Recommended Data on the Electron Impact Ionization of Atoms and Ions: Fluorine to Nickel

Cite as: Journal of Physical and Chemical Reference Data **17**, 1285 (1988); https://doi.org/10.1063/1.555809
Submitted: 11 February 1987 . Published Online: 15 October 2009

M. A. Lennon, K. L. Bell, H. B. Gilbody, J. G. Hughes, A. E. Kingston, M. J. Murray, and F. J. Smith

Recommended Data on the Electron Impact Ionization of Atoms and Ions: Fluorine to Nickel

M. A. Lennon, K. L. Bell, H. B. Gilbody, J. G. Hughes, A. E. Kingston, M. J. Murray, and F. J. Smith

School of Physics and Mathematical Sciences, The Queen's University of Belfast, Northern Ireland

Received February 11, 1987; revised manuscript received February 2, 1988

Experimental and theoretical cross-section data for electron impact ionization of atoms and ions from fluorine to nickel has been assessed and earlier recommendations for light atoms and ions have been revised. Based on this assessment and, in the absence of any data, on the classical scaling laws a recommended cross section has been produced for each species. This has been used to evaluate recommended Maxwellian rate coefficients over a wide range of temperatures. Convenient analytic expressions have been obtained for the recommended cross sections and rate coefficients. The data are presented in both graphical and tabular form and estimates of the reliability of the recommended data are given.

Key words: cross section; electron impact ionization; isoelectronic sequence; rate coefficients.

Contents

List of Tables

List of Figures

1. Introduction

Cross sections and rates for electron impact ionization of positive ions are needed for the development of realistic models for high-temperature plasmas and for interpretation of diagnostic observations in such plasmas. In an earlier paper (Bell *et al.*[1]) a set of recommended cross sections and rate coefficients for light atoms and ions was presented. The recommendations were based on a careful assessment of the best experimental and theoretical data available at the time. The aim of this paper is to extend the earlier recommended data to include electron ionization of atoms and ions from fluorine to nickel and to review the earlier recommendations.

Although more quantitative information concerning the electron impact ionization of positive ions is now available in many cases plasma modelers still have to rely heavily on relatively simple and approximate methods of calculating rates. In particular, the semi-empirical formula of Lotz[2,3] is still widely used. The Lotz formula was designed to reproduce the available experimental data and to predict cross sections for other atoms and ions using the classical scaling law. During the last decade however, there have been considerable advances in calculating and measuring cross sections for ionization of positive ions.

Currently, the most accurate theoretical calculations of the direct single ionization process use variations of the distorted-wave Born with exchange (DWBE) approximation (Younger,[4,5] Jakubowicz and Moores[6]). Calculations using this approximation have been made for the outer subshells of the ground configuration for many of the isoelectronic sequences covered in this paper. Good agreement with experiment is found for simple systems with few initial target electrons, but significant discrepancies arise for more complex ions and for systems where indirect or resonant processes make substantial contributions to the cross section. A few calculations have been made which incorporate a treatment of excitation–autoionization (Falk *et al.*,[7,8] Burke *et al.*[9]) but much work remains to be done.

Experimental data on the ionization of positive ions by electron impact have been derived from intersecting beam studies, plasma measurements, and ion trap methods. There are considerable difficulties inherent in each of these three different approaches, but intersecting beam methods have produced the most reliable and extensive data to date.

The general principles underlying methods based on intersecting beams have been reviewed by Dolder and Peart.[10] A well-defined monoenergetic beam of ions in the required charge state is arranged to intersect a beam of electrons. The interaction energy is specified according to the laboratory energies and angle of intersection of the beams. Ions arising as products of ionization must be carefully separated by the electrostatic or magnetic analyze from the (typically at least 10^8 times) more intense primary ion beam. The product ion yield measured in conjunction with the intensity and spatial distribution of the intersecting beams then allows the ionization cross section to be determined on an absolute basis.

The main difficulties in the intersecting beams approach stem from the low signal to background ratios, the need for proper account of space charge effects in the interaction of the beams, and the possible presence of unknown fractions of long-lived excited states in the primary ion beam. Most of the studies to date have been carried out with singly and doubly charged ions and it is only in the past few years that suitable beams have been provided to permit studies of more heavily charged ions.

Studies based on plasma measurements in magnetically confined plasmas (Kunze,[11] Kallne and Jones[12]) make use of a model which describes the time evolution of spectral lines in terms of ionization rates, electron densities, and electron temperatures. The model assumes a Maxwellian temperature distribution, thermodynamic equilibrium, and radiation produced through collisions with electrons. Ionization rates are determined by fitting the observed time evolution of spectral lines to the model. Large uncertainties in the derived ionization rates arise through the uncertainties in the measured electron temperature and densities. While the method does not permit the energy dependence of the ionization process to be studied, it has provided some data in the ionization threshold region for ions in charge states greater than five, which have so far been unattainable in the intersecting beam experiments.

In the ion trap approach (see review by Dunn[13]), ions may be trapped in a suitable combination of electric and magnetic fields and then bombarded with a well-defined electron beam. Alternatively, the ions may be contained in the space charge of an electron beam (Baker and Hasted[14]). The method provides only relative cross sections which require other techniques for normalization. Other difficulties arise from the dependence of the trapping efficiency on electron energy, the presence of excited ions in the trap, and the inability of the method to distinguish between products formed by single and multiple ionization. In the ion trap approach used by Donets,[15] observations have been carried out using an electron beam ion source (EBIS) in which plasma modeling is used to determine ionization rates. The method has provided data for ions of high charge state at energies well above ionization threshold.

For atoms, the beam-static-target technique, originated by Jones,[16] and later developed by Tate and his co-workers (e.g., Tate and Smith[17]), was used exclusively prior to 1978. This approach is subject to many errors including the determination of the electron trajectory, secondary electron emission current, and accurate measurement of the low target density. The crossed electron-fast atom beam technique first used by Cook and Peterson[18] is free from these sources of error. However, the target atom beam, prepared by charge exchange of the parent ion beam in a gas cell, may contain metastable and long-lived highly excited ions. Recently, a pulsed crossed beam technique incorporating time-of-flight analysis of the collision products has been developed (Shah, Elliott, and Gilbody[19]). A pulsed electron beam intersects at right angles a thermal energy beam of ground state target atoms. This approach is unique in that ionizing collisions occur in the absence of both electric and magnetic fields and is capable of very high precision. It is hoped that this paper will stimulate further experimental and theoretical work, particularly in those areas where there is a paucity of data.

2. Method of Evaluation

Assessment and determination of recommended data for the heavy atoms and ions is extremely difficult because (1) for many ions no experimental or theoretical data exist, (2) for most ions limited experimental data are available and the theoretical data are based largely on the Coulomb–Born approximation, and (3) where data are unavailable many ions will have a significant contribution to the ionization cross section from autoionization.

At large impact energies, the Born or Coulomb–Born approximations should produce reliable results if accurate wavefunctions are used for both the initial and final states. The Born and Coulomb–Born approximations are not valid at low energies and hence in deciding on the recommended cross sections we have generally used experimental data where they are available and extrapolated to high energies if necessary, using the Born or Coulomb–Born approximations. When different experiments yield conflicting results, we have normally used the experimental results which agree best with the theoretical prediction at high energies. If no experimental data are available, we have used theoretical data. Where possible, we have tested the classical scaling law for ionization cross sections in each isoelectronic sequence and also used this scaling to predict recommended cross sections. In general, our predictions were made by scaling from a single recommended data set, or where a selection of data was available for the sequence, by choosing a representative scaling curve (e.g., Na sequence). For species scandium to zinc, we restricted the choice of scaling curve to within this range and so relied heavily on the theoretical data for iron. Our choice of scaling curve was vindicated to an extent by the appearance of the rate coefficient curves for all charge states of a given species.

As mentioned above, one of the most difficult tasks is to recommend cross sections in cases where autoionization may play an important role, partly because the scaling laws do not apply to autoionization; this topic is discussed more fully in Appendix A. In cases where we have used experimental data which include an obvious excitation–autoionization contribution, we have attempted to separate out the contribution from autoionization. We then scale the direct cross section only to obtain approximate cross sections for other ions in the same isoelectronic sequence. For these cases our recommended cross sections may underestimate the actual cross sections.

The data presented in this paper are, we believe, the best data currently available. However, in light of the discussion above, it must be stressed that much of the data are not as reliable as those presented in the earlier paper.

3. Recommended Data

All the recommended cross sections and rates are presented in graphical form in Figs. 1 144, and in the form of analytical fits. The cross-section graphs for all atoms and ions include a representative selection of the available data. To ensure clarity it has not been possible to include all the data in every case but a full bibliography for each species will be provided in a separate report. The recommended rates for a few representative species are compared, in Figs. 21–24, with recent measurements in plasma machines and with the calculated rates of other authors.

Estimates of the reliability of the recommended cross sections are given in the tables as percentages. The percentage error in the rates for each atom should be the same as for the cross sections. These estimates are based on a review of the uncertainties or errors published with the original data.

They normally adopt the error limits given by the authors or authors of the "best" data measurements when these are available but are sometimes modified from an assessment of the scaled cross sections for each isoelectronic sequence.

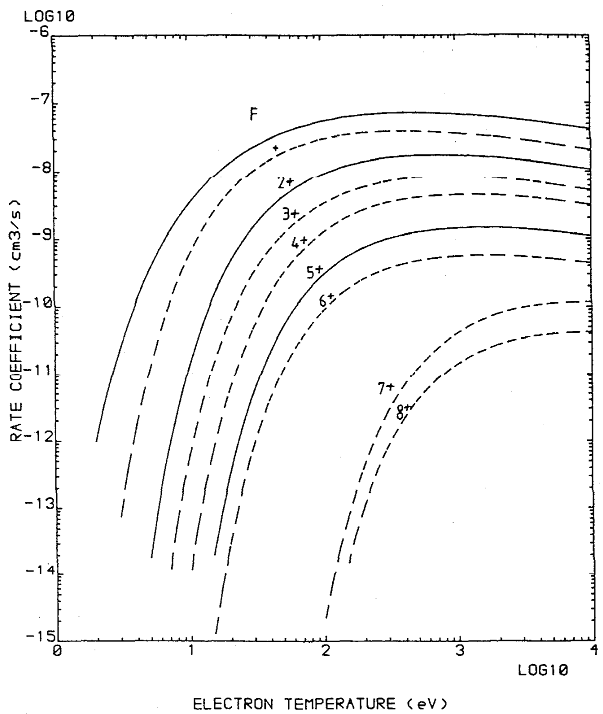

FIG. 1. Electron impact ionization of fluorine and its ions. Recommended rate coefficients.

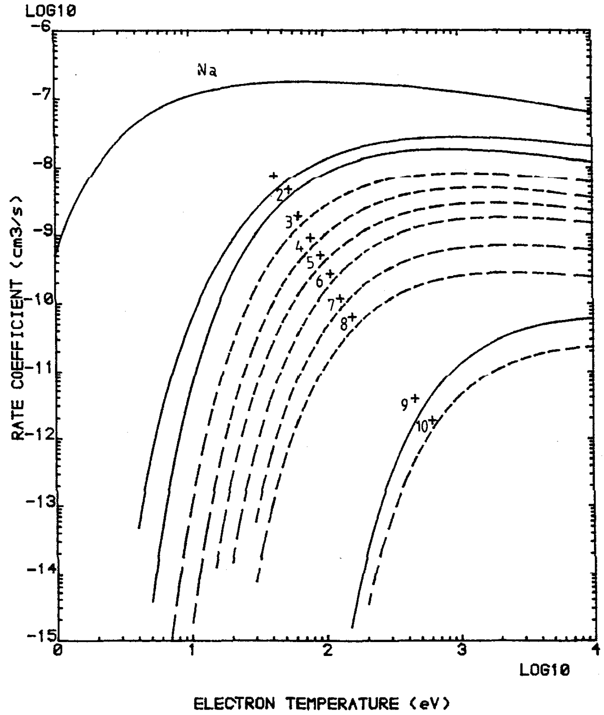

FIG. 3. Electron impact ionization of sodium and its ions. Recommended rate coefficients.

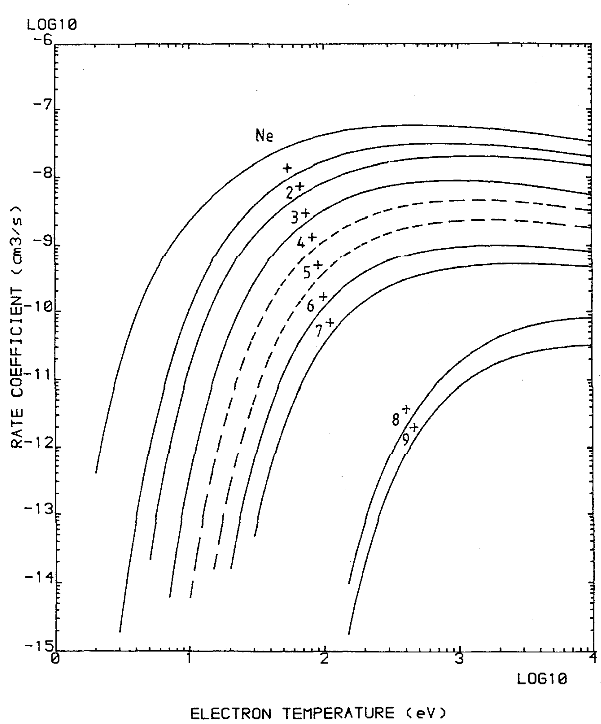

FIG. 2. Electron impact ionization of neon and its ions. Recommended rate coefficients.

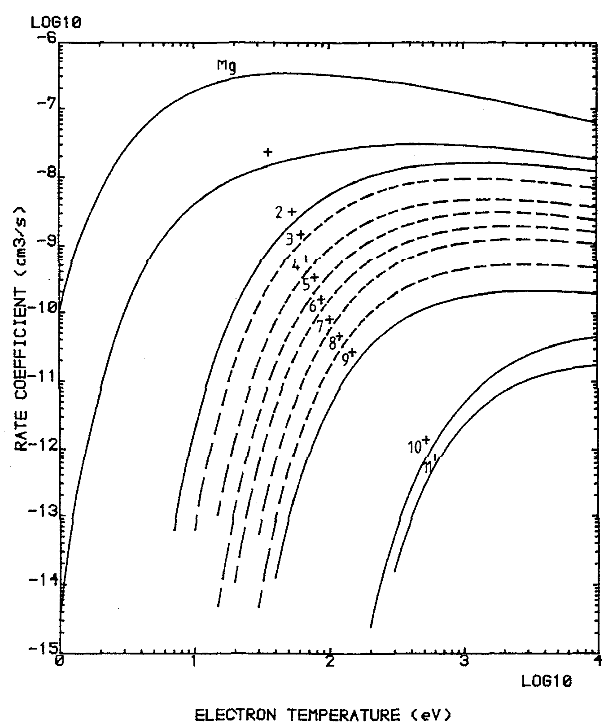

FIG. 4. Electron impact ionization of magnesium and its ions. Recommended rate coefficients.

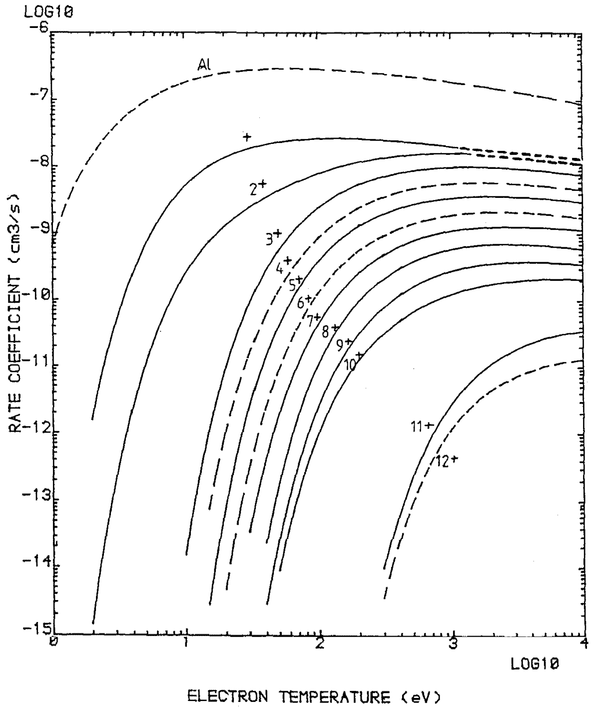

FIG. 5. Electron impact ionization of aluminum and its ions. Recommended rate coefficients.

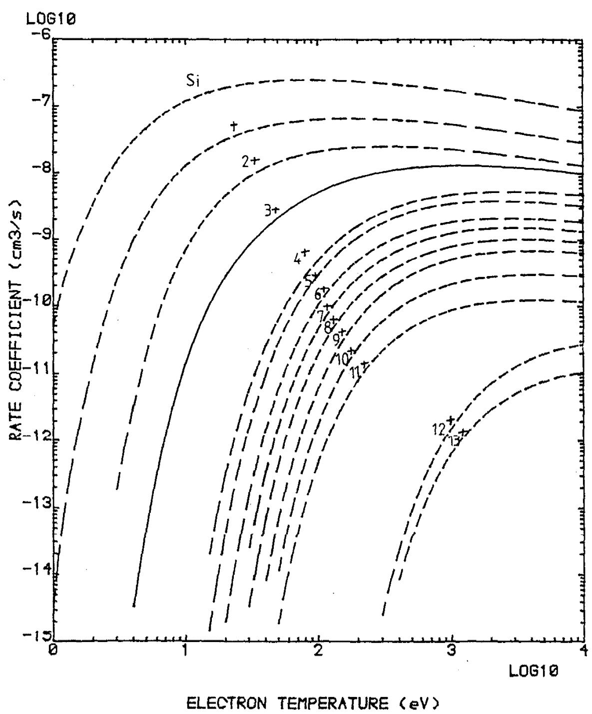

FIG. 6. Electron impact ionization of silicon and its ions. Recommended rate coefficients.

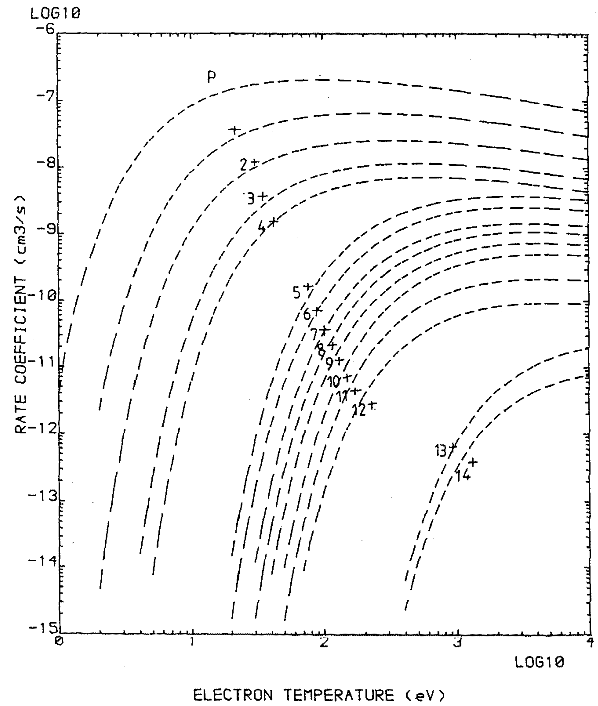

FIG. 7. Electron impact ionization of phosphorus and its ions. Recommended rate coefficients.

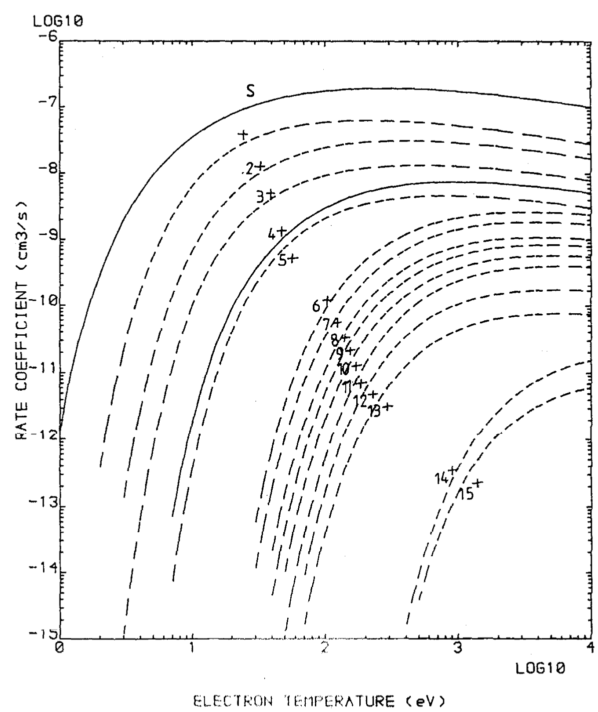

FIG. 8. Electron impact ionization of sulfur and its ions. Recommended rate coefficients.

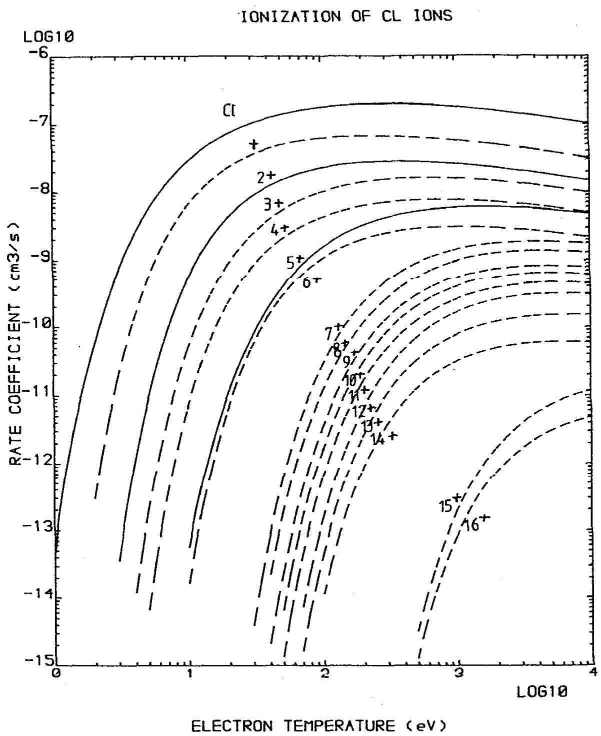

FIG. 9. Electron impact ionization of chlorine and its ions. Recommended rate coefficients.

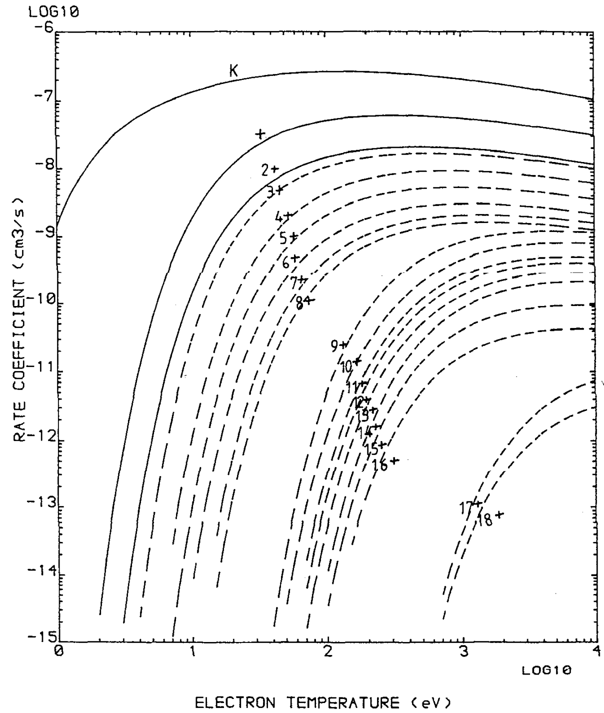

FIG. 11. Electron impact ionization of potassium and its ions. Recommended rate coefficients.

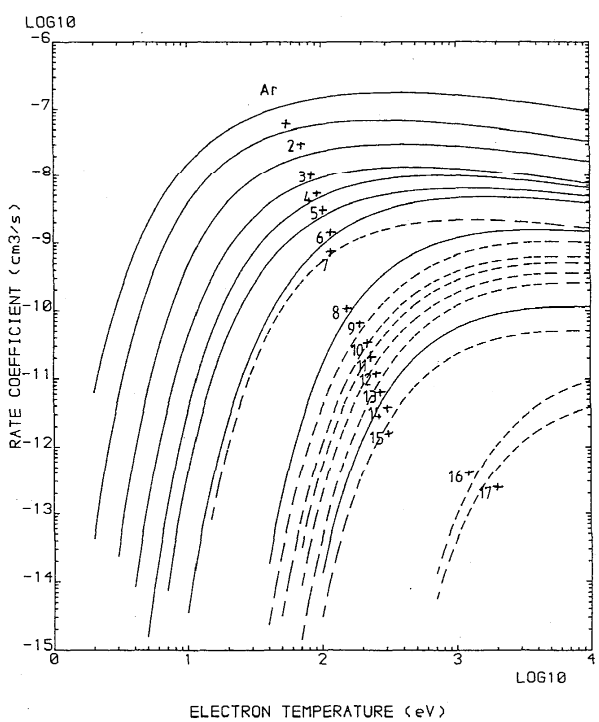

FIG. 10. Electron impact ionization of argon and its ions. Recommended rate coefficients.

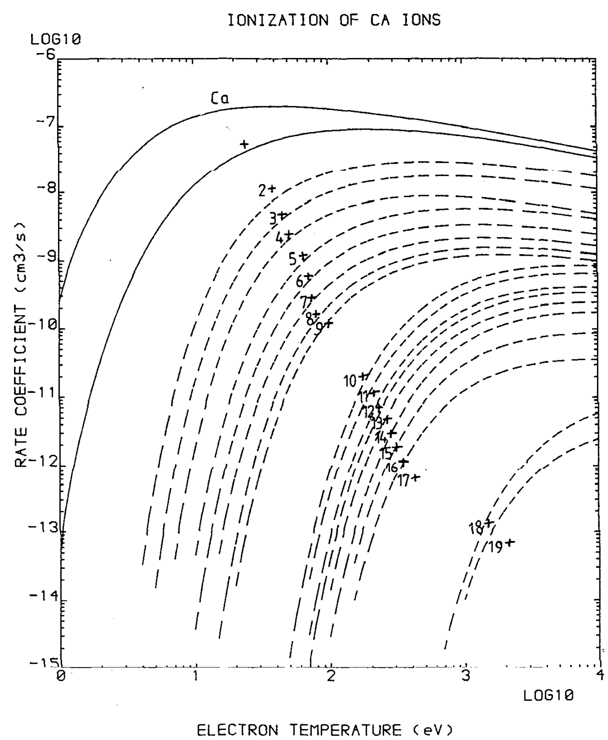

FIG. 12. Electron impact ionization of calcium and its ions. Recommended rate coefficients.

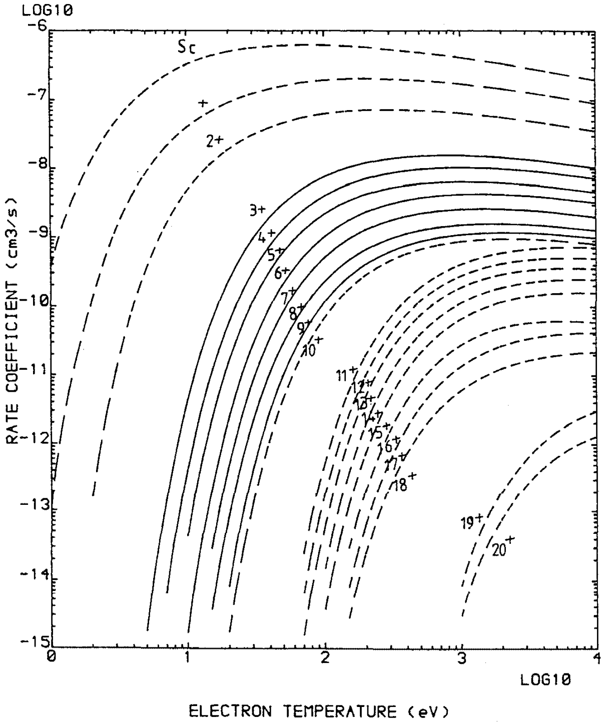

FIG. 13. Electron impact ionization of scandium and its ions. Recommended rate coefficients.

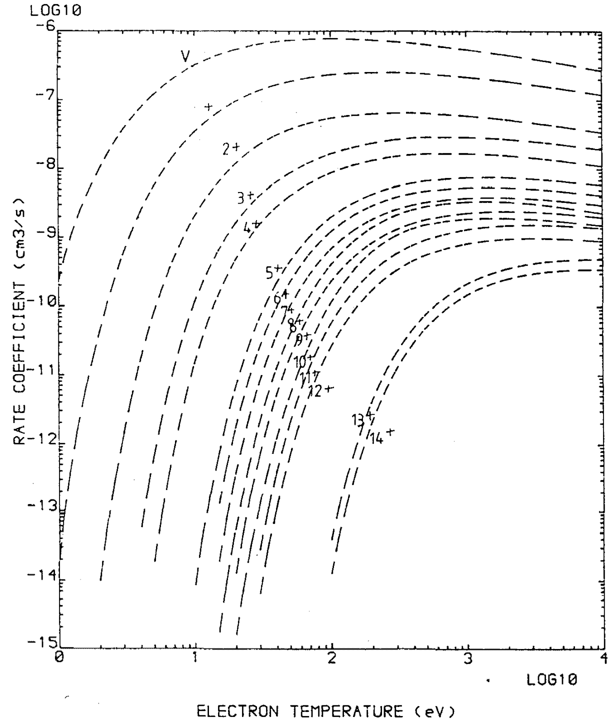

FIG. 15. Electron impact ionization of vanadium and its ions. Recommended rate coefficients.

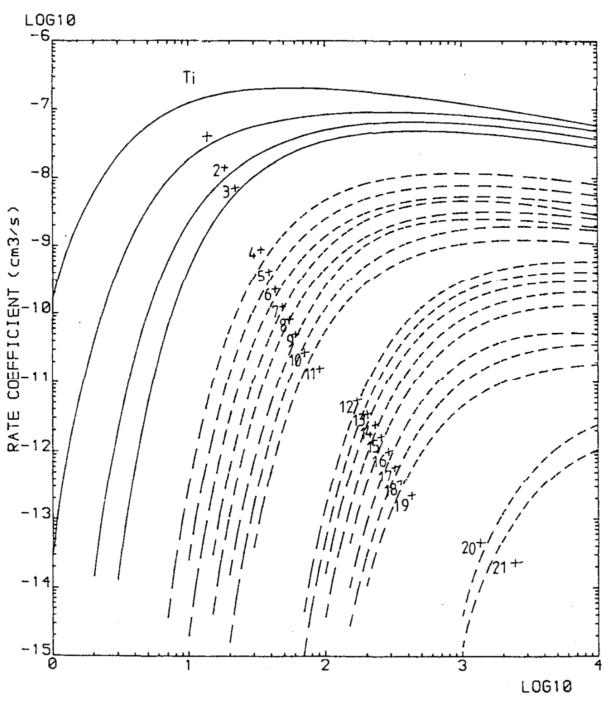

FIG. 14. Electron impact ionization of titanium and its ions. Recommended rate coefficients.

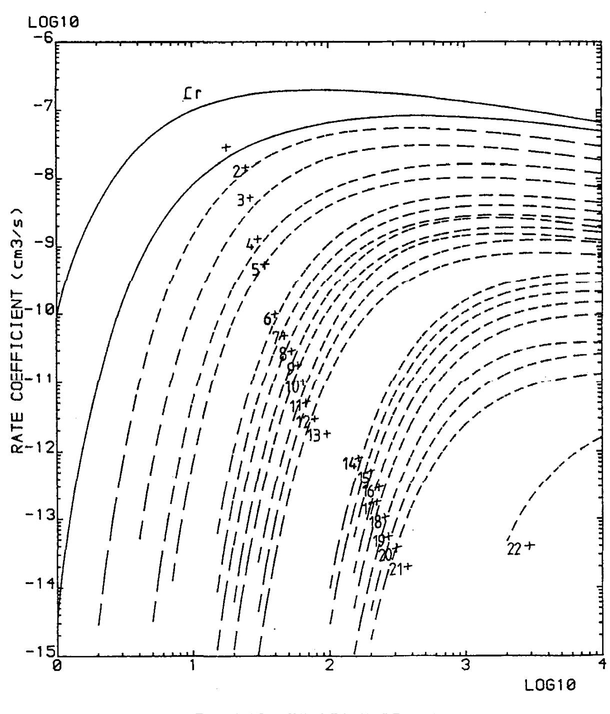

FIG. 16. Electron impact ionization of chromium and its ions. Recommended rate coefficients.

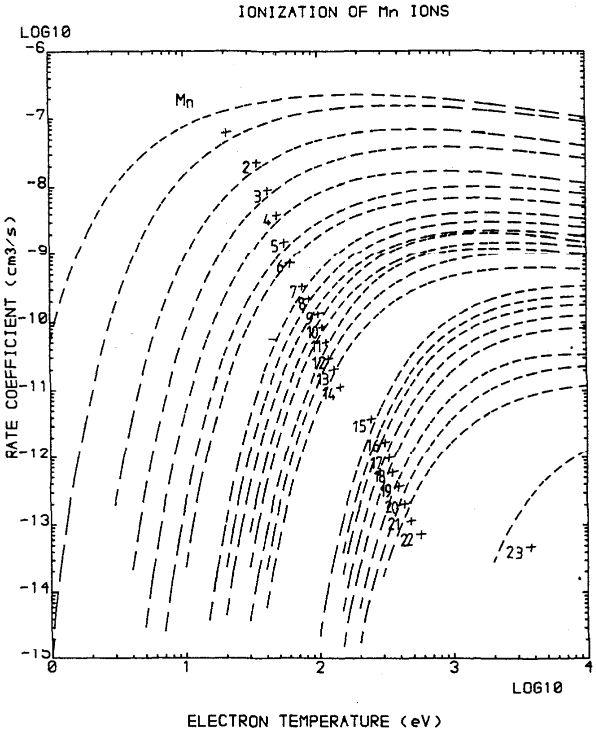

FIG. 17. Electron impact ionization of manganese and its ions. Recommended rate coefficients.

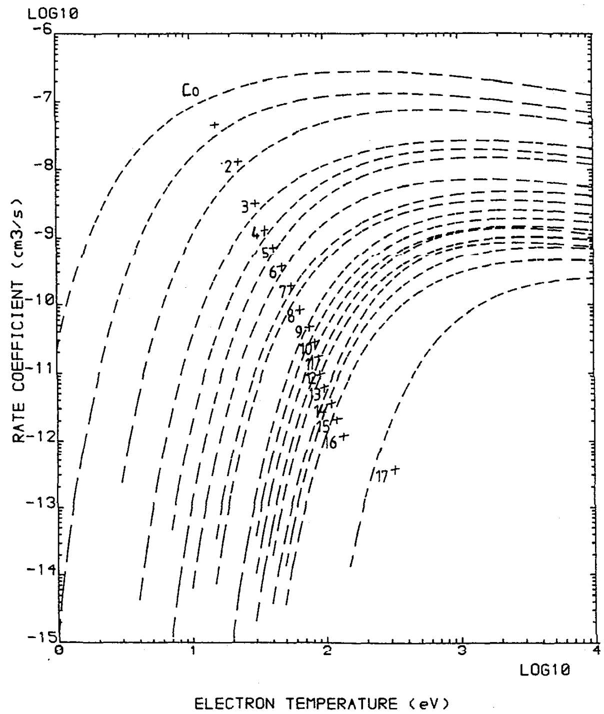

FIG. 19. Electron impact ionization of cobalt and its ions. Recommended rate coefficients.

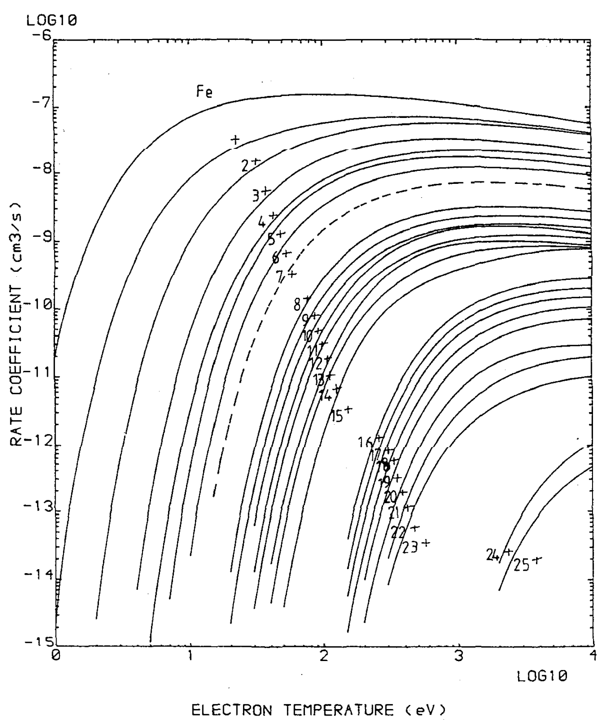

FIG. 18. Electron impact ionization of iron and its ions. Recommended rate coefficients.

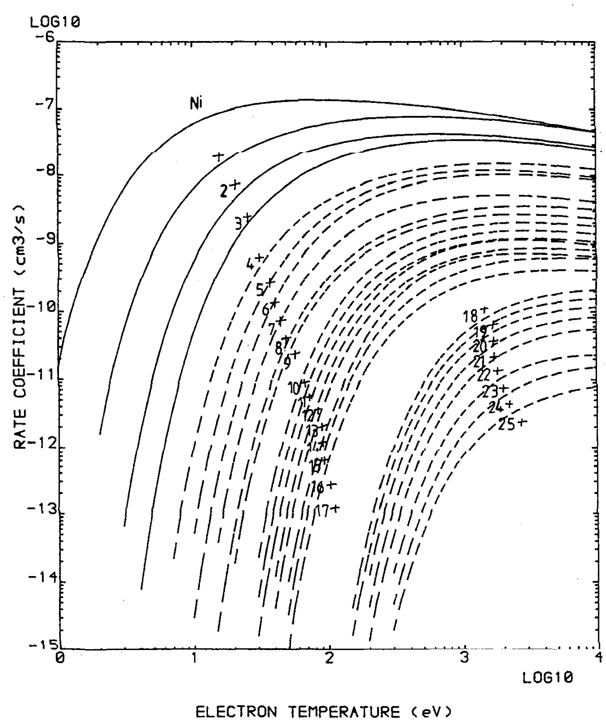

FIG. 20. Electron impact ionization of nickel and its ions. Recommended rate coefficients.

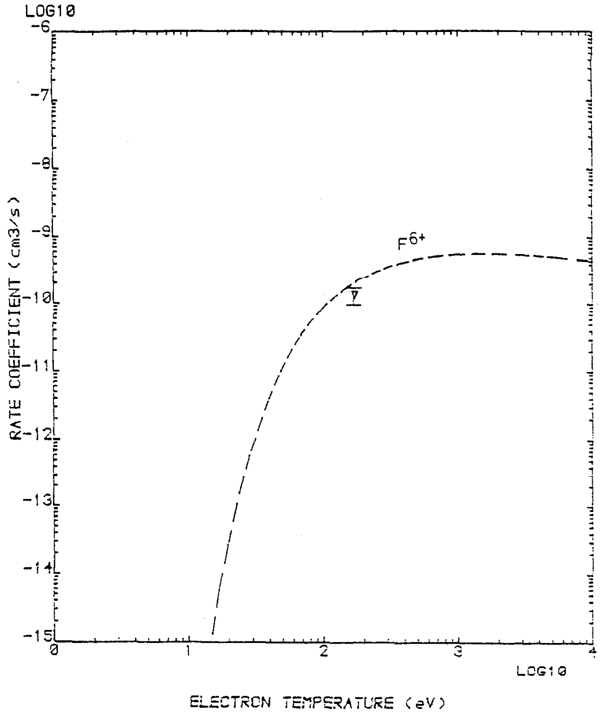

FIG. 21. Comparison of recommended rates for F VII with experimental measurements: - - - recommended; ∇ Greve *et al.* expt. (Ref. 23).

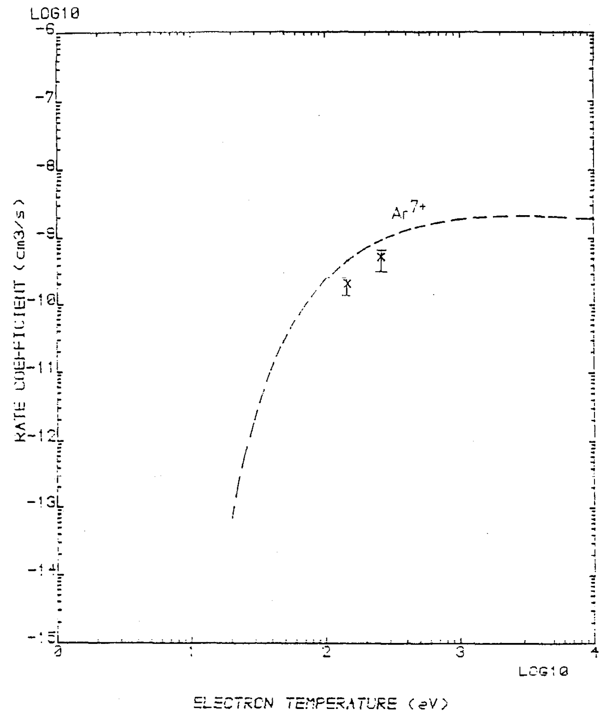

FIG. 23. Comparison of recommended rates for Ar VIII with experimental measurements: - - - recommended; X Datla *et al.*, expt. (Ref. 25).

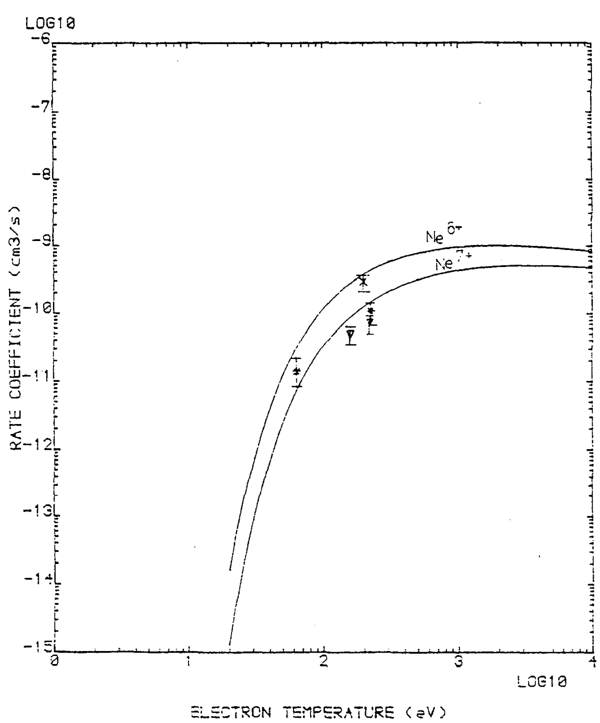

FIG. 22. Comparison of recommended rates for Ne VII and Ne VIII with experimental measurements: — recommended; Ne VIII ∗ Jones *et al.* (Ref. 24); Ne VII X Datla *et al.* (Ref. 25); Ne VII ∇ Greve *et al.* (Ref. 23).

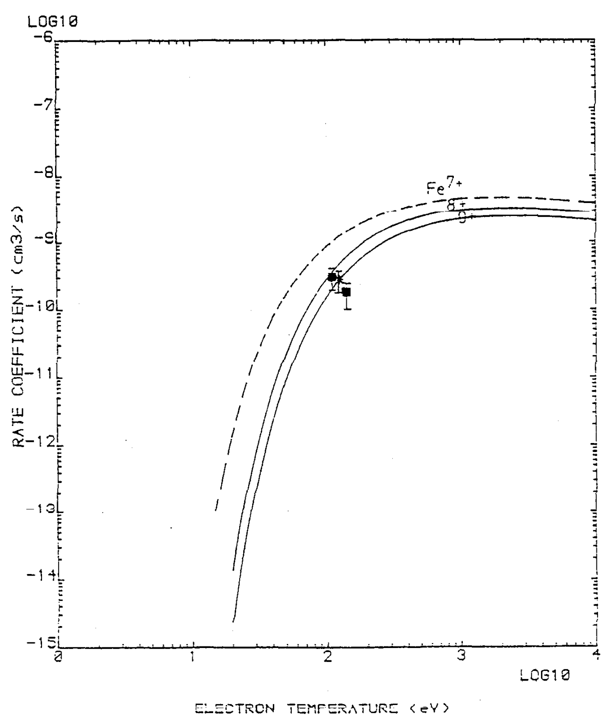

FIG. 24. Comparison of recommended rates for Fe VIII (●), Fe IX (∗), and Fe X (■) with experimental measurements, Datla *et al.* (Ref. 25): - - - recommended rates derived from scaling laws; — recommended rates based on calculation (Ref. 26).

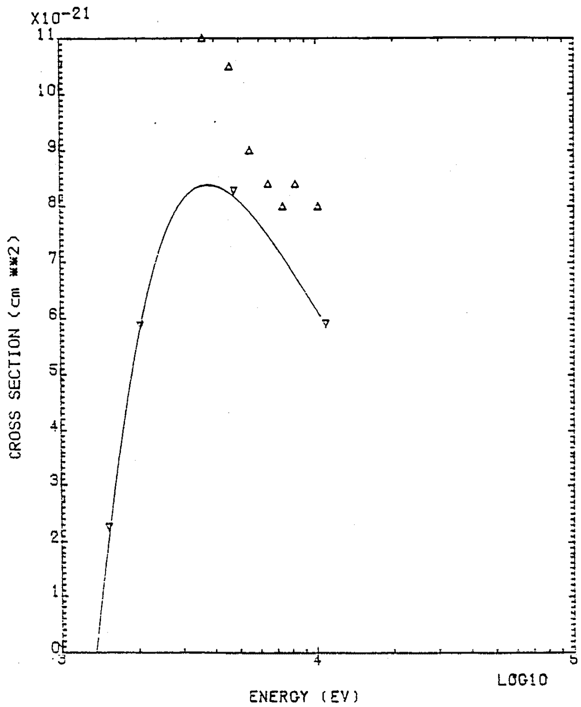

FIG. 25. Electron impact ionization of Ne X (Ne X→Ne XI).

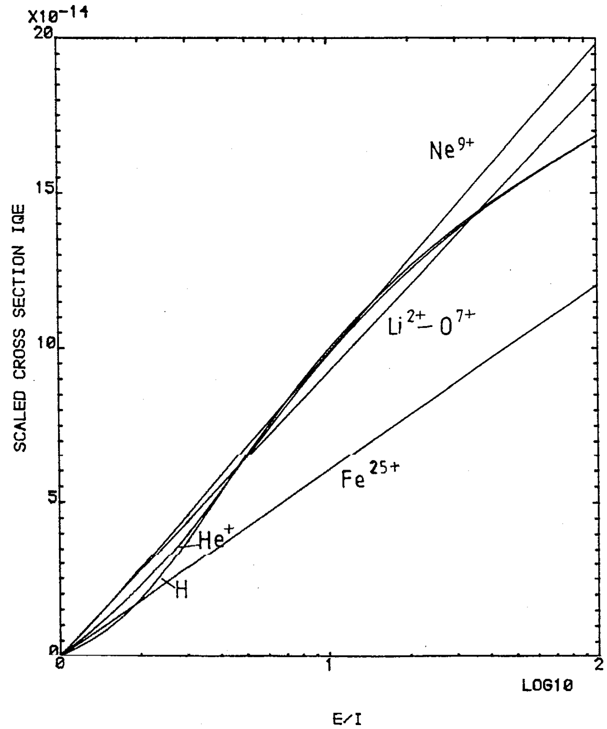

FIG. 27. Scaled cross sections for H-like ions.

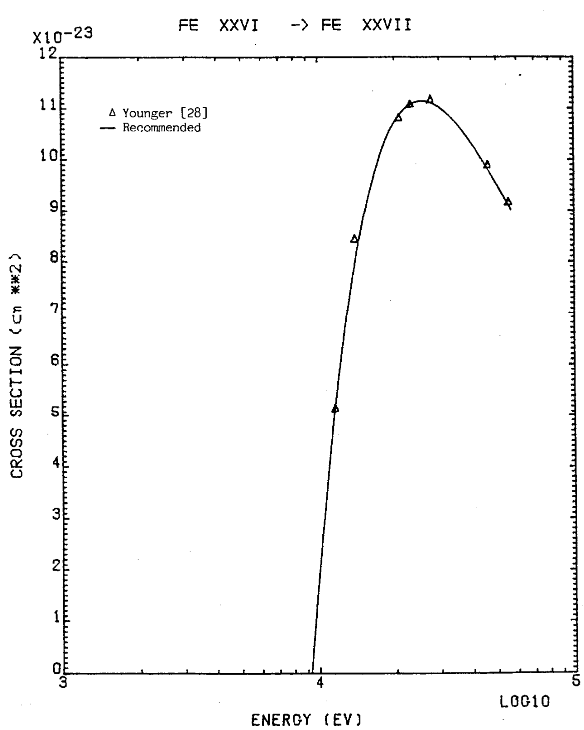

FIG. 26. Electron impact ionization of Fe XXVI (Fe XXVI→Fe XXVII).

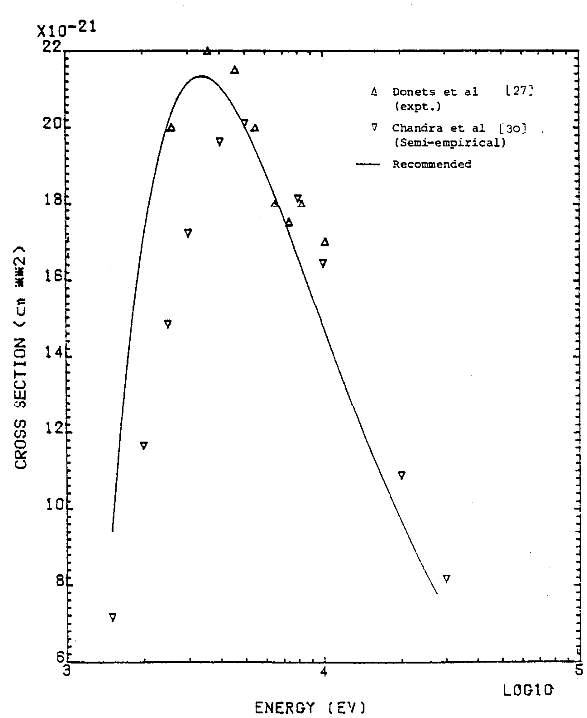

FIG. 28. Electron impact ionization of Ne IX (Ne IX→Ne X).

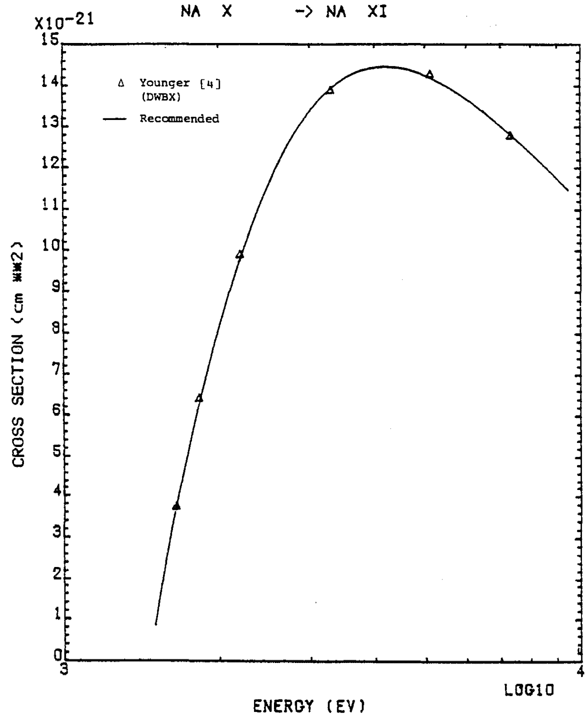

FIG. 29. Electron impact ionization of Na X (Na X → Na XI).

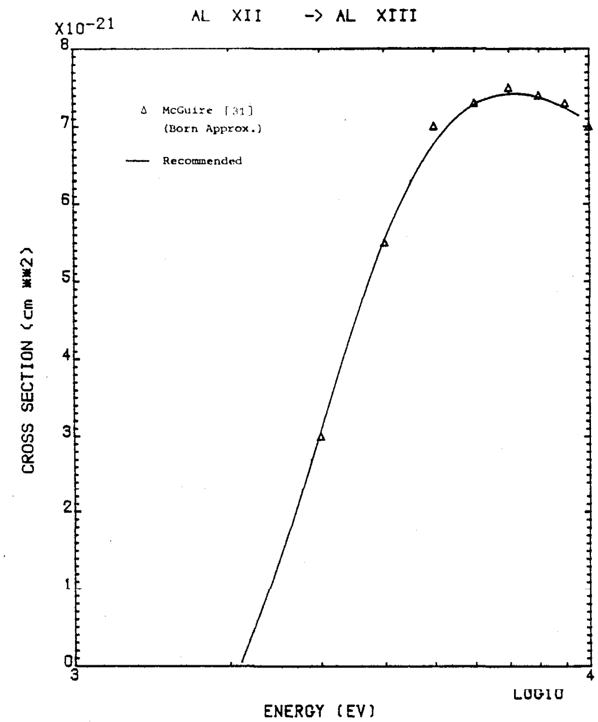

FIG. 31. Electron impact ionization of Al XII (Al XII → Al XIII).

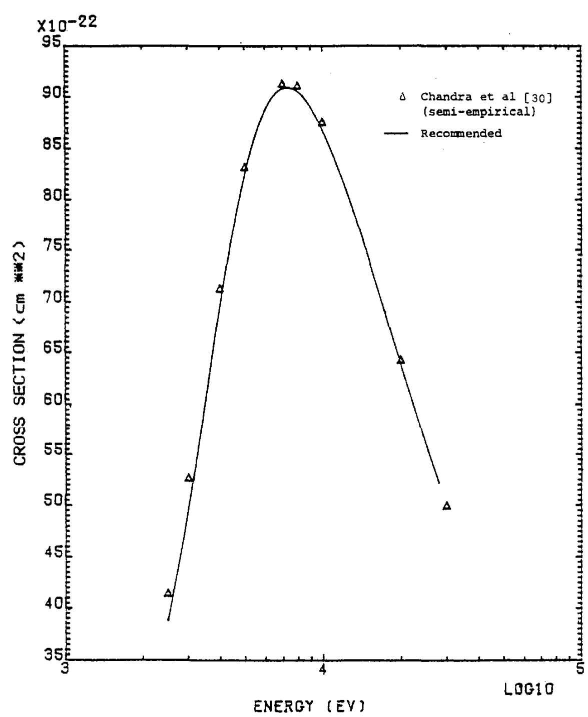

FIG. 30. Electron impact ionization of Mg XI (Mg XI → Mg XII).

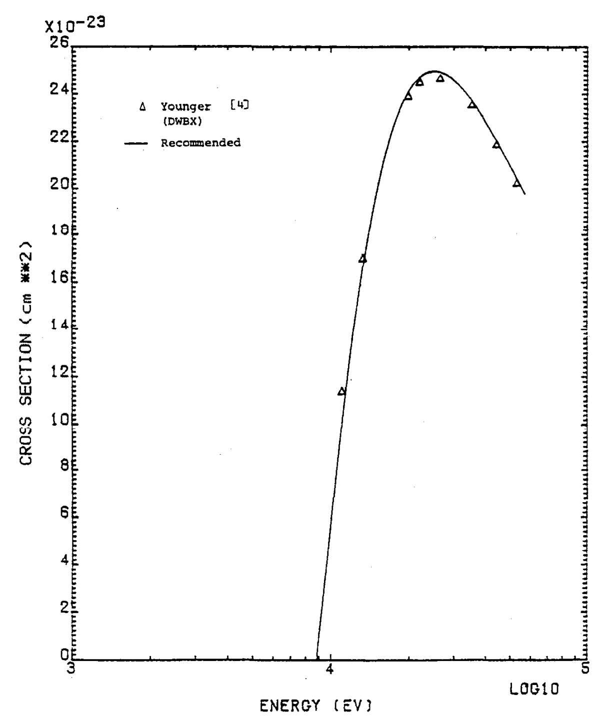

FIG. 32. Electron impact ionization of Fe XXV (Fe XXV → Fe XXVI).

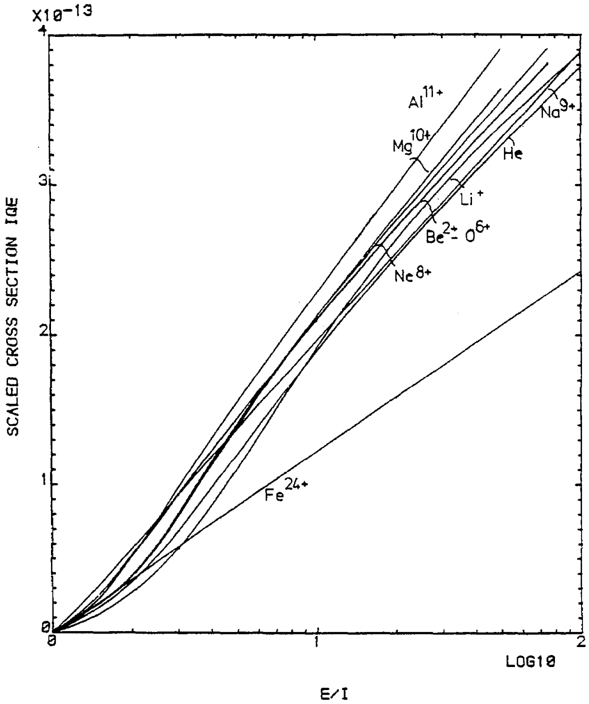

FIG. 33. Scaled cross sections for He-like ions.

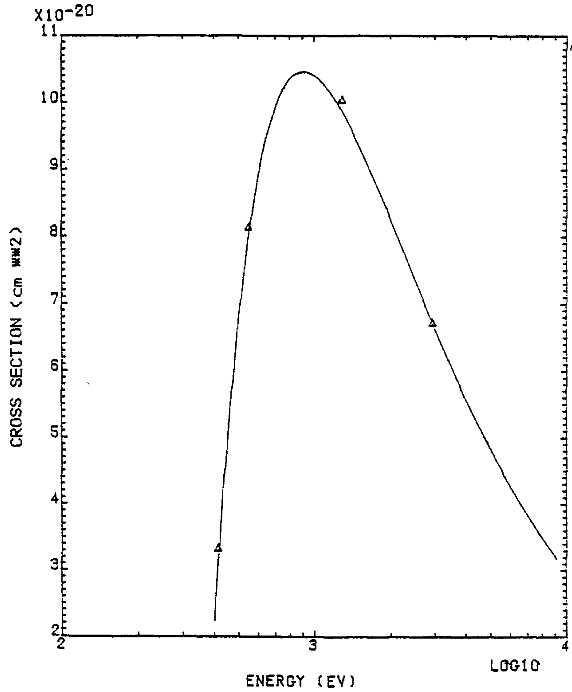

FIG. 35. Electron impact ionization of Mg X (Mg X→Mg XI): △ Younger, DWBX (Ref. 4); — recommended.

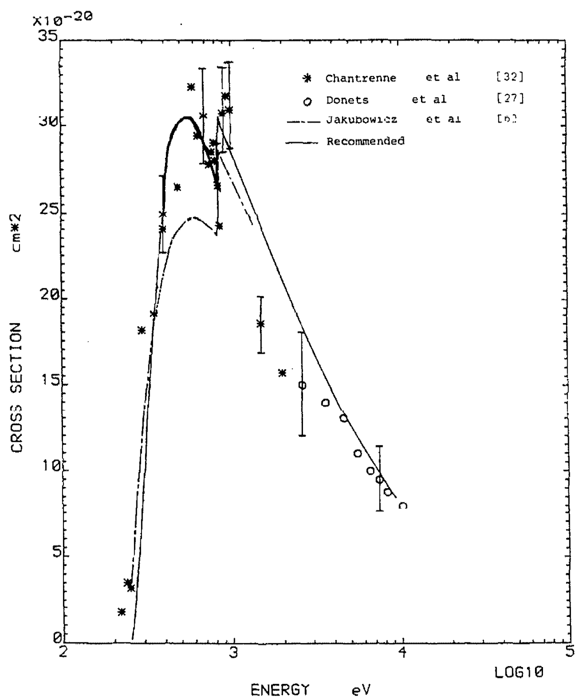

FIG. 34. Electron impact ionization of Ne VIII (Ne VIII→Ne IX).

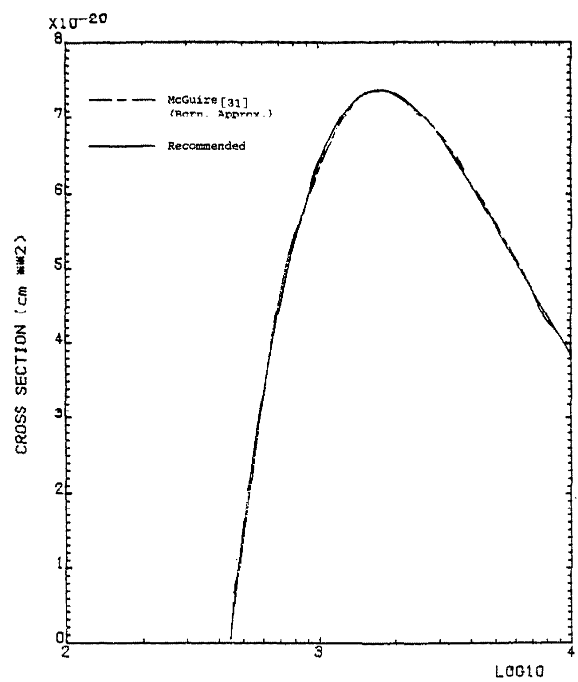

FIG. 36. Electron impact ionization of Al XI (Al XI→Al XII).

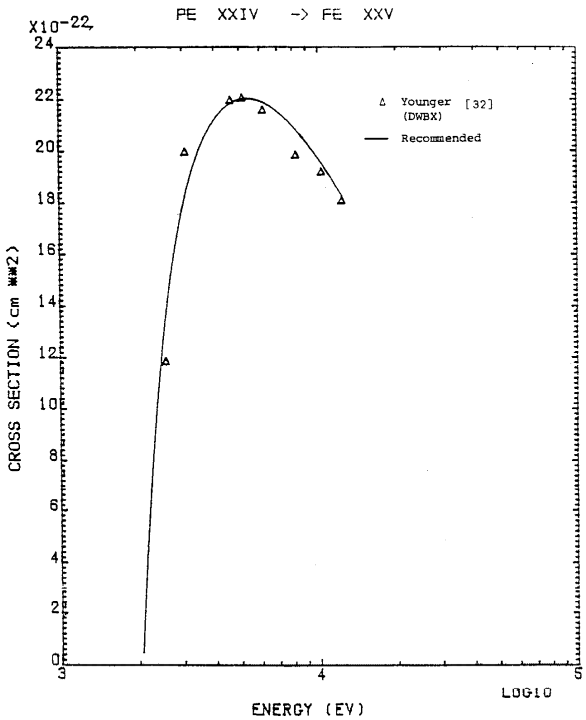

FIG. 37. Electron impact ionization of Fe XXIV (Fe XXIV→Fe XXV).

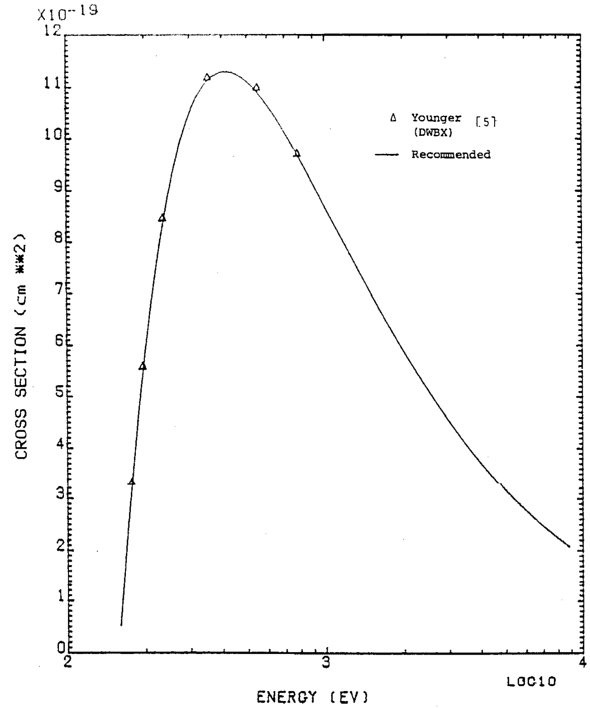

FIG. 39. Electron impact ionization of F VI (F VI→F VII).

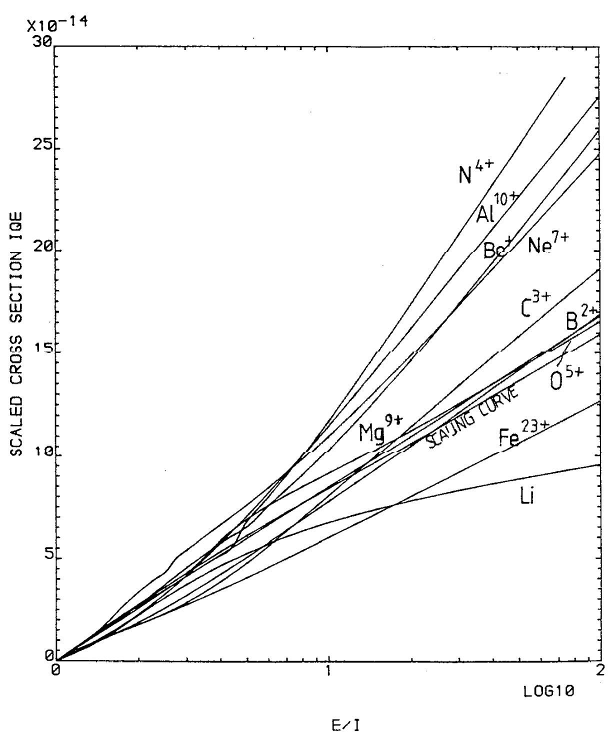

FIG. 38. Scaled cross sections for Li-like ions.

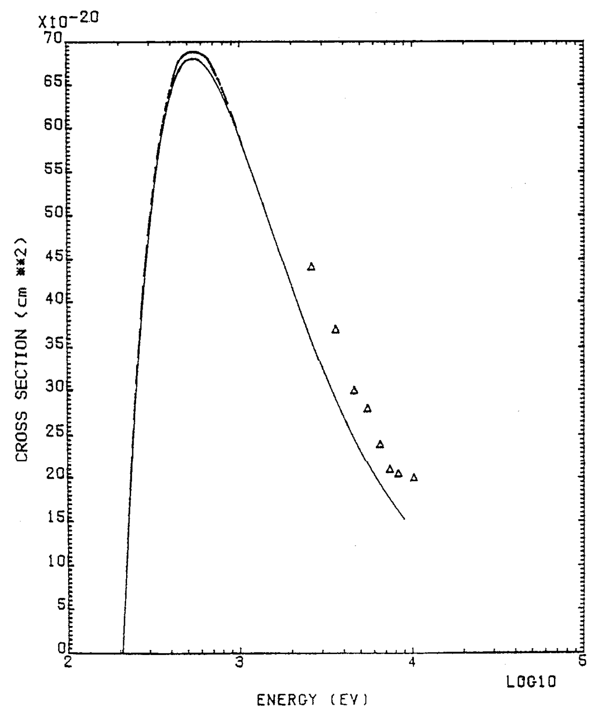

FIG. 40. Electron impact ionization of Ne VII (Ne VII→Ne VIII): Δ Donets *et al.*, expt. (Ref. 27); - - Jakubowicz, CBX (Ref. 20); — recommended.

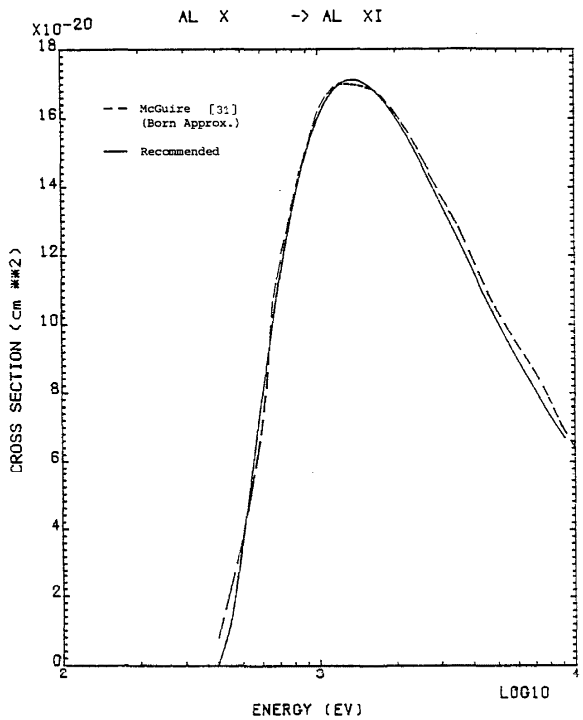

FIG. 41. Electron impact ionization of Al X (Al X → Al XI).

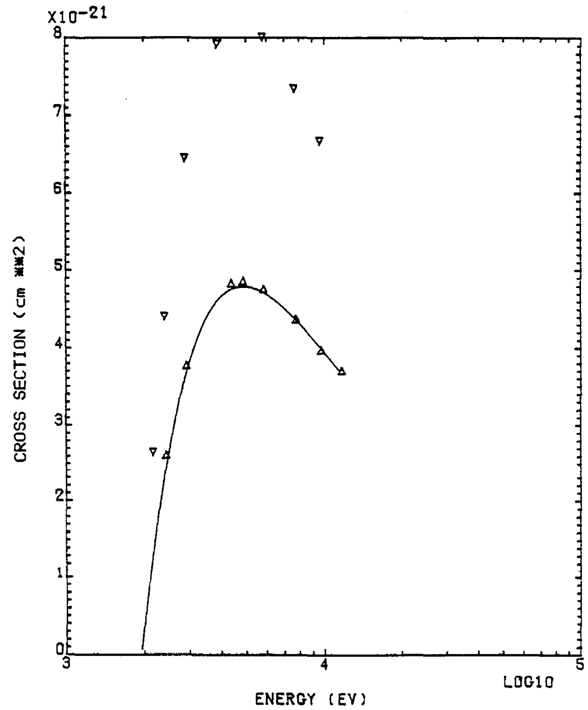

FIG. 43. Electron impact ionization of Fe XXIII (Fe XXIII → FeXXIV): △ Younger, DWBX (Ref. 5); ▽ Jakubowicz, CBX (Ref. 20); — recommended.

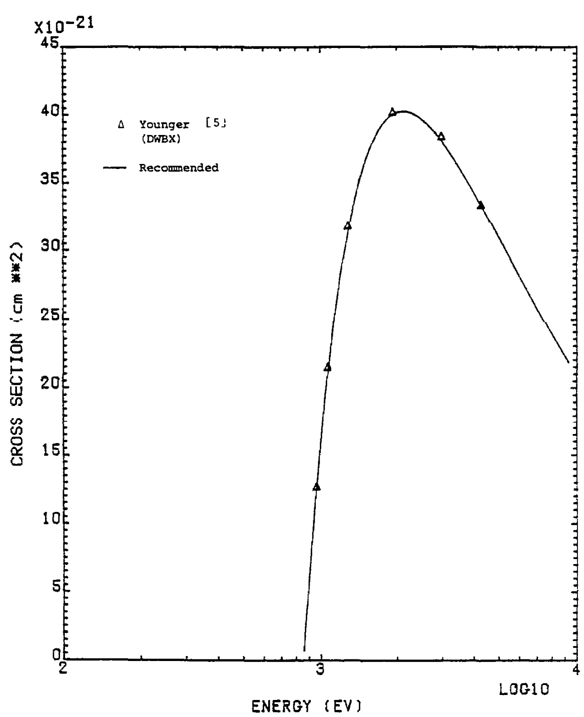

FIG. 42. Electron impact ionization of Ar XV (Ar XV → Ar XVI).

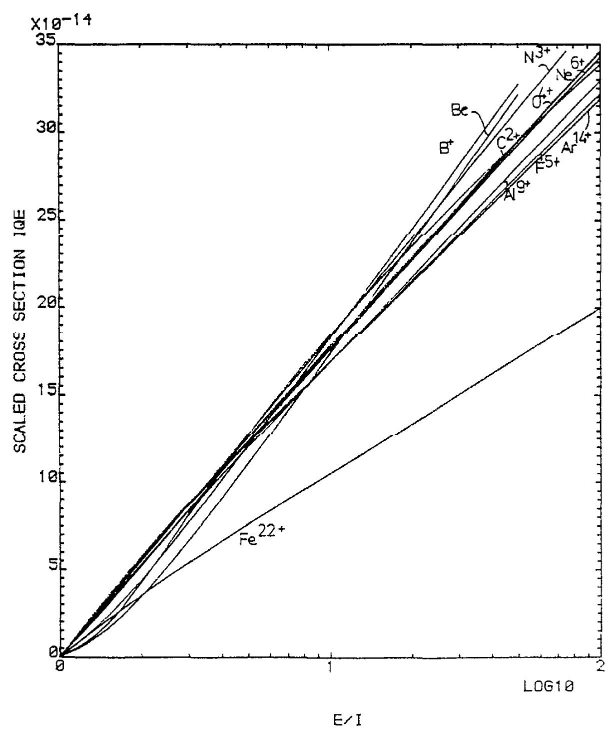

FIG. 44. Scaled cross sections for Be-like ions.

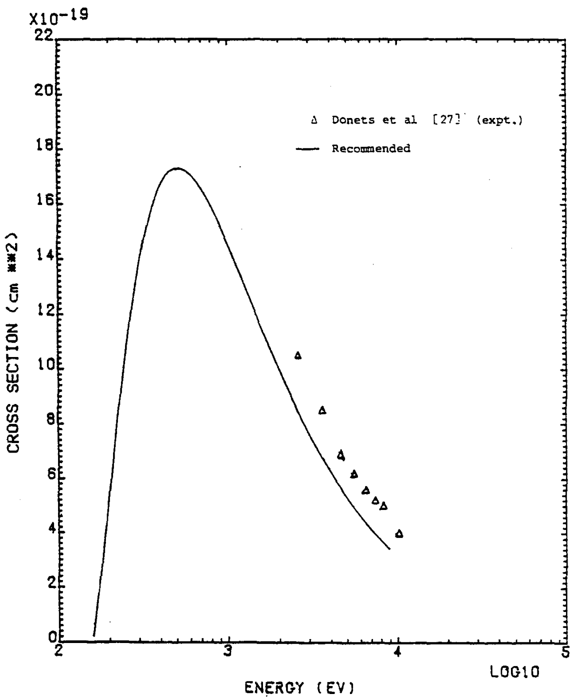

FIG. 45. Electron impact ionization of Ne VI (Ne VI→Ne VII).

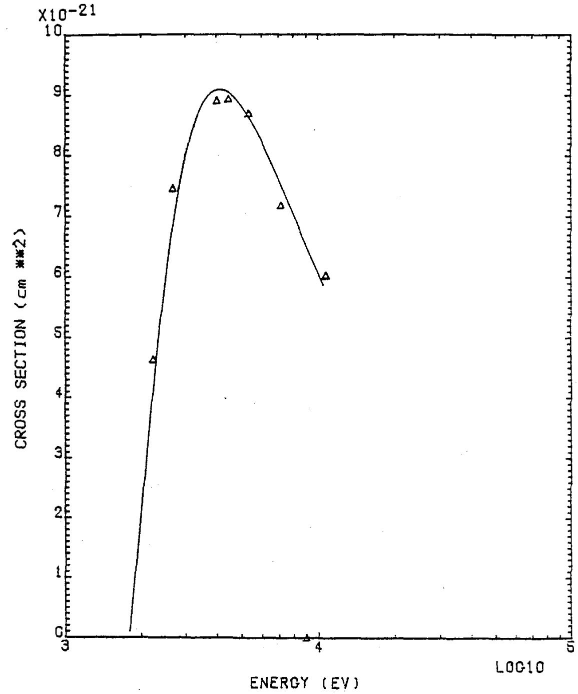

FIG. 47. Electron impact ionization of Fe XXII (Fe XXII→Fe XXIII): Δ Younger, DWBX (Ref. 29); — recommended.

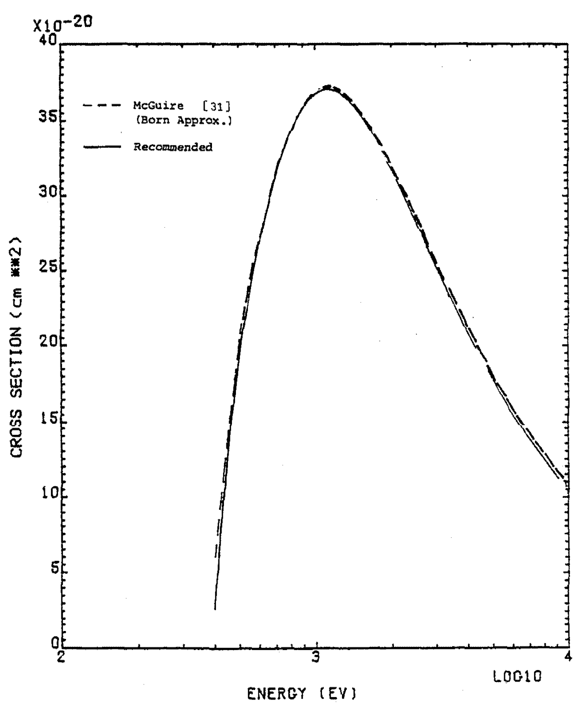

FIG. 46. Electron impact ionization of Al IX (Al IX→Al X).

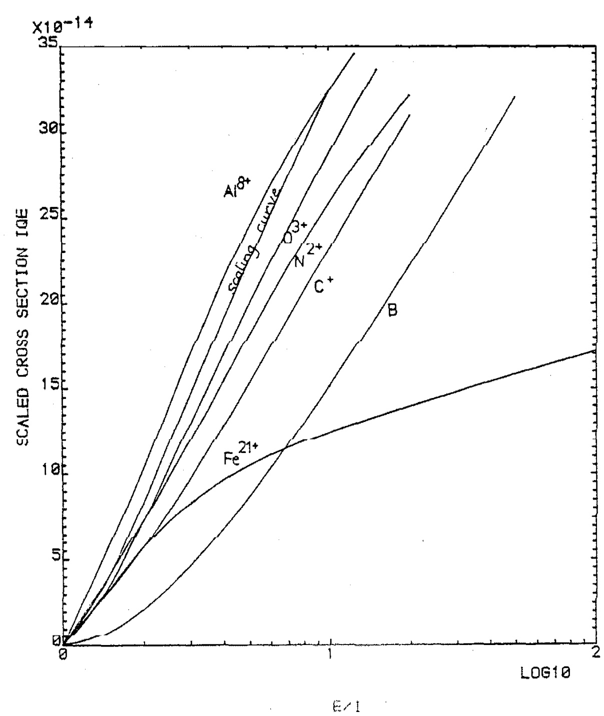

FIG. 48. Scaled cross sections for B-like ions.

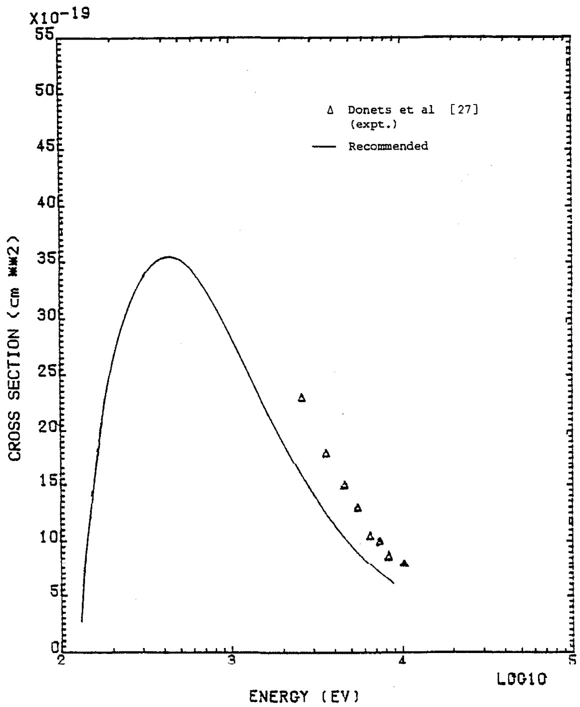

FIG. 49. Electron impact ionization of Ne V (Ne V→Ne VI).

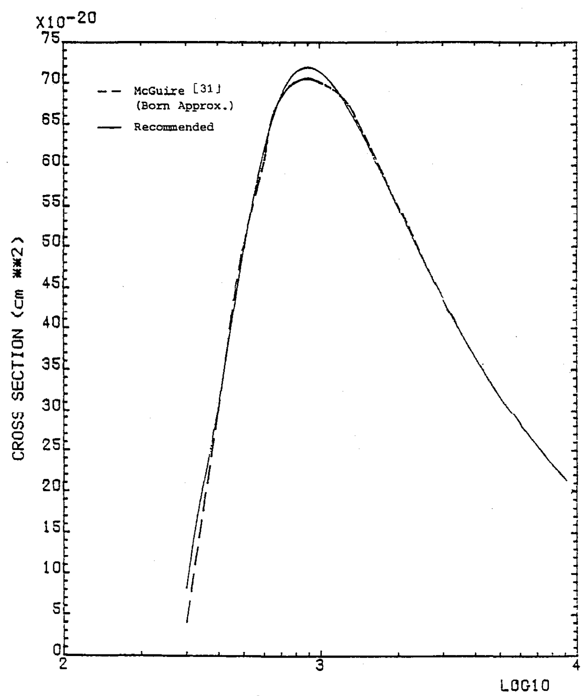

FIG. 50. Electron impact ionization of Al VIII (Al VIII→Al IX).

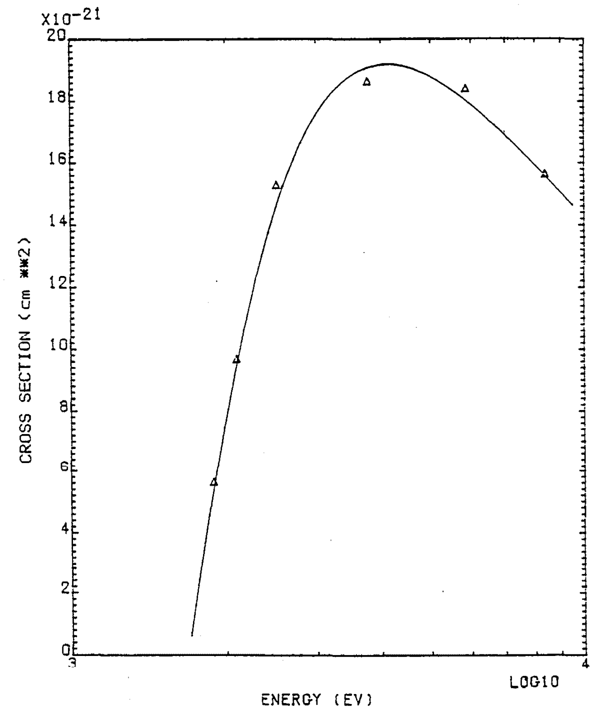

FIG. 51. Electron impact ionization of Fe XXI (Fe XXI→Fe XXII): Δ Younger, DWBX (Ref. 29); — recommended..

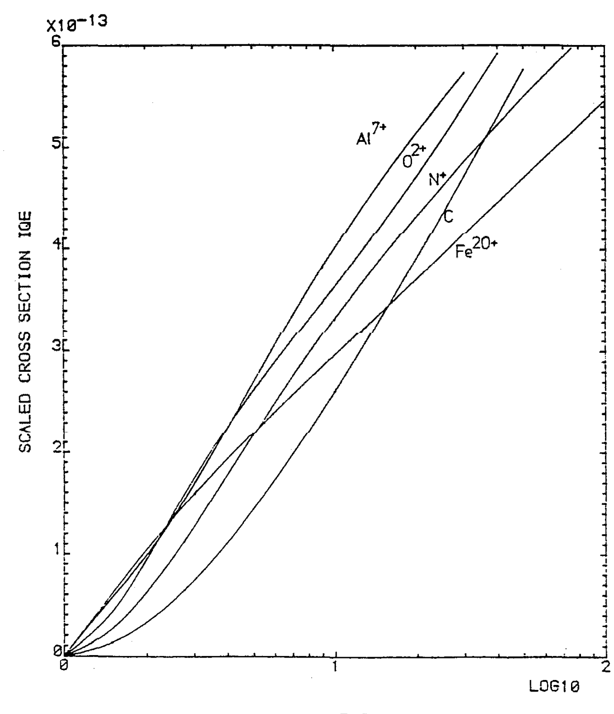

FIG. 52. Scaled cross sections for C-like ions.

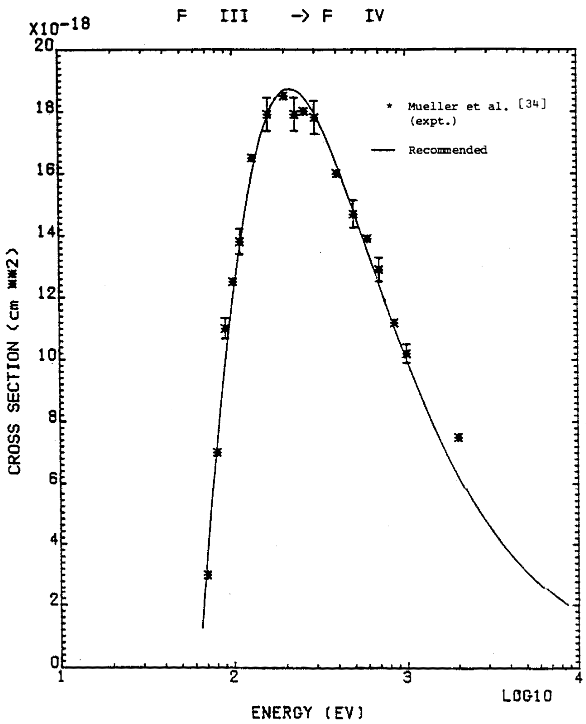

FIG. 53. Electron impact ionization of F III (F III→F IV).

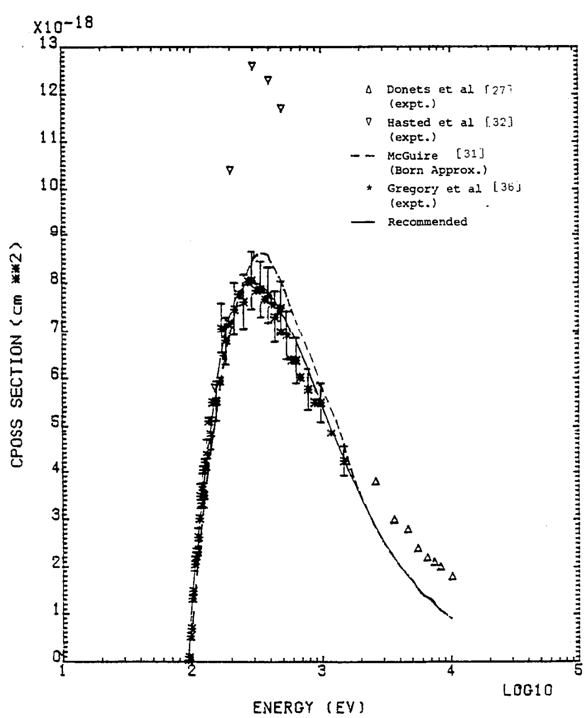

FIG. 54. Electron impact ionization of Ne IV (Ne IV→Ne V).

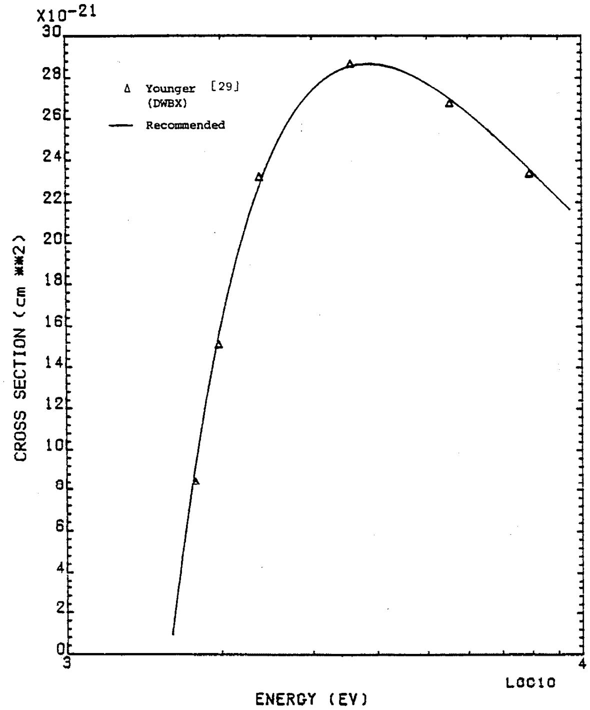

FIG. 55. Electron impact ionization of Fe XX (Fe XX→Fe XXI).

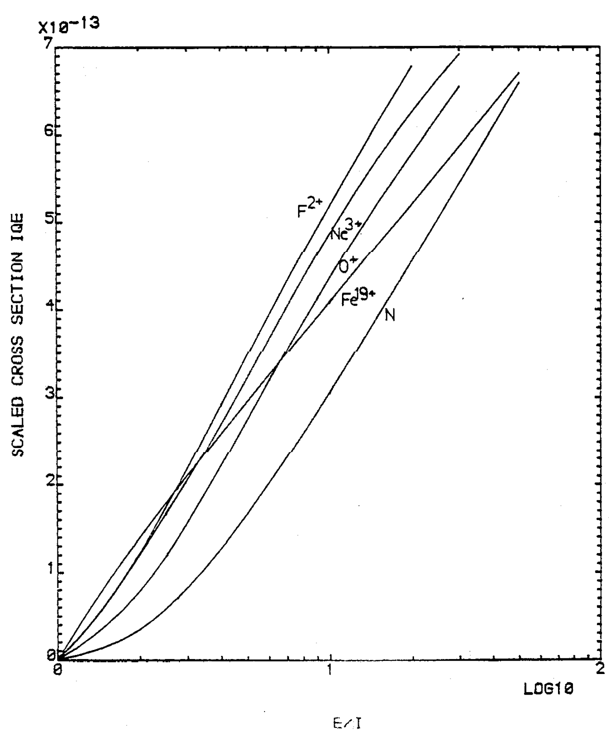

FIG. 56. Scaled cross sections for N-like ions.

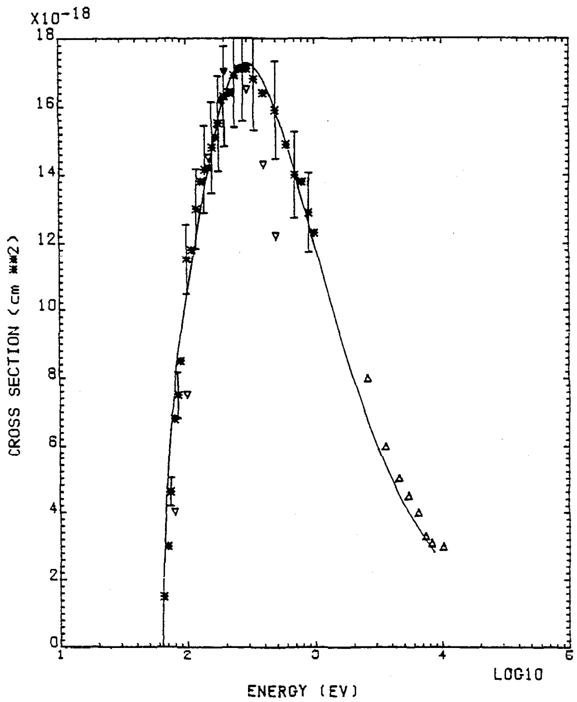

FIG. 57. Electron impact ionization of Ne III (Ne III → Ne IV): * Danjo *et al.*, expt. (Ref. 37); △ Donets *et al.*, expt. (Ref. 27); ▽ Hasted *et al.*, expt. (Ref. 35).

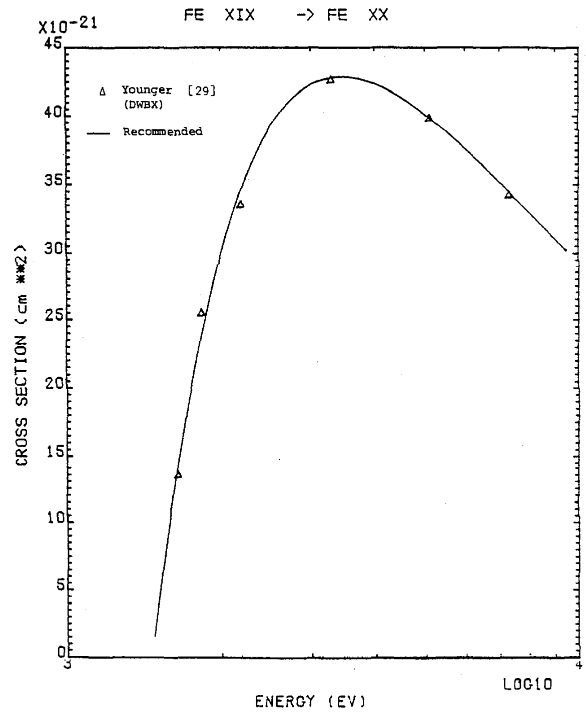

FIG. 59. Electron impact ionization of Fe XIX (Fe XIX → Fe XX).

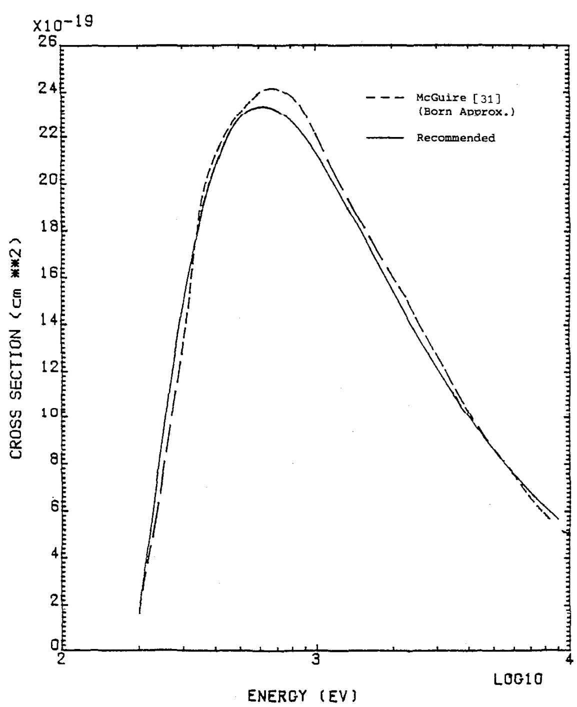

FIG. 58. Electron impact ionization of Al VI (Al VI → Al VII).

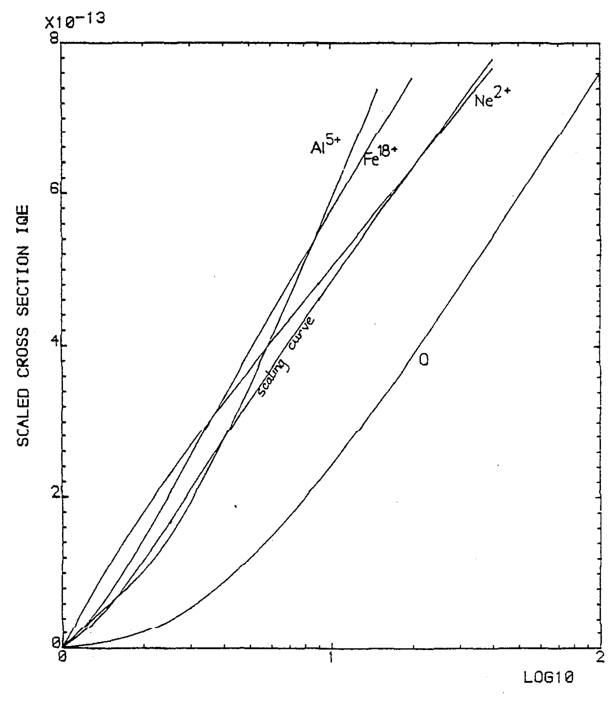

FIG. 60. Scaled cross sections for O-like ions.

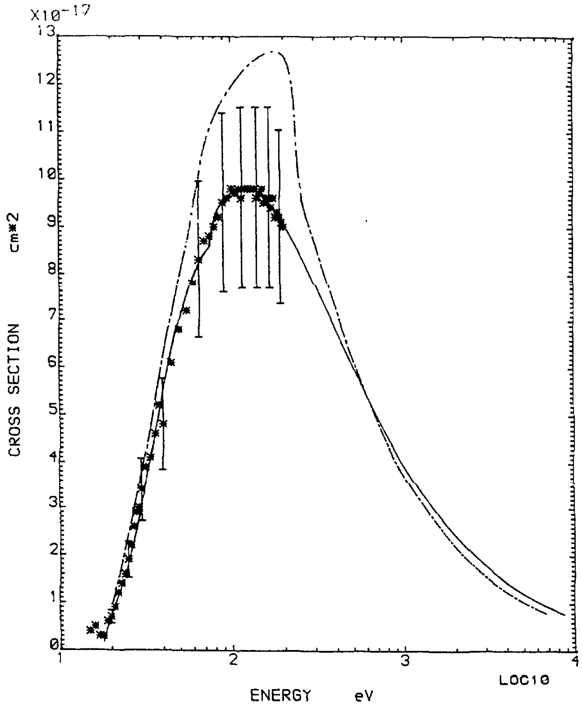

FIG. 61. Electron impact ionization of F I (F I→F II): * Hayes *et al.* (Ref. 38); - - - McGuire (Ref. 39); — recommended.

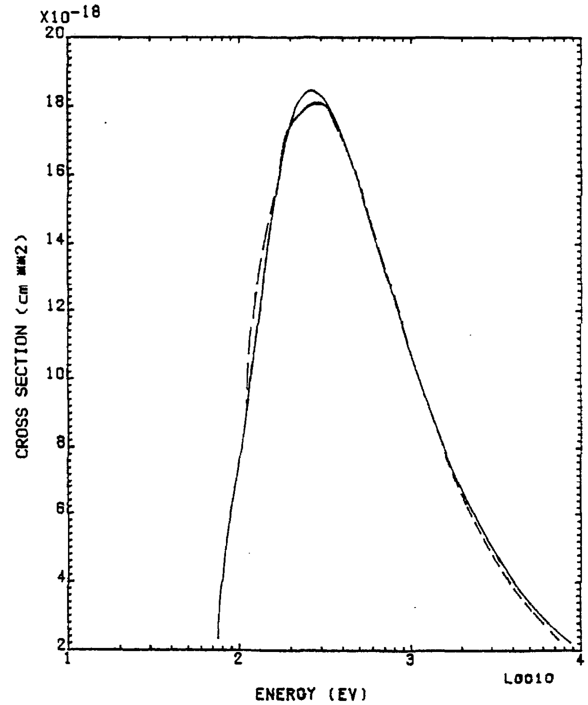

FIG. 63. Electron impact ionization of Na III (Na III→Na IV): - - - Moores (Coulomb–Born approx.); — recommended.

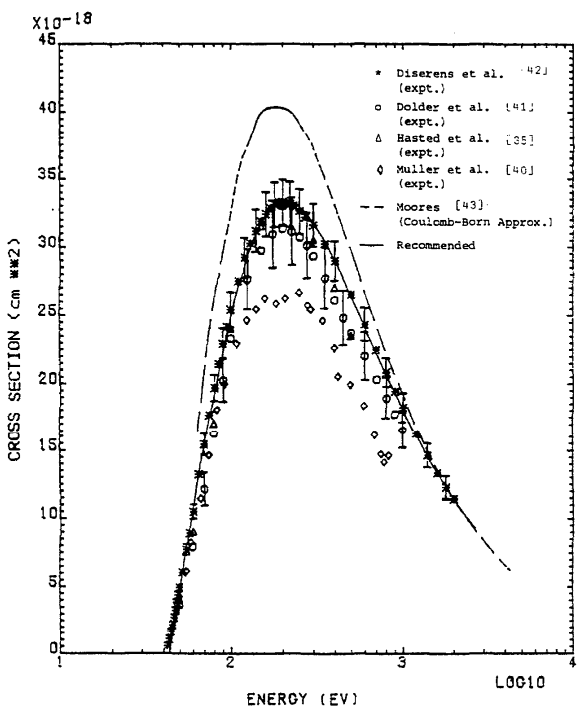

FIG. 62. Electron impact ionization of Ne II (Ne II→Ne III).

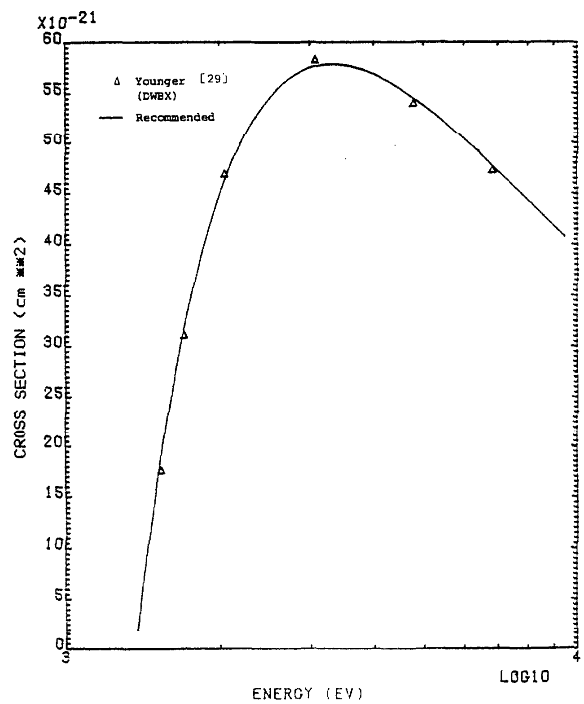

FIG. 64. Electron impact ionization of Fe XVIII (Fe XVIII→Fe XIX).

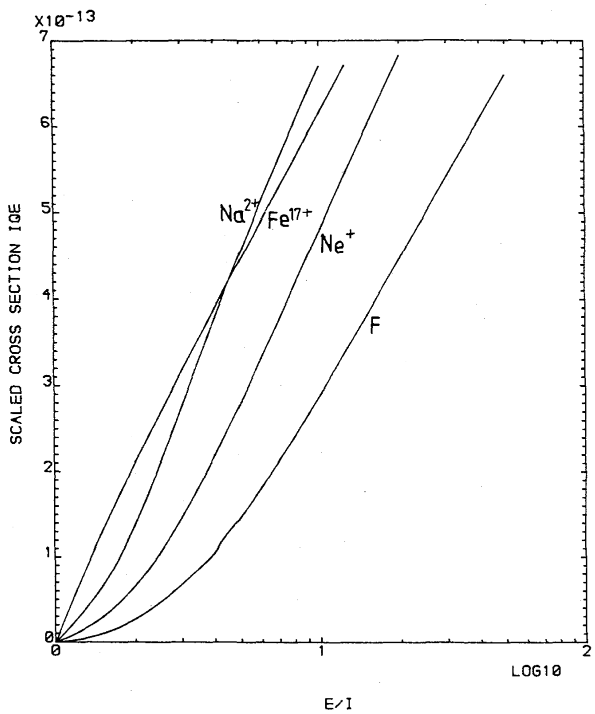

FIG. 65. Scaled cross sections for F-like ions.

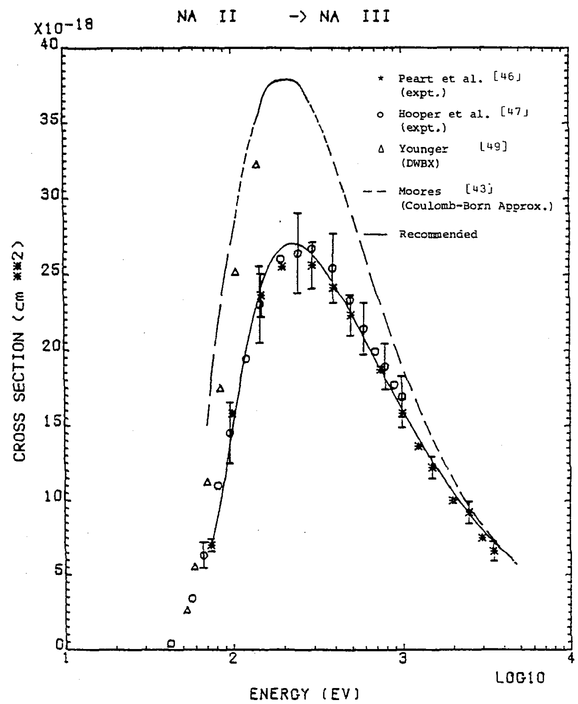

FIG. 67. Electron impact ionization of Na II (Na II → Na III).

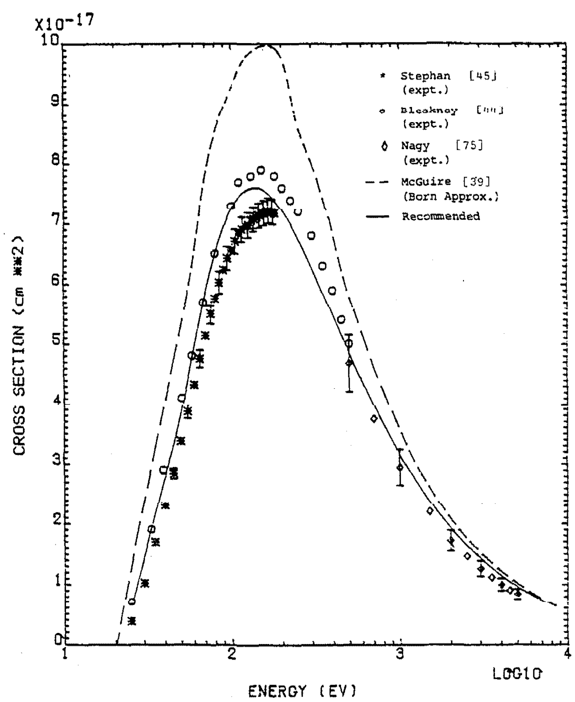

FIG. 66. Electron impact ionization of Ne I (Ne I → Ne II).

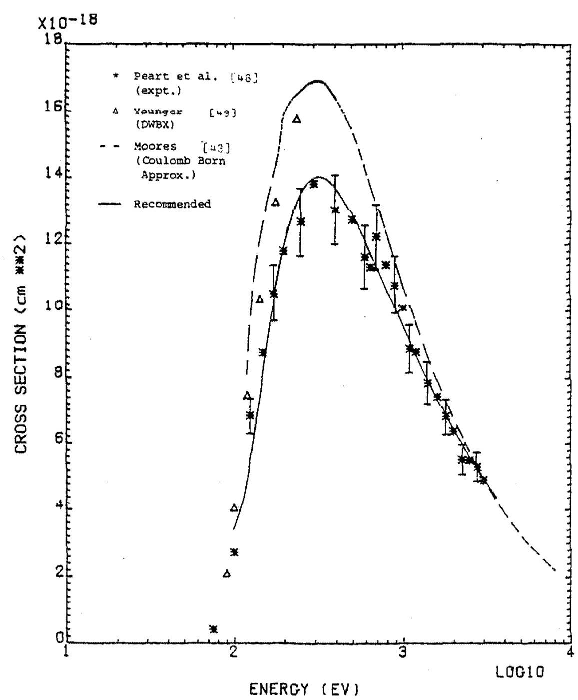

FIG. 68. Electron impact ionization of Mg III (Mg III → Mg IV).

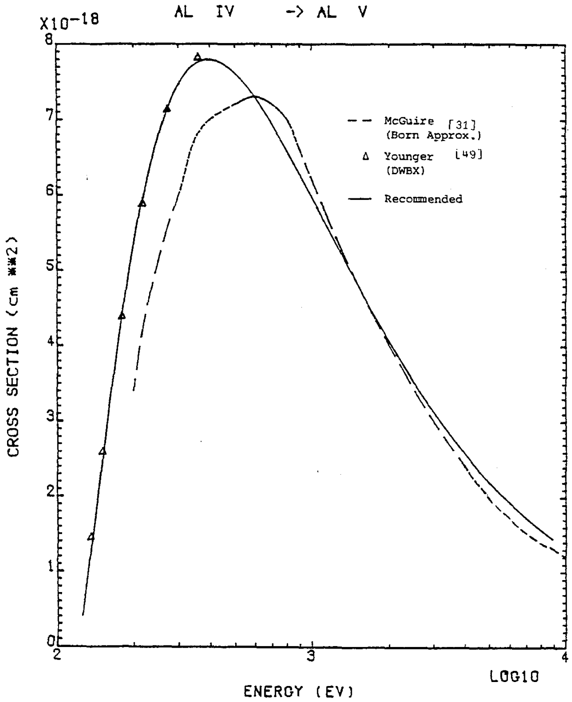

FIG. 69. Electron impact ionization of Al IV (AL IV→Al V).

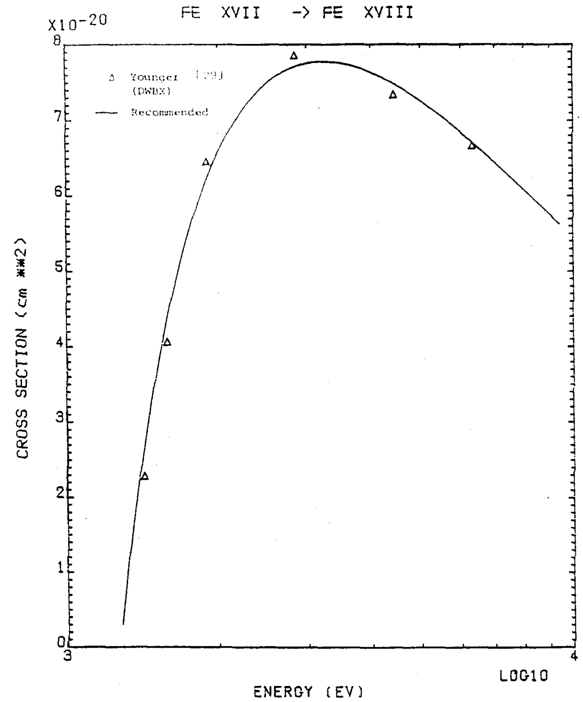

FIG. 71. Electron impact ionization of Fe XVII (Fe XVII→Fe XVIII).

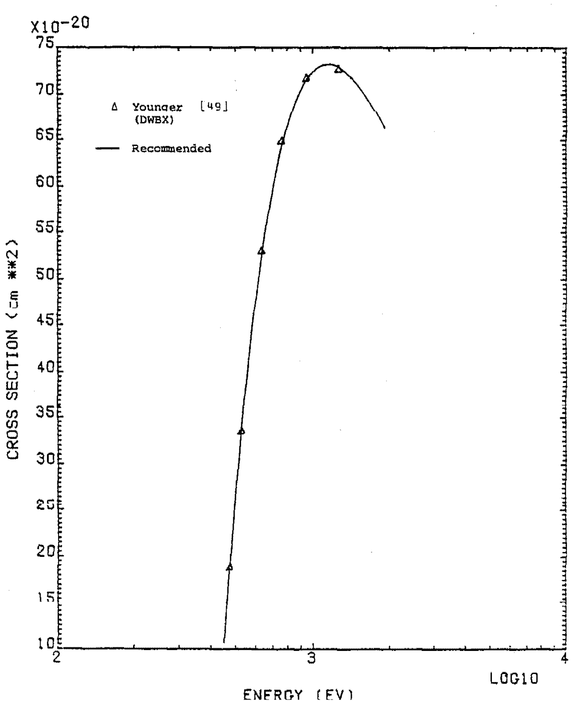

FIG. 70. Electron impact ionization of Ar IX (Ar IX→Ar X).

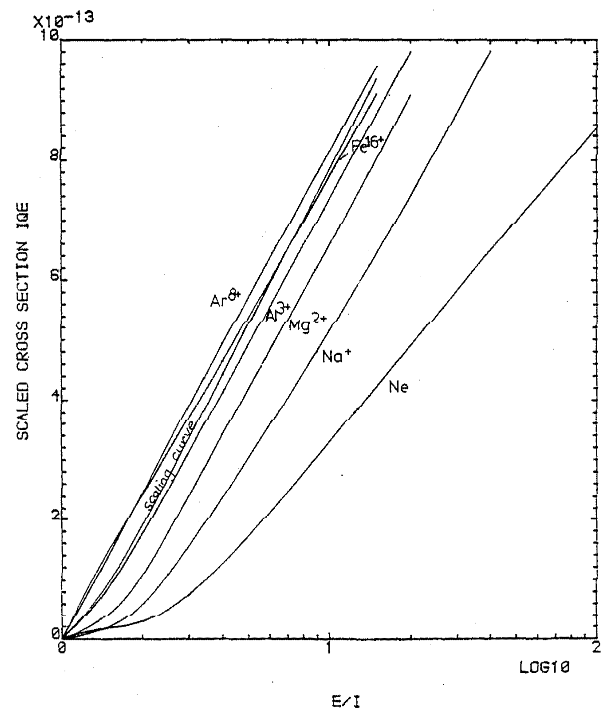

FIG. 72. Scaled cross sections for Ne-like ions.

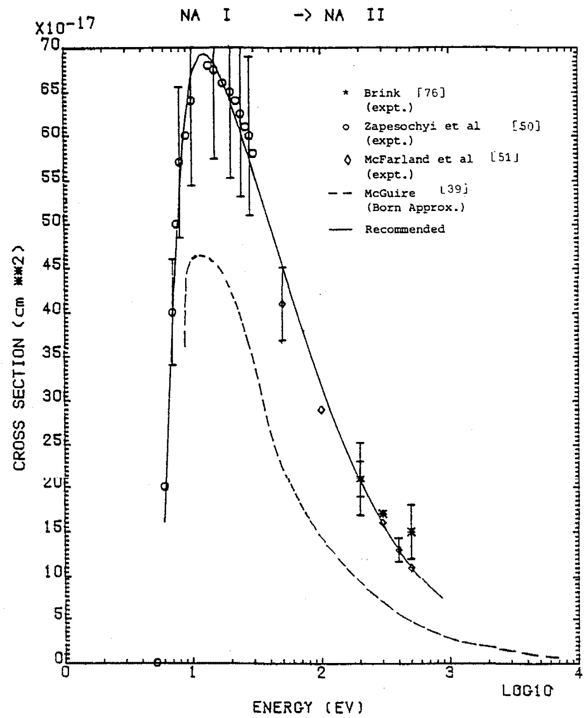

FIG. 73. Electron impact ionization of Na I (Na I→Na II).

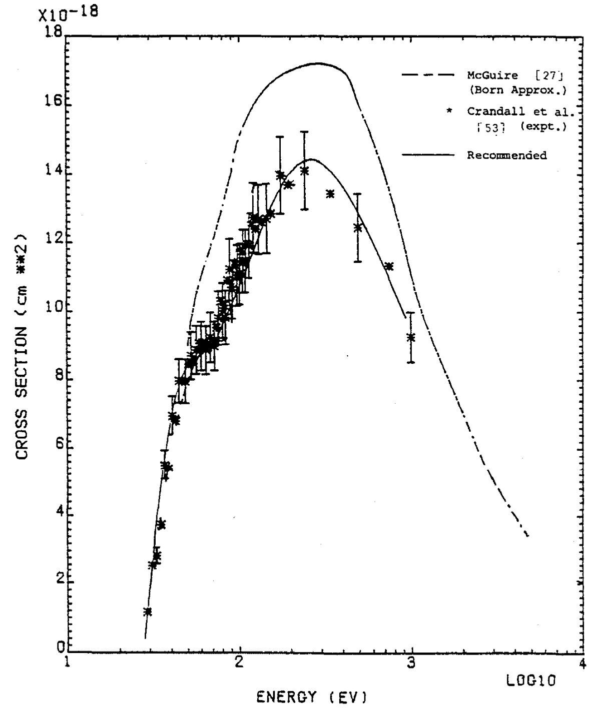

FIG. 75. Electron impact ionization of Al III (Al III→Al IV).

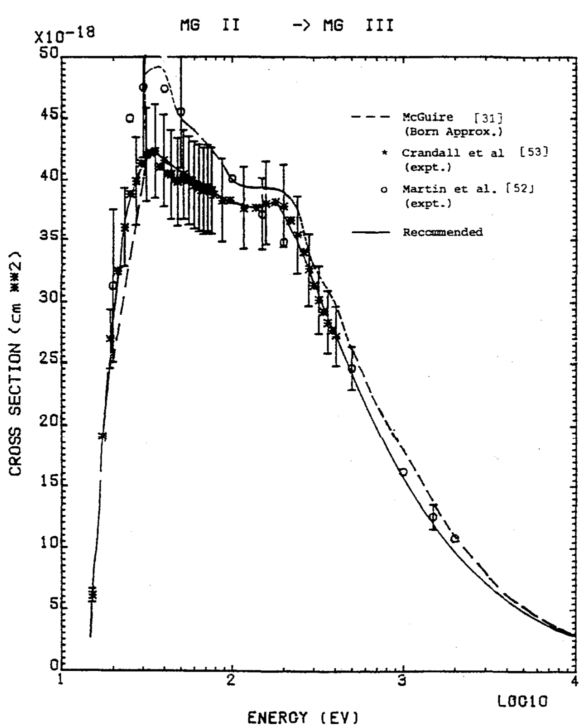

FIG. 74. Electron impact ionization of Mg II (Mg II→Mg III).

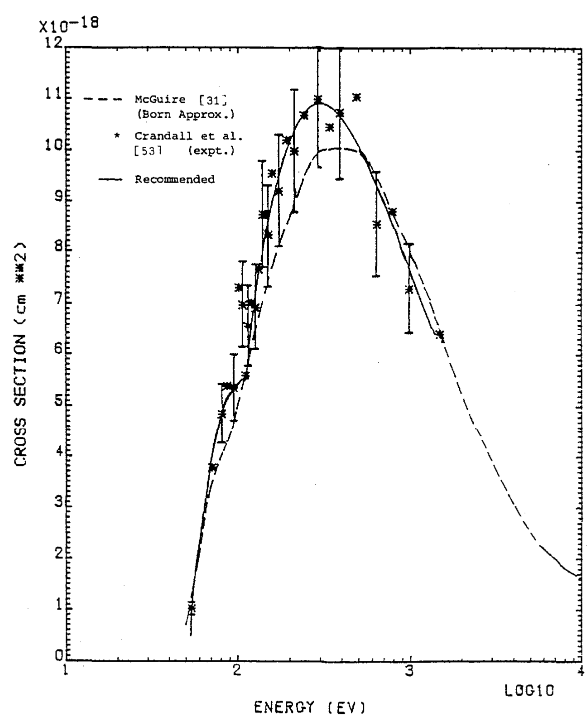

FIG. 76. Electron impact ionization of Si IV (Si IV→Si V).

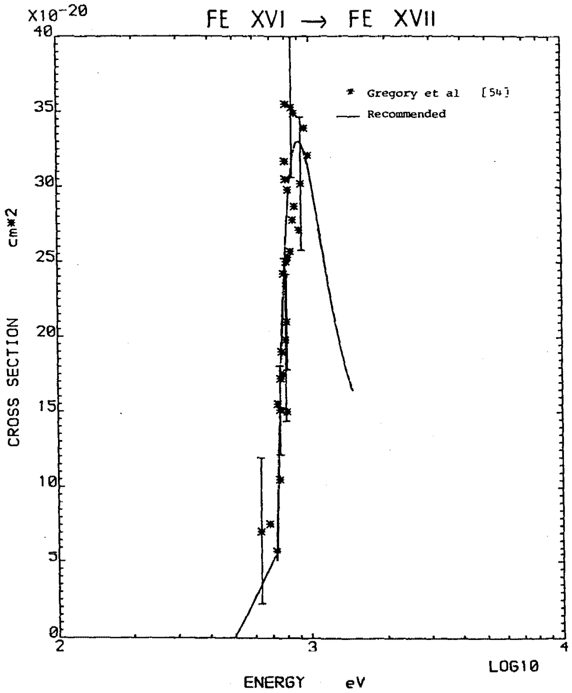

FIG. 77. Electron impact ionization of Fe XVI (Fe XVI→Fe XVII).

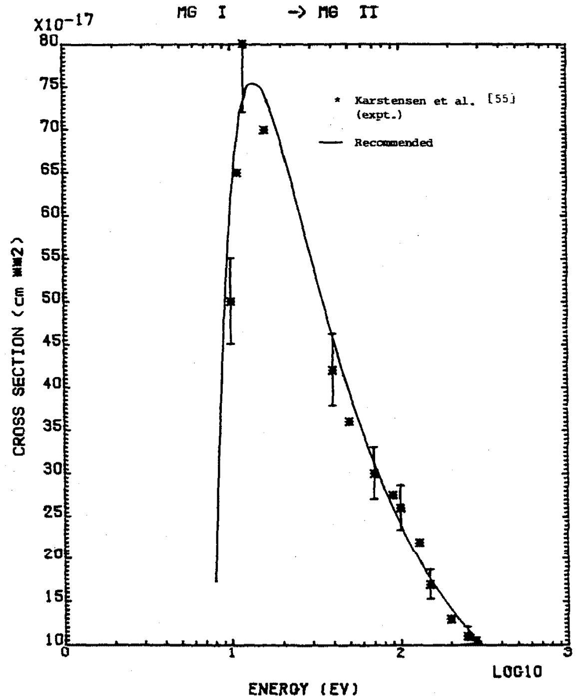

FIG. 79. Electron impact ionization of Mg I (Mg I→Mg II).

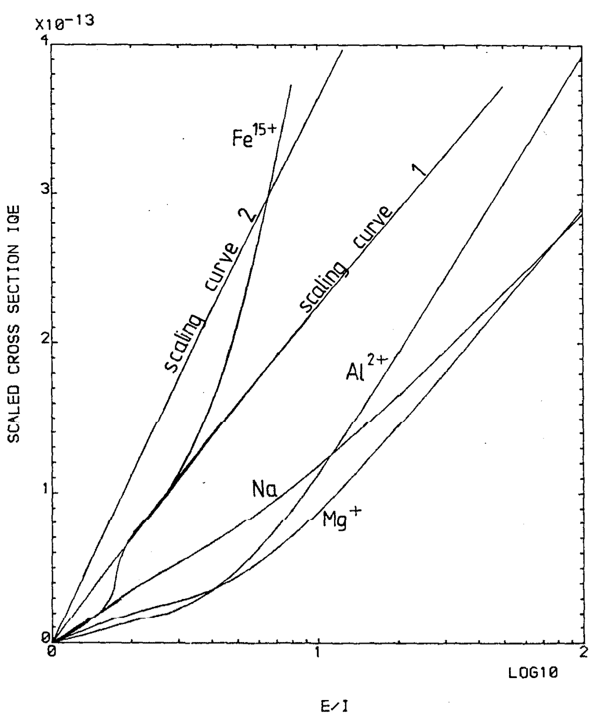

FIG. 78. Scaled cross sections for Na-like ions.

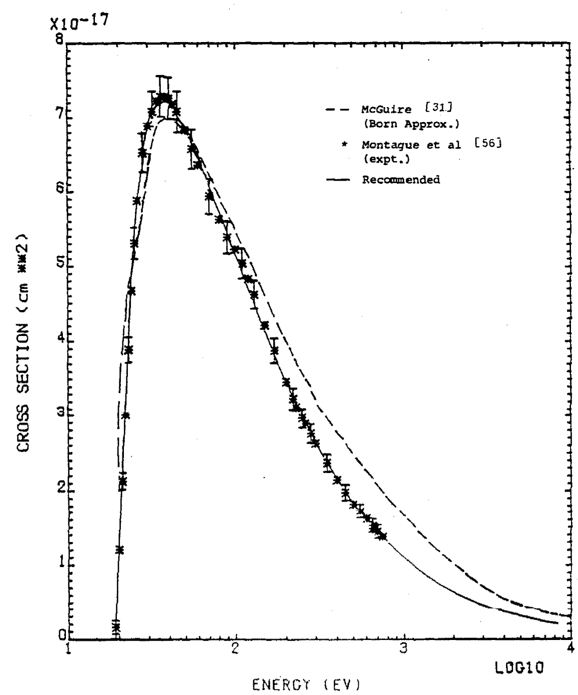

FIG. 80. Electron impact ionization of Al II (Al II→Al III).

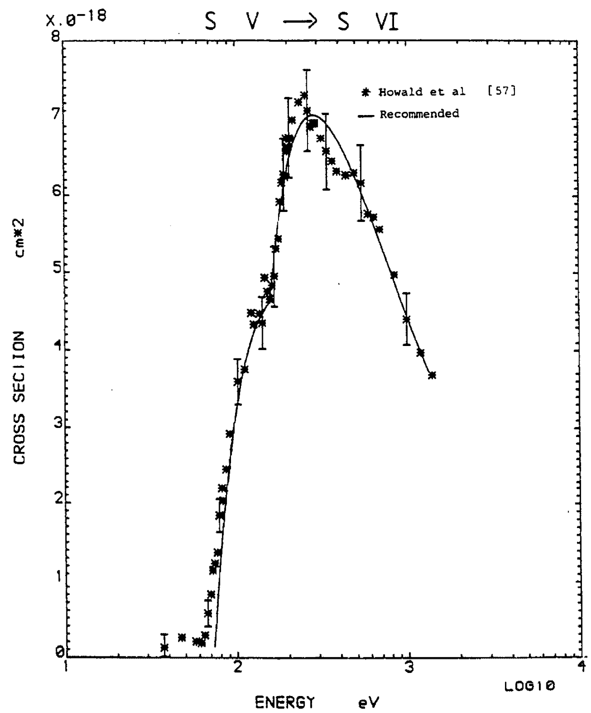

FIG. 81. Electron impact ionization of S V (S V→S VI).

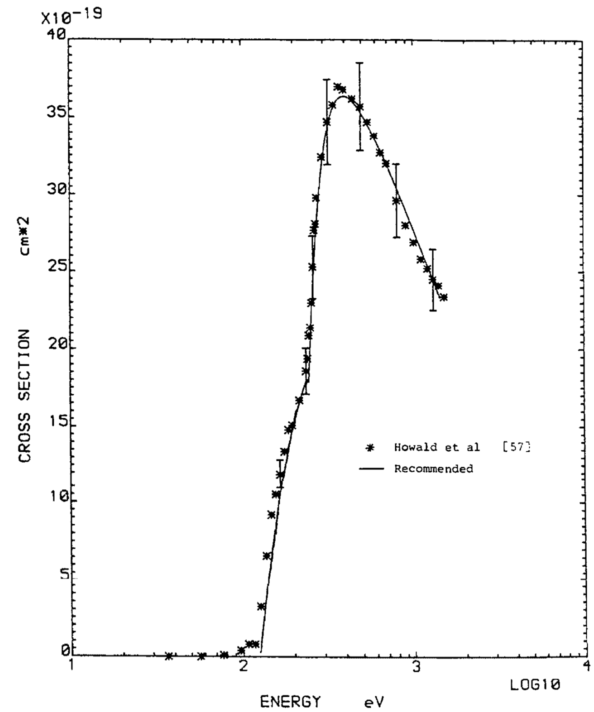

FIG. 83. Electron impact ionization of Ar VII (Ar VII→Ar VIII).

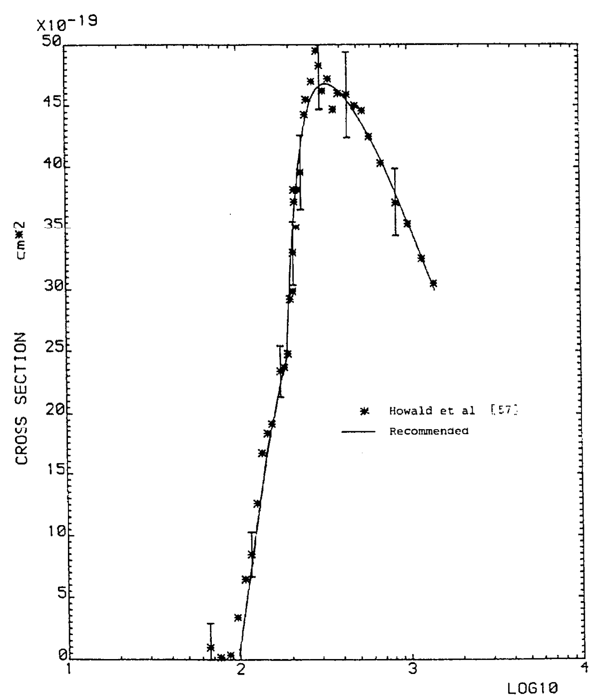

FIG. 82. Electron impact ionization of Cl VI (Cl VI→Cl VII).

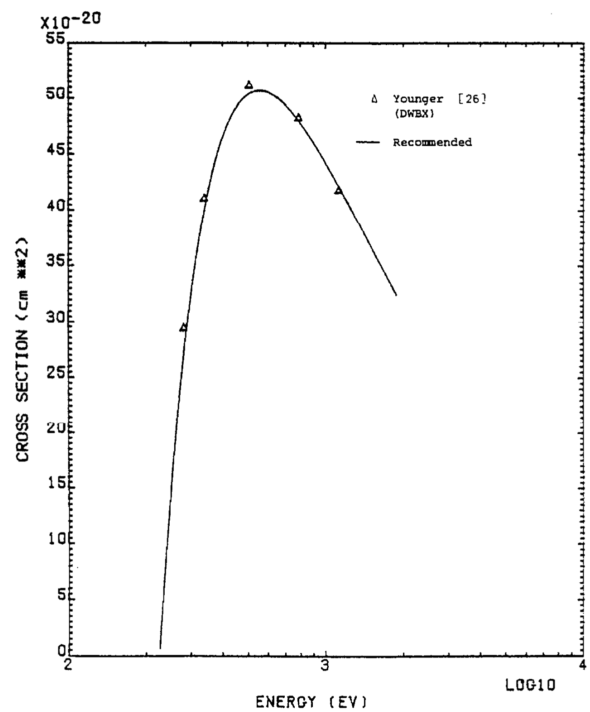

FIG. 84. Electron impact ionization of Sc X (Sc X→Sc XI).

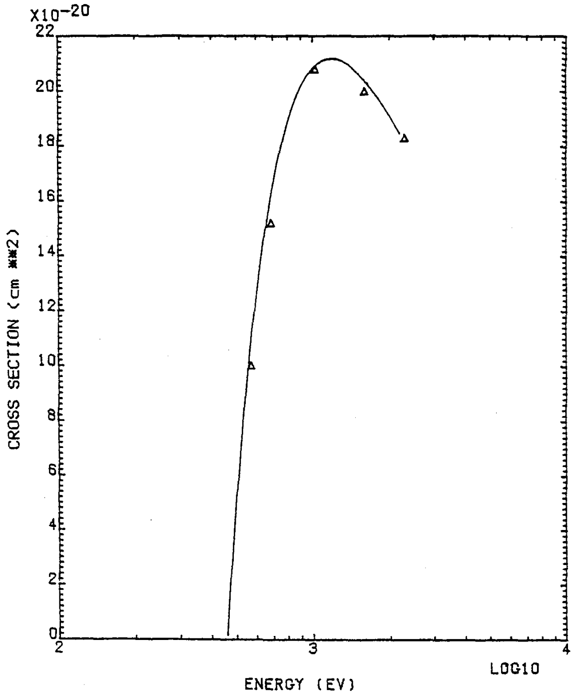

FIG. 85. Electron impact ionization of Fe XV (Fe XV→Fe XVI): △ Younger, DWBX (Ref. 26); — recommended.

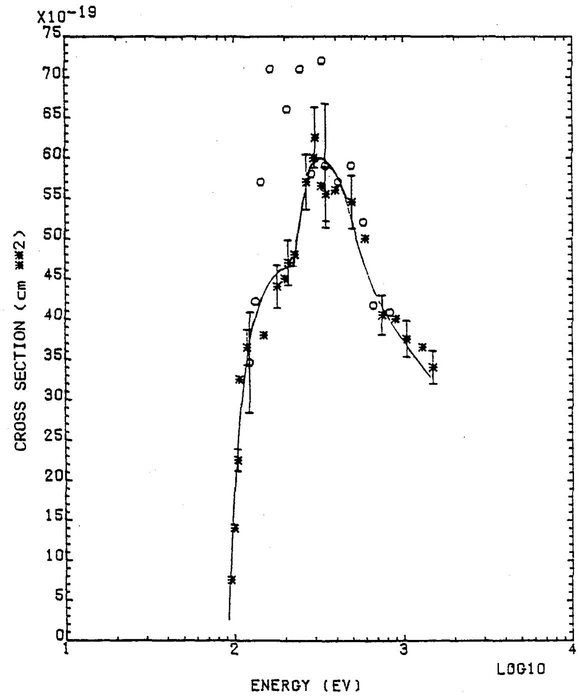

FIG. 87. Electron impact ionization of Ar VI (Ar VI→Ar VII): * Gregory *et al.*, expt (Ref. 58); ○ Muller *et al.*, expt. (Ref. 40); — recommended.

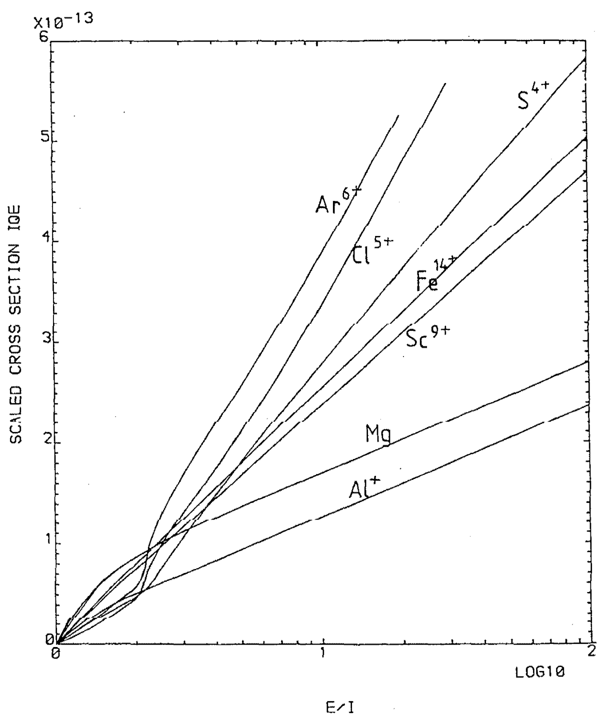

FIG. 86. Scaled cross sections for Mg-like ions.

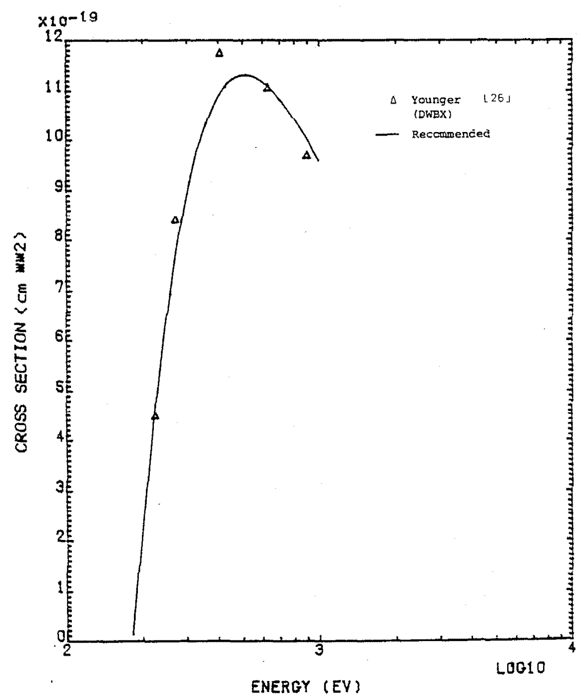

FIG. 88. Electron impact ionization of Sc IX (Sc IX→Sc X).

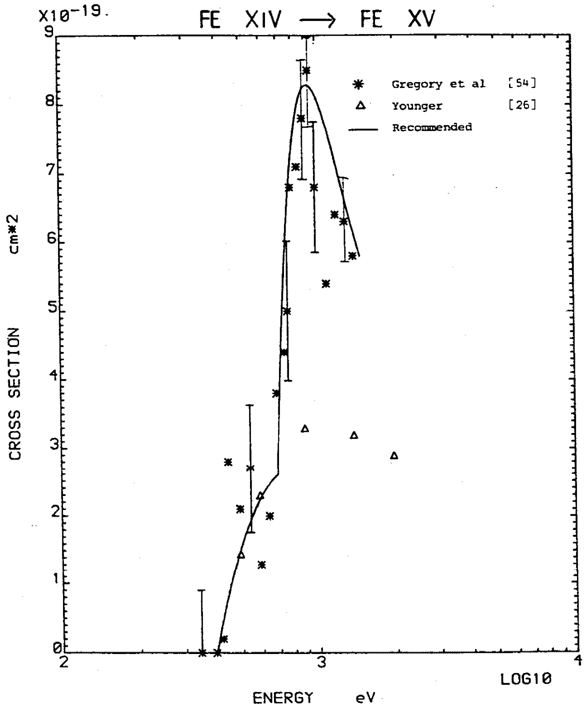

FIG. 89. Electron impact ionization of Fe XIV (Fe XIV→Fe XV).

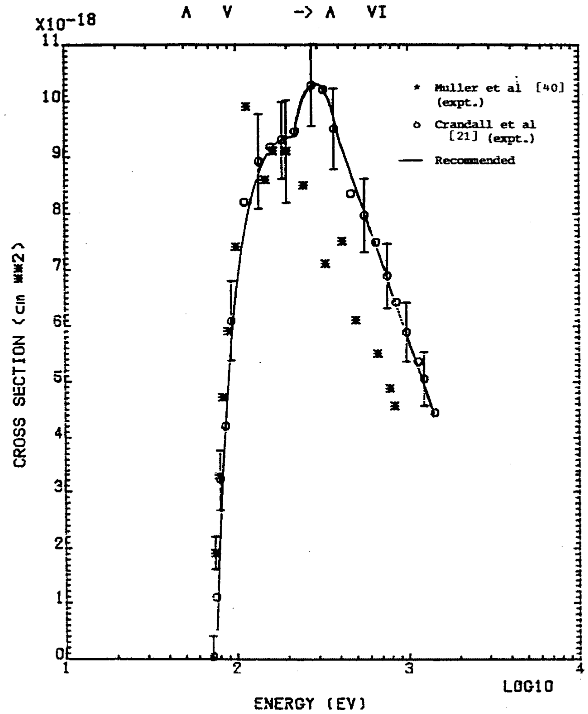

FIG. 91. Electron impact ionization of Ar V (Ar V→Ar VI).

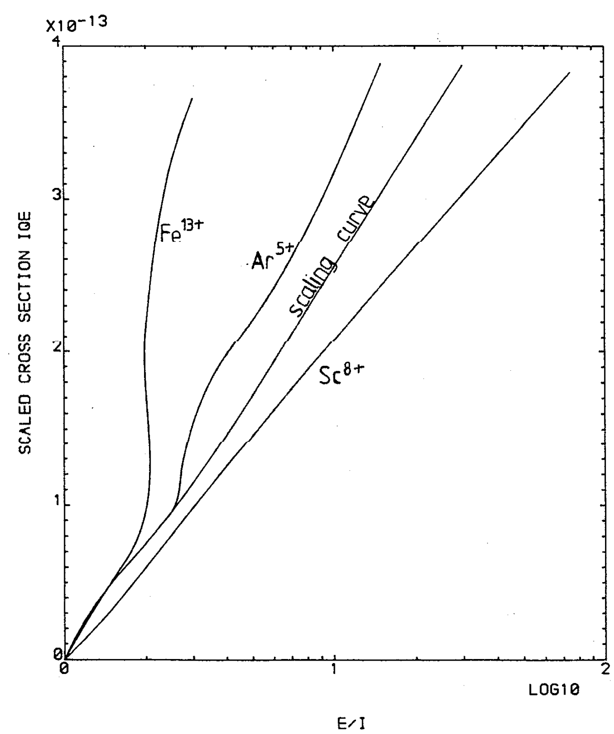

FIG. 90. Scaled cross sections for Al-like ions.

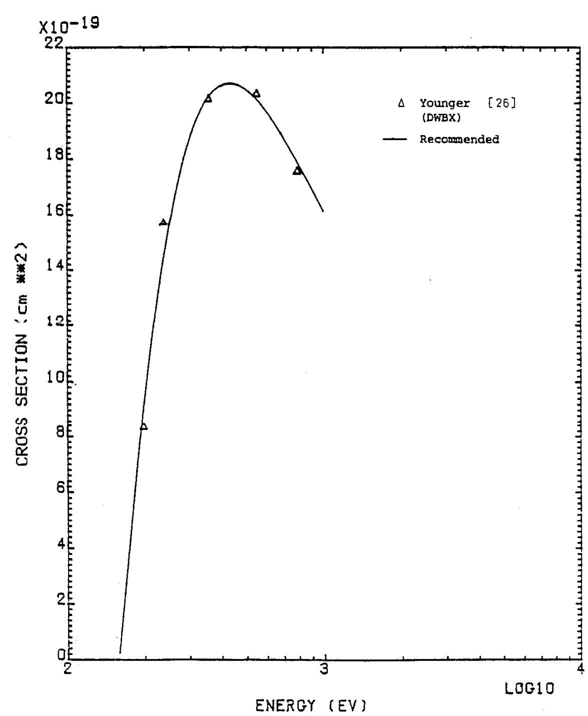

FIG. 92. Electron impact ionization of Sc VIII (Sc VIII→Sc IX).

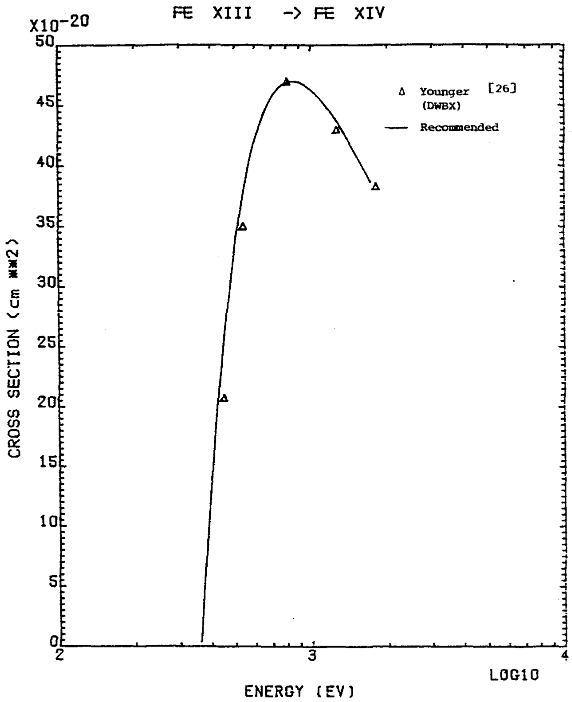

FIG. 93. Electron impact ionization of Fe XIII (Fe XIII → Fe XIV).

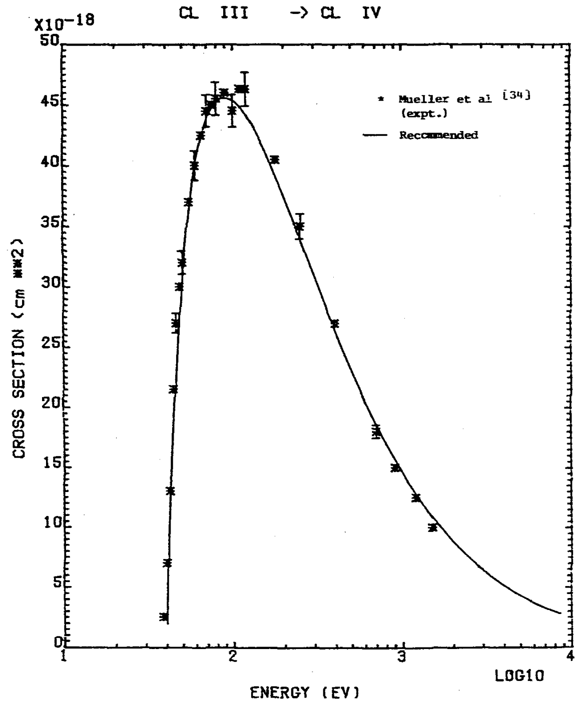

FIG. 95. Electron impact ionization of Cl III (Cl III → Cl IV).

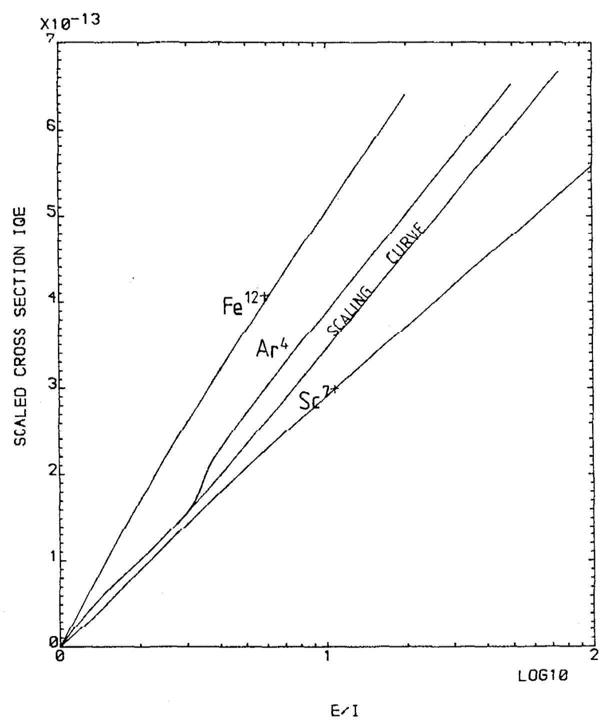

FIG. 94. Scaled cross sections for Si-like ions.

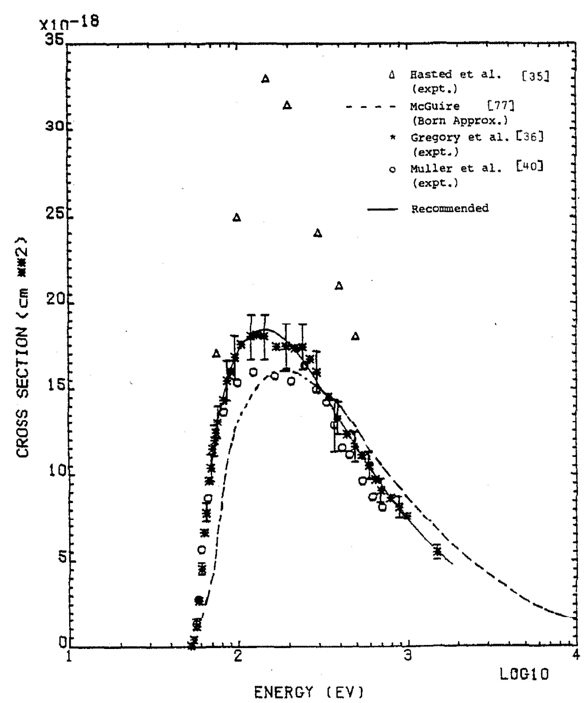

FIG. 96. Electron impact ionization of Ar IV (Ar IV → Ar V).

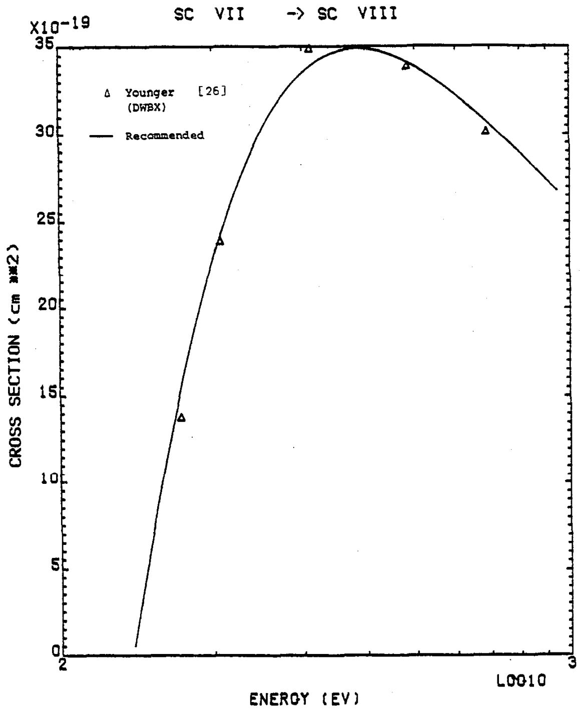

FIG. 97. Electron impact ionization of Sc VII (Sc VII→Sc VIII).

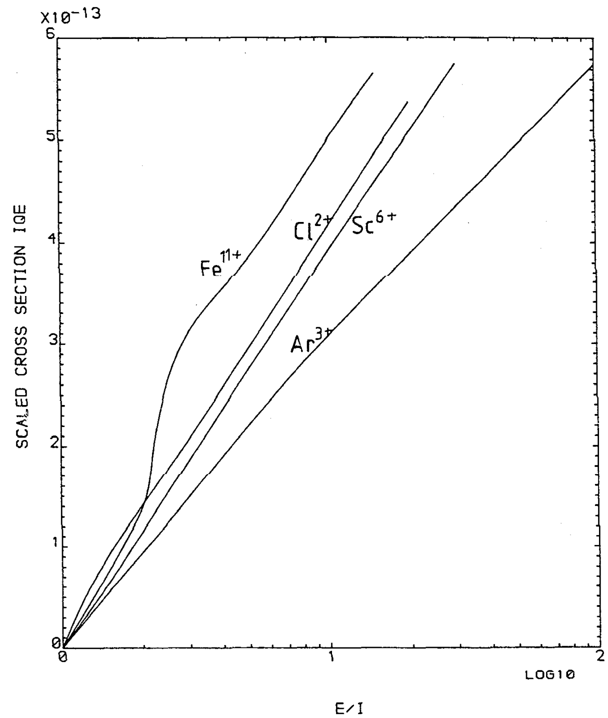

FIG. 99. Scaled cross sections for P-like ions.

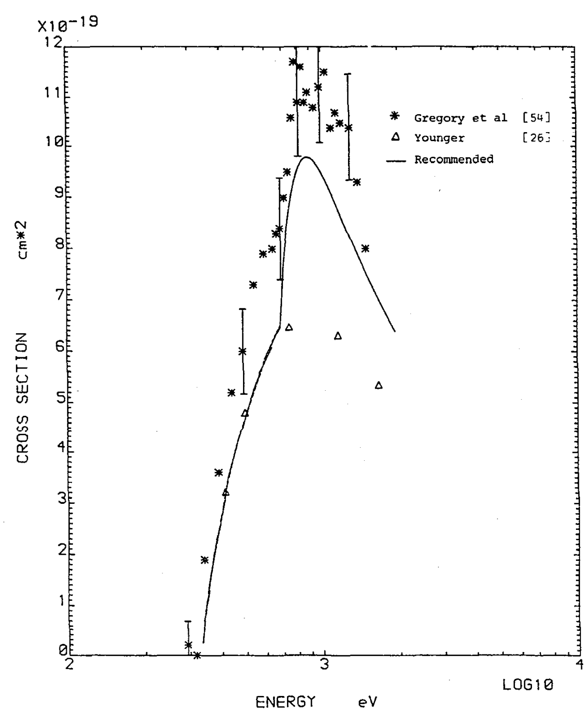

FIG. 98. Electron impact ionization of Fe XII (Fe XII→Fe XIII).

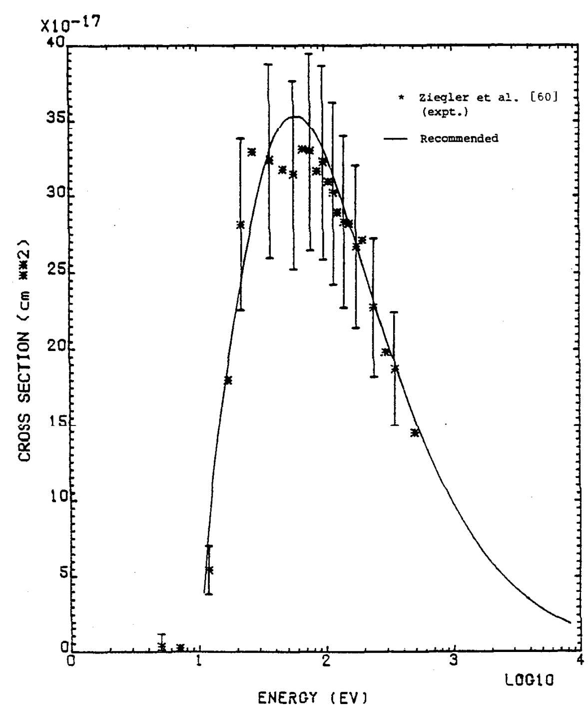

FIG. 100. Electron impact ionization of S I (S I→S II).

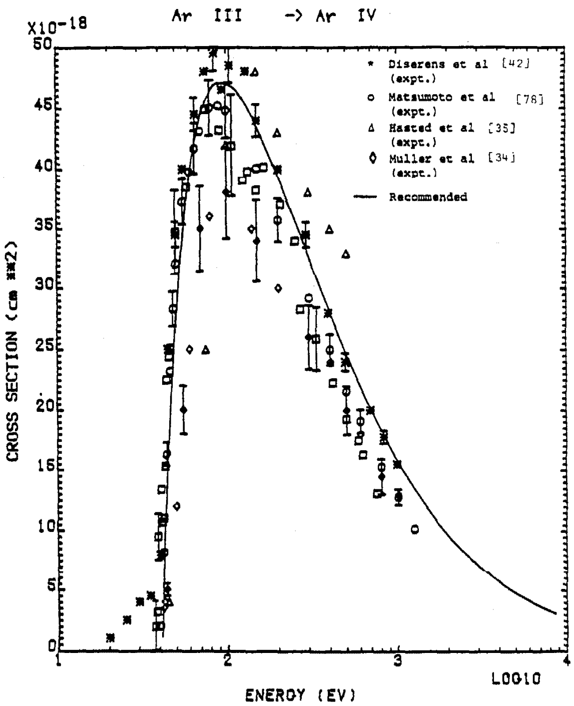

FIG. 101. Electron impact ionization of Ar III (Ar III→Ar IV).

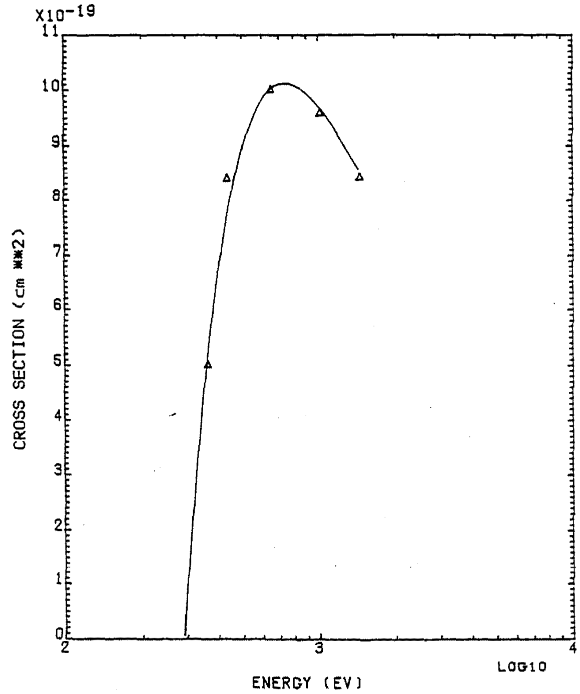

FIG. 103. Electron impact ionization of Fe XI (Fe XI→Fe XII): Δ Younger, DWBX (Ref. 26); — recommended.

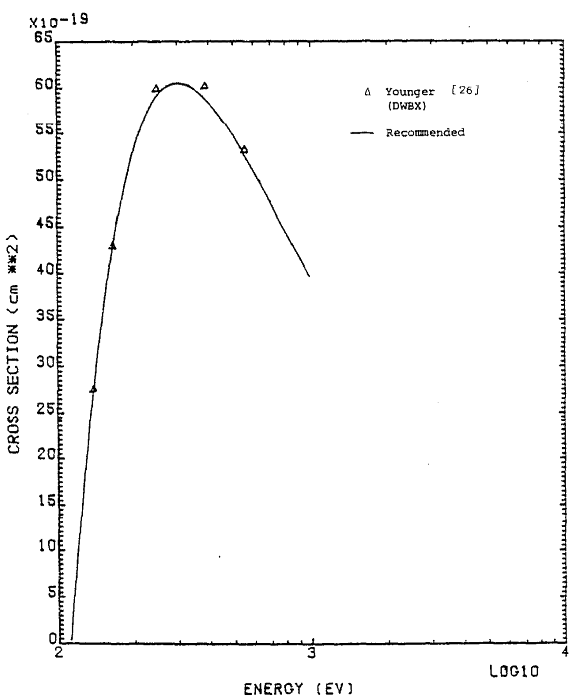

FIG. 102. Electron impact ionization of Sc VI (Sc VI→Sc VII).

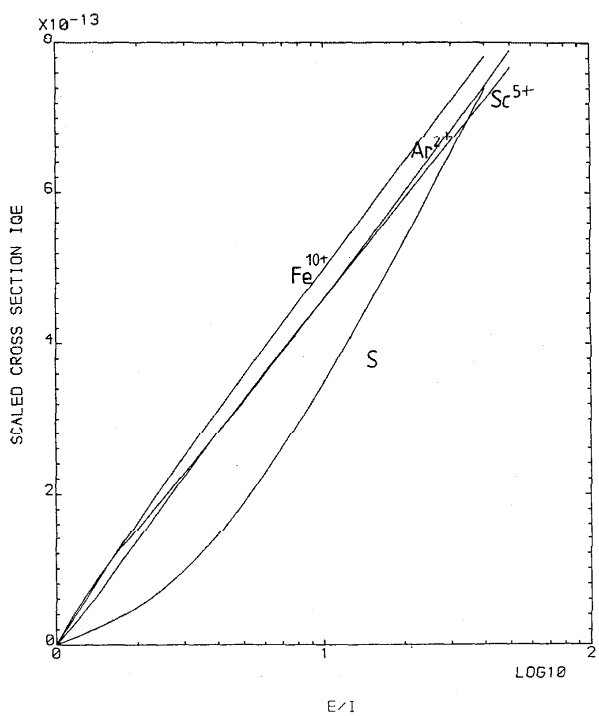

FIG. 104. Scaled cross sections for S-like ions.

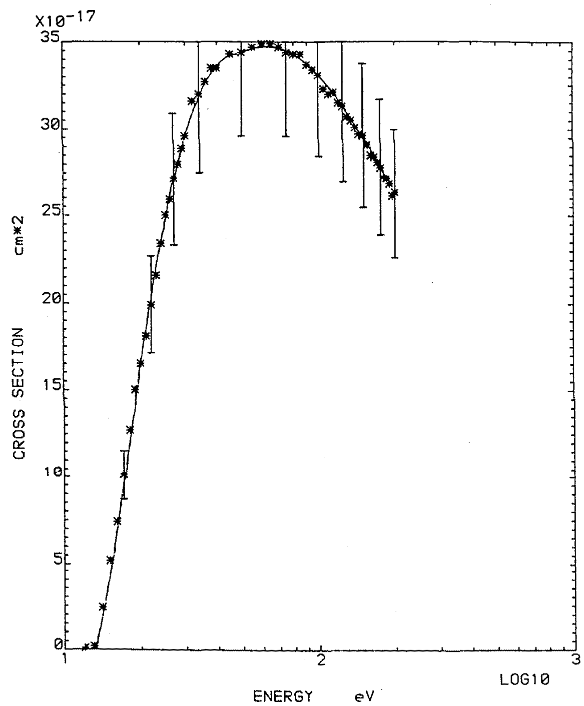

FIG. 105. Electron impact ionization of Cl I (Cl I→Cl II): * Hayes *et al.* (Ref. 38); — recommended.

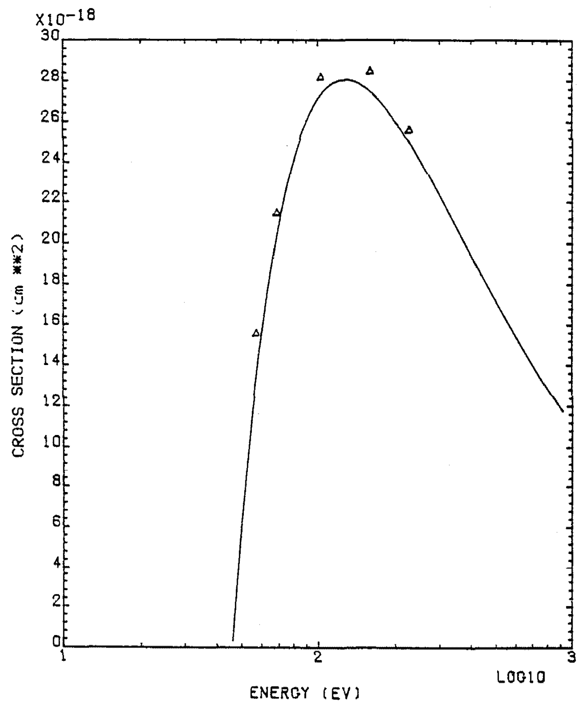

FIG. 107. Electron impact ionization of K III (K III→K IV): △ Younger, DWBX (Ref. 29); — recommended.

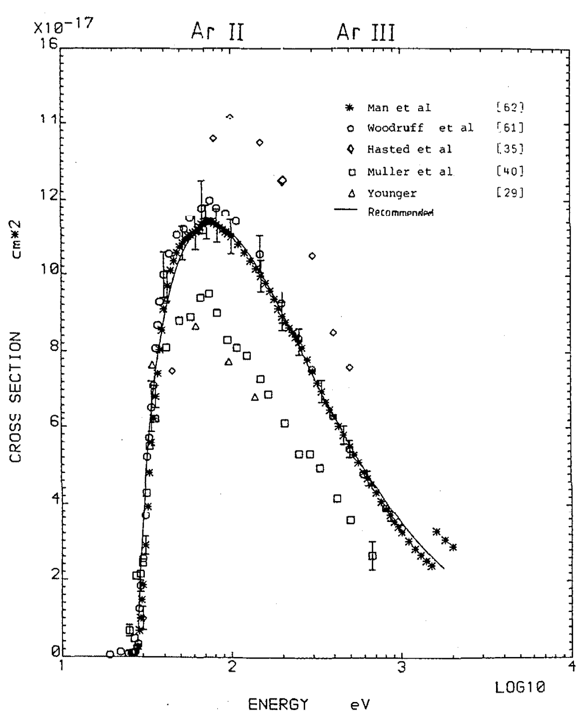

FIG. 106. Electron impact ionization of Ar II (Ar II→Ar III).

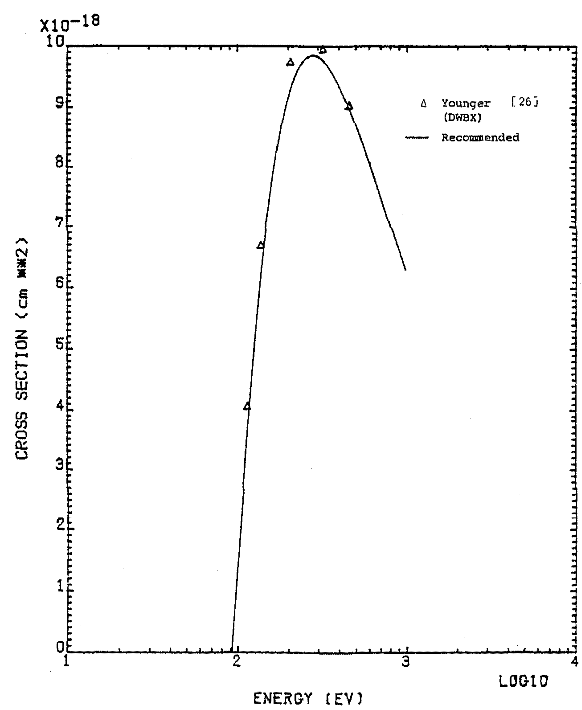

FIG. 108. Electron impact ionization of Sc V (Sc V→Sc VI).

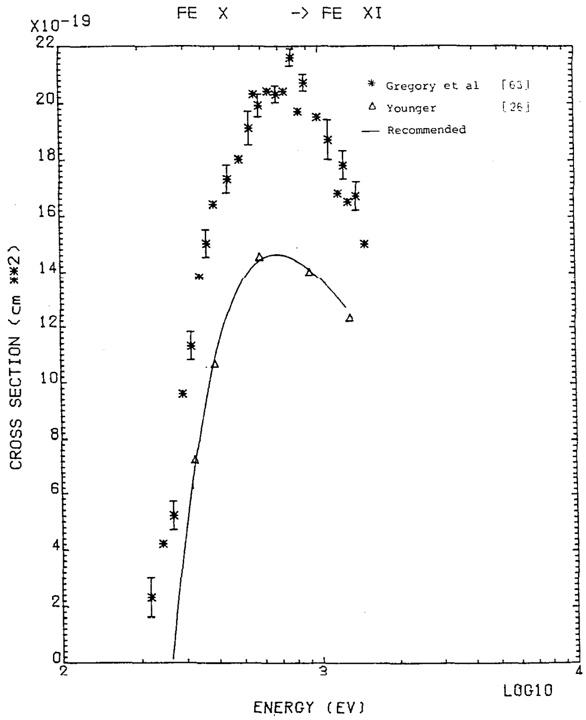

FIG. 109. Electron impact ionization of Fe X (Fe X→Fe XI).

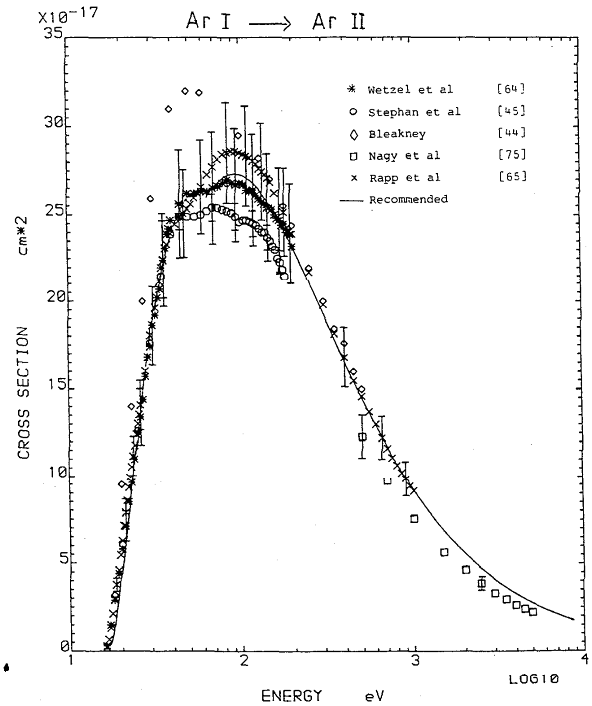

FIG. 111. Electron impact ionization of Ar I (Ar I→Ar II).

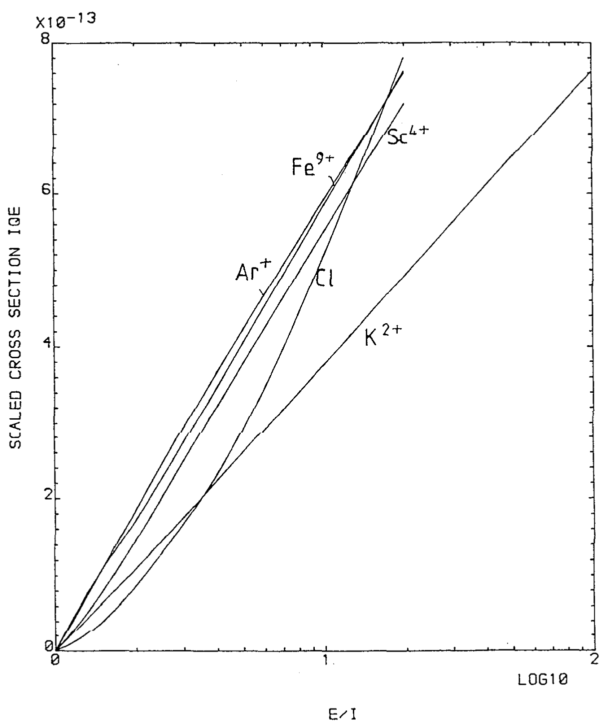

FIG. 110. Scaled cross sections for Cl-like ions.

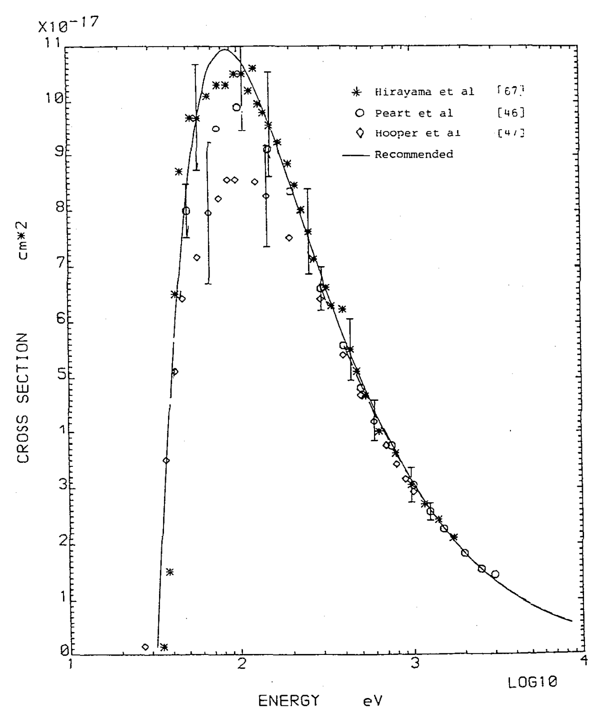

FIG. 112. Electron impact ionization of K II (K II→K III).

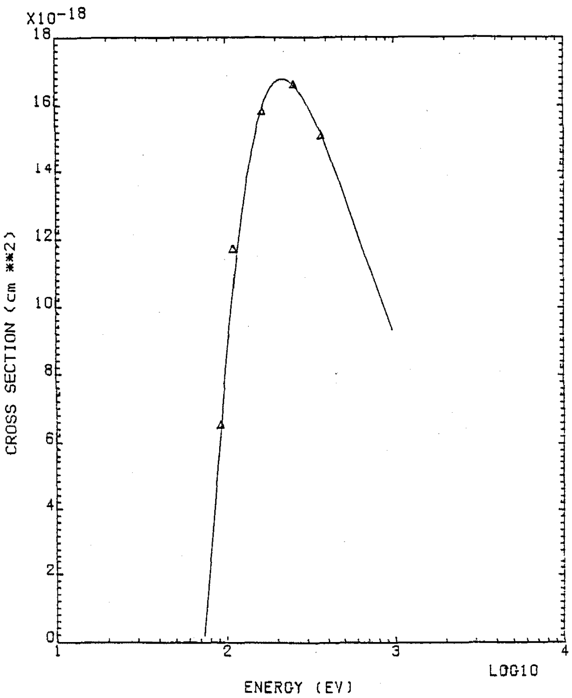

FIG. 113. Electron impact ionization of Sc IV (Sc IV→Sc V): △ Younger, DWBX (Ref. 26); — recommended.

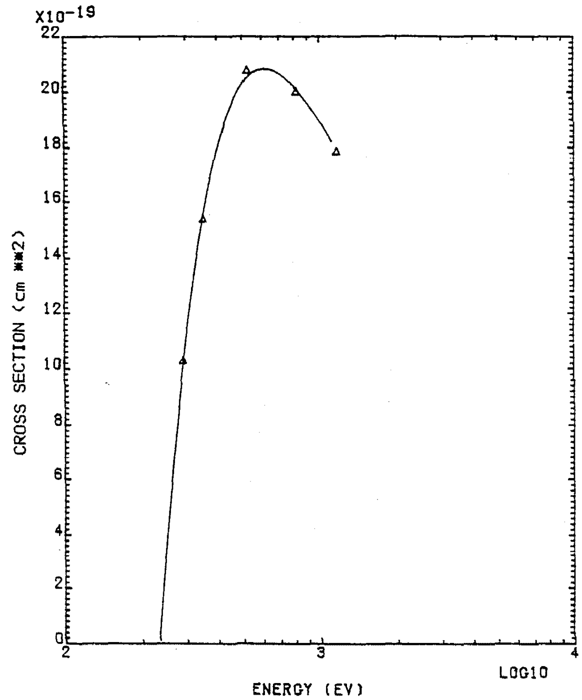

FIG. 115. Electron impact ionization of Fe IX (Fe IX→Fe X): △ Younger, DWBX (Ref. 26); recommended.

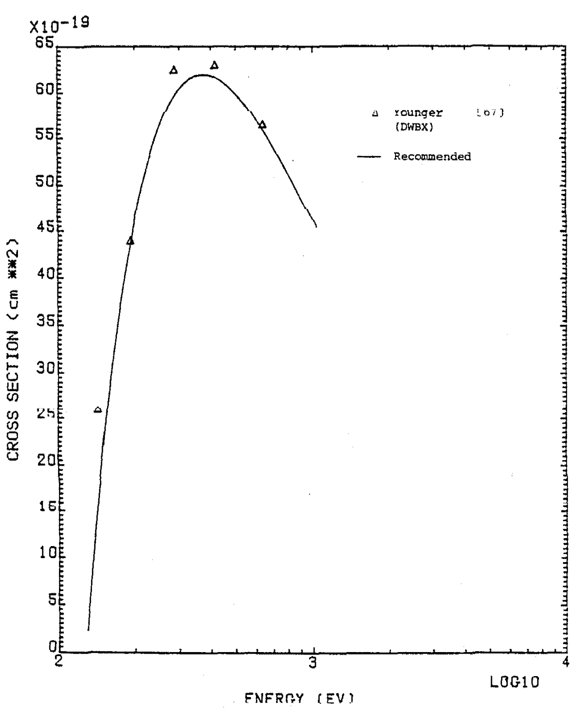

FIG. 114. Electron impact ionization of V VI (V VI→V VII).

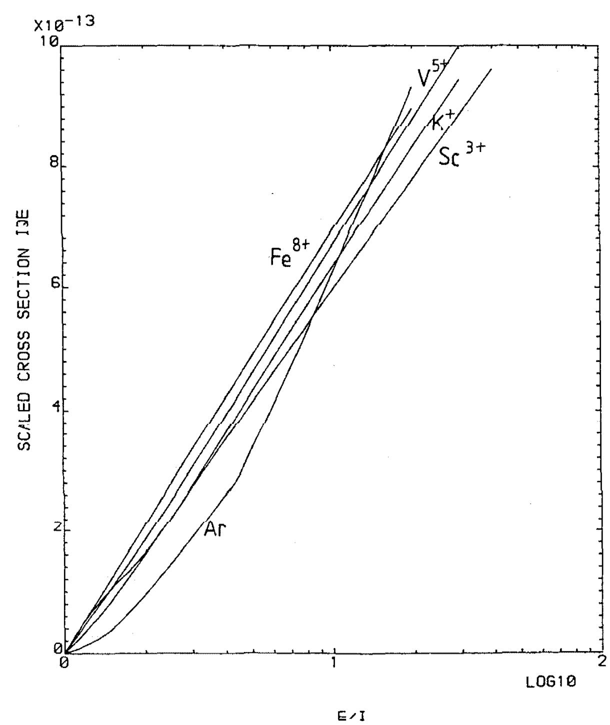

FIG. 116. Scaled cross sections for Ar-like ions.

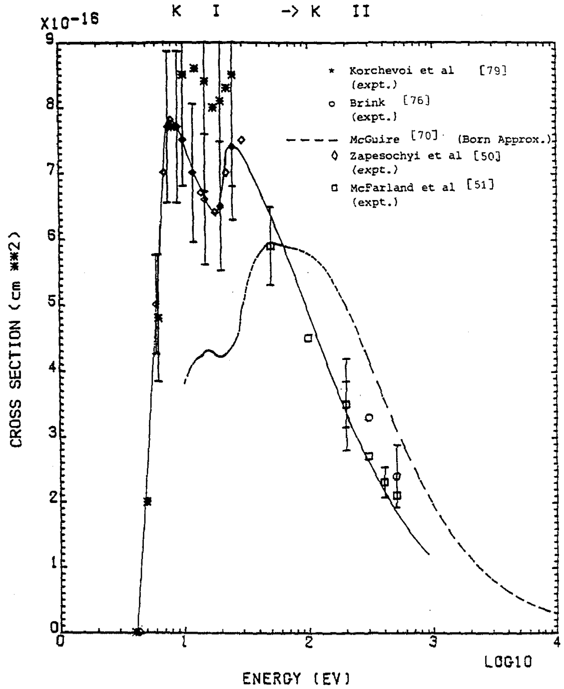

FIG. 117. Electron impact ionization of K I (K I→K II).

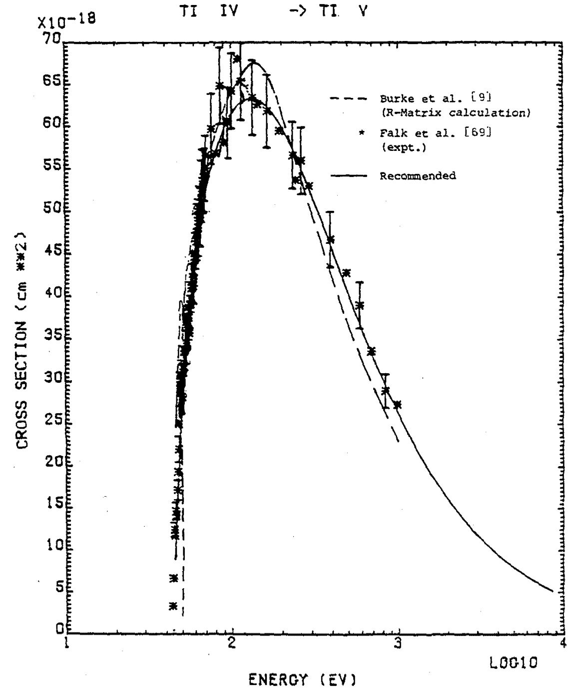

FIG. 119. Electron impact ionization of Ti IV (Ti IV→Ti V).

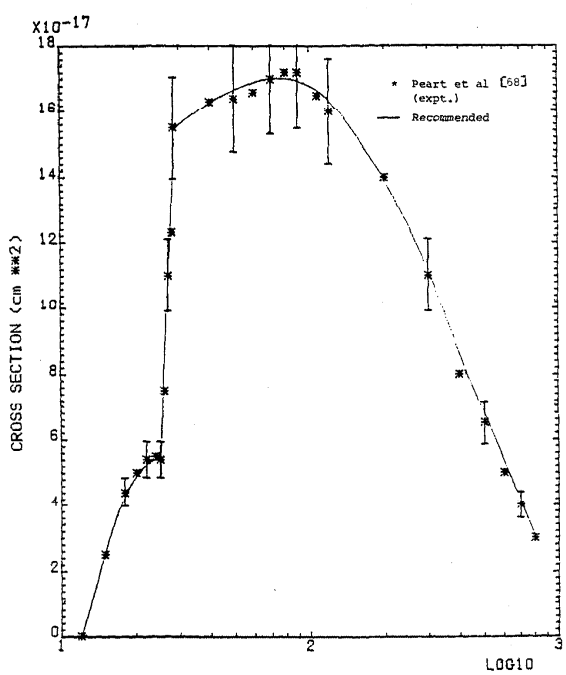

FIG. 118. Electron impact ionization of Ca II (Ca II→Ca III).

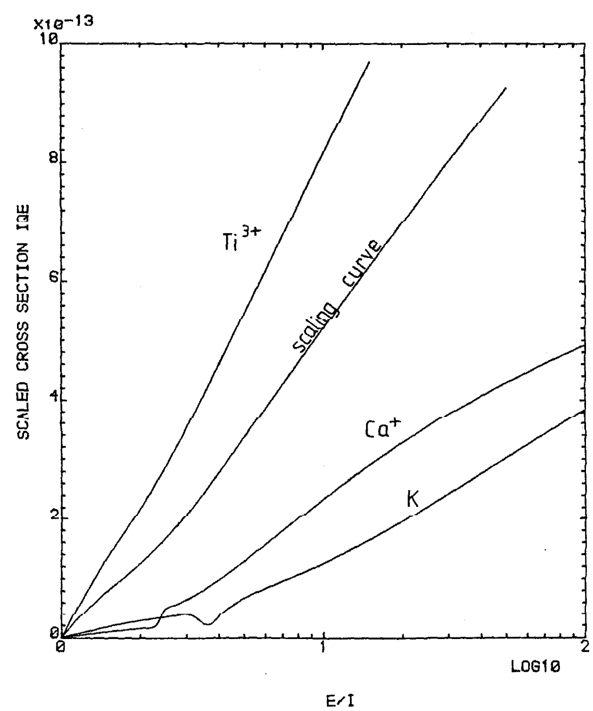

FIG. 120. Scaled cross sections for K-like ions.

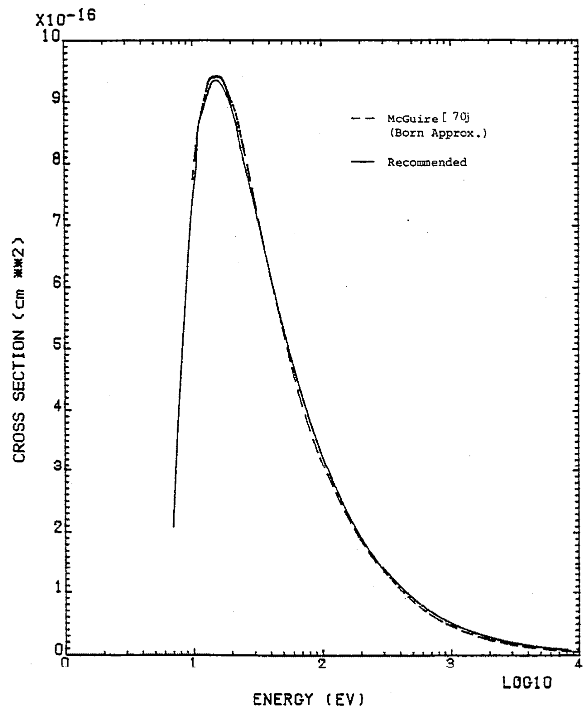

FIG. 121. Electron impact ionization of Ca I (Ca I→Ca II).

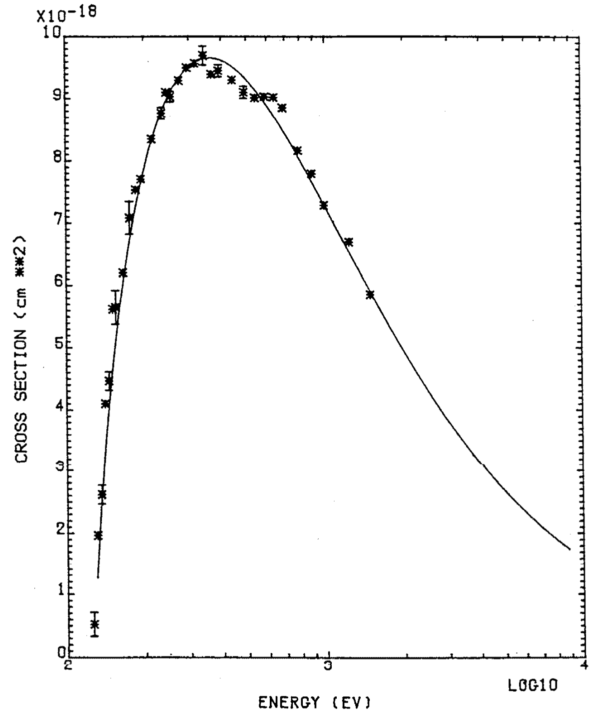

FIG. 123. Electron impact ionization of Fe VII (Fe VII→Fe VIII): * Gregory *et al.* (Ref. 63); — recommended.

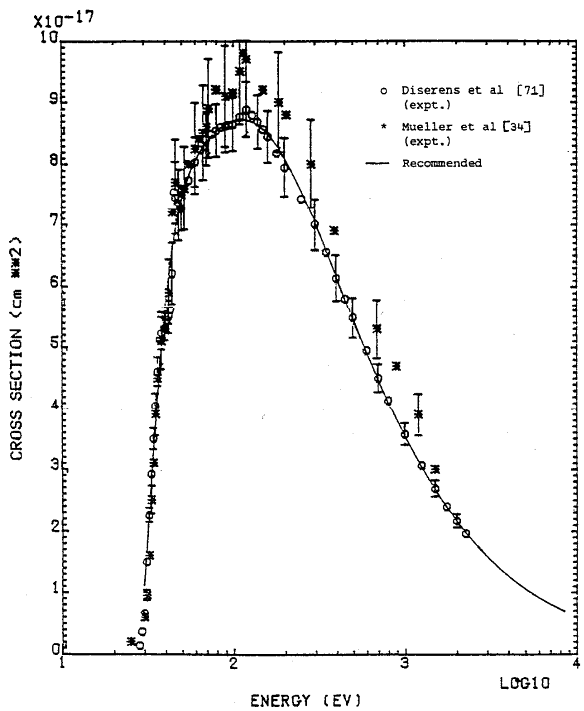

FIG. 122. Electron impact ionization of Ti III (Ti III→Ti IV).

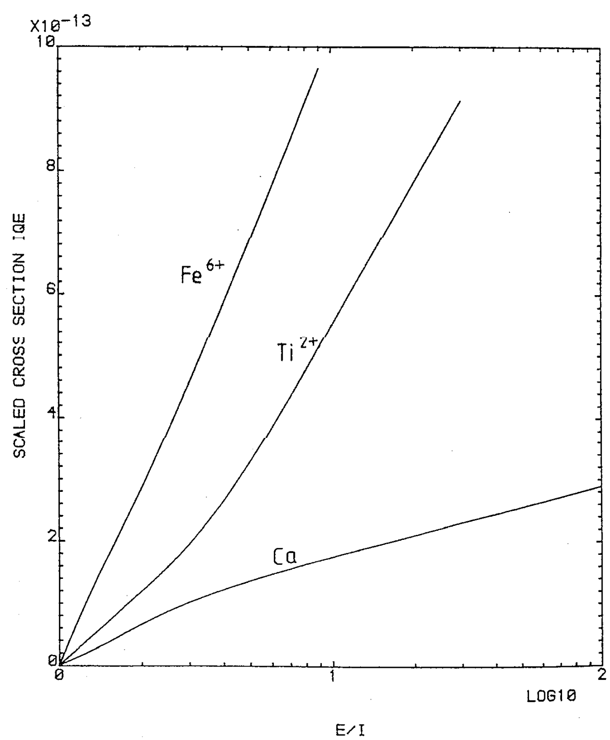

FIG. 124. Scaled cross sections for Ca-like ions.

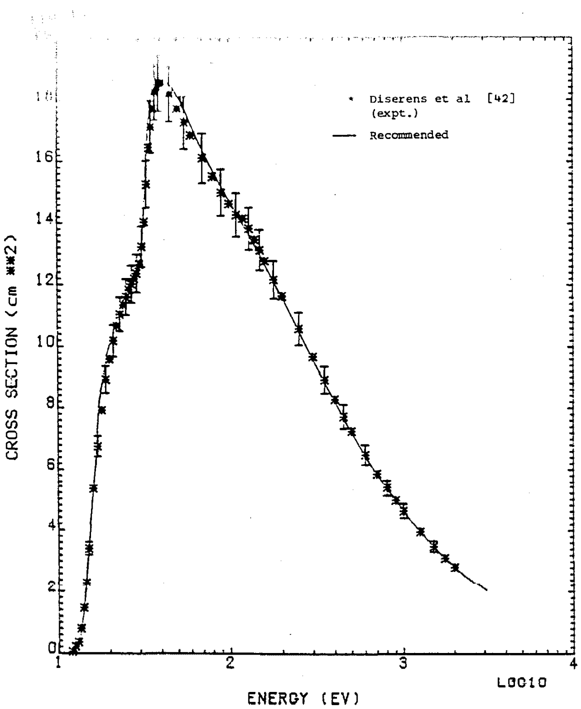

FIG. 125. Electron impact ionization of Ti II (Ti II→Ti III).

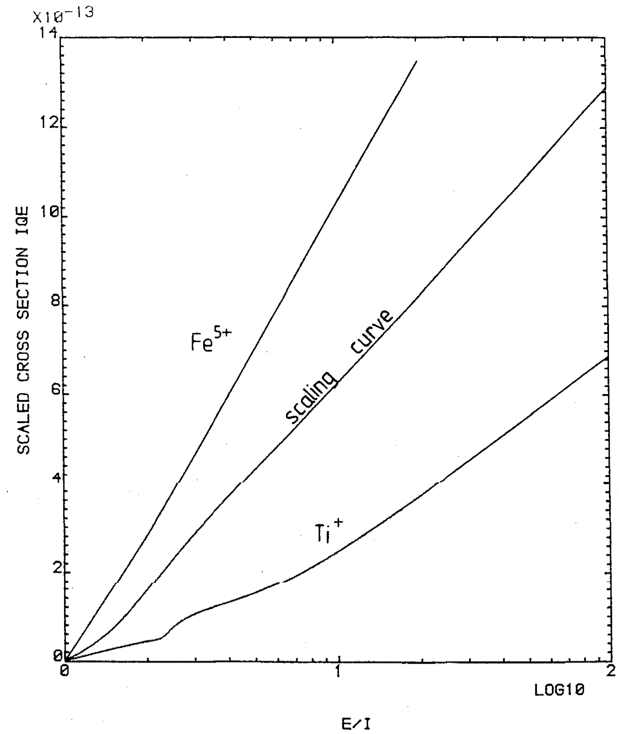

FIG. 127. Scaled cross sections for Sc-like ions.

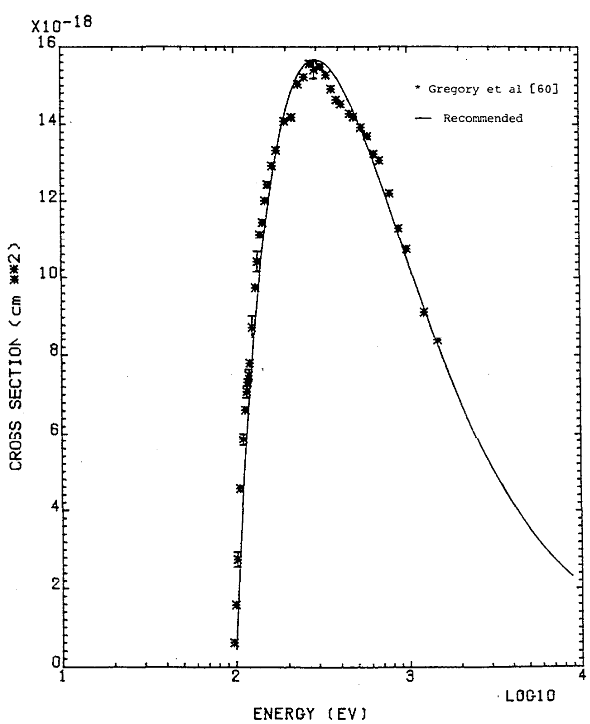

FIG. 126. Electron impact ionization of Fe VI (Fe VI→Fe VII).

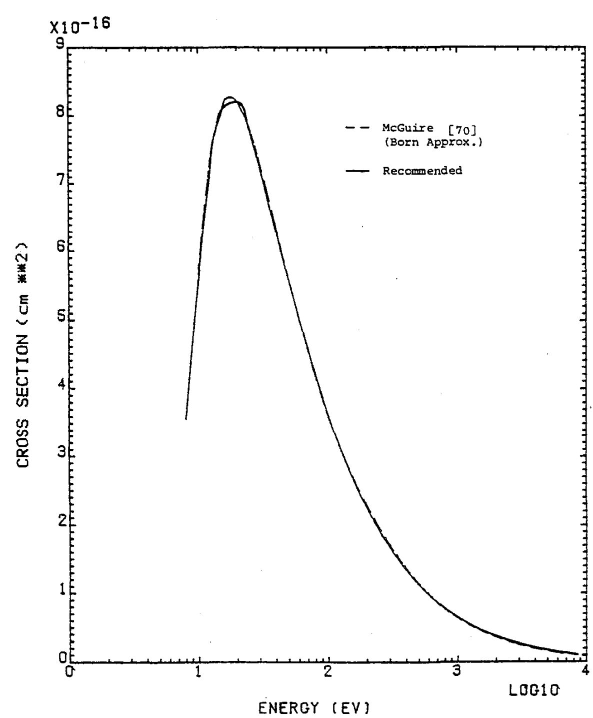

FIG. 128. Electron impact ionization of Ti I (Ti I→Ti II).

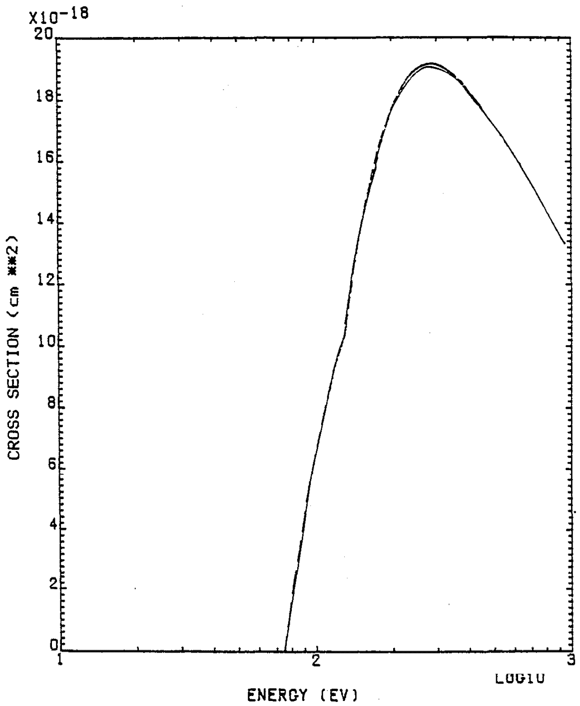

FIG. 129. Electron impact ionization of Fe V (Fe V→Fe VI): - - - Pindzola *et al.* (Ref. 72); — recommended.

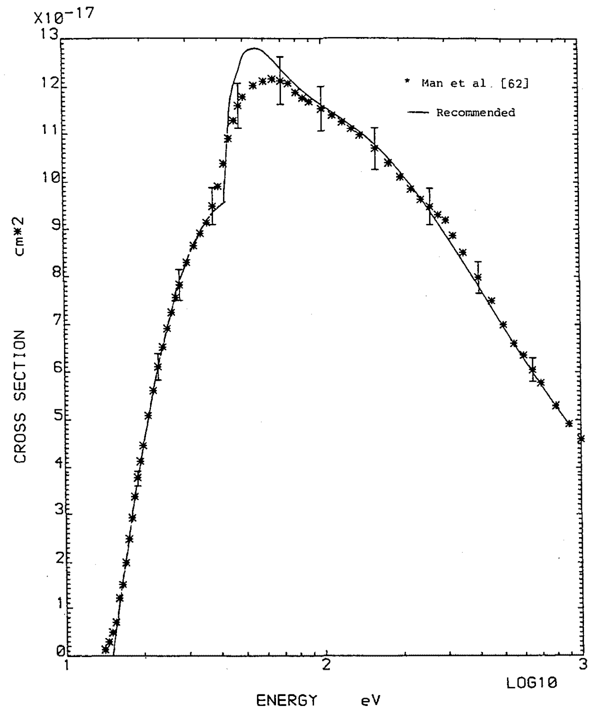

FIG. 131. Electron impact ionization of Cr II (Cr II→Cr III).

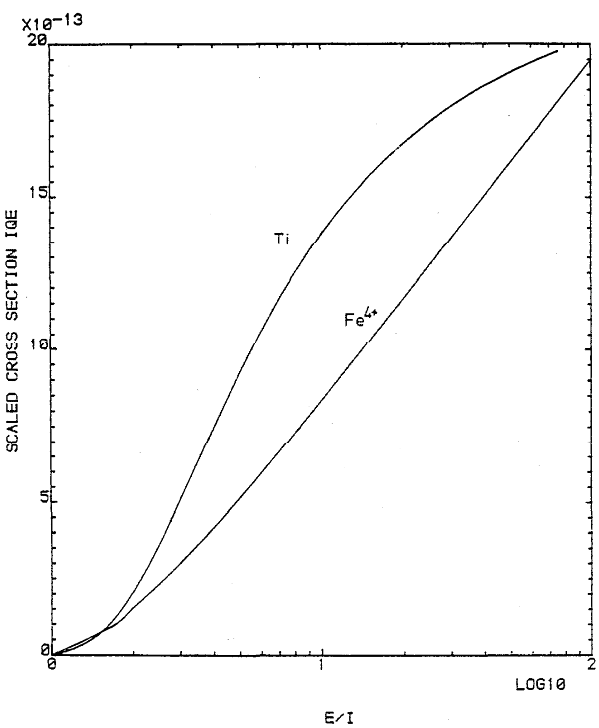

FIG. 130. Scaled cross sections for Ti-like ions.

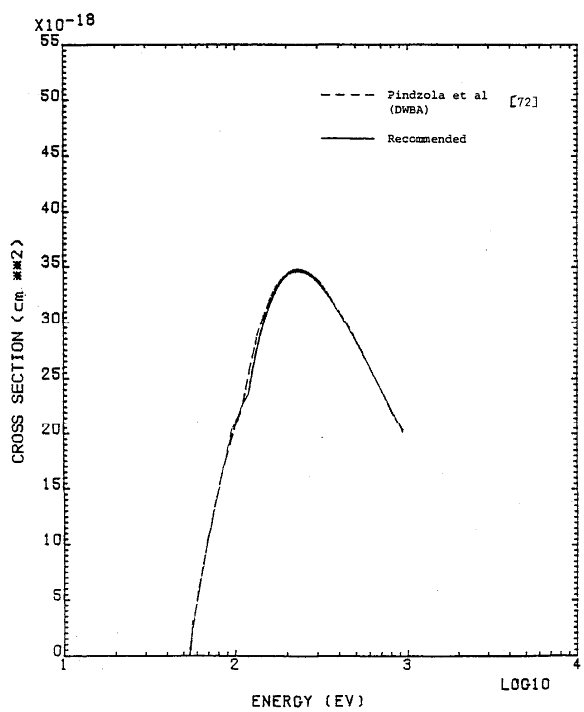

FIG. 132. Electron impact ionization of Fe IV (Fe IV→Fe V).

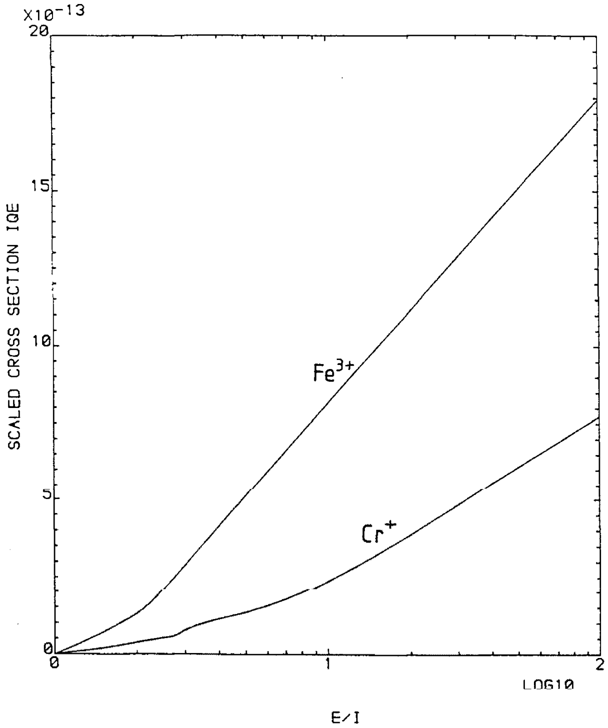

FIG. 133. Scaled cross sections for V-like ions.

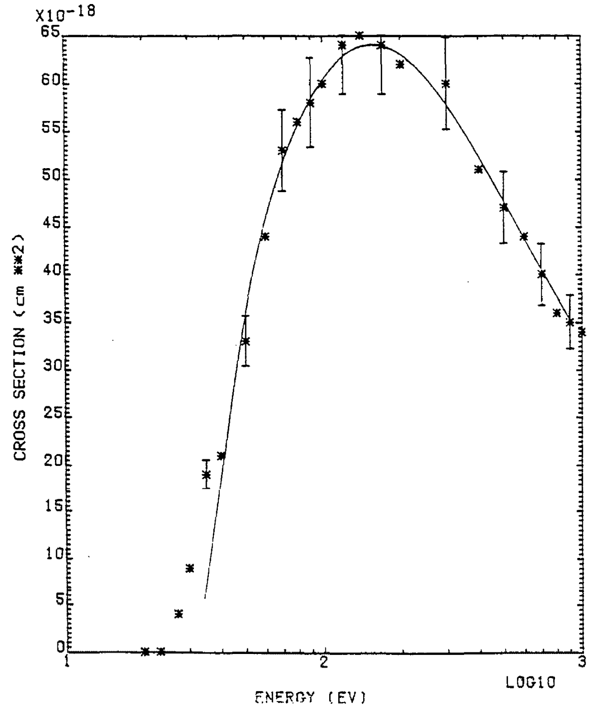

FIG. 135. Electron impact ionization of Fe III (Fe III → Fe IV): * Mueller *et al.*, expt. (Ref. 34); — recommended.

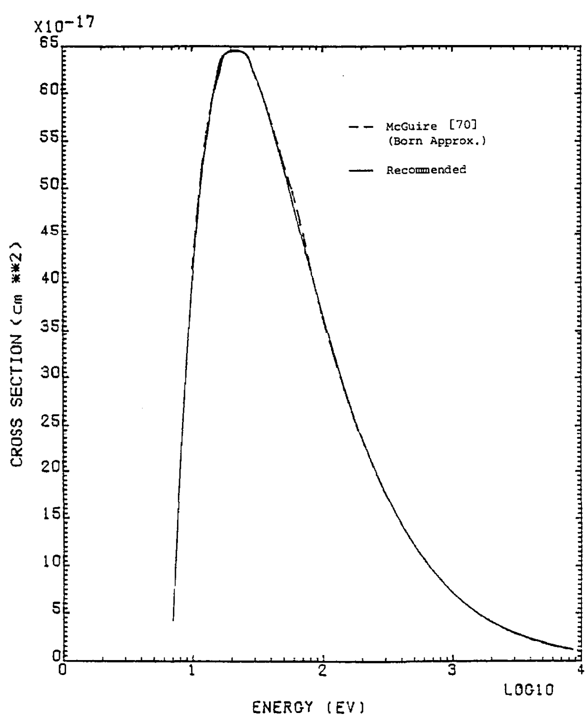

FIG. 134. Electron impact ionization of Cr I (Cr I → Cr II).

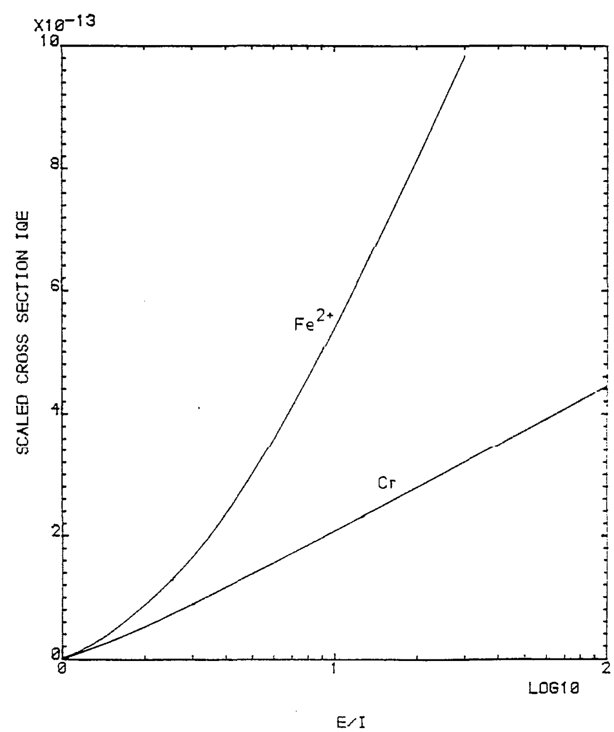

FIG. 136. Scaled cross sections for Cr-like ions.

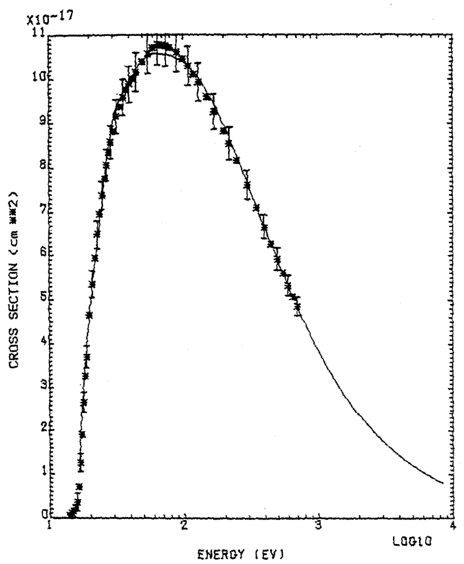

FIG. 137. Electron impact ionization of Fe II (Fe II → Fe III): + Montague *et al.*, expt. (Ref. 73); — recommended.

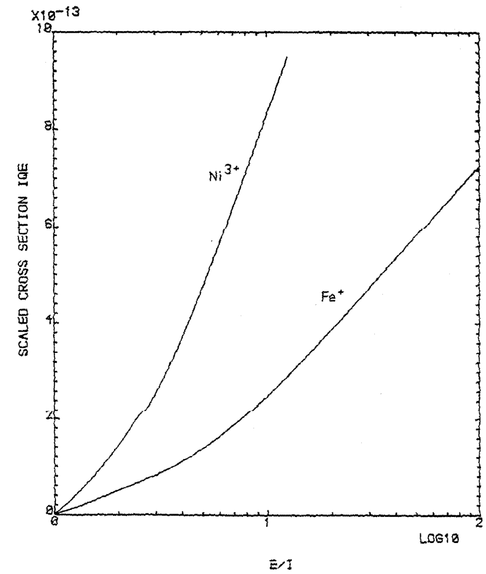

FIG. 139. Scaled cross sections for Mn-like ions.

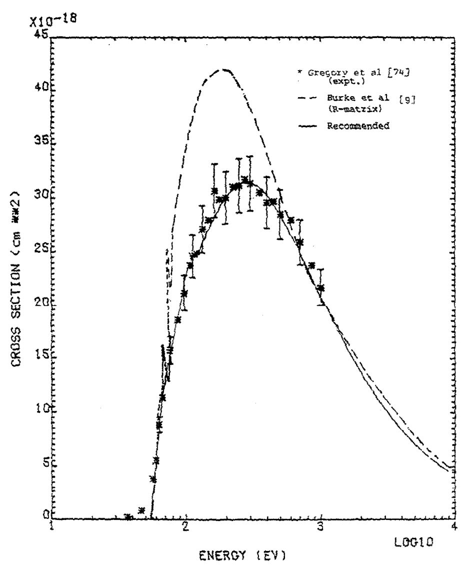

FIG. 138. Electron impact ionization of Ni IV (Ni IV → Ni V).

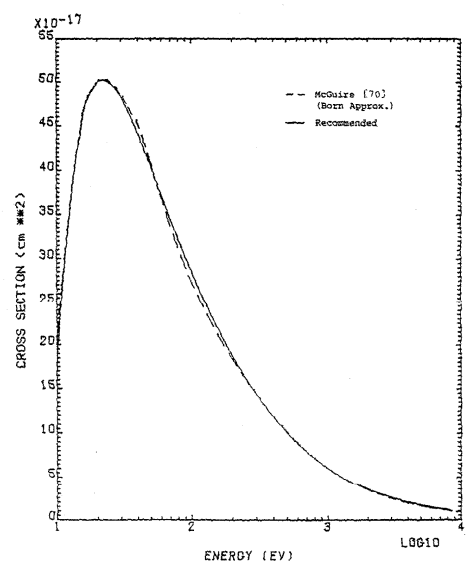

FIG. 140. Electron impact ionization of Fe I (Fe I → Fe II).

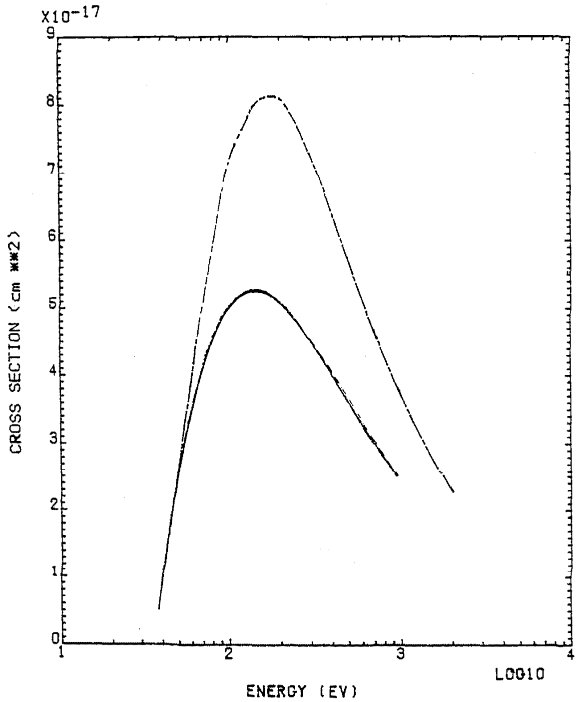

FIG. 141. Electron impact ionization of Ni III (Ni III→Ni IV): - - - Pindzola *et al.*, distorted wave calculation (Ref. 72); – – – Burke *et al.*, R-Matrix calculation (Ref. 9); — recommended.

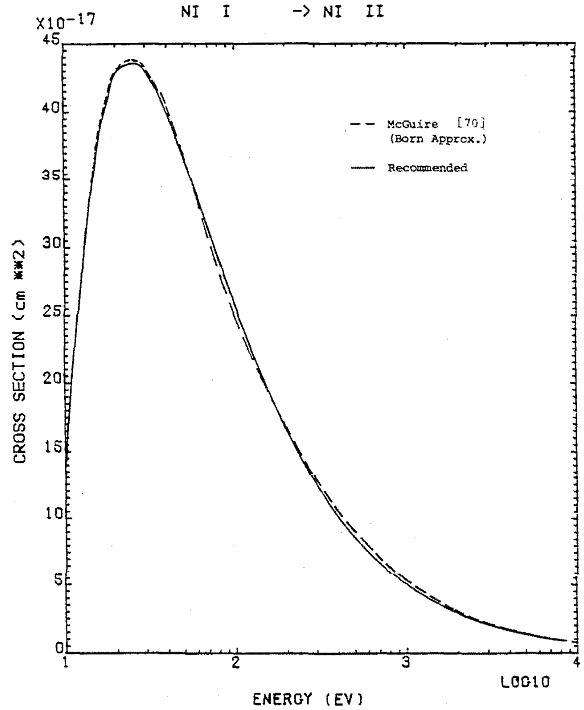

FIG. 143. Electron impact ionization of Ni I (Ni I→Ni II).

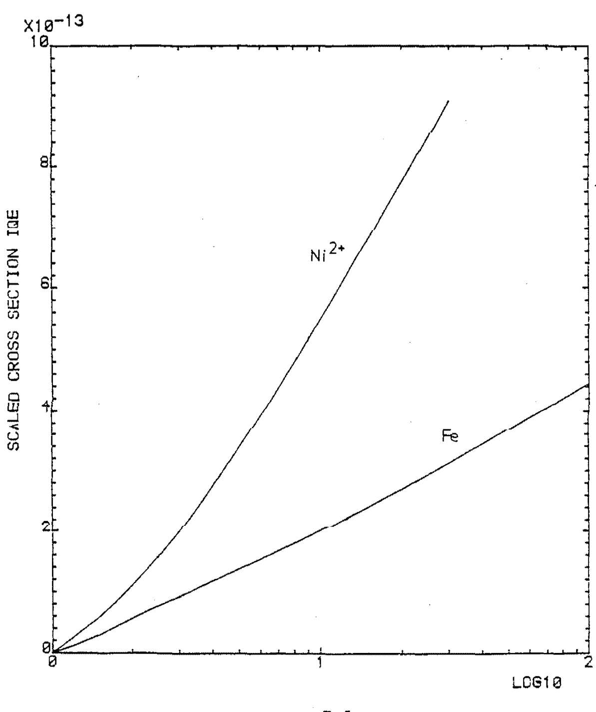

FIG. 142. Scaled cross sections for Fe-like ions.

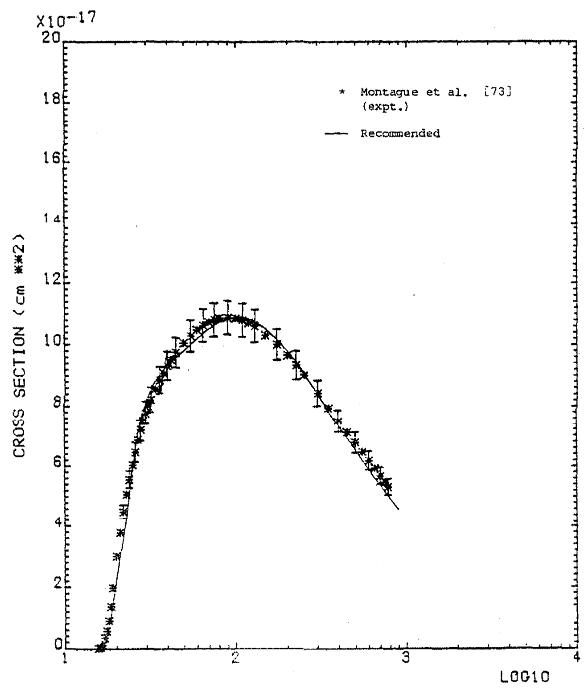

FIG. 144. Electron impact ionization of Ni II (Ni II→Ni III).

4. Revised Recommended Data on Light Atoms and Ions

In an earlier paper (Bell *et al.*[1]), cross sections and rates for electron ionization of light atoms and ions were assessed and recommendations made. A few of these recommendations have now been revised. In particular, for C IV, the recommendation of the theoretical calculation of (Jakubowicz[20]) in preference to the experimental results of Crandall *et al.*[21] has been reversed. The original choice was made because the scaled experimental curve for C IV lay significantly below those for other Li-like ions, while the curve derived from Jakubowicz,[20] results was in much closer agreement. Since then, Crandall *et al.*[22] have refined and repeated their experiment and confirmed their earlier results and their experimental measurements are now recommended. Appropriate coefficients derived from fitting their data are given in Tables 1–3. Also included in their more recent experiment were the first cross-section measurements for B III and improved measurements for O VI; both of these have been fitted and new coefficients are supplied. The new measurements for O VI are consistent with earlier measurements (Crandall *et al.*[21]) except that they are somewhat lower above the excitation–autoionization threshold.

5. Approximate Analytical Formulas

For each species investigated, the recommended cross section has been fitted by the following equation:

$$\sigma(E) = \frac{1}{IE}\left[A\ln\left(\frac{E}{I}\right) + \sum_{i=1}^{N} B_i\left(1-\frac{I}{E}\right)\right], \qquad (1)$$

where E is the incident electron energy, I is the ionization potential, and the coefficients B_i are determined by a least-squares fitting procedure. These coefficients are given in Table 1. This formula ensures the correct behavior of the cross section at both high and low impact energies. If ionization by excitation autoionization is important (Mg II, Al III, Si IV), it is not possible to fit the cross section using Eq. (1); for these ions, we use two fits of the form of Eq. (1), one fit from the ionization threshold and a second fit for energies above the autoionization threshold. The parameter A is a Bethe coefficient and determines the high-energy behavior of the cross section. It may be calculated by fitting the equation

$$\sigma(E) = 1/IE[A\ln(E) + B] \qquad (2)$$

to the high-energy form of the Born approximation or from the equation

$$A = \frac{I}{\pi\alpha}\int_I^\infty \frac{\sigma_{\rm ph}}{E}\,dE, \qquad (3)$$

where $\sigma_{\rm ph}$ is the photoionization cross section and α is the fine structure constant.

The form of Eq. (1) was also dictated by the classical scaling law by which the electron ionization cross section $\sigma(E)$ for an ion of ionization potential I at energy E is given by

$$I^2\sigma(E) = \sigma_c(X), \qquad (4)$$

where $X = E/I$ and where $\sigma_c(X)$ is a scaled cross section which is the same for all ions in a given isoelectronic sequence.

In this work, we found that for hydrogenlike and heliumlike ions the experimental and theoretical data closely satisfied the scaling law except for low values of the nuclear charge. However, for more complex systems, the available data do not satisfy the classical scaling law and so classical scaling is only used if no other data are available.

The rate coefficients $\langle\sigma v\rangle$ (cross sections at a given energy multiplied by electron velocity v at the same energy, evaluated over a Maxwellian velocity distribution) are given by

$$\langle\sigma v\rangle = \left(\frac{8kT}{\pi m}\right)^{1/2}\int_{I/kT}^\infty \sigma(E)\left(\frac{E}{kT}\right) \times\exp\left(\frac{-E}{kT}\right)d\left(\frac{E}{kT}\right), \qquad (5)$$

where m is the electron mass.

For the temperature range $I/10 \leqslant kT \leqslant 10I$, we fit the rate coefficient with the following functional form

$$\langle\sigma v\rangle = \exp\left(\frac{-I}{kT}\right)\left(\frac{kT}{I}\right)^{1/2}\sum_{n=0}^{5} a_n\left[\log_{10}\left(\frac{kT}{I}\right)\right]^n \qquad (6)$$

and for $kT > 10I$ we use the formula

$$\langle\sigma v\rangle = \left(\frac{kT}{I}\right)^{-1/2}\left[\alpha\ln\left(\frac{kT}{I}\right) + \sum_{n=0}^{2}\beta_n\left(\frac{I}{kT}\right)^n\right]. \qquad (7)$$

The coefficients $a_0,\ldots,a_5$ are given in Table 2 and the parameters α, β_0, β_1, and β_2 are given in Table 3. For T in K, I in eV, and $k = 0.8617\times10^{-4}$ eV/K, these coefficients give the rate in $\mathrm{cm^3\,s^{-1}}$. It should be noted that many of the figure and tables in this paper refer to an "electron temperature" which is actually the equivalent electron energy (kT) expressed in eV.

Alternatively, the rates may be accurately computed from the cross sections using the following equation:

$$\langle\sigma v\rangle = 6.692\times10^7\exp\left(\frac{-I}{kT}\right)\sqrt{kT}\sum_{i=1}^{n} w_i x_i \sigma(y_i), \qquad (8)$$

where $y_i = kTx_i + I$ and w_i and x_i are, respectively, the weights and abscissae of the Gauss–Laguerre quadrature formula of degree n. We find that $n = 8$ gives the rates to within 1% accuracy.

Table 1

The parameters I ,A and B_i of equation (1) of the text for the recommended cross sections.The ionisation potential I is given in eV and the parameters A and B_i are in units of 10^{-13} eV^2 cm^2.

SPECIES	I(ev)	A	B_1	B_2	B_3	B_4	B_5	Estimated Error(%)	
H I	13.6	0.185	-0.019	0.123	-0.190	0.953		7	
He I	24.6	0.572	-0.344	-0.523	3.445	-6.821	5.578	5	
He II	54.4	0.185	0.089	0.131	0.388	-1.091	1.354	10	
Li I	5.4	0.085	-0.004	0.757	-0.178			10	
Li II	75.6	0.722	-0.149	-1.301	1.944			12	
Li III	122.4	0.400						10	
Be I	9.3	0.924	-0.770	0.362				20	
Be II	18.2	0.269	0.389	-1.836	3.939	-2.275		20	
	18.2	0.753	-0.582	0.643	-0.966			20	E>5.1I
Be III	153.9	0.796	-0.500	0.884				20	
Be IV	217.7	0.400						20	
B I	8.3	1.106	-1.069	-0.088				20	
B II	25.1	0.907	-0.477	0.197				20	
B III	37.9	0.393	-0.082	-0.303	0.263			20	
B IV	259.4	0.796	-0.500	0.884				20	
B V	340.2	0.400						20	
C I	11.3	2.114	-1.965	-0.608				5	
C II	24.4	1.082	-0.161	-0.856	0.906			10	
C III	47.9	0.715	-0.041	0.175				10	
C III[a]	41.4	0.691	-0.508	0.699	0.014	-0.433		10	
C IV	64.5	0.450	-0.318	1.026	-2.859	1.995		20	
C V	392.1	0.796	-0.500	0.884				20	
C VI	490.0	0.400						10	
N I	14.5	2.265	-1.710	-2.322	1.732			5	
N II	29.6	1.076	-0.829	0.872	-0.162	1.533		10	
N III	47.5	0.500	0.223	2.207	-4.155	3.769		10	
N IV	77.5	0.813	-0.007	-0.046				10	
N IV[a]	69.1	0.327	0.357	-0.042	-0.874	2.167		10	
N V	97.9	0.218	0.238	-0.220	-0.446	2.523	-1.902	10	
	97.9	0.837	-0.214	-2.538	7.488	-11.006	5.523	10	E>4.2I
N VI	552.1	0.796	-0.500	0.884				20	
N VII	667.0	0.400						10	
O I	13.6	2.455	-2.181	-1.570				5	
O II	35.1	1.526	-0.593	-0.399	-0.583	3.235		10	
O III	54.9	1.066	0.442	0.475	-2.961	4.470		7	
O IV	77.4	1.045	-0.652	1.299				10	
O IV[a]	68.6	0.561	0.610	4.652	8.940	6.735		5	
O V	113.9	0.727	0.091	0.022				10	
O V[a]	103.7	0.329	0.610	-2.105	5.913	-3.000		10	
O VI	138.1	0.336	0.080	0.143	-0.731	1.336	-0.785	20	
	320.0	0.801	3.865	-4.605	1.543			20	E>3.2I
O VII	739.3	0.796	-0.500	0.884				20	
O VIII	871.4	0.400						10	

[a]include contributions from metastable ions (see text).

Table 1 --Continued

The parameters I ,A and B_i of equation (1) of the text for the recommended cross sections.The ionisation potential I is given in eV and the parameters A and B_i are in units of 10^{-13} eV^2 cm^2.

SPECIES	I(ev)	A	B_1	B_2	B_3	B_4	B_5	Estimated Error(%)	
F I	17.4	2.790	0.469	-12.900	26.260	-13.430		20	
	30.0	3.925	-0.947	-5.688	4.911	-0.083	-0.160	70	E>4.59I
F II	35.0	2.019	-1.320	1.700				60	
F III	62.7	2.042	-0.586	-0.619	2.072			10	
F IV	87.1	1.066	0.442	0.475	-2.961	4.470		40	
F V	114.2	1.200	-0.652	1.299				60	
F VI	157.2	0.699	0.022	0.226	-0.179			20	
F VII	185.2	0.336	0.080	0.143	-0.731	1.336	-0.785	80	
F VIII	953.9	0.796	-0.500	0.884				50	
F IX	1103.1	0.400						50	
Ne I	21.6	2.192	-0.447	-7.006	5.927			10	
Ne II	41.1	2.705	-2.946	4.862	-15.070	17.780	-5.716	12	
Ne III	63.5	3.701	-1.128	-6.344	4.842			15	
Ne IV	92.5	0.785	1.709	-10.850	41.500	-58.050	30.720	10	
Ne V	126.2	1.066	0.442	0.475	-2.961	4.470		40	
Ne VI	157.9	1.045	-0.652	1.299				60	
Ne VII	207.5	0.737	0.038	0.273	-0.384	0.133		20	
Ne VIII	239.1	0.042	-0.112	2.325	-1.743	0.015		40	
	239.1	0.647	-0.745	2.768	-4.059	1.520		40	E>3.75I
Ne IX	1196.0	0.884	-0.348	0.872	-8.443	17.160	-9.179	15	
Ne X	1360.6	0.434	-0.069	0.093	-0.039			20	
Na I	5.1	0.796	-0.770	2.323	-3.929	1.562		20	
Na II	47.3	3.763	-1.317	-15.440	27.370	-14.920		10	
Na III	71.6	2.794	0.469	-12.940	26.260	-13.430		30	
Na IV	98.9	2.019	-1.320	1.700				60	
Na V	138.2	0.785	1.709	-10.850	41.500	-58.050	30.720	40	
Na VI	172.1	1.066	0.442	0.475	-2.961	4.470		40	
Na VII	208.5	1.200	-0.652	1.299				60	
Na VIII	264.2	0.727	0.091	0.022				40	
Na IX	299.9	0.336	0.080	0.143	-0.731	1.336	-0.785	80	
Na X	1465.1	0.840	-0.031	-0.713	2.448	-2.401	0.715	30	
Na XI	1648.7	0.400						50	
Mg I	7.6	0.484	1.750	-1.562	3.787			15	
Mg II	15.2	0.914	-0.188	-4.383	13.830	-20.570	10.010	15	
Mg III	78.0	4.215	-1.295	-16.660	33.430	-19.570		10	
Mg IV	109.2	2.790	0.469	-12.940	26.260	-13.430		70	
Mg V	141.3	2.019	-1.320	1.700				60	
Mg VI	186.5	0.785	1.709	-10.850	41.500	-58.050	30.720	40	
Mg VII	224.9	1.066	0.442	0.475	-2.961	4.470		40	
Mg VIII	265.9	1.200	-0.652	1.299				60	
Mg IX	328.0	0.727	0.091	0.022				40	
Mg X	367.7	0.361	0.079	-0.112	0.050			40	
Mg XI	1761.8	0.930	-0.234	-0.513	-4.622	12.400	-7.045	30	
Mg XII	1962.6	0.400						50	

Table 1 --Continued

The parameters I ,A and B_1 of equation (1) of the text for the recommended cross sections.The ionisation potential I is given in eV and the parameters A and B_i are in units of 10^{-13} eV^2 cm^2.

SPECIES	I(ev)	A	B_1	B_2	B_3	B_4	B_5	Estimated Error(%)	
Al I	6.0	1.170	0.843	-2.877	1.958			60	
Al II	18.8	0.496	-0.090	4.724	-13.810	15.000	-5.739	10	
Al III	28.0	0.092	0.033	0.263	0.076	-0.218		10	
	45.0	1.997	-1.259	-0.075	-4.600	4.014		10	E>2.86I
Al IV	120.0	3.710	-2.360	2.350	-0.660			40	
Al V	153.7	2.794	0.469	-12.940	26.260	-13.430		70	
Al VI	190.5	2.419	-1.320	1.700				40	
Al VII	241.4	0.785	1.709	-10.850	41.500	-58.050	30.720	40	
Al VIII	284.6	2.003	-0.405	-6.519	16.980	-11.760		30	
Al IX	390.2	0.780	0.907	-0.301	-2.337	9.420	-6.119	30	
Al X	398.0	0.601	-0.549	1.092	0.091			20	
Al XI	442.1	0.718	-0.432	-0.304	0.181			40	
Al XII	2086.0	1.012	-0.678	-0.360	2.830	-1.927		30	
Al XIII	2304.1	0.400						50	
Si I	8.2	1.573	0.722	-2.687	1.856			60	
Si II	16.3	1.170	0.843	-2.877	1.958			60	
Si III	33.5	1.088	0.203	-0.243	0.099			100	
Si IV	54.0	0.246	0.398	-0.826	2.147	-1.597		15	
	90.0	3.557	-0.220	-5.644	5.856	-1.890		15	E>2.02I
Si V	166.8	4.215	-1.295	-16.660	33.430	-19.570		50	
Si VI	205.1	2.794	0.469	-12.940	26.260	-13.430		70	
Si VII	246.5	2.019	-1.320	1.700				60	
Si VIII	303.2	0.785	1.709	-10.850	41.500	-58.050	30.720	40	
Si IX	351.1	1.066	0.442	0.475	-2.961	4.470		40	
Si X	401.4	1.200	-0.652	1.299				60	
Si XI	476.1	0.727	0.091	0.022				40	
Si XII	523.5	0.336	0.080	0.143	-0.731	1.336	-0.785	80	
Si XIII	2437.7	0.796	-0.500	0.884				50	
Si XIV	2673.1	0.400						50	
P I	10.5	1.704	1.518	-2.982	1.774			50	
P II	19.7	1.573	0.722	-2.687	1.856			60	
P III	30.2	1.170	0.843	-2.877	1.958			60	
P IV	51.4	1.088	0.203	-0.243	0.099			100	
P V	65.0	0.907	0.105	0.147	-0.073	-0.001		200	
P VI	220.4	3.500	-2.360	2.350	-0.660			50	
P VII	263.2	2.794	0.469	-12.940	26.260	-13.430		70	
P VIII	309.4	2.019	-1.320	1.700				60	
P IX	371.7	0.785	1.709	-10.850	41.500	-58.050	30.720	40	
P X	424.5	1.066	0.442	0.475	-2.961	4.470		40	
P XI	479.6	1.200	-0.652	1.299				60	
P XII	560.4	0.668	0.197	0.120	0.178			40	
P XIII	611.8	0.336	0.080	0.143	-0.731	1.336	-0.785	80	
P XIV	2816.9	0.796	-0.500	0.884				50	
P XV	3069.8	0.400						50	

Table 1 --Continued

The parameters I ,A and B_1 of equation (1) of the text for the recommended cross sections.The ionisation potential I is given in eV and the parameters A and B_i are in units of 10^{-13} eV^2 cm^2.

SPECIES	I(ev)	A	B_1	B_2	B_3	B_4	B_5	Estimated Error(%)
S I	10.4	3.150	-2.350	-2.032				20
S II	23.3	1.704	1.518	-2.982	1.774			50
S III	34.8	1.666	0.299	-2.148	2.014			60
S IV	47.3	1.170	0.843	-2.877	1.958			60
S V	72.7	0.598	0.198	-0.176	0.051	0.011	0.010	10
	120.0	2.147	1.542	-1.508	0.874	-0.022	-0.050	60 E>2.06I
S VI	88.1	0.907	0.105	0.147	-0.073	-0.001		200
S VII	280.9	3.500	-2.360	2.350	-0.660			50
S VIII	328.2	2.794	0.469	-12.940	26.260	-13.430		70
S IX	379.1	2.019	-1.320	1.700				60
S X	447.1	0.785	1.709	-10.850	41.500	-58.050	30.720	40
S XI	504.8	1.066	0.442	0.475	-2.961	4.470		40
S XII	564.7	1.200	-0.652	1.299				60
S XIII	651.6	0.668	0.197	0.120	-0.178			40
S XIV	707.1	0.336	0.080	0.143	-0.731	1.336	-0.785	80
S XV	3223.8	0.796	-0.500	0.884				50
S XVI	3493.1	0.400						50
Cl I	13.0	2.241	-1.948	1.189	0.023	0.005		15
	20.0	6.102	2.195	-15.616	10.310	-0.588		50 E>3.86I
Cl II	23.8	2.086	1.077	-2.172	0.809			50
Cl III	39.6	1.704	1.518	-2.982	1.774			10
Cl IV	53.5	1.666	0.299	-2.148	2.014			60
Cl V	67.8	1.170	0.843	-2.877	1.958			60
Cl VI	97.0	0.982	-0.633	0.373	0.055	0.013	0.012	10
	170.0	3.572	4.301	-10.709	5.993	0.046	0.056	10 E>2.06I
Cl VII	114.2	0.907	0.105	0.147	-0.073	-0.001		200
Cl VIII	348.3	3.500	-2.360	2.350	-0.660			50
Cl IX	400.0	2.794	0.469	-12.940	26.260	-13.430		70
Cl X	455.6	2.019	-1.320	1.700				60
Cl XI	529.3	0.785	1.709	-10.850	41.500	-58.050	30.720	40
Cl XII	592.0	1.066	0.442	0.475	-2.961	4.470		40
Cl XIII	659.7	1.200	-0.652	1.299				60
Cl XIV	749.7	0.668	0.197	0.120	-0.178			40
Cl XV	809.4	0.336	0.080	0.143	-0.731	1.336	-0.785	80
Cl XVI	3658.4	0.796	-0.500	0.884				50
Cl XVII	3946.2	0.400						50

Table 1 --Continued

The parameters I ,A and B_i of equation (1) of the text for the recommended cross sections.The ionisation potential I is given in eV and the parameters A and B_i are in units of 10^{-13} eV ^{2} cm^2.

SPECIES	I(ev)	A	B1	B2	B3	B4	B5	Estimated Error(%)	
Ar I	15.8	2.532	-2.672	2.543	-0.769	0.008	0.006	15	
	15.8	4.337	3.092	-21.253	14.626	0.018	0.031	10	E>4.13I
Ar II	27.4	2.896	0.777	-4.447	2.867	0.072		15	
Ar III	40.7	2.086	1.077	-2.172	0.809			15	
Ar IV	52.3	1.186	-1.180	11.050	-30.790	36.620	-15.420	10	
Ar V	75.0	1.574	0.722	-2.687	1.856			15	
	126.0	2.798	4.114	-3.103	0.438			15	E>2.93I
Ar VI	91.0	1.170	0.843	-2.877	1.958			10	
	200.0	3.771	16.163	-34.952	20.853			10	E>2.53I
Ar VII	124.3	0.968	-0.306	0.223	-0.005	0.018	0.017	10	
	220.0	3.739	6.817	-13.665	7.357	-0.117	-0.139	10	E>1.93I
Ar VIII	143.5	0.907	0.105	0.147	-0.073	-0.001		200	
Ar IX	422.5	3.512	-0.357	1.158	-0.776			40	
Ar X	478.7	2.794	0.469	-12.940	26.260	-13.430		70	
Ar XI	539.0	2.019	-1.320	1.700				60	
Ar XII	618.2	0.785	1.709	-10.850	41.500	-58.050	30.720	40	
Ar XIII	686.1	1.066	0.442	0.475	-2.961	4.470		40	
Ar XIV	755.7	1.200	-0.652	1.299				60	
Ar XV	854.8	0.668	0.197	0.120	-0.178			20	
Ar XVI	918.0	0.336	0.080	0.143	-0.731	1.336	-0.785	80	
Ar XVII	4120.8	0.796	-0.500	0.884				50	
Ar XVIII	4426.1	0.400						50	
K I	4.3	0.373	-0.349	2.712	-5.253	2.871		20	
	15.0	3.949	7.061	-16.340	8.118	1.257		20	E>5.07I
K II	31.8	2.714	-0.404	2.456	-1.855	0.239		10	
K III	45.8	1.662	-0.040	-0.277	0.288			30	
K IV	60.9	2.086	1.077	-2.172	0.809			50	
K V	82.7	1.755	-0.270	0.772	-0.347			60	
K VI	100.0	1.249	-0.174	1.032	-0.575			60	
K VII	117.6	0.960	-0.249	0.687	-0.326			60	
K VIII	154.9	1.008	0.203	-0.243	0.099			100	
K IX	175.8	0.907	0.105	0.147	-0.073	-0.001		200	
K X	503.4	3.512	-0.357	1.158	-0.776			50	
K XI	564.1	2.794	0.469	-12.940	26.260	-13.430		70	
K XII	629.1	2.019	-1.320	1.700				60	
K XIII	714.0	0.785	1.709	-10.850	41.500	-58.050	30.720	40	
K XIV	787.1	1.066	0.442	0.475	-2.961	4.470		40	
K XV	861.8	1.200	-0.652	1.299				60	
K XVI	968.0	0.668	0.197	0.120	-0.178			40	
K XVII	1034.0	0.336	0.080	0.143	-0.731	1.336	-0.785	80	
K XVIII	4611.0	0.796	-0.500	0.884				50	
K XIX	4933.9	0.400						50	

Table 1 --Continued

The parameters I ,A and B_i of equation (1) of the text for the recommended cross sections.The ionisation potential I is given in eV and the parameters A and $B_i$are in units of 10^{-13} eV ^{2} cm ^{2}.

SPECIES	I(ev)	A	B_1	B_2	B_3	B_4	B_5	Estimated Error(%)	
Ca I	6.1	0.482	-0.043	2.012	-1.310			40	
Ca II	11.9	0.088	0.040	0.549	-0.497			15	
	14.0	0.868	0.946	-2.233	-3.040	6.351		15	E>2.02I
Ca III	50.9	2.857	-0.657	1.214	-0.689			50	
Ca IV	67.1	2.534	1.377	-5.721	7.132	-2.731		50	
Ca V	84.4	1.035	1.846	6.575	-35.340	53.580	-24.840	50	
Ca VI	108.8	1.647	-0.270	0.772	-0.347			60	
Ca VII	127.7	1.149	-0.174	1.032	-0.575			60	
Ca VIII	147.2	0.960	-0.249	0.687	-0.326			60	
Ca IX	188.5	1.008	0.203	-0.243	0.099			100	
Ca X	211.3	0.907	0.105	0.147	-0.073	-0.001		200	
Ca XI	591.3	3.500	-2.360	2.350	-0.660			50	
Ca XII	656.4	2.794	0.469	-12.940	26.260	-13.430		70	
Ca XIII	726.0	2.019	-1.320	1.700				60	
Ca XIV	816.6	0.785	1.709	-10.850	41.500	-58.050	30.720	40	
Ca XV	895.1	1.066	0.442	0.475	-2.961	4.470		40	
Ca XVI	974.0	1.200	-0.652	1.299				60	
Ca XVII	1087.0	0.668	0.197	0.120	-0.178			40	
Ca XVIII	1157.0	0.336	0.080	0.143	-0.731	1.336	-0.785	80	
Ca XIX	5129.0	0.796	-0.500	0.884				50	
Ca XX	5469.7	0.400						50	
Sc I	6.5	2.888	0.753	-21.240	66.290	-75.230	29.080	200	
Sc II	12.8	2.876	-2.321	5.910	-10.306	-1.333	7.738	200	
Sc III	24.8	2.369	0.531	-1.323	-7.778	14.920	-6.092	300	
Sc IV	73.5	2.622	-1.256	2.215	-1.050			30	
Sc V	91.7	2.402	-1.028	1.495	-0.420			30	
Sc VI	111.1	1.842	-0.123	0.908	-0.439			30	
Sc VII	138.0	1.755	-0.270	0.772	-0.347			30	
Sc VIII	158.7	1.249	-0.174	1.032	-0.575			30	
Sc IX	180.0	0.960	-0.249	0.687	-0.326			30	
Sc X	225.3	1.008	0.203	-0.243	0.099			30	
Sc XI	249.8	0.907	0.105	0.147	-0.073	-0.001		200	
Sc XII	685.9	3.441	1.066	-2.774	1.489			50	
Sc XIII	755.5	2.492	1.043	-0.528	-0.113			70	
Sc XIV	829.8	1.912	1.079	-0.035	-0.447			60	
Sc XV	926.0	1.633	0.645	-0.101	-0.239			60	
Sc XVI	1009.0	1.091	0.276	1.052	-0.892			60	
Sc XVII	1094.0	0.189	0.327	1.679	-1.160			100	
Sc XVIII	1213.0	0.414	0.097	0.137	-0.144			60	
Sc XIX	1288.0	0.289	0.110	-0.441	0.269			100	
Sc XX	5675.3	0.525	-0.188	0.489	-0.292			70	
Sc XXI	6033.8	0.260	-0.022	0.051	-0.023			50	

Table 1 --Continued

The parameters I ,A and B_1 of equation (1) of the text for the recommended cross sections.The ionisation potential I is given in eV and the parameters A and B_i are in units of 10^{-13} eV^2 cm^2.

SPECIES	I(ev)	A	B_1	B_2	B_3	B_4	B_5	Estimated Error(%)
Ti I	6.8	0.827	1.270	-8.806	24.520	-26.760	10.040	40
Ti II	13.6	0.618	0.048	0.185	-0.740	0.522		10
	28.0	4.026	8.920	-30.070	31.730	-17.970	5.945	10 E>2.50I
Ti III	27.5	2.876	-2.321	5.910	-10.310	-1.333	7.738	100
Ti IV	43.1	3.570	0.531	-1.323	-7.778	14.920	-6.092	10
Ti V	99.2	2.857	0.209	0.488	-0.379			100
Ti VI	119.4	2.457	0.289	0.484	-0.413			100
Ti VII	140.8	2.034	0.410	0.253	-0.3211			100
Ti VIII	168.5	3.159	-0.878	-3.018	3.196	-2.440	-9.600	50
	305.6	0.028	28.228	-48.217	32.456	0.438	0.647	50 E>2.12I
Ti IX	193.2	1.936	0.542	0.595	-0.518			100
Ti X	215.9	0.772	0.472	0.695	-0.825	-0.018		100
	363.3	2.501	28.312	-55.465	27.441	1.651	2.232	100 E>1.76I
Ti XI	265.2	2.133	0.191	-0.150	0.032			200
Ti XII	291.5	1.507	0.105	0.147	-0.073	-0.001		200
Ti XIII	787.3	3.441	1.066	-2.774	1.489			50
Ti XIV	861.3	2.492	1.043	-0.528	-0.113			70
Ti XV	940.4	1.912	1.079	-0.035	-0.447			60
Ti XVI	1042.0	1.633	0.645	-0.101	-0.239			60
Ti XVII	1131.0	1.091	0.276	1.052	-0.892			60
Ti XVIII	1220.0	0.189	0.327	1.679	-1.160			100
Ti XIX	1342.0	0.414	0.097	0.137	-0.144			60
Ti XX	1425.0	0.289	0.110	-0.441	0.269			100
Ti XXI	6249.0	0.525	-0.188	0.489	-0.292			70
Ti XXII	6625.6	0.260	-0.022	0.051	-0.023			50
V I	6.7	2.258	-0.843	0.622	0.010			100
	9.8	6.113	-1.148	1.583	-0.034			100 E>1.99I
V II	14.6	2.659	-1.068	-0.396	1.036			100
	19.5	6.503	-0.278	-5.663	3.860			100 E>1.74I
V III	29.3	2.888	0.753	-21.240	66.290	-75.230	29.080	200
V IV	46.7	2.876	-2.321	5.910	-10.306	-1.333	7.738	200
V V	65.2	2.369	0.531	-1.323	-7.778	14.920	-6.092	300
V VI	128.1	2.963	-0.303	-0.519	0.767			30
V VII	150.2	2.457	0.289	0.484	-0.413			100
V VIII	173.7	2.034	0.409	0.253	0.321			100
V IX	205.8	3.159	-0.878	-3.018	3.196	-2.440	-9.600	100
	373.0	0.028	28.228	-48.217	32.456	0.438	0.647	100 E>2.12I
V X	230.5	1.936	0.542	0.595	-0.518			100
V XI	255.0	0.772	0.472	0.695	-0.825	-0.018		100
	428.4	2.501	28.312	-55.465	27.441	1.651	2.232	100 E>1.76I
V XII	308.3	2.133	0.191	-0.150	-0.073	0.032		200
V XIII	336.3	1.507	0.105	0.147	-0.073	-0.001		200
V XIV	895.6	3.441	1.066	-2.774	1.489			50
V XV	974.0	2.492	1.043	-0.528	-0.113			70

Table 1 --Continued
The parameters I ,A and B_i of equation (1) of the text for the recommended cross sections.The ionisation potential I is given in eV and the parameters A and B_i are in units of 10^{-13} eV^2 cm^2.

SPECIES	I(ev)	A_1	B_2	B_3	B_4	B_5	B_6	Estimated Error(%)	
Cr I	6.8	1.029	-0.429	0.052	0.074			40	
Cr II	15.0	0.725	-0.344	0.142	0.067			20	
	35.0	5.370	5.856	-19.405	8.233	0.607	2.768	100	E>2.67I
Cr III	31.0	2.659	-1.068	-0.396	1.036			100	
Cr IV	49.1	2.888	0.753	-21.240	66.290	-75.230	29.080	200	
Cr V	69.3	2.876	-2.321	5.910	-10.306	-1.333	7.738	200	
Cr VI	90.6	2.369	0.531	-1.323	-7.778	14.920	-6.092	300	
Cr VII	161.1	2.857	0.209	0.488	-0.379			100	
Cr VIII	184.7	2.457	0.289	0.484	-0.413			100	
Cr IX	209.3	2.034	0.409	0.253	-0.321			100	
Cr X	244.4	3.159	-0.878	-3.018	3.196	-2.440	-9.600	100	
	442.4	0.028	28.228	-48.217	32.456	0.438	0.647	100	E>2.12I
Cr XI	270.8	1.936	0.542	0.595	-0.518			100	
Cr XII	298.0	0.772	0.472	0.695	-0.825	-0.018		100	
	500.6	2.501	28.312	-55.465	27.441	1.651	2.232	100	E>1.76I
Cr XIII	355.0	2.133	0.191	-0.150	0.032			200	
Cr XIV	384.3	1.507	0.105	0.147	-0.073	-0.001		200	
Cr XV	1010.6	3.441	1.066	-2.774	1.489			50	
Cr XVI	1097.0	2.492	1.043	-0.528	-0.113			70	
Cr XVII	1185.0	1.912	1.079	-0.035	-0.447			60	
Cr XVIII	1299.0	1.633	0.645	-0.101	-0.239			60	
Cr XIX	1396.0	1.091	0.276	1.052	-0.892			60	
Cr XX	1496.0	0.189	0.327	1.679	-1.160			100	
Cr XXI	1634.0	0.414	0.097	0.137	-0.144			60	
Cr XXII	1721.4	0.289	0.110	-0.441	0.269			100	
Cr XXIII	7482.0	0.525	-0.188	0.489	-0.292			70	
Mn I	7.4	2.124	-0.530	-9.617	29.170	-40.810	19.290	200	
Mn II	15.6	4.420	-4.810	5.692	-12.977	6.698		200	
Mn III	33.7	2.258	-0.843	0.622	0.010			100	
	49.2	6.113	-1.148	1.583	-0.034			100	E>1.98I
Mn IV	51.2	2.659	-1.068	-0.396	1.036			100	
	68.1	6.503	-0.278	-5.663	3.860			100	E>1.74I
Mn V	72.4	2.888	0.753	-21.240	66.290	-75.230	29.080	200	
Mn VI	95.0	2.876	-2.321	5.910	-10.306	-1.333	7.738	100	
Mn VII	119.3	2.369	0.531	-1.323	-7.778	14.920	-6.092	300	
Mn VIII	196.5	2.856	0.209	0.488	-0.379			100	
Mn IX	221.8	2.457	0.289	0.484	-0.413			100	
Mn X	248.3	2.034	0.409	0.253	-0.321			100	
Mn XI	286.0	3.159	-0.878	-3.018	3.196	-2.440	-9.600	100	
	517.6	0.028	28.228	-48.217	32.456	0.438	0.647	100	E>2.12I
Mn XII	314.4	1.936	0.542	0.595	-0.518			100	
Mn XIII	343.6	0.772	0.472	0.695	-0.825	-0.018		100	
	577.3	2.501	28.312	-55.465	27.441	1.651	2.232	100	E>1.76I
Mn XIV	404.0	2.133	0.191	-0.150	0.032			200	
Mn XV	435.3	1.507	0.105	-0.147	-0.073	-0.001		200	
Mn XVI	1136.2	3.441	1.066	-2.774	1.489			50	
Mn XV	1244.0	2.492	1.043	-0.528	-0.113			70	
Mn XVI	1317.0	1.912	1.079	-0.035	-0.447			60	
Mn XVII	1437.0	1.633	0.645	-0.101	-0.239			60	
Mn XVIII	1539.0	1.091	0.276	1.052	-0.892			60	
Mn XIX	1644.0	0.189	0.327	1.679	-1.160			100	
Mn XX	1788.0	0.414	0.097	0.137	-0.144			60	
Mn XXI	1880.0	0.289	0.110	-0.441	0.269			100	
Mn XXII	8141.4	0.525	-0.188	0.489	-0.292			70	

Table 1 --Continued

The parameters I ,A and B_i of equation (1) of the text for the recommended cross sections.The ionisation potential I is given in eV and the parameters A and B_i are in units of 10^{-13} eV^2 cm^2.

SPECIES	I(ev)	A	B_1	B_2	B_3	B_4	B_5	Estimated Error(%)	
Fe I	7.9	1.142	-0.920	1.782	-1.694			40	
Fe II	16.2	2.124	-0.530	-9.617	29.170	-40.810	19.290	10	
Fe III	30.6	4.420	-2.968	-3.712	1.219	0.043		10	
Fe IV	54.8	2.258	-0.843	0.622	0.010			40	
	80.0	6.113	-1.148	1.583	-0.034			40	E>2.10I
Fe V	75.0	2.659	-1.068	-0.396	1.036			40	
	100.0	6.503	-0.278	-5.663	3.860			40	E>1.79I
Fe VI	99.0	4.397	0.098	-2.681	3.048			10	
Fe VII	125.0	4.612	0.819	-5.126	4.029			10	
Fe VIII	151.1	3.570	0.531	-1.323	-7.778	14.921	-6.092	300	
Fe IX	233.6	2.856	0.209	0.488	-0.379			30	
Fe X	262.1	2.457	0.289	0.484	-0.413			30	
Fe X[a]	214.0	2.432	-0.676	0.598				10	
	262.1	1.950	-0.946	11.125	-7.958			10	E>2.10I
Fe XI	290.3	2.034	0.410	0.253	-0.321			30	
Fe XII	330.8	3.159	-0.878	-3.018	3.196	-2.440	-9.600	20	
	600.0	0.028	28.228	-48.217	32.456	0.438	0.647	20	E>2.12I
Fe XIII	361.0	1.936	0.542	0.595	-0.518			30	
Fe XIV	392.2	0.772	0.472	0.695	-0.825	-0.018		25	
	660.0	2.501	28.312	-55.465	27.441	1.651	2.332	25	E>1.76I
Fe XV	457.0	2.133	0.191	-0.150	0.032			30	
Fe XVI	489.0	0.891	-0.671	0.600	-0.076			25	
	720.0	3.780	17.026	-58.644	44.547	0.057	0.057	25	E>1.49I
Fe XVII	1266.0	3.441	1.066	-2.774	1.489			40	
Fe XVIII	1366.0	2.492	1.043	-0.528	-0.113			30	
Fe XIX	1463.0	1.912	1.079	-0.035	-0.447			40	
Fe XX	1583.0	1.633	0.645	-0.101	-0.239			30	
Fe XXI	1678.0	1.091	0.276	1.052	-0.892			30	
Fe XXII	1789.0	0.189	0.327	1.679	-1.160			30	
Fe XXIII	1950.0	0.414	0.097	0.137	-0.144			30	
Fe XXIV	2046.0	0.289	0.110	-0.441	0.269			40	
Fe XXV	8829.0	0.525	-0.188	0.489	-0.292			40	
Fe XXVI	9277.0	0.260	-0.022	0.051	-0.023			30	
Co I	7.9	2.679	-2.865	6.289	-15.947	9.547		200	
Co II	17.1	3.453	-2.008	-1.621	0.889			200	
Co III	33.5	3.497	-1.698	-1.723	2.329			200	
	42.0	6.044	2.131	-18.370	15.459			200	E>2.48I
Co IV	51.3	4.420	-4.810	5.692	-12.977	6.698		200	
Co V	79.5	2.258	-0.843	0.622	0.010			100	
	119.3	6.613	-1.148	1.583	-0.034			100	E>2.00I
Co VI	102.0	2.659	-1.068	-0.396	1.036			100	
	127.5	6.503	-0.278	-5.663	3.860			100	E>1.80I
Co VII	129.0	2.888	0.753	-21.240	66.290	-75.230	29.080	200	
Co VIII	157.0	2.876	-2.321	5.910	-10.306	-1.333	7.738	200	
Co IX	186.1	2.369	0.531	-1.323	-7.778	14.920	-6.092	300	
Co X	276.0	2.856	0.209	0.488	-0.379			100	
Co XI	305.0	2.457	0.289	0.484	-0.413			100	
Co XII	336.0	2.034	0.409	0.253	-0.321			100	
Co XIII	379.0	3.159	-0.878	-3.018	3.196	-2.440	-9.600	100	
	685.9	0.028	28.228	-48.217	32.456	0.438	0.647	100	E>2.12I
Co XIV	411.0	1.936	0.542	0.595	-0.518			100	
Co XV	444.0	0.772	0.472	0.695	-0.825	-0.018		100	
	745.9	2.501	28.312	-55.465	27.441	1.651	2.232	100	E>1.76I
Co XVI	512.0	2.133	0.191	-0.150	0.032			200	
Co XVII	546.8	1.507	-0.105	0.147	-0.073	-0.001		200	
Co XVIII	1403.0	3.441	1.066	-2.774	1.489			50	

[a]include contributions from metastable ions (see text)

Table 1 --Continued

The parameters I ,A and B_i of equation (1) of the text for the recommended cross sections.The ionisation potential I is given in eV and the parameters A and B_i are in units of 10^{-13} eV^2 cm^2.

SPECIES	I(ev)	A	B_1	B_2	B_3	B_4	B_5	Estimated Error(%)
Ni I	7.6	0.832	-0.766	1.258	-0.679			200
Ni II	18.2	2.679	-2.865	6.289	-15.947	9.547		200
Ni III	36.2	3.453	-2.008	-1.621	0.889			40
Ni IV	54.9	3.497	-1.698	-1.723	2.329			10
	70.0	6.044	2.131	-18.370	15.459			10 E>2.27I
Ni V	76.1	4.420	-4.810	5.692	-12.977	6.698		200
Ni VI	108.0	2.258	-0.843	0.622	0.010			100
	160.6	6.113	-1.148	1.583	-0.034			100 E>2.10I
Ni VII	133.0	2.659	-1.068	-0.396	1.036			100
	166.0	6.503	-0.278	-5.663	3.860			100 E>1.80I
Ni VIII	162.0	2.888	0.753	-21.240	66.290	-75.230	29.080	200
Ni IX	193.0	2.876	-2.321	5.910	-10.306	-1.333	7.738	200
Ni X	224.6	2.369	0.531	-1.323	-7.778	14.920	-6.092	300
Ni XI	321.0	2.856	0.209	0.488	-0.379			100
Ni XII	352.0	2.457	0.289	0.484	-0.413			100
Ni XIII	384.0	2.034	0.410	0.253	-0.321			100
Ni XIV	430.0	3.159	-0.878	-3.018	3.196	-2.440	-9.600	100
	778.3	0.028	28.228	-48.217	32.456	0.438	0.647	100 E>2.12I
Ni XV	464.0	1.936	0.542	0.595	-0.518			100
Ni XVI	499.0	0.772	0.472	0.695	-0.825	-0.018		100
	838.3	2.510	28.312	-55.465	27.441	1.651	2.232	100 E>1.76I
Ni XVII	571.0	2.133	0.191	-0.150	0.032			200
Ni XVIII	607.2	1.507	0.105	0.147	-0.073	-0.001		200
Ni XIX	1547.0	3.441	1.066	-2.774	1.489			50
Ni XX	1639.0	2.492	1.043	-0.528	-0.113			70
Ni XXI	1747.0	1.912	1.079	-0.035	-0.447			60
Ni XXII	1882.0	1.633	0.645	-0.101	-0.239			60
Ni XXIII	2003.0	1.091	0.276	1.052	-0.892			60
Ni XXIV	2123.0	0.189	0.327	1.679	-1.160			100
Ni XXV	2299.0	0.414	0.097	0.137	-0.144			60
Ni XXVI	2398.0	0.289	0.110	-0.441	0.269			100

The coefficients $a_0,...a_5$ in $cm^2\ s^{-1}$ of equation (6) of the text for the recommended rate coefficients.

SPECIES	a_0	a_1	a_2	a_3	a_4	a_5
H						
I	2.3743E-08	-3.6867E-09	-1.0366E-08	-3.8010E-09	3.4159E-09	1.6834E-09
He						
I	1.4999E-08	5.6657E-10	-6.0822E-09	-3.5894E-09	1.5529E-09	1.3207E-09
II	3.4340E-09	-1.6873E-09	-6.9021E-10	9.7746E-11	1.5530E-10	6.2326E-11
Li						
I	9.9655E-08	-5.5941E-08	-5.5228E-08	4.0589E-08	1.4800E-08	-1.3120E-08
II	3.3996E-09	-7.6528E-10	-8.6010E-10	-8.9678E-10	4.1628E-10	3.3162E-10
III	1.1779E-09	-8.7584E-10	-9.3317E-11	2.1125E-10	1.9005E-11	-4.0654E-11
Be						
I	7.4206E-08	-1.5520E-08	-3.9403E-08	7.2155E-09	1.1098E-08	-2.5501E-09
II	3.2777E-08	-1.3769E-08	-2.1724E-08	-1.1818E-09	1.2575E-08	4.4398E-10
III	1.6057E-09	-6.4406E-10	-7.7888E-10	3.3563E-10	2.1913E-10	-1.0612E-10
IV	4.9686E-10	-3.6944E-10	-3.9362E-11	8.9106E-11	8.0167E-12	-1.7149E-11
B						
I	5.8366E-08	1.0047E-08	-3.6230E-08	-7.3448E-09	1.0220E-08	1.6952E-09
II	2.0652E-08	-9.9195E-09	-6.1131E-09	2.7845E-09	1.6549E-09	-6.7894E-10
III	4.8657E-09	-2.8848E-09	-2.9540E-10	2.9492E-11	1.2163E-10	1.0307E-10
IV	7.3382E-10	-2.9435E-10	-3.5596E-10	1.5339E-10	1.0015E-10	-4.8498E-11
V	2.5434E-10	-1.8911E-10	-2.0149E-11	4.5613E-11	4.1037E-12	-8.7782E-12
C						
I	5.9849E-08	1.1903E-08	-3.0141E-08	-1.3693E-08	8.3749E-09	4.0150E-09
II	2.8395E-08	-1.6698E-08	-2.3557E-09	3.2161E-10	9.6017E-10	5.2713E-10
III	9.0159E-09	-6.2930E-09	-1.3198E-09	1.7365E-09	3.2537E-10	-3.8135E-10
III[a]	8.0946E-09	-3.6568E-09	-3.9572E-09	2.3820E-09	1.0515E-09	-7.9302E-10
IV	2.0527E-09	-1.2430E-09	-9.0089E-12	2.8863E-10	-2.1088E-10	3.1898E-11
V	3.9483E-10	-1.5837E-10	-1.9152E-10	8.2530E-11	5.3883E-11	-2.6094E-11
VI	1.4716E-10	-1.0942E-10	-1.1658E-11	2.6391E-11	2.3744E-12	-5.0790E-12
N						
I	4.6209E-08	9.2265E-09	-1.2092E-08	-2.4852E-08	5.1361E-09	8.3068E-09
II	2.4382E-08	-2.2167E-09	-1.4813E-08	-4.4241E-10	4.5235E-09	1.7883E-10
III	1.2956E-08	-8.3356E-09	-2.3669E-09	2.2471E-09	2.6218E-10	-2.6317E-10
IV	4.6349E-09	-3.4666E-09	-3.1032E-10	8.0623E-10	5.7825E-11	-1.4916E-10
IV[a]	4.5344E-09	-2.3692E-09	-3.5514E-10	-4.9395E-10	1.2611E-10	3.3892E-10
V	1.5820E-09	-9.9482E-10	1.1651E-10	8.5902E-11	-4.5891E-11	-2.1455E-11
VI	2.3631E-10	-9.4790E-11	-1.1463E-10	4.9396E-11	3.2250E-11	-1.5618E-11
VII	9.2648E-11	-6.8888E-11	-7.3397E-12	1.6615E-11	1.4948E-12	-3.1976E-12
O						
I	3.3523E-08	1.3434E-08	-6.7039E-09	-1.9954E-08	1.6196E-09	6.5780E-09
II	2.4507E-08	-5.3210E-09	-7.3410E-09	-4.4573E-09	2.4288E-09	1.9817E-09
III	1.4701E-08	-8.8014E-09	-8.1931E-10	-2.3530E-10	1.1077E-10	6.4811E-10
IV	6.2118E-09	-2.5042E-09	-3.0808E-09	1.3556E-09	8.6800E-10	-4.3180E-10
IV[a]	5.7526E-09	-2.3510E-09	-2.3387E-09	1.4063E-09	1.2451E-10	-1.9423E-10
V	2.6145E-09	-2.0277E-09	-1.6569E-10	5.0245E-10	3.0067E-11	-9.8231E-11
V[a]	3.1263E-09	-1.6820E-09	-9.4804E-10	8.4311E-11	5.0189E-10	-4.1921E-11
VI	1.2724E-09	-8.2005E-10	5.3820E-10	-2.5108E-10	-4.8644E-10	4.1506E-11
VII	1.5248E-10	-6.1163E-11	-7.3966E-11	3.1873E-11	2.0810E-11	-1.0078E-11
VIII	6.2049E-11	-4.6136E-11	-4.9156E-12	1.1128E-11	1.0011E-12	-2.1415E-12

[a]include contributions from metastable ions (see text).

Table 2 --Continued

The coefficients $a_0,\ldots a_5$ in $cm^3\ s^{-1}$ of formula (6) of the text for the recommended rate coefficients.

SPECIES	a_0	a_1	a_2	a_3	a_4	a_5
F						
I	3.6013E-08	1.5563E-08	-8.6406E-09	-1.0730E-08	-3.4332E-09	-3.9784E-09
II	3.3233E-08	-1.2808E-08	-1.5565E-08	6.1604E-09	4.3671E-09	-1.9246E-09
III	1.4870E-08	-6.7494E-09	-4.1767E-09	7.0393E-10	1.3921E-09	-4.9538E-11
IV	7.3577E-09	-4.4051E-09	-4.1006E-10	-1.1777E-10	5.5440E-11	3.2438E-10
V	3.9714E-09	-1.7734E-09	-1.7585E-09	8.4699E-10	4.9233E-10	-2.5834E-10
VI	1.5326E-09	-1.1725E-09	-1.5192E-10	3.3961E-10	2.8115E-11	-7.5046E-11
VII	6.2646E-10	-5.0730E-10	-2.5492E-11	1.1862E-10	3.6624E-12	-1.9977E-11
VIII	1.0405E-10	-4.1735E-11	-5.0471E-11	2.1748E-11	1.4199E-11	-6.8764E-12
IX	4.3565E-11	-3.2393E-11	-3.4513E-12	7.8129E-12	7.0291E-13	-1.5036E-12
Ne						
I	2.5262E-08	1.6088E-09	1.5446E-08	-3.5149E-08	-1.0676E-09	1.2656E-08
II	1.7101E-08	2.2362E-09	-9.3287E-09	-2.5361E-09	1.5306E-09	1.4419E-09
III	1.3357E-08	-5.3669E-09	1.7601E-09	-4.9727E-09	-2.6149E-11	2.0181E-09
IV	8.0028E-09	-4.2200E-09	-1.7048E-09	2.9783E-10	1.0403E-09	-3.1671E-10
V	4.2210E-09	-2.5271E-09	-2.3525E-10	-6.7561E-11	3.1805E-11	1.8609E-10
VI	2.1317E-09	-8.5935E-10	-1.0572E-09	4.6520E-10	2.9786E-10	-1.4818E-10
VII	1.0645E-09	-8.3265E-10	-8.2391E-11	2.3639E-10	1.0293E-11	-5.0205E-11
VIII	4.8875E-10	-2.9609E-10	-2.5302E-10	3.1048E-10	2.4755E-11	-9.8284E-11
IX	6.2389E-11	-1.4730E-11	-1.2722E-11	-2.1678E-11	5.3799E-12	1.0130E-11
X	3.2716E-11	-2.2374E-11	-4.8365E-12	6.1474E-12	1.1426E-12	-1.3446E-12
Na						
I	1.6720E-07	-1.1573E-07	-5.4865E-08	9.0828E-08	-1.0853E-09	-2.5271E-08
II	1.3745E-08	4.0232E-09	-3.2887E-09	-1.3301E-08	4.3644E-09	3.5286E-09
III	1.4527E-08	-4.3052E-09	-3.6875E-09	-4.2223E-09	2.8504E-09	1.1271E-09
IV	6.9864E-09	-2.6925E-09	-3.2721E-09	1.2951E-09	9.1806E-10	-4.0459E-10
V	4.3817E-09	-2.3103E-09	-9.3355E-10	1.6293E-10	5.6967E-10	-1.7341E-10
VI	2.6497E-09	-1.5864E-09	-1.4767E-10	-4.2411E-11	1.9965E-11	1.1682E-10
VII	1.6110E-09	-7.1941E-10	-7.1337E-10	3.4359E-10	1.9972E-10	-1.0480E-10
VIII	7.4015E-10	-5.7402E-10	-4.6906E-11	1.4224E-10	8.5120E-12	-2.7809E-11
IX	3.0401E-10	-2.4618E-10	-1.2371E-11	5.7565E-11	1.7773E-12	-9.6946E-12
X	5.8459E-11	-3.8617E-11	-1.0153E-11	9.4312E-12	3.7315E-12	-2.4651E-12
XI	2.3843E-11	-1.7728E-11	-1.8889E-12	4.2759E-12	3.8470E-13	-8.2290E-13
Mg						
I	3.6045E-07	-2.5788E-07	-3.2796E-08	2.3423E-08	1.8689E-08	1.1739E-09
II	1.9246E-08	-1.5700E-08	5.9884E-09	1.5891E-09	1.6470E-10	-2.0317E-09
III	1.0439E-08	-1.3972E-10	-3.9046E-09	-5.0511E-09	3.0207E-09	1.1288E-09
IV	7.7013E-09	-2.2760E-09	-1.9572E-09	-2.2449E-09	1.5136E-09	5.9909E-10
V	4.0934E-09	-1.5775E-09	-1.9171E-09	7.5880E-10	5.3790E-10	-2.3706E-10
VI	2.7947E-09	-1.4736E-09	-5.9543E-10	1.0392E-10	3.6335E-10	-1.1060E-10
VII	1.7740E-09	-1.0621E-09	-9.8870E-11	-2.8395E-11	1.3367E-11	7.8211E-11
VIII	1.1184E-09	-4.9942E-10	-4.9522E-10	2.3852E-10	1.3865E-10	-7.2751E-11
IX	5.3513E-10	-4.1502E-10	-3.3913E-11	1.0284E-10	6.1541E-12	-2.0106E-11
X	2.1841E-10	-1.7819E-10	1.2851E-12	3.6450E-11	-1.5275E-12	-5.6274E-12
XI	3.4293E-11	-7.9122E-12	-5.1945E-12	-1.4295E-11	3.3494E-12	5.9590E-12
XII	1.8357E-11	-1.3649E-11	-1.4543E-12	3.2921E-12	2.9619E-13	-6.3357E-13

Table 2 --Continued

The coefficients $a_0,\ldots a_5$ in $cm^3\ s^{-1}$ of formula (6) of the text for the recommended rate coefficients.

SPECIES	a_0	a_1	a_2	a_3	a_4	a_5
Al						
I	3.0764E-07	-2.8504E-07	1.0518E-07	-2.1274E-08	-2.5008E-08	2.0889E-08
II	3.4571E-08	-3.6648E-08	4.4237E-09	1.4020E-08	-5.4470E-09	-1.6074E-09
III	7.5123E-09	-1.5938E-09	1.4073E-09	1.5321E-09	-2.1459E-09	-1.4920E-09
IV	8.5054E-09	-3.6482E-09	-3.4130E-09	1.5534E-09	9.1573E-10	-4.5723E-10
V	4.6224E-09	-1.3698E-09	-1.1733E-09	-1.3435E-09	9.0696E-10	3.5864E-10
VI	3.2216E-09	-1.4590E-09	-1.2726E-09	5.9352E-10	3.5335E-10	-1.7236E-10
VII	1.8979E-09	-1.0008E-09	-4.0430E-10	7.0631E-11	2.4670E-10	-7.5109E-11
VIII	1.1641E-09	-4.8575E-10	-4.8903E-10	4.4678E-11	2.6327E-10	-5.6104E-11
IX	7.7599E-10	-5.6142E-10	-7.6290E-11	5.8878E-11	4.1333E-11	2.0448E-12
X	3.1767E-10	-7.4149E-11	-2.2087E-10	7.1259E-11	6.3904E-11	-2.6104E-11
XI	1.5212E-10	-5.5464E-11	-3.2421E-11	-5.5857E-12	9.6097E-12	3.8273E-12
XII	3.1729E-11	-8.4732E-12	-1.8390E-11	4.1396E-12	6.2941E-12	-1.8610E-12
XIII	1.4431E-11	-1.0730E-11	-1.1433E-12	2.5881E-12	2.3285E-13	-4.9808E-13
Si						
I	2.5653E-07	-2.1940E-07	5.2700E-08	-2.9152E-10	-1.2481E-08	9.9184E-09
II	6.8182E-08	-6.3174E-08	2.3312E-08	-4.7150E-09	-5.5425E-09	4.6297E-09
III	2.6352E-08	-2.1078E-08	-4.5765E-10	4.5844E-09	-2.4786E-11	-7.7241E-10
IV	8.2109E-09	-2.6004E-10	1.1639E-09	-3.5041E-09	-1.7005E-09	5.1749E-10
V	3.3391E-09	-4.4690E-11	-1.2489E-09	-1.6157E-09	9.6623E-10	3.6106E-10
VI	3.0001E-09	-8.8907E-10	-7.6150E-10	-8.7196E-10	5.8864E-10	2.3277E-10
VII	1.7756E-09	-6.8428E-10	-8.3158E-10	3.2914E-10	2.3332E-10	-1.0283E-10
VIII	1.3487E-09	-7.1121E-10	-2.8731E-10	5.0194E-11	1.7532E-10	-5.3376E-11
IX	9.0972E-10	-5.4465E-10	-5.0701E-11	-1.4561E-11	6.8547E-12	4.0107E-11
X	6.0291E-10	-2.6923E-10	-2.6697E-10	1.2859E-10	7.4743E-11	-3.9219E-11
XI	3.0597E-10	-2.3729E-10	-1.9390E-11	5.8801E-11	3.5187E-12	-1.1496E-11
XII	1.3180E-10	-1.0673E-10	-5.3632E-12	2.4957E-11	7.7051E-13	-4.2030E-12
XIII	2.5469E-11	-1.0216E-11	-1.2354E-11	5.3236E-12	3.4757E-12	-1.6832E-12
XIV	1.1549E-11	-8.5869E-12	-9.1490E-13	2.0711E-12	1.8633E-13	-3.9858E-13
P						
I	2.4034E-07	-2.3352E-07	5.9647E-08	1.8052E-08	-1.6124E-08	4.0926E-09
II	6.8119E-08	-5.8258E-08	1.3994E-08	-7.7408E-11	-3.3142E-09	2.6337E-09
III	2.7175E-08	-2.5179E-08	9.2913E-09	-1.8792E-09	-2.2091E-09	1.8452E-09
IV	1.2571E-08	-1.0128E-08	-1.3787E-10	2.1800E-09	-3.4030E-11	-3.6170E-10
V	7.7244E-09	-5.9709E-09	-6.1435E-10	1.5866E-09	1.1708E-10	-3.2943E-10
VI	3.1605E-09	-1.2751E-09	-1.3507E-09	5.7808E-10	3.6372E-10	-1.7483E-10
VII	2.0627E-09	-6.1129E-10	-5.2358E-10	-5.9952E-10	4.0473E-10	1.6004E-10
VIII	1.2628E-09	-4.8666E-10	-5.9143E-10	2.3409E-10	1.6594E-10	-7.3130E-11
IX	9.9337E-10	-5.2382E-10	-2.1161E-10	3.6970E-11	1.2913E-10	-3.9313E-11
X	6.8428E-10	-4.0968E-10	-3.8137E-11	-1.0953E-11	5.1561E-12	3.0168E-11
XI	4.6169E-10	-2.0617E-10	-2.0444E-10	9.8466E-11	5.7236E-11	-3.0033E-11
XII	2.4283E-10	-2.0556E-10	-5.8043E-12	5.5559E-11	-8.8210E-13	-1.1409E-11
XIII	1.0431E-10	-8.4467E-11	-4.2445E-12	1.9751E-11	6.0980E-13	-3.3263E-12
XIV	2.0502E-11	-8.2238E-12	-9.9453E-12	4.2856E-12	2.7980E-12	-1.3550E-12
XV	9.3842E-12	-6.9776E-12	-7.4343E-13	1.6829E-12	1.5141E-13	-3.2388E-13

Table 2 --Continued

The coefficients $a_0,...a_5$ in $cm^3\ s^{-1}$ of equation (6) of the text for the recommended rate coefficients.

SPECIES	a_0	a_1	a_2	a_3	a_4	a_5
S						
I	1.0050E-07	-1.7409E-08	-4.7119E-09	-2.7351E-08	4.4902E-10	1.0620E-08
II	7.2463E-08	-7.0407E-08	1.7984E-08	5.4427E-09	-4.8615E-09	1.2339E-09
III	2.9585E-08	-2.0779E-08	1.1771E-09	-8.9066E-11	5.0983E-11	8.9350E-10
IV	1.3850E-08	-1.2833E-08	4.7355E-09	-9.5778E-10	-1.1259E-09	9.4046E-10
V	6.9219E-09	-2.0046E-09	1.3487E-10	-1.8041E-09	-9.6418E-10	2.8261E-10
VI	4.9017E-09	-3.7889E-09	-3.8985E-10	1.0068E-09	7.4296E-11	-2.0905E-10
VII	2.1966E-09	-8.8618E-10	-9.3875E-10	4.0177E-10	2.5279E-10	-1.2151E-10
VIII	1.4813E-09	-4.3899E-10	-3.7600E-10	-4.3054E-10	2.9065E-10	1.1493E-10
IX	9.3108E-10	-3.5882E-10	-4.3607E-10	1.7259E-10	1.2235E-10	-5.3920E-11
X	7.5309E-10	-3.9712E-10	-1.6043E-10	2.8027E-11	9.7892E-11	-2.9804E-11
XI	5.2768E-10	-3.1593E-10	-2.9409E-11	-8.4461E-12	3.9761E-12	2.3264E-11
XII	3.6141E-10	-1.6139E-10	-1.6003E-10	7.7079E-11	4.4804E-11	-2.3510E-11
XIII	1.9366E-10	-1.6394E-10	-4.6291E-12	4.4310E-11	-7.0350E-13	-9.0988E-12
XIV	8.3951E-11	-6.7982E-11	-3.4162E-12	1.5897E-11	4.9079E-13	-2.6771E-12
XV	1.6746E-11	-6.7171E-12	-8.1231E-12	3.5004E-12	2.2853E-12	-1.1067E-12
XVI	7.7310E-12	-5.7484E-12	-6.1247E-13	1.3865E-12	1.2474E-13	-2.6683E-13
Cl						
I	1.4193E-07	-1.8637E-08	-5.4395E-08	3.3056E-08	-3.5393E-09	-2.9152E-08
II	7.6144E-08	-7.1433E-08	1.3794E-08	9.3561E-09	-4.2072E-09	-1.6532E-10
III	3.2755E-08	-3.1826E-08	8.1291E-09	2.4602E-09	-2.1976E-09	5.5777E-10
IV	1.5558E-08	-1.0927E-08	6.1901E-10	-4.6838E-11	2.6811E-11	4.6987E-10
V	8.0705E-09	-7.4778E-09	2.7594E-09	-5.5810E-10	-6.5606E-10	5.4801E-10
VI	5.0345E-09	1.0730E-10	-2.1460E-09	-4.3331E-10	8.0799E-11	-5.3312E-10
VII	3.3189E-09	-2.5655E-09	-2.6397E-10	6.8171E-10	5.0306E-11	-1.4155E-10
VIII	1.5909E-09	-6.4183E-10	-6.7991E-10	2.9099E-10	1.8308E-10	-8.8004E-11
IX	1.1011E-09	-3.2631E-10	-2.7949E-10	-3.2003E-10	2.1605E-10	8.5432E-11
X	7.0666E-10	-2.7234E-10	-3.3096E-10	1.3099E-10	9.2860E-11	-4.0924E-11
XI	5.8472E-10	-3.0834E-10	-1.2456E-10	2.1761E-11	7.6006E-11	-2.3140E-11
XII	4.1553E-10	-2.4878E-10	-2.3159E-11	-6.6510E-12	3.1310E-12	1.8320E-11
XIII	2.8619E-10	-1.2780E-10	-1.2673E-10	6.1037E-11	3.5479E-11	-1.8617E-11
XIV	1.5692E-10	-1.3284E-10	-3.7509E-12	3.5903E-11	-5.7003E-13	-7.3726E-12
XV	6.8556E-11	-5.5516E-11	-2.7897E-12	1.2981E-11	4.0079E-13	-2.1862E-12
XVI	1.3852E-11	-5.5565E-12	-6.7196E-12	2.8956E-12	1.8905E-12	-9.1551E-13
XVII	6.4385E-12	-4.7873E-12	-5.1007E-13	1.1547E-12	1.0388E-13	-2.2222E-13

Table 2 --Continued

The coefficients $a_0, \ldots a_5$ in $cm^3\ s^{-1}$ of equation (6) of the text for the recommended rate coefficients.

SPECIES	a_0	a_1	a_2	a_3	a_4	a_5
Ar						
I	9.4727E-08	1.4910E-09	-5.9294E-08	1.7977E-08	1.2962E-08	-9.7203E-09
II	6.8078E-08	-5.5475E-08	1.2767E-08	-1.1473E-09	-3.0150E-09	2.8982E-09
III	3.4021E-08	-3.1916E-08	6.1629E-09	4.1802E-09	-1.8798E-09	-7.3862E-11
IV	1.4352E-08	-1.0159E-08	-3.3282E-09	5.2738E-09	-6.9996E-10	-6.8251E-10
V	1.2291E-08	-9.0236E-09	3.4114E-09	-7.5660E-10	-2.2481E-09	-2.9507E-10
VI	8.4096E-09	-5.6231E-09	3.0354E-09	-1.6819E-09	-1.9348E-09	-1.9936E-11
VII	4.4663E-09	-3.8056E-10	-1.6318E-09	-5.8093E-10	9.0244E-11	-3.2653E-10
VIII	2.3569E-09	-1.8219E-09	-1.8745E-10	4.8411E-10	3.5724E-11	-1.0052E-10
IX	1.6167E-09	-1.1602E-09	-2.1873E-10	3.4069E-10	4.7316E-11	-7.6977E-11
X	8.4111E-10	-2.4926E-10	-2.1350E-10	-2.4447E-10	1.6503E-10	6.5260E-11
XI	5.4928E-10	-2.1168E-10	-2.5725E-10	1.0182E-10	7.2179E-11	-3.1809E-11
XII	4.6315E-10	-2.4423E-10	-9.8662E-11	1.7237E-11	6.0203E-11	-1.8329E-11
XIII	3.3303E-10	-1.9939E-10	-1.8561E-11	-5.3305E-12	2.5094E-12	1.4682E-11
XIV	2.3341E-10	-1.0423E-10	-1.0335E-10	4.9780E-11	2.8936E-11	-1.5183E-11
XV	1.2891E-10	-1.0912E-10	-3.0813E-12	2.9495E-11	-4.6828E-13	-6.0566E-12
XVI	5.6757E-11	-4.5961E-11	-2.3096E-12	1.0747E-11	3.3181E-13	-1.8099E-12
XVII	1.1588E-11	-4.6481E-12	-5.6210E-12	2.4222E-12	1.5814E-12	-7.6583E-13
XVIII	5.4202E-12	-4.0302E-12	-4.2940E-13	9.7206E-13	8.7454E-14	-1.8707E-13
K						
I	3.1851E-07	-2.4952E-07	7.6952E-08	2.5702E-07	-1.6186E-07	-1.4830E-07
II	6.5732E-08	-4.6888E-08	-1.2668E-08	1.7366E-08	2.6754E-09	-4.4242E-09
III	2.0541E-08	-1.4778E-08	-1.5984E-09	3.1030E-09	3.8102E-10	-5.2306E-10
IV	1.8610E-08	-1.7459E-08	3.3712E-09	2.2866E-09	-1.0283E-09	-4.0404E-11
V	9.4108E-09	-6.4343E-09	-1.6549E-09	2.0014E-09	3.9239E-10	-4.7441E-10
VI	5.4938E-09	-3.8422E-09	-1.1147E-09	1.4001E-09	2.5416E-10	-3.5829E-10
VII	3.0251E-09	-1.9566E-09	-7.1159E-10	7.0819E-10	1.7260E-10	-1.8305E-10
VIII	2.2361E-09	-1.8119E-09	-1.3219E-11	3.8678E-10	-9.1742E-12	-6.3388E-11
IX	1.7373E-09	-1.3429E-09	-1.3817E-10	3.5684E-10	2.6333E-11	-7.4093E-11
X	1.2430E-09	-8.9199E-10	-1.6816E-10	2.6193E-10	3.6377E-11	-5.9180E-11
XI	6.5743E-10	-1.9483E-10	-1.6688E-10	-1.9108E-10	1.2899E-10	5.1009E-11
XII	4.3556E-10	-1.6786E-10	-2.0399E-10	8.0739E-11	5.7235E-11	-2.5224E-11
XIII	3.7315E-10	-1.9677E-10	-7.9492E-11	1.3887E-11	4.8505E-11	-1.4768E-11
XIV	2.7101E-10	-1.6225E-10	-1.5104E-11	-4.3378E-12	2.0420E-12	1.1948E-11
XV	1.9168E-10	-8.5596E-11	-8.4877E-11	4.0881E-11	2.3763E-11	-1.2469E-11
XVI	1.0696E-10	-9.0546E-11	-2.5567E-12	2.4473E-11	-3.8856E-13	-5.0254E-12
XVII	4.7479E-11	-3.8448E-11	-1.9320E-12	8.9904E-12	2.7757E-13	-1.5141E-12
XVIII	9.7900E-12	-3.9269E-12	-4.7489E-12	2.0464E-12	1.3361E-12	-6.4702E-13
XIX	4.6053E-12	-3.4243E-12	-3.6485E-13	8.2592E-13	7.4306E-14	-1.5895E-13

Table 2 --Continued

The coefficients $a_0, \ldots a_5$ in $cm^3 \cdot s^{-1}$ of equation (6) of the text for the recommended rate coefficients.

SPECIES	a_0	a_1	a_2	a_3	a_4	a_5
Ca						
I	2.3599E-07	-1.7877E-07	-8.1125E-08	1.0655E-07	1.6919E-08	-3.1873E-08
II	4.8987E-08	1.8455E-08	-2.2676E-08	-2.2471E-08	4.8342E-09	4.7747E-09
III	2.9640E-08	-1.9743E-08	-5.5004E-09	6.2047E-09	1.2919E-09	-1.4829E-09
IV	1.8603E-08	-1.5301E-08	2.6458E-09	2.5617E-11	-2.9638E-10	5.5017E-10
V	1.0953E-08	-1.1219E-08	3.9622E-09	-7.4867E-11	-1.6067E-09	1.0429E-09
VI	5.8549E-09	-3.9804E-09	-1.0662E-09	1.2578E-09	2.5381E-10	-3.0117E-10
VII	3.5305E-09	-2.4569E-09	-7.5056E-10	9.2066E-10	1.7166E-10	-2.3874E-10
VIII	2.1582E-09	-1.3959E-09	-5.0767E-10	5.0525E-10	1.2314E-10	-1.3059E-10
IX	1.6646E-09	-1.3487E-09	-9.8401E-12	2.8792E-10	-6.8292E-12	-4.7186E-11
X	1.3188E-09	-1.0194E-09	-1.0489E-10	2.7089E-10	1.9990E-11	-5.6245E-11
XI	7.1932E-10	-2.9020E-10	-3.0741E-10	1.3157E-10	8.2780E-11	-3.9790E-11
XII	5.2382E-10	-1.5523E-10	-1.3296E-10	-1.5224E-10	1.0278E-10	4.0641E-11
XIII	3.5130E-10	-1.3539E-10	-1.6453E-10	6.5121E-11	4.6164E-11	-2.0344E-11
XIV	3.0509E-10	-1.6088E-10	-6.4993E-11	1.1354E-11	3.9658E-11	-1.2074E-11
XV	2.2348E-10	-1.3380E-10	-1.2455E-11	-3.5770E-12	1.6839E-12	9.8525E-12
XVI	1.5953E-10	-7.1237E-11	-7.0638E-11	3.4023E-11	1.9776E-11	-1.0377E-11
XVII	8.9888E-11	-7.6092E-11	-2.1486E-12	2.0566E-11	-3.2653E-13	-4.2232E-12
XVIII	4.6410E-11	-2.7246E-11	-2.4815E-11	2.8007E-11	2.9035E-12	-8.6120E-12
XIX	8.3448E-12	-3.3472E-12	-4.0479E-12	1.7443E-12	1.1388E-12	-5.5150E-13
XX	3.9455E-12	-2.9337E-12	-3.1257E-13	7.0758E-13	6.3660E-14	-1.3617E-13
Sc						
I	5.5145E-07	-2.2728E-07	-2.1094E-07	-1.3239E-09	1.4246E-07	-3.7003E-08
II	1.5335E-07	-7.8798E-08	-2.5390E-08	3.3319E-08	-8.0219E-09	-4.4119E-09
III	6.6915E-08	-4.9200E-08	1.3241E-08	-7.7300E-09	-3.9492E-09	6.0309E-09
IV	1.4797E-08	-8.2012E-09	-4.8192E-09	3.4662E-09	1.2134E-09	-9.7295E-10
V	9.7545E-09	-5.3698E-09	-2.9586E-09	1.9771E-09	7.7446E-10	-5.3075E-10
VI	6.7758E-09	-4.8403E-09	-1.0719E-09	1.5210E-09	2.4468E-10	-3.5975E-10
VII	4.3627E-09	-2.9828E-09	-7.6719E-10	9.2779E-10	1.8190E-10	-2.1993E-10
VIII	2.7479E-09	-1.9218E-09	-5.5757E-10	7.0033E-10	1.2713E-10	-1.7921E-10
IX	1.5964E-09	-1.0325E-09	-3.7552E-10	3.7373E-10	9.1087E-11	-9.6599E-11
X	1.2741E-09	-1.0324E-09	-7.5319E-12	2.2038E-10	-5.2273E-12	-3.6117E-11
XI	1.0256E-09	-7.9277E-10	-8.1568E-11	2.1066E-10	1.5545E-11	-4.3739E-11
XII	7.7551E-10	-6.5671E-10	6.8898E-11	9.0260E-11	-2.0888E-11	-4.0258E-12
XIII	5.7465E-10	-5.0628E-10	2.2710E-11	1.1527E-10	-1.1236E-11	-1.9836E-11
XIV	4.2404E-10	-3.8729E-10	1.7966E-11	9.7481E-11	-9.5532E-12	-1.8476E-11
XV	2.8124E-10	-2.4618E-10	5.8155E-12	6.0142E-11	-4.2935E-12	-1.1183E-11
XVI	1.8254E-10	-1.5340E-10	-1.7471E-11	5.3793E-11	2.1122E-12	-1.3108E-11
XVII	8.4347E-11	-7.7782E-11	-1.9114E-11	4.1747E-11	3.0674E-12	-1.1975E-11
XVIII	4.7092E-11	-3.9093E-11	-2.3753E-12	1.1243E-11	1.4820E-13	-2.4307E-12
XIX	2.2757E-11	-1.9699E-11	4.6901E-12	3.9632E-13	-1.1919E-12	7.4282E-13
XX	4.7593E-12	-3.0027E-12	-1.2884E-12	1.2338E-12	3.0375E-13	-3.3588E-13
XXI	2.1987E-12	-1.5624E-12	-2.7937E-13	4.2405E-13	6.3593E-14	-9.1152E-14

Table 2 --Continued

The coefficients $a_0,...a_5$ in $cm^3\ s^{-1}$ of equation (6) of the text for the recommended rate coefficients.

SPECIES	a_0	a_1	a_2	a_3	a_4	a_5
Ti						
I	2.3037E-07	-1.8244E-07	2.9796E-10	1.7228E-09	2.9565E-08	-8.1807E-09
II	1.0980E-07	-7.0896E-08	-3.7028E-08	8.0039E-08	3.5894E-09	-5.3642E-08
III	4.8688E-08	-2.5032E-08	-8.0442E-09	1.0588E-08	-2.5573E-09	-1.4022E-09
IV	4.6073E-08	-3.4016E-08	4.4238E-09	-3.2846E-10	-1.4463E-09	2.0414E-09
V	1.2489E-08	-9.6233E-09	-9.9832E-10	2.5774E-09	1.8064E-10	-5.3761E-10
VI	8.3807E-09	-6.5863E-09	-5.9867E-10	1.7878E-09	9.6487E-11	-3.7506E-10
VII	5.5778E-09	-4.5356E-09	-2.4428E-10	1.1913E-09	1.9792E-11	-2.4139E-10
VIII	5.6755E-09	-3.1522E-09	-1.4754E-09	1.0051E-09	2.3068E-10	-1.0671E-09
IX	3.5768E-09	-2.9606E-09	-1.8668E-10	8.3848E-10	1.7368E-11	-1.7979E-10
X	3.8776E-09	-2.0568E-09	-3.3097E-09	2.8224E-09	1.4382E-09	-1.9709E-09
XI	2.0469E-09	-1.5876E-09	-9.9614E-11	3.7066E-10	1.5002E-11	-6.8227E-11
XII	1.2948E-09	-9.8669E-10	-1.0283E-10	2.5341E-10	2.0095E-11	-5.1307E-11
XIII	6.3061E-10	-5.3400E-10	5.6024E-11	7.3395E-11	-1.6985E-11	-3.2736E-12
XIV	4.7206E-10	-4.1590E-10	1.8656E-11	9.4694E-11	-9.2305E-12	-1.6295E-11
XV	3.5147E-10	-3.2101E-10	1.4892E-11	8.0798E-11	-7.9183E-12	-1.5314E-11
XVI	2.3561E-10	-2.0624E-10	4.8720E-12	5.0384E-11	-3.5969E-12	-9.3684E-12
XVII	1.5382E-10	-1.2926E-10	-1.4722E-11	4.5328E-11	1.7799E-12	-1.1046E-11
XVIII	7.1623E-11	-6.6049E-11	-1.6230E-11	3.5449E-11	2.6047E-12	-1.0169E-11
XIX	4.0468E-11	-3.3594E-11	-2.0411E-12	9.6615E-12	1.2736E-13	-2.0888E-12
XX	1.9555E-11	-1.6928E-11	4.0303E-12	3.4056E-13	-1.0242E-12	6.3832E-13
XXI	4.1192E-12	-2.5988E-12	-1.1151E-12	1.0678E-12	2.6289E-13	-2.9070E-13
XXII	1.9108E-12	-1.3578E-12	-2.4278E-13	3.6852E-13	5.5266E-14	-7.9215E-14
V						
I	6.1981E-07	-8.2488E-08	-1.1598E-07	-1.3021E-07	-3.7206E-08	1.6844E-08
II	1.9846E-07	-4.1114E-08	-5.7643E-08	-7.7153E-09	7.2414E-09	-1.0978E-08
III	5.8123E-08	-2.3955E-08	-2.2233E-08	-1.3954E-10	1.5016E-08	-3.9001E-09
IV	2.2000E-08	-1.1305E-08	-3.6425E-09	4.7801E-09	-1.1509E-09	-6.3295E-10
V	1.5649E-08	-1.1506E-08	3.0966E-09	-1.8077E-09	-9.2355E-10	1.4104E-09
VI	7.5159E-09	-5.0668E-09	-8.2979E-10	1.0143E-09	2.2375E-10	-1.6656E-10
VII	5.9387E-09	-4.6672E-09	-4.2423E-10	1.2669E-09	6.8373E-11	-2.6578E-10
VIII	4.0707E-09	-3.3101E-09	-1.7827E-10	8.6939E-10	1.4444E-11	-1.7617E-10
IX	4.2061E-09	-2.3325E-09	-1.0976E-09	7.4218E-10	1.7341E-10	-7.8965E-10
X	2.7447E-09	-2.2719E-09	-1.4325E-10	6.4342E-10	1.3327E-11	-1.3796E-10
XI	3.0303E-09	-1.6154E-09	-2.5988E-09	2.2336E-09	1.1310E-09	-1.5553E-09
XII	1.6337E-09	-1.2671E-09	-7.9506E-11	2.9584E-10	1.1973E-11	-5.4455E-11
XIII	1.0450E-09	-7.9636E-10	-8.2994E-11	2.0453E-10	1.6219E-11	-4.1410E-11
XIV	5.1977E-10	-4.4015E-10	4.6177E-11	6.0495E-11	-1.3999E-11	-2.6982E-12
XV	3.9253E-10	-3.4583E-10	1.5513E-11	7.8741E-11	-7.6754E-12	-1.3549E-11

Table 2 --Continued

The coefficients $a_0, \ldots a_5$ in $cm^3 s^{-1}$ of equation (6) of the text for the recommended rate coefficients.

SPECIES	a_0	a_1	a_2	a_3	a_4	a_5
Cr						
I	1.7476E-07	-9.4892E-08	-3.9137E-08	2.2035E-08	1.0542E-08	-4.5512E-09
II	6.3834E-08	-1.0496E-08	7.3496E-10	1.6572E-09	-1.5398E-08	-1.1101E-08
III	4.6487E-08	-2.3044E-08	-1.1059E-08	3.6743E-09	3.3066E-09	-5.4319E-10
IV	2.6807E-08	-1.1048E-08	-1.0254E-08	-6.4356E-11	6.9254E-09	-1.7988E-09
V	1.2173E-08	-6.2551E-09	-2.0154E-09	2.6449E-09	-6.3679E-10	-3.5022E-10
VI	9.5663E-09	-7.0338E-09	1.8930E-09	-1.1051E-09	-5.6458E-10	8.6219E-10
VII	6.0363E-09	-4.6514E-09	-4.8253E-10	1.2458E-09	8.7311E-11	-2.5985E-10
VIII	4.3538E-09	-3.4216E-09	-3.1101E-10	9.2875E-10	5.0125E-11	-1.9485E-10
IX	3.0781E-09	-2.5029E-09	-1.3482E-10	6.5739E-10	1.0929E-11	-1.3321E-10
X	3.2534E-09	-1.8002E-09	-8.5726E-10	5.7526E-10	1.3909E-10	-6.1204E-10
XI	2.1554E-09	-1.7841E-09	-1.1250E-10	5.0528E-10	1.0466E-11	-1.0834E-10
XII	2.3985E-09	-1.2780E-09	-2.0561E-09	1.7658E-09	8.9468E-10	-1.2299E-09
XIII	1.3219E-09	-1.0252E-09	-6.4330E-11	2.3937E-10	9.6879E-12	-4.4060E-11
XIV	8.5535E-10	-6.5182E-10	-6.7931E-11	1.6741E-10	1.3275E-11	-3.3894E-11
XV	4.3359E-10	-3.6716E-10	3.8520E-11	5.0464E-11	-1.1678E-11	-2.2508E-12
XVI	3.2841E-10	-2.8934E-10	1.2979E-11	6.5878E-11	-6.4216E-12	-1.1336E-11
XVII	2.4847E-10	-2.2694E-10	1.0528E-11	5.7121E-11	-5.5979E-12	-1.0826E-11
XVIII	1.6927E-10	-1.4817E-10	3.5002E-12	3.6198E-11	-2.5841E-12	-6.7306E-12
XIX	1.1217E-10	-9.4262E-11	-1.0736E-11	3.3055E-11	1.2979E-12	-8.0549E-12
XX	5.2747E-11	-4.8641E-11	-1.1953E-11	2.6107E-11	1.9182E-12	-7.4887E-12
XXI	3.0121E-11	-2.5004E-11	-1.5192E-12	7.1911E-12	9.4791E-14	-1.5547E-12
XXII	1.4729E-11	-1.2750E-11	3.0356E-12	2.5651E-13	-7.7143E-13	4.8077E-13
XXIII	3.1441E-12	-1.9836E-12	-8.5114E-13	8.1505E-13	2.0066E-13	-2.2189E-13
Mn						
I	1.4838E-07	-8.0135E-08	9.0054E-09	-9.2603E-09	1.3527E-08	-7.0058E-09
II	8.8002E-08	-1.0186E-08	-4.2403E-08	1.7210E-08	2.7747E-09	-3.8405E-09
III	5.5506E-08	-7.3560E-09	-1.0362E-08	-1.1737E-08	-3.3464E-09	1.5505E-09
IV	3.0361E-08	-6.2935E-09	-8.7940E-09	-1.1945E-09	1.0929E-09	-1.6709E-09
V	1.4971E-08	-6.1704E-09	-5.7270E-09	-3.5942E-11	3.8678E-09	-1.0046E-09
VI	7.5843E-09	-3.8971E-09	-1.2557E-09	1.6479E-09	-3.9674E-10	-2.1820E-10
VII	6.3293E-09	-4.6537E-09	1.2524E-09	-7.3115E-10	-3.7354E-10	5.7044E-10
VIII	4.4808E-09	-3.4528E-09	-3.5820E-10	9.2479E-10	6.4810E-11	-1.9290E-10
IX	3.3085E-09	-2.6001E-09	-2.3634E-10	7.0576E-10	3.8090E-11	-1.4806E-10
X	2.3818E-09	-1.9367E-09	-1.0431E-10	5.0868E-10	8.4513E-12	-1.0308E-10
XI	2.5705E-09	-1.4218E-09	-6.7835E-10	4.5470E-10	1.1052E-10	-4.8374E-10
XII	1.7230E-09	-1.4261E-09	-8.9926E-11	4.0391E-10	8.3662E-12	-8.6605E-11
XIII	1.9369E-09	-1.0318E-09	-1.6600E-09	1.4251E-09	7.2227E-10	-9.9273E-10
XIV	1.0888E-09	-8.4449E-10	-5.2989E-11	1.9717E-10	7.9799E-12	-3.6293E-11
XV	6.6471E-10	-5.2322E-10	-2.1605E-11	1.2068E-10	1.0032E-12	-2.1729E-11
XVI	3.6374E-10	-3.0801E-10	3.2315E-11	4.2335E-11	-9.7968E-12	-1.8882E-12
XV	2.7196E-10	-2.3960E-10	1.0748E-11	5.4553E-11	-5.3177E-12	-9.3874E-12
XVI	2.1207E-10	-1.9369E-10	8.9854E-12	4.8752E-11	-4.7777E-12	-9.2401E-12
XVII	1.4548E-10	-1.2734E-10	3.0083E-12	3.1111E-11	-2.2210E-12	-5.7847E-12
XVIII	9.6906E-11	-8.1434E-11	-9.2746E-12	2.8556E-11	1.1213E-12	-6.9587E-12
XIX	4.5787E-11	-4.2223E-11	-1.0376E-11	2.2662E-11	1.6651E-12	-6.5006E-12
XX	2.6314E-11	-2.1844E-11	-1.3272E-12	6.2823E-12	8.2813E-14	-1.3582E-12
XXI	1.2905E-11	-1.1171E-11	2.6596E-12	2.2474E-13	-6.7590E-13	4.2123E-13
XXII	2.7700E-12	-1.7476E-12	-7.4986E-13	7.1807E-13	1.7679E-13	-1.9549E-13

Table 2 --Continued

The Coefficients $a_0,\ldots a_5$ in $cm^3\ s^{-1}$ of equation (6) of the text for the recommended rate Coefficients.

SPECIES	a_0	a_1	a_2	a_3	a_4	a_5
Fe						
I	1.4438E-07	-8.0018E-08	-6.1752E-08	5.6502E-08	1.2350E-08	-1.7668E-08
II	4.6220E-08	-2.4962E-08	2.8052E-09	-2.8845E-09	4.2137E-09	-2.1823E-09
III	3.1854E-08	-6.5835E-09	-9.6937E-10	-9.7571E-09	4.6362E-10	3.7842E-09
IV	2.6806E-08	-3.6843E-09	-5.1535E-09	-5.3097E-09	-1.5243E-09	5.4680E-10
V	1.7044E-08	-3.5184E-09	-4.8036E-09	-8.1005E-10	5.3660E-10	-8.6145E-10
VI	1.6782E-08	-1.1367E-08	-1.0568E-09	1.3535E-09	3.8491E-10	-3.5614E-11
VII	1.1953E-08	-9.0145E-09	7.8471E-10	4.2928E-10	-1.3921E-10	2.2825E-10
VIII	7.0220E-09	-5.1840E-09	6.7396E-10	-5.0238E-11	-2.2033E-10	3.1119E-10
IX	3.4559E-09	-2.6630E-09	-2.7626E-10	7.1325E-10	4.9986E-11	-1.4878E-10
X	2.5755E-09	-2.0241E-09	-1.8398E-10	5.4941E-10	2.9652E-11	-1.1526E-10
X[a]	3.1976E-09	-1.7127E-09	-8.6297E-10	2.7782E-10	1.7720E-10	-1.2381E-10
XI	1.8841E-09	-1.5320E-09	-8.2512E-11	4.0239E-10	6.6853E-12	-8.1537E-11
XII	2.0632E-09	-1.1461E-09	-5.3609E-10	3.6543E-10	8.3700E-11	-3.8793E-10
XIII	1.4003E-09	-1.1590E-09	-7.3105E-11	3.2825E-10	6.8052E-12	-7.0384E-11
XIV	1.5835E-09	-8.3969E-10	-1.3512E-09	1.1517E-09	5.8712E-10	-8.0439E-10
XV	9.0502E-10	-7.0193E-10	-4.4043E-11	1.6388E-10	6.6328E-12	-3.0166E-11
XVI	7.0756E-10	-5.4427E-10	-6.1952E-10	1.3037E-09	1.8274E-10	-7.5815E-10
XVII	3.0926E-10	-2.6188E-10	2.7475E-11	3.5994E-11	-8.3295E-12	-1.6054E-12
XVIII	2.3635E-10	-2.0823E-10	9.3405E-12	4.7411E-11	-4.6215E-12	-8.1583E-12
XIX	1.8113E-10	-1.6543E-10	7.6745E-12	4.1639E-11	-4.0807E-12	-7.8921E-12
XX	1.2583E-10	-1.1014E-10	2.6019E-12	2.6908E-11	-1.9209E-12	-5.0032E-12
XXI	8.5117E-11	-7.1528E-11	-8.1464E-12	2.5083E-11	9.8490E-13	-6.1122E-12
XXII	4.0335E-11	-3.7195E-11	-9.1402E-12	1.9963E-11	1.4668E-12	-5.7265E-12
XXIII	2.3104E-11	-1.9180E-11	-1.1653E-12	5.5160E-12	7.2710E-14	-1.1925E-12
XXIV	1.1366E-11	-9.8394E-12	2.3426E-12	1.9795E-13	-5.9534E-13	3.7102E-13
XXV	2.4528E-12	-1.5475E-12	-6.6399E-13	6.3583E-13	1.5654E-13	-1.7310E-13
XXVI	1.1533E-12	-8.1952E-13	-1.4654E-13	2.2243E-13	3.3357E-14	-4.7812E-14
Co						
I	1.6480E-07	-6.9856E-08	-2.3434E-08	4.5391E-08	-2.3208E-08	-3.9506E-09
II	9.6359E-08	-3.7217E-08	-1.7784E-08	-3.9764E-09	5.2883E-09	2.7130E-09
III	5.2454E-08	-1.3506E-08	-6.2987E-09	-3.4530E-09	-2.0283E-09	-1.2264E-09
IV	1.4814E-08	-1.7147E-09	-7.1381E-09	2.8970E-09	4.6709E-10	-6.4650E-10
V	1.5637E-08	-1.5529E-09	-2.6640E-09	-3.8074E-09	-1.2160E-09	5.4113E-10
VI	1.1790E-08	-1.9547E-09	-5.2327E-09	1.6775E-10	1.5619E-09	-1.0700E-09
VII	6.2949E-09	-2.5944E-09	-2.4079E-09	-1.5112E-11	1.6262E-09	-4.2239E-10
VIII	3.5698E-09	-1.8343E-09	-5.9105E-10	7.7564E-10	-1.8674E-10	-1.0271E-10
IX	3.2466E-09	-2.3871E-09	6.4244E-10	-3.7504E-10	-1.9160E-10	2.9261E-10
X	2.6910E-09	-2.0736E-09	-2.1511E-10	5.5538E-10	3.8922E-11	-1.1585E-10
XI	2.0517E-09	-1.6124E-09	-1.4656E-10	4.3767E-10	2.3622E-11	-9.1821E-11
XII	1.5131E-09	-1.2303E-09	-6.6264E-11	3.2315E-10	5.3688E-12	-6.5482E-11
XIII	1.6850E-09	-9.3202E-10	-4.4471E-10	2.9802E-10	7.2463E-11	-3.1708E 10
XIV	1.1528E-09	-9.5417E-10	-6.0165E-11	2.7023E-10	5.5974E-12	-5.7943E-11
XV	1.3188E-09	-7.0271E-10	-1.1306E-09	9.7097E-10	4.9194E-10	-6.7628E-10
XVI	7.6318E-10	-5.9192E-10	-3.7141E-11	1.3820E-10	5.5933E-12	-2.5438E-11
XVII	4.5951E-10	-3.3070E-10	-4.9416E-11	8.4544E-11	1.0901E 11	-1.7275E-11
XVIII	2.6508E-10	-2.2447E-10	2.3550E-11	3.0853E-11	-7.1397E-12	-1.3761E-12

[a]includes contributions from metastable ions (see text).

Table 2 --Continued

The coefficients $a_0,...a_5$ in $cm^3\ s^{-1}$ of equation (6) of the text for the recommended rate coefficients.

SPECIES	a_0	a_1	a_2	a_3	a_4	a_5
Ni						
I	1.1655E-07	-3.9394E-08	-6.9896E-08	3.4807E-08	1.7806E-08	-1.1861E-08
II	4.6772E-08	-1.9826E-08	-6.6507E-09	1.2882E-08	-6.5867E-09	-1.1212E-09
III	3.1226E-08	-1.2061E-08	-5.7631E-09	-1.2886E-09	1.7137E-09	8.7919E-10
IV	2.4688E-08	-7.2247E-09	-2.3266E-09	-6.6474E-10	-1.3530E-09	-1.0559E-09
V	8.1992E-09	-9.4906E-10	-3.9507E-09	1.6034E-09	2.5852E-10	-3.5782E-10
VI	9.4899E-09	-1.5693E-09	-1.4282E-09	-1.7224E-09	-7.9560E-10	1.3403E-10
VII	7.9357E-09	-1.3089E-09	-3.5502E-09	1.2384E-10	1.0690E-09	-7.2708E-10
VIII	4.4730E-09	-1.8435E-09	-1.7110E-09	-1.0738E-11	1.1556E-09	-3.0014E-10
IX	2.6192E-09	-1.3458E-09	-4.3365E-10	5.6908E-10	-1.3701E-10	-7.5354E-11
X	2.4493E-09	-1.8009E-09	4.8466E-10	-2.8294E-10	-1.4455E-10	2.2075E-10
XI	2.1454E-09	-1.6532E-09	-1.7150E-10	4.4279E-10	3.1031E-11	-9.2362E-11
XII	1.6548E-09	-1.3005E-09	-1.1821E-10	3.5301E-10	1.9052E-11	-7.4059E-11
XIII	1.2384E-09	-1.0070E-09	-5.4237E-11	2.6449E-10	4.3943E-12	-5.3596E-11
XIV	1.3942E-09	-7.7133E-10	-3.6759E-10	2.4655E-10	5.9741E-11	-2.6231E-10
XV	9.6101E-10	-7.9545E-10	-5.0157E-11	2.2528E-10	4.6663E-12	-4.8305E-11
XVI	1.1078E-09	-5.8895E-10	-9.4984E-10	8.1444E-10	4.1319E-10	-5.6768E-10
XVII	6.4800E-10	-5.0259E-10	-3.1536E-11	1.1734E-10	4.7492E-12	-2.1599E-11
XVIII	4.3068E-10	-3.2820E-10	-3.4204E-11	8.4292E-11	6.6843E-12	-1.7066E-11
XIX	2.2895E-10	-1.9387E-10	2.0340E-11	2.6647E-11	-6.1664E-12	-1.1885E-12
XX	1.7983E-10	-1.5843E-10	7.1068E-12	3.6073E-11	-3.5163E-12	-6.2073E-12
XXI	1.3881E-10	-1.2678E-10	5.8813E-12	3.1910E-11	-3.1272E-12	-6.0481E-12
XXII	9.7064E-11	-8.4964E-11	2.0071E-12	2.0757E-11	-1.4818E-12	-3.8596E-12
XXIII	6.5266E-11	-5.4846E-11	-6.2464E-12	1.9233E-11	7.5519E-13	-4.6867E-12
XXIV	3.1201E-11	-2.8773E-11	-7.0704E-12	1.5443E-11	1.1347E-12	-4.4298E-12
XXV	1.8048E-11	-1.4982E-11	-9.1032E-13	4.3089E-12	5.6799E-14	-9.3158E-13
XXVI	8.9580E-12	-7.7545E-12	1.8462E-12	1.5601E-13	-4.6919E-13	2.9241E-13

Table 3

The parameters α, β_0, β_1 and β_2 in $cm^3\ s^{-1}$ of equation(7) of the text for the recommended rate coefficients.

SPECIES	α	β_0	β_1	β_2
H I	2.4617E-08	9.5987E-08	-9.2464E-07	3.9974E-06
He I	3.1373E-08	4.7894E-08	-7.7361E-07	3.7367E-06
He II	3.0755E-09	1.1892E-08	-1.1505E-07	5.0451E-07
Li I	4.5456E-08	2.7800E-07	-1.5830E-06	5.4652E-06
Li II	7.3446E-09	5.3440E-10	-5.6346E-08	2.9555E-07
Li III	1.9755E-09	-1.0918E-09	8.8579E-10	6.0762E-09
Be I	2.1732E-07	-2.1648E-07	2.8113E-07	5.3070E-07
Be II	6.4891E-08	-1.1198E-07	6.4469E-07	-1.9617E-06
Be III	2.7903E-09	-2.4350E-10	-9.8088E-09	5.2155E-08
Be IV	8.3329E-10	-4.6056E-10	3.7364E-10	2.5630E-09
B I	3.0952E-07	-4.9239E-07	1.3750E-06	-2.5382E-06
B II	4.8123E-08	-4.1483E-08	5.5408E-08	1.0022E-07
B III	1.1270E-08	-9.8068E-09	9.3591E-09	4.9053E-08
B IV	1.2752E-09	-1.1129E-10	-4.4828E-09	2.3836E-08
B V	4.2656E-10	-2.3576E-10	1.9126E-10	1.3120E-09
C I	3.7442E-07	-6.5826E-07	2.0520E-06	-4.4688E-06
C II	6.0150E-08	-4.0215E-08	-2.7928E-08	5.5510E-07
C III	1.4438E-08	-5.3357E-09	-1.0432E-08	1.0585E-07
C III[a]	1.7372E-08	-1.5019E-08	4.1269E-08	-8.8550E-08
C IV	5.8147E-09	-5.5184E-09	-4.9521E-09	8.9187E-08
C V	6.8613E-10	-5.9877E-11	-2.4120E-09	1.2825E-08
C VI	2.4680E-10	-1.3641E-10	1.1066E-10	7.5911E-10
N I	2.7367E-07	-4.2976E-07	9.8343E-07	-9.5697E-07
N II	4.4713E-08	3.0447E-08	-5.2724E-07	2.4876E-06
N III	1.0237E-08	3.4197E-08	-2.9137E-07	1.2317E-06
N IV	7.9790E-09	-4.9210E-09	6.3774E-09	1.4940E-08
N IV[a]	3.8072E-09	1.5620E-08	-1.4346E-07	6.1961E-07
N V	5.7833E-09	-8.5338E-09	1.8667E-08	-1.0922E-08
N VI	4.1067E-10	-3.5838E-11	-1.4436E-09	7.6760E-09
N VII	1.5538E-10	-8.5878E-11	6.9670E-11	4.7792E-10
O I	3.2684E-07	-6.7409E-07	2.3910E-06	-6.0366E-06
O II	4.9066E-08	2.1777E-08	-5.4684E-07	2.7249E-06
O III	1.7523E-08	2.7812E-08	-3.1460E-07	1.4290E-06
O IV	1.0268E-08	4.8158E-10	-4.3931E-08	2.1921E-07
O IV[a]	6.6074E-09	1.6482E-08	-1.7855E-07	8.0360E-07
O V	4.0023E-09	-1.5956E-09	-7.2622E-10	1.9731E-08
O V[a]	2.0855E-09	7.7560E-09	-4.8817E-08	1.7611E-07
O VI	9.3640E-10	4.2792E-10	1.3924E-09	-5.9247E-09
O VII	2.6498E-10	-2.3124E-11	-9.3150E-10	4.9530E-09
O VIII	1.0406E-10	-5.7515E-11	4.6660E-11	3.2007E-10

[a]include contributions from metastable ions (see text).

Table 3 --Continued

The parameters α, β_0, β_1 and β_2 in cm^3 s^{-1} of equation(7) of the text for the recommended rate coefficients.

SPECIES	α	β_0	β_1	β_2
F I	1.5983E-07	-1.7137E-07	2.4310E-07	3.5797E-07
F II	6.5335E-08	-2.4577E-08	-1.2451E-07	8.5803E-07
F III	2.7519E-08	-4.2937E-09	-1.0914E-07	6.1649E-07
F IV	8.7700E-09	1.3920E-08	-1.5746E-07	7.1521E-07
F V	6.5767E-09	-2.0089E-10	-2.4124E-08	1.2489E-07
F VI	2.3742E-09	-1.0723E-09	7.6167E-10	6.3073E-09
F VII	8.9229E-10	-3.5857E-10	9.4272E-10	1.7592E-09
F VIII	1.8081E-10	-1.5779E-11	-6.3560E-10	3.3796E-09
F IX	7.3063E-11	-4.0382E-11	3.2760E-11	2.2473E-10
Ne I	1.4653E-07	-1.8777E-07	1.5661E-08	1.9135E-06
Ne II	6.8776E-08	-6.7699E-08	-5.8184E-08	9.9526E-07
Ne III	4.9004E-08	-6.2454E-08	9.7285E-08	1.2381E-07
Ne IV	5.9079E-09	3.1706E-08	-3.0211E-07	1.3212E-06
Ne V	5.0312E-09	7.9856E-09	-9.0330E-08	4.1030E-07
Ne VI	3.5235E-09	1.6526E-10	-1.5076E-08	7.5226E-08
Ne VII	1.6501E-09	-7.7528E-10	6.4215E-10	4.2509E-09
Ne VIII	1.1711E-09	-1.5638E-09	6.5758E-09	-1.9520E-08
Ne IX	1.4296E-10	-6.4412E-11	-1.9539E-10	1.5283E-09
Ne X	5.7831E-11	-3.4043E-11	2.7058E-11	1.8361E-10
Na I	4.5717E-07	-7.1069E-07	2.9812E-06	-8.8617E-06
Na II	7.7410E-08	-1.2865E-07	4.3354E-07	-1.1049E-06
Na III	3.0835E-08	-1.2713E-08	-4.6939E-08	3.3613E-07
Na IV	1.3735E-08	-5.1667E-09	-2.6175E-08	1.8038E-07
Na V	3.2338E-09	1.7364E-08	-1.6545E-07	7.2351E-07
Na VI	3.1583E-09	5.0129E-09	-5.6704E-08	2.5756E-07
Na VII	2.6679E-09	-8.1494E-11	-9.7859E-09	5.0662E-08
Na VIII	1.1330E-09	-4.5171E-10	-2.0559E-10	5.5859E-09
Na IX	4.3301E-10	-1.7401E-10	4.5748E-10	-8.5371E-10
Na X	1.0018E-10	-5.2739E-11	3.9007E-11	2.6865E-10
Na XI	3.9987E-11	-2.2101E-11	1.7930E-11	1.2299E-10
Mg I	1.5438E-07	1.1452E-06	-7.7060E-06	2.9787E-05
Mg II	1.0316E-07	-2.0686E-07	6.7435E-07	-1.4370E-06
Mg III	4.0946E-08	-6.0569E-08	2.2281E-07	-6.4160E-07
Mg IV	1.6353E-08	-6.7389E-09	-2.4939E-08	1.7844E-07
Mg V	8.0475E-09	-3.0272E-09	-1.5336E-08	1.0569E-07
Mg VI	2.0626E-09	1.1075E-08	-1.0553E-07	4.6147E-07
Mg VII	2.1145E-09	3.3562E-09	-3.7964E-08	1.7244E-07
Mg VIII	1.8521E-09	-5.6574E-11	-6.7934E-09	3.5170E-08
Mg IX	8.1918E-10	-3.2659E-10	-1.4864E-10	4.0386E-09
Mg X	3.4285E-10	-1.7295E-10	1.4048E-10	1.0354E-09
Mg XI	8.4151E-11	-4.5992E-11	-1.0480E-10	9.4380E-10
Mg XII	3.0787E-11	-1.7016E-11	1.3804E-11	9.4694E-11

Table 3 --Continued

The parameters α, β_0, β_1 and β_2 in $cm^3\ s^{-1}$ of equation(7) of the text for the recommended rate coefficients.

SPECIES	α	β_0	β_1	β_2
Al I	5.3461E-07	-3.3911E-07	-8.2783E-08	4.4186E-06
Al II	4.0646E-08	-1.4667E-08	7.1283E-08	-1.7912E-07
Al III	4.4271E-08	-6.7959E-08	1.3572E-07	-2.5467E-08
Al IV	1.8889E-08	-1.3881E-08	8.7837E-09	8.0277E-08
Al V	9.8114E-09	-4.0452E-09	-1.4935E-08	1.0695E-07
Al VI	6.1582E-09	-2.4963E-09	-9.3384E-09	7.0632E-08
Al VII	1.4011E-09	7.5191E-09	-7.1645E-08	3.1331E-07
Al VIII	2.7919E-09	-3.7030E-09	2.0150E-08	-7.6661E-08
Al IX	6.7744E-10	1.0052E-09	-5.9183E-09	2.0515E-08
Al X	5.0645E-10	2.3786E-10	-3.8152E-09	1.7220E-08
Al XI	5.1666E-10	-6.8352E-10	1.6857E-09	-2.2334E-09
Al XII	7.1084E-11	-4.7764E-11	4.1002E-11	1.5861E-10
Al XIII	2.4203E-11	-1.3377E-11	1.0852E-11	7.4443E-11
Si I	4.5234E-07	-2.8674E-07	2.6614E-08	3.0515E-06
Si II	1.1849E-07	-7.5156E-08	-1.8347E-08	9.7928E-07
Si III	4.1697E-08	-2.1015E-08	1.6161E-08	1.2797E-07
Si IV	2.7879E-08	-3.0290E-08	6.6071E-08	-4.3121E-08
Si V	1.3097E-08	-1.9374E-08	7.1268E-08	-2.0522E-07
Si VI	6.3678E-09	-2.6255E-09	-9.6934E-09	6.9415E-08
Si VII	3.4907E-09	-1.3131E-09	-6.6522E-09	4.5842E-08
Si VIII	9.9567E-10	5.3435E-09	-5.0915E-08	2.2266E-07
Si IX	1.0843E-09	1.7211E-09	-1.9468E-08	8.8430E-08
Si X	9.9844E-10	-3.0498E-11	-3.6623E-09	1.8960E-08
Si XI	4.6838E-10	-1.8673E-10	-8.4989E-11	2.3091E-09
Si XII	1.8772E-10	-7.5439E-11	1.9833E-10	-3.7011E-10
Si XIII	4.4259E-11	-3.8624E-12	-1.5558E-10	8.2728E-10
Si XIV	1.9368E-11	-1.0705E-11	8.6844E-12	5.9572E-11
P I	3.3563E-07	-1.2750E-07	-1.0304E-07	2.1480E-06
P II	1.2011E-07	-7.6139E-08	7.0671E-09	8.1029E-07
P III	4.7224E-08	-2.9954E-08	-7.3125E-09	3.9031E-07
P IV	1.9768E-08	-9.8569E-09	7.5290E-09	6.0656E-08
P V	1.1577E-08	-4.1379E-09	-3.6184E-09	5.9782E-08
P VI	7.1582E-09	-5.3386E-09	3.3358E-09	3.0926E-08
P VII	4.3783E-09	-1.8052E-09	-6.6648E-09	4.7727E-08
P VIII	2.4826E-09	-9.3389E-10	-4.7311E-09	3.2603E-08
P IX	7.3334E-10	3.9356E-09	-3.7500E-08	1.6399E-07
P X	8.1564E-10	1.2946E-09	-1.4644E-08	6.6516E-08
P XI	7.6457E-10	-2.3355E-11	-2.8045E-09	1.4519E-08
P XII	3.3686E-10	-1.1454E-10	7.8651E-11	7.3998E-10
P XIII	1.4857E-10	-5.9704E-11	1.5697E-10	-2.9292E-10
P XIV	3.5629E-11	-3.1092E-12	-1.2525E-10	6.6596E-10
P XV	1.5738E-11	-8.6985E-12	7.0568E-12	4.8408E-11

Table 3 --Continued

The parameters α, β_0, β_1 and β_2 in $cm^2 s^{-1}$ of equation(7) of the text for the recommended rate coefficients.

SPECIES	α	β_0	β_1	β_2
S I	6.3216E-07	-1.2178E-06	4.3144E-06	-1.0841E-05
S II	1.0119E-07	-3.8443E-08	-3.1066E-08	6.4763E-07
S III	5.4238E-08	-2.5651E-08	-8.0491E-08	7.0568E-07
S IV	2.4069E-08	-1.5267E-08	-3.7270E-09	1.9893E-07
S V	1.0929E-08	-1.8560E-09	-7.8981E-09	7.1849E-08
S VI	7.3463E-09	-2.6258E-09	-2.2961E-09	3.7936E-08
S VII	4.9750E-09	-3.7104E-09	2.3184E-09	2.1494E-08
S VIII	3.1442E-09	-1.2964E-09	-4.7863E-09	3.4275E-08
S IX	1.8305E-09	-6.8856E-10	-3.4883E-09	2.4039E-08
S X	5.5596E-10	2.9836E-09	-2.8429E-08	1.2432E-07
S XI	6.2898E-10	9.9832E-10	-1.1293E-08	5.1294E-08
S XII	5.9851E-10	-1.8282E-11	-2.1953E-09	1.1365E-08
S XIII	2.6866E-10	-9.1349E-11	6.2726E-11	5.9015E-10
S XIV	1.1957E-10	-4.8052E-11	1.2633E-10	-2.3575E-10
S XV	2.9101E-11	-2.5396E-12	-1.0230E-10	5.4395E-10
S XVI	1.2966E-11	-7.1661E-12	5.8137E-12	3.9880E-11
Cl I	4.5655E-07	-5.3482E-07	1.1889E-06	-8.3208E-07
Cl II	1.2015E-07	-8.2545E-08	2.0277E-07	-1.8255E-07
Cl III	4.5742E-08	-1.7377E-08	-1.4043E-08	2.9274E-07
Cl IV	2.8522E-08	-1.3489E-08	-4.2329E-08	3.7110E-07
Cl V	1.4025E-08	-8.8960E-09	-2.1717E-09	1.1592E-07
Cl VI	1.0784E-08	-7.0403E-09	9.2842E-09	3.9130E-08
Cl VII	4.9742E-09	-1.7779E-09	-1.5547E-09	2.5686E-08
Cl VIII	3.6032E-09	-2.6873E-09	1.6791E-09	1.5567E-08
Cl IX	2.3372E-09	-9.6362E-10	-3.5577E-09	2.5477E-08
Cl X	1.3893E-09	-5.2260E-10	-2.6475E-09	1.8245E-08
Cl XI	4.3166E-10	2.3166E-09	-2.2074E-08	9.6530E-08
Cl XII	4.9529E-10	7.8614E-10	-8.8925E-09	4.0392E-08
Cl XIII	4.7394E-10	-1.4477E-11	-1.7384E-09	8.9999E-09
Cl XIV	2.1769E-10	-7.4019E-11	5.0826E-11	4.7819E-10
Cl XV	9.7647E-11	-3.9240E-11	1.0317E-10	-1.9252E-10
Cl XVI	2.4073E-11	-2.1008E-12	-8.4623E-11	4.4996E-10
Cl XVII	1.0798E-11	-5.9680E-12	4.8417E-12	3.3212E-11

Table 3 --Continued

The parameters α, β_0, β_1 and β_2 in cm^3 s^{-1} of equation(7) of the text for the recommended rate coefficients.

SPECIES	α	β_0	β_1	β_2
Ar I	4.2289E-07	-5.8297E-07	1.2344E-06	-7.2826E-07
Ar II	1.1797E-07	-6.2819E-08	3.5545E-09	6.4742E-07
Ar III	5.3683E-08	-3.6881E-08	9.0599E-08	-8.1562E-08
Ar IV	2.0984E-08	-5.9493E-09	3.2025E-09	3.5037E-08
Ar V	1.3241E-08	-4.8558E-10	4.2300E-09	1.5412E-08
Ar VI	8.9221E-09	-4.5833E-10	-1.7639E-08	1.4964E-07
Ar VII	5.2507E-09	-2.6181E-09	1.9998E-09	1.6111E-08
Ar VIII	5.6316E-09	-8.5833E-09	2.4557E-08	-4.8193E-08
Ar IX	2.7063E-09	-1.4709E-09	1.4175E-09	6.5592E-09
Ar X	1.7853E-09	-7.3608E-10	-2.7177E-09	1.9461E-08
Ar XI	1.0799E-09	-4.0621E-10	-2.0579E-09	1.4181E-08
Ar XII	3.4191E-10	1.8349E-09	-1.7484E-08	7.6459E-08
Ar XIII	3.9696E-10	6.3005E-10	-7.1269E-09	3.2372E-08
Ar XIV	3.8653E-10	-1.1807E-11	-1.4178E-09	7.3400E-09
Ar XV	1.7883E-10	-6.0806E-11	4.1753E-11	3.9283E-10
Ar XVI	8.0841E-11	-3.2487E-11	8.5410E-11	-1.5938E-10
Ar XVII	2.0137E-11	-1.7573E-12	-7.0788E-11	3.7640E-10
Ar XVIII	9.0904E-12	-5.0242E-12	4.0760E-12	2.7960E-11
K I	4.5489E-07	-2.5113E-07	1.2623E-07	3.1916E-06
K II	1.0657E-07	-6.3591E-08	6.3742E-08	2.6213E-07
K III	3.5871E-08	-2.0550E-08	9.0010E-09	1.5644E-07
K IV	2.9365E-08	-2.0174E-08	4.9559E-08	-4.4615E-08
K V	1.5625E-08	-7.2622E-09	-1.1146E-09	7.3772E-08
K VI	8.3583E-09	-2.7147E-09	-3.7374E-09	4.3439E-08
K VII	5.0401E 09	2.1976E-09	-1.1938E-09	2.6024E-08
K VIII	3.4989E-09	-1.7297E-09	1.3139E-09	1.0734E-08
K IX	4.1511E-09	-6.3251E-09	1.8095E-08	-3.5506E-08
K X	2.0806E-09	-1.1308E-09	1.0898E-09	5.0428E-09
K XI	1.3954E-09	-5.7534E-10	-2.1242E-09	1.5212E-08
K XII	8.5629E-10	-3.2211E-10	-1.6318E-09	1.1245E-08
K XIII	2.7547E-10	1.4784E-09	-1.4087E-08	6.1603E-08
K XIV	3.2303E-10	5.1272E-10	-5.7997E-09	2.6344E-08
K XV	3.1743E-10	-9.6963E-12	-1.1643E-09	6.0278E-09
K XVI	1.4838E-10	-5.0454E-11	3.4645E-11	3.2595E-10
K XVII	6.7626E-11	-2.7176E-11	7.1449E-11	-1.3333E-10
K XVIII	1.7013E-11	-1.4847E-12	-5.9806E-11	3.1800E-10
K XIX	7.7237E-12	-4.2689E-12	3.4632E-12	2.3756E-11

Table 3 --Continued

The parameters α, β_0 , β_1 and β_2 in $cm^3\ s^{-1}$ of equation(7) of the text for the recommended rate coefficients.

SPECIES	α	β_0	β_1	β_2
Ca I	2.1359E-07	1.7715E-07	-7.5822E-07	1.9334E-06
Ca II	1.1091E-07	1.7203E-07	-2.5824E-06	1.2200E-05
Ca III	5.2633E-08	-3.1408E-08	3.1482E-08	1.2947E-07
Ca IV	3.0852E-08	-1.6428E-08	9.2956E-10	1.6931E-07
Ca V	8.9311E-09	1.1108E-08	-6.4426E-08	2.4660E-07
Ca VI	9.7146E-09	-4.4593E-09	-1.0232E-09	4.6913E-08
Ca VII	5.3283E-09	-1.6249E-09	-2.7978E-09	2.8676E-08
Ca VIII	3.5957E-09	-1.5678E-09	-8.5166E-10	1.8566E-08
Ca IX	2.6046E-09	-1.2875E-09	9.7805E-10	7.9904E-09
Ca X	1.9765E-09	-7.0647E-10	-6.1778E-10	1.0207E-08
Ca XI	1.6292E-09	-1.2150E-09	7.5921E-10	7.0386E-09
Ca XII	1.1118E-09	-4.5841E-10	-1.6925E-09	1.2120E-08
Ca XIII	6.9065E-10	-2.5980E-10	-1.3162E-09	9.0701E-09
Ca XIV	2.2523E-10	1.2087E-09	-1.1517E-08	5.0367E-08
Ca XV	2.6637E-10	4.2279E-10	-4.7824E-09	2.1723E-08
Ca XVI	2.6418E-10	-8.0696E-12	-9.6901E-10	5.0166E-09
Ca XVII	1.2470E-10	-4.2400E-11	2.9114E-11	2.7392E-10
Ca XVIII	1.1002E-10	-1.4680E-10	6.2240E-10	-1.8381E-09
Ca XIX	1.4502E-11	-1.2655E-12	-5.0977E-11	2.7106E-10
Ca XX	6.6171E-12	-3.6572E-12	2.9670E-12	2.0353E-11
Sc I	1.1555E-06	-7.8499E-07	5.9763E-07	3.1513E-06
Sc II	4.2032E-07	-3.0961E-07	-1.2505E-06	1.0362E-05
Sc III	1.2868E-07	-6.0400E-08	-2.8938E-07	2.2600E-06
Sc IV	2.7863E-08	-1.6335E-08	7.5355E-09	1.0632E-07
Sc V	1.8317E-08	-9.8180E-09	-4.7193E-09	1.1369E-07
Sc VI	1.0526E-08	-3.8468E-09	-4.2395E-09	5.8049E-08
Sc VII	7.2434E-09	-3.3666E-09	-5.1672E-10	3.4199E-08
Sc VIII	4.1807E-09	-1.3578E-09	-1.8694E-09	2.1728E-08
Sc IX	2.6598E-09	-1.1597E-09	-6.2997E-10	1.3733E-08
Sc X	1.9936E-09	-9.8552E-10	7.4863E-10	6.1161E-09
Sc XI	1.5371E-09	-5.4940E-10	-4.8042E-10	7.9374E-09
Sc XII	1.2817E-09	-7.9240E-10	1.0265E-09	2.9414E-09
Sc XIII	8.0312E-10	-3.1205E-10	3.4526E-10	1.4745E-09
Sc XIV	5.3529E-10	-1.2616E-10	7.2686E-11	1.0093E-09
Sc XV	3.8782E-10	-1.4049E-10	1.4898E-10	6.8044E-10
Sc XVI	2.2779E-10	-3.2907E-11	-3.1356E-11	4.4079E-10
Sc XVII	3.4954E-11	1.3834E-10	-4.4096E-10	8.8406E-10
Sc XVIII	6.5579E-11	-2.1705E-11	1.1936E-11	1.5064E-10
Sc XIX	4.1882E-11	-3.2379E-11	4.5202E-11	1.1039E-10
Sc XX	8.2174E-12	-4.3668E-12	3.6119E-12	1.9837E-11
Sc XXI	3.7123E-12	-1.9623E-12	9.8849E-13	1.3689E-11

Table 3 --Continued

The parameters α, β_0, β_1 and β_2 in $cm^3\ s^{-1}$ of equation(7) of the text for the recommended rate coefficients.

SPECIES	α	β_0	β_1	β_2
Ti I	3.1088E-07	-7.2891E-08	-4.7033E-08	7.0474E-07
Ti II	1.8184E-07	-1.6910E-07	3.5426E-07	3.5956E-07
Ti III	1.3353E-07	-9.8556E-08	-3.9593E-07	3.2869E-06
Ti IV	8.4432E-08	-4.1998E-08	-1.1327E-07	1.0714E-06
Ti V	1.9345E-08	-8.5172E-09	2.9625E-09	6.7742E-08
Ti VI	1.2609E-08	-5.1053E-09	1.1929E-09	4.3813E-08
Ti VII	8.1471E-09	-3.1182E-09	1.0030E-09	2.5848E-08
Ti VIII	3.5359E-11	1.6356E-08	-8.7909E-08	3.4271E-07
Ti IX	4.8240E-09	-1.1152E-09	-2.0296E-09	2.1814E-08
Ti X	2.4170E-09	2.3674E-09	-1.6504E-08	9.9520E-08
Ti XI	3.3039E-09	-1.7128E-09	1.3613E-09	9.9067E-09
Ti XII	2.0263E-09	-8.8180E-10	-1.9440E-11	8.7792E-09
Ti XIII	1.0422E-09	-6.4434E-10	8.3468E-10	2.3918E-09
Ti XIV	6.5974E-10	-2.5634E-10	2.8362E-10	1.2112E-09
Ti XV	4.4369E-10	-1.0457E-10	6.0247E-11	8.3657E-10
Ti XVI	3.2489E-10	-1.1769E-10	1.2481E-10	5.7004E-10
Ti XVII	1.9195E-10	-2.7729E-11	-2.6422E-11	3.7143E-10
Ti XVIII	2.9681E-11	1.1747E-10	-3.7444E-10	7.5070E-10
Ti XIX	5.6354E-11	-1.8652E-11	1.0257E-11	1.2945E-10
Ti XX	3.5990E-11	-2.7824E-11	3.8843E-11	9.4863E-11
Ti XXI	7.1121E-12	-3.7794E-12	3.1261E-12	1.7169E-11
Ti XXII	3.2262E-12	-1.7053E-12	8.5905E-13	1.1897E-11
V I	1.3253E-06	-6.5540E-07	-2.2345E-07	7.8098E-06
V II	5.0616E-07	-4.4484E-07	7.0105E-07	8.3178E-07
V III	1.2179E-07	-8.2739E-08	6.2990E-08	3.3215E-07
V IV	6.0300E-08	-4.4418E-08	-1.7940E-07	1.4866E-06
V V	3.0092E-08	-1.4125E-08	-6.7675E-08	5.2852E-07
V VI	1.3673E-08	-7.8799E-09	-2.6209E-10	7.9074E-08
V VII	8.9348E-09	-3.6177E-09	8.4532E-10	3.1046E-08
V VIII	5.9458E-09	-2.2757E-09	7.3201E-10	1.8864E-08
V IX	2.6222E-11	1.2129E-08	-6.5200E-08	2.5415E-07
V X	3.7018E-09	-8.5577E-10	-1.5574E-09	1.6740E-08
V XI	1.8876E-09	1.8489E-09	-1.2901E-08	7.7750E-08
V XII	2.6370E-09	-1.3671E-09	1.0865E-09	7.9069E-09
V XIII	1.6355E-09	-7.1171E-10	-1.5690E-11	7.0858E-09
V XIV	8.5905E-10	-5.3109E-10	6.8798E-10	1.9714E-09
V XV	5.4860E-10	-2.1316E-10	2.3584E-10	1.0072E-09

Table 3 --Continued

The parameters α, β_0, β_1 and β_2 in $cm^3\ s^{-1}$ of equation(7) of the text for the recommended rate coefficients.

SPECIES	α	β_0	β_1	β_2
Cr I	3.9118E-07	-3.3201E-07	4.6472E-07	7.3151E-07
Cr II	1.7355E-07	-1.5842E-07	8.3745E-08	1.5538E-06
Cr III	1.0329E-07	-7.4557E-08	6.0232E-10	7.1560E-07
Cr IV	5.6173E-08	-3.8160E-08	2.9052E-08	1.5319E-07
Cr V	3.3365E-08	-2.4577E-08	-9.9264E-08	8.2255E-07
Cr VI	1.8396E-08	-8.6349E-09	-4.1371E-08	3.2309E-07
Cr VII	9.3502E-09	-4.1167E-09	1.4319E-09	3.2742E-08
Cr VIII	6.5503E-09	-2.6522E-09	6.1972E-10	2.2761E-08
Cr IX	4.4961E-09	-1.7210E-09	5.5383E-10	1.4265E-08
Cr X	2.0301E-11	9.3903E-09	-5.0481E-08	1.9676E-07
Cr XI	2.9070E-09	-6.7204E-10	-1.2231E-09	1.3146E-08
Cr XII	1.4941E-09	1.4635E-09	-1.0212E-08	6.1544E-08
Cr XIII	2.1336E-09	-1.1061E-09	8.7911E-10	6.3976E-09
Cr XIV	1.3386E-09	-5.8254E-10	-1.2842E-11	5.7997E-09
Cr XV	7.1661E-10	-4.4303E-10	5.7390E-10	1.6445E-09
Cr XVI	4.5898E-10	-1.7834E-10	1.9732E-10	8.4266E-10
Cr XVII	3.1367E-10	-7.3926E-11	4.2592E-11	5.9142E-10
Cr XVIII	2.3341E-10	-8.4555E-11	8.9668E-11	4.0954E-10
Cr XIX	1.3998E-10	-2.0221E-11	-1.9267E-11	2.7086E-10
Cr XX	2.1858E-11	8.6512E-11	-2.7576E-10	5.5285E-10
Cr XXI	4.1945E-11	-1.3883E-11	7.6345E-12	9.6349E-11
Cr XXII	2.7107E-11	-2.0957E-11	2.9256E-11	7.1449E-11
Cr XXIII	5.4286E-12	-2.8848E-12	2.3861E-12	1.3105E-11
Mn I	7.0111E-07	-1.2292E-06	3.4885E-06	-5.9540E-06
Mn II	4.7821E-07	-8.4558E-07	2.7007E-06	-5.9470E-06
Mn III	1.1872E-07	-5.8705E-08	-2.0119E-08	6.9997E-07
Mn IV	7.7437E-08	-6.8056E-08	1.0726E-07	1.2727E-07
Mn V	3.1372E-08	-2.1312E-08	1.6225E-08	8.5555E-08
Mn VI	2.0788E-08	-1.5312E-08	-6.1845E-08	5.1248E-07
Mn VII	1.2171E-08	-5.7130E-09	-2.7372E-08	2.1376E-07
Mn VIII	6.9407E-09	-3.0556E-09	1.0622E-09	2.4306E-08
Mn IX	4.9776E-09	-2.0154E-09	4.7093E-10	1.7296E-08
Mn X	3.4789E-09	-1.3315E-09	4.2830E-10	1.1037E-08
Mn XI	1.6041E-11	7.4201E-09	-3.9891E-08	1.5548E-07
Mn XII	2.3238E-09	-5.3721E-10	-9.7768E-10	1.0508E-08
Mn XIII	1.2066E-09	1.1819E-09	-8.2462E-09	4.9700E-08
Mn XIV	1.7575E-09	-9.1112E-10	7.2412E-10	5.2698E-09
Mn XV	1.1116E-09	-6.9644E-10	1.2131E-09	5.3504E-10
Mn XVI	6.0117E-10	-3.7166E-10	4.8145E-10	1.3796E-09
Mn XV	3.8008E-10	-1.4768E-10	1.6340E-10	6.9780E-10
Mn XVI	2.6771E-10	-6.3095E-11	3.6352E-11	5.0477E-10
Mn XVII	2.0061E-10	-7.2672E-11	7.7066E-11	3.5198E-10
Mn XVIII	1.2093E-10	-1.7469E-11	-1.6645E-11	2.3400E-10
Mn XIX	1.8974E-11	7.5096E-11	-2.3937E-10	4.7990E-10
Mn XX	3.6644E-11	-1.2128E-11	6.6697E-12	8.4173E-11
Mn XXI	2.3750E-11	-1.8361E-11	2.5633E-11	6.2601E-11
Mn XXII	4.7827E-12	-2.5415E-12	2.1022E-12	1.1545E-11

Table 3 --Continued

The parameters α, β_0, β_1 and β_2 in $cm^3\ s^{-1}$ of equation(7) of the text for the recommended rate coefficients.

SPECIES	α	β_0	β_1	β_2
Fe I	3.4615E-07	-4.3391E-07	1.7618E-06	-5.3387E-06
Fe II	2.1839E 07	3.8290E 07	1.0867E 06	-1.8547E-06
Fe III	1.7440E-07	-3.0831E-07	9.7983E-07	-2.1350E-06
Fe IV	5.7171E-08	-2.8314E-08	-8.8711E-09	3.3389E-07
Fe V	4.3518E-08	-3.8256E-08	6.0497E-08	7.0196E-08
Fe VI	2.9872E-08	-1.3735E-08	-3.2735E-08	3.1433E-07
Fe VII	2.2084E-08	-1.3772E-08	-2.4295E-09	1.5878E-07
Fe VIII	1.2868E-08	-6.3969E-09	-1.7293E-08	1.6341E-07
Fe IX	5.3531E-09	-2.3566E-09	8.1922E-10	1.8746E-08
Fe X	3.8749E-09	-1.5690E-09	3.6660E-10	1.3464E-08
Fe X[a]	3.0753E-09	1.8735E-09	-3.2075E-09	1.2798E-09
Fe XI	2.7519E-09	-1.0533E-09	3.3880E-10	8.7309E-09
Fe XII	1.2853E-11	5.9454E-09	-3.1955E-08	1.2457E-07
Fe XIII	1.8887E-09	-4.3681E-10	-7.9390E-10	8.5387E-09
Fe XIV	9.8710E-10	9.6683E-10	-6.7401E-09	4.0644E-08
Fe XV	1.4608E-09	-7.5731E-10	6.0188E-10	4.3801E-09
Fe XVI	1.3093E-09	1.3465E-10	-1.5877E-08	9.2218E-08
Fe XVII	5.1112E-10	-3.1599E-10	4.0934E-10	1.1730E-09
Fe XVIII	3.3031E-10	-1.2834E-10	1.4200E-10	6.0644E-10
Fe XIX	2.2865E-10	-5.3890E-11	3.1048E-11	4.3113E-10
Fe XX	1.7351E-10	-6.2854E-11	6.6654E-11	3.0443E-10
Fe XXI	1.0622E-10	-1.5344E-11	-1.4621E-11	2.0553E-10
Fe XXII	1.6715E-11	6.6154E-11	-2.1087E-10	4.2276E-10
Fe XXIII	3.2174E-11	-1.0649E-11	5.8561E-12	7.3905E-11
Fe XXIV	2.0919E-11	-1.6173E-11	2.2577E-11	5.5139E-11
Fe XXV	4.2349E-12	-2.2505E-12	1.8614E-12	1.0223E-11
Fe XXVI	1.9472E-12	-1.0293E-12	5.1849E-13	7.1805E-12
Co I	8.1357E-07	-1.3676E-06	3.5156E-06	-4.4266E-06
Co II	3.2793E-07	-4.4021E-07	1.1180E-06	-1.5995E-06
Co III	1.4860E-07	-1.0720E-07	-2.2348E-07	2.2694E-06
Co IV	8.0501E-08	-1.4234E-07	4.5462E-07	-1.0011E-06
Co V	3.3983E-08	-1.6955E-08	-4.0129E-09	1.9331E-07
Co VI	3.0228E-08	-2.6592E-08	4.1751E-08	4.6664E-08
Co VII	1.3191E-08	-8.9608E-09	6.8220E-09	3.5972E-08
Co VIII	9.7845E-09	-7.2074E-09	-2.9110E-08	2.4122E-07
Co IX	6.2430E-09	-2.9305E-09	-1.4040E-08	1.0965E-07
Co X	4.1682E-09	-1.8350E-09	6.3789E-10	1.4597E-08
Co XI	3.0868E-09	-1.2499E-09	2.9204E-10	1.0726E-08
Co XII	2.2100E-09	-8.4587E-10	2.7209E-10	7.0117E-09
Co XIII	1.0516E-11	4.8642E-09	-2.6150E-08	1.0192E-07
Co XIV	1.5547E-09	-3.5942E-10	-6.5412E-10	7.0305E-09
Co XV	8.2156E-10	8.0472E-10	-5.6149E-09	3.3840E-08
Co XVI	1.2319E-09	-6.3862E-10	5.0755E-10	3.6937E-09
Co XVII	7.8873E-10	-4.5240E-10	3.9552E-10	2.3136E-09
Co XVIII	4.3812E-10	-2.7086E-10	3.5087E-10	1.0054E-09

[a]includes contributions from metastable ions (see text).

Table 3 --Continued

The parameters α, β_0, β_1 and β_2 in $cm^3\ s^{-1}$ of equation(7) of the text for the recommended rate coefficients.

SPECIES	α	β_0	β_1	β_2
Ni I	2.6366E-07	-2.0322E-07	2.7985E-07	2.6778E-07
Ni II	2.3090E-07	-3.8813E-07	9.9775E-07	1.2563E-06
Ni III	1.0627E-07	-1.4265E-07	3.6229E-07	5.1833E-07
Ni IV	6.9061E-08	-4.9755E-08	-1.0610E-07	1.0766E-06
Ni V	4.4555E-08	-7.8783E-08	2.5162E-07	5.5408E-07
Ni VI	2.0100E-08	-9.9498E-09	-3.0294E-09	1.1756E-07
Ni VII	2.0347E-08	-1.7900E-08	2.8098E-08	3.1384E-08
Ni VIII	9.3730E-09	-6.3674E-09	4.8476E-09	2.5561E-08
Ni IX	7.1788E-09	-5.2880E-09	-2.1358E-08	1.7698E-07
Ni X	4.7098E-09	-2.2108E-09	-1.0592E-08	8.2721E-08
Ni XI	3.3232E-09	-1.4630E-09	5.0857E-10	1.1638E-08
Ni XII	2.4897E-09	-1.0081E-09	2.3555E-10	8.6511E-09
Ni XIII	1.8089E-09	-6.9233E-10	2.2270E-10	5.7389E-09
Ni XIV	8.6999E-12	4.0242E-09	-2.1634E-08	8.4321E-08
Ni XV	1.2961E-09	-2.9963E-10	-5.4531E-10	5.8610E-09
Ni XVI	6.9216E-10	6.7400E-10	-4.7117E-09	2.8411E-08
Ni XVII	1.0460E-09	-5.4224E-10	4.3095E-10	3.1362E-09
Ni XVIII	6.7402E-10	-2.9331E-10	-6.4663E-12	2.9202E-09
Ni XIX	3.7839E-10	-2.3393E-10	3.0304E-10	8.6836E-10
Ni XX	2.5132E-10	-9.7652E-11	1.0805E-10	4.6142E-10
Ni XXI	1.7523E-10	-4.1299E-11	2.3794E-11	3.3039E-10
Ni XXII	1.3385E-10	-4.8487E-11	5.1419E-11	2.3484E-10
Ni XXIII	8.1444E-11	-1.1765E-11	-1.1211E-11	1.5760E-10
Ni XXIV	1.2930E-11	5.1174E-11	-1.6312E-10	3.2703E-10
Ni XXV	2.5133E-11	-8.3186E-12	4.5746E-12	5.7732E-11
Ni XXVI	1.6487E-11	-1.2746E-11	1.7793E-11	4.3456E-11

6. Review of Data Sources

In this section, we describe the experimental and theoretical data available for each species and outline the decisions made in determining a recommended curve. The data were analyzed within isoelectronic sequences and our recommended cross sections are discussed and presented in this way. Each recommended curve is illustrated graphically together with a representative selection of the assessed data. The collection and analysis of data was completed on 31 August 1987.

6.1. The Hydrogen Sequence

Ne X: The only available data for Ne X are the experimental measurements of Donets and Ovsyannikov[27] and the DWBX calculations of Younger.[28] The experimental points were determined using a trapped ion technique and appear in many cases to present an overestimate of the electron ionization cross section. Therefore, our recommended curve favors the calculation of Younger.[28]

Fe XXVI: The DWBX calculation of Younger[29] is the only data available and therefore our recommended curve is a fit to these points.

F IX, Na XI–Ca XX: Recommended cross sections for these members of the hydrogen sequence are obtained by using $A = 4.0 \times 10^{-14}$ eV^2 cm^2 and $B_i = 0$ for all i in Eq. (1), which accurately simulates the Younger[4] calculations for C VI and agrees well with his calculations for Ne X.

Sc XXI–Ni XXVIII: Recommended cross sections for ions in this region of the sequence are obtained by classically scaling the Younger[29] calculations for Fe XXVI.

6.2. The Helium Sequence

Ne IX: The trapped ion results of Donets and Ovsyannikov[27] and the empirical data points of Chandra and Narain[30] differ in both magnitude and energy dependence over most of the energy range. Our recommended curve is based on careful consideration of the scaled cross sections for this sequence.

Na X: We recommend the DWBX calculation of Younger.[4]

Mg XI: In this case our recommended curve is a fit through the empirical points of Chandra and Narain.[30] Analysis of the scaled cross sections for this sequence lends confidence to this recommendation.

Al XII: We recommend the Born approximation calculation of McGuire.[31]

Fe XXV: Our recommended curve is a fit to the DWBX calculation of Younger.[4]

F VIII, Si XIII–Ca XIX: For these ions our recommended cross sections have been obtained by scaling the B IV curve according to classical scaling laws.

Sc XX–Ni XXVII: Our recommended cross sections are derived by classical scaling of the Fe XXV curve.

6.3. The Lithium Sequence

Ne VIII: Our recommended curve follows the data of Chantrenne *et al.*[32] The cross section exhibits a sharp increase in magnitude at about five times threshold energy where the $1s\,2s^2\ {}^2S$, $1s\,2s\ ({}^1S)\ 2p$, $1s\,2s\ ({}^3S)\ 2p\ {}^2P$ states give rise to autoionization. At high energies the trapped ion results of Donets and Ovsyannikov[27] lie on the recommended curve.

Mg X: The DWBX cross section of Younger[4] is recommended for Mg X.

Al XI: The theoretical data of McGuire[31] are the only data available.

Fe XXIV: As for Mg X, the DWBX results of Younger[33] are recommended.

F VII, Na IX, Si XII–Ca XVIII: In the absence of any data for these ions, our recommended cross sections are derived from scaling the O VI curve without the autoionization contribution.

Sc XIX–Ni XXVI: The recommended cross sections for these ions are obtained by scaling the Fe XXIV results using classical scaling laws.

6.4. The Beryllium Sequence

F VI: Our recommended curve follows the DWBX calculation of Younger[5] up to 1000 eV and is extrapolated to 10 keV using Eq. (2).

Ne VII: The Coulomb–Born calculation of Jakubowicz and Moores[20] is the data on which we base our recommendation up to 1 keV. This curve is extrapolated to 10 keV using Eq. (2) and is seen to lie 15%–20% lower than the experimental results of Donets and Ovsyannikov.[27]

Al X: In the absence of any experimental data we recommend the Born approximation results of McGuire.[31]

Ar XV: The DWBX calculation of Younger[5] is the only data available. Our recommended curve is a fit to these results and is in good agreement with the scaled data for other ions in this sequence.

Fe XXIII: The CBX calculation of Jakubowicz[20] and DWBX calculation of Younger[5] predict ionization cross sections of the same overall energy dependence but greatly differing magnitudes. Our recommendation is based on the data of Younger.[5]

Na VIII, Mg IX, Si XI: There are no data for these ions of the beryllium sequence and our recommended cross sections are derived from scaling the O V curve classically.

P XII–Ca XVII: For this group of ions we recommend cross sections based on classical scaling of the Ar XV cross section.

Sc XVIII–Ni XXV: Again, we must rely on scaling the Fe XXIII curve to obtain recommended cross sections for these ions for which there are no data available.

6.5. The Boron Sequence

Ne VI: In the absence of any reliable data our recommended curve is derived from the curve for O IV by classical scaling.

Al IX: We recommend the theoretical results of McGuire[31] in the absence of experimental results.

Fe XXII: The DWBX calculation of Younger[29] is the basis for our recommended cross sections.

F V, Na VII, Mg VIII, Si X–Ca XVI: Our recommended cross sections for these ions are an empirical estimate based on an analysis of the scaled cross-section data.

Sc XVII–Ni XXIV: We scale the Fe XXII curve to obtain cross sections for the ions in this sequence.

6.6. The Carbon Sequence

Ne V: Our recommended curve which predicts cross sections up to 35% lower than the high-energy values of Donets and Ovsyannikov,[27] is derived from scaling the O III curve.

Al VIII: The calculations of McGuire[31] are the recommended cross sections.

Fe XXI: We recommend the DWBX results of Younger.[29]

F IV, Na VI, Mg VII, Si IX–Ca XV: For each of these ions, for which no data exist we obtain recommended cross sections by scaling the O III curve.

Sc XVI–Ni XXIII: In this region of the carbon sequence we obtain recommended cross sections by scaling the Fe XXI curve.

6.7. The Nitrogen Sequence

F III: Our recommended curve is a fit to the recent crossed beam experimental data of Mueller *et al.*[34]

Ne IV: There are three sets of experimental data for Ne IV; the results of Donets *et al.*[27] and Hasted and Awad[35] were obtained using a trapped ion technique and are not independently absolute. Our recommended curve favors the crossed beam data of Gregory *et al.*[36] and merges smoothly with the calculation of McGuire[31] above 1 keV. It should be noted that in the experiment of Gregory *et al.*,[36] it was not possible to extract the ground state cross section from the measured values which include contributions from the $2p^3\ {}^2D^0$ and $2p^3\ {}^2P^0$ metastable ions. The effect of these ions is expected to be small at high energies where the cross section is slowly varying; however, the initial rise in the cross section near threshold may be shifted or broadened due to the metastable content of the beam. Our recommended curve, therefore, does not represent a ground state cross-section recommendation.

Fe XX: We rely on the DWBX calculation of Younger[29] for our recommended values.

Na V–Ca XIV: For these ions our recommended cross sections are obtained by classical scaling of the Ne IV recommended curve.

Sc IV–Ni XXII: Again, there are no data for ions in this region except the DWBX results of Younger.[29] We therefore recommend cross sections for these ions by scaling the isoelectronic Fe XX curve.

6.8. The Oxygen Sequence

Ne III: Of the three sets of experimental data shown, we recommend the crossed beam measurements of Danjo *et al.*[37] The remaining measurements of Hasted and Awad[35] and Donets and Ovsyannikov[27] were carried out using the less reliable trapped ion technique.

Al VI: As for some other aluminum ions we have only the theoretical data of McGuire[31] on which to base our recommendation.

Fe XIX: The DWBX calculation of Younger[29] is recommended.

F II, Na IV, Mg V, Si VII–Ca XIII: In the absence of any data for these ions our recommended cross sections are an empirical estimate based on an analysis of the scaled cross-section data.

Sc XIV–Ni XXI: Recommended cross sections for these ions are obtained by classical scaling of the Fe XIX recommended curve.

6.9. The Fluorine Sequence

F I: The recent data of Hayes *et al.*[38] are fitted in two sections and extrapolated to 10 keV using Eq. (2). Agreement with the Born approximation of McGuire[39] is very good.

Ne II: Of the three absolute cross-section measurements available, Muller *et al.*,[40] Dolder *et al.*[41] and Diserens *et al.*,[42] our recommended curve favors the most recent crossed beam measurements of Diserens *et al.*[42] These experimental results agree very closely with the high-energy Coulomb–Born results of Moores.[43]

Na III: In the absence of any experimental measurements, we base our recommended cross sections on the results of Moores.[43]

Fe XVIII: The Younger[29] calculation is recommended.

F I, Mg IV–Ca XII: Our recommended cross sections for these ions are obtained by scaling the Na III recommended curve.

Sc XIII–Ni XX: The Fe XVIII recommended curve is scaled classically to provide recommended cross sections for these ions.

6.10. The Neon Sequence

Ne I: In recommending cross sections for this species we take account of the long standing data of Bleakney[44] and more recent measurements of Stephan, Helm, and Mark.[45] Both sets of data are in good agreement at very low energies but differ in magnitude at the peak of the cross section by 25%. At high energies our recommended curve merges with the calculation of McGuire.[39]

Na II: Our recommended cross sections are based on the crossed beam data of Peart and Dolder[46] and Hooper *et al.*[47] which are in good agreement with one another over the entire energy range. At high energies the experimental work merges with the theoretical results of Moores.[43]

Mg III: As for Na II, our recommendation is based on the work of Peart, Martin, and Dolder[48] which agrees with the high-energy results of Moores.[43]

Al IV: Of the two theoretical data sets, we favor the DWBX values of Younger[49] at low energy due to the correct threshold cutoff behavior. Above 1 keV, the two data sets agree very closely lending confidence to the recommendation.

Ar IX: We rely on the DWBX calculation of Younger[49] for our recommended cross-section values.

Fe XVII: As for Ar IX, we have only the calculation of Younger on which to base our recommendation.

Si V–Cl VIII, K X–Ca XI: For these ions, our recommended cross sections are obtained by adopting an empirical estimate based on an analysis of the scaled cross sections.

Sc XII–Ni XIX: The Fe XVII recommended curve is scaled classically to obtain recommended cross sections for these ions.

6.11. The Sodium Sequence

Na I: Our recommended curve follows the crossed beam data of Zapesochnyi and Aleksakhin[50] up to 30 eV and the high-energy values of McFarland and Kinney[51] out to 500 eV. The curve is extrapolated to high energies using Eq. (2).

Mg II: The crossed beam experiments of Martin, Peart, and Dolder[52] and of Crandall *et al.*[53] are seen to be in reasonable absolute agreement. Our recommended curve favors the more recent, more detailed measurements which in spite of the lack of definitive structure show a substantial increase in the ionization cross section in the region 50–55 eV, approximately 18% greater than the estimate of the cross section for the direct ionization process.

Al III: As for Mg II, we recommend the data of Crandall *et al.*,[53] and extrapolation of this fit shows reasonable agreement with the high-energy results of McGuire.[31] Unlike Mg II, the anticipated excitation autoionization structures are more apparent in the data and do occur as sharp steps within the estimated 2-eV experimental energy spread.

Si IV: Our recommended curve is a fit in two distinct regions to the data of Crandall *et al.*[53] The excitation–autoionization resonances are again apparent in the data in the region of the $2p$ excitation threshold, 100–135 eV.

Fe XVI: The data of Gregory *et al.*[54] show that indirect processes dominate the ionization of Fe^{15+} with excitation–autoionization accounting for up to 75% or more of the total cross section in the energy range studied. However, the uncertainties involved in predicting these cross sections is reflected in our error estimate, a factor of 3.

P V–Sc XI: For the remaining ions in this sequence we adopt an empirical estimate for the recommended cross sections by analysis of the scaled cross-section data.

Ti XIII–Mn XV, Co XVII, Ni XVIII: Due to the evidence from Crandall *et al.*[53] that the relative importance of induced processes increases with increasing charge, we adopt a second scaling curve for these high Z ions.

6.12. The Magnesium Sequence

Mg I: Our recommended curve follows the only experimental data available for Mg I, that of Karstensen and Schneider.[55]

Al II: The recommended cross section for Al II is that due to Montague and Harrison.[56] Their data points are the derived ground state cross-section values having adjusted their actual measurements for the presence of an estimated 9% fraction of metastable $3s3p\ ^3(P_{0,2})$ ions in the primary beam.

S V: The experimental data of Howald *et al.*[57] have been fitted through the threshold for removal of one electron from the ground state $1s$ level of S^{4+} at 72.7 eV. The observed threshold near 62.5 eV indicates that there is a substantial metastable $3s$, $3p$, ^3P population in the S^{4+} beam. The cross section is fitted in two sections to allow for the abrupt change in slope near 170 eV, which marks the onset of indirect excitation–autoionization attributed to $2p$-nl excitation. The apparent additional structure at 550 eV is unexplained.

Cl VI: As for S V we recommend the recent data of Howald *et al.*[57]; an allowance for the presence of a significant metastable $3p$ population with a threshold of 85 eV is made by fitting through 97 eV, the ionization threshold for the ground $3s^2\ ^1S$ level. The fit is again in two parts, the excitation–autoionization contribution appearing at 200 eV.

Ar VII: The experimental data of Howald *et al.*[57] are fitted in two parts to provide recommended cross sections. The low-energy region 1–240 eV if fitted through the threshold for ground state ionization of Ar^{6+}. The high-energy region 240–1500 eV, fitted separately, shows a large excitation–autoionization contribution; the importance of this effect is seen to increase markedly along the magnesium sequence.

Sc X, Fe XV: The DWBX results of Younger[26] are recommended in the absence of any experimental data.

Si III, P IV, K VIII, Ca IX: Recommended cross sections for these ions are based on scaling the Sc X data.

Ti XI–Mn XIV, Co XVI, Ni XVII: We scale the Fe XV cross sections to provide recommended cross sections for these ions.

6.13. The Aluminum Sequence

Ar VI: Our recommended curve is a fit to the recent crossed beam measurements of Gregory *et al.*[58]

Sc IX: We rely on the DWBX calculation of Younger[26] for our recommended cross sections.

Al I–Cl V: We obtain recommended cross sections by scaling the Ar VI curve.

Fe XIV: The data shown are the distorted-wave direct ionization calculation for $3s^2\ 3p$ ground state ions by Younger[26] and the experimental measurements of Gregory *et al.*[54] also for a ground state beam. The contribution of indirect processes constitutes over 50% of the total peak cross section. Our fit is to the experimental data of Gregory *et al.*[54] in two sections. Below the threshold for ionization by indirect processes (690 eV), the distorted-wave calculation agrees well with experiment.

K VII, Ca VIII: For these ions we scale the Sc IX curve to provide recommended cross sections.

Ti X–Ni XVI: The recommended Fe XIV curve is scaled to provide recommended cross sections for these ions.

6.14. The Silicon Sequence

Ar V: The data of Crandall *et al.*[21] are fitted in two distinct regions to provide our recommended cross sections. The data of Muller *et al.*[40] are consistently lower than that of Crandall *et al.*[21] above 200 eV, the onset of excitation–autoionization.

Sc VIII, Fe XIII: Our recommended curve follows the calculation of Younger.[26]

Si I–Cl IV: We scale the Ar V cross section without the autoionization contribution to provide recommended cross sections for these ions.

K VI–Ca VII: The Sc VIII curve is scaled classically.

Ti IX–Ni XV: To obtain recommendations for these ions we scale the Fe XIII curve.

6.15. The Phosphorous Sequence

Cl III: We recommend the recent crossed beam data of Mueller *et al.*[34]

Ar IV: Of the two sets of absolute experimental measurements, Muller *et al.*[40] and Gregory *et al.*[36] we recommend the latter. The two data sets are in very good agreement from threshold, 59.8 to 80 eV, but differ in magnitude by about 20% over the higher energy range. It should be noted that an unknown fraction of metastable $3p^3\ ^2D^0$ and $3p^3\ ^2P^0$ ions was possible for both experiments and as indicated by Gregory *et al.*[32] the effect of these ions may be to shift or broaden the initial rise in the cross section near threshold. At high energies where the cross section is slowly varying, little effect is expected in the measured cross section due to metastables in the beam.

Sc VII: The Younger[26] calculations provide the data for the recommended cross sections.

Fe XII: Gregory *et al.*[54] have measured this ionization cross section for an incident ion beam containing a mixture of ground state ($3s^2\ 3p^3$) and metastable $3s^2\ 3p^2\ 3d$ ions. The onset of excitation–autoionization above 700 eV is marked and contributes as much as 30% of the total near the peak cross section. However, their data lies 20% higher than the calculation of Pindzola *et al.*[59] for a ground state ion beam.

We provide fit parameters to the data of Gregory *et al.*[54] but recommend a fit based on a cross section 20% lower overall in keeping with a ground state ion prediction.

P I, S II: The recommended values for these ions are derived from the scaled Cl III curve.

K V, Ca VI: We obtain the recommended cross sections by scaling the Sc VII curve.

Ti VIII–Ni XIV: Classical scaling of the Fe XII ground state curve provided recommended cross sections for this group of ions.

6.16. The Sulfur Sequence

S I: Our recommended curve is a best fit to the experimental data of Ziegler *et al.*[60]

Ar III: For Ar III, there is very good agreement between the various cross beam measurements of the cross section over the low-energy region. The trapped ion measurements of Hasted and Awad[35] appear to be an overestimate of the cross section as observed earlier for other species. Our recommended curve favors the data of Diserens *et al.*[42] and Mueller *et al.*[34] over the entire energy range and is extrapolated to 10 keV using Eq. (2).

Sc VI, Fe XI: The DWBX calculation of Younger[26] provides the only possible data for these species.

Cl II–Ca V: The Ar III curve is scaled classically to provide recommended cross sections for these ions.

Ti VII–Ni XIII: Again, we scale the Younger[26] data for Fe XI to obtain recommended cross sections.

6.17. The Chlorine Sequence

Cl I: The experimental data of Hayes *et al.*[38] is recommended.

Ar II: Our recommended curve follows the data of Woodruff *et al.*[61] and Mann *et al.*[62] Despite the excellent agreement between Woodruff,[61] Mann,[62] and Muller[40] in the threshold region, there is a marked discrepancy between their measurements over the high-energy range. This effect has been noted before in the data of Muller *et al.*[40] for Ar V, Ar IV, and Ar III. The uncertainty in the peak cross section is illustrated by the error bars.

K III: In the absence of experimental data we recommend the DWBX calculation of Younger.[29]

Sc V, Fe X: For Sc V, our recommended curve follows the calculated values of Younger.[26] The crossed beam data of Gregory *et al.*[63] for *Fe X* is known to contain significant contribution from metastable ions. Therefore, our recommended curve for the ground state cross sections for this species is based on the calculated values of Younger.[26] However, we have calculated rate coefficients based on the experimental data and these are presented in the tables together with the estimates for ground state ionization described above.

Cl I, Ca IV: The recommendations for these ions are obtained by scaling the Ar II recommended curve.

Ti VI–Ni XII: Our recommended Fe X curve is scaled for these ions.

6.18. The Argon Sequence

Ar I: Our recommended curve takes account of several experimental measurements which show good agreements both at threshold and high energy. Our curve is a fit to the data of Wetzel *et al.*[64] up to 200 eV. At high energies the data of Rapp *et al.*[65] and Bleakney[44] have been fitted and extrapolated to 10 keV. The error bars indicate the degree of uncertainty in the peak cross section.

K II: For K II, the available experimental measurements are in good agreement over much of the energy range, with the exception of the peak region where our fit favors the recent data of Hirayama *et al.*[66] Between 60 eV and 150 eV the data points of Peart and Dolder[46] lie just within the error bars of the earlier work by Hooper *et al.*[47] and Hirayama *et al.*[66] overlap within experimental error limits. Agreement is particularly good in the high-energy region.

Sc IV, V VI, Fe IX: The work of Younger[67] for V VI and Younger[26] for Sc IV and Fe IX is recommended in the absence of any experimental data.

Ca III: We scale the K II recommended curve to provide recommended cross sections for Ca III.

Ti V, Cr VII–Ni XI: The Fe IX recommended curve is scaled to obtain our recommended values for ions in this region of the argon isoelectronic sequence.

6.19. The Potassium Sequence

K I: Our recommended curve follows the crossed beam data of Zapesochnyi and Aleksakhin[50] up to 30 eV and the work of McFarland and Kinney[51] up to 500 eV. The complex structure in the cross section around 10–20 eV is accounted for by p electron excitation of the alkali atom followed by its ionization with ejection of the p electron.

Ca II: The ionization cross section is dominated by a very abrupt rise centered at 27.5 eV. This marks the onset of autoionization, in particular the Ca^+ $3p^6 4s$ level is excited to Ca^+ $3p^5 3d(^3P)4s\,^2P$ at a threshold of 24.95 eV. Our recommended curve is a fit in two distinct regions to the data of Peart *et al.*[68]

Ti IV: The recommended curve is a fit to the experimental points of Falk *et al.*[69] For this species, excitation–autoionization involving $n=0$ transitions, $np^6 nd^m \rightarrow np^5 nd^{m+1}$, completely dominate the ionization processes. It is noted that a metastable content of $<10\%$ was estimated by examining the cross section below the threshold for ionization of the ground state, and using Lotz formula estimates for ionization from metastable states. This proportion of metastable ions was believed to have an insignificant effect on the cross section.

Sc III, V V–Ni X: In the absence of any data for these ions we adopt an empirical estimate of the cross section based on an analysis of the scaled cross-section data. For Fe VIII consideration of the shell structure of iron, which is very apparent in the graph of rate coefficients for this species, prompted us to recommend cross sections for Fe VIII which are scaled directly from the Ti IV curve.

6.20. The Calcium Sequence

Ca I: For Ca I our recommended curve is a fit to the Born approximation of McGuire.[70]

Ti III: Our recommended curve is a fit to the recent crossed beam results of Diserens *et al.*,[71] which is substantiated by the recently published data of Mueller *et al.*[34]

Fe VII: The recent experimental data of Gregory *et al.*[63] are recommended for this species.

Sc II, V IV–Mn VI, Co VIII, Ni IX: To recommend cross sections for these ions, careful consideration was given to the scaled cross-section curves for the experimental data in this sequence. The Ti III and Fe VII curves are seen to differ by a factor of 2. However, in the recent measurements of Gregory *et al.*[63] for Fe VII, the cross section is thought to be considerably enhanced due to the autoionizing $3p$–$4p$ transition. Indeed, using the Fe VII curve to scale cross sections for Co VIII and NI IX produces rate coefficients in excess of those for Co VII and Ni VIII, respectively.

We have therefore decided to use the Ti III curve as a scaling curve for the calciumlike ions but quote an uncertainty of 300%.

6.21. The Scandium Sequence

Ti II: The cross section measurements of Diserens *et al.*[42] have been fitted in two distinct regions to provide our recommended cross sections for Ti II.

Fe VI: The recent experimental data of Gregory *et al.*[63] are recommended for this species.

Sc I, V III–Mn V, Co VII, Ni VIII: Our recommended cross sections for these ions are based on an empirical scaling curve chosen by consideration of the available scaled data for this sequence. The scaled curves for Ti II and Fe VI differ by a factor of 4 in magnitude. Our choice of scaling curve, for which we quote an uncertainty of 300%, lies roughly midway between these two curves. This case reflects the difficulty encountered in predicting cross sections for cases where autoionization may play an important role.

6.22. The Titanium Sequence

Ti I: Our recommended curve follows the McGuire[70] calculation as for Ca I.

Fe V: This very recent data by Pindzola *et al.*[72] are recommended for Fe V in the absence of any experimental measurements.

V II–Ni VII: We scale the Fe V data to provide recommended cross sections for these ions.

6.23. The Vanadium Sequence

Cr II: The experimental data of Mann *et al.*[62] are fitted in two sections. Excitation–autoionization processes enhance the cross section in the region above 40 eV. Some further structure is observed around 300 eV the origin of which is uncertain.

Fe IV: The calculation of Pindzola *et al.*[72] is recommended for this ion.

V I–Ni VI: For all other ions in this sequence we derive recommended cross sections by scaling the Fe IV curve.

6.24. The Chromium Sequence

Cr I: The McGuire[70] calculation is recommended in the absence of any experimental data.

Fe III: We produce recommended cross sections based on a fit to the data of Mueller *et al.*[34] using a threshold energy of 30.65 eV.

Mn II, Co IV, Ni V: We scale the Fe III recommended curve to produce recommended cross sections for these ions.

6.25. The Manganese Sequence

Fe II: The experimental measurements of Montague *et al.*[73] are fitted to produce recommended cross sections for Fe II. It should be noted that in this experiment the target beam contained a substantial component of metastable ^4D and other long-lived excited Fe^+ ions in addition to the ground state ^6D ions. However, Montague *et al.*[73] concludes that the measured cross section is insensitive to the presence of these excited ions, at least at electron energies above 30 eV.

Ni IV: Our recommended curve follows the experimental data of Gregory and Howald.[74]

Co III: This recommended cross section is derived by scaling the Fe II recommended curve.

6.26. The Iron Sequence

Fe I: Our recommended cross sections are derived from a fit to the calculation of McGuire.[70]

Ni III: The calculation due to Burke *et al.*[9] is the sum of the direct ionization process obtained using the Lotz formula and the excitation–autoionization contribution obtained by a seven-state R-matrix calculation. A similar method used for Ni IV, produced cross sections 30% larger than the values obtained experimentally. The Lotz formula for direct ionization may be the reason for this discrepancy. We therefore recommend the distorted-wave calculation of Pindzola[72] for the direct ionization process.

Co II: We scale the Ni III recommended curve to obtain cross sections for electron ionization of Co II.

7. Belfast Database

The ionization data described in this paper are part of the Belfast Database on Atomic and Molecular Physics. The database will be kept up-to-date on the computers at Queen's University, Belfast. Requests for data on for on-line access to the database may be made in writing to Dr. M. A. Lennon, Department of Computer Science, Queen's University of Belfast.

8. Acknowledgments

This work was supported by the United Kingdom Atomic Energy Authority, Culham Laboratory under Contract No. CUL/351. Our thanks are due to Mr. M. F. A. Harrison for his expert advice and critical comment on the work described in this paper. Additionally, we would like to thank Dr. D. H. Crandall and his co-workers at the Oak Ridge National Laboratory for informing us of their recent experimental work, and Dr. D. C. Gregory at the same establishment for providing a copy of a recent report and data on iron prior to publication.

9. Appendix A: Ionization via Autoionizing Levels

Some ionization cross sections such as for Ca^+ are anomalously large due to the fact that as well as direct ionization

$$e + Ca^+ \rightarrow Ca^{2+} + e + e,$$

we also have a contribution from ionization via autoionizing levels. In this process an electron is first excited to a resonance level, which is above the first ionization potential

$$e + Ca^+ \rightarrow e + (Ca^+)^{**}.$$

The resonance level then autoionizes leaving the ion in a higher state of ionization

$$(Ca^+)^{**} \rightarrow Ca^{2+} + e.$$

This type of process has been studied both experimentally and theoretically. It has been observed experimentally that autoionization is important for the ionization of Ca^+, Ti^{3+}, Mg^+, Al^{2+}, and Si^{3+}. Theoretically it has been studied for Ca^+, Ti^{3+}, Ni^{2+}, Ni^{3+}, Hf^{3+}, and Zr^{3+}.

Autoionization is most important when a low lying resonance state is just above the first ionization potential. If we study a particular isoelectronic sequence, it is found that at high Z, the possible autoionizing levels lie below the ionization potential but as Z decreases the levels rise and at some Z may lie just above the ionization potential. At this Z the ionization cross section may be greatly enhanced. However, as Z becomes smaller the resonance levels become much higher than the ionization potential and only contribute slightly to the ionization cross section.

Consideration of the relative positions of the autoionizing levels for some ions has enabled us to make a rough plan (Table A.1) of the ions for which we consider autoionizing contributions will be important. Predictions are based on analysis of the position of the autoionizing levels with respect to the ionization potential. It is obvious that for these isoelectronic sequences, classical scaling laws will not apply and for this reason we scale only the direct cross-section contribution where possible. Some exceptions include, recommendations for the Na-like, Al-like, and P-like ions close to Fe XVI, Fe XIV, and Fe XII, respectively; for these cases the excitation–autoionization contribution dominates the cross section.

Table A 1. Species for which an excitation-autoionisation contribution to the ionisation cross section is expected or observed.

Species	Initial charge state															
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV	XVI
Cl	-	-	-	-	-	O	-	-	-	-	-	-	-	-	-	-
Ar	-	-	-	-	O	O	O	-	-	-	-	-	-	-	-	-
K	O	-	-	-	-	-	-	KEY:-		-	-	-	-	-	-	-
Ca	-	O	-	-	-	-	-	-	E: AUTOIONIZATION EXPECTED							
Sc	-	-	E	-	-	-	-	-	O: AUTOIONIZATION OBSERVED							
Ti	-	O	EO	EO	-	-	-	-	-	-	-	-	-	-	-	-
V	-	-	E	E	-	-	-	-	-	-	-	-	-	-	-	-
Cr	-	O	E	E	-	-	-	-	-	-	-	-	-	-	-	-
Mn	-	-	E	E	E	-	-	-	-	-	-	-	-	-	-	-
Fe	-	-	E	E	E	-	-	-	-	-	-	O	-	O	-	O
Co	-	-	-	E	E	-	-	-	-	-	-	-	-	-	-	-
Ni	-	-	-	O	E	-	-	-	-	-	-	-	-	-	-	-

.
.
.
.

10. REFERENCES

[1]K. L. Bell, H. B. Gilbody, J. G. Hughes, A. E. Kingston, and F. J. Smith, J. Phys. Chem. Ref. Data **12**, 891 (1983).

[2]W. Lotz, Astrophys. J. Suppl. **14**, 207 (1967).

[3]W. Lotz, Z. Phys. **216**, 241 (1968).

[4]S. M. Younger, Phys. Rev. A **22**, 111 (1980).

[5]S. M. Younger, Phys. Rev. A **24**, 1278 (1981).

[6]H. Jakubowicz and D. L. Moores, J. Phys. B **14**, 3733 (1981).

[7]R. A. Falk, G. H. Dunn, D. C. Griffin, C. Bottcher, D. C. Gregory, D. H. Crandall, and M. S. Pindzola, Phys. Rev. Lett. **47**, 494 (1981).

[8]R. A. Falk, G. H. Dunn, D. C. Gregory, and D. H. Crandall, Phys. Rev. A. **27**, 762 (1983).

[9]P. G. Burke, W. C. Fon, A. E. Kingston, and J. H. Tait (private communication, 1984).

[10]K. T. Dolder and B. Peart, Rep. Prog. Phys. **39**, 693 (1976).

[11]H. J. Kunze, Phys. Rev. A **3**, 937 (1971).

[12]E. Kallne and L. A. Jones, J. Phys. B. **10**, 3637 (1977).

[13]G. H. Dunn, IEEE Trans. Nucl. Sci. **23**, 926 (1976).

[14]F. A. Baker and J. B. Hasted, Philos. Trans. R. Soc. London, Ser. A **261**, 33 (1966).

[15]E. D. Donets, IEEE Trans. Nucl. Sci. **23**, 897 (1976).

[16]T. J. Jones, Phys. Rev. **29**, 822 (1927).

[17]J. T. Tate and P. T. Smith, Phys. Rev. **39**, 270 (1932).

[18]C. J. Cook and J. R. Peterson, Phys. Rev. Lett. **9**, 164 (1962).

[19]M. B. Shah, D. S. Elliott, and H. B. Gilbody, J. Phys. B **20**, 3501 (1987).

[20]H. Jakubowicz, Ph. D. thesis, University of London, 1980.

[21]D. H. Crandall, R. A. Phaneuf, D. C. Gregory, Report No. ORNL/TM-7020, Oak Ridge National Laboratory, 1979.

[22]D. H. Crandall, R. A. Phaneuf, D. C. Gregory, A. M. Howald, D. W. Mueller, T. J. Morgan, G. H. Dunn, and R. J. W. Henry (private communication, 1985).

[23]P. Greve, M. Kato, H. J. Kunze, and R. S. Hornady, Phys. Rev. A **24**, 429 (1981).

[24]L. A. Jones, E. Kallne, and D. B. Thomson, J. Phys. B **10**, 187 (1977).

[25]R. U. Datla, L. A. Nugent, and H. R. Griem. Phys. Rev. A **14**, 979 (1976).

[26]S. M. Younger, J. Quant. Spectrosc. Radiat. Transfer **29**, 61 (1983).

[27]E. D. Donets, V. P. Ovsyannikov, and J. I. N. R. Dubna, Report No. P7-10780 Translation ORNL-TR-4616, Oak Ridge National Laboratory, 1977.

[28]S. M. Younger, Phys. Rev. A **22**, 1425 (1980).

[29]S. M. Younger, Phys. Rev. A **25**, 3396 (1982).

[30]S. Chandra and U. Narain, J. Phys. B **8**, 770 (1975).

[31]E. J. McGuire, Phys. Rev. A **26**, 125 (1982).

[32]S. Chantrenne, P. DeFrance, S. Rachafi, Belic, and F. Brouillard, Int. Conf. Phys. Electron. Atomic Collisions **14**, 299 (1985).

[33]S. M. Younger, J. Quant. Spectrosc. Radiat. Transfer **27**, 541 (1982).

[34]D. W. Mueller, T. J. Morgan, G. H. Dunn, D. C. Gregory, and D. H. Crandall, Phys. Rev. A **31**, 2905 (1985).

[35]J. B. Hasted and G. L. Awad, J. Phys. B **5**, 1719 (1972).

[36]D. C. Gregory, D. F. Dittner, and D. H. Crandall, Phys. Rev. A **27**, 724 (1982).

[37]A. Danjo, A. Matsumoto, S. Ohtani, H. Suzuki, H. Tawara, K. Wakiya, and M. Yoshino, J. Phys. Soc. Jpn. **53**, 4091 (1984).

[38]T. R. Hayes, R. C. Wetzel, and R. S. Freund, Phys. Rev. A **35**, 578 (1987).

[39]E. J. McGuire, Phys. Rev. A **3**, 267 (1971).

[40]A. Muller, E. Salzborn, R. Frodl, R. Becker, H. Klein, and H. Winter, J. Phys. B **13**, 1877 (1980).

[41]K. T. Dolder, M. F. A. Harrison, and P. C. Thonemann, Proc. R. Soc. London, Ser. A **274**, 546 (1963).

[42]M. J. Diserens, M. F. A. Harrison, and A. C. H. Smith, J. Phys. B **17**, L621 (1984).

[43]D. L. Moores, J. Phys. B **5**, 286 (1972).
[44]W. Bleakney, Phys. Rev. **36**, 1303 (1930).
[45]K. Stephan, H. Helm, and T. D. Mark, J. Chem. Phys. **73**, 3763 (1980).
[46]B. Peart and K. T. Dolder, J. Phys. B **1**, 240 (1968).
[47]J. W. Hooper, W. C. Lineberger, and F. M. Bacon, Phys. Rev. **141**, 165 (1966).
[48]B. Peart, S. O. Martin, and K. T. Dolder, J. Phys. B **2**, 1176 (1969).
[49]S. M. Younger, Phys. Rev. A **23**, 1138 (1981).
[50]I. P. Zapesochnyi and I. S. Aleksakhin, Sov. Phys. JETP **28**, 41 (1969).
[51]R. H. McFarland and J. D. Kinney, Phys. Rev. A **137**, 1058 (1965).
[52]S. O. Martin, B. Peart, and K. T. Dolder, J. Phys. B **1**, 537 (1968).
[53]D. H. Crandall, R. A. Phaneuf, R. A. Falk, D. S. Belic, and G. H. Dunn, Phys. Rev. A **25**, 143 (1982).
[54]D. C. Gregory, L. J. Wang, F. W. Meyer, and K. Rinn, Phys. Rev. A **35**, 3256 (1987).
[55]F. Karstensen and M. Schneider, J. Phys. B **11**, 167 (1978).
[56]R. G. Montague and M. F. A. Harrison, J. Phys. B **16**, 3045 (1983).
[57]A. M. Howald, D. C. Gregory, F. W. Meyer, R. A. Phaneuf, A. Muller, N. Djuric, and G. H. Dunn, Phys. Rev. A **33**, 3799 (1986).
[58]D. C. Gregory, D. H. Crandall, R. A. Phaneuf, A. M. Howald, G. H. Dunn, R. A. Falk, D. W. Mueller, and T. J. Morgan, ORNL Report No. ORNL/TM-9501, Oak Ridge National Laboratory, 1985.
[59]M. S. Pindzola, D. C. Griffin, and C. Bottcher, Phys. Rev. A **34** 3668 (1986).
[60]D. L. Ziegler, J. H. Newman, L. N. Goeller, K. A. Smith, and R. F. Stebbings, Planet and Space Sci. **30**, 1269 (1982).
[61]P. R. Woodruff, M. C. Hublet, and M. F. A. Harrison, J. Phys. B **11**, L305 (1978).
[62]K. F. Mann, A. C. H. Smith, and M. F. A. Harrison, J. Phys. B **20**, 2571 (1987).
[63]D. C. Gregory, F. W. Meyer, A. Muller, and P. DeFrance, Phys. Rev. A **34**, 3657 (1986).
[64]R. C. Wetzel, F. A. Baiocchi, T. R. Hayes, and R. S. Freund, Phys. Rev. A **35**, 559 (1987).
[65]D. Rapp and P. Englander-Golden, J. Chem. Phys. **43**, 1464 (1965).
[66]T. Hiryama, K. Oda, Y. Morikawa, T. Ono, Y. Ikezaki, S. Koboayashi, T. Takayanagi, K. Wakiya, and H. Suzuki, Int. Conf. Phys. Electron. Atomic Collisions **14**, 303 (1985).
[67]S. M. Younger, Phys. Rev. A **26**, 3177 (1982).
[68]B. Peart and K. T. Dolder, J. Phys. B **8**, 56 (1975).
[69]R. A. Falk and G. H. Dunn, Phys. Rev. A **27**, 754 (1983).
[70]E. J. McGuire, Phys. Rev. A **16**, 62 (1977).
[71]M. J. Diserens, Ph. D. thesis, University College London, 1985.
[72]M. S. Pindzola, D. C. Griffin, C. Bottcher, D. C. Gregory, A. M. Howald, R. A. Phaneuf, D. H. Crandall, G. H. Dunn, D. W. Mueller, and T. J. Morgan, Report No. ORNL/TM-9436. Dist. Category UC-20, UC-20F, Oak Ridge National Laboratory, 1985.
[73]R. G. Montague, M. J. Diserens, and M. F. A. Harrison, J. Phys. B **17**, 2085 (1984).
[74]D. C. Gregory and A. M. Howald, Phys. Rev. A **34**, 97 (1986).
[75]P. Nagy, A. Skutlartz, and V. Schmidt, J. Phys. B **13**, 1249 (1980).
[76]G. O. Brink, Phys. Rev. **36**, 1303 (1930).
[77]E. J. McGuire, Phys. Rev. A **28**, 2091 (1983).
[78]A. Matsumoto, S. Ohtani, A. Danjo, H. Hanashiro, T. Hino, Y. Kondo, H. Suzuki, H. Tawara, K. Wakiya, and M. Yashino, Int. Conf. Phys. Electron. Atomic Collisions **13**, 198 (1983).
[79]Y. P. Korchevoi and A. M. Przonski, Sov. Phys. JETP **24**, 1089 (1967).