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ATOMIC AND MOLECULAR COLLISION CROSS SECTIONS OF INTEREST IN CONTROLLED THERMONUCLEAR RESEARCH

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ABSTRACT

A graphical compilation is presented of atomic and molecular cross sections of interest to controlled thermonuclear research. The present compilation is a revision of ORNL-3113, published in 1960. The cross sections are shown, as a function of energy, for collision processes involving molecular ion dissociation, charge exchange, excitation, ionization, photoionization, scattering, energy loss, secondary products, and recombination. Pertinent nuclear cross sections are also included. A bibliography is given covering the literature since 1950.

INTRODUCTION

This report is a revision of a previous compilation of atomic and molecular cross sections available in the literature since 1950. The work was undertaken as a guide for investigators in the thermonuclear field at Oak Ridge National Laboratory. The comprehensive surveys of Massey and Burhop[1] and Allison and Warshaw[2] summarize the data prior to 1950. This compilation is principally limited to atomic and molecular collision processes that may be encountered in the attempts to develop a high density, high temperature plasma. In addition to presenting the cross sections in graphical form, we have compiled a bibliography in each section.

In the original papers, the cross sections are stated in a variety of units (πa_0^2, collision probability, etc.). Previously the compilation reduced the cross sections to cm^2/gas atom, however, experiments in the past three years have indicated that in the low energy region a diatomic molecule cannot be regarded as two separate atoms. Consequently, all cross sections are now reduced to cm^2/molecule. In addition, the cross sections are plotted as a function of both particle velocity and particle.

The 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.

In many measurements (notatable in charge exchange) the data of many investigators are consistent within a few per cent; however, for convenience and to avoid duplication, only a representative sample is reproduced.

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[2] S. K. Allison and S. D. Warshaw, Passage of Heavy Particles through Matter, Revs. Modern Phys. 25: 779 (1953).

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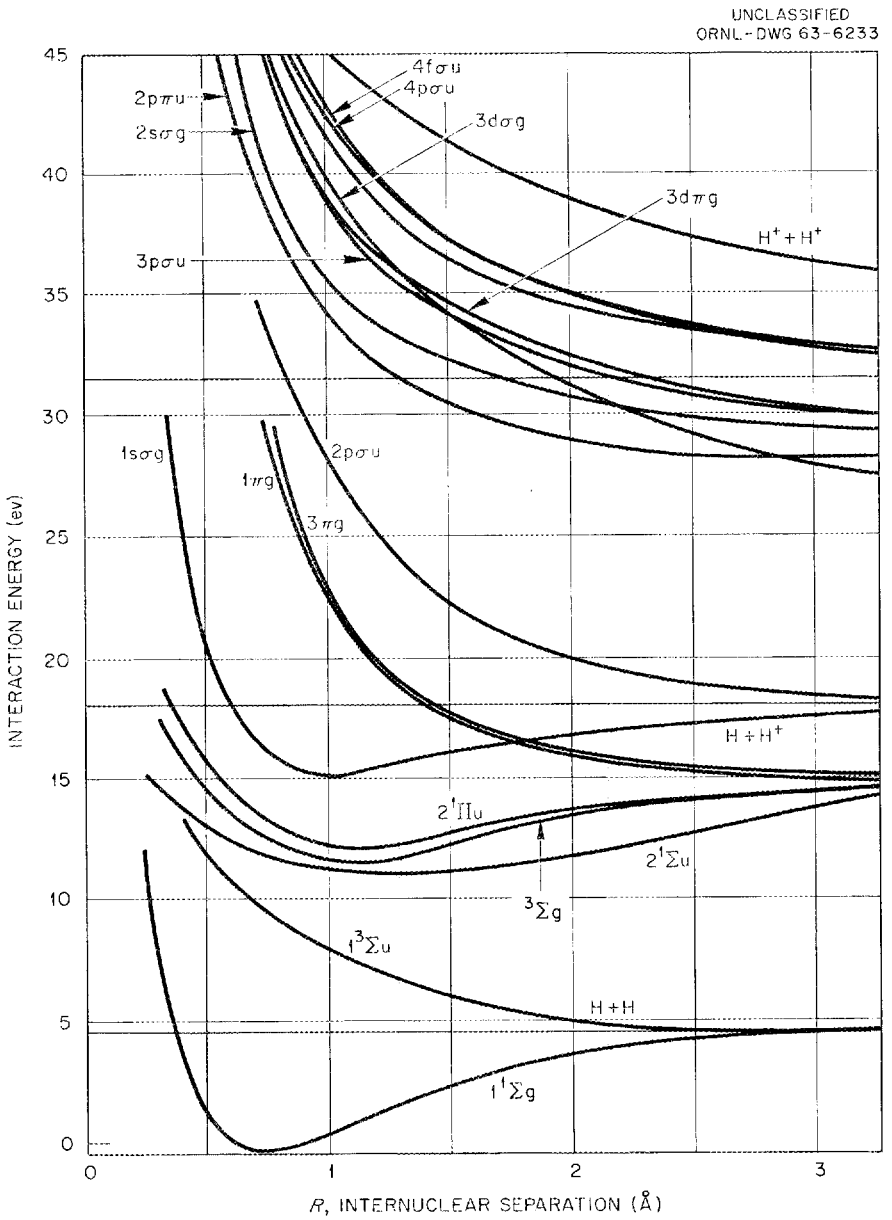

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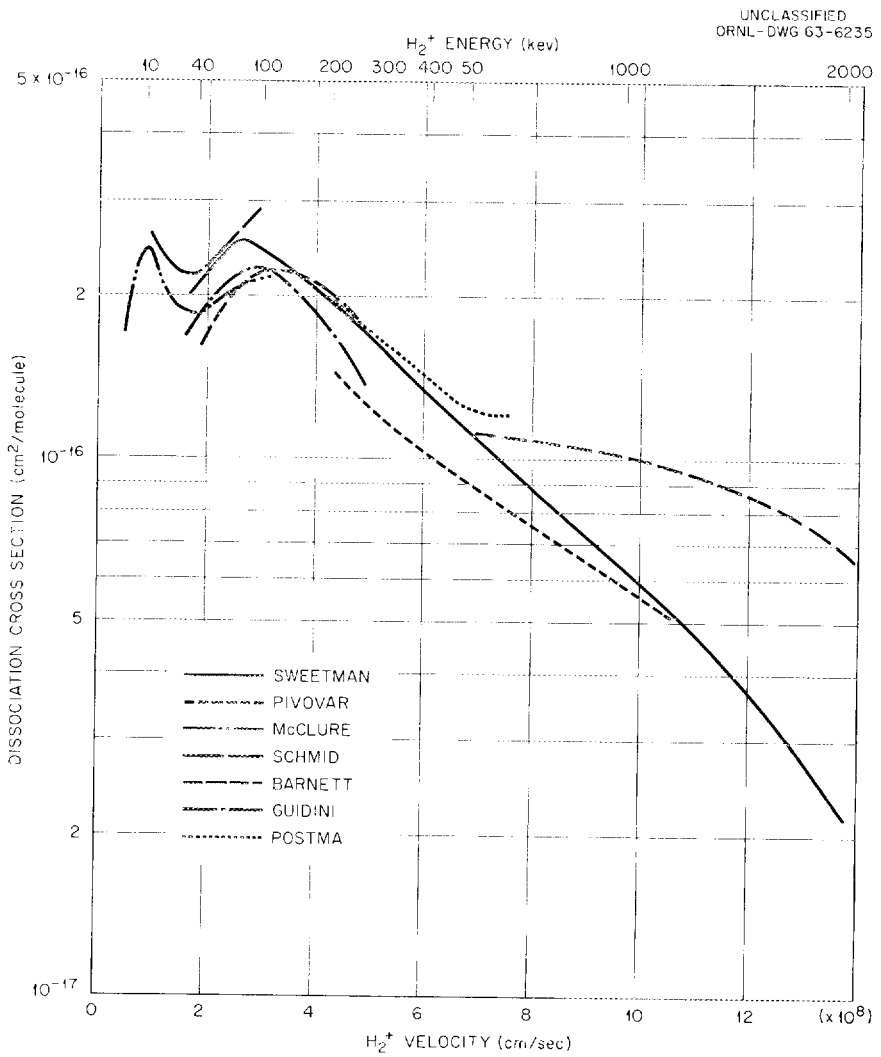

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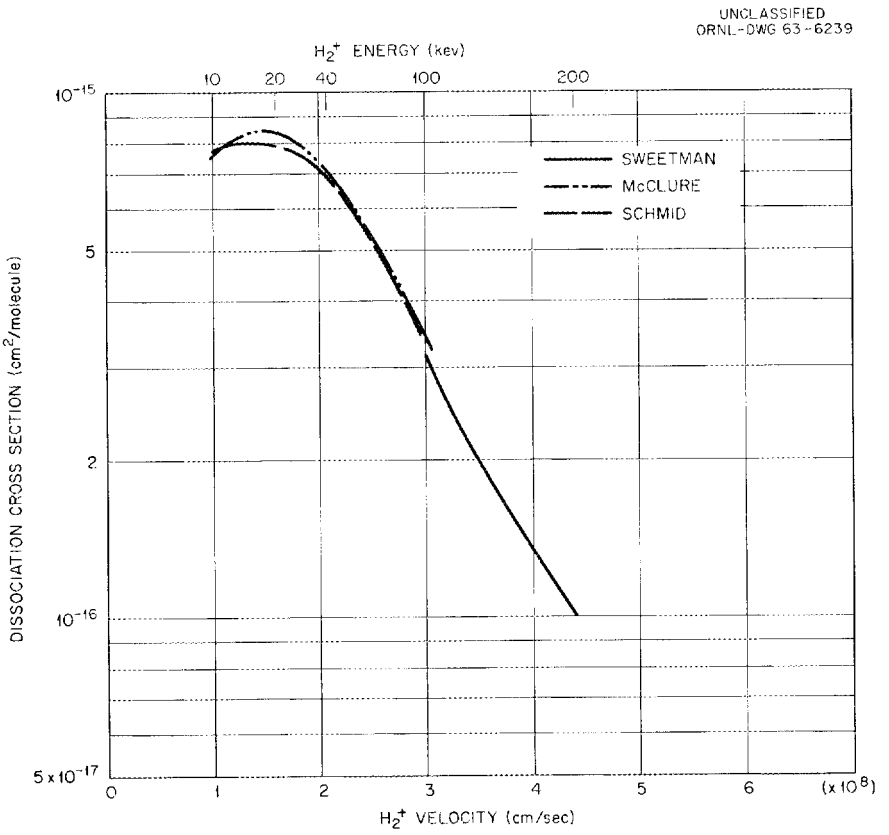

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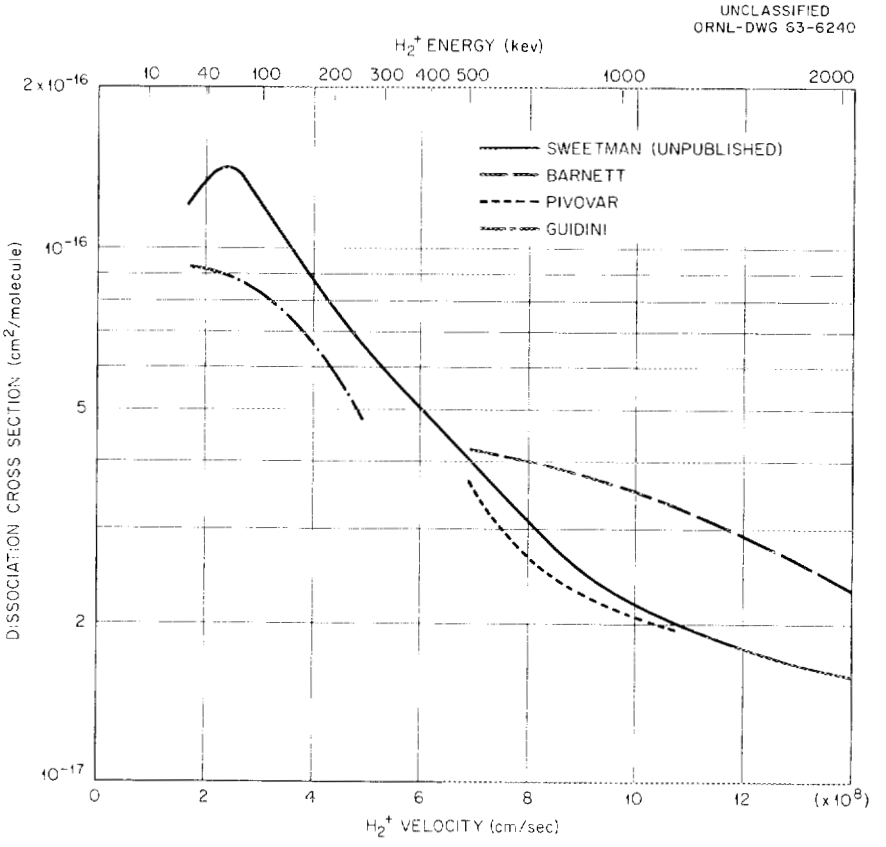

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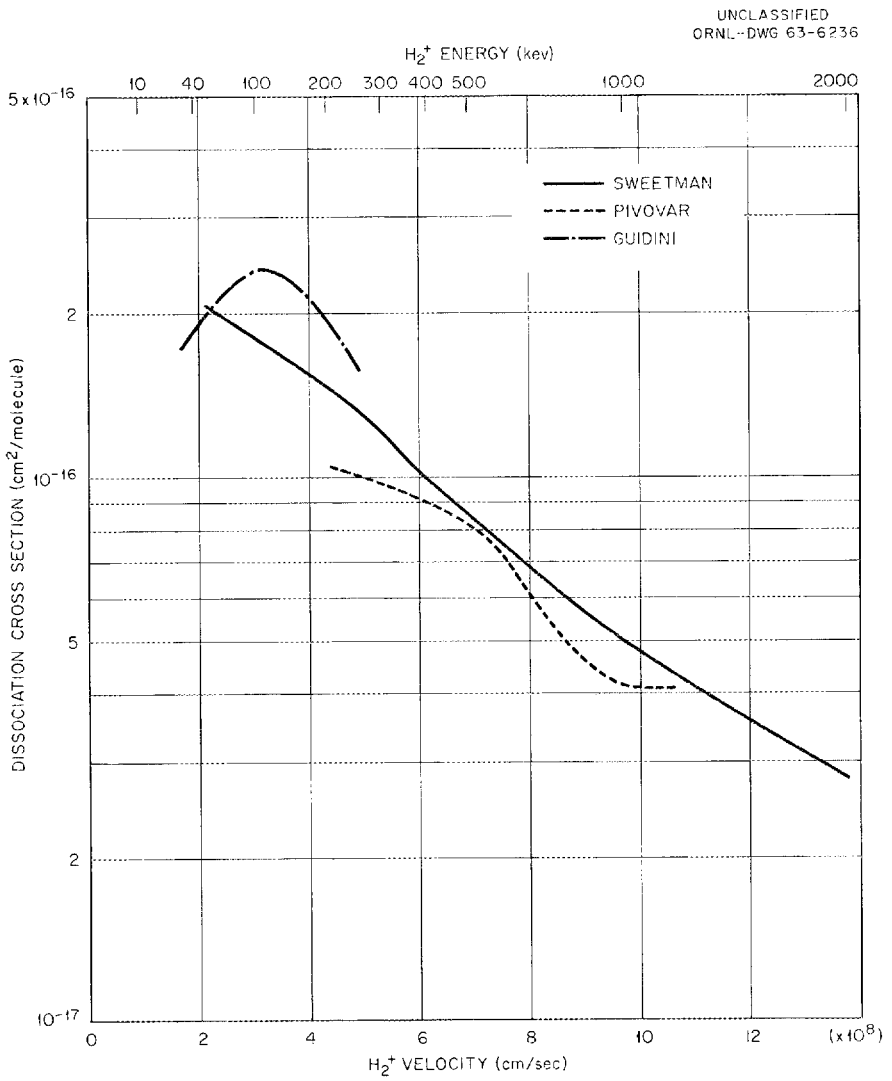

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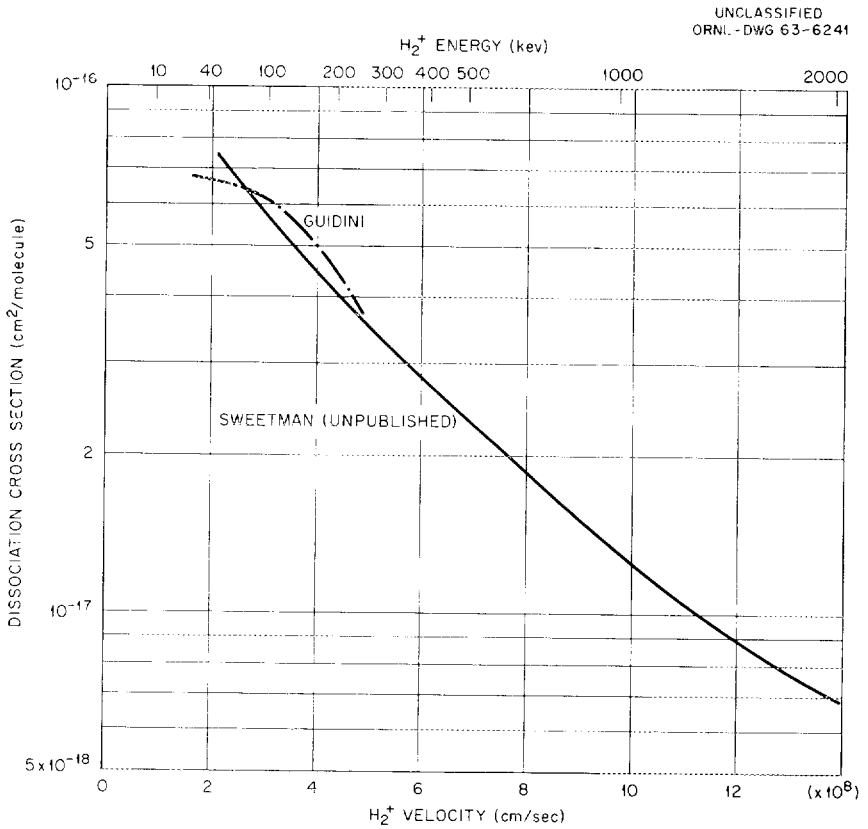

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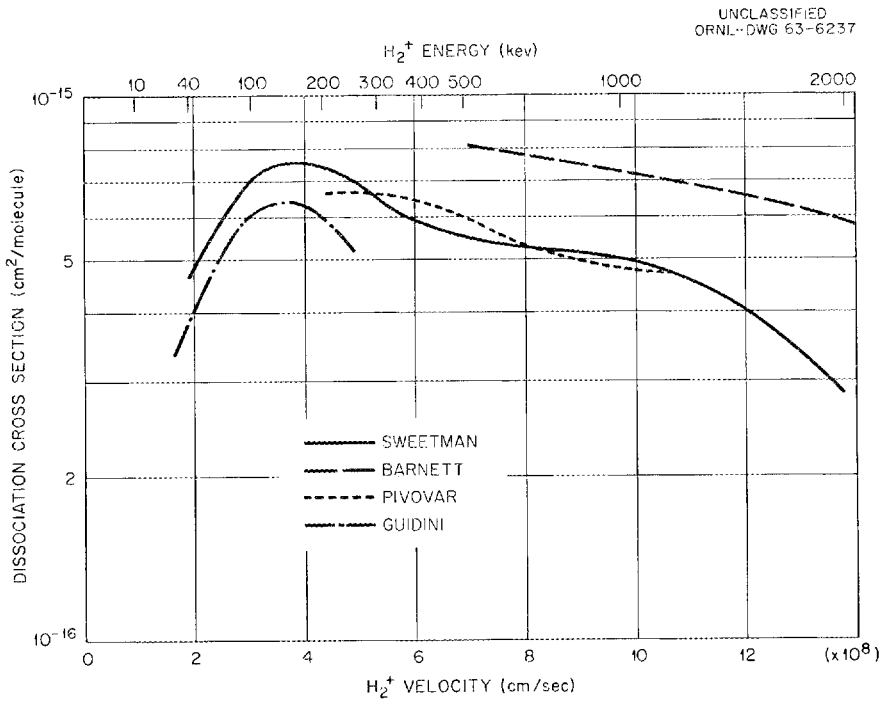

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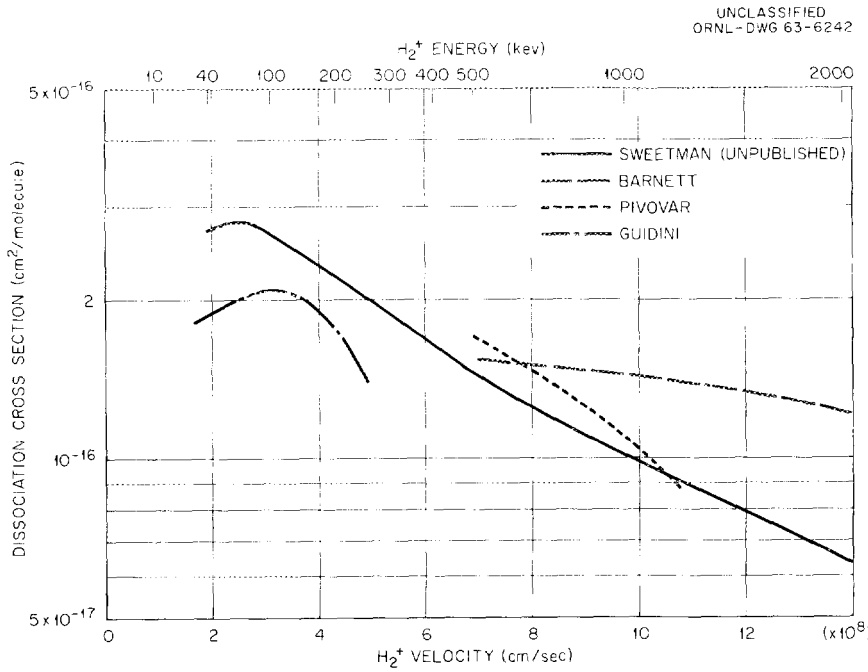

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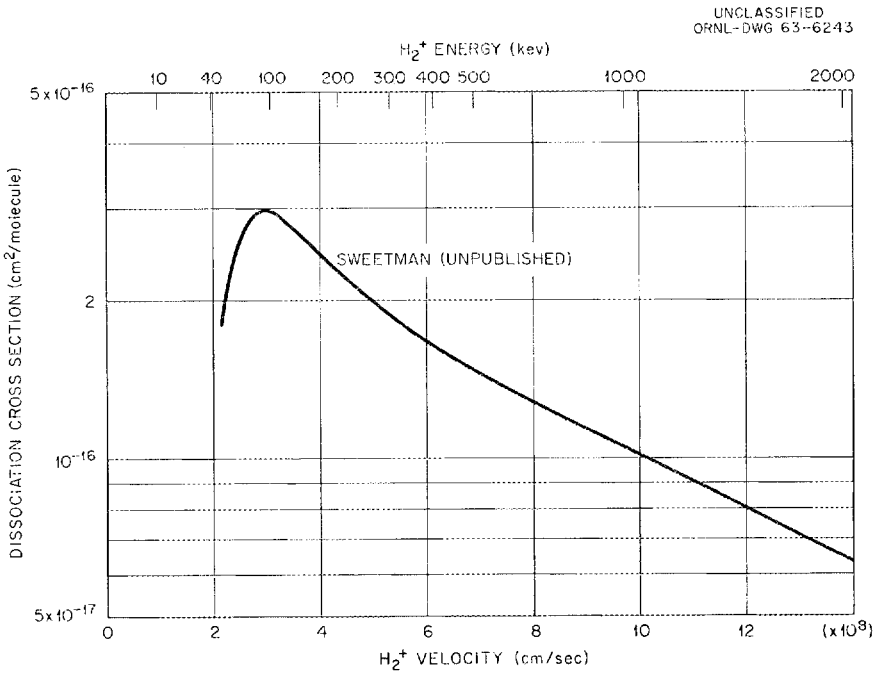

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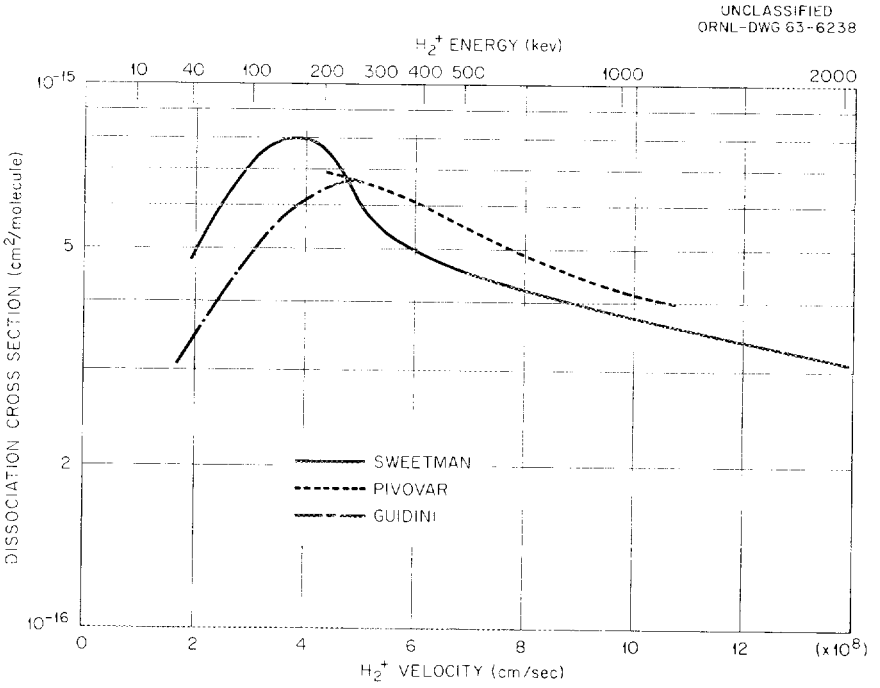

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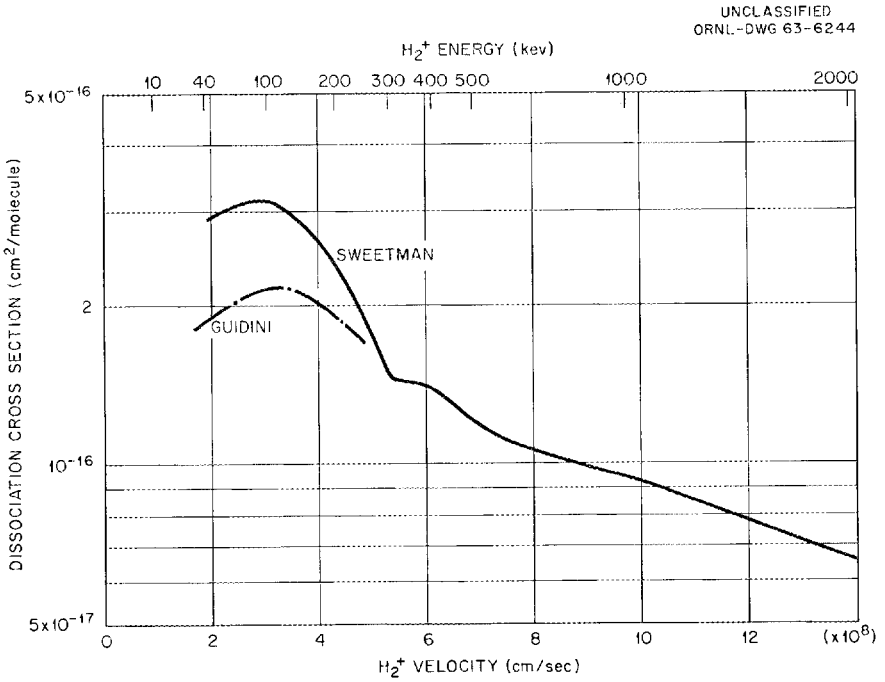

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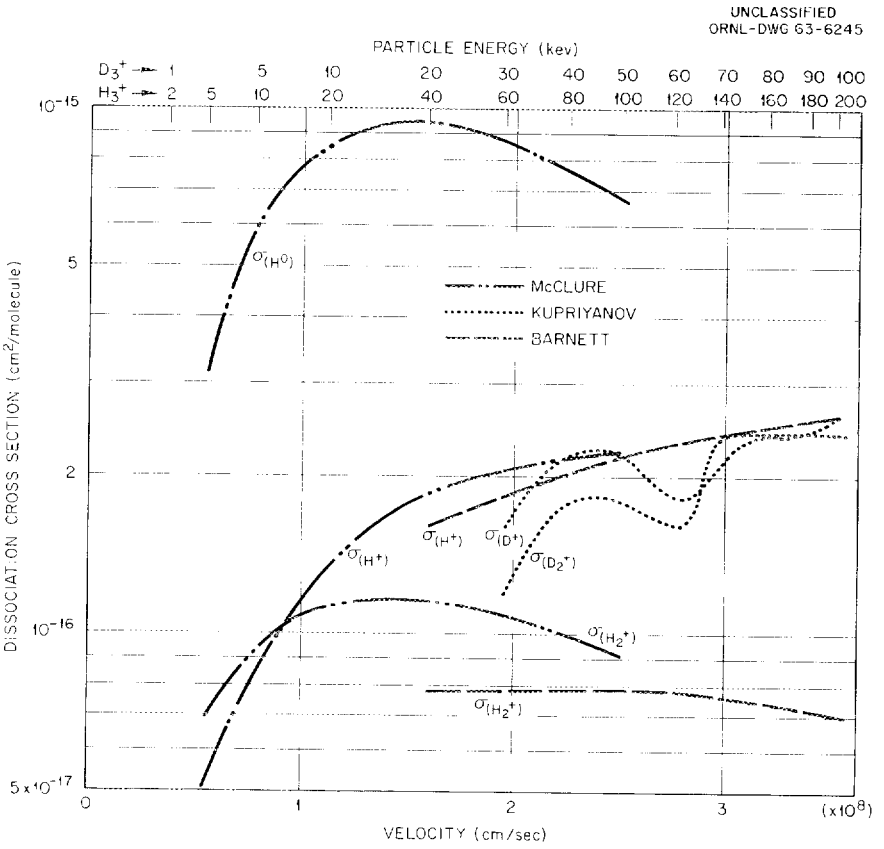

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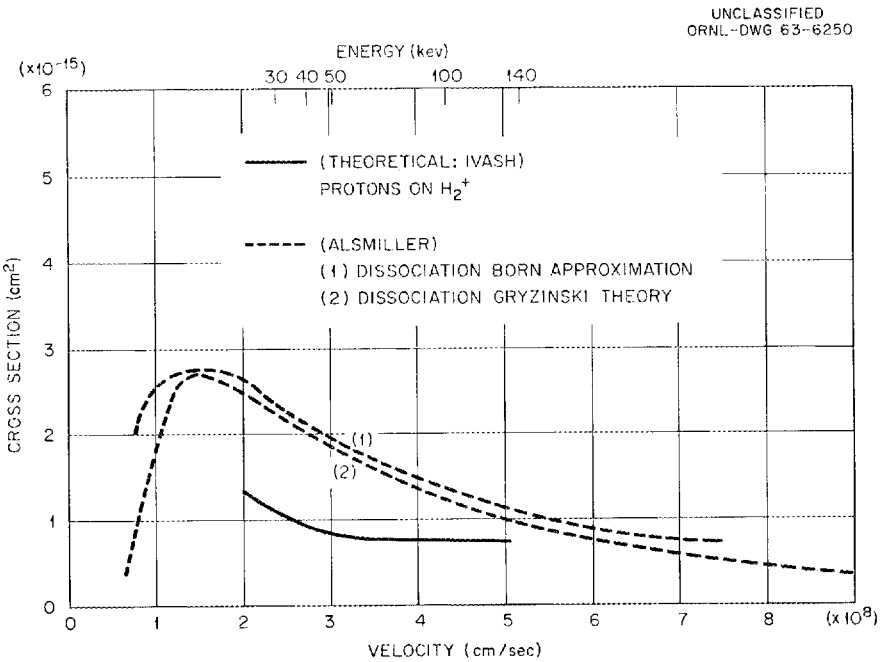

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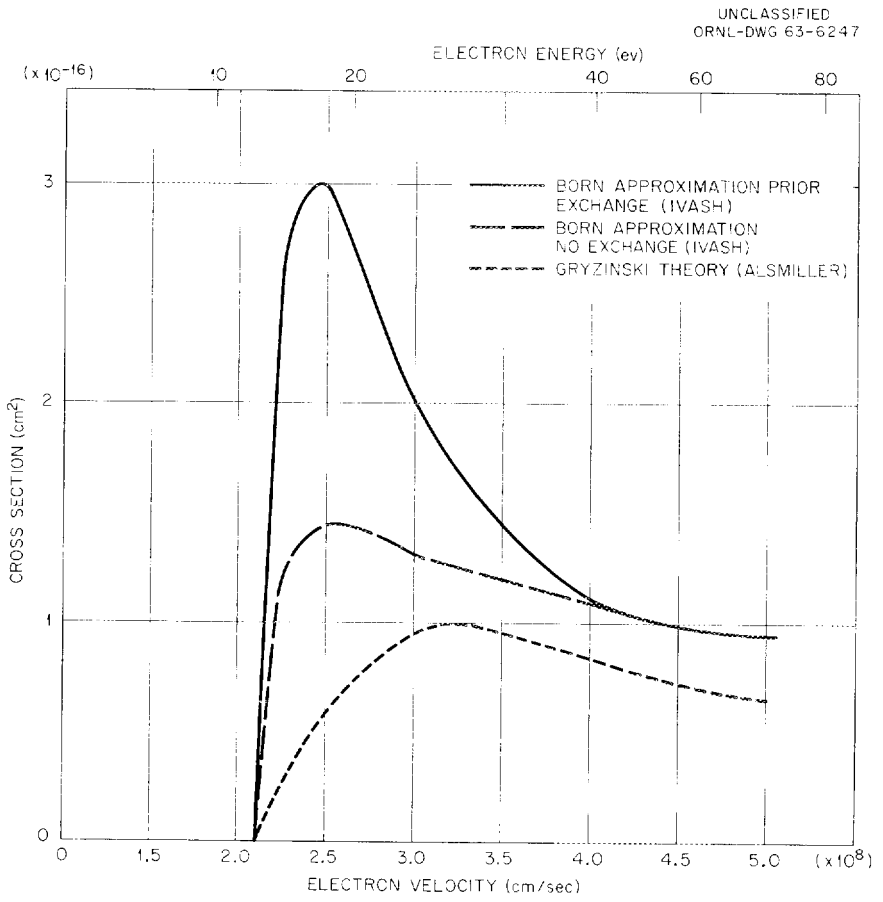

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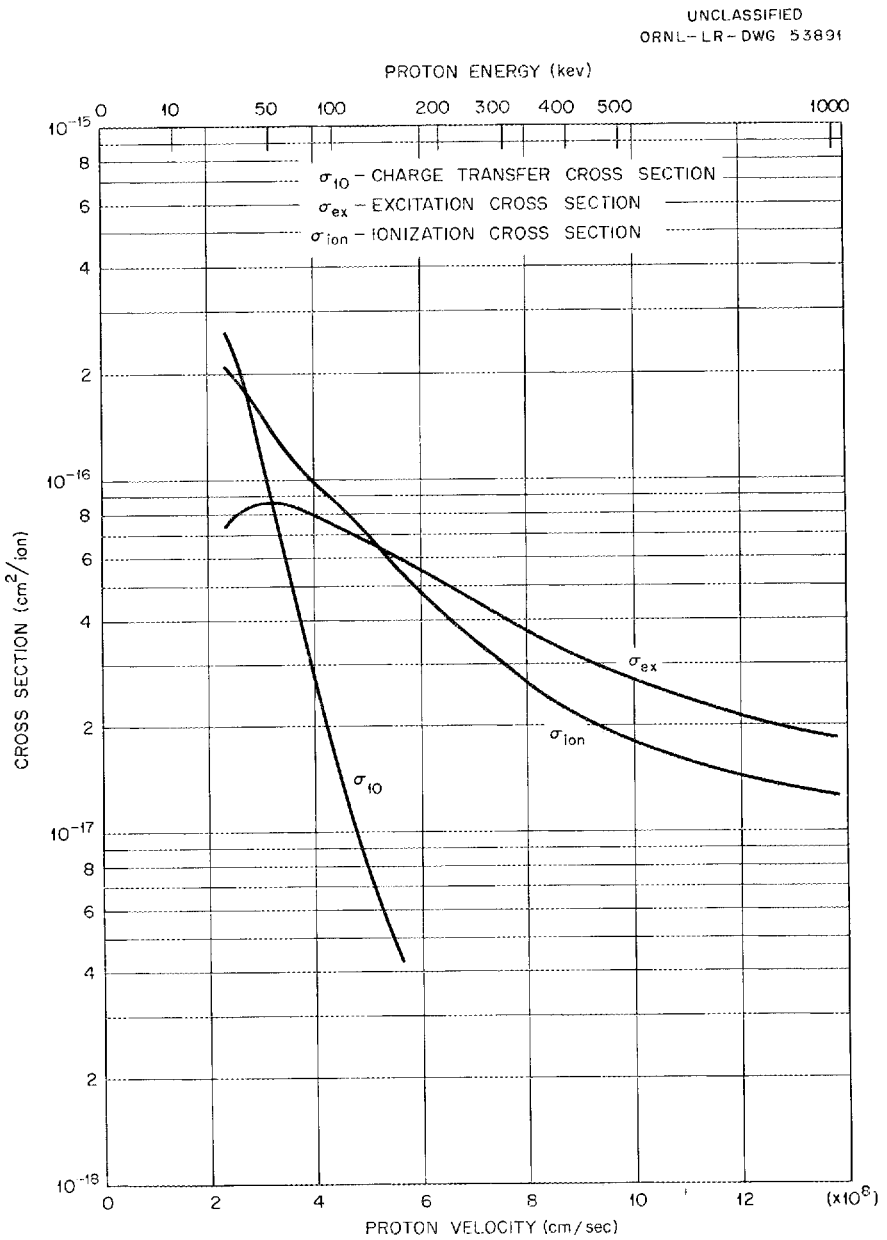
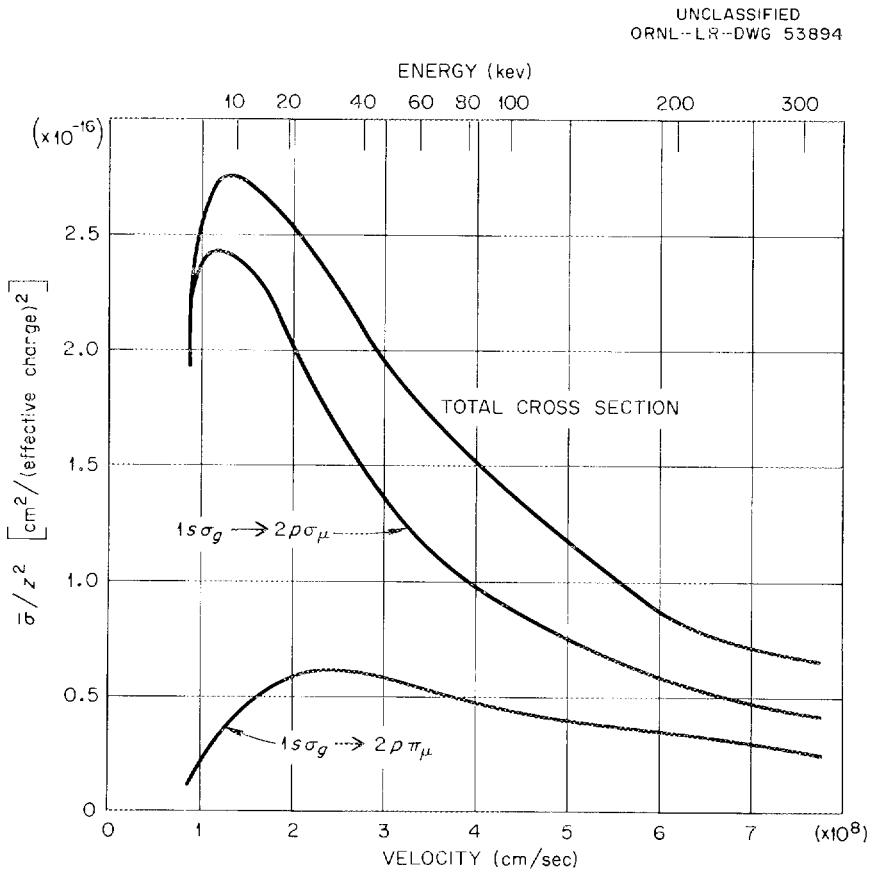
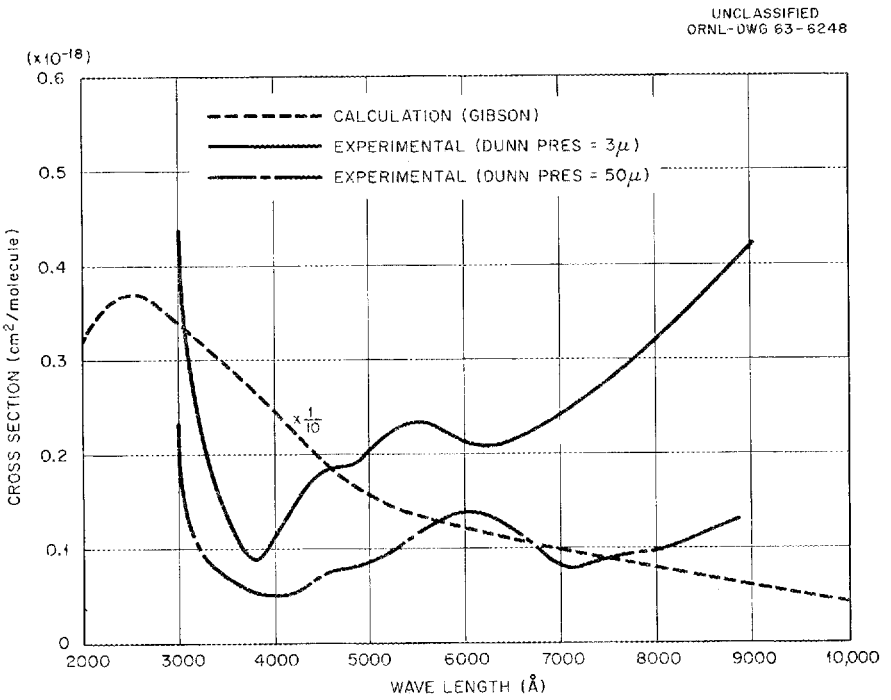


Cross Sections for Dissociation, Ionization, and Excitation of H_2^+ by Protons.



Cross Sections for Dissociation of H_2^+ by Carbon Particles of Charge Z.



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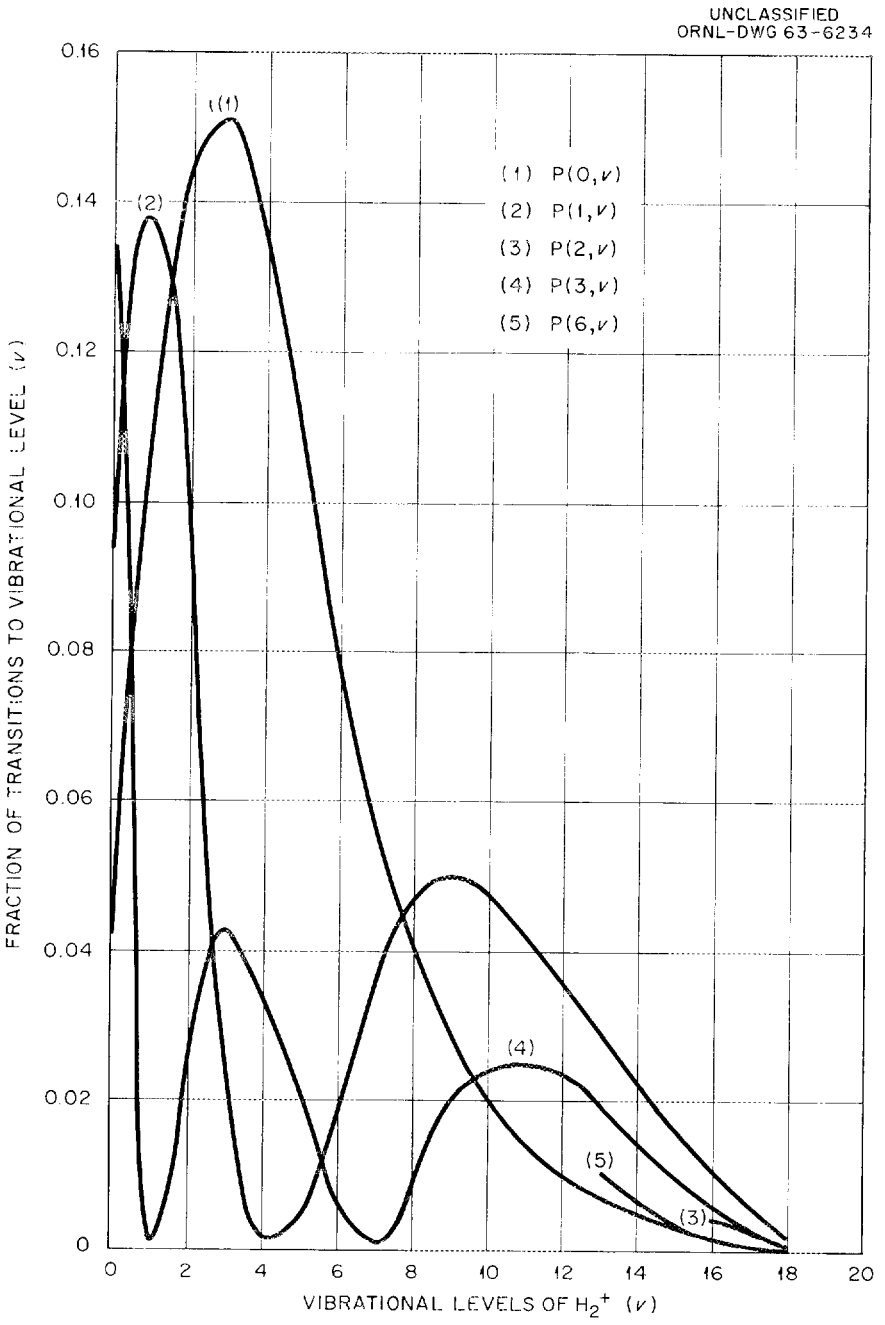

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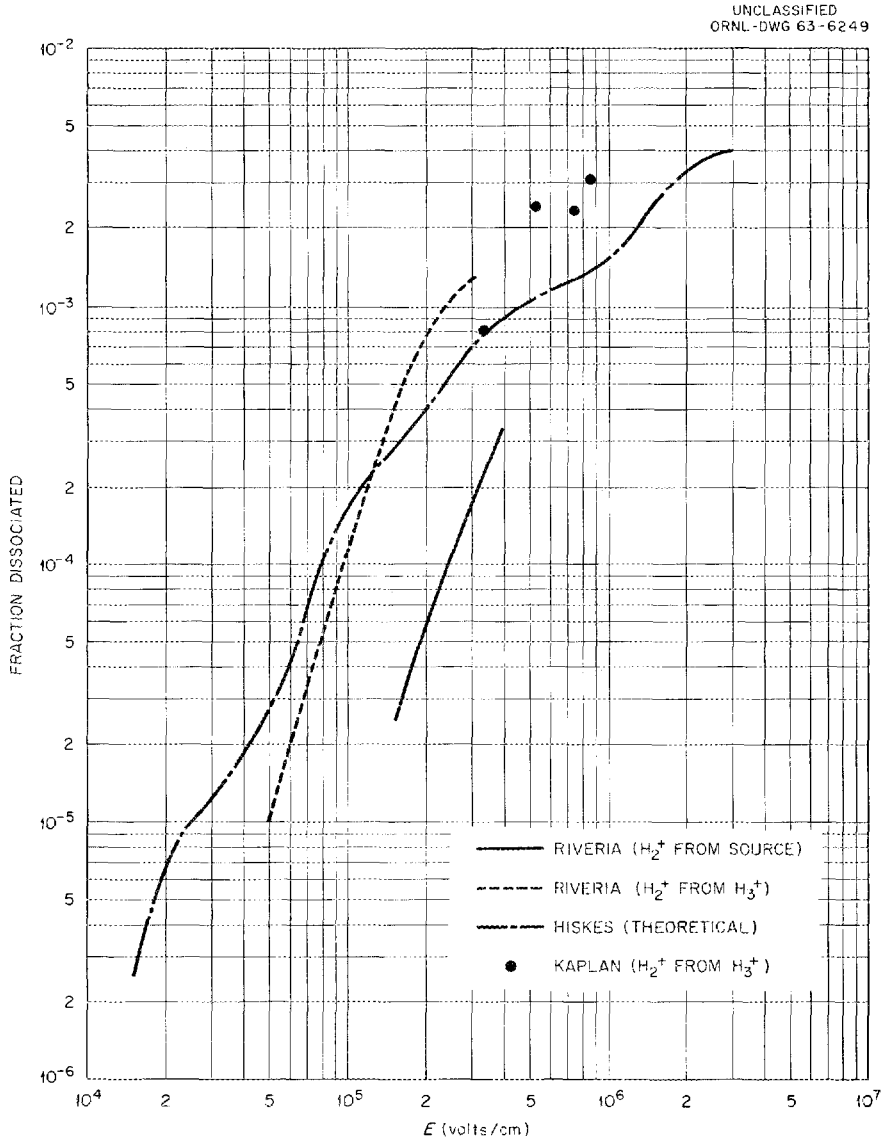

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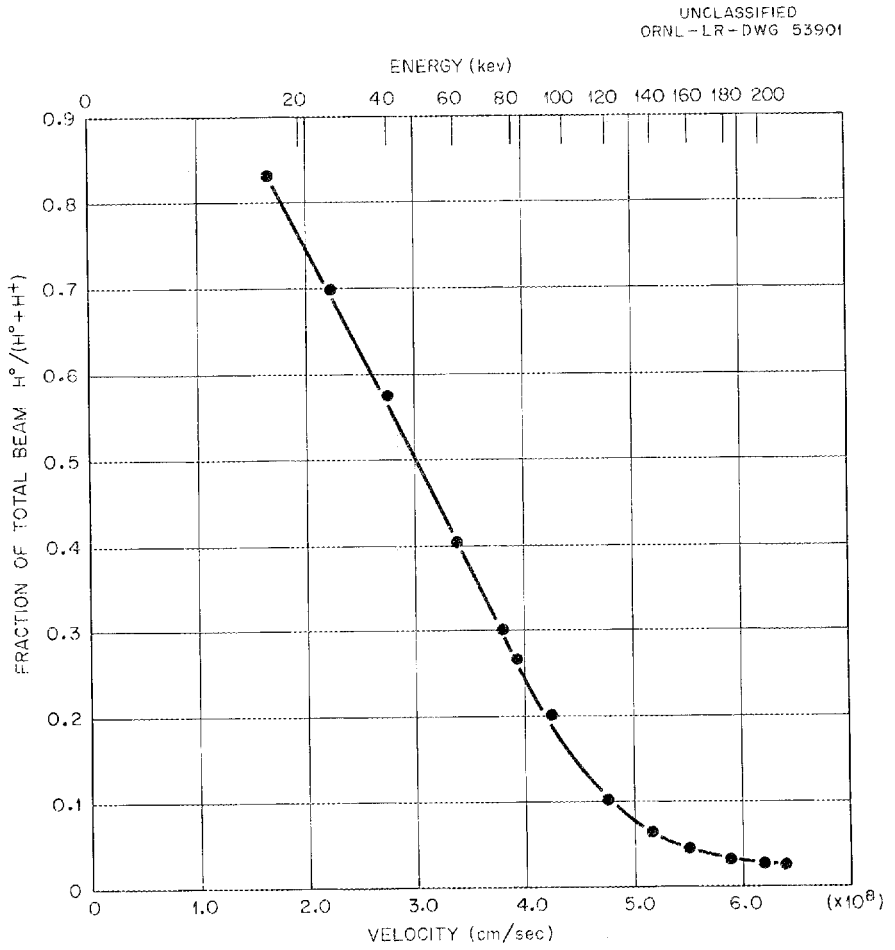
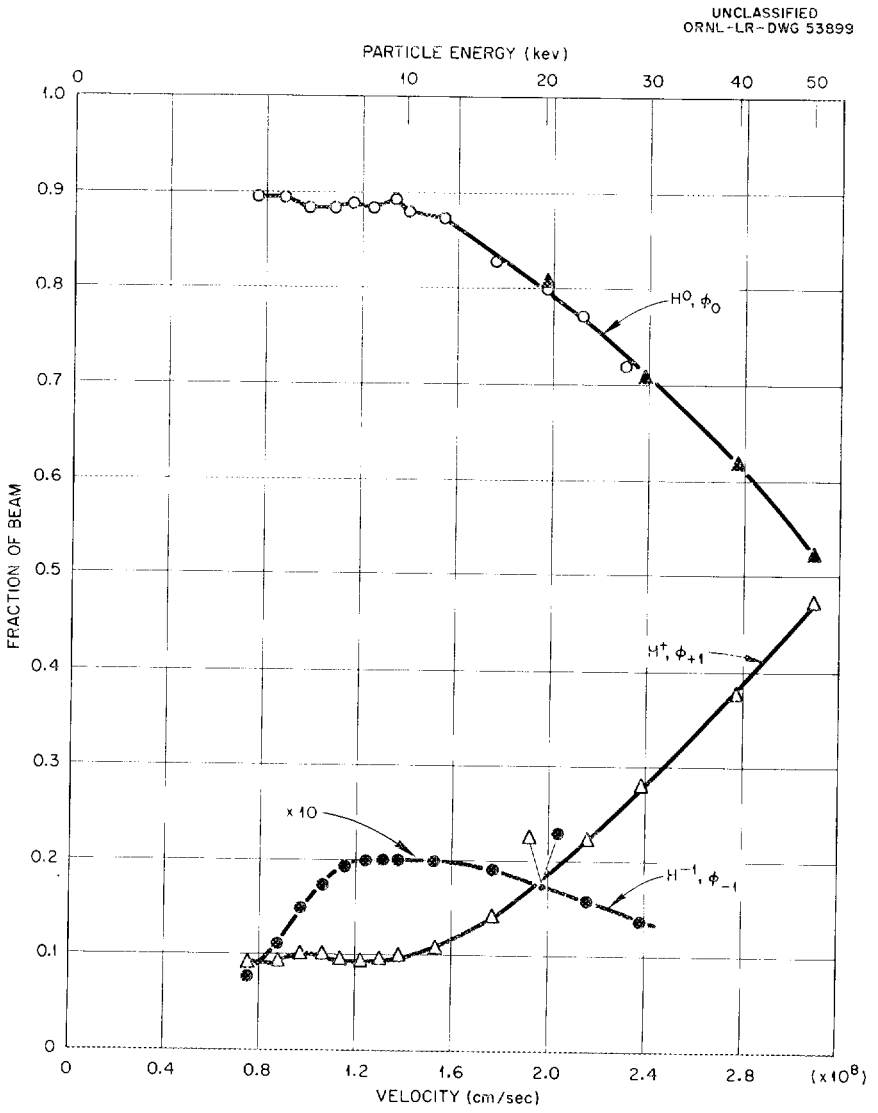
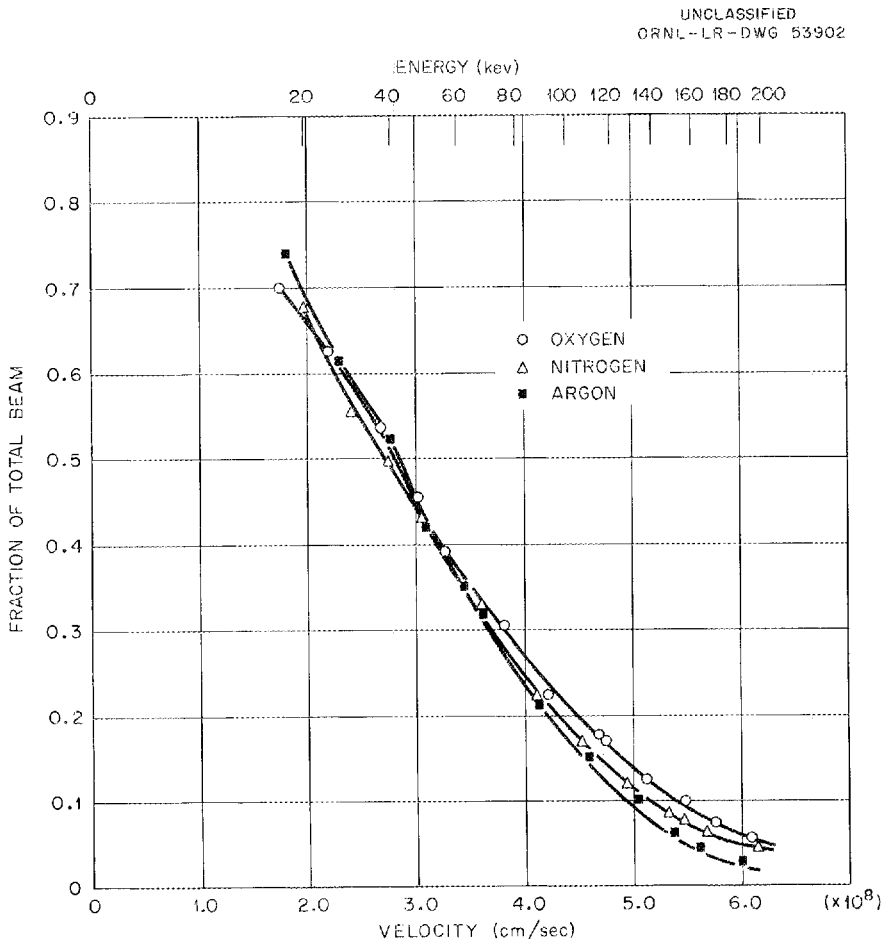


Equilibrium Fractions of H^0 in Hydrogen Gas.



Fraction of Beam in +1, 0, −1 Charge State After Passage Through "Thick" Target. H in Hydrogen Gas.



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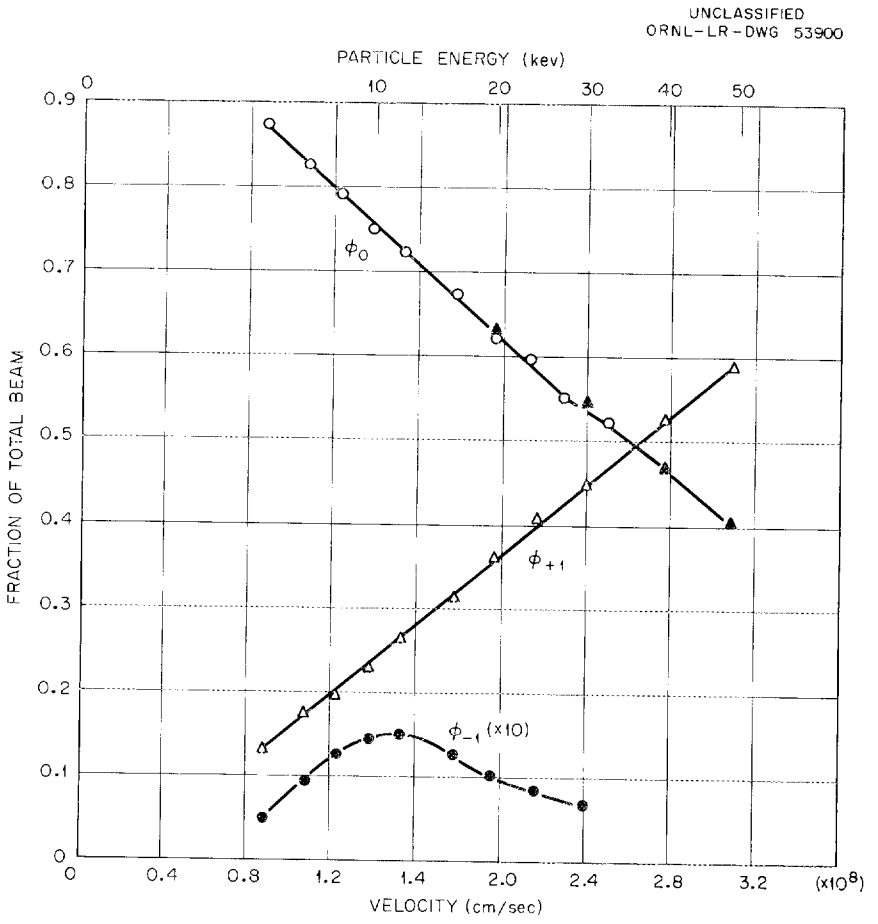

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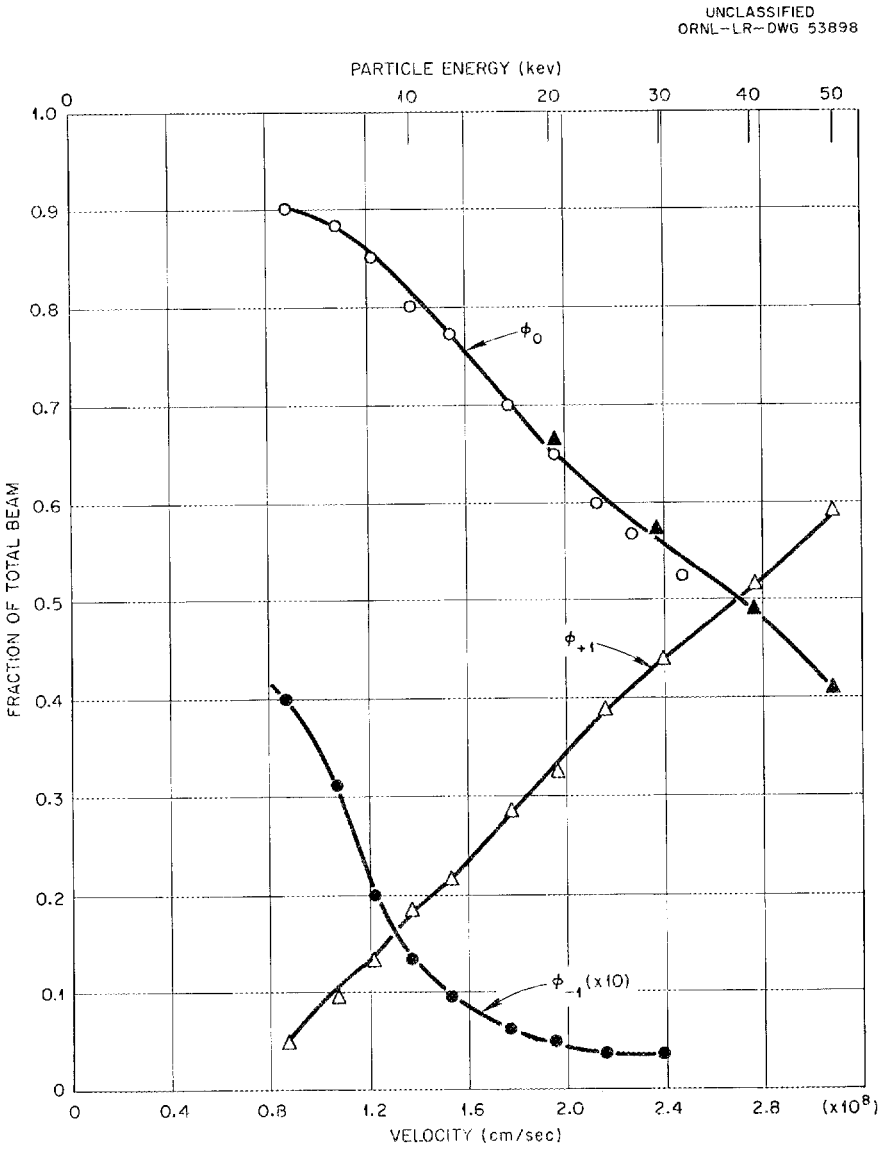
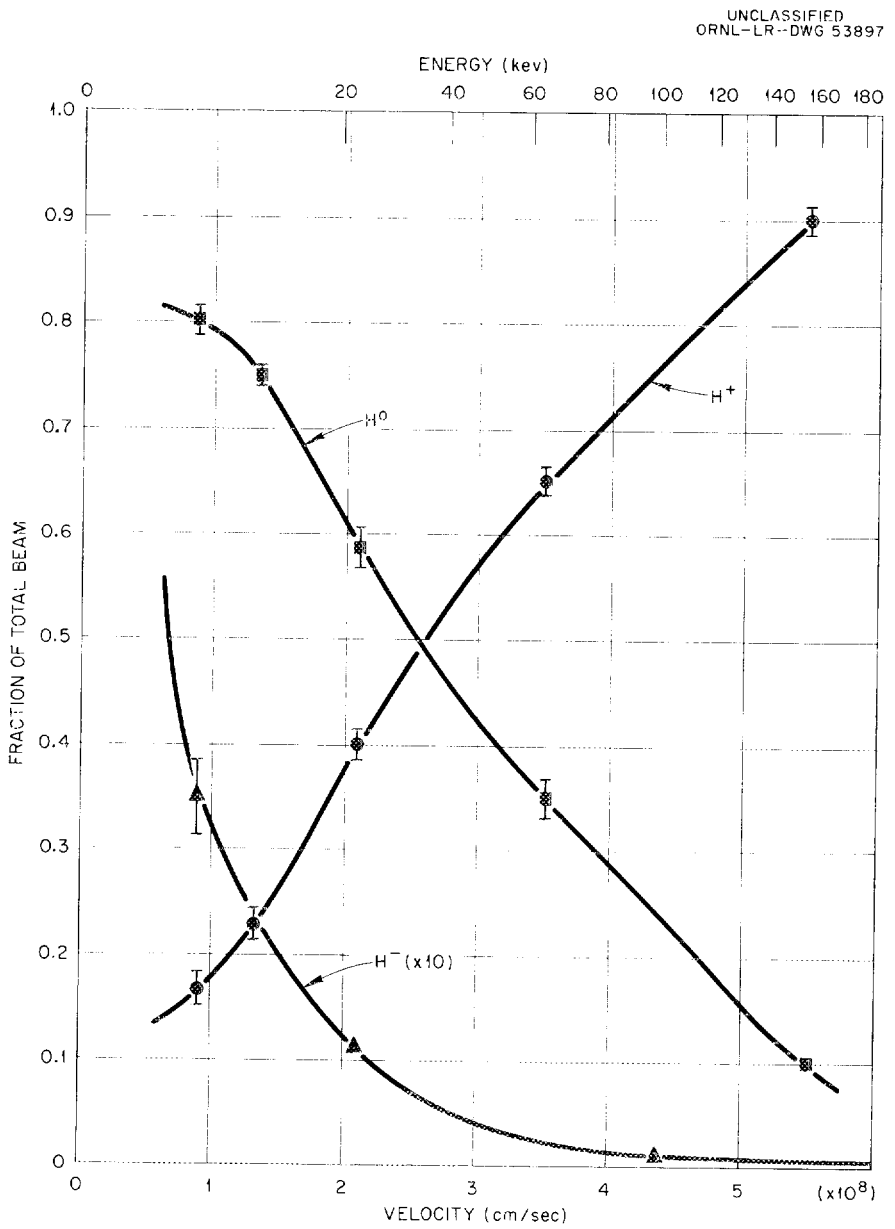


Fraction of Beam in +1, 0, −1 Charge State After Passage Through "Thick" Target. H in Argon Gas.



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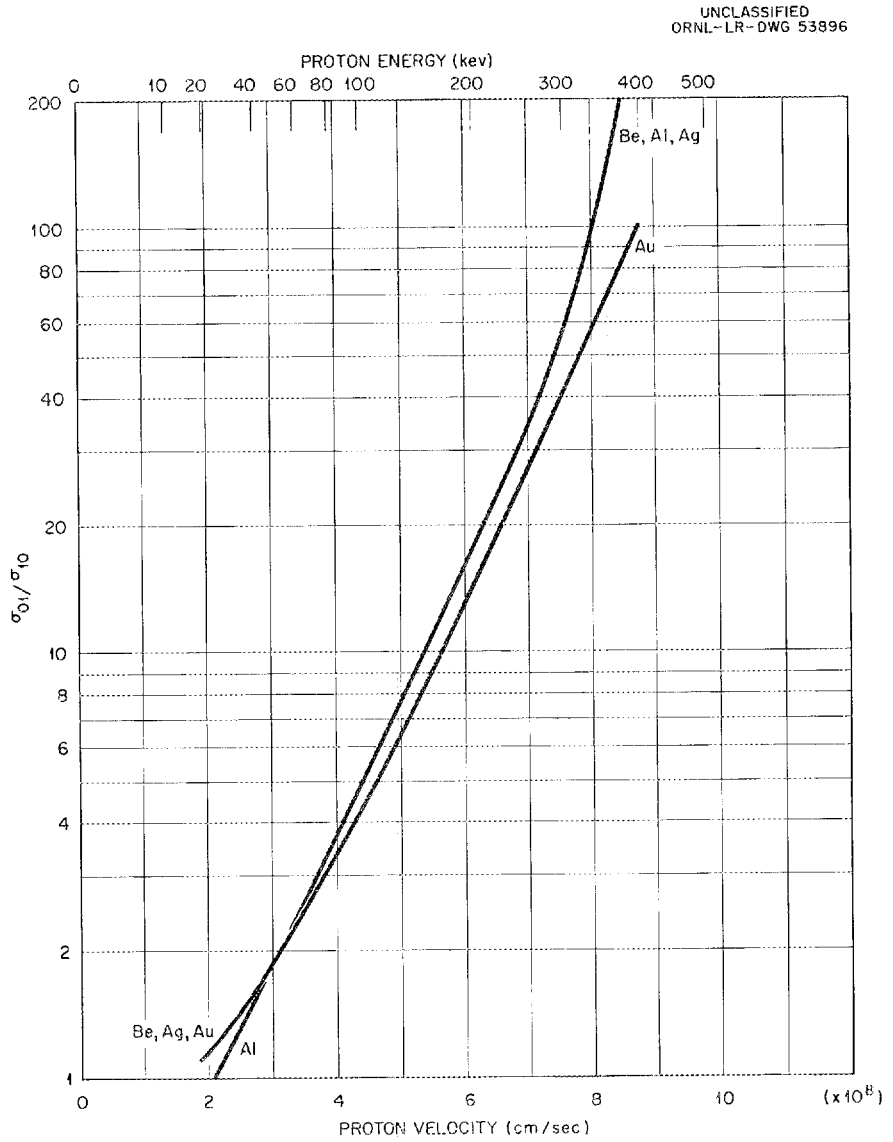
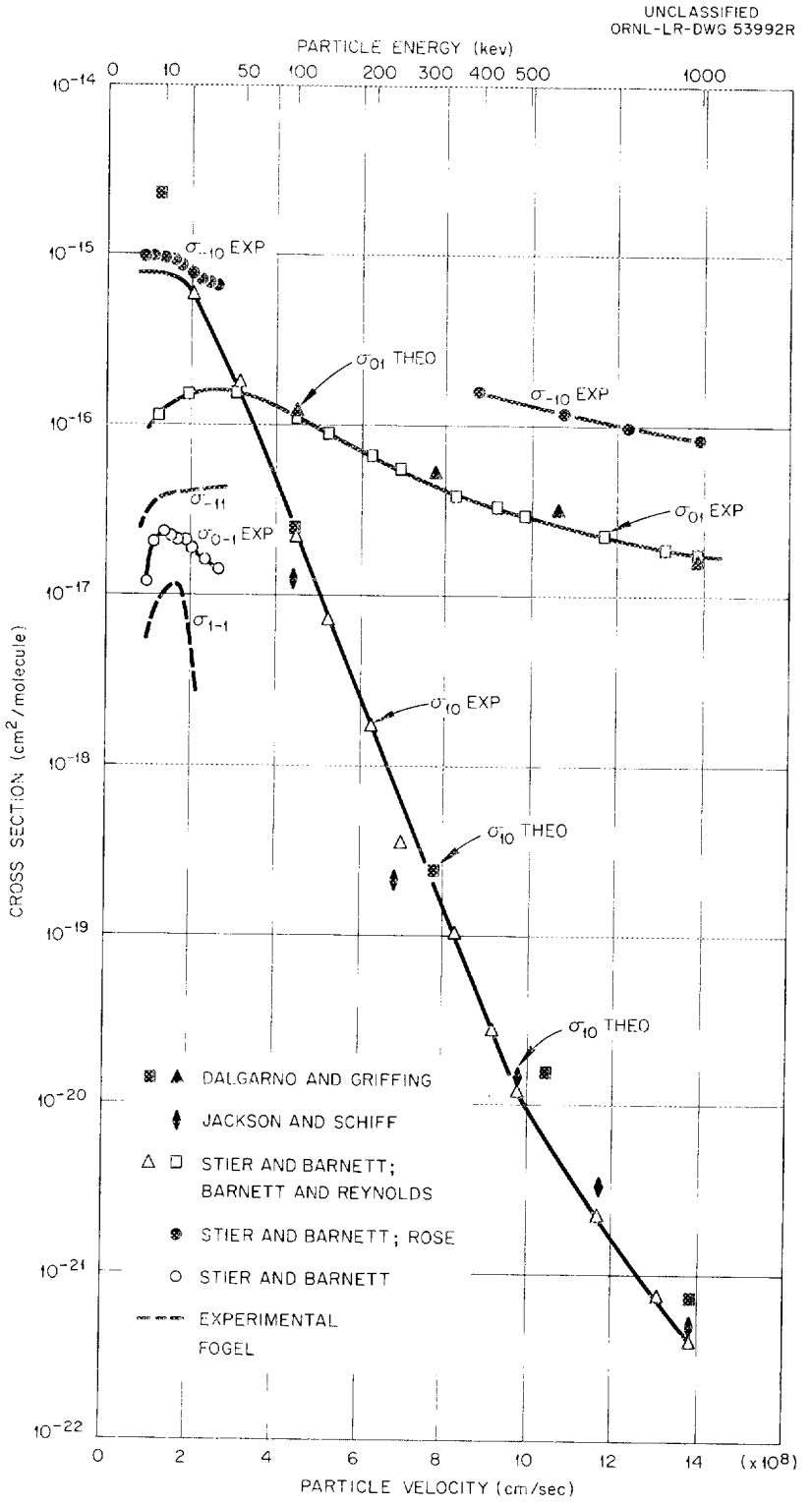
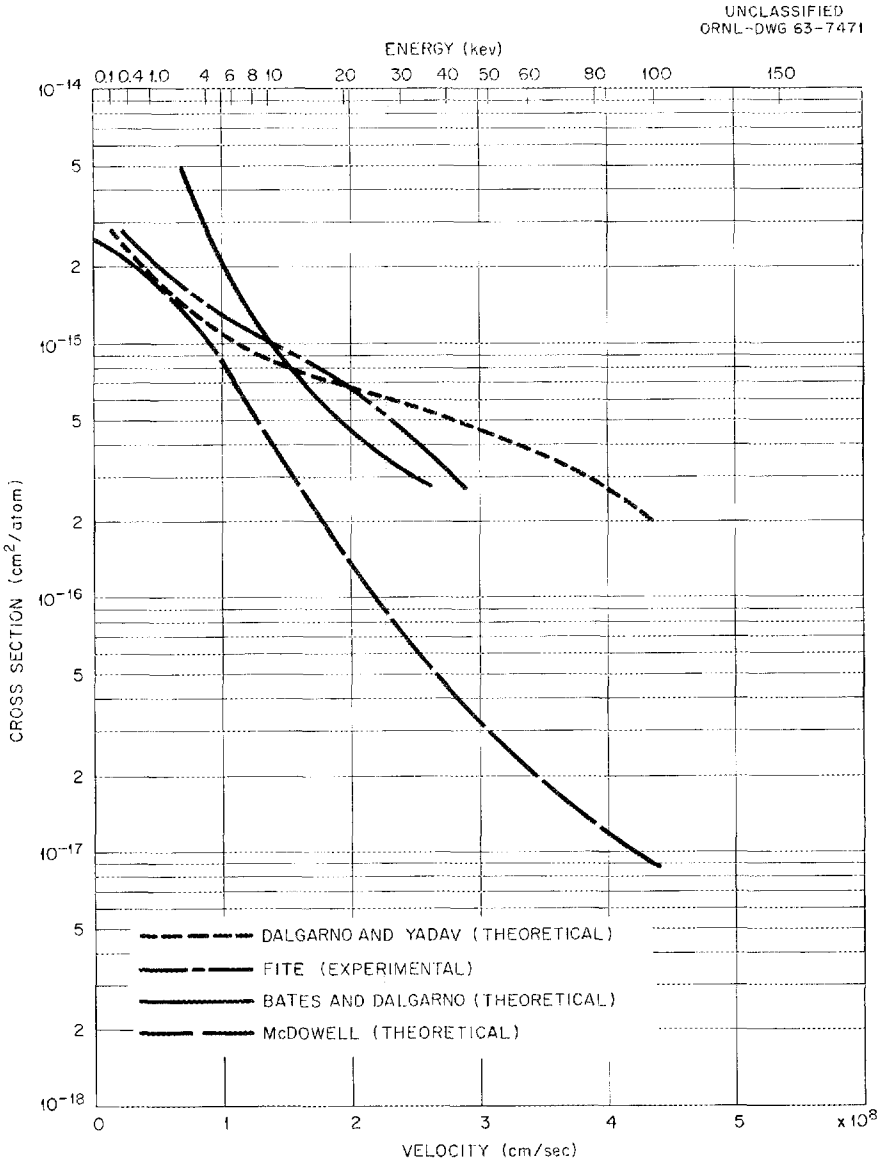


The Ratio of the Electron Capture Cross Section to the Electron Loss Cross Section for Protons in Various Metals.



Charge Transfer Cross Sections of Hydrogen Atoms and Ions in Hydrogen Gas.



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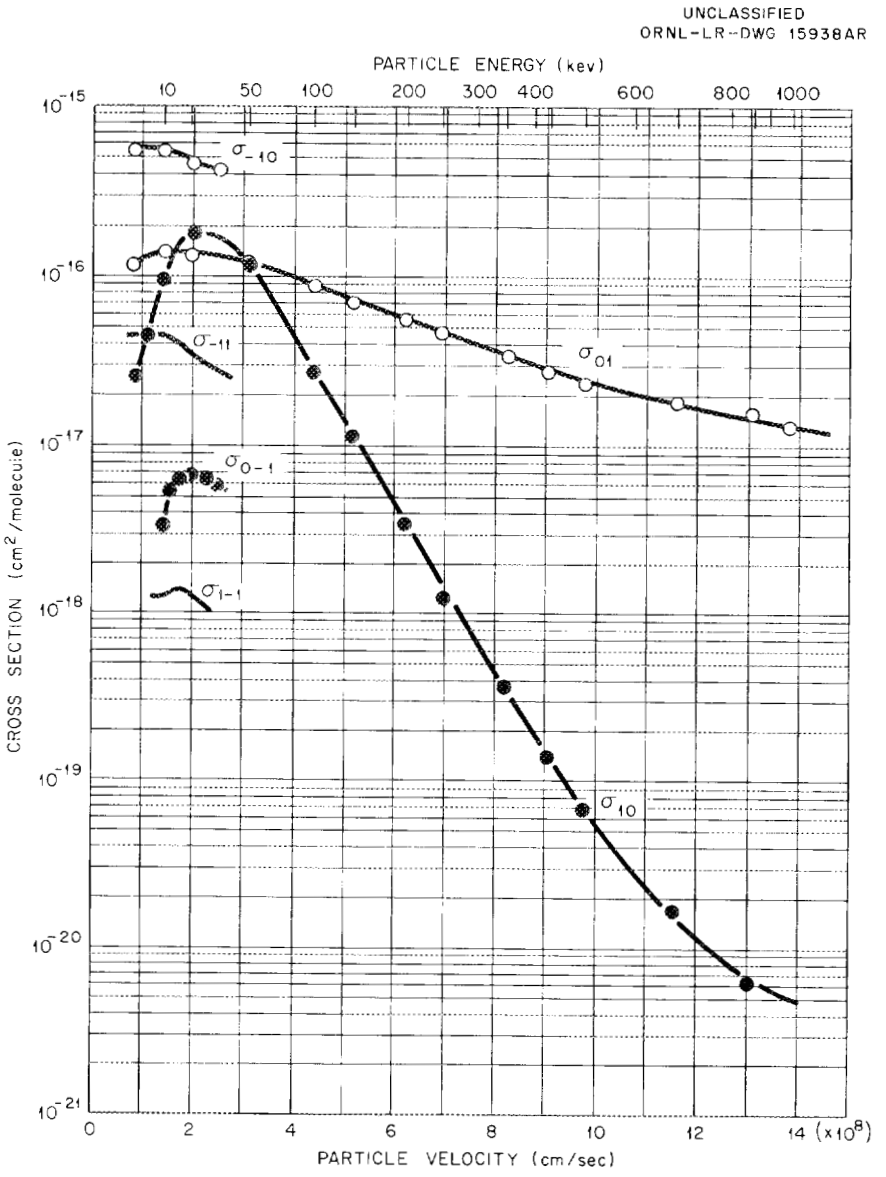

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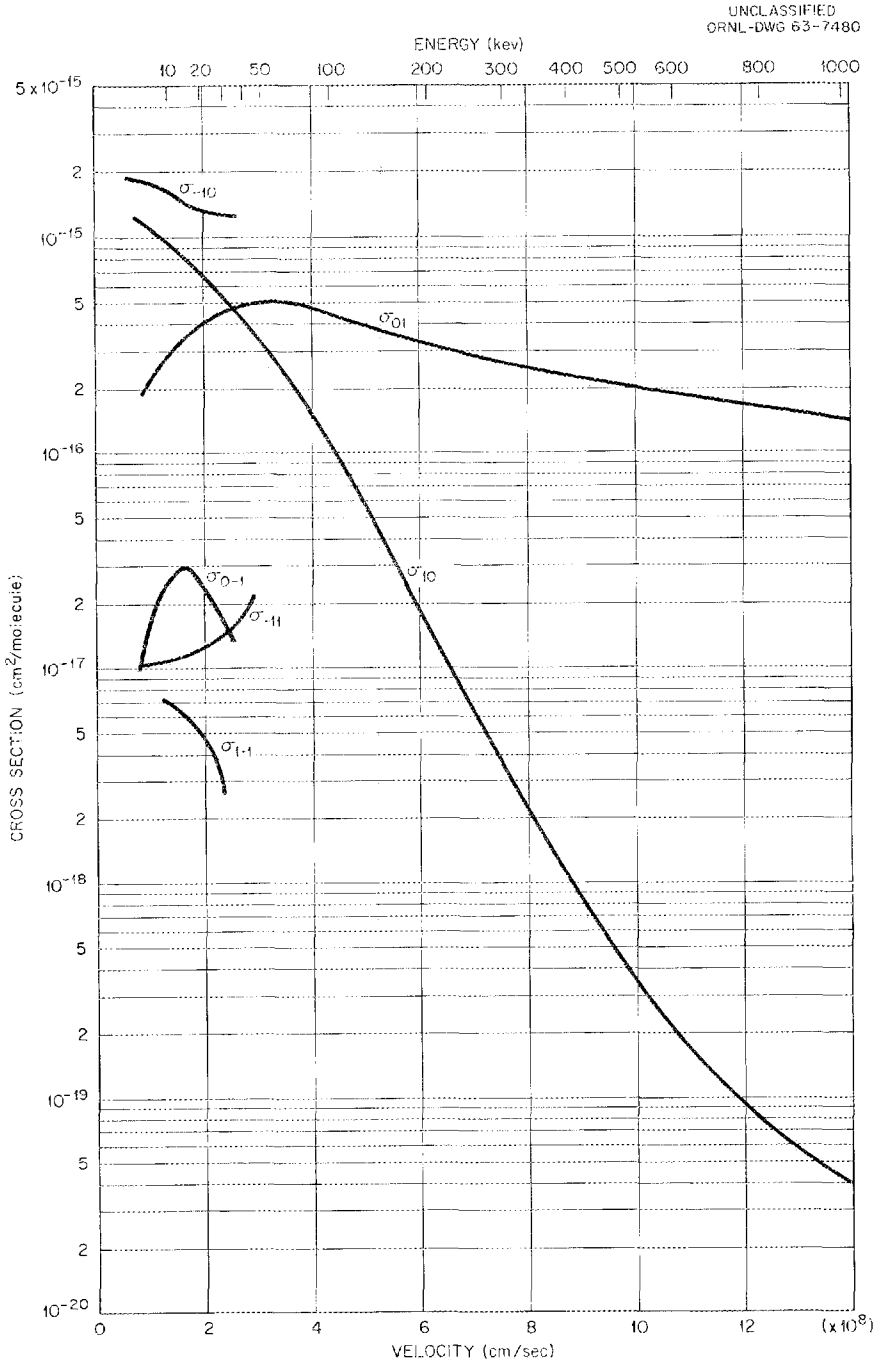

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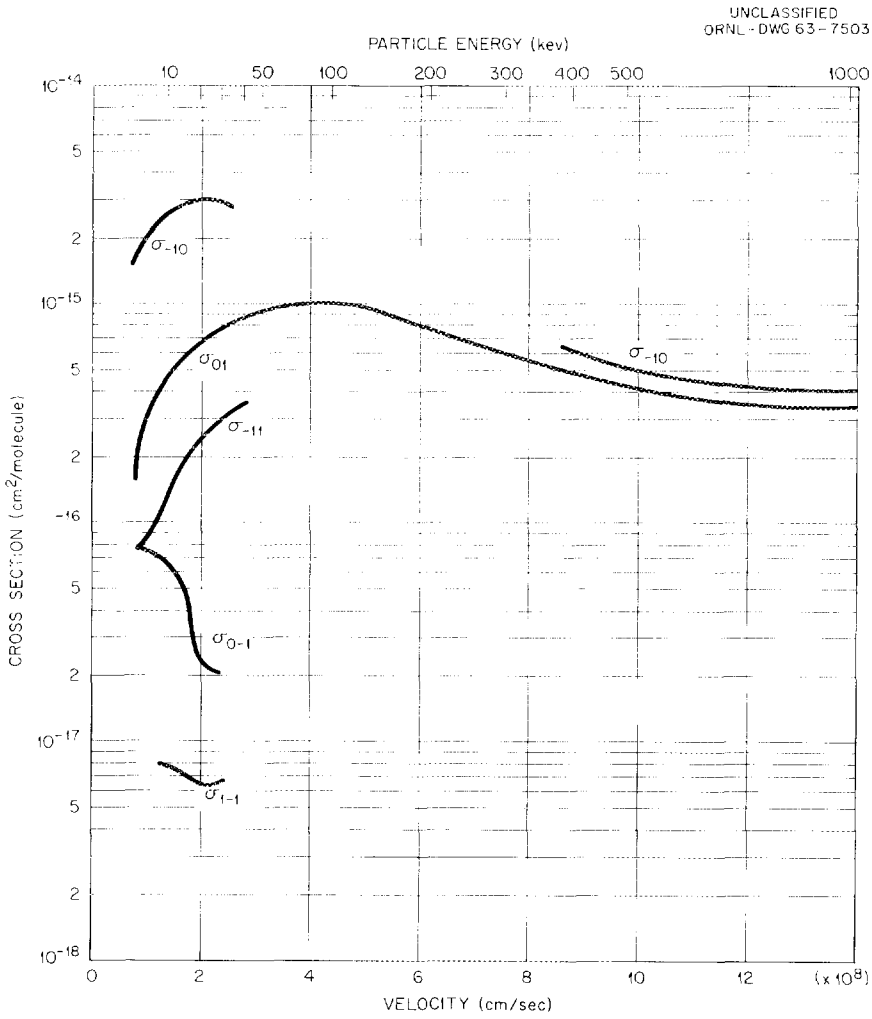

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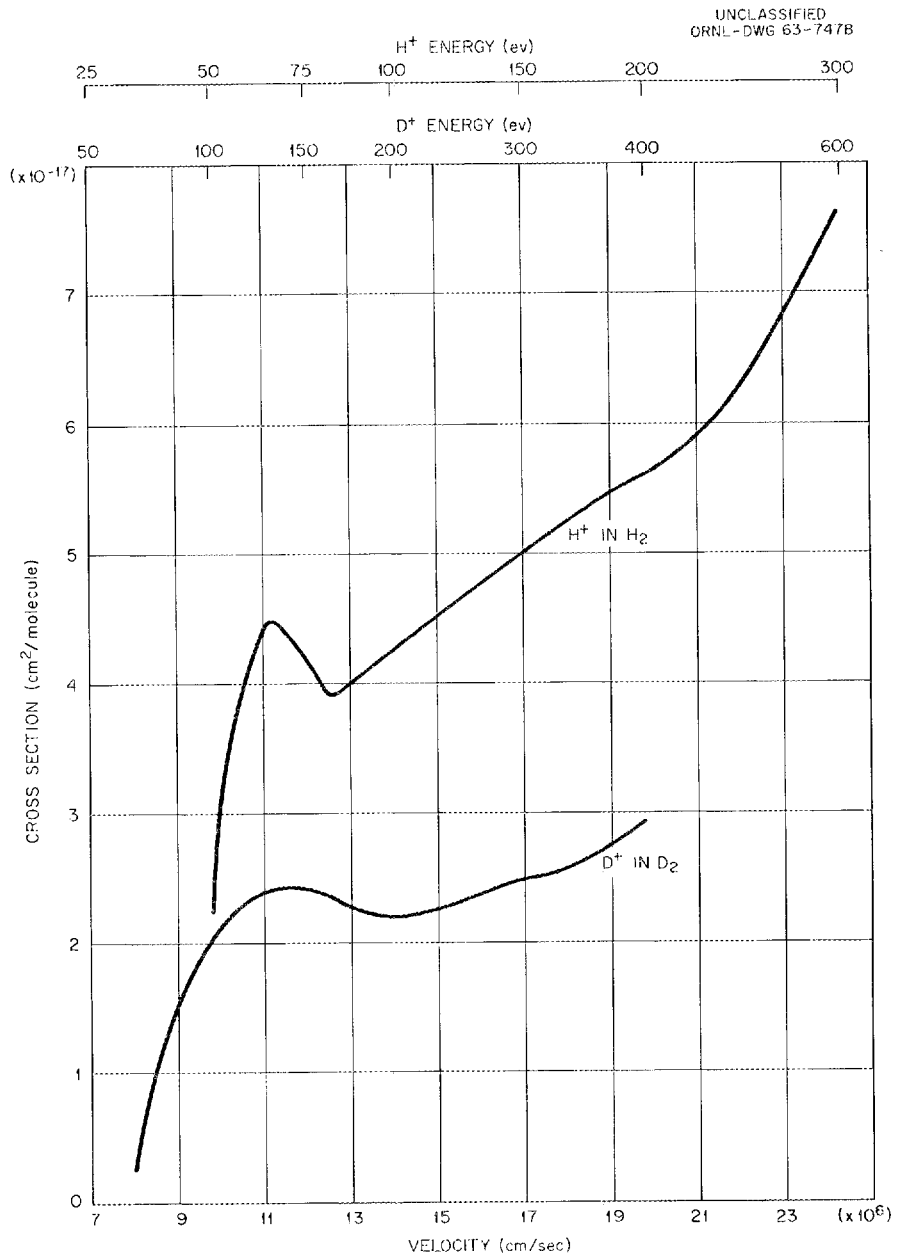

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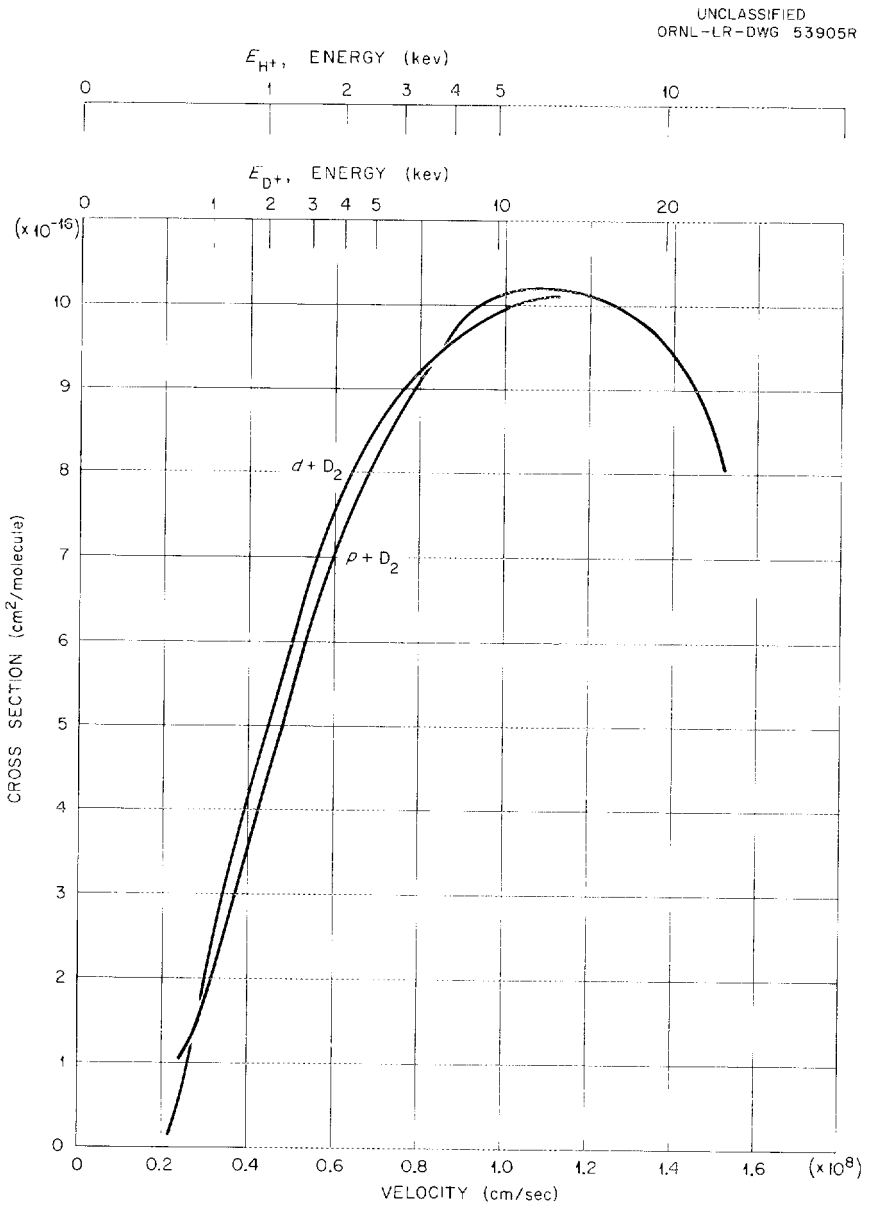

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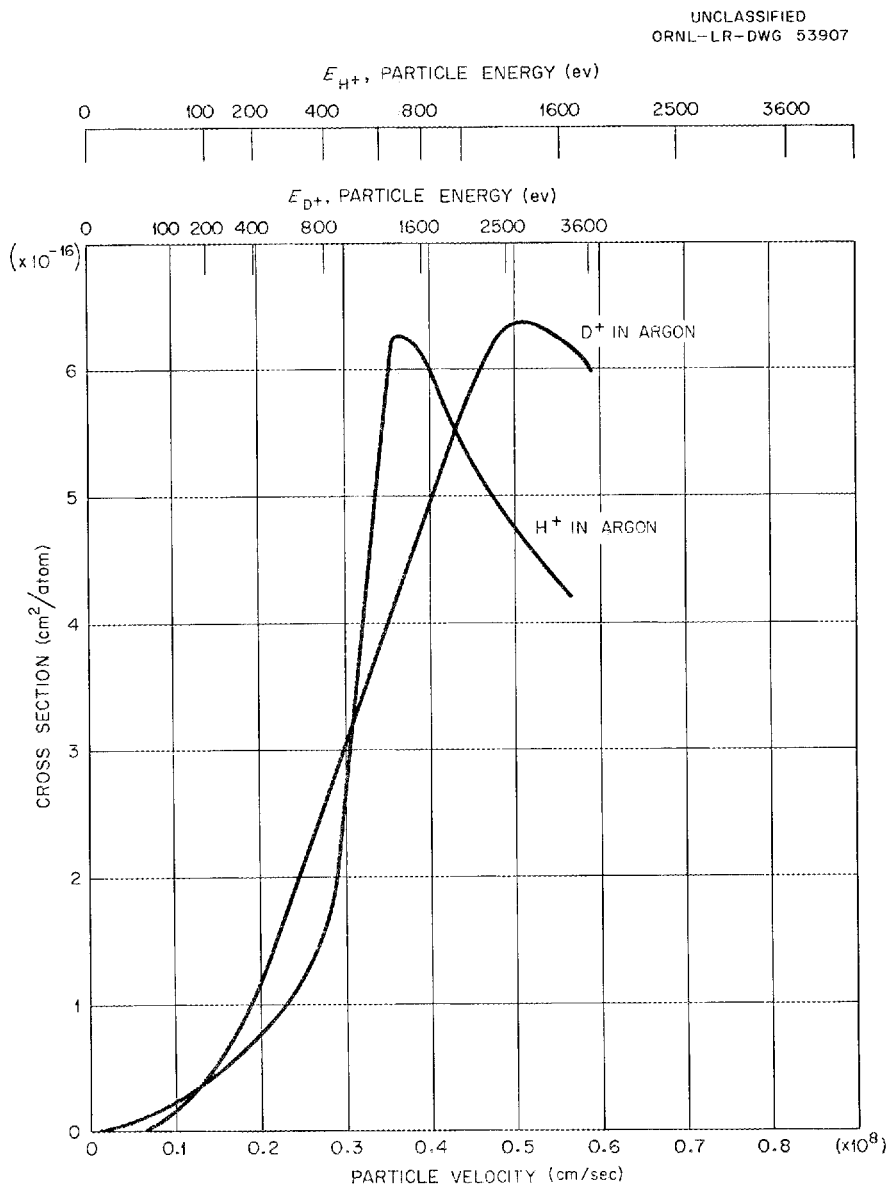

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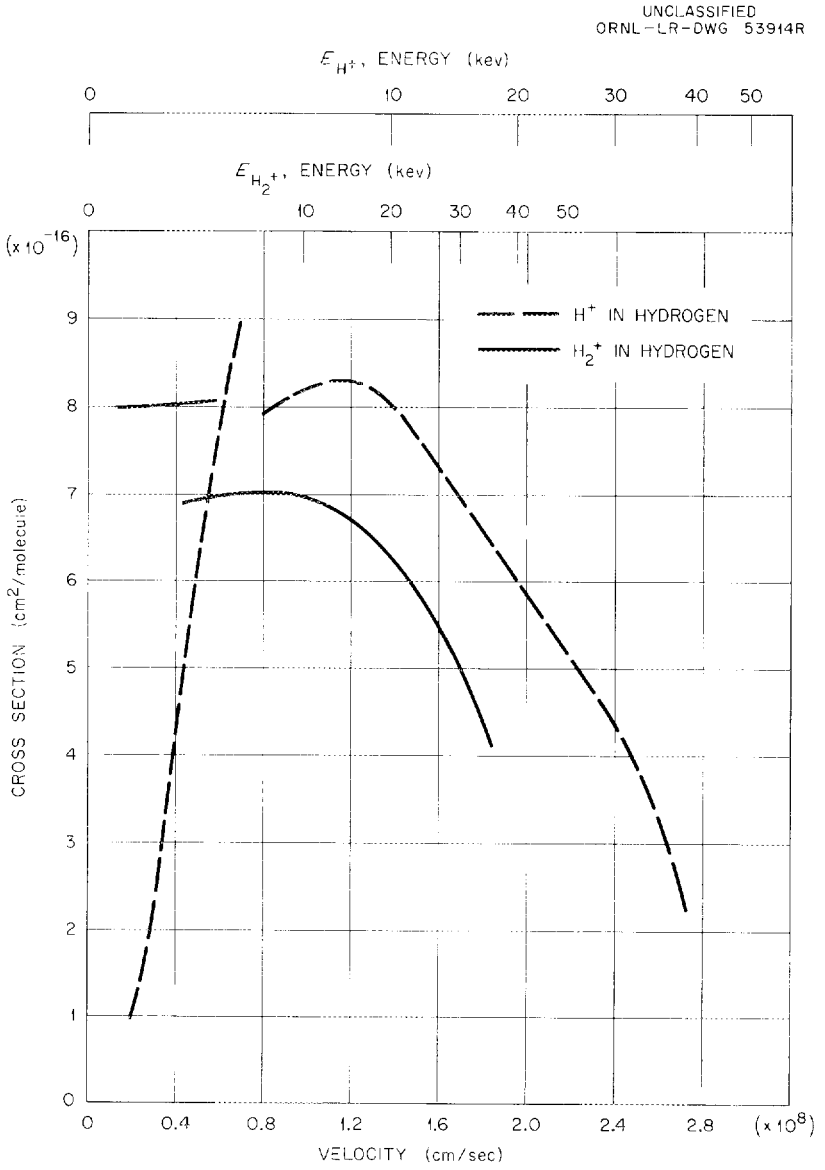

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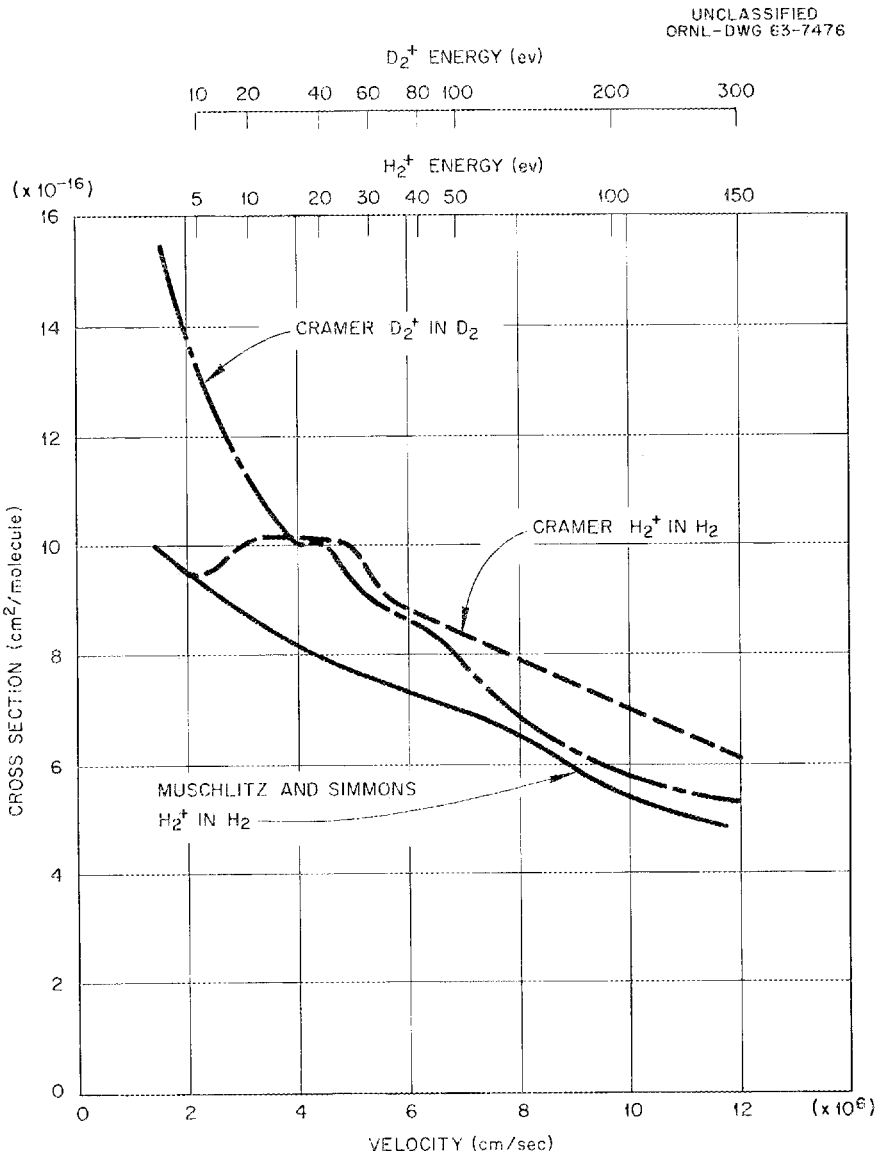

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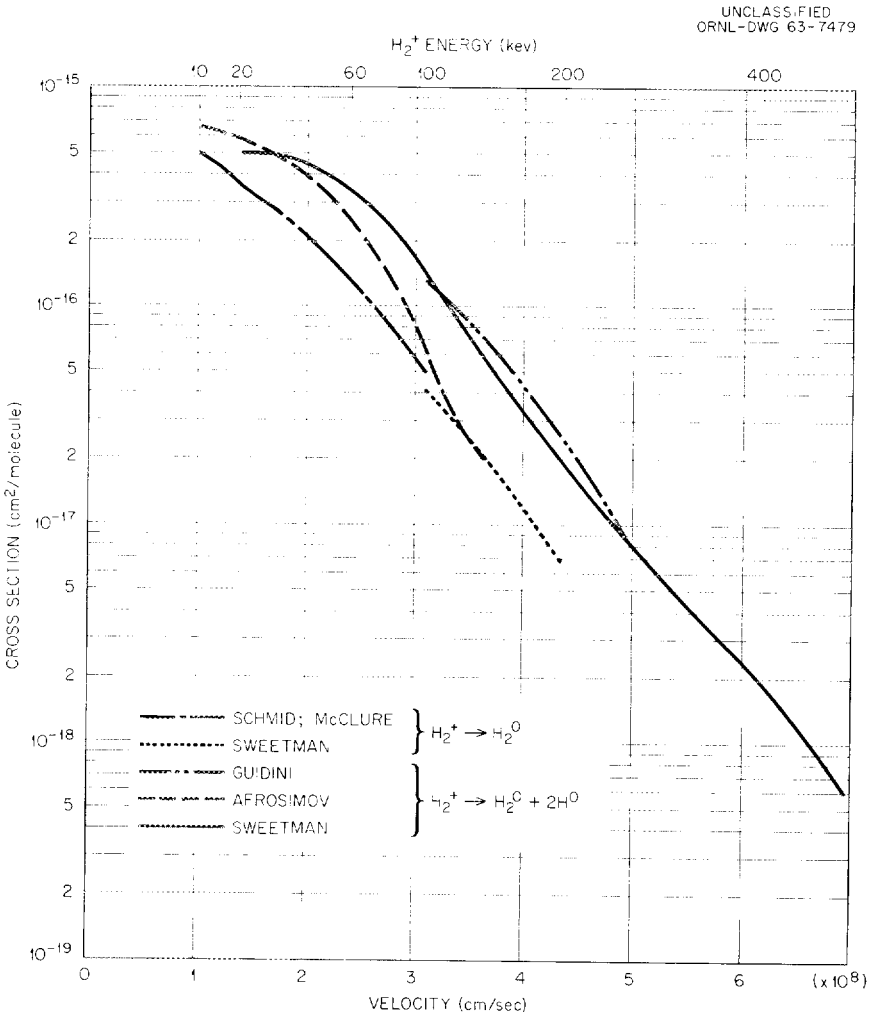

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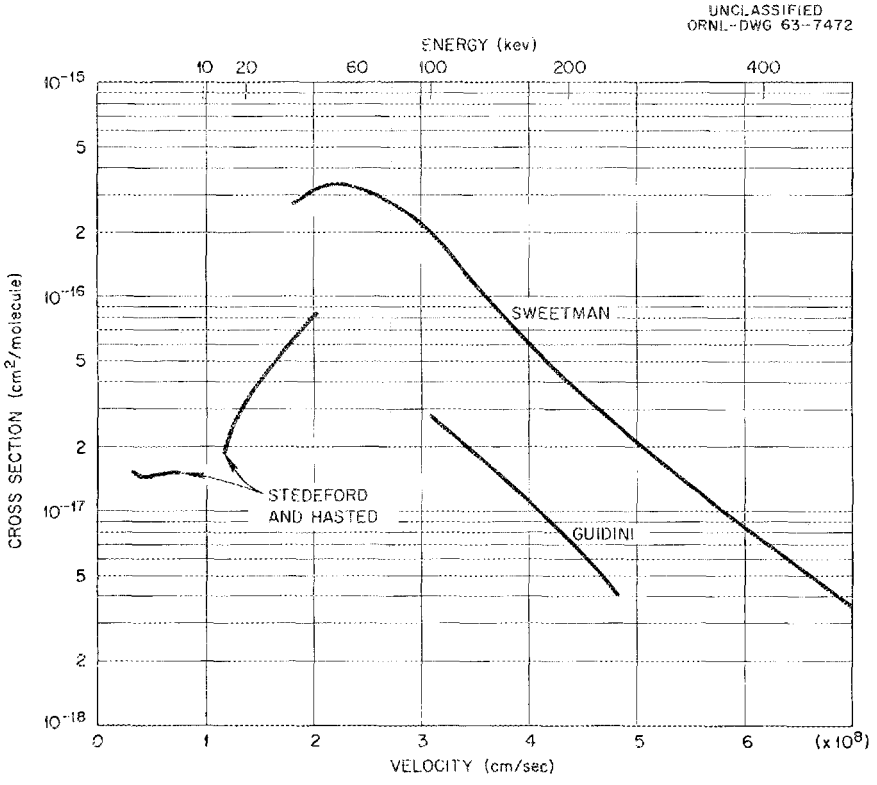

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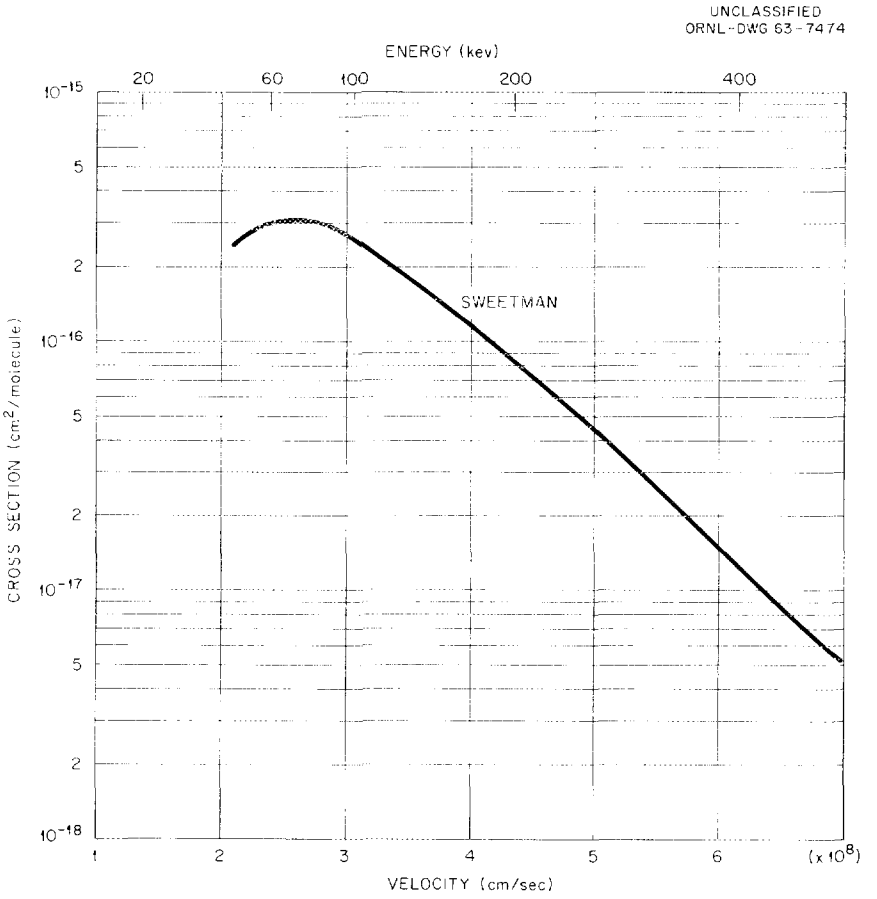

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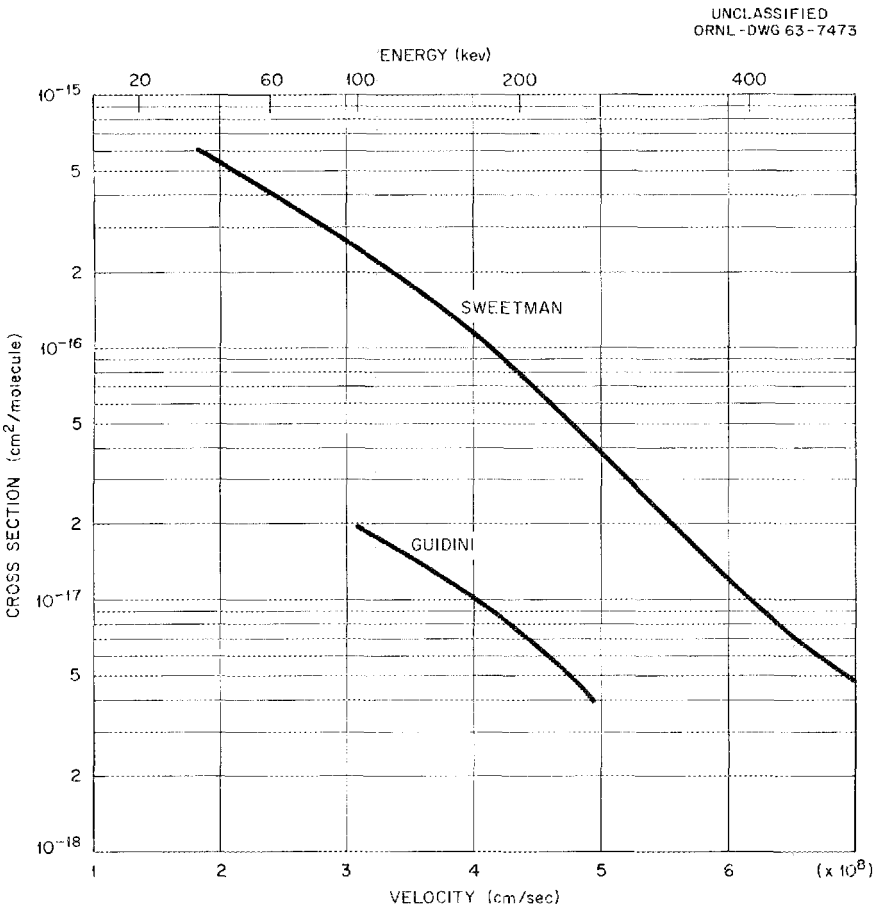

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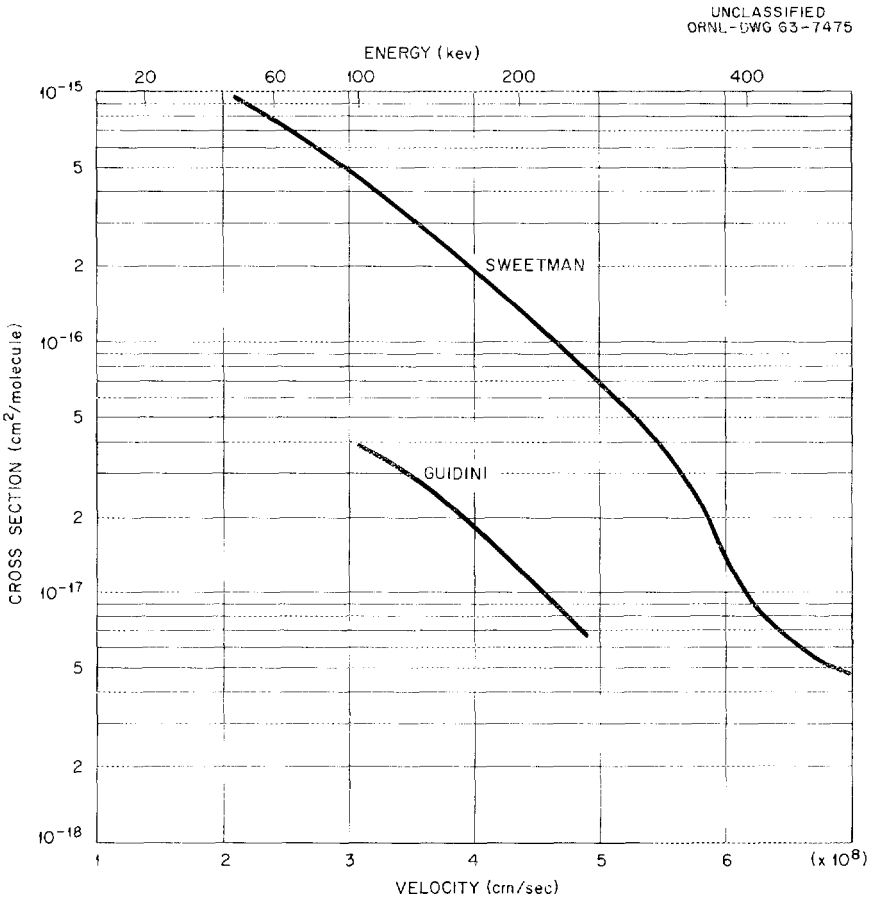

Electron Capture Cross Sections of H_2^+ in Argon Gas.

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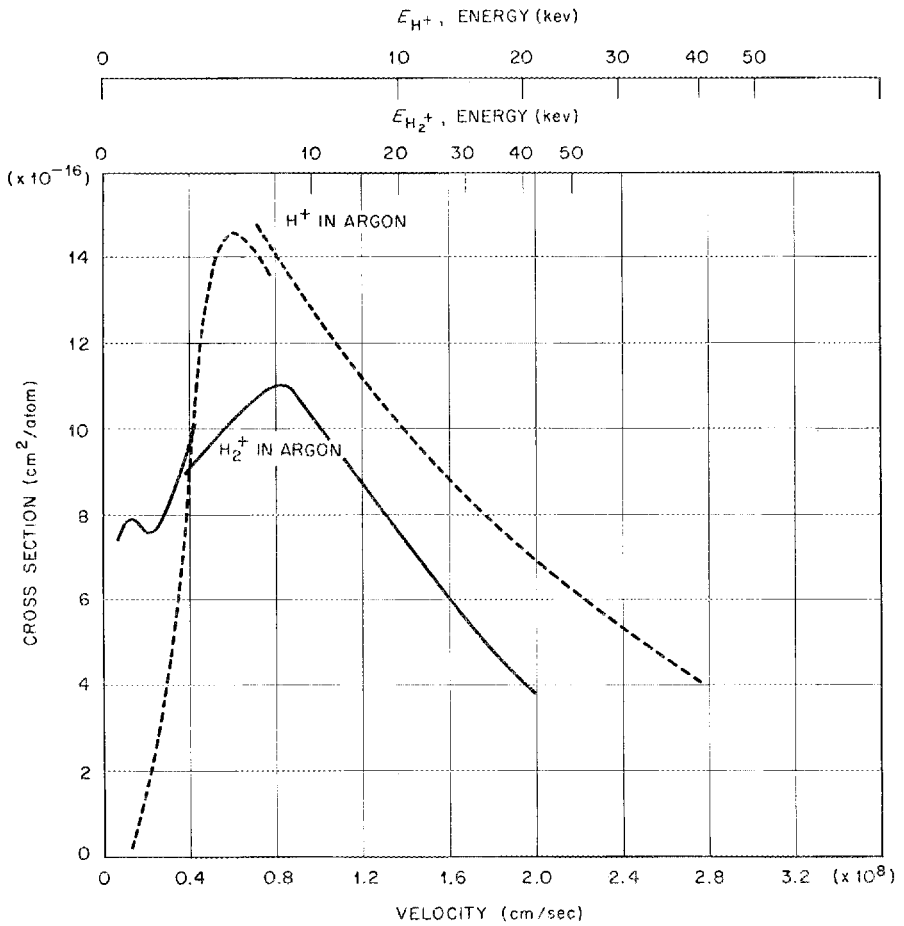

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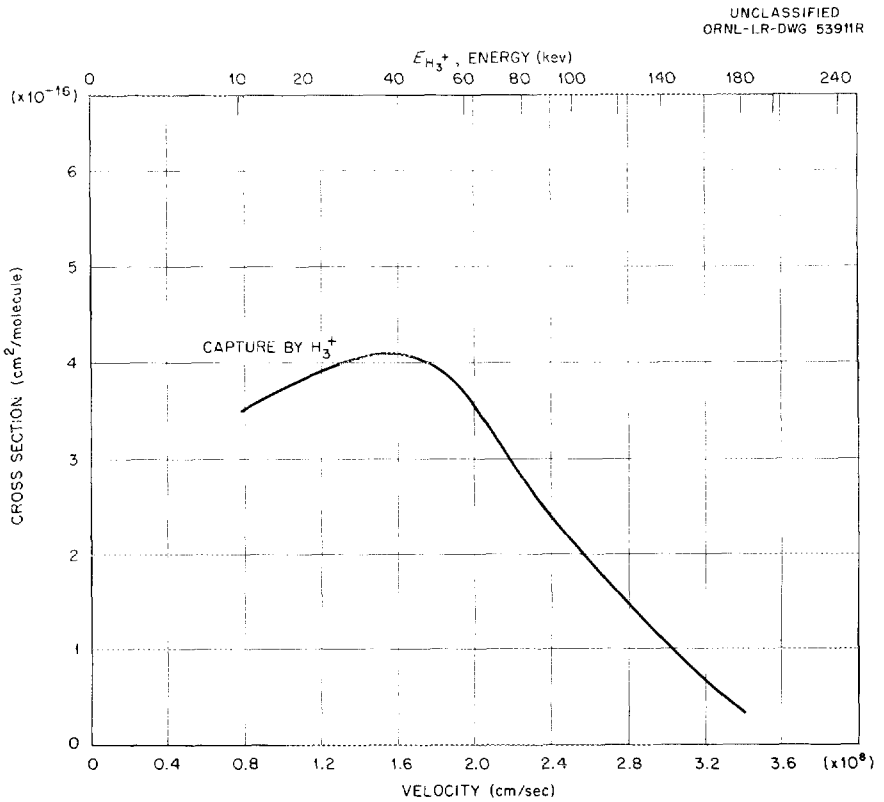

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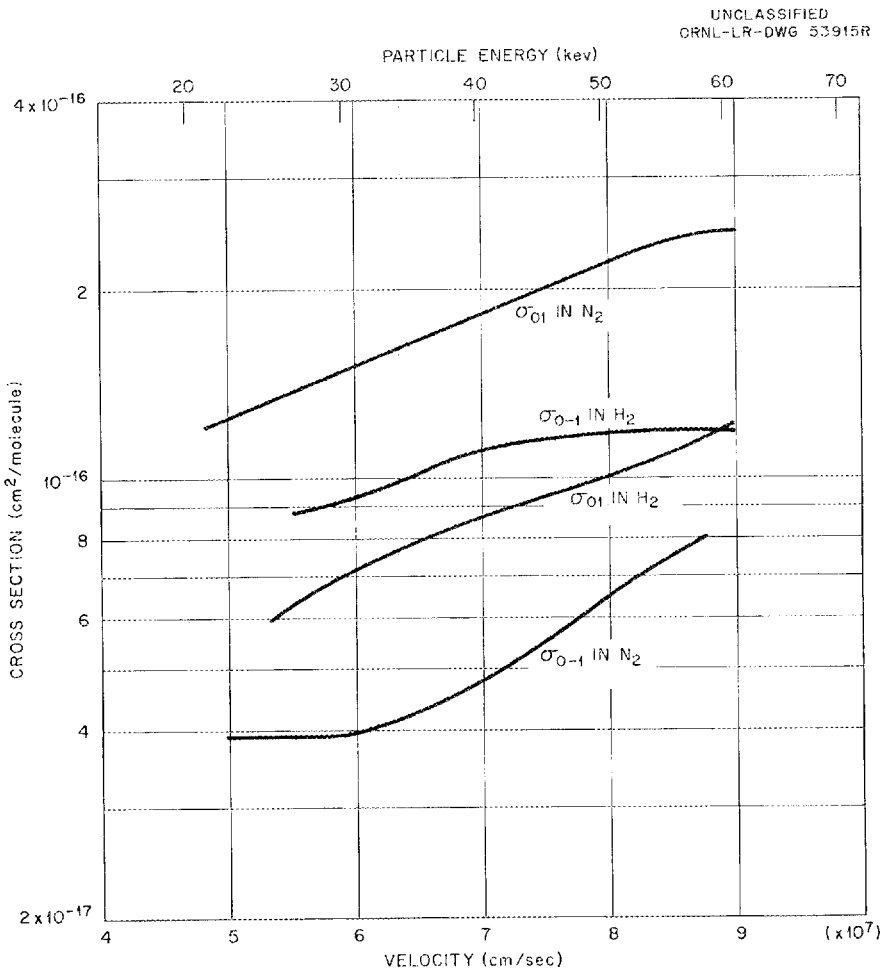
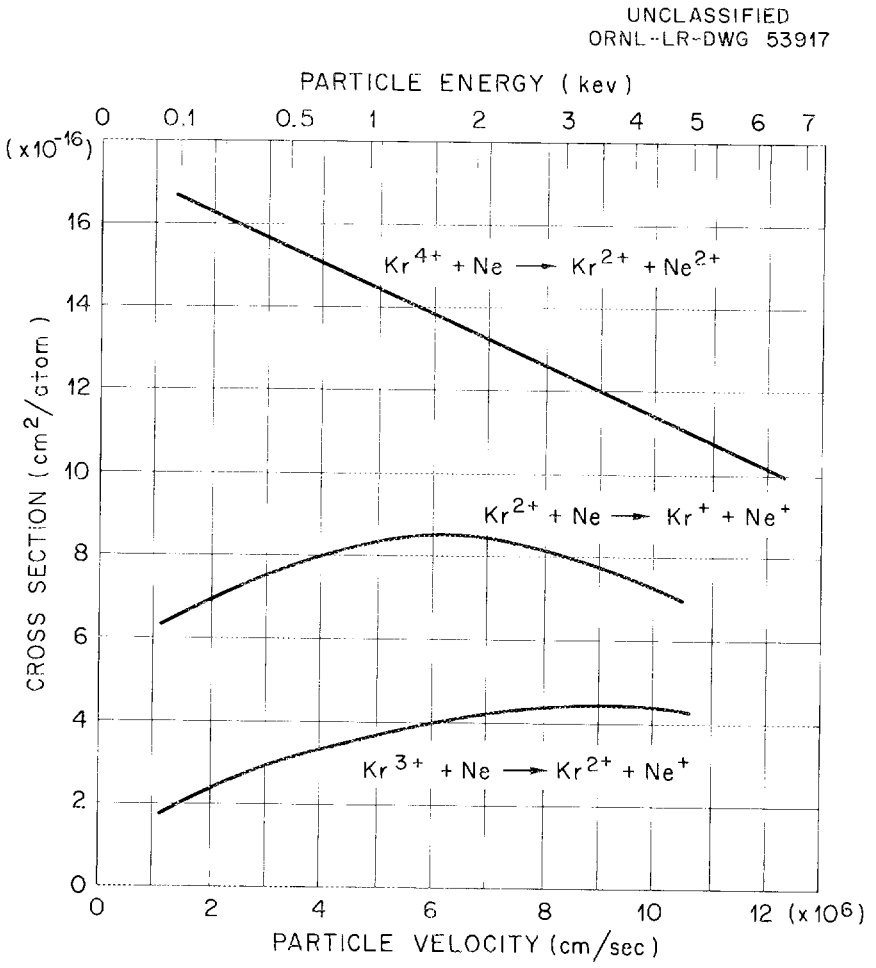


Electron Capture and Loss Cross Sections of Oxygen Atoms in Hydrogen and Nitrogen Gas.



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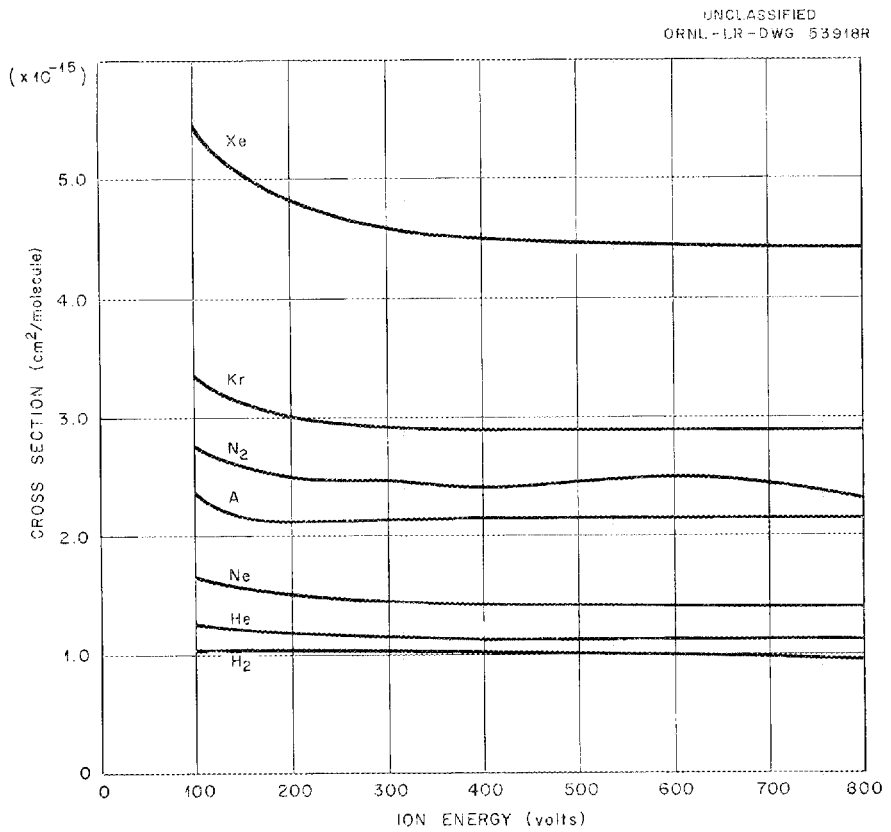
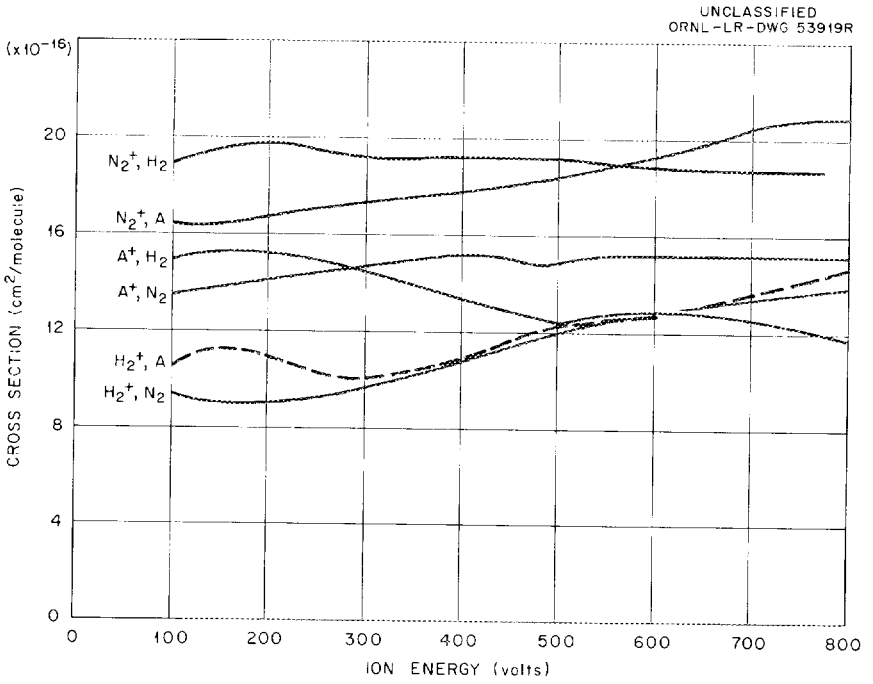


Electron Capture Cross Sections for Symmetric Reactions: Ions in Their Own Gases.



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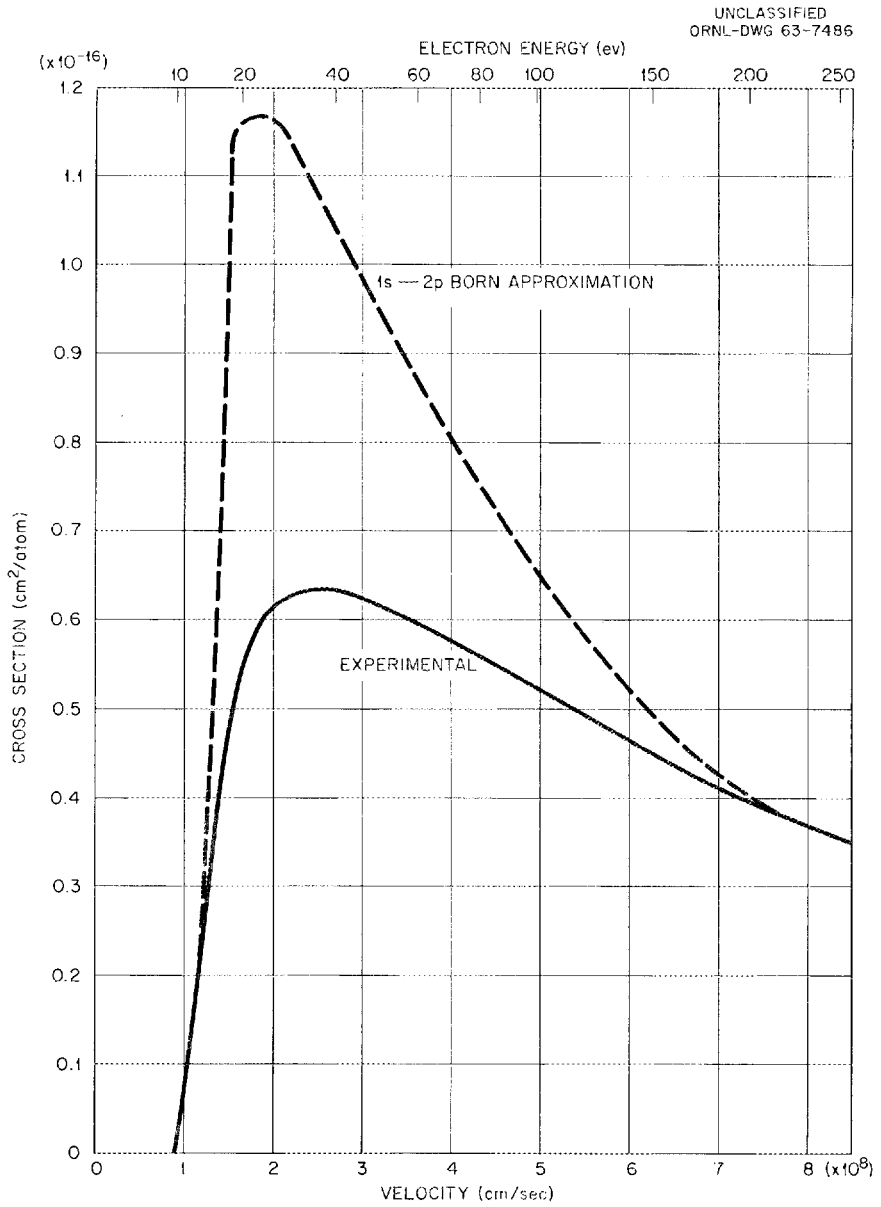
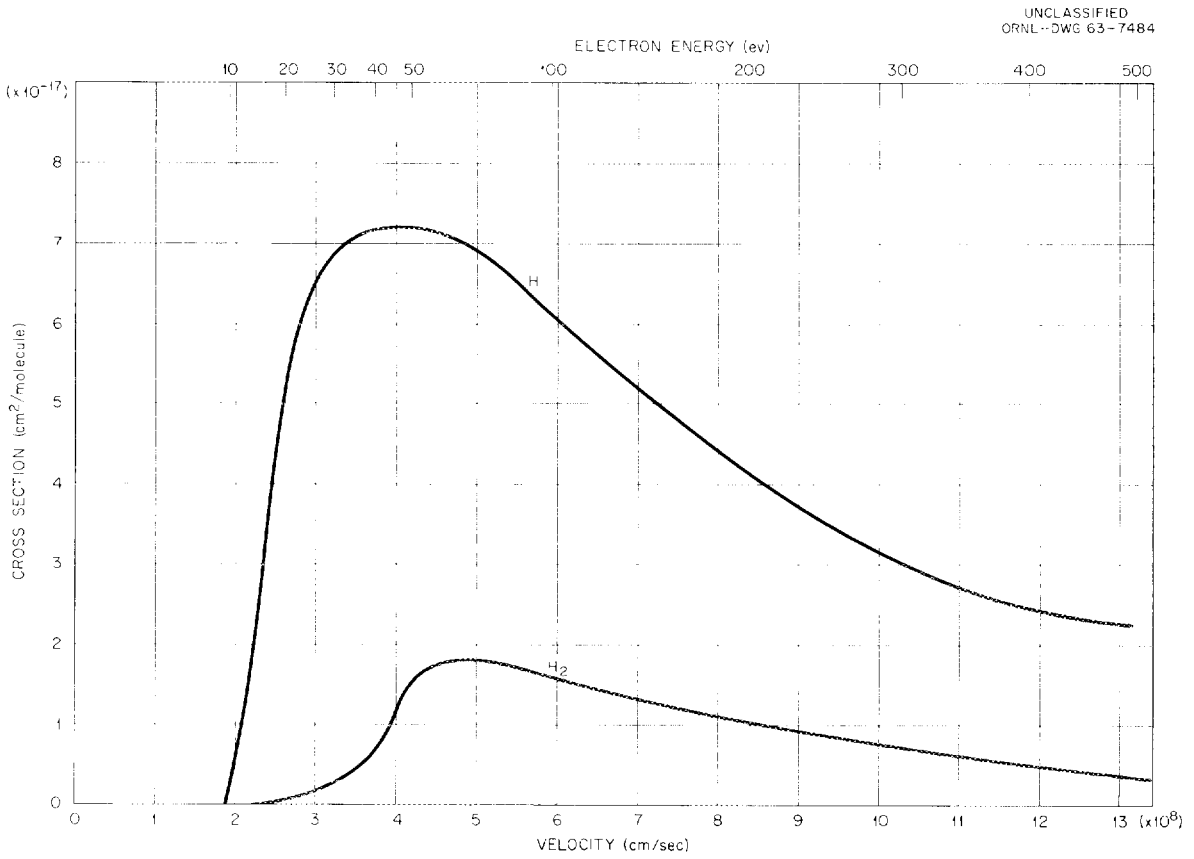


Cross Sections for Excitation of Lyman-Alpha Radiation from Hydrogen Atoms by Electron Impact.



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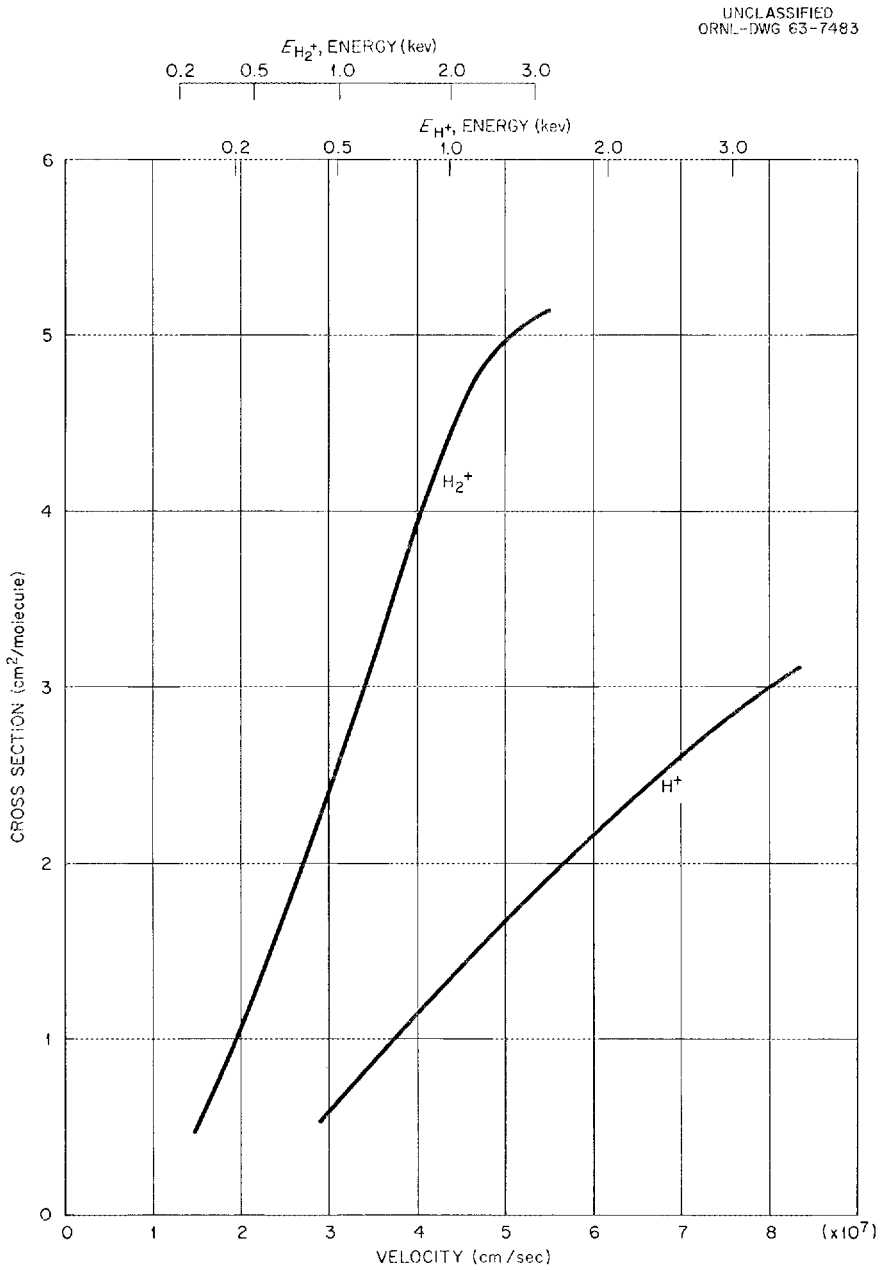

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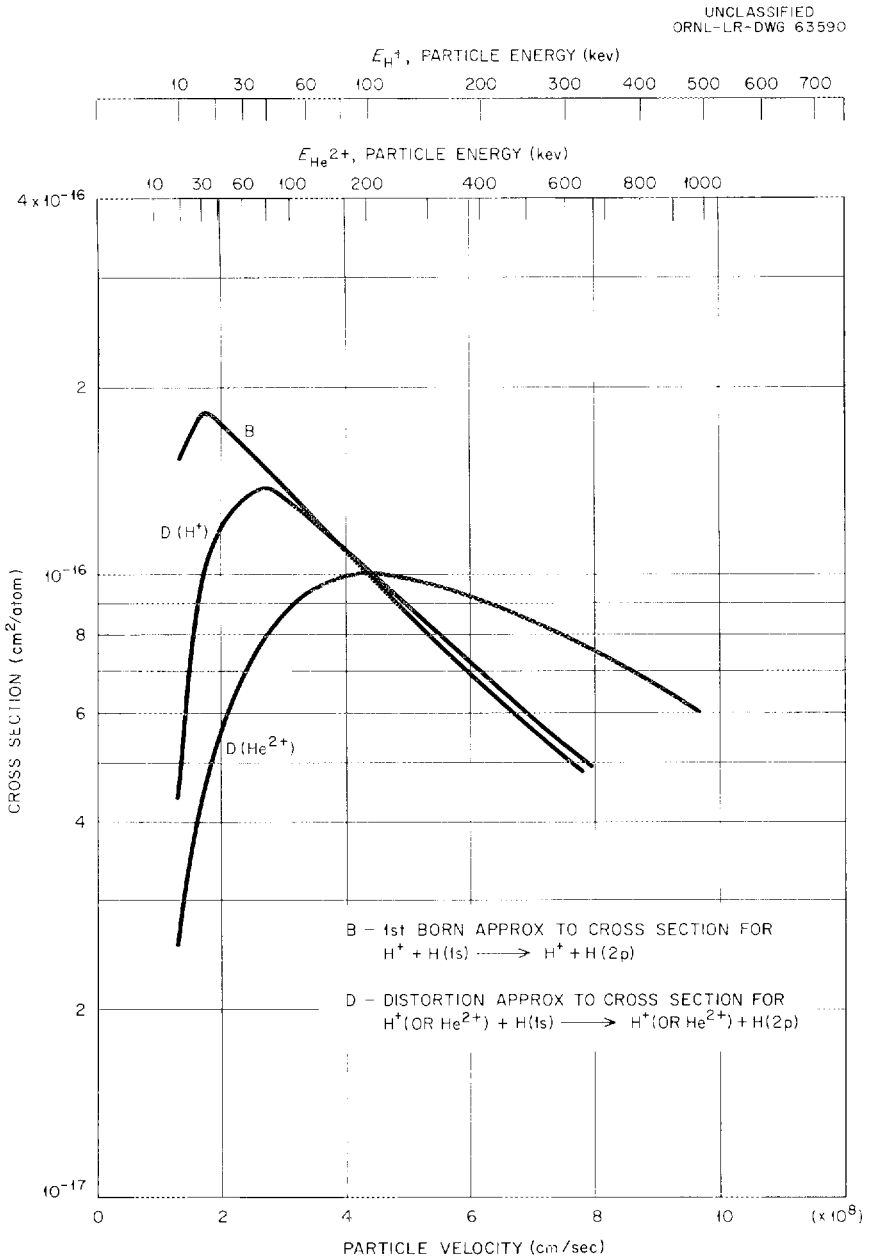

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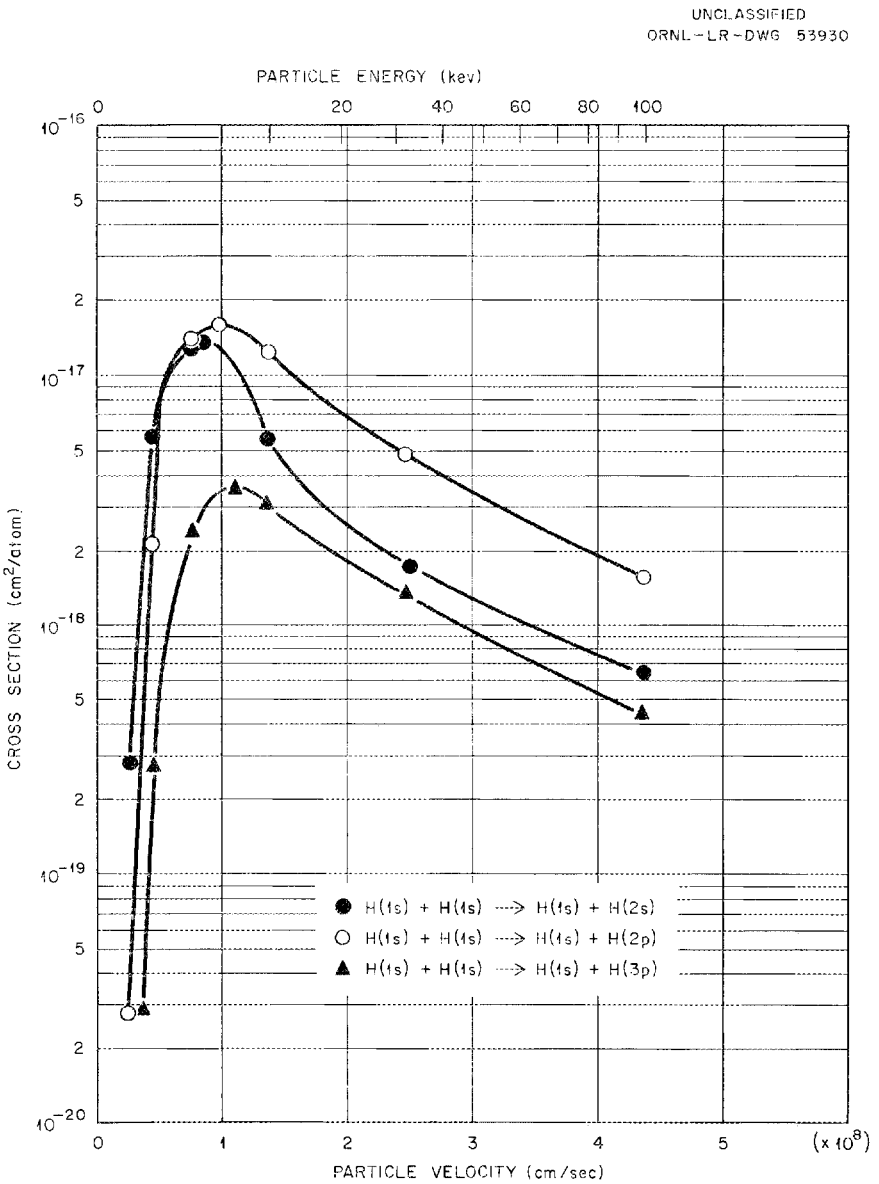

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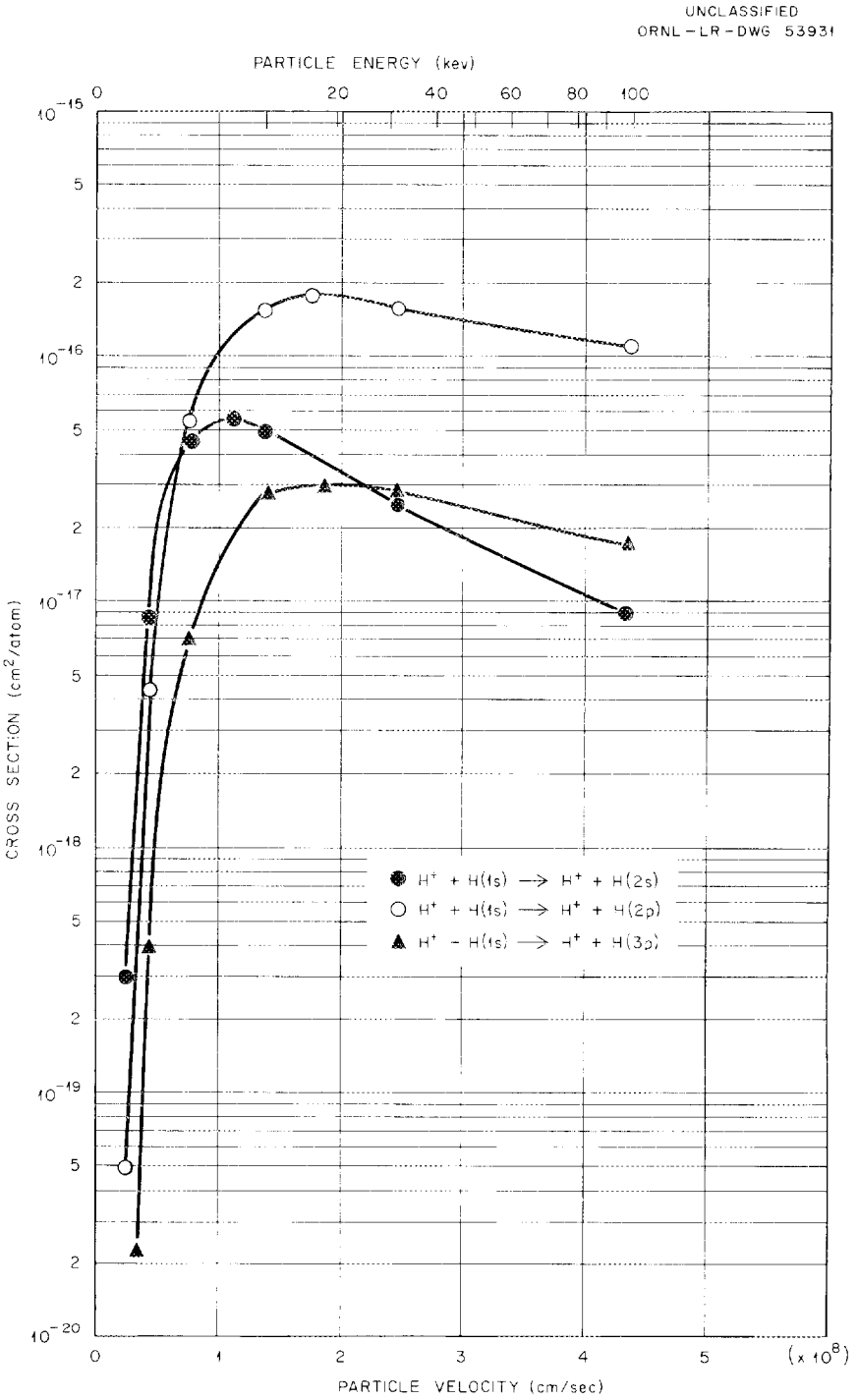

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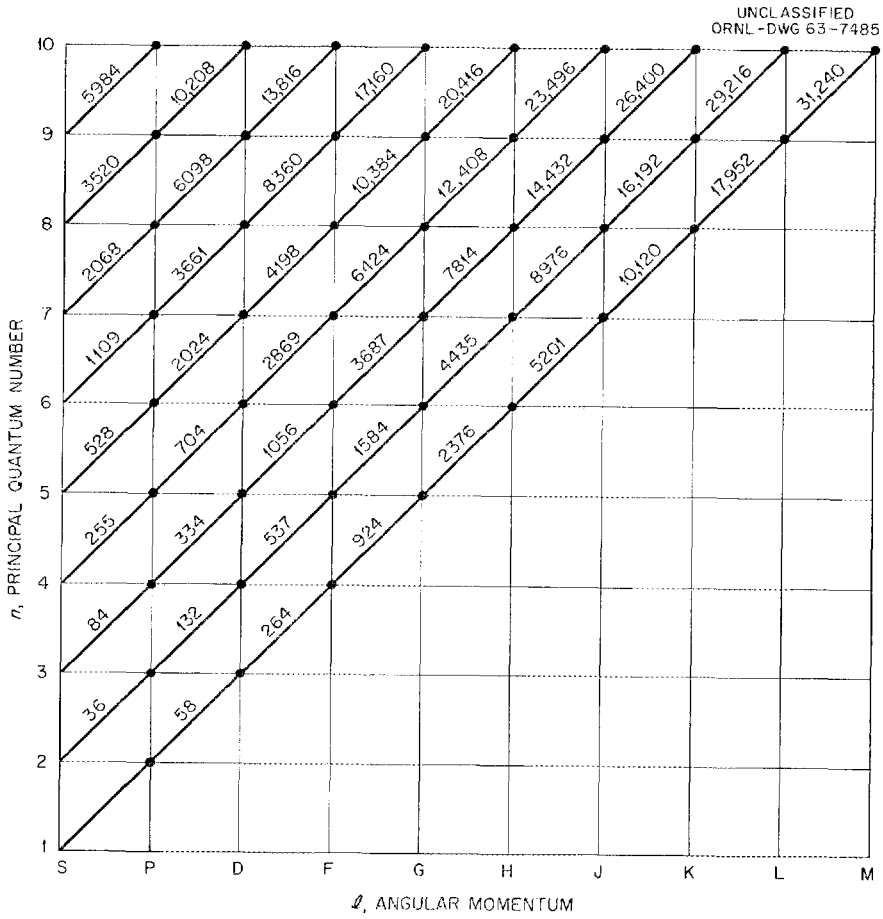
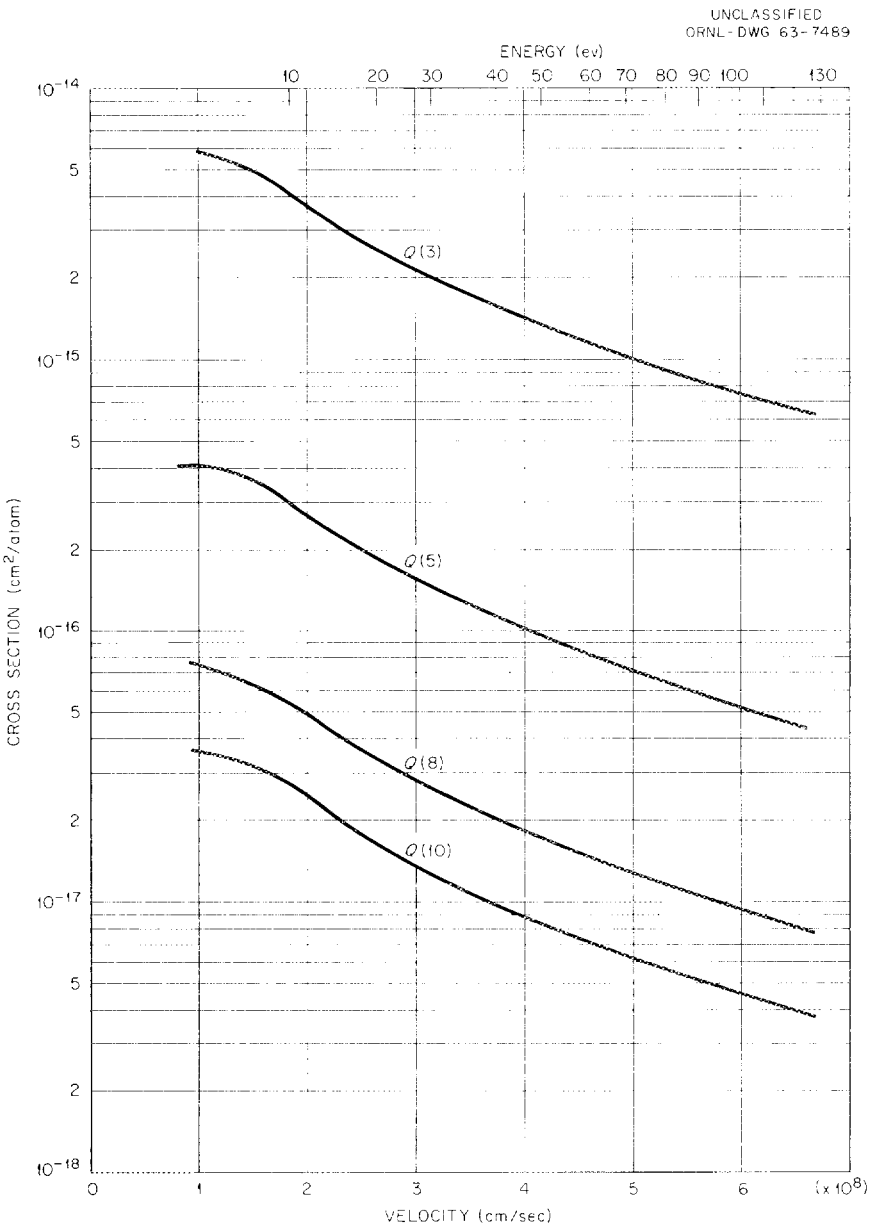
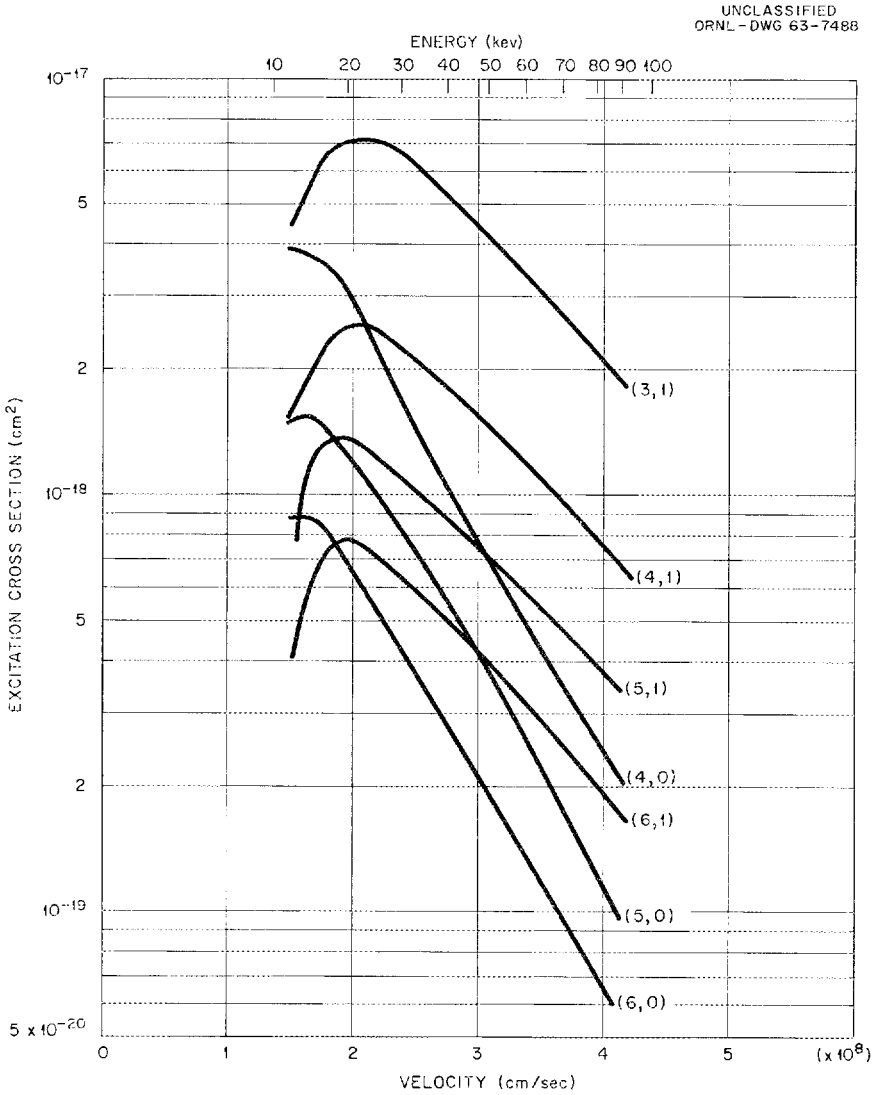


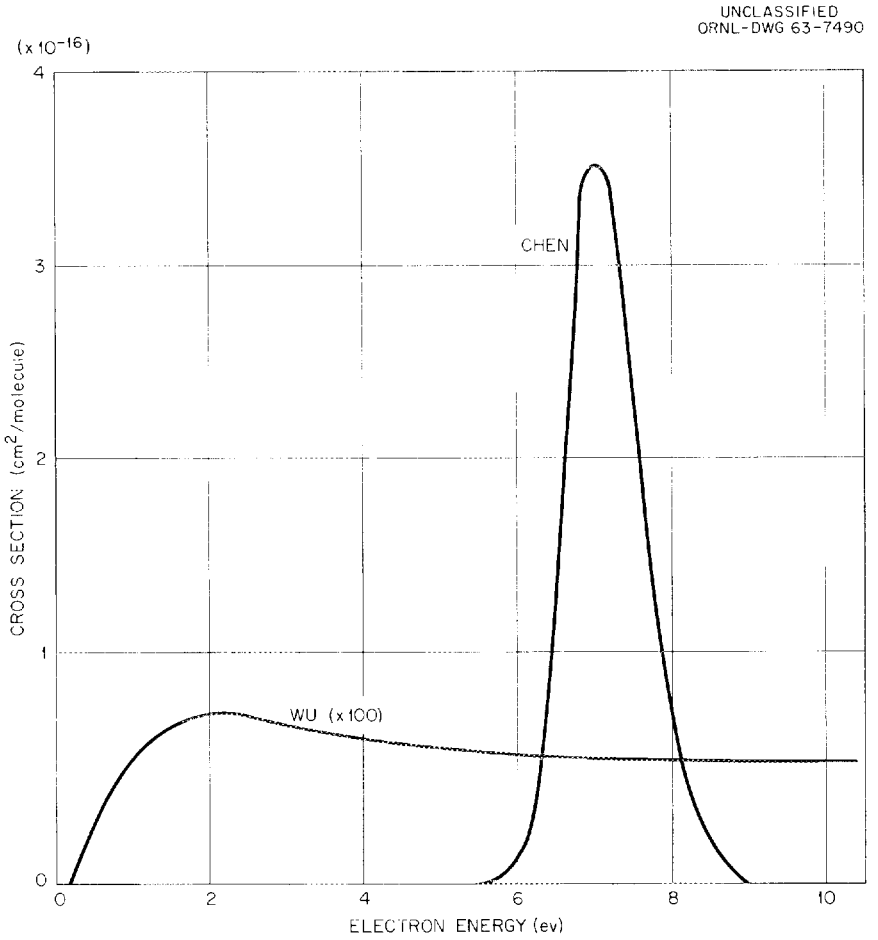
Cross Sections for Excitation of Hydrogen Atoms by 10 ev Electrons.



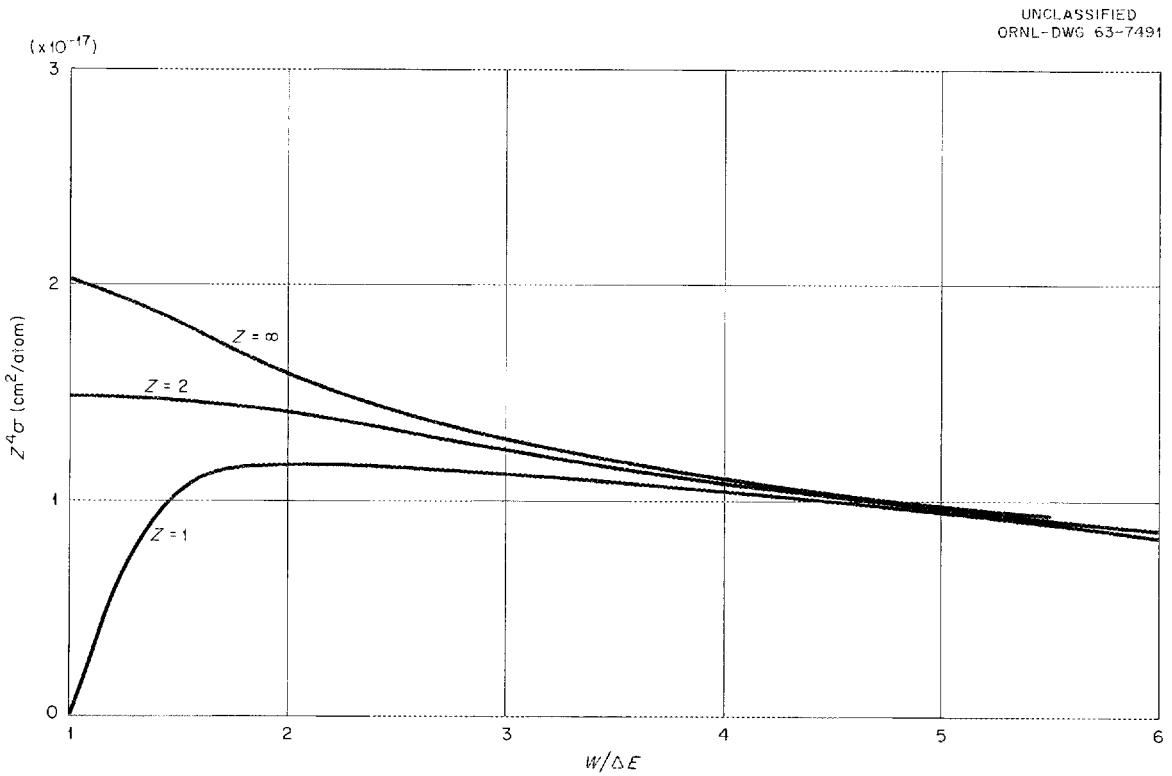
Cross Sections [Q(n)] for the Total Excitation of Discrete Levels (n) of Hydrogen Atoms from the 2S Level by Electrons.



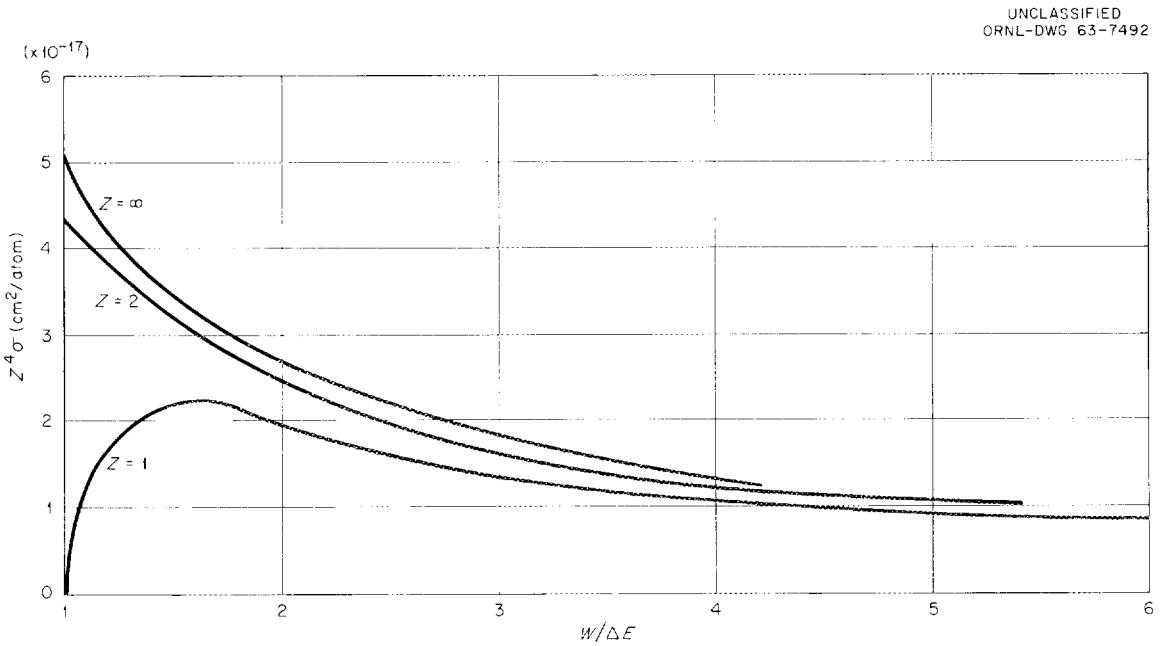
Born Approximation Cross Sections for the Excitation of Level (n,1) from the 2S Level in Atomic Hydrogen by Proton Impact.



Cross Sections for Vibrational Excitation of Hydrogen by Electron Impact.



Cross Sections for 1S to 2P Excitation in Hydrogenic Ions.



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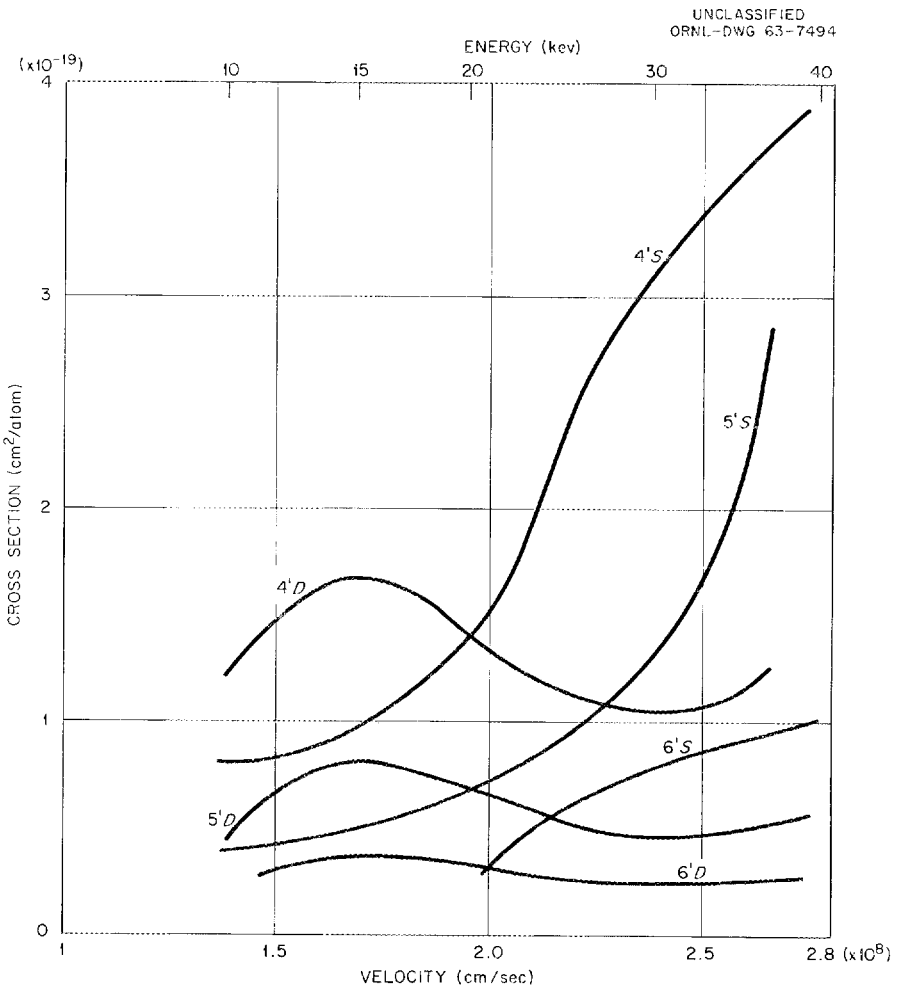
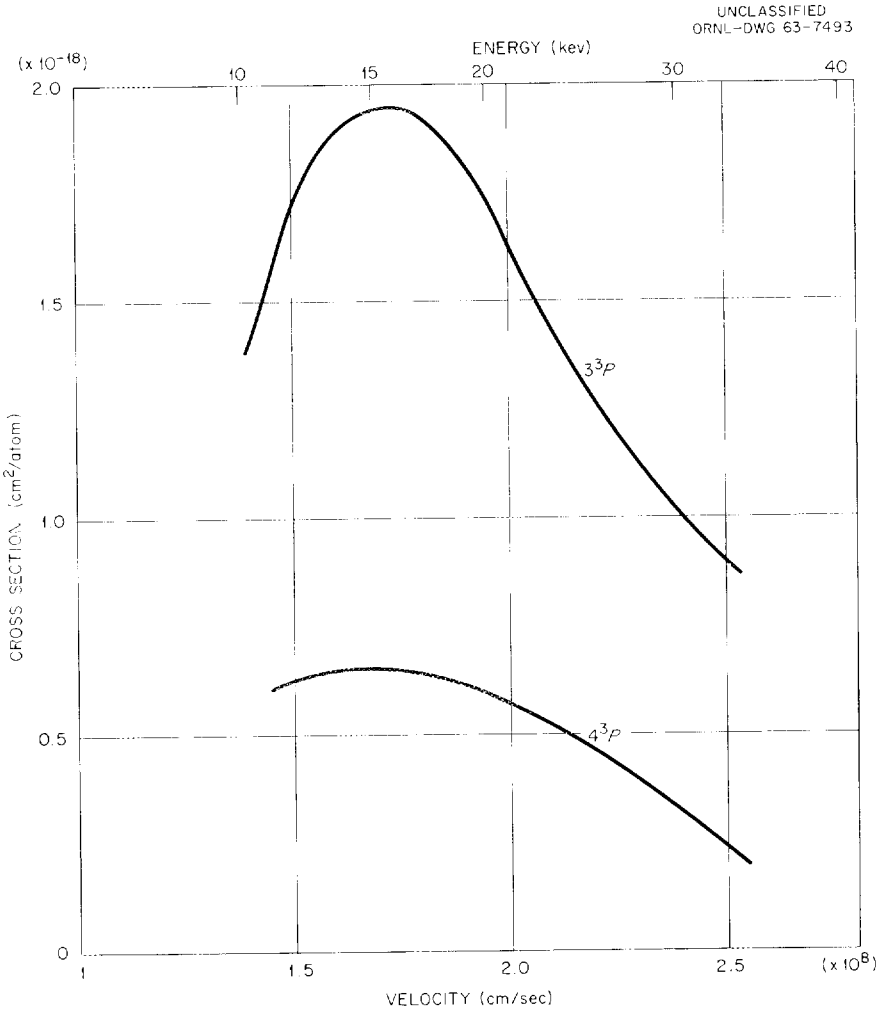
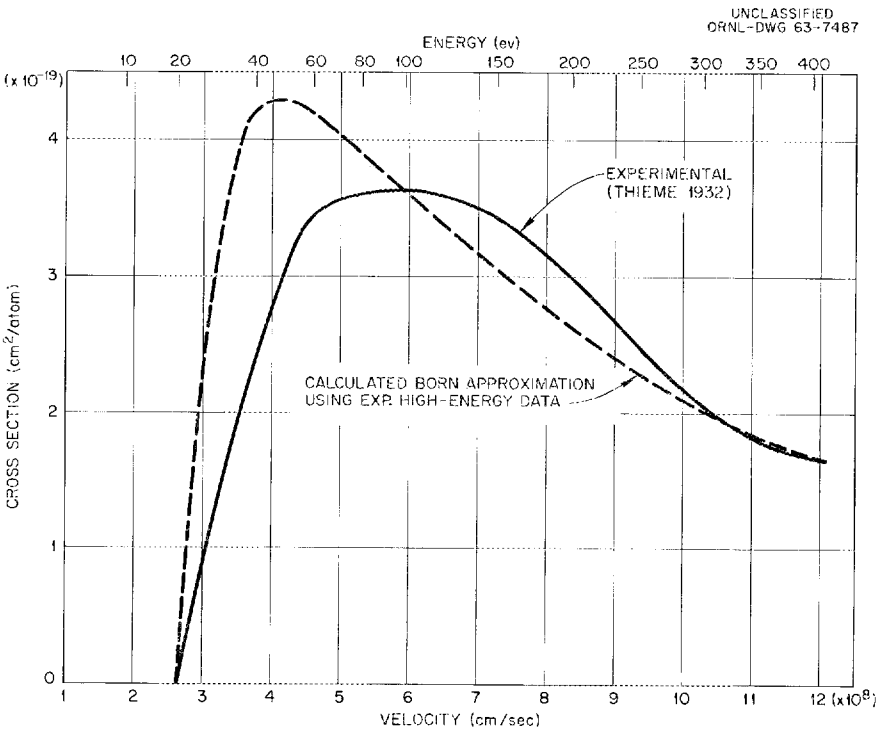


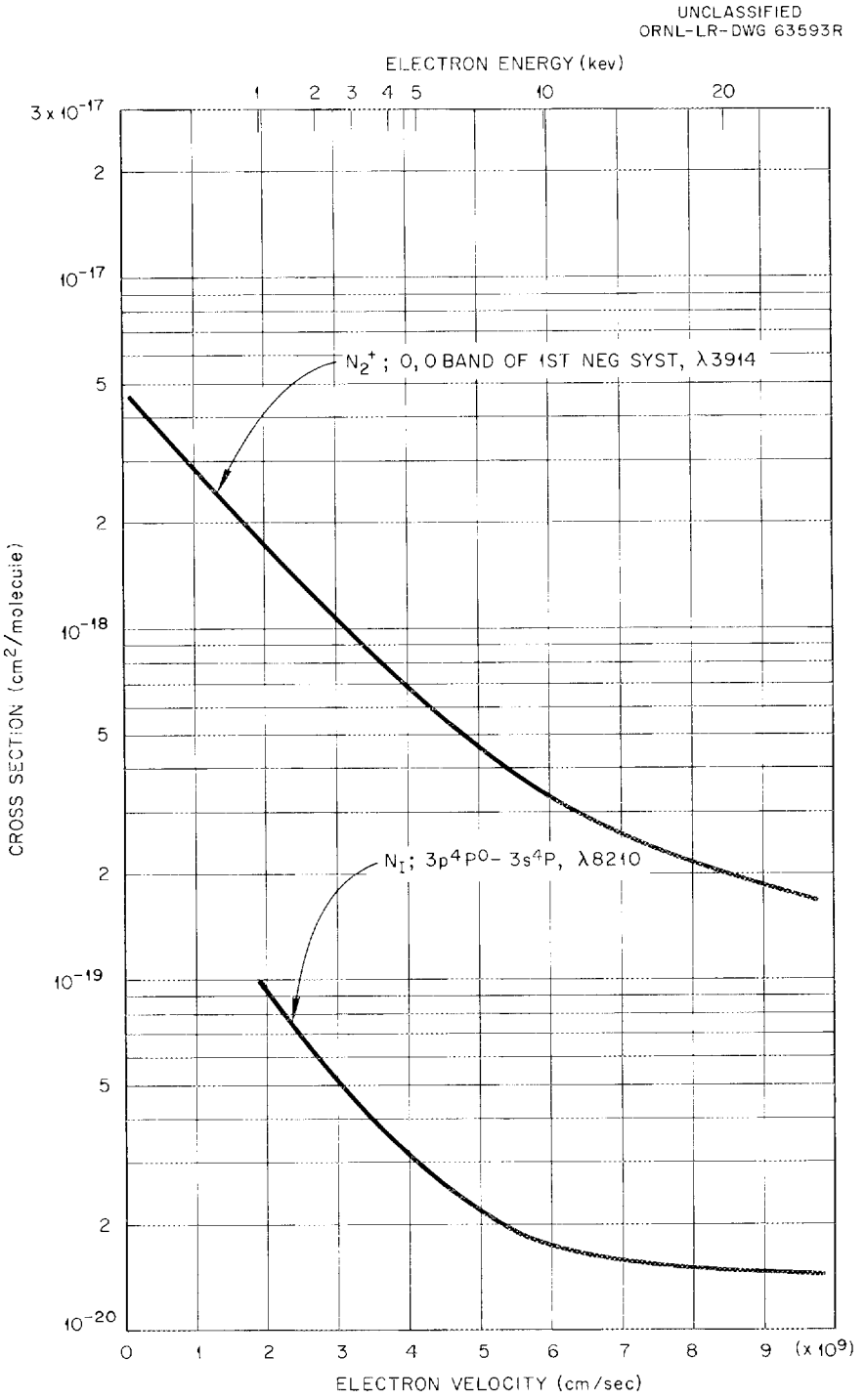
Cross Sections for Excitation of Helium by Proton Impact.



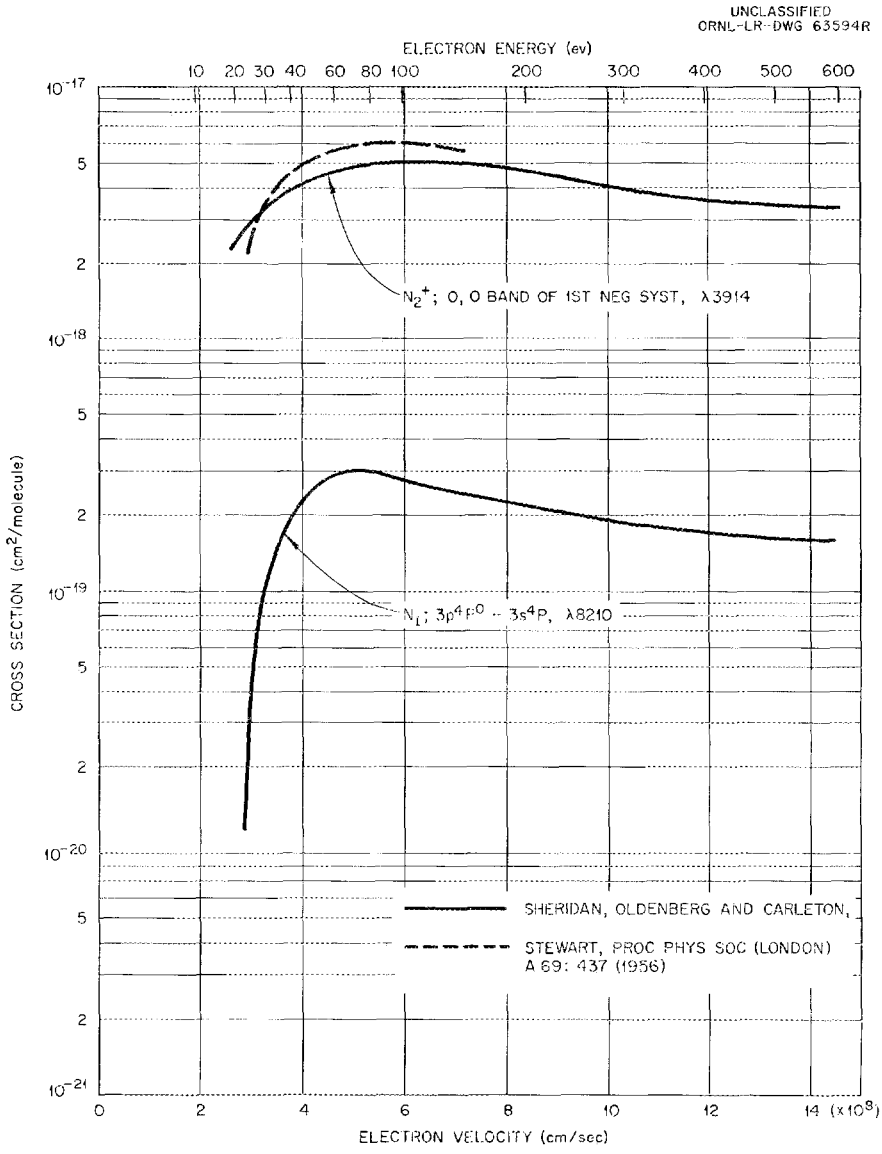
Cross Sections for Excitation of Helium by Hydrogen Atom Impact.



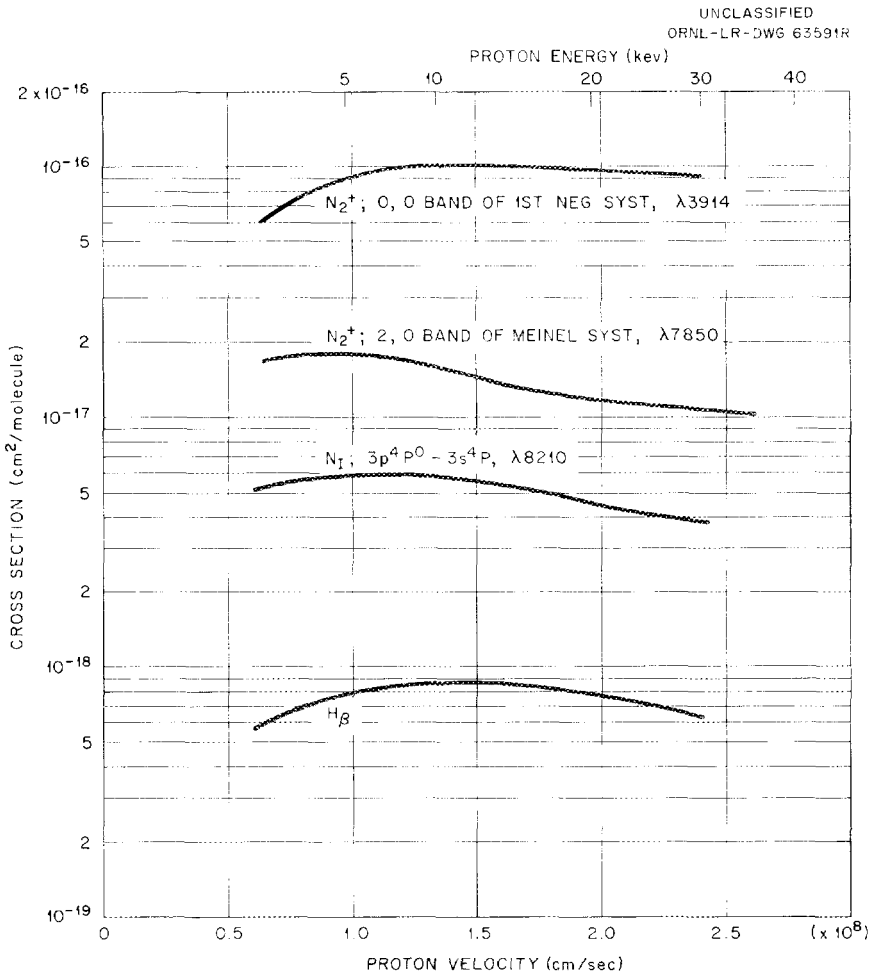
Cross Sections for Excitation of the 3^1P Level of Helium by Electron Impact.



Cross Sections for Excitation of Nitrogen by Electron Impact.



Cross Sections for Excitation of Nitrogen by Electron Impact.



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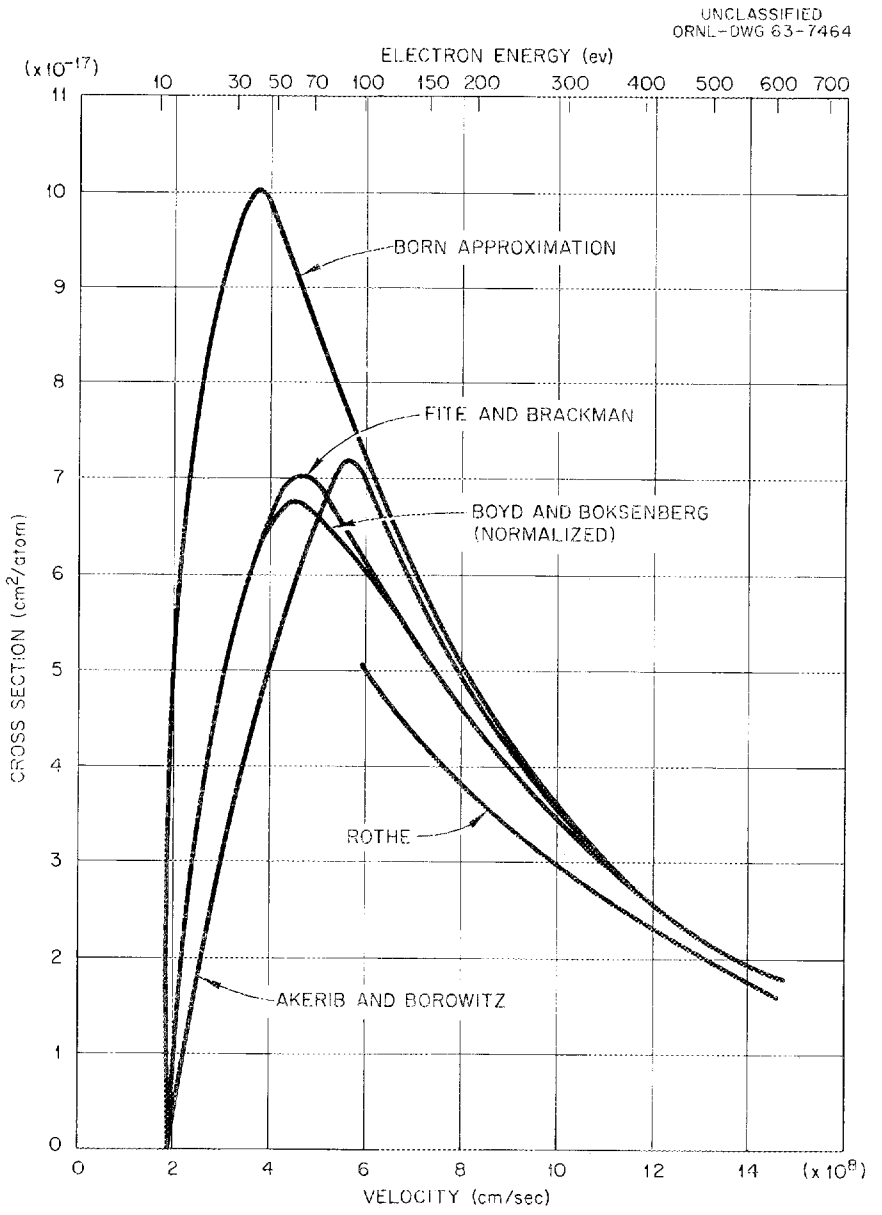

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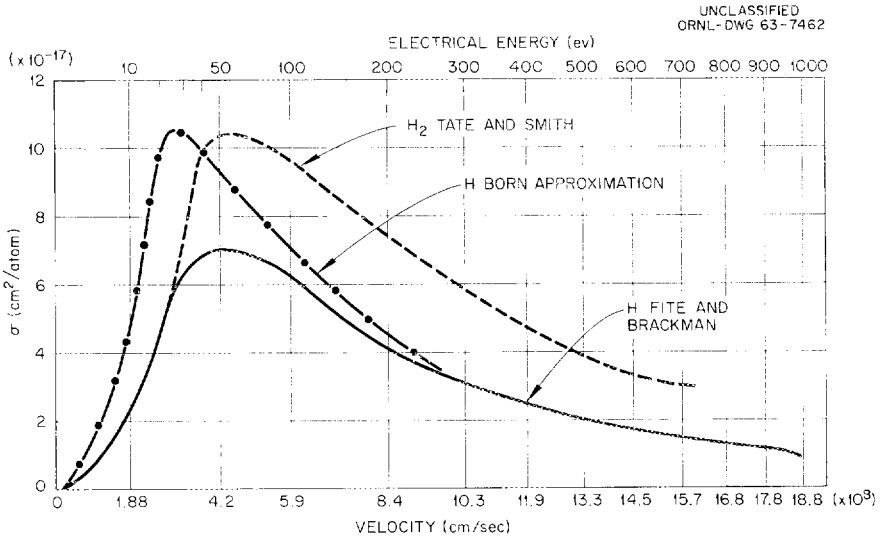

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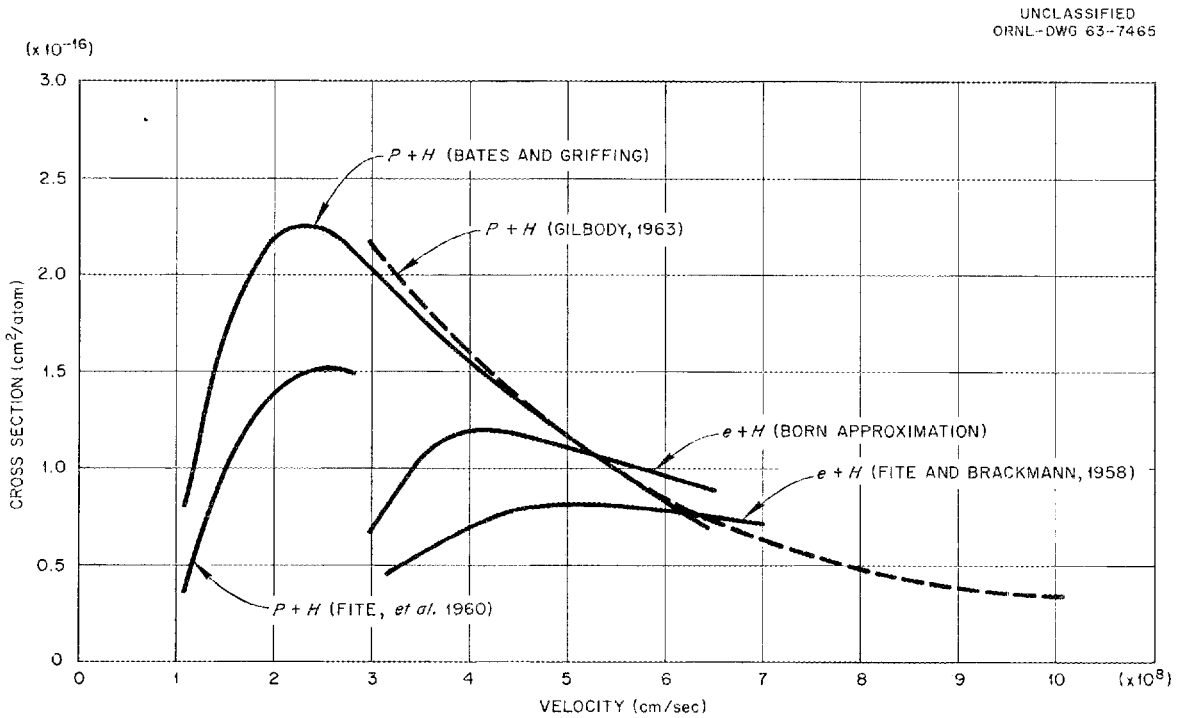

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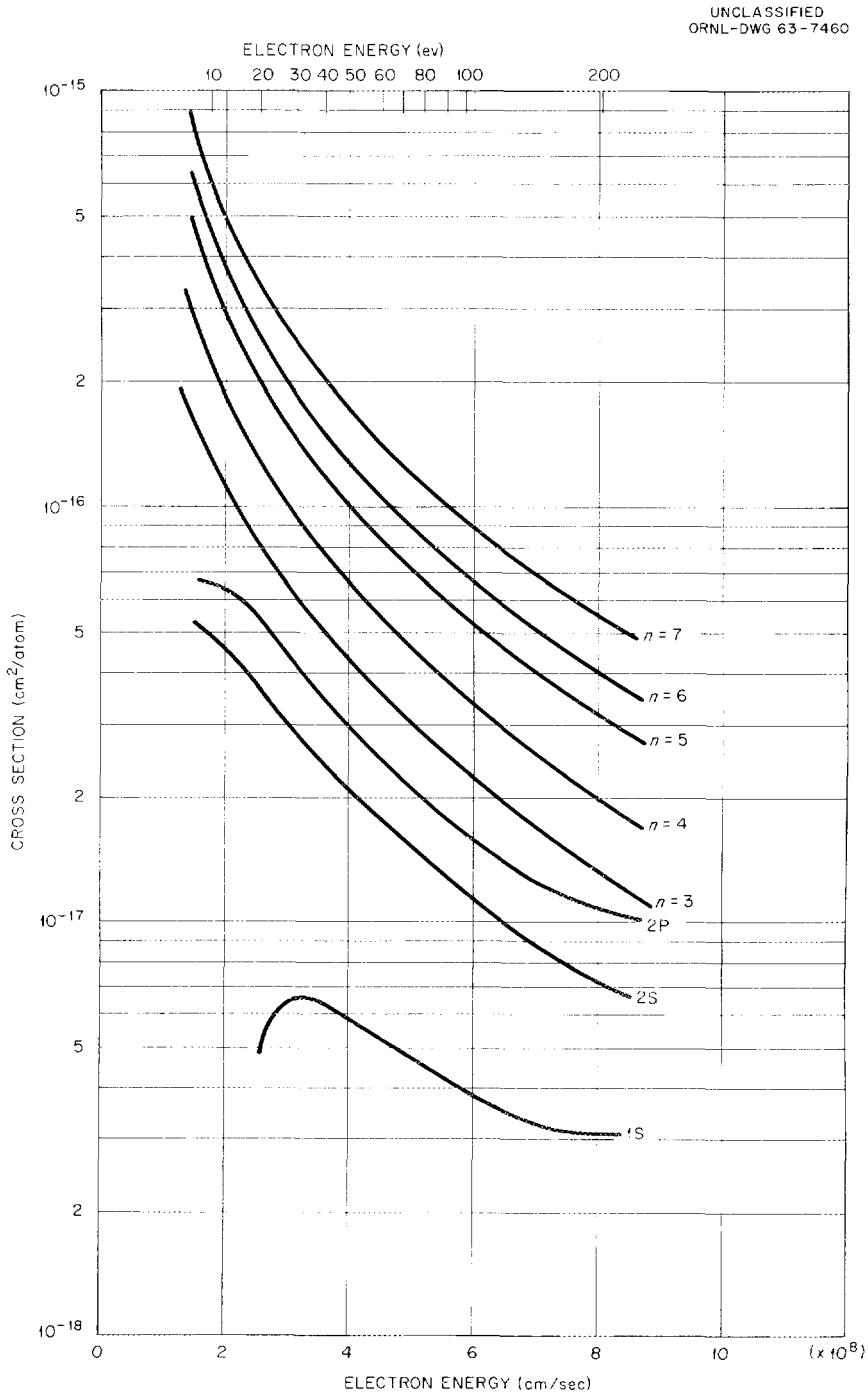

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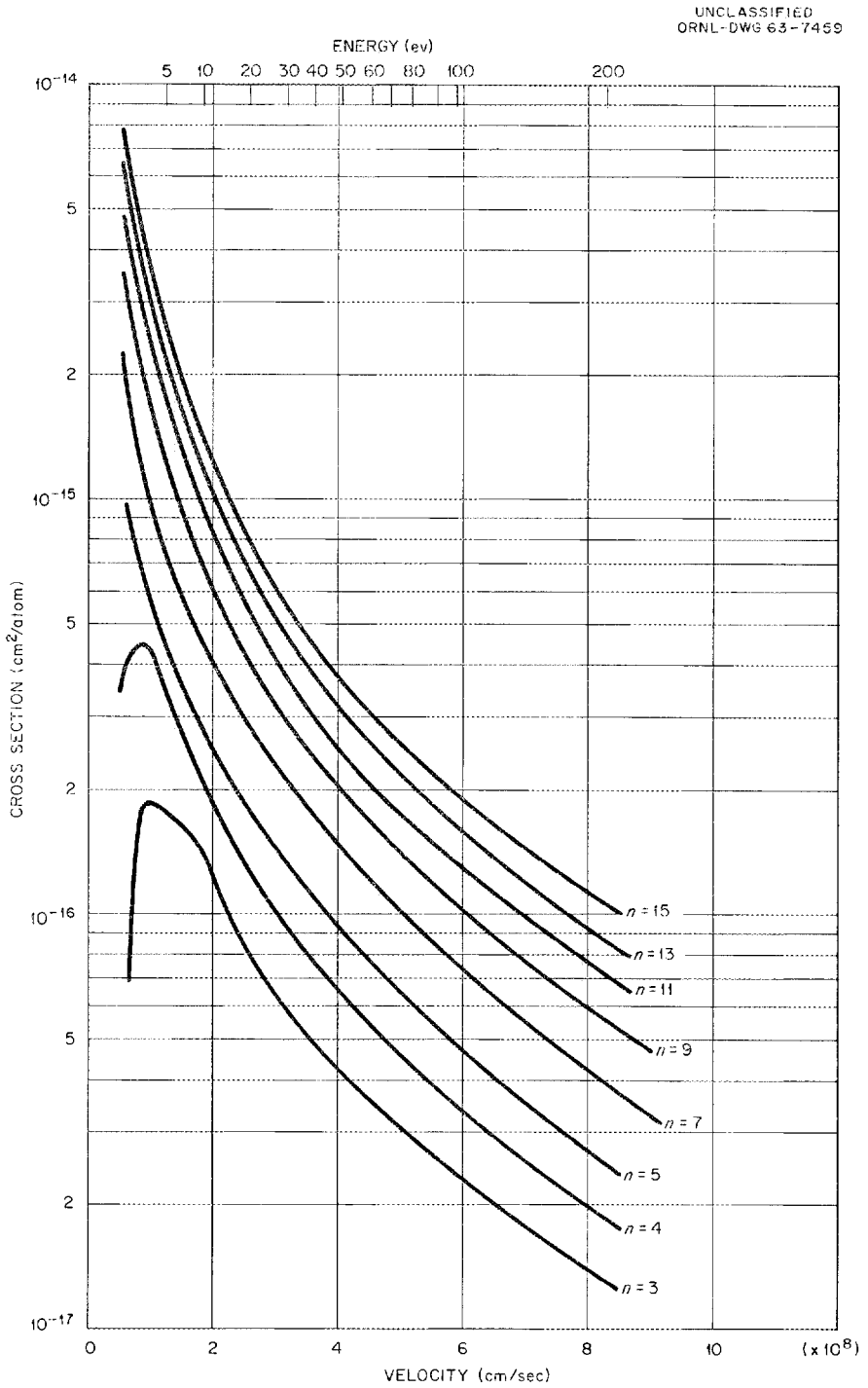

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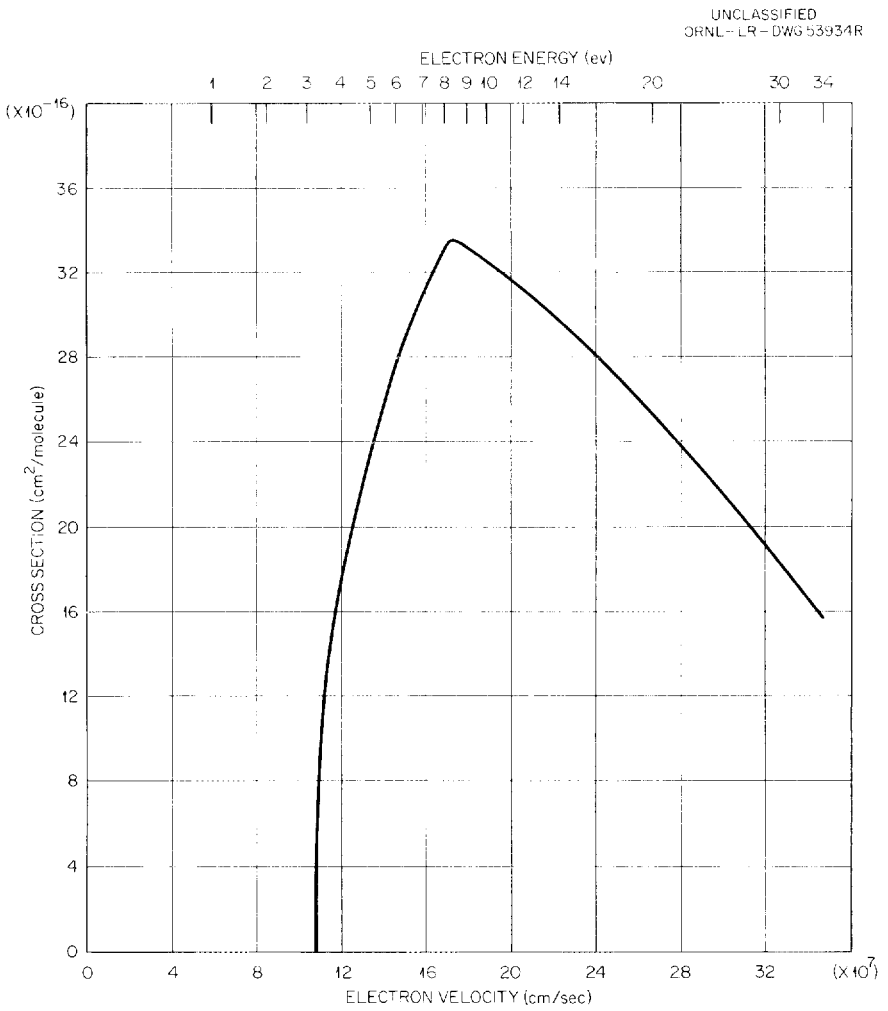

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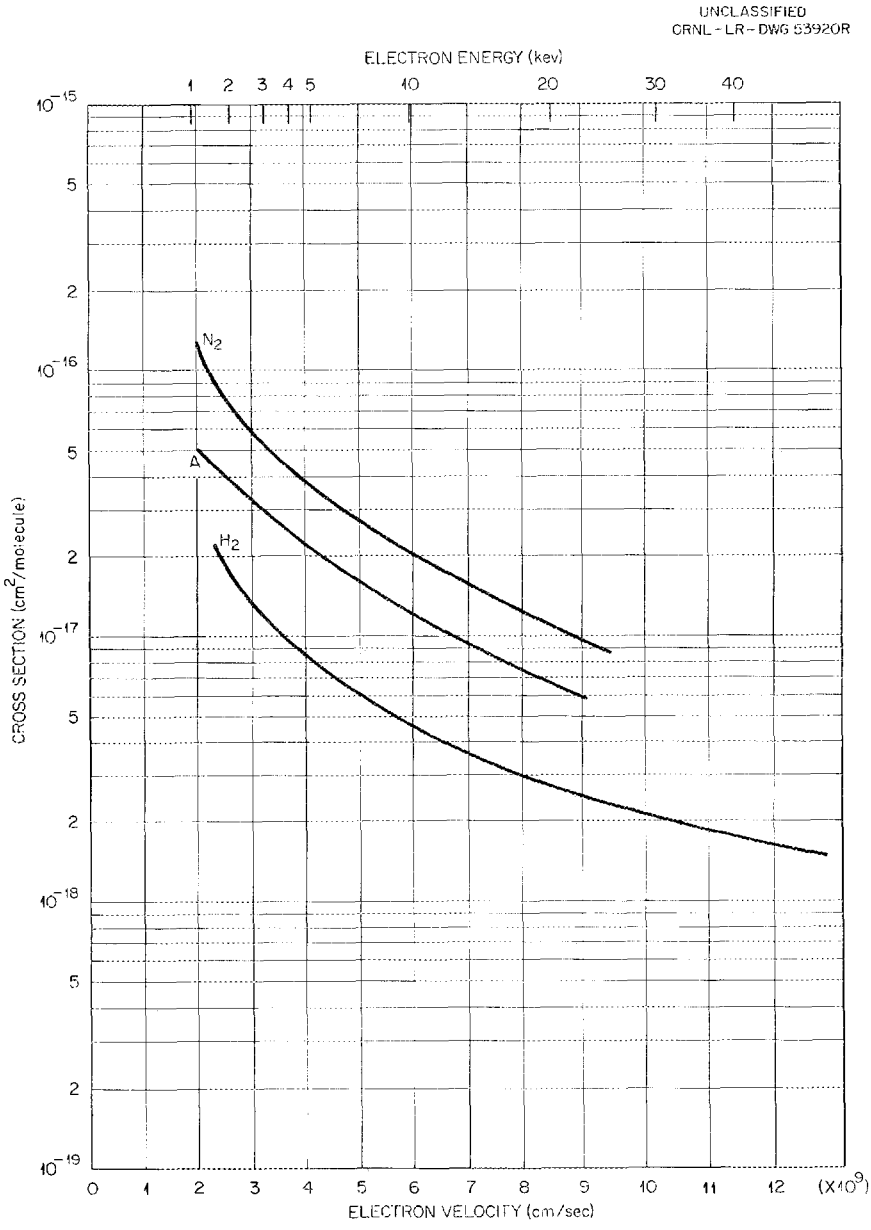

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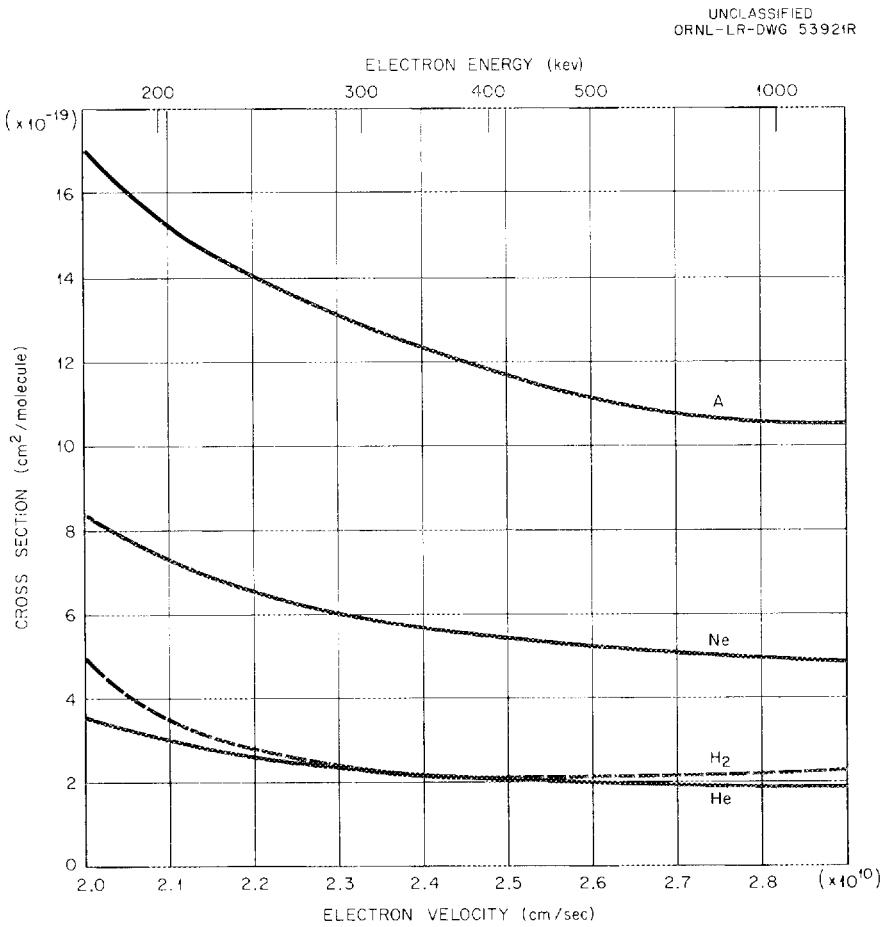

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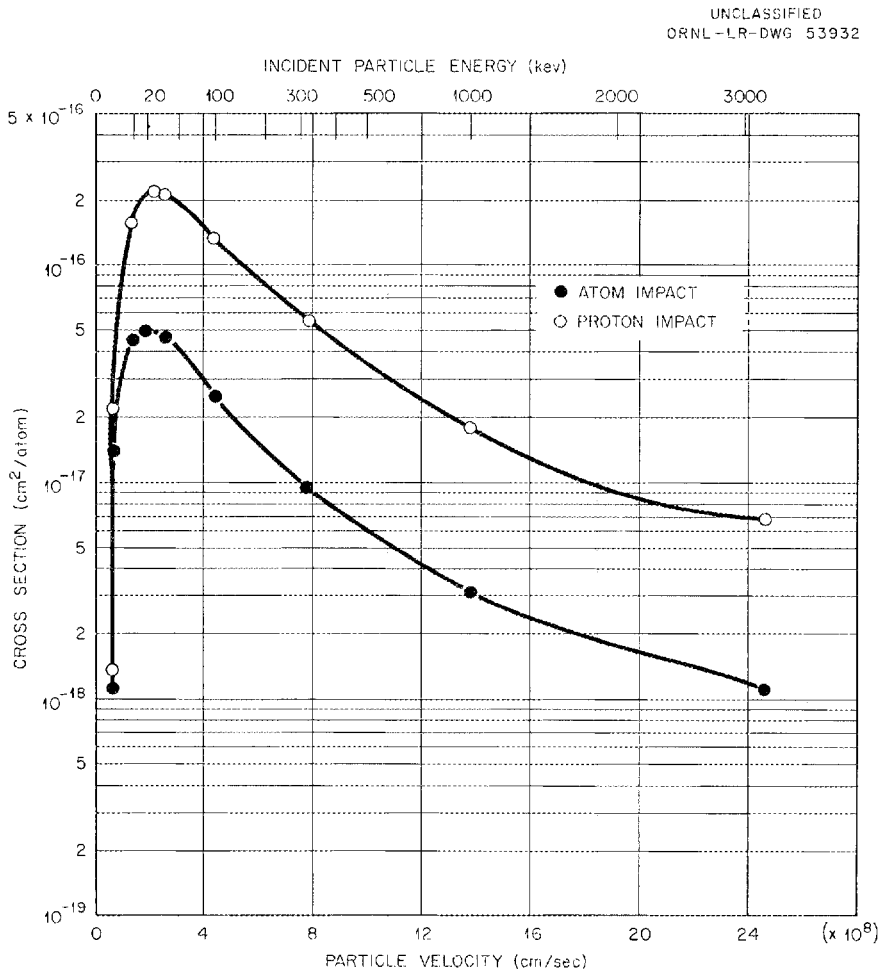

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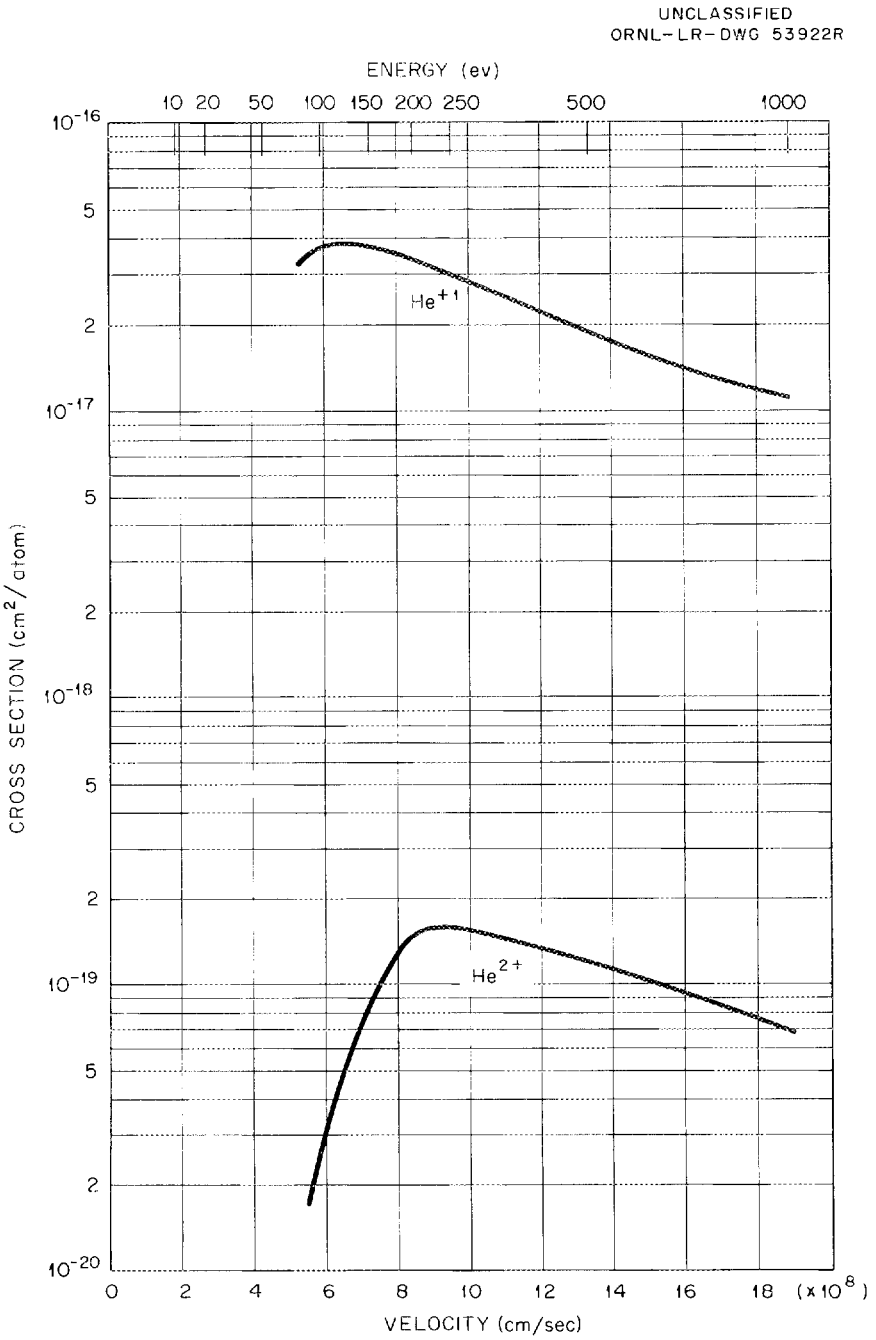

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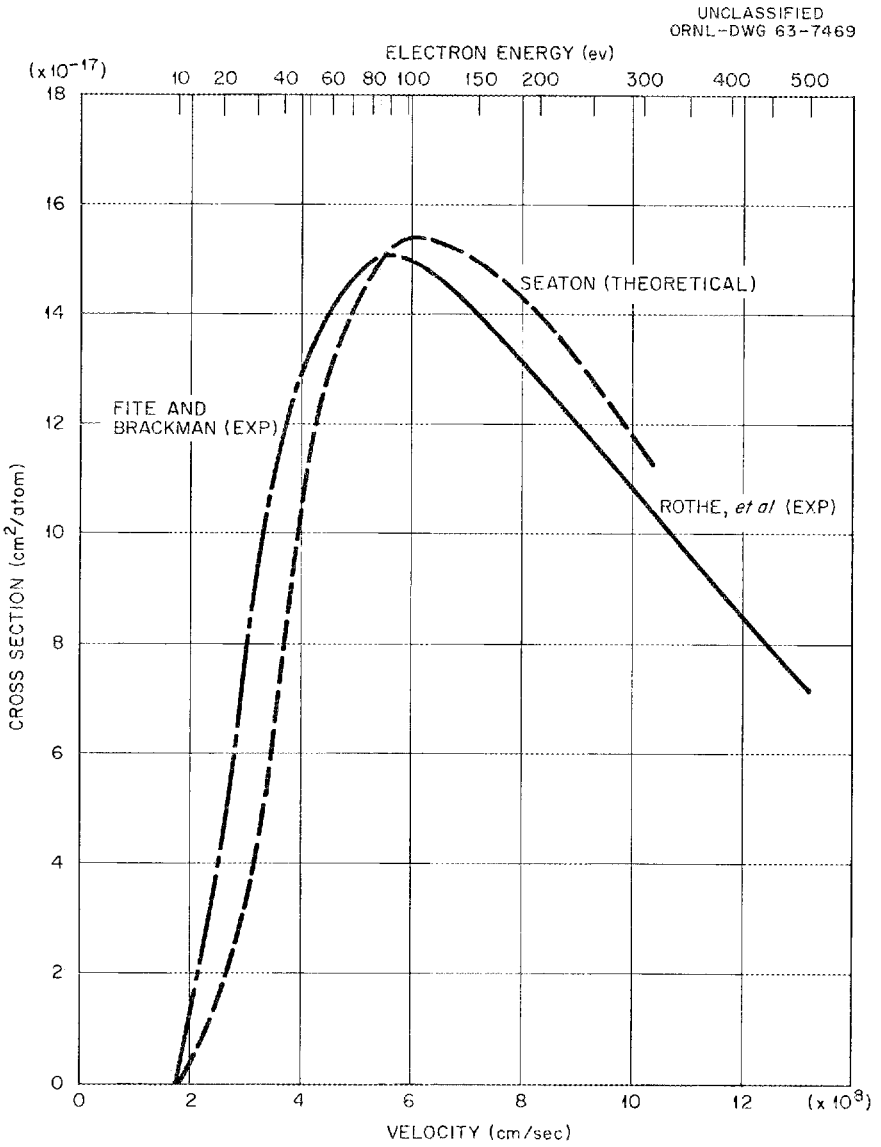

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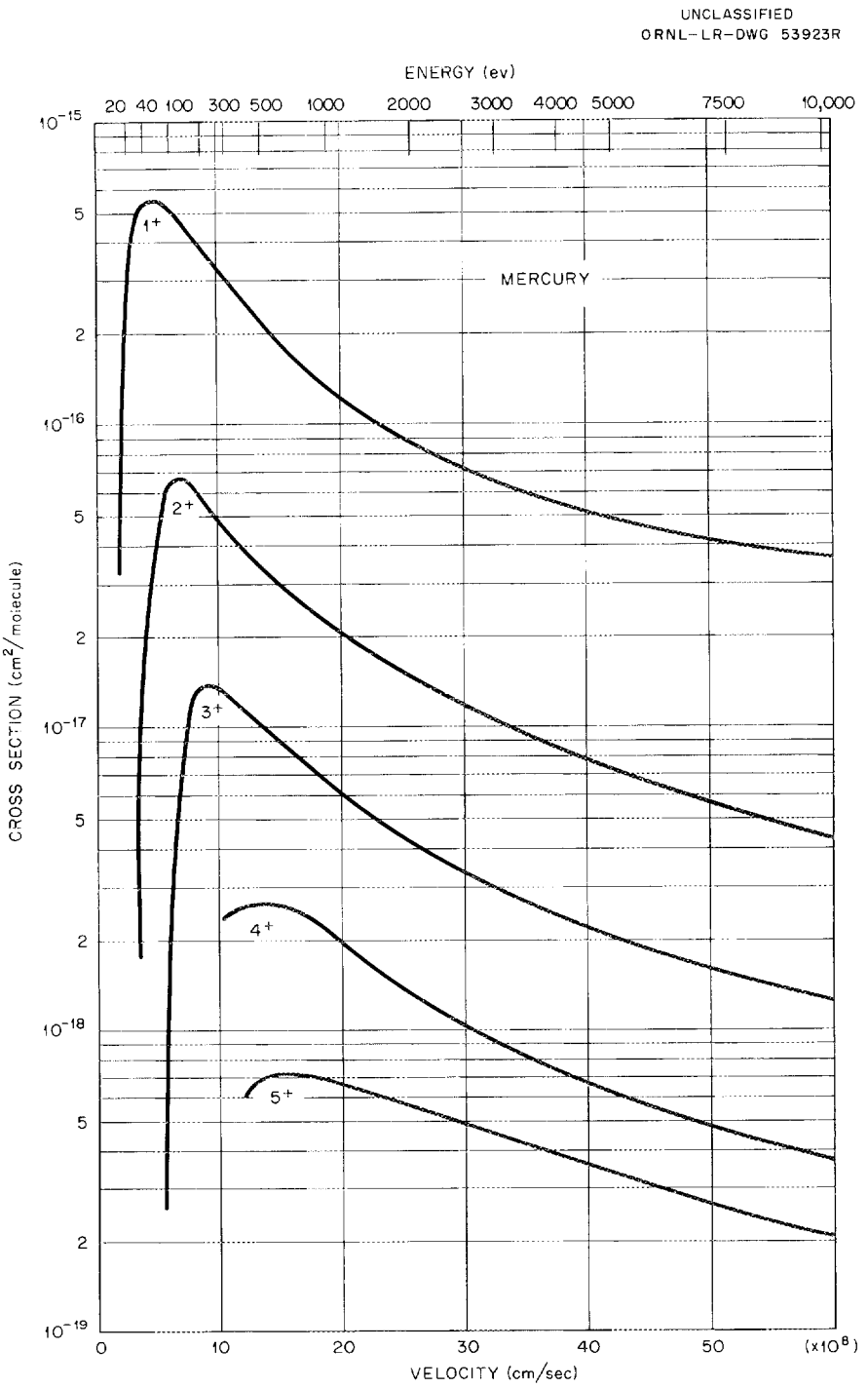
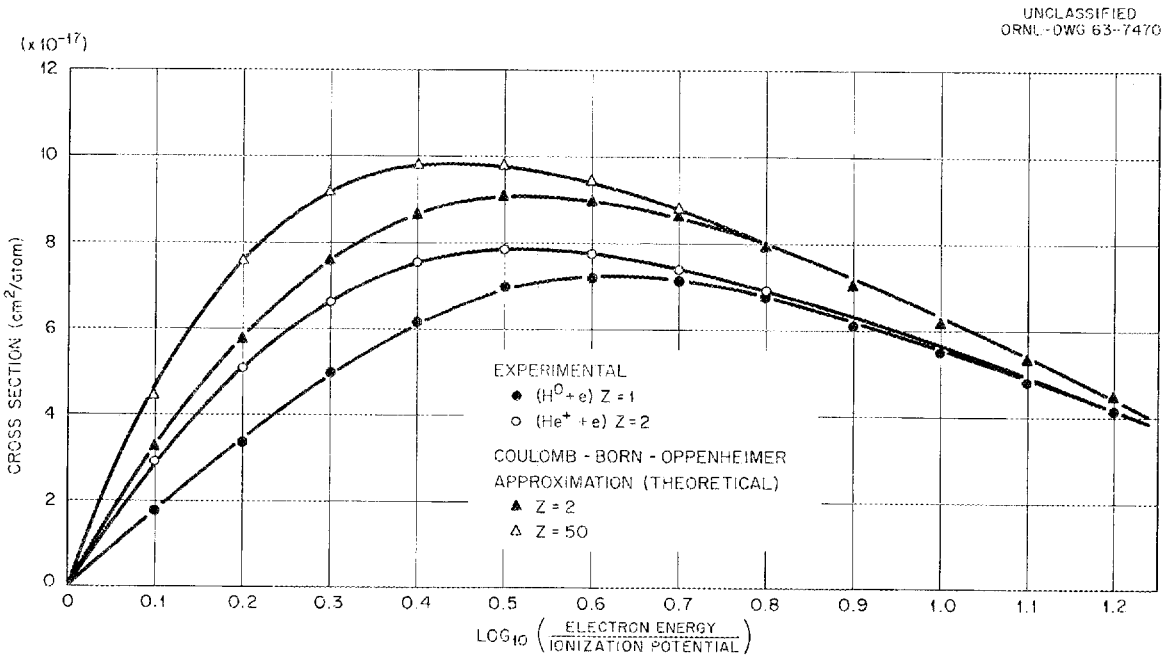
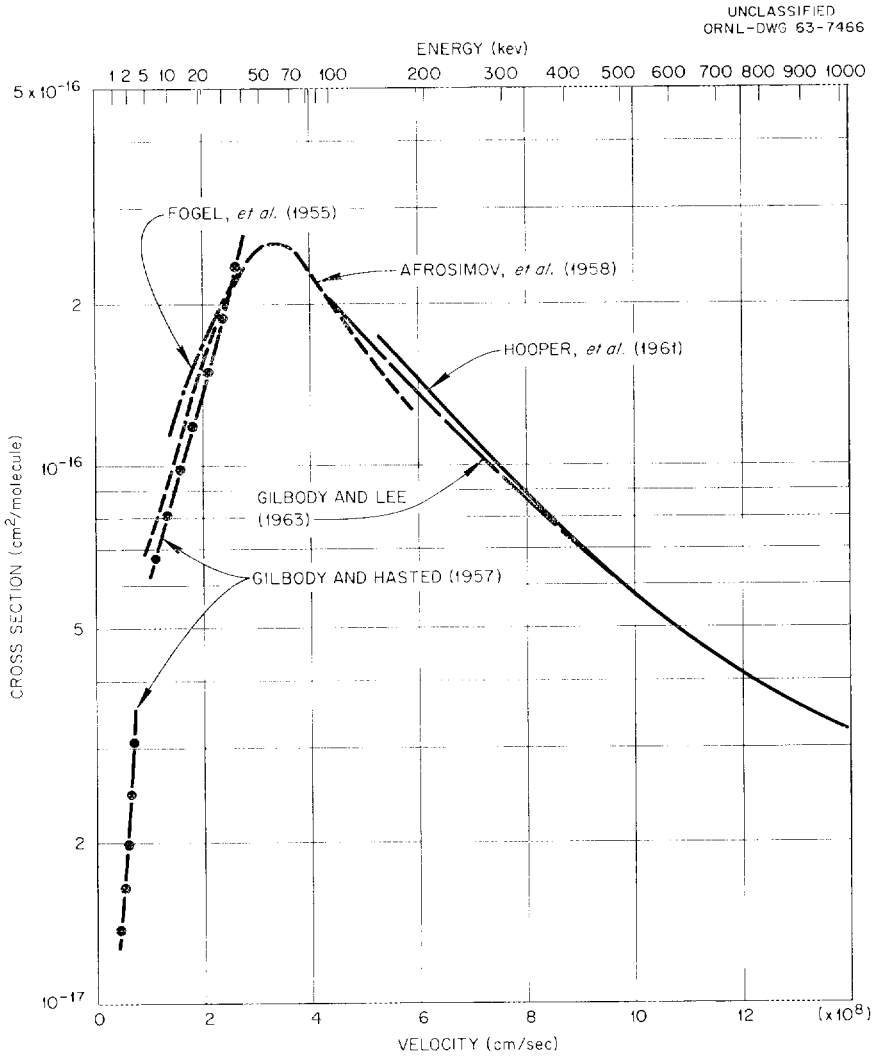


Cross Sections for Ionization of Mercury by Electron Impact.



Cross Sections for Ionization of Hydrogenic Positive Ions by Electron Impact.



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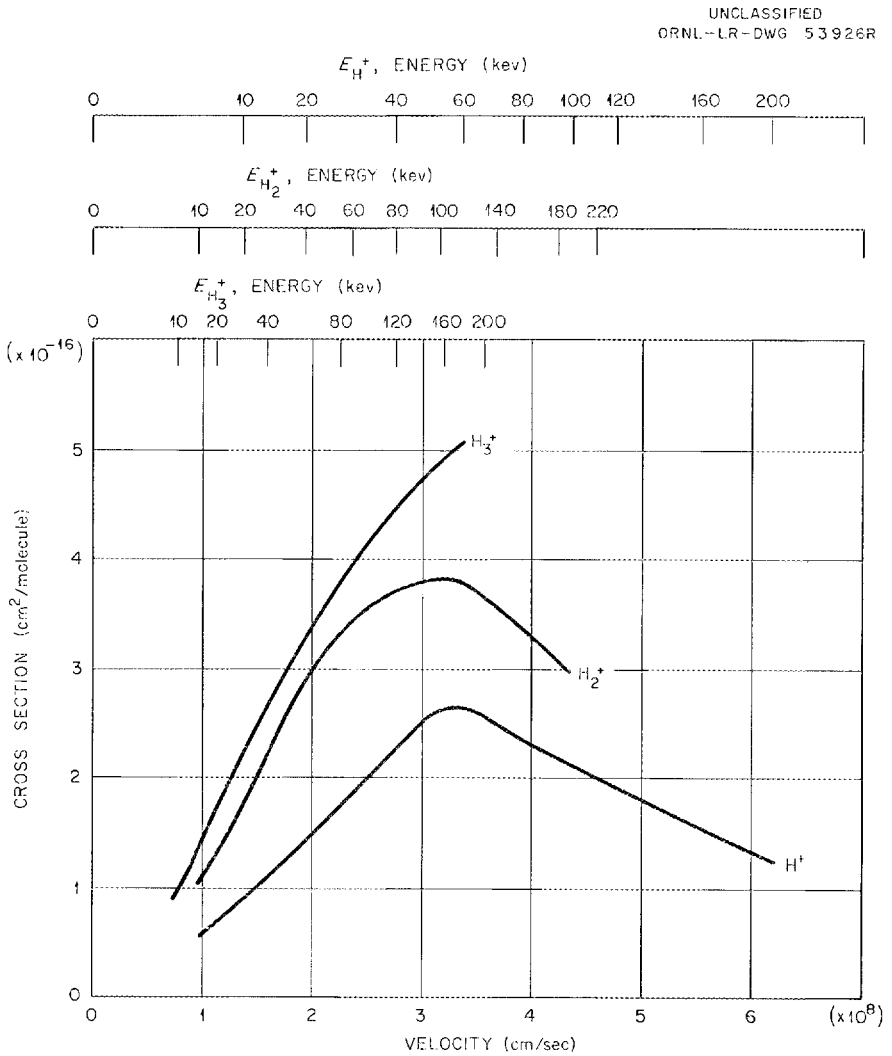

Cross Sections for Production of Free Electrons in Hydrogen by H^+, H_2^+, and H_3^+ Ion Impact.

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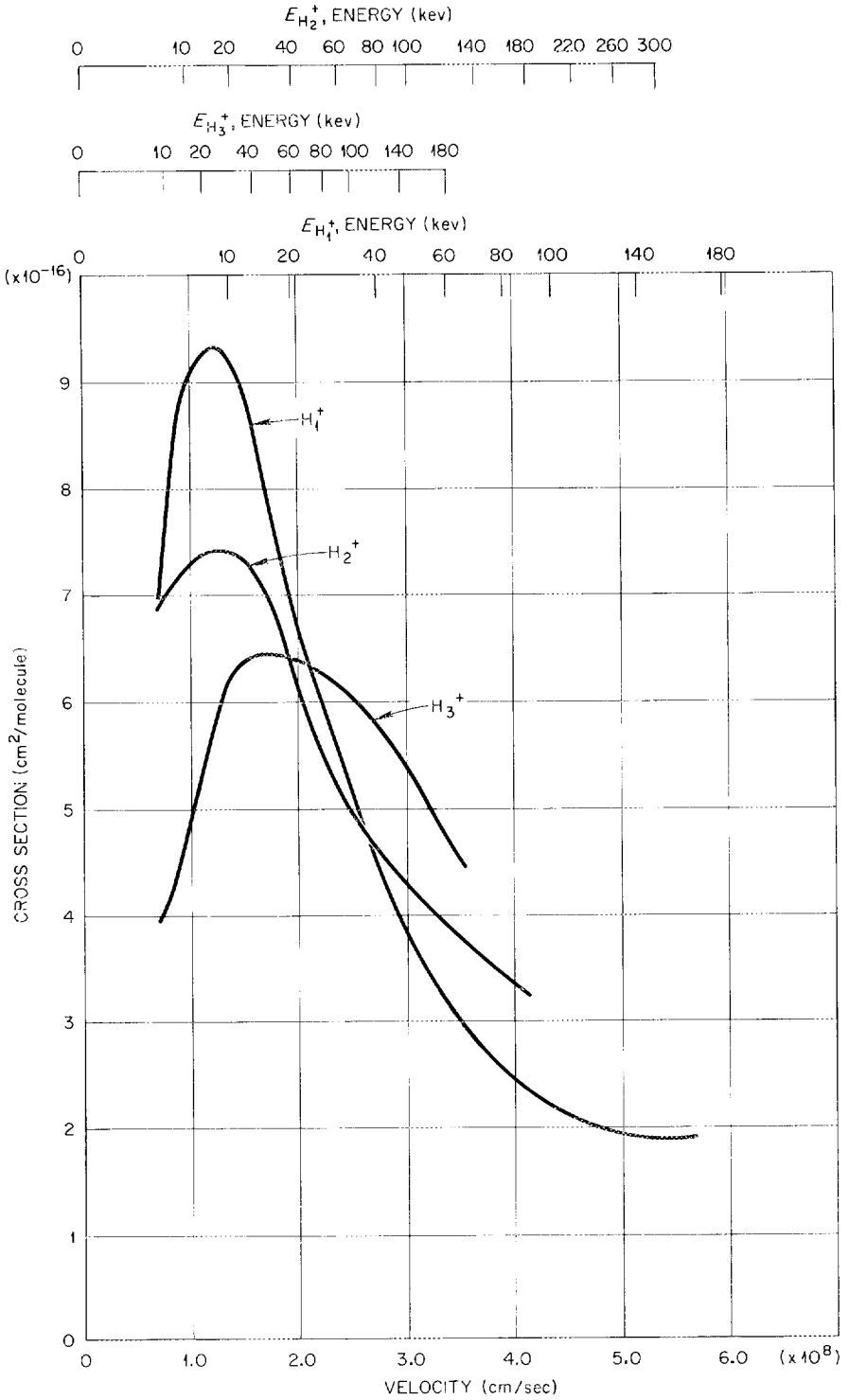

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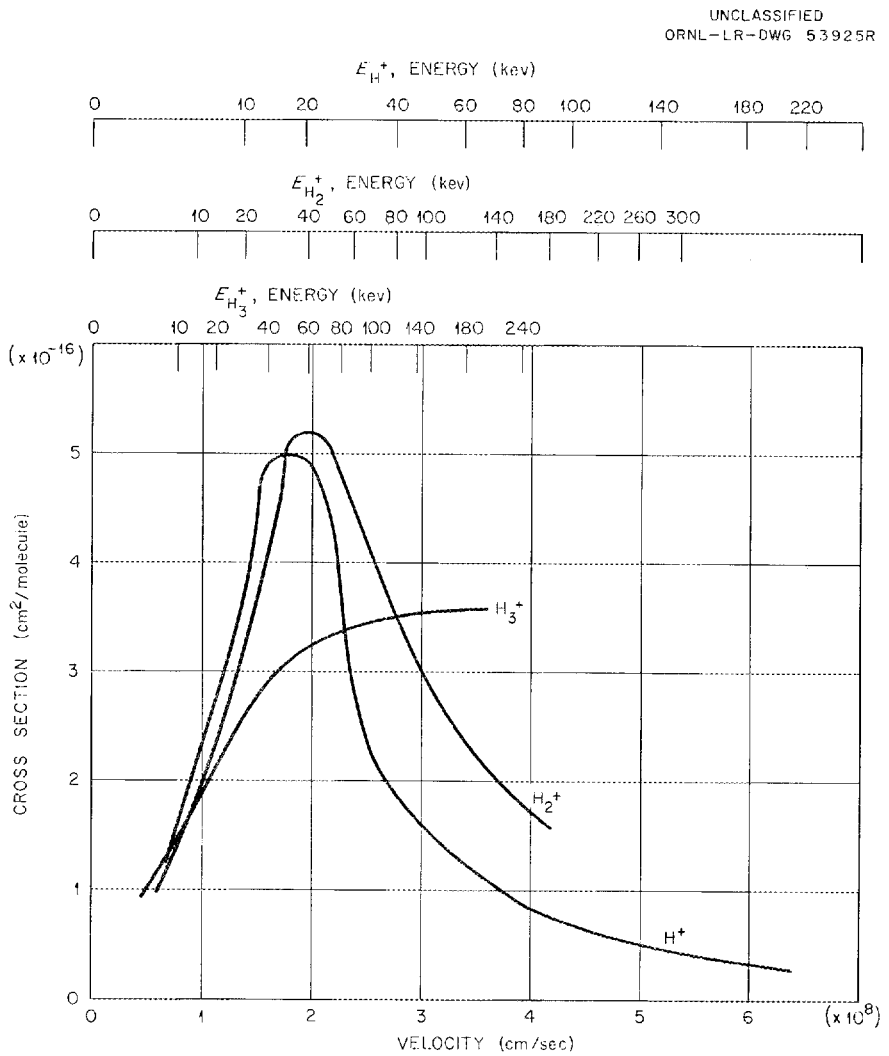

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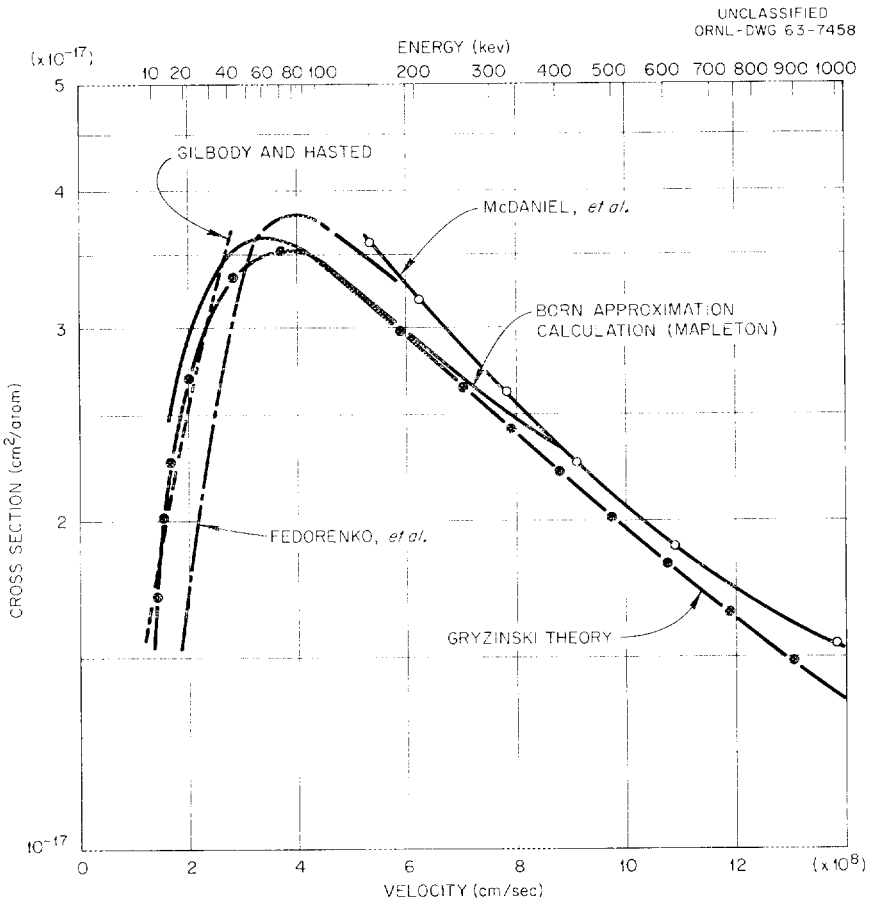
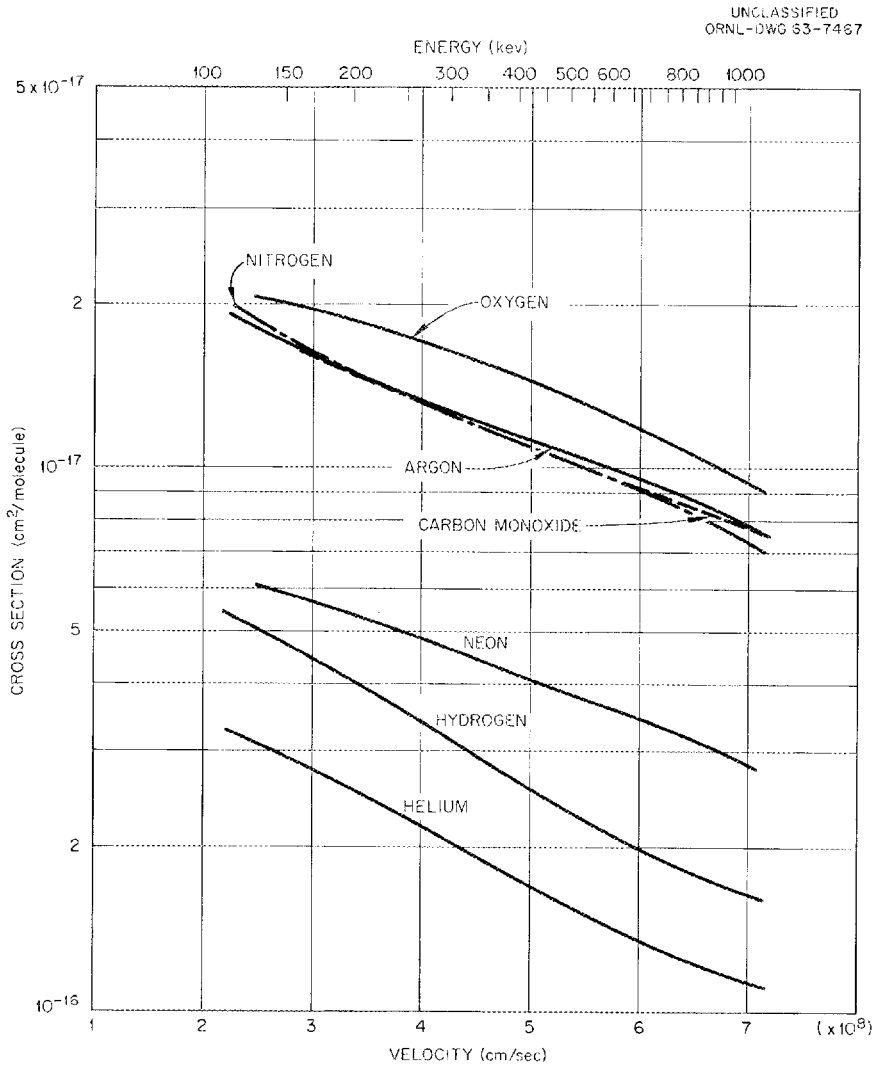
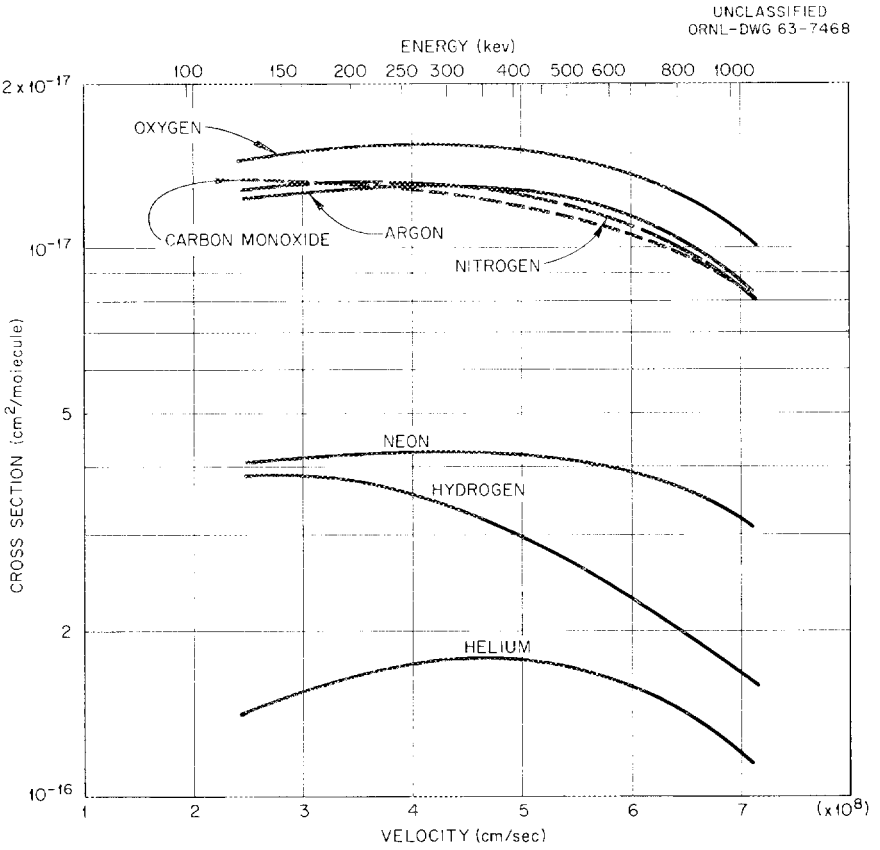


Cross Sections for Production of Electrons in Helium by H^+ Ion Impact.



Cross Sections for Production of Positive Ions in Hydrogen, Helium, Nitrogen, Oxygen, Neon, Argon, and Carbon Monoxide by He^+ Ion Impact.



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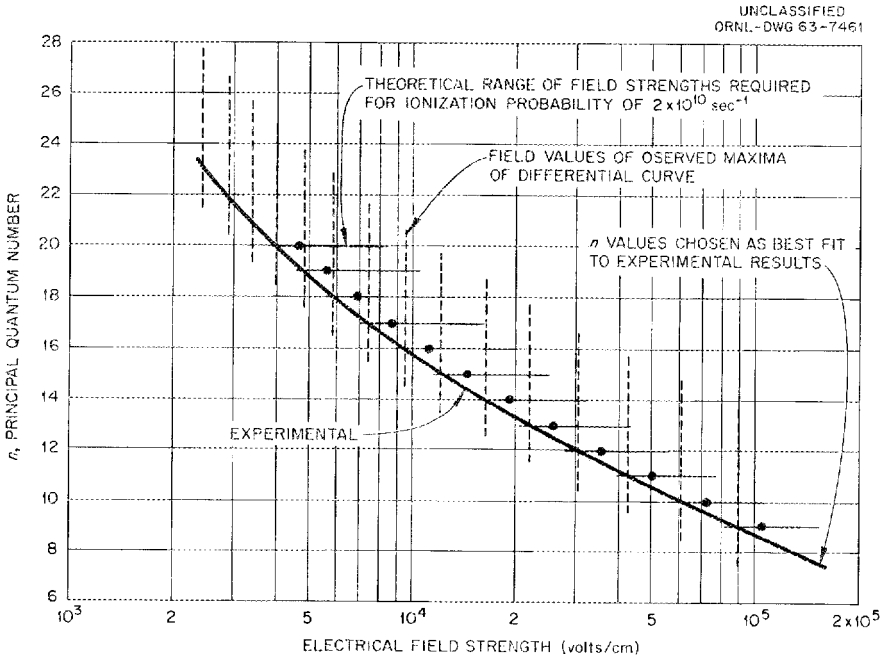
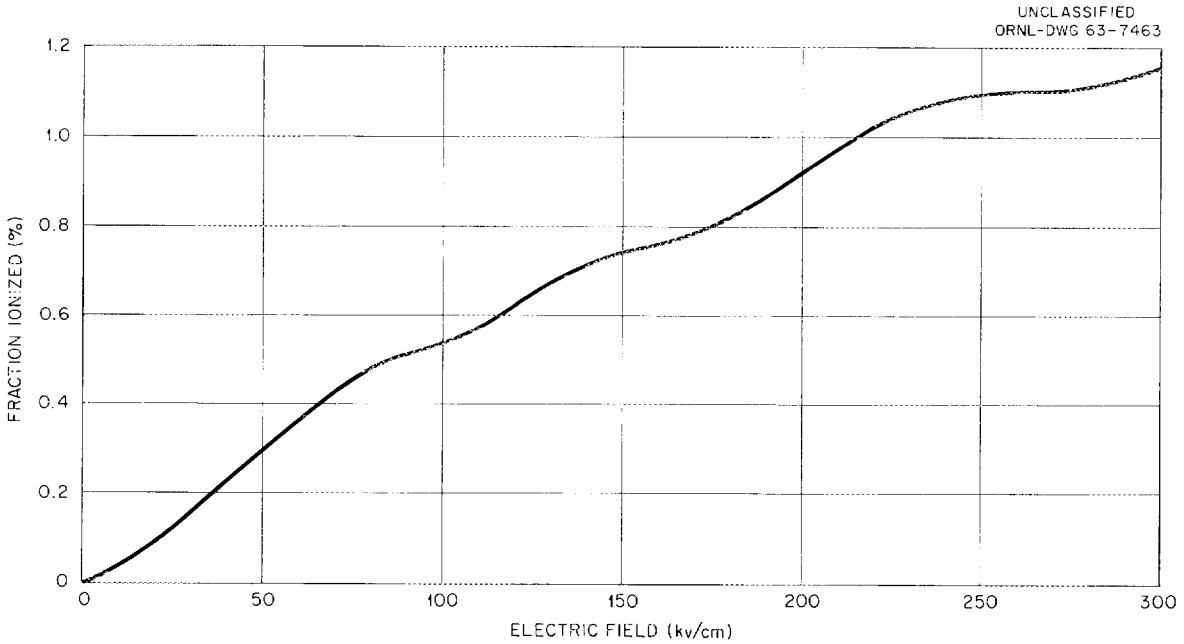


The Electric Field Required to Ionize the Various n States of Hydrogen Atoms.



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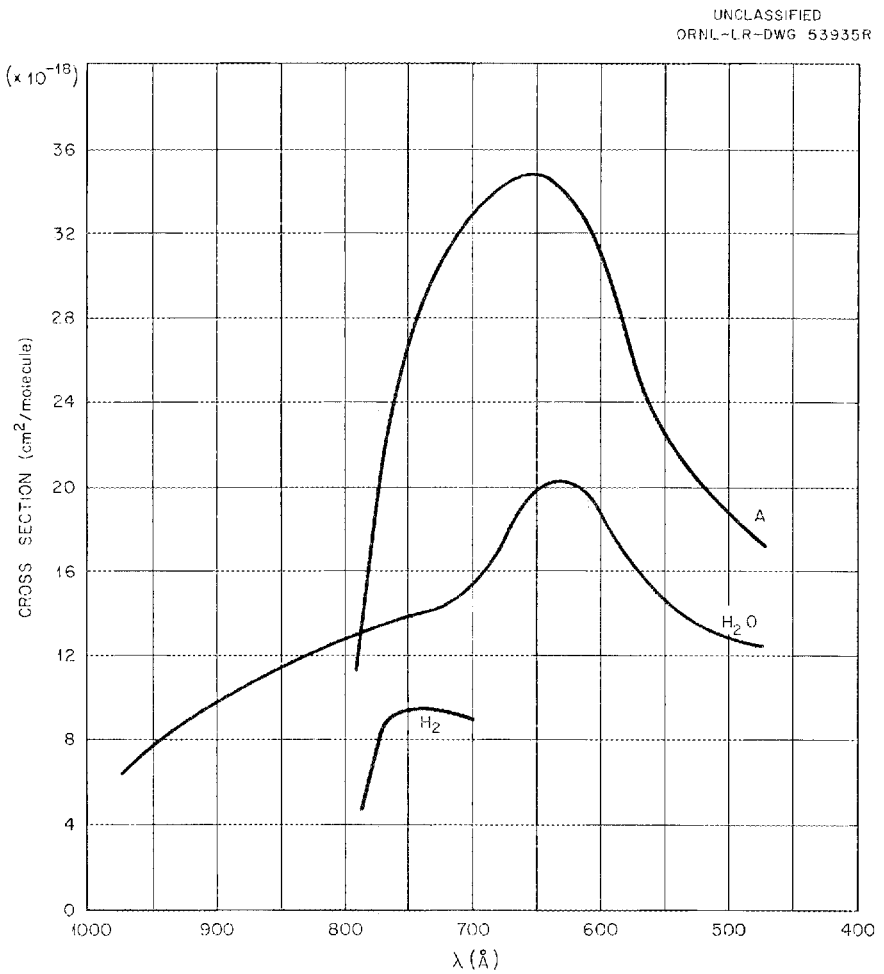
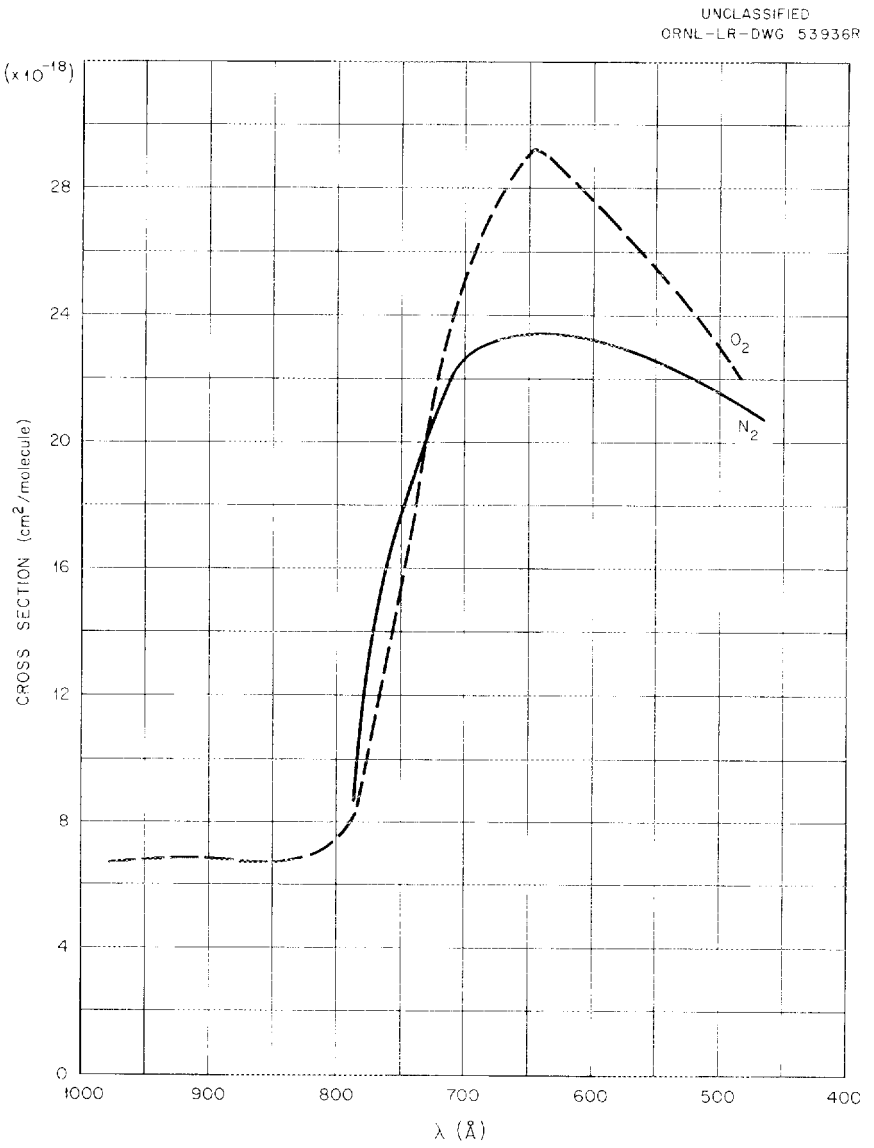


Cross Sections for the Photoionization of Hydrogen, Argon, and Water Vapor.



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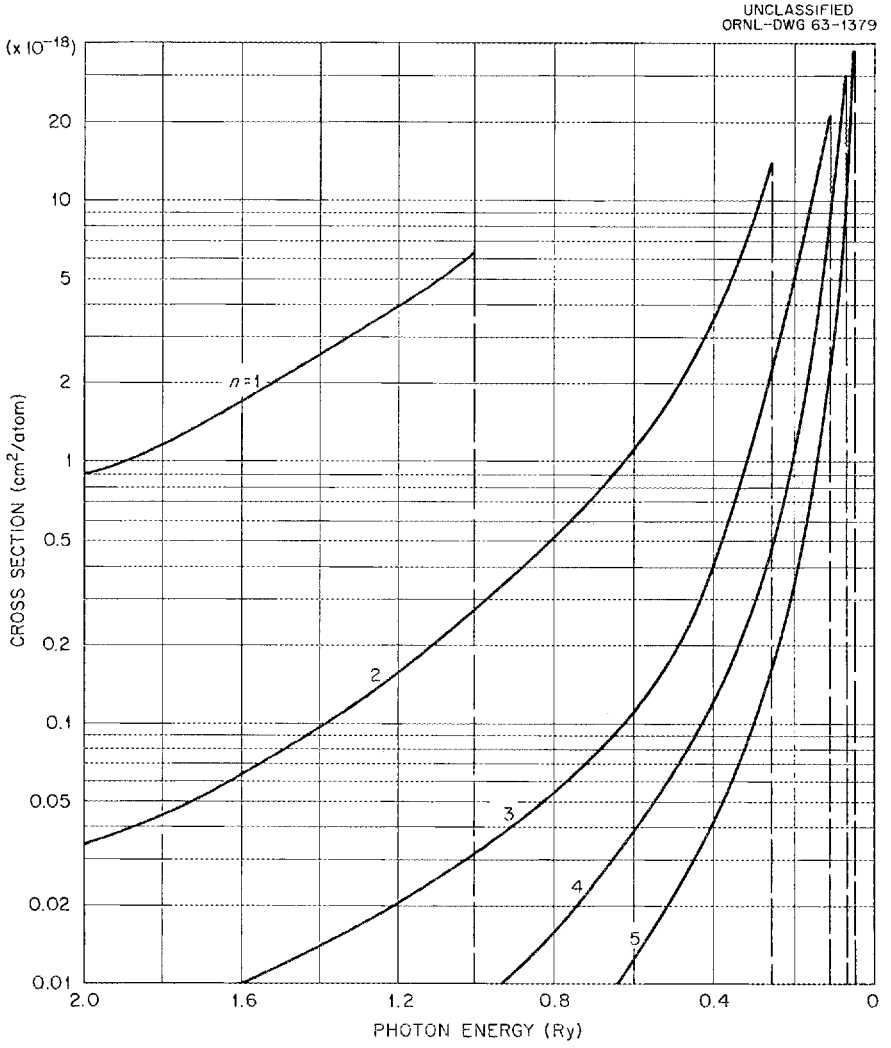

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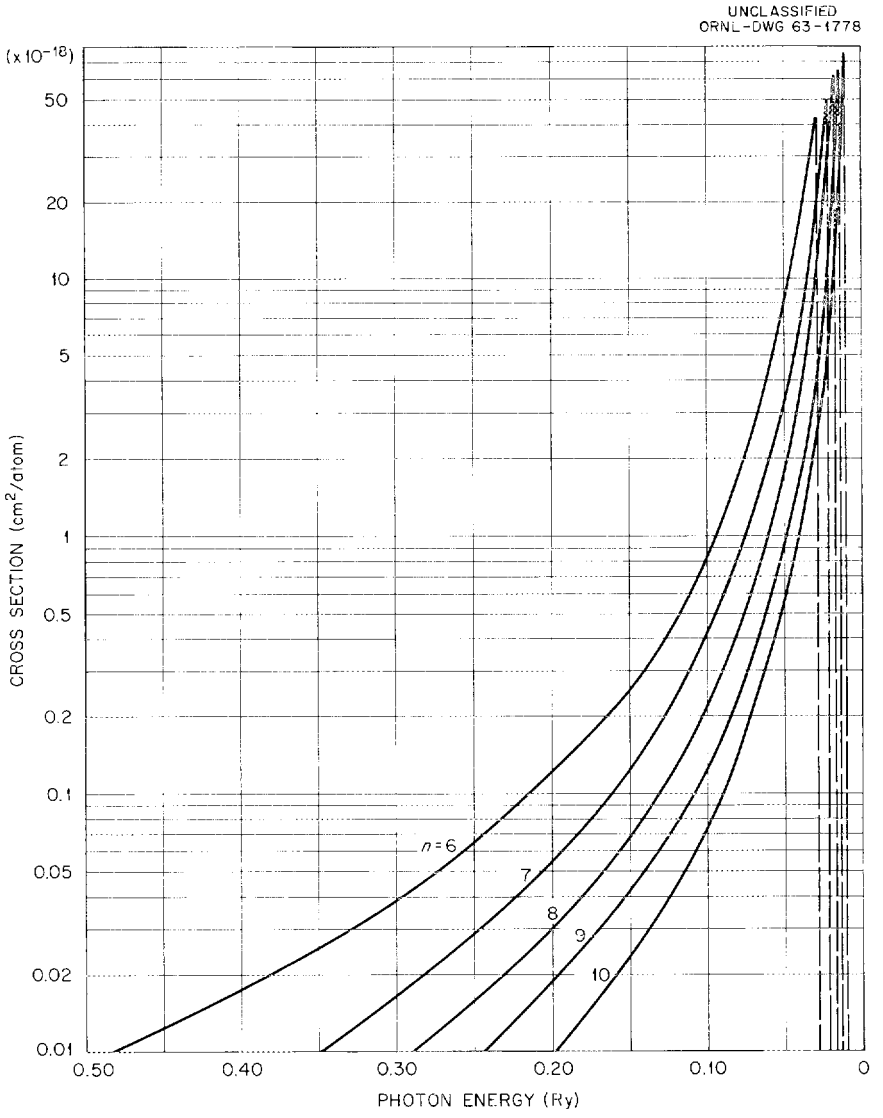

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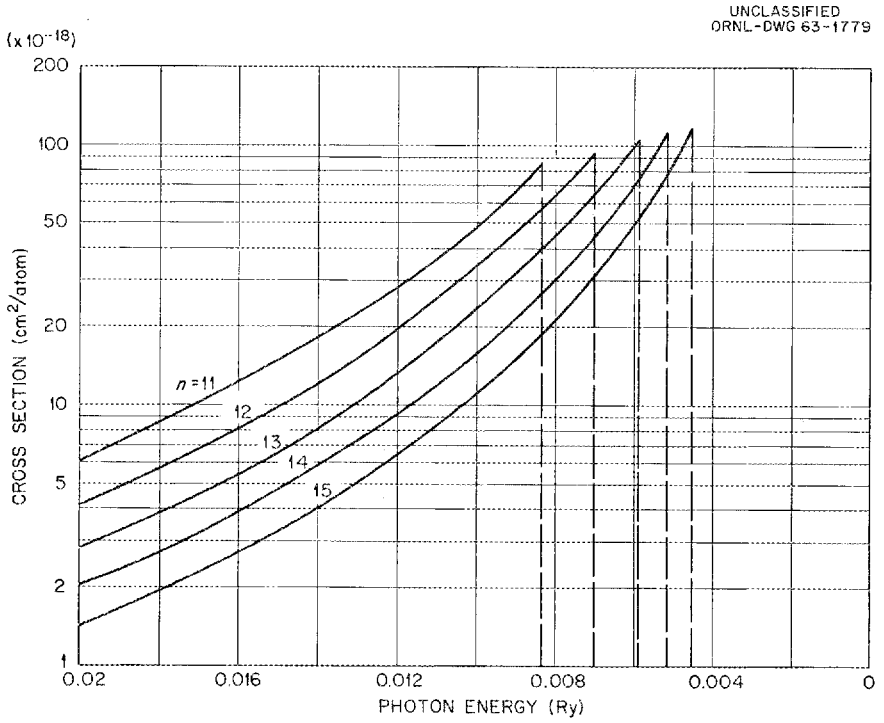

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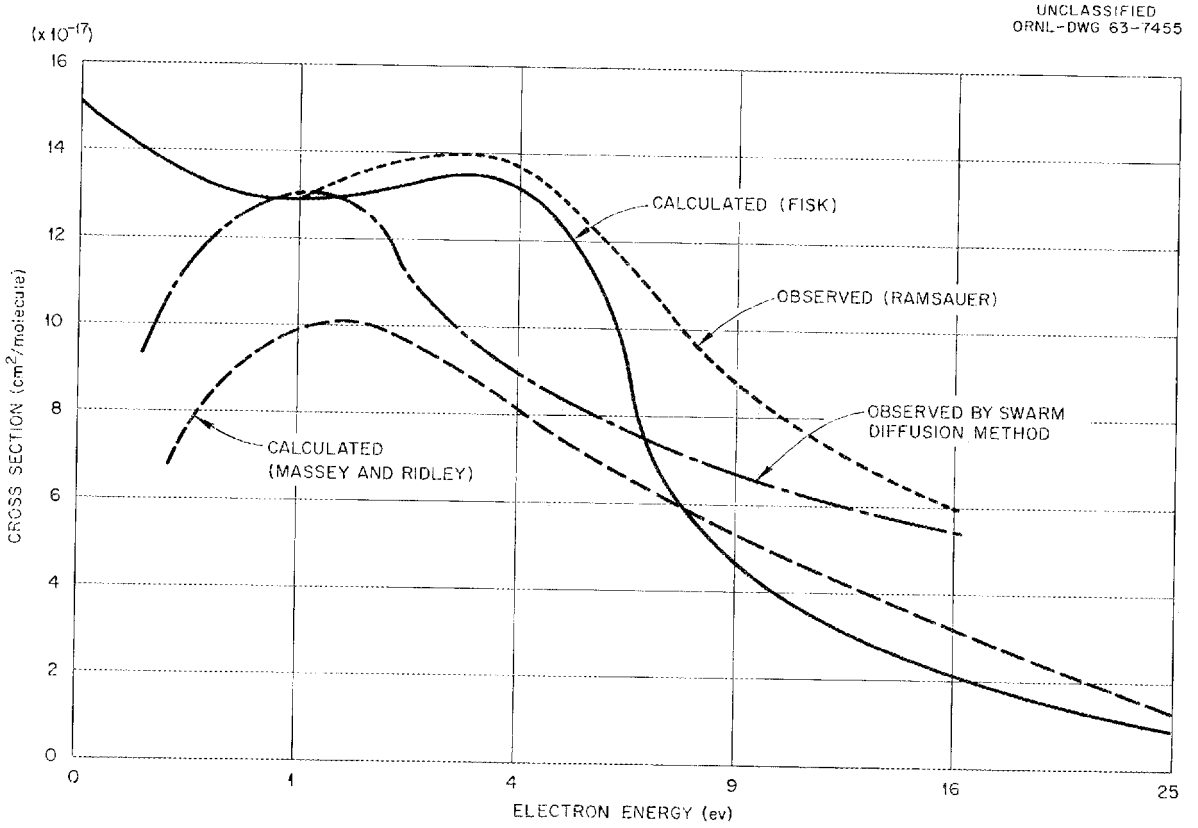

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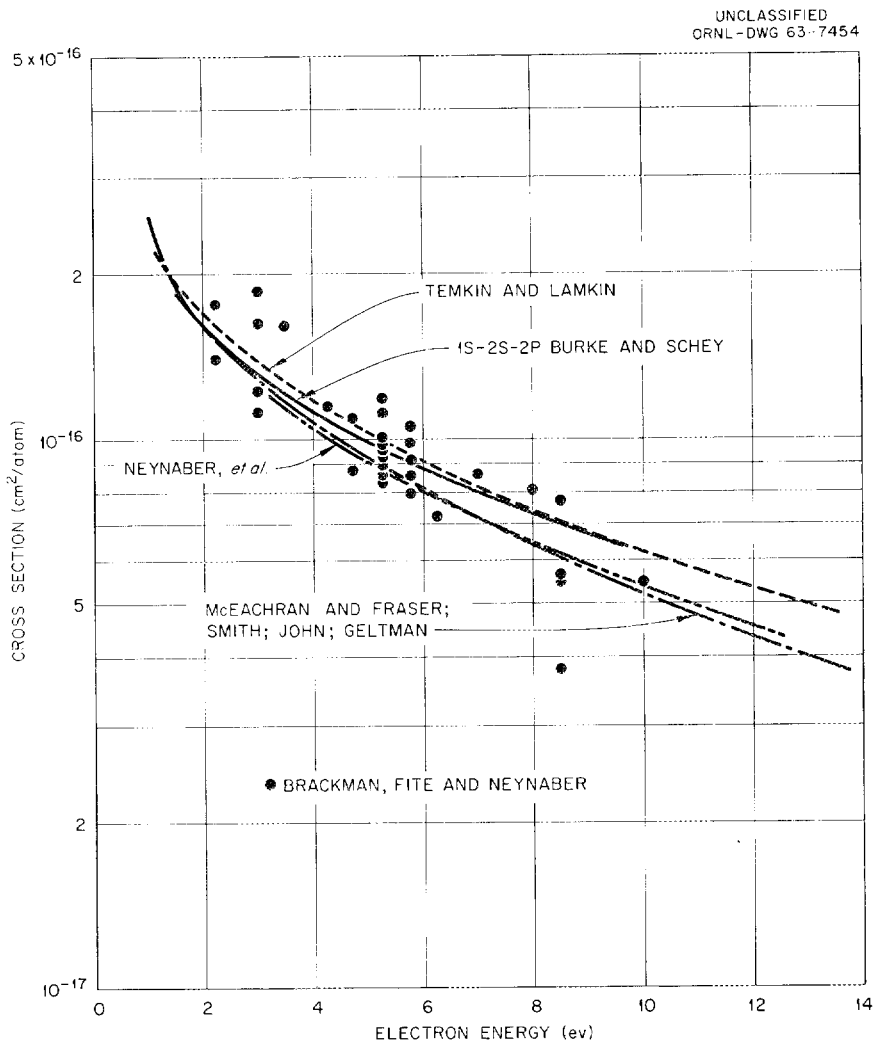

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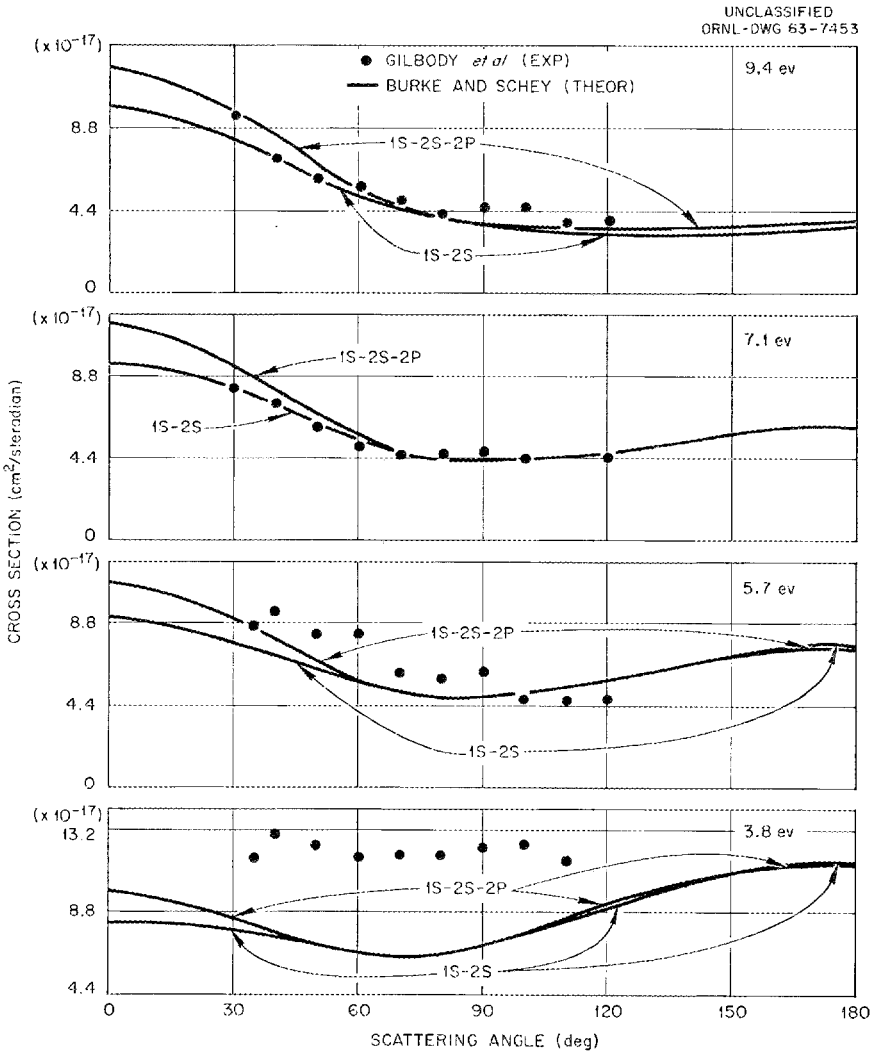

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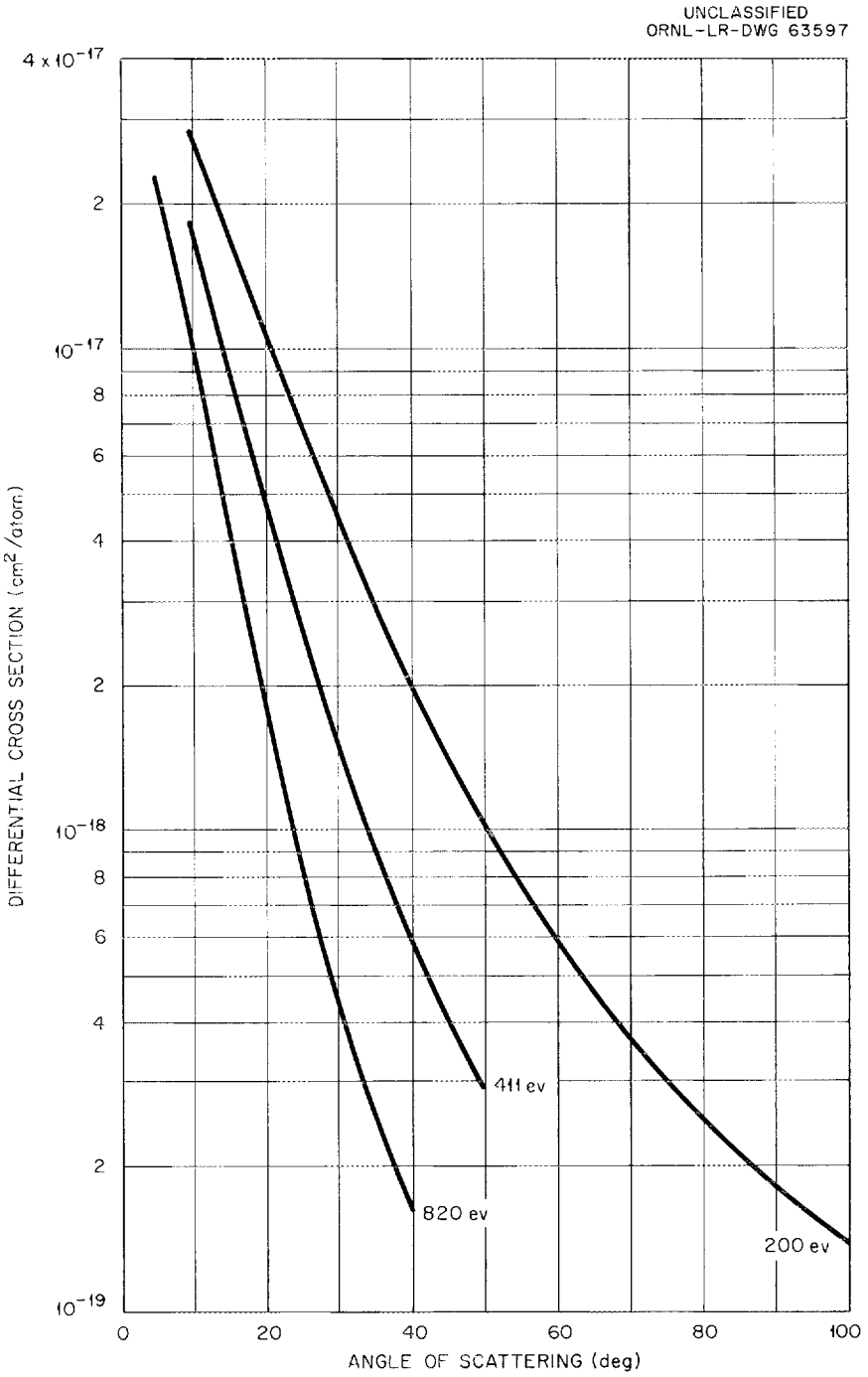

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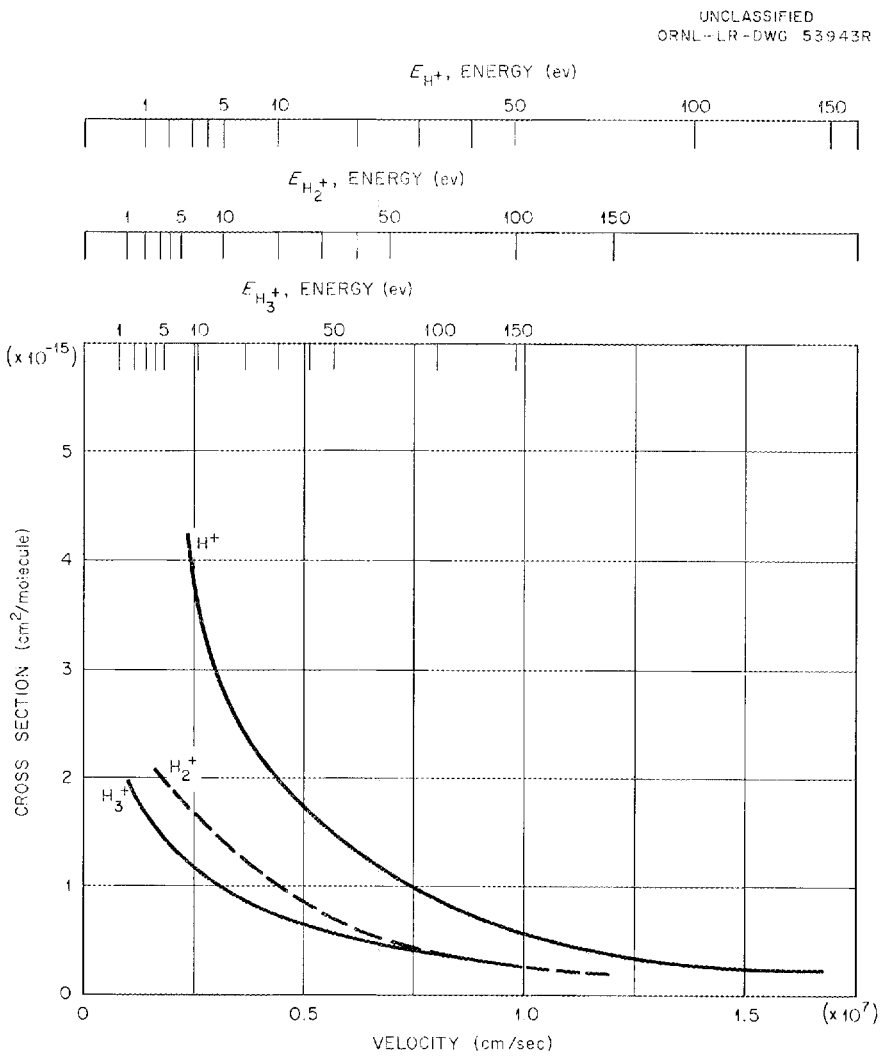

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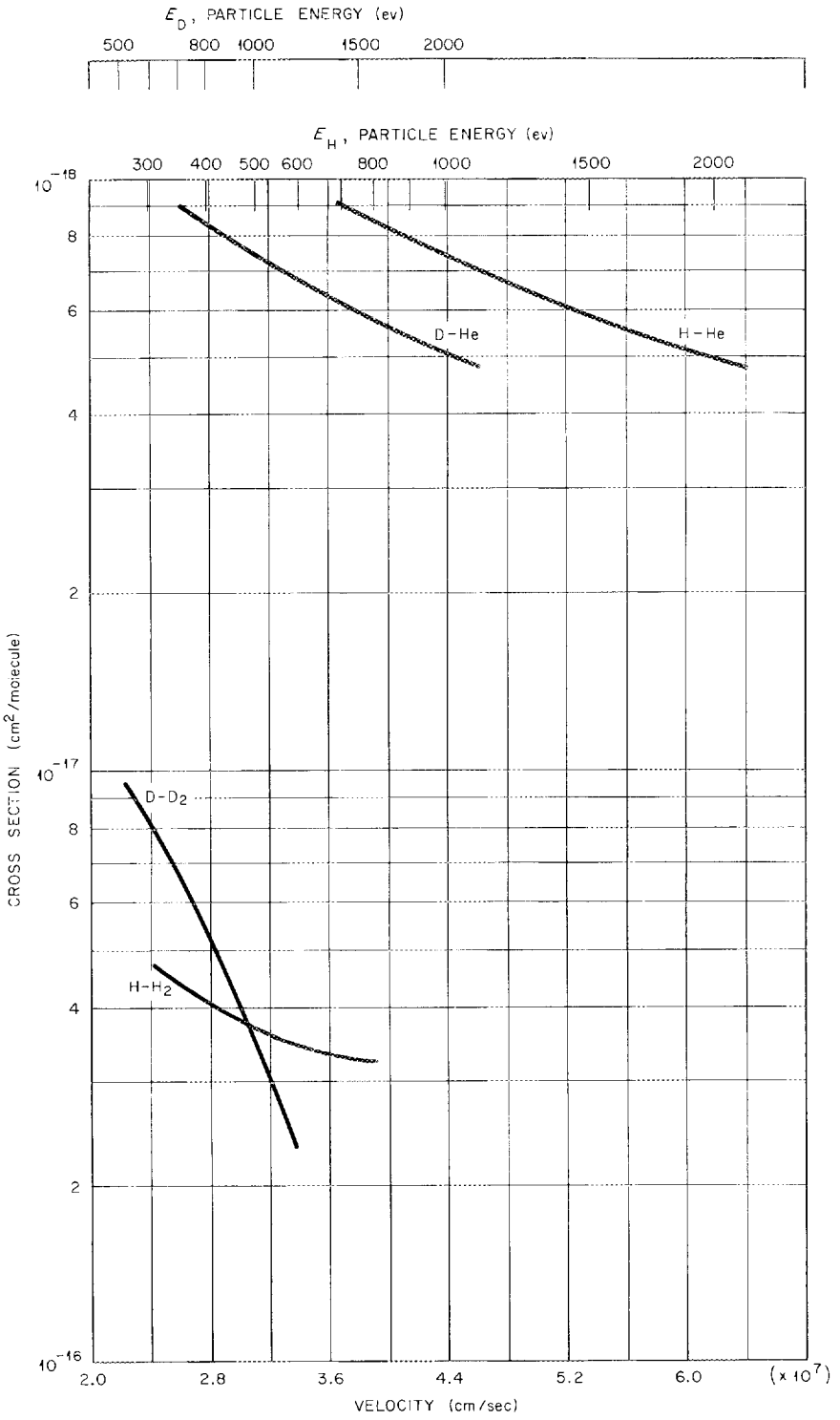

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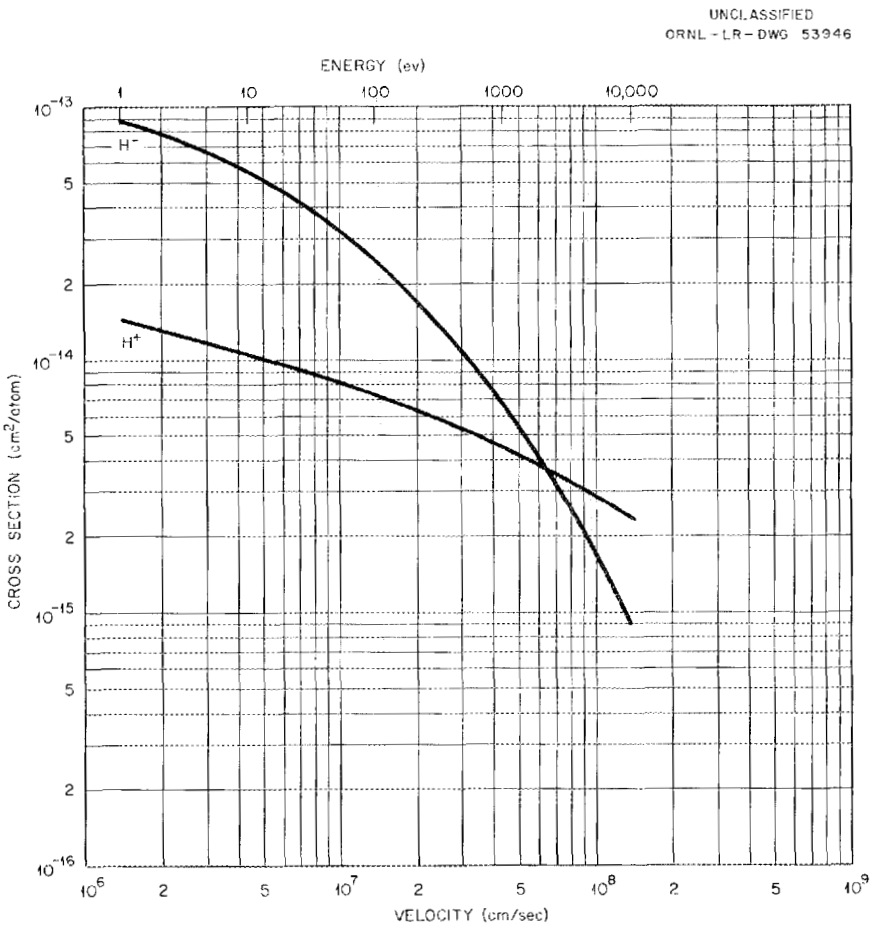

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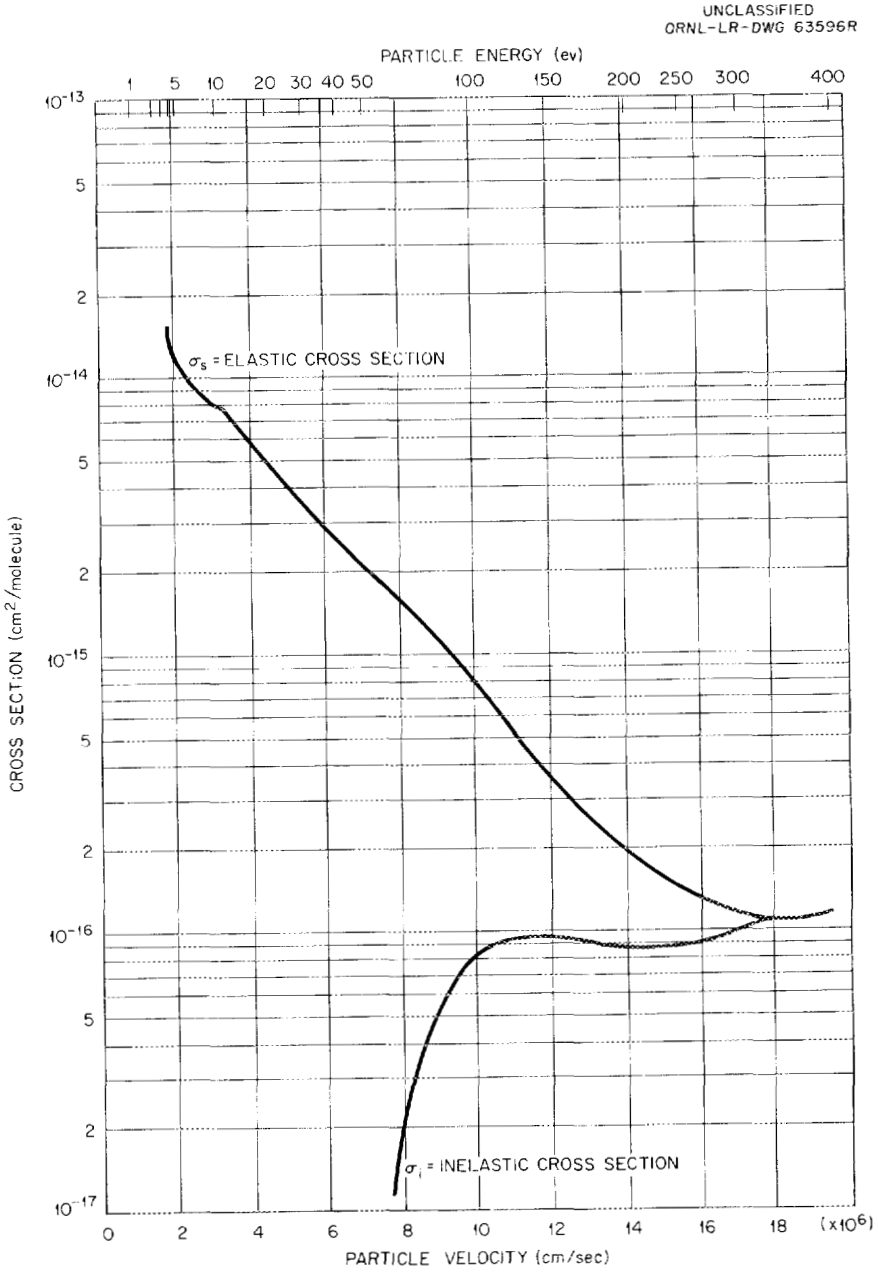

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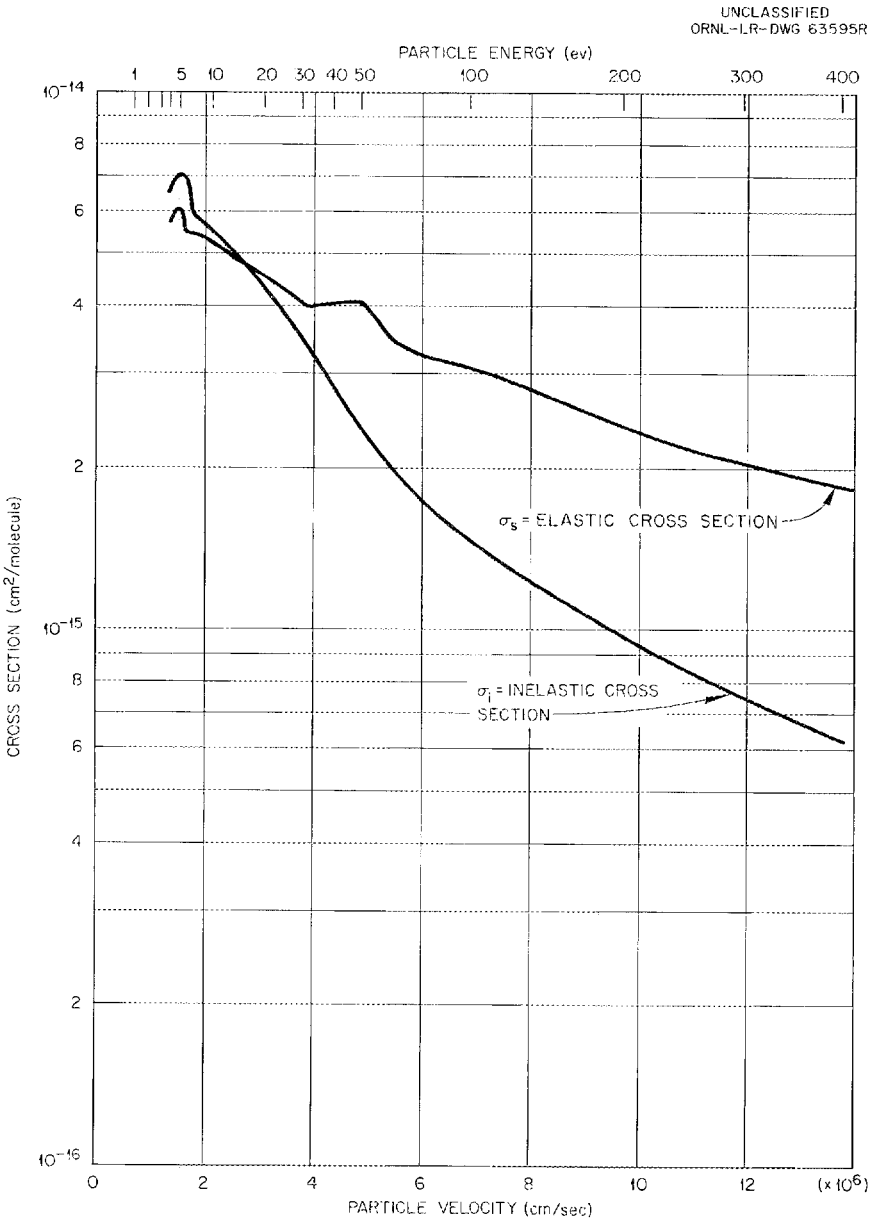

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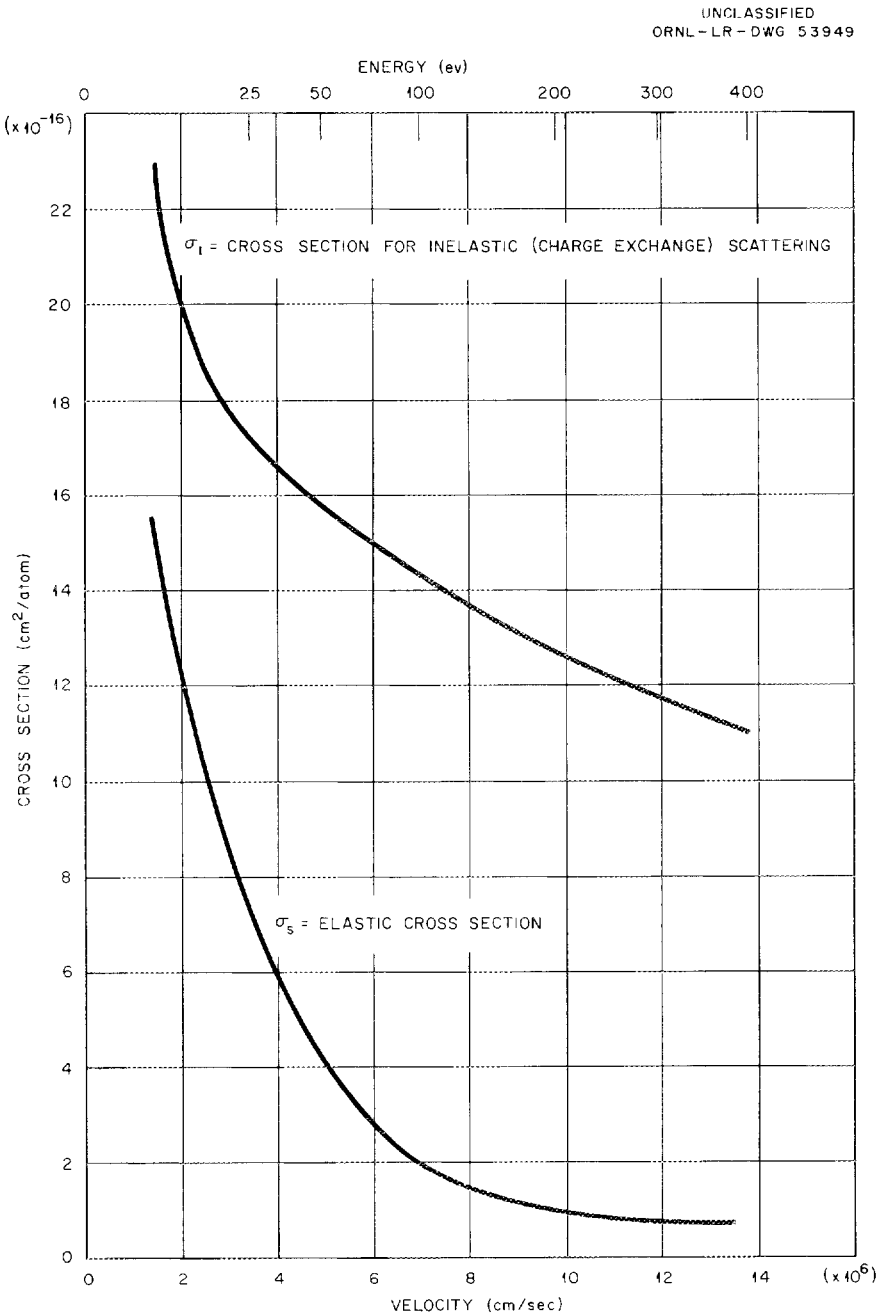

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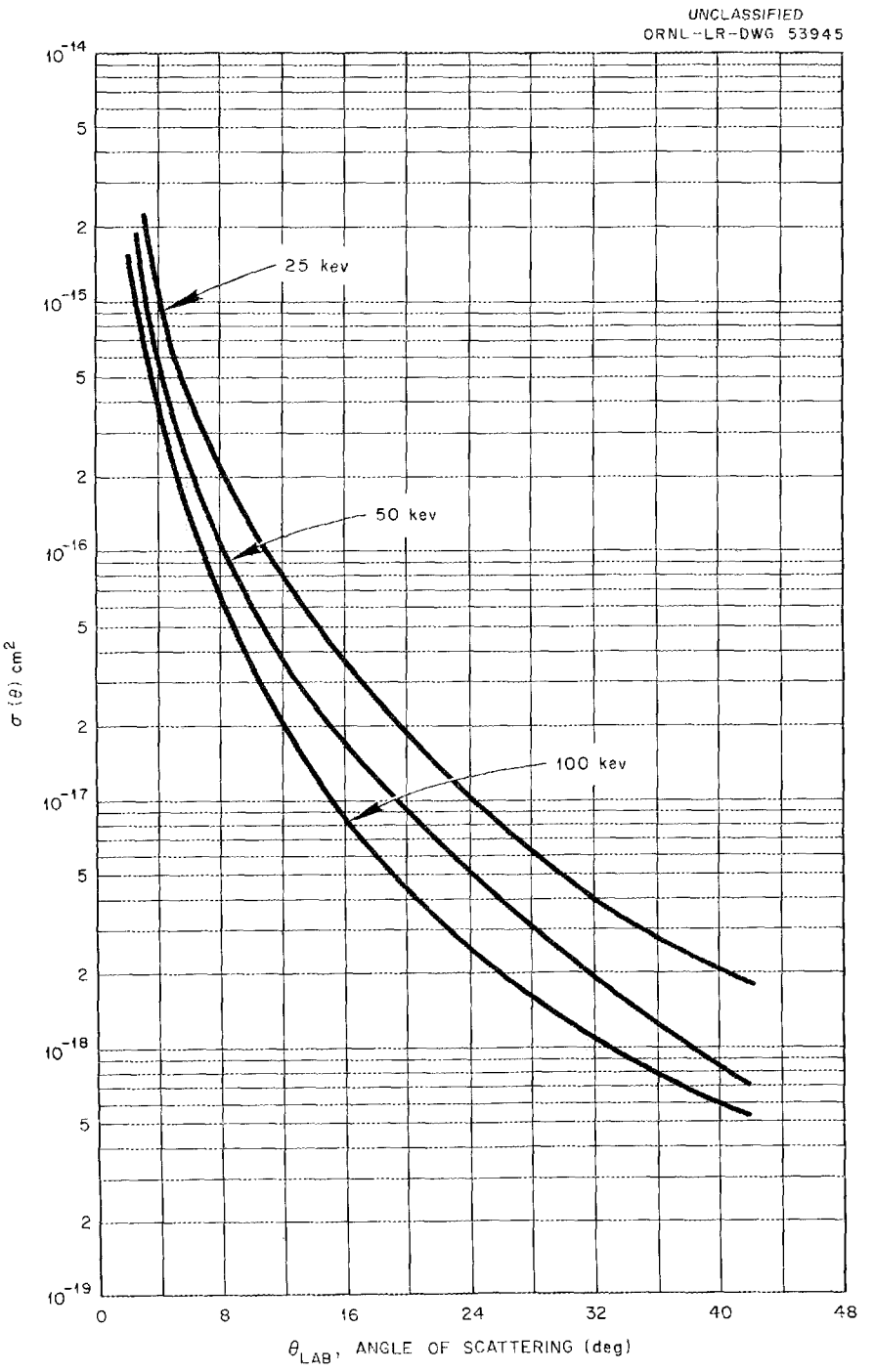

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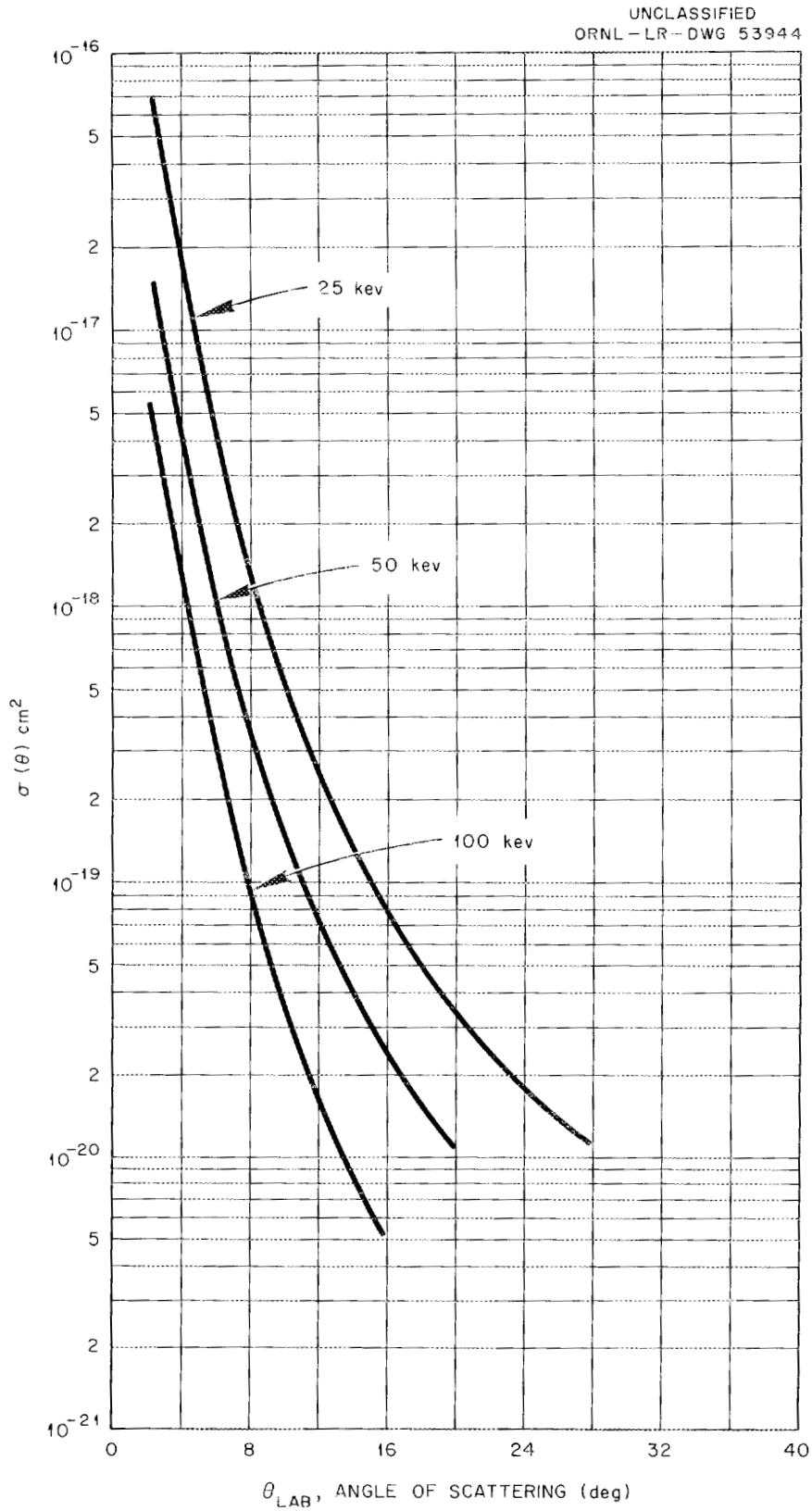

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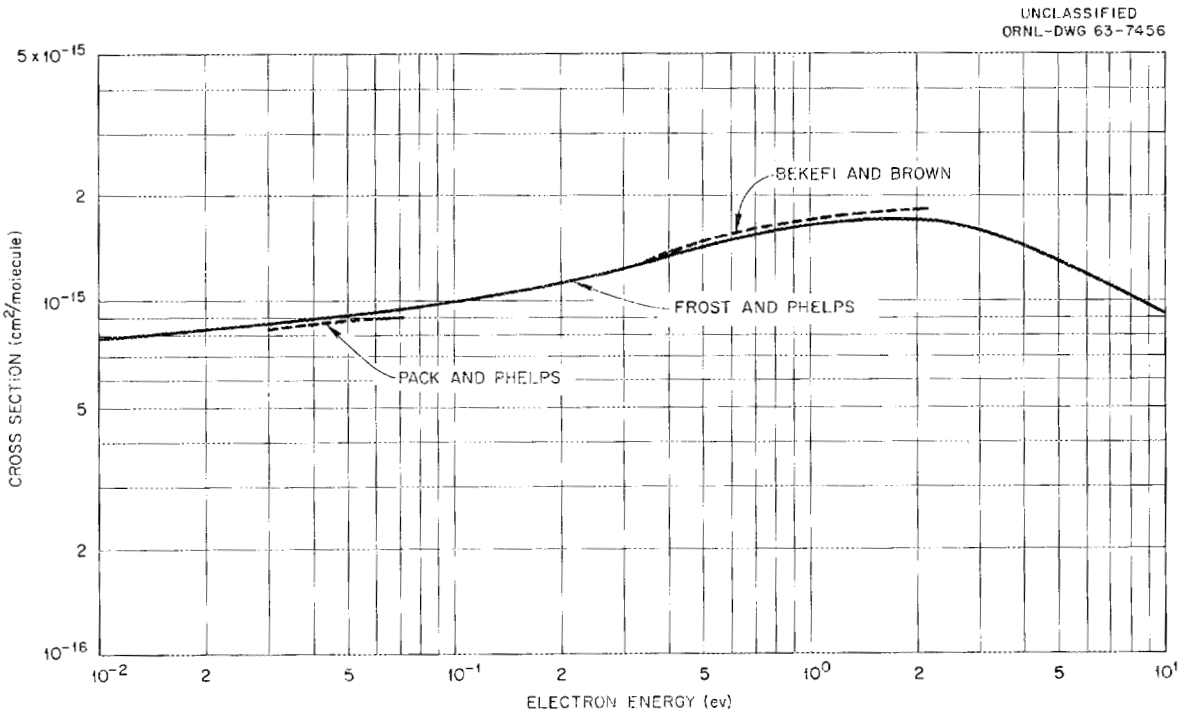

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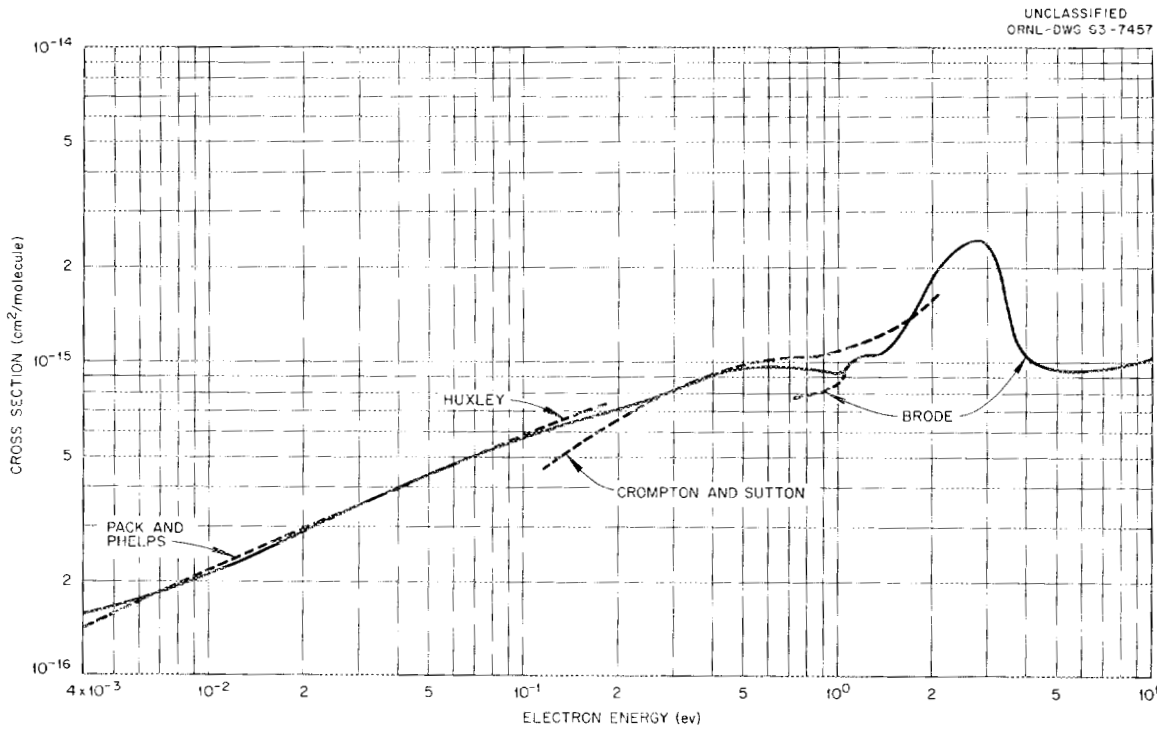

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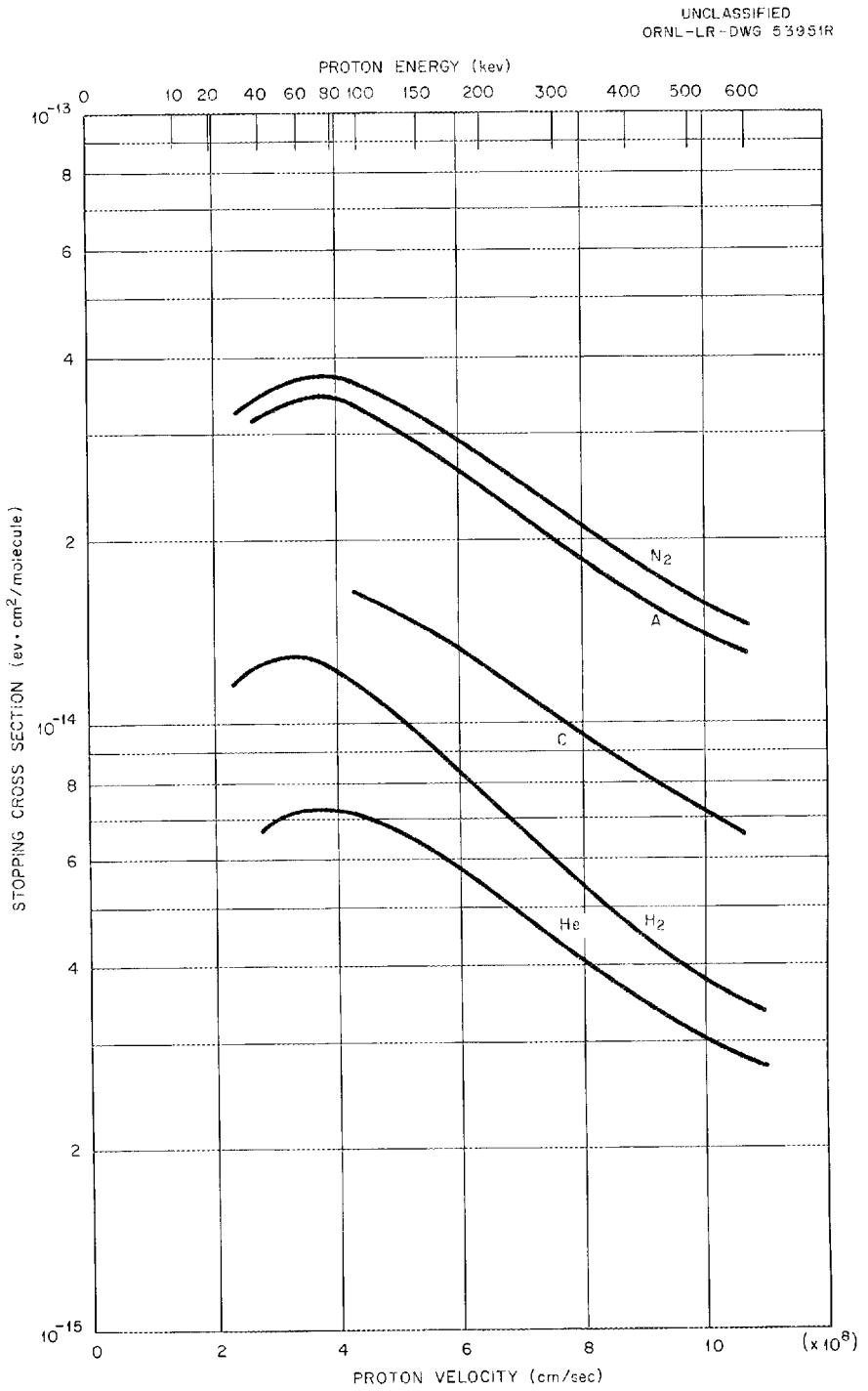
TABLE

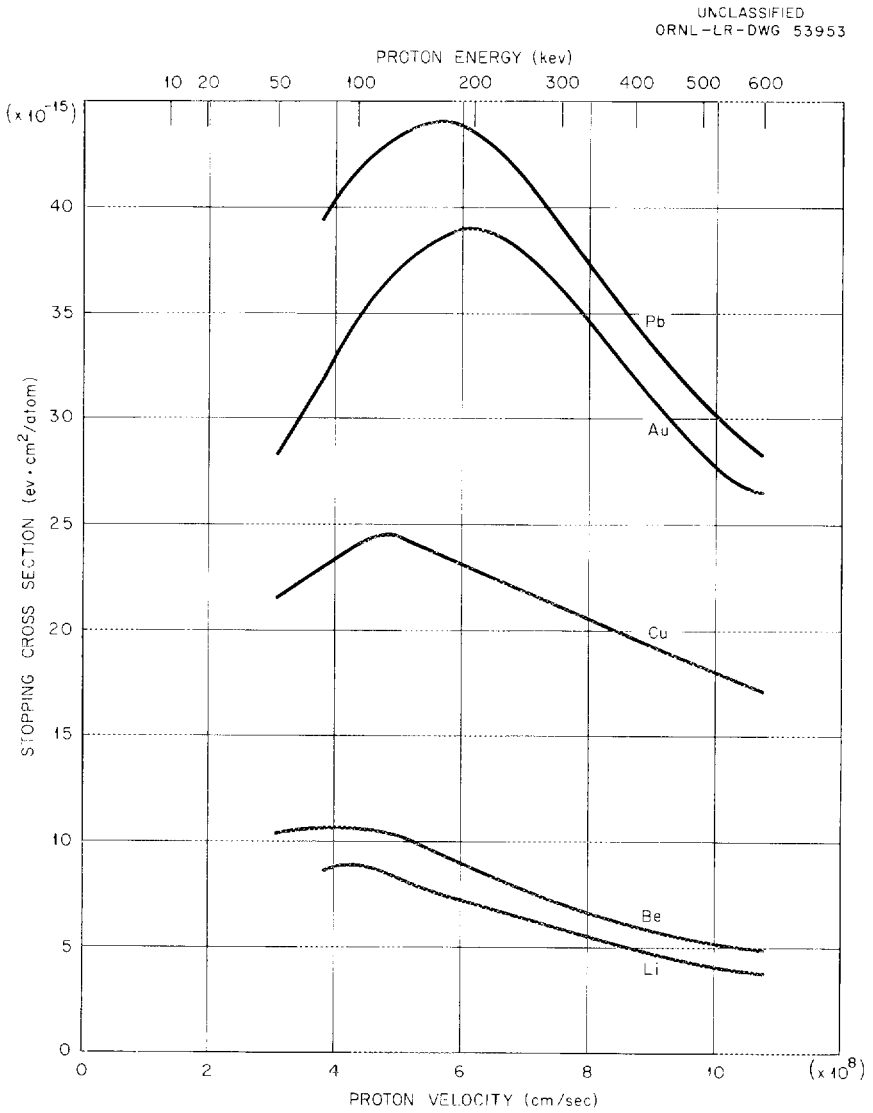
CONVERSION FACTORS FOR ENERGY LOSS MEASUREMENTS

$$(10^{-15}\ \text{ev} - \text{cm}^2) = A\left(\frac{\text{Kev} - \text{cm}^2}{\text{mg}}\right) = B\left(\frac{\text{Mev}}{\text{cm}}\right)$$

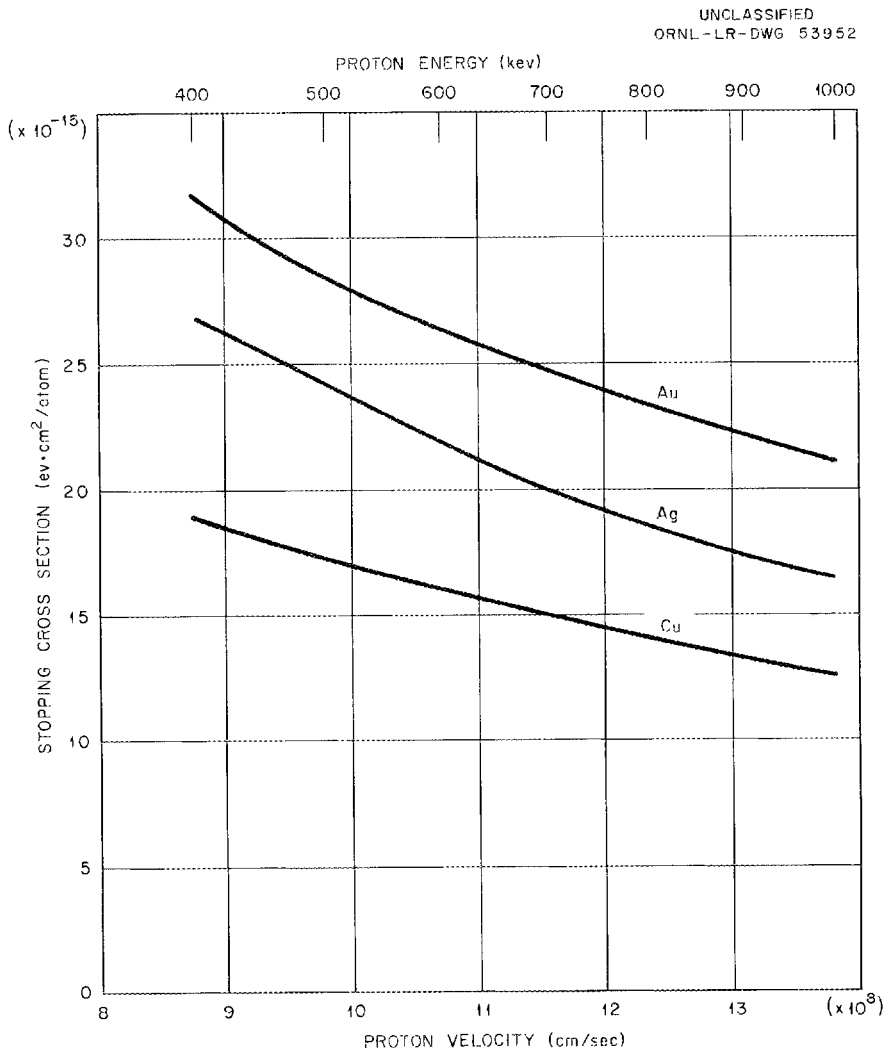
MATERIAL	A	B	ρ(g/cc at °C-760mm)	ρ(g/lit at °C-760mm)
H_2	598	0.0509		0.090
He	150	0.0255		0.178
Be	66.8	124	1.84	
B	55.7	130	3.33-2.34	
C	50.1	113	2.25-3.52	
N_2	43.0	0.0509		1.25
O_2	38.8	0.0509		1.43
Al	22.3	60.3	2.7	
A	15.1	0.02547		1.78
Fe	10.8	84.8	7.6-7.9	
Ni	10.3	91.3	8.6-8.9	
Cu	9.48	84.7	8.3-8.9	
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



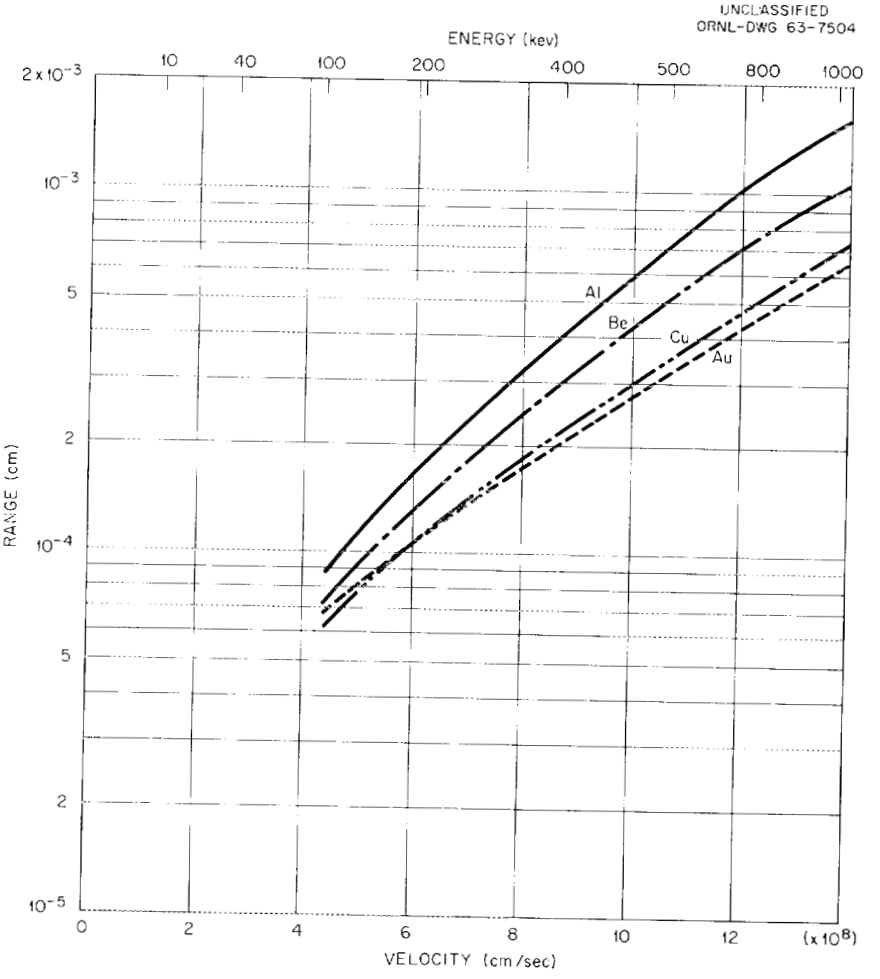
Cross Sections for Stopping of Protons in Hydrogen, Helium, Carbon, Nitrogen, and Argon.



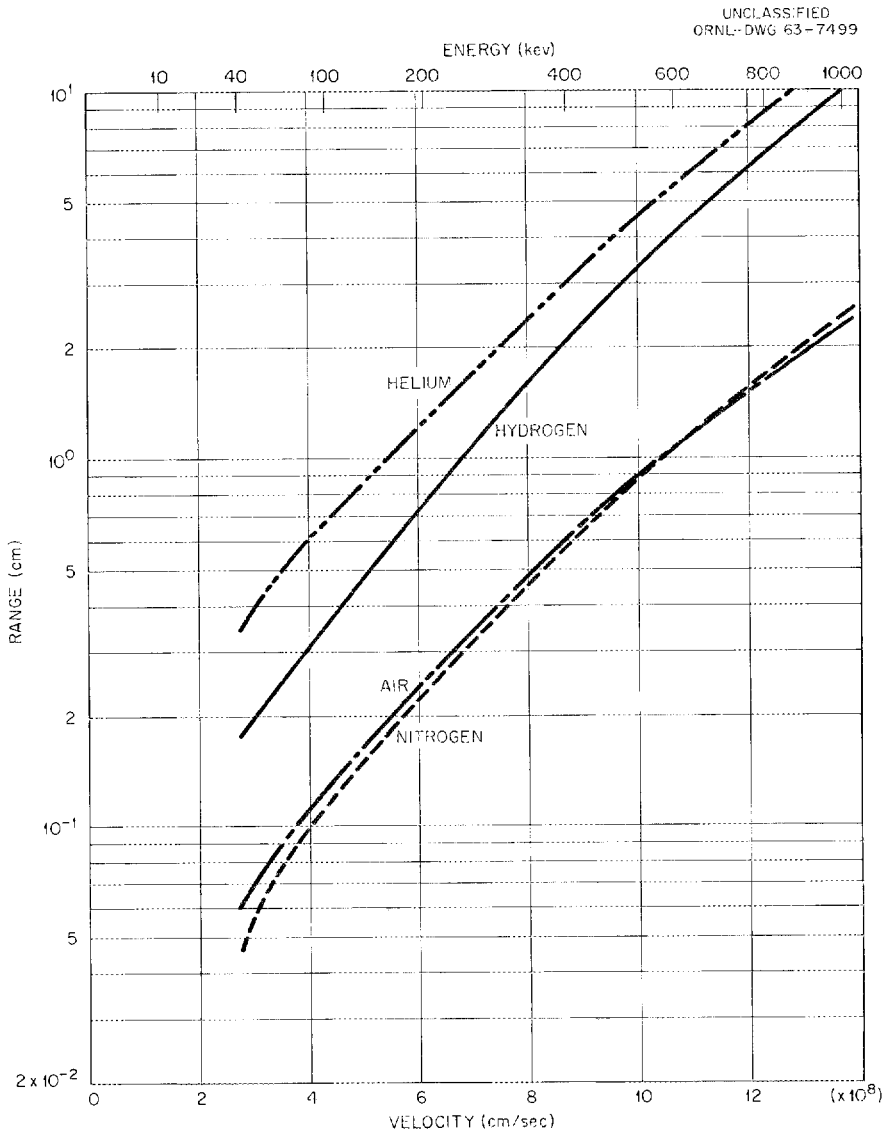
Cross Sections for Stopping of Protons in Lithium, Beryllium, Copper, Gold, and Lead.



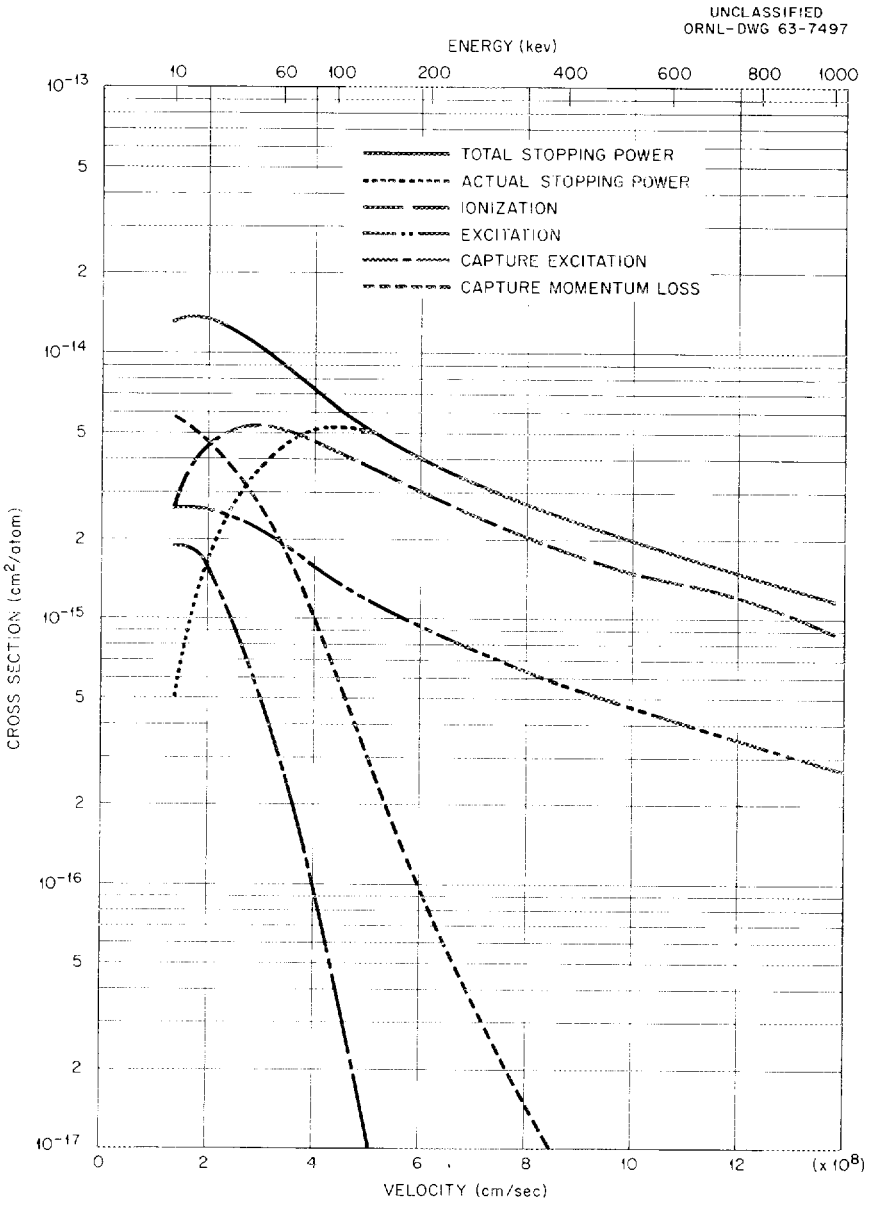
Cross Sections for the Stopping of Protons in Copper, Silver, and Gold.



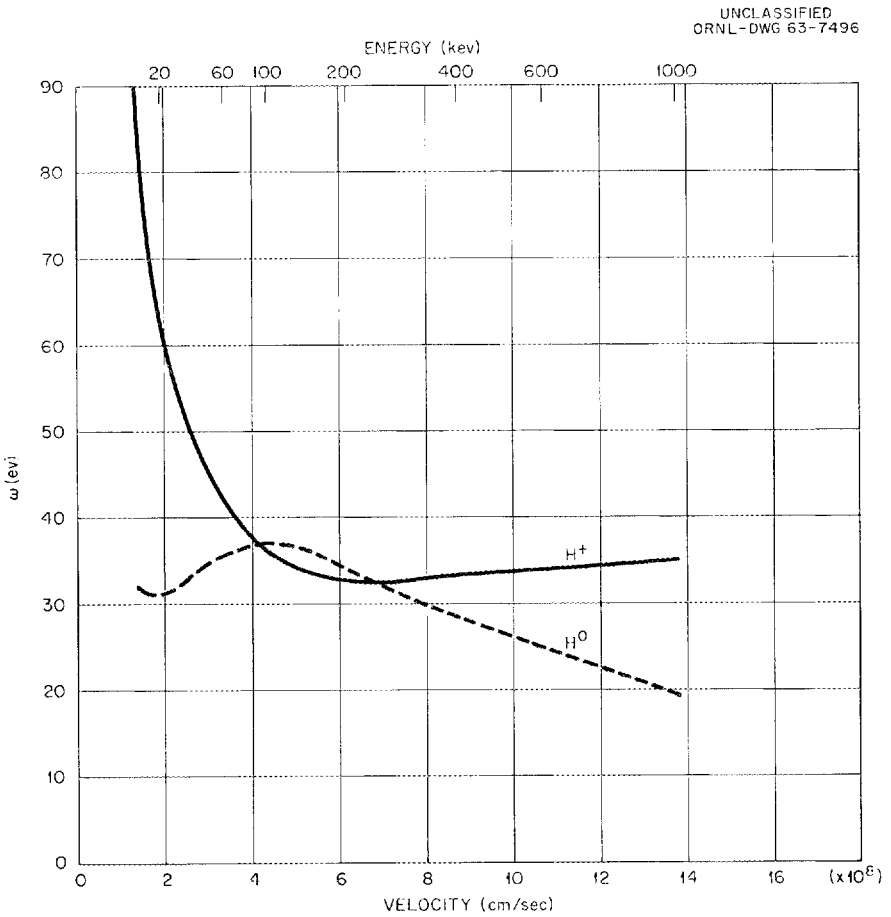
Mean Ranges for Protons in Copper, Gold, Aluminum, and Beryllium.



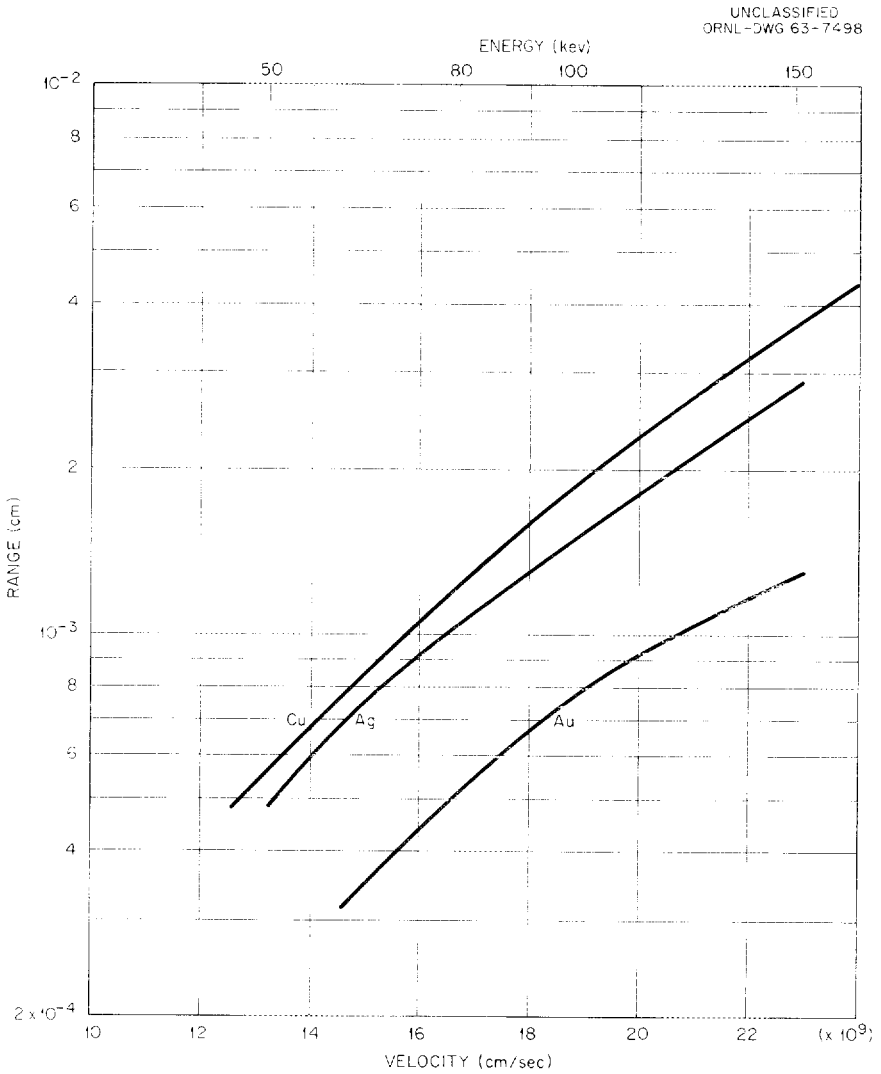
Mean Ranges for Protons in Hydrogen, Helium, Nitrogen, and Air at 0°C and 760 mm Hg.



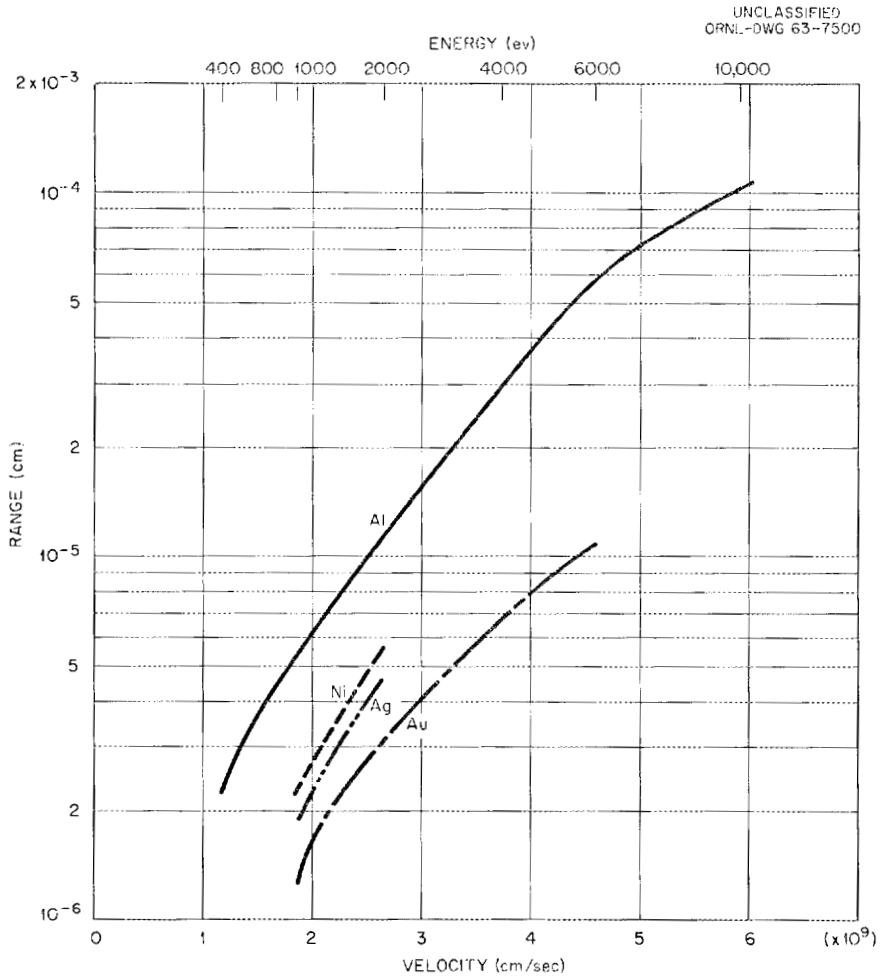
Contributions of Various Energy Loss Collision Processes to the Total Stopping Power of Protons in Atomic Hydrogen.



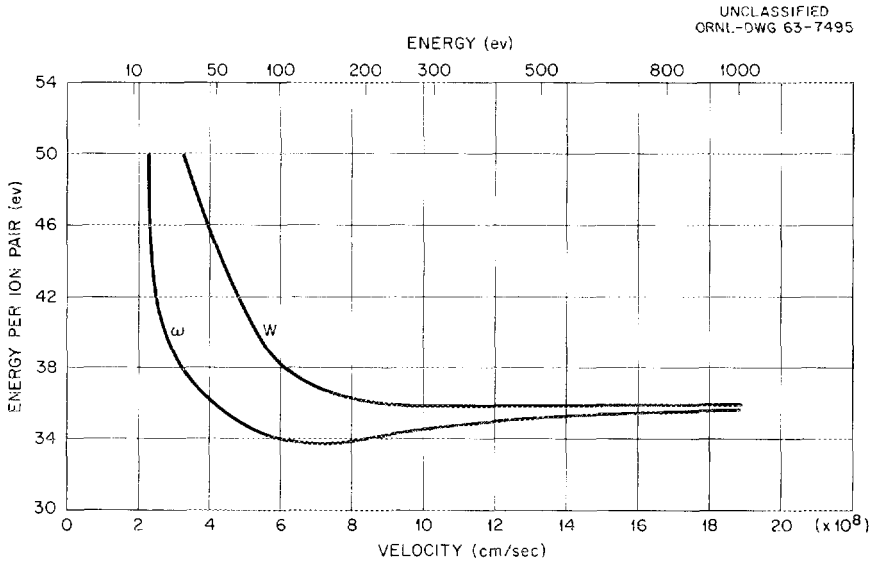
Mean Specific Energy per Ion Pair for a Proton Beam and a H^0 Beam in Atomic Hydrogen.



Maximum Ranges of Electrons in Copper, Silver, and Gold.



Maximum Ranges of Electrons in Gold, Silver, Nickel, and Aluminum.



Mean Specific Energy (ω) per Ion Pair and the Average Energy (W) per Ion Pair for Electrons in Atomic Hydrogen.

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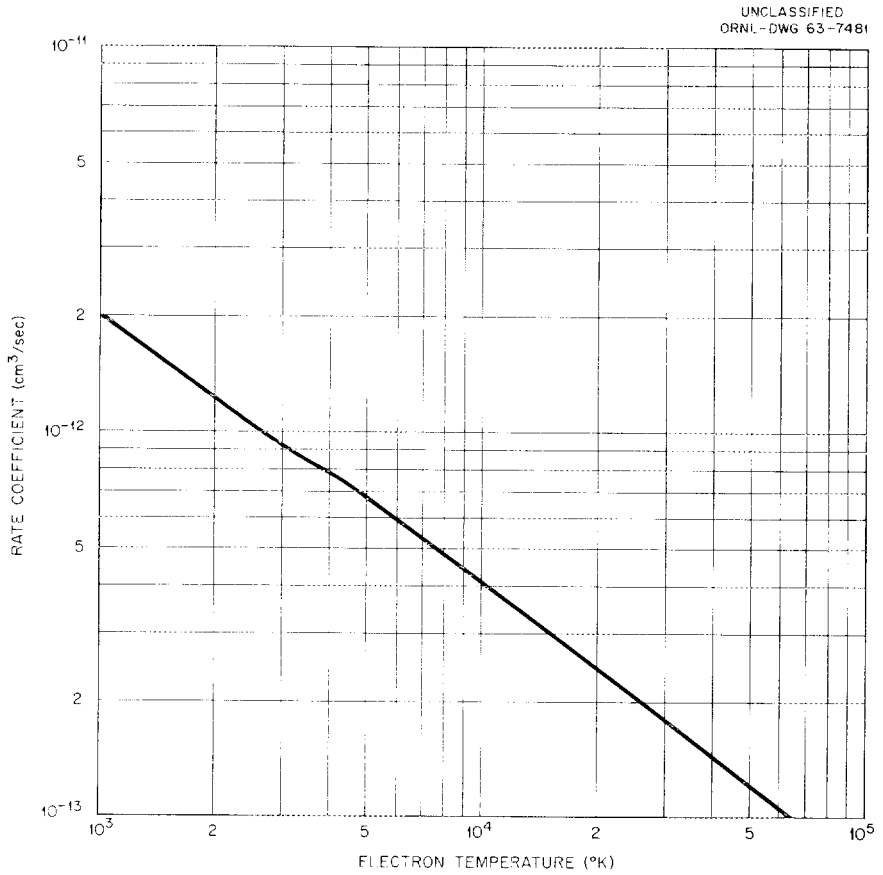

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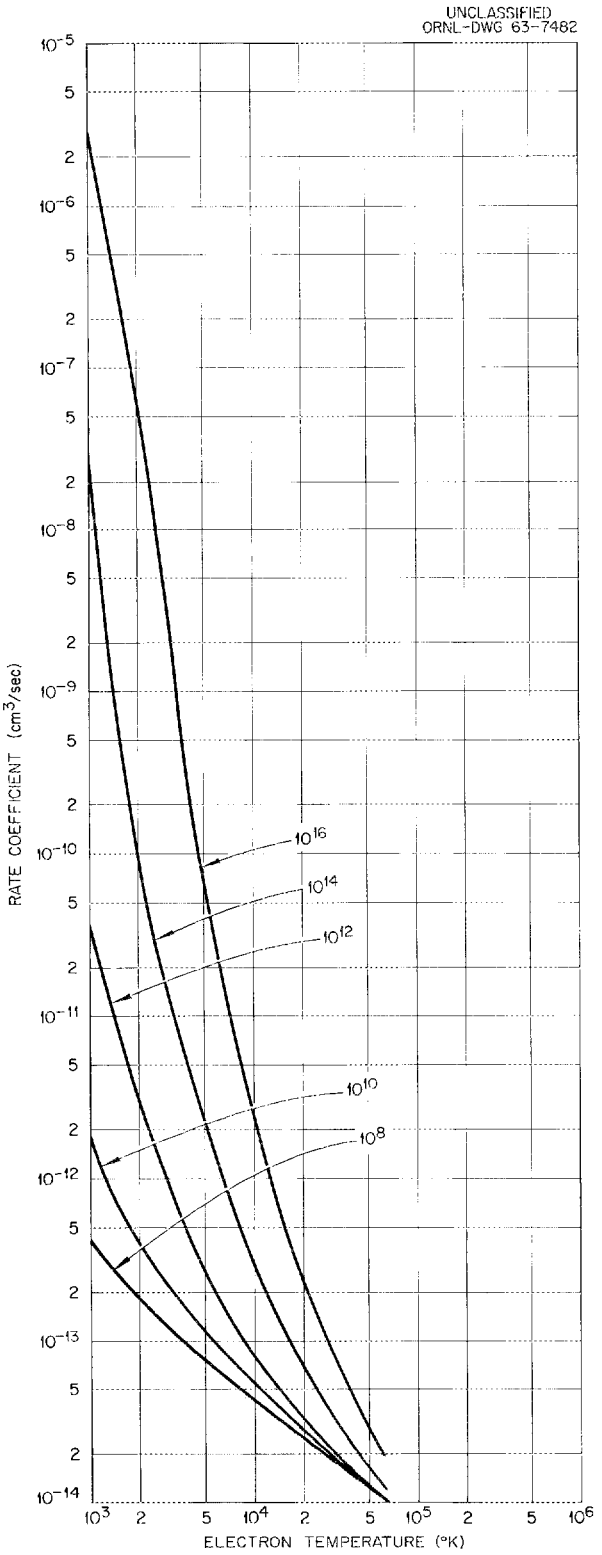

Collisional-Radiative Recombination Coefficient for Protons in an Optically Thin Plasma.

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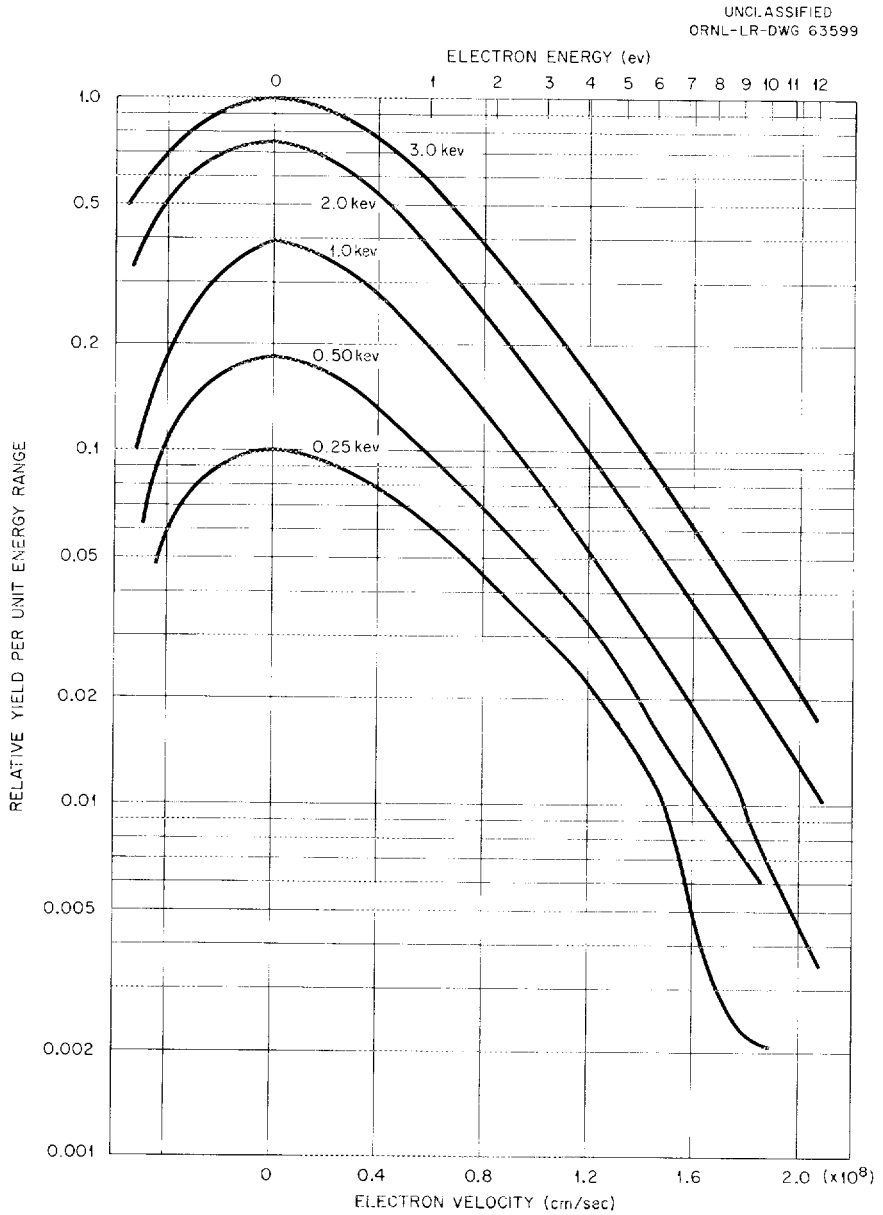
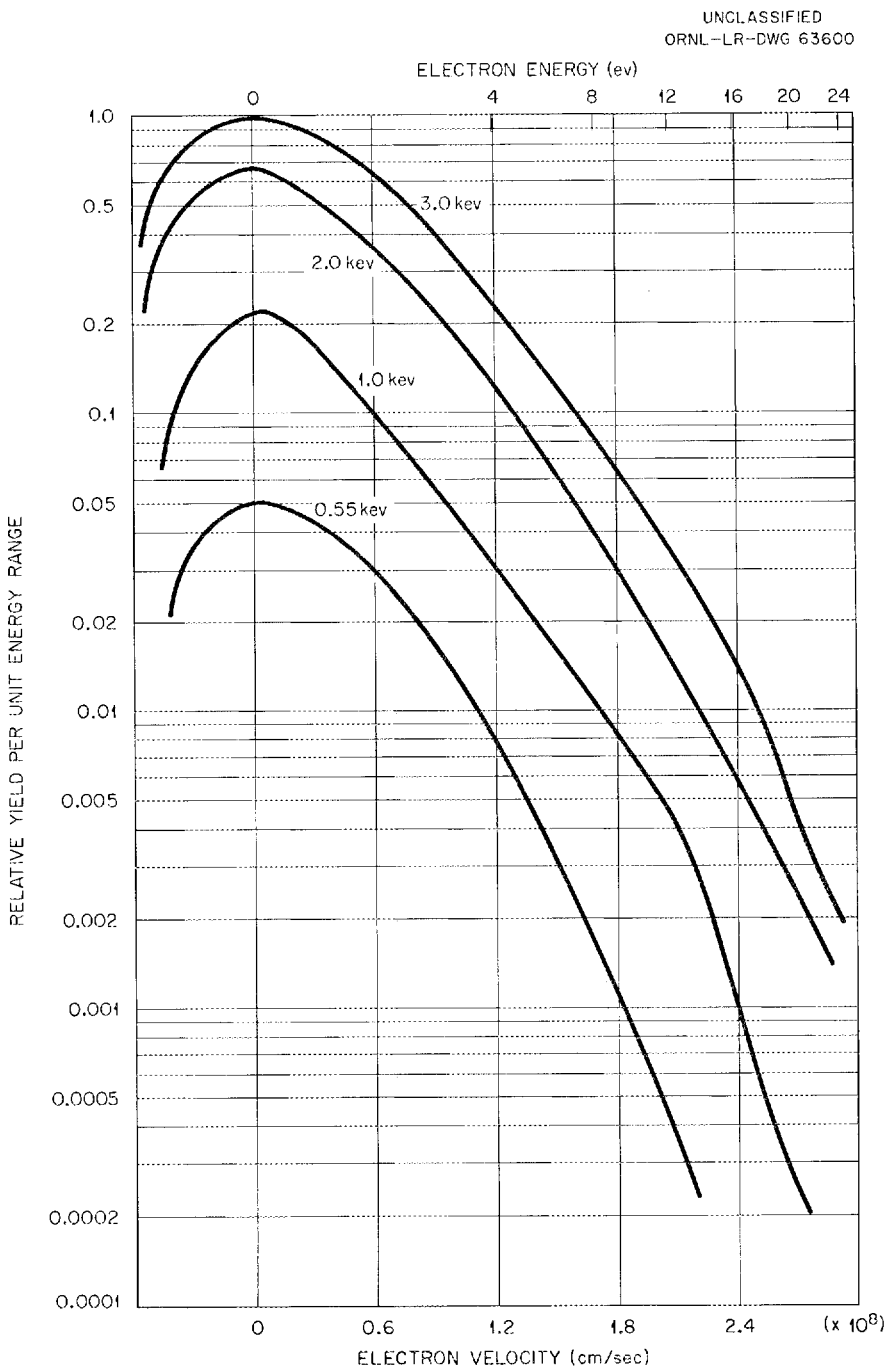


The Relative Energy Distribution of Electrons Resulting from H^+ Passing Through Hydrogen.



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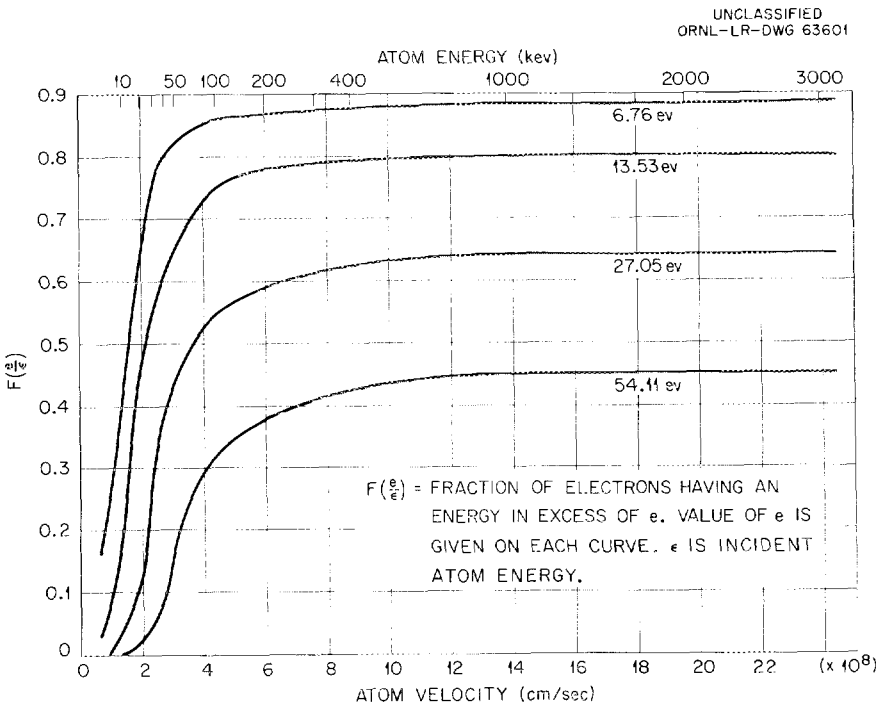

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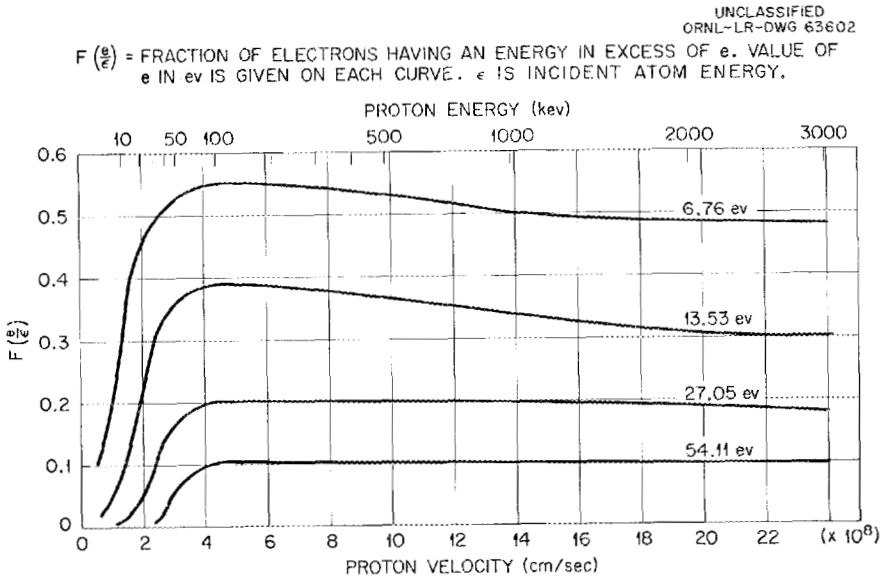

Energy Distribution of Electrons Resulting from the Reaction:
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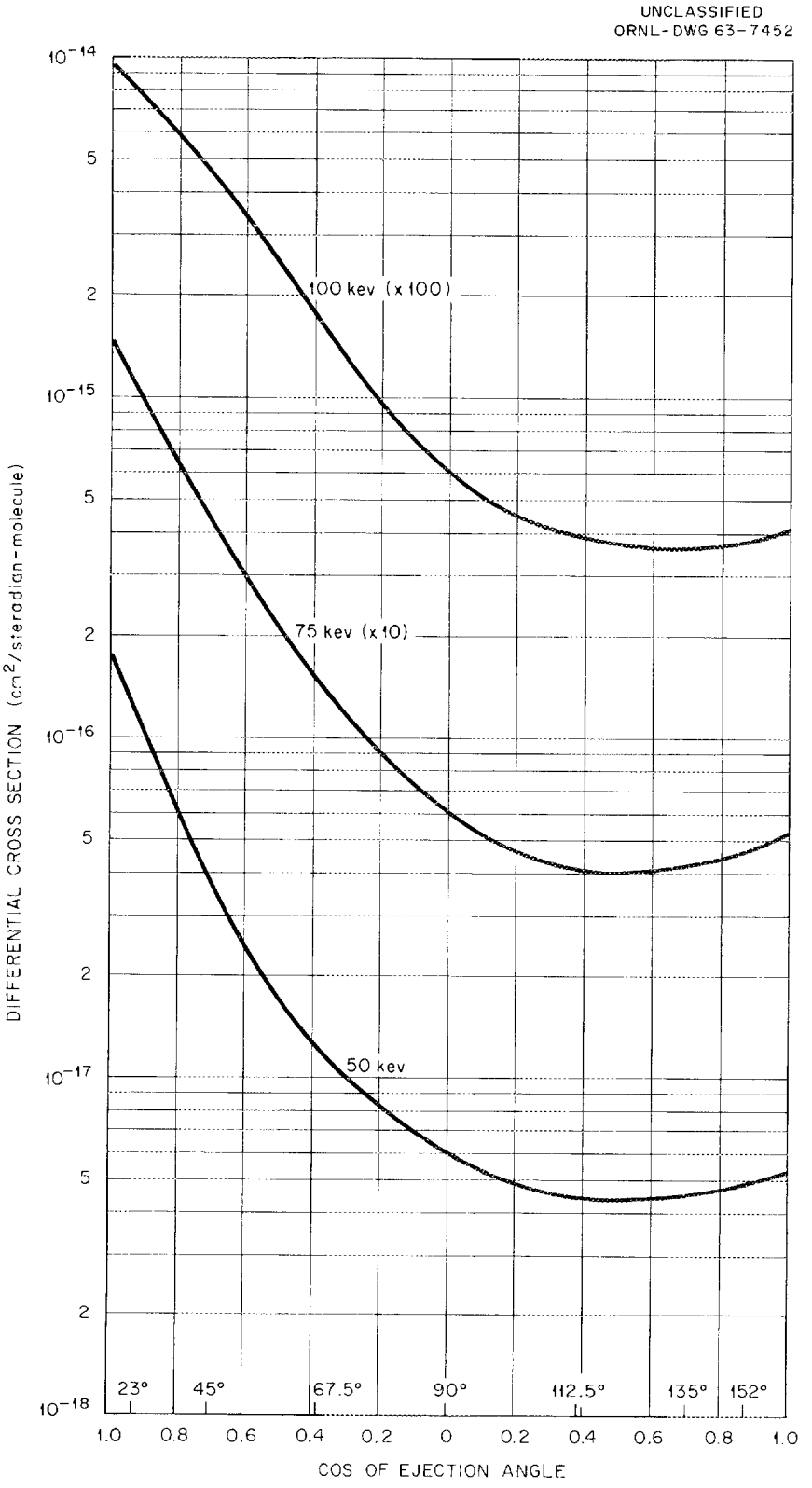

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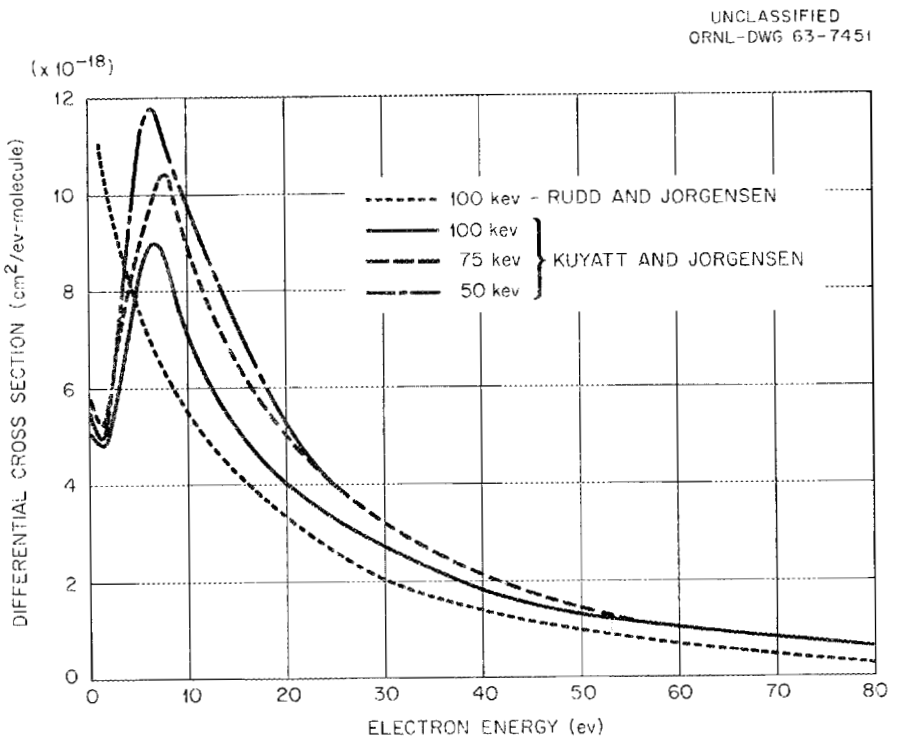

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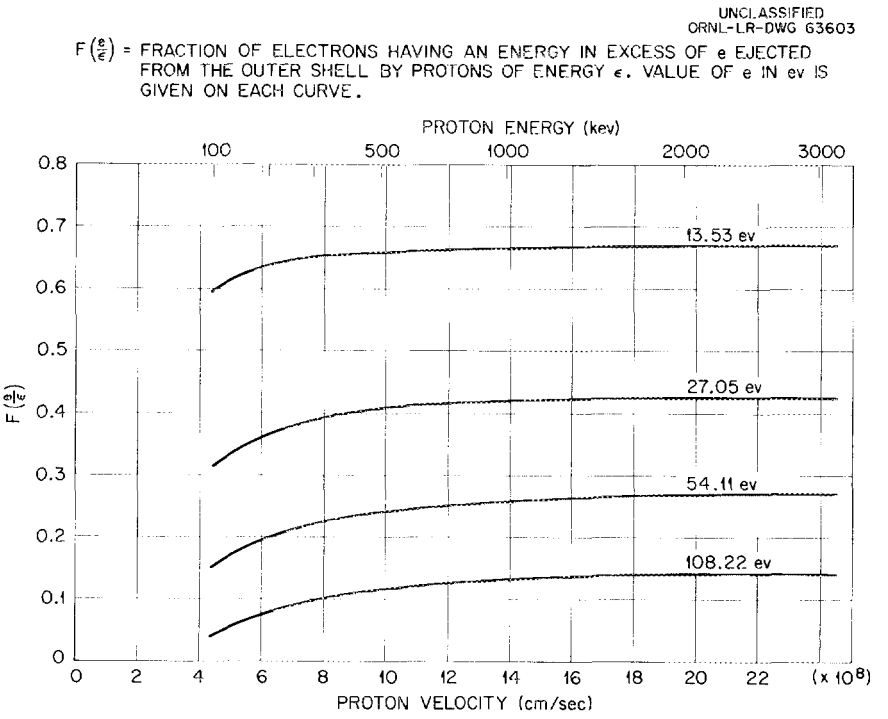

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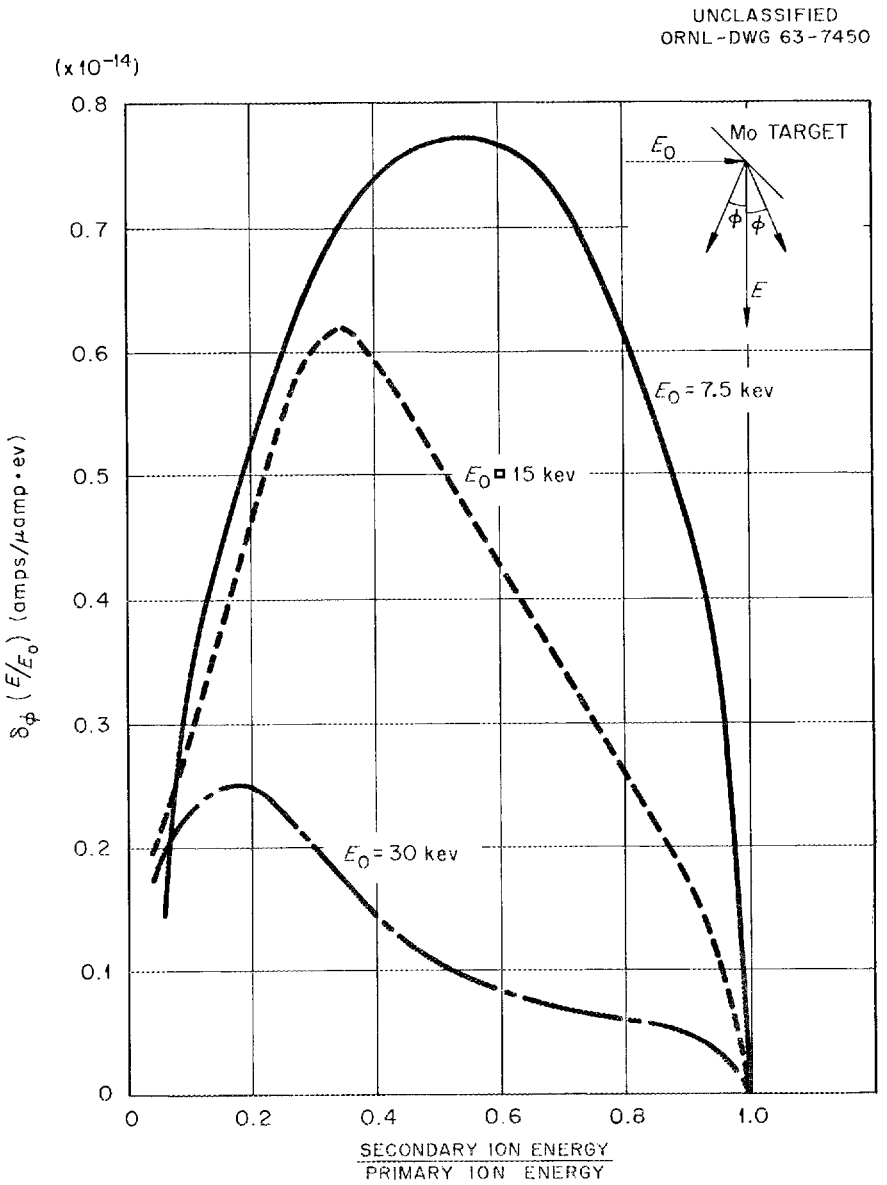

Energy Distribution of Secondary Ions from a Mo Target Bombarded by Protons.

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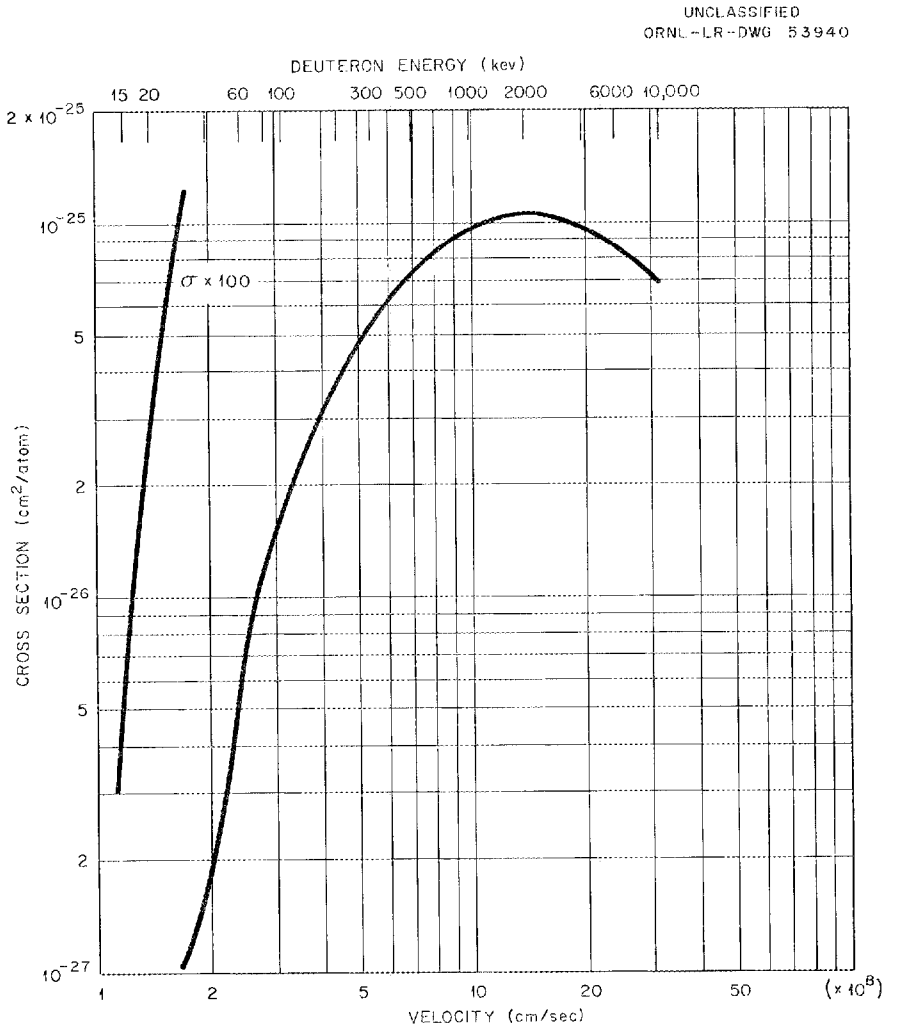

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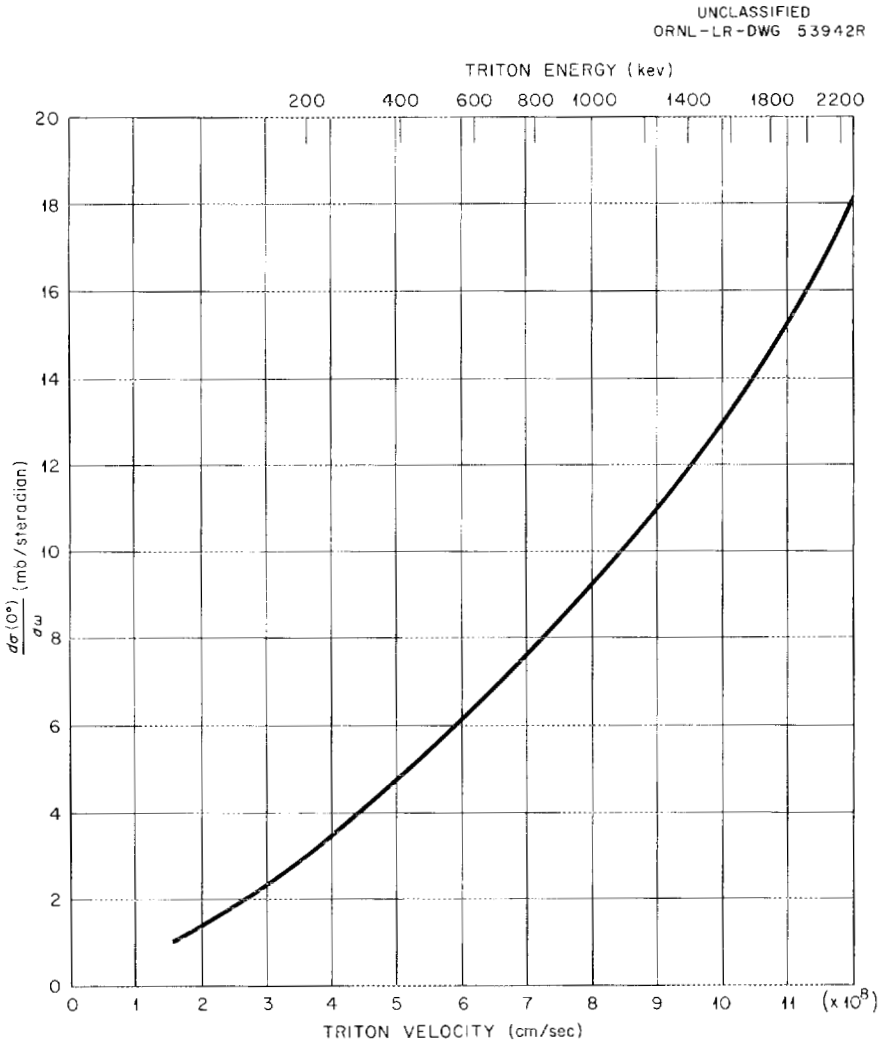

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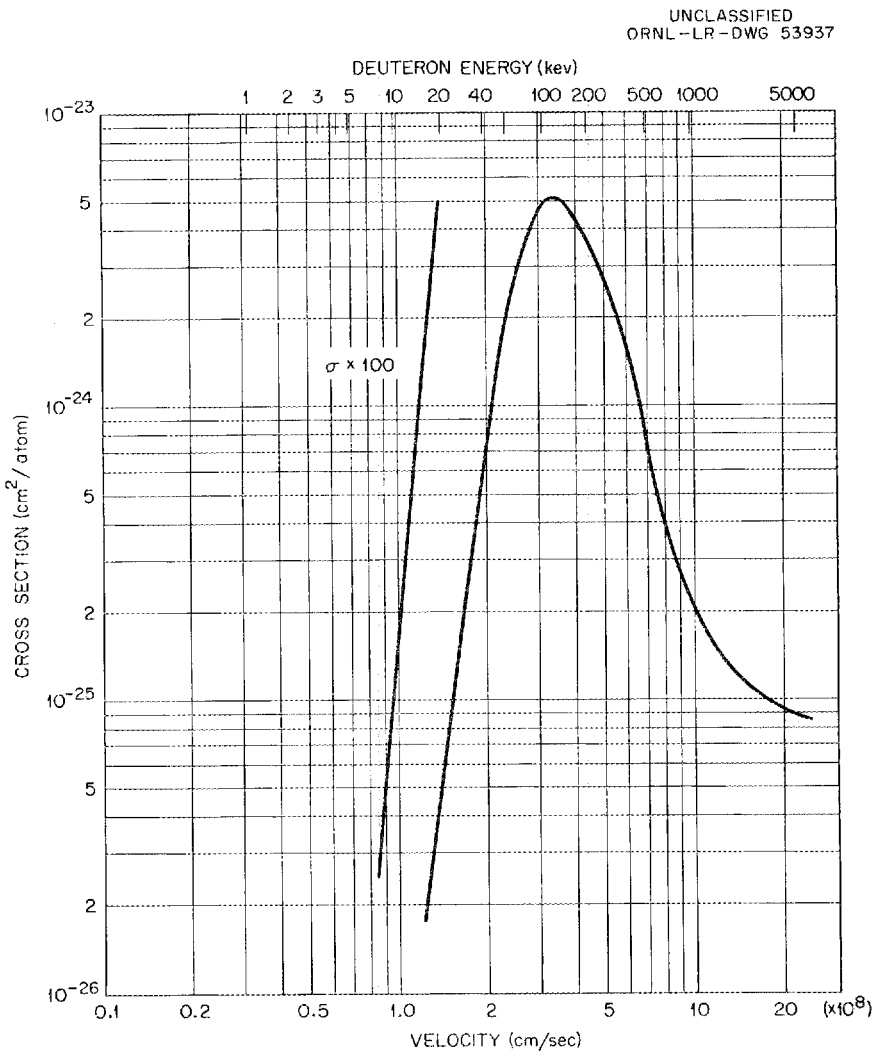

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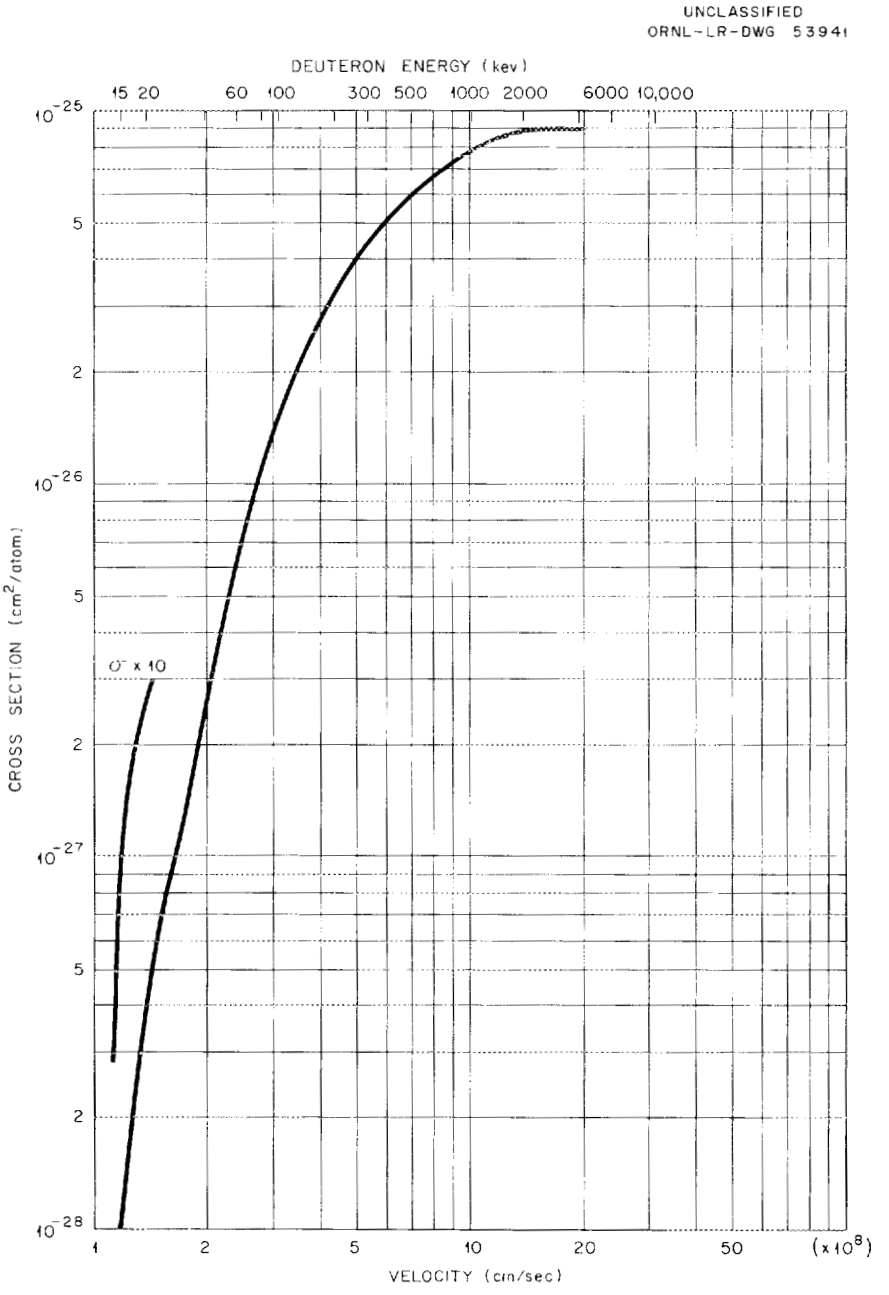

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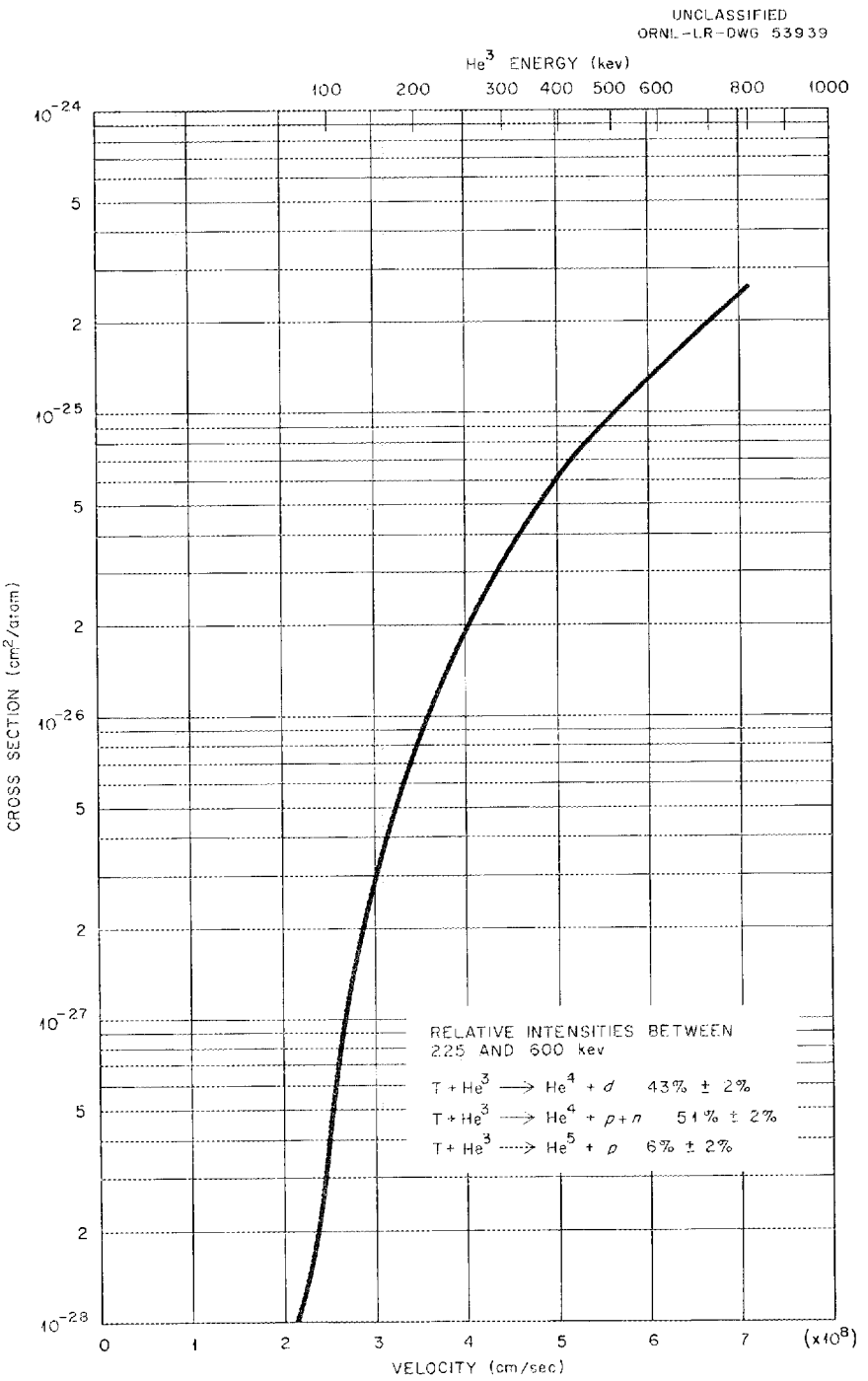

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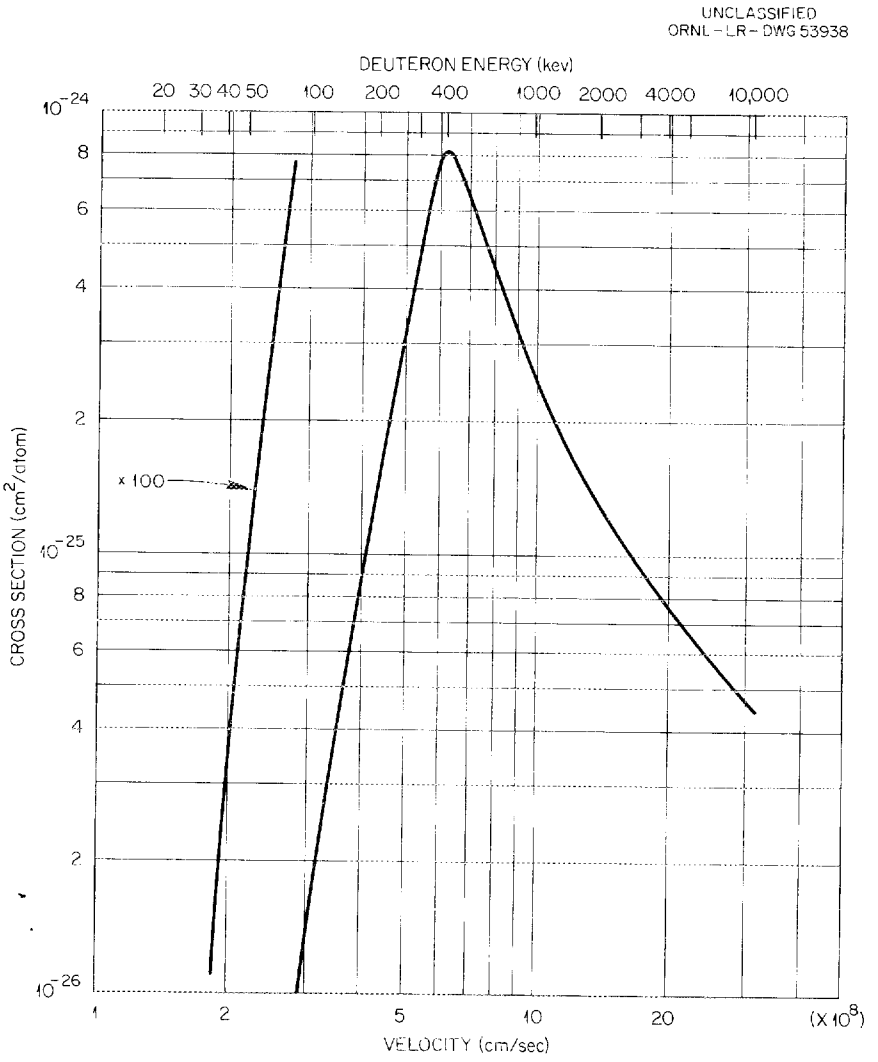

Cross Sections for the $He^3(d,p)He^4$ Reaction.

APPENDIX A. LISTING OF JOURNALS AND REPORT ABBREVIATIONS

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LIST OF JOURNALS REFERRED TO IN THE BIBLIOGRAPHY

Abbreviation	Journal
Acta Cryst.	Acta Crystallographica
Acta Phys. Acad. Sci. Hun.	Acta Physica Academiae Scientiarum Hungaricae
Acta Phys. Hungar.	Acta Physica Hungarica
Advan. Electron. Electron Phys.	Advances in Electronics and Electron Physics
Advan. Phys.	Advances in Physics
Akad. Wiss. Lit. (Mainz) Abhand., Math.-Nat. Kl.	Akademie der Wissenschaften und der Literatur (Mainz), Abhandlungen der Mathematisch Naturwissenschaftlichen Klasse
AIEE Trans., Part I - Commun. Electron.	American Institute of Electrical Engineers - Communications and Electronics
Am. J. Phys.	American Journal of Physics
Ann. Astrophys.	Anales d'Astrophysique
Ann. Geophys.	Anales de'Geophysique
Anales Real Soc. Espan. Fis. Quim. (Madrid)	Anales de la Real Sociedad Espanola de Fisica y Quimica (Madrid)
Ann. Soc. Sci. Bruxelles, Ser.	Anales de la Societe Scientifique de Bruxelles, Serie
Ann. Physik	Annalen der Physik
Ann. Inst. Henri Poincare	Annals de l'Institut Henri Poincare
Ann. Radioelect.	Annales de Radioelectrcite
Ann. Phys. (N.Y.)	Annals of Physics
Ann. N. Y. Acad. Sci.	Annals of the New York Academy of Sciences
Appl. Phys. Letters	Applied Physics Letters
Appl. Sci. Res.	Applied Scientific Research
Arkiv Fysik	Arkiv för Fysik

Abbreviation	Journal
Astronautics	Astronautics
Astrophys. J.	Astrophysical Journal
At. Energ. (USSR)	Atomnaya Energiya
Australian J. Phys.	Australian Journal of Physics
Australian J. Sci. Res.	Australian Journal of Scientific Research
Brit. J. Appl. Phys.	British Journal of Applied Physics
Bull. Acad. Polon. Sci., Ser. Math., Astr., Phys.	Bulletin de la Academies Polonaise des Sciences, Serie des Sciences, Mathematiques, Astronomiques, et Physiques
Bull. Classe Sci., Acad. Roy. Belg.	Bulletin de la Classe des Sciences, Academie Royale Belgique
Bull., Acad. Sci. USSR, Phys. Ser.	Bulletin of the Academy of Science of the USSR, Physical Series
Bull. Am. Phys. Soc.	Bulletin of the American Physical Society
Bull. Astron. Inst. Czech.	Bulletin of the Astronomical Institutes of Czechoslavakia
Bull. Chem. Soc. Japan	Bulletin of the Chemical Society of Japan
Cahier de Phys.	Cahier de Physique
Can. J. Chem.	Canadian Journal of Chemistry
Can. J. Phys.	Canadian Journal of Physics
Compt. Rend.	Comptes Rendus Hebdomadaires des Seances de l'Academie des Sciences
Discussions Faraday Soc.	Discussions of the Faraday Society
Dissertation Abstr.	Dissertation Abstracts
Dokl. Akad. Nauk SSSR	Doklady Akademii Nauk SSSR
Encyclopedia Phys.	Encyclopedia of Physics
Energia Nucl.	Energia Nuclear

Abbreviation	Journal
Ergeb. Exakt. Naturw.	Ergebnisse der Exakten Naturwissenschaften
Exp. Tech. Physik	Experimentalle Technik der Physik
Fiz. Metal. i Metalloved.	Fizika Metallov i Metallovedenie
Health Phys.	Health Physics
Helv. Phys. Acta	Helvetica Physica Acta
Helv. Phys. Acta, Suppl.	Helvetica Physica Acta, Supplementum
Indian J. Phys.	Indian Journal of Physics
Instr. Exp. Tech. (USSR)	Instruemnts and Experimental Techniques (USSR)
Izvest. Akad. Nauk SSSR, Ser. Fiz.	Izvestiia Akademii Nauk SSSR, Seriia Fizicheskaia
J. Am. Chem. Soc.	Journal of the American Chemical Society
J. Appl. Phys.	Journal of Applied Physics
J. Atmospheric Terrest. Phys.	Journal of Atmospheric and Terrestrial Physics
J. Chem. Phys.	Journal of Chemical Physics, The
J. Chem. Soc.	Journal of the Chemical Society (London)
J. Electron. Control	Journal of Electronics and Control
J. Elisha Mitchell Sci. Soc.	Journal of the Elisha Mitchell Scientific Society
J. Franklin Inst.	Journal of the Franklin Institute
J. Math. Phys.	Journal of Mathematical Physics (AIP)
J. Mol. Spectry.	Journal of Molecular Spectroscopy
J. Opt. Soc. Am.	Journal of the Optical Society of America
J. Phys. Soc. Japan	Journal of the Physical Society of Japan

Abbreviation	Journal
J. Phys. Chem. Solids	Journal of the Physics and Chemistry of Solids
J. Phys. Radium	Journal de Physique et le Radium
J. Quant Spectry. Radiative Transfer	Journal of Quantitative Spectroscopy and Radiative Transfer
J. Res. Natl. Bur. Std. (U.S.)	Journal of Research of the National Bureau of Standards
Kgl. Danske Videnskab. Selskab, Mat.-Fys. Medd.	Kongelige Danske Videnskabernes Selskab, Matematisk-Fysiske Meddeleser
Latvijas PSR Zinatnu Akad. Vestis	Latvijas PSR Zinatnu Akademija Vestis (Bulletin of the Academy of Sciences of the Latvian SSR)
Mem. Soc. Roy. Sci. Liege	Memoirs de la Societe Royale des Sciences de Liege
Monthly Notices, Roy. Astron. Soc.	Monthly Notices of the Royal Astronomical Society
Nature	Nature
Naturwiss.	Naturwissenschaften
Nucl. Fusion	Nuclear Fusion
Nucl. Phys.	Nuclear Physics
Nucl. Instr. Methods	Nuclear Instruments and Methods
Nucleonics	Nucleonics
Nuovo Cimento	Nuovo Cimento
Opt. Spectry. (USSR)	Optics and Spectroscopy (USSR)
Opt. Spektrospkopiya	Optika i Spektroskopiya
Phillips Res. Rep.	Phillips Research Reports
Phil. Mag.	Philosophical Magazine

Abbreviation	Journal
Phil. Trans. Roy. Soc. London	Philosophical Transactions of the Royal Society of London
Physica	Physica
Phys. Rev.	Physical Review, The
Phys. Rev. Letters	Physical Review Letters
Phys. Med. Biol.	Physics in Medicine and Biology
Phys. Fluids	Physics of Fluids, The
Phys. Letters	Physics of Letters
Phys. Metals Metallog	Physics of Metals and Metallography
Phys. Stat. Solidi	Physics of Status Solidi
Phys. Today	Physics Today
Plasma Phys.	Plasma Physics
Planetary Space Sci.	Planetary and Space Science
Pribory i Tekhn. Eksperim.	Pribory i Tekhnika Eksperimenta
Proc., Congres International Phys. Nucl.	Proceedings, Congres International de Physique Nucleaire
Proc. Cambridge Phil. Soc.	Proceedings of the Cambridge Philosophical Society
Proc. Natl. Inst. Sci. India	Proceedings of the National Institute of Sciences of India
Proc. Phys. Soc. (GB)	Proceedings of the Physical Society of Great Britain
Proc. Phys. Soc. (London)	Proceedings of the Physical Society of London
Proc. Roy. Soc. (London)	Proceedings of the Royal Society of London
Progr. Cryog.	Progress in Cryogenics
Progr. Phys.	Progress in Physics
Progr. Physiol.	Progress in Physiology (Peking)
Progr. Theoret. Phys. (Kyoto)	Progress of Theoretical Physics (Kyoto)

Abbreviation	Journal
Radiation Res.	Radiation Research
Radiotekhn. i Elektron.	Radiotekhnika i Elektronika
Report, Centre d'Etudes Nucl. de Saclay	Report, Centre d'Etudes Nucleaires de Saclay
Rep. Progr. Phys.	Reports on Progress in Physics
Res. Foundation Rep.	Research Foundation Report
Rev. Sci. Instr.	Review of Scientific Instruments, The
Rev. Mod. Phys.	Reviews of Modern Physics
Ricerca Sci.	Ricerca Scientifica
Sci. Rep. Saitama Univ., Ser.	Science Reports of the Saitama University, Series
Sci. Rep. Tohoku Univ.	Science Reports of the Tohoku University
Soviet Astron. - AJ	Soviet Astronomy - AJ
Soviet J. At. Energy, Suppl.	Soviet Journal of Atomic Energy, Supplement
Soviet Open Sources	Soviet Open Sources
Soviet Phys. - Doklady	Soviet Physics - Doklady
Soviet Phys. - JETP	Soviet Physics - Journal of Experimental and Theoretical Physics
Soviet Phys. - Solid State	Soviet Physics - Solid State
Soviet Phys. - Tech. Phys.	Soviet Physics - Technical Physics
Soviet Phys. - Usp.	Soviet Physics - Uspekhi
Stud. Cercetari Fiz. Roumania	Studii si Cercetari de Fizica Roumania
Trans. Faraday Soc.	Transactions of the Faraday Society
Ukr. Fiz. Zh.	Ukrains'kii Fizichii Zhurnal
Usp. Fiz. Nauk	Uspekhi Fizicheskikh Nauk

Abbreviation	Journal
Vestn. Leningr. Univ., Ser. Fiz. i Khim.	Vestnik Leningradskogo Universiteta, Seriya Fiziki i Khimii
Vistas Astron.	Vistas in Astronomy
Z. Angew. Physik	Zeitschrift für Angewandte Physik
Z. Elektrochem.	Zeitschrift für Elektrochemie
Z. Naturforsch.	Zeitschrift für Naturforschung
Z. Physik	Zeitschrift für Physik
Z. Physik Chem. (Leipzig)	Zeitschrift für Physikalishe Chemie (Leipzig)
Zh. Eksperim. i Teor. Fiz.	Zhurnal Eksperimental'noi i Teoreticheskoi Fiziki
Zh. Techn. Fiz.	Zhurnal Technicheskoi Fiziki
Proc. 2nd International Conference on Atomic Collisions, Boulder, Colorado	Second International Conference on Atomic Collisions, Boulder, Colorado, 1961
Proc. 4th International Conference on Ionization Phenomena in Gases, Uppsala	Fourth International Conference on Ionization Phenomena in Gases, Uppsala, 1959
Proc. 5th International Conference on Ionization Phenomena in Gases, Munich	Fifth International Conference on Ionization Phenomena in Gases, Munich, 1961
Second Geneva Conference	Second International Conference on the Peaceful Uses of Atomic Energy, Geneva, 1958

LIST OF REPORTS REFERRED TO IN THE BIBLIOGRAPHY

REPORT SYMBOL	ISSUING INSTALLATION
AASU	Navy (Anti-Aircraft Study)
AEC	Atomic Energy Commission
AECU	Atomic Energy Commission
AERE Inf/Bib	Atomic Energy Research Establishment, Harwell (Informal Bibliography)
AERE Lib/Trans	Atomic Energy Research Establishment, Harwell (Library Translation)
AERE-TR	Atomic Energy Research Establishment, Harwell
AFCRC-TN	Air Force Cambridge Research Center
AFCRC-TR	Air Force Cambridge Research Center
AFCRL	Air Force Cambridge Research Laboratory
AFOSR	Air Force Office of Scientific Research
AFSWC-TR	Air Force Special Weapons Center
ANL	Argonne National Laboratory, Illinois
ARL-TN	Air Material Command, Aircraft Radiation Laboratory, Wright-Patterson AFB, Ohio AVCO Manufacturing Corp., Avco Research Laboratory, Everett, Massachusetts Ramo-Wooldridge Corp., Aeronautical Research Laboratory, Los Angeles, California Thompson Products, Inc., Antenna Research Laboratory, Columbus, Ohio Wright Air Development Center, Aeronautical Research Laboratory, Wright-Patterson AFB, Ohio
AROD	Office of the Chief of Research and Development, Army Research Office, Washington, D.C.
ASTIA-AD	Armed Services Technical Information Agency
BNL	Brookhaven National Laboratory
CEA	Commissariat a l'Energie Atomique, Paris
CWR	Curtiss-Wright Corporation
CX	New York University

FTD-TT	Russian Translations
GA	General Atomics
GACD	General Atomic Division of General Dynamics Corp., California
GCA-TR	Geophysics Corporation of America Bedford, Massachusetts
GM-AD	General Atomics Division of General Dynamics Corp., California
HE	Fluid Mechanics Laboratory or Institute of Engineering Research, Berkeley, California
IA	Franklin Institute of Laboratories for Research and Development, Philadelphia
ISC	Iowa State College
JINR-P	Joint Institute for Nuclear Research, Dubna, USSR, Laboratory of Theoretical Physics
LA	Los Alamos Scientific Laboratory
LMSD	Lockheed Aircraft Corporation
MIT-TR	Massachusetts Institute of Technology
NASA-TN-D	National Aeronautics and Space Administration, Goddard Space Flight Center, Greenbelt, Maryland
NASA-TR-R	National Aeronautics and Space Administration, Goddard Space Flight Center, Greenbelt, Maryland
NBS	National Bureau of Standards
NBS-C	National Bureau of Standards, Boulder, Colorado
NP	Technical Information Service Extension, AEC
NP-tr	Non-Project Translation
NRL	Naval Research Laboratory, Washington, D.C.

NYO	New York Operations Office, AEC
ORNL	Oak Ridge National Laboratory
ORO	Oak Ridge Operations Office, AEC
RADC-TN	Rome Air Development Center, Griffiss AFB, New York
RISÖ	Atomenergikommissioner, Denmark
SCTM	Sandia Corporation
SRB	Lockheed Aircraft Corporation, Missles and Space Division, Sunnyvale, California
TID	Technical Information Service Extension, AEC
UCRL	University of California Radiation Laboratory
WADC-TN	Wright Air Development Center Wright-Patterson AFB, Ohio
Wis-AEC	University of Wisconsin, Naval Research Laboratory
ZPh	General Dynamics/Convair, San Diego, California

APPENDIX B. ENERGY, VELOCITY, AND MOMENTUM TABLES FOR ELECTRONS, PROTONS, H_2^+, H_3^+, AND HELIUM IONS

APPENDIX B. ENERGY, VELOCITY, AND MOMENTUM TABLES FOR ELECTRONS, PROTONS, H_2^+, H_3^+, AND HELIUM IONS

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Table 1. Energy, Velocity, and Momentum for H^+ Ions

Energy (kev)	Velocity (cm/sec)	H ρ (Gauss-cm)	Energy (kev)	Velocity (cm/sec)	H ρ (Gauss-cm)
0	0	0	540	10.17×10^8	10.55×10^4
10	1.384×10^8	1.435×10^4	560	10.37	10.75
20	1.955	2.027	580	10.53	10.92
30	2.399	2.488	600	10.71	11.11
40	2.765	2.867	620	10.89	11.29
50	3.095	3.209	640	11.08	11.49
60	3.39	3.52	660	11.23	11.65
70	3.66	3.79	680	11.40	11.82
80	3.92	4.06	700	11.58	12.01
90	4.15	4.30	720	11.74	12.17
100	4.38	4.54	740	11.90	12.34
120	4.79	4.97	760	12.06	12.51
140	5.18	5.37	780	12.21	12.66
150	5.36	5.56	800	12.37	12.83
160	5.54	5.74	820	12.52	12.98
180	5.87	6.09	840	12.69	13.16
200	6.19	6.42	860	12.82	13.29
220	6.50	6.74	880	12.98	13.46
240	6.76	7.01	900	13.12	13.61
260	7.05	7.31	920	13.27	13.76
280	7.32	7.59	940	13.40	13.90
300	7.58	7.86	960	13.54	14.04
320	7.84	8.13	980	13.69	14.20
340	8.07	8.37	1000	13.84	14.35
360	8.30	8.61	2000	19.55	20.27
380	8.53	8.85	3000	23.90	24.78
400	8.75	9.07	4000	27.65	28.67
420	8.97	9.30	5000	30.9	32.04
440	9.19	9.53	6000	33.9	35.15
460	9.39	9.74	7000	36.6	37.95
480	9.59	9.94	8000	39.1	40.54
500	9.78	10.14	9000	41.5	43.04
520	9.98	10.35	10000	43.7	45.32

Table 2. Energy, Velocity, and Momentum for H_2^+ Ions

Energy (kev)	Velocity (cm/sec)	H ρ (Gauss-cm)	Energy (kev)	Velocity (cm/sec)	H ρ (Gauss-cm)
0	0	0	540	7.18×10^8	14.89×10^4
10	0.980×10^8	2.032×10^4	560	7.32	15.18
20	1.380	2.862	580	7.44	15.43
30	1.693	3.511	600	7.57	15.70
40	1.953	4.051	620	7.69	15.95
50	2.183	4.528	640	7.82	16.22
60	2.396	4.969	660	7.94	16.47
70	2.590	5.372	680	8.05	16.70
80	2.770	5.745	700	8.18	16.97
90	2.935	6.087	720	8.29	17.19
100	3.09	6.41	740	8.40	17.42
120	3.38	7.01	760	8.52	17.67
140	3.66	7.59	780	8.62	17.88
160	3.91	8.11	800	8.74	18.13
180	4.14	8.59	820	8.84	18.33
200	4.37	9.06	840	8.96	18.58
220	4.59	9.52	860	9.05	18.77
240	4.78	9.91	880	9.17	19.02
260	4.98	10.33	900	9.26	19.20
280	5.17	10.72	920	9.36	19.41
300	5.36	11.11	940	9.46	19.62
320	5.54	11.49	960	9.56	19.83
340	5.70	11.82	980	9.66	20.03
360	5.86	12.15	1000	9.78	20.28
380	6.03	12.51	2000	13.83	28.68
400	6.18	12.82	3000	16.92	35.09
420	6.34	13.15	4000	19.57	40.59
440	6.49	13.46	5000	21.85	45.32
460	6.64	13.77	6000	24.00	49.78
480	6.77	14.04	7000	25.90	53.72
500	6.92	14.35	8000	27.70	57.45
520	7.05	14.62	9000	29.35	60.87
			10000	30.90	64.09

Table 3. Energy, Velocity, and Momentum for H_3^+ Ions

Energy (kev)	Velocity (cm/sec)	H ρ (Gauss-cm)	Energy (kev)	Velocity (cm/sec)	H ρ (Gauss-cm)
0	0	0	280	4.23×10^8	13.12×10^4
10	0.79×10^8	2.45×10^4	300	4.38	13.58
20	1.13	3.50	400	5.05	15.66
40	1.6	4.96	500	5.65	17.52
60	1.96	6.08	600	6.19	19.19
80	2.26	7.01	700	6.68	20.71
100	2.52	7.81	800	7.15	22.17
110	2.65	8.22	900	7.58	23.51
120	2.77	8.59	1000	7.99	24.78
130	2.88	8.93	1200	8.75	27.13
140	2.98	9.24	1400	9.45	29.30
150	3.1	9.61	1600	10.1	31.32
160	3.2	9.92	1800	10.7	33.18
170	3.3	10.23	2000	11.3	35.04
180	3.4	10.54	2200	11.8	36.59
200	3.57	11.07	2300	12.1	37.52
240	3.91	12.12	2400	12.4	38.45

Table 4. Energy, Velocity, and Momentum for He^+ Ions

Energy (kev)	Velocity (cm/sec)	H ρ (Gauss-cm)	Energy (kev)	Velocity (cm/sec)	H ρ (Gauss-cm)
0	0	0	460	4.69×10^8	19.45×10^4
10	0.692×10^8	2.870×10^4	480	4.80	19.91
20	0.978	4.057	500	4.89	20.28
30	1.200	4.977	520	4.99	20.70
40	1.383	5.737	540	5.09	21.11
50	1.548	6.421	560	5.18	21.49
60	1.70	7.05	580	5.27	21.86
70	1.83	7.59	600	5.36	22.23
80	1.96	8.13	620	5.45	22.60
90	2.08	8.63	640	5.54	22.98
100	2.19	9.08	660	5.62	23.31
120	2.40	9.95	680	5.70	23.64
140	2.59	10.74	700	5.79	24.02
160	2.77	11.49	720	5.87	24.35
180	2.94	12.20	740	5.95	24.68
200	3.10	12.86	760	6.03	25.01
220	3.25	13.48	780	6.11	25.34
240	3.38	14.02	800	6.19	25.68
260	3.53	14.64	820	6.26	25.97
280	3.66	15.18	840	6.35	26.34
300	3.79	15.72	860	6.41	26.59
320	3.92	16.26	880	6.49	26.92
340	4.04	16.76	900	6.56	27.21
360	4.15	17.21	920	6.64	27.54
380	4.27	17.71	940	6.70	27.79
400	4.38	18.17	960	6.77	28.08
420	4.49	18.62	980	6.85	28.41
440	4.60	19.08	1000	6.92	28.70

Table 5. Energy, Velocity, and Momentum for Electrons

Energy (ev)	Velocity (cm/sec)	H ρ (Gauss-cm)	Energy (ev)	Velocity (cm/sec)	H ρ (Gauss-cm)
0	0	0	300	10.29×10^8	57.88
10	1.879×10^8	10.51	310	10.47	58.89
20	2.655	14.93	320	10.61	59.68
30	3.255	18.31	330	10.79	60.69
40	3.760	21.15	340	10.93	61.48
50	4.19	23.57	350	11.10	62.44
60	4.61	25.93	360	11.27	63.39
70	4.97	27.96	370	11.41	64.18
80	5.32	29.93	380	11.59	65.19
90	5.63	31.67	390	11.71	65.87
100	5.94	33.41	400	11.89	66.88
110	6.23	35.04	410	12.01	67.56
120	6.50	36.56	420	12.17	68.46
130	6.77	38.08	430	12.31	69.24
140	7.02	39.49	440	12.45	70.03
150	7.27	40.89	450	12.60	70.87
160	7.53	42.36	460	12.73	71.60
170	7.74	43.54	470	12.87	72.39
180	7.97	44.83	480	13.02	73.24
190	8.17	45.96	490	13.16	74.02
200	8.39	47.19	500	13.28	74.70
210	8.60	48.37	520	13.52	76.05
220	8.80	49.50	540	13.80	77.63
230	9.00	50.63	560	14.05	79.03
240	9.19	51.69	580	14.30	80.44
250	9.39	52.82	600	14.54	81.79
260	9.56	53.77	620	14.79	83.19
270	9.75	54.84	640	15.02	84.49
280	9.92	55.80	660	15.25	85.78
290	10.10	56.81	680	15.48	87.07

Table 5. Energy, Velocity, and Momentum for Electrons

Energy (ev)	Velocity (cm/sec)	H ρ (Gauss-cm)	Energy (ev)	Velocity (cm/sec)	H ρ (Gauss-cm)
700	15.71×10^8	88.37	1300	21.40×10^8	120.4
720	15.94	89.66	1320	21.58	121.4
740	16.14	90.79	1340	21.77	122.5
760	16.38	92.14	1360	21.90	123.2
780	16.59	93.32	1380	22.05	124.0
800	16.80	94.50	1400	22.23	125.0
820	17.00	95.63	1420	22.39	125.9
840	17.21	96.81	1440	22.56	126.9
860	17.41	97.93	1460	22.70	127.7
880	17.62	99.11	1480	22.85	128.5
900	17.82	100.2	1500	22.99	129.3
920	18.02	101.4	1520	23.17	130.3
940	18.22	102.5	1540	23.33	131.2
960	18.40	103.5	1560	23.45	131.9
980	18.59	104.6	1580	23.60	132.7
1000	18.79	105.7	1600	23.76	133.6
1020	18.90	106.3	1620	23.90	134.4
1040	19.17	107.8	1640	24.05	135.3
1060	19.34	108.8	1660	24.20	136.1
1080	19.53	109.9	1680	24.35	137.0
1100	19.70	110.8	1700	24.50	137.8
1120	19.89	111.9	1720	24.60	138.4
1140	20.08	112.9	1740	24.75	139.2
1160	20.22	113.7	1760	24.90	140.1
1180	20.40	114.7	1780	25.05	140.9
1200	20.59	115.8	1800	25.20	141.7
1220	20.78	116.9	1820	25.35	142.6
1240	20.94	117.8	1840	25.50	143.4
1260	21.08	118.6	1860	25.60	144.0
1280	21.24	119.5	1880	25.75	144.8

Table 5. Energy, Velocity, and Momentum for Electrons

Energy (ev)	Velocity (cm/sec)	H ρ (Gauss-cm)	Energy (ev)	Velocity (cm/sec)	H ρ (Gauss-cm)
1900	25.90×10^8	145.7	2650	30.55×10^8	171.8
1920	26.05	146.5	2700	30.80	173.3
1940	26.20	147.4	2750	31.10	174.9
1960	26.33	148.1	2800	31.40	176.6
1980	26.40	148.5	2850	31.70	178.3
2000	26.55	149.3	2900	31.95	179.7
2020	26.70	150.2	2950	32.20	181.1
2040	26.80	150.7	3000	32.55	183.1
2060	26.95	151.6	3050	32.77	184.3
2080	27.10	152.4	3100	33.05	185.9
2100	27.25	153.3	3150	33.30	187.3
2120	27.35	153.8	3200	33.55	188.7
2140	27.50	154.7	3250	33.80	190.1
2160	27.60	155.3	3300	34.10	191.8
2180	27.75	156.1	3350	34.35	193.2
2200	27.85	156.6	3400	34.60	194.6
2220	27.95	157.2	3450	34.85	196.0
2240	28.10	158.1	3500	35.10	197.4
2260	28.25	158.9	3550	35.35	198.8
2280	28.35	159.5	3600	35.60	200.3
2300	28.50	160.3	3650	35.85	201.7
2320	28.60	160.9	3700	36.10	203.1
2340	28.70	161.4	3750	36.35	204.5
2360	28.85	162.3	3800	36.60	205.9
2380	28.95	162.8	3850	36.80	207.0
2400	29.05	163.4	3900	37.03	208.3
2450	29.37	165.2	3950	37.25	209.5
2500	29.70	167.1	4000	37.50	210.9
2550	29.95	168.5	4050	37.75	212.3
2600	30.20	169.9	4100	38.00	213.7
			4150	38.20	214.9

Table 5. Energy, Velocity, and Momentum for Electrons

Energy (ev)	Velocity (cm/sec)	H ρ (Gauss-cm)	Energy (ev)	Velocity (cm/sec)	H ρ (Gauss-cm)
4200	38.43×10^8	216.2	5800	45.20×10^8	254.2
4250	38.65	217.4	5850	45.40	255.4
4300	38.92	218.9	5900	45.60	256.5
4350	39.13	220.1	5950	45.78	257.5
4400	39.35	221.3	6000	45.95	258.5
4450	39.60	222.7	6050	46.18	259.8
4500	39.80	223.8	6100	46.35	260.7
4550	40.00	225.0	6150	46.50	261.6
4600	40.25	226.4	6200	46.70	262.7
4650	40.45	227.5	6250	46.90	263.8
4700	40.70	228.9	6300	47.10	264.9
4750	40.90	230.1	6350	47.30	266.1
4800	41.10	231.2	6400	47.50	267.2
4850	41.30	232.3	6450	47.65	268.0
4900	41.51	233.5	6500	47.90	269.4
4950	41.70	234.6	6550	48.00	270.0
5000	41.95	236.0	6600	48.20	271.1
5050	42.20	237.4	6650	48.40	272.2
5100	42.40	238.5	6700	48.55	273.1
5150	42.60	239.6	6750	48.75	274.2
5200	42.80	240.7	6800	48.90	275.1
5250	43.00	241.9	6850	49.10	276.2
5300	43.20	243.0	6900	49.30	277.3
5350	43.40	244.1	6950	49.45	278.2
5400	43.60	245.2	7000	49.65	279.3
5450	43.80	246.4	7050	49.80	280.1
5500	44.00	247.5	7100	50.00	281.2
5550	44.20	248.6	7150	50.20	282.4
5600	44.40	249.7	7200	50.40	283.5
5650	44.60	250.9	7250	50.50	284.1
5700	44.80	252.0	7300	50.65	284.9
5750	45.00	253.1	7350	50.85	286.0

Table 5. Energy, Velocity, and Momentum for Electrons

Energy (ev)	Velocity (cm/sec)	H ρ (Gauss-cm)	Energy (ev)	Velocity (cm/sec)	H ρ (Gauss-cm)
7400	51.05×10^8	287.2	8700	55.40×10^8	311.6
7450	51.20	288.0	8750	55.55	312.5
7500	51.40	289.1	8800	55.70	313.3
7550	51.55	290.0	8850	55.85	314.2
7600	51.70	290.8	8900	56.00	315.0
7650	51.90	291.9	8950	56.20	316.1
7700	52.05	292.8	9000	56.35	317.0
7750	52.25	293.9	9050	56.45	317.5
7800	52.40	294.8	9100	56.60	318.4
7850	52.60	295.9	9150	56.75	319.2
7900	52.75	296.7	9200	56.90	320.1
7950	52.90	297.6	9250	57.10	321.2
8000	53.05	298.4	9300	57.20	321.7
8050	53.25	299.5	9350	57.40	322.9
8100	53.45	300.7	9400	57.50	323.4
8150	53.55	301.2	9450	57.65	324.3
8200	53.75	302.3	9500	57.80	325.1
8250	53.90	303.2	9550	58.00	326.2
8300	54.10	304.3	9600	58.10	326.8
8350	54.20	304.9	9650	58.30	327.9
8400	54.40	306.0	9700	58.40	328.5
8450	54.55	306.8	9750	58.60	329.6
8500	54.70	307.7	9800	58.75	330.5
8550	54.90	308.8	9850	58.90	331.3
8600	55.05	309.7	9900	59.05	332.2
8650	55.20	310.5	9950	59.20	333.0
			10000	59.40	334.1

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