F. Erko, Ya. M. Fogel, and A.V. Zats, Sixth International Conference on the Physics of Electronic and Atomic Collisions: Abstract of Papers, Cambridge, Mass. p. 809, MIT Press, 1969.

Notes:

See Note (40) at end of chapter.


ORNL-DWG 74-5617
CROSS SECTION (cm²)
10⁻¹⁶
5
2
10⁻¹⁷
5
2
10⁻¹⁸
5
2
10⁻¹⁹
He⁺
He⁰
10⁻¹
2
5
10⁰
2
5
10¹
2
5
10²
ENERGY (keV)

Excitation Cross Sections for the Reactions

$He^{+} + H_2 \rightarrow He^{+} + H + H(2s,3s,2p,3p)$

Energy (keV)	Cross Section for State nℓ (cm^2)			
	2s	3s	2p	3p
5.0 E-02			2.2 E-17	
6.0 E-02			2.6 E-17	
8.0 E-02			3.5 E-17	
1.0 E-01			4.4 E-17	
2.0 E-01			5.9 E-17	
4.0 E-01			6.0 E-17	
6.0 E-01			5.2 E-17	
8.0 E-01			4.7 E-17	
1.0 E 00			4.4 E-17	
2.0 E 00			3.5 E-17	
4.0 E 00			3.3 E-17	
6.0 E 00			3.3 E-17	
8.0 E 00	3.0 E-18		3.4 E-17	
1.0 E 01	4.0 E-18	2.1 E-19	3.5 E-17	2.4 E-19
1.5 E 01	4.4 E-18	2.4 E-19	3.7 E-17	2.4 E-19
2.0 E 01	3.0 E-18	2.3 E-19	3.8 E-17	2.7 E-19
3.0 E 01	4.0 E-18	2.1 E-19	3.7 E-17	2.4 E-19

References:

$He^{+} + H_2 \rightarrow He^{+} + H + H(2s)$: E.P. Andreev, V.A. Ankudinov, and S.V. Bobashev, Fifth International Conference on the Physics of Electronic & Atomic Collisions: Abstract of Papers, p.309, Publishing House Nauka, Leningrad, USSR (1967).

$He^{+} + H_2 \rightarrow He^{+} + H + H(3s)$: V.A. Ankudinov, S.V. Bobashev, and E.P. Andreev, Soviet Phys-JETP 25, 236 (1967).

$He^{+} + H_2 \rightarrow He^{+} + H + H(2p)$: B. Van Zyl, D. Jaecks, D. Pretzer, and R. Geballe, Phys. Rev. 158, 29 (1967).

$He^{+} + H_2 \rightarrow He^{+} + H + H(3p)$: E.P. Andreev, V.A. Ankudinov, and S.V. Bobashev, Fifth International Conference on the Physics of Electronic & Atomic Collisions: Abstract of Papers, p.309, Publishing House Nauka, Leningrad, USSR (1967); V.A. Ankudinov, S.V. Bobashev, and E.P. Andreev, Soviet Phys-JETP 25, 236 (1967).

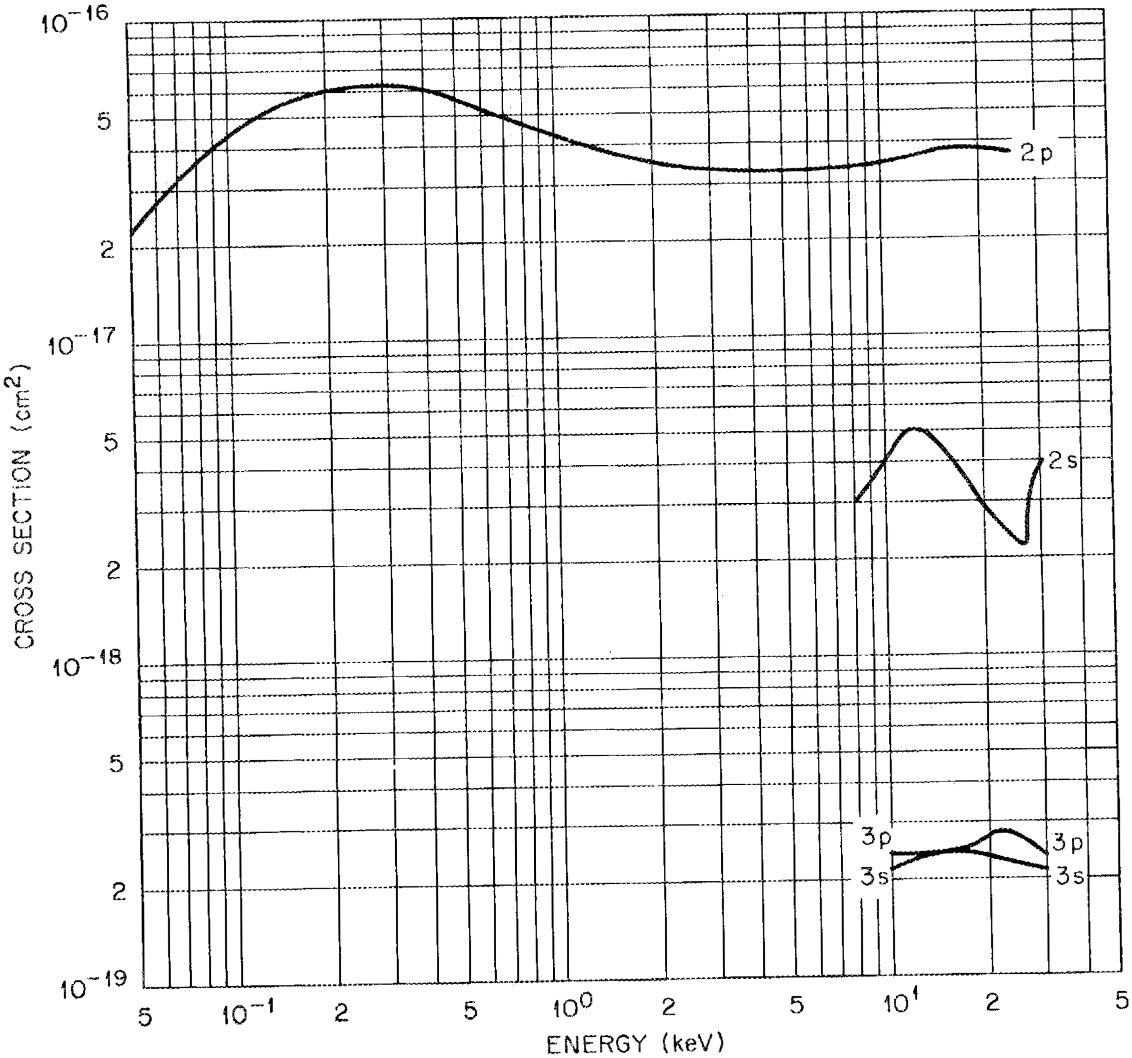
Notes:

See Notes (32), (33), (35), and (39) at end of chapter.

Accuracy:

Systematic error < 50%. Random error < 10%.

ORNL-DWG 74-5618



Excitation Cross Sections for the Reactions

$$He^{+} + He \rightarrow He^{+} + He^{*} \; (4^{1}S,\ 4^{1}P,\ 4^{1}D)$$

Energy (keV)	Cross Sections for Excited State nℓ (cm^2)		
	4^1S	4^1P	4^1D
5.0 E 00	2.2 E-20		5.3 E-20
6.0 E 00	2.6 E-20		5.6 E-20
8.0 E 00	3.7 E-20		6.5 E-20
1.0 E 01	4.9 E-20		7.7 E-20
1.5 E 01	3.5 E-20	3.0 E-19	6.9 E-20
2.0 E 01	4.0 E-20	3.0 E-19	1.1 E-19
3.0 E 01	4.9 E-20	2.6 E-19	2.8 E-19
4.0 E 01	7.8 E-20	3.3 E-19	2.9 E-19
5.0 E 01	9.9 E-20	3.0 E-19	2.0 E-19
6.0 E 01	8.7 E-20	2.6 E-19	1.2 E-19
7.0 E 01	7.2 E-20	2.4 E-19	8.1 E-20
8.0 E 01	6.8 E-20	2.2 E-19	7.3 E-20
1.0 E 02	6.6 E-20		6.7 E-20

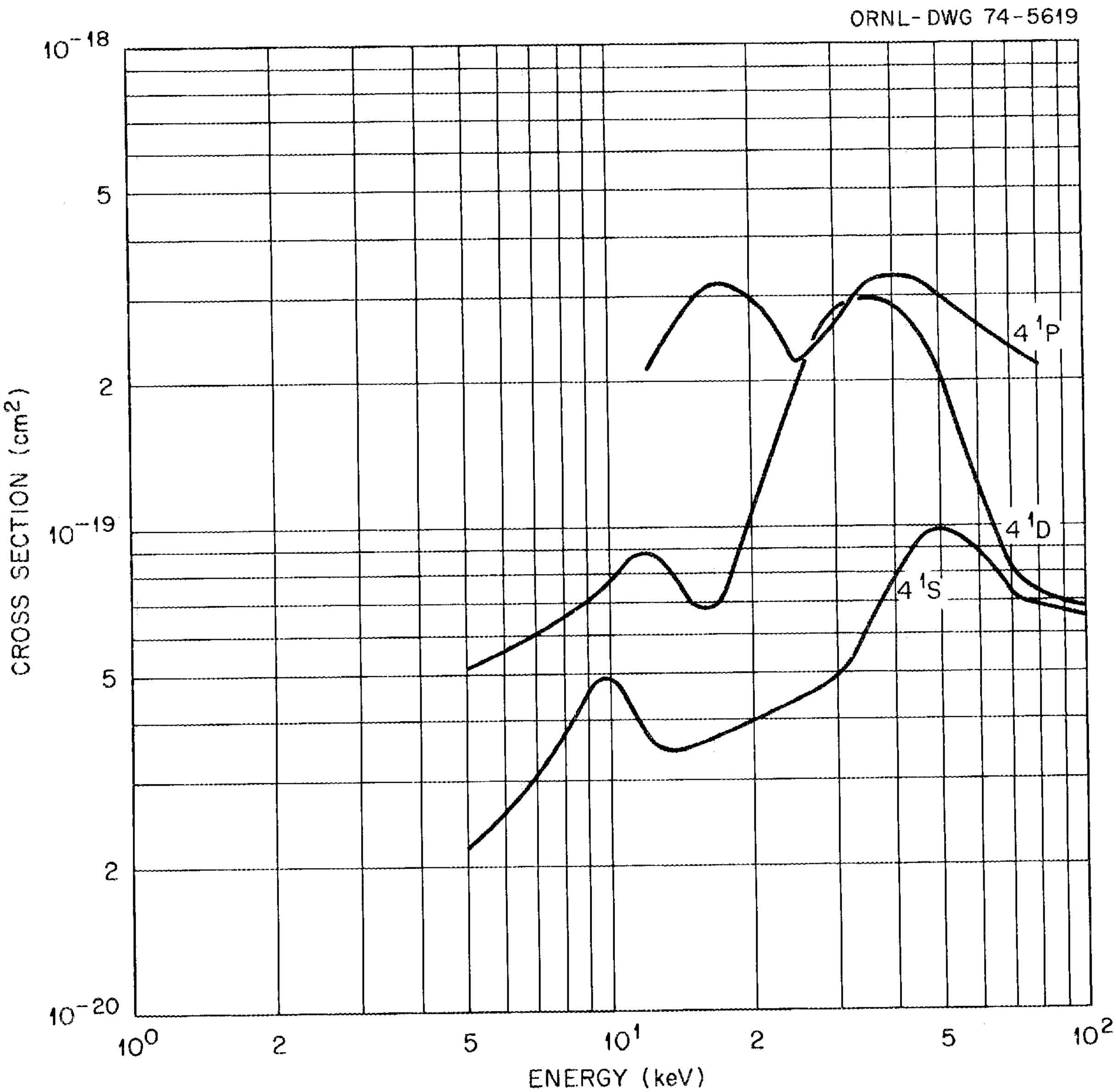
Reference:

F. J. de Heer and J. Van den Bos, Physica 31, 365 (1965).

Notes:

See Note (44) at end of chapter.

Accuracy: Systematic error < 10%. Random error < 5%.


ORNL-DWG 74-5619
CROSS SECTION (cm²)
ENERGY (keV)
10⁻¹⁸
5
2
10⁻¹⁹
5
2
10⁻²⁰
10⁰
2
5
10¹
2
5
10²
4 ¹P
4 ¹D
4 ¹S

Excitation Cross Sections for the Reactions

$$He^{+} + He \rightarrow He^{+} + He^{*}\ (4^3S,\ 4^3P,\ 4^3D)$$

Energy (keV)	Cross Sections for Excited State $n\ell$ (cm^2)		
	4^3S	4^3P	4^3D
5.0 E 00	2.2 E-20		
7.5 E 00	4.0 E-20	1.3 E-20	1.3 E-19
1.0 E 01	3.4 E-20	5.8 E-20	1.1 E-19
1.5 E 01	7.0 E-20	1.2 E-19	1.3 E-19
2.0 E 01	3.2 E-20	1.3 E-19	1.6 E-19
3.0 E 01	5.9 E-20	1.4 E-19	3.2 E-19
4.0 E 01	8.2 E-20	2.0 E-19	3.7 E-19
5.0 E 01	9.6 E-20	2.5 E-19	2.2 E-19
6.0 E 01	1.1 E-19	2.6 E-19	1.8 E-19
7.0 E 01	1.4 E-19	2.5 E-19	1.5 E-19
8.0 E 01	1.2 E-19	2.3 E-19	1.1 E-19
9.0 E 01	1.1 E-19	2.0 E-19	8.8 E-20
10.0 E 01	1.1 E-19		7.5 E-20

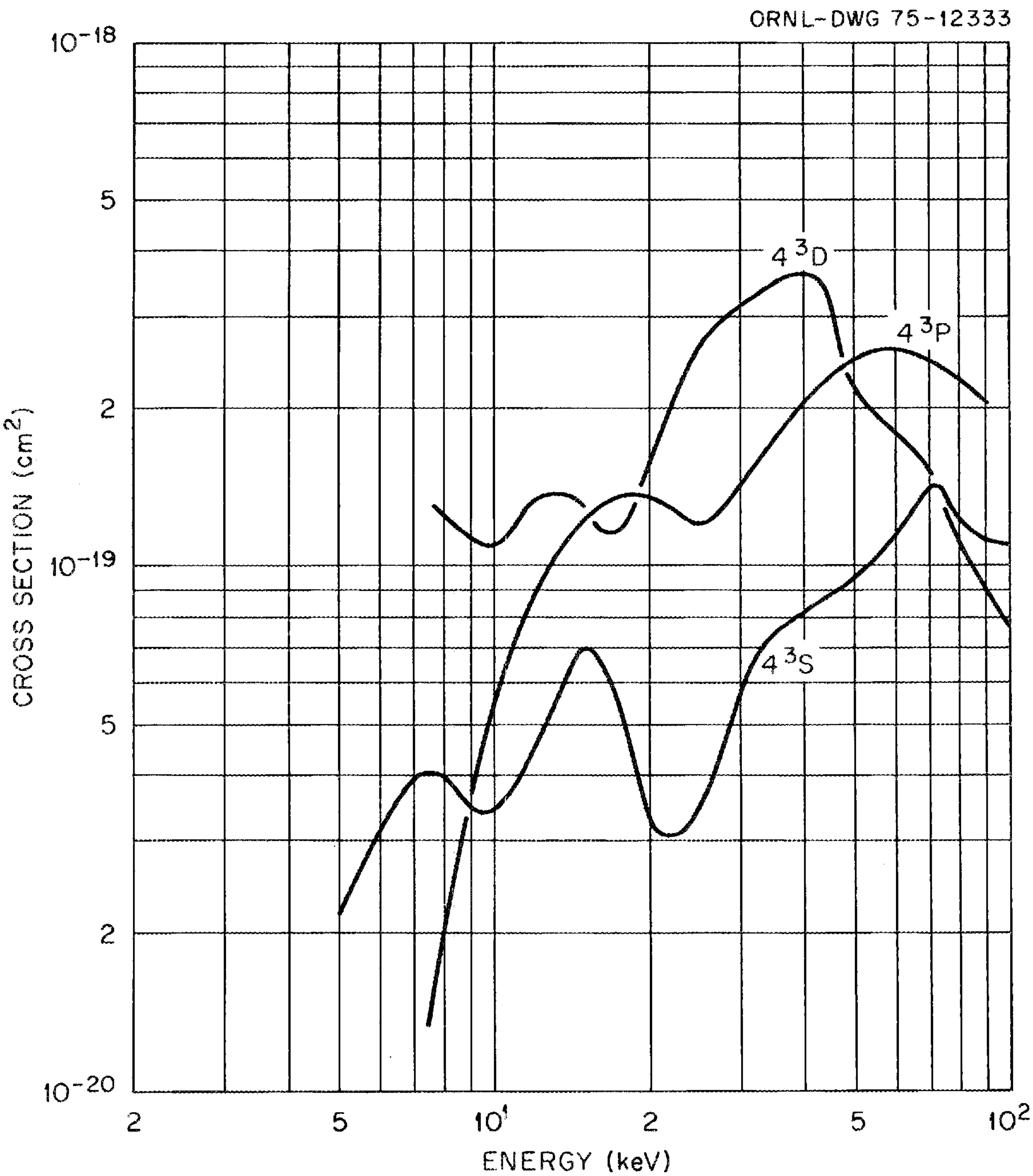
References:

F. J. de Heer and J. Van den Bos, Physica 31, 365 (1965).

Notes:

See Note (44) at end of chapter.

Accuracy: Systematic error < 10%. Random error < 5%.


ORNL-DWG 75-12333
10^{-18}
5
2
10^{-19}
5
2
10^{-20}
CROSS SECTION (cm^2)
2
5
10^1
2
5
10^2
ENERGY (keV)
$4\,^3D$
$4\,^3P$
$4\,^3S$

Notes

(1) The theoretical values of Cheshire et al. for energies above 25 keV are presented separately. Although not yet confirmed by experiment at high energies, they do provide a useful method for estimating cross sections at high energies.

(2) The experimental data represent cross sections for emission of Lyman-alpha radiation. They are equal to the cross section for formation of the level only if cascade can be neglected; for the 2s level this is probably true but for the 2p level it may be in error.

(3) The theoretical values of Cheshire are presented for energies greater than 25 keV. Consult this paper for theoretical values of cross sections above 100 keV. Although not yet confirmed by experiment at these higher energies, they do provide a useful method for estimating cross sections at high energies.

(4) The experimental data represent cross sections for the formation of the 2s and 2p levels only if cascade into these levels can be neglected. Morgan, et al., have estimated that cascade contribution to the measured cross section is less than 1% over their energy range.

(5) In all cases these cross sections have been deduced on the (unsubstantiate assumption that cascade into the relevant levels can be neglected. With the exception of the 2p level this assumption is justified; there is insufficient data to permit a correction for the 2p level.

(6) There is good evidence [R. H. Hughes et al. Phys. Rev. A 1, 1424 (1970)] that cross sections for ns states decrease as n^{-3} at energies above 60 keV; this fact may be utilized to predict cross sections for higher n states.

(7) In all cases these cross sections have been deduced on the (unsubstantiated) assumption that cascade into relevant states can be neglected. For the ns states this assumption is justified.

(8) The 2s notation represents the cross sections for field induced emission of Lyman-alpha emission (2s → 2p → 1s). If cascade can be neglected this is equal to the cross section for H(2s) formation.

(9) The 2p notation represents the cross sections for Lyman-alpha emission. If cascade can be neglected then this is equal to the cross section for H(2p) formation.

(10) The 3p cross sections are for H(3p) formation deduced from emission measurements on the (unsubstantiated) assumption that cascade can be neglected.

(11) The 1606 Å band is the Lyman band of H_2 [$B'\Sigma_u^+ \rightarrow x\,'\Sigma_q^+$, (4,11), (5,12), and (6,13)].

(12) The 4180 Å band of H_2 is for the transitions $[3d\ ^1\Pi_g \rightarrow 2p\ ^1\Sigma_u^+\ (1,0)]$.

(13) Data on polarization of emissions can be found in R. H. Hughes et al., Phys. Rev. A 1, 1424 (1970) and in T. D. Baily et al., Phys. Rev. 167, 81 (1968).

(14) Some of these measurements have been done with D^+ projectiles. In these cases the cross section for D^+ impact appears to be the same as for H^+ projectiles of the same velocity.

(15) There is good evidence [R. H. Hughes et al., Phys. Rev. 164, 166 (1967)] that cross sections for ns states decrease as n^{-3} at energies above 80 keV. This fact may be utilized to predict cross sections for higher n states.

(16) In all cases the cross sections have been deduced on the (unsubstantiated) assumption that cascade into relevant levels can be neglected.

(17) It is generally found that the cross section for formation of H(ns) at energies greater than 80 keV decreases as n^{-3}; this rule may be used to extrapolate to other ns levels.

(18) These data are for formation of all states having a given principal quantum number n. It is known that the cross section $\sigma(n)$ for formation of such a state is proportional to n^{-3}. It is conventional to determine the coefficient $\sigma(n) \times n^3$, and it is this coefficient that is given here.

(19) The data presented here have been measured for states ranging between 10 and 15.

(20) These data are for formation of all states having a principal quantum number n. It is known that the cross section $\sigma(n)$ for for formation of such a state is proportional to n^{-3}. It is conventional to determine the coefficient $\sigma(n) \times n^{-3}$; it is that coefficient that is given here.

(21) Il'in et al. also present data for a Li vapor target over the same energy range.

(22) These data are theoretical predictions. For experimental data obtained since the graph was made see T. J. Morgan, J. Geddes, and H. B. Gilbody, J. Phys. B 7, 142 (1974).

(23) These data are derived from emission measurements on the (unsubstantiated) assumption that cascade into the excited state may be neglected. This assumption probably does not involve an error of 10% in most cases.

(24) These data are derived from emission measurements on the (unsubstantiated) assumption that cascade into the excited state may be neglected. There is no evidence with which the validity of the assumption can be tested.

(25) For H(2s) and H(2p) formation, we have used a theoretical calculation by Levy at energies of 100 keV and greater. These calculations have not been confirmed experimentally above 100 keV but are expected to be reliable.

(26) These data are derived from emission measurements on the assumption that cascade into the excited state may be neglected. With the exception of the 2p level, this is justified and in this case the resulting error does not exceed 10%.

(27) These data are experimental values from a single publication; no confirming data from other sources are available.

(28) There are no theoretical data available to permit extension of the energy range or to include other states.

(29) These cross sections are for emission of Lyman-alpha radiation and were quoted as equal to the level excitation cross sections on the (unsubstantiated) assumption that cascade could be neglected.

(30) According to Ford et al. [Phys. Rev. A 7, 1928 (1973)], the cross sections for H(3p) formation are approximately the same as for H(3s) and H(3d) formation above 75 keV.

(31) These cross sections were derived from emission measurements on the (unsubstantiated) assumption that cascade may be neglected. In all cases this is probably a good assumption.

(32) The excitation cross sections for H(2s) are determined from the field induced emission of Lyman-alpha (2s → 2p → 1s). If cascade can be neglected these are equal to the cross section for H(2s) formation.

(33) The excitation cross sections for H(2p) are the cross sections for Lyman-alpha (2p → 1s) emission. If cascade can be neglected then these are equal to the cross sections for H(2p) formation.

(34) The excitation cross sections for H(3p) are emission cross sections, and if cascade can be neglected these are equal to the cross sections for H(3p) formation.

(35) The n = 3 → 2 transition is the 6563 Å Balmer-alpha radiation.

(36) There are data for D_2^+ impact by Van Zyl et al. Phys. Rev. A 136, 1561 (1969) that are in good agreement with these data for H(2p) formation when plotted on the same velocity scale.

(37) According to Ford et al. [Phys. Rev. A 5, 1705 (1972)] the cross section for H(3p) formation is approximately the same as that for H(3s) and H(3d) formation at energies above 75 keV.

(38) This cross section is determined from emission measurements on the (unsubstantiated) assumption that cascade may be neglected.

(39) The H(3s) and H(3p) cross sections are deduced from emission measurements on the (unsubstantiated) assumption that cascade may be neglected.

(40) The Balmer-alpha emission is the $n = 3 \rightarrow 2$ transition (6563 Å).

(41) Data for other excited states are available in the reference cited and are also tabulated by Thomas (Excitation in Heavy Particle Collisions; Wiley-Interscience, New York, 1972, Chapter 6). Also given by Thomas are other data for these same states that are in general agreement with the values adopted here.

(42) Some data above 75 keV impact energy have been taken for D^+ impact. These indicate that D^+ behaves the same as H^+ ions of the same energy.

(43) Excitation by triplet states by proton impact is formally forbidden because electron spin is not conserved. There are no reliable measurements that indicate this rule to be violated.

(44) Data for other excited states are available in the reference cited and are also tabulated by Thomas (Excitation in Heavy Particle Collisions, Wiley-Interscience, New York, 1972, Chapter 6).

(45) It is generally found that the cross section for formation of H(ns) at energies above 80 keV decreases as n^{-3}; this rule may be used to extrapolate to other ns levels.

(46) Some measurements with incident D^+ are available. In general these cross sections are the same as for H^+ projectiles of the same velocity.

(47) In our opinion the data for Cs and K may be unreliable in magnitude; other estimates of the cross section for Cs targets are up to two orders of magnitude less than those shown here. The relative magnitudes should be reliable.

A.3 Heavy Particle Dissociation

Cross Sections for the Conversion of Fast H_2^+ Ions into Protons in Passage Through H_2 and H

Energy (keV)	Cross Section (cm^2)	
	H	H_2
3.2 E-03		3.3 E-17
4.0 E-03		6.6 E-17
6.0 E-03		8.8 E-17
8.0 E-03		8.6 E-17
1.0 E-02		8.0 E-17
3.0 E 00	1.6 E-16	2.1 E-16
6.0 E 00	2.1 E-16	2.4 E-16
1.0 E 01	2.4 E-16	2.4 E-16
2.0 E 01	2.3 E-16	2.1 E-16
3.0 E 01	2.0 E-16	1.9 E-16
4.0 E 01	1.9 E-16	1.9 E-16
6.0 E 01	1.8 E-16	2.2 E-16
1.0 E 02	1.6 E-16	2.3 E-16
2.0 E 02		1.8 E-16
4.0 E 02		1.2 E-16
7.0 E 02		8.0 E-17
1.0 E 03		6.3 E-17
3.0 E 03		1.4 E-17
2.0 E 04		4.9 E-18

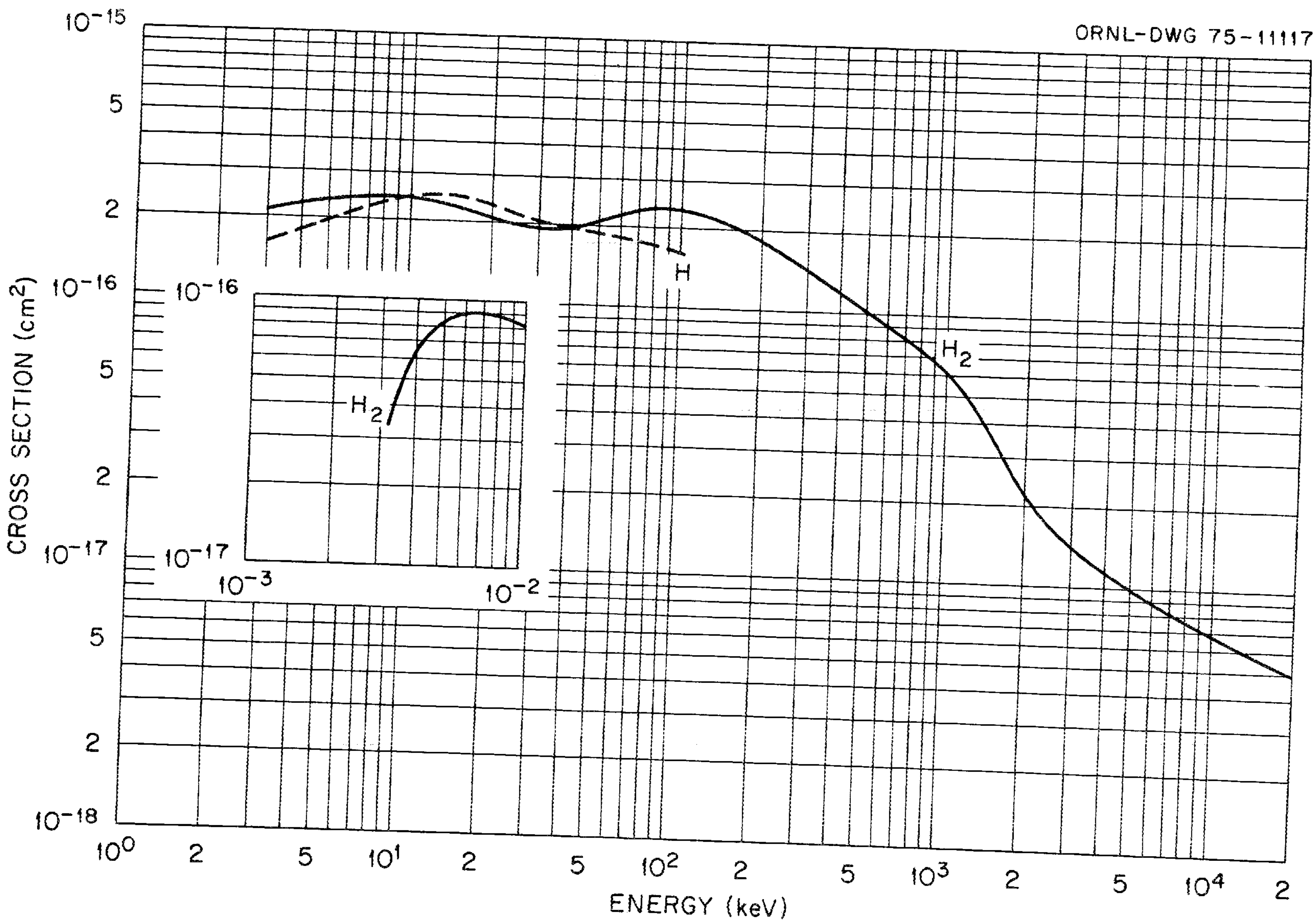
References:

$H_2^+ + H_2$: C. F. Barnett and J. A. Ray, Atomic Collision Processes, North-Holland Publ. Co., Amsterdam, p. 743 (1964); K. H. Berkner, S. N. Kaplan, R. V. Pyle, and J. W. Stearns, Phys. Rev. 146, 91 (1966); J. Guidini, C. R. Acad. Sci. Paris 253, 829 (1961); R. N. Il'in, B. I. Kikiani, V. A. Oparin, E. S. Solov'ev, and N. V. Fedorenko, Sov. Phys.-JETP 19, 817 (1964); S. E. Kupriyanov, N. N. Tunitskii, and A. A. Perov, Sov. Phys.-Tech. Phys. 8, 932 (1964); G. W. McClure, Phys. Rev. 130, 1852 (1963); T. F. Moran and J. R. Roberts, J. Chem. Phys. 49, 3411 (1968); L. I. Pivovar, V. M. Tubaev, and M. T. Novikov, Sov. Phys.-JETP, 13, 23 (1961); A. Schmid, Z. Phys. 161, 550 (1961); E. S. Solov'ev, R. N. Il'in, V. A. Oparin, and N. V. Fedorenko, Sov. Phys.-JETP 26, 1097 (1968); D. R. Sweetman, Proc. Roy. Soc. London, 256A, 416 (1960); J. F. Williams and D. N. F. Dunbar, Phys. Rev. 149, 62 (1966).

$H_2^+ + H$: G. W. McClure, Phys. Rev. 153, 182 (1967).

Accuracy:

± 25%.



ORNL-DWG 75-11117
CROSS SECTION (cm²)
ENERGY (keV)
H
H₂
10⁻¹⁵
5
2
10⁻¹⁶
5
2
10⁻¹⁷
5
2
10⁻¹⁸
10⁰
2
5
10¹
2
5
10²
2
5
10³
2
5
10⁴
2
10⁻¹⁶
10⁻¹⁷
10⁻³
10⁻²

Dissociation Cross Sections for the Formation of Fast H^+ and H° for H_2 Molecules in H_2

Energy (keV)	Cross Section (cm^2)	
	$\sigma(H^+)$	$\sigma(H^\circ)$
6.0 E 00	2.4 E-17	
1.0 E 01	3.8 E-17	2.4 E-16
1.5 E 01	3.6 E-17	
2.0 E 01	4.3 E-17	
4.0 E 01	6.7 E-17	
6.0 E 01	6.7 E-17	
9.0 E 01	3.5 E-17	
3.0 E 02	6.3 E-17	
6.0 E 02	3.1 E-17	
9.0 E 02	2.4 E-17	
1.2 E 03	2.2 E-17	

References:

G. W. McClure, Phys. Rev. 134, A1226 (1964); K. H. Berkner, T. J. Morgan, R. V. Pyle, and J. W. Stearns, Phys. Rev. A 8, 2870 (1973).

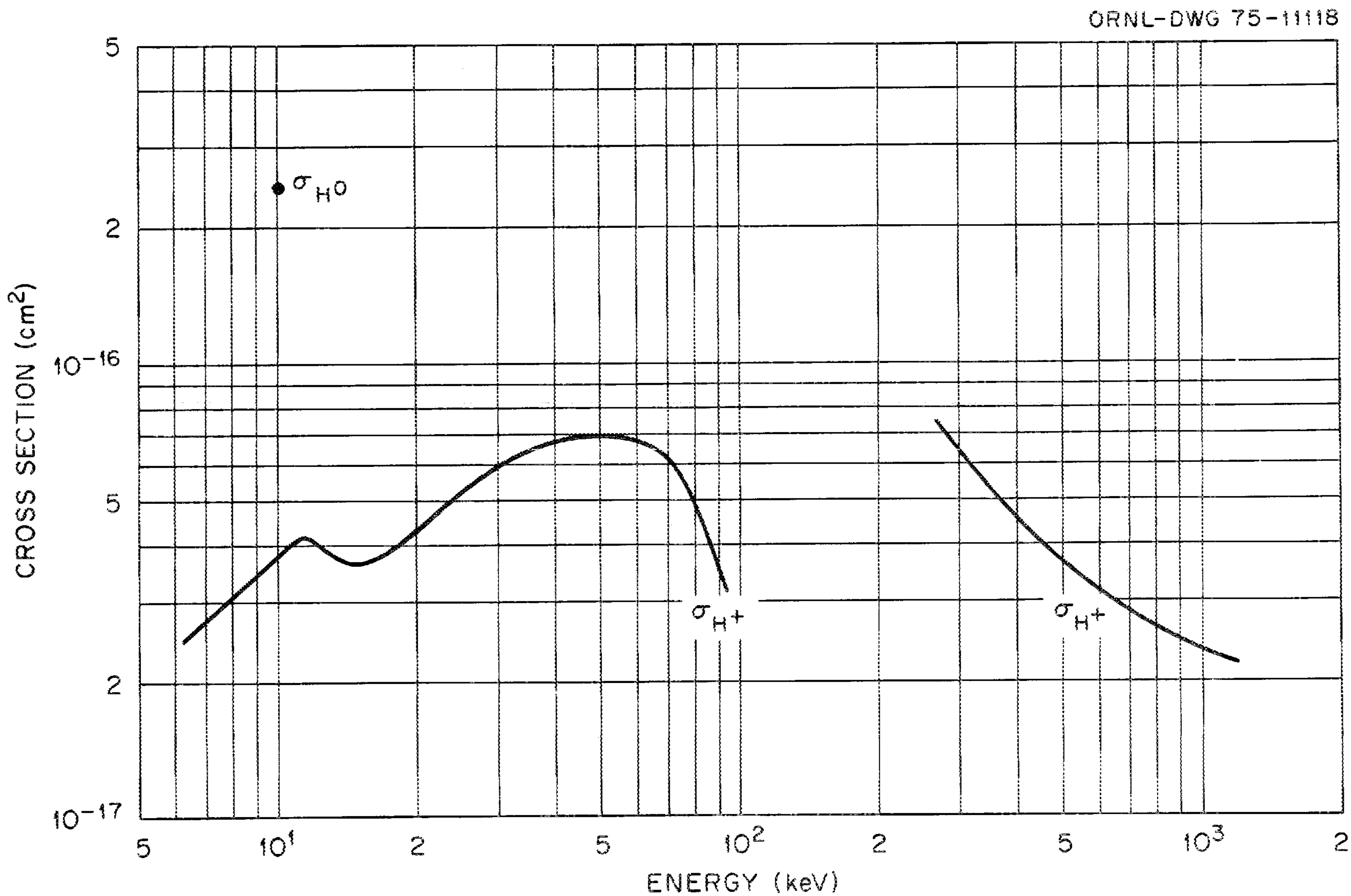
Accuracy:

Unknown.

Notes:

The low energy data is from McClure's paper, while the high energy data is taken from Berkner et al.

$\sigma_{(H^\circ)}$ is the sum of the cross sections for the reactions $H_2 \rightarrow H^+ + H$ and $2(H_2 \rightarrow H + H)$.
$\sigma_H(H^+)$ is the sum of the cross sections for the reactions $H_2 \rightarrow H^+ + H$ and $2(H_2 \rightarrow H^+ + H^+)$.



ORNL-DWG 75-11118
CROSS SECTION (cm2)
ENERGY (keV)
σH0
σH+
σH+
5
2
10−16
5
2
10−17
5
10^1
2
5
10^2
2
5
10^3
2

A.3.5

Partial Cross Section for Dissociation of Fast H_2^+ Ions in Passage through Hydrogen and Helium. $H_2^+ \rightarrow H^+ + H^o$

Energy (keV)	Cross Sections (cm^2)	
	H_2	He
1.7 E 00	1.6 E-16	
3.0 E 00	1.6 E-16	
6.0 E 00	1.7 E-16	
1.0 E 01	1.7 E-16	
2.0 E 01	1.6 E-16	
5.0 E 01	1.4 E-16	6.7 E-17
7.0 E 01	1.2 E-16	6.6 E-17
1.0 E 02	1.0 E-16	6.2 E-17
2.0 E 02	6.8 E-16	4.5 E-17
5.0 E 02	3.7 E-16	2.2 E-17
7.0 E 02	2.9 E-16	1.7 E-17
1.0 E 03	2.2 E-16	1.2 E-17
1.5 E 03	1.7 E-16	8.2 E-18
2.0 E 03	1.4 E-16	6.2 E-18

References:

$H_2^+ + H_2$: J. Guidini, C. R. Acad. Sci. Paris, 253, 829 (1961); L. I. Pivovar, V. M. Tubeav, and M. T. Novikov, Sov. Phys.-JETP 13, 23 (1961); D. R. Sweetman, unpublished; N. N. Tunitski, E. S. Zhurkin, and M. V. Tikhomirov, Sov. Phys.-JETP Letters, 12, 210 (1970).

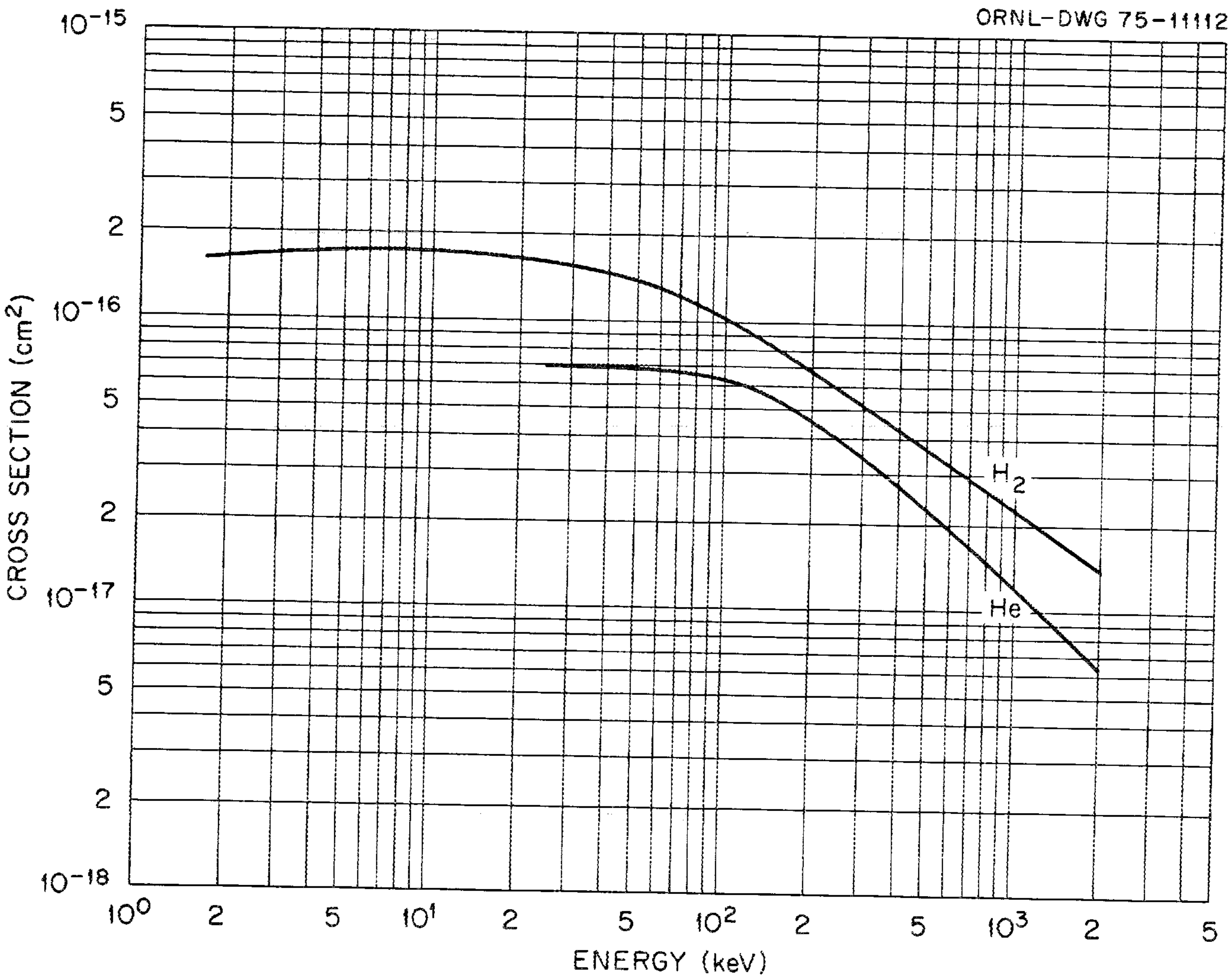
$H_2^+ + He$: J. Guidini, C. R. Acad. Sci. Paris, 253, 829 (1961); L. I. Pivovar, V. M. Tubeav, and M. T. Novikov, Sov. Phys.-JETP 13, 23 (1961); D. R. Sweetman, unpublished.

Accuracy:

For energies less than 100 keV ± 40%.
For energies greater than 100 keV ±20%.

Notes:

At the lower impact energies the accuracy of the results of the various investigators depends on the initial vibrational state distribution of the H_2^+ ion.



ORNL-DWG 75-11112
CROSS SECTION (cm^2)
ENERGY (keV)
H_2
He
10^{-15}
5
2
10^{-16}
5
2
10^{-17}
5
2
10^{-18}
10^0
2
5
10^1
2
5
10^2
2
5
10^3
2
5

Dissociation Cross Sections for the Formation of Protons for H_2^+ in He and the Formation of Fast H^o Atoms for H_2^+ in H_2

Energy (keV)	Cross Sections (cm^2)	
	σ_{H^+}(He)	$\sigma_{H^o}(H_2)$
2.0 E 00	3.7 E-17	
4.0 E 00	7.6 E-17	5.1 E-16
6.0 E 00	1.0 E-16	6.3 E-16
8.0 E 00	1.2 E-16	7.1 E-16
1.0 E 01	1.3 E-16	7.7 E-16
3.0 E 01	1.8 E-16	8.3 E-16
5.0 E 01	2.0 E-16	6.9 E-16
7.0 E 01	2.0 E-16	5.3 E-16
1.0 E 02	2.0 E-16	3.6 E-16
2.0 E 02	1.7 E-16	1.2 E-16
3.0 E 02	1.2 E-16	
7.0 E 02	5.9 E-16	
1.0 E 03	4.2 E-16	

References:

H_2^++He: R. N. Il'in, B. I. Kikiani, V. A. Oparin, E. S. Solov'ev, and N. V. Fedorenko, Sov. Phys. JETP 19, 817 (1964); J. Guidini, C. R. Acad. Sci. Paris 253, 829 (1961); L. I. Pivovar, V. M. Tubaev, M. T. Novikov, Sov. Phys.-JETP 13, 23 (1961); J. F. Williams and D. N. F. Dunbar, Phys. Rev. 149, 62 (1966).

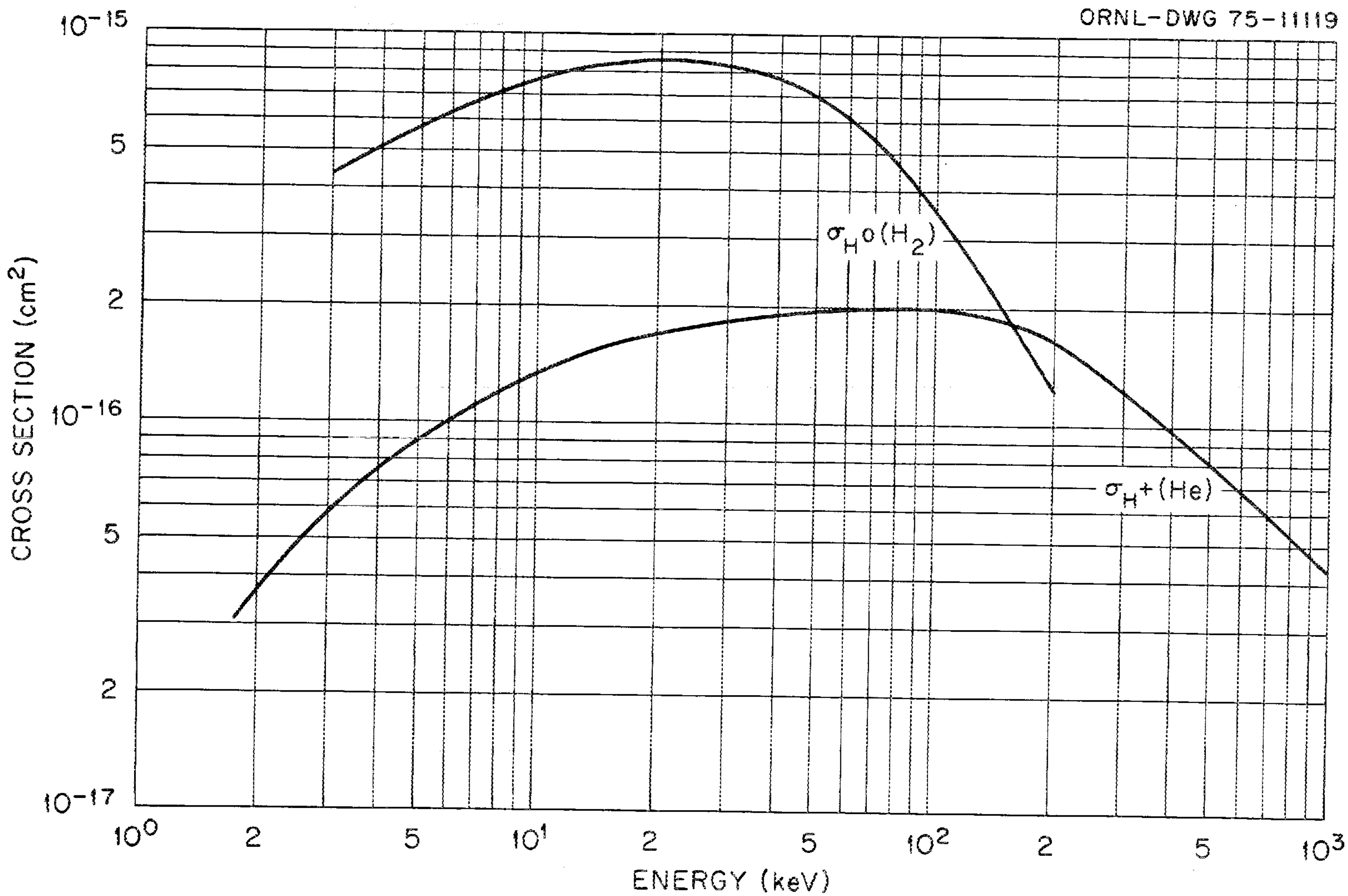
H_2^++H_2: G. W. McClure, Phys. Rev. 130, 1852 (1963); A. Schmid, Z. Phys. 161, 550 (1961); E. S. Solov'ev, R. N. Il'in, V. A. Oparin, and N. V. Fedorenko, Sov. Phys.-JETP 26, 1097 (1968); D. R. Sweetman, Proc. Roy. Soc. London 256A, 416 (1960).

Accuracy:

± 20%. The high energy data (> 100 keV) for σ_{H+} (He) has discrepancies of ± 40%.

Notes:

σ_{H+}(He) refers to the sum of the reactions $H_2^+ + He \rightarrow (H^+ + H^o) + 2(H^o + H^o)$.
$\sigma_{H^o}(H_2)$ refers to the sum of the reactions $H_2^+ + H_2 \rightarrow (H^+ + H^o) + 2(H^o + H^o)$.


ORNL-DWG 75-11119
10^{-15}
5
2
10^{-16}
5
2
10^{-17}
CROSS SECTION (cm^2)
$\sigma_{H^0}(H_2)$
$\sigma_{H^+}(He)$
10^0
2
5
10^1
2
5
10^2
2
5
10^3
ENERGY (keV)

Dissociation Cross Sections for the Formation of Protons for H_2^+ in N_2 and Ne

Energy (keV)	Cross Sections (cm^2)	
	$\sigma_{H^+}(N_2)$	$\sigma_{H^+}(Ne)$
2.0 E 00		6.5 E-17
4.0 E 00	2.0 E-16	9.5 E-17
6.0 E 00	2.5 E-16	1.2 E-16
1.0 E 01	3.3 E-16	1.5 E-16
2.0 E 01	4.6 E-16	2.1 E-16
4.0 E 01	5.9 E-16	2.6 E-16
6.0 E 01	6.5 E-16	3.0 E-16
1.0 E 02	7.0 E-16	3.3 E-16
1.5 E 02	7.0 E-16	3.2 E-16
3.0 E 02	6.5 E-16	
7.0 E 02	5.4 E-16	
1.0 E 03	4.8 E-16	
2.0 E 03	3.0 E-16	

References:

$H_2^+ + N_2$: J. Guidini, C. R. Acad. Sci., Paris, 253, 829 (1961); R. N. Il'in, B. I. Kikiani, V. A. Oparin, E. S. Solov'ev, and N. V. Fedorenko, Sov. Phys.-JETP 19, 817 (1964); L. I. Pivovar, V. M. Tubeav, and M. T. Novikov, Sov. Phys.-JETP 13, 23 (1961); D. R. Sweetman, unpublished; J. F. Williams and D. N. F. Dunbar, Phys. Rev. 149, 62 (1966).

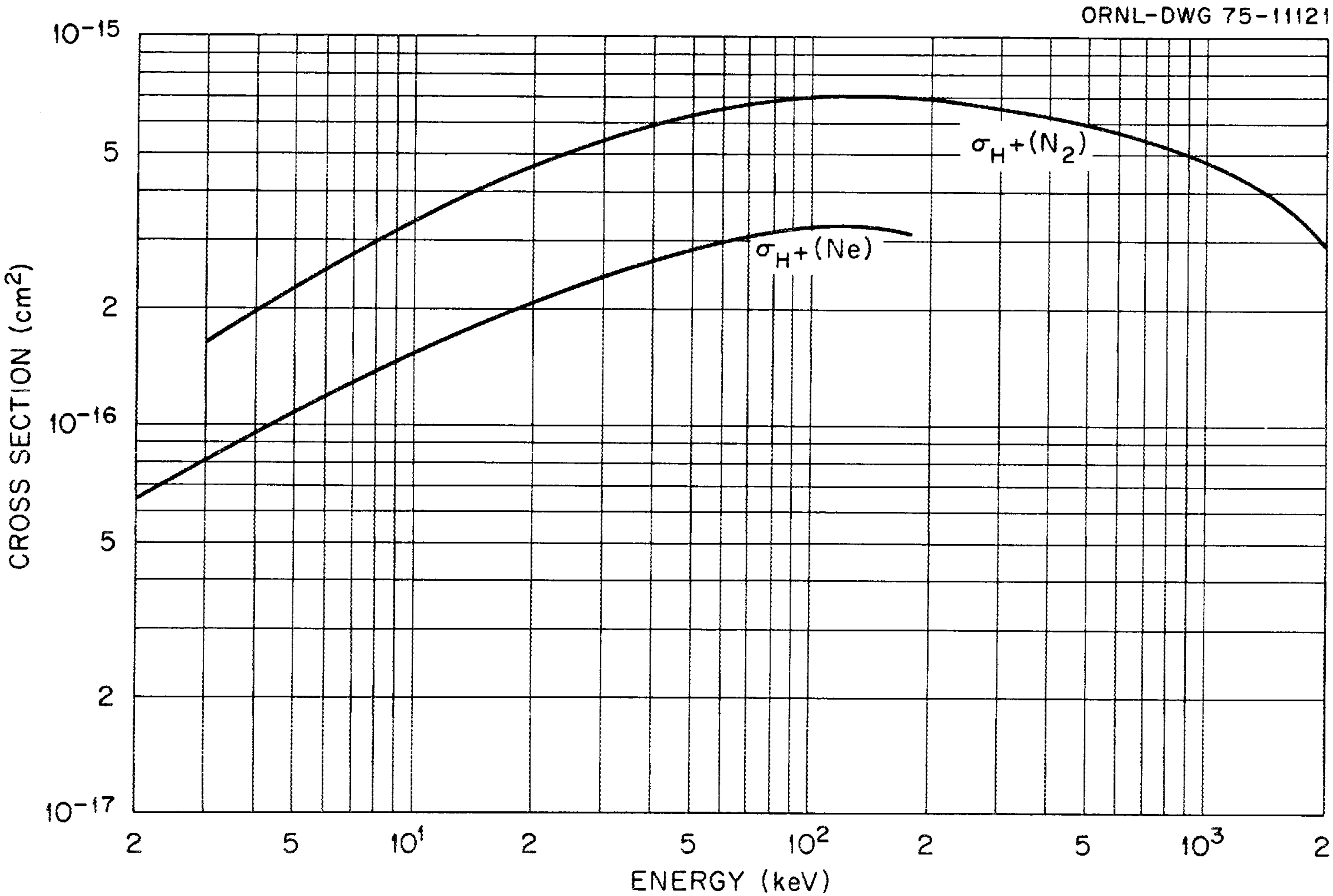
H_2^++Ne: E. S. Solov'ev, R. N. Il'in, V. A. Oparin, and N. V. Fedorenko, Sov. Phys.-JETP 26, 1097 (1968); J. F. Williams and D. N. F. Dunbar, Phys. Rev. 149, 62 (1966).

Accuracy:

$\pm$ 25%.

Note:

σ_{H^+} is the cross section for the sum of the reactions $H_2^+ + X \rightarrow (H^+ + H^\circ) + 2(H^+ + H^+)$.


ORNL-DWG 75-11121
CROSS SECTION (cm²)
ENERGY (keV)
σH+(N2)
σH+(Ne)
10^-15
5
2
10^-16
5
2
10^-17
2
5
10^1
2
5
10^2
2
5
10^3
2

Cross Sections for the Production Protons
and H Atoms for H_2^+ in Mg and Na

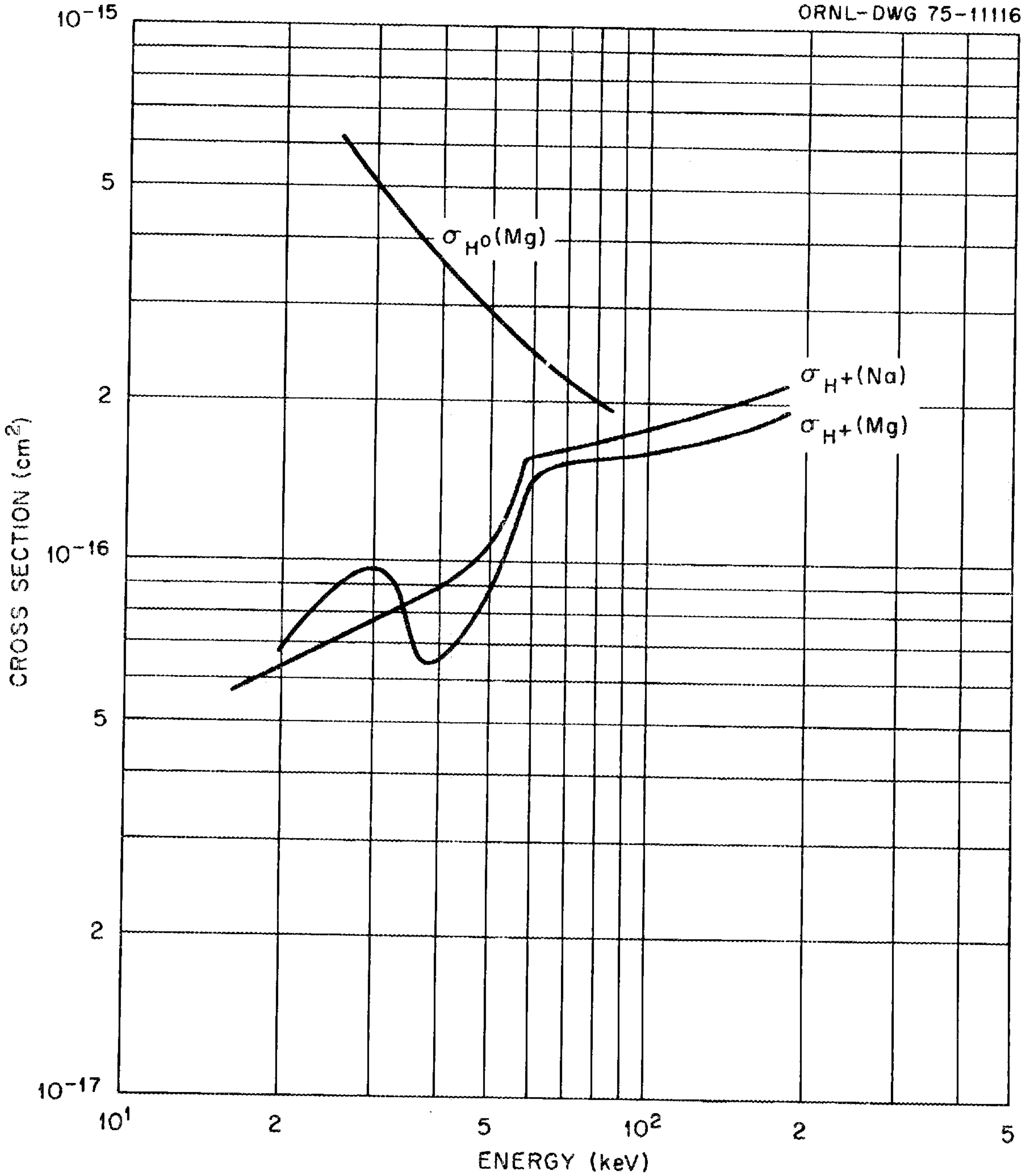
Energy (keV)	Cross Section (cm^2)		
	σ_{H^+}(Mg)	σ_{H^+}(Na)	σ_{H°(Mg)
2.0 E 01	6.8 E-17	6.3 E-17	
3.0 E 01	9.7 E-17	7.7 E-17	4.9 E-16
4.0 E 01	6.5 E-17	9.0 E-17	3.6 E-16
5.0 E 01	8.9 E-17	1.1 E-16	2.9 E-16
6.0 E 01	1.4 E-16	1.6 E-16	2.4 E-16
8.0 E 01	1.6 E-16	1.7 E-16	2.0 E-16
1.0 E 02	1.6 E-16	1.8 E-16	
1.5 E 02	1.8 E-16	2.0 E-16	
1.8 E 02	1.9 E-16	2.2 E-16	

References:

E. S. Solov'ev, R. N. Il'in, V. A. Oparin, and N. V. Fedorenko, Sov. Phys.-JETP 26, 1097 (1968).

Accuracy:

± 30%.


ORNL-DWG 75-11116
σ_{H^0}(Mg)
σ_{H^+}(Na)
σ_{H^+}(Mg)
CROSS SECTION (cm²)
10^{-15}
5
2
10^{-16}
5
2
10^{-17}
10^1
2
5
10^2
2
5
ENERGY (keV)

Dissociation Cross Sections for the Production of Protons for the Reaction Products ($H^{+}+H^{\circ}$) for H_2^{+} in Ar

Energy (keV)	Cross Section (cm^2)	
	σ_{H^+}	$\sigma_{H^{+}+H^{\circ}}$
2.0 E 00	8.7 E-17	
4.0 E 00	1.3 E-16	
7.0 E 00	1.8 E-16	
1.0 E 01	2.2 E-16	
2.0 E 01	3.3 E-16	
4.0 E 01	4.6 E-16	2.3 E-16
7.0 E 01	5.7 E-16	2.4 E-16
1.0 E 02	6.4 E-16	2.3 E-16
2.0 E 02	6.6 E-16	1.9 E-16
4.0 E 02	5.6 E-16	1.5 E-16
7.0 E 02	4.7 E-16	1.2 E-16
1.0 E 03	4.1 E-16	1.0 E-16
2.0 E 03	3.1 E-16	7.5 E-17

Reference:

$H_2^{+}+Ar \rightarrow \sigma_{H^+}$: J. Guidini, C. R. Acad. Sci. Paris, 253, 829 (1961); R. N. Il'in, B. I. Kikiani, V. A. Oparin, E. S. Solov'ev, and N. V. Fedorenko, Sov. Phys.-JETP 19, 817 (1964); L. I. Pivovar, V. M. Tubaev, and M. T. Novikov, Sov. Phys.-JETP 13, 23 (1961); D. R. Sweetman, unpublished; J. F. Williams and D. N. F. Dunbar, Phys. Rev. 149, 62 (1966).

$H_2^{+} + Ar \rightarrow \sigma_{H^{+}+H^{\circ}}$: J. Guidini, C. R. Acad. Sci. Paris, 253, 829 (1961); L. I. Pivovar, V. M. Tubaev, and M. T. Novikov, Sov. Phys.-JETP 13, 23 (1961); D. R. Sweetman, unpublished.

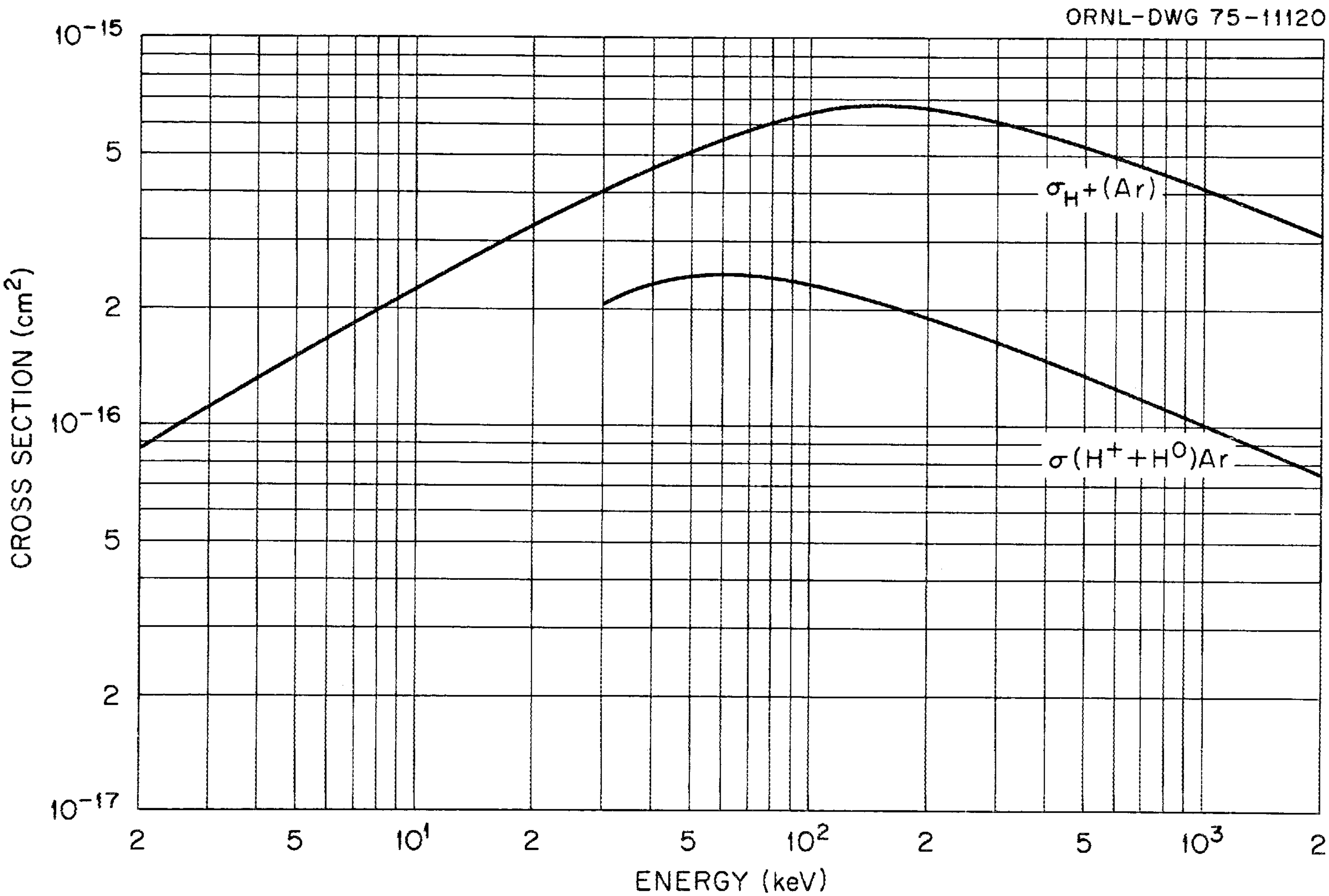
Accuracy:

± 25%.

Notes:

σ_{H^+} refers to the sum of the reactions $H_2^{+} + Ar \rightarrow (H^{+}+H^{\circ}) + 2(H^{+}+H^{+})$.

$\sigma_{H^{+}+H^{\circ}}$ refers to the reaction $H_2^{+} + Ar \rightarrow H^{+}+H^{\circ}$.


ORNL-DWG 75-11120
10^{-15}
5
2
10^{-16}
5
2
10^{-17}
CROSS SECTION (cm^2)
2
5
10^1
2
5
10^2
2
5
10^3
2
ENERGY (keV)
$\sigma_{H^+}(Ar)$
$\sigma(H^+ + H^0)Ar$

Cross Sections for the Formation of Electronically Excited H Atoms from the Dissociation of H_2^+ and H_3^+ in H_2, Ne, Mg, and Na

Energy (keV/proton)	Cross Sections (cm^2)				
	$H_2^+ + H_2$	$H_2^+ + Na$	$H_2^+ + Ne$	$H_3^+ + H_2$	$H_3^+ + Mg$
1.0 E 01		1.2 E-16		1.4 E-16	
2.0 E 01		2.2 E-16		1.4 E-16	3.1 E-16
3.0 E 01	1.2 E-16	1.4 E-16	7.8 E-17	1.3 E-16	3.0 E-16
4.0 E 01	1.4 E-16	8.9 E-17	8.8 E-17	1.2 E-16	2.9 E-16
5.0 E 01	1.6 E-16	6.8 E-17	1.0 E-16	1.2 E-16	2.8 E-16
6.0 E 01	1.7 E-16	5.8 E-17	1.1 E-16	1.1 E-16	2.7 E-16
7.0 E 01	1.7 E-16	5.4 E-17	1.3 E-16		
8.0 E 01	1.7 E-16	5.4 E-17	1.4 E-16		
9.0 E 01	1.6 E-16	5.5 E-17	1.4 E-16		

References:

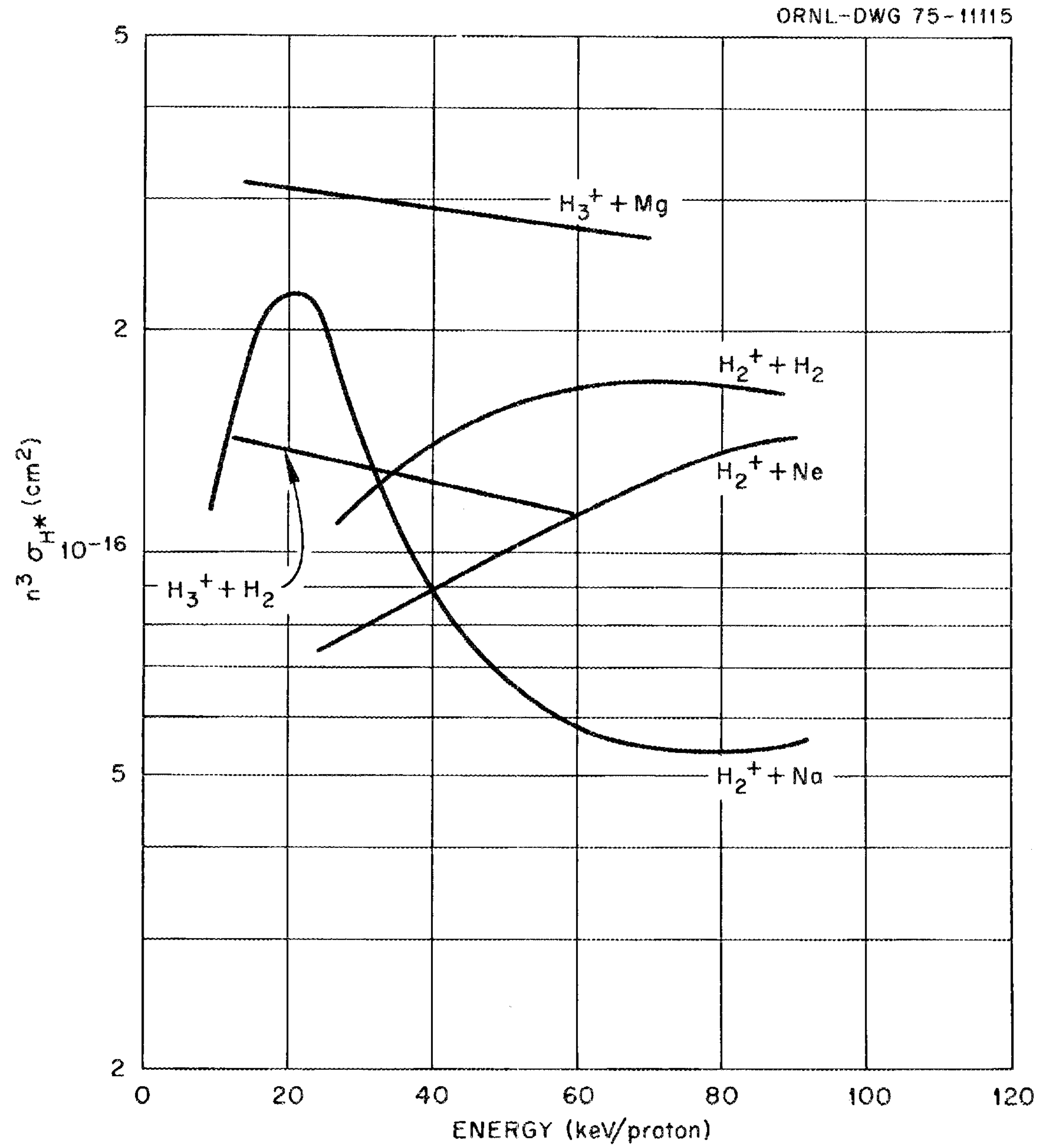
E. S. Solov'ev, R. N. Il'in, V. A. Oparin and N. V. Fedorenko, Sov. Phys.-JETP 26, 1097 (1968).

Accuracy:

± 30%.

Notes:

To obtain the cross section for formation of level n, divide the tabulated cross section by n^3.


ORNL-DWG 75-11115
5
2
10^{-16}
5
2
$n^3 \sigma_{H^*}$ (cm^2)
0
20
40
60
80
100
120
ENERGY (keV/proton)
$H_3^+ + Mg$
$H_2^+ + H_2$
$H_2^+ + Ne$
$H_3^+ + H_2$
$H_2^+ + Na$

Dissociation Cross Section for HD^+ Ions in He and Ne

Energy (eV)	Cross Sections (cm^2)			
	σ_1(He)	σ_1(Ne)	σ_2(He)	σ_2(Ne)
5.0 E 00	1.6 E-17	4.4 E-17	2.3 E-17	7.2 E-17
1.0 E 01	1.9 E-17	5.0 E-17	3.0 E-17	7.9 E-17
1.5 E 01	2.4 E-17	4.7 E-17	4.0 E-17	7.2 E-17
2.0 E 01	2.9 E-17	8.0 E-17	4.9 E-17	1.1 E-16
2.5 E 01	2.2 E-17	8.2 E-17	3.6 E-17	1.1 E-16
3.0 E 01	2.1 E-17	5.0 E-17	3.3 E-17	9.3 E-17
3.5 E 01	2.1 E-17	5.0 E-17	3.8 E-17	9.0 E-17
4.0 E 01	2.3 E-17	5.1 E-17	3.9 E-17	8.9 E-17
4.5 E 01	2.1 E-17	4.8 E-17	3.5 E-17	8.6 E-17

Reference:

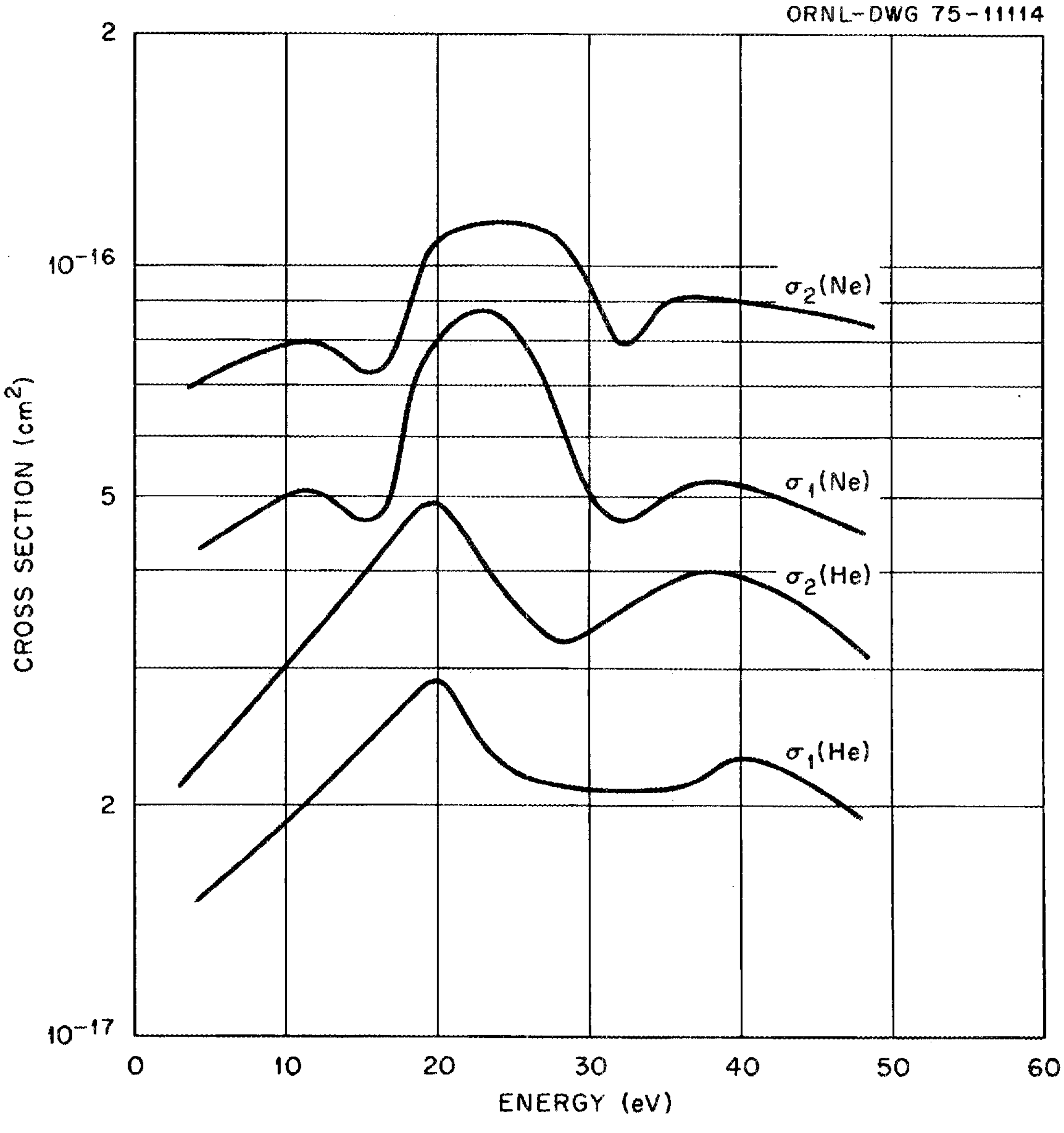
R. W. Rozett and W. S. Koski, J. Chem. Phys. 49, 2691 (1968).

Accuracy:

Unknown

Notes:

σ_1 is for reaction products H^++D and σ_2 is for H+D^+.


ORNL-DWG 75-11114
2
10^{-16}
5
2
10^{-17}
CROSS SECTION (cm^2)
σ_2(Ne)
σ_1(Ne)
σ_2(He)
σ_1(He)
0
10
20
30
40
50
60
ENERGY (eV)

Dissociation Cross Sections for the Production of Fast H^+ and H_2^+ from H_3^+ in H_2

Energy (keV)	Cross Sections (cm^2)	
	$\sigma(H^+)$	$\sigma(H_2^+)$
2.0 E 00	1.2 E-17	3.1 E-17
4.0 E 00	3.4 E-17	6.1 E-17
6.0 E 00	5.5 E-17	8.0 E-17
8.0 E 00	7.2 E-17	9.6 E-17
1.0 E 01	8.6 E-17	1.1 E-16
3.0 E 01	1.8 E-16	1.3 E-16
5.0 E 01	2.1 E-16	1.2 E-16
7.0 E 01	2.2 E-16	1.1 E-16
1.0 E 02	2.3 E-16	9.9 E-17
3.0 E 02	2.3 E-16	6.6 E-17
5.0 E 02	2.0 E-16	5.3 E-17
7.0 E 02	1.6 E-16	4.2 E-17
1.0 E 03	1.3 E-16	3.7 E-17
1.8 E 03	7.3 E-17	2.0 E-17

References:

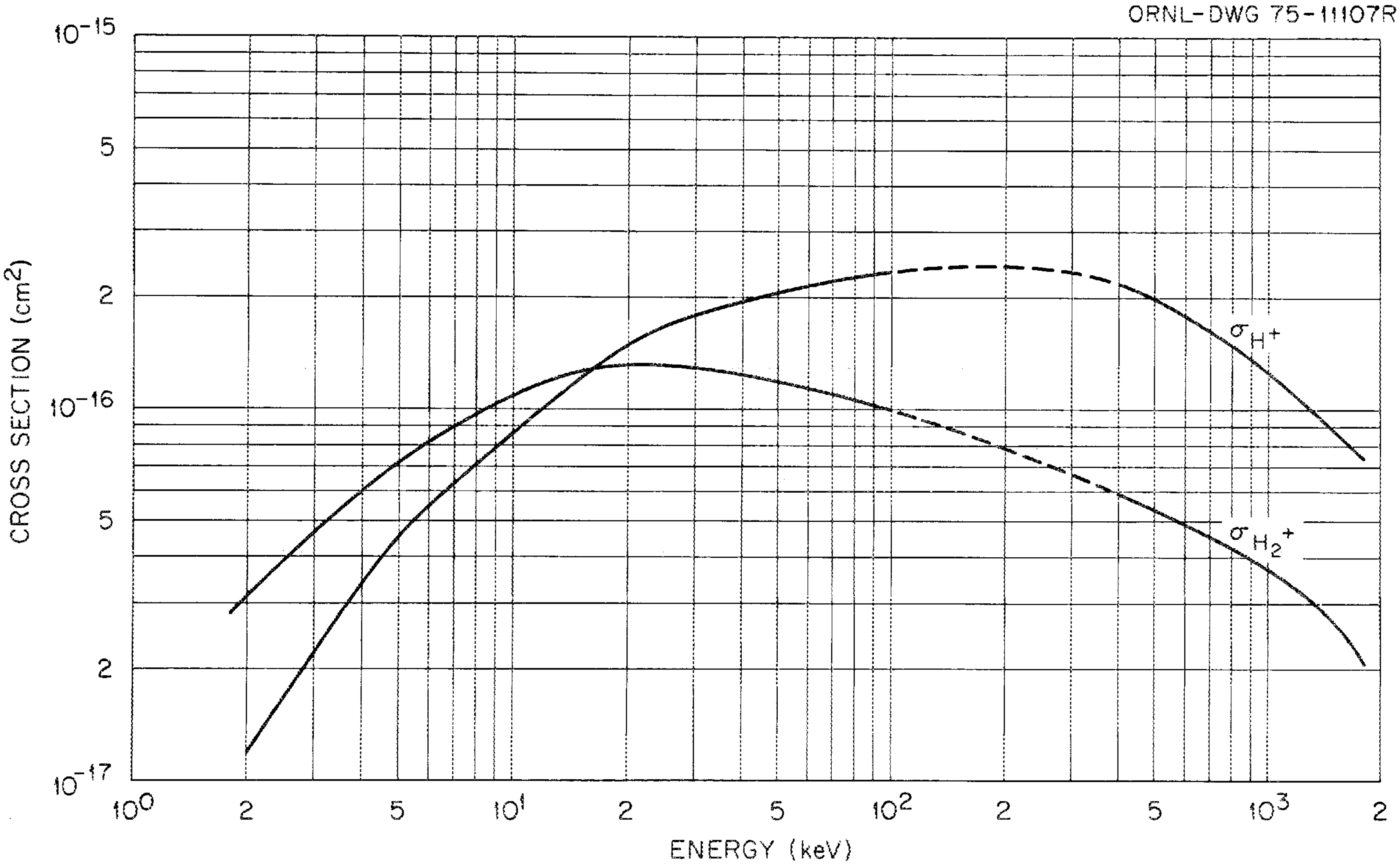
K. H. Berkner, T. J. Morgan, R. V. Pyle, and J. W. Stearns, Phys. Rev. A 8, 2870 (1973); J. F. Williams and D. N. F. Dunbar, Phys. Rev. 149, 62 (1966); G. W. McClure, Phys. Rev. 130, 1852 (1963).

Accuracy:

± 30%.

Notes:

Large variations in measured dissociation cross sections have been abscribed to the influence of H_3^+ ions in high vibrationally excited states formed in the ion source.


ORNL-DWG 75-11107R
CROSS SECTION (cm²)
ENERGY (keV)
σ_{H^+}
$\sigma_{H_2^+}$
10^{-15}
10^{-16}
10^{-17}
10^0
10^1
10^2
10^3

Dissociation Cross Sections for the Production of H° and H_2° from H_3^+ in H_2

Energy (keV)	Cross Sections (cm^2)	
	$\sigma(H^{\circ})$	$\sigma(H_2^{\circ})$
4.5 E 00	3.2 E-16	2.3 E-16
6.0 E 00	4.3 E-16	2.7 E-16
8.0 E 00	5.4 E-16	3.0 E-16
1.0 E 01	6.2 E-16	3.4 E-16
3.0 E 01	9.6 E-16	4.3 E-16
5.0 E 01	9.4 E-16	3.7 E-16
7.0 E 01	8.5 E-16	2.8 E-16
1.0 E 02	6.7 E-16	1.9 E-16
3.0 E 02	2.6 E-16	3.7 E-17
5.0 E 02	1.7 E-16	1.7 E-17
7.0 E 02	1.3 E-16	1.1 E-17
1.0 E 03	9.2 E-17	7.8 E-18
1.8 E 03	5.5 E-17	6.1 E-18

References:

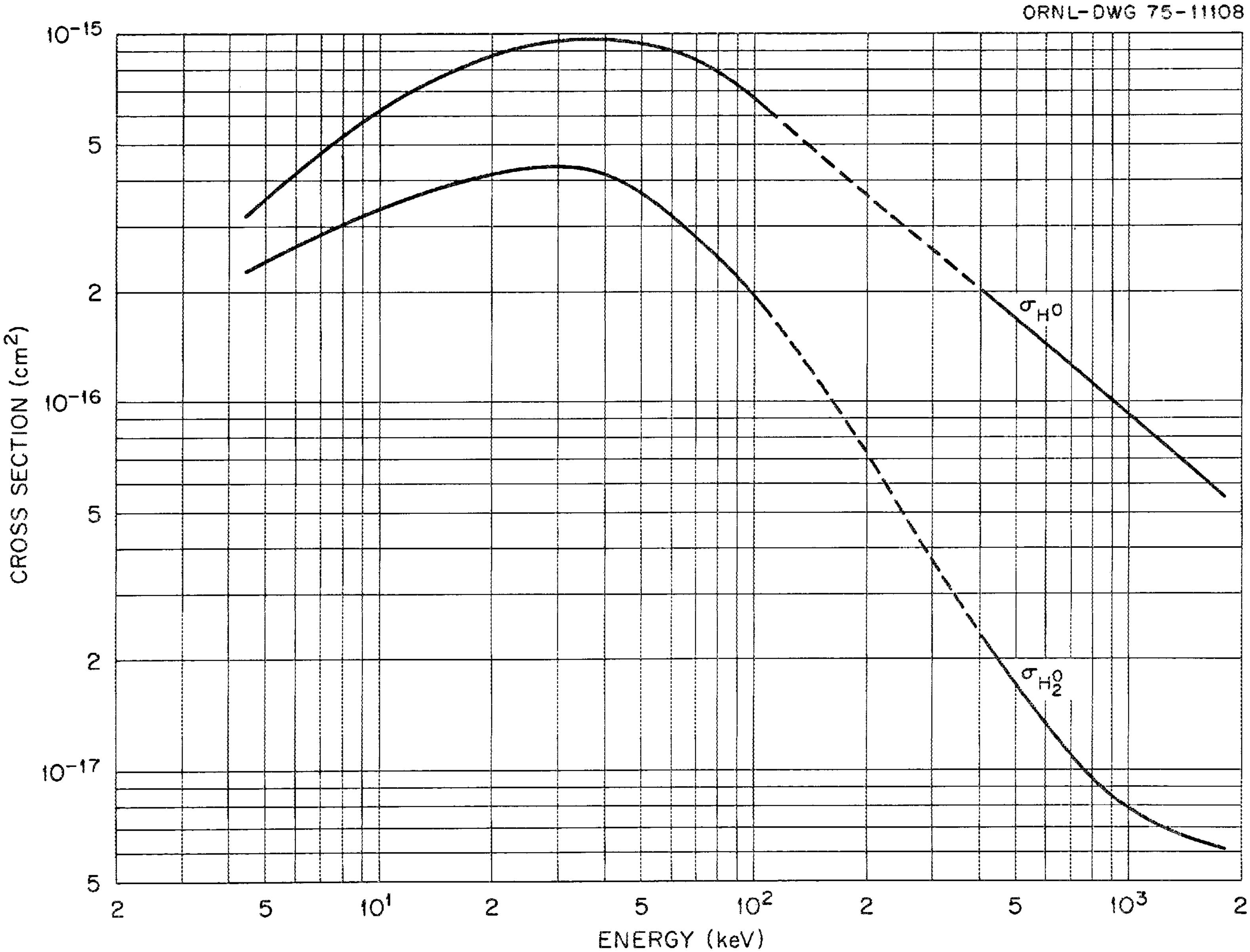
K. H. Berkner, T. J. Morgan, R. V. Pyle, and J. W. Stearns, Phys. Rev. A 8, 2870 (1973); G. W. McClure, Phys. Rev. 130, 1852 (1963).

Accuracy:

± 30%.

Notes:

Large variations in measured dissociation cross sections have been abscribed to the influence of H_3^+ ions in high vibrationally excited states formed in the ion source.


ORNL-DWG 75-11108
CROSS SECTION (cm^2)
ENERGY (keV)
10^{-15}
5
2
10^{-16}
5
2
10^{-17}
5
2
5
10^1
2
5
10^2
2
5
10^3
2
σ_{H^0}
$\sigma_{H_2^0}$

A.3.23

Cross Sections for the Formation of Fast H^+ and H_2^+ from the Dissociation of H_3^+ in He and Ne

Energy (keV)	Cross Sections (cm^2)			
	σ_{H^+}(He)	σ_{H^+}(Ne)	$\sigma_{H_2^+}$(He)	$\sigma_{H_2^+}$(Ne)
3.0 E 00	2.2 E-17	2.6 E-17	1.7 E-17	2.2 E-17
5.0 E 00	3.6 E-17	4.2 E-17	2.8 E-17	3.5 E-17
7.0 E 00	4.8 E-17	5.6 E-17	3.7 E-17	4.5 E-17
1.0 E 01	6.4 E-17	7.4 E-17	4.8 E-17	5.8 E-17
2.0 E 01	9.8 E-17	1.2 E-16	7.3 E-17	8.7 E-17
3.0 E 01	1.2 E-16	1.4 E-16	8.8 E-17	1.0 E-16
5.0 E 01	1.4 E-16	1.8 E-16	1.1 E-16	1.2 E-16

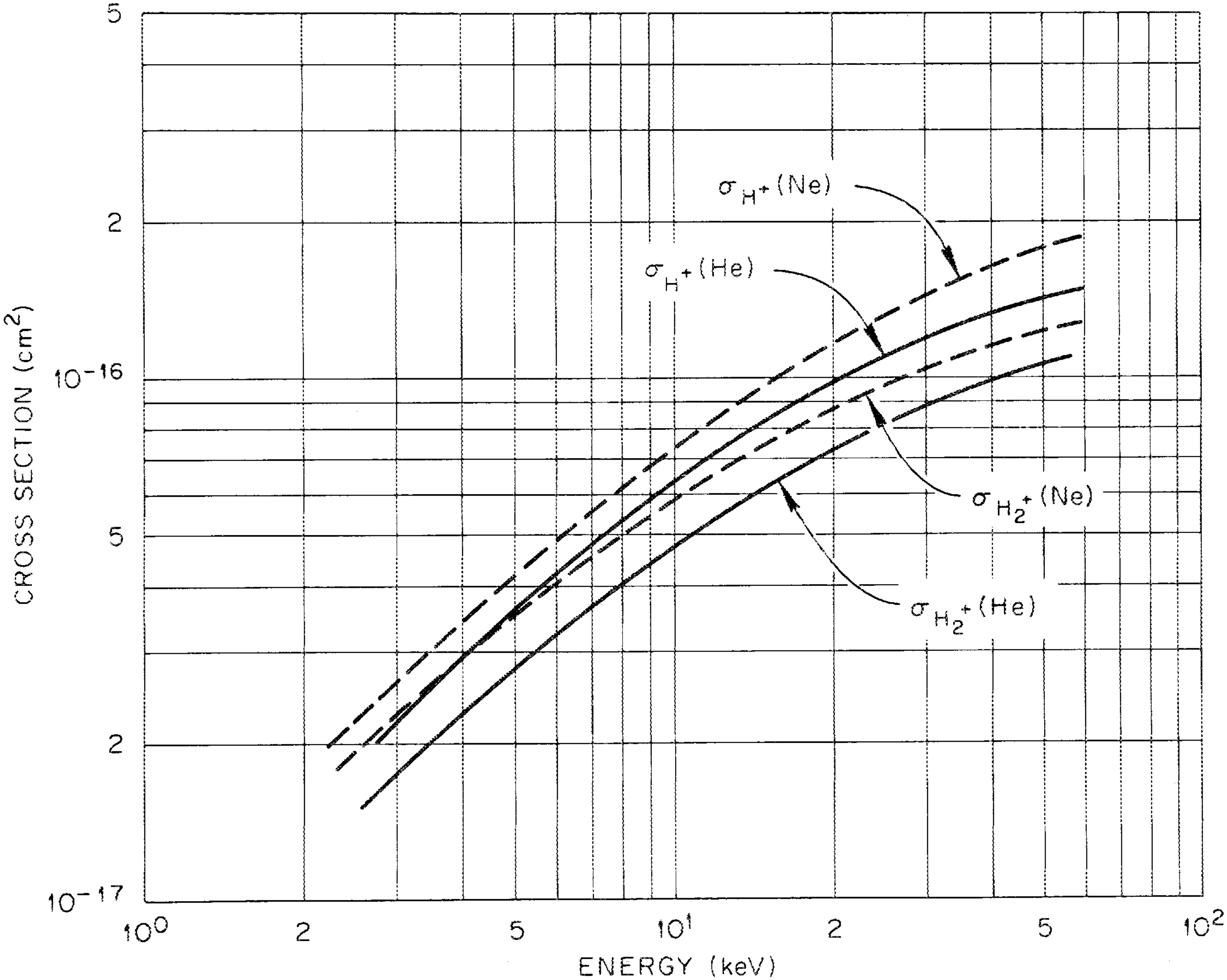
References:

J. F. Williams and D. N. F. Dunbar, Phys. Rev. 149, 62 (1966).

Accuracy:

± 20%.

ORNL-DWG 75-11113R



Cross Sections for the Formation of H^+, H_2^+, and $(H_2^\circ + H^\circ)$ from the Dissociation of H_3^+ in Water Vapor

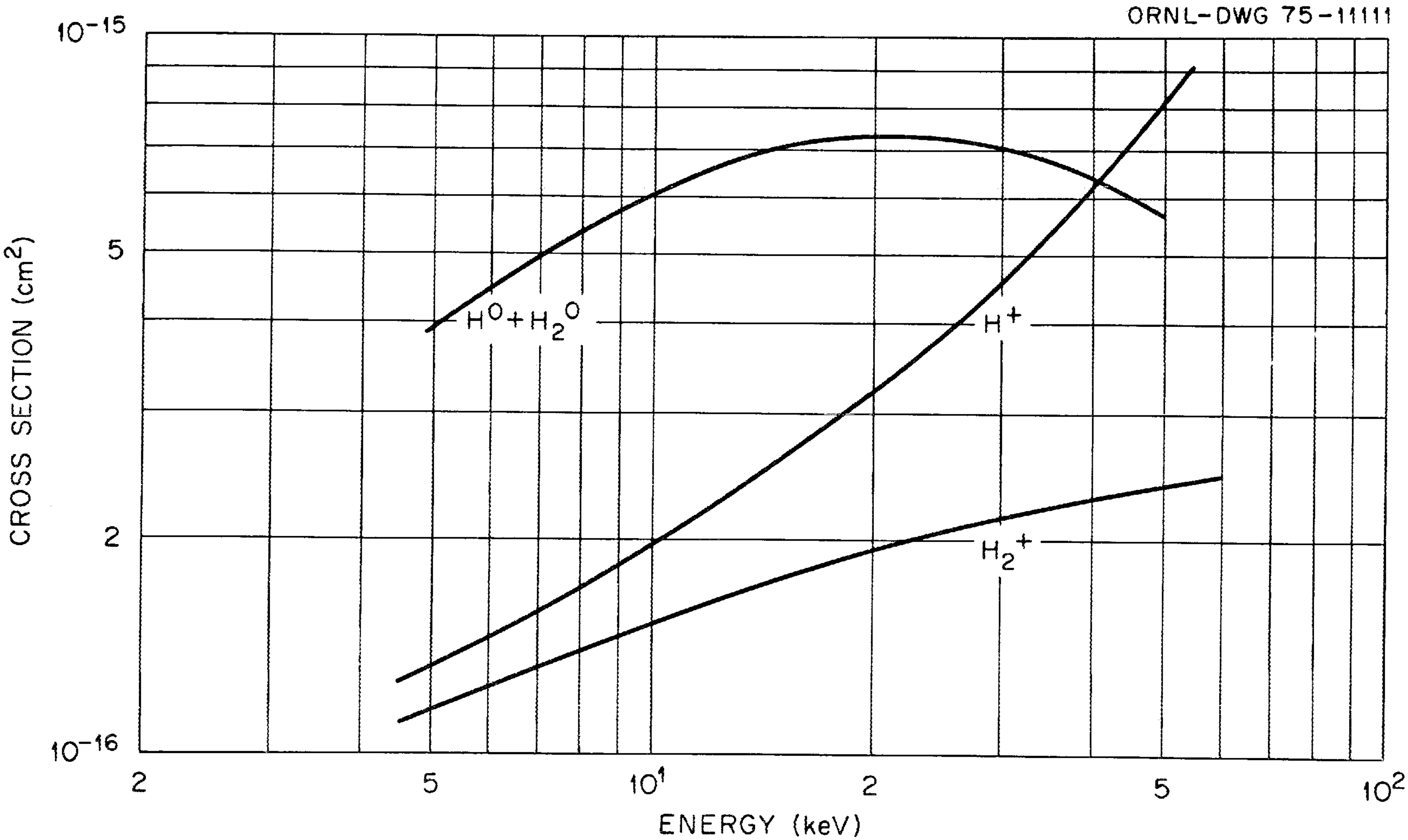
Energy (keV)	Cross Sections (cm^2)		
	$\sigma(H^\circ + H_2^\circ)$	$\sigma(H^+)$	$\sigma(H_2^+)$
4.5 E 00		1.3 E-16	1.1 E-16
6.0 E 00	4.5 E-16	1.4 E-16	1.2 E-16
8.0 E 00	5.4 E-16	1.7 E-16	1.4 E-16
1.0 E 01	6.1 E-16	2.0 E-16	1.5 E-16
2.0 E 01	7.4 E-16	3.2 E-16	1.9 E-16
4.0 E 01	6.4 E-16	6.2 E-16	2.3 E-16
5.0 E 01	5.6 E-16	8.2 E-16	2.4 E-16
6.0 E 01			2.5 E-16

Reference:

R. Dagnac, J. Angles, D. Blanc, D. Molina and R. Pradal, C. R. Acad. Sci. Paris B 273, 460 (1971).

Accuracy:

± 30%.


ORNL-DWG 75-11111
CROSS SECTION (cm^2)
10^{-15}
5
2
10^{-16}
H^0+H_2O
H^+
H_2^+
2
5
10^1
2
5
10^2
ENERGY (keV)

A.3.27

Total and Partial Cross Sections for the Dissociation of HeH^+ in He

Energy (keV)	Cross Sections (cm^2)			
	σ_T	$\sigma(He^+ + H^+)$	$\sigma(He^+ + H^\circ)$	$\sigma(He^\circ + H^+)$
5.0 E 01	2.1 E-16			
1.0 E 02	3.2 E-16			
3.0 E 02	2.2 E-16			
5.0 E 02	1.4 E-16	6.4 E-17	3.4 E-17	1.9 E-17
7.0 E 02	1.1 E-16	5.8 E-17	2.9 E-17	1.5 E-17
9.0 E 02	9.6 E-17	5.3 E-17	2.6 E-17	1.2 E-17
1.0 E 03	9.2 E-17	5.0 E-17	2.4 E-17	1.1 E-17

Energy	$\sigma(He^\circ + H^\circ)$	$\sigma(He^{++} + H^+)$	$\sigma(He^{++} + H^\circ)$
5.0 E 02	2.4 E-17	1.5 E-18	1.3 E-18
7.0 E 02	1.0 E-17	1.6 E-18	1.4 E-18
9.0 E 02	4.3 E-18	1.6 E-18	1.3 E-18
1.0 E 03	3.0 E-18	1.6 E-18	1.3 E-18

References:

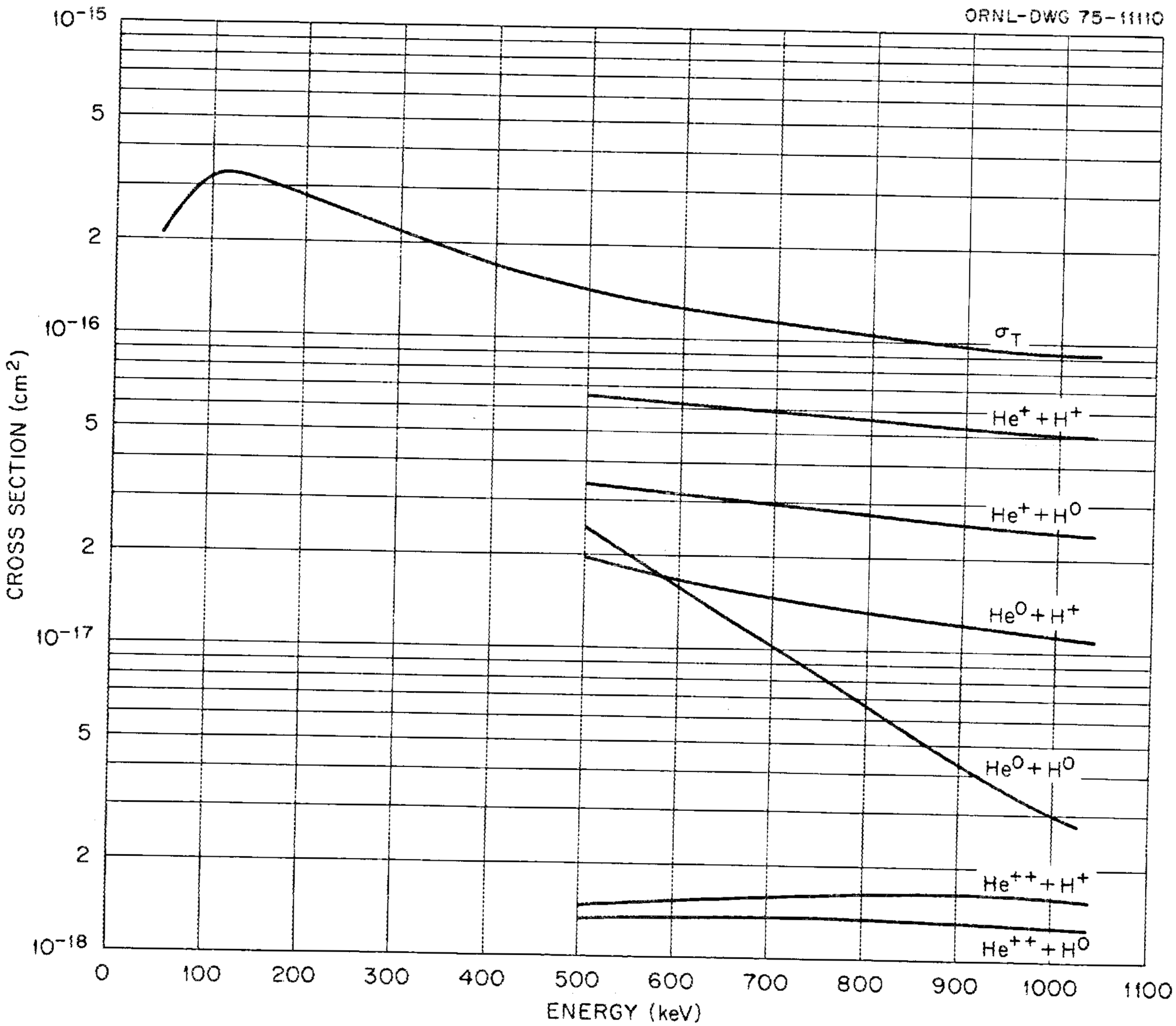
J. W. Stearn, K. H. Berkner, R. V. Pyle, B. P. Briegleb and M. L. Warren, Phys. Rev. A 4, 1960 (1971); W. D. Wilson, Lawrence Radiation Laboratory, Report No. UCRL-16308.

Accuracy:

Estimated to be ±20%.

Note:

σ_T is the total dissociation cross section obtained from the sum of the partial cross sections.


ORNL-DWG 75-11110
CROSS SECTION (cm^2)
ENERGY (keV)
10^{-15}
10^{-16}
10^{-17}
10^{-18}
5
2
0
100
200
300
400
500
600
700
800
900
1000
1100
σ_T
$He^+ + H^+$
$He^+ + H^0$
$He^0 + H^+$
$He^0 + H^0$
$He^{++} + H^+$
$He^{++} + H^0$

Total and Partial Cross Sections for the Dissociation of HeH^+ in H_2

Energy (keV)	Cross Sections (cm^2)			
	σ_T	$\sigma(He^+ + H^+)$	$\sigma(He^+ + H^\circ)$	$\sigma(He^\circ + H^+)$
5.0 E 01	6.9 E-16			
1.0 E 02	5.6 E-16			
3.0 E 02	2.6 E-16			
5.0 E 02	1.4 E-16	5.9 E-17	2.6 E-17	1.6 E-17
7.0 E 02	1.1 E-16	5.6 E-17	2.2 E-17	1.2 E-17
9.0 E 02	9.1 E-17	5.3 E-17	2.0 E-17	1.0 E-17
1.0 E 03	8.6 E-17	4.9 E-17	1.9 E-17	9.4 E-18

Energy	$\sigma(He^\circ + H^\circ)$	$\sigma(He^{++} + H^+)$	$\sigma(He^{++} + H^\circ)$
5.0 E 02	2.8 E-17	1.8 E-18	1.5 E-18
7.0 E 02	1.2 E-17	1.9 E-18	1.3 E-18
9.0 E 02	5.9 E-19	1.8 E-18	1.3 E-18
1.0 E 03	4.3 E-19	1.7 E-18	1.2 E-18

References:

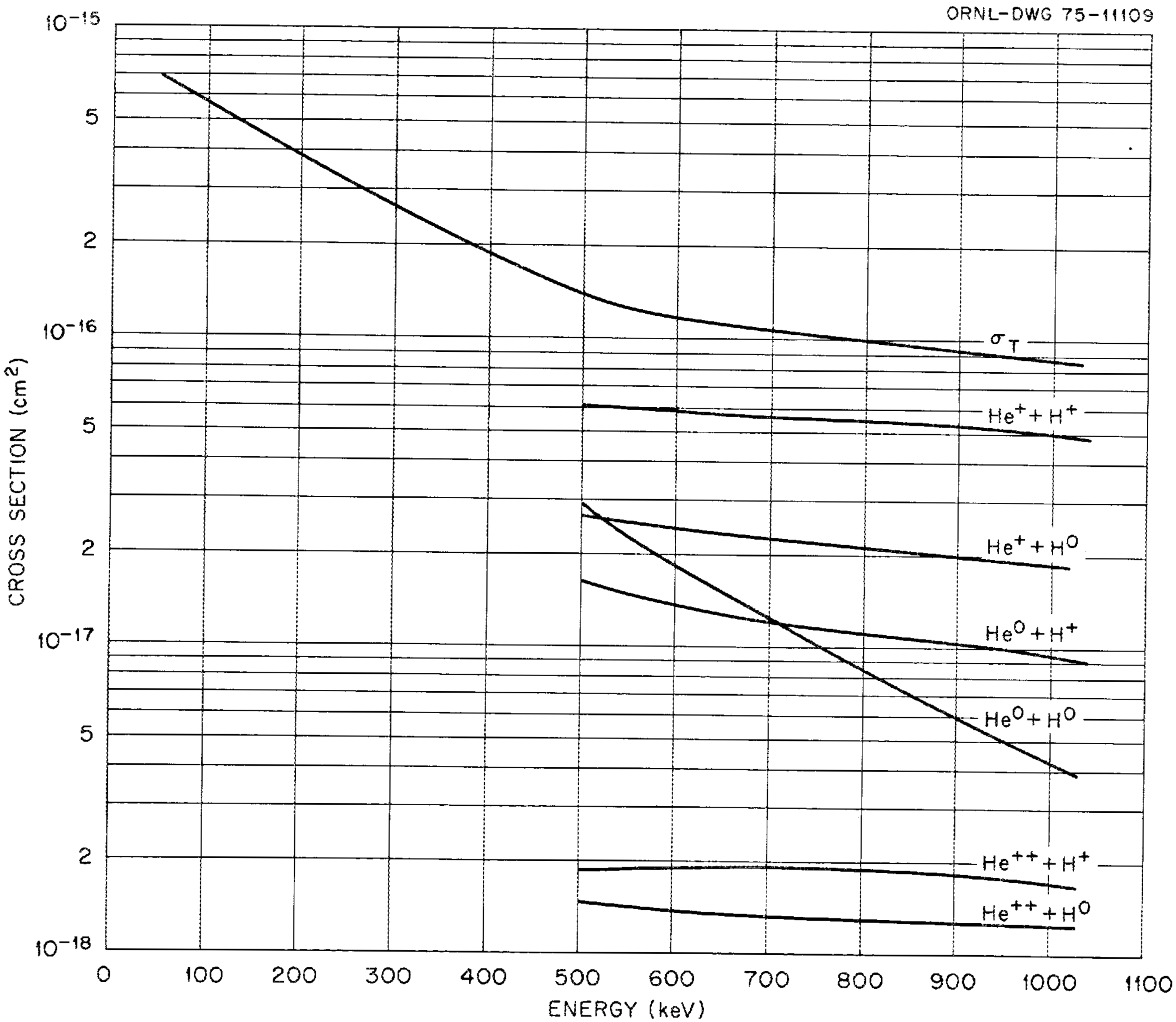
J. W. Stearn, K. H. Berkner, R. V. Pyle, B. P. Briegleb and M. L. Warren, Phys. Rev. A 4, 1960 (1971); W. D. Wilson, Lawrence Radiation Laboratory, Report No. UCRL-16308.

Accuracy:

Estimated to be $\pm$20%.

Note:

σ_T is the total dissociation cross section obtained from the sum of the partial cross sections.


ORNL-DWG 75-11109
CROSS SECTION (cm²)
ENERGY (keV)
10⁻¹⁵
5
2
10⁻¹⁶
5
2
10⁻¹⁷
5
2
10⁻¹⁸
0
100
200
300
400
500
600
700
800
900
1000
1100
σT
He⁺ + H⁺
He⁺ + H⁰
He⁰ + H⁺
He⁰ + H⁰
He⁺⁺ + H⁺
He⁺⁺ + H⁰

(Continuations)

Cross Sections for the Conversion of Fast H_2^+ Ions into

Protons in Passage Through H_2 and H

Notes:

(1) The proton production cross sections is the sum of the cross sections for the following reactions: $H_2^+ \rightarrow H^+ + H$ and $2(H_2^+ \rightarrow H^+ + H^+)$.

(2) The discrepancies in the cross sections measured by different observers, particularly at the lower impact energies, probably arise mainly through the use of H_2^+ beams having different vibrational energies.

(3) For H_2 target only two measurements have been made above 1 MeV - at 3 and 20 MeV.

A.4 Electron Capture Cross Sections

Electron Capture Cross Sections for H^-, H° and H^+ Passing Through Atomic Hydrogen

Energy (keV)	Cross Sections (cm^2)		
	σ_{-10}	σ_{0-1}	σ_{10}
	$H^- + H^\circ \rightarrow H^\circ + H^-$	$H^\circ + H^\circ \rightarrow H^- + H^+$	$H^+ + H^\circ \rightarrow H + H^+$
2.0 E-03			5.6 E-15
5.0 E-03			5.2 E-15
7.0 E-03			5.0 E-15
1.0 E-02			4.8 E-15
3.0 E-02		3.0 E-18	4.1 E-15
5.0 E-02	8.2 E-16	5.9 E-18	3.7 E-15
7.0 E-02	7.7 E-16	9.2 E-18	3.4 E-15
1.0 E-01	7.3 E-16	1.3 E-17	3.2 E-15
3.0 E-01	5.9 E-16	1.0 E-17	2.4 E-15
5.0 E-01	5.1 E-16	3.6 E-18	2.1 E-15
7.0 E-01	4.6 E-16		1.9 E-15
1.0 E 00	4.1 E-16		1.7 E-15
3.0 E 00	2.6 E-16		1.3 E-15
5.0 E 00	1.5 E-16		1.1 E-15
7.0 E 00	1.0 E-16		9.6 E-16
1.0 E 01			8.3 E-16
3.0 E 01			4.0 E-16
5.0 E 01			1.1 E-16
7.0 E 01			4.2 E-17
1.0 E 02			1.4 E-17
2.2 E 02			5.4 E-19

References:

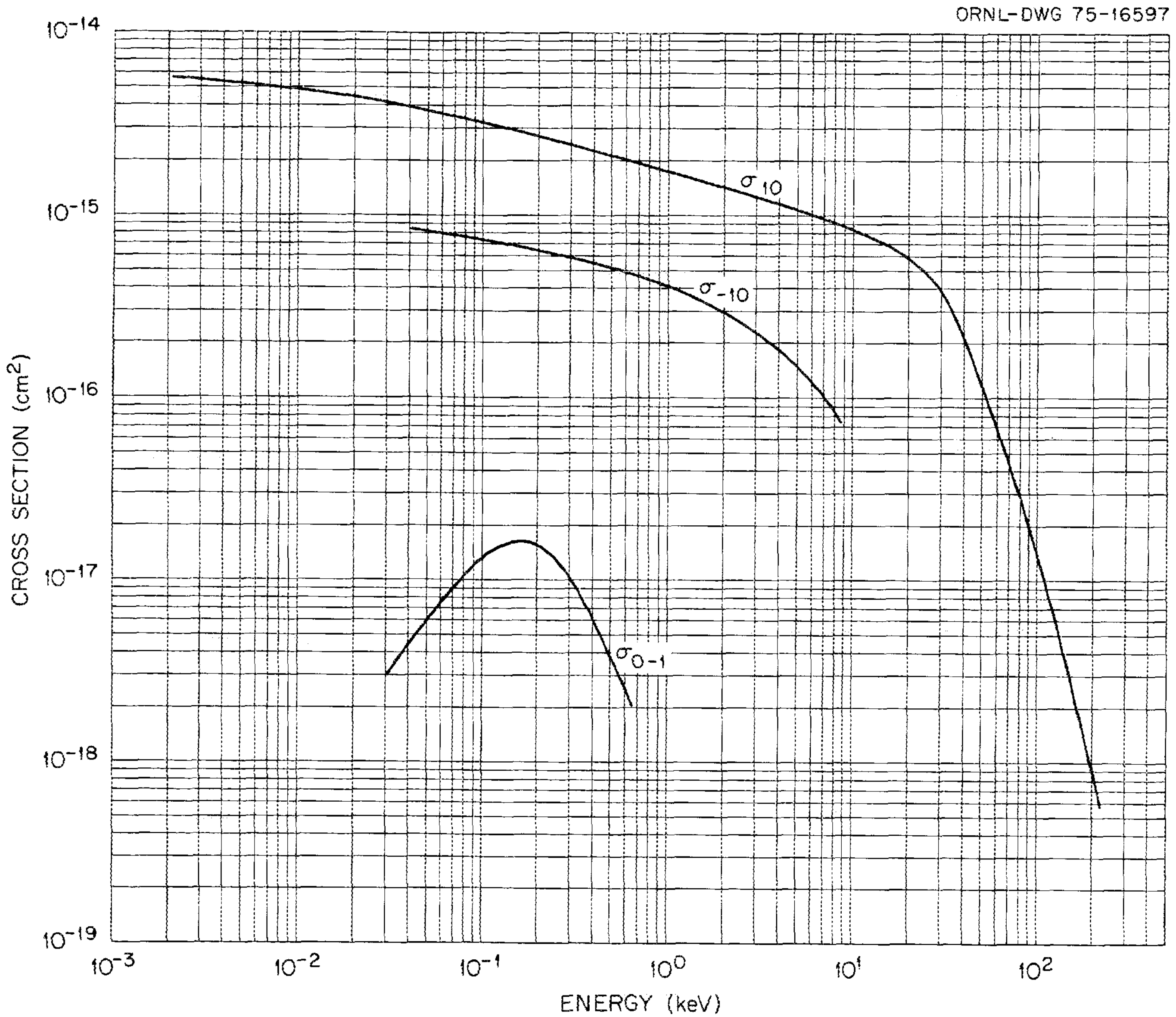
$H^- + H$: D. G. Hummer, R. F. Stebbings, W. L. Fite, L. M. Branscomb, Phys. Rev. 119, 668 (1960).

$H^\circ + H^\circ$: G. W. McClure, Phys. Rev. 166, 22 (1968).

$H^+ + H^\circ$: V. A. Belyaev, B. D. Brezhnev, and E. M. Erastov, Sov. Phys.-JETP 25, 777 (1967)); G. W. McClure, Phys. Rev. 148, 47 (1966); W. L. Fite, A. C. H. Smith and R. F. Stebbings, Proc. Roy. Soc. (London) A268, 527 (1962); W. L. Fite, R. F. Stebbings, D. G. Hummer, and R. T. Brackman, Phys. Rev. 119, 663 (1960); A. B. Whittkower, G. Ryding, and H. B. Gilbody, Proc. Phys. Soc. 89, 541 (1966).

Accuracy:

$\pm$ 20%.


ORNL-DWG 75-16597
CROSS SECTION (cm^2)
ENERGY (keV)
10^{-14}
10^{-15}
10^{-16}
10^{-17}
10^{-18}
10^{-19}
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
σ_{10}
σ_{-10}
σ_{0-1}

A.4.3

Electron Capture Cross Sections for H^+ and H° Passing Through H_2

Energy (keV)	Cross Sections (cm^2)		
	σ_{10}	σ_{1-1}	σ_{0-1}
	$H^+ + H_2 \rightarrow H^\circ$	$H^+ + H_2 \rightarrow H^-$	$H^\circ + H_2 \rightarrow H^-$
5.0 E-02	2.7 E-17		
1.0 E-01	4.1 E-17		
2.0 E-01	7.3 E-17	1.2 E-20	
5.0 E-01	2.3 E-16	4.4 E-20	
1.0 E 00	5.2 E-16	1.2 E-19	
2.0 E 00	8.5 E-16	3.8 E-19	4.5 E-18
5.0 E 00	8.6 E-16	1.6 E-18	2.1 E-17
1.0 E 01	8.5 E-16	4.7 E-18	2.2 E-17
2.0 E 01	6.0 E-16	1.0 E-17	1.9 E-17
4.0 E 01	2.6 E-16	2.5 E-18	9.5 E-18
6.0 E 01	1.1 E-16	2.2 E-19	5.3 E-18
1.0 E 02	2.8 E-17	1.0 E-20	2.1 E-18
2.0 E 02	1.8 E-18	1.2 E-22	1.4 E-19
4.0 E 02	5.7 E-20	1.3 E-24	6.0 E-21
6.0 E 02	7.2 E-21	2.4 E-26	
1.0 E 03	4.6 E-22	2.6 E-28	
2.0 E 03	1.2 E-23		
3.0 E 03	2.4 E-24		

References:

$H^+ + H_2 \rightarrow H^\circ$: V. V. Afrosimov, G. A. Leǐko, Yu. A. Mamaev, and M. N. Panov, Sov. Phys.-JETP 29, 648 (1969); J. Abbe and J. Adloff, Bull. Soc. Chim. France 6, 1212 (1964); C. F. Barnett and H. K. Reynolds, Phys. Rev. 109, 355 (1958); K. H. Berkner, R. V. Pyle, and J. W. Stearns, Nuc. Fusion 10, 145 (1970); W. H. Cramer, J. Chem. Phys. 35, 836 (1961); R. Curran, T. M. Donahue, and W. H. Kasner, Phys. Rev. 114, 490 (1959); F. J. de Heer, J. Schotten and H. Moustafa, Physica 32, 1766 (1966); J. Desesquelles, G. D. Cao, and M. Dufay Compt. Rend. 262B, 1329 (1966); Ya. M. Fogel, L. I. Krupnik, and B. G. Safronov, Sov. Phys.-JETP 1, 415 (1955); Yu. S. Gordeev and M. N. Panov, Sov. Phys.-Tech. Phys. 9, 656 (1964); O. Hollricher, Z. Physik 187, 41 (1965); D. W. Koopman, Phys. Rev. 154, 79 (1967); F. L. Ribe, Phys. Rev. 83, 1217 (1951); P. M. Stier and C. F. Barnett, Phys. Rev. 103, 896 (1956); U. Schryber, Hel. Phy. Act. A40, 1023 (1967); F. Schwirzke, Z. Physik 157, 510 (1960); L. H. Welsh, K. H. Berkner, S. N. Kaplan, and R. V. Pyle, Phys. Rev. 158, 85 (1967); J. B. H. Stedeford and J. B. Hasted, Proc. Roy Soc. (London) A227, 466 (1955); J. F. Williams, Phys. Rev. 179, 240 (1969); L. H. Toburen, M. Y. Nakai, and R. A. Langley, Phys. Rev. 171, 114 (1968).

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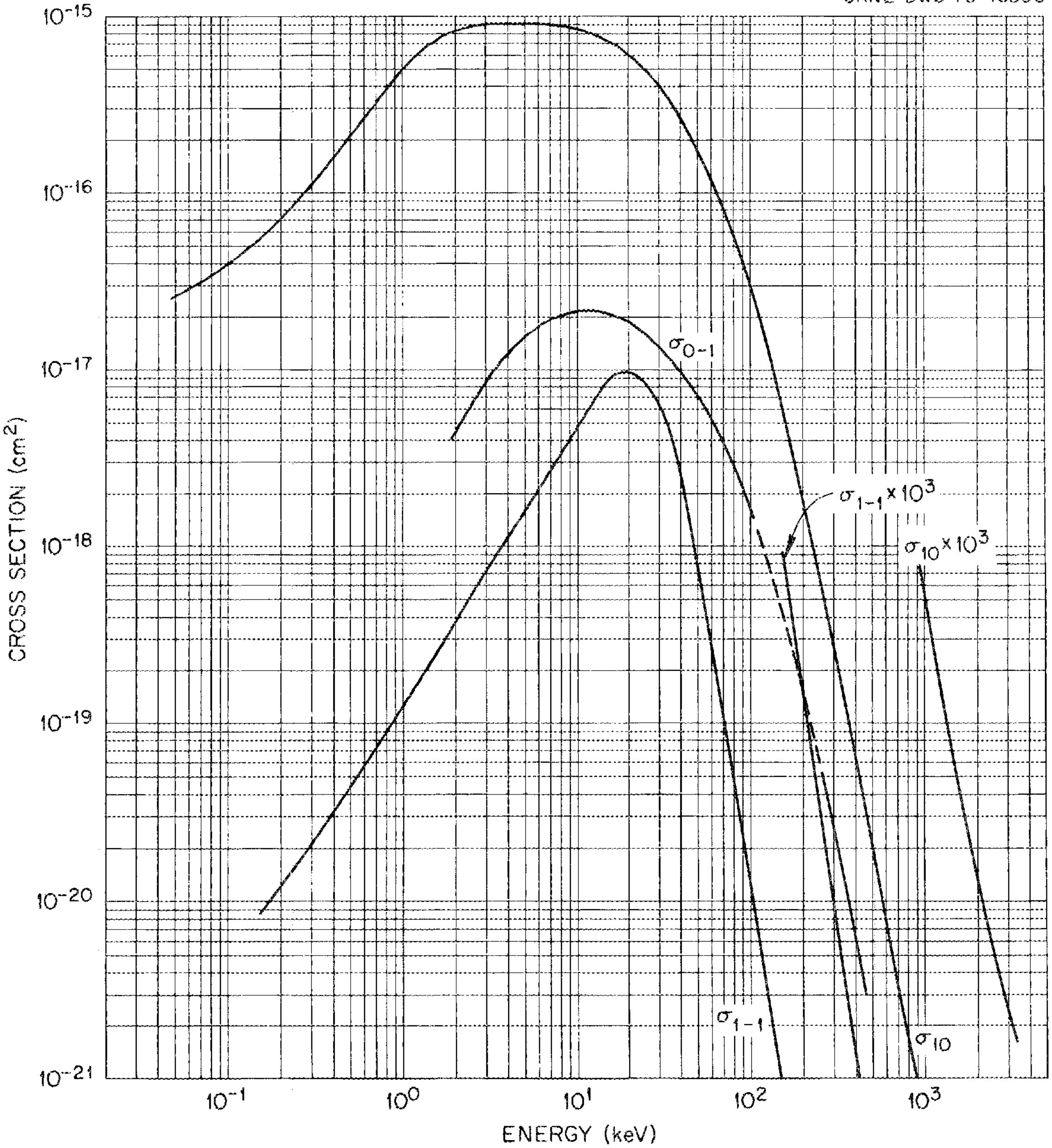
ORNL-DWG 75-16596



Electron Capture Cross Sections for H^+ and H°

Passing Through Helium

Energy (keV)	Cross Sections (cm^2)		
	σ_{10} $H^+ + He \rightarrow H^\circ$	σ_{1-1} $H^+ + He \rightarrow H^-$	σ_{0-1} $H^\circ + He \rightarrow H^-$
2.0 E-01	1.5 E-18		
5.0 E-01	2.9 E-18		
1.0 E 00	5.2 E-18	1.6 E-21	
2.0 E 00	1.0 E-17	4.7 E-21	5.4 E-19
5.0 E 00	3.1 E-17	2.3 E-20	2.3 E-18
1.0 E 01	1.0 E-16	1.0 E-19	4.8 E-18
2.0 E 01	2.1 E-16	3.5 E-19	6.6 E-18
5.0 E 01	1.1 E-16	5.0 E-19	4.7 E-18
1.0 E 02	3.0 E-17	3.3 E-20	1.3 E-18
2.0 E 02	3.3 E-18	1.0 E-21	2.3 E-19
5.0 E 02	8.3 E-20		1.0 E-20
1.0 E 03	3.6 E-21		
2.0 E 03	1.1 E-22		
5.0 E 03	8.5 E-25		
1.0 E 04	1.4 E-26		

References:

$H^+ + He \rightarrow H^\circ$: V. V. Afrosimov, Yu. A. Mamaev, M. N. Panov, and N. V. Fedorenko, Sov. Phys.-Tech. Phys. 14, 109 (1969); S. K. Allison, Rev. Mod. Phys. 30, 1137 (1958); C. F. Barnett and H. K. Reynolds, Phys. Rev. 109, 355 (1958); K. H. Berkner, S. N. Kaplan, G. A. Paulikas, and R. V. Pyle, Phys. Rev. 140, A729 (1965); L. Colli, F. Cristofori, G. E. Frigerio, and P. G. Stone, Phys. Letters 3, 62 (1962); F. J. de Heer, J. Schutten, and H. Moustafa, Physica 32, 1766 (1966); J. B. H. Stedeford and J. B. Hasted, Proc. Roy. Soc. (London) 227A, 466 (1954); J. Desesquelles, G. D. Cao, and M. Dufay, Compt. Rend. 262B, 1329 (1966); U. Schryber, Hel. Phy. Act. A40, 1023 (1962); P. M. Stier and C. F. Barnett, Phys. Rev. 103, 896 (1956); L. H. Toburen and M. Y. Nakai, Phys. Rev. 177, 191 (1969); L. M. Welsh, K. H. Berkner, S. N. Kaplan, and R. V. Pyle, Phys. Rev. 158, 85 (1967); J. F. Williams, Phys. Rev. 157, 97 (1967).

$H^+ + He \rightarrow H^-$: V. F. Kozlov and S. A. Bonder, Sov. Phys.-JETP 23, 195 (1966); Ya. M. Fogel, Sov. Phys.-Usp. 3, 390 (1960); U. Schryber, Hel. Phy. Act. A40, 1023 (1967); L. H. Toburen and M. Y. Nakai, Phys. Rev. 177, 191 (1969); J. F. Williams, Phys. Rev. 150, 7 (1966).

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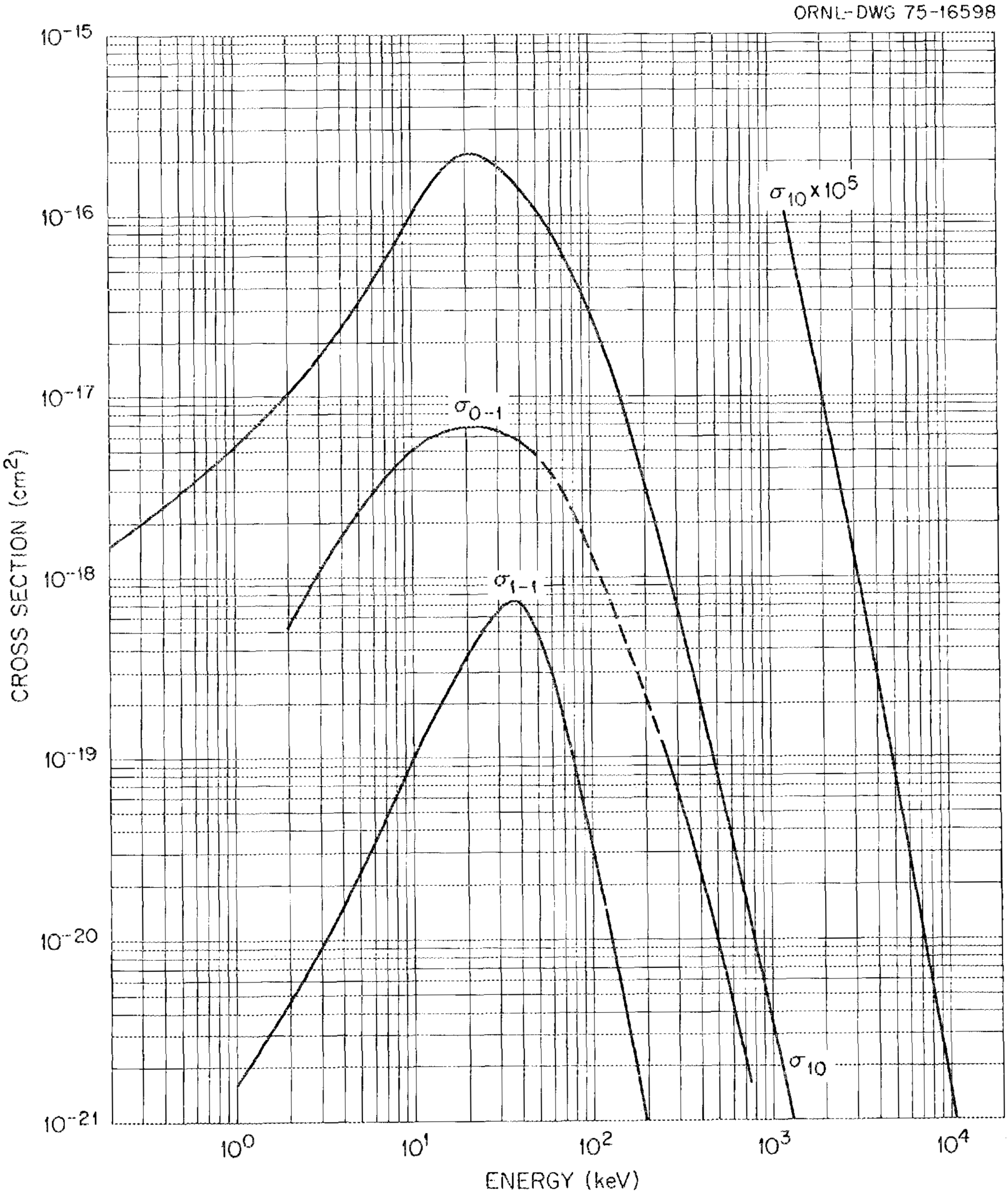

ORNL-DWG 75-16598
10^{-15}
10^{-16}
10^{-17}
10^{-18}
10^{-19}
10^{-20}
10^{-21}
CROSS SECTION (cm^2)
$\sigma_{10} \times 10^5$
σ_{0-1}
σ_{1-1}
σ_{10}
10^0
10^1
10^2
10^3
10^4
ENERGY (keV)

Electron Capture Cross Sections for H^+ and H° Passing Through N_2

Energy (keV)	Cross Sections (cm^2)		
	σ_{10}	σ_{0-1}	σ_{1-1}
	$H^+ + N_2 \rightarrow H^\circ$	$H^\circ + N_2 \rightarrow H^-$	$H^+ + N_2 \rightarrow H^-$
5.0 E-02	3.3 E-17		
7.0 E-02	4.1 E-17		
1.0 E-01	5.5 E-17		
2.0 E-01	1.0 E-16		
4.0 E-01	2.1 E-16		
7.0 E-01	3.8 E-16		
1.0 E 00	5.7 E-16		
2.0 E 00	1.0 E-15		
4.0 E 00	1.2 E-15		
7.0 E 00	1.1 E-15		
1.0 E 01	1.1 E-15		6.9 E-18
2.0 E 01	7.8 E-16		4.9 E-18
4.0 E 01	4.0 E-16	1.5 E-17	1.8 E-18
7.0 E 01	1.9 E-16	2.3 E-17	4.9 E-19
1.0 E 02	1.0 E-16	2.9 E-17	1.7 E-19
2.0 E 02	1.5 E-17	2.0 E-17	5.0 E-21
4.0 E 02	1.2 E-18	8.5 E-18	7.8 E-23
7.0 E 02	1.8 E-19	5.4 E-18	3.4 E-24
1.0 E 03	5.9 E-20	1.8 E-18	6.5 E-25
2.0 E 03	6.5 E-21	4.4 E-19	
4.0 E 03	4.1 E-22	8.0 E-20	
7.0 E 03	2.7 E-23	1.2 E-20	
1.0 E 04	4.5 E-24	3.0 E-21	
2.0 E 04	1.5 E-25		
4.0 E 04	5.0 E-27		

References:

$H^+ + N_2 \rightarrow H^\circ$: E. Acerbi, M. Castiglione, G. Dutto, F. Resmini, G. Succi, and G. Taglioferri, Nuovo Cimento 50B, 176 (1967); S. K. Allison, Rev. Mod. Phys. 30, 1137 (1958); C. F. Barnett and H. K. Reynolds, Phys. Rev. 109, 355 (1958); F. J. de Heer, J. Schutten, and H. Moustafa, Physica 32, 1766 (1966); M. Dufay, J. Desquelles, M. Druetta, and M. Eidelsberg, Ann. Geophys. 22, 614 (1966); H. B. Gilbody and J. B. Hasted, Proc. Roy. Soc. 238, 334 (1956); D. W. Koopman, Phys. Rev. 166, 57 (1968); R. J. McNeal and D. C. Clark, J. Geophys. Res. 74, 5065 (1969); U. Schryber, Helv. Phys. Acta 40, 1023 (1967); P. M. Stier and C. F. Barnett, Phys. Rev. 103, 896 (1956); L. H. Toburen, M. Y. Nakai, and R. A. Langley, Phys. Rev. 171, 114 (1968); M. Welsh, K. H. Berkner, S. N. Kaplan, and R. V. Pyle, Phys. Rev. 158, 85 (1967).

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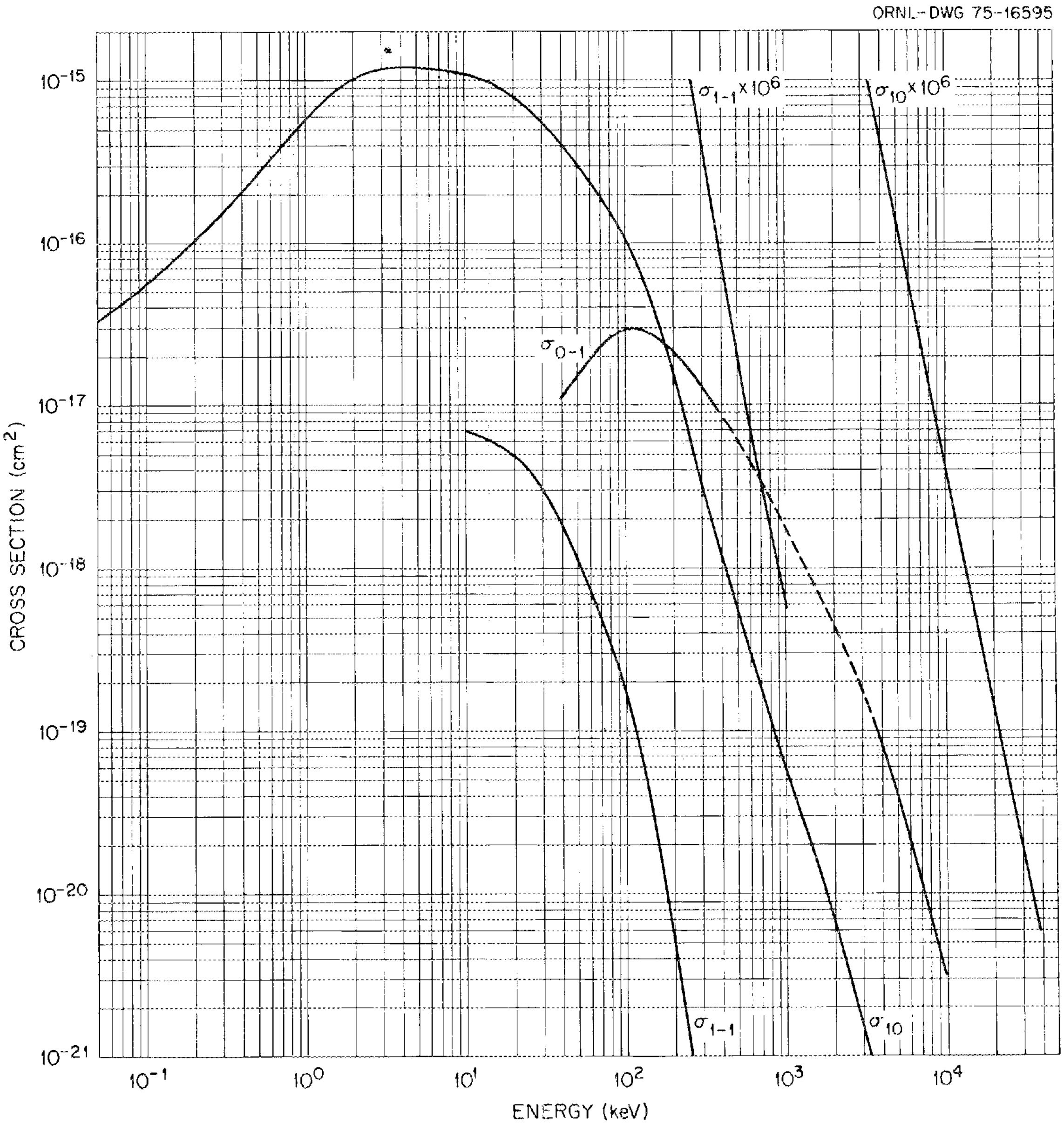
ORNL-DWG 75-16595
CROSS SECTION (cm²)
ENERGY (keV)
10⁻¹⁵
10⁻¹⁶
10⁻¹⁷
10⁻¹⁸
10⁻¹⁹
10⁻²⁰
10⁻²¹
10⁻¹
10⁰
10¹
10²
10³
10⁴
σ1-1 x 10⁶
σ10 x 10⁶
σ0-1
σ1-1
σ10

Electron Capture Cross Sections for H^+ and H° Passing Through O and O_2

Energy (keV)	Cross Sections (cm^2).			
	$\sigma_{10}(O_2)$	$\sigma_{10}(O)$	σ_{0-1}	σ_{1-1}
	$H^+ + O_2 \rightarrow H^\circ$	$H^+ + O \rightarrow H^-$	$H^\circ + O_2 \rightarrow H^-$	$H^+ + O_2 \rightarrow H^-$
5.0 E-02	1.4 E-15			
7.0 E-02	1.6 E-15	9.8 E-16		
1.0 E-01	1.8 E-15	9.5 E-16		
2.0 E-01	1.8 E-15	9.1 E-16		
4.0 E-01	1.5 E-15	8.7 E-16		
7.0 E-01	1.3 E-15	8.5 E-16		
1.0 E 00	1.1 E-15	8.3 E-16		
2.0 E 00	9.9 E-16	7.9 E-16		
4.0 E 00	9.5 E-16	7.6 E-16	1.8 E-17	
7.0 E 00	8.6 E-16	7.1 E-16	2.2 E-17	
1.0 E 01	7.9 E-16	6.9 E-16	2.1 E-17	5.7 E-18
2.0 E 01	5.7 E-16		1.6 E-17	4.1 E-18
4.0 E 01	3.4 E-16			
7.0 E 01	1.8 E-16			
1.0 E 02	1.1 E-16			
2.0 E 02	2.1 E-17			
4.0 E 02	1.6 E-18			
7.0 E 02	2.4 E-19			
1.0 E 03	7.5 E-20			
2.0 E 03	6.3 E-21			
4.0 E 03	5.0 E-22			
7.0 E 03	3.5 E-23			
1.0 E 04	6.5 E-24			
2.0 E 04	2.3 E-25			
4.0 E 04	1.1 E-26			

References:

$H^+ + O_2 \rightarrow H^\circ$: E. Acerbi, M. Castiglioni, G. Dutto, F. Resmini, G. Succi, and G. Taglioferri, Nuovo Cimento 50B, 176 (1967); S. K. Allison, Rev. Mod. Phys. 30, 1137 (1958); F. J. de Heer, J. Schutten, and H. Moustafa, Physica 32, 1766 (1966); J. Desquelles, G. D. Cao, and M. Dufay Compt. Rend. 262B, 1329 (1966); M. Dufay, Ann. Geophys. 22, 641 (1966); D. W. Koopman, Phys. Rev. 166, 57 (1968); L. H. Toburen M. Y. Nakai, and R. A. Langley, Phys. Rev. 171, 114 (1968); U. Schryber, Helv. Phys. Acta 40, 1023 (1967); R. F. Stebbings, A. C. H. Smith, and H. Ehrhardt, J. Geophys. Res. 69, 2349 (1964); P. M. Stier and C. F. Barnett, Phys. Rev. 103, 896 (1956).

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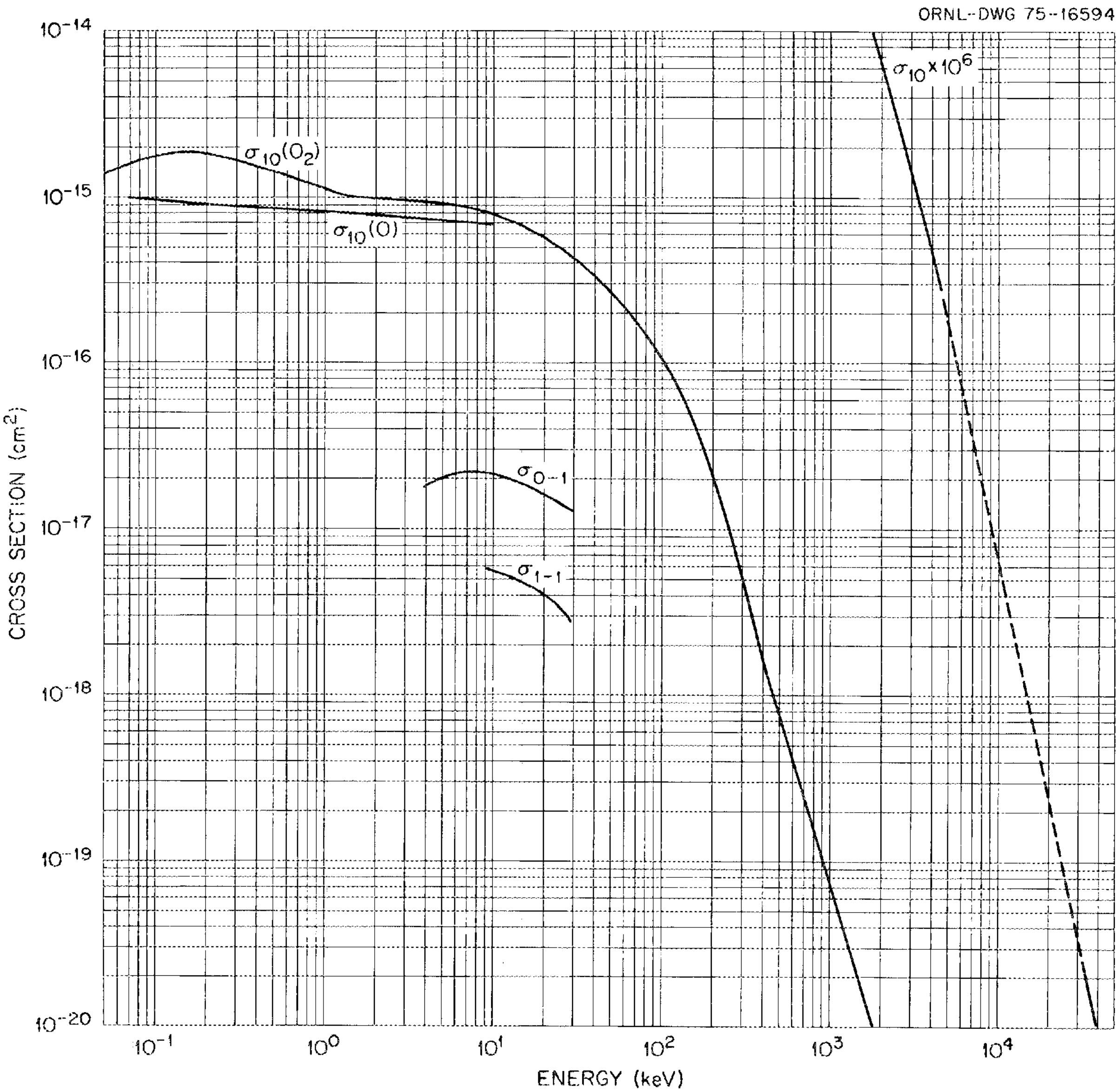


ORNL-DWG 75-16594
CROSS SECTION (cm²)
ENERGY (keV)
σ10 x 10⁶
σ10(O2)
σ10(O)
σ0-1
σ1-1
10⁻¹⁴
10⁻¹⁵
10⁻¹⁶
10⁻¹⁷
10⁻¹⁸
10⁻¹⁹
10⁻²⁰
10⁻¹
10⁰
10¹
10²
10³
10⁴

Electron Capture Cross Sections for H^+ and H° Passing Through Ne Gas

Energy (keV)	Cross Sections (cm^2)		
	σ_{10}	σ_{0-1}	σ_{1-1}
	$H^+ + Ne \rightarrow H^\circ$	$H^\circ + Ne \rightarrow H^-$	$H^+ + Ne \rightarrow H^-$
4.0 E-01	8.6 E-18		
7.0 E-01	2.1 E-17		
1.0 E 00	3.5 E-17		
2.0 E 00	8.8 E-17	1.7 E-18	4.3 E-20
4.0 E 00	1.8 E-16	6.0 E-18	1.7 E-19
7.0 E 00	2.8 E-16	1.3 E-17	4.4 E-19
1.0 E 01	3.0 E-16	1.5 E-17	7.2 E-19
2.0 E 01	2.3 E-16	1.1 E-17	6.0 E-19
4.0 E 01	1.3 E-16	4.5 E-18	1.5 E-19
7.0 E 01	7.6 E-17		
1.0 E 02	4.7 E-17		
2.0 E 02	1.4 E-17		
4.0 E 02	2.1 E-18		
7.0 E 02	2.6 E-19		
1.0 E 03	5.0 E-20		
2.0 E 03	4.2 E-21		
4.0 E 03	3.2 E-22		

References:

$H^+ + Ne \rightarrow H^\circ$: V. V. Afrosimov, R. N. Il'in, and E. S. Solov'ev, Sov. Phys.-Tech. Phys. 5, 661 (1960); S. K. Allison, Rev. Mod. Phys. 30, 1137 (1958); F. J. de Heer, J. Schutten, and H. Moustafa, Physica 32, 1766 (1966); J. B. H. Stedeford and J. B. Hasted, Proc. Roy. Soc. (London) A227, 466 (1955); P. M. Stier and C. F. Barnett, Phys. Rev. 103, 896 (1956); U. Schryber, Helv. Phys. Acta 40, 1023 (1967); J. F. Williams and D. N. F. Dunbar, Phys. Rev. 149, 62 (1966).

$H^\circ + Ne \rightarrow H^-$: S. K. Allison, Rev. Mod. Phys. 30, 1137 (1958); P. M. Stier and C. F. Barnett, Phys. Rev. 103, 896 (1956); J. F. Williams, Phys. Rev. 153, 117 (1967).

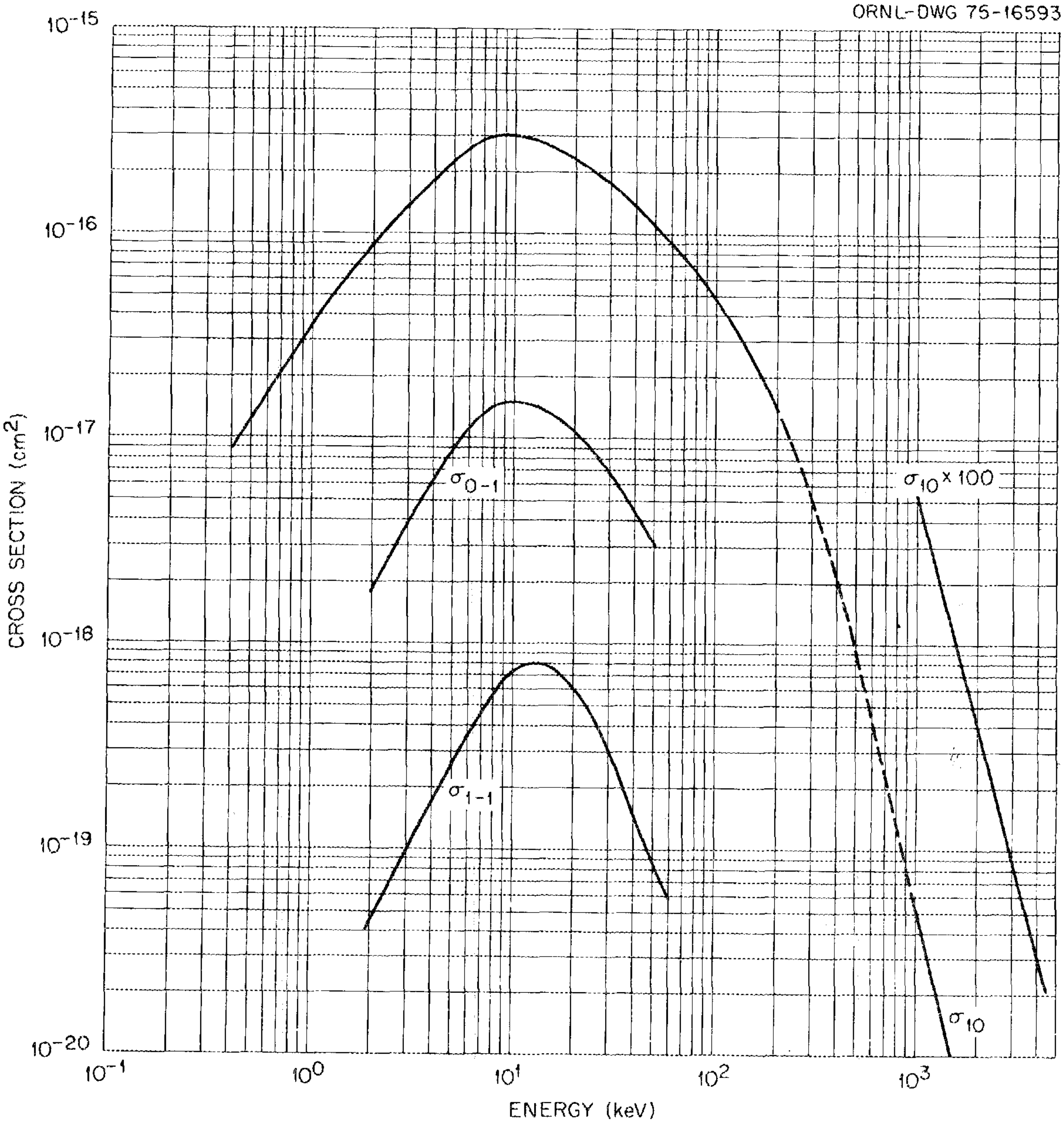
$H^+ + Ne \rightarrow H^-$: S. K. Allison, Rev. Mod. Phys. 30, 1137 (1958); V. F. Kozlow and S. A. Bondar, Sov. Phys.-JETP 23, 195 (1966); Ya. M. Fogel, R. V. Mitin, V. F. Kozlow, and N. D. Romashko, Sov. Phys.-JETP 8, 390 (1959); J. F. Williams, Phys. Rev. 150, 7 (1966).

Accuracy:

σ_{10} - ± 20% σ_{0-1} - ± 25% σ_{1-1} = unreliable data.

Notes:

σ_{10} has not been measured between 200 keV and 1 MeV.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CROSS SECTION (cm²)
ENERGY (keV)
10⁻¹⁵
10⁻¹⁶
10⁻¹⁷
10⁻¹⁸
10⁻¹⁹
10⁻²⁰
10⁻¹
10⁰
10¹
10²
10³
σ0-1
σ1-1
σ10 x 100
σ10

Electron Capture Cross Sections for H^+ and H° Passing Through Ar

Energy (keV)	Cross Sections (cm^2)		
	σ_{10}	σ_{1-1}	σ_{0-1}
	$H^+ + Ar \rightarrow H^\circ$	$H^+ + Ar \rightarrow H^-$	$H^\circ + Ar \rightarrow H^-$
7.0 E-02	3.2 E-17		
1.0 E-01	5.8 E-17		
2.0 E-01	1.6 E-16		
4.0 E-01	4.0 E-16		
7.0 E-01	7.2 E-16		
1.0 E 00	9.3 E-16		
2.0 E 00	1.3 E-15	8.7 E-19	4.4 E-17
4.0 E 00	1.5 E-15	2.2 E-18	3.6 E-17
7.0 E 00	1.4 E-15	2.3 E-18	2.7 E-17
1.0 E 01	1.2 E-15	1.9 E-18	2.2 E-17
2.0 E 01	8.2 E-16	4.2 E-18	1.2 E-17
4.0 E 01	4.6 E-16	3.2 E-18	6.0 E-18
7.0 E 01	2.3 E-16	6.0 E-18	2.5 E-18
1.0 E 02	1.1 E-16	1.1 E-19	1.3 E-18
2.0 E 02	8.8 E-18	1.5 E-21	2.5 E-19
4.0 E 02	6.3 E-19	5.0 E-23	4.6 E-20
7.0 E 02	1.9 E-19	6.4 E-24	8.4 E-21
1.0 E 03	8.0 E-20	1.7 E-24	6.0 E-21
2.0 E 03	1.1 E-20		
4.0 E 03	7.5 E-22		
7.0 E 03	7.9 E-23		
1.0 E 04	1.9 E-23		
2.0 E 04	1.2 E-24		
4.0 E 04	7.2 E-26		

References:

$H^+ + Ar \rightarrow H^\circ$: V. V. Afrosimov, Yu. A. Mamaev, M. N. Panov, V. Uroskevich, Sov. Phys.-Tech. Phys. 12, 512 (1967); V. V. Afrosimov, R. N. Ilin, E. S. Solovév, Sov. Phys.-Tech. Phys. 5, 661 (1960); E. Acerbi, M. Castiglioni, G. Dutto, F. Resmini, G. Succi, and G Tagliaferri, Nuovo Cimento, 50B, 176 (1967); C. F. Barnett and H. K. Reynolds, Phys. Rev. 109, 355 (1958); K. H. Berkner, S. N. Kaplan, G. A. Paulikas, and R. V. Pyle, Phys. Rev. 140, A729 (1965); L. M. Welsh, K. H. Berkner, S. N. Kaplan, N. Selig, and R. V. Pyle, Phys. Rev. 158, 85 (1967); P. M. Stier and C. F. Barnett, Phys. Rev. 103, 896 (1956); Yu. S. Gordeev and M. N. Panov, Sov. Phys.-Tech. Phys. 9, 656 (1964); F. J. de Heer, J. Schutten, and H. Moustafa, Physica 32, 1766 (1966); D. W. Koopman, Phys. Rev. 154, 79 (1967); G. Monnom, Report #EUR-CEA-FC-762 (1975); U. Schryber, Helv. Phys. Acta 40, 1023 (1967); L. H. Toburen, M. Y. Nakai, and R. A. Langley, Phys. Rev. 171, 114 (1968); J. F. Williams and D. N. F. Dunbar, Phys. Rev. 149, 62 (1966); P. M. Stier and C. F. Barnett, Phys. Rev. 103, 896 (1956).

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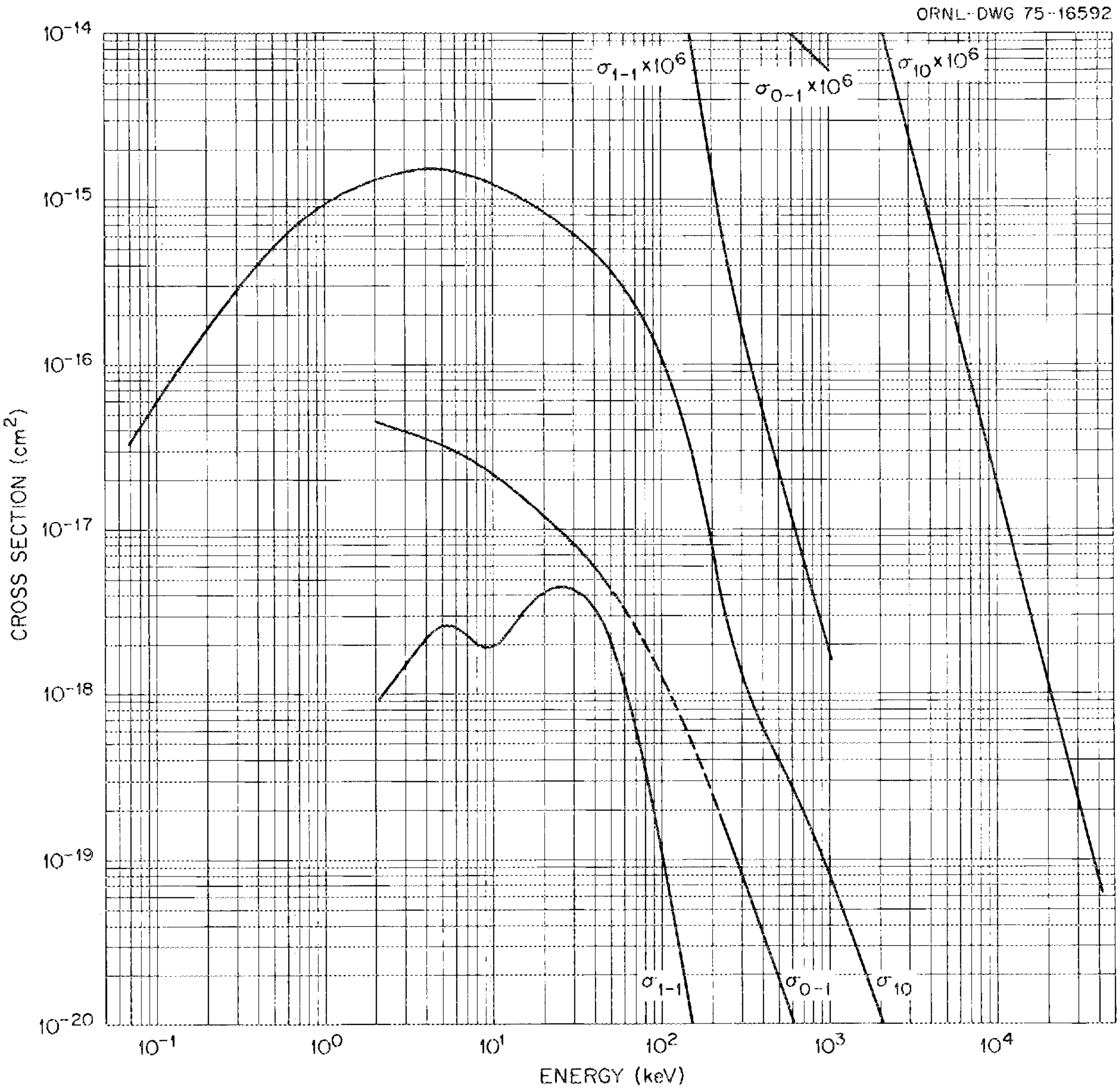
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$\sigma_{1-1} \times 10^6$
$\sigma_{0-1} \times 10^6$
$\sigma_{10} \times 10^6$
σ_{1-1}
σ_{0-1}
σ_{10}
CROSS SECTION (cm^2)
ENERGY (keV)
10^{-14}
10^{-15}
10^{-16}
10^{-17}
10^{-18}
10^{-19}
10^{-20}
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
10^{4}

Electron Capture Cross Sections for H^+ in H_2O and CH_4

Energy (keV)	Cross Sections (cm^2)	
	σ_{10} $H^+ + H_2O \rightarrow H^\circ$	σ_{10} $H^+ + CH_4 \rightarrow H^\circ$
5.0 E-02	3.0 E-15	
7.0 E-02	2.9 E-15	3.8 E-15
1.0 E-01	2.8 E-15	3.8 E-15
2.0 E-01	2.6 E-15	3.6 E-15
5.0 E-01	2.3 E-15	3.1 E-15
7.5 E-01	2.2 E-15	2.8 E-15
1.0 E 00	2.1 E-15	2.7 E-15
2.0 E 00	1.8 E-15	2.2 E-15
5.0 E 00	1.4 E-15	1.7 E-15
7.5 E 00	1.2 E-15	1.5 E-15
1.0 E 01	1.1 E-15	1.3 E-15
2.0 E 01	7.6 E-16	9.3 E-16
5.0 E 01	3.5 E-16	4.5 E-16
7.5 E 01	1.8 E-16	2.4 E-16
1.0 E 02	9.0 E-17	1.0 E-16
2.0 E 02	1.1 E-17	8.0 E-18
5.0 E 02	4.3 E-19	2.9 E-19
7.5 E 02	9.2 E-20	7.4 E-20
1.0 E 03	3.4 E-20	3.0 E-20
2.5 E 03	1.6 E-21	1.1 E-21

References:

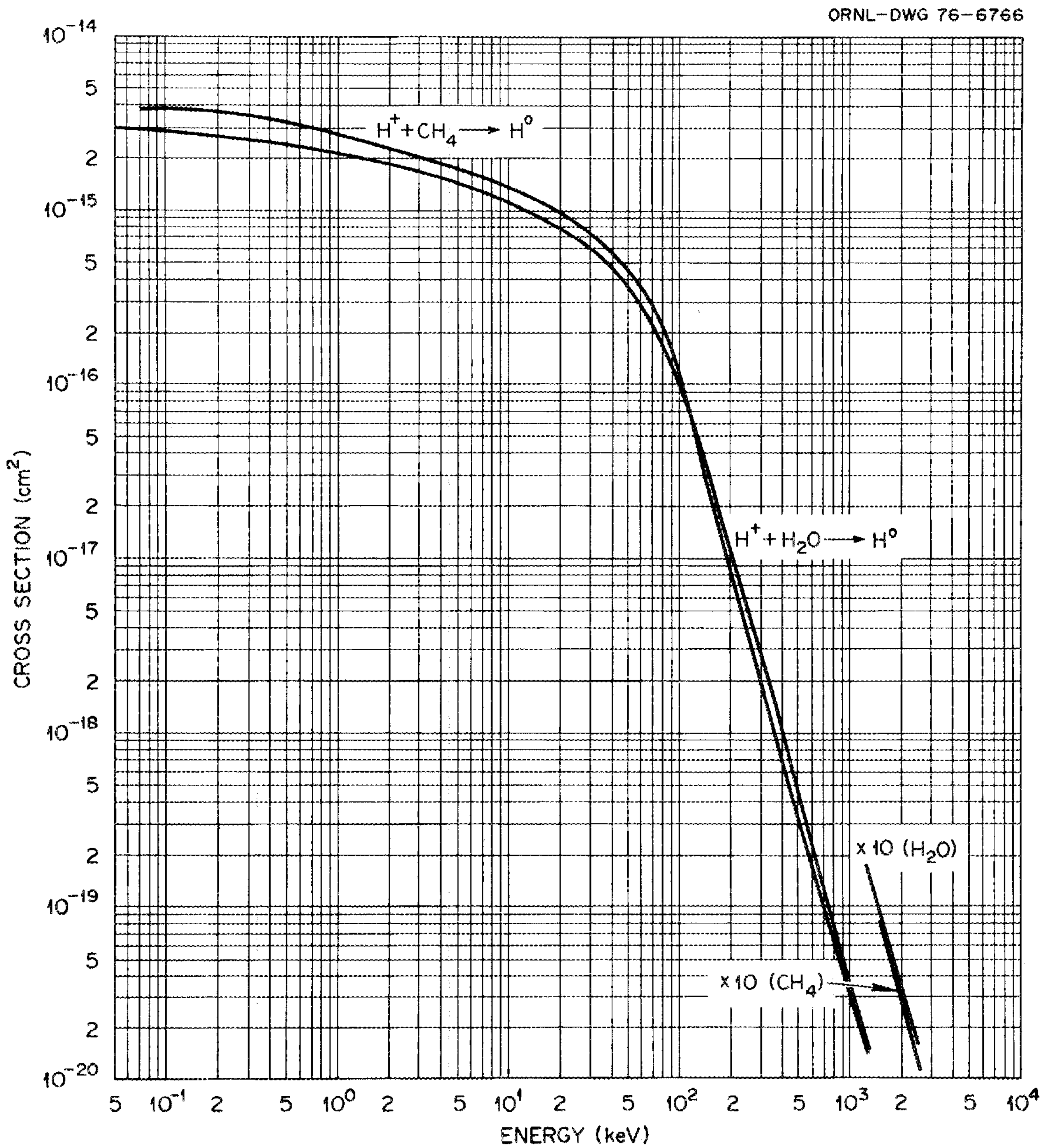
$H^+ + H_2O \rightarrow H^\circ$: K. H. Berkner, R. V. Pyle, and J. W. Stearns, Nucl. Fusion 10, 145 (1970); E. S. Chambers, Report No. UCRL-14214 (1965); M. A. Coplan and K. W. Ogilvie, J. Chem. Phys. 52, 4154 (1970); R. Dagnac, D. Blanc, and D. Molina, J. Phys. B. 3, 1239 (1970); D. W. Koopman, Phys. Rev. 166, 57 (1968); L. H. Toburen, M. Y. Nakai, and R. A. Langley, Phys. Rev. 171, 114 (1968).

$H^+ + CH_4 \rightarrow H^\circ$: K. H. Berkner, R. V. Pyle, and J. W. Stearns, Nucl. Fusion 10, 145 (1970); E. S. Chambers, Report No. UCRL-14214 (1965); J. G. Collins and P. Kerbarle, J. Chem. Phys. 46, 1087 (1967); J. Desesquelles, G. D. Cao, and M. Dufay, Compt. Rend. 262B, 1329 (1966); D. W. Koopman, J. Chem. Phys. 49, 5203 (1968); R. J. McNeal, J. Chem. Phys. 53, 4308 (1970); L. H. Toburen, M. Y. Nakai, and R. A. Langley, Phys. Rev. 171, 114 (1968).

Accuracy:

$H^+ + H_2O$: ± 25%

$H^+ + CH_4$: ± 25%.


ORNL-DWG 76-6766
H⁺+CH₄ → H°
H⁺+H₂O → H°
x 10 (H₂O)
x 10 (CH₄)
CROSS SECTION (cm²)
ENERGY (keV)

Electron Capture Cross Sections for H^+ in CO and CO_2

Energy (keV)	Cross Sections (cm^2)	
	σ_{10} $H^+ + CO \rightarrow H^\circ$	σ_{10} $H^+ + CO_2 \rightarrow H^\circ$
2.5 E-02	4.7 E-16	
5.0 E-02	7.7 E-16	2.9 E-15
7.5 E-02	1.0 E-15	2.8 E-15
1.0 E-01	1.3 E-15	2.7 E-15
2.0 E-01	1.7 E-15	2.4 E-15
5.0 E-01	1.9 E-15	1.9 E-15
7.5 E-01	1.8 E-15	1.7 E-15
1.0 E 00	1.8 E-15	1.5 E-15
2.0 E 00	1.7 E-15	1.3 E-15
5.0 E 00	1.3 E-15	1.1 E-15
7.5 E 00	1.1 E-15	1.0 E-15
1.0 E 01	1.0 E-15	9.4 E-16
2.0 E 01	6.8 E-16	7.5 E-16
5.0 E 01	2.5 E-16	3.8 E-16
7.5 E 01	1.3 E-16	2.3 E-16
1.0 E 02	7.9 E-17	1.6 E-16
2.0 E 02	1.5 E-17	2.5 E-17
5.0 E 02	6.5 E-19	1.1 E-18
7.5 E 02	1.8 E-19	2.6 E-19
1.0 E 03	6.7 E-20	9.0 E-20
2.5 E 03	3.0 E-21	3.6 E-21

References:

$H^+ + CO \rightarrow H^\circ$: K. H. Berkner, R. V. Pyle, and J. W. Stearns, Nucl. Fusion 10, 145 (1970); E. S. Chambers, Report No. UCRL-14214 (1965); J. Desesquelles, G. D. Cao, and M. Dufay, Compt. Rend. 262B, 1329 (1966); H. B. Gilbody and J. B. Hasted, Proc. Roy. Soc. London 238A, 334 (1956); E. Gustafsson and and E. Lindholm, Ark. Fysik, 18, 219 (1960); R. J. McNeal, J. Chem. Phys. 53, 4308 (1970); M. C. Poulizac, J. Desesquelles, M. Dufay, Annls. Astrophys. 30, 301 (1967); L. H. Toburen, M. Y. Nakai, and R. A. Langley, Phys. Rev. 171, 114 (1968).

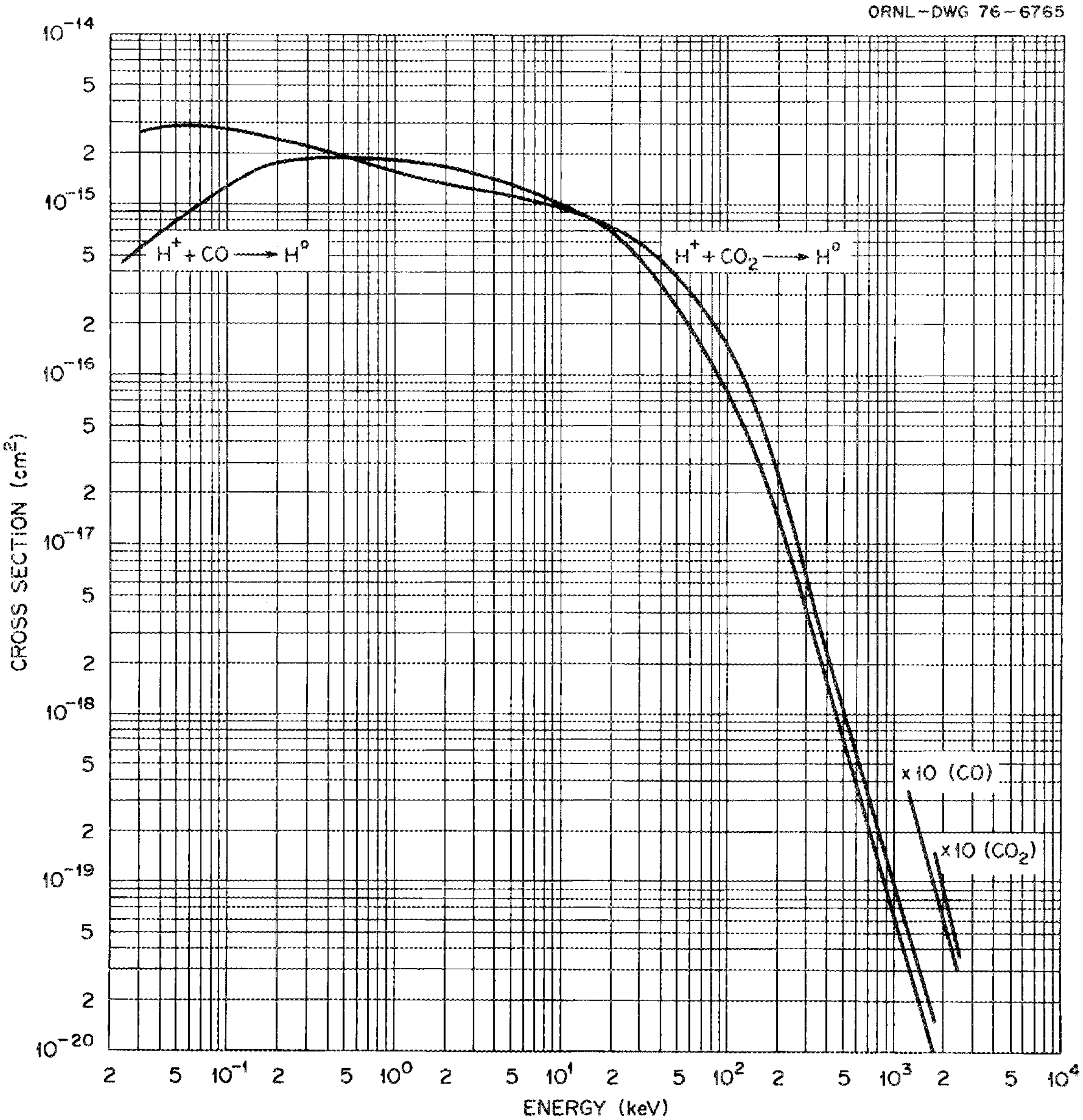
$H^+ + CO_2 \rightarrow H^\circ$: M. A. Coplan and K. W. Ogilvie, J. Chem. Phys. 52, 4154 (1970); J. Desesquelles, G. D. Cao, M. Dufay, Compt. Rend. 262B, 1329 (1966); D. W. Koopman, Phys. Rev. 166, 57 (1968); R. J. McNeal, J. Chem. Phys. 53, 4308 (1970); L. H. Toburen, M. Y. Nakai, and R. A. Langley, Phys. Rev. 171, 114 (1968).

Note: K. H. Berkner, et al. results are for incident D°. Data is plotted at 1/2 E.

Accuracy:

$H^+ + CO \rightarrow H^\circ$: $\pm$ 20%

$H^+ + CO_2 \rightarrow H^\circ$: $\pm$ 20%. Below 1 keV uncertainty is large.


ORNL-DWG 76-6765
CROSS SECTION (cm²)
ENERGY (keV)
H⁺ + CO ⟶ H°
H⁺ + CO₂ ⟶ H°
x10 (CO)
x10 (CO₂)
10⁻¹⁴
5
2
10⁻¹⁵
10⁻¹⁶
10⁻¹⁷
10⁻¹⁸
10⁻¹⁹
10⁻²⁰
10⁻¹
10⁰
10¹
10²
10³
10⁴

Electron Capture Cross Sections of H^+ in Li Vapor

Energy (keV)	Cross Sections (cm^2)	
	σ_{10} $H^+ + Li \rightarrow H^\circ$	σ_{1-1} $H^+ + Li \rightarrow H^-$
1.0 E 00	2.3 E-15	9.5 E-18
2.0 E 00	4.2 E-15	2.4 E-17
4.0 E 00	8.2 E-15	5.6 E-17
7.0 E 00	5.3 E-15	5.8 E-17
1.0 E 01	3.0 E-15	2.8 E-17
2.0 E 01	2.9 E-16	2.0 E-18
4.0 E 01	4.1 E-17	
7.0 E 01	2.2 E-17	
1.0 E 02	1.1 E-17	
2.0 E 02	2.6 E-18	
4.0 E 02	6.0 E-19	

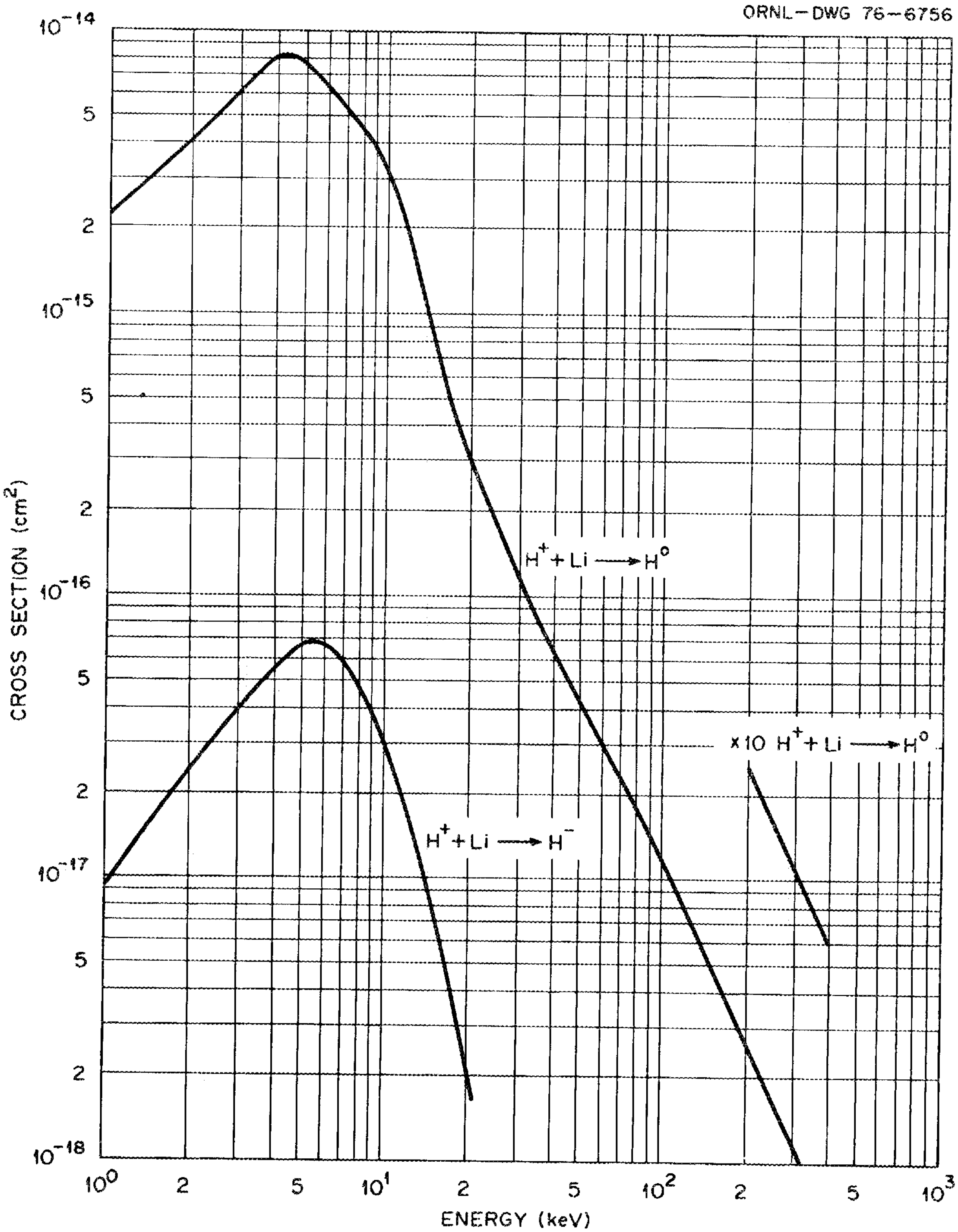
References:

$H^+ + Li \rightarrow H^\circ$: B. A. D'yachkov, Sov. Atom. Energy 27, 958 (1969); W. Grüebler, P. A. Schmelzbach, V. König and P. Marmier, Helv. Phys. Acta. 43, 254 (1970); R. N. Il'in, V. A. Oparin, E. S. Solov'ev, and N. V. Fedorenko, Sov. Phys.-Tech. Phys. 11, 92 (1967).

$H^+ + Li \rightarrow H^-$: U. Grüebler, P. A. Schmelzbach, V. König, and P. Marmier, Helv. Phys. Acta. 43, 254 (1970).

Accuracy:

Unknown.


ORNL-DWG 76-6756
CROSS SECTION (cm²)
ENERGY (keV)
H⁺+Li ⟶ H°
H⁺+Li ⟶ H⁻
×10 H⁺+Li ⟶ H°
10⁻¹⁴
5
2
10⁻¹⁵
5
2
10⁻¹⁶
5
2
10⁻¹⁷
5
2
10⁻¹⁸
10⁰
2
5
10¹
2
5
10²
2
5
10³

Electron Capture Cross Sections for H^+ in Na Vapor

Energy (keV)	Cross Sections (cm^2)	
	σ_{10} $H^+ + Na \rightarrow H^\circ$	σ_{1-1} $H^+ + Na \rightarrow H^-$
5.0 E-01	2.7 E-15	
7.0 E-01	3.3 E-15	3.8 E-17
1.0 E 00	4.4 E-15	6.5 E-17
2.0 E 00	8.3 E-15	1.9 E-16
4.0 E 00	1.2 E-14	5.0 E-16
6.0 E 00	8.0 E-15	4.2 E-16
8.0 E 00	4.2 E-15	2.3 E-16
1.0 E 01	2.2 E-15	1.4 E-16
2.0 E 01	3.2 E-16	
4.0 E 01	7.5 E-17	
6.0 E 01	5.0 E-17	
1.0 E 02	3.7 E-17	
1.8 E 02	2.1 E-17	

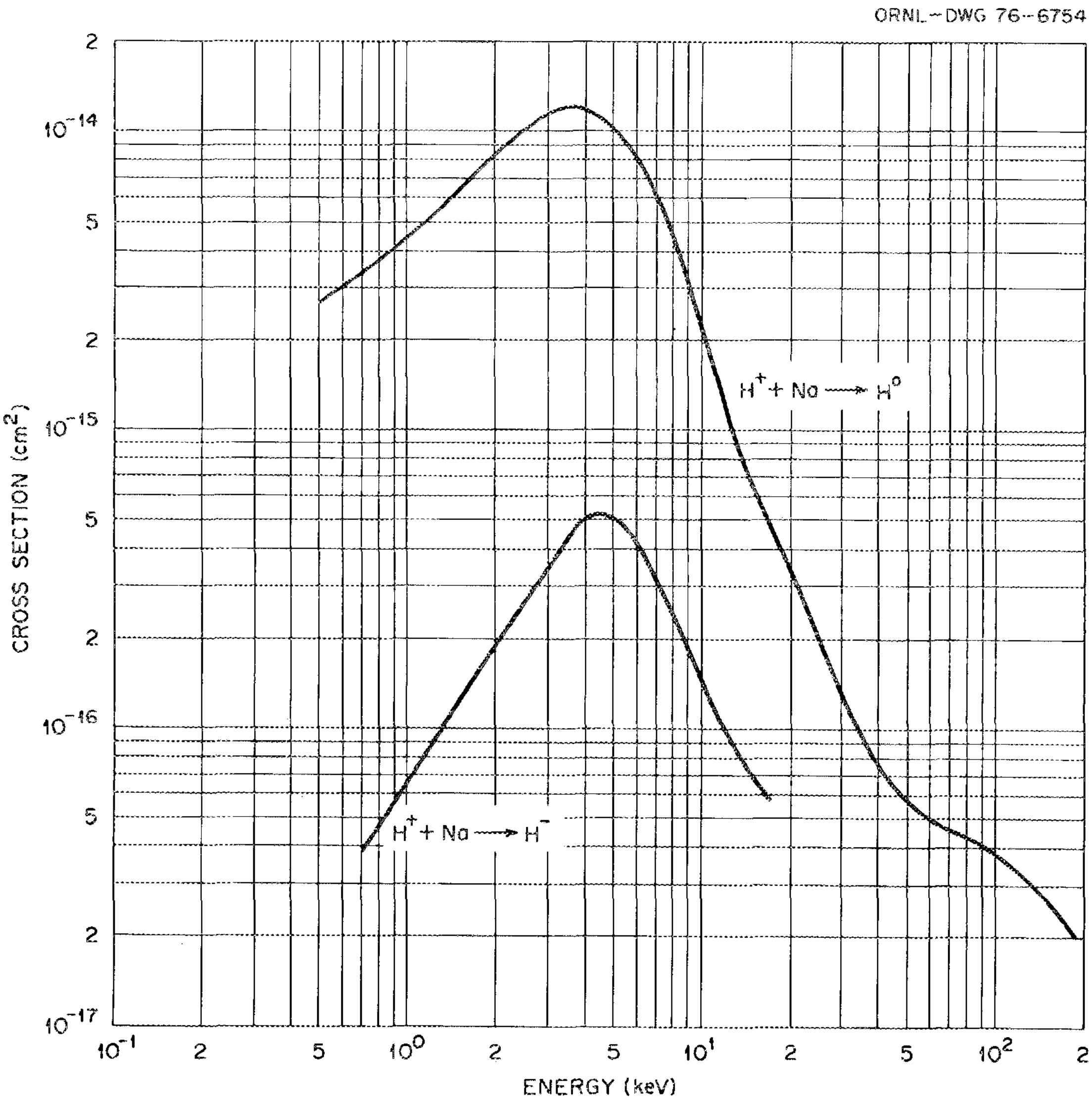
References:

$H^+ + Na \rightarrow H^\circ$: W. Grüebler, P. A. Schmelzbach, V. König and P. Marmier, Helv. Phys. Acta. 43, 254 (1970); R. N. Il'in, V. A. Oparin, E. S. Solov'ev, and N. V. Fedorenko, Sov. Phys.-Tech. Phys. 11, 921 (1967).

$H^+ + Na \rightarrow H^-$: W. Grüebler, P. A. Schmelzbach, V. König, and P. Marmier, Helv. Phys. Acta. 43, 254 (1970).

Accuracy:

Unknown.


ORNL-DWG 76-6754
CROSS SECTION (cm^2)
2
10^{-14}
5
2
10^{-15}
5
2
10^{-16}
5
2
10^{-17}
10^{-1}
2
5
10^0
2
5
10^1
2
5
10^2
2
ENERGY (keV)
$H^+ + Na \longrightarrow H^0$
$H^+ + Na \longrightarrow H^-$

Electron Capture Cross Sections of H^+ in K Vapor

Energy (keV)	Cross Sections (cm^2)	
	σ_{10}	$\sigma_{1\bar{1}}$
	$H^+ + K \rightarrow H^\circ$	$H^+ + K \rightarrow H^-$
6.0 E-01	5.2 E-15	2.2 E-17
1.0 E 00	7.4 E-15	3.2 E-17
2.0 E 00	9.5 E-15	4.0 E-17
4.0 E 00	7.8 E-15	3.4 E-17
7.0 E 00	4.5 E-15	2.1 E-17
1.0 E 01	2.5 E-15	1.3 E-17
2.0 E 01	6.9 E-16	3.4 E-18
4.0 E 01	3.7 E-16	
7.0 E 01	2.4 E-16	
1.0 E 02	1.2 E-16	
1.8 E 02	2.6 E-17	

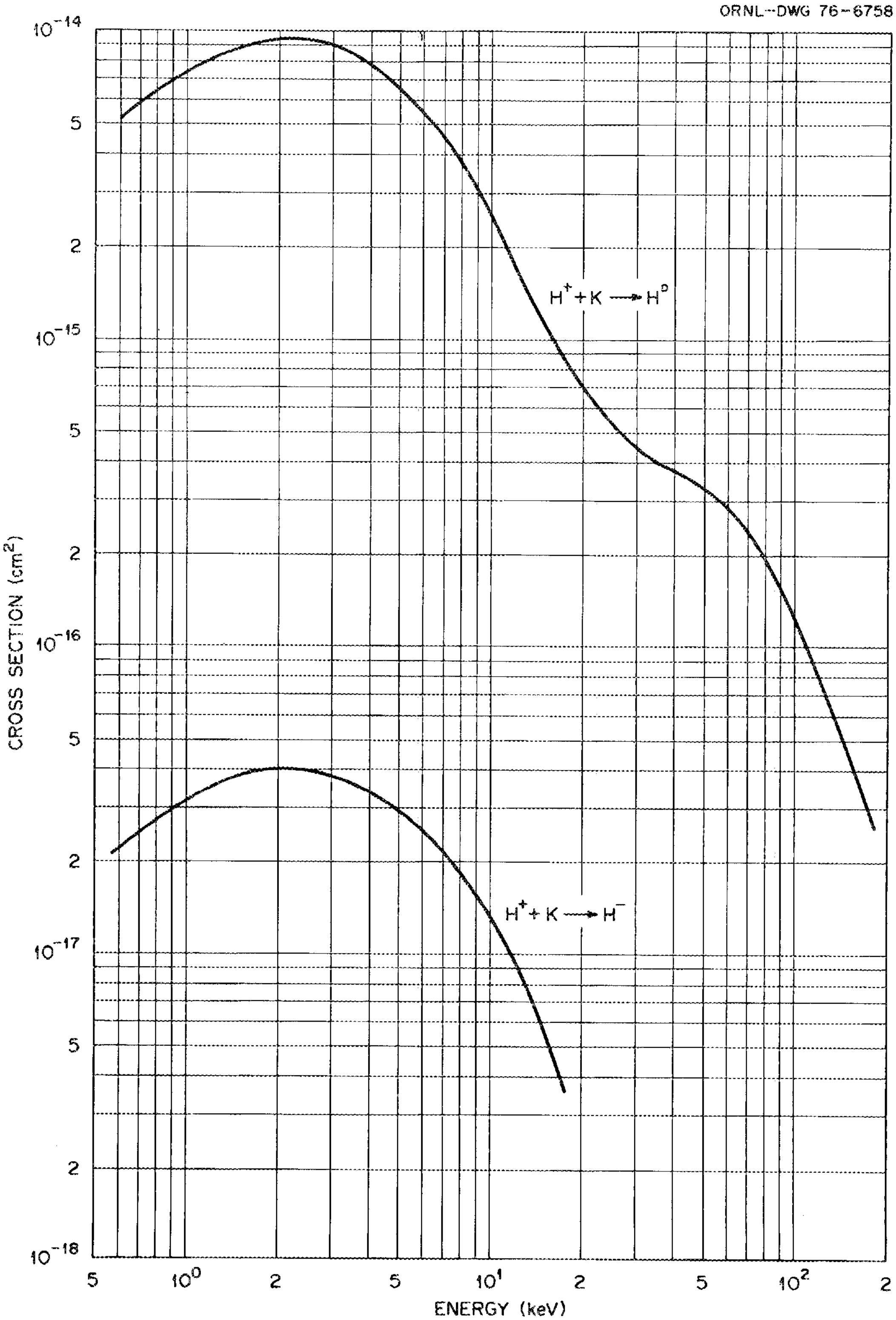
References:

$H^+ + K \rightarrow H^\circ$: W. Grüebler, P. A. Schmelzbach, V. König, and P. Marmier, Helv. Phys. Acta. 43, 254 (1970); R. N. Il'in, V. A. Oparin, E. S. Solov'ev, and N. V. Fedorenko, Sov. Phys.-Tech. Phys. 11, 921 (1967).

$H^+ + K \rightarrow H^-$: W. Grüebler, P. A. Schmelzbach, V. König, and P. Marmier. Helv. Phys. Acta. 43, 254 (1970).

Accuracy:

Unknown.


ORNL-DWG 76-6758
CROSS SECTION (cm²)
ENERGY (keV)
H⁺+K → H⁰
H⁺+K → H⁻
10⁻¹⁴
5
2
10⁻¹⁵
5
2
10⁻¹⁶
5
2
10⁻¹⁷
5
2
10⁻¹⁸
5
10⁰
2
5
10¹
2
5
10²
2

Electron Capture Cross Sections for H^+ in Mg Vapor

Energy (keV)	Cross Sections (cm^2)	
	σ_{10} $H^+ + Mg \rightarrow H^\circ$	σ_{1-1} $H^+ + Mg \rightarrow H^-$
5.0 E 00	1.5 E-15	1.0 E-16
7.0 E 00	2.1 E-15	8.6 E-17
1.0 E 01	1.8 E-15	6.3 E-17
2.0 E 01	6.3 E-16	2.0 E-17
4.0 E 01	7.2 E-17	3.4 E-18
7.0 E 01	1.6 E-17	1.1 E-18
1.0 E 02	1.2 E-17	
1.8 E 02	9.6 E-18	

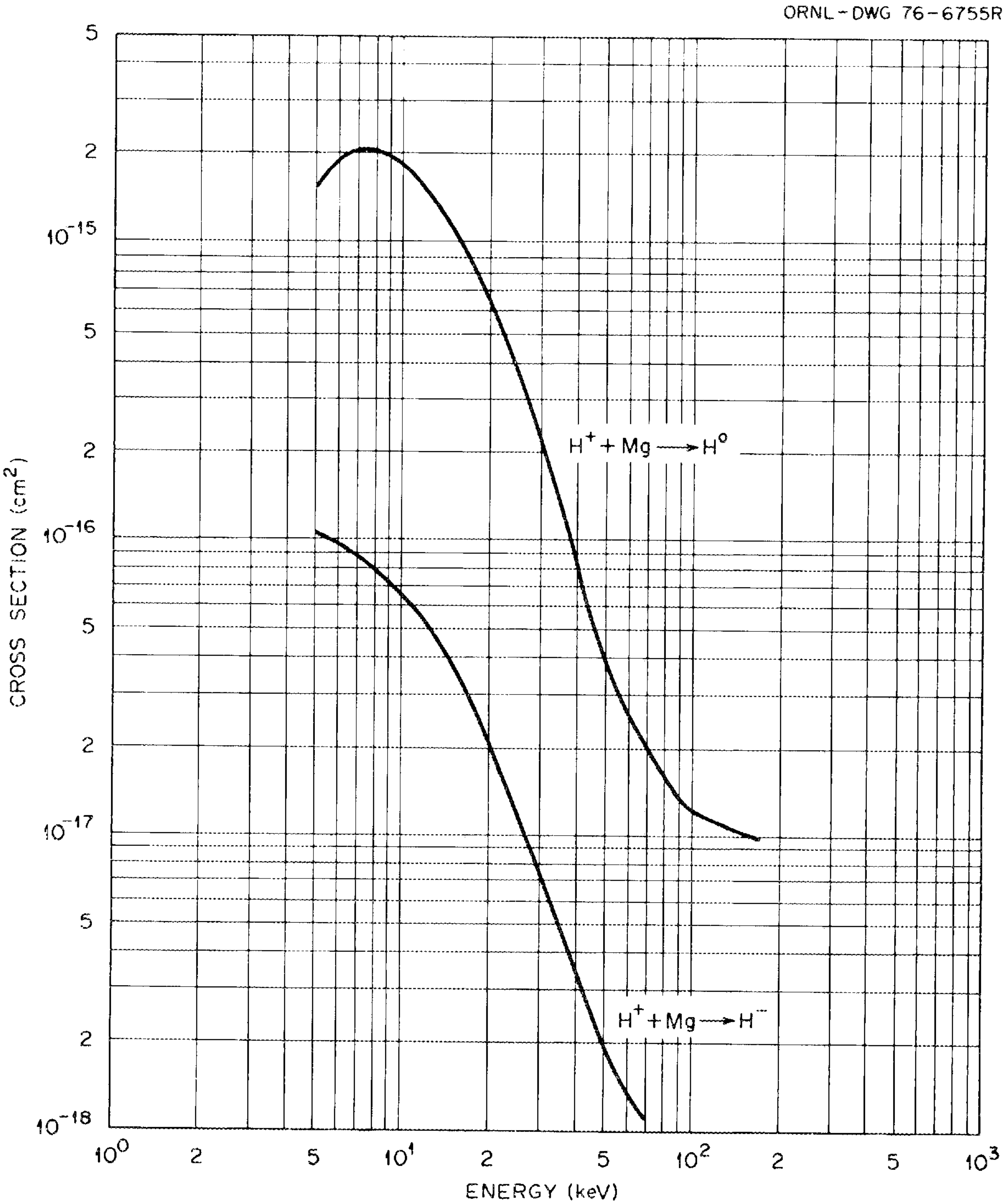
References:

$H^+ + Mg \rightarrow H^\circ$: K. H. Berkner, R. V. Pyle, and J. W. Stearns, Phys. Rev. 178, 248 (1969); A. H. Futch and K. G. Moses, 5th Int. Conf. Elect. Atom. Coll., p. 12, Leningrad, USSR (1967); R. N. Il'in, V. A. Oparin, E. S. Solov'ev, and N. V. Fedorenko, Sov. Phys.-Tech. Phys. 11, 921 (1967).

$H^+ + Mg \rightarrow H^-$: K. H. Berkner, R. V. Pyle, and J. W. Stearns, Phys. Rev. 178, 248 (1969).

Accuracy:

Unknown.



ORNL-DWG 76-6755R
CROSS SECTION (cm^2)
ENERGY (keV)
5
2
10^{-15}
5
2
10^{-16}
5
2
10^{-17}
5
2
10^{-18}
10^0
2
5
10^1
2
5
10^2
2
5
10^3
$H^+ + Mg \longrightarrow H^0$
$H^+ + Mg \longrightarrow H^-$

Electron Capture Cross Sections of H^+ in Cs Vapor

Energy (keV)	Cross Sections (cm^2)		
	σ_{10}	σ_{0-1}	σ_{1-1}
	$H^+ + Cs \rightarrow H^\circ$	$H^\circ + Cs \rightarrow H^-$	$H^+ + Cs \rightarrow H^-$
2.5 E-01		3.8 E-16	1.0 E-16
5.0 E-01	1.0 E-14	3.4 E-16	7.4 E-17
7.0 E-01	9.4 E-15	2.9 E-16	6.0 E-17
1.0 E 00	8.7 E-15	2.3 E-16	4.7 E-17
2.0 E 00	7.2 E-15	1.4 E-16	2.8 E-17
4.0 E 00	5.3 E-15	7.2 E-17	1.3 E-17
7.0 E 00	3.7 E-15	3.7 E-17	4.2 E-18
1.0 E 01	2.8 E-15	2.4 E-17	1.5 E-18
2.0 E 01	1.5 E-15		1.4 E-19
4.0 E 01	9.3 E-16		
7.0 E 01	3.2 E-16		
1.0 E 02	2.0 E-16		
1.8 E 02	3.2 E-17		

References:

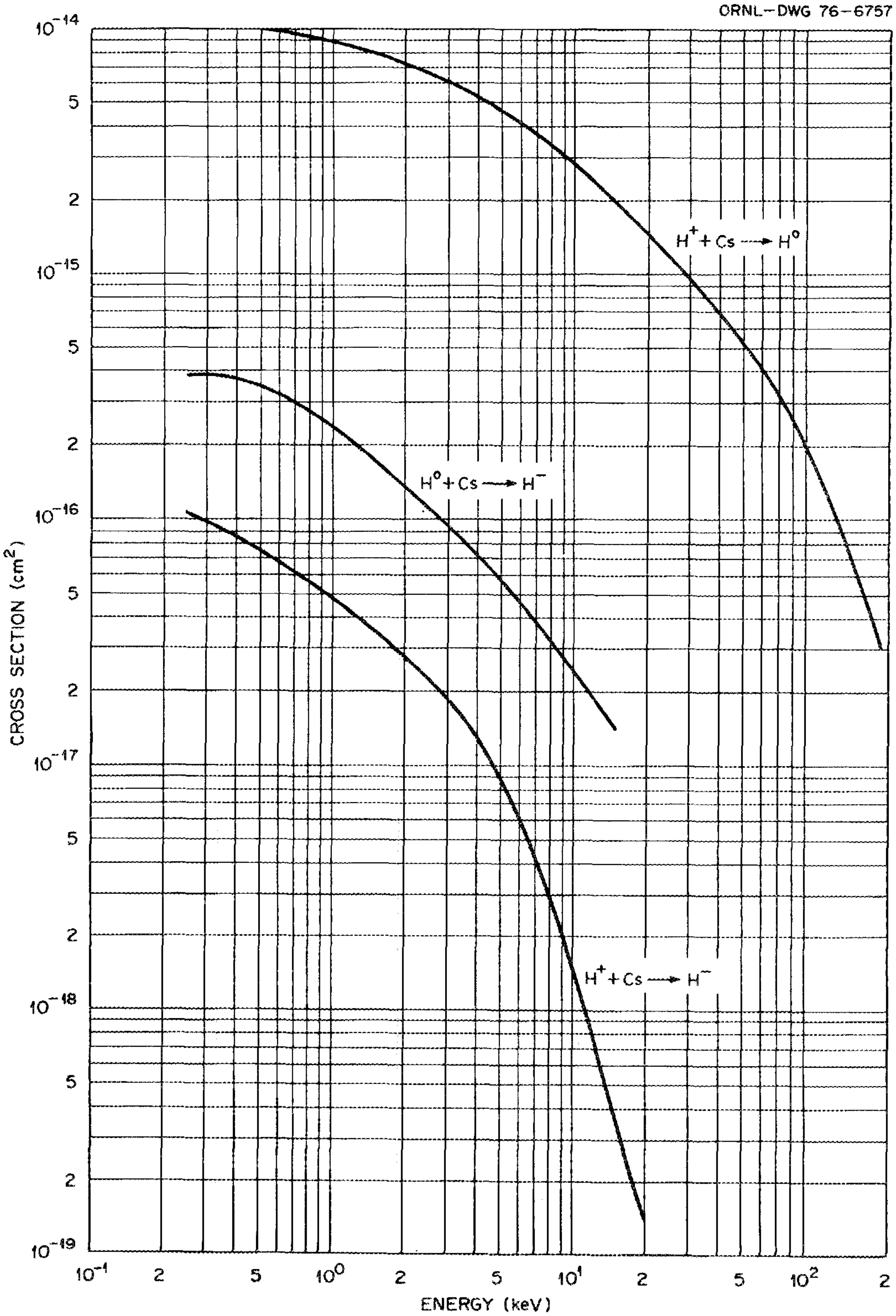
$H^+ + Cs \rightarrow H^\circ$: W. Grüebler, P. A. Schmelzbach, V. König, and P. Marmier, Helv. Phys. Acta. 43, 254 (1970); R. N. Il'in, V. A. Oparin, E. S. Solov'ev, and N. V. Fedorenko, Sov. Phys.-Tech. Phys. 11, 92 (1967); A. S. Schlachter, P. J. Bjorkholm, D. H. Loyd, L. W. Anderson, and W. Haeberli, Phys. Rev. 177, 184 (1969); G. Spiess, A. Valance, and P. Pradel, Phys. Rev. A 6, 746 (1972); V. N. Tuan, G. Gautherin, and A. S. Schlachter, Phys. Rev. A 9, 1242 (1972).

$H^\circ + Cs \rightarrow H^-$: C. Cisneros, I. Alvarez, C. F. Barnett and J. A. Ray, Phys. Rev. A , (1976); A. S. Schlachter, P. J. Bjorkholm, D. H. Loyd, L. W. Anderson and W. Haeberli, Phys. Rev. 177, 184 (1969).

$H^+ + Cs \rightarrow H^-$: C. Cisneros, I. Alvarez, C. F. Barnett and J. A. Ray, Phys. Rev. A (1976); W. Grüebler, P. A. Schmelzbach, V. König, and P. Marmier, Helv. Phys. Acta. 43, 254 (1970); A. S. Schlachter, P. J. Bjorkholm, D. H. Loyd, L. W. Anderson, and W. Haeberli, Phys. Rev. 177, 184 (1969).

Accuracy:

Unknown.


ORNL-DWG 76-6757
CROSS SECTION (cm^2)
ENERGY (keV)
$H^+ + Cs \rightarrow H^0$
$H^0 + Cs \rightarrow H^-$
$H^+ + Cs \rightarrow H^-$
10^{-14}
5
2
10^{-15}
10^{-16}
10^{-17}
10^{-18}
10^{-19}
10^{-1}
10^{0}
10^{1}
10^{2}

Electron Capture Cross Sections for the Reactions

$H_2^+ + H_2$ and $H_2^+ + H$

Energy (keV)	Cross Sections (cm^2)	
	σ_{10} $H_2^+ + H_2 \rightarrow H_2^\circ$	σ_{10} $H_2^+ + H \rightarrow H_2^\circ$
5.0 E-03	1.1 E-15	
7.0 E-03	1.1 E-15	
1.0 E-02	1.1 E-15	
2.0 E-02	1.0 E-15	
4.0 E-02	9.5 E-16	
7.0 E-02	8.8 E-16	
1.0 E-01	8.5 E-16	8.1 E-16
2.0 E-01	7.8 E-16	8.8 E-16
4.0 E-01	7.2 E-16	9.5 E-16
7.0 E-01	6.7 E-16	9.9 E-16
1.0 E 00	6.5 E-16	1.0 E-15
2.0 E 00	6.0 E-16	1.1 E-15
4.0 E 00	5.5 E-16	1.0 E-15
7.0 E 00	5.0 E-16	9.0 E-16
1.0 E 01	4.6 E-16	7.1 E-16
2.0 E 01	3.6 E-16	
4.0 E 01	2.1 E-16	
7.0 E 01	9.4 E-17	
1.0 E 02	4.5 E-17	
2.0 E 02	7.8 E-18	

References:

$H_2^+ + H_2$: W. H. Cramer, J. Chem. Phys. 35, 836 (1961); H. B. Gilbody and J. B. Hasted, Proc. Roy. Soc. A 238, 334 (1956); Yu. S. Gordeev and M. N. Panov, Sov. Phys.-Tech. Phys. 9, 656 (1964); H. C. Hayden and R. C. Amme, Phys. Rev. 172, 104 (1968); D. W. Koopman, Phys. Rev. 154, 79 (1967); J. J. Leventhal, T. F. Moran, L. Friedman, J. Chem. Phys. 46, 4666 (1967); G. W. McClure, Phys. Rev. 130, 1852 (1963); A. Schmid, Z. Phys. 161, 550 (1961); J. B. H. Stedeford and J. B. Hasted, Proc. Roy. Soc. A227, 466 (1955); D. R. Sweetman, Proc. Roy. Soc. (London) A256, 416 (1960); D. W. Vance and T. L. Bailey, J. Chem. Phys. 44, 486 (1966).

$H_2^+ + H$: W. L. Fite, R. T. Brackman, and W. R. Snow, Phys. Rev. 112, 1161 (1958).

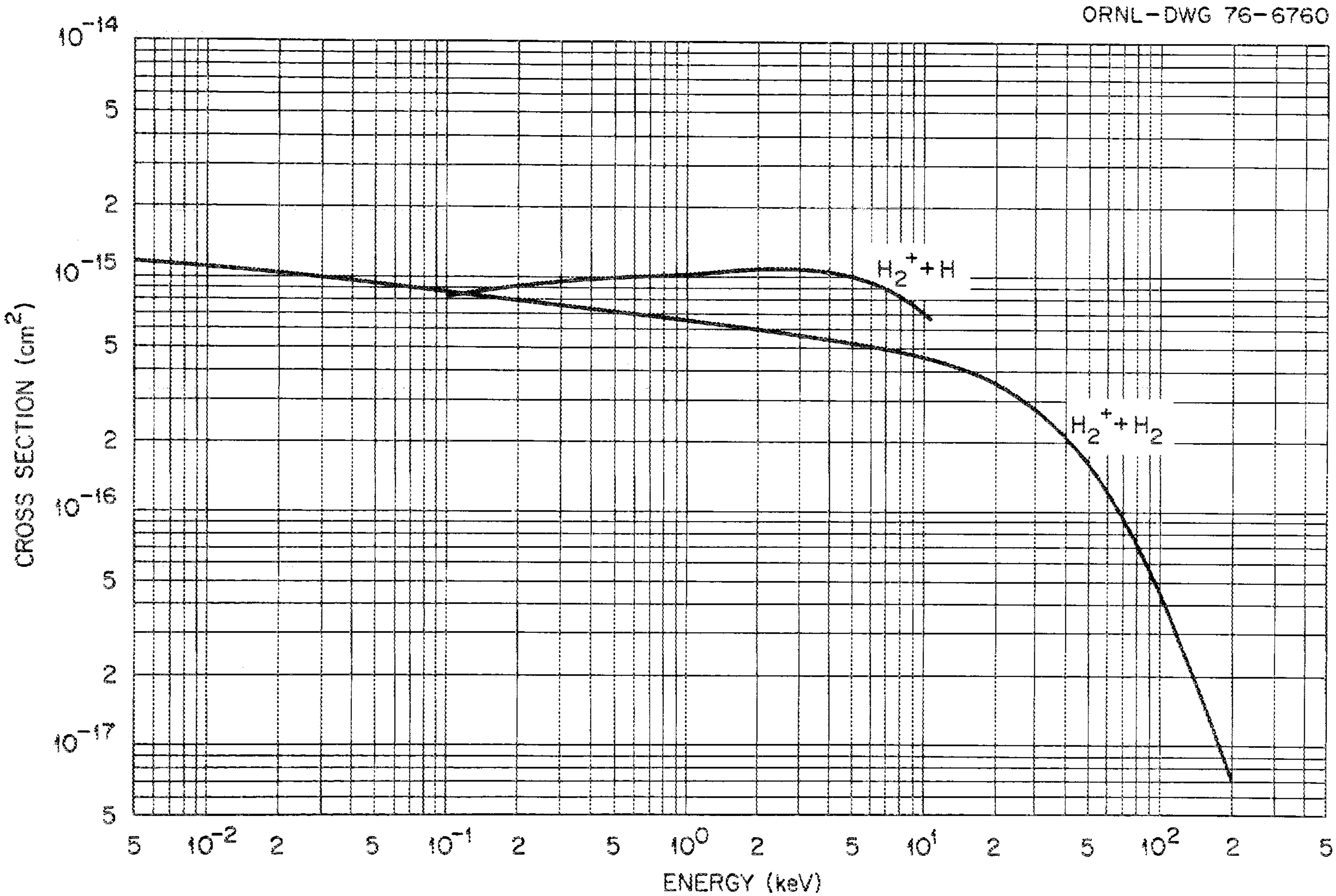
Accuracy:

$H_2^+ + H_2$: ± 40%.

$H_2^+ + H$: ± 20%.

Note:

Some investigators have found that the cross sections were dependent on the vibrational state of the H_2^+ ion.


ORNL-DWG 76-6760
CROSS SECTION (cm^2)
10^{-14}
5
2
10^{-15}
5
2
10^{-16}
5
2
10^{-17}
5
$H_2^+ + H$
$H_2^+ + H_2$
5
10^{-2}
2
5
10^{-1}
2
5
10^{0}
2
5
10^{1}
2
5
10^{2}
2
5
ENERGY (keV)

Electron Capture Cross Sections for

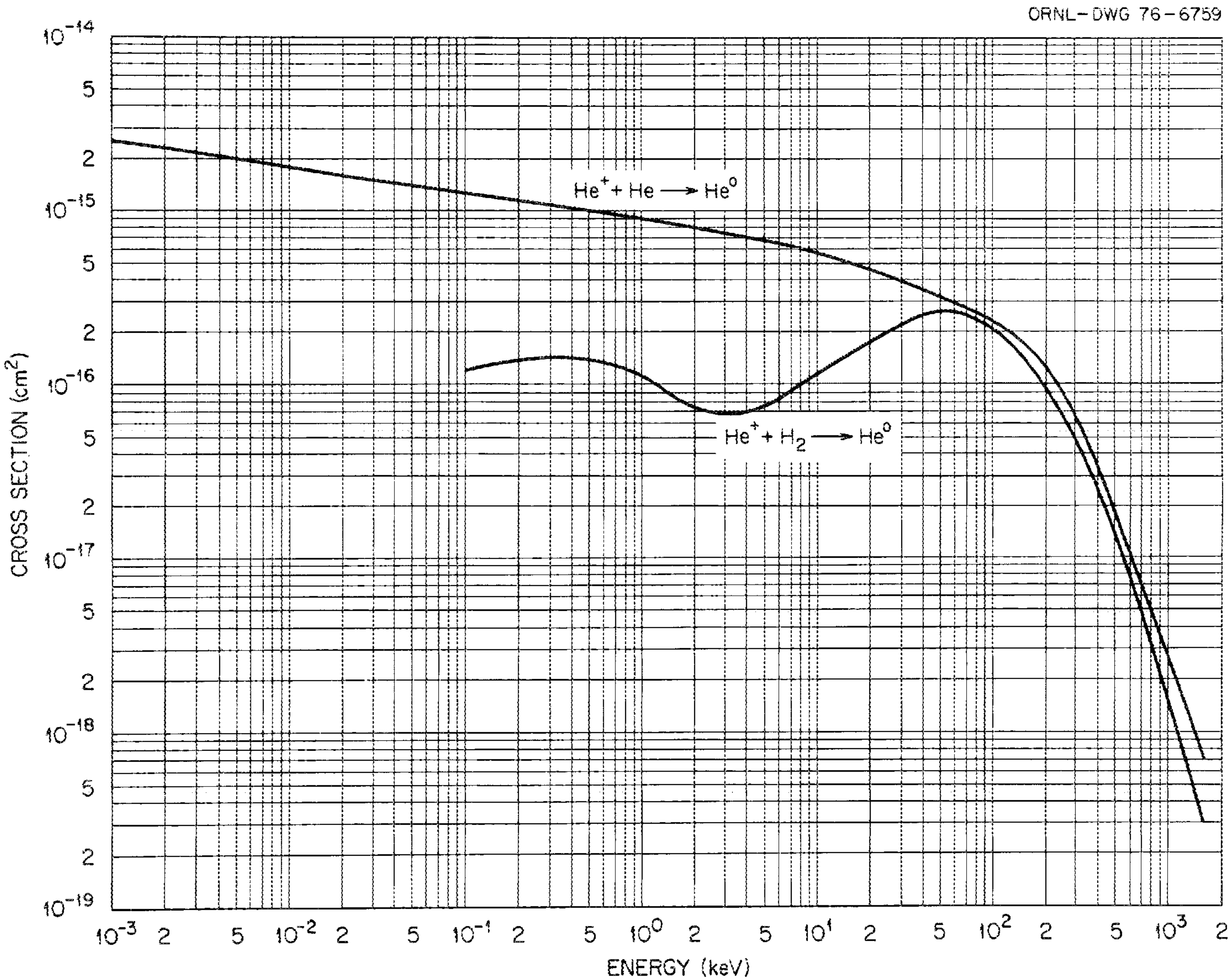
He^+ in H_2 and He

Energy (keV)	Cross Sections (cm^2)	
	σ_{10} $He^+ + H_2 \rightarrow He^\circ$	σ_{10} $He^+ + He \rightarrow He^\circ$
1.0 E-03		2.5 E-15
2.0 E-03		2.3 E-15
4.0 E-03		2.1 E-15
7.0 E-03		1.9 E-15
1.0 E-02		1.8 E-15
2.0 E-02		1.6 E-15
4.0 E-02		1.4 E-15
7.0 E-02		1.3 E-15
1.0 E-01	1.2 E-16	1.3 E-15
2.0 E-01	1.4 E-16	1.2 E-15
4.0 E-01	1.4 E-16	1.1 E-15
7.0 E-01	1.3 E-16	9.7 E-16
1.0 E 00	1.1 E-16	9.1 E-16
2.0 E 00	7.5 E-17	8.1 E-16
4.0 E 00	7.0 E-17	7.2 E-16
7.0 E 00	9.0 E-17	6.3 E-16
1.0 E 01	1.1 E-16	5.8 E-16
2.0 E 01	1.7 E-16	4.7 E-16
4.0 E 01	2.5 E-16	3.5 E-16
7.0 E 01	2.6 E-16	2.8 E-16
1.0 E 02	2.1 E-16	2.3 E-16
2.0 E 02	1.0 E-16	1.3 E-16
4.0 E 02	2.5 E-17	3.5 E-17
7.0 E 02	5.5 E-18	7.5 E-18
1.0 E 03	1.6 E-18	2.8 E-18
1.6 E 03	3.0 E-19	7.0 E-19

References:

$He^+ + H_2$: S. K. Allison, J. Cuevas, P. G. Murphy, Phys. Rev. 102, 1041 (1956); C. F. Barnett and P. M. Stier, Phys. Rev. 109, 385 (1958); H. B. Gilbody, J. B. Hasted, J. V. Ireland, A. R. Lee, E. W. Thomas and A. S. Whiteman, Proc. Roy. Soc. London, A274, 40 (1963); F. J. DeHeer, J. Schutten and H. Moustafa, Physica 32, 1793 (1966); L. I. Pivovar, V. M. Tubaev, and M. T. Novikov, Sov. Phys.-JETP 14, 20 (1962); J. B. H. Stedeford and J. B. Hasted, Proc. Roy. Soc. London A227, 466 (1955); A. B. Wittkower, G. Levy, and H. B. Gilbody, Proc. Phys. Soc. London 91, 862 (1967).

(continued at end of chapter)


ORNL-DWG 76-6759
$He^+ + He \longrightarrow He^0$
$He^+ + H_2 \longrightarrow He^0$
CROSS SECTION (cm^2)
ENERGY (keV)
10^{-14}
5
2
10^{-15}
5
2
10^{-16}
5
2
10^{-17}
5
2
10^{-18}
5
2
10^{-19}
10^{-3} 2 5 10^{-2} 2 5 10^{-1} 2 5 10^{0} 2 5 10^{1} 2 5 10^{2} 2 5 10^{3} 2

Electron Capture Cross Sections for

He^+ in O_2 and N_2

Energy (keV)	Cross Sections (cm^2)	
	σ_{10} $He^+ + N_2 \to He°$	σ_{10} $He^+ + O_2 \to He°$
1.0 E-03	6.0 E-15	
2.0 E-03	5.2 E-15	3.0 E-15
5.0 E-03	4.0 E-15	2.7 E-15
1.0 E-02	3.0 E-15	2.2 E-15
2.0 E-02	2.1 E-15	1.8 E-15
5.0 E-02	1.4 E-15	1.4 E-15
1.0 E-01	1.2 E-15	1.3 E-15
2.0 E-01	1.1 E-15	1.3 E-15
5.0 E-01	9.7 E-16	1.2 E-15
1.0 E 00	9.2 E-16	1.1 E-15
2.0 E 00	8.6 E-16	1.0 E-15
5.0 E 00	8.0 E-16	9.4 E-16
1.0 E 01	7.5 E-16	8.6 E-16
2.0 E 01	7.0 E-16	7.7 E-16
5.0 E 01	6.2 E-16	6.5 E-16
1.0 E 02	4.7 E-16	4.8 E-16
2.0 E 02	2.5 E-16	3.0 E-16
5.0 E 02	6.0 E-17	
1.0 E 03	9.2 E-18	
1.5 E 03	2.5 E-18	

References:

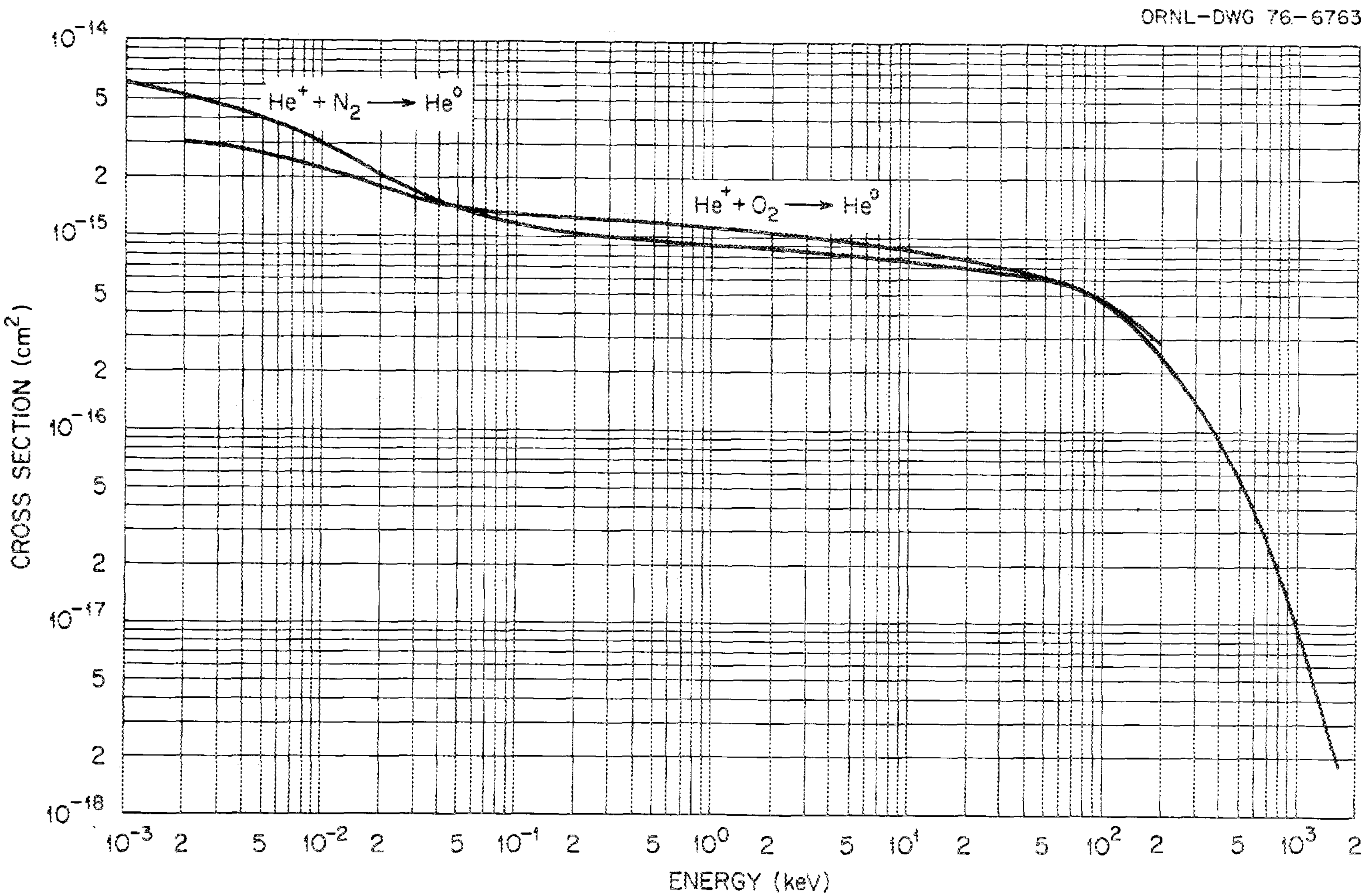
$He^+ + N_2$: C. F. Barnett and P. M. Stier, Phys. Rev. 109, 385 (1958); F. J. De Heer, J. Schutten, and H. Moustafa, Physica 32, 1793 (1966); D. W. Koopman, Phys. Rev. 166, 57 (1968); R. C. C. Lao, R. Rozett, and W. S. Koski, J. Chem. Phys. 49, 4202 (1968); P. Mahadevan and C. D. Magnuson, Fifth Int. Conf. on Electron and Atomic Collisions, p. 405, Leningrad (1967); V. S. Nikolaev, I. S. Dmitriev, L. N. Fateeva, and Ya. A. Teplova, Sov. Phys.-JETP 13, 695 (1961); L. I. Pivovar, V. M. Tubaev, and M. T. Novikov, Sov. Phys.-JETP 14, 20 (1962); R. F. Stebbings, J. A. Rutherford, and B. R. Turner, Planet. Space Sci. 13, 1125 (1965); R. F. Stebbings, A. C. H. Smith, and E. Ehrhardt, J. Chem. Phys. 39, 968 (1963).

$He^+ + O_2$: C. F. Barnett and P. M. Stier, Phys. Rev. 109, 385 (1958); F. J. De Heer, J. Schutten, and H. Mostafa, Physica 32, 1793 (1966); W. L. Fite, A. C. H. Smith, R. F. Stebbings, and J. L. Rutherford, J. Geophys. Res. 68, 3225 (1963); D. W. Koopman, Phys. Rev. 166, 57 (1968); P. Mahadevan and C. D. Magnuson, Fifth Int. Conf. on Electron and Atomic Collisions, p. 405, Leningrad (1967); P. Mahadevan and C. D. Magnuson, Phys. Rev. 171, 103 (1968); R. F. Stebbings, A. C. H. Smith and E. Ehrhardt, J. Chem. Phys. 39, 968 (1963).

Accuracy:

$He^+ + N_2$: ± 25%.

$He^+ + O_2$: ± 25%.



ORNL-DWG 76-6763
He⁺ + N₂ → He⁰
He⁺ + O₂ → He⁰
CROSS SECTION (cm²)
ENERGY (keV)

A.4.35

Electron Capture Cross Sections for

He^{++} in H and H_2

Energy (keV)	Cross Sections (cm^2)		
	σ_{21} $He^{++}+H \rightarrow He^{+}$	σ_{21} $He^{++}+H_2 \rightarrow He^{+}$	σ_{20} $He^{++}+H_2 \rightarrow He^{\circ}$
6.0 E 00	3.7 E-16		
8.0 E 00	5.4 E-16		
1.0 E 01	7.2 E-16	1.7 E-16	1.0 E-17
2.0 E 01	1.4 E-15	5.2 E-16	1.8 E-17
5.0 E 01	1.6 E-15	1.0 E-15	5.7 E-17
7.5 E 01	1.4 E-15	1.0 E-15	6.9 E-17
1.0 E 02		8.3 E-16	6.8 E-17
2.0 E 02		3.7 E-16	3.0 E-17
5.0 E 02		5.5 E-17	2.2 E-18
7.5 E 02		1.5 E-17	4.8 E-19
1.0 E 03		5.2 E-18	1.6 E-19
1.4 E 03		1.3 E-18	4.7 E-20
2.0 E 03		3.0 E-19	
3.0 E 03		4.4 E-20	
3.8 E 03		1.8 E-20	

References:

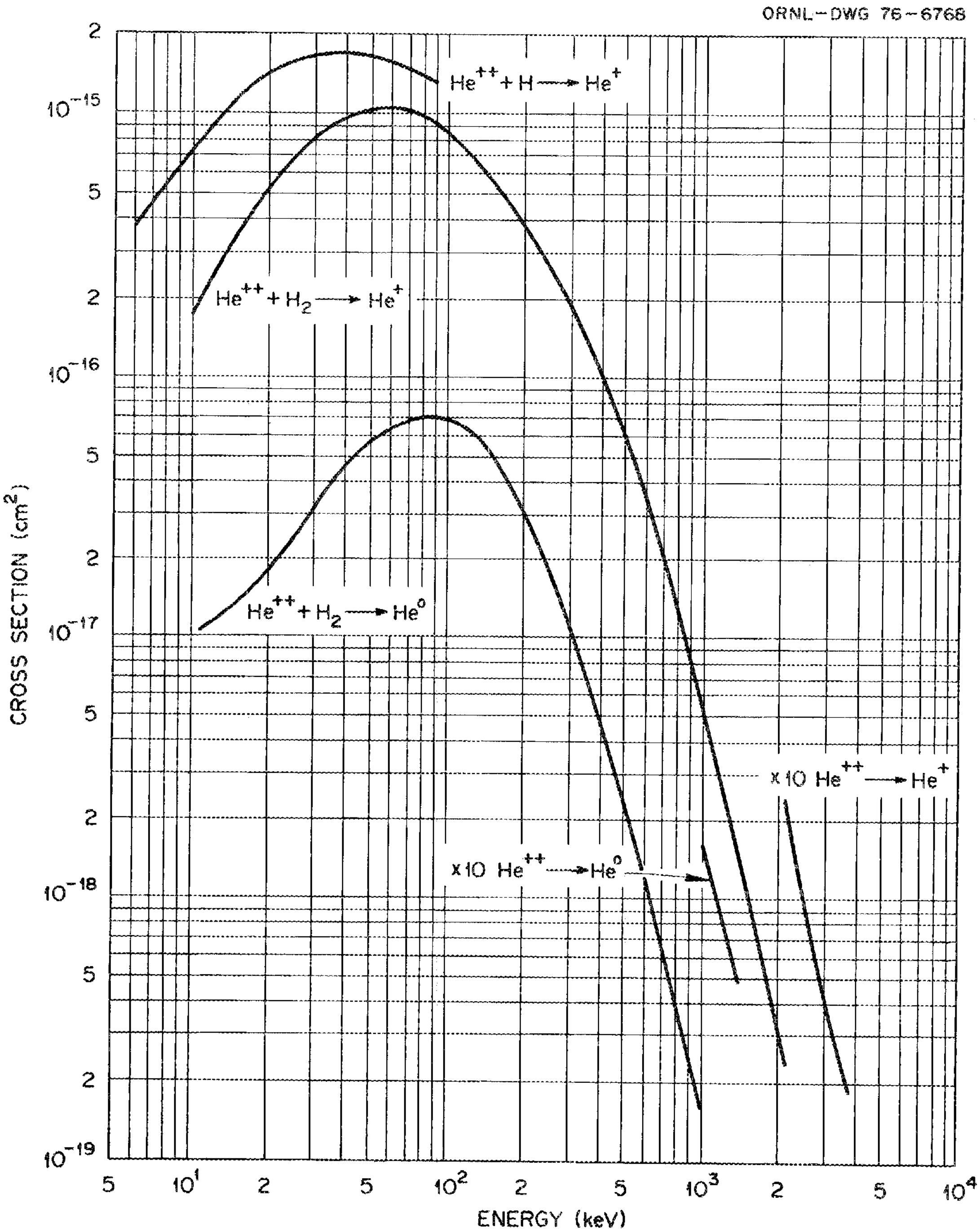
$He^{++}+H \rightarrow He^{+}$: W. L. Fite, A. C. H. Smith, and R. F. Stebbings, Proc. Roy. Soc. London A268, 527 (1962); J. E. Bayfield and G. A. Khayrallah, Phys. Rev. A 12, 869 (1975); M. B. Shah and H. B. Gilbody, J. Phys. B7, 630 (1974).

$He^{++}+H_2$: S. K. Allison, Phys. Rev. 109, 76 (1958); S. K. Allison, J. Cuevas, and P. G. Murphy, Phys. Rev. 102, 1041 (1956); R. A. Baragiola and I. B. Nemirovsky, Nucl. Inst. and Meth. 110, 511 (1973); J. E. Bayfield and G. A. Khayrallah, Phys. Rev. A 11, 920 (1975); P. Hvelplund, J. Heinemeier, E. H. Pedersen and F. R. Simpson, 9th Int. Conf. Atomc. & Elect. Coll. p. 185, Seattle, Wash. (1975); L. I. Pivovar, M. T. Novikov and V. M. Tubaev, Sov. Phys.-JETP 15, 1035 (1962); L. I. Pivovar, V. M. Tubaev, and M. T. Novikov, Sov. Phys.-JETP 14, 20 (1962); M. B. Shah and H. B. Gilbody, J. Phys. B 7, 256 (1974).

Accuracy:

$He^{++}+H$: ± 40%.

$He^{++}+H_2$: ± 40%.


ORNL-DWG 76-6768
$He^{++} + H \rightarrow He^{+}$
$He^{++} + H_2 \rightarrow He^{+}$
$He^{++} + H_2 \rightarrow He^{0}$
x10 $He^{++} \rightarrow He^{+}$
x10 $He^{++} \rightarrow He^{0}$
CROSS SECTION (cm^2)
ENERGY (keV)
2
10^{-15}
5
2
10^{-16}
5
2
10^{-17}
5
2
10^{-18}
5
2
10^{-19}
5
10^{1}
2
5
10^{2}
2
5
10^{3}
2
5
10^{4}

Electron Capture Cross Sections for He^{++} in He

Energy (keV)	Cross Sections (cm^2) σ_{20} $He^{++}+He \rightarrow He^{\circ}$	σ_{21} $He^{++}+He \rightarrow He^{+}$
6.0 E-02	4.0 E-16	
1.0 E-01	3.2 E-16	
2.0 E-01	2.6 E-16	
4.0 E-01	2.2 E-16	
7.0 E-01	2.0 E-16	1.3 E-17
1.0 E 00		1.6 E-17
2.0 E 00		2.1 E-17
5.0 E 00		3.2 E-17
7.5 E 00		3.9 E-17
1.0 E 01	1.6 E-16	4.5 E-17
2.0 E 01	1.5 E-16	7.1 E-17
5.0 E 01	1.2 E-16	1.8 E-16
7.5 E 01	1.1 E-16	2.7 E-16
1.0 E 02	9.0 E-17	3.3 E-16
2.0 E 02	4.0 E-17	2.4 E-16
5.0 E 02	5.1 E-18	7.0 E-17
7.5 E 02	9.5 E-19	3.3 E-17
1.0 E 03	2.6 E-19	2.0 E-17
1.4 E 03	3.6 E-20	6.0 E-18
3.0 E 03		3.0 E-19
6.8 E 03		7.3 E-20

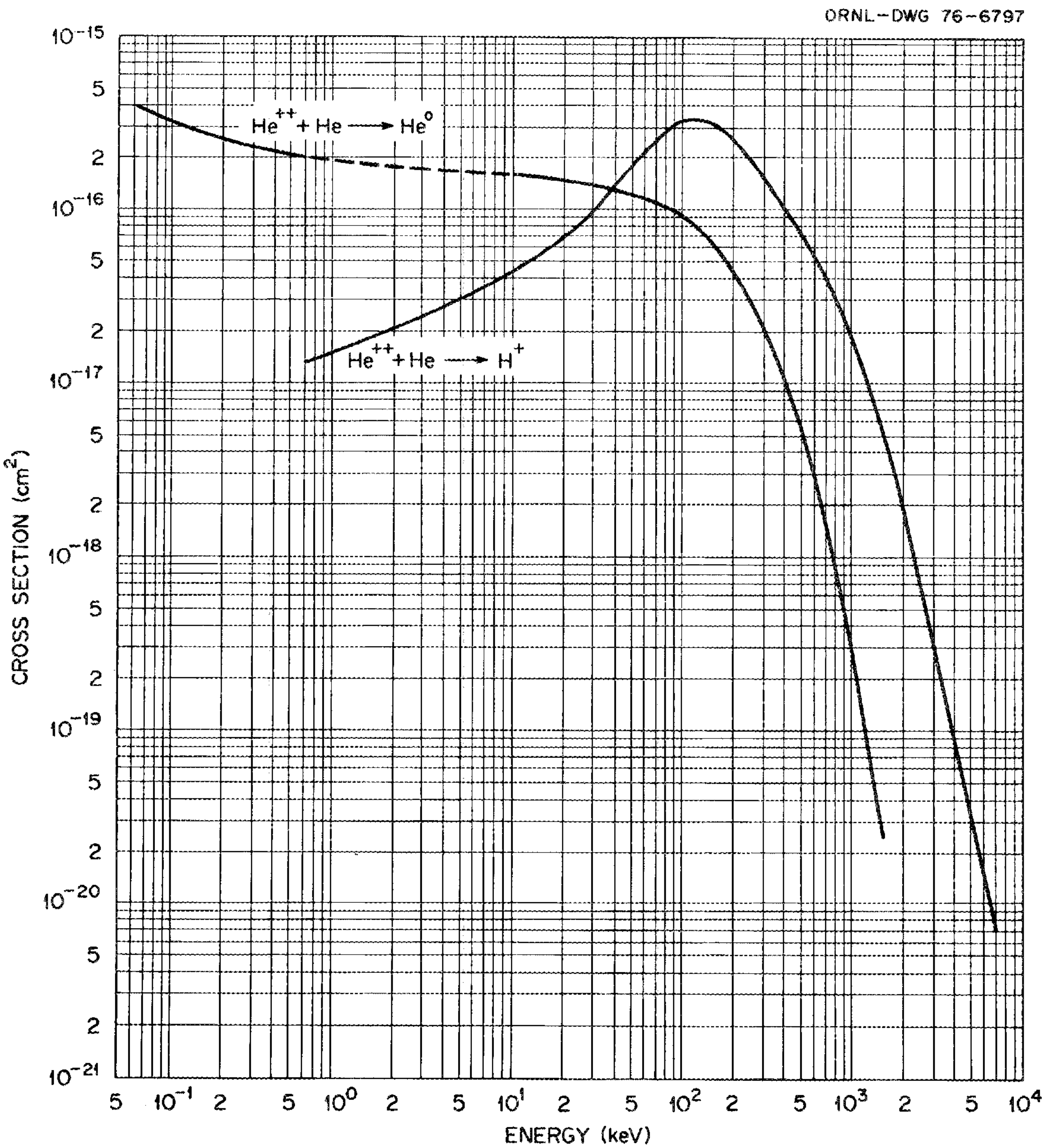
References:

$He^{++}+He \rightarrow He^{+}$: V.V. Afrosimov, G.A. Leĭko, Yu. A. Mamaev, and M.N. Panov, Sov. Phys.-JETP 40, 661 (1975); S. K. Allison, Phys. Rev. 109, 76 (1958); J. E. Bayfield and G. A. Khayrallah, Phys. Rev. A 11, 920 (1975); K. H. Berkner, R. V. Pyle, J. W. Stearns, and J. C. Warren, Phys. Rev. 166, 44 (1968); G. R. Hertel and W. S. Koski, J. Chem. Phys. 40, 3452 (1964); P. Hvelplund, J. Heinemeier, E. H. Pedersen, and F. R. Simpson, 9th Int. Conf. Elect. and Atom. Coll., p. 185, Seattle, Wash. (1975); V. S. Nikolaev, I. S. Dmitriev, L. N. Fateeva, and Ya. A. Teplova, Sov. Phys.-JETP 13, 695 (1961); L. I. Pivovar, V. M. Tubaev, and M. T. Novikov, Sov. Phys.-JETP 14, 20 (1962); L. I. Pivovar, M. R. Novikov, and V. M. Tubaev, Soc. Phys.-JEPT 15, 1035 (1962); M. B. Shah and H. B. Gilbody, J. Phys. B 7, 256 (1974).

$He^{++}+He \rightarrow He^{\circ}$: S. K. Allison, Phys. Rev. 109, 76 (1958); J. E. Bayfield and G. A. Khayrallah, Phys. Rev. A 11, 920 (1975); K. H. Berkner, R. V. Pyle, J. W. Stearns, and J. C. Warren, Phys. Rev. 166, 44 (1968); V. S. Nikolaev, L. N. Fateeva, I. S. Dmitriev, and Ya. A. Teplova, Sov. Phys.-JETP 14, 67 (1962); L. I. Pivovar, M. T. Novikov, and V. M. Tubaev, Soc. Phys.-JETP 15, 1035 (1962); H. Schrey and B. Huber, Z. Phy. A 273, 401 (1975); M. B. Shah and H. B. Gilbody, J. Phys. B 7, 256 (1974).

Accuracy:

$He^{++}+He \rightarrow He^{+}$: ± 25%. $He^{++}+He \rightarrow He^{\circ}$: ± 20%.


ORNL-DWG 76-6797
$He^{++} + He \longrightarrow He^{0}$
$He^{++} + He \longrightarrow H^{+}$
CROSS SECTION (cm^2)
ENERGY (keV)
10^{-15}
10^{-16}
10^{-17}
10^{-18}
10^{-19}
10^{-20}
10^{-21}
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
10^{4}

Electron Capture Cross Sections for He^{++} in N_2 and O_2

Energy (keV)	Cross Sections (cm^2)			
	σ_{21} $He^{++}+N_2 \rightarrow He^+$	σ_{20} $He^{++}+N_2 \rightarrow He^\circ$	σ_{21} $He^{++}+O_2 \rightarrow He^+$	σ_{20} $He^{++}+O_2 \rightarrow He^\circ$
1.0 E 01	5.6 E-16	2.5 E-16	5.6 E-16	3.6 E-16
2.0 E 01	8.9 E-16	3.1 E-16	8.1 E-16	3.8 E-16
3.0 E 01	1.1 E-15	3.3 E-16	8.4 E-16	3.7 E-16
5.0 E 01	1.2 E-15	3.3 E-16	8.5 E-16	3.2 E-16
7.0 E 01	1.2 E-15	3.1 E-16		
1.0 E 02	1.1 E-15	2.6 E-16		
2.0 E 02	6.1 E-16	1.0 E-16		
4.0 E 02	2.0 E-16	1.2 E-17		
7.0 E 02	7.3 E-17	2.0 E-18		
1.0 E 03	3.4 E-17	6.0 E-19		
1.5 E 03	7.7 E-18	1.4 E-19		

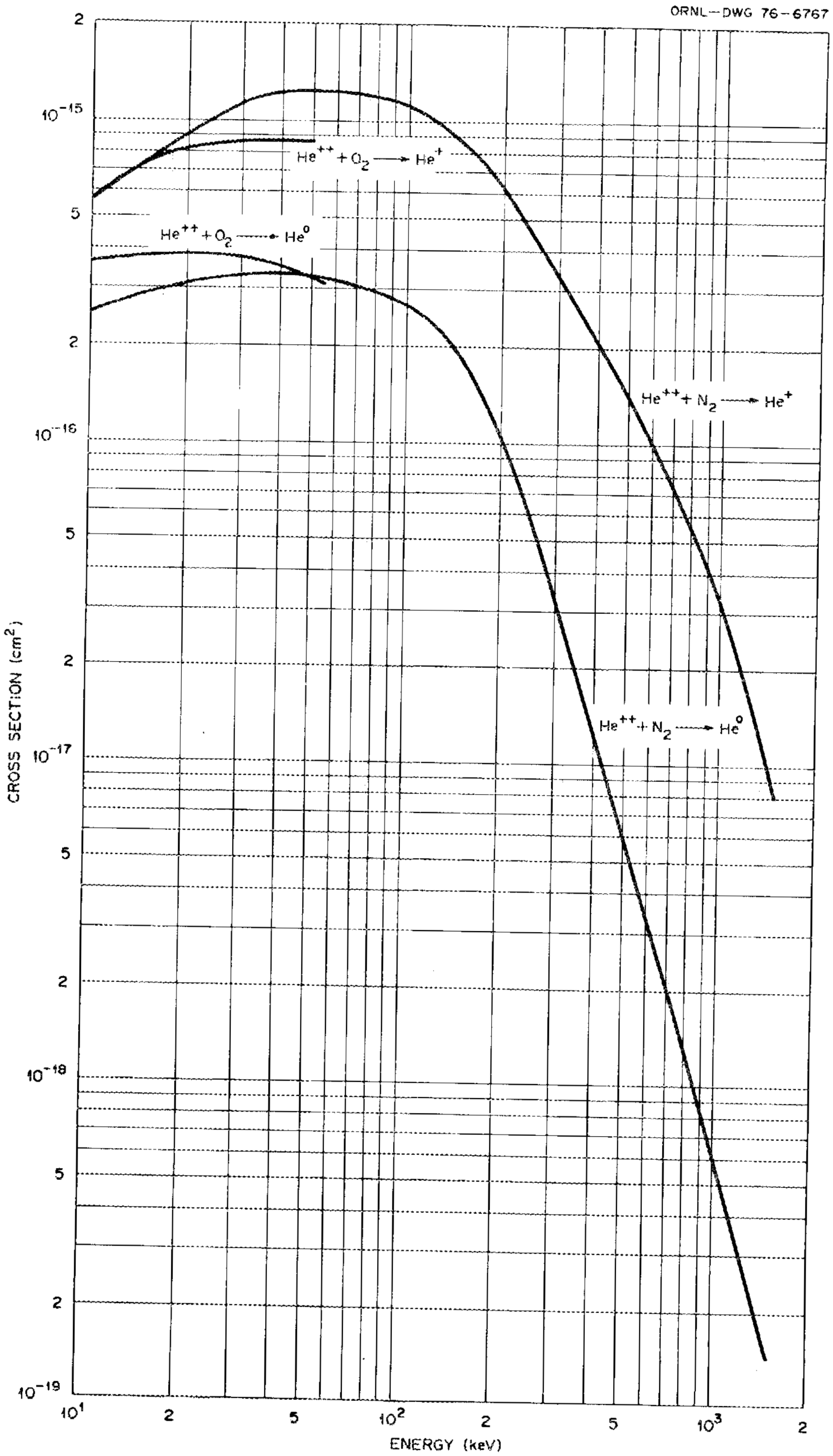
References:

$He^{++}+N_2$: J. E. Bayfield and G. A. Khayrallah, Phys. Rev. A 11, 920 (1975); V. S. Nikolaev, I. S. Dmitriev, L. N. Fateeva, and Ya. A. Teplova, Sov. Phys.-JETP 13, 695 (1961); V. S. Nikolaev, L. N. Fateeva, I. S. Dmitriev, and Ya. A. Teplova, Sov. Phys.-JETP 14, 67 (1962); L. I. Pivovar, M. T. Novikov, and V. M. Tubaev, Sov. Phys.-JETP 15, 1035 (1962); L. I. Pivovar, V. M. Tubaev, and M. T. Novikov, Sov. Phys.-JETP 14, 20 (1962); M. B. Shah and H. B. Gilbody, J. Phys. B 7, 256 (1974).

$He^{++}+O_2$: M. B. Shah and H. B. Gilbody, J. Phys. B 7, 256 (1974).

Accuracy:

$He^{++}+N_2$ - ± 20%. $He^{++}+O_2$ - ± 20%.


ORNL–DWG 76–6767
CROSS SECTION (cm²)
ENERGY (keV)
He⁺⁺ + O₂ → He⁺
He⁺⁺ + O₂ → He⁰
He⁺⁺ + N₂ → He⁺
He⁺⁺ + N₂ → He⁰
10⁻¹⁵
10⁻¹⁶
10⁻¹⁷
10⁻¹⁸
10⁻¹⁹
10¹
10²
10³

Electron Capture Cross Sections for C^+ and C° in H_2

Energy (keV)	Cross Sections (cm^2)		
	σ_{10}	σ_{1-1}	σ_{0-1}
	$C^+ + H_2 \rightarrow C^\circ$	$C^+ + H_2 \rightarrow C^-$	$C^\circ + H_2 \rightarrow C^-$
2.5 E-02	1.0 E-16		
4.0 E-02	1.1 E-16		
7.0 E-02	1.2 E-16		
1.0 E-01	1.3 E-16		
2.0 E-01	1.5 E-16		
4.0 E-01	1.6 E-16		
7.0 E-01	1.9 E-16		
1.0 E 00	1.9 E-16		
2.0 E 00	1.8 E-16		
4.0 E 00	1.7 E-16		
7.0 E 00	1.7 E-16		
1.0 E 01	2.0 E-16	3.1 E-19	
2.5 E 01	4.3 E-16	1.0 E-18	4.5 E-17
4.0 E 01	5.0 E-16	2.2 E-18	4.2 E-17
5.5 E 01		4.0 E-18	5.1 E-17
6.5 E 01			5.5 E-17

References:

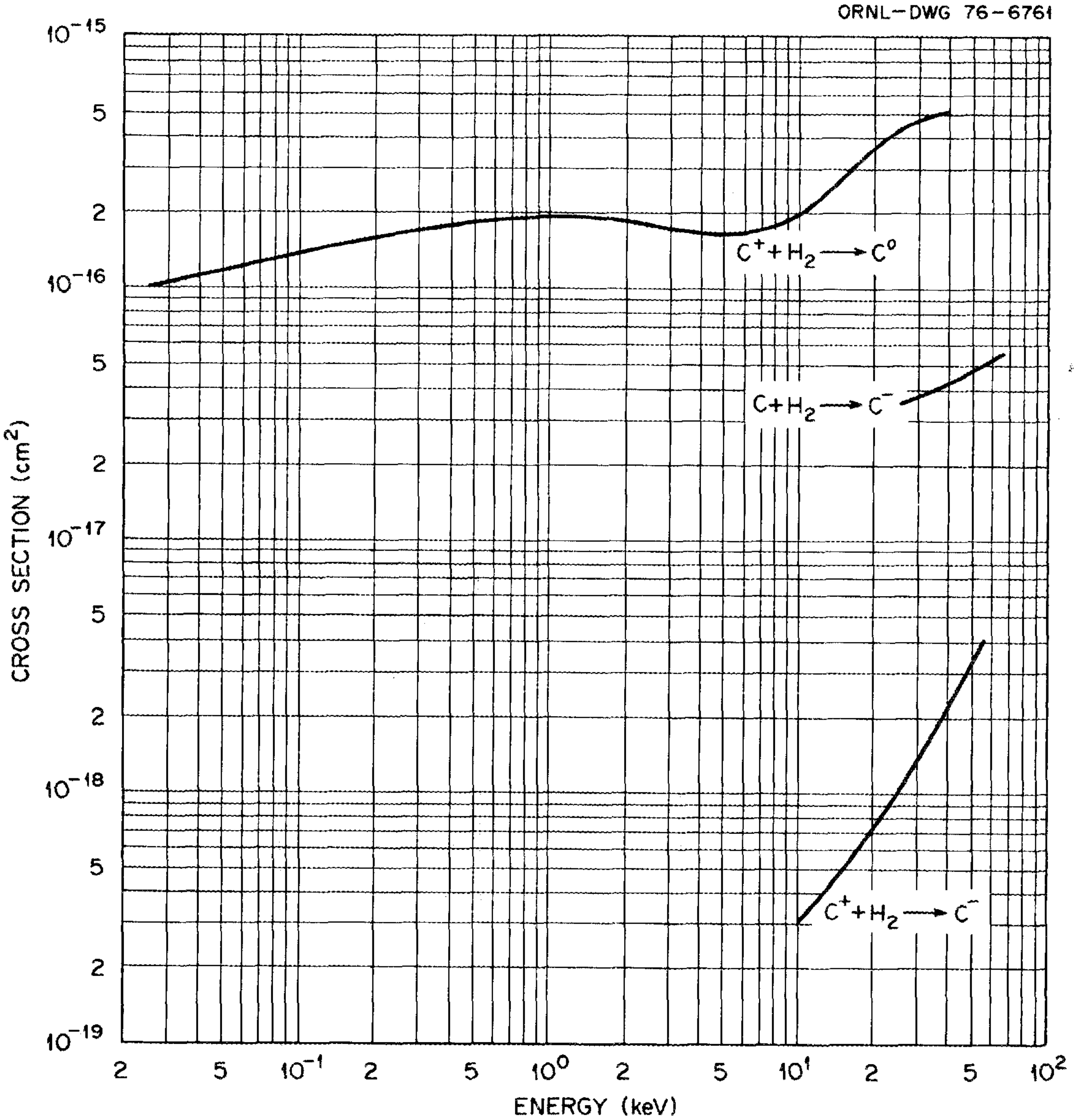
$C^+ + H_2 \rightarrow C^\circ$: H. B. Gilbody and J. B. Hasted, Proc. Roy. Soc. A238, 334 (1956): E. Gustafsson and E. Lindholm, Ark. Fysik, 18, 219 (1960).

$C^+ + H_2 \rightarrow C^-$: Ya. M. Fogel, R. V. Mitin, and A. G. Koval, Sov. Phys.-JETP 4, 359 (1957).

$C + H_2 \rightarrow C^-$: Ya. M. Fogel, V. A. Ankudinov, and D. V. Pilipenko, Sov. Phys.-JETP, 8, 601 (1959).

Accuracy:

Unknown.



ORNL-DWG 76-6761
CROSS SECTION (cm^2)
ENERGY (keV)
$C^+ + H_2 \longrightarrow C^0$
$C + H_2 \longrightarrow C^-$
$C^+ + H_2 \longrightarrow C^-$

Electron Capture Cross Sections for the Reactions

$N^+ + H_2$ and $N^+ + H$

Energy (keV)	Cross Sections (cm^2)	
	σ_{10} $N^+ + H_2 \rightarrow N°$	σ_{10} $N^+ + H \rightarrow N°$
2.5 E-02	1.7 E-16	
4.0 E-02	2.2 E-16	
7.0 E-02	3.1 E-16	
1.0 E-01	3.4 E-16	
2.0 E-01	4.6 E-16	
4.0 E-01	5.5 E-16	
7.0 E-01	6.0 E-16	4.0 E-16
1.0 E 00	6.0 E-16	4.5 E-16
2.0 E 00	6.0 E-16	5.9 E-16
4.0 E 00	6.2 E-16	7.8 E-16
7.0 E 00	6.8 E-16	9.2 E-16
1.0 E 01	8.5 E-16	1.0 E-15
2.0 E 01	1.1 E-15	
3.5 E 01	1.2 E-15	

References:

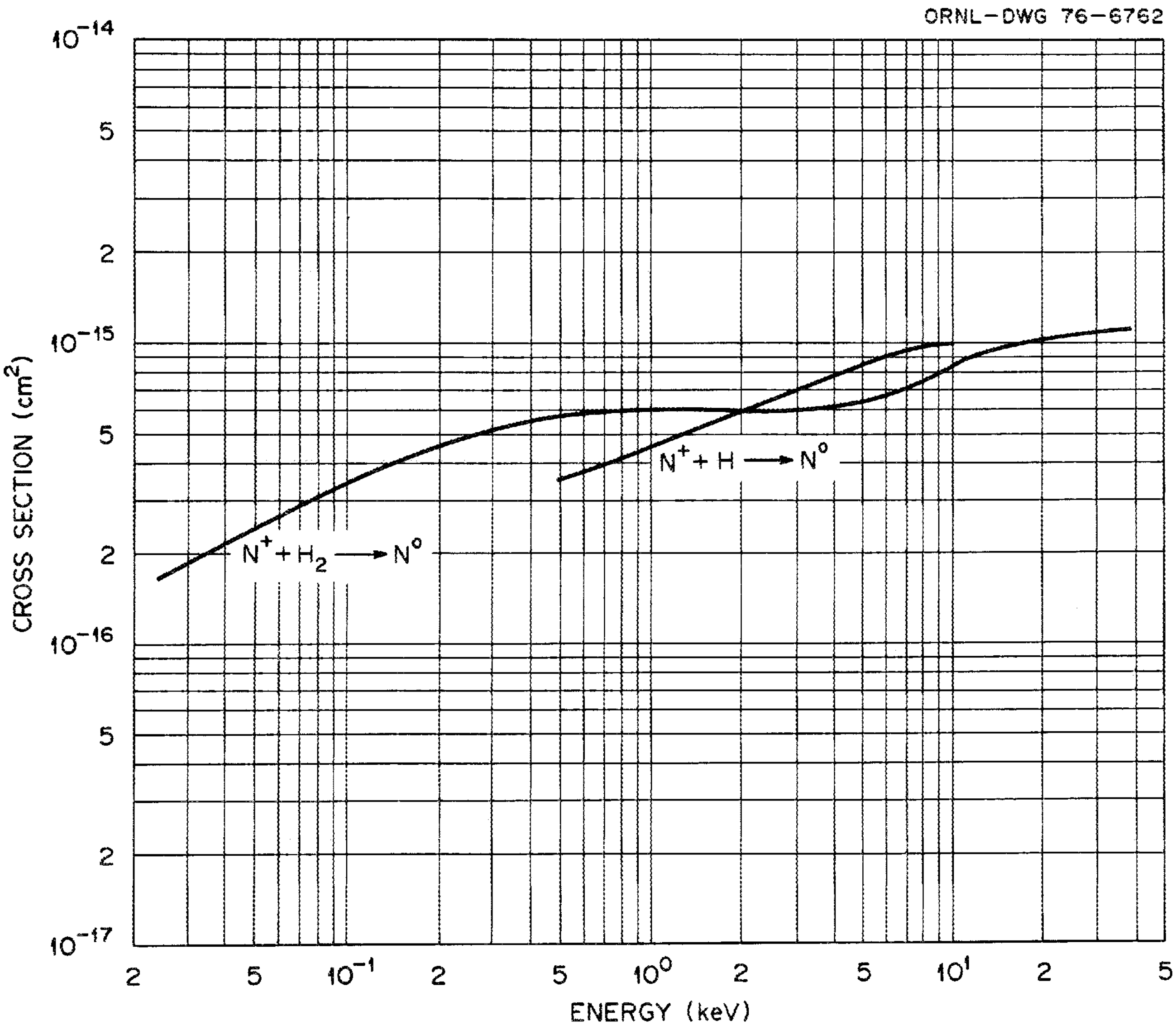
$N^+ + H_2$: F. J. De Heer, W. Huizenga, and J. Kistemaker, Physica 23, 181 (1957); H. B. Gilbody and J. B. Hasted, Proc. Roy. Soc. A238, 334 (1956); E. Gustafsson and E. Lindholm, Ark. Fysik 18, 219 (1960).

$N^+ + H$: R. F. Stebbings, W. L. Fite and D. G. Hummer, J. Chem. Phys. 33, 1226 (1960).

Accuracy:

$N^+ + H_2$: ± 50%.

$N^+ + H$: ± 20%.


ORNL-DWG 76-6762
CROSS SECTION (cm^2)
ENERGY (keV)
10^{-14}
5
2
10^{-15}
5
2
10^{-16}
5
2
10^{-17}
2
5
10^{-1}
2
5
10^{0}
2
5
10^{1}
2
5
$N^+ + H_2 \longrightarrow N^0$
$N^+ + H \longrightarrow N^0$

Electron Capture Cross Sections for the Reactions

$O^+ + H \rightarrow O^\circ$, $O^+ + H_2 \rightarrow O^\circ$, and $O^+ + H_2 \rightarrow O^-$

Energy (keV)	Cross Sections (cm^2)		
	σ_{10}	σ_{10}	$\sigma_{1\bar{1}}$
	$O^+ + H \rightarrow O^\circ$	$O^+ + H_2 \rightarrow O^\circ$	$O^+ + H_2 \rightarrow O^-$
2.5 E-02	1.4 E-15		
4.0 E-02	1.4 E-15		
7.0 E-02	1.3 E-15		
1.0 E-01	1.3 E-15		
2.0 E-01	1.2 E-15		
4.0 E-01	1.1 E-15		
7.0 E-01	1.0 E-15		
1.0 E 00	9.8 E-16		
2.0 E 00	9.2 E-16		
4.0 E 00	8.6 E-16		
7.0 E 00	8.1 E-16		
1.0 E 01			
2.0 E 01			
5.0 E 01		8.0 E-16	6.1 E-17
7.0 E 01		7.0 E-16	5.5 E-17
1.0 E 02		5.7 E-16	4.6 E-17
2.0 E 02		3.4 E-16	2.8 E-17
5.0 E 02		1.5 E-16	

References:

$O^+ + H \rightarrow O^\circ$: W. L. Fite, A. C. H. Smith, and R. F. Stebbings, Proc. Roy. Soc. A268, 527 (1962): R. F. Stebbings, W. L. Fite, and D. G. Hummer, J. Chem. Phys. 33, 1226 (1960).

$O^+ + H_2 \rightarrow O^-$: T. Jorgensen, Jr., G. E. Kuyatt, W. W. Lang, D. C. Lorentz, and C. A. Sautter, Phys. Rev. 140, A 1481 (1965).

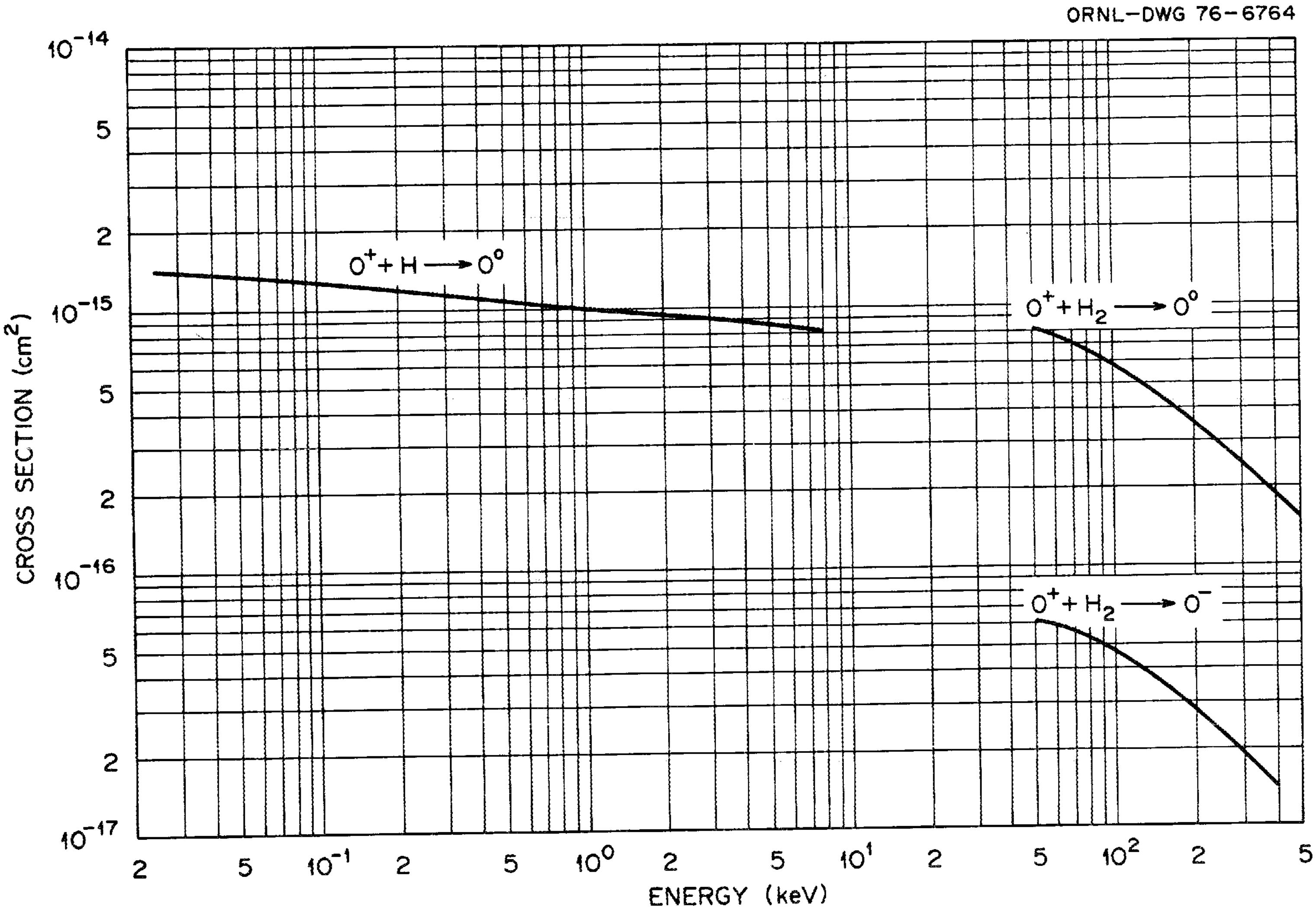
$O^+ + H_2 \rightarrow O^\circ$: T. Jorgensen, Jr., G. E. Kuyatt, W. W. Lang, D. C. Lorentz, and C. A. Sautter, Phys. Rev. 140, A1481 (1965); J. Ø. Olsen and P. Hvelplund, J. Phys. B 7, 1331 (1974).

Accuracy:

$O^+ + H_2 \rightarrow O^\circ$: ± 25%.

$O^+ + H \rightarrow O^\circ$: ± 20%.

$O^+ + H_2 \rightarrow O^-$: ± 25%.


ORNL-DWG 76-6764
$O^+ + H \longrightarrow O^0$
$O^+ + H_2 \longrightarrow O^0$
$O^+ + H_2 \longrightarrow O^-$
CROSS SECTION (cm^2)
ENERGY (keV)
10^{-14}
5
2
10^{-15}
5
2
10^{-16}
5
2
10^{-17}
2
5
10^{-1}
2
5
10^0
2
5
10^1
2
5
10^2
2
5

Electron Capture Cross Sections for

O° and O^{++} in H_2

Energy (keV)	Cross Sections (cm^2)		
	σ_{21}	σ_{20}	$\sigma_{0\bar{1}}$
	$O^{++}+H_2 \rightarrow O^+$	$O^{++}+H_2 \rightarrow O^{\circ}$	$O^{\circ}+H_2 \rightarrow O^-$
2.5 E 01			8.9 E-17
5.0 E 01	4.7 E-16	2.4 E-17	1.2 E-16
7.0 E 01	4.6 E-16	2.4 E-17	1.4 E-16
1.0 E 01	4.6 E-16	2.4 E-17	1.4 E-16
2.0 E 02	4.7 E-16	2.4 E-17	8.7 E-17
3.0 E 02	4.8 E-16	2.4 E-17	6.2 E-17
5.0 E 02	5.1 E-16		4.1 E-17

References:

$O^{++}+H_2 \rightarrow O^+$: T. Jorgensen, Jr., G. E. Kuyatt, W. W. Lang, D. C. Lorentz, and C. A. Sautter, Phys. Rev. 140, A1481 (1965); J. Ø. Olsen and P. Hvelplund, J. Phys. B 7, 1331 (1974).

$O^{++}+H_2 \rightarrow O^{\circ}$: T. Jorgensen, Jr., G. E. Kuyatt, W. W. Lang, D. C. Lorentz, and C. A. Sautter, Phys. Rev. 140, A1481 (1965); J. Ø. Olsen and P. Hvelplund, J. Phys. B 7, 1331 (1974).

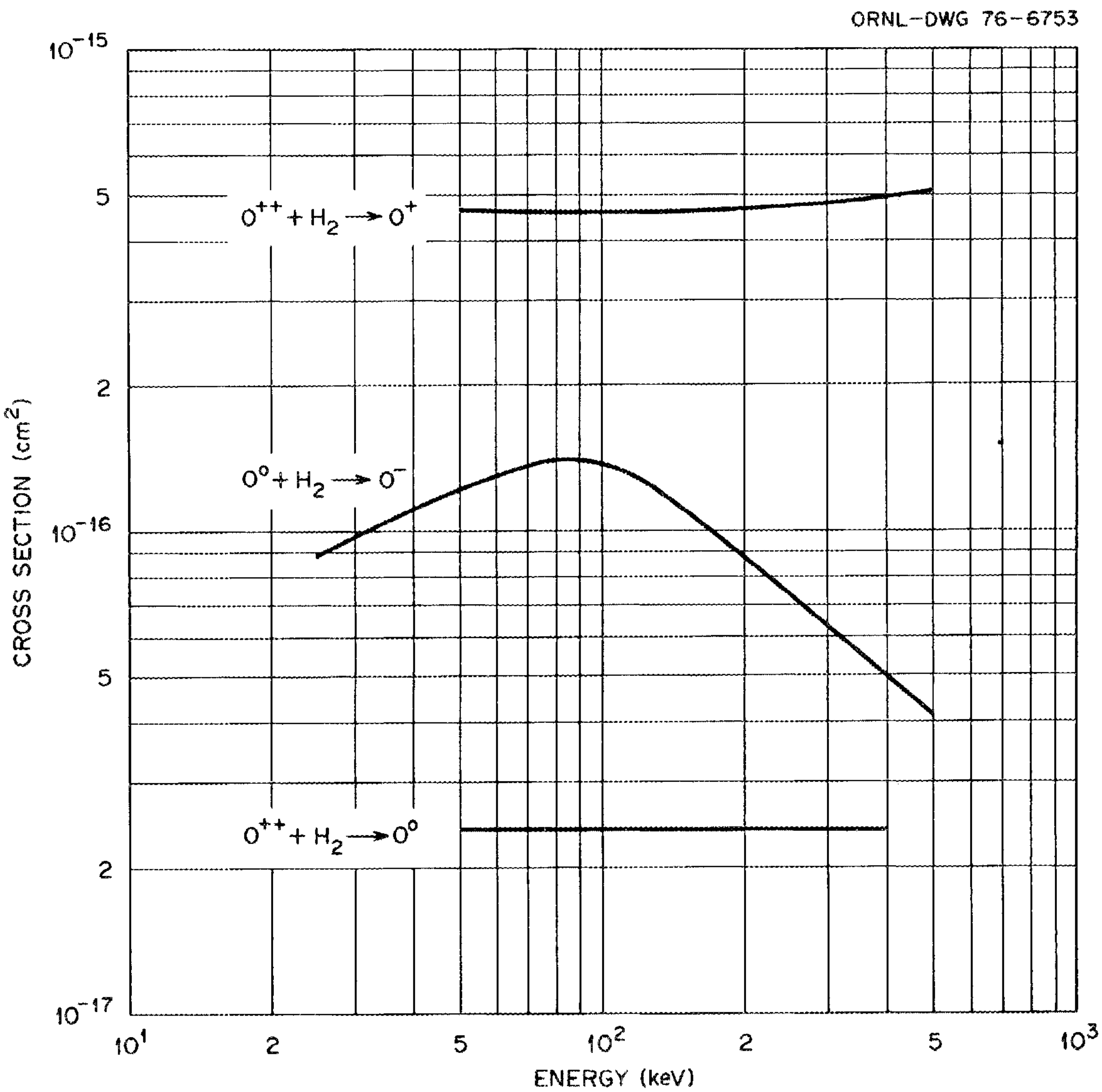
$O^{\circ}+H_2 \rightarrow O^-$: Ya. M. Fogel, V. A. Ankudinov, D. V. Pilipenko, Sov. Phys.-JETP 8, 601 (1959); T. Jorgensen, Jr., G. E. Kuyatt, W. W. Lang, D. C. Lorentz, and C. A. Sautter, Phys. Rev. 140, A1481 (1965); J. Ø. Olsen and P. Hvelplund, J. Phys. B 7, 1331 (1974).

Accuracy:

$O^{++}+H_2 \rightarrow O^+$: ± 20%.

$O^{++}+H_2 \rightarrow O^{\circ}$: Unknown.

$O^{\circ}+H_2 \rightarrow O^-$: ± 40%.



ORNL-DWG 76-6753
$O^{++} + H_2 \longrightarrow O^+$
$O^0 + H_2 \longrightarrow O^-$
$O^{++} + H_2 \longrightarrow O^0$
CROSS SECTION (cm^2)
10^{-15}
5
2
10^{-16}
5
2
10^{-17}
10^1
2
5
10^2
2
5
10^3
ENERGY (keV)

(Continuations)

Electron Capture Cross Sections for H^+ and H° Passing Through H_2

References: (contd.)

$H^+ + H_2 \rightarrow H^-$: V. V. Afrosimov, G. A. Leiko, Yu. A. Mamaev, M. N. Panov, and N. V. Fedorenko, Sov. Phys.-JETP 35, 1070 (1972); V. F. Kozlov and S. A. Bondar, Sov. Phys.-JETP 23, 195 (1966); G. M. McClure, Phys. Rev. 132, 1636 (1963); Ya. M. Fogel, R. V. Mitin, V. F. Kozlov, and N. D. Romashko, Sov. Phys.-JETP 35, 390 (1959); U. Schryber, Hel. Phy. Act. A40, 1023 (1967); L. H. Toburen and M. Y. Nakai, Phys. Rev. 177, 191 (1969); J. F. Williams, Phys. Rev. 150, 7 (1966); J. F. Williams, Phys. Rev. 157, 97 (1967).

$H^\circ + H_2 \rightarrow H^-$: V. V. Afrosimov, G. A. Leǐko, Yu. A. Mamaev, M. N. Panov, and N. V. Fedorenko, Sov. Phys.-JETP 35, 1070 (1972); G. M. McClure, Phys. Rev. 134, A1226 (1964); T. Jorgensen, Jr., C. E. Kuyatt, W. W. Lang, D. C. Lorentz, and C. A. Sautter, Phys. Rev. 140, A1481 (1965); U. Schryber, Hel. Phy. Act. A40, 1023 (1967); P. M. Stier and C. F. Barnett, Phys. Rev. 103, 896 (1956); J. F. Williams, Phys. Rev. 153, 116 (1967).

Accuracy:

σ_{10} ± 30%

σ_{1-1} ± 50%

σ_{0-1} ± 40%

Notes:

σ_{1-1} has not been plotted for energies greater than 400 keV. For cross sections between 400-1000 keV see J. F. Williams, Phys. Rev. 157, 97 (1967).

Electron Capture Cross Sections for H^+ and H° Passing Through Helium

References: (contd.)

$H^\circ + He \rightarrow H^-$: Ya. M. Fogel, V. A. Ankudinov, D. V. Pilipenko, and N. V. Topolia, Sov. Phys.-JETP 34, 400 (1958); P. M. Stier and C. F. Barnett, Phys. Rev. 103, 896 (1956); U. Schryber, Hel. Phy. Act. A40, 1023 (1967).

Accuracy:

σ_{10} ± 25%

σ_{1-1} E > 10 keV ± 25%; E > 10 keV ± 60%

σ_{0-1} ± 25%

Notes:

Berkner, *et al.*, results for D^+ in He has been plotted at E/2.

(Continuations)

Electron Capture Cross Sections for H^+ and H° Passing Through N_2

References: (contd.)

$H^\circ + N_2 \rightarrow H^-$: S. K. Allison, Rev. Mod. Phys. 30, 1137 (1958); Ya. M. Fogel, V. A. Ankudinov, D. V. Pilipenko, and N. V. Topolia, Sov. Phys.-JETP 7, 400 (1958); D. V. Pilipenko and Ya. M. Fogel, Sov. Phys.-Tech, Phys. 15, 646 (1962); P. M. Stier and C. F. Barnett, Phys. Rev. 103, 896 (1956).

$H^+ + N_2 \rightarrow H^-$: S. K. Allison, Rev. Mod. Phys. 30, 1137 (1958); Ya. M. Fogel and R. V. Miten, Sov. Phys.-JETP 3, 334 (1956); U. Schryber, Helv. Phys. Acta. A40, 1023 (1967); L. H. Toburen, M. Y. Nakai, and R. A. Langley, Phys. Rev. 171, 114 (1968).

Accuracy:

σ_{10} ± 20%

σ_{1-1} ± 20%

σ_{0-1} ± 25%

Electron Capture Cross Sections for H^+ and H° Passing Through O and O_2

References: (contd.)

$H^+ + O \rightarrow H^-$: R. F. Stebbings, A. C. H. Smith, and H. Ehrhardt, J. Geophys. Res. 69, 2349 (1964).

$H^\circ + O_2 \rightarrow H^-$: Ya. M. Fogel, V. A. Aukudinov, D. V. Pilipenko, and N. V. Topolia, Sov. Phys.-Tech. Phys. 7, 400 (1958); D. V. Pilipenko and Ya. M. Fogel, Sov. Phys.-JETP 15, 646 (1962); P. M. Stier and C. F. Barnett, Phys. Rev. 103, 896 (1956).

$H^+ + O_2 \rightarrow H^-$: Ya. M. Fogel and R. V. Mitin, Sov. Phys.-JETP 3, 334 (1956).

Accuracy:

σ_{10} (O_2) = ± 30%

σ_{0-1} (O_2) = ± 25%

σ_{10} (O) = ± 30%

σ_{1-1} = unknown

(Continuations)

Electron Capture Cross Sections for H^+ and H°

Passing Through Ar

References: (contd.)

$H^+ + Ar \rightarrow H^-$: V. V. Afrosimov, Yu. A. Mamaev, M. P. Panov, and V. Uroskevich, Sov. Phys.-Tech. Phys. 12, 512 (1967); Ya. M. Fogel, Sov. Phys.-Usp. 3, 390 (1960); V. V. Afrosimov, R. N. Il'in, and E. S. Solov'ev, Sov. Phys.-Tech. Phys. 5, 661 (1960); U. Schryber, Helv. Phys. Acta 40, 1023 (1967); L. H. Toburen, M. Y. Nakai, and R. A. Langley, Phys. Rev. 177, 191 (1969); J. F. Williams, Phys. Rev. 150, 7 (1966).

$H^\circ + Ar \rightarrow H^-$: T. M. Donahue and F. Hushfar, Phys. Rev. 124, 138 (1961); Ya. M. Fogel, V. A. Ankudinov, D. V. Phipenko, and N. V. Topolia, Sov. Phys.-JETP 7, 400 (1958); U. Schryber, Helv. Phys. Acta 40, 1023 (1967); P. M. Stier and C. F. Barnett, Phys. Rev. 103, 896 (1956); J. F. Williams, Phys. Rev. 153, 117 (1967).

Accuracy:

σ_{10} - ± 25% σ_{0-1} ± 40% σ_{1-1} ± 40%

Electron Capture Cross Sections for

He^+ in H_2 and He

References: (contd.)

$He^+ + He$: S. K. Allison, J. Cuevas, P. G. Murphy, Phys. Rev. 102, 1041 (1956); C. F. Barnett and P. M. Stier, Phys. Rev. 109, 385 (1958); N. V. Fedorenko, L. G. Filippenko, and I. P. Flaks, Sov. Phys.-Tech. Phys. 5, 45 (1960); A. Galli, A. Giardini-Guidoni, G. G. Volpi, Nuovo Cimento 26, 845 (1962); F. J. DeHeer, J. Schutten and H. Moustafa, Physica 32, 1793 (1966); H. B. Gilbody, J. B. Hasted, J. V. Ireland, A. R. Lee, E. W. Thomas, and A. S. Whiteman, Proc. Roy. Soc. London A274, 40 (1963); H. B. Gilbody and J. B. Hasted, Proc. Roy. Soc. London A238, 334 (1956); H. C. Hayden and N. G. Utterback, Phys. Rev. 135, A1575 (1964); P. Mahadevan and G. D. Magnuson, Phys. Rev. 171, 103 (1968); L. I. Pivovar, V. M. Tubaev, and M. T. Novikov, Sov. Phys.-JETP 14, 20 (1962); R. F. Potter, J. Chem. Phys. 22, 974 (1954); W. N. Shelton and P. A. Stoycheff, Phys. Rev. A 3, 613 (1971); J. B. H. Stedeford and J. B. Hasted, Proc. Roy. Soc. London A227, 446 (1954).

Accuracy:

$He^+ + H_2$: ± 15%

$He^+ + He$: ± 15%

A.5 Ionization and Stripping by Heavy Particles

Cross Sections for Ionization of Atomic H by H^+

Energy (keV)	Cross Section (cm^2)
5.3 E 00	4.06 E-17
1.0 E 01	9.14 E-17
3.0 E 01	1.49 E-16
5.0 E 01	1.71 E-16
1.0 E 02	1.42 E-16
1.5 E 02	1.07 E-16
2.0 E 02	8.40 E-17
2.5 E 02	6.88 E-17
3.0 E 02	5.59 E-17
4.0 E 02	4.18 E-17

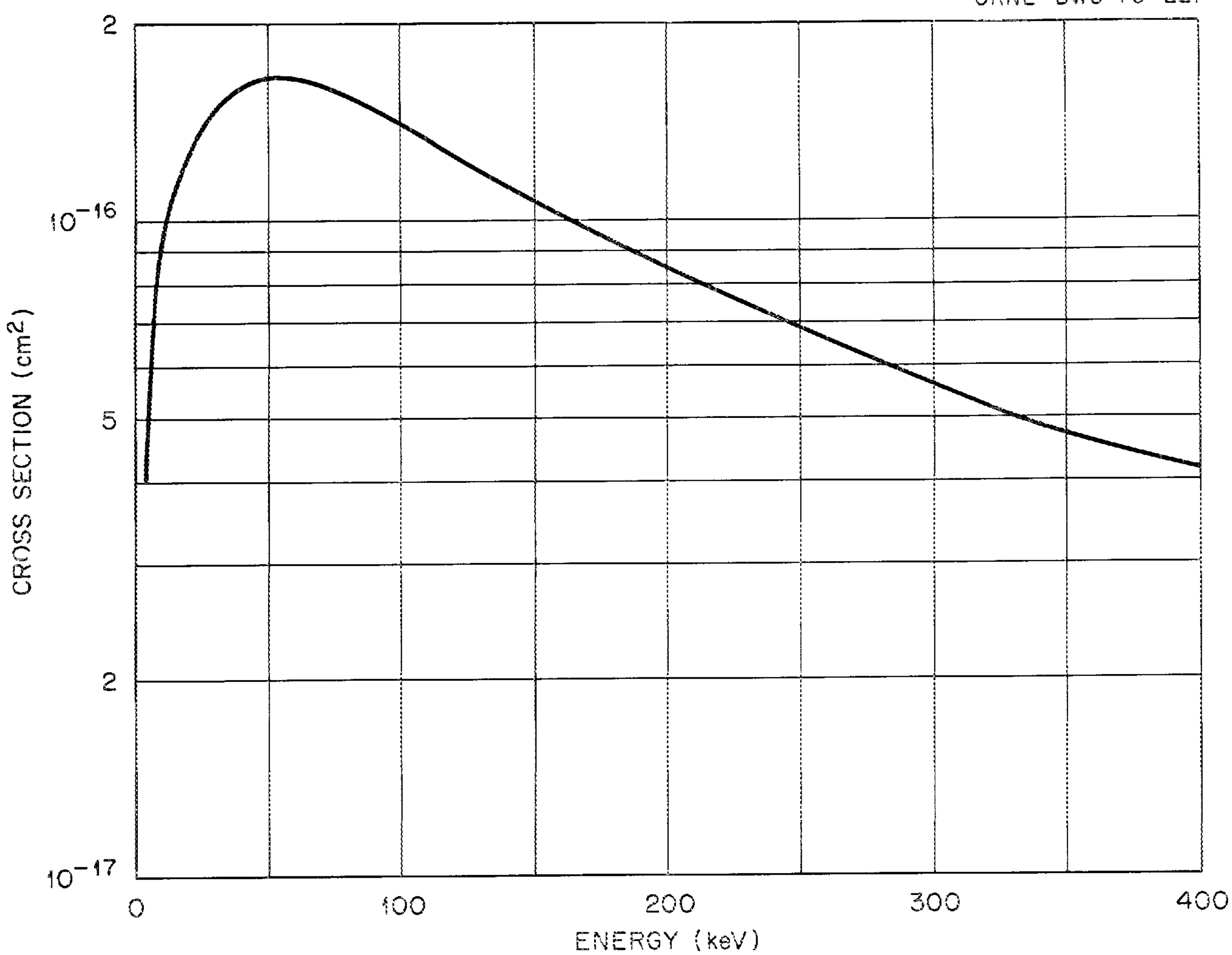
References:

W.L. Fite, R.F. Stebbings, D.G. Hummer, and R.T. Brackmann, Phys. Rev. 119, 663 (1960); H.B. Gilbody and J.V. Ireland, Proc. Roy. Soc. A-277, 137 (1964).

Accuracy:

± 20%.

ORNL-DWG 75-221



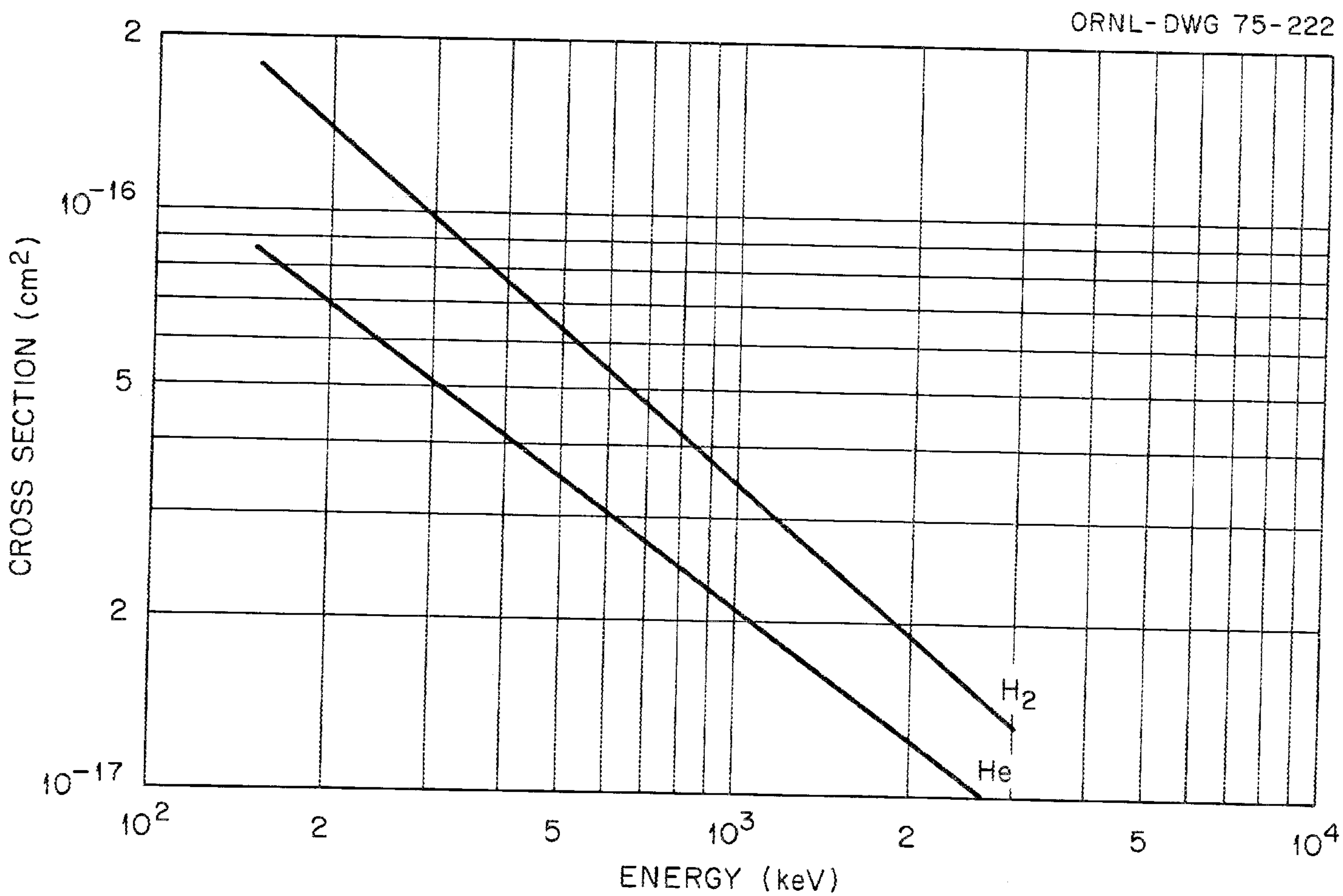
Cross Sections for the Production of

Positive Charges in H_2 and He by H^+

Energy (keV)	Cross Sections (cm^2)	
	H_2	He
1.5 E 02	1.77 E-16	8.66 E-17
2.0 E 02	1.40 E-16	6.99 E-17
4.0 E 02	7.59 E-17	4.16 E-17
6.0 E 02	5.37 E-17	3.08 E-17
8.0 E 02	4.18 E-17	2.48 E-17
1.0 E 03	3.44 E-17	2.09 E-17
2.0 E 03	1.91 E-17	1.24 E-17
3.0 E 03	1.35 E-17	9.29 E-18

References:

E.W. McDaniel, J.W. Hooper, D.W. Martin, and D.S. Harmer, Proc. Fifth Int. Conf. on Ionization Phenomena in Gases (Munich, 1961) North-Holland Publishing Co. (Amsterdam) Vol. 1, 60 (1962); L.I. Pivovar and Yu. Z. Levchenko, Sov. Phys.-JETP 25, 27 (1967).


ORNL-DWG 75-222
CROSS SECTION (cm^2)
10^{-16}
10^{-17}
2
5
2
H_2
He
10^2
2
5
10^3
2
5
10^4
ENERGY (keV)

Cross Sections for Production of Free Electrons in H_2 and He by Protons

Energy (keV)	Cross Sections (cm^2) H_2	He
1.0 E 00	2.81 E-17	
2.0 E 00	4.18 E-17	
4.0 E 00	6.19 E-17	
6.0 E 00	7.96 E-17	
8.0 E 00	9.29 E-17	
1.0 E 01	1.05 E-16	2.18 E-17
2.0 E 01	1.55 E-16	3.60 E-17
4.0 E 01	2.27 E-16	6.08 E-17
6.0 E 01	2.57 E-16	8.23 E-17
8.0 E 01	2.47 E-16	9.52 E-17
1.0 E 02	2.26 E-16	9.87 E-17
2.0 E 02	1.36 E-16	7.01 E-17
4.0 E 02	7.48 E-17	4.15 E-17
6.0 E 02	5.30 E-17	3.04 E-17
8.0 E 02	4.20 E-17	2.47 E-17
1.0 E 03	3.35 E-17	2.09 E-17
2.0 E 03	1.84 E-17	1.23 E-17
3.0 E 03	1.30 E-17	9.00 E-18

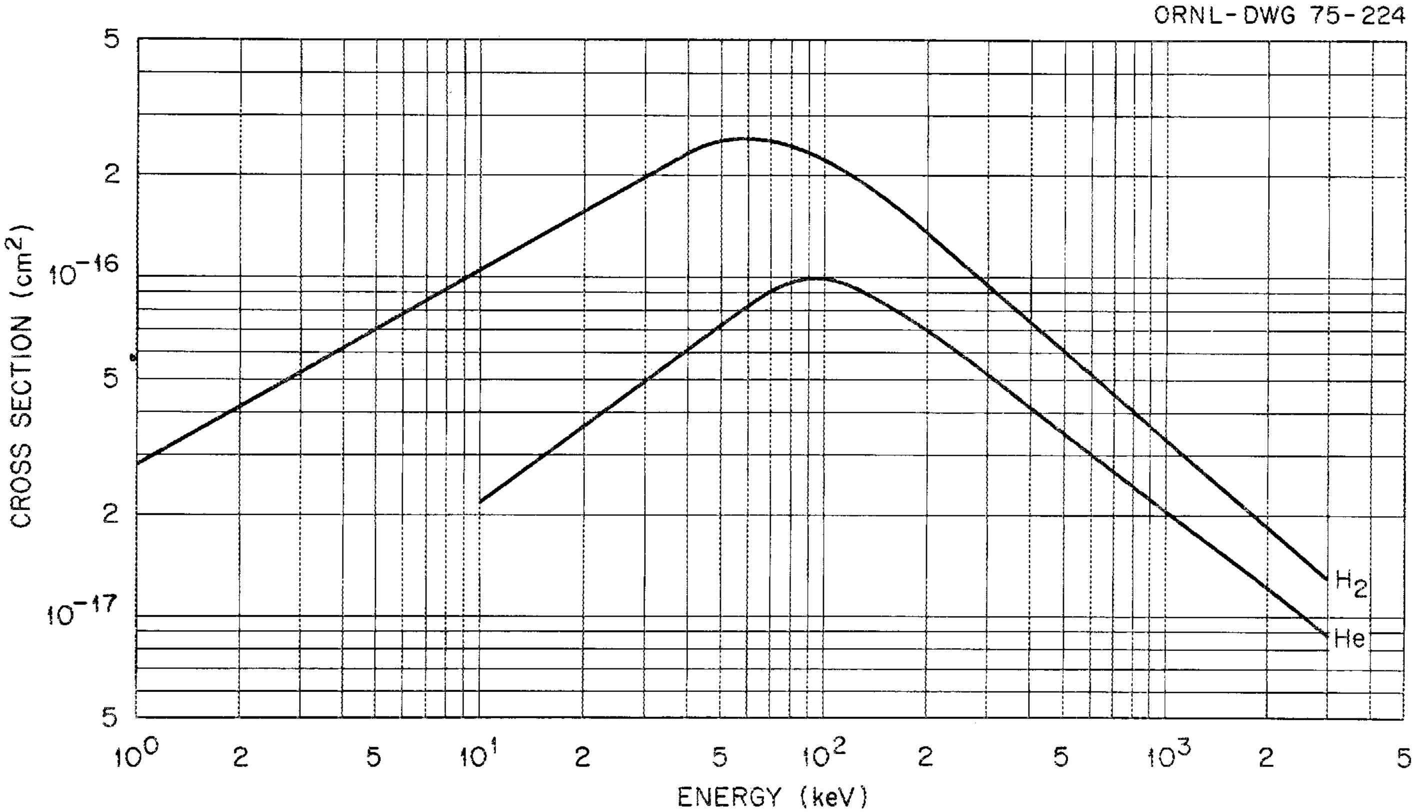
References:

$H^+ + H_2$: J.W. Hooper, E.W. McDaniel, D.W. Martin, and D.S. Harmer, Phys. Rev. 121, 1123 (1961); L.I. Pivovar and Yu. Z. Levchenko, Soviet Phys.-JETP 25, 27 (1967); Yu. S. Gordeev and M.N. Panov, Soviet Phys.-Tech. Phys. 9, 656 (1964); E.S. Solov'ev, R.N. Il'in, V.A. Oparin, and N.V. Fedorenko, Soviet Phys.-JETP 15, 459 (1962); F.J. de Heer, J. Schutten, and H. Moustafa, Physica 32, 1766 (1966); V.V. Afrosimov, R.N. Il'in, and N.V. Fedorenko, Soviet Phys.-JETP 7, 968 (1958); F. Schwirzke, Z. Phys. 157, 510 (1960); Ya. M. Fogel, L.I. Krupnik, and B.G. Safronov, Soviet Phys.-JETP 1, 415 (1955); H.B. Gilbody and A.R. Lee, Proc. Phys. Soc. A-274, 365 (1963); M.E. Rudd, C.A. Sautter, and C.L. Bailey, Phys. Rev. 151, 20 (1966).

H^+ + He: E.W. McDaniel, J.W. Hooper, D.W. Martin, and D.S. Harmer, Proc. Fifth Int. Conf. on Ionization Phenomena in Gases (Munich, 1961) North-Holland Publishing Co. (Amsterdam) Vol. 1, 60 (1962); L.I. Pivovar and Yu. Z. Levchenko, Soviet Phys.-JETP 25, 27 (1967); F.J. de Heer, J. Schutten, and H. Moustafa, Physica 32, 1766 (1966); H.B. Gilbody and A.R. Lee, Proc. Roy. Soc. A-274, 365 (1963); N.V. Fedorenko, V.V. Afrosimov, R.N. Il'in, and E.S. Solov'ev, Proc. Fourth Int. Conf. on Ionization Phenomena in Gases (Uppsala, 1959), North Holland Publishing Co. (Amsterdam) Vol. 1, IA-47 (1960).

Accuracy:

± 25%.


ORNL-DWG 75-224
CROSS SECTION (cm^2)
5
2
10^{-16}
5
2
10^{-17}
5
10^0
2
5
10^1
2
5
10^2
2
5
10^3
2
5
ENERGY (keV)
H_2
He

Cross Sections for the Production of Slow

H_2^+ and H^+ from H^+ and H^0 Impact on H_2

Energy (keV)	Cross Sections (cm^2)			
	$H^+ + H_2 \rightarrow H_2^+$	$H^+ + H_2 \rightarrow H^+$	$H^0 + H_2 \rightarrow H_2^+$	$H^0 + H_2 \rightarrow H^+$
5.0 E 00	8.1 E-16	4.0 E-17	4.0 E-17	2.6 E-18
1.0 E 01	8.0 E-16	9.3 E-17	8.2 E-17	1.1 E-17
2.0 E 01	6.2 E-16	1.2 E-16	1.3 E-16	1.7 E-17
3.0 E 01	4.8 E-16	8.7 E-17	1.3 E-16	1.6 E-17
4.0 E 01	3.8 E-16	6.3 E-17	1.2 E-16	1.5 E-17
5.0 E 01	3.4 E-16	4.4 E-17	1.2 E-16	1.2 E-17

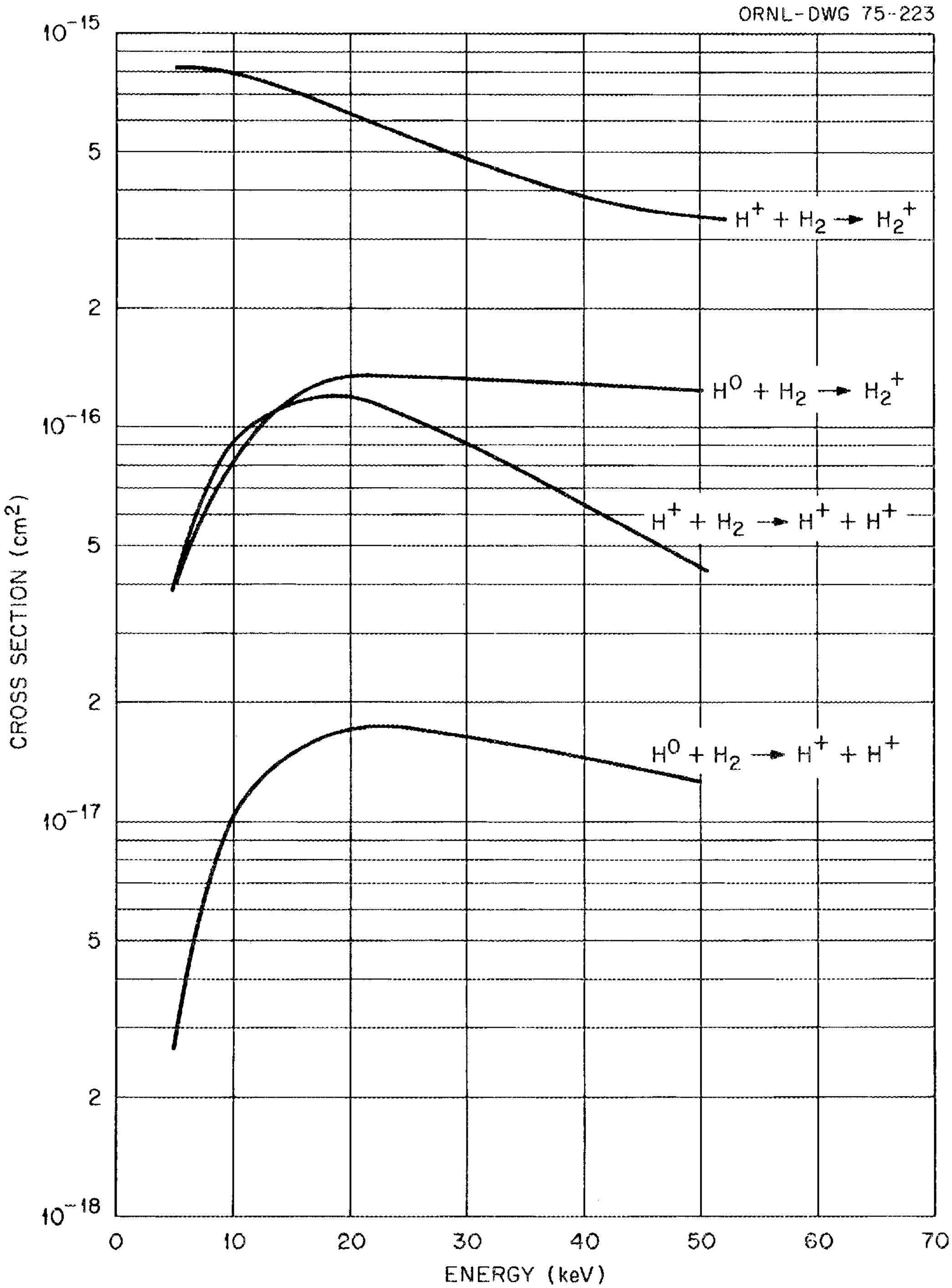
References:

$H^+ + H_2$: V.V. Afrosimov, G.A. Leĭko, Yu. A. Mamaev, M.M. Panov, and N.V. Fedorenko, Sov. Phys.-JETP 35, 1070 (1972); R. Browning and H.B. Gilbody, J. Phys. B 1, 1149 (1968).

$H^0 + H_2$: V.V. Afrosimov, G.A. Leĭko, Yu. A. Mamaev, M.M. Panov, and N.V. Fedorenko, Sov. Phys.-JETP 35, 1070 (1972).

Accuracy:

± 20%.


ORNL-DWG 75-223
CROSS SECTION (cm^2)
ENERGY (keV)
10^{-15}
5
2
10^{-16}
5
2
10^{-17}
5
2
10^{-18}
0
10
20
30
40
50
60
70
$H^+ + H_2 \rightarrow H_2^+$
$H^0 + H_2 \rightarrow H_2^+$
$H^+ + H_2 \rightarrow H^+ + H^+$
$H^0 + H_2 \rightarrow H^+ + H^+$

Cross Sections for Positive Ion Production in N_2 and O_2 by H^+

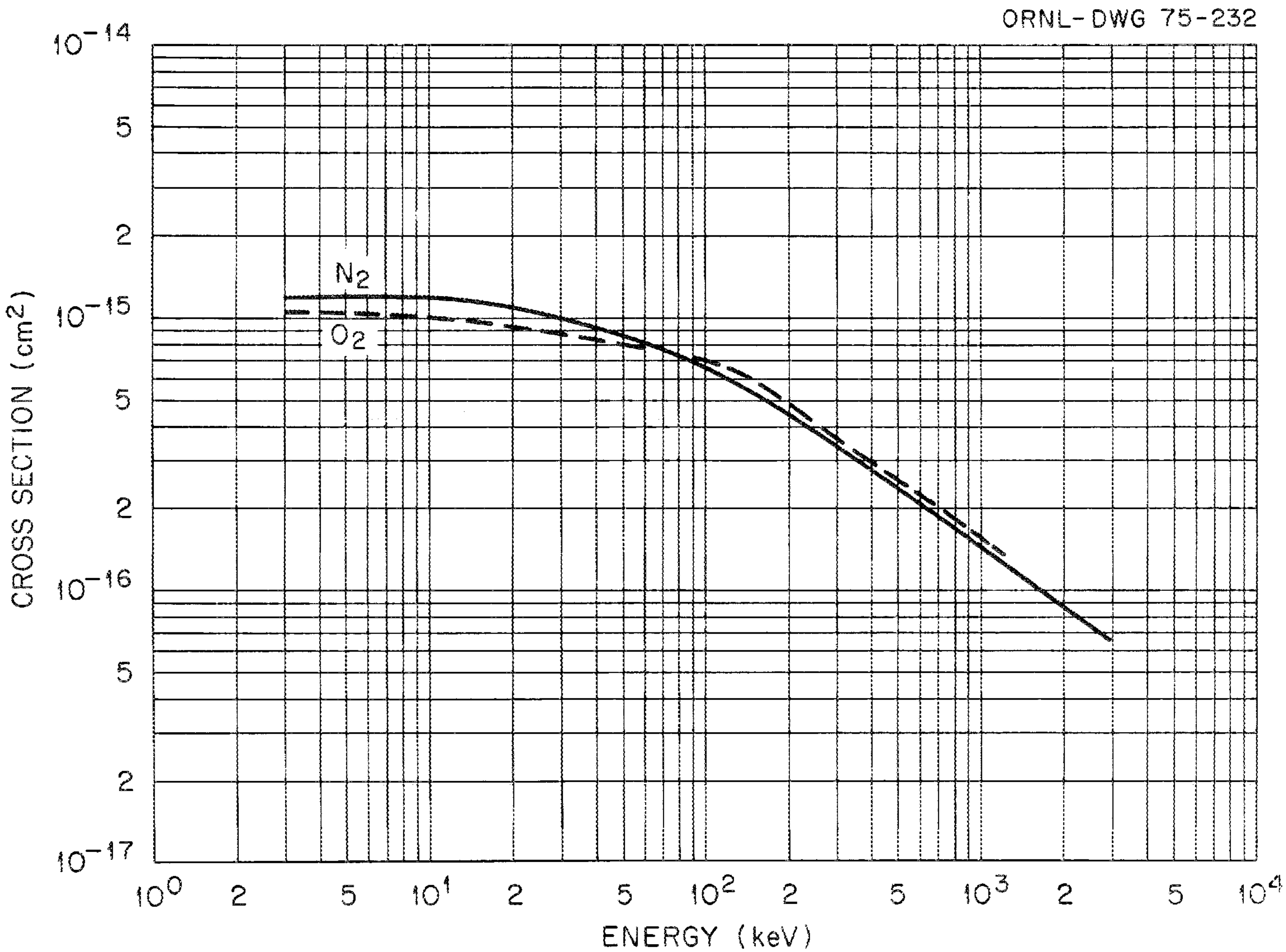
Energy (keV)	Cross Sections (cm^2)	
	N_2	O_2
5.0 E 00	1.2 E-15	1.1 E-15
8.0 E 00	1.2 E-15	1.0 E-15
1.0 E 01	1.2 E-15	9.2 E-16
3.0 E 01	9.7 E-16	9.0 E-16
6.0 E 01	8.0 E-16	7.7 E-16
1.0 E 02	6.7 E-16	7.0 E-16
3.0 E 02	3.4 E-16	4.1 E-16
6.0 E 02	2.1 E-16	2.2 E-16
1.0 E 03	1.4 E-16	1.5 E-16
3.0 E 03	6.4 E-17	

References:

E.W. McDaniel, J.W. Hooper, D.W. Martin, and D.S. Harmer, Proc. Fifth Int. Conf. on Ionization Phenomena in Gases (Munich, 1961) North-Holland Publishing Co. (Amsterdam) Vol. 1, 60 (1962); L.I. Pivovar, and Yu. Z. Levchenko, Sov. Phys.-JETP 25, 27 (1967); R. Browning and H.B. Gilbody, J. Phys. 1, 1149 (1968).

Accuracy:

$\pm$ 20%.


ORNL-DWG 75-232
N_2
O_2
CROSS SECTION (cm^2)
10^{-14}
5
2
10^{-15}
5
2
10^{-16}
5
2
10^{-17}
10^0
2
5
10^1
2
5
10^2
2
5
10^3
2
5
10^4
ENERGY (keV)

Cross Sections for Electron Production in N_2 and O_2 by H^+

Energy (keV)	Cross Sections (cm^2)	
	N_2	O_2
1.0 E 00	8.00 E-17	
2.0 E 00	1.28 E-16	5.50 E-17
4.0 E 00	1.92 E-16	9.90 E-17
6.0 E 00	2.49 E-16	1.40 E-16
1.0 E 01	3.40 E-16	2.10 E-16
2.0 E 01	5.00 E-16	3.35 E-16
4.0 E 01	6.60 E-16	5.10 E-16
6.0 E 01	7.00 E-16	6.00 E-16
1.0 E 02	6.10 E-16	6.00 E-16
2.0 E 02	4.10 E-16	4.40 E-16
4.0 E 02	2.62 E-16	2.95 E-16
6.0 E 02	2.03 E-16	2.22 E-16
1.0 E 03	1.46 E-16	1.58 E-16
2.0 E 03	8.60 E-17	
3.0 E 03	6.20 E-17	

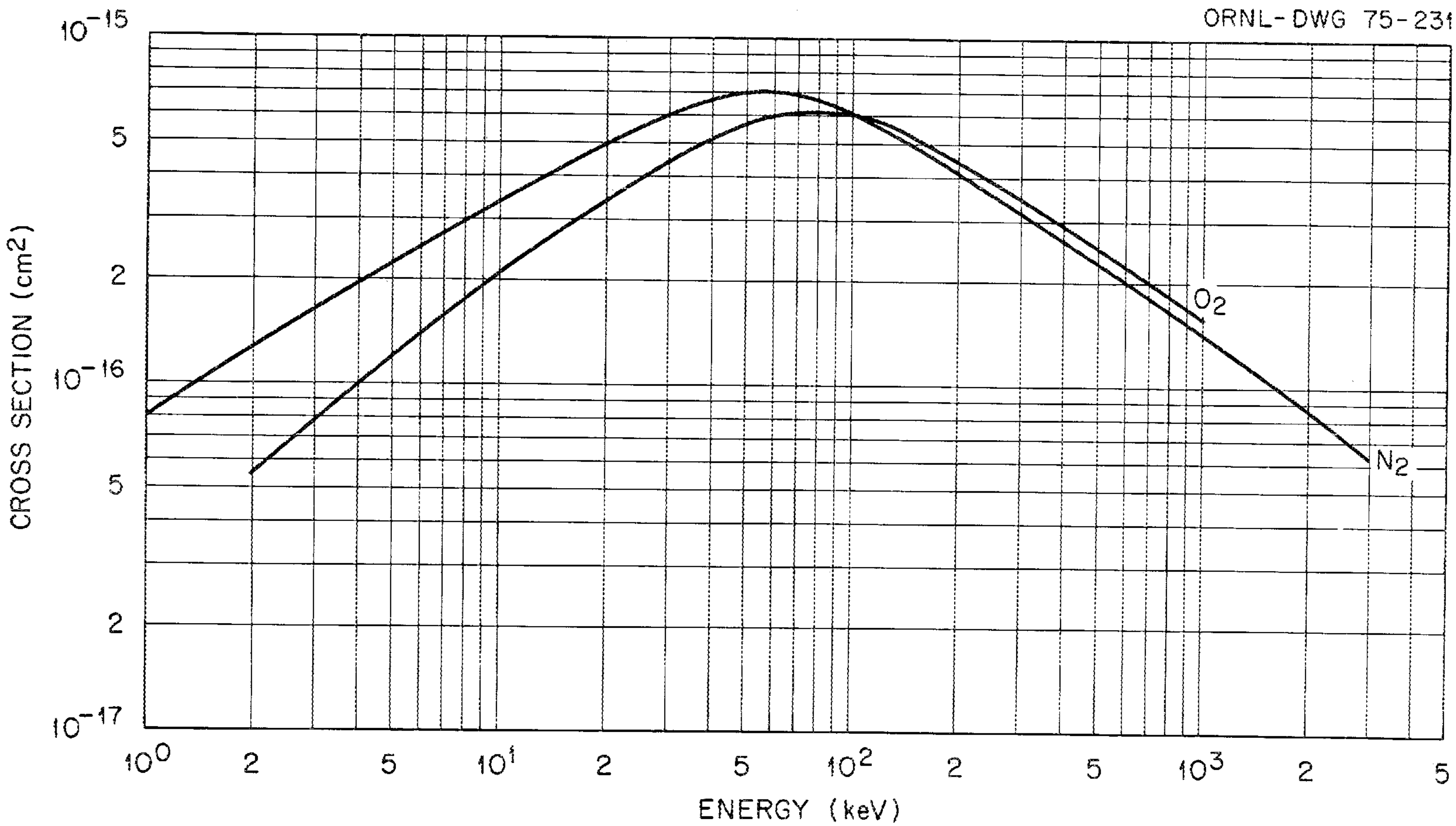
References:

$H^+ + N_2$: E.W. McDaniel, J.W. Hooper, D.W. Martin, and D.S. Harmer, Proc. Fifth Int. Conf. on Ionization Phenomena in Gases (Munich, 1961), North-Holland Publishing Co. (Amsterdam) Vol. 1, 60 (1962); F.J. de Heer, J. Schutten, and H. Moustafa, Physica 32, 1766 (1966); J.B. Crooks and M.E. Rudd, Phys. Rev. A 3, 1628 (1971); L.I. Pivovar and Yu. Z. Levchenko, Soviet Physics-JETP 25, 27 (1967); E.S. Solov'ev, R.N. Il'in, V.A. Oparin, and N.V. Fedorenko, Sov. Phys.-JETP 15, 459 (1962); Yu. S. Gordeev and M.N. Panov, Sov. Phys.-Tech. Phys. 9, 656 (1964); R.J. McNeal and D.C. Clark, J. Geophys. Res. 74, 5065 (1969); M.J. Dufay, M.D. Desesquelles, and M. Eidelsberg, Ann. Geophys. 22, 614 (1966); J.G. Collins and P. Kebarle, J. Chem. Phys. 46, 1082 (1967).

$H^+ + O_2$: E.W. McDaniel, J.W. Hooper, D.W. Martin, and D.S. Harmer, Proc. Fifth Int. Conf. on Ionization Phenomena in Gases (Munich 1961), North-Holland Publishing Co. (Amsterdam) Vol. 1, 60 (1962); F.J. de Heer, J. Schutten, and H. Moustafa, Physica 32, 1766 (1966); J.B. Crooks and M.E. Rudd, Phys. Rev. A 3, 1628 (1971); M.J. Dufay, M.D. Desesquelles, and M. Eidelsberg, Ann. Geophys. 22, 614 (1966); R.J. McNeal and J.H. Birely, Rev. Geophys. and Space Phys. 11, 633 (1973).

Accuracy:

$\pm$ 50%.



A.5.13

Cross Sections for Production of N_2^+, N^+, and N^{2+} Ions by Protons in N_2 Gas

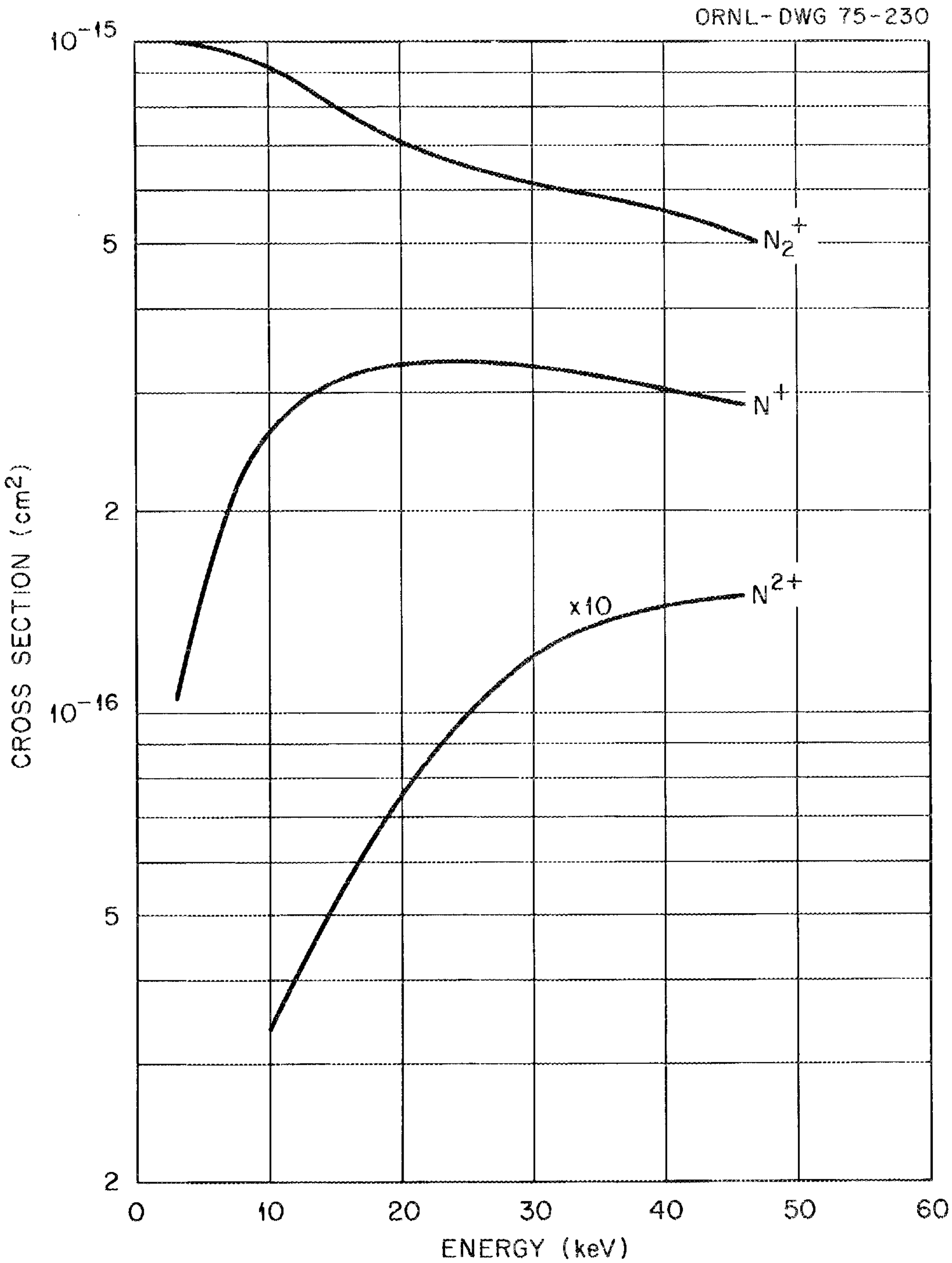
Energy (keV)	Cross Sections (cm^2)		
	N^+	N_2^+	N^{2+}
3.0 E 00	1.05 E-16	1.00 E-15	
1.0 E 01	2.64 E-16	9.20 E-16	3.37 E-18
2.0 E 01	3.23 E-16	7.10 E-16	7.58 E-18
3.0 E 01	3.27 E-16	6.21 E-16	1.23 E-17
4.0 E 01	3.07 E-16	5.60 E-16	1.45 E-17
4.6 E 01	2.86 E-16	5.00 E-16	1.49 E-17

References:

R. Browning and H.B. Gilbody, J. Phys. B 1, 1149 (1968).

Accuracy:

± 20%.



ORNL-DWG 75-230
10^{-15}
5
2
10^{-16}
5
2
CROSS SECTION (cm^2)
0
10
20
30
40
50
60
ENERGY (keV)
N_2^+
N^+
N^{2+}
x10

Cross Sections for Production of O_2^+, O^+, and O^{2+} Ions by Protons in O_2

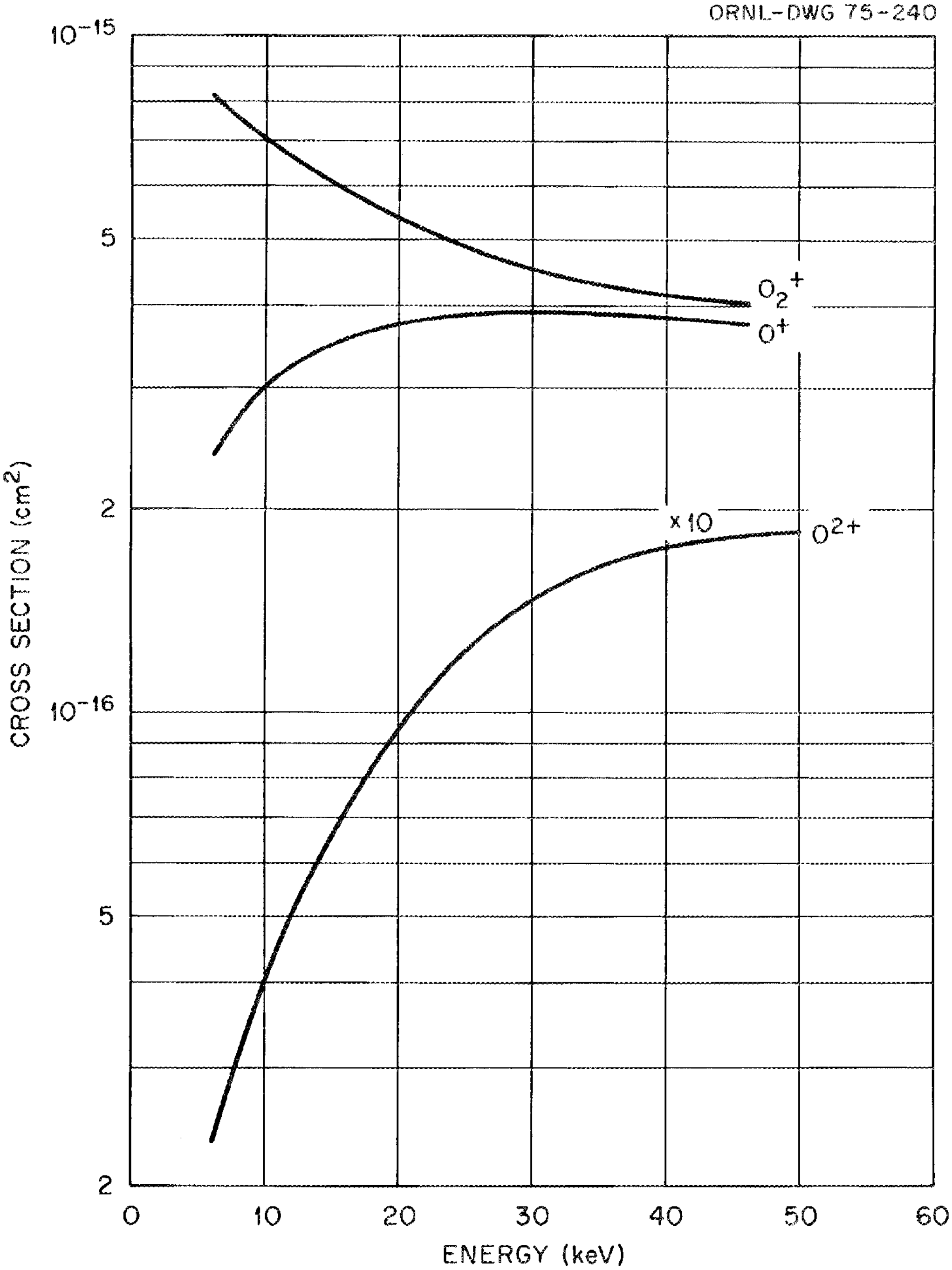
Energy (keV)	Cross Sections (cm^2)		
	O^+	O_2^+	O^{2+}
6.0 E 00	2.40 E-16	8.12 E-16	2.34 E-18
1.0 E 01	3.08 E-16	7.00 E-16	4.26 E-18
2.0 E 01	3.76 E-16	5.40 E-16	9.64 E-18
3.0 E 01	3.87 E-16	4.47 E-16	1.47 E-17
4.0 E 01	3.81 E-16	4.12 E-16	1.77 E-17
4.6 E 01	3.75 E-16	4.00 E-16	1.84 E-17

References:

R. Browning and H.B. Gilbody, J. Phys. B 1, 1149 (1968).

Accuracy:

± 20%.


ORNL-DWG 75-240
10^{-15}
5
2
10^{-16}
5
2
CROSS SECTION (cm^2)
0
10
20
30
40
50
60
ENERGY (keV)
O_2^+
O^+
×10
O^{2+}

Angular Distributions of Electrons from 300-keV Proton Impact in H_2

Angle (deg)	Cross Sections (cm^2/eV sr)		
	150 eV	300 eV	500 eV
10	1.00 E-20	1.52 E-21	1.58 E-21
20	6.38 E-21	1.87 E-21	2.07 E-21
30	7.03 E-21	2.95 E-21	1.56 E-21
40	1.00 E-20	4.15 E-21	5.00 E-22
50	1.45 E-20	3.38 E-21	9.97 E-23
60	1.16 E-20	5.40 E-22	2.17 E-23
70	4.97 E-21	7.00 E-23	
80	9.71 E-22		
90	3.08 E-22		
100	1.39 E-22		
110	7.10 E-23		

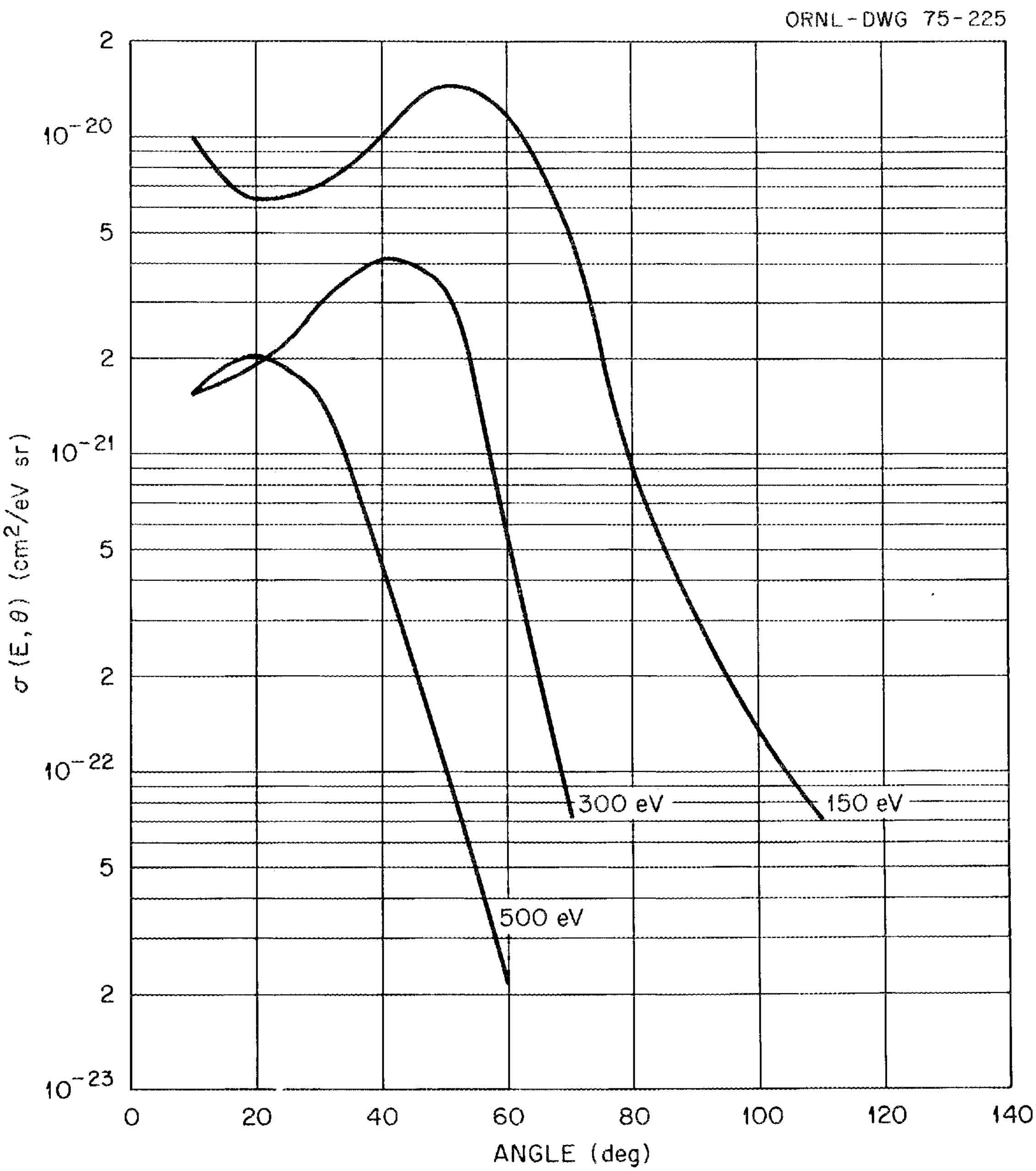
References:

M.E. Rudd and J.H. Macek, Case Studies in Atomic Physics 3, 73 (1972).

M.E. Rudd, C.A. Sautter, and C.L. Bailey, Phys. Rev. 151, 20 (1966).

Accuracy:

$\pm$ 20%.


ORNL-DWG 75-225
$\sigma(E,\theta)$ (cm^2/eV sr)
2
10^{-20}
5
2
10^{-21}
5
2
10^{-22}
5
2
10^{-23}
0
20
40
60
80
100
120
140
ANGLE (deg)
300 eV
150 eV
500 eV

Angular Distribution of Electrons of Various Energies from 300-keV Proton Impacts in H_2

Angle (deg)	Cross Sections (cm^2/eV sr)		
	10 eV	20 eV	60 eV
10	5.31 E-19	2.34 E-19	4.89 E-20
20	4.79 E-19	2.16 E-19	3.42 E-20
30	5.11 E-19	2.40 E-19	3.84 E-20
40	5.21 E-19	2.56 E-19	4.48 E-20
50	5.11 E-19	2.59 E-19	5.49 E-20
60	4.79 E-19	2.43 E-19	5.99 E-20
70	4.32 E-19	2.08 E-19	5.08 E-20
80	3.51 E-19	1.61 E-19	2.71 E-20
90	2.48 E-19	9.94 E-20	9.81 E-21
100	1.62 E-19	5.60 E-20	3.52 E-21
110	1.23 E-19	3.71 E-20	2.01 E-21
120	9.65 E-20	2.73 E-20	1.31 E-21
130	8.76 E-20	2.25 E-20	1.10 E-21
140	8.11 E-20	1.95 E-20	9.16 E-22
150	7.70 E-20	1.74 E-20	8.24 E-22
160	7.31 E-20	1.62 E-20	7.20 E-22

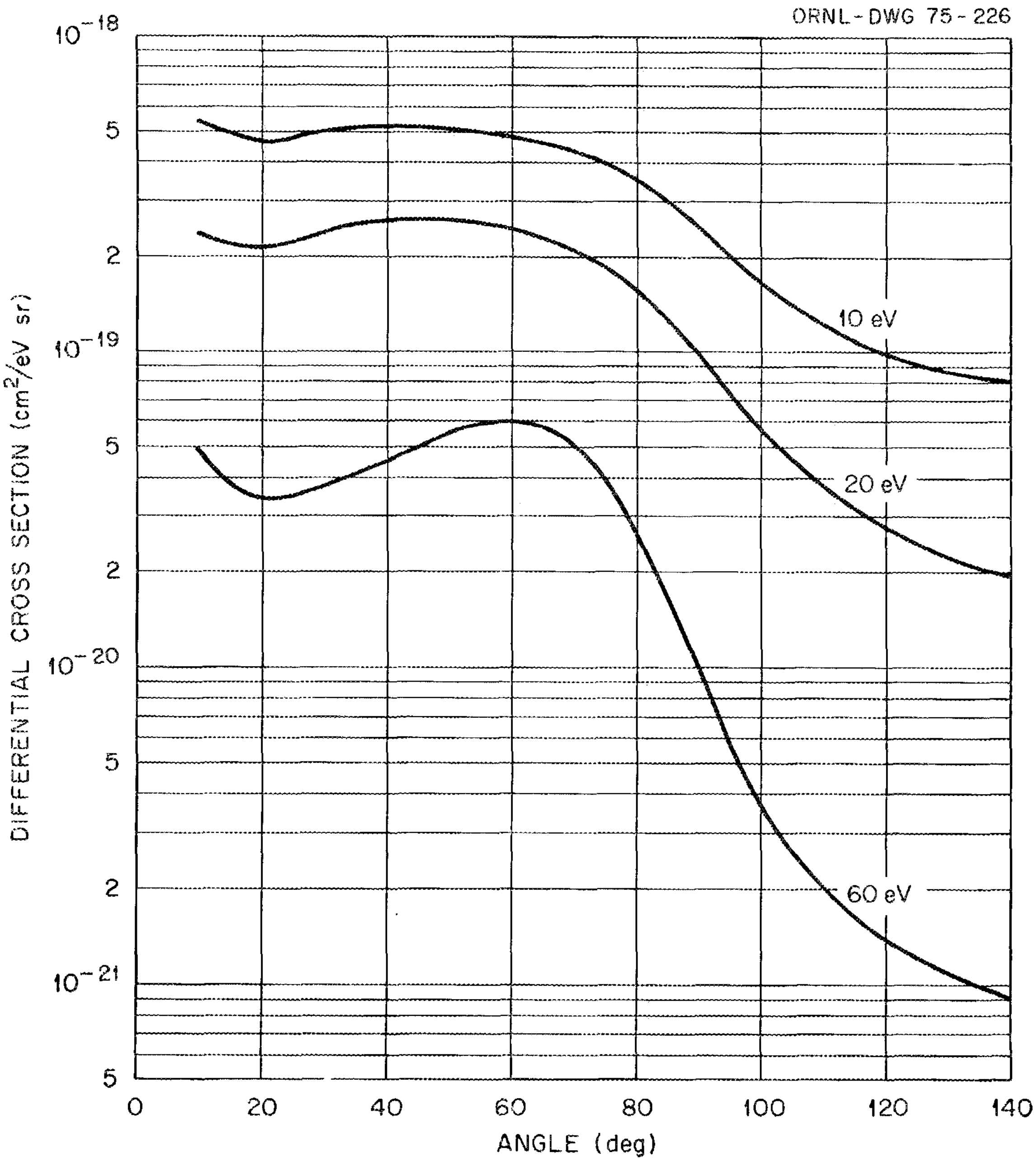
References:

M.E. Rudd and J.H. Macek, Case Studies in Atomic Physics 3, 73 (1972).

M.E. Rudd, C.A. Sautter, and C.L. Bailey, Phys. Rev. 151, 20 (1966).

Accuracy:

$\pm$ 20%.


ORNL-DWG 75-226
DIFFERENTIAL CROSS SECTION (cm²/eV sr)
10⁻¹⁸
5
2
10⁻¹⁹
5
2
10⁻²⁰
5
2
10⁻²¹
5
0
20
40
60
80
100
120
140
ANGLE (deg)
10 eV
20 eV
60 eV

Differential Cross Sections for Ejection of Electrons from H_2 Molecules by 50-keV H^+ Projectiles

(The electron energy distributions were measured at various angles, shown alongside the curves, from the incident beam direction.)

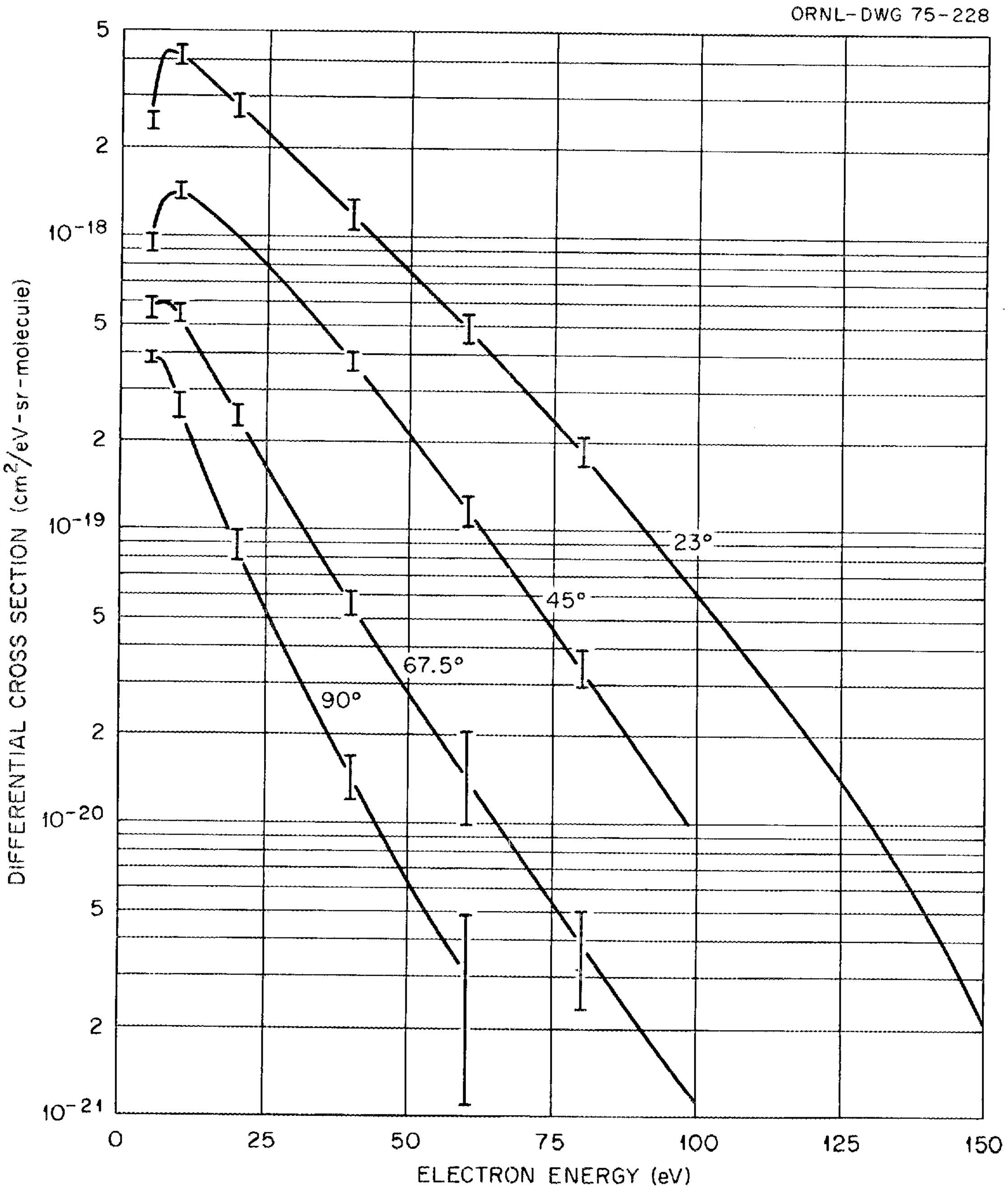
Energy (eV)	Differential Cross Sections (cm^2/eV-sr-molecule)			
	90°	67.5°	45°	23°
5.0 E 00	3.80 E-19	5.70 E-19	9.30 E-19	2.40 E-18
1.0 E 01	2.69 E-19	5.39 E-19	1.40 E-18	4.10 E-18
1.5 E 01	1.45 E-19	3.59 E-19	1.20 E-18	3.38 E-18
2.0 E 01	8.70 E-20	2.42 E-19	9.80 E-19	2.76 E-18
3.0 E 01	3.34 E-20	1.13 E-19	6.19 E-19	1.80 E-18
4.0 E 01	1.41 E-20	5.58 E-20	3.70 E-19	1.18 E-18
5.0 E 01	6.40 E-21	2.79 E-20	2.10 E-19	7.59 E-19
6.0 E 01	3.00 E-21	1.41 E-20	1.14 E-19	4.83 E-19
7.0 E 01		7.39 E-21	6.20 E-20	3.00 E-19
8.0 E 01		3.90 E-21	3.32 E-20	1.81 E-19
9.0 E 01		2.08 E-21	1.73 E-20	1.06 E-19
1.0 E 02		1.13 E-21		6.10 E-20
1.1 E 02				3.47 E-20
1.2 E 02				1.92 E-20
1.3 E 02				1.02 E-20
1.4 E 02				5.01 E-21
1.5 E 02				2.02 E-21

Reference:

C.E. Kuyatt and T. Jorgensen, Phys. Rev. 130, 1444 (1963).

Accuracy:

Estimates of total error are indicated by the vertical bars on the drawing.


ORNL-DWG 75-228
DIFFERENTIAL CROSS SECTION (cm²/eV-sr-molecule)
5
2
10⁻¹⁸
5
2
10⁻¹⁹
5
2
10⁻²⁰
5
2
10⁻²¹
0
25
50
75
100
125
150
ELECTRON ENERGY (eV)
23°
45°
67.5°
90°

Differential Cross Sections for Ejection of Electrons from

He Atoms by 50-keV H^+ Projectiles

(The electron energy distributions were measured at various angles, shown alongside the curves, from the incident beam direction.)

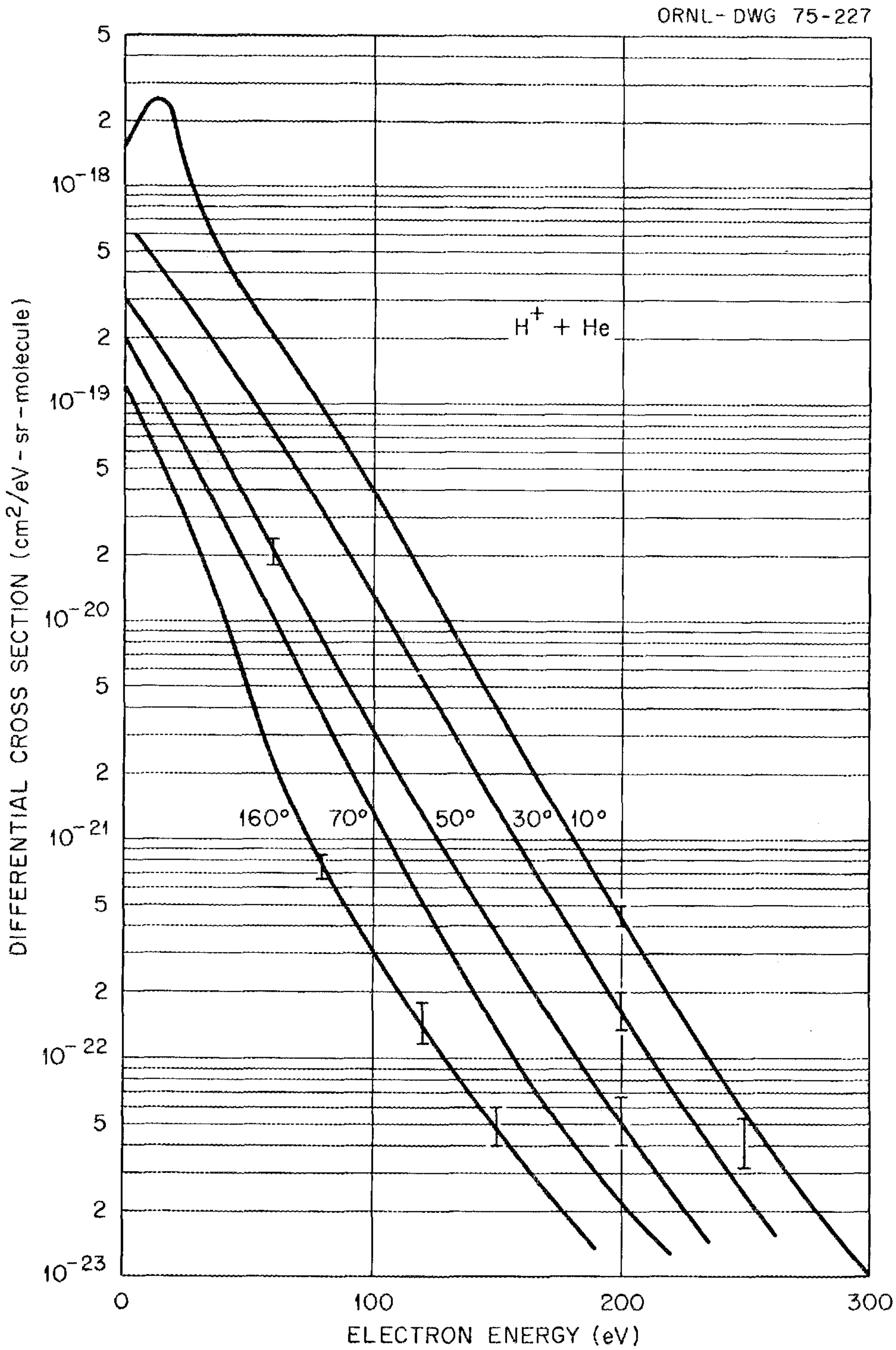
Energy (eV)	Differential Cross Sections (cm^2/eV-sr-molecule)				
	160°	70°	50°	30°	10°
0 E 01	1.20 E-19	2.00 E-19			1.51 E-18
2.0 E 01	4.00 E-20	7.79 E-20	1.46 E-19	3.46 E-19	2.00 E-18
4.0 E 01	1.03 E-20	2.97 E-20	5.49 E-20	1.63 E-19	4.75 E-19
6.0 E 01	2.29 E-21	1.01 E-20	2.08 E-20	7.72 E-20	2.04 E-19
8.0 E 01	7.60 E-22	3.68 E-21	8.00 E-21	3.14 E-20	9.40 E-20
1.0 E 02	3.10 E-22	1.33 E-21	3.14 E-21	1.31 E-20	4.00 E-20
1.2 E 02	1.40 E-22	5.15 E-22	1.30 E-21	5.40 E-21	1.60 E-20
1.4 E 02	6.80 E-23	2.12 E-22	5.44 E-22	2.14 E-21	6.22 E-21
1.6 E 02	3.40 E-23	8.97 E-23	2.40 E-22	8.90 E-22	2.50 E-21
1.8 E 02	1.80 E-23	4.30 E-23	1.09 E-22	3.77 E-22	1.01 E-21
2.0 E 02		2.25 E-23	5.02 E-23	1.63 E-22	4.39 E-22
2.2 E 02		1.29 E-23	2.45 E-23	7.20 E-23	1.89 E-22
2.4 E 02				3.38 E-23	8.33 E-23
2.6 E 02				1.69 E-23	3.93 E-23
2.8 E 02					1.92 E-23
3.0 E 02					1.06 E-23

Reference:

M.E. Rudd and T. Jorgensen, Phys. Rev. 131, 666 (1963).

Accuracy:

Estimates of total error are indicated by the vertical bars on the drawing.


ORNL-DWG 75-227
H+ + He
160°
70°
50°
30°
10°
DIFFERENTIAL CROSS SECTION (cm2/eV-sr-molecule)
ELECTRON ENERGY (eV)
5
2
10-18
10-19
10-20
10-21
10-22
10-23
0
100
200
300

Cross Sections for Production of Slow

Electrons in Collisions of H_2^+ and H_3^+ in H_2

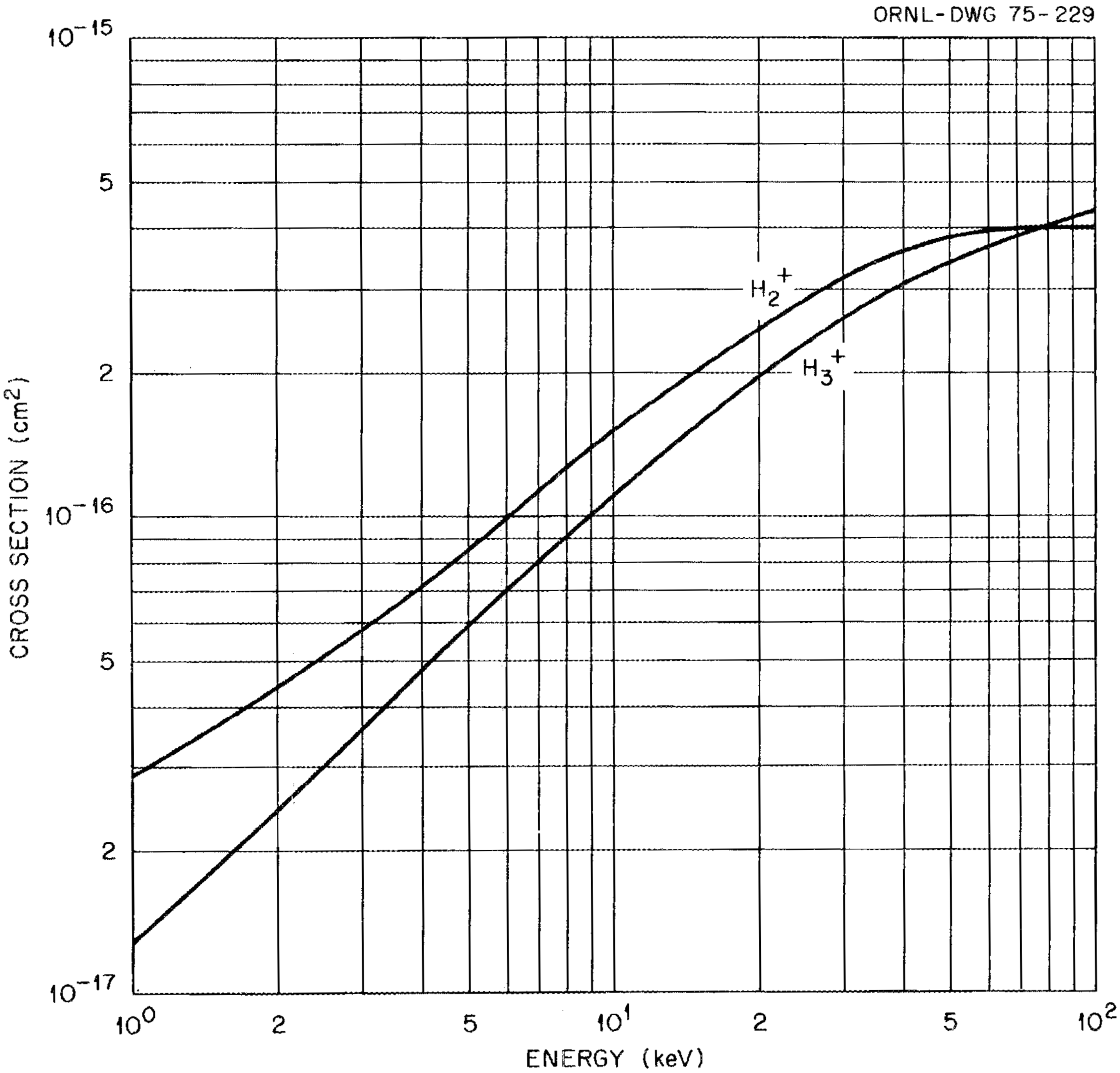
Energy (keV)	Cross Sections (cm^2)	
	H_2^+	H_3^+
1.0 E 00	2.9 E-17	1.3 E-17
3.0 E 00	5.7 E-17	3.6 E-17
6.0 E 00	1.0 E-16	7.2 E-17
1.0 E 01	1.6 E-16	1.1 E-16
3.0 E 01	3.2 E-16	2.6 E-16
6.0 E 01	4.0 E-16	3.6 E-16
1.0 E 02	4.0 E-16	4.3 E-16

References:

Yu. S. Gordeev and M.N. Panov, Sov. Phys.-Tech. Phys. 9, 656 (1964); V.V. Afrosimov, R.N. Il'in, and N.V. Fedorenko, Sov. Phys.-Tech. Phys. 3, 2080 (1958).

Accuracy:

± 25%.


ORNL-DWG 75-229
10^{-15}
5
2
10^{-16}
5
2
10^{-17}
CROSS SECTION (cm^2)
H_2^+
H_3^+
10^0
2
5
10^1
2
5
10^2
ENERGY (keV)

Cross Sections for Electron Loss or Stripping of H Atoms in H and H_2

Energy (keV)	Cross Sections (cm^2/molecule) H	H_2
1.2 E 00	3.0 E-18	
2.0 E 00	2.0 E-17	6.0 E-17
5.0 E 00	4.2 E-17	7.3 E-17
7.0 E 00	5.6 E-17	7.4 E-17
1.0 E 01	7.7 E-17	9.2 E-17
2.0 E 01	1.2 E-16	1.3 E-16
5.0 E 01	8.8 E-17	1.5 E-16
7.0 E 01	7.5 E-17	1.3 E-16
1.0 E 02	6.2 E-17	1.1 E-16
2.0 E 02	4.3 E-17	7.0 E-17
5.0 E 02		3.2 E-17
7.0 E 02		2.3 E-17
1.0 E 03		1.7 E-17
2.0 E 03		9.2 E-18
5.0 E 03		4.1 E-18
7.0 E 03		3.1 E-18
1.0 E 04		2.3 E-18

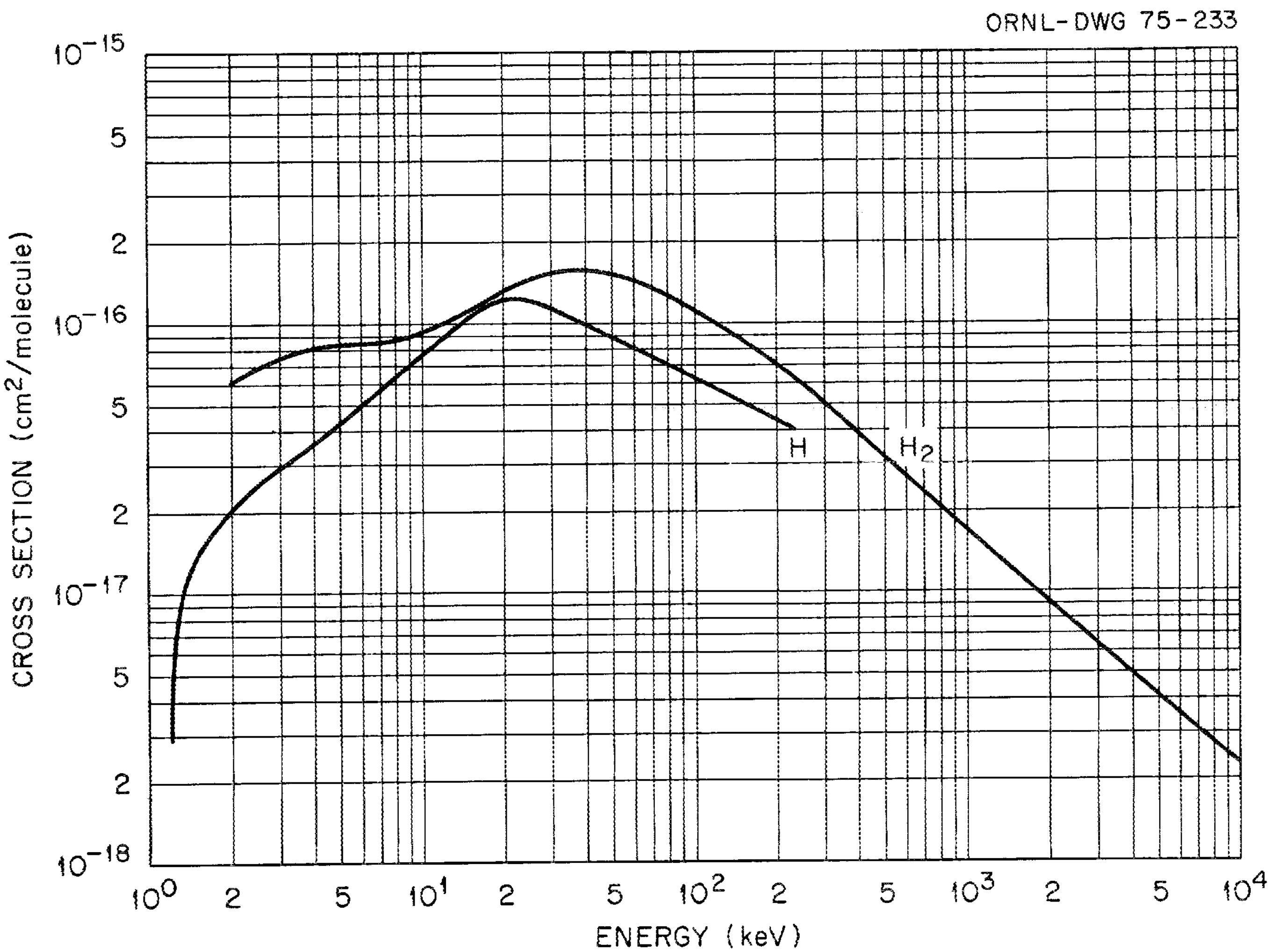
References:

H + H: G.W. McClure, Phys. Rev. 166, 22 (1968); A.B. Wittkower, G. Levy, and H.B. Gilbody, Proc. Phys. Soc. 91, 306 (1967); L.M. Welsh, K.H. Berkner, S.N. Kaplan, and R.V. Pyle, Phys. Rev. 158, 85 (1967).

H + H_2: C.F. Barnett and H.K. Reynolds, Phys. Rev. 109, 355 (1958); P.M. Stier and C.F. Barnett, Phys. Rev. 103, 896 (1956); G.W. McClure, Phys. Rev. 134, A-1226 (1964); L.H. Toburen, M.Y. Nakai, and R.A. Langley, Phys. Rev. 171, 114 (1968); J.F. Williams, Phys. Rev. 157, 97 (1967); K.H. Berkner, S.N. Kaplan, and R.V. Pyle, Phys. Rev. 134, A1461 (1964); L.M. Welsh, K.H. Berkner, S.N. Kaplan, and R.V. Pyle, Phys. Rev. 158, 85 (1967).

Accuracy:

± 25%


ORNL-DWG 75-233
CROSS SECTION (cm²/molecule)
ENERGY (keV)
H
H₂
10⁻¹⁵
5
2
10⁻¹⁶
5
2
10⁻¹⁷
5
2
10⁻¹⁸
10⁰
2
5
10¹
2
5
10²
2
5
10³
2
5
10⁴

Total Apparent Cross Section for the Production of Slow Positive Ions by H^{o} Atoms Incident on H_2 and He

Energy (keV)	H_2 Cross Section (cm^2)	He Cross Section (cm^2)
1.5 E 02	9.15 E-17	4.00 E-17
2.0 E 02	8.01 E-17	3.80 E-17
3.0 E 02	6.20 E-17	3.15 E-17
4.0 E 02	4.99 E-17	2.61 E-17

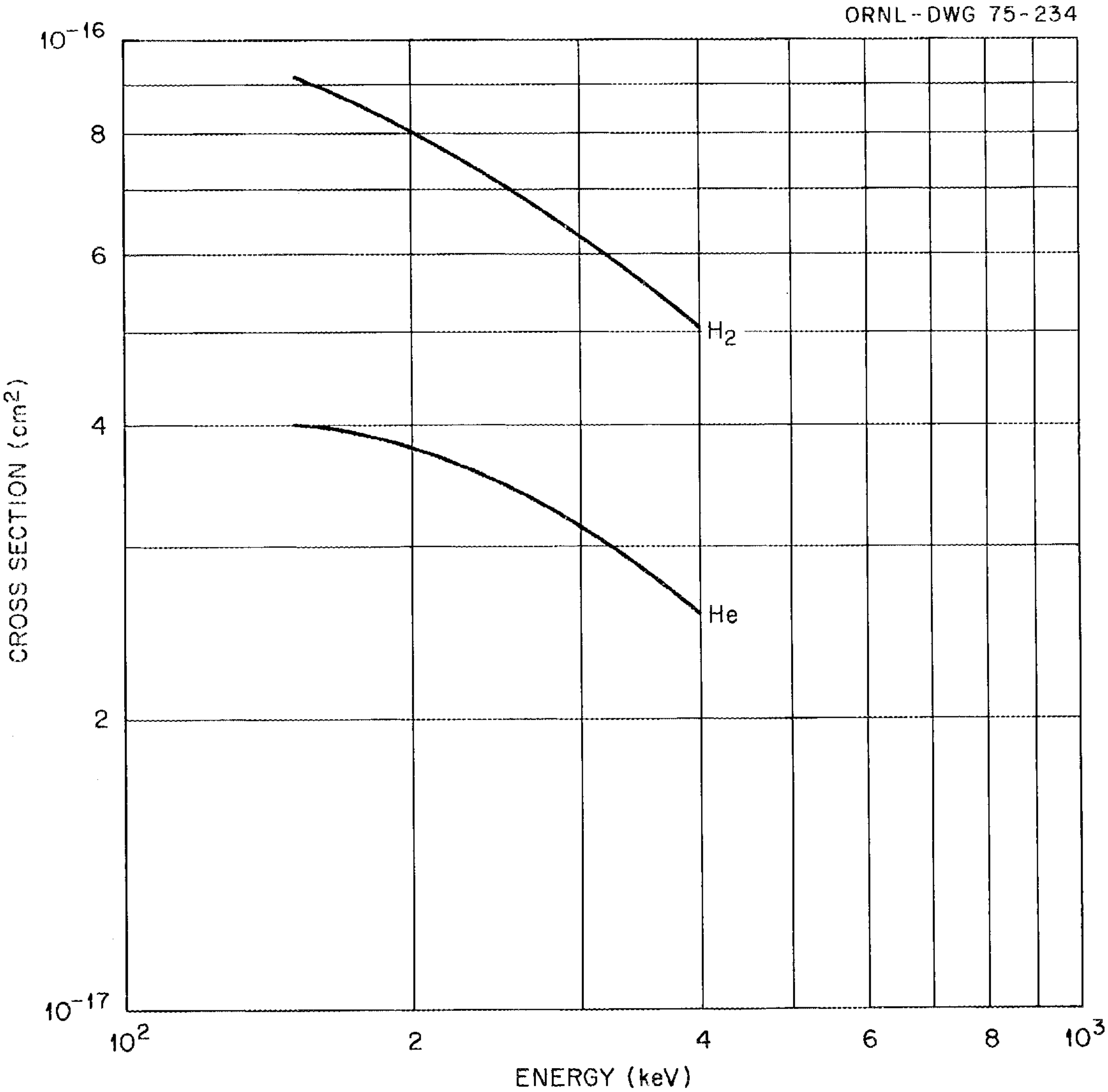
References:

H_2: L.J. Puckett, G.O. Taylor, and D.W. Martin, Phys. Rev. 178, 271 (1969).

He: L.J. Puckett, G.O. Taylor, and D.W. Martin, Phys. Rev. 178, 271 (1969).

Accuracy:

± 20%.


ORNL-DWG 75-234
CROSS SECTION (cm^2)
10^{-16}
8
6
4
2
10^{-17}
H_2
He
10^2
2
4
6
8
10^3
ENERGY (keV)

Total Cross Section for the Production of

Free Electrons by H^o Atoms in H_2 and He

Energy (keV)	Cross Sections (cm^2)	
	H_2	He
1.5 E 02	1.91 E-16	1.08 E-16
2.0 E 02	1.67 E-16	1.04 E-16
2.5 E 02	1.35 E-16	9.00 E-17
3.0 E 02	1.12 E-16	8.00 E-17
3.3 E 02	1.00 E-16	7.50 E-17

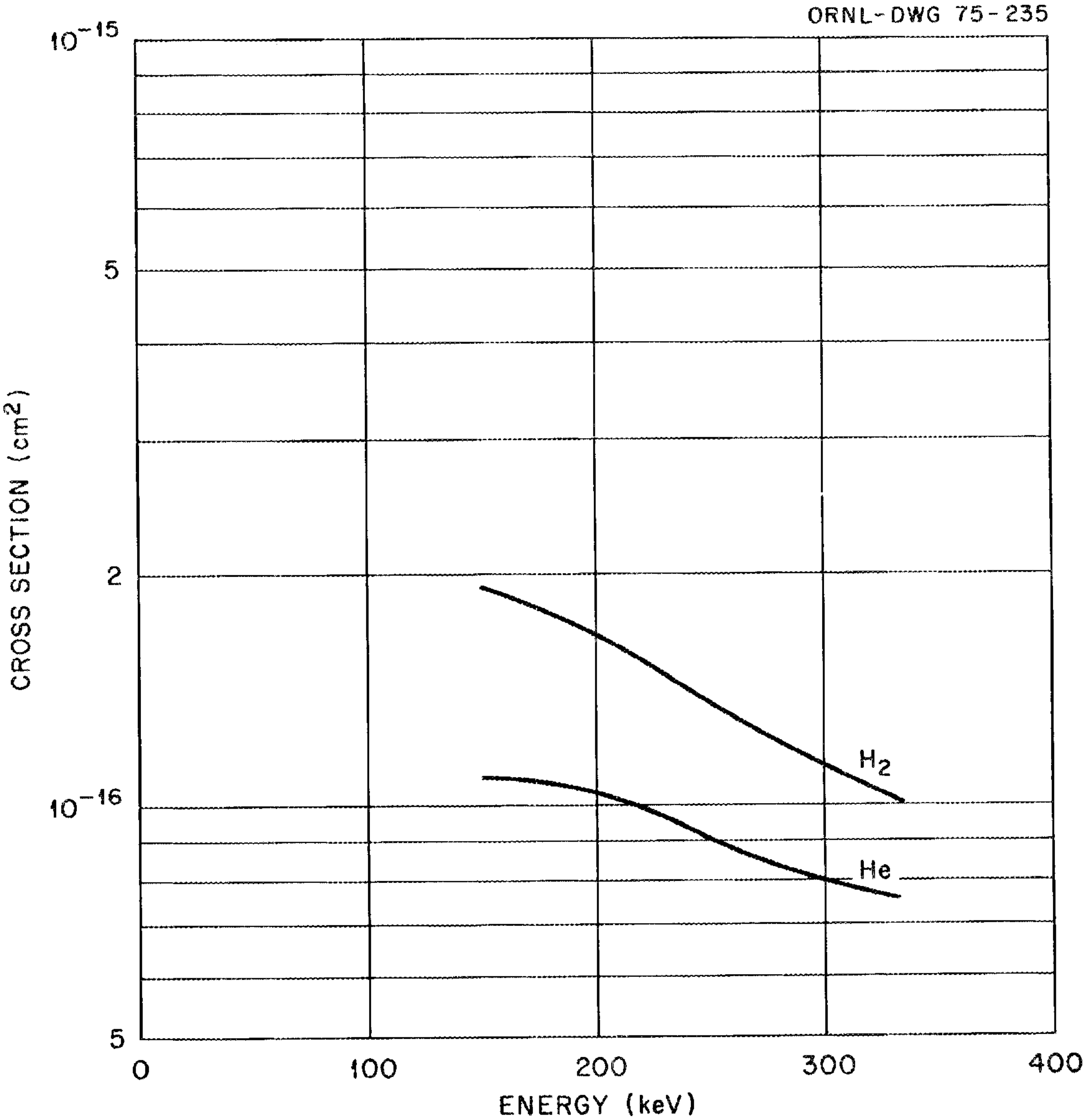
Reference:

H_2: L.J. Puckett, G.O. Taylor, and D.W. Martin, Phys. Rev. 178, 271 (1969).

He: L.J. Puckett, G.O. Taylor, and D.W. Martin, Phys. Rev. 178, 271 (1969).

Accuracy:

± 20%.


ORNL-DWG 75-235
10^{-15}
5
2
10^{-16}
5
0
100
200
300
400
ENERGY (keV)
CROSS SECTION (cm^2)
H_2
He

Cross Sections for Electron Loss or Stripping for Metastable H(2s) Atoms in H_2 and He

Energy (keV)	Cross Sections (cm^2)	
	H_2	He
5.0 E 00	2.5 E-16	2.9 E-16
1.0 E 01	2.9 E-16	3.4 E-16
1.5 E 01	3.5 E-16	3.2 E-16
2.0 E 01	3.9 E-16	3.1 E-16
4.0 E 01	4.5 E-16	2.3 E-16
5.0 E 01	4.5 E-16	2.0 E-16
1.0 E 02	3.2 E-16	1.3 E-16
2.0 E 02	2.0 E-16	7.7 E-17
4.0 E 02	1.0 E-16	5.5 E-17
5.0 E 02	8.0 E-17	5.0 E-17

References:

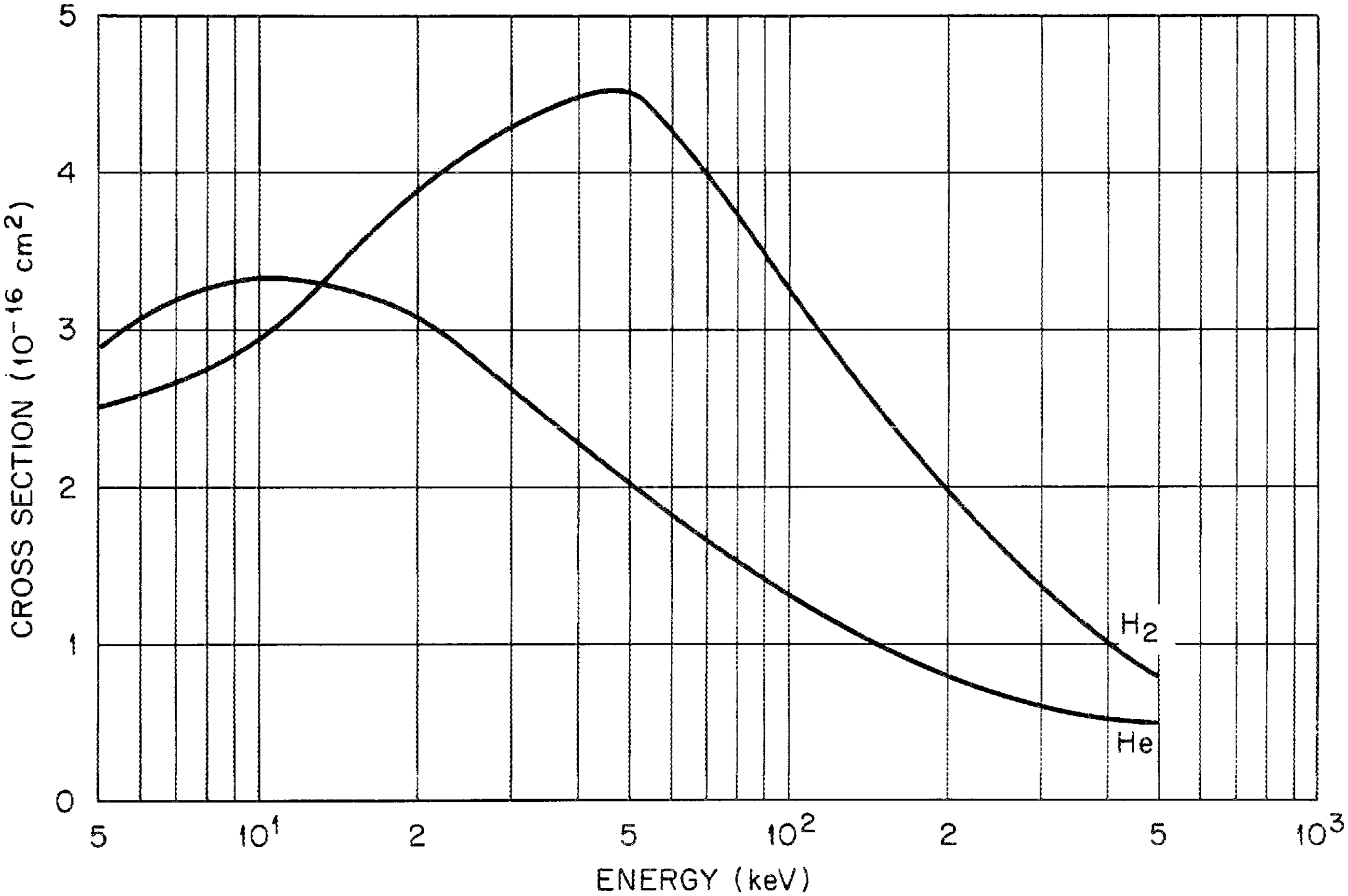
H(2s) + H_2: H.B. Gilbody, R.M. Reynolds, and G.I. Riddell, J. Phys. B 4, 94 (1971); H.B. Gilbody and J.L. Corr, J. Phys. B 7, 1953 (1974).

H(2s) + He: H.B. Gilbody, R. Browning, R.M. Reynolds, and G.I. Riddell, J. Phys. B 4, 94 (1971); R.H. Hughes and S.S. Choe, Phys. Rev. A 6, 1413 (1972); H.B. Gilbody and J.L. Corr, J. Phys. B 7, 1953 (1974).

Accuracy:

$\pm$ 20%

ORNL-DWG 75-236



Cross Sections for Electron Stripping

H Atoms in He and Ne

Energy (keV)	Cross Sections (cm^2)	
	He	Ne
4.2 E 00	1.22 E-16	6.67 E-17
6.0 E 00	1.44 E-16	8.91 E-17
8.0 E 00	1.49 E-16	1.09 E-16
1.0 E 01	1.47 E-16	1.23 E-16
2.0 E 01	1.35 E-16	1.69 E-16
5.0 E 01	1.23 E-16	2.00 E-16
8.0 E 01	9.70 E-17	1.99 E-16
1.0 E 02	9.18 E-17	1.94 E-16
2.0 E 02	5.76 E-17	1.62 E-16
5.0 E 02	2.56 E-17	
8.0 E 02	1.63 E-17	
1.0 E 03	1.33 E-17	
2.0 E 03	7.05 E-18	
5.0 E 03	2.58 E-18	
8.0 E 03	1.98 E-18	
1.0 E 04	1.60 E-18	
1.5 E 04	1.13 E-18	

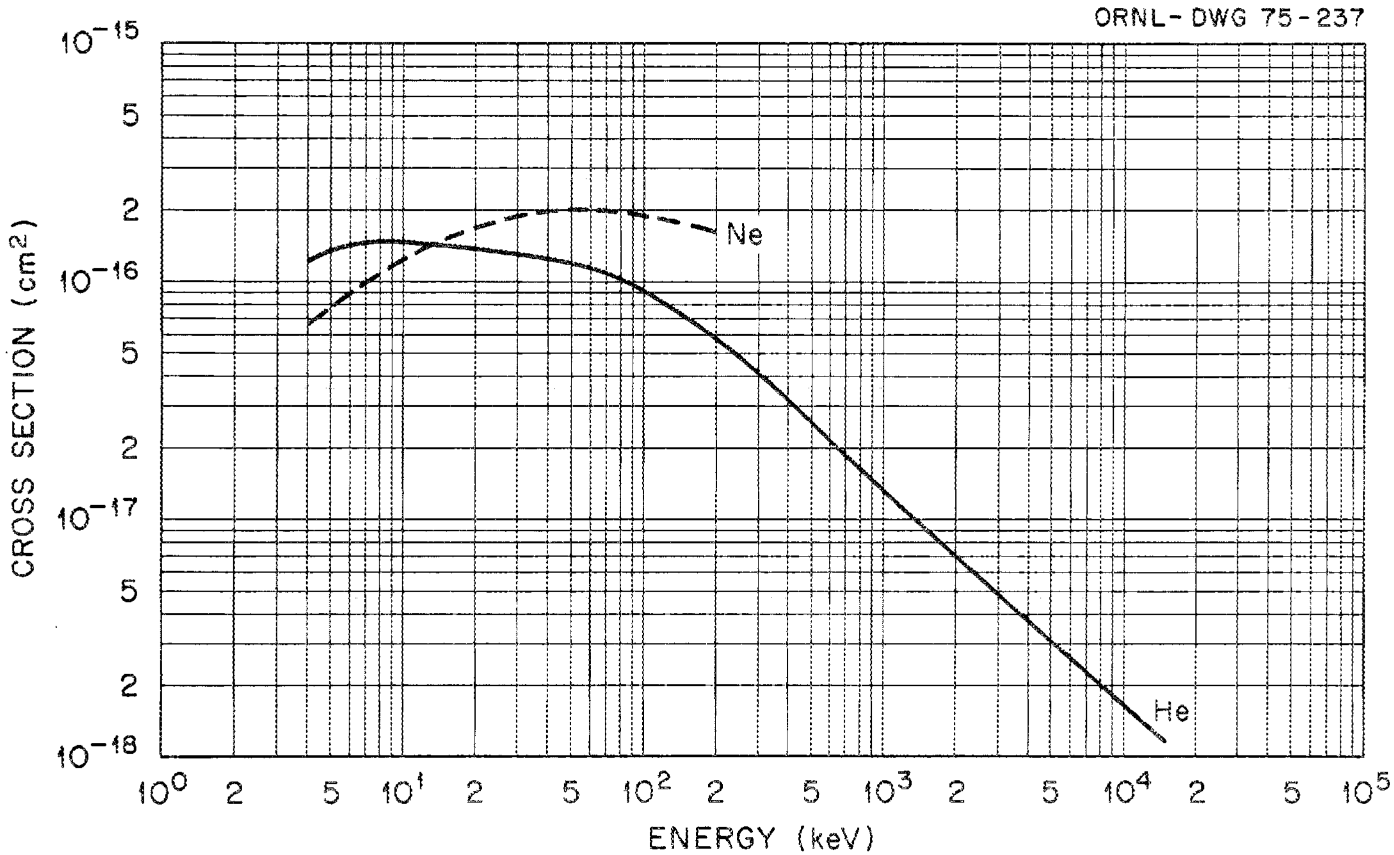
References:

H + He: C.F. Barnett and H.K. Reynolds, Phys. Rev. 109, 355 (1958); P.M. Stier and C.F. Barnett, Phys. Rev. 103, 896 (1958); G.W. McClure, Phys. Rev. 134, A-1226 (1964); L.H. Toburen, M.Y. Nakai, and R.A. Langley, Phys. Rev. 171, 114 (1968); J.F. Williams, Phys. Rev. 157, 97 (1967); K.H. Berkner, S.N. Kaplan, and R.V. Pyle, Phys. Rev. 134, A-1461 (1964); L.M. Welsh, K.H. Berkner, S.N. Kaplan, and R.V. Pyle, Phys. Rev. 158, 85 (1967).

H + Ne: P.M. Stier and C.F. Barnett, Phys. Rev. 103, 896 (1956).

Accuracy:

$\pm$ 20%.


ORNL-DWG 75-237
CROSS SECTION (cm²)
10⁻¹⁵
5
2
10⁻¹⁶
5
2
10⁻¹⁷
5
2
10⁻¹⁸
Ne
He
10⁰ 2 5 10¹ 2 5 10² 2 5 10³ 2 5 10⁴ 2 5 10⁵
ENERGY (keV)

Cross Sections for Electron Loss of H Atoms in N_2, O_2, and H_2O

Energy (keV)	Cross Sections (cm^2)		
	N_2	O_2	H_2O
3.0 E 00		1.29 E-16	
4.0 E 00	1.68 E-16	1.68 E-16	
6.0 E 00	2.28 E-16	2.22 E-16	
8.0 E 00	2.78 E-16	2.68 E-16	
1.0 E 01	3.14 E-16	3.00 E-16	
2.0 E 01	4.18 E-16	3.90 E-16	
5.0 E 01	4.84 E-16	4.52 E-16	
1.0 E 02	4.62 E-16	4.36 E-16	3.18 E-16
2.0 E 02	3.74 E-16	3.66 E-16	2.70 E-16
5.0 E 02	2.36 E-16	2.66 E-16	1.55 E-16
1.0 E 03	1.54 E-16	1.51 E-16	9.81 E-17
1.5 E 03	1.10 E-16	1.15 E-16	7.10 E-17
2.0 E 03	8.88 E-17	9.48 E-17	5.70 E-17
5.0 E 03	3.90 E-17		
1.0 E 04	2.02 E-17		

References:

$H + N_2$: C.F. Barnett and H.K. Reynolds, Phys. Rev. 109, 355 (1958); P.M. Stier and C.F. Barnett, Phys. Rev. 103, 896 (1956); L.H. Toburen, M.Y. Nakai, and R.A. Langley, Phys. Rev. 171, 114 (1968); K.H. Berkner, S.N. Kaplan, and R.V. Pyle, Phys. Rev. 134, A-1461 (1964); L.M. Welsh, K.H. Berkner, S.N. Kaplan, and R.V. Pyle, Phys. Rev. 158, 85 (1967); U. Schryber, Hel. Phys. Acta 40, 1023 (1967); H. Tawara and A. Russek, Rev. Mod. Phys. 45, 178 (1973).

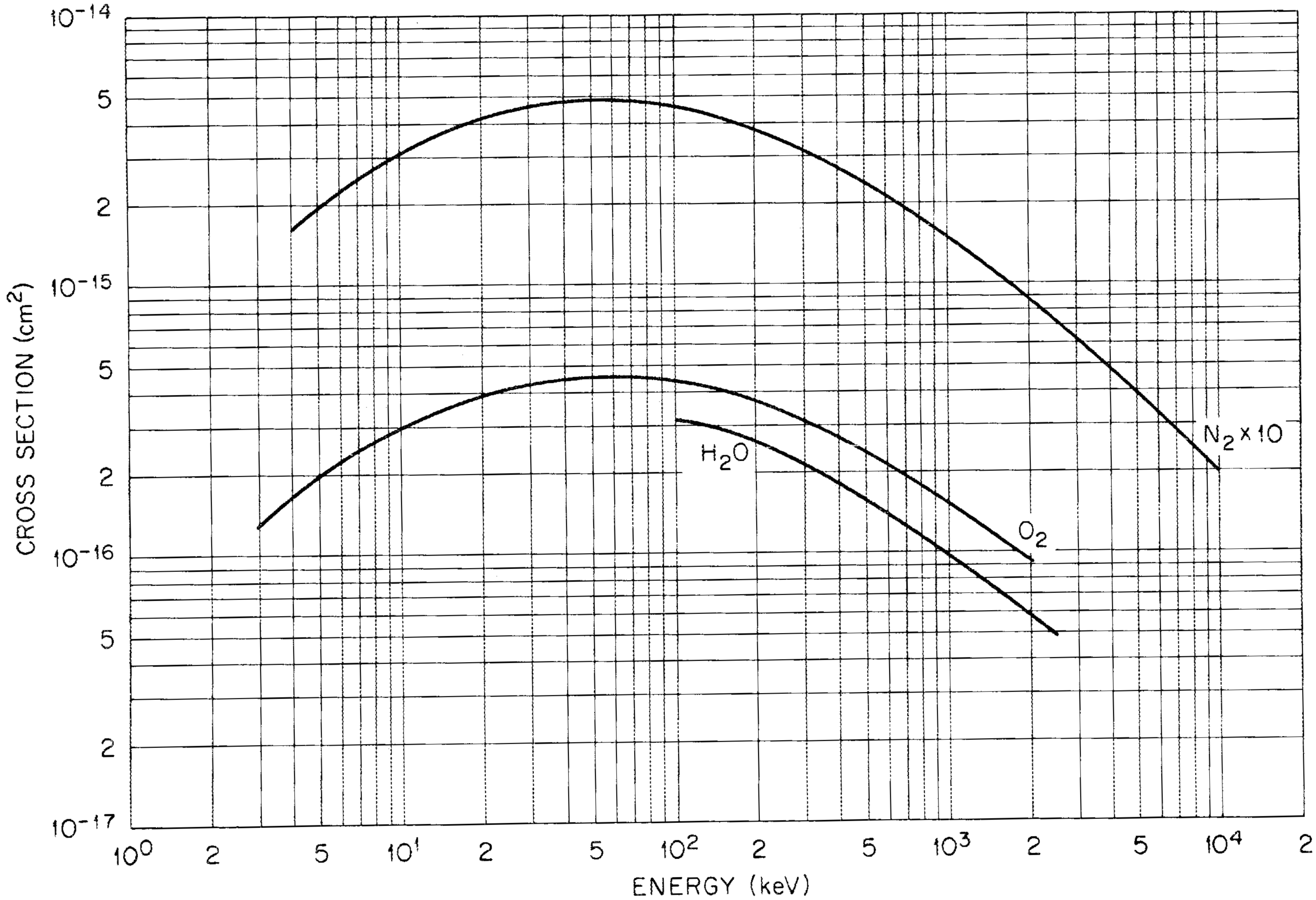
$H + O_2$: P.M. Stier and C.F. Barnett, Phys. Rev. 103, 896 (1956); L.H. Toburen, M.Y. Nakai, and R.A. Langley, Phys. Rev. 171, 114 (1968); H. Tawara and A. Russek, Rev. Mod. Phys. 45, 178 (1973).

$H + H_2O$: L.H. Toburen, M.Y. Nakai, and R.A. Langley, Phys. Rev. 171, 114 (1968).

Accuracy:

± 25%.

ORNL-DWG 75-238R



A.5.39

Cross Sections for Electron Production in N_2 and O_2 by H Atom Impact

Energy (keV)	Cross Sections (cm^2)	
	N_2	O_2
1.0 E-01	8.0 E-18	1.5 E-17
2.0 E-01	2.4 E-17	3.7 E-17
4.0 E-01	5.9 E-17	8.3 E-17
6.0 E-01	9.0 E-17	1.2 E-16
1.0 E 00	1.5 E-16	1.7 E-16
2.0 E 00	2.6 E-16	2.5 E-16
4.0 E 00	4.2 E-16	3.7 E-16
6.0 E 00	5.0 E-16	4.3 E-16
1.0 E 01	7.4 E-16	5.0 E-16
2.0 E 01	1.0 E-15	
4.0 E 01	1.1 E-15	
6.0 E 01	1.0 E-15	
1.0 E 02	8.0 E-16	
2.0 E 02	5.8 E-16	
4.0 E 02	4.2 E-16	

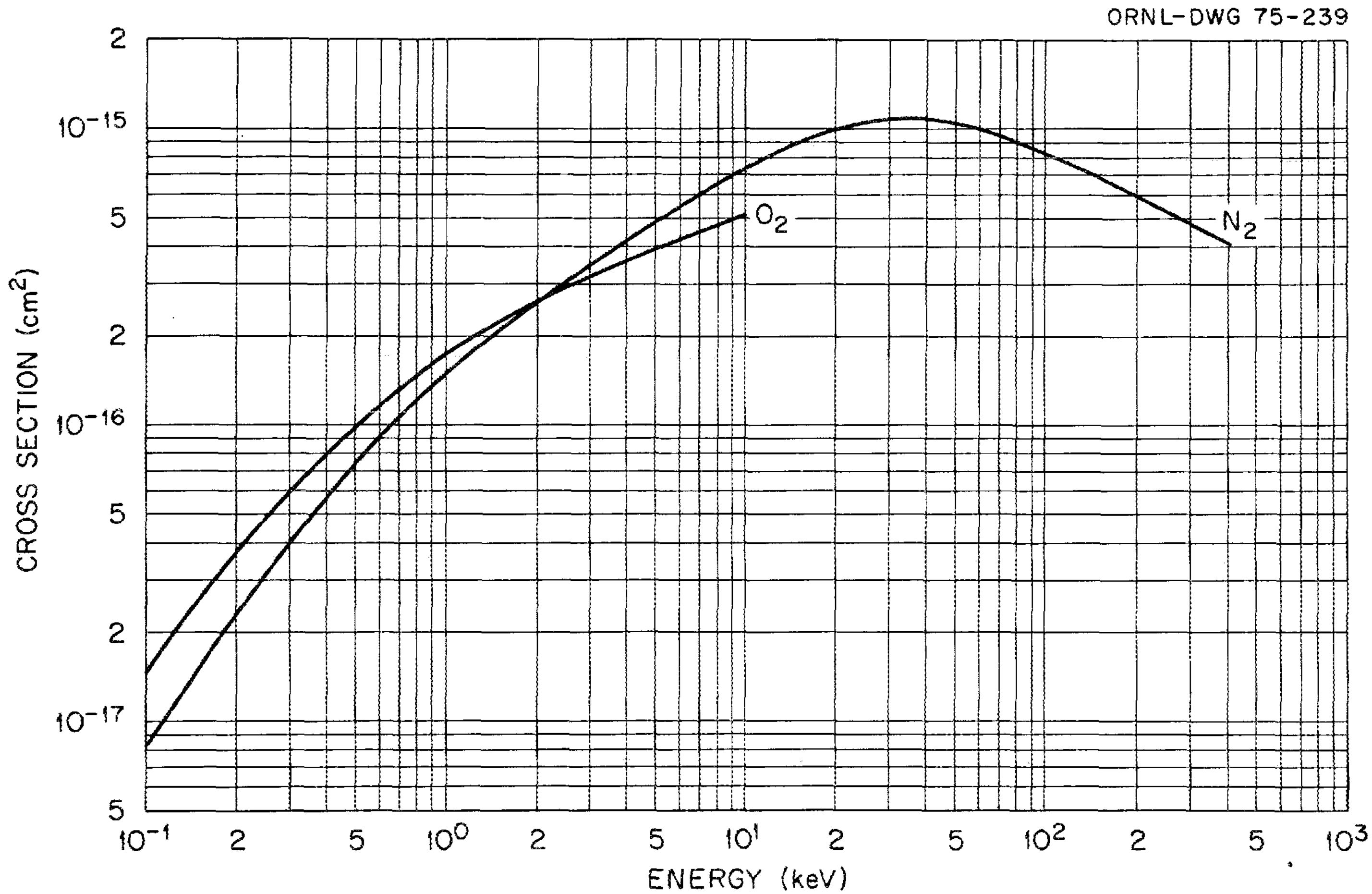
References:

$H + N_2$: H.H. Fleischmann and R.A. Young, Phys. Lett. 29A, 287 (1969); L.J. Puckett, G.O. Taylor, and D.W. Martin, Phys. Rev. 178, 271 (1969); E.S. Solov'ev, R.N. Il'in, V.A. Oparin, and N.V. Fedorenko, Sov. Phys.-JETP 15, 459 (1962); R.J. McNeal and D.C. Clark, J. Geophys. Res. 74, 5065 (1969).

$H + O_2$: H.H. Fleischmann and R.A. Young, Phys. Lett. 29A, 287 (1969); R.J. McNeal, D.C. Clark, and R.A. Klingbery, Phys. Rev. A 2, 131 (1970).

Accuracy:

± 50%.



ORNL-DWG 75-239
CROSS SECTION (cm^2)
ENERGY (keV)
O_2
N_2
2
10^{-15}
5
2
10^{-16}
5
2
10^{-17}
5
10^{-1}
2
5
10^{0}
2
5
10^{1}
2
5
10^{2}
2
5
10^{3}

Cross Sections for One Electron Loss of H Atoms in Na, K, and Mg

Energy (keV)	Cross Sections (cm^2)				
	K	Na_1	Na_2	Mg_1	Mg_2
4.0 E 00				1.9 E-17	
6.0 E 00	2.6 E-16			3.3 E-17	
8.0 E 00	3.6 E-16			5.2 E-17	
1.0 E 01	4.6 E-16			7.6 E-17	
1.5 E 01	5.9 E-16	4.8 E-16	2.4 E-16	1.8 E-16	2.7 E-16
2.0 E 01	5.3 E-16	4.0 E-16	3.1 E-16	3.3 E-16	2.5 E-16
2.5 E 01	4.5 E-16		3.5 E-16	3.3 E-16	3.0 E-16
3.0 E 01			3.8 E-16	3.1 E-16	3.3 E-16
4.0 E 01			3.9 E-16	1.5 E-16	3.1 E-16
6.0 E 01			3.7 E-16		2.8 E-16

References:

H + K: R.A. Nieman, Ph.D. Thesis, University of Pittsburgh, Pittsburgh, PA.

H + Na: R.A. Nieman, Ph.D. Thesis, University of Pittsburgh, Pittsburgh, PA.

H + Na_2: V.A. Oparin, R.N. Il'in, and E.S. Solov'ev, Sov. Phys.-JETP 25, 240 (1967).

H + Mg_2: V.A. Oparin, R.N. Il'in, and E.S. Solov'ev, Sov. Phys.-JETP 25, 240 (1967).

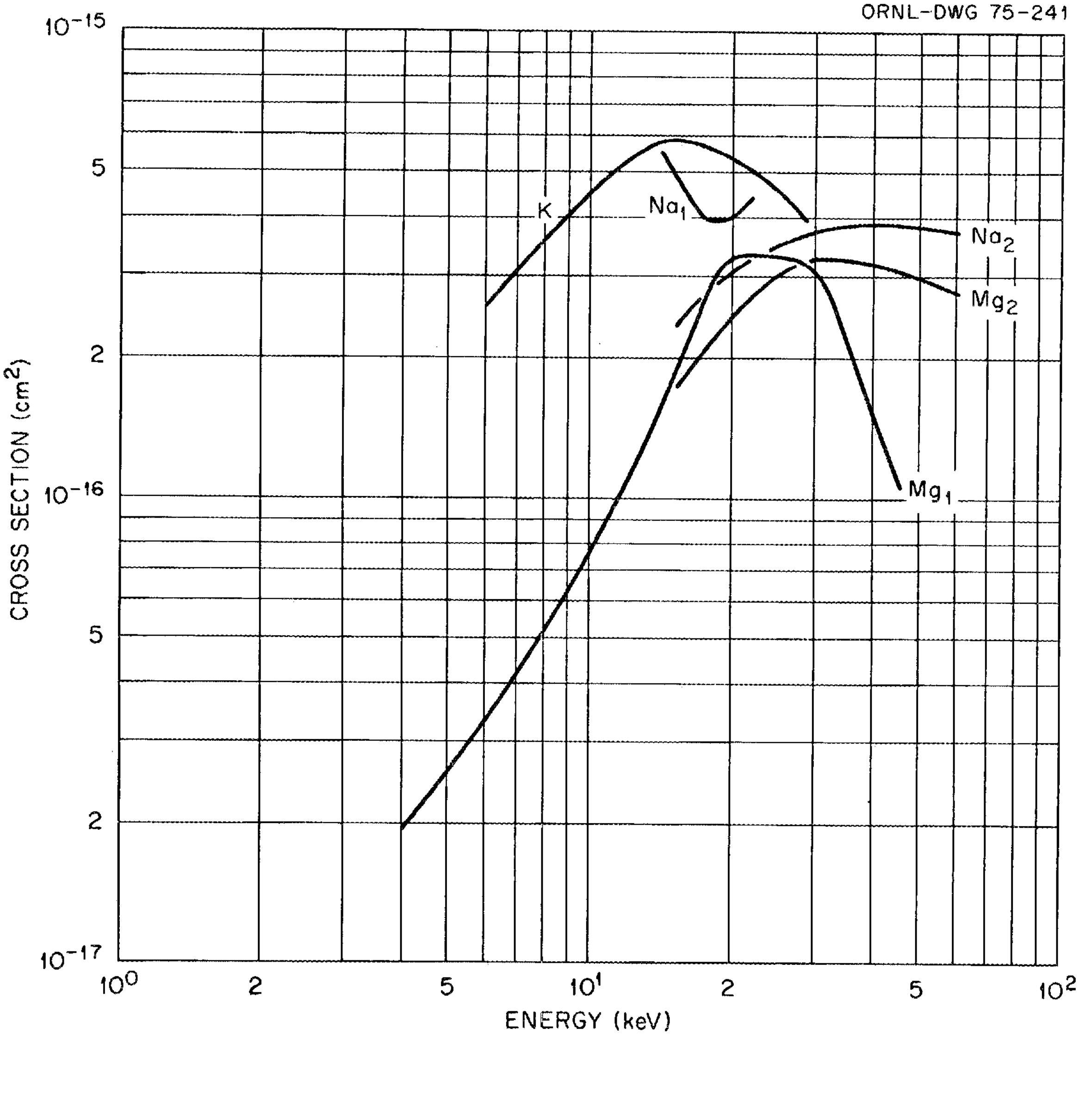
H + Mg_1: A.H. Futch and K.G. Moses, Fifth Intl. Conf. on Electronic & Atomic Collisions (Leningrad, 1967) Publishing House Nauka (Leningrad) p. 12 (1967).

Accuracy:

The accuracy is no better than a factor of 2 to 3.

Note:

Na_2 and Mg_2 refer to a different set of measurements and not a molecule.


ORNL-DWG 75-241
CROSS SECTION (cm²)
ENERGY (keV)
10⁻¹⁵
5
2
10⁻¹⁶
5
2
10⁻¹⁷
10⁰
2
5
10¹
2
5
10²
K
Na1
Na2
Mg2
Mg1

Cross Sections for One Electron Loss of H_2 and D_2 in H_2 and D_2 Gas

Energy (keV)	Cross Sections (cm^2)	
	$H_2 + H_2$	$D_2 + D_2$
5.0 E-02	5.0 E-19	3.8 E-19
7.5 E-02	2.8 E-18	1.3 E-18
1.0 E-01	5.7 E-18	2.7 E-18
2.0 E-01	1.4 E-17	8.7 E-18
3.0 E-01	1.9 E-17	1.3 E-17
5.0 E-01	2.2 E-17	1.7 E-17
6.0 E 00	5.2 E-17	
1.0 E 01	6.7 E-17	
2.0 E 01	1.2 E-16	
5.0 E 01	1.8 E-16	
1.0 E 02	2.0 E-16	
1.2 E 02	2.0 E-16	

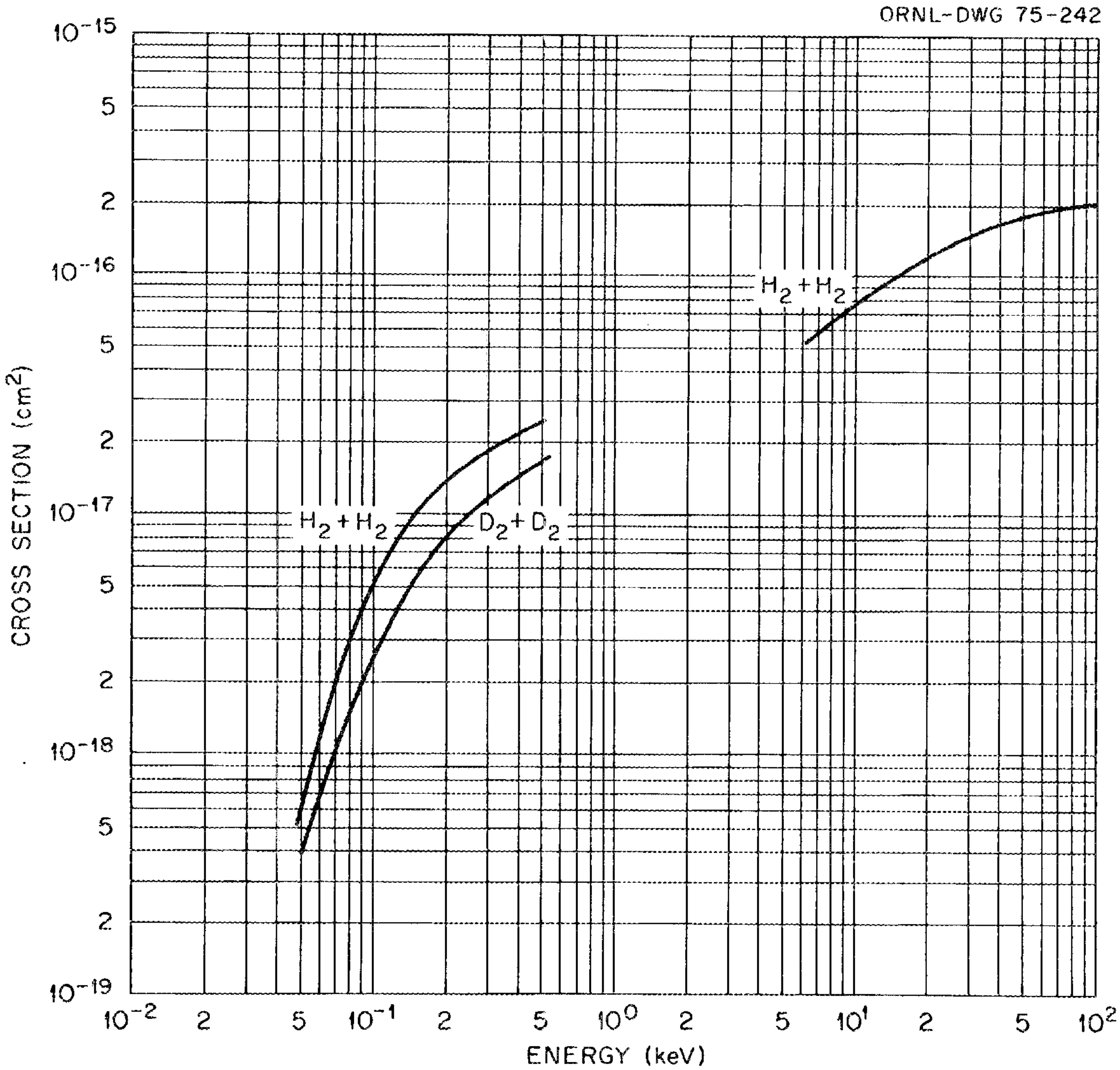
References:

$H_2 + H_2$: R.K. Peterson and M. Eisner, Phys. Rev. A 8, 1289 (1973); G.W. McClure, Phys. Rev. 134, A 1226 (1964); T.J. Morgan, K.H. Berkner, and R.V. Pyle, Phys. Rev. A 5, 1591 (1972).

$D_2 + D_2$: R.K. Peterson and M. Eisner, Phys. Rev. A 8, 1289 (1973).

Accuracy:

± 20%.


ORNL-DWG 75-242
CROSS SECTION (cm²)
ENERGY (keV)
H₂ + H₂
D₂ + D₂
H₂ + H₂
10⁻¹⁵
10⁻¹⁶
10⁻¹⁷
10⁻¹⁸
10⁻¹⁹
10⁻²
10⁻¹
10⁰
10¹
10²

Cross Sections for Electron Production in Collisions of H^- with H Atoms

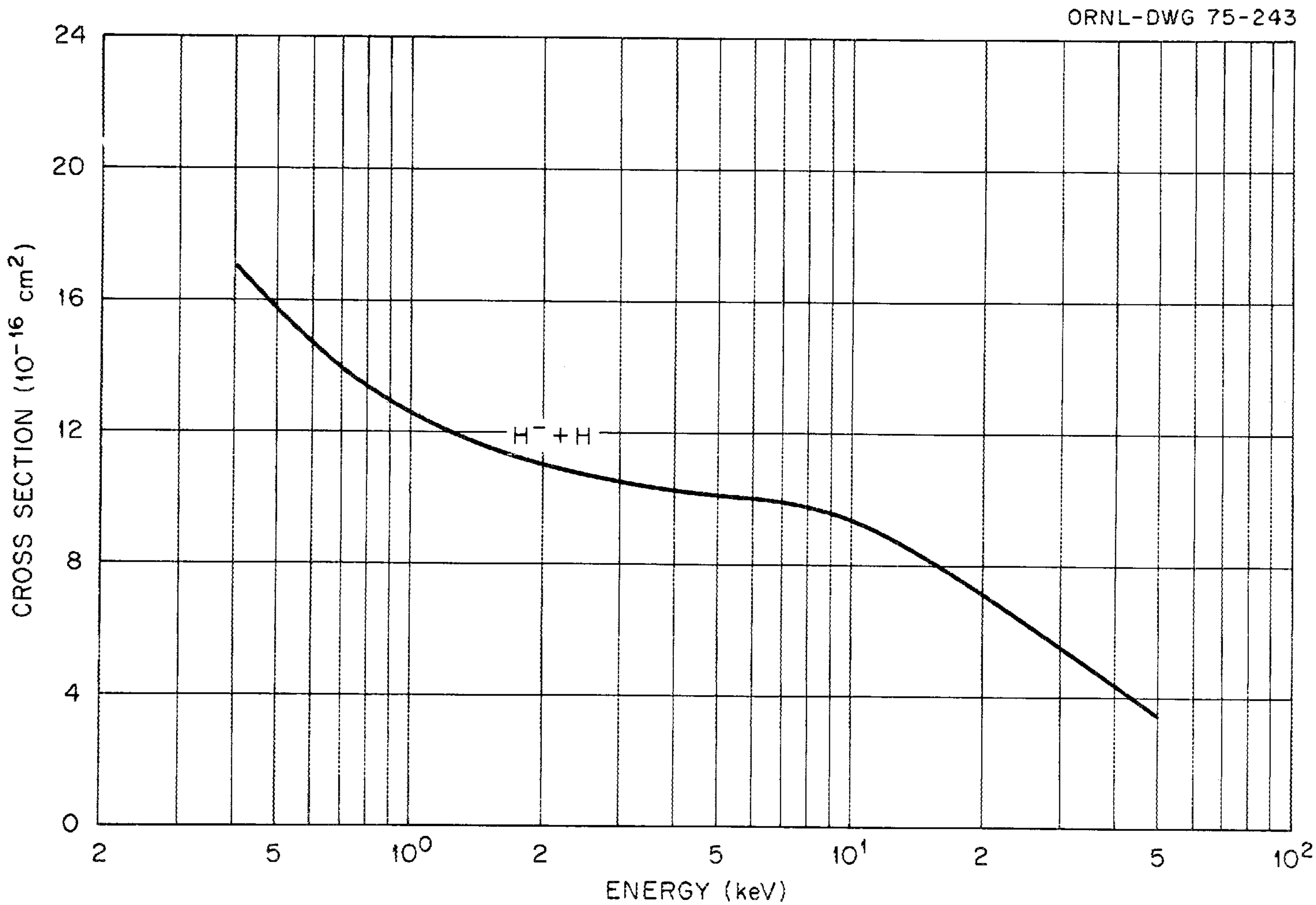
Energy (keV)	Cross Sections (cm^2)
4.0 E-01	1.70 E-15
6.0 E-01	1.48 E-15
8.0 E-01	1.34 E-15
1.0 E 00	1.26 E-15
2.0 E 00	1.11 E-15
4.0 E 00	1.02 E-15
6.0 E 00	1.00 E-15
8.0 E 00	9.80 E-16
1.0 E 01	9.40 E-16
2.0 E 01	7.10 E-16
4.0 E 01	4.40 E-16
5.0 E 01	3.40 E-16

References:

D.G. Hummer, R.F. Stebbings, W.L. Fite, and L.M. Branscomb, Phys. Rev. 119, 668 (1960).

Accuracy:

± 30%.


ORNL-DWG 75-243
CROSS SECTION (10^{-16} cm^2)
ENERGY (keV)
$H^- + H$
24
20
16
12
8
4
0
2
5
10^0
2
5
10^1
2
5
10^2

A.5.47

Cross Sections for One Electron Loss or Stripping for H^- in H_2 and He

Energy (keV)	Cross Sections (cm^2) H_2	He
2.0 E-01	7.5 E-16	4.6 E-16
5.0 E-01	1.0 E-15	5.2 E-16
1.0 E 00	1.1 E-15	5.8 E-16
2.0 E 00	1.2 E-15	6.1 E-16
5.0 E 00	1.2 E-15	6.0 E-16
1.0 E 01	1.0 E-15	5.4 E-16
2.0 E 01	8.7 E-16	4.4 E-16
5.0 E 01	6.0 E-16	3.2 E-16
1.0 E 02	4.0 E-16	2.2 E-16
2.0 E 02	2.6 E-16	1.5 E-16
5.0 E 02	1.3 E-17	7.3 E-17
1.0 E 03	7.2 E-17	4.0 E-17
2.0 E 03	3.3 E-17	2.2 E-17
5.0 E 03	1.2 E-17	9.0 E-18
1.0 E 04	5.5 E-18	4.7 E-18
1.7 E 04	2.7 E-18	

References:

H^- + H_2: J.F. Williams, Phys. Rev. 154, 9 (1967); P.M. Stier and C.F. Barnett, Phys. Rev. 103, 896 (1956); P.H. Rose, R.J. Connor, and R.P. Bastide, Bull. Am. Phys. Soc. II-3, 40 (1958); G.I. Dimov and V.G. Dudnikov, Sov. Phys.-Tech. Phys. 11, 919 (1967); K.H. Berkner, S.N. Kaplan, and R.V. Pyle, Phys. Rev. 134, A1461 (1964); R. Smythe and J.W. Toevs, Phys. Rev. 139, A-15 (1965); H. Tawara and A. Russek, Rev. Mod. Phys. 45, 178 (1973); J.S. Risley and R. Geballe, Phys. Rev. A 9, 2485 (1974); F.R. Simpson and H.B. Gilbody, J. Phys. B 5, 1959 (1972).

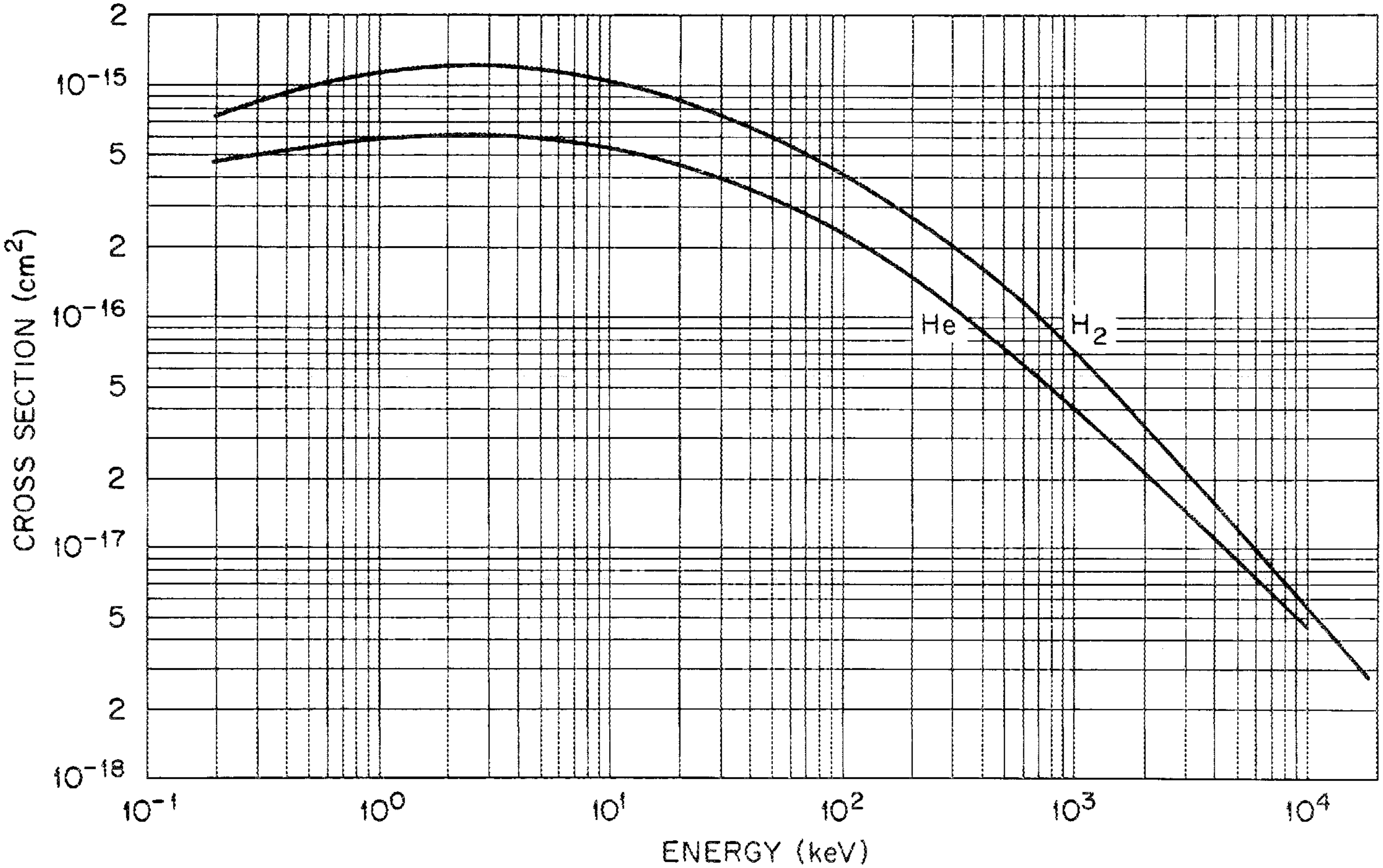
H^- + He: J.F. Williams, Phys. Rev. 154, 9 (1967); G.I. Dimov and V.G. Dudnikov, Sov. Phys.-Tech. Phys. 11, 919 (1967); P.M. Stier and C.F. Barnett, Phys. Rev. 103, 896 (1956); K.H. Berkner, S.N. Kaplan, and R.V. Pyle, Phys. Rev. 134, A-1461 (1964); F.R. Simpson and H.B. Gilbody, J. Phys. B 5, 1959 (1972); J.S. Risley and R. Geballe, Phys. Rev. A 9, 2485 (1974); H. Tawara and A. Russek, Rev. Mod. Phys. 45, 178 (1973).

Accuracy: ± 25%.

Note:

For total detachment cross sections ($\sigma_{-10} + 2\sigma_{-11}$) see J.S. Risley and R. Geballe, Phys. Rev. A 9, 2485 (1974); J.S. Risley, Phys. Rev. A 10, 731 (1974); J.B. Hasted and R.A. Smith, Proc. Roy. Soc. (Lond.) A235, 349 (1956); J.B.H. Stedeford and J.B. Hasted, Proc. Roy. Soc. (Lond.) A227, 466 (1955); E.E. Muschlitz, Jr., T.L. Bailey, and J.H. Simons, J. Chem. Phys. 24, 1202 (1956) and J. Chem. Phys. 26, 711 (1957).

ORNL-DWG 75-244



A.5.49

Cross Sections for Loss of Two Electrons in Collisions of H^- with H_2 and He

Energy (keV)	Cross Sections (cm^2)	
	H_2	He
2.0 E 00	2.1 E-17	2.7 E-17
5.0 E 00	3.1 E-17	4.7 E-17
1.0 E 01	4.0 E-17	5.1 E-17
2.0 E 01	4.4 E-17	4.3 E-17
5.0 E 01	4.2 E-17	2.3 E-17
1.0 E 02	3.0 E-17	1.2 E-17
2.0 E 02	1.7 E-17	6.0 E-18
5.0 E 02	7.0 E-18	2.5 E-18
1.0 E 03	3.5 E-18	1.3 E-18
2.0 E 03	1.7 E-18	6.5 E-19
5.0 E 03	6.5 E-19	2.7 E-19
1.0 E 04	3.0 E-19	1.4 E-19

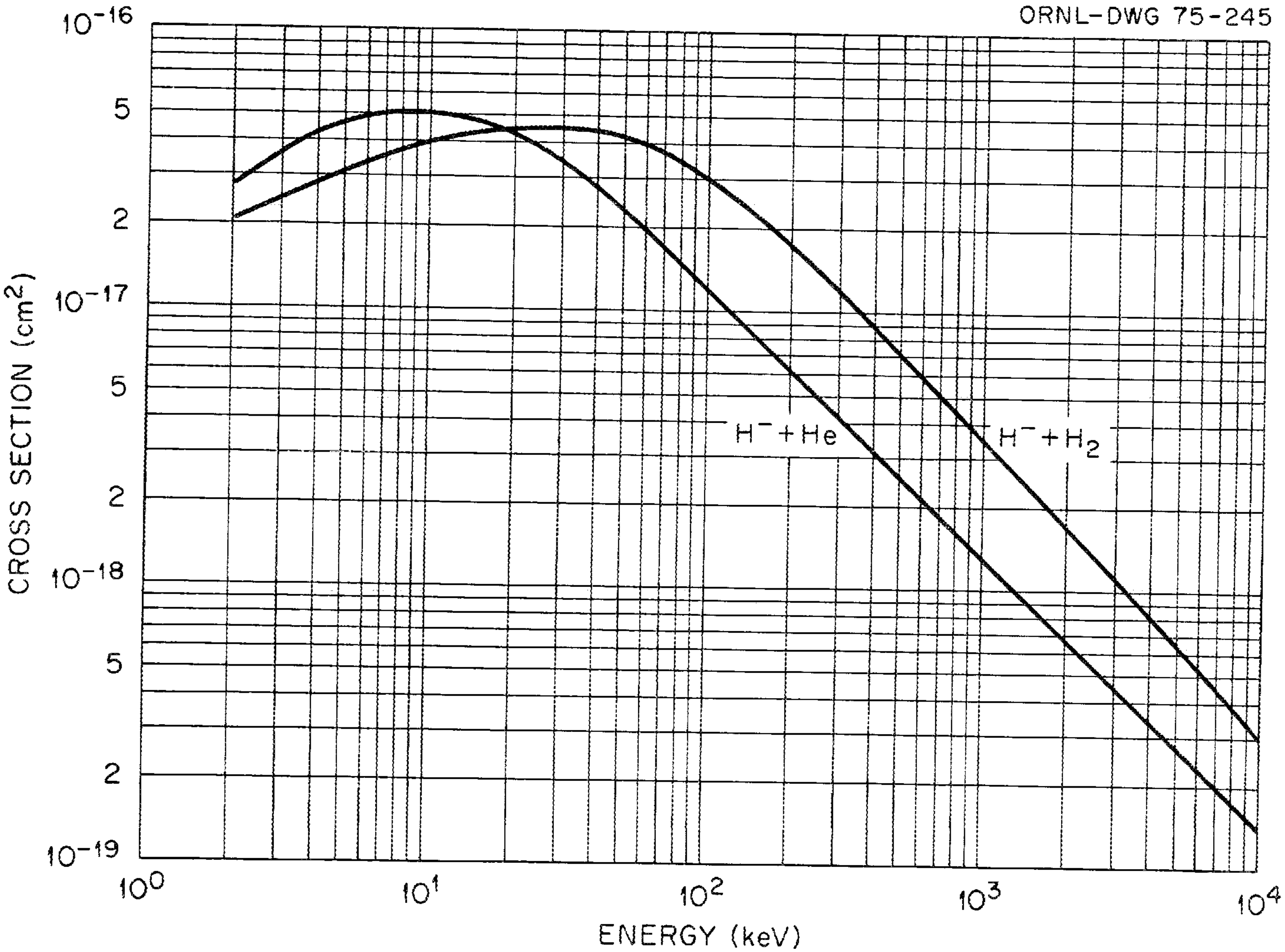
References:

H^- + H_2: H. Tawara and A. Russek, Rev. Mod. Phys. 45, 178 (1973); J.F. Williams, Phys. Rev. 154, 9 (1967); K.H. Berkner, S.N. Kaplan, and R.V. Pyle, Phys. Rev. 134, A-1461 (1964); R. Smythe and J.W. Toevs, Phys. Rev. 139, A-15 (1965); G. Tisone and L.M. Branscomb, Bull. Am. Phys. Soc. 9, 535 (1964); Ya. M. Fogel, V.A. Ankudinov, and R.E. Slabospitski, Sov. Phys.-JETP 5, 382 (1957).

H^- + He: J.F. Williams, Phys. Rev. 154, 9 (1967); G.I. Dimov, and V.G. Dudnikov, Sov. Phys.-Tech. Phys. 11, 919 (1967); K.H. Berkner, S.N. Kaplan, and R.V. Pyle, Phys. Rev. 134, A-1461 (1964); Ya. M. Fogel, V.A. Ankudinov, and R.E. Slabospitski, Sov. Phys.-JETP 5, 382 (1957).

Accuracy:

± 25%.


ORNL-DWG 75-245
CROSS SECTION (cm^2)
ENERGY (keV)
10^{-16}
5
2
10^{-17}
5
2
10^{-18}
5
2
10^{-19}
10^0
10^1
10^2
10^3
10^4
$H^- + He$
$H^- + H_2$

Cross Sections for One Electron Loss or Stripping for H^- in O_2 and N_2

Energy (keV)	Cross Sections (cm^2)	
	N_2	O_2
2.0 E-01	1.1 E-15	1.5 E-15
5.0 E-01	1.6 E-15	1.4 E-15
1.0 E 00	1.9 E-15	1.3 E-15
2.0 E 00	2.1 E-15	1.1 E-15
5.0 E 00	1.9 E-15	1.1 E-15
1.0 E 01	1.7 E-15	1.1 E-15
2.0 E 01	1.5 E-15	1.2 E-15
5.0 E 01	1.2 E-15	1.1 E-15
1.0 E 02	9.8 E-16	1.0 E-15
2.0 E 02	7.5 E-16	9.0 E-15
5.0 E 02	4.6 E-16	5.8 E-15
1.0 E 03	3.0 E-16	3.6 E-15
2.0 E 03	1.9 E-16	2.1 E-15
5.0 E 03	1.0 E-16	9.8 E-15
1.0 E 04	5.5 E-17	5.3 E-15
1.5 E 04	3.8 E-17	4.0 E-15

References:

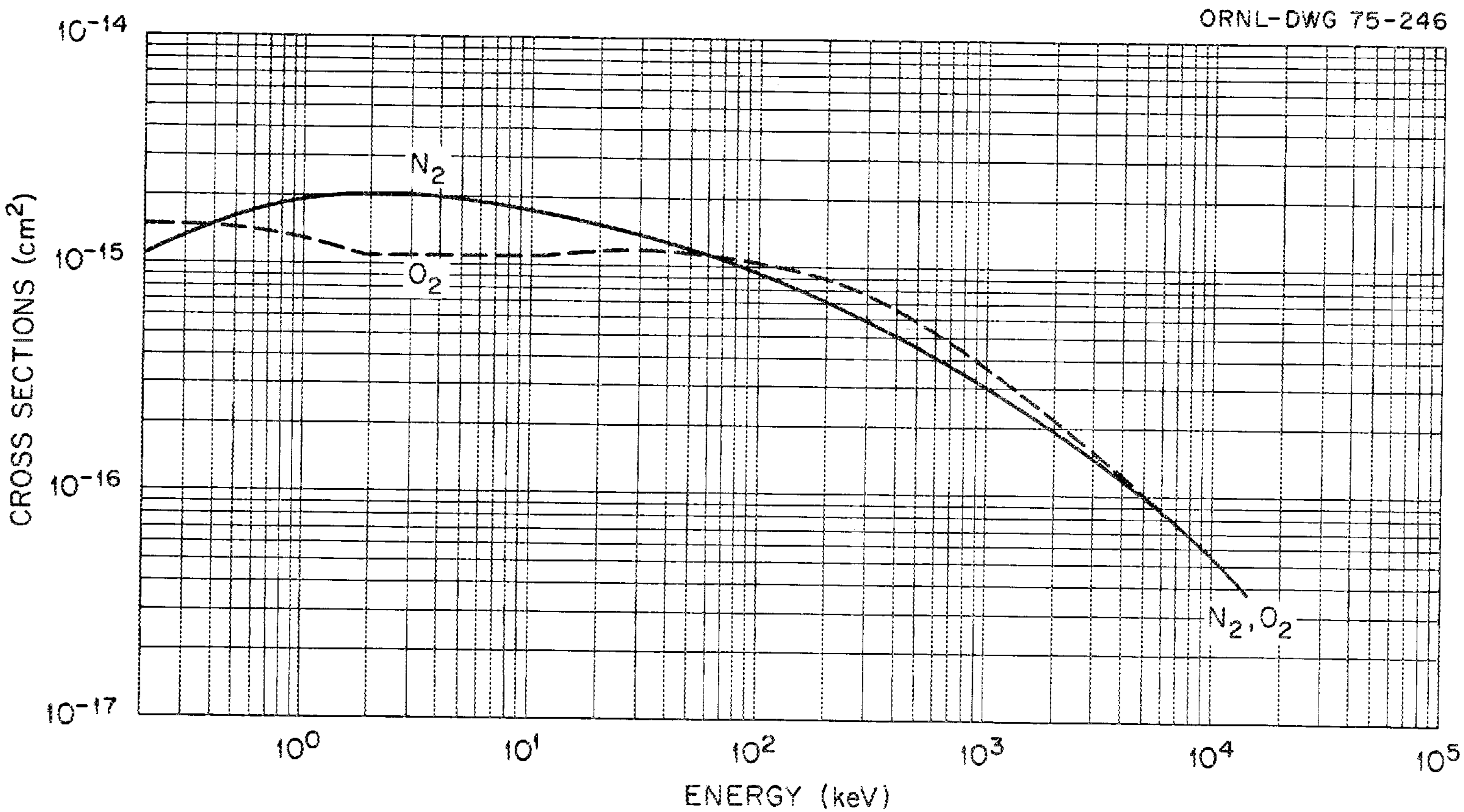
$H^- + N_2$: H. Tawara and A. Russek, Rev. Mod. Phys. 45, 178 (1973); G.I. Dimov and V.G. Dudnikov, Sov. Phys.-Tech. Phys. 11, 919 (1967); K.H. Berkner, S.N. Kaplan, and R.V. Pyle, Phys. Rev. 134, A-1461 (1964); I. Kovacs, Nucl. Instr. Meth. 51, 224 (1967); J.S. Risley and R. Geballe, Phys. Rev. A 9, 2485 (1974); R. Smythe and J.W. Toevs, Phys. Rev. 139, A-15 (1965); P.M. Stier and C.F. Barnett, Phys. Rev. 103, 896 (1956).

$H^- + O_2$: P.M. Stier and C.F. Barnett, Phys. Rev. 103, 896 (1956); P.M. Rose, R.J. Connor, and R.P. Bastide, Bull. Am. Phys. Soc. II-3, 40 (1958); J.S. Risley and R. Geballe, Phys. Rev. A 9, 2485 (1974); R. Smythe and J.W. Toevs, Phys. Rev. 139, A-15 (1965); D.V. Phipenko, V.A. Gusev, and Ya. M. Fogel, Sov. Phys.-JETP 22, 965 (1966).

Accuracy: ± 25%.

Note:

For total detachment cross sections ($\sigma_{-10} + 2\sigma_{-11}$) see:
J.S. Risley and R. Geballe, Phys. Rev. A 9, 2485 (1974); R. Smythe and J.W. Toevs, Phys. Rev. 139, A-15 (1965); J.S. Risley, Phys. Rev. A 10, 731 (1974); T.L. Bailey and P. Mahadevan, J. Chem. Phys. 52, 179 (1970).


ORNL-DWG 75-246
CROSS SECTIONS (cm²)
10⁻¹⁴
10⁻¹⁵
10⁻¹⁶
10⁻¹⁷
N₂
O₂
N₂, O₂
10⁰
10¹
10²
10³
10⁴
10⁵
ENERGY (keV)

A.5.53

Cross Sections for Loss of Two Electrons by H^- in N_2 and O_2

Energy (keV)	Cross Sections (cm^2) N_2	O_2
5.0 E 00	1.1 E-16	8.4 E-17
1.0 E 01	1.1 E-16	9.2 E-17
2.0 E 01	1.3 E-16	1.2 E-16
4.0 E 01	1.8 E-16	1.6 E-16
5.0 E 01	2.0 E-16	
1.0 E 02	3.0 E-16	
2.0 E 02	2.8 E-16	
5.0 E 02	1.1 E-16	
1.0 E 03	4.7 E-17	
2.0 E 03	2.0 E-17	
5.0 E 03	6.5 E-18	
1.0 E 04	2.7 E-18	

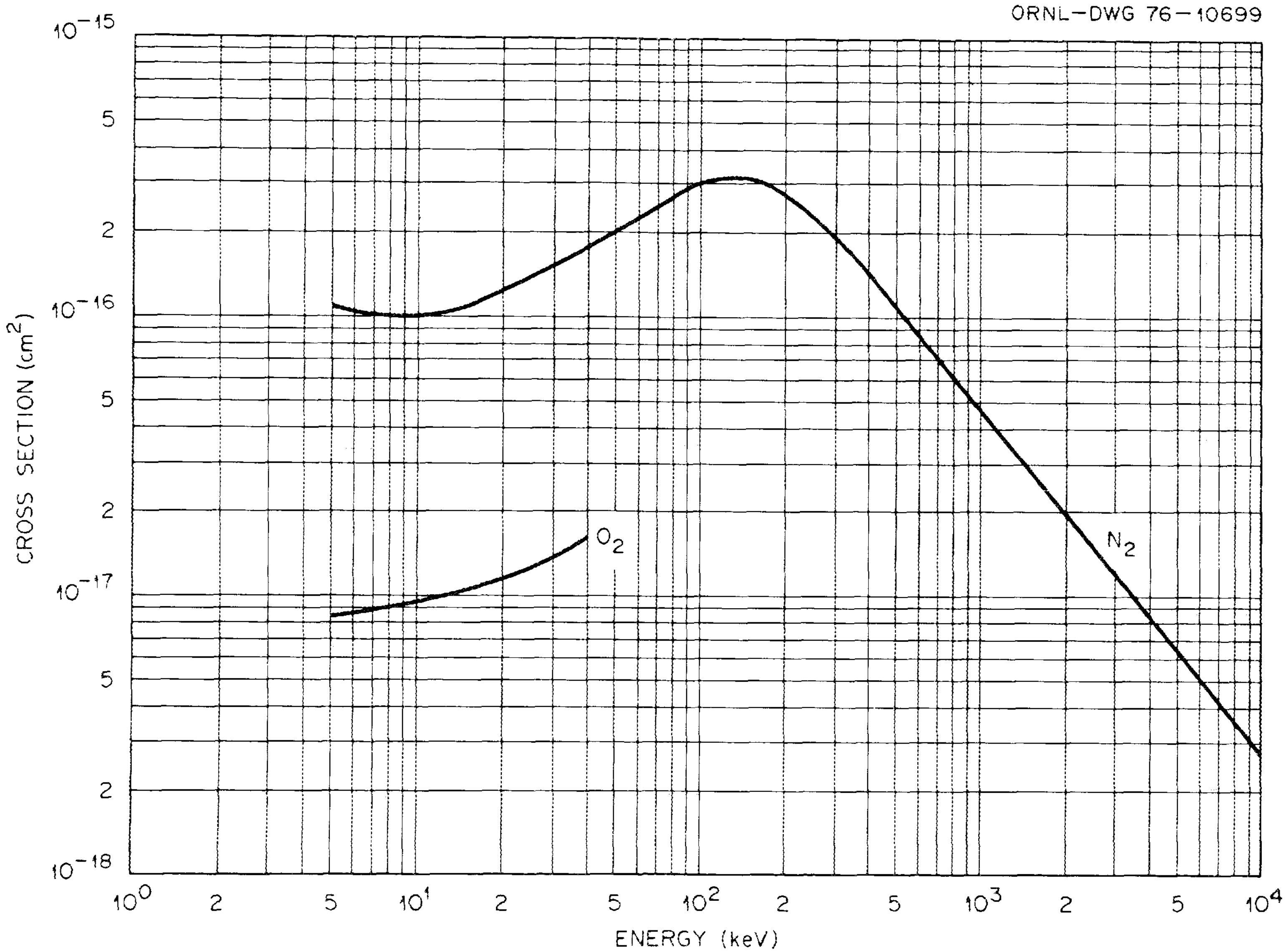
References:

H^- + N_2: Ya. M. Fogel, V.A. Ankudinov, and R.E. Slabospitski, Sov. Phys.-JETP 5, 382 (1957); K.H. Berkner, S.N. Kaplan, and R.V. Pyle, Phys. Rev. 134, A-1461 (1964); I. Kovacs, Nucl. Instr. Meth. 51, 224 (1967); H. Tawara and A. Russek, Rev. Mod. Phys. 45, 178 (1973).

H^- + O_2: Ya. M. Fogel, V.A. Ankudinov, and R.E. Slabospitski, Sov. Phys.-JEPT 5, 382 (1957).

Accuracy:

± 25%.


ORNL-DWG 76-10699
CROSS SECTION (cm2)
ENERGY (keV)
10−15
5
2
10−16
5
2
10−17
5
2
10−18
100
2
5
101
2
5
102
2
5
103
2
5
104
O2
N2

Cross Sections for Single Electron Loss or Stripping for H^- in Ar and Ne

Energy (keV)	Cross Sections (cm^2)	
	Ar	Ne
2.0 E 00	6.5 E-16	3.0 E-16
4.0 E 00	8.3 E-16	3.3 E-16
6.0 E 00	9.7 E-16	3.5 E-16
1.0 E 01	1.2 E-15	3.7 E-16
2.0 E 01	1.6 E-15	4.2 E-16
5.0 E 01	1.5 E-15	4.9 E-16
7.0 E 01	1.3 E-15	
1.0 E 02	1.2 E-15	
2.0 E 02	9.0 E-16	
5.0 E 02	6.0 E-16	
7.0 E 02	5.0 E-16	
1.0 E 03	4.0 E-16	
2.0 E 03	2.6 E-16	
5.0 E 03	1.3 E-16	
7.0 E 03	1.0 E-16	
1.0 E 04	7.5 E-17	

References:

H^- + Ar: K.H. Berkner, S.N. Kaplan, and R.V. Pyle, Phys. Rev. 134, A1461 (1964); J.B. Hasted and J.B.H. Stedeford, Proc. Roy. Soc. (London) A227, 466 (1955); P.M. Stier and C.F. Barnett, Phys. Rev. 103, 896 (1956); J.F. Williams, Phys. Rev. 154, 9 (1967).

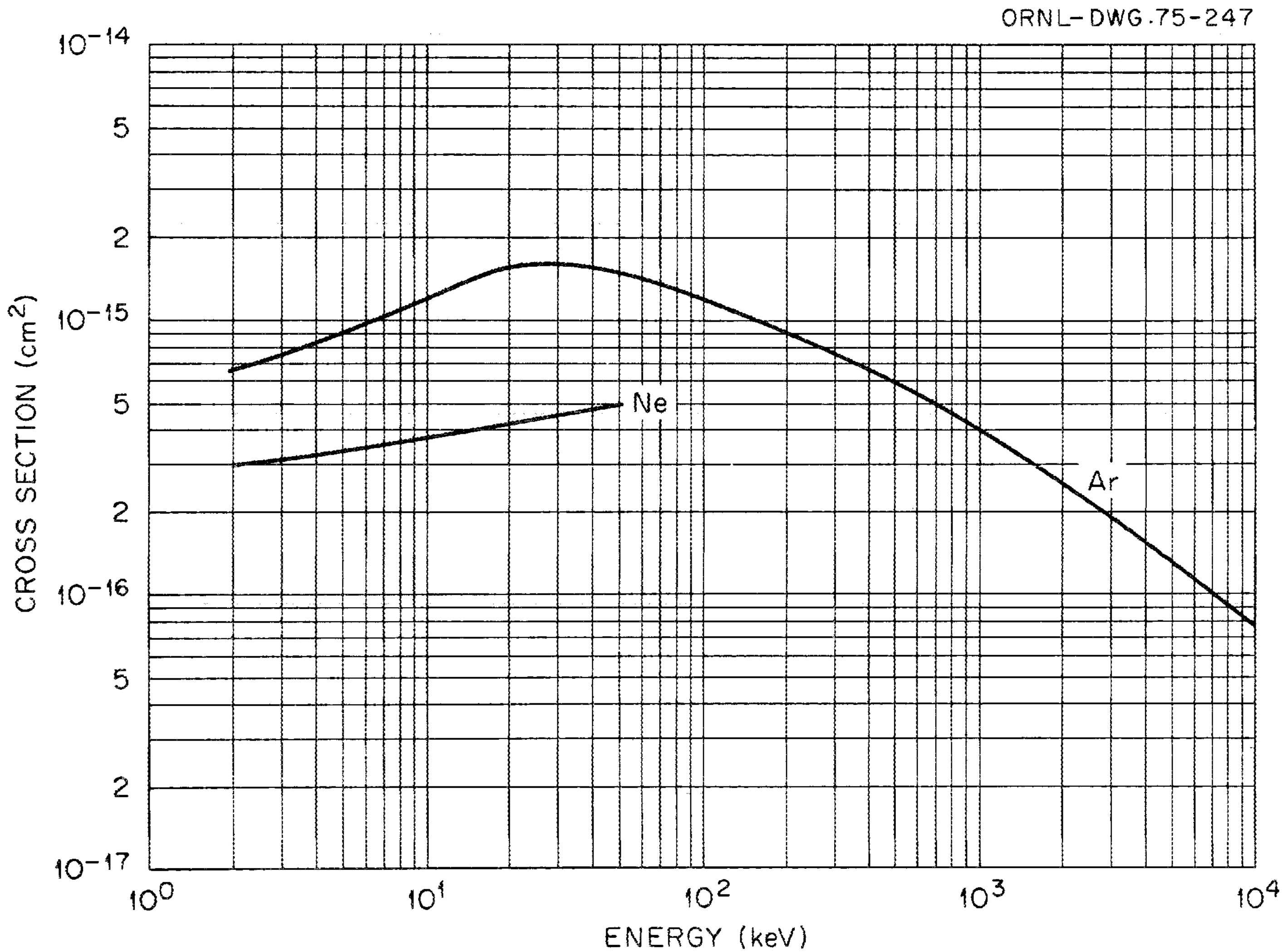
H^- + Ne: R. Smythe and J.W. Toevs, Phys. Rev. 139, A15 (1965); P.M. Stier and C.F. Barnett, Phys. Rev. 103, 896 (1956); J.F. Williams, Phys. Rev. 154, 9 (1967).

Accuracy:

± 25%

Note:

Berkner, et al., result for H^- + Ar at 10 MeV were obtained from D^- + Ar at 20 MeV.


ORNL-DWG.75-247
CROSS SECTION (cm2)
ENERGY (keV)
Ne
Ar
10−14
5
2
10−15
5
2
10−16
5
2
10−17
100
101
102
103
104

Cross Sections for One Electron Loss

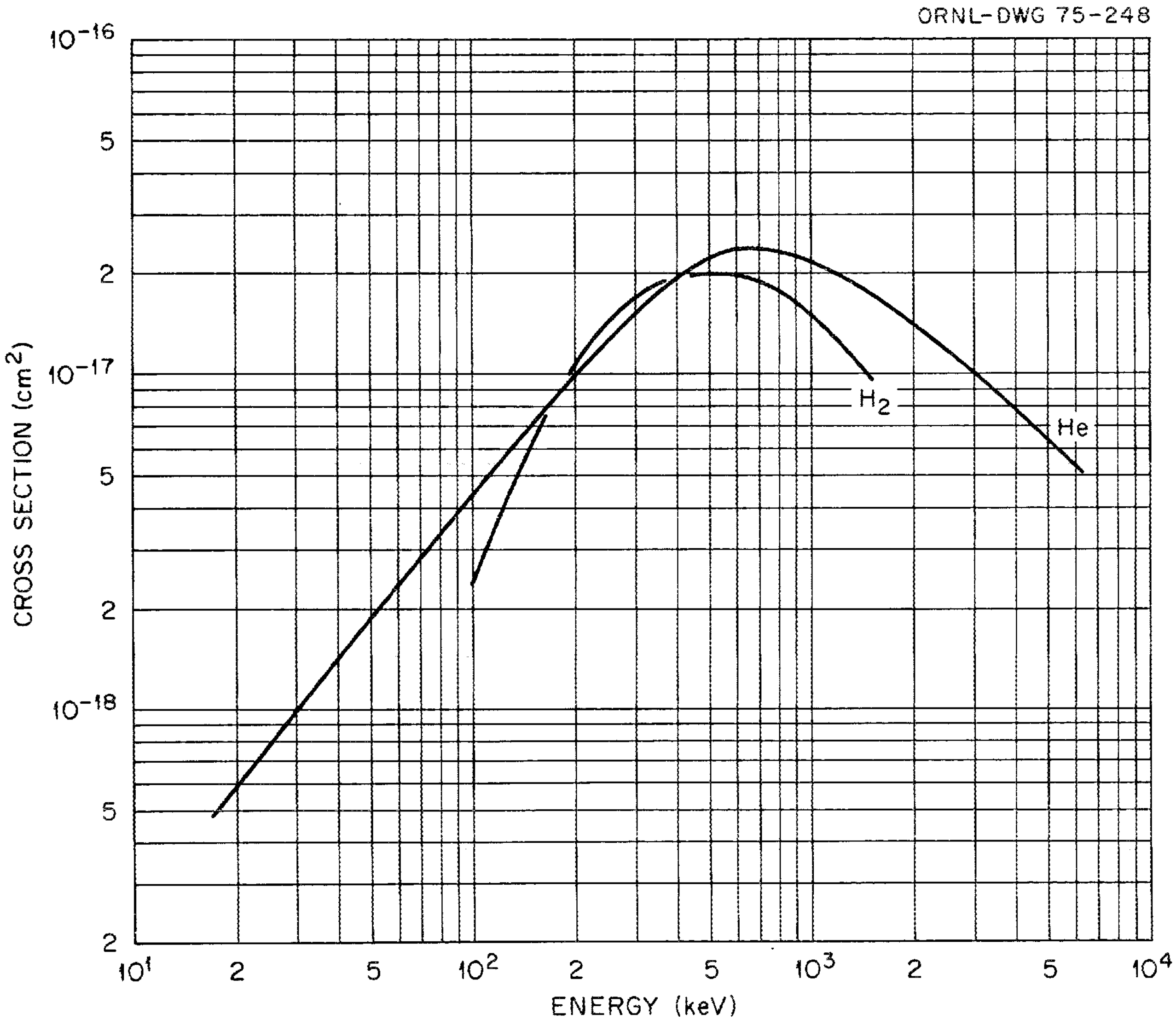
of He^+ Ions in H_2 and He

Energy (keV)	Cross Sections (cm^2)	
	H_2	He
2.0 E 01		6.0 E-19
5.0 E 01		1.9 E-18
8.0 E 01		3.4 E-18
1.0 E 02	2.4 E-18	4.4 E-18
2.0 E 02	1.1 E-17	1.0 E-17
5.0 E 02	2.0 E-17	2.2 E-17
8.0 E 02	1.8 E-17	2.3 E-17
1.0 E 03	1.5 E-17	2.2 E-17
1.5 E 03	9.6 E-18	1.8 E-17
2.0 E 03		1.4 E-17
4.0 E 03		7.7 E-18
6.0 E 03		5.2 E-18

References:

$He^+ + H_2$: S.K. Allison, J. Cuevas, and P.G. Murphy, Phys. Rev. 102, 1041 (1956); L.I. Pivovar, V.M. Tubaev, and M.T. Novikov, Sov. Phys.-JETP 14, 20 (1962); S.K. Allison, Phys. Rev. 109, 76 (1958); R.C. Dehmel, H.K. Chau, and H.H. Fleischmann, Atomic Data 5, 231 (1973).

$He^+ + He$: S.K. Allison, J. Cuevas, and P.G. Murphy, Phys. Rev. 102, 1041 (1956); P.R. Jones, F.P. Ziemba, H.A. Moses, and E. Everhart, Phys. Rev. 113, 182 (1959); N.V. Fedorenko, V.V. Afrosimov, and D.M. Kaminker, Sov. Phys.-Tech. Phys. 1, 1861 (1956); I. S. Dmitriev, V.S. Nikolaev, L.N. Fateeva, and Ya. A. Teplova, Sov. Phys.-JETP 15, 11 (1962); S.K. Allison, Phys. Rev. 109, 76 (1958); L.I. Pivovar, V.M. Tubaev, and M.T. Novikov, Sov. Phys.-JETP 14, 20 (1962); R.C. Dehmel, H.K. Chau, and H.H. Fleischmann, Atomic Data 5, 231 (1973); A.R. Lee and H.B. Gilbody, 3rd Int. Conf. on Phys. of Electronic & Atomic Collisions (London, 1963) North-Holland Publishing Co. (Amsterdam) p. 692 (1964).


ORNL-DWG 75-248
CROSS SECTION (cm^2)
ENERGY (keV)
10^{-16}
10^{-17}
10^{-18}
10^{1}
10^{2}
10^{3}
10^{4}
H_2
He

Cross Sections for the Production of Slow Electrons by He^+ Ions in H_2 and He

Energy (keV)	Cross Sections (cm^2) H_2	He
1.0 E-01	2.2 E-17	2.4 E-17
2.0 E-01	3.7 E-17	2.5 E-17
5.0 E-01	4.1 E-17	2.7 E-17
7.0 E-01	4.0 E-17	2.8 E-17
1.0 E 00	3.9 E-17	2.9 E-17
2.0 E 00	3.9 E-17	3.2 E-17
5.0 E 00	4.0 E-17	3.8 E-17
7.0 E 00	4.0 E-17	4.1 E-17
1.0 E 01	4.0 E-17	4.4 E-17
2.0 E 01	5.0 E-17	5.2 E-17
5.0 E 01	1.2 E-16	7.3 E-17
7.0 E 01	1.7 E-16	8.6 E-17
1.0 E 02	2.4 E-16	1.1 E-16
2.0 E 02	3.5 E-16	1.8 E-16
5.0 E 02	2.8 E-16	1.8 E-16
7.0 E 02	2.4 E-16	1.6 E-16
1.0 E 03	2.1 E-16	1.3 E-16
1.8 E 03	1.5 E-16	9.0 E-17

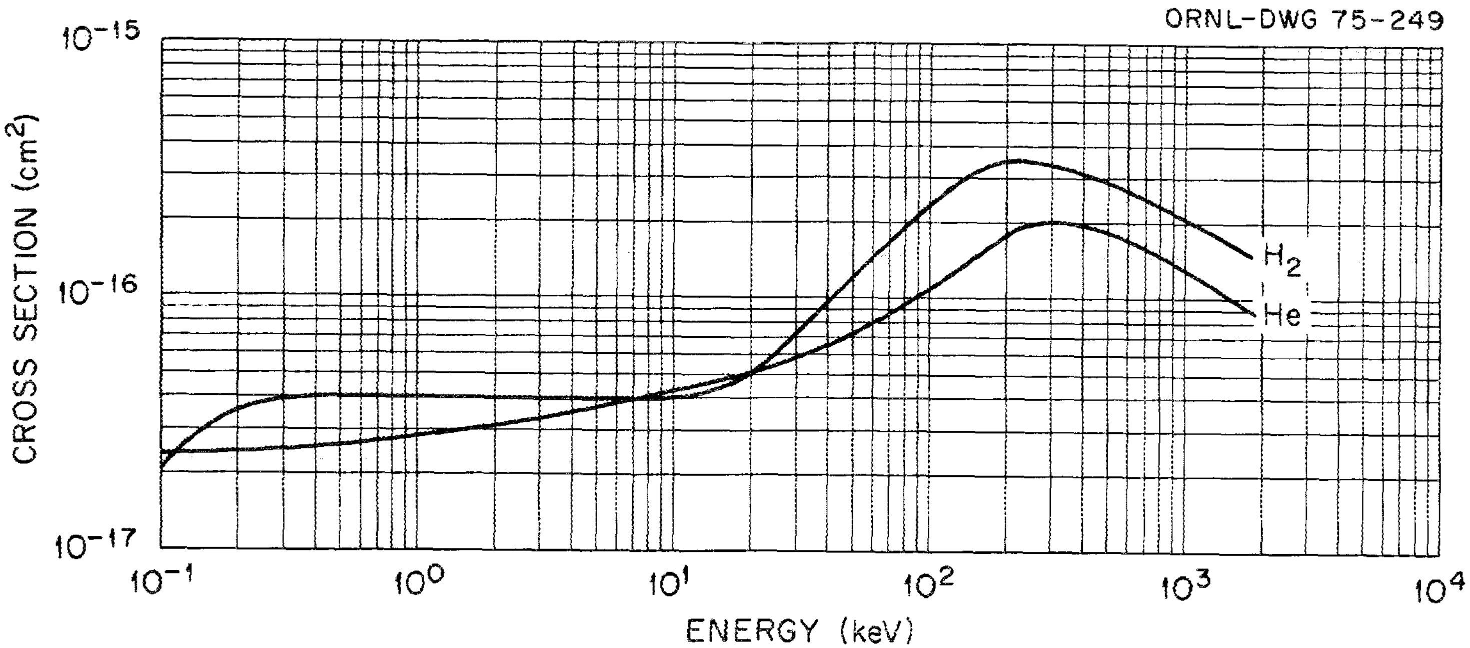
References:

$He^+ + H_2$: R.A. Langley, D.W. Martin, D.S. Harmer, J.W. Hooper, and E.W. McDaniel, Phys. Rev. 136, A379 (1964); L.I. Pivovar, Yu. Z. Levchenko, and A.N. Grigor'ev, Sov. Phys.-JETP 27, 699 (1968); H.B. Gilbody and J.B. Hasted, Proc. Roy. Soc. A240, 382 (1957); H.B. Gilbody, J.B. Hasted, J.V. Ireland, A.R. Lee, E.W. Thomas, and A.S. Whitman, Proc. Roy. Soc. A274, 40 (1963); E.S. Solov'ev, R.N. Il'in, V.A. Oparin, and N.V. Fedorenko, Sov. Phys.-JETP 18, 342 (1964); F.J. de Heer, J. Schutten, and H. Moustafa, Physica 32, 1793 (1966).

He^+ + He: F.J. de Heer, J. Schutten, and H. Moustafa, Physica 32, 1793 (1966); E.S. Solov'ev, R.N. Il'in, V.A. Oparin, and N.V. Fedorenko, Sov. Phys.-JETP 18, 342 (1964); N.V. Fedorenko, V.V. Afrosimov, and D.M. Kaminker, Sov. Phys.-JETP 1, 1861 (1956); H.B. Gilbody, J.B. Hasted, J.V. Ireland, A.R. Lee, E.W. Thomas, and A.S. Whiteman, Proc. Roy. Soc. A274, 40 (1963); H.B. Gilbody and J.B. Hasted, Proc. Roy. Soc. A240, 382 (1957); L.I. Pivovar, Yu. Z. Levchenko, and A.N. Grigor'ev, Sov. Phys.-JETP 27, 699 (1968); R.A. Langley, D.W. Martin, D.S. Harmer, J.W. Hooper, and E.W. McDaniel, Phys. Rev. 136, A379 (1964).

Accuracy:

± 25%.


ORNL-DWG 75-249
CROSS SECTION (cm²)
10⁻¹⁵
10⁻¹⁶
10⁻¹⁷
ENERGY (keV)
10⁻¹
10⁰
10¹
10²
10³
10⁴
H₂
He

Cross Sections for the Production of Positive

Ions by He^+ Ions in H_2 and He

Energy (keV)	Cross Sections (cm^2)	
	H_2	He
3.0 E 00	1.3 E-16	
5.0 E 00	1.1 E-16	
7.0 E 00	1.2 E-16	
1.0 E 01	1.5 E-16	5.6 E-16
2.0 E 01	2.2 E-16	5.4 E-16
5.0 E 01	4.0 E-16	4.2 E-16
7.0 E 01	4.7 E-16	3.8 E-16
1.0 E 02	5.3 E-16	3.4 E-16
2.0 E 02	4.5 E-16	2.7 E-16
5.0 E 02	2.8 E-16	1.8 E-16
7.0 E 02	2.3 E-16	1.4 E-16
1.0 E 03	1.8 E-16	1.1 E-16
1.8 E 03	1.3 E-16	0.8 E-16

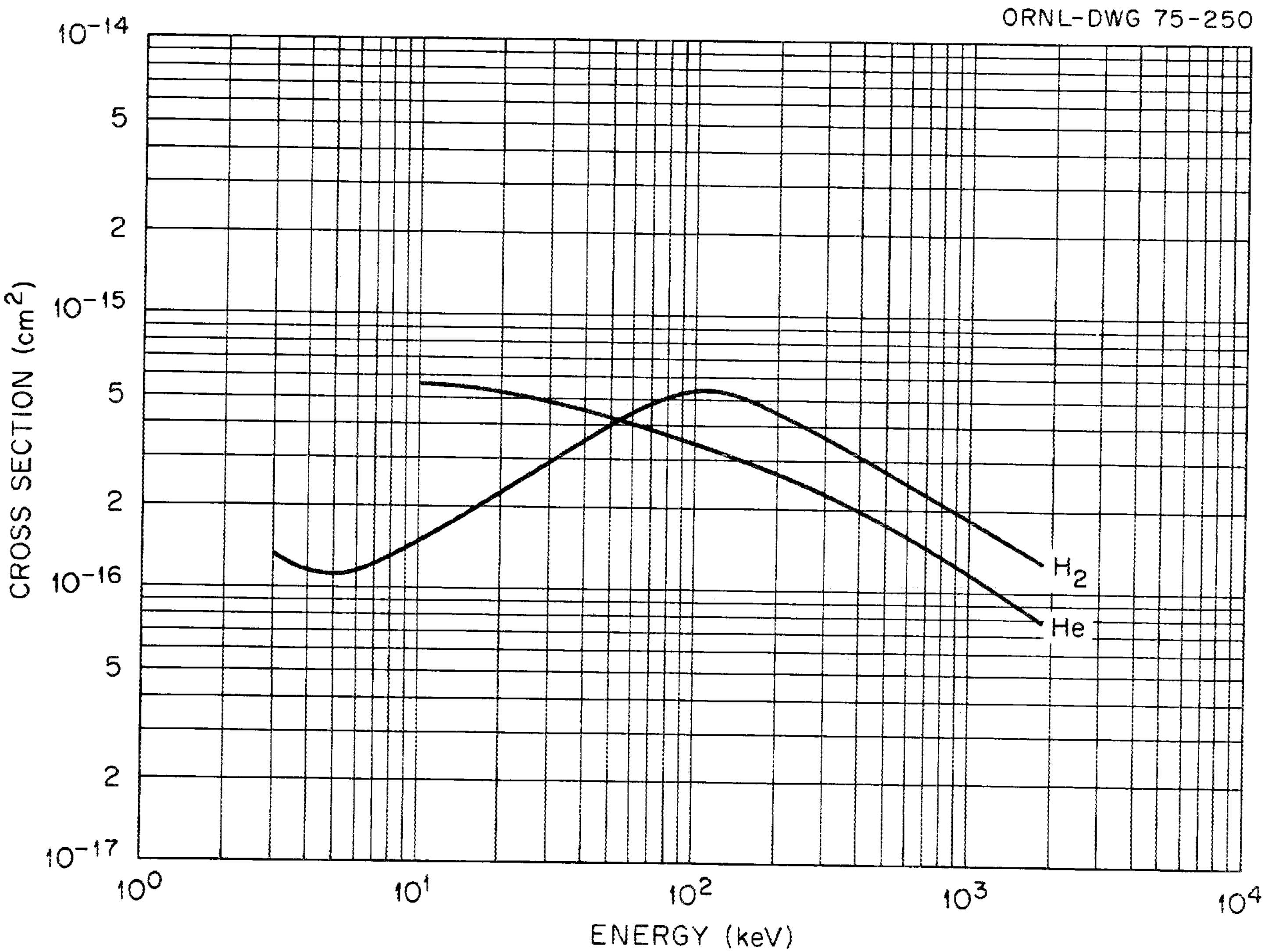
References:

$He^+ + H_2$: R.A. Langley, D.W. Martin, D.S. Harmer, J.W. Hooper, and E.W. McDaniel, Phys. Rev. 136, A379 (1964); L.I. Pivovar, Yu. Z. Levchenko, and A.N. Grigor'ev, Sov. Phys.-JETP 27, 699 (1968); H.B. Gilbody, J.B. Hasted, J.V. Ireland, A.R. Lee, E.W. Thomas, and A.S. Whiteman, Proc. Roy. Soc. A274, 40 (1963); E.S. Solov'ev, R.N. Il'in, V.A. Oparin, and N.V. Fedorenko, Sov. Phys.-JETP 18, 342 (1964); F.J. de Heer, J. Schutten, and H. Moustafa, Physica 32, 1793 (1966); R. Browning, C.J. Latimer, and H.B. Gilbody, J. Phys. B 2, 534 (1969).

He^+ + He: N.V. Fedorenko, V.V. Afrosimov, and D.M. Kaminker, Sov. Phys.-JETP 1, 1861 (1956); F.J. de Heer, J. Schutten, and H. Moustafa, Physica 32, 1793 (1966); E.S. Solov'ev, R.N. Il'in, V.A. Oparin, and N.V. Fedorenko, Sov. Phys.-JETP 18, 342 (1964); H.B. Gilbody, J.B. Hasted, J.V. Ireland, A.R. Lee, E.W. Thomas, and A.S. Whiteman, Proc. Roy. Soc. A274, 40 (1963); L.I. Pivovar, Yu. Z. Levchenko, and A.N. Grigor'ev, Sov. Phys.-JETP 27, 699 (1968); R.A. Langley, D.W. Martin, D.S. Harmer, J.W. Hooper, and E.W. McDaniel, Phys. Rev. 136, A 379 (1964).

Accuracy:

± 25%.



ORNL-DWG 75-250
CROSS SECTION (cm^2)
10^{-14}
5
2
10^{-15}
5
2
10^{-16}
5
2
10^{-17}
10^0
10^1
10^2
10^3
10^4
ENERGY (keV)
H_2
He

A.5.63

Cross Sections for Production of N_2^+, N^+, and N^{2+} by He^+ in N_2

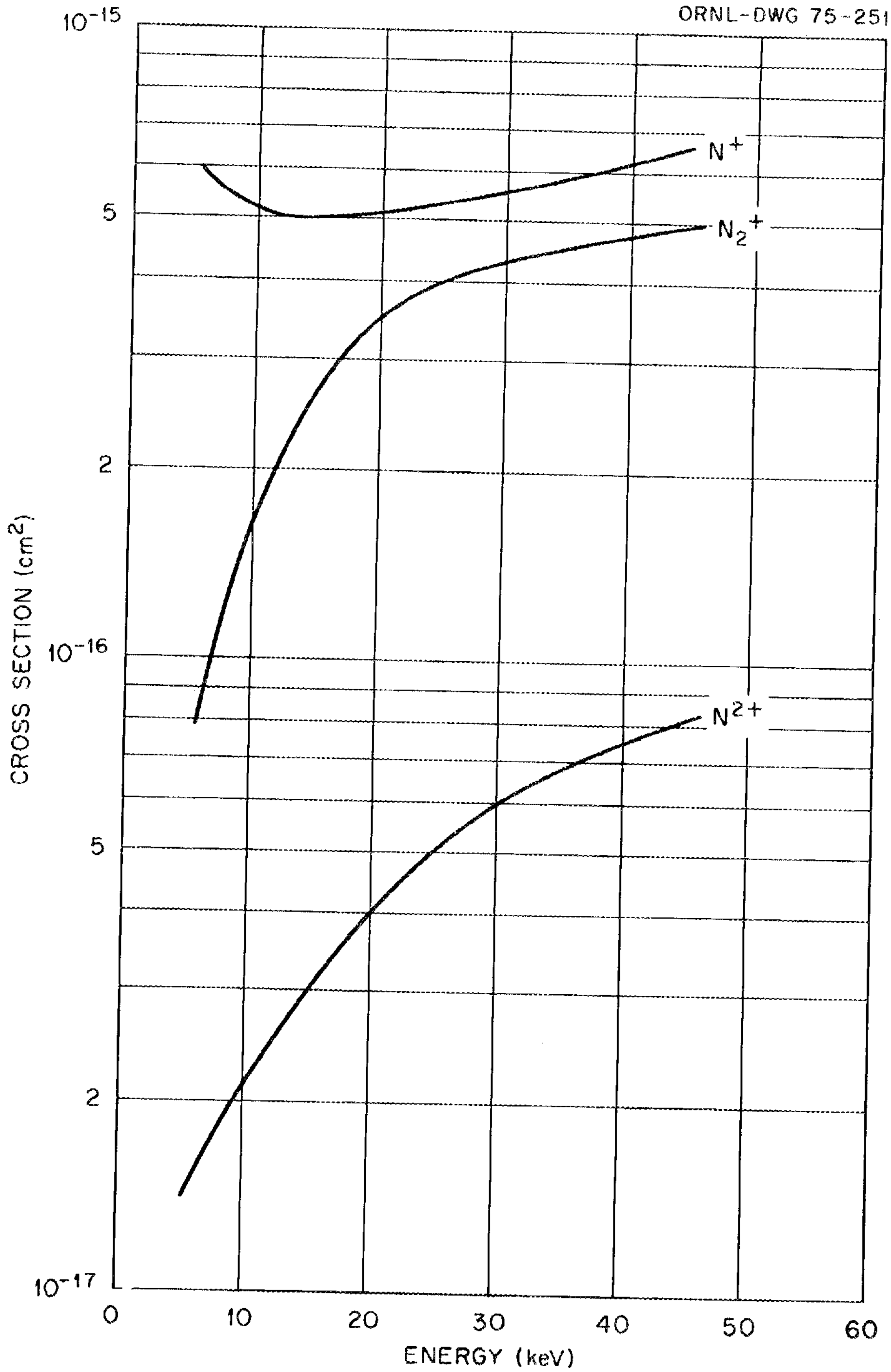
Energy (keV)	Cross Sections (cm^2)		
	N_2^+	N^+	N^{2+}
5.5 E 00	7.81 E-17	5.99 E-16	1.44 E-17
1.0 E 01	1.67 E-16	5.16 E-16	2.20 E-17
2.0 E 01	3.47 E-16	5.16 E-16	4.03 E-17
3.0 E 01	4.34 E-16	5.56 E-16	5.99 E-17
4.0 E 01	4.76 E-16	6.04 E-16	7.66 E-17
4.6 E 01	4.98 E-16	6.65 E-16	8.28 E-17

References:

R. Browning, C.J. Latimer, and H.B. Gilbody, J. Phys. B 2, 534 (1969).

Accuracy:

± 20%.


ORNL-DWG 75-251
10^{-15}
5
2
10^{-16}
5
2
10^{-17}
CROSS SECTION (cm^2)
N^+
N_2^+
N^{2+}
0
10
20
30
40
50
60
ENERGY (keV)

Cross Sections for the Production of

O_2^+, O^+, and O^{2+} Ions by He^+ in O_2

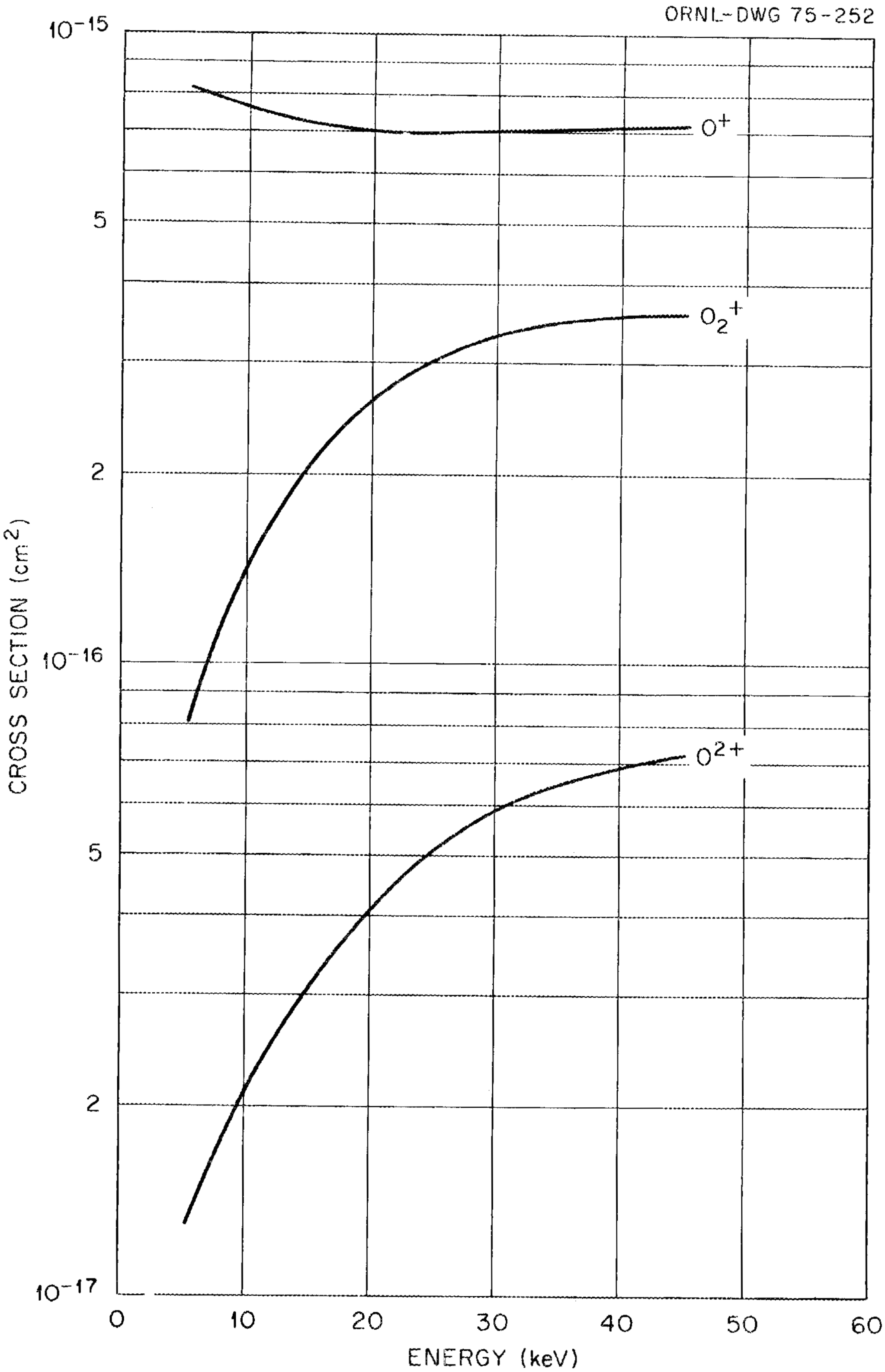
Energy (keV)	Cross Sections (cm^2)		
	O_2^+	O^+	O^{2+}
5.5 E 00	8.22 E-17	8.20 E-16	1.31 E-17
1.0 E 01	1.43 E-16	7.64 E-16	2.17 E-17
2.0 E 01	2.62 E-16	6.95 E-16	4.18 E-17
3.0 E 01	3.34 E-16	7.06 E-16	5.98 E-17
4.0 E 01	3.56 E-16	7.22 E-16	6.99 E-17
4.5 E 01	3.59 E-16	7.24 E-16	7.10 E-17

References:

R. Browning, C.J. Latimer, and H.B. Gilbody, J. Phys. B 2, 534 (1969).

Accuracy:

± 20%.



ORNL-DWG 75-252
10^{-15}
5
2
10^{-16}
5
2
10^{-17}
CROSS SECTION (cm^2)
0
10
20
30
40
50
60
ENERGY (keV)
O^+
O_2^+
O^{2+}

Cross Sections for Positive Ion Production by He^{++} Ions in H_2 and He

Energy (keV)	Cross Sections (cm^2) H_2	He
6.8 E 00	3.1 E-16	
1.0 E 01	4.2 E-16	
2.0 E 01	6.8 E-16	
4.0 E 01	1.2 E-15	
6.0 E 01	1.3 E-15	
8.0 E 01	1.3 E-15	
1.0 E 02	1.3 E-15	
1.5 E 02	1.3 E-15	5.7 E-16
2.0 E 02	1.2 E-15	5.4 E-16
4.0 E 02	8.1 E-16	4.0 E-16
6.0 E 02	6.3 E-16	3.2 E-16
8.0 E 02	5.1 E-16	2.6 E-16
1.0 E 02	4.5 E-16	2.3 E-16

References:

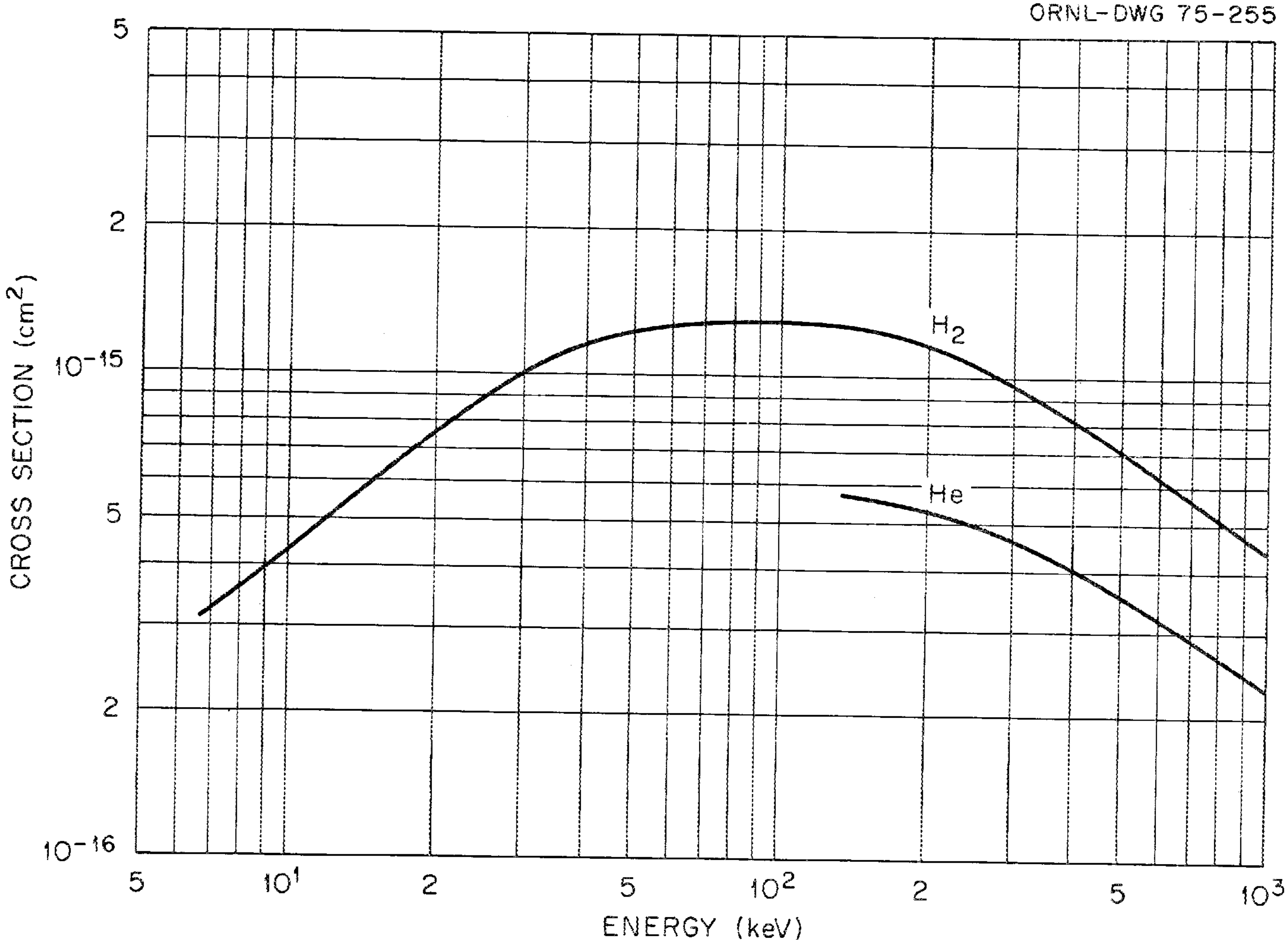
He^{++} + H_2: L.J. Puckett, G.O. Taylor, and D.W. Martin, Phys. Rev. 178, 271 (1969); R.A. Langley, D.W. Martin, D.S. Harmer, J.W. Hooper, and E.W. McDaniel, Phys. Rev. 136, A 379 (1964); W.G. Graham, C.J. Latimer, R. Browning, and H.B. Gilbody, J. Phys. B 7, L405 (1974).

He^{++} + He: L.J. Puckett, G.O. Taylor, and D.W. Martin, Phys. Rev. 178, 271 (1969); R.A. Langley, D.W. Martin, D.S. Harmer, J.W. Hooper, and E.W. McDaniel, Phys. Rev. 136, A379 (1964).

Accuracy:

± 20%.

ORNL-DWG 75-255


CROSS SECTION (cm²)
5
2
10⁻¹⁵
5
2
10⁻¹⁶
H₂
He
5
10¹
2
5
10²
2
5
10³
ENERGY (keV)

A.5.69

Cross Sections for the Production of Free

Electrons by He^{++} in H_2 and He

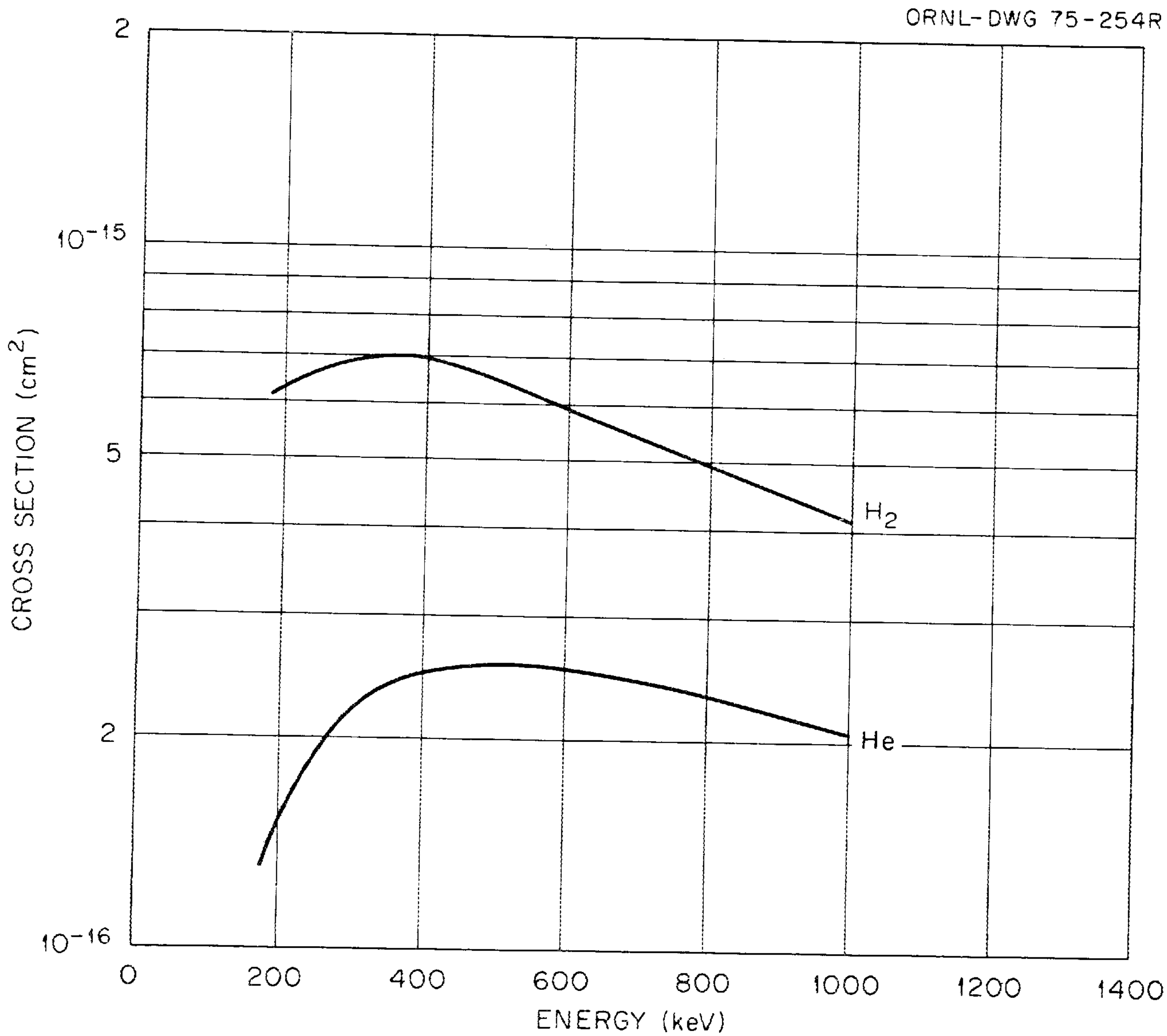
Energy (keV)	Cross Sections (cm^2)	
	H_2	He
1.8 E 02		1.3 E-16
2.0 E 02	6.3 E-16	1.5 E-16
4.0 E 02	6.9 E-16	2.5 E-16
6.0 E 02	5.9 E-16	2.5 E-16
8.0 E 02	4.9 E-16	2.3 E-16
1.0 E 03	4.2 E-16	2.1 E-16

References:

He^{++} + H_2, He: L.J. Puckett, G.O. Taylor, and D.W. Martin, Phys. Rev. 178, 271 (1969).

Accuracy:

± 20%.


ORNL-DWG 75-254R
CROSS SECTION (cm^2)
2
10^{-15}
5
2
10^{-16}
H_2
He
0
200
400
600
800
1000
1200
1400
ENERGY (keV)

Cross Sections for One and Two Electron Loss

for He Atoms in H_2 and He

Energy (keV)	Cross Sections (cm^2)			
	One Electron Loss (σ_{01})		Two Electron Loss (σ_{01})	
	H_2	He	H_2	He
3.0 E 00		2.7 E-18		
4.0 E 00	5.0 E-18	4.5 E-18		
5.0 E 00	7.3 E-18	8.0 E-18		
1.0 E 01	1.7 E-17	2.3 E-18		
2.0 E 01	3.3 E-17	4.2 E-18		
5.0 E 01	6.0 E-17	7.0 E-18		
1.0 E 02	9.0 E-17	9.2 E-18		
2.0 E 02	1.2 E-16	9.8 E-18	2.5 E-18	3.9 E-18
5.0 E 02	1.1 E-16	9.0 E-18	5.0 E-18	5.2 E-18
8.0 E 02	9.4 E-17	7.7 E-18	3.7 E-18	3.7 E-18
1.0 E 03	8.2 E-17	7.0 E-18	2.8 E-18	2.8 E-18
2.0 E 03	5.1 E-17	4.3 E-18	1.1 E-18	1.3 E-18
3.0 E 03	3.8 E-17	2.7 E-18	7.4 E-19	
4.0 E 03	3.0 E-17	2.0 E-18		

References:

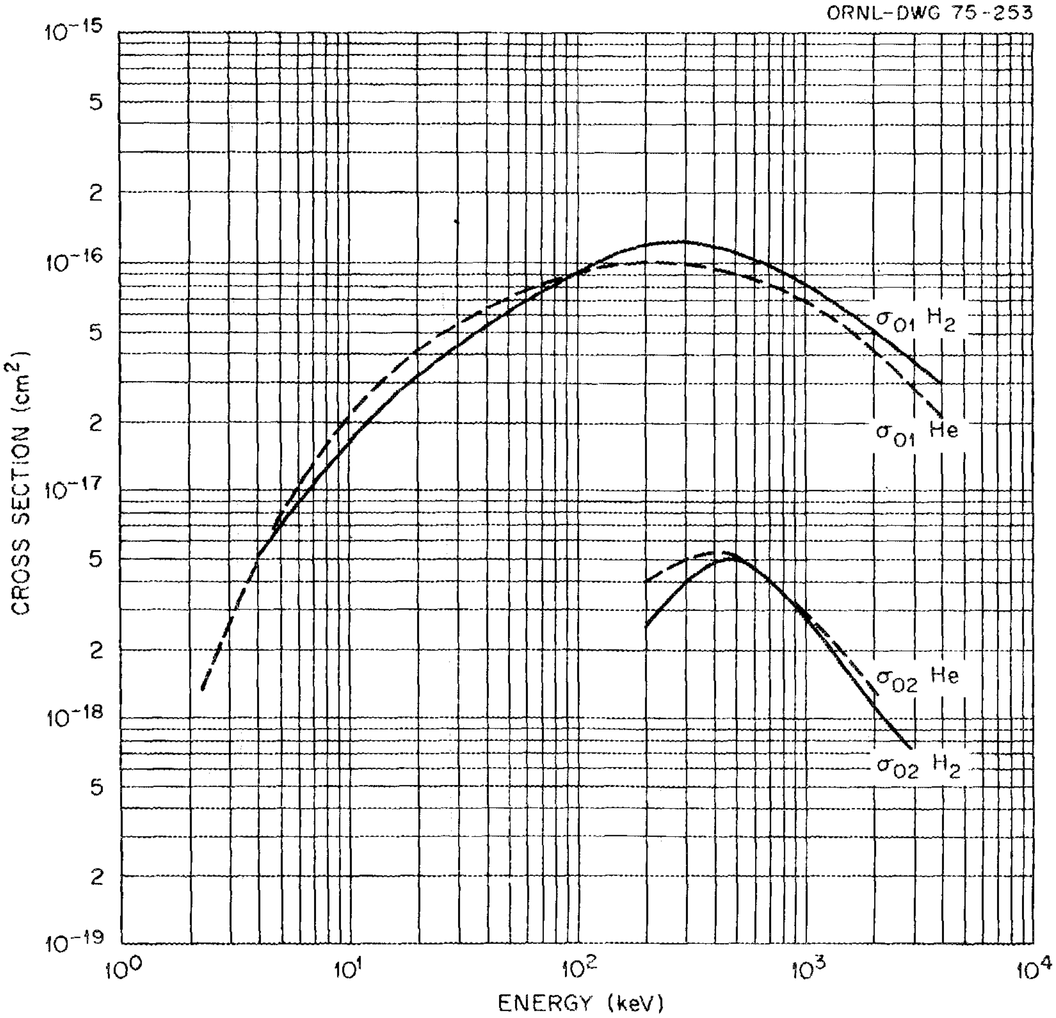
He + H_2: E.H. Pedersen and P. Hvelplund, J. Phys. B 7, 132 (1974); P. Hvelplund and E.H. Pedersen, Phys. Rev. A 9, 2434 (1974); H.B. Gilbody, K.F. Dunn, R. Browning, and C.J. Latimer, J. Phys. B 3, 1105 (1970); C.F. Barnett and P.M. Stier, Phys. Rev. 109, 385 (1958); H. Tawara, J. Phys. Soc. Jap. 31, 871 (1971); S.K. Allison, Rev. Mod. Phys. 30, 1137 (1958); Ya. M. Fogel, V.A. Ankudinov, and D.V. Pilipenko, Sov. Phys.-JETP 11, 18 (1960); H.B. Gilbody, R. Browning, G. Levy, A.I. McIntosh, and K.F. Dunn, J. Phys. B 1, 863 (1968); A.B. Wittkower, G. Levy, and H.B. Gilbody, Proc. Phys. Soc. 91, 862 (1967).

He + He: E.H. Pedersen and P. Hvelplund, J. Phys. B 7, 132 (1974); P. Hvelplund and E.H. Pedersen, Phys. Rev. A 9, 2434 (1974); C.F. Barnett and P.M. Stier, Phys. Rev. 109, 386 (1958); H. Tawara, J. Phys. Soc. Jap. 31, 236 (1971); S.K. Allison, Rev. Mod. Phys. 30, 1137 (1958); Ya. M. Fogel, V.A. Ankudinov, and D.V. Pilipenko, Sov. Phys.-JETP 11, 18 (1960); H.B. Gilbody, K.F. Dunn, R. Browning, and C.J. Latimer, J. Phys. B 3, 1105 (1970); W.L. Williams and F.M. Goldberg, VII Int. Conf. on the Phys. of Electronic & Atomic Collisions, North Holland Publishing Co. Amsterdamm (1971) p. 1087; H.B. Gilbody, R. Browning, G. Levy, A.I. McIntosh, and K.F. Dunn, J. Phys. B 1, 863 (1968); A.B. Wittkower, G. Levy, and H.B. Gilbody, Proc. Phys. Soc. 91, 862 (1967).

Note:

Measurements made before 1970 did not properly take into account the presence of He metastable states.

Accuracy: ± 25%.


ORNL-DWG 75-253
CROSS SECTION (cm^2)
ENERGY (keV)
10^{-15}
5
2
10^{-16}
5
2
10^{-17}
5
2
10^{-18}
5
2
10^{-19}
10^0
10^1
10^2
10^3
10^4
σ_{01} H_2
σ_{01} He
σ_{02} He
σ_{02} H_2

Cross Sections for Ionization of H_2 and He by He Atoms

Energy (keV)	Cross Sections (cm^2)	
	H_2	He
4.6 E-02	2.5 E-20	
5.0 E-02	3.5 E-19	
7.0 E-02	6.0 E-19	
1.0 E-01	2.2 E-18	
2.0 E-01	1.0 E-17	
5.0 E-01	2.9 E-17	
9.0 E-01	4.3 E-17	
3.0 E 00	3.8 E-17	
5.0 E 00	5.0 E-17	
1.0 E 01	7.7 E-17	
2.0 E 01	1.1 E-16	5.0 E-17
5.0 E 01	1.8 E-16	8.4 E-17
1.0 E 02	2.4 E-16	1.3 E-16
2.0 E 02	2.6 E-16	1.4 E-16
5.0 E 02	1.9 E-16	1.1 E-16
1.0 E 03	1.2 E-16	7.3 E-17

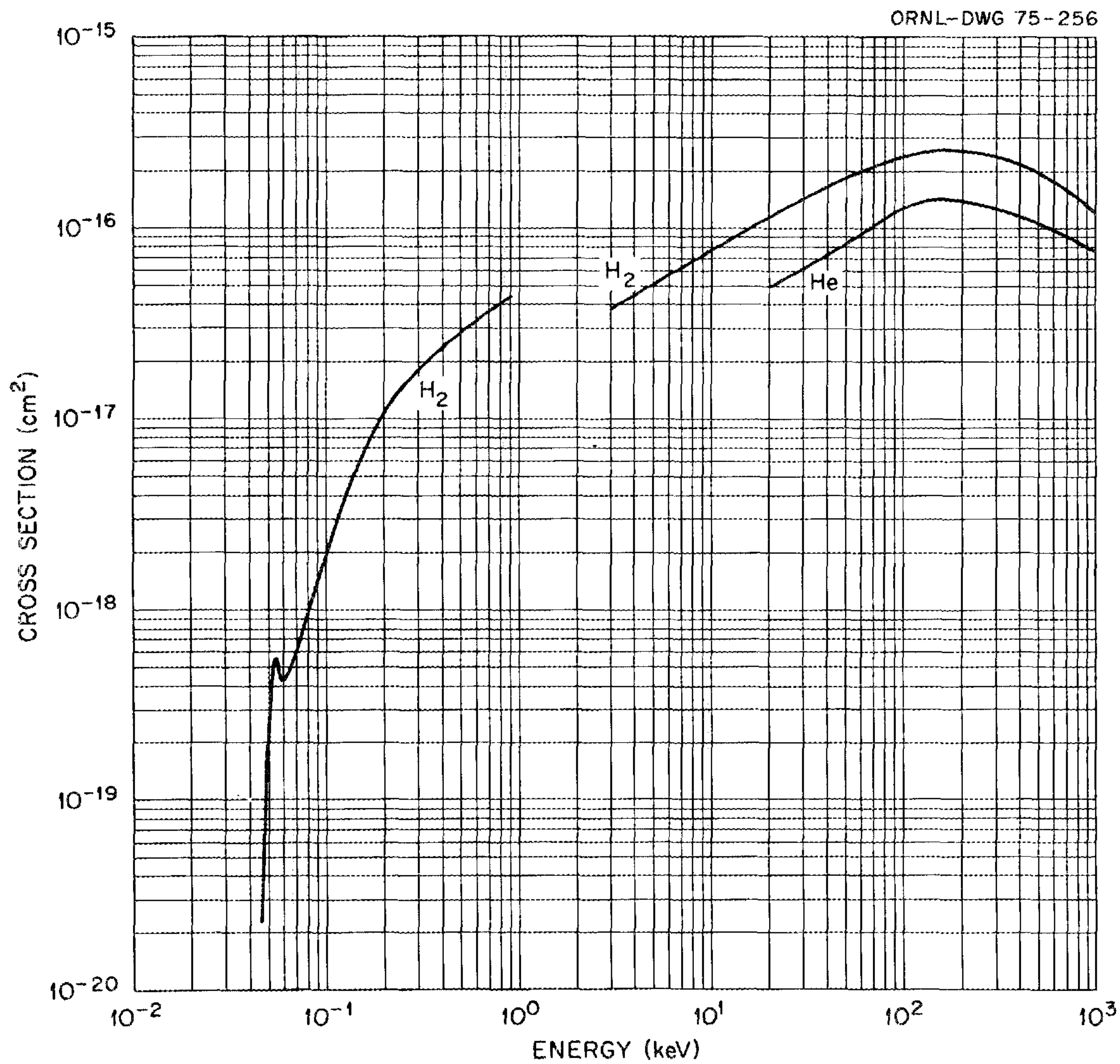
References:

He + H_2: N.G. Utterback, Phys. Rev. Letts. 12, 295 (1964); L.J. Puckett, G.O. Taylor, and D.W. Martin, Phys. Rev. 178, 271 (1969); E.S. Solov'ev, R.N. Il'in, V.A. Oparin, and N.V. Fedorenko, Sov. Phys.-JETP 18, 342 (1964); E.S. Solov'ev, R.N. Il'in, V.A. Oparin, and N.V. Fedorenko, 3rd Int. Conf. on Phys. of Electronic & Atomic Collisions (London, 1963) North-Holland Publishing Co. (Amsterdamm) p. 692 (1964); R. Browning, C.J. Latimer, and H.B. Gilbody, J. Phys. B 3, 667 (1970).

He + He: L.J. Puckett, G.O. Taylor, and D.W. Martin, Phys. Rev. 178, 271 (1969); E.S. Solov'ev, R.N. Il'in, V.A. Oparin, and N.V. Fedorenko, Sov. Phys.-JETP 18, 342 (1964); E.S. Solov'ev, R.N. Il'in, V.A. Oparin, and N.V. Fedorenko, 3rd Int. Conf. on Phys. of Electronic & Atomic Collisions (London, 1963) North-Holland Publishing Co. (Amsterdamm) p. 692 (1964).

Accuracy:

± 25%.


ORNL-DWG 75-256
CROSS SECTION (cm^2)
ENERGY (keV)
10^{-15}
10^{-16}
10^{-17}
10^{-18}
10^{-19}
10^{-20}
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
H_2
H_2
He

A.6 Equilibrium Fractions

Equilibrium Fractions of a Hydrogen Beam in H and H_2

Energy (keV)	Equilibrium Fractions				
	H		H_2		
	$F_{0\,\infty}$	$F_{1\,\infty}$	$F_{\bar{1}\,\infty}$	$F_{0\,\infty}$	$F_{1\,\infty}$
2.0 E 00	9.86 E-01	1.41 E-02			
4.0 E 00	9.71 E-01	2.91 E-02	1.10 E-02	8.95 E-01	9.50 E-02
6.0 E 00	9.54 E-01	4.54 E-02	1.64 E-02	8.75 E-01	9.50 E-02
8.0 E 00	9.36 E-01	6.30 E-02	1.95 E-02	8.70 E-01	9.50 E-02
1.0 E 01	9.24 E-01	7.85 E-02	2.00 E-02	8.65 E-01	9.70 E-02
2.0 E 01	8.12 E-01	1.68 E-01	1.80 E-02	8.20 E-01	1.75 E-01
3.0 E 01	7.33 E-01	2.60 E-01	1.40 E-02	7.25 E-01	2.75 E-01
4.0 E 01	6.61 E-01	3.50 E-01		6.25 E-01	3.80 E-01
6.0 E 01	4.00 E-01	5.50 E-01		4.40 E-01	5.40 E-01
8.0 E 01	2.50 E-01	7.50 E-01		2.90 E-01	6.85 E-01
9.0 E 02	1.52 E-01	9.50 E-01		1.90 E-01	8.20 E-01
2.0 E 02				2.40 E-02	9.75 E-01
3.0 E 02				5.25 E-03	9.95 E-01
4.0 E 02				1.20 E-03	1.00 E 00
6.0 E 02				1.60 E-04	1.00 E 00
8.0 E 02				5.40 E-05	1.00 E 00

References:

$H^+ + H$: There is no direct measurement for this case. We have here generated fractions using the formulae $F_{0\,\infty} = \sigma_{10}/(\sigma_{10} + \sigma_{01})$ and $F_{1\,\infty} = \sigma_{01}/(\sigma_{10} + \sigma_{01})$; the values of σ_{01} and σ_{10} are from M. Tawara and A. Russek, Rev. Mod. Phys. 45, 178 (1973). There is a slight error (perhaps as much as 2%) in neglect of negative state formation and loss.

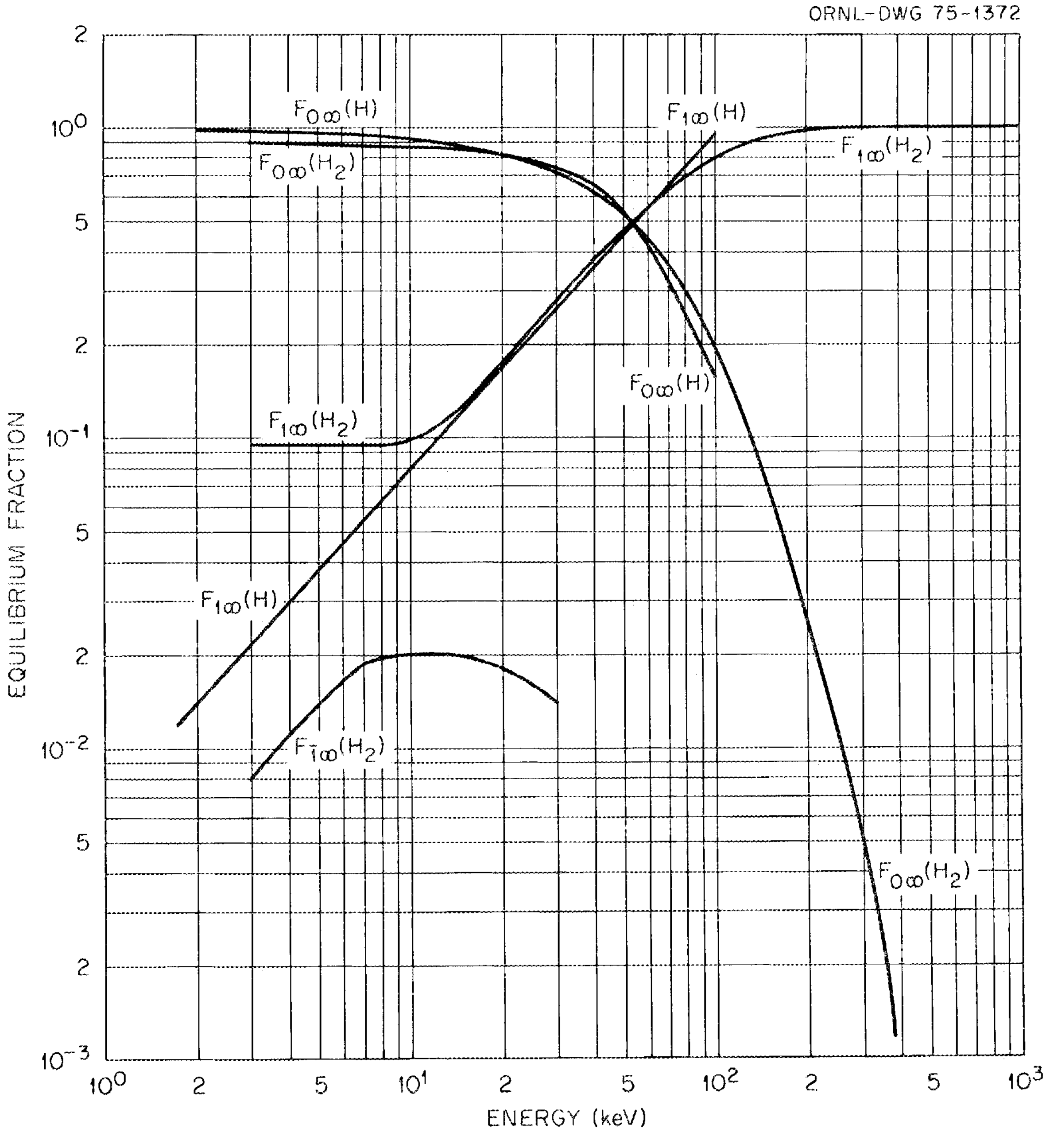
$H^+ + H_2$, Experimental: From the review by S.K. Allison and M. Garcia-Munoz, "Atomic and Molecular Processes," (ed. D.R. Bates, Academic Press, N.Y. 1962) page 721. Also derived values (see Note 1 at end of chapter) are used above 1000 keV based on cross section values of L. Toburen et al., Phys. Rev. 171, 114 (1968) and U. Schryber, Helv. Phys. Acta 39, 562 (1966).

Accuracy:

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

Notes:

See Note (4) at end of chapter.


ORNL-DWG 75-1372
EQUILIBRIUM FRACTION
ENERGY (keV)
$F_{0\infty}(H)$
$F_{0\infty}(H_2)$
$F_{1\infty}(H)$
$F_{1\infty}(H_2)$
$F_{\bar{1}\infty}(H_2)$
2
10^0
5
2
10^{-1}
5
2
10^{-2}
5
2
10^{-3}
10^0
2
5
10^1
2
5
10^2
2
5
10^3

Equilibrium Fractions of a Hydrogen Beam in He and Ar

Energy (keV)	He $F_{\bar{1}\infty}$	He $F_{0\infty}$	He $F_{1\infty}$	Ar $F_{\bar{1}\infty}$	Ar $F_{0\infty}$	Ar $F_{1\infty}$
4.0 E 00		1.25 E-01	9.00 E-01	4.00 E-02	9.20 E-01	5.50 E-02
6.0 E 00		2.38 E-01	7.60 E-01	3.10 E-03	8.80 E-01	9.30 E-02
8.0 E 00		3.35 E-01	6.55 E-01	2.00 E-02	8.50 E-01	1.32 E-01
1.0 E 01		4.10 E-01	5.80 E-01	1.30 E-02	8.20 E-01	1.67 E-01
2.0 E 01	9.20 E-03	6.00 E-01	3.90 E-01	5.00 E-03	6.75 E-01	3.25 E-01
3.0 E 01	9.55 E-03	6.00 E-01	3.95 E-01		5.75 E-01	4.30 E-01
4.0 E 01		5.45 E-01	4.50 E-01		4.85 E-01	5.15 E-01
6.0 E 01		4.40 E-01	5.55 E-01		3.55 E-01	6.50 E-01
8.0 E 01		3.35 E-01	6.75 E-01		2.50 E-01	7.50 E-01
1.0 E 02		2.54 E-01	7.45 E-01		1.75 E-01	8.40 E-01
2.0 E 02		6.05 E-02	9.40 E-01		3.10 E-02	9.50 E-01
3.0 E 02		1.75 E-02	9.60 E-01		8.30 E-03	9.90 E-01
4.0 E 02		6.45 E-03	9.80 E-01		3.25 E-03	9.98 E-01
6.0 E 02		1.55 E-03	1.00 E 00		1.00 E-03	1.00 E 00
8.0 E 02		5.20 E-04	1.00 E 00		8.93 E-04	1.00 E 00
1.0 E 03		3.60 E-04	1.00 E 00		1.20 E-04	1.00 E 00

References:

H^+ + He, Experimental: From the review by S.K. Allison and M. Garcia-Munoz, "Atomic and Molecular Processes" (ed. D.R. Bates, Academic Press, N.Y. 1962) page 721. Also derived values (see Note 1 at end of chapter) are used above 1000 keV based on the cross section values of L. Toburen et al., Phys. Rev. 171, 114 (1968) and U. Schryber, Helv. Phys. Acta 39, 562 (1966).

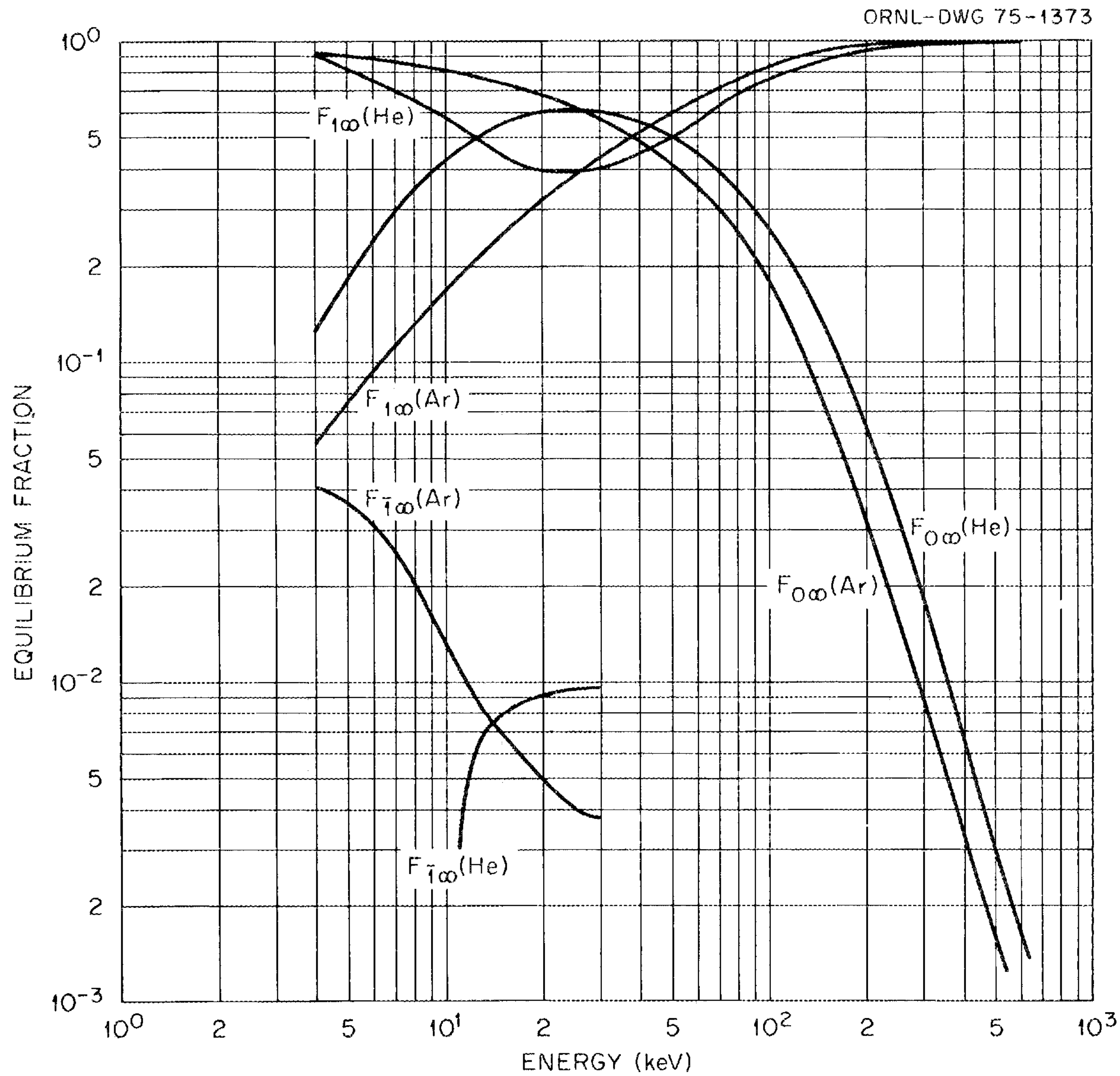
H^+ + Ar: P.M. Stier and C.F. Barnett, Phys. Rev. 103, 896 (1956). P.M. Stier, C. F. Barnett, and G.E. Evans, Phys. Rev. 96, 973 (1954). Also derived values (see Note 1 at end of chapter) are used above 250 keV based on the cross section values of L. Toburen et al., Phys. Rev. 171, 114 (1968).

Accuracy:

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

Notes:

See Note (4) at end of chapter.


ORNL-DWG 75-1373
EQUILIBRIUM FRACTION
ENERGY (keV)
$F_{1\infty}$(He)
$F_{1\infty}$(Ar)
$F_{\bar{1}\infty}$(Ar)
$F_{\bar{1}\infty}$(He)
$F_{0\infty}$(He)
$F_{0\infty}$(Ar)

Equilibrium Fractions of a Hydrogen Beam in N_2 and O_2

Energy (keV)	Equilibrium Fractions					
	N_2			O_2		
	$F_{\bar{1}\infty}$	$F_{0\infty}$	$F_{1\infty}$	$F_{\bar{1}\infty}$	$F_{0\infty}$	$F_{1\infty}$
4.0 E 00	3.70 E-03	8.90 E-01	1.25 E-01	1.66 E-02	8.60 E-01	1.35 E-01
6.0 E 00	9.05 E-03	8.45 E-01	1.62 E-01	1.78 E-02	8.00 E-01	1.87 E-01
8.0 E 00	1.23 E-02	8.00 E-01	1.95 E-01	1.70 E-02	7.60 E-02	2.28 E-01
1.0 E 01	1.36 E-02	7.60 E-01	2.24 E-01	1.56 E-02	7.25 E-01	2.63 E-01
2.0 E 01	1.00 E-02	6.40 E-01	3.50 E-01	1.05 E-02	6.05 E-01	3.85 E-01
3.0 E 01	6.05 E-03	5.45 E-01	4.55 E-01	7.50 E-03	5.30 E-01	4.70 E-01
4.0 E 01		4.80 E-01	5.40 E-01		4.70 E-01	5.38 E-01
6.0 E 01		3.55 E-01	6.55 E-01		3.65 E-01	6.45 E-01
8.0 E 01		2.55 E-01	7.40 E-01		2.80 E-01	7.25 E-01
1.0 E 02		1.86 E-01	8.05 E-01		2.12 E-01	7.75 E-01
2.0 E 02		3.60 E-02	9.60 E-01		5.10 E-02	9.40 E-01
3.0 E 02		1.00 E-02	9.90 E-01		1.54 E-02	9.80 E-01
4.0 E 02		4.05 E-03	1.00 E 00		6.50 E-03	9.90 E-01
6.0 E 02		1.14 E-03	1.00 E 00		1.95 E-03	1.00 E 00
8.0 E 02		5.00 E-04	1.00 E 00		7.64 E-04	1.00 E 00
1.0 E 03		2.80 E-04	1.00 E 00		4.38 E-04	1.00 E 00
2.0 E 03		7.53 E-05	1.00 E 00		6.90 E-05	1.00 E 00

References:

$H^+ + N_2$, Experimental: From the review by S.K. Allison and M. Garcia-Munoz, "Atomic and Molecular Processes" (ed. D.R. Bates, Academic Press, N.Y. 1962) page 721. Also derived values (see Note 1 at end of chapter) are used above 1000 keV based on the cross section values of L. Toburen et al., Phys. Rev. 171, 114 (1968).

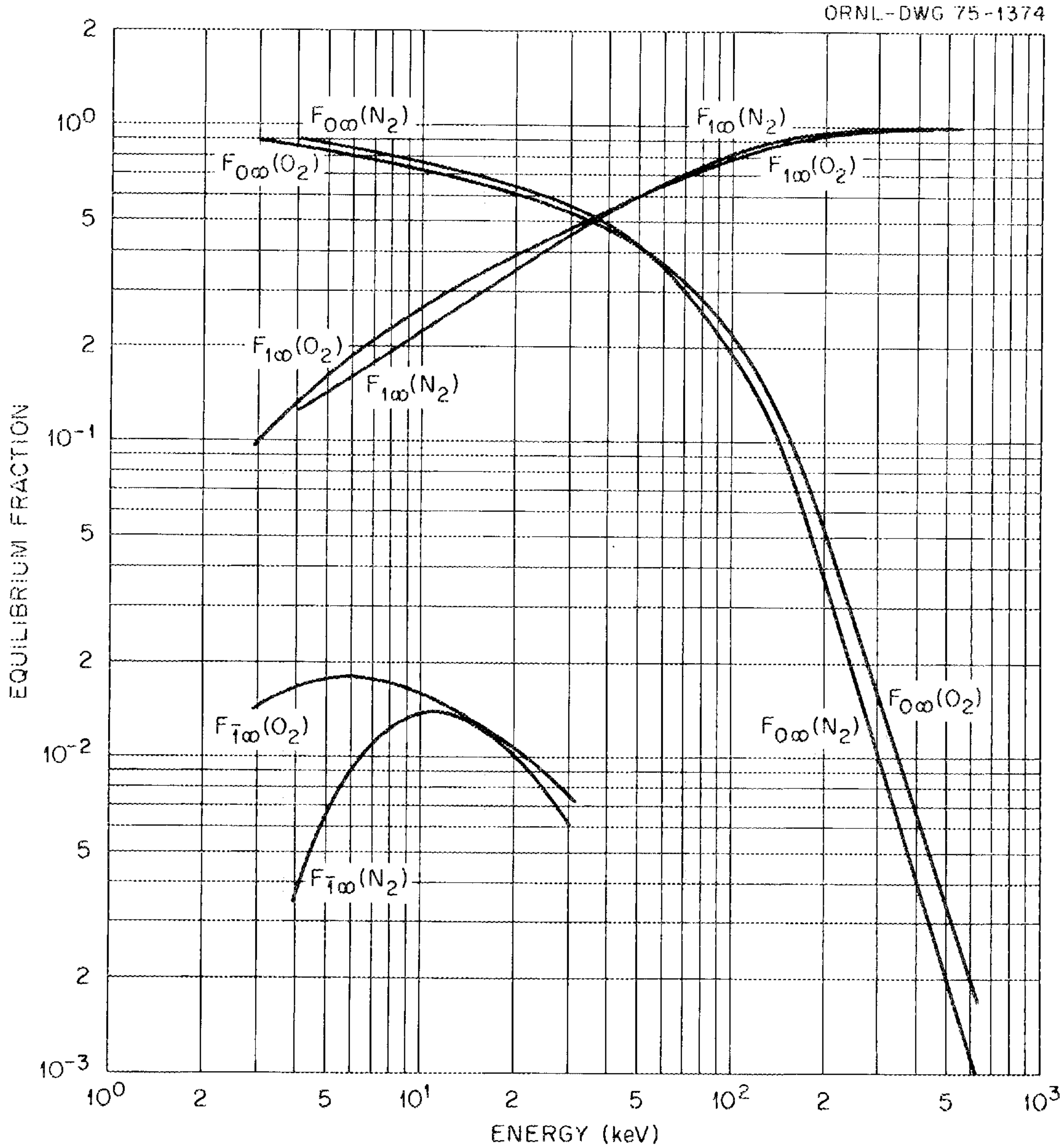
$H^+ + O_2$, Experimental: From the review by S.K. Allison and M. Garcia-Munoz, "Atomic and Molecular Processes" (ed. D.R. Bates, Academic Press, N.Y. 1962) page 721. Also derived values (see Note 1 at end of chapter) are used above 1000 keV based on the cross section values of L. Toburen et al., Phys. Rev. 171, 114 (1968).

Accuracy:

Systematic error is negligible. Random error < 5%.

Notes:

See Note (4) at end of chapter.


ORNL-DWG 75-1374
EQUILIBRIUM FRACTION
ENERGY (keV)
$F_{0\infty}(N_2)$
$F_{0\infty}(O_2)$
$F_{1\infty}(N_2)$
$F_{1\infty}(O_2)$
$F_{\bar{1}\infty}(O_2)$
$F_{\bar{1}\infty}(N_2)$
2
10^0
5
10^{-1}
10^{-2}
10^{-3}
10^1
10^2
10^3

Equilibrium Fractions of a Hydrogen Beam in H_2O

Energy (keV)	Equilibrium Fractions		
	H_2O		
	$F_{\bar{1}\,\infty}$	$F_{0\,\infty}$	$F_{1\,\infty}$
4.0 E 00	3.60 E-02		
6.0 E 00	4.30 E-02		
8.0 E 00	4.50 E-02		
1.0 E 01	4.45 E-02		
2.0 E 01	2.78 E-02		
3.0 E 01	1.50 E-02	5.40 E-01	4.50 E-01
4.0 E 01		4.85 E-01	5.20 E-01
6.0 E 01		3.70 E-01	6.25 E-01
8.0 E 01		2.80 E-01	7.10 E-01
1.0 E 02		2.10 E-01	7.70 E-01
2.0 E 02		3.60 E-01	9.60 E-01
3.0 E 02		1.22 E-02	9.80 E-01
4.0 E 02		5.65 E-03	9.90 E-01
6.0 E 03		1.92 E-03	1.00 E 00
8.0 E 02		6.07 E-04	1.00 E 00
1.0 E 03		2.86 E-04	1.00 E 00
2.0 E 03		5.73 E-05	1.00 E 00

References:

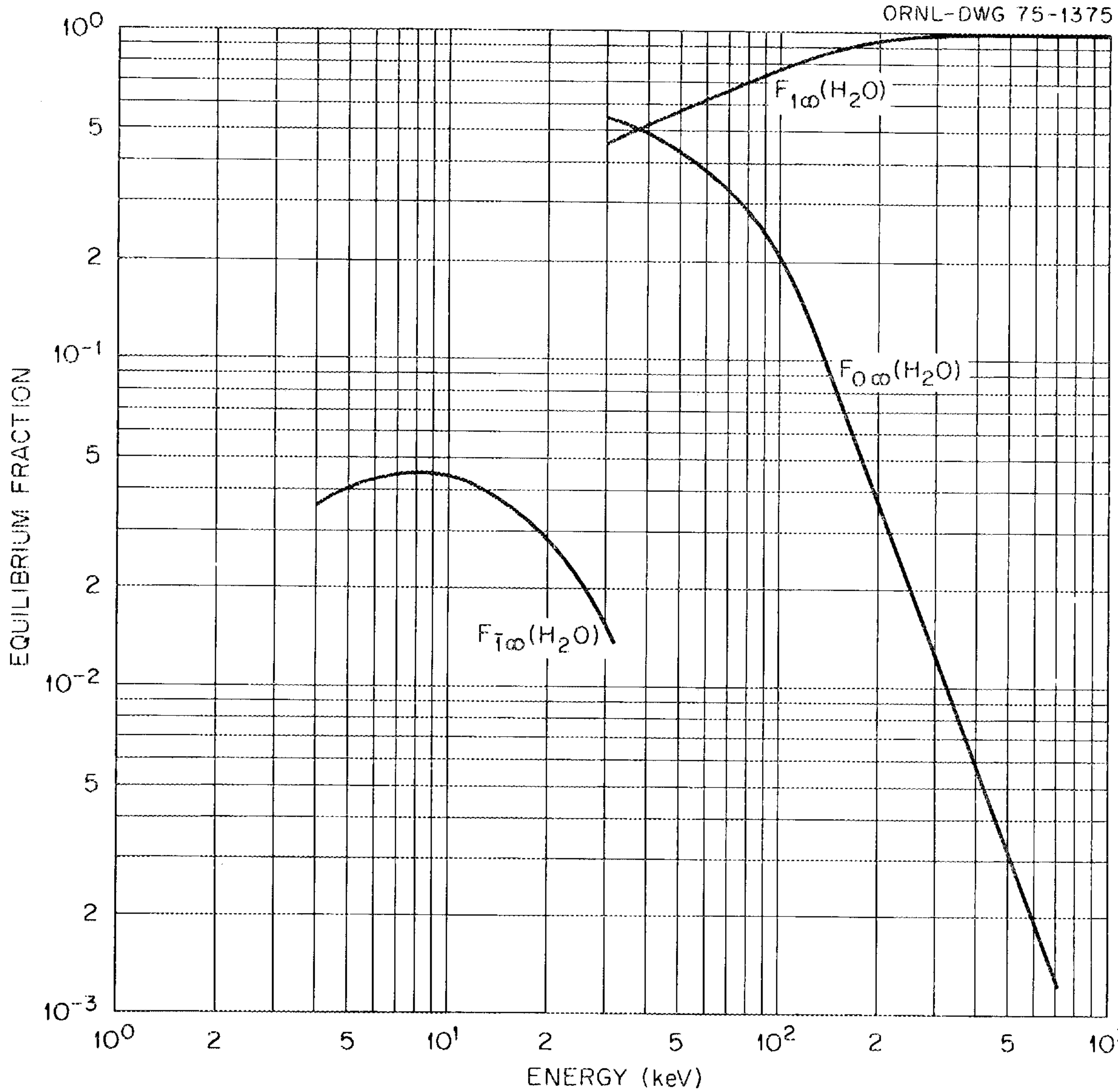
$H^+ + H_2O$: At energies above 100 keV we have generated fractions using the formulae $F_{0\,\infty} = \sigma_{10}/(\sigma_{10} + \sigma_{01})$ and $F_{1\,\infty} = \sigma_{01}/(\sigma_{10} + \sigma_{01})$; the values of σ_{01} and σ_{10} are from L. Toburen, *et al.*, Phys. Rev. 171, 114 (1968). There is a slight error (perhaps as much as 2%) in neglect of negative state formation and loss. $F_{\bar{1}\,\infty}$ at low energies ($E \leq 30$ keV) is from N.B. Brooks, *et al.*, Physics Letts. 6, 169 (1963); $F_{\bar{1}\,\infty}$, $F_{0\,\infty}$, and $F_{1\,\infty}$ at 30 keV are by A.B. Wittkower, *et al.*, Phys. Letts. 13, 134 (1964).

Accuracy:

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

Notes:

See Note (4) at end of chapter.


ORNL-DWG 75-1375
$F_{1\infty}(H_2O)$
$F_{0\infty}(H_2O)$
$F_{\bar{1}\infty}(H_2O)$
EQUILIBRIUM FRACTION
ENERGY (keV)
10^0
5
2
10^{-1}
5
2
10^{-2}
5
2
10^{-3}
10^0
2
5
10^1
2
5
10^2
2
5
10^3

Equilibrium Fractions of a Hydrogen Beam in Li and Na

Energy (keV)	Equilibrium Fractions					
	Li			Na		
	$F_{\bar{1}\infty}$	$F_{0\infty}$	$F_{1\infty}$	$F_{\bar{1}\infty}$	$F_{0\infty}$	$F_{1\infty}$
6.0 E-01	4.68 E-02	9.44 E-01		8.00 E-02	9.25 E-01	
8.0 E-01	4.80 E-02	9.40 E-01		9.50 E-02	9.10 E-01	
1.0 E 00	4.92 E-02	9.35 E-01		1.04 E-01	9.00 E-01	
2.0 E 00	5.64 E-02	9.28 E-01		1.20 E-01	8.75 E-01	
4.0 E 00	5.88 E-02	9.28 E-01	8.00 E-03	1.06 E-01	8.75 E-01	1.05 E-02
6.0 E 00	4.60 E-02	9.25 E-01	2.15 E-02	8.60 E-02	8.90 E-01	1.68 E-02
8.0 E 00	3.21 E-02	9.18 E-01	4.41 E-02	6.80 E-02	9.20 E-01	2.45 E-02
1.0 E 01	2.40 E-02	9.00 E-01	7.86 E-02	5.20 E-02	9.30 E-01	3.50 E-02
2.0 E 01	8.50 E-03	4.40 E-01	6.03 E-01		6.40 E-01	3.30 E-01
4.0 E 01		9.55 E-02	9.08 E-01			
6.0 E 01		6.15 E-02	9.40 E-01			
8.0 E 01		4.32 E-02	9.58 E-01			
1.0 E 02		3.16 E-02	9.65 E-01			
2.0 E 02		1.13 E-02	9.82 E-01			
4.0 E 02		3.92 E-03	9.88 E-01			

References:

H^+ + Li, Experimental: W. Grüebler, et al., Helv. Phys. Acta 43, 254 (1970). Derived values (see Note 1 at end of chapter) are used above 200 keV based on the cross sections by B.A. Dyachkov, Soviet Atomic Energy 27, 958 (1969).

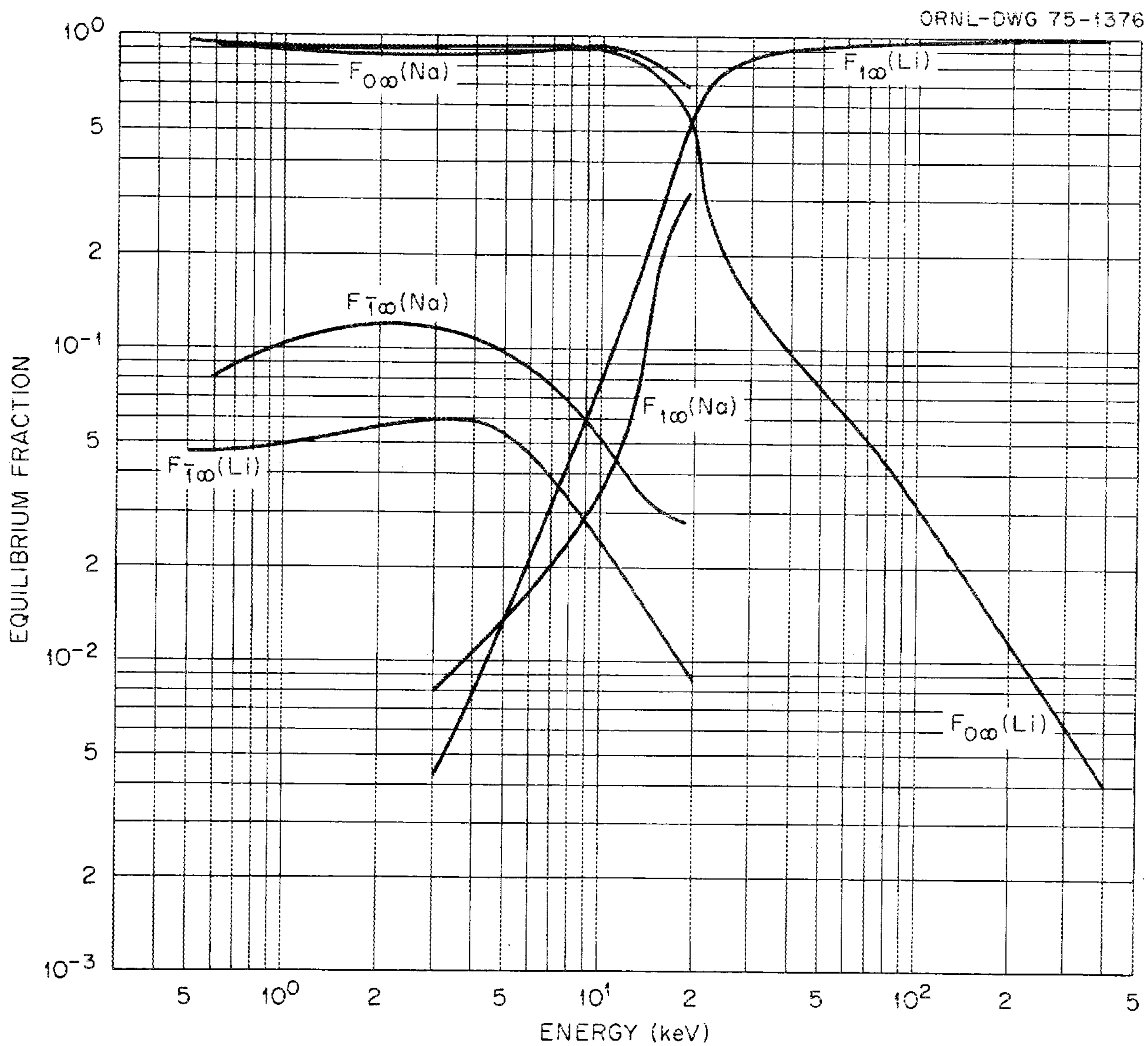
H^+ + Na, Experimental: W. Grüebler, et al., Helv. Phys. Acta 43, 254 (1970).

Accuracy:

Systematic error is negligible. Random error < ± 4%.

Notes:

See Note (4) at end of chapter.



ORNL-DWG 75-1376
$F_{0\infty}$(Na)
$F_{1\infty}$(Li)
$F_{\bar{1}\infty}$(Na)
$F_{1\infty}$(Na)
$F_{\bar{1}\infty}$(Li)
$F_{0\infty}$(Li)
EQUILIBRIUM FRACTION
ENERGY (keV)
10^0
5
2
10^{-1}
5
2
10^{-2}
5
2
10^{-3}
5
10^0
2
5
10^1
2
5
10^2
2
5

Equilibrium Fractions of a Hydrogen Beam in K and Cs

Energy (keV)	Equilibrium Fractions					
	K			Cs		
	$F_{\bar{1}\infty}$	$F_{0\infty}$	$F_{1\infty}$	$F_{\bar{1}\infty}$	$F_{0\infty}$	$F_{1\infty}$
4.0 E-01	1.21 E-01					
5.0 E-01	1.20 E-01	8.80 E-01				
6.0 E-01	1.32 E-01	8.72 E-01				
8.0 E-01	1.39 E-01	8.61 E-01				
1.0 E 00	1.30 E-01	7.7 E-01		1.50 E-01		
1.5 E 00	1.10 E-01	7.9 E-01		8.27 E-02	9.16 E-01	1.07 E-03
2.0 E 00	9.30 E-02	9.07 E-01		5.70 E-02	9.41 E-01	1.75 E-03
3.0 E 00	6.59 E-02	9.30 E-01	8.01 E-03	3.53 E-02	9.68 E-01	3.65 E-03
4.0 E 00	4.88 E-02	9.40 E-01	1.35 E-02	2.59 E-02	9.68 E-01	6.12 E-03
5.0 E 00	3.80 E-02	9.41 E-01	2.11 E-02	2.04 E-02	9.69 E-01	1.01 E-02
6.0 E 00	2.93 E-02	9.43 E-01	3.17 E-02	1.66 E-02	4.67 E-01	1.68 E-02
8.0 E 00	1.81 E-02	9.12 E-01	7.01 E-02	1.22 E-02	9.45 E-01	4.23 E-02
1.0 E 01	1.10 E-02	8.50 E-01	1.40 E-01	9.58 E-03	9.05 E-01	8.58 E-02
1.5 E 01	4.22 E-03	6.55 E-01	3.37 E-01	5.84 E-03	8.07 E-01	1.87 E-01
2.0 E 01				4.00 E-03	7.06 E-01	2.90 E-01

References:

H^+ + K, Experimental: W. Grübler et al., Helv. Phys. Acta 43, 254 (1970).

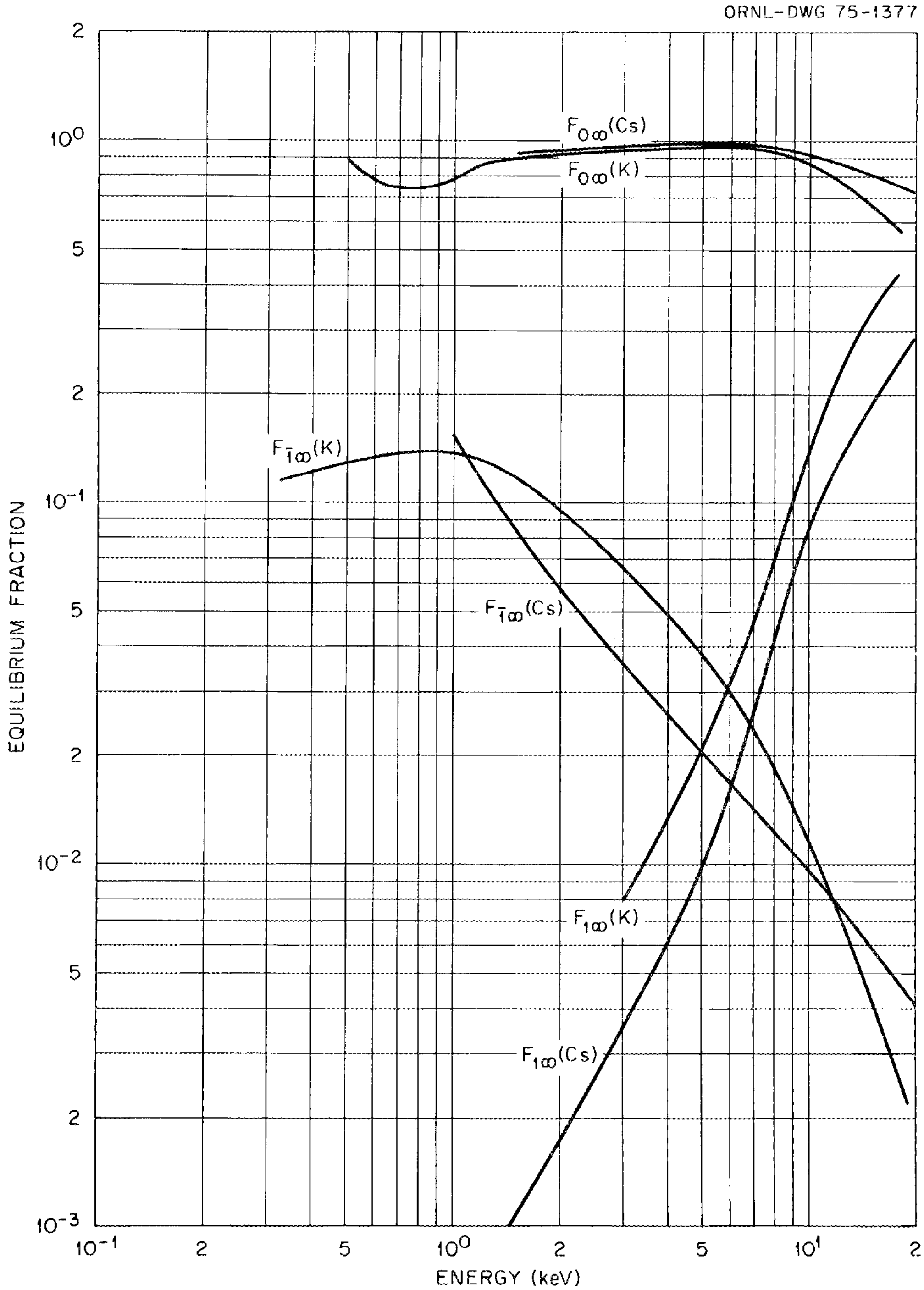
H^+ + Cs, Experimental: A.S. Schlachter et al., Phys. Rev. 177, 184 (1969).

Accuracy:

Systematic error is negligible. Random error < $\pm$ 4%.

Notes:

See Note (4) at end of chapter.


ORNL-DWG 75-1377
EQUILIBRIUM FRACTION
ENERGY (keV)
$F_{0\infty}(Cs)$
$F_{0\infty}(K)$
$F_{\bar{1}\infty}(K)$
$F_{\bar{1}\infty}(Cs)$
$F_{1\infty}(K)$
$F_{1\infty}(Cs)$
2
10^0
5
2
10^{-1}
5
2
10^{-2}
5
2
10^{-3}
10^{-1}
2
5
10^0
2
5
10^1
2

Equilibrium Excited State Fractions for Hydrogen Beams Traversing Sodium and Potassium

Energy (keV)	Excited State Fraction x n^3*		
	Na	Mg	K
1.5 E 01	1.00 E-01	4.50 E-02	
2.0 E 01	4.20 E-01	3.83 E-01	3.1 E-01
2.5 E 01	3.30 E-01	4.55 E-01	
3.0 E 01	2.50 E-01	4.67 E-01	
4.0 E 01	1.23 E-01	2.37 E-01	
6.0 E 01	1.09 E-01	8.60 E-02	
8.0 E 01	5.00 E-02	4.76 E-02	
1.0 E 02	5.00 E-02	3.10 E-02	

*See Note (2) at end of chapter.

References:

H + Na, Experimental: V.A. Oparin, R.N. Il'in, and E.S. Solov'ev, Zh. Eks. Teor. Fiz. 52, 369 (1967). [Soviet Phys. JETP 25, 240 (1967)].

H + K, Experimental: R.N. Il'in, V.A. Oparin, E.S. Solov'ev, N.V. Fedorenko, Zh. Tekh. Fiz. 36, 1241 (1966). [Soviet Phys. Tech. Phys. 11, 921 (1967)].

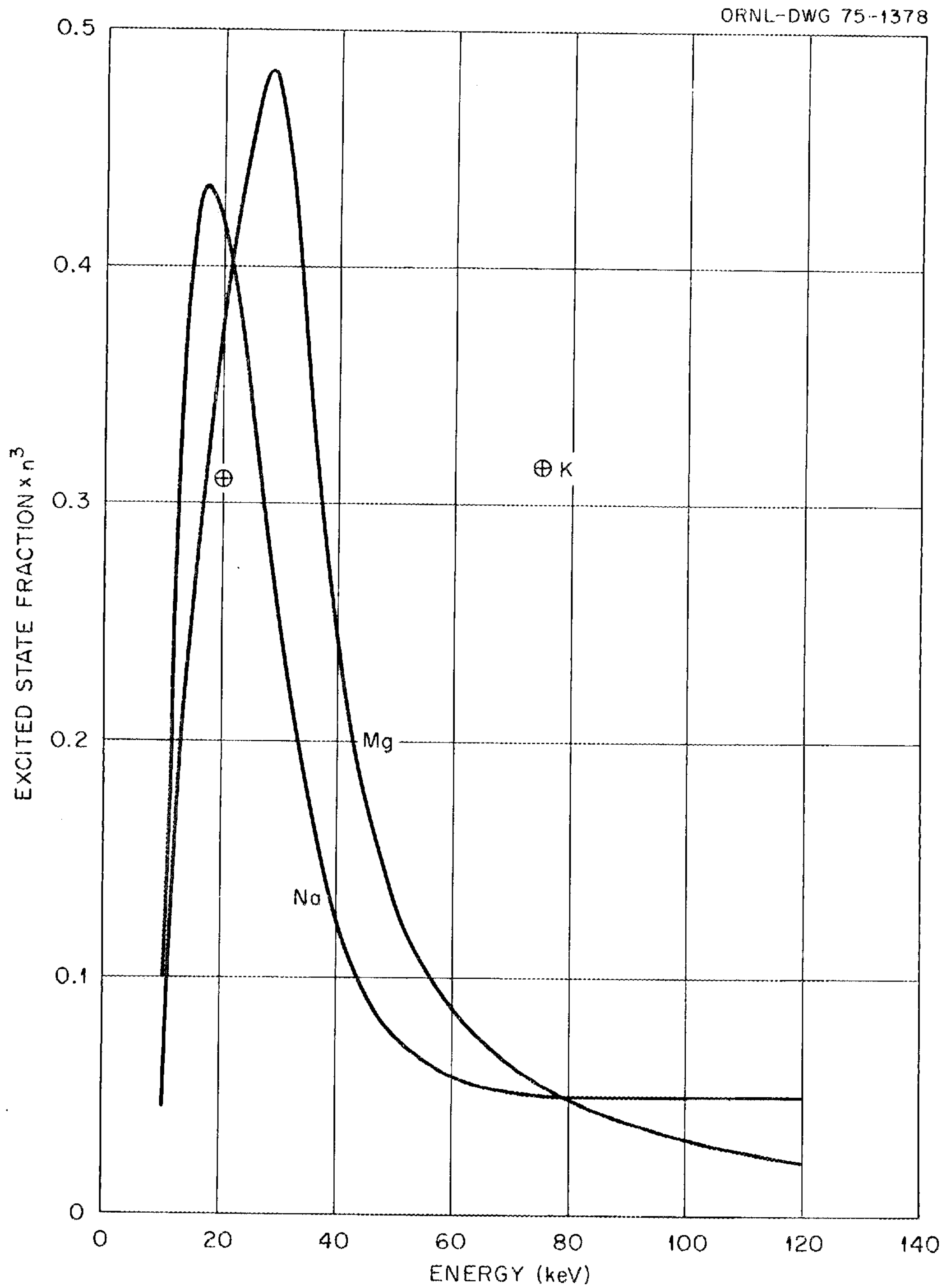
H + Mg, Experimental: V.A. Oparin, R.N. Il'in, and E.S. Solov'ev, Zh. Eks. Teor. Fiz. 52, 369 (1967). [Soviet Phys. JETP 25, 240 (1967)].

Accuracy:

Systematic error < $\pm$ 10%.

Notes:

See Note (3) at end of chapter.


ORNL-DWG 75-1378
0.5
0.4
0.3
0.2
0.1
0
EXCITED STATE FRACTION x n^3
⊕
⊕ K
Mg
Na
0
20
40
60
80
100
120
140
ENERGY (keV)

A.6.16

Equilibrium Fractions of a Hydrogen Beam in Aluminum and Gold Foils

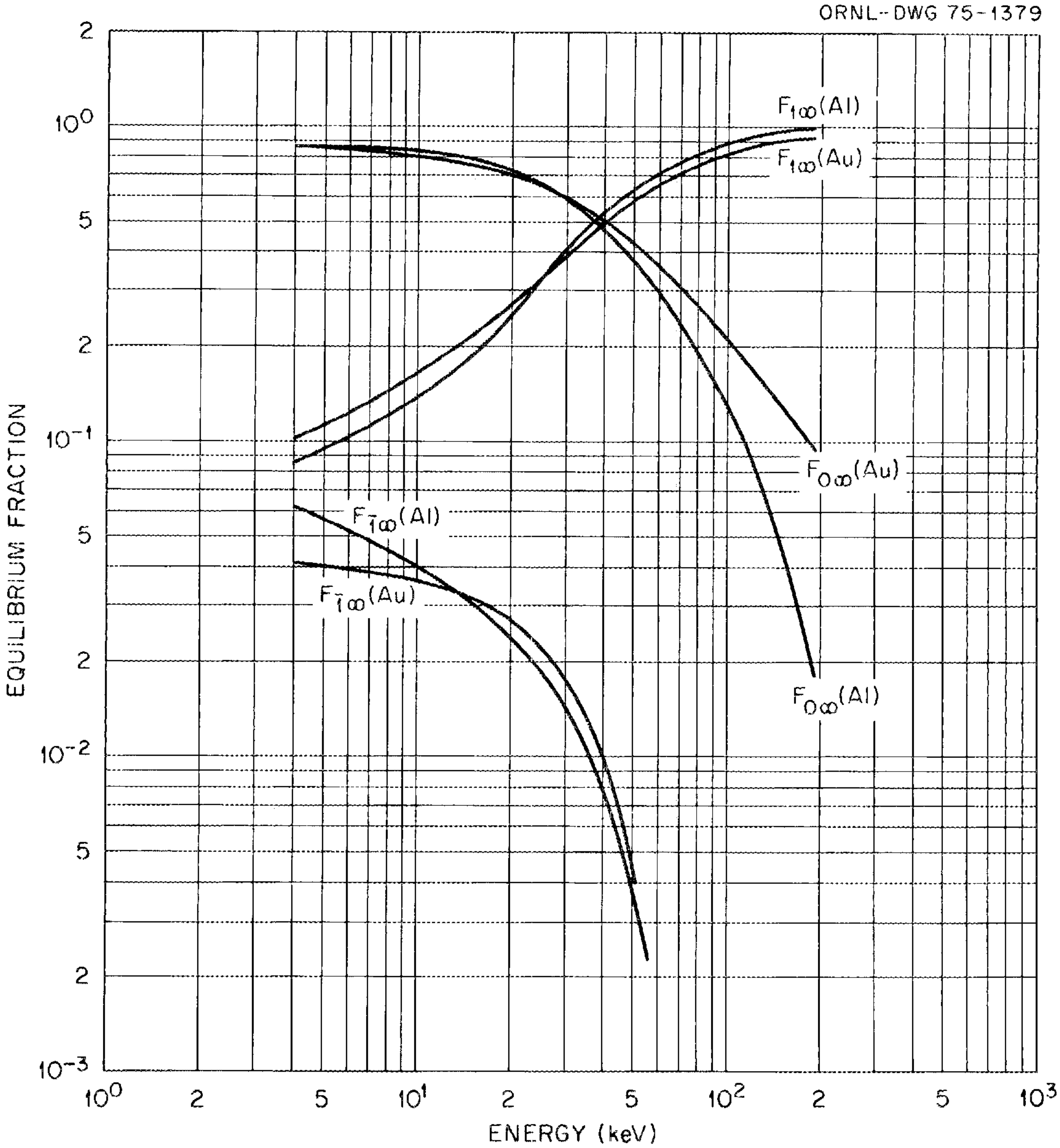
Energy (keV)	Equilibrium Fractions					
	Al			Au		
	$F_{\bar{1}\infty}$	$F_{0\infty}$	$F_{1\infty}$	$F_{\bar{1}\infty}$	$F_{0\infty}$	$F_{1\infty}$
4.0 E 00	6.20 E-02	8.56 E-01	8.20 E-02	4.11 E-02	8.59 E-01	1.00 E-01
6.0 E 00	5.21 E-02	8.45 E-01	1.02 E-01	3.93 E-02	8.44 E-01	1.23 E-01
8.0 E 00	4.59 E-02	8.13 E-01	1.99 E-01	3.74 E-02	8.01 E-01	1.44 E-01
1.0 E 01	4.00 E-02	8.18 E-01	1.42 E-01	3.60 E-02	8.00 E-01	1.65 E-01
1.5 E 01	3.06 E-02	7.71 E-01	1.85 E-01	3.16 E-02	7.50 E-01	2.14 E-01
2.0 E 01	2.40 E-02	7.25 E-01	2.51 E-01	2.69 E-02	7.00 E-01	2.68 E-01
3.0 E 01	1.41 E-02	5.85 E-01	4.01 E-01	1.79 E-02	5.90 E-01	3.80 E-01
4.0 E 01	8.00 E-03	4.58 E-01	5.34 E-01	9.58 E-02	4.92 E-01	4.97 E-01
6.0 E 01		2.90 E-01	7.10 E-01		3.58 E-01	6.55 E-01
8.0 E 01		1.92 E-01	8.10 E-01		2.69 E-01	7.52 E-01
1.0 E 02		1.20 E-01	8.80 E-01		2.10 E-01	8.09 E-01
1.5 E 02		4.50 E-02	9.55 E-01		1.28 E-01	9.00 E-01

Reference:

H + Al, Au, Experimental: J.A. Phillips, Phys. Rev. 97, 404 (1955).

Accuracy:

Random error < $\pm$ 5%.


ORNL-DWG 75-1379
$F_{1\infty}(Al)$
$F_{1\infty}(Au)$
$F_{0\infty}(Au)$
$F_{0\infty}(Al)$
$F_{\bar{1}\infty}(Al)$
$F_{\bar{1}\infty}(Au)$
EQUILIBRIUM FRACTION
ENERGY (keV)
2
10^0
5
2
10^{-1}
5
2
10^{-2}
5
2
10^{-3}
10^0
2
5
10^1
2
5
10^2
2
5
10^3

Yield of H^o and H^- Observed for an H_2^+ Beam Traversing H_2 and H_2O

Energy (keV)	Yield (H^o and H^- Atoms Per Incident H_2^+ Ion)		
	H_2 Target	H_2O Target	
	H^o Yield	H^- Yield	H^o Yield
1.0 E 01		6.15 E-02	
1.5 E 01		8.17 E-02	
2.0 E 01		7.78 E-02	
3.0 E 01		6.27 E-02	
4.0 E 01			
6.0 E 01	1.40 E 00		1.16 E 00
8.0 E 01	1.12 E 00		9.40 E-01
1.0 E 02	9.20 E-01		7.82 E-01
1.5 E 02	6.08 E-01		5.47 E-01
2.0 E 02	4.24 E-01		3.98 E-01
3.0 E 02	2.35 E-01		2.35 E-01
4.0 E 02	1.46 E-01		1.51 E-01

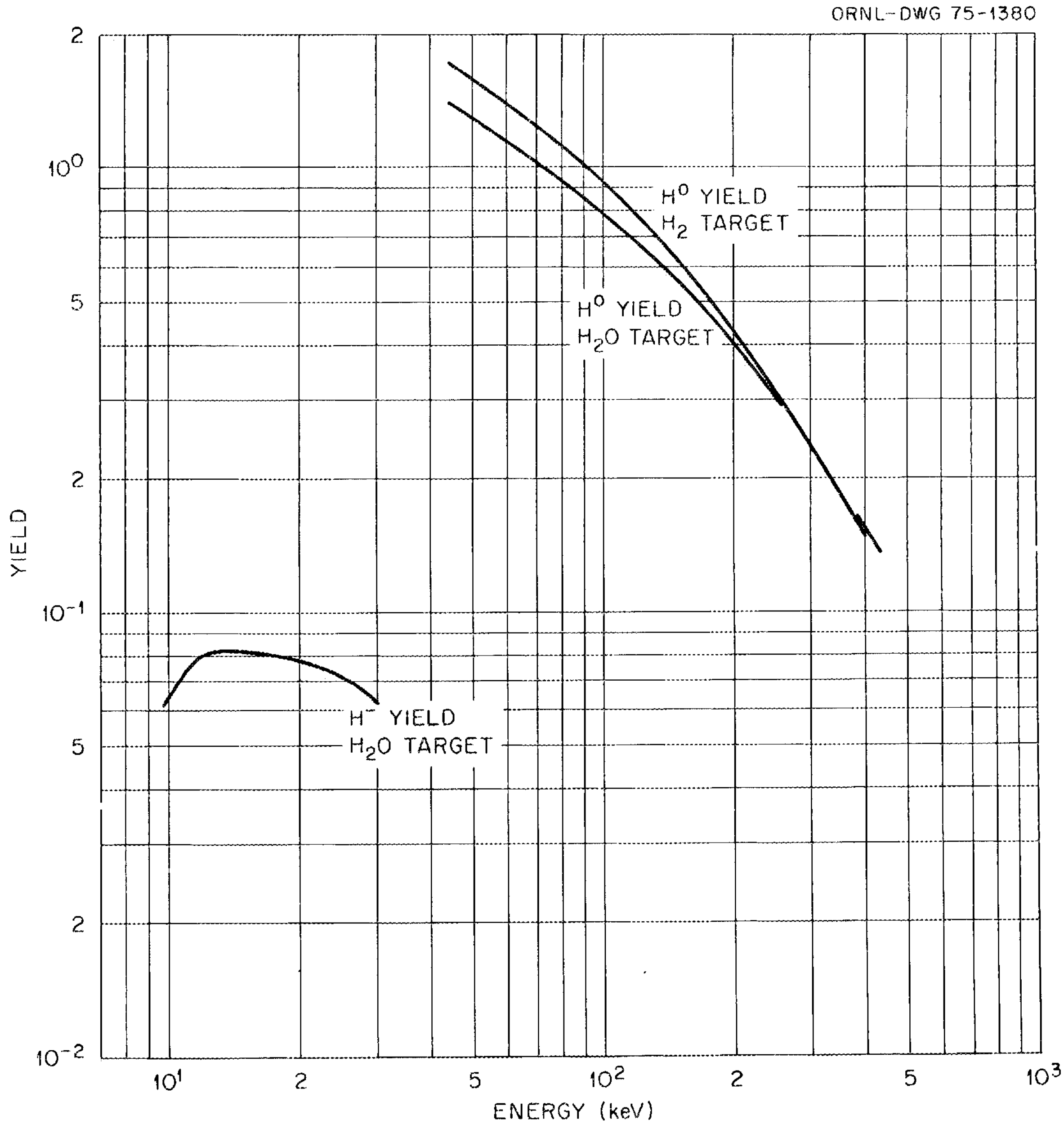
References:

$H_2^+ + (H_2 + H_2O) \rightarrow H^o$, Experimental: C.F. Barnett, M. Rankin, J.A. Ray, Proc. 6th Intl. Conf. on Ionization Phenomena in Gases (SERMA, Paris 1963) Vol. 1 page 63.

$H_2^+ + H_2O \rightarrow H^-$, Experimental: N.B. Brooks, M. Roos, R.P. Bastide, P.H. Rose, and A.B. Wittkower, Phys. Letts. 6, 169 (1963).

Accuracy:

Random error < $\pm$ 20%.


ORNL-DWG 75-1380
2
10^0
5
2
10^{-1}
5
2
10^{-2}
YIELD
10^1
2
5
10^2
2
5
10^3
ENERGY (keV)
H^0 YIELD
H_2 TARGET
H^0 YIELD
H_2O TARGET
H^- YIELD
H_2O TARGET

Yield of H^o and H^- Observed for an H_3^+ Beam Traversing H_2 and H_2O

Energy (keV)	Yield (H^o and H^- Atoms Per Incident H_3^+ Ion)		
	H_2 Target	H_2O Target	
	H^o Yield	H^- Yield	H^o Yield
1.0 E 01		5.50 E-02	
1.5 E 01		1.36 E-01	
2.0 E 01		1.66 E-01	
3.0 E 01		9.30 E-01	
4.0 E 01			2.53 E 00
6.0 E 01			2.24 E 00
8.0 E 01	2.74 E 00		1.98 E 00
1.0 E 02	2.30 E 00		1.73 E 00
1.5 E 02	1.58 E 00		1.30 E 00
2.0 E 02	1.16 E 00		1.01 E 00
3.0 E 02	7.20 E-01		6.92 E 00
4.0 E 02			5.05 E 00
5.0 E 02			3.90 E 00

References:

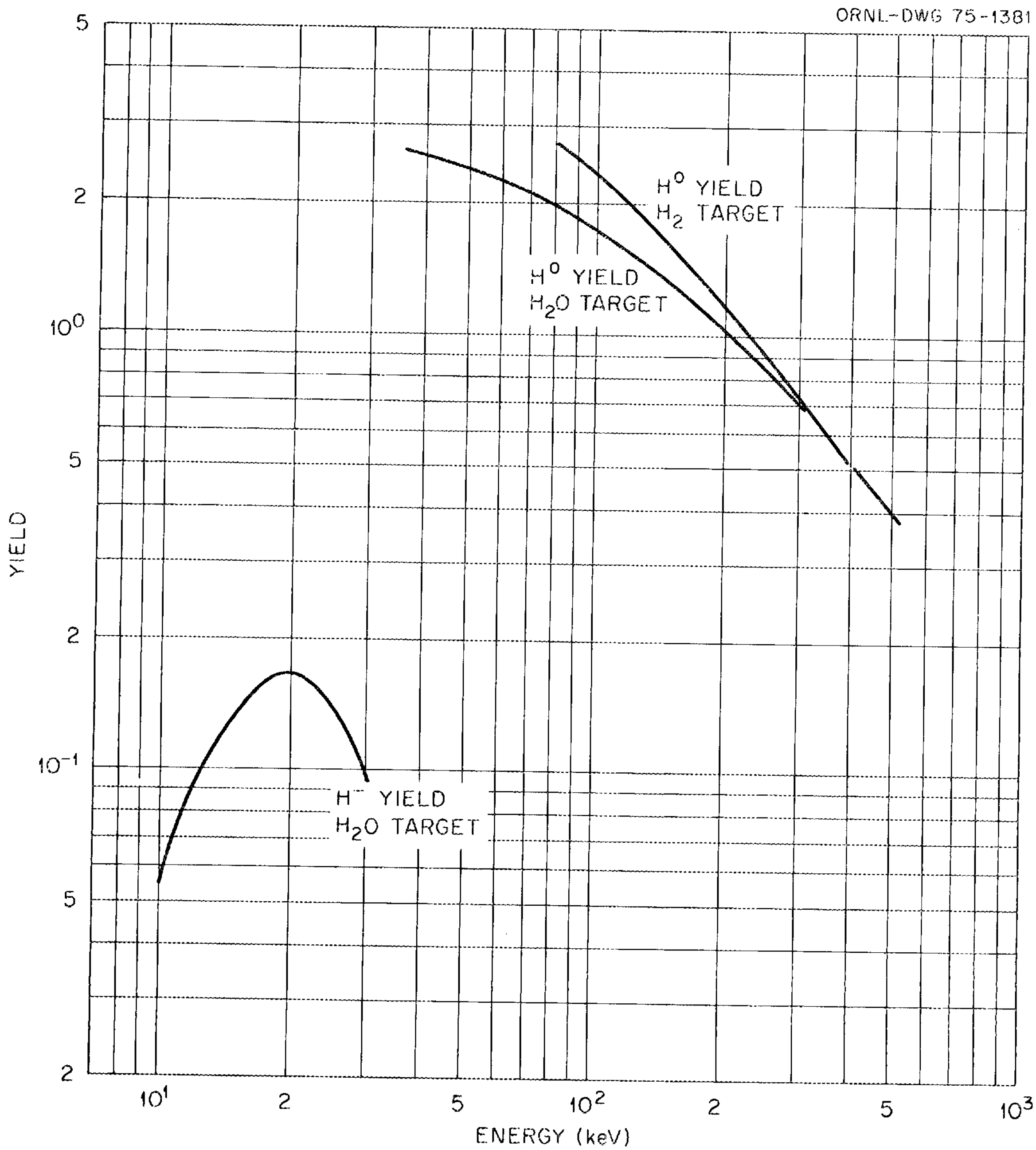
$H_3^+ + H_2 \rightarrow H^o$, Experimental: C.F. Barnett, M. Rankin, J.A. Ray, Proc. 6th Intl. Conf. on Ionization Phenomena in Gases (SERMA, Paris 1963) Vol. 1 page 63. C.R. Middleton, M.F. Payne, A.C. Riviere, J. Phys. B 4, L88 (1971).

$H_3^+ + H_2O \rightarrow H^-$, Experimental: N.B. Brooks, M. Roos, R.P. Bastide, P.M. Rose, and A.B. Wittkower, Phys. Letts. 6, 169 (1963).

$H_3^+ + H_2O \rightarrow H^o$, Experimental: C.F. Barnett, M. Rankin, J.A. Ray, Proc. 6th Intl. Conf. on Ionization Phenomena in Gases (SERMA, Paris 1963) Vol. 1 page 63.

Accuracy:

Random error < $\pm$ 20%.


ORNL-DWG 75-1381
H⁰ YIELD
H2 TARGET
H⁰ YIELD
H2O TARGET
H⁻ YIELD
H2O TARGET
YIELD
ENERGY (keV)
5
2
10⁰
5
2
10⁻¹
5
2
10¹
2
5
10²
2
5
10³

Fractions of H_3^+, H_2^+, H_2, H^+, and H as a Function of

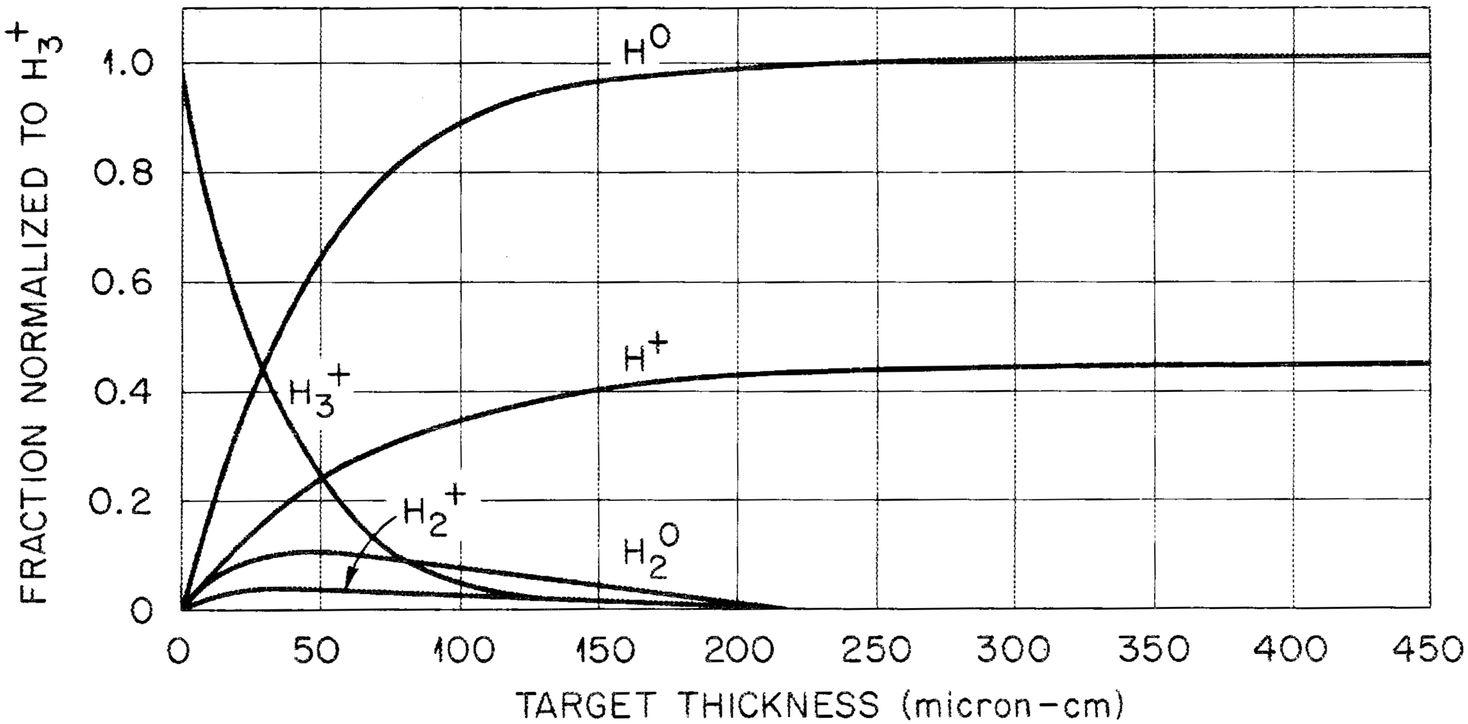
Target Thickness for 100-keV H_3^+ Traversing H_2

Target Thickness (micron-cm)	Fractions of Components Normalized to H_3^+				
	H_3^+	H_2^+	H_2^o	H^+	H^o
0.0 E 00	1.0 E 00				
2.5 E 01	5.0 E-01	3.6 E-02	8.8 E-02	1.4 E-01	3.8 E-01
5.0 E 01	2.4 E-01	3.9 E-02	1.0 E-01	2.4 E-01	6.4 E-01
7.5 E 01	1.1 E-01	3.3 E-02	9.3 E-02	3.0 E-01	8.0 E-01
1.0 E 02	5.0 E-02	2.4 E-02	8.0 E-02	3.4 E-01	8.9 E-01
1.5 E 02	1.2 E-02	1.2 E-02	4.7 E-02	4.0 E-01	9.7 E-01
2.0 E 02			1.0 E-02	4.3 E-01	9.9 E-01
3.0 E 02				4.4 E-01	1.08 E 00
4.0 E 02				4.5 E-01	1.01 E 00

Reference:

Theoretical, based on experimental data: C.F. Barnett, M. Rankin, J.A. Ray, Proc. 6th Intl. Conf. on Ionization Phenomena in Gases (SERMA, Paris 1963) Vol. 1 page 63.

ORNL-DWG 63-2112



Equilibrium Fractions of a Helium Beam in H_2 and He

Energy (keV)	Equilibrium Fractions						
	H_2				He		
	$F_{\bar{1}\infty}$	$F_{0\infty}$	$F_{1\infty}$	$F_{2\infty}$	$F_{0\infty}$	$F_{1\infty}$	$F_{2\infty}$
8.0 E 00			1.51 E-01		9.70 E-01	2.90 E-02	
1.0 E 01			1.57 E-01		9.62 E-01	3.71 E-02	
2.0 E 01			1.63 E-01		9.05 E-01	7.50 E-02	
3.0 E 01			1.64 E-01		8.65 E-01	1.09 E-01	
4.0 E 01	5.20 E-05	8.30 E-01	1.68 E-01		8.30 E-01	1.40 E-01	2.42 E-03
6.0 E 01	1.00 E-04	8.10 E-01	1.98 E-01		7.90 E-01	1.99 E-01	3.40 E-03
8.0 E 01	1.60 E-04	7.60 E-01	2.40 E-01		7.60 E-01	2.50 E-01	4.66 E-03
1.0 E 02	2.00 E-04	7.00 E-01	2.89 E-01	1.00 E-03	7.07 E-01	2.94 E-01	6.26 E-03
2.0 E 02	1.70 E-04	4.38 E-01	5.50 E-01	1.23 E-02	5.00 E-01	4.68 E-01	2.05 E-02
3.0 E 03		2.46 E-01	6.90 E-01	6.68 E-02	3.60 E-01	5.90 E-01	5.00 E-02
4.0 E 02		1.18 E-01	7.30 E-01	1.67 E-01	2.51 E-01	6.49 E-01	9.90 E-02
6.0 E 02					1.14 E-01	6.23 E-01	2.58 E-01
8.0 E 02					4.99 E-02	5.20 E-01	4.63 E-01
1.0 E 03					1.94 E-02	3.80 E-01	6.00 E-01
2.0 E 03						1.04 E-01	8.51 E-01
3.0 E 03						3.91 E-02	9.35 E-01
4.0 E 03						1.80 E-02	9.70 E-01
5.0 E 03						9.60 E-03	9.86 E-01

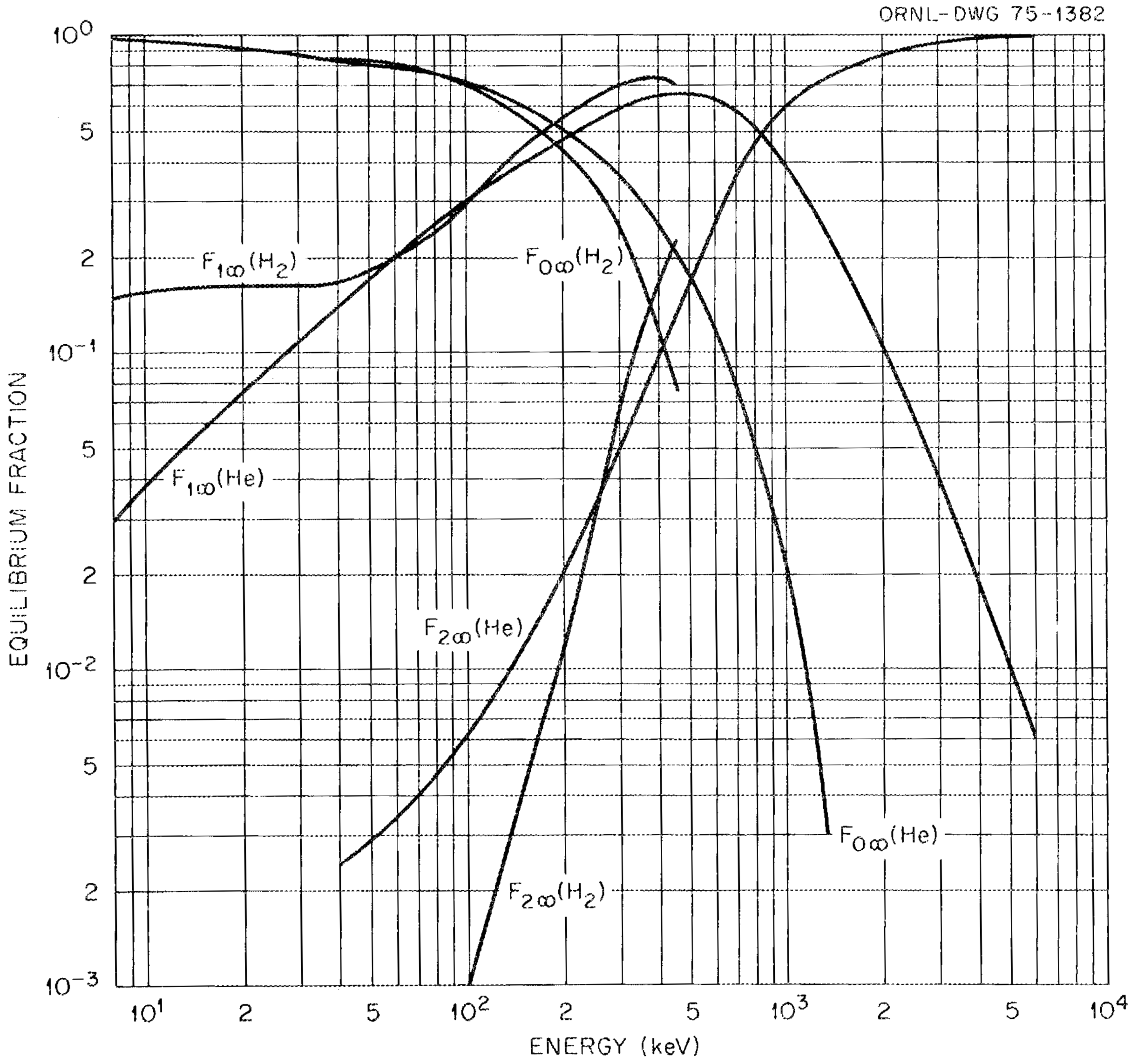
References:

$H^+ + H_2$, Experimental: From the review by S. K. Allison and M. Garcia Munoz, "Atomic and Molecular Processes" (ed. D.R. Bates, Academic Press, N.Y. 1962) page 721.

$H^+ + He$, Experimental: C.F. Barnett and P.M. Stier, Phys. Rev. 109, 385 (1958). W. Meckbach and I.B. Nemirovsky, Phys. Rev., 153, 13 (1967). V.S. Nikolaev, et al., Zh. Eks. Teor. Fiz. 39, 905 (1961). [Soviet Phys. JETP 12, 627 (1961)].

Accuracy:

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


ORNL-DWG 75-1382
EQUILIBRIUM FRACTION
ENERGY (keV)
10^0
5
2
10^{-1}
5
2
10^{-2}
5
2
10^{-3}
10^1
2
5
10^2
2
5
10^3
2
5
10^4
$F_{1\infty}(H_2)$
$F_{0\infty}(H_2)$
$F_{1\infty}(He)$
$F_{2\infty}(He)$
$F_{0\infty}(He)$
$F_{2\infty}(H_2)$

Equilibrium Fractions of a Helium Beam in N_2 and O_2

Energy (keV)	Equilibrium Fractions					
	N_2			O_2		
	$F_{0\,\infty}$	$F_{1\,\infty}$	$F_{2\,\infty}$	$F_{0\,\infty}$	$F_{1\,\infty}$	$F_{2\,\infty}$
4.0 E 00	9.80 E-01	2.02 E-02				
6.0 E 00	9.63 E-01	2.75 E-02				
8.0 E 00	9.64 E-01	3.58 E-02		9.73 E-01	2.70 E-01	
1.0 E 01	9.55 E-01	4.42 E-02		9.61 E-01	3.91 E-02	
2.0 E 01	9.06 E-01	9.42 E-02		9.00 E-01	1.00 E-01	
3.0 E 01	8.57 E-01	1.43 E-01		8.50 E-01	1.50 E-01	
4.0 E 01	8.12 E-01	1.90 E-01		8.00 E-01	2.00 E-01	
6.0 E 01	7.24 E-01	2.76 E-01		7.09 E-01	2.91 E-01	2.02 E-03
8.0 E 01	6.50 E-01	3.50 E-01	2.36 E-03	6.40 E-01	3.56 E-01	4.18 E-03
1.0 E 02	5.84 E-01	4.12 E-01	4.13 E-03	5.83 E-01	4.10 E-01	7.02 E-03
2.0 E 02	3.46 E-01	6.19 E-01	3.50 E-02	3.86 E-01	5.81 E-01	3.39 E-02
3.0 E 02	2.00 E-01	6.90 E-01	1.10 E-01			
4.0 E 02	1.08 E-01	6.89 E-01	2.04 E-01			
6.0 E 02	3.80 E-02	5.70 E-01	3.99 E-01			
8.0 E 02		3.95 E-01	5.65 E-01			
1.0 E 03		2.80 E-01	7.20 E-01			
2.0 E 03		7.90 E-02	9.21 E-01			
3.0 E 03		3.38 E-02	9.66 E-01			
4.0 E 03		1.80 E-02	9.91 E-01			
6.0 E 03		7.50 E-03	9.92 E-01			

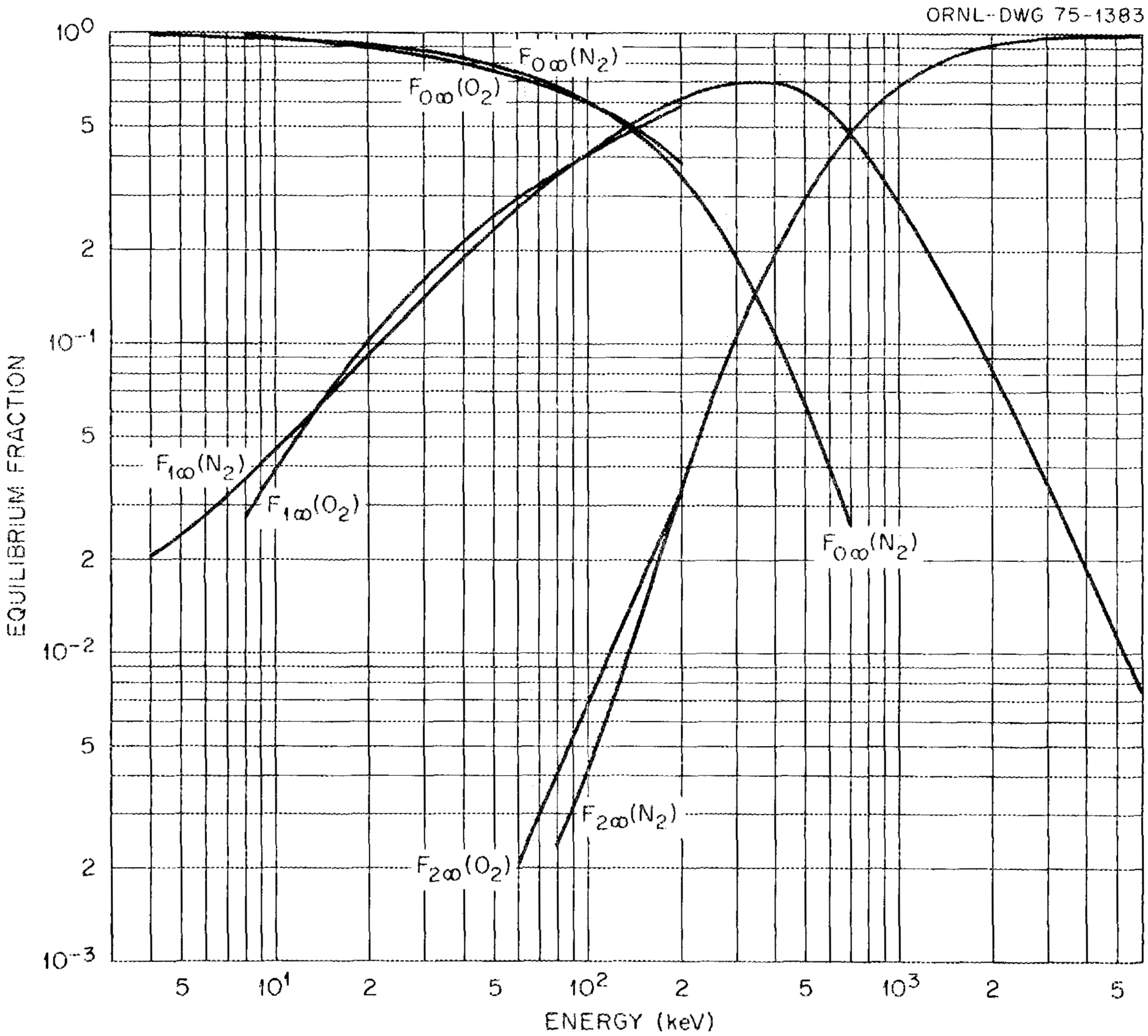
References:

$He^+ + N_2$, Experimental: From the review by S.K. Allison and M. Garcia-Munoz, "Atomic and Molecular Processes," (ed. D.R. Bates, Academic Press N.Y. 1962) page 721. V.S. Nikolaev et al., Zh. Eks. Teor. Fiz. 39, 905 (1961) [Soviet Phys. JETP 12, 627 (1961)].

$He^+ + O_2$, Experimental: From the review by S.K. Allison and M. Garcia-Munoz, "Atomic and Molecular Processes," (ed. D.R. Bates, Academic Press N.Y. 1962) page 721.

Accuracy:

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


ORNL-DWG 75-1383
EQUILIBRIUM FRACTION
ENERGY (keV)
$F_{0\infty}(N_2)$
$F_{0\infty}(O_2)$
$F_{1\infty}(N_2)$
$F_{1\infty}(O_2)$
$F_{0\infty}(N_2)$
$F_{2\infty}(N_2)$
$F_{2\infty}(O_2)$
10^0
5
2
10^{-1}
5
2
10^{-2}
5
2
10^{-3}
5
10^1
2
5
10^2
2
5
10^3
2
5

Equilibrium Fractions of a Helium Beam in Ar

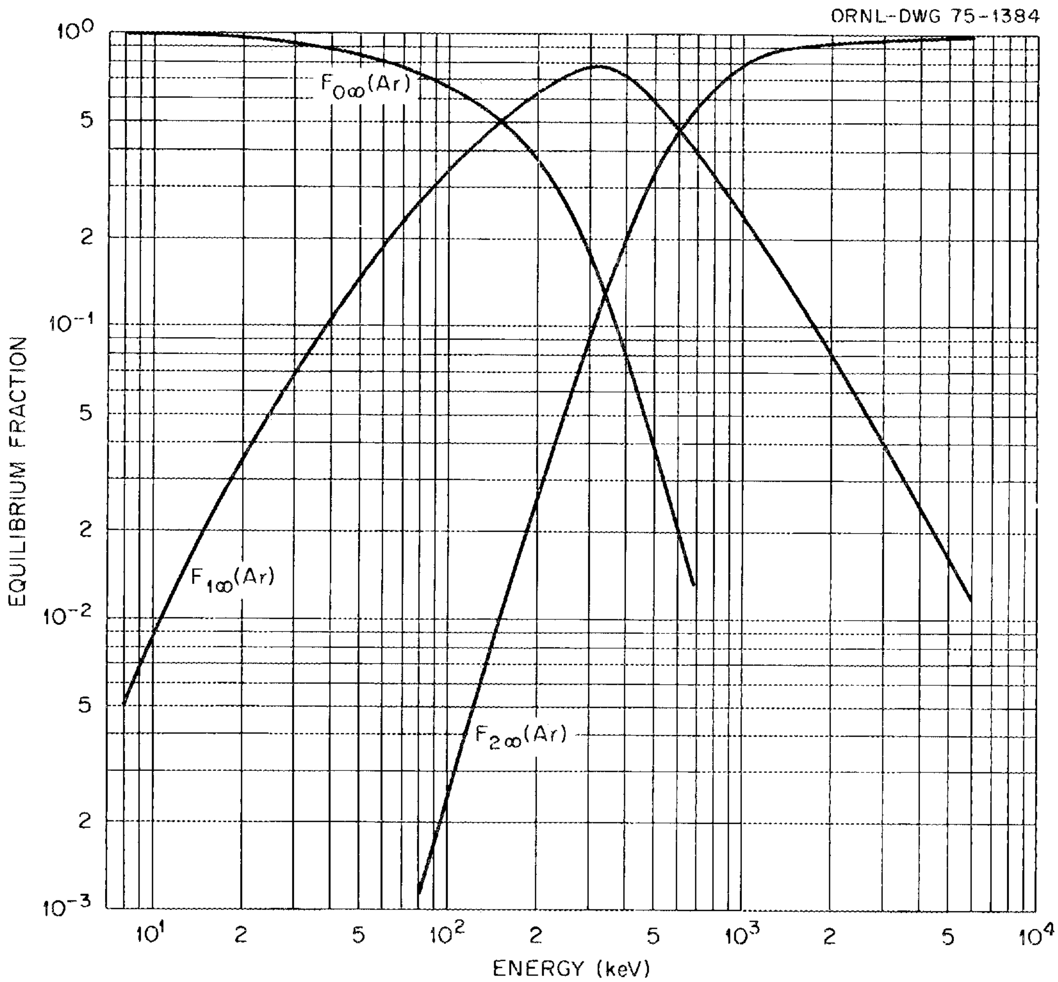
Energy (keV)	Equilibrium Fractions		
	Ar		
	$F_{0\,\infty}$	$F_{1\,\infty}$	$F_{2\,\infty}$
8.0 E 00	9.95 E-01	5.00 E-03	
1.0 E 01	9.91 E-01	8.70 E-03	
2.0 E 01	9.65 E-01	3.51 E-02	
3.0 E 01	9.30 E-01	6.90 E-02	
4.0 E 01	8.91 E-01	1.09 E-01	
6.0 E 01	8.08 E-01	1.92 E-01	
8.0 E 01	7.23 E-01	2.76 E-01	1.10 E-03
1.0 E 02	6.53 E-01	3.44 E-01	2.53 E-03
2.0 E 02	3.53 E-01	6.20 E-01	2.70 E-02
3.0 E 02	1.36 E-01	7.70 E-01	9.39 E-02
4.0 E 02	6.90 E-02	7.14 E-01	2.07 E-01
6.0 E 02	1.90 E-02	4.90 E-01	4.90 E-01
8.0 E 02		3.33 E-01	6.67 E-01
1.0 E 03		2.35 E-01	7.65 E-01
2.0 E 03		8.00 E-02	9.20 E-01
3.0 E 03		4.00 E-02	9.60 E-01
4.0 E 03		2.40 E-02	9.68 E-01
5.0 E 03		1.60 E-02	9.84 E-01

References:

He^{+} + Ar, Experimental: From the review by S.K. Allison and M. Garcia-Munoz, "Atomic and Molecular Processes," (ed. D.R. Bates, Academic Press, N.Y. 1962) page 721. V.S. Nikolaev et al., Zh. Eks. Teor. Fix. 39, 905 (1961) [Soviet Phys. JETP 12, 627 (1961)].

Accuracy:

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


ORNL-DWG 75-1384
EQUILIBRIUM FRACTION
ENERGY (keV)
$F_{0\infty}$(Ar)
$F_{1\infty}$(Ar)
$F_{2\infty}$(Ar)
10^0
5
2
10^{-1}
5
2
10^{-2}
5
2
10^{-3}
10^1
2
5
10^2
2
5
10^3
2
5
10^4

Notes

(1) At very high energies the equilibrium fractions are expected to be given by $F_{0\,\infty} = \sigma_{10}/(\sigma_{10} + \sigma_{01})$ and $F_{1\,\infty} = \sigma_{01}/(\sigma_{10} + \sigma_{01})$ where σ_{01} is the cross section for electron stripping from H and σ_{10} is the cross section for electron capture by H^+. We have used direct measurements of fractions wherever possible but where these are not available we have generated values using cross sections from the references cited.

(2) The equilibrium-excited state fraction referred to here is the fraction of the neutral flux that appears in a state of principal quantum number n (i.e. the fraction summed over all angular momentum states of a given n). It is not the fraction of the total flux including H^+, H^0, H^-. It is found that the excited state fraction of the neutral beam decreases as n^{-3}. Thus it is convenient and conventional to quote the fraction measured for a given n, multiplied by n^3; we adopt that convention here. It should be noted that the n^{-3} rule holds only for the higher principal quantum number states and the data reproduced here are determined for $n \geq 10$. Use of these data to estimate populations for small n may be subject to error. In order to determine the fraction of excited neutrals of a given state n, in the total flux of particles, one simply takes the value of $F_{0\,\infty}$ for the reaction from the relevant preceding table, multiplying by the figure given here and dividing by the cube of the principal quantum number of interest.

(3) The reader is cautioned that an equilibrium excited state fraction of the neutral beam is not the greatest fraction observed in the neutral beam; the greatest fraction occurs at a lower pressure than the equilibrium fraction and may exceed the equilibrium fraction by a factor of three. See the references quoted here for details.

(4) Deuterons are expected to have the same fractions as protons of equal velocity.

A.7 Stopping Cross Sections and Particle Range for Heavy Particles in Gases and Metals

Stopping Cross Sections for Protons and H Atoms in Atomic Hydrogen

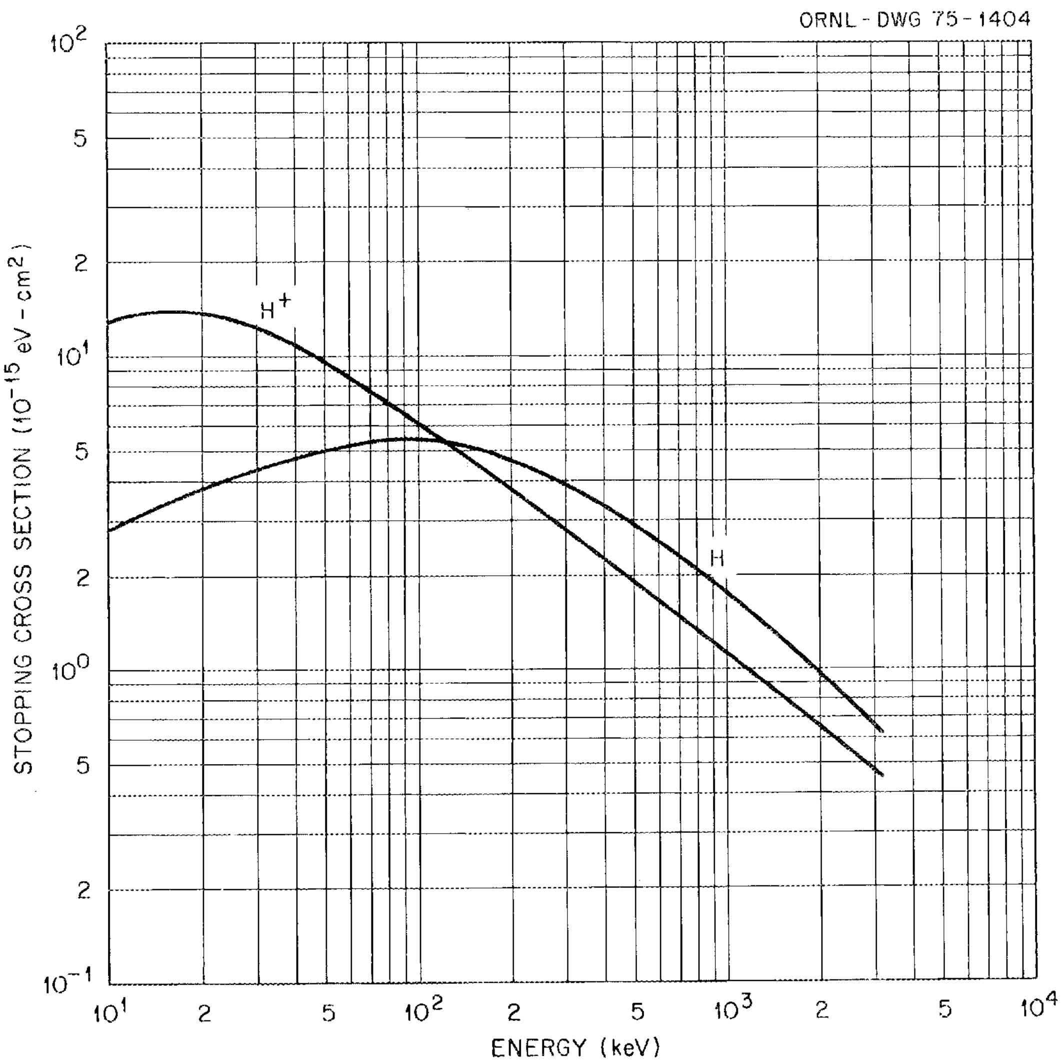
Energy (keV)	Stopping Cross Sections ($eV-cm^2/atom$)	
	H^+	H
1.0 E 01	1.28 E-14	2.80 E-15
2.0 E 01	1.36 E-14	3.78 E-15
3.0 E 01	1.22 E-14	4.32 E-15
4.0 E 01	1.10 E-14	4.70 E-15
6.0 E 01	8.50 E-15	5.20 E-15
8.0 E 01	7.00 E-15	5.40 E-15
1.0 E 02	6.15 E-15	5.41 E-15
2.0 E 02	3.74 E-15	4.61 E-15
3.0 E 02	2.78 E-15	3.88 E-15
4.0 E 02	2.24 E-15	3.31 E-15
6.0 E 02	1.66 E-15	2.55 E-15
8.0 E 02	1.32 E-15	2.18 E-15
1.0 E 03	1.12 E-15	1.74 E-15
2.0 E 03	6.50 E-16	9.60 E-16
3.0 E 03	4.70 E-16	6.50 E-16

Reference:

H^+ + H and H + H Theoretical: A. Dalgarno and G.W. Griffing, Proc. Roy. Soc. A 232, 423 (1955).

Accuracy:

See Note (4) at end of chapter.


ORNL-DWG 75-1404
10^2
5
2
10^1
5
2
10^0
5
2
10^{-1}
STOPPING CROSS SECTION (10^{-15} eV - cm^2)
H^+
H
10^1
2
5
10^2
2
5
10^3
2
5
10^4
ENERGY (keV)

Stopping Cross Sections for Protons in Gases

(H_2, He, N_2)

Energy (keV)	Stopping Cross Sections ($eV-cm^2$/target particle)		
	H_2	He	N_2
1.0 E 01	7.68 E-15	3.37 E-15	2.20 E-14
2.0 E 01	1.02 E-14	4.88 E-15	2.78 E-14
3.0 E 01	1.16 E-14	5.81 E-15	3.04 E-14
4.0 E 01	1.23 E-14	6.40 E-15	3.34 E-14
6.0 E 01	1.25 E-14	7.15 E-15	3.56 E-14
8.0 E 01	1.24 E-14	7.30 E-15	3.62 E-14
1.0 E 02	1.16 E-14	7.20 E-15	3.60 E-14
2.0 E 02	7.84 E-15	5.50 E-15	2.84 E-14
3.0 E 02	5.80 E-15	4.40 E-15	2.22 E-14
4.0 E 02	4.76 E-15	3.68 E-15	1.84 E-14
6.0 E 02	3.36 E-15	2.72 E-15	1.43 E-14
8.0 E 02	2.68 E-15	2.30 E-15	1.19 E-14
1.0 E 03	2.26 E-15	1.90 E-15	1.03 E-14
2.0 E 03	1.28 E-15	1.12 E-15	6.40 E-15
3.0 E 03	9.24 E-16	8.03 E-16	4.76 E-15
4.0 E 03	7.36 E-16	6.35 E-16	3.76 E-15
5.0 E 03	6.08 E-16	5.18 E-16	3.20 E-15
6.0 E 03	5.30 E-16	4.55 E-16	2.80 E-15
8.0 E 03	4.12 E-16	3.55 E-16	2.24 E-15
1.0 E 04	3.40 E-16	2.99 E-16	

*[Data are in eV - cm^2/molecule for H_2 and N_2; eV - cm^2/atom for He].

Reference:

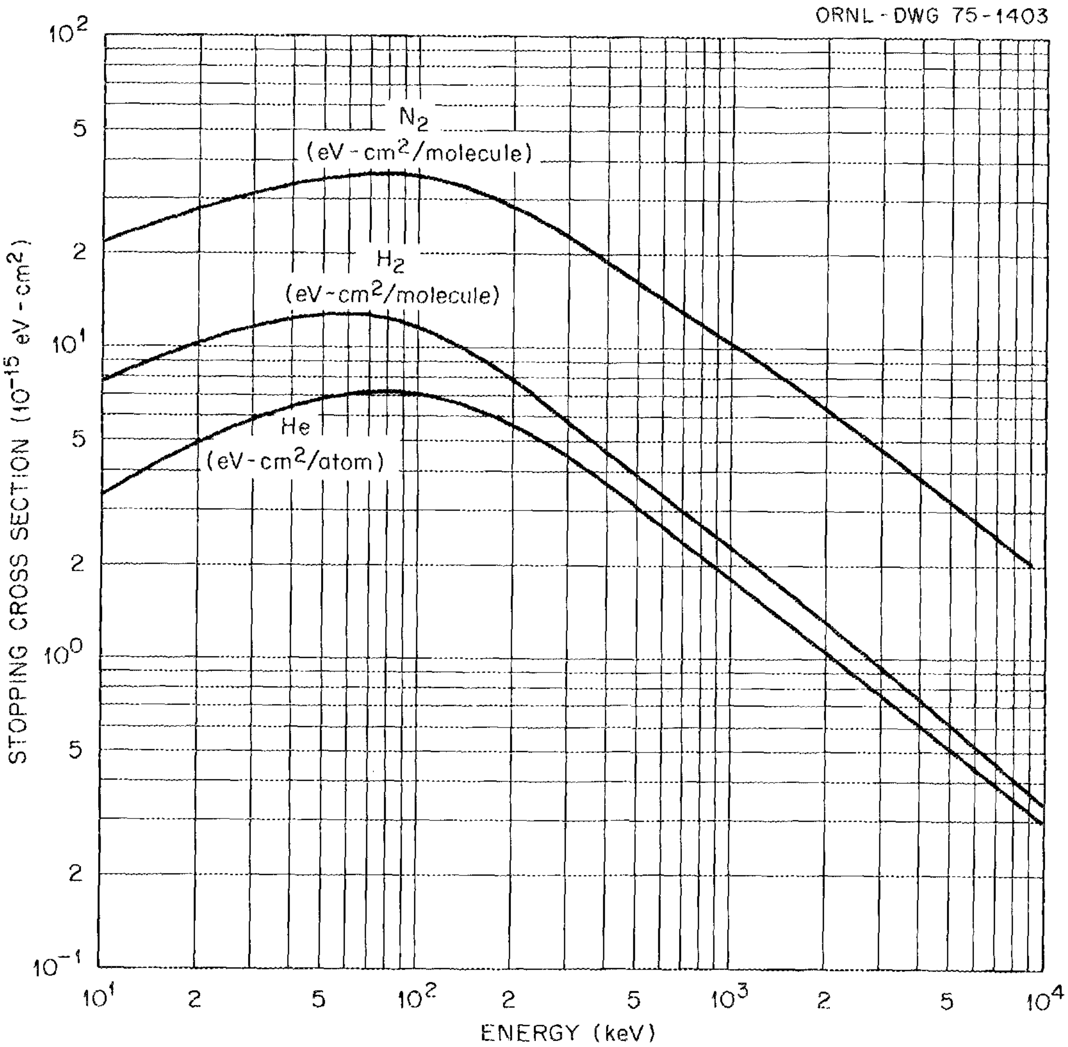
H^+ + (H_2,He) Exp. and Theoretical: From the review by W. Whaling, Handbuch der Physik, ed. S. Flügge, Springer-Verlag, Berlin 1958, Volume 34, page 193.

H^+ + N_2 Exp. and Theoretical: From the review by W. Whaling, Handbuch der Physik,, ed. S. Flugge, Springer-Verlag, Berlin 1958, Volume 34, page 173.

Notes:

See Notes (1), (5), and (10) at end of chapter.

Accuracy: Systematic error < $\pm$ 2%. Random error < 3%.


ORNL-DWG 75-1403
N_2
(eV-cm^2/molecule)
H_2
(eV-cm^2/molecule)
He
(eV-cm^2/atom)
STOPPING CROSS SECTION (10^{-15} eV-cm^2)
ENERGY (keV)
10^2
5
2
10^1
5
2
10^0
5
2
10^{-1}
10^1
2
5
10^2
2
5
10^3
2
5
10^4

Stopping Cross Sections for Protons in Carbon and Iron

Energy (keV)	Stopping Cross Sections ($eV\text{-}cm^2/atom$)	
	C	Fe
1.0 E 00	3.02 E-15	
2.0 E 00	4.20 E-15	
3.0 E 00	5.00 E-15	
4.0 E 00	5.64 E-15	
6.0 E 00	6.71 E-15	
8.0 E 00	7.60 E-15	
1.0 E 01	8.31 E-15	
2.0 E 01	1.09 E-14	
3.0 E 01	1.24 E-14	
4.0 E 01	1.34 E-14	
6.0 E 01	1.47 E-14	
8.0 E 01	1.50 E-14	
1.0 E 02	1.51 E-14	
2.0 E 02	1.28 E-14	2.72 E-14
3.0 E 02	1.02 E-14	2.41 E-14
4.0 E 02	8.61 E-15	2.11 E-14
6.0 E 02	6.60 E-15	1.73 E-14
8.0 E 02	5.40 E-15	1.47 E-14
1.0 E 03	4.61 E-15	1.28 E-14
2.0 E 03	2.82 E-15	8.00 E-15
3.0 E 03	2.10 E-15	6.10 E-15
4.0 E 03	1.70 E-15	5.00 E-15
6.0 E 03	1.25 E-15	3.78 E-15
8.0 E 03		3.10 E-15
1.0 E 04		2.63 E-15

References:

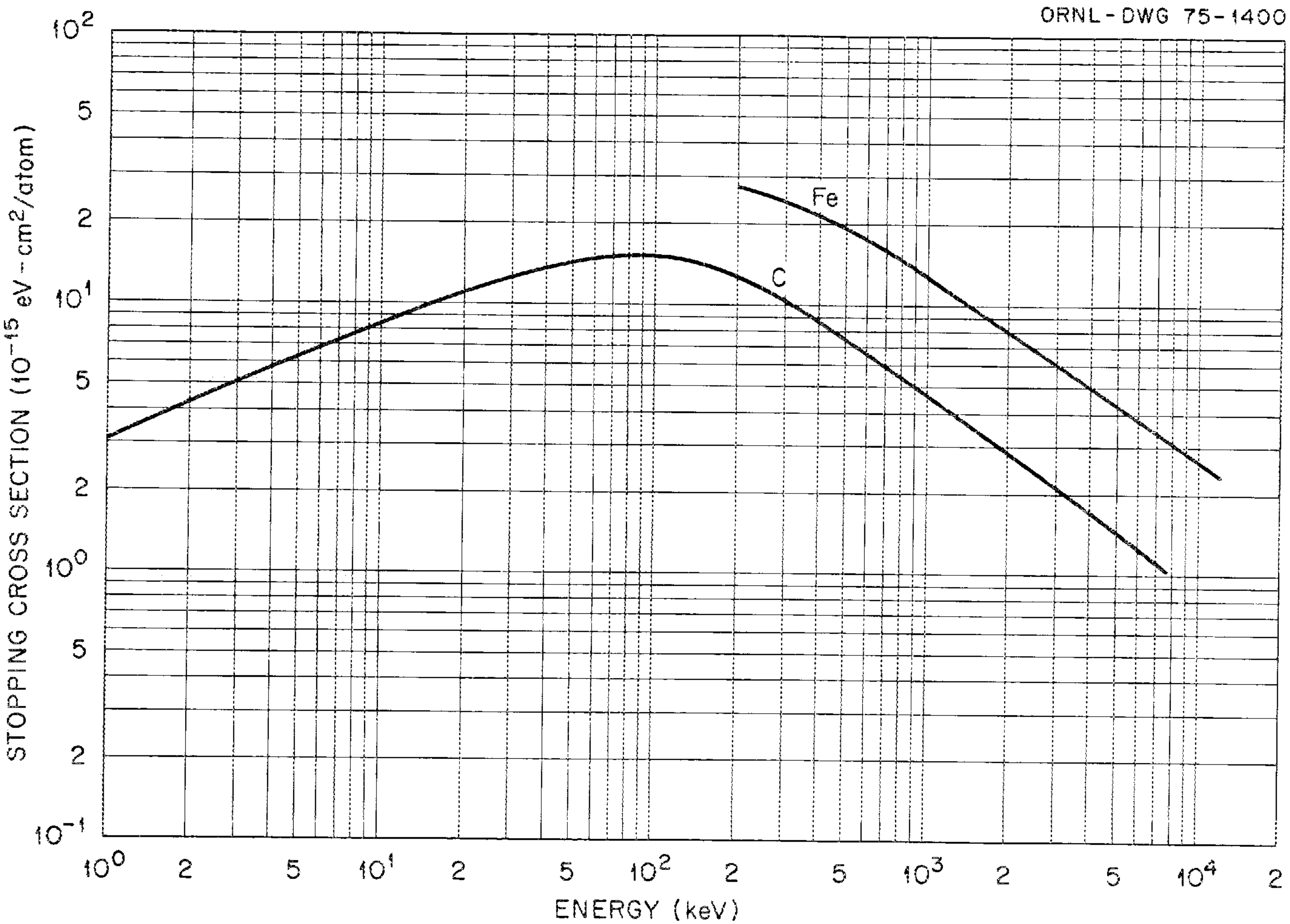
H^+ + C Exp. and Theoretical: From the review by W. Whaling, Handbuch der Physik, ed. S. Flügge, Springer-Verlag, Berlin 1958, Volume 34, page 193; J.N. Omrod and H.E. Duckworth, Can. J. Phys. 41, 1424 (1963); E.P. Arkhipov and Yu. V. Gott, Zh. Eksp. Teor. Fiz. 56, 1146 (1969) [Soviet Physics JETP 29, 615 (1969)].

H^+ + Fe Exp.: M. Bader, R.E. Pixley, F.S. Mozer, and W. Whaling, Phys. Rev. 103, 32 (1956); H.H. Andersen, C.C. Hanke, H. Simonsen, H. Sorensen, and P. Vajda, Phys. Rev. 175, 389 (1968).

Notes:

See Notes (1), (2), (5), (10), and (11) at end of chapter.

Accuracy: Systematic error < ± 2%. Random error < ± 1%.


ORNL-DWG 75-1400
STOPPING CROSS SECTION (10^{-15} eV-cm^2/atom)
ENERGY (keV)
Fe
C
10^2
5
2
10^1
5
2
10^0
5
2
10^{-1}
10^0
2
5
10^1
2
5
10^2
2
5
10^3
2
5
10^4
2

Stopping Cross Sections for Protons in Copper, Molybdenum, Tungsten, and Gold

Energy (keV)	Stopping Cross Sections ($eV-cm^2/atom$)			
	Cu	Mo	W	Au
1.0 E 00	3.45 E-15			
2.0 E 00	4.78 E-15			
3.0 E 00	5.78 E-15			
4.0 E 00	6.66 E-15			
6.0 E 00	8.10 E-15			
8.0 E 00	9.38 E-15			
1.0 E 01	1.04 E-14			1.94 E-14
2.0 E 01	1.53 E-14			2.60 E-14
3.0 E 01	1.82 E-14			2.99 E-14
4.0 E 01	2.02 E-14			3.28 E-14
6.0 E 01	2.27 E-14			3.60 E-14
8.0 E 01	2.40 E-14			3.80 E-14
1.0 E 02	2.49 E-14			3.91 E-14
2.0 E 02	2.34 E-14			3.93 E-14
3.0 E 02	2.11 E-14			3.59 E-14
4.0 E 02	1.91 E-14			3.20 E-14
6.0 E 02	1.66 E-14			2.83 E-14
8.0 E 02	1.45 E-14			2.32 E-14
1.0 E 03	1.30 E-14	1.30 E-14	1.83 E-14	2.14 E-14
2.0 E 03	9.00 E-15	9.80 E-15	1.38 E-14	1.54 E-14
3.0 E 03	6.92 E-15	8.00 E-15	1.10 E-14	1.23 E-14
4.0 E 03	5.67 E-15	7.00 E-15	9.40 E-15	1.03 E-14
6.0 E 03	4.28 E-15	5.70 E-15	8.10 E-15	8.20 E-15
8.0 E 03	3.42 E-15			6.97 E-15
1.0 E 04	2.91 E-15			6.00 E-15

References:

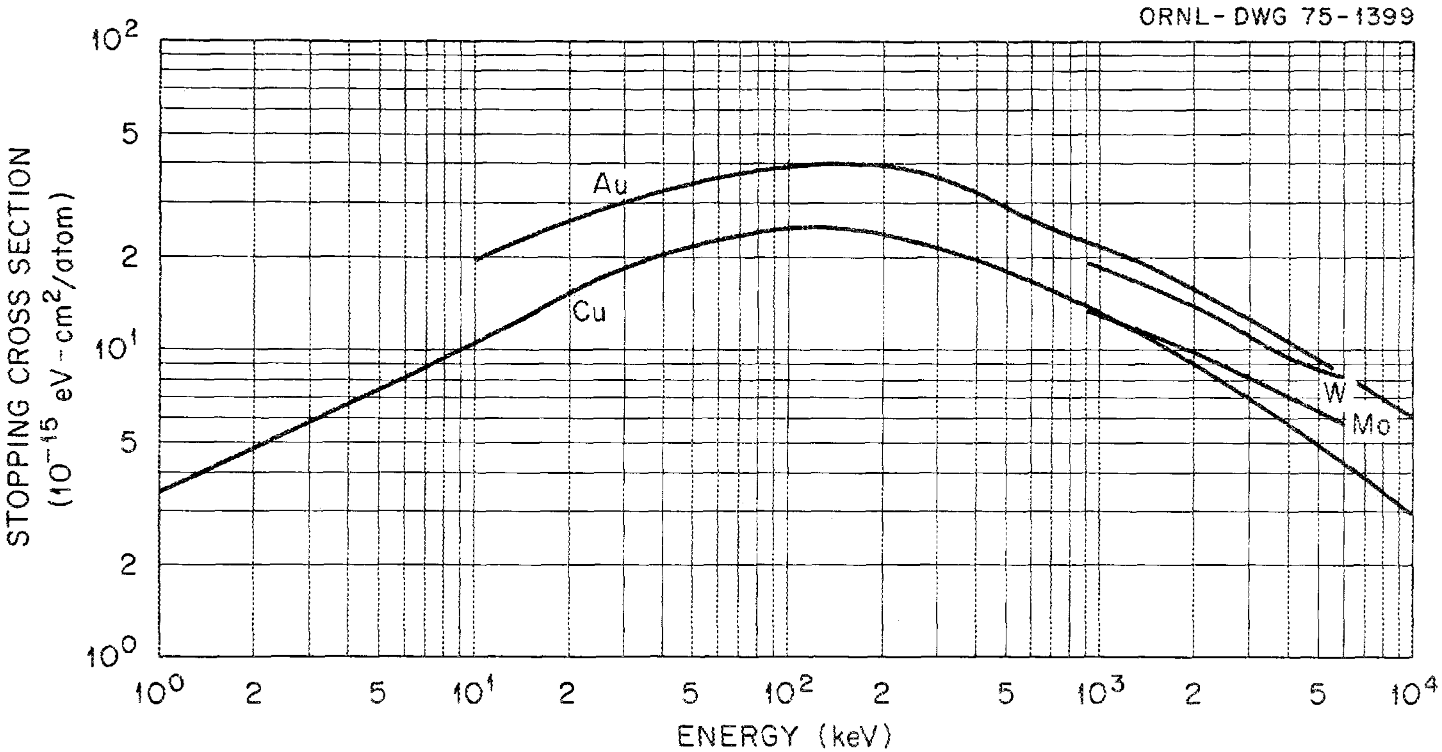
H^+ + (Cu,Au) Exp. and Theoretical: From the review by W. Whaling, Handbuch der Physik, ed. S. Flügge, Springer-Verlag, Berlin 1958, Volume 34, page 193. A. Valenzuela, W. Meckbach, A.J. Kestelman, and J.C. Eckardt, Phys. Rev. B 6, 95 (1972) (normalized to Whaling). K. Morita, H. Akimune, and T. Suita, J. Phys. Soc. Japan 25, 1525 (1968) (normalized to Valenzuela). E.P. Arkhipov and Yu. V. Gott, Zh. Eksp. Teor. Fiz. 56, 1146 (1969) (Soviet Phys. JETP 29, 615 (1969) [normalized to Morita].

H^+ + Mo Exp.: E.I. Sirofinin, A.F. Tulinov, A. Fiderkevich, and K.S. Shyshkin, Radiation Effects 15, 149 (1972).

H^+ + W Exp.: E.I. Sirofinin, A.F. Tulinov, A. Fiderkevich, and K.S. Shyshkin, Radiation Effects 15, 149 (1972).

Notes: See Notes (1), (2), (10), (12), and (13) at end of chapter.

Accuracy: Systematic error < ± 2%. Random error < ± 1%.


ORNL-DWG 75-1399
STOPPING CROSS SECTION
(10^{-15} eV-cm^2/atom)
ENERGY (keV)
Au
Cu
W
Mo
10^2
5
2
10^1
5
2
10^0
10^0
2
5
10^1
2
5
10^2
2
5
10^3
2
5
10^4

Range of H^+ in H_2, He, and N_2*

Energy (keV)	Range (cm)		
	H_2	He	N_2
4.0 E 00	3.87 E-02		
6.0 E 00	4.92 E-02		
8.0 E 00	5.83 E-02		
1.0 E 00	6.75 E-02		
2.0 E 00	1.10 E-01		3.50 E-02
3.0 E 00	1.43 E-01		4.59 E-02
4.0 E 00	1.74 E-01	3.46 E-01	5.58 E-02
6.0 E 00	2.36 E-01	4.61 E-01	7.50 E-02
8.0 E 01	2.97 E-01	5.68 E-01	9.55 E-02
1.0 E 02	3.62 E-01	6.74 E-01	1.17 E-01
2.0 E 02	7.80 E-01	1.29 E 00	2.40 E-01
3.0 E 02	1.37 E-00	2.09 E 00	3.98 E-01
4.0 E 02	2.13 E-00	3.07 E 00	5.93 E-01
6.0 E 02	4.12 E-00	5.53 E 00	1.08 E 00
8.0 E 02	6.72 E-00	8.65 E 00	1.69 E 00
1.0 E 03	9.91 E-00	1.25 E 01	2.49 E 00
2.0 E 03	3.38 E 01	4.04 E 01	7.42 E 00
3.0 E 03	7.03 E 01	8.28 E 01	1.46 E 01
4.0 E 03	1.18 E 02	2.87 E 02	2.39 E 01
6.0 E 03	2.46 E 02	4.83 E 02	4.85 E 01
8.0 E 03	4.17 E 02	5.98 E 02	8.07 E 01
1.0 E 04	6.28 E 02	7.24 E 02	1.20 E 02

*[For target at 760 mm Hg pressure and 15°C temperature].

References:

H^+ + H_2 Exp.: From the review by W. Whaling, Handbuch der Physik, ed. S. Flügge, Springer-Verlag, Berlin 1958, Volume 34, page 193.
C.J. Cook, E. Jones, Jr., and T. Jorgensen, Jr., Phys. Rev. 91, 1417 (1953).

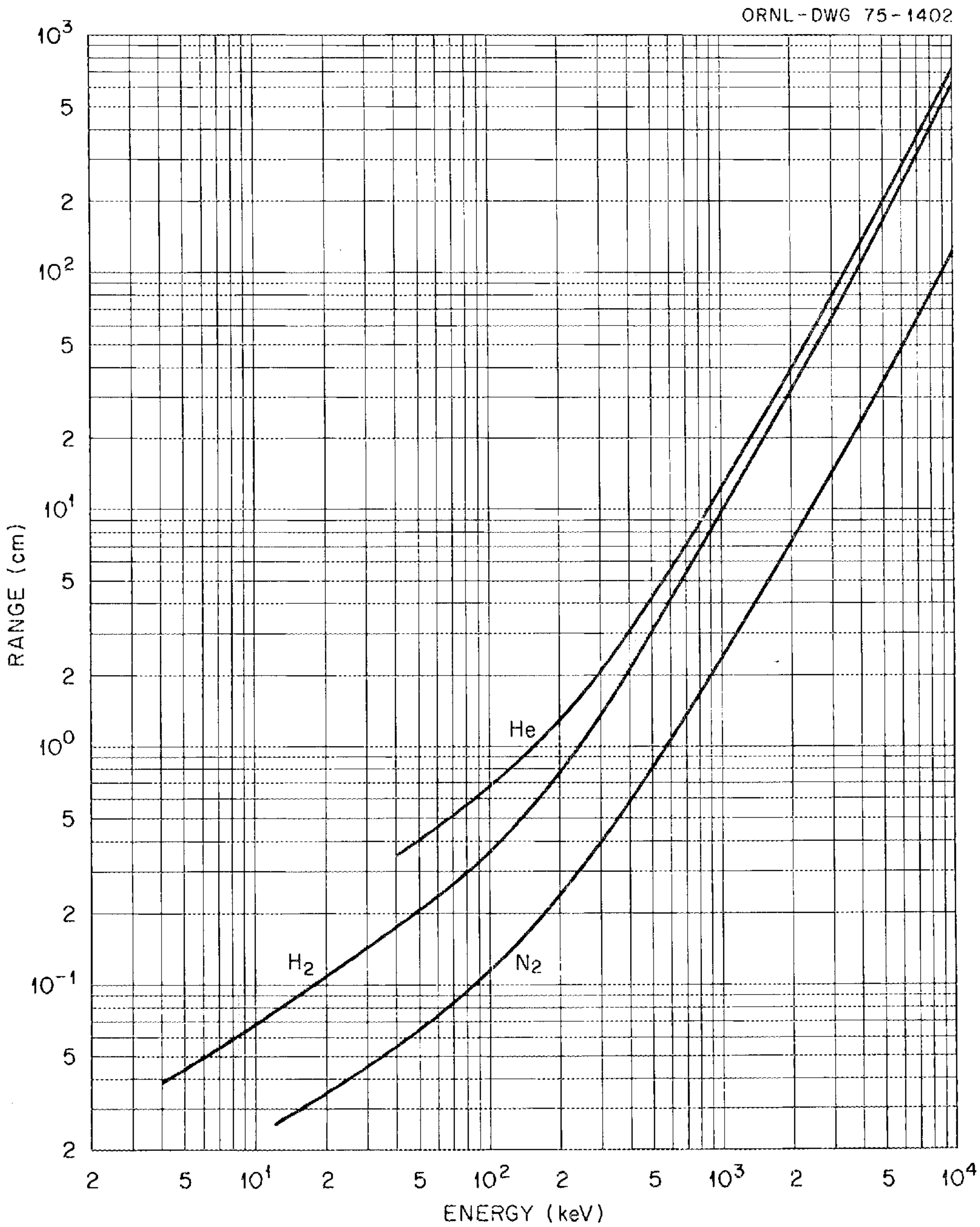
H^+ + (He,N_2) Exp.: From the review by W. Whaling, Handbuch der Physik, ed. S. Flügge, Springer-Verlag, Berlin 1958, Volume 34, page 193.

Notes:

See Notes (3), (5), (9), (10), and (15) at end of chapter.

Accuracy:

Systematic error < ± 2%. Random error < ± 1.5%.


ORNL-DWG 75-1402
RANGE (cm)
ENERGY (keV)
He
H_2
N_2
10^3
5
2
10^2
5
2
10^1
5
2
10^0
5
2
10^{-1}
5
2
2
5
10^1
2
5
10^2
2
5
10^3
2
5
10^4

Range of H^+ in Solid C, Cu, and Au

Energy (keV)	Range (mg/cm^2)		
	C	Cu	Au
2.5 E 00		3.73 E-02	7.60 E-02
3.0 E 00		4.39 E-02	8.90 E-02
4.0 E 00		5.60 E-02	1.12 E-01
6.0 E 00		7.68 E-02	1.51 E-01
8.0 E 00		9.63 E-02	1.83 E-01
1.0 E 01		1.14 E-01	2.10 E-01
2.0 E 01	9.10 E-02	1.90 E-01	3.30 E-01
3.0 E 01	1.15 E-01	2.50 E-01	4.40 E-01
4.0 E 01	1.38 E-01	3.03 E-01	5.50 E-01
6.0 E 01	1.74 E-01	4.00 E-01	7.65 E-01
8.0 E 01	2.09 E-01	4.80 E-01	9.80 E-01
1.0 E 02	2.40 E-01	5.60 E-01	1.19 E 00
2.0 E 02	4.02 E-01	1.00 E 00	2.19 E 00
3.0 E 02	5.75 E-01	1.47 E 00	3.05 E 00
4.0 E 02	9.95 E-01	2.00 E 00	4.02 E 00
6.0 E 02	1.23 E 00	3.20 E 00	6.29 E 00
8.0 E 02	1.81 E 00	4.60 E 00	8.94 E 00
1.0 E 03	2.53 E 00	6.08 E 00	1.19 E 01
2.0 E 03	2.77 E 00	1.63 E 01	3.03 E 01
3.0 E 03	1.54 E 01	3.03 E 01	5.47 E 01
4.0 E 03	2.58 E 01	4.72 E 01	8.41 E 01
6.0 E 03	5.40 E 01	9.10 E 01	1.56 E 02
8.0 E 03	9.20 E 01	1.47 E 02	2.43 E 02
1.0 E 04	1.41 E 02	2.15 E 02	3.45 E 02

References

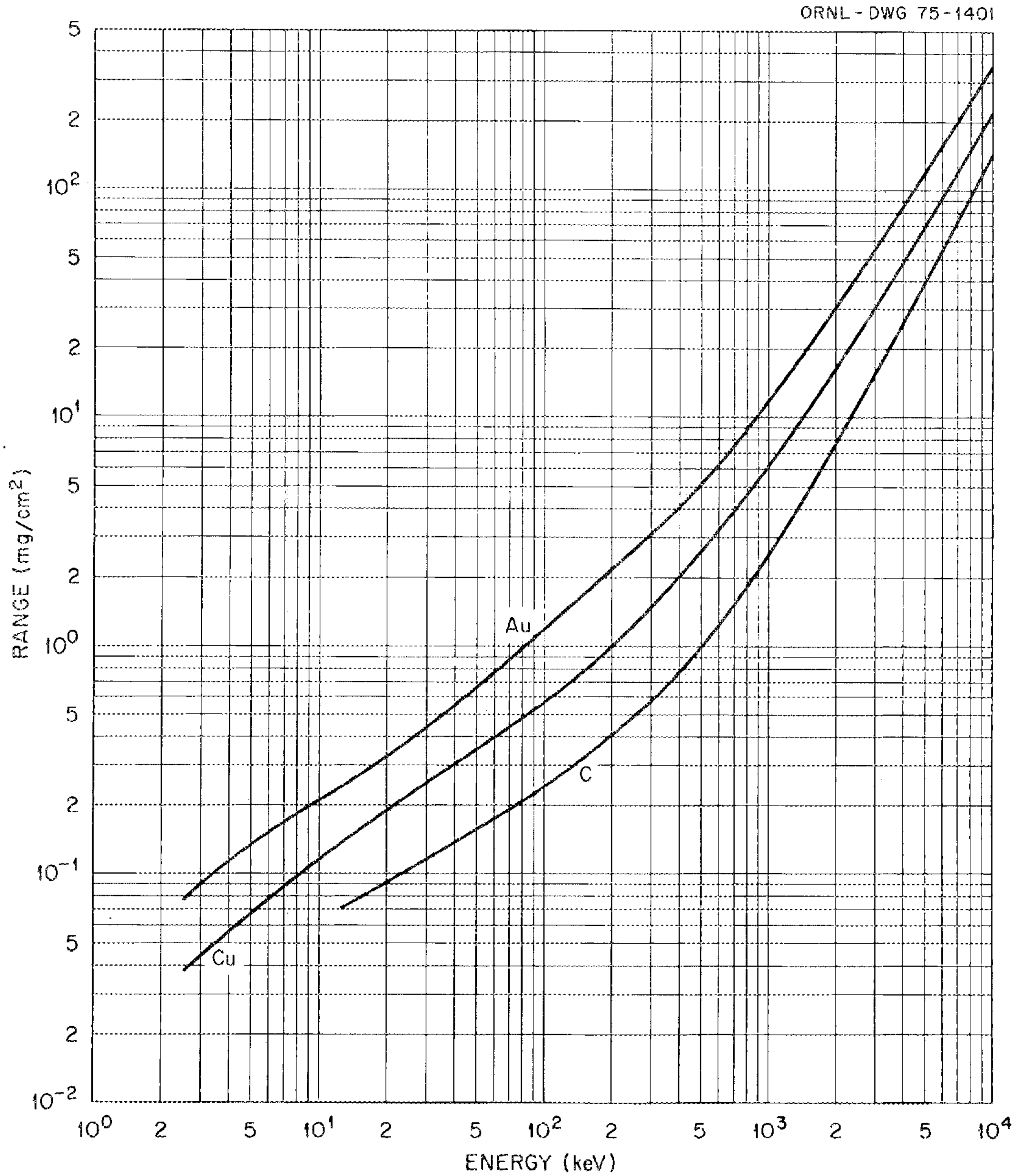
H^+ + C Theoretical: L.C. Northcliffe and R.F. Schilling, Nuclear Data Tables A 7, 233 (1970).

H^+ + (Cu,Au) Theoretical: From the review by W. Whaling, Handbuch der Physik, ed. S. Flügge, Springer-Verlag, Berlin 1958, Volume 34, page 193. Experimental (E < 10 keV) R.L. Hines, Phys. Rev. 132, 701 (1963).

Notes:

See Notes (3), (5), (7), (10), and (14) at end of chapter.

Accuracy: See Note (6) at end of chapter.


ORNL-DWG 75-1401
RANGE (mg/cm^2)
ENERGY (keV)
Au
Cu
C
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
10^{4}
2
5

Ranges of Helium Ions in Gases (H_2, He, N_2)

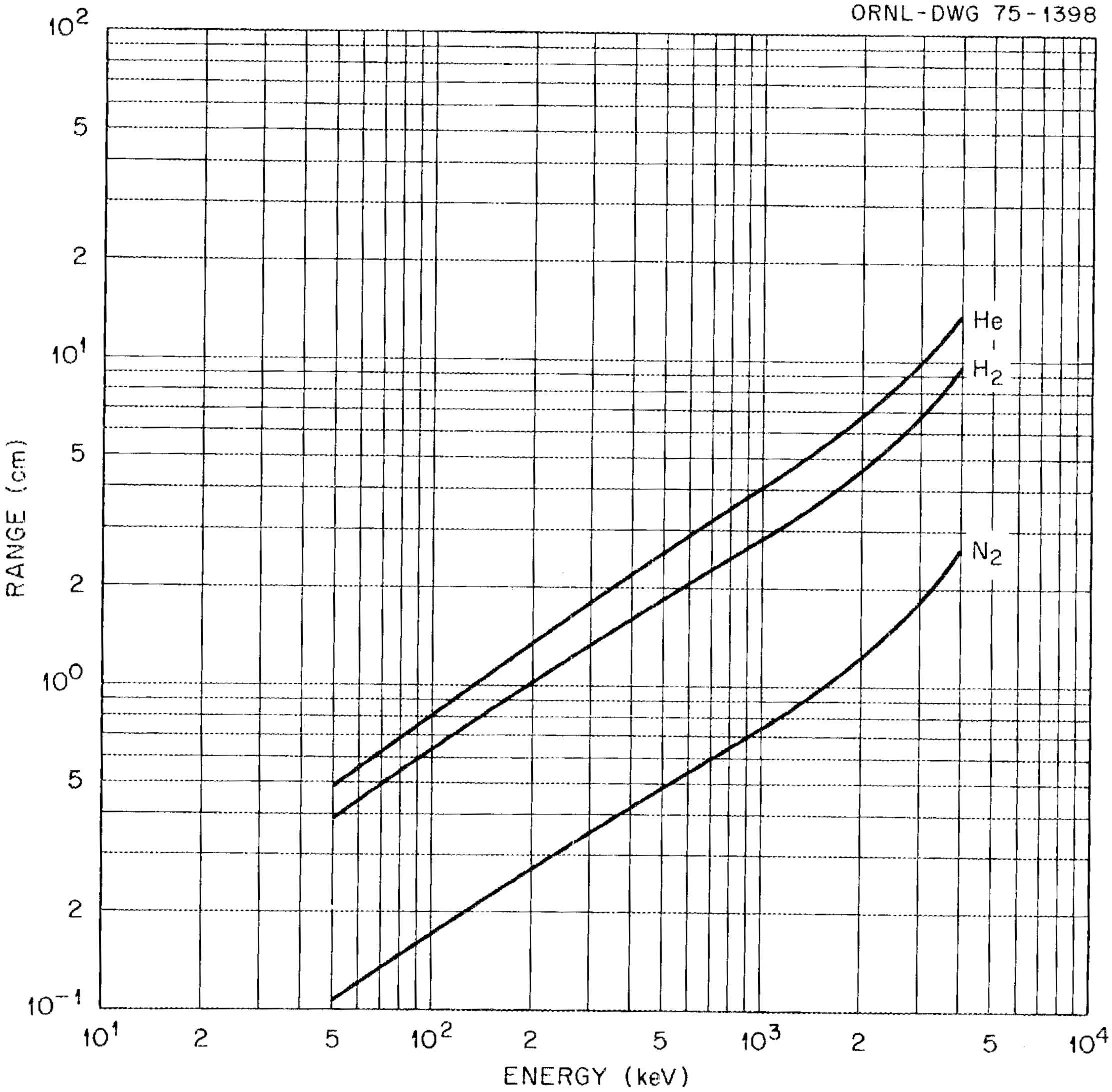
Energy (keV)	Range (cm) [For target at 760 mm Hg Pressure and 15° C temperature]		
	H_2	He	N_2
5.0 E 01	3.82 E-01	4.88 E-01	1.05 E-01
6.0 E 01	4.40 E-01	5.55 E-01	1.20 E-01
8.0 E 01	5.42 E-01	6.85 E-01	1.45 E-01
1.0 E 02	6.34 E-01	7.92 E-01	1.69 E-01
2.0 E 02	1.01 E 00	1.32 E 00	2.68 E-01
3.0 E 02	1.31 E 00	3.79 E 00	3.49 E-01
4.0 E 02	1.60 E 00	2.19 E 00	4.20 E-01
6.0 E 02	2.03 E 00	2.89 E 00	5.40 E-01
8.0 E 02	2.46 E 00	3.48 E 00	6.44 E-01
1.0 E 03	2.82 E 00	4.04 E 00	7.40 E-01
2.0 E 03	4.60 E 00	6.75 E 00	1.23 E 00
3.0 E 03	6.80 E 00	9.80 E 00	1.81 E 00
4.0 E 03	9.61 E 00	1.40 E 01	2.64 E 00

References:

Experimental and Theoretical: From the review by L.C. Northcliffe and R.F. Schilling, Nuclear Data Tables A 7, 233 (1970).

Accuracy:

Not specified.


ORNL-DWG 75-1398
RANGE (cm)
ENERGY (keV)
He
H_2
N_2
10^2
5
2
10^1
5
2
10^0
5
2
10^{-1}
10^1
2
5
10^2
2
5
10^3
2
5
10^4

Ranges of Helium Ions in Solids (C, Cu, Au)

Energy (keV)	Range (mg/cm^2)		
	C	Cu	Au
5.0 E 01	9.90 E-02		7.46 E-01
6.0 E 01	1.11 E-01		8.22 E-01
8.0 E 01	1.35 E-01		9.76 E-01
1.0 E 02	1.55 E-01		1.11 E 00
2.0 E 02	2.35 E-01		1.62 E 00
3.0 E 02	2.99 E-01		2.01 E 00
4.0 E 02	3.56 E-01		2.36 E 00
6.0 E 02	4.59 E-01		2.95 E 00
8.0 E 02	5.59 E-01		3.54 E 00
1.0 E 03	6.58 E-01		4.10 E 00
2.0 E 03	1.22 E 00		7.04 E 00
3.0 E 03	1.90 E 00	5.10 E 00	1.02 E 01
4.0 E 03	2.85 E 00	7.01 E 00	1.42 E 01

References:

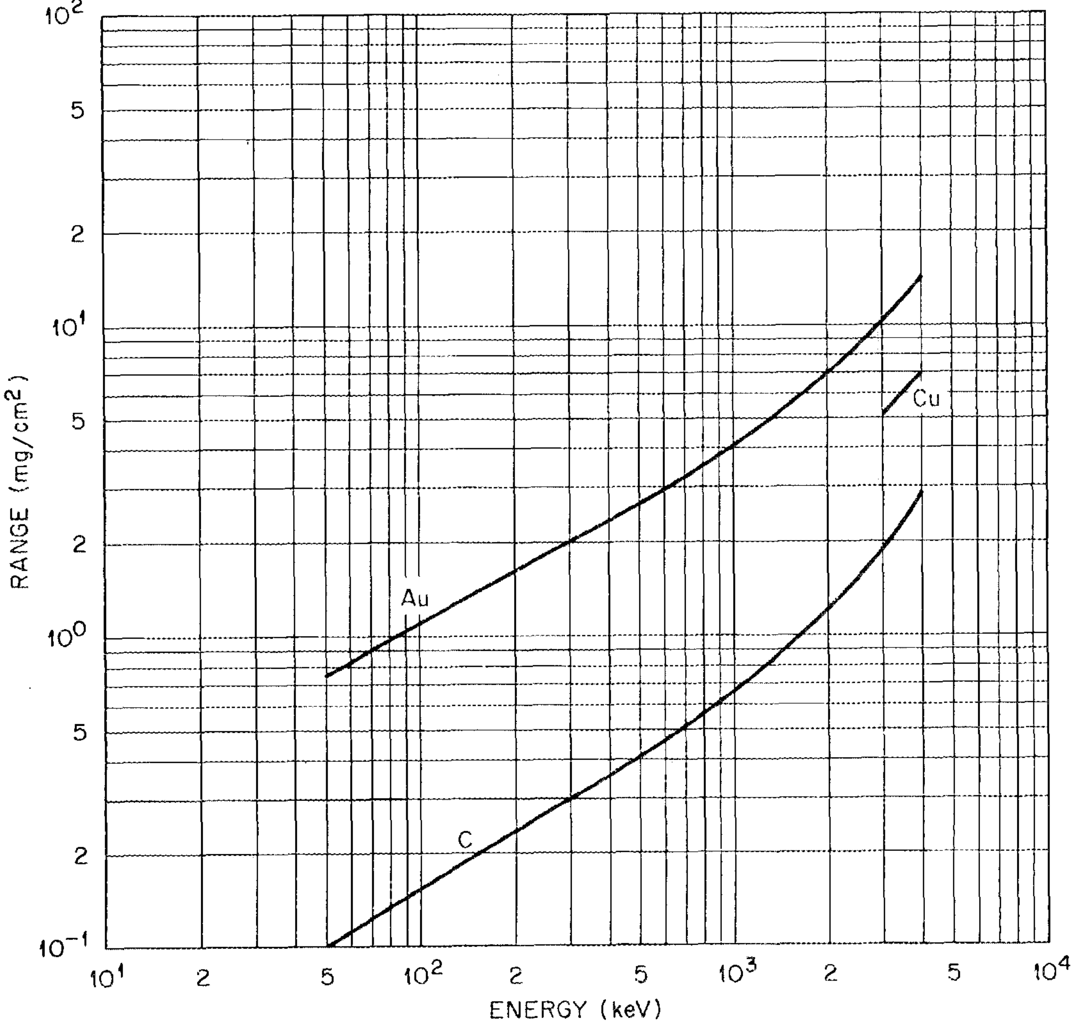
He^+ + C and Au, Experimental and Theoretical: From the review by L.C. Northcliffe, and R.F. Schilling, Nuclear Data Tables A 7, 233 (1970).

He^+ + Cu, Experimental and Theoretical: From the review by W. Whaling, Handbuch der Physik Band 34 (Springer Verlag, Berlin 1958) page 193.

Accuracy:

Unspecified.

ORNL-DWG 75-1397



Conversion Factors for Energy Loss Measurements

$$(10^{-15}\ \mathrm{eV - cm^2}) = A\left(\frac{\mathrm{keV - cm^2}}{\mathrm{mg}}\right) = B\left(\frac{\mathrm{MeV}}{\mathrm{cm}}\right)$$

Material	A	B	ρ(g/cc at °C-760mm)	ρ(g/lit at °C-760mm)
H_2	598	0.0509		0.090
He	150	0.0255		0.178
Be	66.8	124	1.84	
B	55.7	130	3.33 - 2.34	
C	50.1	113	2.25 - 3552	
N_2	43.0	0.0509		1.25
O_2	38.8	0.0509		1.43
Al	22.3	60.3	2.7	
A	15.1	0.02547		1.78
Fe	10.8	84.8	7.6 - 7.9	
Ni	10.3	91.3	8.6 - 8.9	
Cu	9.48	84.7	8.3 - 8.9	
Zn	9.21	65.8	7.1	
Pd	5.64	68.6	12.2	
Ag	5.58	58.6	10.4 - 10.6	
Ta	3.33	55.3	16.6	
W	3.27	63.2	18.6 - 19.1	
Pt	3.09	65.9	21.4	
Au	3.05	59.0	19.3	
H_2O	33.42	0.0764	1.0	
CO_2	13.68	0.0764		1.98

Notes

(1) It is emphasized that the stopping cross section is for the energy loss of protons. Hydrogen atoms may exhibit a much smaller energy loss. Unfortunately there is only a single experiment where the projectile beam is maintained in a purely atomic state throughout, and this experiment is for H_2 [see S. N. Allison et al., Phys. Rev. 127, 792 (1962)]. See also first data set for this section.

(2) The stopping cross sections are for a solid target. There is no direct information as to whether the stopping cross section in a gas would be the same - although this would seem to be a reasonable assumption.

(3) A distinction between "mean range" and "extrapolated ionization range" is made by W. Whaling [Handbuch der Physik, ed. S. Flügge, Springer-Verlag, Berlin 1958, Volume 34, page 193]. In general the difference is small, and the distinction has not been observed here.

(4) These data are theoretical and have not yet been confirmed directly by experiment. They are however in good agreement with experimental measurements for H^+ and H in H_2 when such measurements are divided by two [see S. K. Allison et al., Phys. Rev. 127, 792 (1962)].

(5) An extensive tabulation of semi-empirical data for various projectiles and targets is to be found in the work of L. C. Northcliffe and R. F. Schilling, Nuclear Data Tables A 7, 233 (1970). This also provides prescriptions for interpolation to any media.

(6) These data are theoretical and have not yet been confirmed directly by experiment at these energies.

(7) Extensive tabulations of theoretical range-energy relations for impact energies up to 10^5 MeV are to be found in the work of R. M. Sternheimer, Phys. Rev. 115, 137 (1959).

(8) The work of Hines quoted here is actually a measurement for D_2^+ impact. Following Hines we have derived an equivalent value for H^+ by assuming D_2^+ behaves as two isolated D^+ ions of equal energy, and the range is twice that for protons of equal velocity.

(9) The references given also contain data for many other gases.

(10) Deuterons behave the same as protons of equal velocity.

(11) Cross sections for higher energies may be obtained by the formula: $E = A/E[\ell n(E/2) + B]10^{-15}$. E is energy in MeV; Z is target atomic number. The constants A and B for carbon are as follows: A = 1.44, B = 5.14.

(12) Cross sections for higher energies are the same as in Note (11) with: $A = 6.95$, $B = 5.21$ for Cu; $A = 18.9$; $B = 5.22$ for Au.

(13) The references given contain data for many other metals.

(14) At low energies the range R is expected, on theoretical grounds, to vary with impact energy E approximately as $R = KE^{1/2}$. This may be used to extrapolate the data given here to lower energies.

(15) At the lowest energies of this table, the range R and energy E(keV) are related by $R = KE^{n}$. Data may be extrapolated down to lower energies using: $K = 0.0147$, $n = 0.67$ for H_2; $K = 0.00439$, $n = 0.71$ for N_2.

A.8 Positive-Negative Ion Neutralization Cross Section

Cross Section for the Two-Body Recombination of H^+ and H^- Ions

Barycentric Energy (eV)	Recombination Cross Section (cm^2)
	$H^+ + H^- \rightarrow H + H$
1.0 E-01	2.84 E-13
2.0 E-01	1.71 E-13
3.0 E-01	1.25 E-13
5.0 E-01	8.61 E-14
1.0 E 00	5.18 E-14
2.0 E 00	3.45 E-14
3.0 E 00	2.70 E-14
5.0 E 00	2.00 E-14
1.0 E 01	1.43 E-14
2.0 E 01	1.36 E-14
3.0 E 01	1.50 E-14
5.0 E 01	1.77 E-14
1.0 E 02	2.32 E-14
2.0 E 02	1.97 E-14
3.0 E 02	1.50 E-14
5.0 E 02	1.27 E-14
7.0 E 02	1.36 E-14
1.0 E 03	1.24 E-14
2.0 E 03	7.26 E-15
3.0 E 03	5.40 E-15
5.0 E 03	3.38 E-15

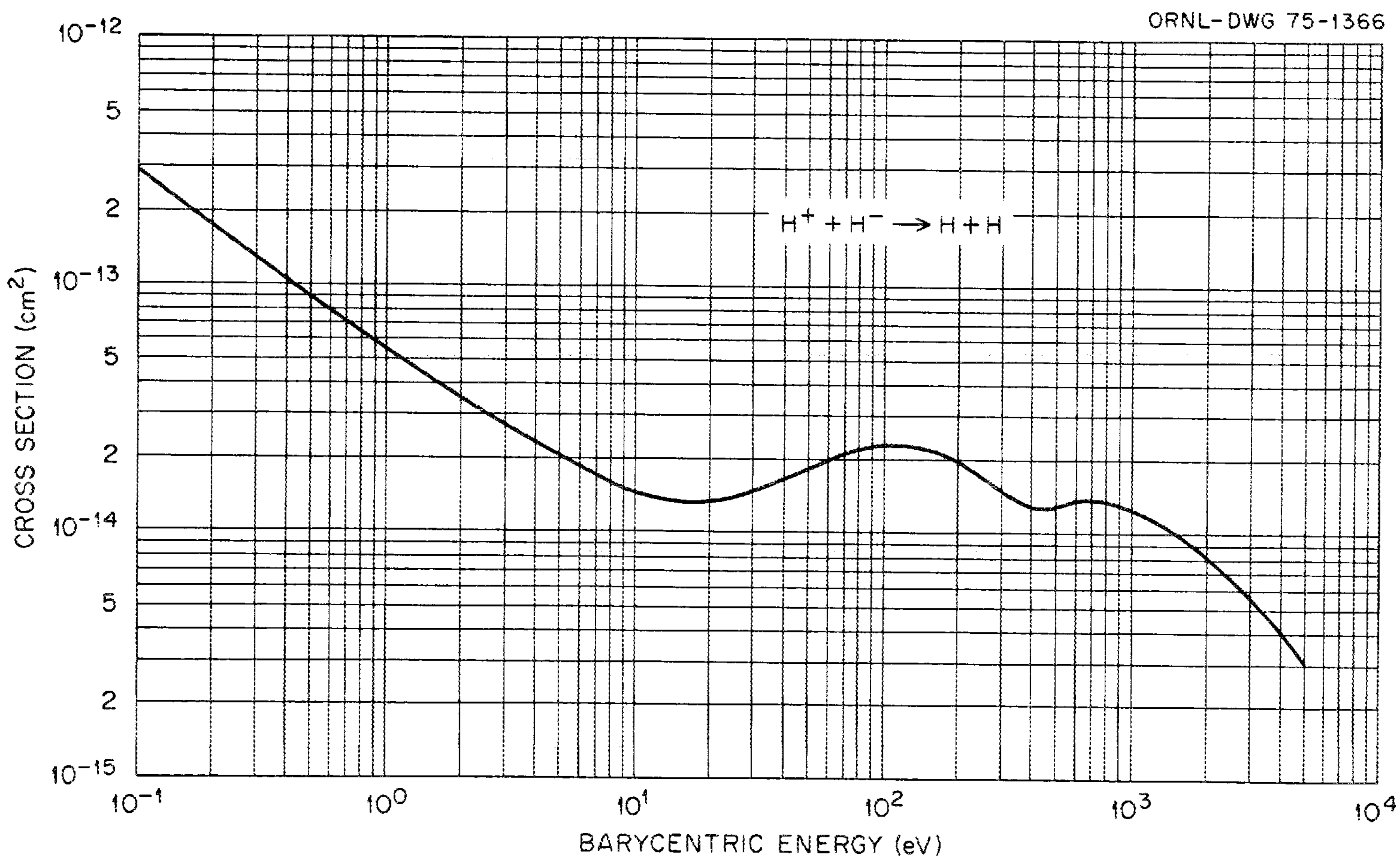
References:

J. Moseley, W. Aberth, and J.R. Peterson, Phys. Rev. Letts. 24, 435 (1970).

R.D. Rundel, R.L. Aitken, and M.F.A. Harrison, J. Phys. B 2, 954 (1969).

Accuracy:

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


ORNL-DWG 75-1366
$H^+ + H^- \rightarrow H + H$
CROSS SECTION (cm^2)
10^{-12}
5
2
10^{-13}
5
2
10^{-14}
5
2
10^{-15}
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
10^{4}
BARYCENTRIC ENERGY (eV)

Cross Sections for the Two-Body Recombination of He^+ with H^- Ions and of He^+ with D^- Ions

Barycentric Energy (eV)	Recombination Cross Section (cm^2)	
	$He^+ + D^-$	$He^+ + H^-$
1.0 E 00	1.00 E-13	
2.0 E 00	7.36 E-14	
3.0 E 00	6.14 E-14	
5.0 E 00	5.09 E-14	
1.0 E 01	3.88 E-14	
2.0 E 01	2.98 E-14	
3.0 E 01	2.59 E-14	
5.0 E 01	2.18 E-14	
1.0 E 02	1.78 E-14	
2.0 E 02	1.53 E-14	
3.0 E 02	1.42 E-14	1.44 E-14
5.0 E 02	1.25 E-14	1.23 E-14
9.0 E 02		1.09 E-14
1.5 E 03		9.06 E-15
2.0 E 03		9.27 E-15
4.0 E 03		4.42 E-15
6.0 E 03		1.93 E-15

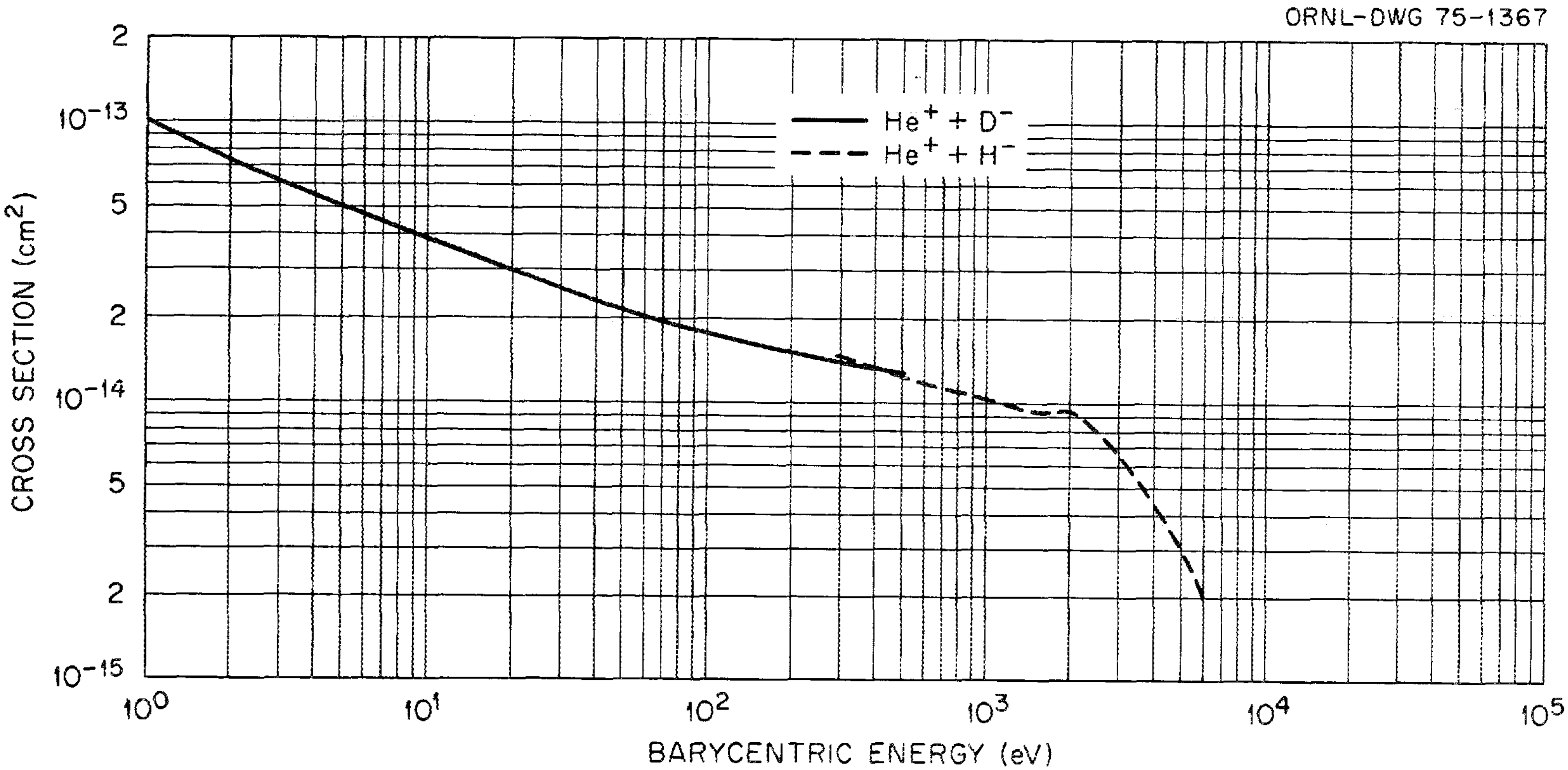
References:

$He^+ + H^-$: T.D. Gailey and M.F.A. Harrison, J. Phys. B 3, 1098 (1970).

$He^+ + D^-$: R.E. Olson, J.R. Peterson, and J.T. Moseley, J. Chem. Phys. 53, 3391 (1970).

Accuracy:

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


ORNL-DWG 75-1367
He$^+$ + D$^-$
He$^+$ + H$^-$
CROSS SECTION (cm^2)
2
10^{-13}
5
2
10^{-14}
5
2
10^{-15}
10^0
10^1
10^2
10^3
10^4
10^5
BARYCENTRIC ENERGY (eV)

Cross Sections for the Two-Body Recombination of N^+ with O^- Ions, of O^+ with O^- Ions, and of H_2^+ with D^- Ions

Barycentric Energy (eV)	Recombination Cross Section (cm^2)		
	$N^+ + O^-$	$O^+ + O^-$	$H_2^+ + D^-$
1.0 E-01		9.38 E-13	7.21 E-13
1.2 E-01	8.45 E-13	8.00 E-13	6.00 E-13
2.0 E-01	5.50 E-13	4.92 E-13	3.72 E-13
3.0 E-01	4.00 E-13	3.51 E-13	2.67 E-13
5.0 E-01	2.74 E-13	2.32 E-13	1.86 E-13
1.0 E 00	1.83 E-13	1.42 E-13	1.16 E-13
2.0 E 00	1.21 E-13	1.00 E-13	7.41 E-14
3.0 E 00	9.73 E-14	8.36 E-14	5.75 E-14
5.0 E 00	7.41 E-14	7.02 E-14	4.51 E-14
5.6 E 00	7.23 E-14	6.68 E-14	4.21 E-14
1.0 E 01	5.62 E-14	5.88 E-14	4.39 E-14
1.5 E 01	4.81 E-14	5.46 E-14	3.60 E-14
2.0 E 01		5.25 E-14	2.77 E-14
3.0 E 01			3.10 E-14
4.0 E 01			2.94 E-14
5.0 E 01			2.66 E-14
6.0 E 01			2.53 E-14

References:

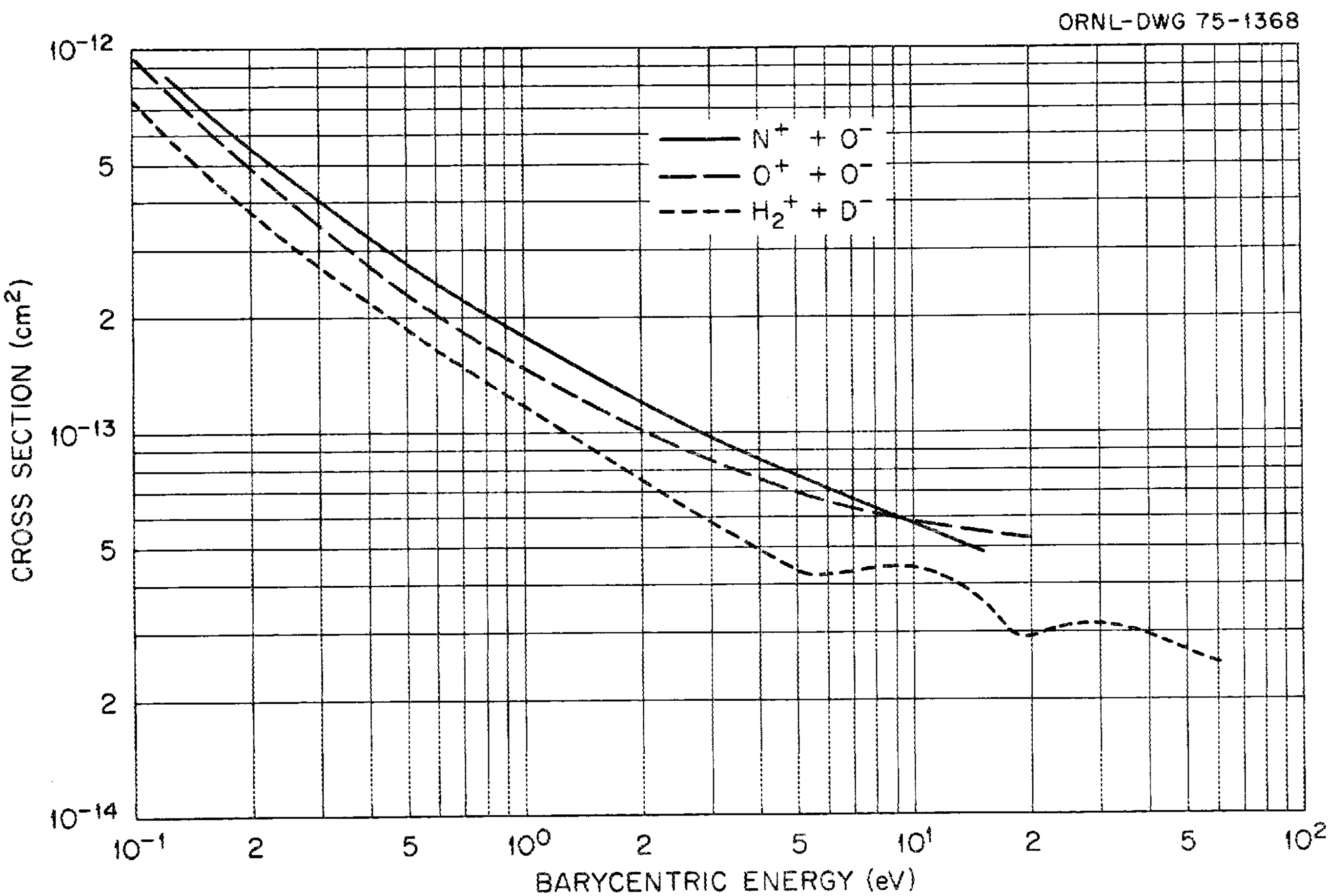
$N^+ + O^-$: W. Aberth and J.R. Peterson, Phys. Rev. A 1, 158 (1970).

$O^+ + O^-$: J.T. Moseley, W. Aberth, and J.R. Peterson, J. Geophys. Res. 77, 255 (1972).

$H_2^+ + D^-$: W. Aberth, J.T. Moseley, and J.R. Peterson, Two Body Ion-Ion Neutralization Cross Sections, AFCRL Report No. 71-0481, Air Force Cambridge Research Laboratories, Bedford, Mass. (1971); J.T. Moseley, R.E. Olson, and J.R. Peterson, Case Studies in Atomic Physics 5, 1 (1975).

Accuracy:

The total error is believed not to exceed $\pm$ 35%


ORNL-DWG 75-1368
$N^+ + O^-$
$O^+ + O^-$
$H_2^+ + D^-$
CROSS SECTION (cm^2)
10^{-12}
5
2
10^{-13}
5
2
10^{-14}
10^{-1}
2
5
10^0
2
5
10^1
2
5
10^2
BARYCENTRIC ENERGY (eV)

Cross Sections for the Two-Body Recombination of

O_2^+ with O_2^- Ions and of N_2^+ with O_2^- Ions

Barycentric Energy (eV)	Recombination Cross Section (cm^2)	
	$N_2^+ + O_2^-$	$O_2^+ + O_2^-$
1.5 E-01	1.20 E-12	2.42 E-12
2.0 E-01	1.00 E-12	1.91 E-12
3.0 E-01	7.20 E-13	1.48 E-12
4.0 E-01	6.12 E-13	1.25 E-12
6.0 E-01	4.88 E-13	1.03 E-12
1.0 E 00	3.57 E-13	7.48 E-13
2.0 E 00	2.21 E-13	3.87 E-13
3.0 E 00	1.64 E-13	2.29 E-13
4.0 E 00	1.27 E-13	1.73 E-13
4.5 E 00	1.13 E-13	1.80 E-13
5.0 E 00	1.20 E-13	1.95 E-13
6.0 E 00	1.42 E-13	1.55 E-13
7.0 E 00	1.59 E-13	1.35 E-13
8.0 E 00	1.52 E-13	1.29 E-13
9.0 E 00	1.42 E-13	1.07 E-13
1.0 E 01	1.27 E-13	1.00 E-13
1.2 E 01	9.12 E-14	1.09 E-13
1.4 E 01		9.00 E-14
1.5 E 01	1.18 E-13	
2.0 E 01	6.73 E-14	
2.5 E 01	7.30 E-14	
2.8 E 01	5.53 E-14	
3.2 E 01	6.22 E-14	
4.4 E 01	4.98 E-14	
5.0 E 01	5.98 E-14	
7.0 E 01	3.66 E-14	
8.0 E 01	4.33 E-14	
9.0 E 01	4.10 E-14	

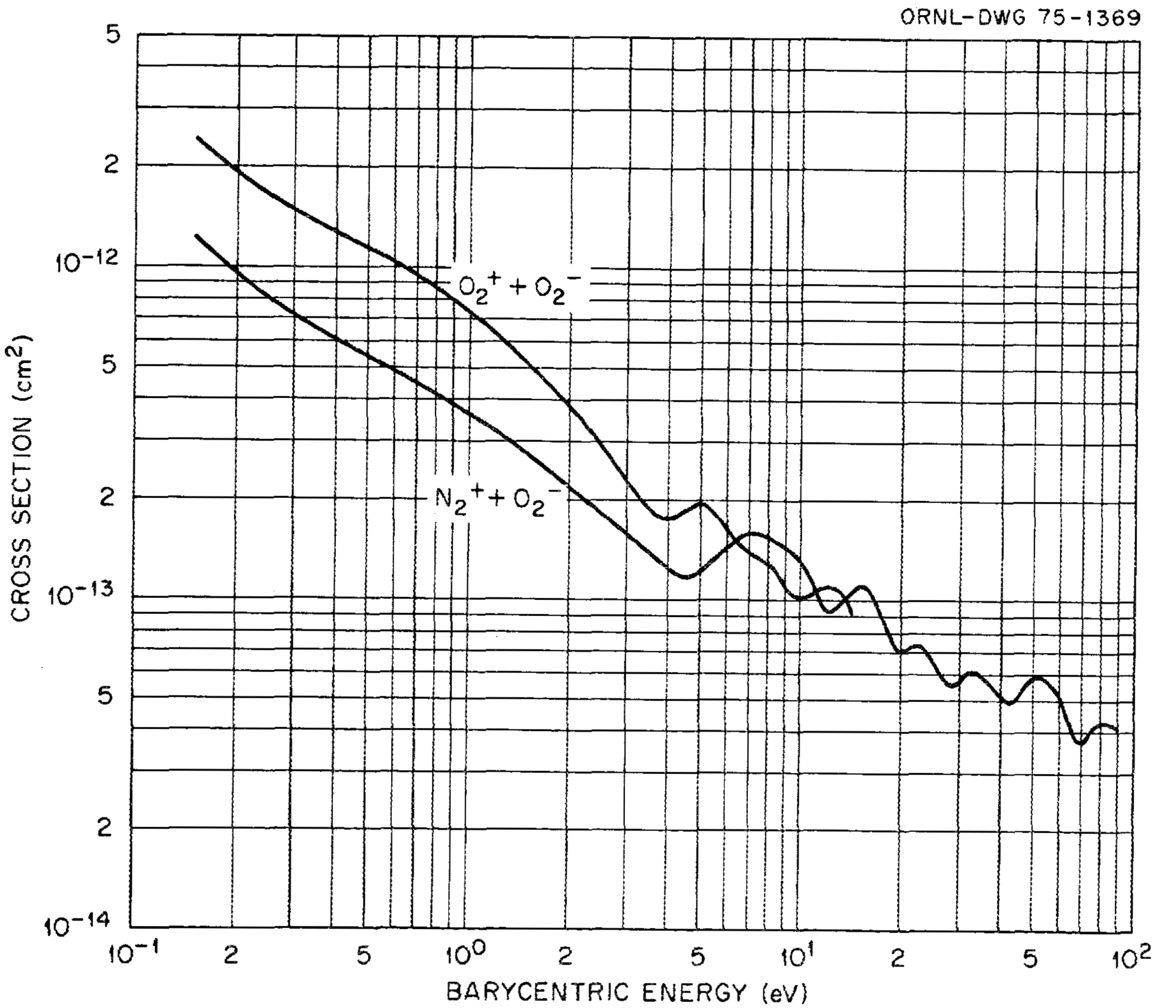
References:

$O_2^+ + O_2^-$: J.R. Peterson, W. Aberth, J.T. Moseley, and J.R. Sheridan, Phys. Rev. A 3, 1651 (1971).

$N_2^+ + O_2^-$: W. Aberth and J.R. Peterson, Phys. Rev. A 1, 158 (1970).

Accuracy:

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


ORNL-DWG 75-1369
CROSS SECTION (cm²)
5
2
10⁻¹²
5
2
10⁻¹³
5
2
10⁻¹⁴
10⁻¹
2
5
10⁰
2
5
10¹
2
5
10²
BARYCENTRIC ENERGY (eV)
O₂⁺ + O₂⁻
N₂⁺ + O₂⁻

Cross Sections for the Two-Body Recombination of

O_2^+ with O^- Ions and of NO^+ with O^- Ions

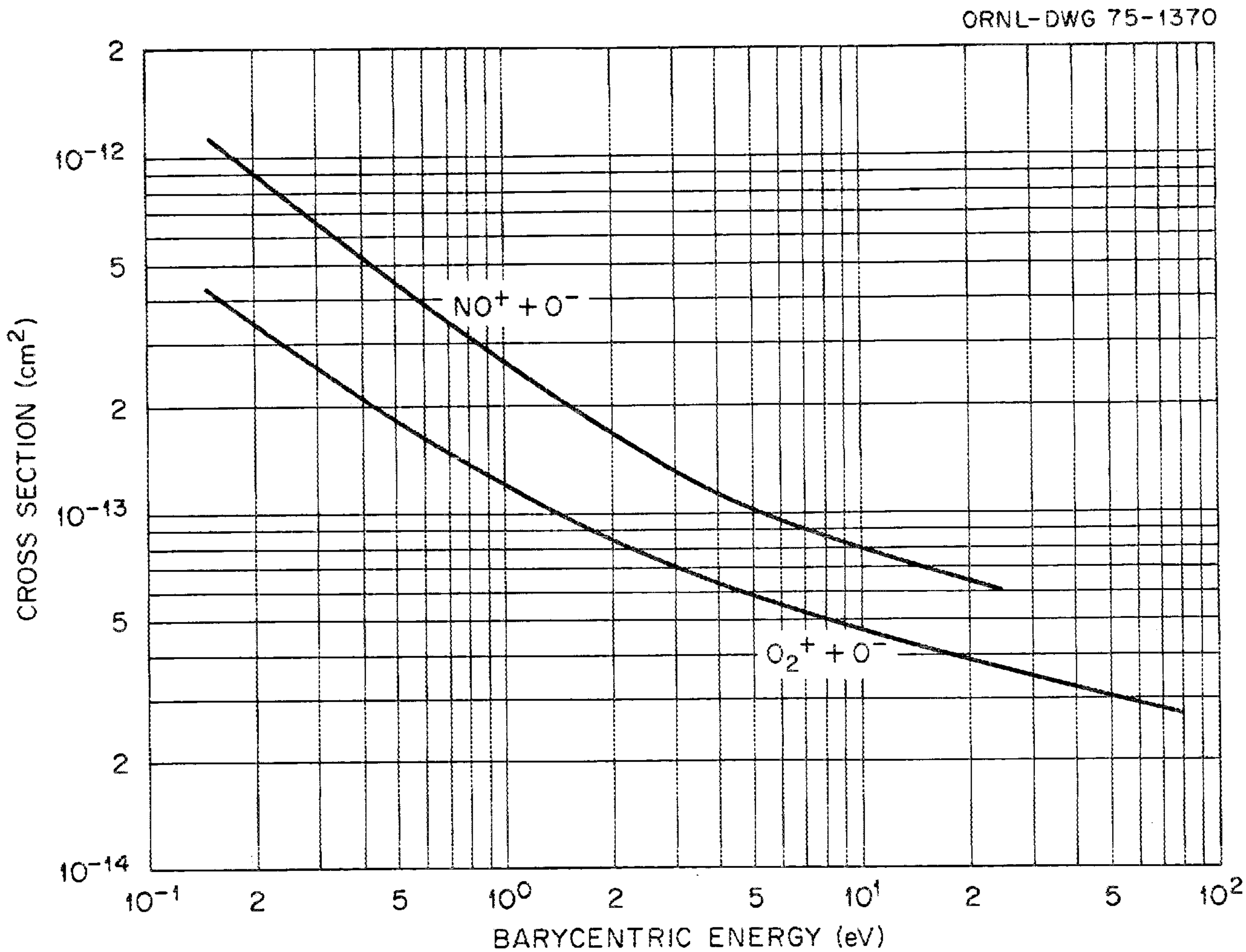
Barycentric Energy (eV)	Recombination Cross Section (cm^2)	
	$NO^+ + O^-$	$O_2^+ + O^-$
1.5 E-01	1.12 E-12	4.17 E-13
2.0 E-01	8.97 E-13	3.44 E-13
3.0 E-01	6.41 E-13	2.53 E-13
5.0 E-01	4.44 E-13	1.83 E-13
1.0 E 00	2.71 E-13	1.19 E-13
2.0 E 00	1.66 E-13	8.53 E-14
5.0 E 00	1.00 E-13	5.88 E-14
1.0 E 01	7.94 E-14	4.74 E-14
2.0 E 01	6.30 E-14	3.80 E-14
2.5 E 01	5.93 E-14	3.37 E-14
5.0 E 01		3.11 E-14
8.0 E 01		2.67 E-14

Reference:

J.T. Moseley, W. Aberth, and J.R. Peterson, J. Geophys. Res. 77, 255 (1972).

Accuracy:

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


ORNL-DWG 75-1370
CROSS SECTION (cm^2)
BARYCENTRIC ENERGY (eV)
$NO^+ + O^-$
$O_2^+ + O^-$
2
10^{-12}
5
2
10^{-13}
5
2
10^{-14}
10^{-1}
2
5
10^0
2
5
10^1
2
5
10^2

A.9 Ion-Molecule and Atom-Molecule Interchange Reactions

Cross Section for the Ion-Molecule Reaction $H_2^+ + H_2 \rightarrow H_3^+ + H$

Interaction Energy (eV)	Cross Section (cm^2)
1.0 E-01	3.40 E-15
5.0 E-01	2.03 E-15
1.0 E 00	1.22 E-15
1.5 E 00	7.82 E-16
2.0 E 00	5.30 E-16
2.5 E 00	3.65 E-16
3.0 E 00	2.58 E-16
3.5 E 00	1.88 E-16
4.0 E 00	1.42 E-16
4.5 E 00	1.10 E-16
5.0 E 00	8.80 E-17
5.5 E 00	7.20 E-17
6.0 E 00	5.95 E-17

Reference:

R.H. Neynaber and S.M. Trujillo, Phys. Rev. 167, 63 (1968).

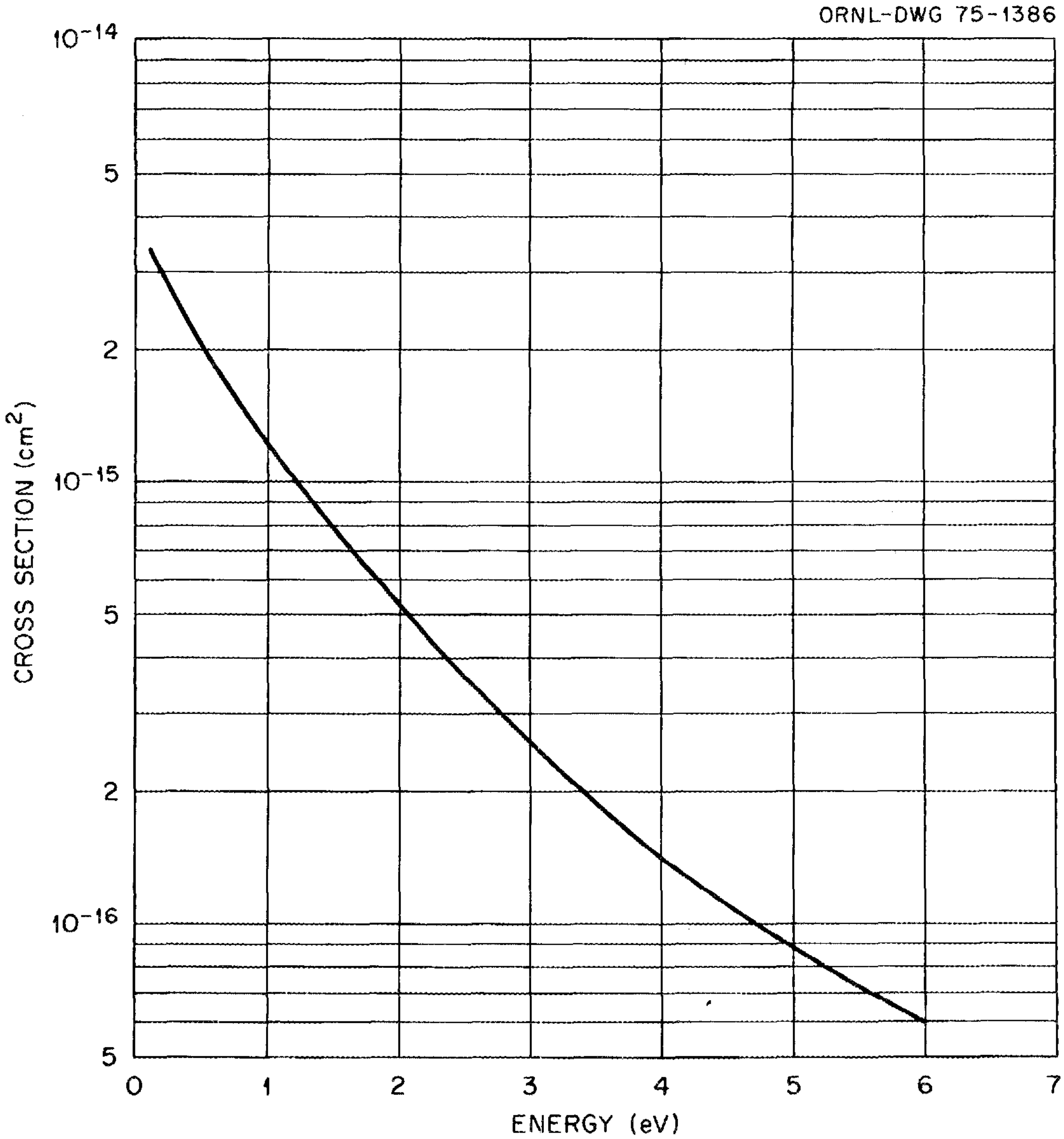
A.B. Lees and P.K. Rol, J. Chem. Phys. 61, 4444 (1974).

Accuracy:

The total error is believed not to exceed ± 40%.

Note:

The states of the reactants are unknown.


ORNL-DWG 75-1386
10^{-14}
5
2
10^{-15}
5
2
10^{-16}
5
CROSS SECTION (cm^2)
0
1
2
3
4
5
6
7
ENERGY (eV)

Cross Sections for the Production of D^+, HD^+, and D_2^+ by Proton Impact on D_2

Energy (eV)	Cross Section (cm^2)		
	$H^+ + D_2 \rightarrow D^+ + (HD)$	$H^+ + D_2 \rightarrow HD^+ + (D)$	$H^+ + D_2 \rightarrow D_2^+ + (H)$
3.5 E-01	1.16 E-15		
5.0 E-01	7.70 E-16		
7.0 E-01	5.00 E-16		
1.0 E 00	3.10 E-16		
1.5 E 00	1.65 E-16		
1.7 E 00	1.36 E-16		2.00 E-19
2.0 E 00	1.08 E-16	2.50 E-19	7.00 E-19
3.0 E 00	5.50 E-17	1.50 E-17	1.05 E-17
4.0 E 00	3.35 E-17	2.40 E-17	2.90 E-17
5.0 E 00	2.35 E-17	2.45 E-17	5.10 E-17
7.0 E 00	1.55 E-17	1.35 E-17	6.50 E-17
9.0 E 00	1.25 E-17	5.20 E-18	3.15 E-17
1.5 E 01	9.25 E-18	5.35 E-19	1.65 E-17
2.0 E 01	8.10 E-18	3.45 E-19	1.33 E-17
3.0 E 01	6.45 E-18	2.63 E-19	1.00 E-17
4.0 E 01	5.10 E-18	2.71 E-19	8.30 E-18
6.0 E 01	3.45 E-18	2.06 E-19	6.50 E-18
8.0 E 01	2.43 E-18	1.90 E-19	5.50 E-18
1.0 E 02	1.90 E-18	1.80 E-19	4.85 E-18

Reference:

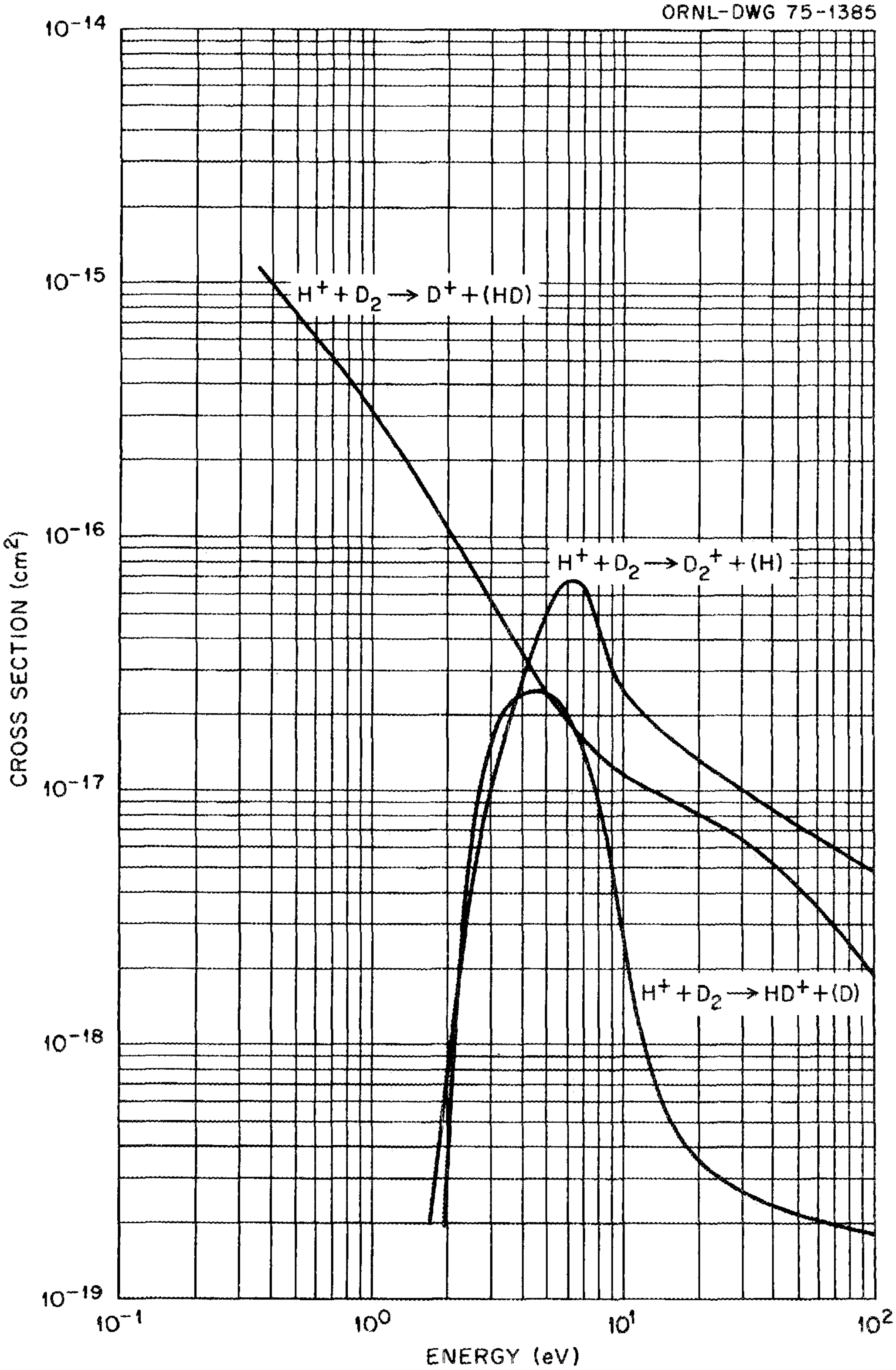
W.B. Maier, J. Chem. Phys. 54, 2732 (1971).

Accuracy:

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

Note:

At the higher energies, the undetected products may differ from the neutral products in parentheses.


ORNL-DWG 75-1385
CROSS SECTION (cm²)
ENERGY (eV)
H⁺ + D₂ → D⁺ + (HD)
H⁺ + D₂ → D₂⁺ + (H)
H⁺ + D₂ → HD⁺ + (D)
10⁻¹⁴
10⁻¹⁵
10⁻¹⁶
10⁻¹⁷
10⁻¹⁸
10⁻¹⁹
10⁻¹
10⁰
10¹
10²

Rate Coefficients, k, of Thermal Energy Ion-Molecule Reactions at Room Temperature

Reaction	k	Uncertainty	Reference
$H_2^+ + H_2 \rightarrow H_3^+ + H$	1.95×10^{-9} cm^3/sec	± 20%	M.T. Bowers, D.D. Elleman, & J. King, J. Chem. Phys. 50, 4787 (1969).
$HD^+ + HD \rightarrow H_2D^+ + D$	0.75×10^{-9} cm^3/sec	± 20%	M.T. Bowers, D.D. Elleman, & J. King, J. Chem. Phys. 50, 4787 (1969).
$HD^+ + HD \rightarrow HD_2^+ + H$	1.05×10^{-9} cm^3/sec	± 20%	M.T. Bowers, D.D. Elleman, & J. King, J. Chem. Phys. 50, 4787 (1969).
$D_2^+ + D_2 \rightarrow D_3^+ + D$	1.6×10^{-9} cm^3/sec	± 20%	M.T. Bowers, D.D. Elleman, & J. King, J. Chem. Phys. 50, 4787 (1969).
$H_3^+ + He \rightarrow$ products	$< 3.0 \times 10^{-12}$ cm^3/sec	V.	V. Aquilanti, A. Galli, A. Giardini-Guidoni, & G.G. Volpi, J. Chem. Phys. 43, 1969 (1965).
$He^+ + H_2 \rightarrow$ products	1.1×10^{-13} cm^3/sec	± 10%	R. Johnsen and M.A. Biondi, J. Chem. Phys. 61, 2112 (1974).
$He^+ + D_2 \rightarrow$ products	5×10^{-14} cm^3/sec	± 20%	
$He_2^+ + H_2 \rightarrow$ products	5.3×10^{-10} cm^3/sec	± 30%	N.G. Adams, D.K. Bohme, & E.E. Ferguson, J. Chem. Phys. 52, 5101 (1970).
$H^- + H \rightarrow H_2 + e$	1.8×10^{-9} cm^3/sec	Factor of 2	F.C. Fehsenfeld, C.J. Howard, & E.E. Ferguson, J. Chem. Phys. 58, 5841 (1973).
$He^+ + 2He \rightarrow He_2^+ + He$	10.2×10^{-32} cm^6/sec	± 10%	E.C. Beaty & P.L. Patterson, Phys. Rev. 137, A-364 (1965).
$H^+ + 2H_2 \rightarrow H_3^+ + H_2$	3.05×10^{-29} cm^6/sec	± 5%	E. Graham, D.R. James, W.C. Keever, I.R. Gatland, D.L. Albritton, & E.W. McDaniel, J. Chem. Phys. 59, 4648 (1973).
$D^+ + 2D_2 \rightarrow D_3^+ + D_2$	3.05×10^{-29} cm^6/sec	± 5%	E. Graham, D.R. James, W.C. Keever, I.R. Gatland, D.L. Albritton, & E.W. McDaniel, J. Chem. Phys. 59, 4648 (1973).
$HeH^+ + H_2 \rightarrow H_3^+ + He$	1.4×10^{-9} cm^3/sec	± 15%	K.R. Ryan & I.G. Graham, J. Chem. Phys. 59, 4260 (1973).

Rate Coefficients, k, of Thermal Energy Neutral-Neutral Reactions

Reaction	Temp. (°K)	k	Uncertainty	Reference
$H_2 + D \rightarrow HD + H$	299°K	$1.75 \pm 0.06 \times 10^8$ cm^3/mole-sec	± 5%	A.A. Westenberg & N. De Haas, J. Chem. Phys. 47, 1393 (1967).
$H + D_2 \rightarrow HD + D$	299°K	$1.56 \pm 0.12 \times 10^7$ cm^3/mole-sec	± 8%	A.A. Westenberg & N. De Haas, J. Chem. Phys. 47, 1393 (1967).
$H + H_2 \rightarrow H_2 + H$	299°K	$1.6 \pm 0.3 \times 10^8$ cm^3/mole-sec	± 20%	K.A. Quickert & D.J. Le Roy, J. Chem. Phys. 53, 1325 (1970).
$D + D_2 \rightarrow D_2 + D$	358.1°K	$2.7 \pm 0.8 \times 10^8$ cm^3/mole-sec	± 30%	D.J. Le Roy, B.A. Ridley, and K.A. Quickert, Discussions Faraday Soc. 44, 92 (1967).
$H + H + H_2 \rightarrow H_2 + H_2$	298°K	$2.94 \pm 0.15 \times 10^{15}$ cm^6/$mole^2$-sec	± 10%	D.W. Trainor, D.O. Ham, & F. Kaufman, J. Chem. Phys. 58, 4599 (1973).
$H + H + He \rightarrow H_2 + He$	298°K	$2.54 \pm 0.15 \times 10^{15}$ cm^6/$mole^2$-sec	± 10%	D.W. Trainor, D.O. Ham, & F. Kaufman, J. Chem. Phys. 58, 4599 (1973).
$D + D + D_2 \rightarrow D_2 + D_2$	298°K	$2.21 \pm 0.11 \times 10^{15}$ cm^6/$mole^2$-sec	± 10%	D.W. Trainor, D.O. Ham, & F. Kaufman, J. Chem. Phys. 58, 4599 (1973).

B. Photon Collisions

B.1 Photoabsorption and Photoionization

Photoabsorption and Photoionization in Atomic Hydrogen

$h\nu + H$

Photon Wavelength (Å)	Photon Energy (keV)	Cross Section (cm^2) Absorption	Ionization
911.753 (Threshold)	1.36 E-02	Same as Ionization.	6.31 E-18
900	1.38 E-02	See Note (1)	6.12 E-18
800	1.55 E-02		4.46 E-18
700	1.77 E-02		3.10 E-18
600	2.07 E-02		2.02 E-18
500	2.48 E-02		1.22 E-18
400	3.10 E-02		6.43 E-19
300	4.13 E-02		2.78 E-19
200	6.20 E-02		8.20 E-20
100	1.24 E-01		9.92 E-21
80	1.55 E-01		4.90 E-21
60	2.07 E-01		1.97 E-21
50	2.48 E-01		1.10 E-21
40	3.10 E-02		5.39 E-22
30	4.13 E-02		2.10 E-22
20	6.20 E-02		5.56 E-23
10	1.24 E-00		5.55 E-24

Reference:

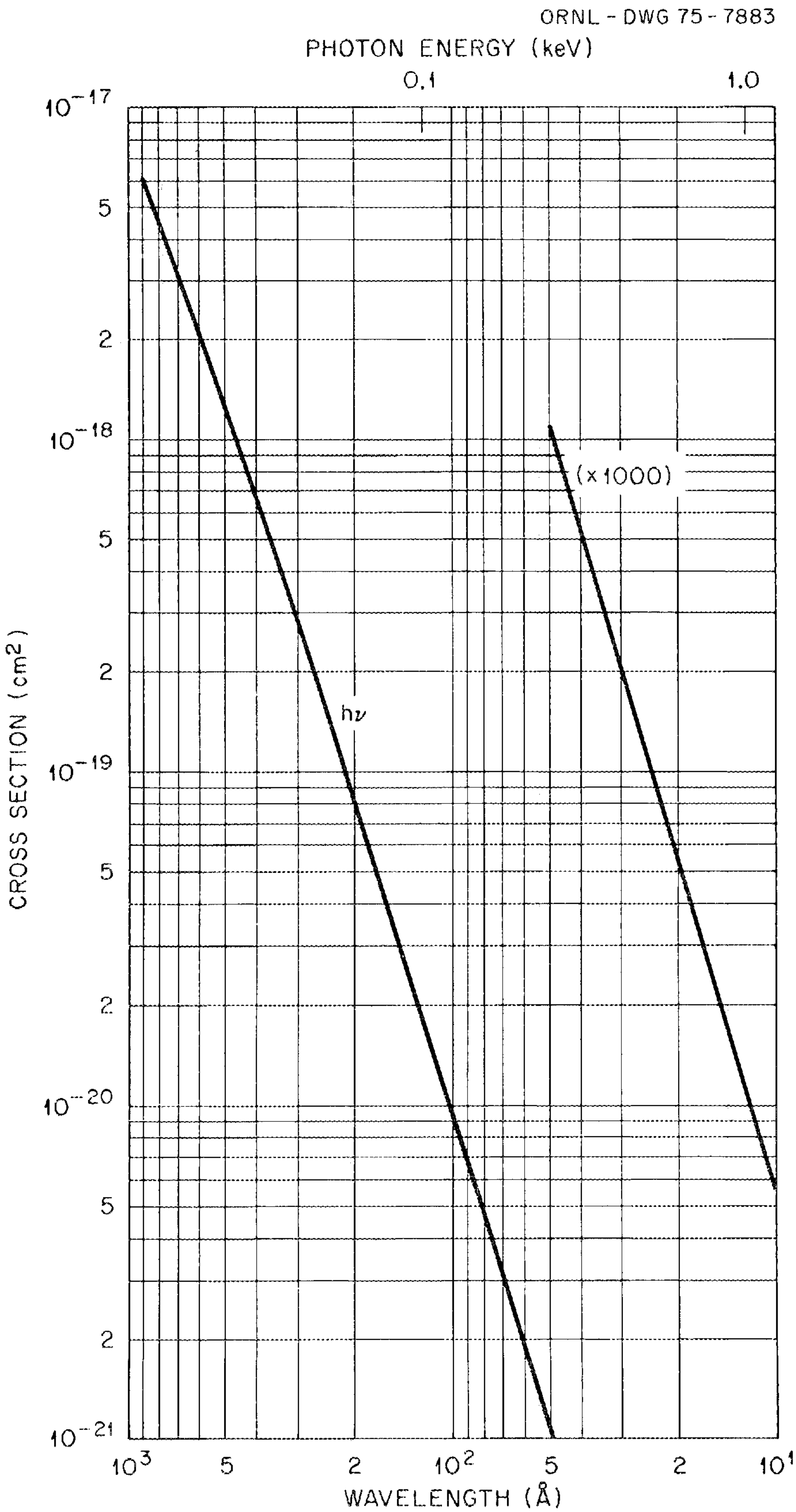
Theoretical: J.A.R. Samson, Advances in Atomic & Molecular Physics 2, 177 (1966) [Publ. Academic Press, N.Y., Ed. D.R. Bates and I. Estermann].

Accuracy:

Unspecified.

Notes:

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


ORNL-DWG 75-7883
PHOTON ENERGY (keV)
0.1
1.0
10^{-17}
5
2
10^{-18}
5
2
10^{-19}
5
2
10^{-20}
5
2
10^{-21}
CROSS SECTION (cm^2)
(×1000)
hν
10^3
5
2
10^2
5
2
10^1
WAVELENGTH (Å)

Photoabsorption and Photoionization in Molecular Hydrogen

$h\nu + H_2$

$h\nu + D_2$ (See Note 4)

Photon Wavelength (Å)	Photon Energy (keV)	Cross Section (cm^2) Absorption	Ionization
860	1.44 E-02	0.00	
850	1.46 E-02	5.00 E-18	
800	1.55 E-02	6.20 E-18	3.00 E-18
750	1.65 E-02	2.00 E-17	9.40 E-18
700	1.77 E-02	1.06 E-17	1.02 E-17
650	1.91 E-02	8.70 E-18	8.70 E-18
600	2.07 E-02	7.23 E-18	7.23 E-18
550	2.25 E-02	5.68 E-18	Same as
500	2.48 E-02	4.37 E-18	Absorption
450	2.76 E-02	3.22 E-18	Below 550
400	3.10 E-02	2.28 E-18	Å. See
350	3.54 E-02	1.52 E-18	Note (6)
300	4.13 E-02	9.47 E-19	
250	4.96 E-02	5.30 E-19	
200	6.20 E-02	2.54 E-19	
150	8.26 E-02	9.90 E-20	
100	1.24 E-01	2.60 E-20	
80	1.55 E-01	1.24 E-20	
60	2.07 E-01	4.72 E-21	
40	3.10 E-01	1.35 E-21	
20	6.20 E-02	1.69 E-22	

References:

Experimental (880 to 200 Å): G.R. Cook and P.H. Metzger, J. Opt. Soc. Am. 54, 968 (1964). J.A.R. Samson and R.B. Cairns, J. Opt. Soc. Am. 55, 1035 (1965). Semiempirical (below 60 Å). B.L. Henke, J. Appl. Phys. 28, 98 (1957).

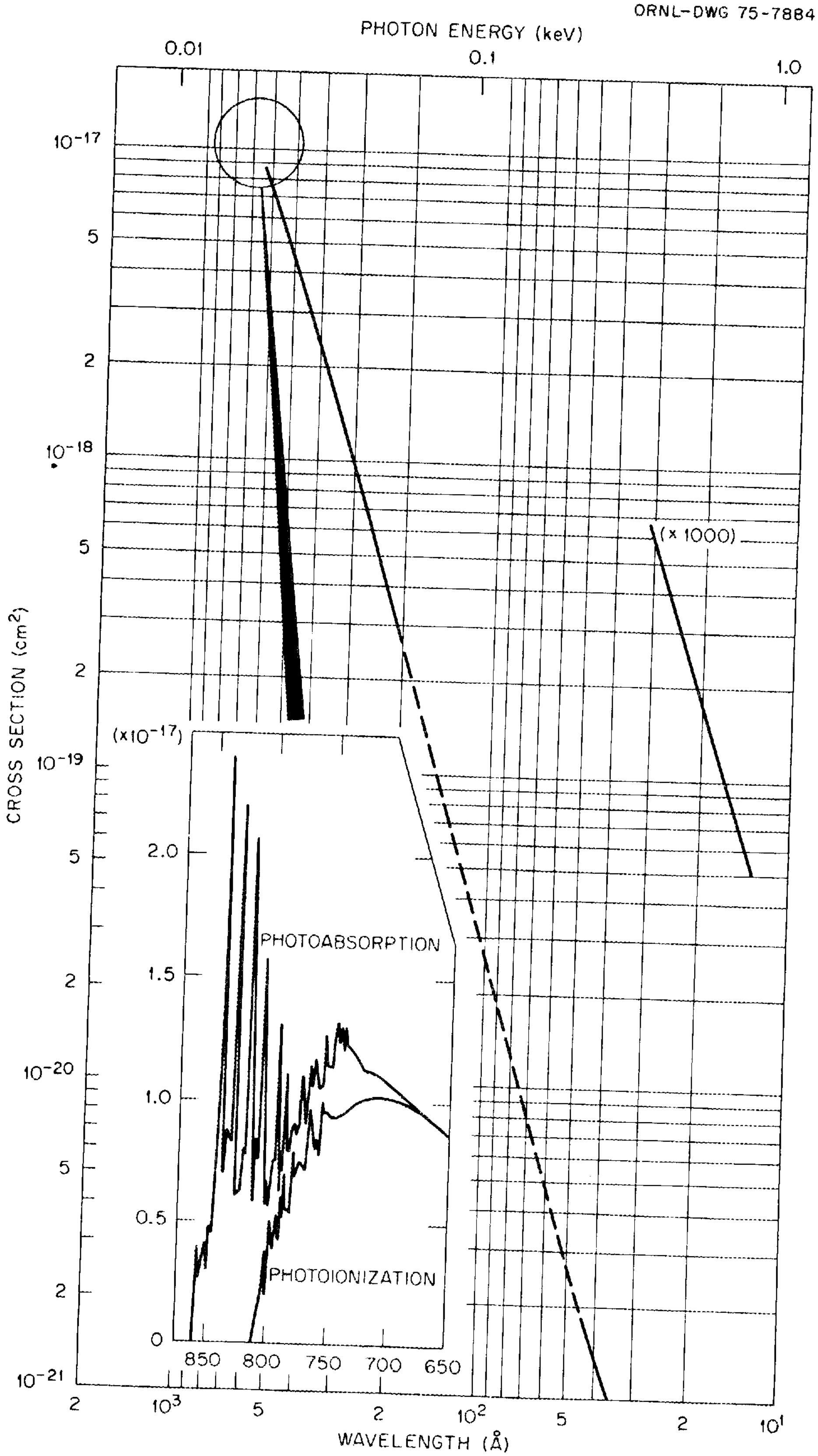
Accuracy:

Total error < ± 8%.

Notes:

See Notes (4), (5), (6), (7), and (8) at end of chapter.

ORNL-DWG 75-7884



Photoionization of Molecular Hydrogen; the Ratio of Dissociated to Undissociated Product Ions

$h\nu + H_2 \rightarrow H^+ + H + e$ (Cross Section σ_1)

$h\nu + H_2 \rightarrow H_2^+ + e$ (Cross Section σ_2)

$h\nu + D_2 \rightarrow D^+ + D + e$ (Cross Section σ_3)

$h\nu + D_2 \rightarrow D_2^+ + e$ (Cross Section σ_4)

Photon Wavelength (Å)	Photon Energy (keV)	Cross Section Ratios σ_1/σ_2	Cross Section Ratios σ_3/σ_4
685 (Threshold)	1.81 E-02		
650	1.91 E-02	1.70 E-02	6.50 E-03
600	2.04 E-02	2.04 E-02	7.80 E-03
550	2.26 E-02	2.08 E-02	8.00 E-03
500	2.48 E-02	2.08 E-02	8.14 E-03
450	2.76 E-02	2.55 E-02	1.43 E-02

Reference:

Experimental: R. Browning and J. Fryar, J. Phys. B 6, 364 (1973).

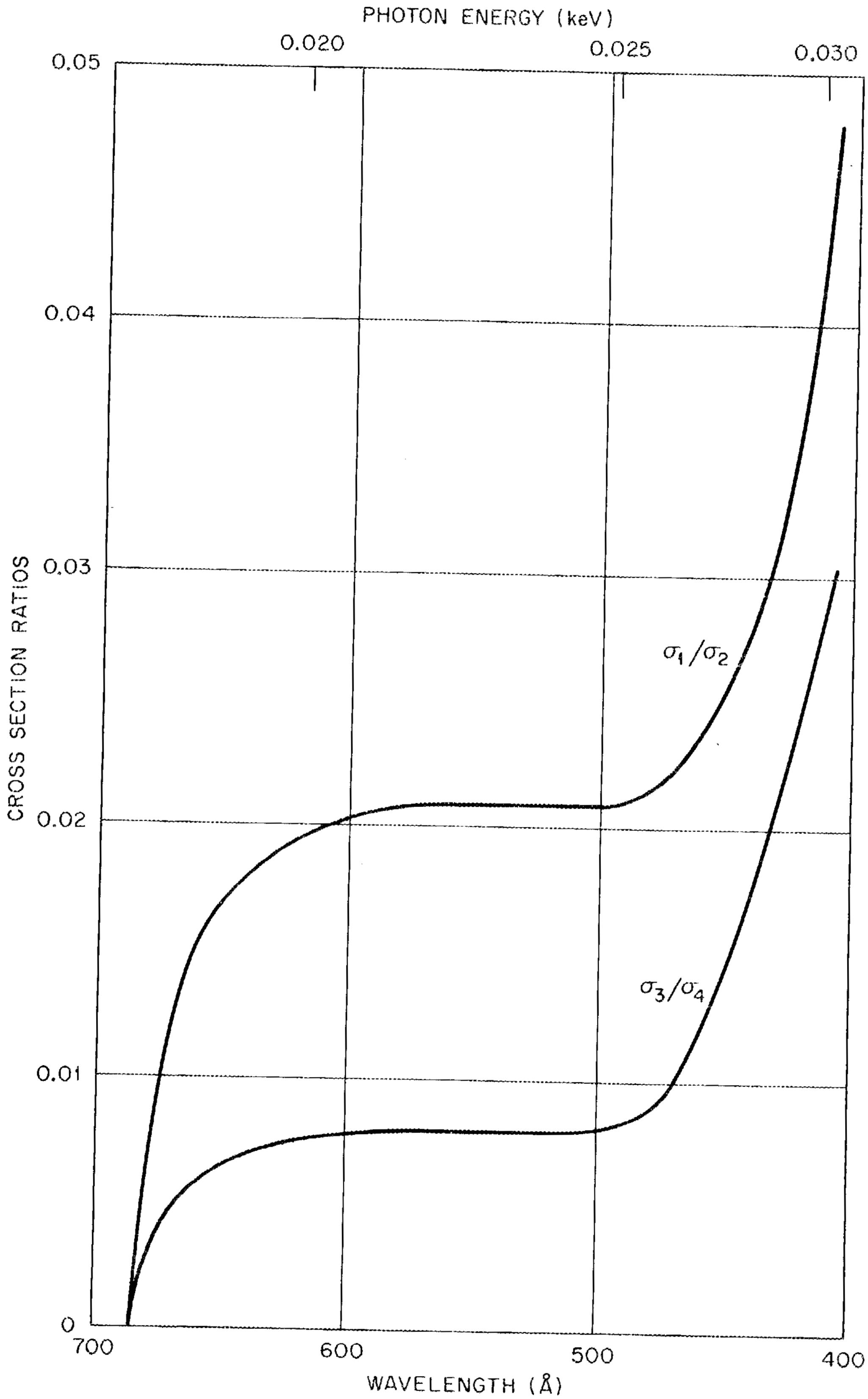
Accuracy:

Systematic error < ± 8%. Random error < ± 10%.

Notes:

See Note (9) at end of chapter.

ORNL-DWG 75-7885



Photoabsorption and Photoionization in Helium

$h\nu + He$

Photon Wavelength (Å)	Photon Energy (keV)	Cross Section (cm^2) Absorption	Ionization
504.26 (Threshold)	2.46 E-02	7.36 E-18	Same as Absorption. See Note (1).
500	2.48 E-02	7.20 E-18	
450	2.76 E-02	6.20 E-18	
400	3.10 E-02	5.00 E-18	
350	3.54 E-02	3.84 E-18	
300	4.13 E-02	2.85 E-18	
250	4.96 E-02	1.98 E-18	
200	6.20 E-02	1.25 E-18	
150	8.26 E-02	6.20 E-19	
100	1.24 E-01	2.00 E-19	
80	1.55 E-01	1.10 E-19	
60	2.07 E-01	5.21 E-20	
50	2.48 E-01	3.25 E-20	
40	3.10 E-01	1.86 E-20	
30	4.13 E-01	8.56 E-21	
20	6.20 E-01	2.61 E-21	

References:

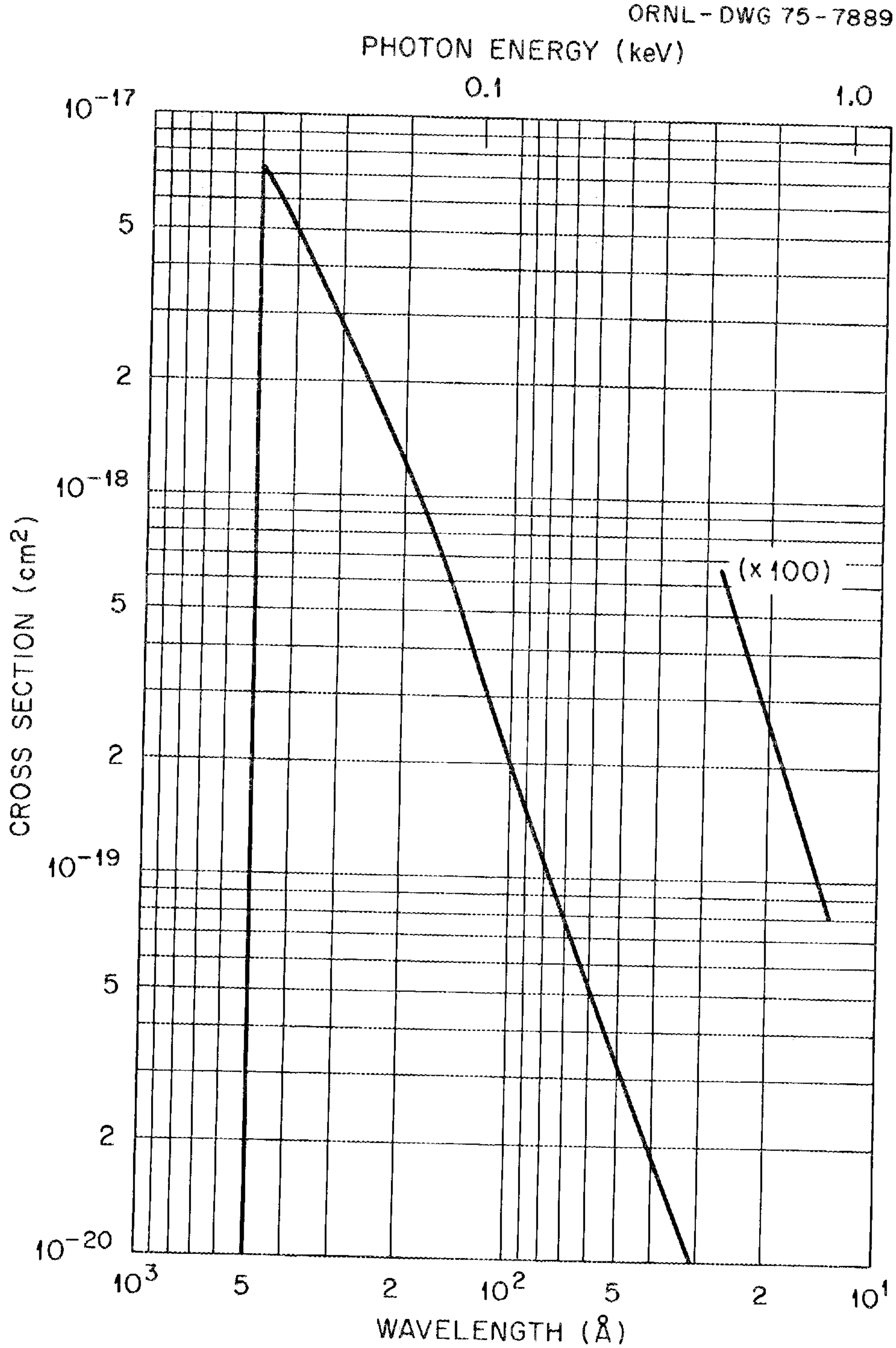
Experimental: J.A.R. Samson, Advances in Atomic and Molecular Physics 2, 177 (1966) [publ. Academic Press N.Y., Ed. D.R. Bates and I. Estermann].
W.S. Watson, J. Phys. B 5, 2292 (1972).

Accuracy:

Systematic error < ± 5%. Random error < ± 3%.

Notes:

See Notes (1), (3), (14), (15), and (16) at end of chapter.


ORNL-DWG 75-7889
PHOTON ENERGY (keV)
0.1
1.0
10^{-17}
5
2
10^{-18}
5
2
10^{-19}
5
2
10^{-20}
CROSS SECTION (cm^2)
(x100)
10^3
5
2
10^2
5
2
10^1
WAVELENGTH (Å)

Photoionization and Photoabsorption in Atomic C and C^{3+}

$h\nu + C, C^{3+}$

Photon Wavelength (Å)	Photon Energy (keV)	Cross Section (cm^2) C	C^{3+}
190	5.26 E-02		3.22 E-18
180	5.55 E-02		3.00 E-18
140	8.85 E-02		2.05 E-18
125	1.00 E-01	5.28 E-19	1.70 E-18
100	1.24 E-01	3.28 E-19	1.15 E-18
80	1.55 E-01	1.98 E-19	7.54 E-19
60	2.07 E-01	1.03 E-19	4.11 E-19
50	2.48 E-01	6.86 E-20	2.75 E-19
40	3.10 E-01	8.06 E-19	1.60 E-19
20	6.20 E-01	1.56 E-20	
10	1.24 E 00	2.35 E-20	

References:

$h\nu + C$; Theoretical - T. L. John and D. J. Morgan, Phys. Letts. 45A, 135 (1973).

$h\nu + C^{3+}$; Semiempirical - Wm. J. Viegele, Atomic Data Tables 5, 51 (1973).

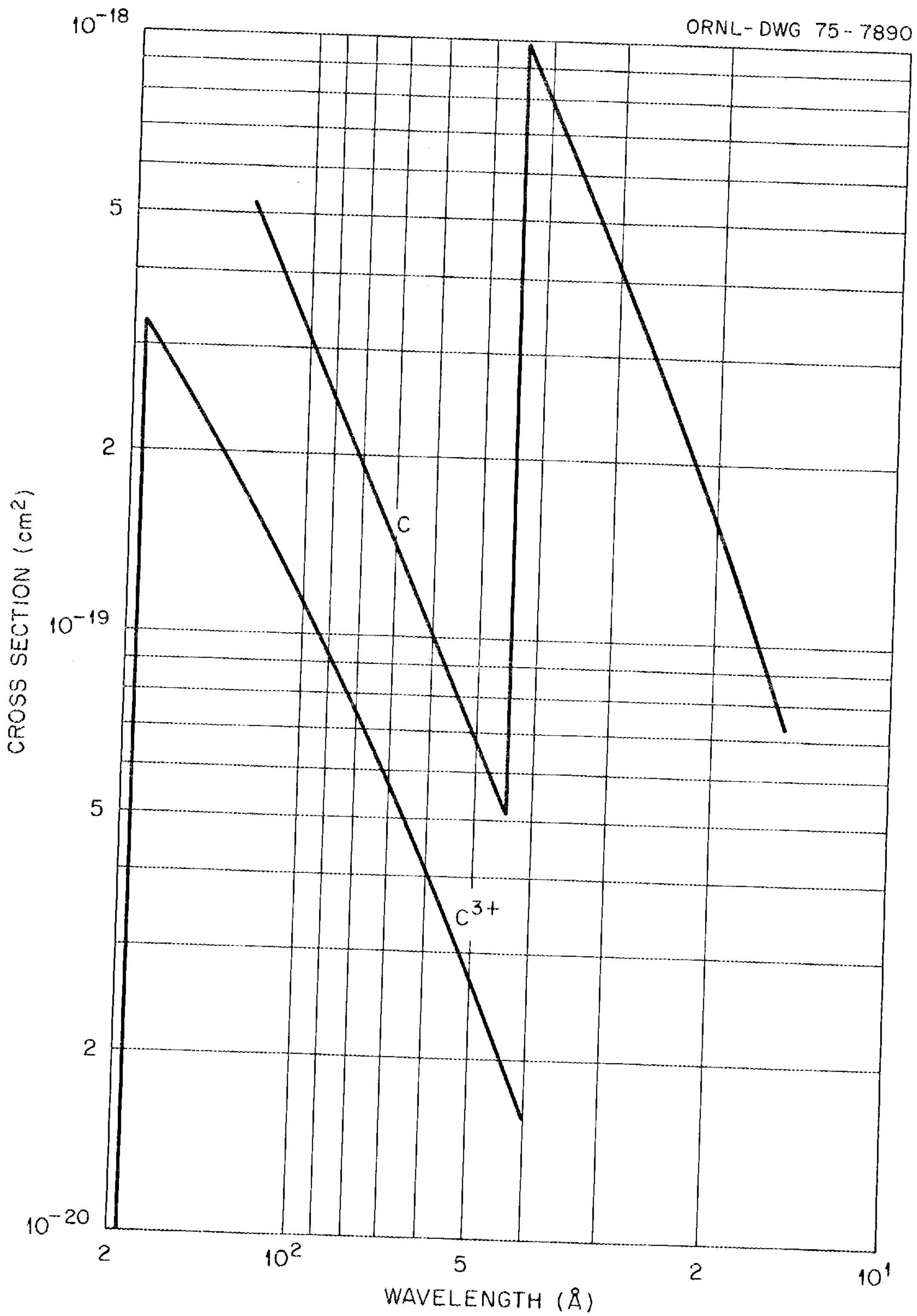
Accuracy:

$h\nu + C$ - Total error < ± 5%

$h\nu + C^{3+}$ - Unknown

Notes:

For photoabsorption of C see Notes 1 and 17 at end of chapter.



ORNL-DWG 75-7890
10^{-18}
5
2
10^{-19}
5
2
10^{-20}
CROSS SECTION (cm^2)
C
C^{3+}
2
10^2
5
2
10^1
WAVELENGTH (Å)

Photoabsorption and Photoionization of Atomic Molybdenum, Tungsten and Gold

$h\nu$ + (Mo, W, Au)

Photon Wavelength (Å)	Photon Energy (keV)	Cross Section (cm^2) Mo	W	Au
125	1.00 E-01	7.98 E-19	3.56 E-18	2.07 E-18
100	1.24 E-01	8.23 E-19	4.87 E-18	1.61 E-18
90	1.38 E-01	8.23 E-19	5.31 E-18	1.66 E-18
80	1.55 E-01	8.10 E-19	5.67 E-18	1.80 E-18
70	1.77 E-01	7.70 E-19	5.90 E-18	2.25 E-18
60	2.07 E-01	6.87 E-19	5.97 E-18	3.90 E-18
50	2.48 E-01	2.00 E-18	5.71 E-18	4.91 E-18
40	3.10 E-01	4.52 E-18	5.16 E-18	5.21 E-18
30	4.13 E-01	3.94 E-18	3.91 E-18	4.80 E-18
20	6.20 E-01	2.16 E-18	3.77 E-18	3.41 E-18
15	8.26 E-01	1.20 E-18	2.73 E-18	2.30 E-18
10	1.24 E 00	4.70 E-19	1.72 E-18	1.07 E-18

Reference:

Semiempirical: Wm. J. Viegele, Atomic Data Tables 5, 51 (1973).

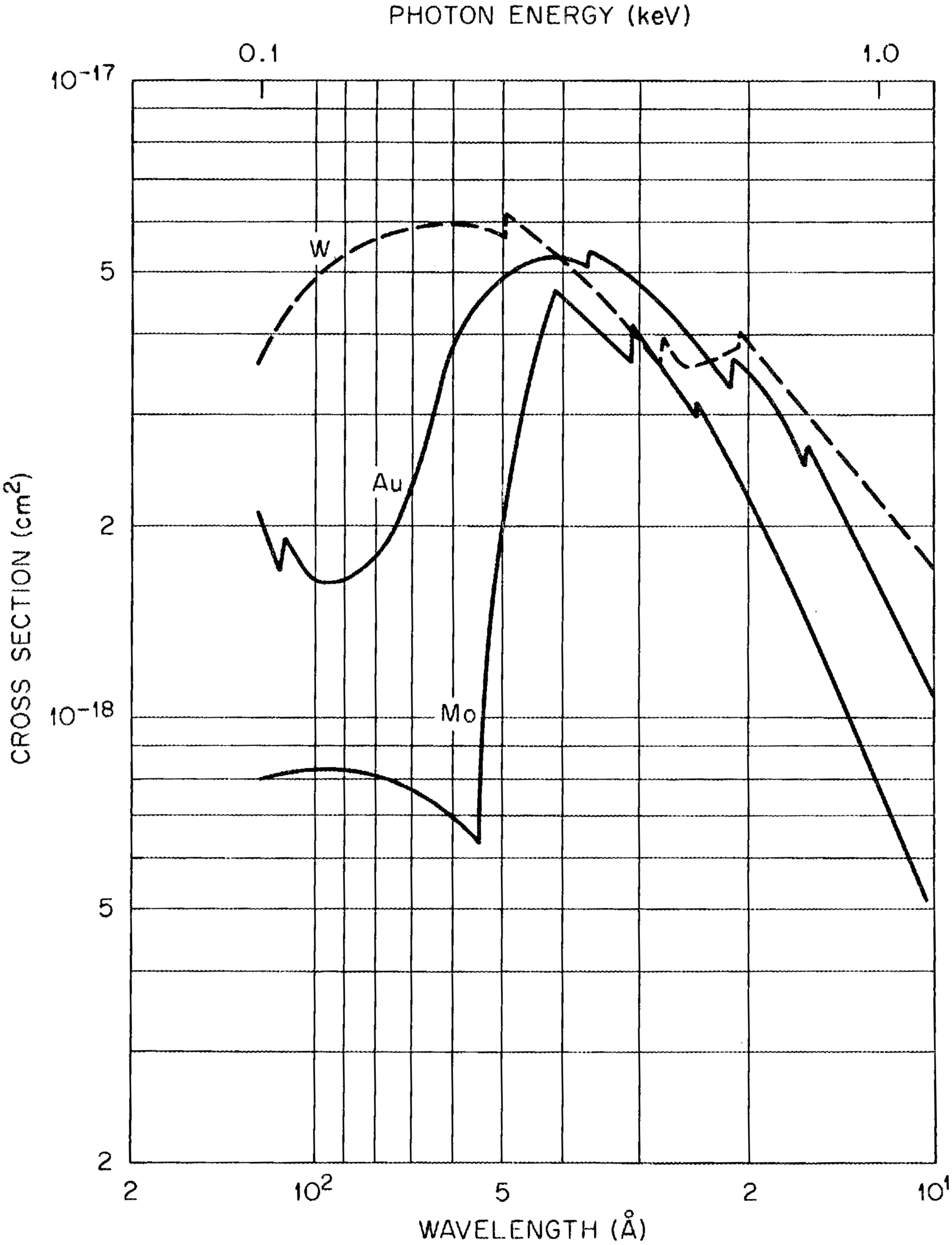
Accuracy:

Total error < ± 5%

Notes:

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

ORNL-DWG 75-7936



Notes

(1) For atomic targets such as this, the photoabsorption cross section at wavelengths below the ionization limit (indicated by the word "threshold" in the table) is confidently expected to be equal to the photoionization cross section. [See J.A.R. Samson, "Advances in Atomic and Molecular Physics," Academic Press, N.Y. Eds. D.R. Bates and I.M. Estermann 2, 177 (1966)]. We show here only the cross section (absorption or ionization) actually measured or calculated; the other cross section (ionization or absorption respectively) is expected to be the same. Exceptions to this may occur at discrete structure in the absorption curve; such structure is however of only a few Å width and its influence is irrelevant when absorption of broad radiation continua is being considered.

The general equality of ionization and attenuation cross sections breaks down at very high photon energies ($E > 1$ keV) because appreciable attenuation occurs through scattering. We have terminated our tabulation at 10 Å and scattering is insignificant for the situations we cover. For tabulations of separate cross sections for ionization and absorption at photon energies from 100 eV to 1 MeV see Wm. J. Veigele, Atomic Data 5, 51 (1973).

(2) Although these data are theoretical, it is expected that their accuracy will be very high. They have been confirmed by experiment at a single wavelength. For details see reference cited.

(3) For information on cross sections at higher photon energies, see the extensive tabular data of Wm. J. Viegele, Atomic Data 5, 51 (1973).

(4) The cross sections for absorption and ionization in D_2 have been given by G.R. Cook and P.H. Metzger, J. Opt. Soc. Am. 54, 968 (1964). They are almost identical to those for H_2 except for a wavelength shift of the absorption bands according to the isotope rule.

(5) It should be noted that the structure in these cross sections is too fine to be reproduced adequately in a table of any reasonable length. In the region of structure, the data we tabulate here represent a smooth line that represents roughly the behavior of the average structure. In any application where the structure is of importance the reader must refer to the original paper of G.R. Cook and P.H. Metzger that is cited. For a very fine resolution study of these structure with detailed identification of the transitions from which they arise, see W.A. Chupka and J. Berkowitz, J. Chem. Phys. 51, 4244 (1969).

(6) For wavelengths below 650 Å the ionization and absorption cross sections become equal. At wavelengths below 550 Å there have been no direct measurements of the ionization cross section, but it seems reasonable to take it as being equal to the measured absorption cross section.

(7) The cross sections shown here are for the formation of both atomic and molecular ions. Data on the following graph shows that, for wavelengths between 600 and 400 Å, at least 96% of the ions are undissociated (i.e. H_2^+ or D_2^+ ions).

(8) At wavelengths below 680 Å the photoabsorption gives rise entirely to ion formation; above 680 Å much of the absorption is to excited molecular states and to dissociation of the neutral molecule into two neutral atoms. An extensive tabulation of theoretical cross sections for photodissociation into two neutral atoms is given in the work of A.C. Allison and A. Dalgarno, Atomic Data Tables 1, 91 (1969); there are no experimental studies of this cross section.

(9) These data are cross section ratios as indicated. At wavelengths above 682 Å it is not energetically possible to cause dissociative photoionization. Combining these data with the measured cross sections for ion formation (shown on the preceding graph) one could generate separate cross sections for formation of the atomic and molecular ions.

(10) It is important to note that this cross section is greatly dependent on the vibrational state of the molecular ion. The data presented here are for a particular distribution among vibrational levels of the electronic ground state; this distribution will be appropriate to a low pressure source using an electron beam of energy that is high compared with threshold energies for the various excited states. For H_2^+ (or D_2^+) ions produced by any other means the cross sections may be substantially different from those given here. There are no experimental measurements for dissociation from a single, known, vibrational state, although such measurements are now possible. [N.P.F.B. Van Asselt, J.G. Maas, and J. Los, Chem. Phys. Letts. 24, 555 (1974)].

Theoretical ross sections are available and are discussed in the following table. With these one can generate a cross section for any known initial distribution among vibrational states.

(11) The experimental data extend only down to 2500 Å. They are however completely consistent with a theoretical calculation given in the reference cited, and we have used that calculation to extend the data to lower wavelengths.

(12) It seems likely that photoabsorption cross sections will be the same as the photodissociation cross sections given here; there is, however, no proof of this.

(13) The cross sections given here are for the first three vibrational states. Dunn has described the calculation in Phys. Rev. 172, 1 (1968), but presents there only representative data. The unpublished report cited contains calculated cross sections for all of the 19 vibrational states of H_2^+ and the 27 vibrational states of D_2^+; the complete tabulation is far too extensive to reproduce here.

(14) Absorption will occur at discrete wavelengths above the ionization threshold that correspond to excitation of excited states of the target atom. This represents photoexcitation. There appear to be no measurements of cross sections for such processes in this case.

(15) Discrete structure in the photoabsorption curve has been observed at wavelengths around 206 Å [R. Madden, K. Codling, Astrophys. J. 141, 364 (1965)]. The structure is, however, of the order an Ångstrom in width and we have omitted it from the table and graph. The structure arises by two electron excitation to an autoionizing state.

(16) In addition to the cross section for photoionization, there is also information on the cross section for removal of one electron and excitation of the other. For details see the experiment of M.O. Krause and F. Wuilleumier, J. Phys. B. 5, L143 (1972); and the theoretical work of K.L. Bell, A.E. Kingston, and I.R. Taylor, J. Phys. B 6, 1228 (1973).

(17) In addition to the data shown here, there are some predictions and measurements of absorption and ionization cross sections, close to the ionization threshold of 11.3 eV. The predictions show considerable differences and do not agree with the single experimental measurement too well; moreover the experiment is based on shock tube data and may not be reliable. For further details the reader is referred to the following references. W. Holfmann and G.L. Weissler, J. Opt. Soc. Am. 61, 223 (1971); D.R. Bates and M.J. Seaton, Mon. Notes. Roy. Astron. Soc. 109, 698 (1949); F. Praderie, Ann. D'Astrophys. 27, 129 (1964).

B.2 Photodissociation

Photodissociation of H_2^+ and D_2^+

$$h\nu + (H_2^+, D_2^+) \rightarrow (H, D) + (H^+, D^+)$$

Photon Wavelength (Å)	Photon Energy (keV)	Cross Sections (cm^2) H_2^+	D_2^+
1.5 E 04	8.26 E-04	2.00 E-19	1.15 E-19
1.4 E 04	8.85 E-04	2.18 E-19	1.26 E-19
1.3 E 04	9.54 E-04	2.35 E-19	1.40 E-19
1.2 E 04	1.03 E-03	2.60 E-19	1.57 E-19
1.1 E 04	1.13 E-03	2.88 E-19	1.80 E-19
1.0 E 04	1.24 E-03	3.15 E-19	2.12 E-19
9.0 E 03	1.38 E-03	3.75 E-19	2.54 E-19
8.0 E 03	1.55 E-03	4.30 E-19	3.16 E-19
7.0 E 03	1.77 E-03	5.25 E-19	4.09 E-19
6.0 E 03	2.07 E-03	6.60 E-19	5.53 E-19
5.0 E 03	2.48 E-03	9.00 E-19	8.00 E-19
4.0 E 03	3.10 E-03	1.08 E-18	1.25 E-18
3.0 E 03	4.13 E-03	2.00 E-18	2.10 E-18
2.0 E 03	6.20 E-03	2.95 E-18	3.25 E-18
1.5 E 03	8.27 E-03	2.80 E-18	2.71 E-18
1.0 E 03	1.24 E-02	1.82 E-18	1.63 E-18
9.0 E 02	1.38 E-02	1.80 E-18	1.60 E-18
8.0 E 02	1.55 E-02	1.60 E-18	1.68 E-18
7.0 E 02	1.77 E-02	6.00 E-19	9.00 E-19
6.0 E 02	2.07 E-02	6.00 E-20	1.10 E-19
5.0 E 02	2.48 E-02	0.00 E-20	0.00 E-19

References:

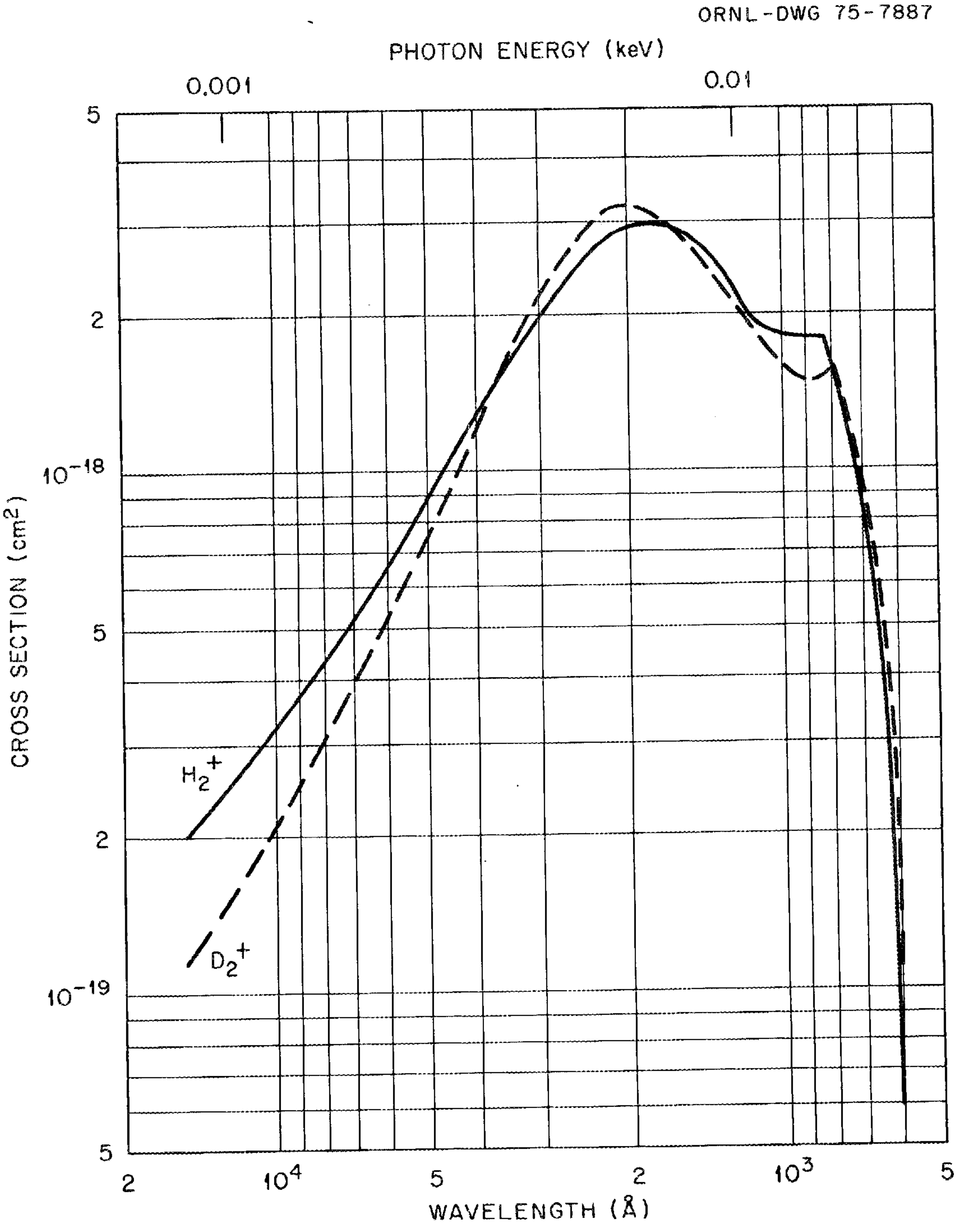
$h\nu + H_2^+, D_2^+$: F. Von Busch and G. H. Dunn, Phys. Rev. A 5, 1726 (1972).

Accuracy:

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

Notes:

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


ORNL-DWG 75-7887
PHOTON ENERGY (keV)
0.001
0.01
5
2
10^{-18}
5
2
10^{-19}
5
CROSS SECTION (cm^2)
H_2^+
D_2^+
2
10^4
5
2
10^3
5
WAVELENGTH (Å)

Photodissociation of H_2^+ from Selected Vibrational States (Theoretical)

$$h\nu + H_2^+ (1s\sigma_g, v = 0, 1, 2) \rightarrow H_2^+ (2p\sigma_u) \rightarrow H + H^+$$

Photon Wavelength (Å)	Photon Energy (keV)	Cross Section (cm^2) v = 0	v = 1	v = 2
4000	3.10 E-03			2.801 E-24
3000	4.13 E-03		1.416 E-22	2.504 E-20
2000	6.20 E-03	2.390 E-20	1.059 E-18	7.384 E-18
1500	8.27 E-03	1.807 E-18	7.866 E-18	2.677 E-19
1000	1.24 E-02	6.058 E-18	2.913 E-18	1.248 E-19
900	1.38 E-02	3.078 E-18	3.910 E-18	2.256 E-18
800	1.55 E-02	8.977 E-19	2.072 E-18	2.616 E-18
700	1.77 E-02	1.069 E-19	3.824 E-19	7.538 E-19
600	2.07 E-02	3.440 E-21	1.657 E-20	4.367 E-20
500	2.48 E-02	1.020 E-23	5.661 E-23	1.806 E-22

<u>Reference</u>:

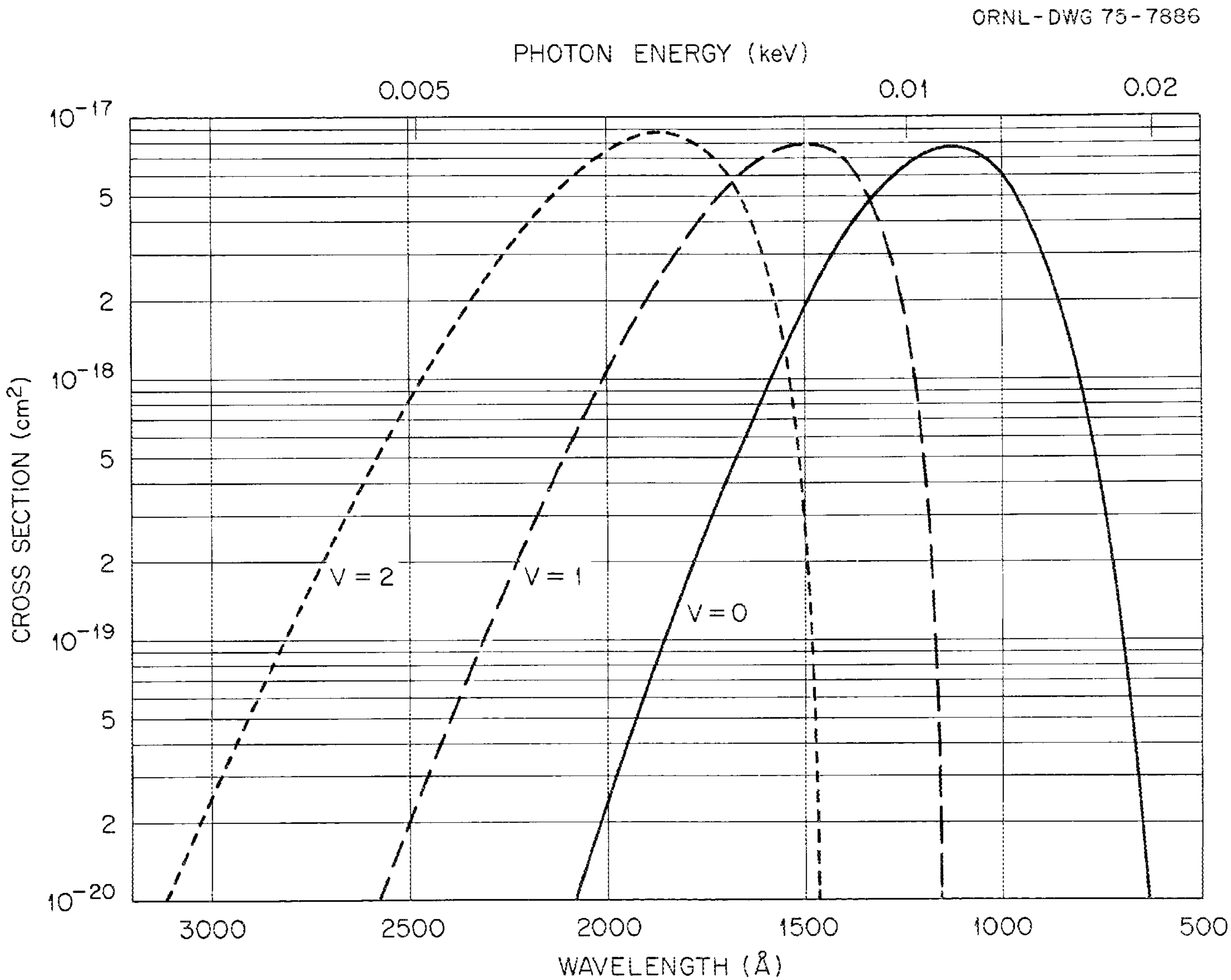
Theoretical: G.H. Dunn, Phys. Rev. <u>172</u>, 1 (1968); G.H. Dunn, JILA Report No. 92, (1968) (unpublished).

<u>Accuracy</u>:

Essentially exact.

<u>Notes</u>:

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


ORNL-DWG 75-7886
PHOTON ENERGY (keV)
0.005
0.01
0.02
10^{-17}
5
2
10^{-18}
5
2
10^{-19}
5
2
10^{-20}
CROSS SECTION (cm^2)
V = 2
V = 1
V = 0
3000
2500
2000
1500
1000
500
WAVELENGTH (Å)

Photodissociation of D_2^+ from Selected Vibrational States (Theoretical)

$$h\nu + D_2^+ (1s\sigma_g, v = 0, 1, 2) \rightarrow D_2^+ (2p\sigma_u) \rightarrow D + D^+$$

Photon Wavelength (Å)	Photon Energy (keV)	Cross Section (cm^2) v = 0	v = 1	v = 2
3500	3.54 E-03			1.40 E-26
3000	4.13 E-03		5.287 E-26	2.418 E-23
2000	6.20 E-03	1.326 E-21	1.057 E-19	1.940 E-18
1500	8.27 E-03	8.599 E-19	7.007 E-18	5.284 E-18
1000	1.24 E-02	7.134 E-18	3.484 E-18	2.917 E-20
900	1.38 E-02	3.053 E-18	4.666 E-18	3.082 E-18
800	1.55 E-02	6.164 E-19	1.849 E-18	2.829 E-18
700	1.77 E-02	3.117 E-20	1.640 E-19	4.167 E-19
600	2.07 E-02	3.744 E-22	2.325 E-21	7.926 E-21
500	2.48 E-02	3.107 E-25	1.983 E-24	4.768 E-24

Reference:

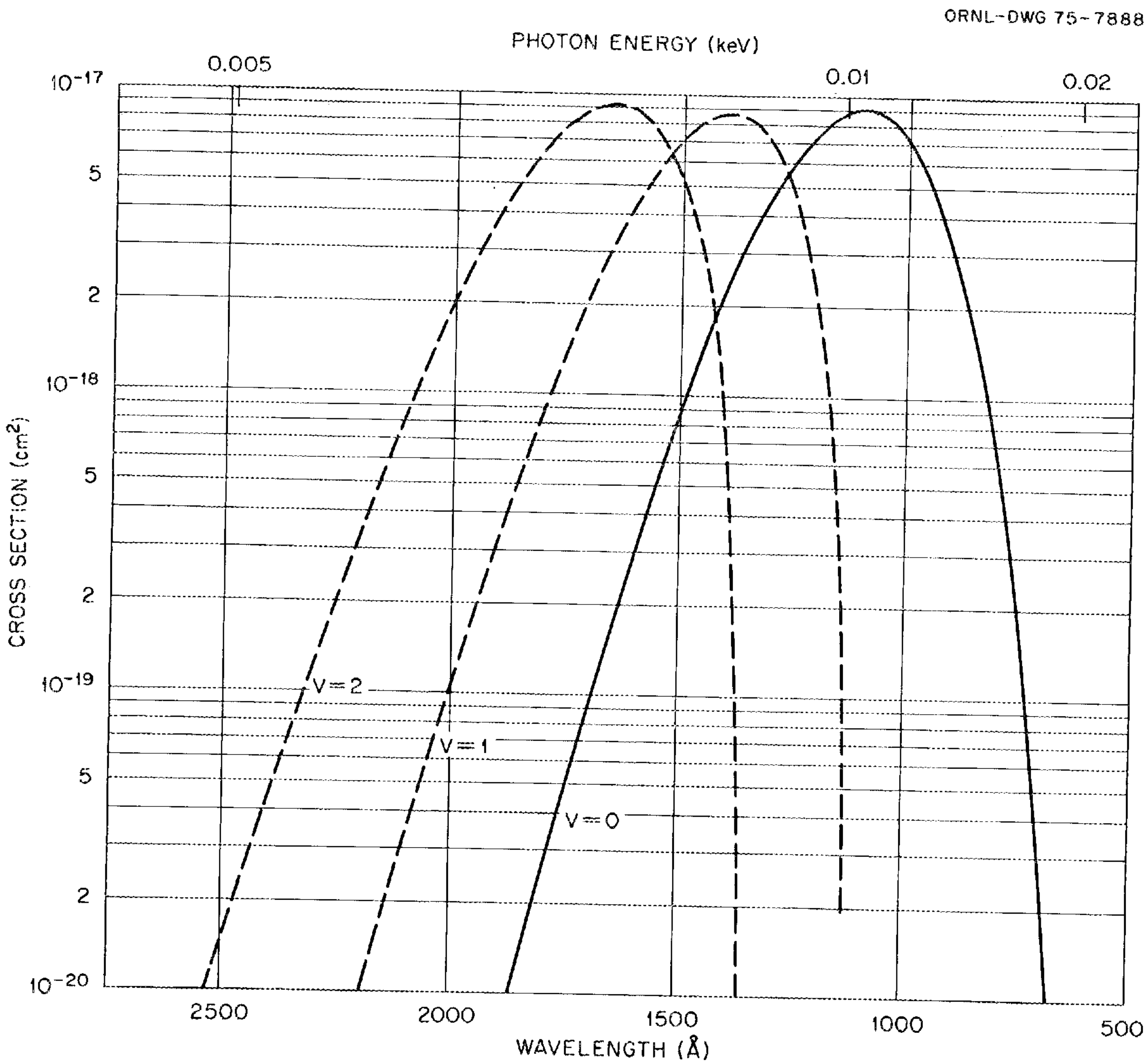
Theoretical: G.H. Dunn, Phys. Rev. 172, 1 (1968); G.H. Dunn, Joint Institute for Laboratory Astrophysics Report No. 92, (1968) (unpublished).

Accuracy:

Essentially exact.

Notes:

See Notes (12) and (13) at end of chapter.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PHOTON ENERGY (keV)
0.005
0.01
0.02
10^{-17}
5
2
10^{-18}
5
2
10^{-19}
5
2
10^{-20}
CROSS SECTION (cm^2)
V=2
V=1
V=0
2500
2000
1500
1000
500
WAVELENGTH (Å)

B.3 Photodetachment

Cross Sections for Photodetachment of an Electron from H^- and C^-

λ (Å)	Energy (eV)	Cross Sections (cm^2) H^-	C^-
5.0 E 02	2.48 E 01	8.1 E-19	
6.0 E 02	2.07 E 01	1.2 E-18	
8.0 E 02	1.55 E 01	3.9 E-18	
9.0 E 02	1.38 E 01	5.3 E-18	
9.7 E 02	1.28 E 01	2.7 E-17	
1.0 E 03	1.24 E 01	2.2 E-17	
1.5 E 03	8.27 E 00	6.9 E-18	
2.0 E 03	6.20 E 00	9.9 E-18	
3.0 E 03	4.13 E 00	1.6 E-17	
4.0 E 03	3.10 E 00	2.2 E-17	1.3 E-17
6.0 E 03	2.07 E 00	3.4 E-17	1.4 E-17
8.0 E 03	1.55 E 00	4.1 E-17	1.4 E-17
1.0 E 04	1.24 E 00	3.7 E-17	2.9 E-19
1.2 E 04	1.03 E 00	2.5 E-17	
1.4 E 04	8.86 E-01	1.1 E-17	
1.6 E 04	7.75 E-01	5.9 E-19	

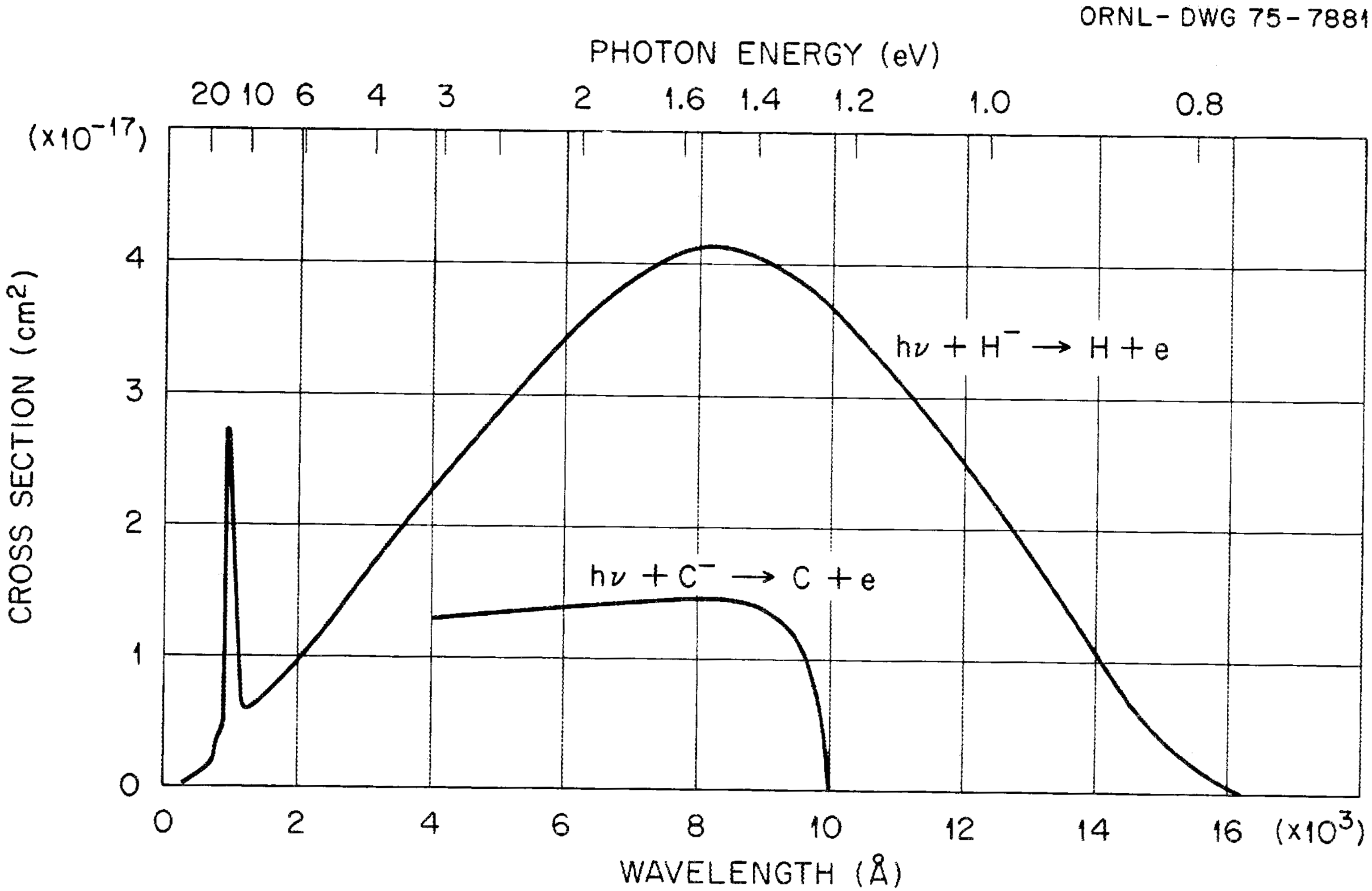
References:

$h\nu + H^-$: L. M. Branscomb and S. J. Smith, Phys. Rev. 98, 1028 (1955); S. J. Smith and D. S. Burch, Phys. Rev. 116, 1125 (1959); D. Feldman, Z. Naturforsch. 25-a, 621 (1970); J. Macek, Proc. Phys. Soc. 92, 365 (1967); L. M. Branscomb, "Physics of the One- and Two-Electron Atoms", pp.669-699, North-Holland Publishing Co. (Amsterdam) 1969).

$h\nu + C^-$: M. L. Seman and L. M. Branscomb, Phys. Rev. 125, 1602 (1962); D. Feldman, Z. Naturforsch. 25-a, 621 (1970).

Accuracy:

The total error is believed not to exceed ± 10%.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PHOTON ENERGY (eV)
20 10 6 4 3 2 1.6 1.4 1.2 1.0 0.8
(x10^-17)
CROSS SECTION (cm^2)
0 1 2 3 4
hν + H⁻ → H + e
hν + C⁻ → C + e
0 2 4 6 8 10 12 14 16 (x10^3)
WAVELENGTH (Å)

Cross Sections, σ, for Photodetachment of an Electron

from the O^- and O_2^- Ions

λ (Å)	Energy (eV)	$h\nu + O_2^- \rightarrow O_2 + e$ Cross Section (cm^2)	$h\nu + O^- \rightarrow O + e$ Cross Section (cm^2)
4.2 E 03	2.95 E 00	2.4 E-18	6.4 E-18
4.4 E 03	2.82 E 00	2.3 E-18	6.4 E-18
4.8 E 03	2.58 E 00	2.0 E-18	6.4 E-18
5.2 E 03	2.38 E 00	1.7 E-18	6.4 E-18
5.6 E 03	2.21 E 00	1.5 E-18	6.4 E-18
6.0 E 03	2.07 E 00	1.3 E-18	6.3 E-18
6.4 E 03	1.94 E 00	1.1 E-18	6.1 E-18
6.8 E 03	1.82 E 00	1.0 E-18	5.8 E-18
7.2 E 03	1.72 E 00	9.0 E-19	5.3 E-18
8.0 E 03	1.55 E 00	7.3 E-19	3.6 E-18
8.4 E 03	1.48 E 00	6.6 E-19	1.3 E-18
8.6 E 03	1.44 E 00	6.0 E-19	1.4 E-19
9.0 E 03	1.38 E 00	5.6 E-19	
1.0 E 04	1.24 E 00	4.3 E-19	
1.2 E 04	1.03 E 00	2.7 E-19	
1.6 E 04	7.75 E 01	1.4 E-19	
2.0 E 04	6.20 E 01	4.3 E-20	

References:

O^-: L.M. Branscomb and S.J. Smith, Phys. Rev. 98, 1127 (1955); L.M. Branscomb, D.S. Burch, S.J. Smith, and S. Geltman, Phys. Rev. 111, 504 (1958).

O_2^-: D.S. Burch, S.J. Smith, and L.M. Branscomb, Phys. Rev. 112, 171 (1958); Phys. Rev. 114, 1652 (1959).

Accuracy:

O^-: The total error is believed not to exceed ± 10%.

O_2^-: The total error is believed not to exceed ± 15%.

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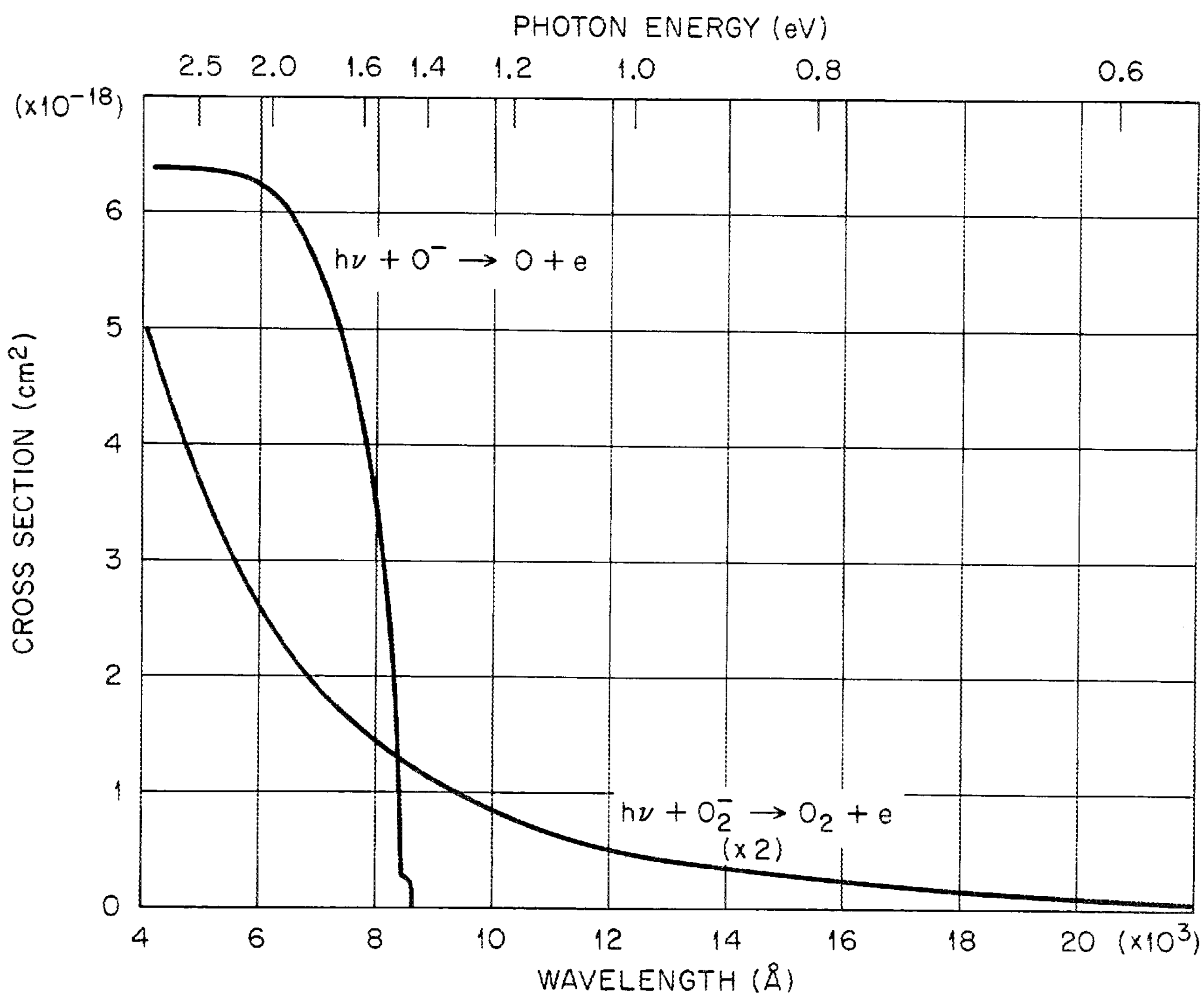

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