JAERI-Data/Code
95-008

ANALYTIC CROSS SECTIONS FOR COLLISIONS OF H, H_2, He AND Li ATOMS AND IONS WITH ATOMS AND MOLECULES. III

July 1995

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編集兼発行　日本原子力研究所
印　　刷　いばらき印刷㈱

JAERI-Data/Code 95-008

Analytic Cross Sections for Collisions of H, H_2, He and Li Atoms and Ions with Atoms and Molecules. III

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(Received June 14, 1995)

Analytic expressions fitted to Barnett's recommended data are given for the collision cross sections of H, H_2, He, and Li atoms and ions colliding with atoms and molecules. The collisions treated are ionization collisions, charge-production collisions, electron-loss collisions, and electron detachment collisions. The analytic expressions use the semiempirical functional forms proposed by Green and McNeal and some modified forms to make it possible not only to interpolate but also to extrapolate the recommended data.

Keywords: Cross Section, Ionization, Charge Production, Electron Loss, Electron Detachment, H, H_2, He, Li

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This report was prepared as an account of work supported partly by a research contract of JAERI with University of Osaka prefecture in the fiscal year 1994.

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JAERI-Data/Code 95-008

H、H_2、He、Liの原子及びイオンと原子分子の衝突に対する解析的断面積 Ⅲ

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(1995年6月14日受理)

H、H_2、He、Liの原子及びイオンと原子分子との衝突における断面積の推奨値に対して解析的表式をあてはめた。対象にした衝突過程は、電離、荷電粒子生成、電子損失、及び電子脱離である。解析的表式として、推奨値の内外挿ができるようにGreen and McNealの経験式を変形したものを採用した。

本報は、大阪府立大学への委託調査を含む。
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1 Introduction

For diagnostics and modeling of plasmas in thermonuclear-fusion research, data on cross sections for inelastic collisions between atoms, molecules and ions, especially of the lightest elements, are important. Barnett [1] published recommended data on such cross sections for the elements of hydrogen, helium and lithium. To facilitate interpolation, Barnett gave also least-squares Chebyshev polynomial fits to the recommended cross sections as a function of projectile energy. The polynomial fits, however, cannot be used for extrapolation, because they often show physically unreasonable behavior just outside the energy range of the data used. This inconvenience can be removed by using analytic expressions that approximate low-energy and high-energy asymptotic trends.

Green and McNeal [2] proposed semiempirical expressions for inelastic collision cross sections of hydrogen atoms and ions with gaseous atoms and molecules. By using the same functional forms as the Green-McNeal expressions and some modified forms, Nakai *et al.* [3] published a number of analytic cross sections for charge transfer of hydrogen atoms and ions colliding with gaseous atoms and molecules. Analytic cross sections are also available for the following reactions: charge transfer of hydrogen atoms and ions colliding with metal vapors [4], single-electron capture of hydrogen ions leading to specified excited states of hydrogen [5], charge transfer of helium atoms and ions colliding with gaseous atoms and molecules [6], single-electron capture by multiply-charged ions colliding with H, H_2 and He [7], and ionization of H, H_2 and He by multiply-charged ions [8]. The publications from Ref. 3 to Ref. 8 are the products of the joint research program of data compilation sponsored by Japan Atomic Energy Research Institute.

Presently a project of formulating analytic expressions fitted to Barnett's recommended data is in progress. In previous reports [9,10], analytic expressions for the cross sections of the following reactions were given:

(1) Electron capture by H, H^+, $H_2{}^+$, He^+, and He^{2+} colliding with atoms, molecules, and ions (H, He, Li; H_2; H^-, He^+).

(2) Electron capture into excited states by H^+, He^+, and He^{2+} colliding with atoms and molecules (H, He, Li; H_2).

(3) Excitation and spectral line emission by H, H^+, He^+, He, and He^{2+} colliding with atoms and molecules (H, He, Li; H_2).

The present report is a sequel to the previous reports, and treats the cross sections for the following types of collisions: ionization collisions, charge-production collisions,

electron-loss collisions and electron-detachment collisions. The possible error of analytic expressions when they are used for the extrapolation of the recommended data was discussed in one of the previous reports [9].

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2 List of Analytic Expressions

In the Tables of the present report the analytic expression used for each reaction is denoted as Equation m-n, where m represents the principal number assigned to a group of expressions that use the same basic function or a set of basic functions, and n represents the subnumber equal to the total number of adjustable parameters in the expression.
The meanings of symbols are as follows:

σ	Cross section of process
σ_0	Unit of cross section, 10^{-16} cm^2
E	Projectile energy (in keV/amu)
E_{R}	Rydberg energy multiplied by the ratio of the atomic mass of projectile species to the electron mass (25.0 keV for the projectiles of H and H^+, 50.0 keV for the projectile of $H_2{}^+$, 99.27 keV for the projectiles of He^+ and He^{2+})
a_i $(i = 1, 2, \ldots)$	Adjustable parameters

$\boldsymbol{m = 2}$

$n = 2 \quad \sigma = \sigma_0 a_1 (x/E_{\mathrm{R}})^{a_2}.$

$\boldsymbol{m = 3}$

$n = 3 \quad \sigma = f(E)$
$n = 5 \quad \sigma = f(E) + a_4 f(E/a_5),$

where

$$f(x) = \sigma_0 a_1 (x/E_{\mathrm{R}})^{a_2} / [1 + (x/a_3)^{2a_2}].$$

$\boldsymbol{m = 4}$

$n = 4 \quad \sigma = f(E)$
$n = 6 \quad \sigma = f(E) + a_5 f(E/a_6)$
$n = 8 \quad \sigma = f(E) + a_5 f(E/a_6) + a_7 f(E/a_8),$

where

$$f(x) = \sigma_0 a_1 (x/E_{\mathrm{R}})^{a_2} / [1 + (x/a_3)^{a_2 + a_4}].$$

$m = 6$

$n = 5 \quad \sigma = f(E, a_2)$
$n = 6 \quad \sigma = f(E, a_6)$
$n = 8 \quad \sigma = f(E, a_6) + a_7 f(E/a_8, a_6)$
$n = 10 \quad \sigma = f(E, a_6) + a_7 f(E/a_8, a_6) + a_9 f(E/a_{10}, a_6),$

where

$$f(x, \alpha) = \sigma_0 a_1 (x/E_{\mathrm{R}})^{a_2} / [1 + (x/a_3)^{a_2+a_4} + (x/a_5)^{a_2+\alpha}].$$

$m = 7$

$n = 5 \quad \sigma = f(E, a_2)$
$n = 9 \quad \sigma = f(E, a_6) + a_7 g(E/a_8, a_2, a_5, a_9),$

where

$$f(x, \alpha) = \sigma_0 a_1 (x/E_{\mathrm{R}})^{a_2} / [1 + (x/a_3)^{a_2+a_4} + (x/a_5)^{a_2+\alpha}]$$
$$g(x, \beta, \gamma, \delta) = \sigma_0 a_1 (x/E_{\mathrm{R}})^{\beta} / [1 + (x/a_\gamma)^{a_\beta+a_\delta}].$$

The function $f(x, \alpha)$ should be computed with double precision arithmetic in Fortran.

$m = 8$

$n = 10 \quad \sigma = f(E) + a_9 f(E/a_{10})$
$n = 13 \quad \sigma = f(E) + a_9 f(E/a_{10}) + g(E),$

where

$$f(x) = \sigma_0 a_1 (x/E_{\mathrm{R}})^{a_2} / [1 + (x/a_3)^{a_2+a_4} + (x/a_5)^{a_2+a_6} + (x/a_7)^{a_2+a_8}]$$

$$g(x) = \begin{cases} \sigma_0 a_{11} / \{1 + [|x - a_{12}|/a_{13}]^{a_2}\} & \text{for } x \leq 1.2\times10^{-2} \text{ keV} \\ 0 & \text{for } x > 1.2\times10^{-2} \text{ keV}. \end{cases}$$

$m = 11$

$n = 10 \quad \sigma = f(E, a_2, a_4) + a_7 f(E/a_8, a_9, a_{10}),$

where

$$f(x, \alpha, \beta) = \sigma_0 a_1 (x/E_{\mathrm{R}})^{\alpha} / [1 + (x/a_3)^{\alpha+\beta} + (x/a_5)^{\alpha+a_6}].$$

$m = 18$

$n = 8 \quad \sigma = f(E) + a_7 g(E/a_8, a_2)$
$n = 9 \quad \sigma = f(E) + a_7 g(E/a_8, a_9),$

where

$$f(x) = \sigma_0 a_1 (x/E_{\mathrm{R}})^{a_2} / [1 + (x/a_3)^{a_2+a_4} + (x/a_5)^{a_2+a_6}]$$
$$g(x, \alpha) = \sigma_0 a_1 (x/E_{\mathrm{R}})^{\alpha} / [1 + (x/a_5)^{\alpha+a_6}].$$

3 Explanation and List of Tables

Explanation of Tables

The followings are given for each process:

Range of recommended data	Energy range in which Barnett's recommended data are available
Accuracy	Accuracy of recommended data
Analytic exparession	Functional form of analytic expression, values of constants, values of adjustable parameters, and rms and maximum deviations of analytic expression from recommended data

List of Tables

Ionization and Production of Charged Particles

$H + H_2 \rightarrow$ Total Slow Positive Ion Production
$H + H_2 \rightarrow$ Total Slow Electron Production
$H + H_2 \rightarrow H + H_2{}^+ + e$
$H^+ + H \rightarrow H^+ + H^+ + e$
$H^+ + H^- \rightarrow H_2{}^+ + e$
$H^+ + H_2 \rightarrow$ Total Slow Electron Production
$H^+ + H_2 \rightarrow H^+ + H_2^+ + e$
$H^+ + H_2 \rightarrow$ Total Production of $H_2{}^+$
$H^+ + H_2 \rightarrow$ Total Production of H^+
$H^+ + He \rightarrow$ Electrons and H^-
$H^+ + He \rightarrow H^+ + He^+ + e$
$H^+ + He \rightarrow (H + He^+)$ or $(H^+ + He^+ + e)$
$H^+ + He \rightarrow H^+ + He^{2+} + 2e$
$H^+ + He \rightarrow (H^- + He^{2+})$ or $(H^+ + He^{2+} + 2e)$
$H^+ + He^+ \rightarrow H^+ + He^{2+} + e$
$H^+ + He^+ \rightarrow (H^+ + He^{2+} + e)$ or $(H^0 + He^{2+})$
$H^+ + Li \rightarrow H^+ + Li^+ + e$
$He(2^1S) + H \rightarrow He + H^+ + e$
$He(2^1S) + H \rightarrow HeH^+ + e$
$He(2^1S) + H \rightarrow (He + H^+ + e)$ or $(HeH^+ + e)$
$He(2^3S) + H \rightarrow He + H^+ + e$

$He(2^3S) + H \rightarrow HeH^+ + e$
$He(2^3S) + H \rightarrow (He + H^+ + e)$ or $(HeH^+ + e)$
$He(2^3S) + H_2 \rightarrow$ Total Ionization
$He(2^3S) + H_2 \rightarrow$ Rearrangement Ionization
$He(2^1S) + H_2 \rightarrow$ Total Ionization
$He(2^1S) + H_2 \rightarrow$ Rearrangement Ionization
$He + H_2 \rightarrow$ Total Slow Positive Ion Production
$He + H_2 \rightarrow$ Total Slow Electron Production
$He + H_2 \rightarrow He + H_2^+ + e$
$He + H_2 \rightarrow$ Total H^+ Production
$He + He \rightarrow$ Total Slow Positive Ion Production
$He + He \rightarrow$ Total Slow Electron Production
$He + He \rightarrow He + He^+ + e$
$He + He \rightarrow He + He^{2+} + 2e$
$He^+ + He^+ \rightarrow He^+ + He^{2+} + e$
$He^+ + He^+ \rightarrow (He + He^{2+})$ or $(He^+ + He^{2+} + e)$
$He^+ + H \rightarrow He^+ + H^+ + e$
$He^+ + H_2 \rightarrow$ Total Slow Positive Ion Production
$He^+ + H_2 \rightarrow$ Total Slow Electron Production
$He^+ + H_2 \rightarrow (He + H_2^+)$ or $(He^+ + H_2^+ + e)$
$He^+ + H_2 \rightarrow$ Total H^+ Production
$He^+ + H_2 \rightarrow He^+ + 2H^+ + 2e$
$He^+ + He \rightarrow$ Total Slow Positive Ion Production
$He^+ + He \rightarrow$ Total Slow Electron Production
$He^+ + He \rightarrow He^+ + He^+ + e$
$He^+ + He \rightarrow He^+ + He^{2+} + 2e$
$He^+ + Li \rightarrow He^+ + Li^+ + e$
$He^{2+} + H \rightarrow He^{2+} + H^+ + e$
$He^{2+} + H_2 \rightarrow$ Total Slow Positive Ion Production
$He^{2+} + H_2 \rightarrow$ Total Slow Electron Production
$He^{2+} + H_2 \rightarrow$ Total H_2^+ Production
$He^{2+} + H_2 \rightarrow H_2^+$ Production by Single Ionization
$He^{2+} + H_2 \rightarrow$ Total H^+ Production
$He^{2+} + H_2 \rightarrow H^+$ Production by Ionization Collisions
$He^{2+} + He \rightarrow$ Total Slow Positive Ion Production
$He^{2+} + He \rightarrow$ Total Slow Electron Production
$He^{2+} + He \rightarrow He^{2+} + He^+ + e$
$He^{2+} + He \rightarrow He^{2+} + He^{2+} + 2e$
$He^{2+} + Li \rightarrow He^{2+} + Li^+ + e$

Electron Loss or Stripping Collisions

$H + H \rightarrow H^+ + H + e$
$H(2s) + H(1s) \rightarrow H^+ + H + e$
$H + H_2 \rightarrow H^+ + H_2 + e$
$H(2s) + H_2 \rightarrow H^+ + H_2 + e$
$H + He \rightarrow H^+ + He + e$
$H(2s) + He \rightarrow H^+ + He + e$
$He + H \rightarrow He^+ + H + e$
$He + H_2 \rightarrow He^+ + H_2 + e$
$He + H_2 \rightarrow He^{2+} + H_2 + 2e$
$He^* + H_2 \rightarrow He$ or He^+
$He^* + H_2 \rightarrow He^+ + H_2 + e$
$He^* + H_2 \rightarrow He + H_2$
$He + He \rightarrow He^+ + He + e$
$He + He \rightarrow He^{2+} + He + 2e$
$He^+ + H \rightarrow He^{2+} + H + e$
$He^+ + H_2 \rightarrow He^{2+} + H_2 + e$
$He^+ + He \rightarrow He^{2+} + He + e$

Electron Detachment Collisions

$H^- + H \rightarrow H + H + e$
$H^- + H \rightarrow (H + H + e)$ or $(H + H^-)$
$H^- + H \rightarrow H^+ + H + 2e$
$H^- + H^+ \rightarrow H + H^+ + e$
$H^- + H_2 \rightarrow H + H_2 + e$
$H^- + H_2 \rightarrow H^+ + H_2 + 2e$
$H^- + He \rightarrow H + He + e$
$H^- + He \rightarrow H^+ + He + 2e$
$He^- + H \rightarrow He + H + e$
$He^- + H_2 \rightarrow He + H_2 + e$
$He^- + H_2 \rightarrow He^+ + H_2 + 2e$
$He^- + He \rightarrow He + He + e$
$He^- + He \rightarrow He^+ + He + 2e$
$Li^- + H_2 \rightarrow Li + H_2 + e$
$Li^- + H_2 \rightarrow Li^+ + H_2 + 2e$
$Li^- + He \rightarrow (Li + He + e)$ or $(Li^+ + He + 2e)$

4 Tables of Parameters for Analytic Expressions

Ionization and Production of Charged Particles

$H + H_2 \rightarrow$ Total Slow Positive Ion Production

Range of recommended data: 4.0×10^{-2} keV/amu $\leq E \leq 4.0\times10^{2}$ keV/amu.
Accuracy: 20%.
Analytic expression: Equation 18-9, $E_R = 25.0$ keV.
Values of a_i ($i = 1, 2, \ldots, 9$) are as follows.

a_1	a_2	a_3	a_4	a_5
1.174E+01	1.609E+00	1.046E+01	7.236E−02	2.123E+01

a_6	a_7	a_8	a_9
8.935E−01	6.649E−03	5.455E−03	2.180E+00

The expression represents the recommended data with an rms deviation of 1.7%.
The maximum deviation is 3.3% at 7.0×10^{-2} keV/amu.
See Graph 1.

$H + H_2 \rightarrow$ Total Slow Electron Production

Range of recommended data: 8.0×10^{-2} keV/amu $\leq E \leq 4.0\times10^{2}$ keV/amu.
Accuracy: 20%.
Analytic expression: Equation 6-8, $E_R = 25.0$ keV.
Values of a_i ($i = 1, 2, \ldots, 8$) are as follows.

a_1	a_2	a_3	a_4
3.360E+05	4.849E+00	7.769E−01	−1.728E+00

a_5	a_6	a_7	a_8
3.093E+00	5.443E−01	3.735E−01	1.054E−01

The expression represents the recommended data with an rms deviation of 3.0%.
The maximum deviation is 5.5% at 3.0 keV/amu.
See Graph 2.

$$\mathbf{H + H_2 \rightarrow H + H_2{}^+ + e}$$

Range of recommended data: 0.20 keV/amu $\leq E \leq 4.0\times10^2$ keV/amu.
Accuracy: 30%.
Analytic expression: Equation 6-8, $E_R = 25.0$ keV.
Values of a_i ($i = 1, 2, \ldots, 8$) are as follows.

a_1	a_2	a_3	a_4
5.286E+02	2.356E+00	2.982E−01	−1.251E+00

a_5	a_6	a_7	a_8
3.956E+00	5.588E−01	6.073E−04	3.E−02

The value of a_8 was assumed.
The expression represents the recommended data with an rms deviation of 2.7%.
The maximum deviation is 7.0% at 2.0×10^2 keV/amu.
See Graph 3.

$$\mathbf{H^+ + H \rightarrow H^+ + H^+ + e}$$

Range of recommended data: 9.4 keV/amu $\leq E \leq 1.5\times10^3$ keV/amu.
Accuracy: 25% for $E > 40$ keV/amu; unknown for $E \leq 40$ keV/amu.
Analytic expression: Equation 6-6, $E_R = 25.0$ keV.
Values of a_i ($i = 1, 2, \ldots, 6$) are as follows.

a_1	a_2	a_3	a_4	a_5	a_6
1.712E+00	2.367E+00	3.432E+01	6.208E−02	3.678E+01	9.238E−01

The expression represents the recommended data with an rms deviation of 1.2%.
The maximum deviation is 2.4% at 30 keV/amu.
See Graph 4.

$$\mathbf{H^+ + H^- \rightarrow H_2{}^+ + e}$$

Range of recommended data: 2.0×10^{-6} keV/amu $\leq E \leq 7.0\times10^{-3}$ keV/amu.
Accuracy: 30%.
Analytic expression: Equation 6-10, $E_R = 25.0$ keV.
Values of a_i ($i = 1, 2, \ldots, 10$) are as follows.

a_1	a_2	a_3	a_4	a_5
6.762E+14	2.656E+00	1.205E−04	2.683E−01	2.890E−04

a_6	a_7	a_8	a_9	a_{10}
1.673E+00	2.182E+01	2.901E−02	1.163E+04	1.E−04

The value of a_{10} was assumed.
The expression represents the recommended data with an rms deviation of 1.7%.
The maximum deviation is 3.2% at 1.0×10^{-3} keV/amu.
See Graph 5.

$H^+ + H_2 \rightarrow$ Total Slow Electron Production

Range of recommended data: 0.50 keV/amu $\leq E \leq 5.0\times10^3$ keV/amu.
Accuracy: 25%.
Analytic expression: Equation 4-4, $E_R = 25.0$ keV.
Values of a_i ($i = 1, 2, 3, 4$) are as follows.

a_1	a_2	a_3	a_4
1.766E+00	1.231E+00	5.192E+01	8.331E−01

The expression represents the recommended data with an rms deviation of 1.3%.
The maximum deviation is 2.6% at 7.0×10^2 keV/amu.
See Graph 6.

$H^+ + H_2 \rightarrow H^+ + H_2{}^+ + e$

Range of recommended data: 5.0 keV/amu $\leq E \leq 3.8\times10^3$ keV/amu.
Accuracy: 30%.
Analytic expression: Equation 6-8, $E_R = 25.0$ keV.
Values of a_i ($i = 1, 2, \ldots, 8$) are as follows.

a_1	a_2	a_3	a_4
1.204E+00	2.873E+00	3.832E+01	−3.393E−01

a_5	a_6	a_7	a_8
4.533E+01	8.950E−01	8.011E−02	1.500E−01

The expression represents the recommended data with an rms deviation of 2.0%.
The maximum deviation is 5.1% at 20 keV/amu.
See Graph 7.

$H^+ + H_2 \rightarrow$ Total Production of $H_2{}^+$

Range of recommended data: 6.0 keV/amu $\leq E \leq 3.5\times10^3$ keV/amu.
Accuracy: 30%.
Analytic expression: Equation 6-5, $E_R = 25.0$ keV.
Values of a_i ($i = 1, 2, \ldots, 5$) are as follows.

a_1	a_2	a_3	a_4	a_5
1.024E+02	1.110E+00	4.818E+00	5.626E−01	1.794E+01

The expression represents the recommended data with an rms deviation of 0.9%.
The maximum deviation is 1.9% at 4.0×10^2 keV/amu.
See Graph 8.

$H^+ + H_2 \rightarrow$ Total Production of H^+

Range of recommended data: 5.0 keV/amu $\leq E \leq 50$ keV/amu.
Accuracy: 30%.
Analytic expression: Equation 4-4, $E_R = 25.0$ keV.
Values of a_i ($i = 1, 2, 3, 4$) are as follows.

a_1	a_2	a_3	a_4
4.967E+00	1.587E+00	1.579E+01	1.412E+00

The expression represents the recommended data with an rms deviation of 1.1%.
The maximum deviation is 2.0% at 25 keV/amu.
See Graph 9.

$H^+ + He \rightarrow$ Electrons and H^-

Range of recommended data: 0.44 keV/amu $\leq E \leq 5.0\times10^3$ keV/amu.
Accuracy: 20% for $E > 40$ keV/amu; unknown for $E \leq 40$ keV/amu.
Analytic expression: Equation 4-4, $E_R = 25.0$ keV.
Values of a_i ($i = 1, 2, 3, 4$) are as follows.

a_1	a_2	a_3	a_4
4.394E−01	1.518E+00	6.347E+01	7.855E−01

The expression represents the recommended data with an rms deviation of 1.2%.
The maximum deviation is 2.7% at 4.0×10^3 keV/amu.
See Graph 10.

$$\mathbf{H^+ + He \rightarrow H^+ + He^+ + e}$$

Range of recommended data: 10 keV/amu $\leq E \leq 5.0\times10^3$ keV/amu.
Accuracy: 30%.
Analytic expression: Equation 6-6, $E_R = 25.0$ keV.
Values of a_i ($i = 1, 2, \ldots, 6$) are as follows.

a_1	a_2	a_3	a_4	a_5	a_6
2.586E+00	2.262E+00	1.356E+01	−4.569E−01	3.253E+01	8.800E−01

The expression represents the recommended data with an rms deviation of 2.5%.
The maximum deviation is 4.9% at 2.0×10^3 keV/amu.
See Graph 11.

$$\mathbf{H^+ + He \rightarrow (H + He^+) \text{ or } (H^+ + He^+ + e)}$$

Range of recommended data: 5.0 keV/amu $\leq E \leq 5.0\times10^3$ keV/amu.
Accuracy: 30%.
Analytic expression: Equation 6-6, $E_R = 25.0$ keV.
Values of a_i ($i = 1, 2, \ldots, 6$) are as follows.

a_1	a_2	a_3	a_4	a_5	a_6
1.008E+01	1.989E+00	1.665E+01	7.356E−01	2.690E+02	2.891E+00

The expression represents the recommended data with an rms deviation of 2.1%.
The maximum deviation is 4.1% at 7.0 keV/amu.
See Graph 12.

$$\mathbf{H^+ + He \rightarrow H^+ + He^{2+} + 2e}$$

Range of recommended data: 20 keV/amu $\leq E \leq 5.0\times10^3$ keV/amu.
Accuracy: 20%.
Analytic expression: Equation 6-8, $E_R = 25.0$ keV.
Values of a_i ($i = 1, 2, \ldots, 8$) are as follows.

a_1	a_2	a_3	a_4
8.946E−03	5.826E+00	2.148E+01	−1.293E+00

a_5	a_6	a_7	a_8
3.516E+01	1.349E+00	8.835E−03	3.103E+01

The expression represents the recommended data with an rms deviation of 2.3%.
The maximum deviation is 4.5% at 3.0×10^2 keV/amu.
See Graph 13.

$$\mathbf{H^+ + He \rightarrow (H^- + He^{2+}) \text{ or } (H^+ + He^{2+} + 2e)}$$

Range of recommended data: 10 keV/amu $\leq E \leq 5.0\times10^3$ keV/amu.
Accuracy: 20%.
Analytic expression: Equation 6-8, $E_R = 25.0$ keV.
Values of a_i ($i = 1, 2, \ldots, 8$) are as follows.

a_1	a_2	a_3	a_4
1.958E−01	3.244E+00	9.941E+00	−9.091E−01

a_5	a_6	a_7	a_8
2.462E+01	1.544E+00	6.928E−03	4.068E+01

The expression represents the recommended data with an rms deviation of 2.7%.
The maximum deviation is 6.3% at 1.0×10^2 keV/amu.
See Graph 14.

$$\mathbf{H^+ + He^+ \rightarrow H^+ + He^{2+} + e}$$

Range of recommended data: 20 keV/amu $\leq E \leq 5.0\times10^2$ keV/amu.
Accuracy: 60%.
Analytic expression: Equation 6-6, $E_R = 25.0$ keV.
Values of a_i ($i = 1, 2, \ldots, 6$) are as follows.

a_1	a_2	a_3	a_4	a_5	a_6
2.262E−02	3.996E+00	1.833E+01	−1.825E+00	5.274E+01	9.498E−01

The expression represents the recommended data with an rms deviation of 1.0%.
The maximum deviation is 2.5% at 3.0×10^2 keV/amu.
See Graph 15.

$$\mathbf{H^+ + He^+ \rightarrow (H^+ + He^{2+} + e) \text{ or } (H + He^{2+})}$$

Range of recommended data: 3.7 keV/amu $\leq E \leq 5.0\times10^2$ keV/amu.
Accuracy: 30%.
Analytic expression: Equation 6-8, $E_R = 25.0$ keV.
Values of a_i ($i = 1, 2, \ldots, 8$) are as follows.

a_1	a_2	a_3	a_4
7.992E−01	4.558E+00	1.608E+01	−1.423E+00

a_5	a_6	a_7	a_8
2.739E+01	1.086E+00	4.554E−03	1.300E−01

The expression represents the recommended data with an rms deviation of 0.8%.
The maximum deviation is 1.7% at 1.0×10^2 keV/amu.
See Graph 16.

$H^+ + Li \rightarrow H^+ + Li^+ + e$

Range of recommended data: 25 keV/amu $\leq E \leq 2.3\times10^3$ keV/amu.
Accuracy: 30%.
Analytic expression: Equation 6-8, $E_R = 25.0$ keV.
Values of a_i ($i = 1, 2, \ldots, 8$) are as follows.

a_1	a_2	a_3	a_4
3.114E−01	9.699E−01	1.061E+02	6.517E−01

a_5	a_6	a_7	a_8
1.216E+03	1.377E+00	2.781E+03	1.E−04

The value of a_8 was assumed.
The expression represents the recommended data with an rms deviation of 0.5%.
The maximum deviation is 0.7% at 70 keV/amu.
See Graph 17.

$He(2^1S) + H \rightarrow$ Total Ionization

Range of recommended data: 2.0×10^{-5} keV/amu $\leq E \leq 1.3\times10^{-4}$ keV/amu.
Accuracy: 100%.
Analytic expression: Equation 2-2, $E_R = 99.27$ keV.
Values of a_i ($i = 1, 2$) are as follows.

a_1	a_2
9.569E−02	−4.377E−01

The expression represents the recommended data with an rms deviation of 2.0%.
The maximum deviation is 3.0% at 1.3×10^{-4} keV/amu.
See Graph 18.

$He(2^1S) + H \rightarrow He + H^+ + e$

Range of recommended data: 1.8×10^{-5} keV/amu $\leq E \leq 1.3\times10^{-4}$ keV/amu.
Accuracy: 100%.
Analytic expression: Equation 2-2, $E_R = 99.27$ keV.
Values of a_i ($i = 1, 2$) are as follows.

a_1	a_2
3.578E−01	−3.321E−01

The expression represents the recommended data with an rms deviation of 2.6%.
The maximum deviation is 3.5% at 4.0×10^{-5} keV/amu.
See Graph 19.

$He(2^1S) + H \rightarrow HeH^+ + e$

Range of recommended data: 1.9×10^{-5} keV/amu $\leq E \leq 1.3\times10^{-4}$ keV/amu.
Accuracy: 100%.
Analytic expression: Equation 4-4, $E_R = 99.27$ keV.
Values of a_i ($i = 1, 2, 3, 4$) are as follows.

a_1	a_2	a_3	a_4
9.568E+02	2.236E−01	2.374E−05	1.675E+00

The expression represents the recommended data with an rms deviation of 1.4%.
The maximum deviation is 2.8% at 1.0×10^{-4} keV/amu.
See Graph 20.

$He(2^3S) + H \rightarrow$ Total Ionization

Range of recommended data: 1.3×10^{-5} keV/amu $\leq E \leq 1.3\times10^{-2}$ keV/amu.
Accuracy: 100%.
Analytic expression: Equation 6-8, $E_R = 99.27$ keV.
Values of a_i ($i = 1, 2, \ldots, 8$) are as follows.

a_1	a_2	a_3	a_4
6.653E+15	2.663E+00	1.982E−04	2.367E−01

a_5	a_6	a_7	a_8
1.091E−03	1.385E+00	2.177E+01	2.602E−03

The expression represents the recommended data with an rms deviation of 1.8%.
The maximum deviation is 4.1% at 1.5×10^{-3} keV/amu.
See Graph 21.

$He(2^3S) + H \rightarrow He + H^+ + e$

Range of recommended data: 1.2×10^{-5} keV/amu $\leq E \leq 1.3\times10^{-2}$ keV/amu.
Accuracy: 100%.
Analytic expression: Equation 6-8, $E_R = 99.27$ keV.
Values of a_i ($i = 1, 2, \ldots, 8$) are as follows.

a_1	a_2	a_3	a_4
1.677E+14	2.462E+00	2.928E−04	2.116E−01

a_5	a_6	a_7	a_8
1.530E−03	1.605E+00	1.035E+01	8.440E−03

The expression represents the recommended data with an rms deviation of 0.5%.
The maximum deviation is 1.2% at 8.0×10^{-3} keV/amu.
See Graph 22.

$He(2^3S) + H \rightarrow HeH^+ + e$

Range of recommended data: 1.2×10^{-5} keV/amu $\leq E \leq 1.3\times10^{-2}$ keV/amu.
Accuracy: 100%.
Analytic expression: Equation 6-10, $E_R = 99.27$ keV.
Values of a_i ($i = 1, 2, \ldots, 10$) are as follows.

a_1	a_2	a_3	a_4	a_5
2.515E+18	2.599E+00	2.370E−05	9.661E−01	1.194E−04

a_6	a_7	a_8	a_9	a_{10}
5.131E+00	4.654E−02	2.182E+01	7.304E+00	4.9E−02

The value of a_{10} was assumed.
The expression represents the recommended data with an rms deviation of 2.7%.
The maximum deviation is 6.9% at 8.0×10^{-3} keV/amu.
See Graph 23.

$He(2^3S) + H_2 \rightarrow$ Total Ionization

Range of recommended data: 2.0×10^{-5} keV/amu $\leq E \leq 1.7\times10^{-4}$ keV/amu.
Accuracy: Unknown.

Analytic expression: Equation 3-3, $E_R = 99.27$ keV.
Values of a_i ($i = 1, 2, 3$) are as follows.

a_1	a_2	a_3
9.500E+07	1.2225E+00	6.306E−04

The expression represents the recommended data with an rms deviation of 0.8%.
The maximum deviation is 2.0% at 1.5×10^{-4} keV/amu.
See Graph 24.

He(2^3S) + H_2 → Rearrangement Ionization

Range of recommended data: 3.0×10^{-5} keV/amu $\leq E \leq 7.5\times10^{-4}$ keV/amu.
Accuracy: Unknown.
Analytic expression: Equation 3-5, $E_R = 99.27$ keV.
Values of a_i ($i = 1, 2, \ldots, 5$) are as follows.

a_1	a_2	a_3	a_4	a_5
5.701E+03	7.428E−01	6.327E−01	5.071E−04	2.E−05

The value of a_5 was assumed.
The expression represents the recommended data with an rms deviation of 2.2%.
The maximum deviation is 3.2% at 8.0×10^{-5} keV/amu.
See Graph 25.

He(2^1S) + H_2 → Total Ionization

Range of recommended data: 2.8×10^{-5} keV/amu $\leq E \leq 1.8\times10^{-4}$ keV/amu.
Accuracy: Unknown.
Analytic expression: Equation 4-4, $E_R = 99.27$ keV.
Values of a_i ($i = 1, 2, 3, 4$) are as follows.

a_1	a_2	a_3	a_4
7.586E+08	1.3530E+00	1.510E−04	6.414E−01

The expression represents the recommended data with an rms deviation of 0.9%.
The maximum deviation is 1.7% at 1.5×10^{-4} keV/amu.
See Graph 26.

$He(2^1S) + H_2 \rightarrow$ Rearrangement Ionization

Range of recommended data: 3.0×10^{-5} keV/amu $\leq E \leq 7.5\times10^{-4}$ keV/amu.
Accuracy: Unknown.
Analytic expression: Equation 4-4, $E_R = 99.27$ keV.
Values of a_i ($i = 1, 2, 3, 4$) are as follows.

a_1	a_2	a_3	a_4
2.093E+07	1.2617E+00	8.425E−05	8.615E−01

The expression represents the recommended data with an rms deviation of 4.3%.
The maximum deviation is 9.0% at 1.1×10^{-4} keV/amu.
See Graph 27.

$He + H_2 \rightarrow$ Total Slow Positive Ion Production

Range of recommended data: 0.76 keV/amu $\leq E \leq 2.5\times10^{2}$ keV/amu.
Accuracy: 20%.
Analytic expression: Equation 6-6, $E_R = 99.27$ keV.
Values of a_i ($i = 1, 2, \ldots, 6$) are as follows.

a_1	a_2	a_3	a_4	a_5	a_6
1.817E+05	2.4275E+00	4.231E−01	−5.281E−01	4.316E+00	1.0337E+00

The expression represents the recommended data with an rms deviation of 0.5%.
The maximum deviation is 1.2% at 2.0×10^{2} keV/amu.
See Graph 28.

$He + H_2 \rightarrow$ Total Slow Electron Production

Range of recommended data: 1.2×10^{-3} keV/amu $\leq E \leq 2.5\times10^{2}$ keV/amu.
Accuracy: 20% for 1.0×10^{-3} keV/amu $\leq E \leq 1.2\times10^{-3}$ keV/amu; unknown for 1.2×10^{-3} keV/amu $\leq E \leq 37$ keV/amu; 20% for $E > 37$ keV/amu.
Analytic expression: Equation 8-13, $E_R = 99.27$ keV.
Values of a_i ($i = 1, 2, \ldots, 13$) are as follows.

a_1	a_2	a_3	a_4	a_5
2.070E+24	9.2182E+00	1.681E−01	−2.7031E+00	2.199E−01

a_6	a_7	a_8	a_9	a_{10}
-4.647E−01	4.449E−01	8.358E−01	2.311E−01	1.106E−02

a_{11}	a_{12}	a_{13}
4.507E−03	1.4094E−03	1.019E−04

The expression represents the recommended data with an rms deviation of 3.5%.
The maximum deviation is 11% at 2.0×10^{-3} keV/amu.
See Graph 29.

He + H_2 → He + H_2^+ + e

Range of recommended data: 0.74 keV/amu $\leq E \leq$ 12 keV/amu.
Accuracy: Unknown.
Analytic expression: Equation 4-4, $E_R = 99.27$ keV.
Values of a_i ($i = 1, 2, 3, 4$) are as follows.

a_1	a_2	a_3	a_4
1.150E+01	8.671E−01	1.883E+01	7.314E−01

The expression represents the recommended data with an rms deviation of 0.3%.
The maximum deviation is 0.6% at 2.0 keV/amu.
See Graph 30.

He + H_2 → Total H^+ Production

Range of recommended data: 0.74 keV/amu $\leq E \leq$ 11 keV/amu.
Accuracy: Unknown.
Analytic expression: Equation 4-8, $E_R = 99.27$ keV.
Values of a_i ($i = 1, 2, \ldots, 8$) are as follows.

a_1	a_2	a_3	a_4
6.885E+01	1.484E+00	3.822E+00	1.519E+00

a_5	a_6	a_7	a_8
5.870E−01	1.994E−01	1.066E+02	1.E+02

The value of a_8 was assumed.
The expression represents the recommended data with an rms deviation of 1.3%.
The maximum deviation is 2.8% at 3.0 keV/amu.
See Graph 31.

He + He → Total Slow Positive Ion Production

Range of recommended data: 5.0 keV/amu $\leq E \leq 2.5\times10^2$ keV/amu.
Accuracy: Unknown.
Analytic expression: Equation 4-4, $E_R = 99.27$ keV.
Values of a_i ($i = 1, 2, 3, 4$) are as follows.

a_1	a_2	a_3	a_4
6.128E+00	8.519E−01	3.600E+01	6.017E−01

The expression represents the recommended data with an rms deviation of 1.3%.
The maximum deviation is 2.2% at 5.0 keV/amu.
See Graph 32.

He + He → Total Slow Electron Production

Range of recommended data: 2.7×10^{-2} keV/amu $\leq E \leq 2.5\times10^2$ keV/amu.
Accuracy: Unknown.
Analytic expression: Equation 6-8, $E_R = 99.27$ keV , $E_{th} = 2.259\times10^{-2}$ keV. The parameter E_{th} was used as an additional adjustable parameter.
Values of a_i ($i = 1, 2, \ldots, 8$) are as follows.

a_1	a_2	a_3	a_4
2.081E+04	2.145E+00	3.035E−01	−8.153E−01

a_5	a_6	a_7	a_8
4.353E+00	6.886E−01	1.447E−02	8.019E−03

The expression represents the recommended data with an rms deviation of 1.4%.
The maximum deviation is 4.0% at 3.5×10^{-2} keV/amu.
See Graph 33.

He + He → He + He^+ + e

Range of recommended data: 12 keV/amu $\leq E \leq 45$ keV/amu.
Accuracy: Unknown.
Analytic expression: Equation 4-4, $E_R = 99.27$ keV.
Values of a_i ($i = 1, 2, 3, 4$) are as follows.

a_1	a_2	a_3	a_4
9.294E+00	1.1061E+00	5.509E+01	5.149E−01

The expression represents the recommended data with an rms deviation of 0.3%.
The maximum deviation is 0.5% at 15 keV/amu.
See Graph 34.

$$\mathbf{He + He \rightarrow He + He^{2+} + 2e}$$

Range of recommended data: 13 keV/amu $\leq E \leq$ 45 keV/amu.
Accuracy: Unknown.
Analytic expression: Equation 6-5, $E_R = 99.27$ keV.
Values of a_i ($i = 1, 2, \ldots, 5$) are as follows.

a_1	a_2	a_3	a_4	a_5
8.046E+03	6.2095E+00	1.1819E+01	−8.286E−01	1.8E+02

The value of a_5 was assumed.
The expression represents the recommended data with an rms deviation of 0.1%.
The maximum deviation is 0.3% at 25 keV/amu.
See Graph 35.

$$\mathbf{He^{+} + He^{+} \rightarrow He^{+} + He^{2+} + e}$$

Range of recommended data: 10 keV/amu $\leq E \leq$ 58 keV/amu.
Accuracy: Factor of 2.
Analytic expression: Equation 6-5, $E_R = 99.27$ keV.
Values of a_i ($i = 1, 2, \ldots, 5$) are as follows.

a_1	a_2	a_3	a_4	a_5
4.305E+01	3.581E+00	1.099E+01	−1.523E+00	8.194E+01

The expression represents the recommended data with an rms deviation of 0.7%.
The maximum deviation is 1.1% at 35 keV/amu.
See Graph 36.

$$\mathbf{He^{+} + He^{+} \rightarrow (He + He^{2+}) \text{ or } (He^{+} + He^{2+} + e)}$$

Range of recommended data: 5.9 keV/amu $\leq E \leq$ 67 keV/amu.
Accuracy: 50%.
Analytic expression: Equation 6-6, $E_R = 99.27$ keV.
Values of a_i ($i = 1, 2, \ldots, 6$) are as follows.

a_1	a_2	a_3	a_4	a_5	a_6
8.202E+01	2.663E+00	1.020E+01	−3.236E−01	4.571E+01	4.243E+00

The expression represents the recommended data with an rms deviation of 0.6%.
The maximum deviation is 1.4% at 6.0 keV/amu.
See Graph 37.

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

Range of recommended data: 6.3 keV/amu $\leq E \leq 8.0\times10^3$ keV/amu.
Accuracy: Unknown.
Analytic expression: Equation 4-4, $E_R = 99.27$ keV.
Values of a_i ($i = 1, 2, 3, 4$) are as follows.

a_1	a_2	a_3	a_4
1.456E+01	1.7472E+00	4.798E+01	8.787E−01

The expression represents the recommended data with an rms deviation of 4.0%.
The maximum deviation is 8.5% at 6.3 keV/amu.
See Graph 38.

$He^+ + H_2 \rightarrow$ Total Slow Positive Ion Production

Range of recommended data: 0.75 keV/amu $\leq E \leq 5.0\times10^2$ keV/amu.
Accuracy: 50%.
Analytic expression: Equation 6-8, $E_R = 99.27$ keV.
Values of a_i ($i = 1, 2, \ldots, 8$) are as follows.

a_1	a_2	a_3	a_4
1.065E+07	4.168E+00	2.387E+00	−6.592E−01

a_5	a_6	a_7	a_8
4.842E+00	7.270E−01	2.994E−01	1.194E−02

The expression represents the recommended data with an rms deviation of 1.3%.
The maximum deviation is 3.4% at 40 keV/amu.
See Graph 39.

$He^+ + H_2 \rightarrow$ Total Slow Electron Production

Range of recommended data: 2.5 keV/amu $\leq E \leq 5.0\times10^2$ keV/amu.
Accuracy: 50%.
Analytic expression: Equation 4-6, $E_R = 99.27$ keV.
Values of a_i ($i = 1, 2, \ldots, 6$) are as follows.

a_1	a_2	a_3	a_4	a_5	a_6
2.415E+01	1.4765E+00	4.077E+01	5.981E−01	9.168E−02	5.299E−02

The expression represents the recommended data with an rms deviation of 0.6%.
The maximum deviation is 1.3% at 10 keV/amu.
See Graph 40.

$He^+ + H_2 \rightarrow (He + H_2{}^+)$ or $(He^+ + H_2{}^+ + e)$

Range of recommended data: 0.73 keV/amu $\leq E \leq 8.0\times10^2$ keV/amu.
Accuracy: 20%.
Analytic expression: Equation 4-6, $E_R = 99.27$ keV.
Values of a_i ($i = 1, 2, \ldots, 6$) are as follows.

a_1	a_2	a_3	a_4	a_5	a_6
1.115E+02	1.4948E+00	1.682E+01	5.784E−01	5.702E−02	3.919E−02

The expression represents the recommended data with an rms deviation of 2.4%.
The maximum deviation is 5.1% at 7.0 keV/amu.
See Graph 41.

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

Range of recommended data: 0.74 keV/amu $\leq E \leq 12$ keV/amu.
Accuracy: Unknown.
Analytic expression: Equation 18-8, $E_R = 99.27$ keV.
Values of a_i ($i = 1, 2, \ldots, 8$) are as follows.

a_1	a_2	a_3	a_4
9.317E+14	9.721E−01	1.520E−08	7.168E−01

a_5	a_6	a_7	a_8
1.440E−02	4.763E+00	9.310E-12	8.5E+02

The value of a_8 was assumed.
The expression represents the recommended data with an rms deviation of 1.8%.
The maximum deviation is 5.0% at 10 keV/amu.
See Graph 42.

$He^+ + H_2 \rightarrow He^+ + 2H^+ + 2e$

Range of recommended data: 25 keV/amu $\leq E \leq 9.0\times10^2$ keV/amu.
Accuracy: 20%.
Analytic expression: Equation 7-5, $E_R = 99.27$ keV.
Values of a_i ($i = 1, 2, \ldots, 5$) are as follows.

a_1	a_2	a_3	a_4	a_5
2.046E+00	1.610E+00	1.740E+01	8.632E−02	2.099E+01

The expression represents the recommended data with an rms deviation of 1.7%.
The maximum deviation is 3.9% at 9.0×10^2 keV/amu.
See Graph 43.

$He^+ + He \rightarrow$ Total Slow Positive Ion Production

Range of recommended data: 2.5 keV/amu $\leq E \leq 2.8\times10^3$ keV/amu.
Accuracy: 20% for $E > 30$–40 keV/amu; unknown for $E < 30$–40 keV/amu.
Analytic expression: Equation 4-6, $E_R = 99.27$ keV.
Values of a_i ($i = 1, 2, \ldots, 6$) are as follows.

a_1	a_2	a_3	a_4	a_5	a_6
2.821E+00	3.735E−01	8.884E+01	9.075E−01	3.673E+00	4.636E−02

The expression represents the recommended data with an rms deviation of 1.4%.
The maximum deviation is 4.0% at 2.0×10^2 keV/amu.
See Graph 44.

$He^+ + He \rightarrow$ Total Slow Electron Production

Range of recommended data: 2.5 keV/amu $\leq E \leq 5.0\times10^2$ keV/amu.
Accuracy: 20% for $E > 30$–40 keV/amu; unknown for $E < 30$–40 keV/amu.
Analytic expression: Equation 4-4, $E_R = 99.27$ keV.
Values of a_i ($i = 1, 2, 3, 4$) are as follows.

a_1	a_2	a_3	a_4
2.898E+00	8.157E−01	1.260E+02	9.962E−01

The expression represents the recommended data with an rms deviation of 2.2%.
The maximum deviation is 3.4% at 1.1×10^2 keV/amu.
See Graph 45.

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

Range of recommended data: 12 keV/amu $\leq E \leq 7.8\times10^2$ keV/amu.
Accuracy: 20%.
Analytic expression: Equation 4-4, $E_R = 99.27$ keV.
Values of a_i ($i = 1, 2, 3, 4$) are as follows.

a_1	a_2	a_3	a_4
1.689E+00	−4.421E−01	1.179E+03	1.011E+00

The expression represents the recommended data with an rms deviation of 1.0%.
The maximum deviation is 2.1% at 12 keV/amu.
See Graph 46.

$$\mathbf{He^+ + He \rightarrow He^+ + He^{2+} + 2e}$$

Range of recommended data: 12 keV/amu $\leq E \leq 7.5\times10^2$ keV/amu.
Accuracy: 20%.
Analytic expression: Equation 4-6, $E_R = 99.27$ keV.
Values of a_i ($i = 1, 2, \ldots, 6$) are as follows.

a_1	a_2	a_3	a_4	a_5	a_6
2.672E−01	1.187E+00	7.322E+01	1.686E+00	2.025E−02	1.190E+01

The expression represents the recommended data with an rms deviation of 1.5%.
The maximum deviation is 3.4% at 60 keV/amu.
See Graph 47.

$$\mathbf{He^+ + Li \rightarrow He^+ + Li^+ + e}$$

Range of recommended data: 8.2 keV/amu $\leq E \leq 34$ keV/amu.
Accuracy: Unknown.
Analytic expression: Equation 3-3, $E_R = 99.27$ keV.
Values of a_i ($i = 1, 2, 3$) are as follows.

a_1	a_2	a_3
5.211E+02	1.237E+00	1.100E+01

The expression represents the recommended data with an rms deviation of 4.0%.
The maximum deviation is 6.2% at 25 keV/amu.
See Graph 48.

$He^{2+} + H \rightarrow He^{2+} + H^{+} + e$

Range of recommended data: 31 keV/amu $\leq E \leq 5.5\times10^2$ keV/amu.
Accuracy: Unknown.
Analytic expression: Equation 4-4, $E_R = 99.27$ keV.
Values of a_i ($i = 1, 2, 3, 4$) are as follows.

a_1	a_2	a_3	a_4
5.285E+01	2.433E+00	4.406E+01	7.137E−01

The expression represents the recommended data with an rms deviation of 1.6%.
The maximum deviation is 2.5% at 2.0×10^2 keV/amu.
See Graph 49.

$He^{2+} + H_2 \rightarrow$ Total Slow Positive Ion Production

Range of recommended data: 2.0 keV/amu $\leq E \leq 3.0\times10^2$ keV/amu.
Accuracy: 25%.
Analytic expression: Equation 4-4, $E_R = 99.27$ keV.
Values of a_i ($i = 1, 2, 3, 4$) are as follows.

a_1	a_2	a_3	a_4
1.039E+02	8.517E−01	2.147E+01	7.497E−01

The expression represents the recommended data with an rms deviation of 3.5%.
The maximum deviation is 5.9% at 7.0 keV/amu.
See Graph 50.

$He^{2+} + H_2 \rightarrow$ Total Slow Electron Production

Range of recommended data: 2.5 keV/amu $\leq E \leq 5.0\times10^2$ keV/amu.
Accuracy: 25%.
Analytic expression: Equation 6-8, $E_R = 99.27$ keV.
Values of a_i ($i = 1, 2, \ldots, 8$) are as follows.

a_1	a_2	a_3	a_4
1.554E+02	2.167E+00	2.646E+01	−2.210E−02

a_5	a_6	a_7	a_8
6.722E+01	1.663E+00	1.401E−01	1.782E−02

The expression represents the recommended data with an rms deviation of 0.8%.
The maximum deviation is 2.0% at 70 keV/amu.
See Graph 51.

$He^{2+} + H_2 \rightarrow$ Total H_2^+ Production

Range of recommended data: 2.1 keV/amu $\leq E \leq 5.4\times10^2$ keV/amu.
Accuracy: 25%.
Analytic expression: Equation 18-9, $E_R = 99.27$ keV.
Values of a_i ($i = 1, 2, \ldots, 9$) are as follows.

a_1	a_2	a_3	a_4	a_5
1.584E+02	1.219E+00	3.753E+01	−7.190E+00	6.315E+01

a_6	a_7	a_8	a_9
6.183E−01	2.322E−01	1.582E−01	1.794E+00

The expression represents the recommended data with an rms deviation of 2.2%.
The maximum deviation is 4.8% at 20 keV/amu.
See Graph 52.

$He^{2+} + H_2 \rightarrow H_2^+$ Production by Single Ionization

Range of recommended data: 2.5 keV/amu $\leq E \leq 5.4\times10^2$ keV/amu.
Accuracy: 25%.
Analytic expression: Equation 18-9, $E_R = 99.27$ keV.
Values of a_i ($i = 1, 2, \ldots, 9$) are as follows.

a_1	a_2	a_3	a_4	a_5
9.105E+03	5.226E+00	3.846E+01	−3.955E−01	4.665E+01

a_6	a_7	a_8	a_9
7.965E−01	2.496E−03	2.715E+00	1.161E+00

The expression represents the recommended data with an rms deviation of 3.5%.
The maximum deviation is 8.5% at 15 keV/amu.
See Graph 53.

$He^{2+} + H_2 \rightarrow$ Total H^+ Production

Range of recommended data: 2.3 keV/amu $\leq E \leq 4.6\times10^2$ keV/amu.
Accuracy: 25%.
Analytic expression: Equation 4-6, $E_R = 99.27$ keV.
Values of a_i ($i = 1, 2, \ldots, 6$) are as follows.

a_1	a_2	a_3	a_4	a_5	a_6
1.640E+01	1.170E+00	7.607E+01	7.849E−01	3.212E−01	2.361E−02

The expression represents the recommended data with an rms deviation of 2.6%.
The maximum deviation is 4.7% at 40 keV/amu.
See Graph 54.

$He^{2+} + H_2 \rightarrow H^+$ Production by Ionization Collisions

Range of recommended data: 2.3 keV/amu $\leq E \leq 6.0\times10^2$ keV/amu.
Accuracy: 25%.
Analytic expression: Equation 4-6, $E_R = 99.27$ keV.
Values of a_i ($i = 1, 2, \ldots, 6$) are as follows.

a_1	a_2	a_3	a_4	a_5	a_6
8.564E+00	8.853E−01	3.784E+01	1.156E+00	4.229E+01	1.E−03

The value of a_6 was assumed.
The expression represents the recommended data with an rms deviation of 3.4%.
The maximum deviation is 5.4% at 40 keV/amu.
See Graph 55.

$He^{2+} + He \rightarrow$ Total Slow Positive Ion Production

Range of recommended data: 9.0 keV/amu $\leq E \leq 2.9\times10^3$ keV/amu.
Accuracy: 30%.
Analytic expression: Equation 4-4, $E_R = 99.27$ keV.
Values of a_i ($i = 1, 2, 3, 4$) are as follows.

a_1	a_2	a_3	a_4
3.192E+01	8.313E−01	3.117E+01	7.765E−01

The expression represents the recommended data with an rms deviation of 3.0%.
The maximum deviation is 5.7% at 2.9×10^3 keV/amu.
See Graph 56.

$He^{2+} + He \rightarrow$ Total Slow Electron Production

Range of recommended data: 5.0 keV/amu $\leq E \leq 2.8\times10^3$ keV/amu.
Accuracy: 50%.

Analytic expression: Equation 6-6, $E_R = 99.27$ keV.
Values of a_i ($i = 1, 2, \ldots, 6$) are as follows.

a_1	a_2	a_3	a_4	a_5	a_6
2.347E+03	3.921E+00	9.139E+00	−1.350E+00	2.827E+01	8.606E−01

The expression represents the recommended data with an rms deviation of 1.4%.
The maximum deviation is 2.3% at 70 keV/amu.
See Graph 57.

$$\mathbf{He^{2+} + He \rightarrow He^{2+} + He^{+} + e}$$

Range of recommended data: 1.5 keV/amu $\leq E \leq 2.4\times10^3$ keV/amu.
Accuracy: 30%.
Analytic expression: Equation 18-9, $E_R = 99.27$ keV.
Values of a_i ($i = 1, 2, \ldots, 9$) are as follows.

a_1	a_2	a_3	a_4	a_5
4.848E+00	3.394E+00	8.579E+01	5.529E−01	4.833E+02

a_6	a_7	a_8	a_9
3.127E+00	3.528E−02	1.164E+00	4.455E−01

The expression represents the recommended data with an rms deviation of 5.7%.
The maximum deviation is 12% at 4.0 keV/amu.
See Graph 58.

$$\mathbf{He^{2+} + He \rightarrow He^{2+} + He^{2+} + 2e}$$

Range of recommended data: 14 keV/amu $\leq E \leq 2.7\times10^3$ keV/amu.
Accuracy: 50%.
Analytic expression: Equation 6-10, $E_R = 99.27$ keV.
Values of a_i ($i = 1, 2, \ldots, 10$) are as follows.

a_1	a_2	a_3	a_4	a_5
6.663E−02	2.102E+00	1.455E+02	1.567E+00	5.385E+02

a_6	a_7	a_8	a_9	a_{10}
6.256E+00	5.497E−02	1.311E−01	2.759E−02	1.428E+01

The expression represents the recommended data with an rms deviation of 4.8%.
The maximum deviation is 12% at 70 keV/amu.
See Graph 59.

$$\mathbf{He^{2+} + Li \rightarrow He^{2+} + Li^{+} + e}$$

Range of recommended data: 6.6 keV/amu $\leq E \leq 1.5\times10^3$ keV/amu.
Accuracy: 30% for $E > 20$ keV/amu; Unknown for $E \leq 20$ keV/amu.
Analytic expression: Equation 4-4, $E_R = 99.27$ keV.
Values of a_i ($i = 1, 2, 3, 4$) are as follows.

a_1	a_2	a_3	a_4
5.845E+03	2.5452E+00	1.712E+01	8.875E−01

The expression represents the recommended data with an rms deviation of 3.3%.
The maximum deviation is 6.5% at 40 keV/amu.
See Graph 60.

Electron Loss or Stripping Collisions

$$\mathbf{H + H \rightarrow H^{+} + H + e}$$

Range of recommended data: 1.2 keV/amu $\leq E \leq 3.5\times10^3$ keV/amu.
Accuracy: 20%.
Analytic expression: Equation 6-8, $E_R = 25.0$ keV.
Values of a_i ($i = 1, 2, \ldots, 8$) are as follows.

a_1	a_2	a_3	a_4
7.707E+02	5.756E+00	6.392E+00	−1.699E+00

a_5	a_6	a_7	a_8
9.632E+00	7.725E−01	3.874E−01	2.220E−01

The expression represents the recommended data with an rms deviation of 3.5%.
The maximum deviation is 8.3% at 40 keV/amu.
See Graph 61.

$$\mathbf{H(2s) + H(1s) \rightarrow H^{+} + H + e}$$

Range of recommended data: 5.0 keV/amu $\leq E \leq 1.0\times10^2$ keV/amu.
Accuracy: Unknown.
Analytic expression: Equation 6-8, $E_R = 25.0$ keV.
Values of a_i ($i = 1, 2, \ldots, 8$) are as follows.

a_1	a_2	a_3	a_4
5.319E+05	4.830E+00	1.770E+00	−4.451E−01

a_5	a_6	a_7	a_8
4.022E+00	1.782E+00	5.614E−01	8.515E+00

The expression represents the recommended data with an rms deviation of 0.2%.
The maximum deviation is 0.3% at 8.0 keV/amu.
See Graph 62.

$$\mathbf{H + H_2 \rightarrow H^+ + H_2 + e}$$

Range of recommended data: 6.0×10^{-2} keV/amu $\leq E \leq 2.0\times10^{4}$ keV/amu.
Accuracy: 30%.
Analytic expression: Equation 8-10, $E_R = 25.0$ keV.
Values of a_i ($i = 1, 2, \ldots, 10$) are as follows.

a_1	a_2	a_3	a_4	a_5
1.251E+03	3.698E+00	1.215E+00	−1.581E+00	5.878E+00

a_6	a_7	a_8	a_9	a_{10}
5.277E−01	1.222E+01	1.263E+00	5.550E−01	8.026E−02

The expression represents the recommended data with an rms deviation of 2.3%.
The maximum deviation is 5.3% at 15 keV/amu.
See Graph 63.

$$\mathbf{H(2s) + H_2 \rightarrow H^+ + H_2 + e}$$

Range of recommended data: 0.50 keV/amu $\leq E \leq 5.0\times10^{2}$ keV/amu.
Accuracy: 50%.
Analytic expression: Equation 6-8, $E_R = 25.0$ keV.
Values of a_i ($i = 1, 2, \ldots, 8$) are as follows.

a_1	a_2	a_3	a_4
3.623E+01	2.248E+00	9.728E+00	−3.641E−01

a_5	a_6	a_7	a_8
1.473E+01	7.888E−01	1.186E+00	1.221E−01

The expression represents the recommended data with an rms deviation of 1.3%.
The maximum deviation is 2.3% at 2.0 keV/amu.
See Graph 64.

$\mathbf{H + He \rightarrow H^{+} + He + e}$

Range of recommended data: 5.0×10^{-2} keV/amu $\leq E \leq 2.0\times10^{4}$ keV/amu.
Accuracy: 15%.
Analytic expression: Equation 6-8, $E_{\mathrm{R}} = 25.0$ keV.
Values of a_i ($i = 1, 2, \ldots, 8$) are as follows.

a_1	a_2	a_3	a_4
2.339E+01	2.3014E+00	1.821E+00	−9.823E−01

a_5	a_6	a_7	a_8
1.415E+01	9.461E−01	1.377E+00	1.171E−01

The expression represents the recommended data with an rms deviation of 4.4%.
The maximum deviation is 7.5% at 0.10 keV/amu.
See Graph 65.

$\mathbf{H(2s) + He \rightarrow H^{+} + He + e}$

Range of recommended data: 0.50 keV/amu $\leq E \leq 5.0\times10^{2}$ keV/amu.
Accuracy: 50%.
Analytic expression: Equation 6-8, $E_{\mathrm{R}} = 25.0$ keV.
Values of a_i ($i = 1, 2, \ldots, 8$) are as follows.

a_1	a_2	a_3	a_4
8.352E+07	4.870E+00	6.119E−01	−6.840E−01

a_5	a_6	a_7	a_8
1.163E+00	6.787E−01	1.189E−01	3.486E+02

The expression represents the recommended data with an rms deviation of 2.0%.
The maximum deviation is 4.2% at 4.0 keV/amu.
See Graph 66.

$\mathbf{He + H \rightarrow He^{+} + H + e}$

Range of recommended data: 50 keV/amu $\leq E \leq 1.2\times10^{3}$ keV/amu.
Accuracy: 15%.
Analytic expression: Equation 4-4, $E_{\mathrm{R}} = 99.27$ keV.
Values of a_i ($i = 1, 2, 3, 4$) are as follows.

a_1	a_2	a_3	a_4
2.505E+00	4.553E−02	8.002E+01	1.097E+00

The expression represents the recommended data with an rms deviation of 1.2%.
The maximum deviation is 2.4% at 7.0×10^2 keV/amu.
See Graph 67.

$$\mathbf{He + H_2 \rightarrow He^+ + H_2 + e}$$

Range of recommended data: 0.5 keV/amu $\leq E \leq 1.0\times10^3$ keV/amu.
Accuracy: 15%.
Analytic expression: Equation 6-6, $E_R = 99.27$ keV.
Values of a_i ($i = 1, 2, \ldots, 6$) are as follows.

a_1	a_2	a_3	a_4	a_5	a_6
2.215E+04	2.736E+00	1.224E+00	−6.835E−01	7.687E+00	8.610E−01

The expression represents the recommended data with an rms deviation of 1.5%.
The maximum deviation is 2.4% at 70 keV/amu.
See Graph 68.

$$\mathbf{He + H_2 \rightarrow He^{2+} + H_2 + 2e}$$

Range of recommended data: 50 keV/amu $\leq E \leq 8.0\times10^2$ keV/amu.
Accuracy: Unknown.
Analytic expression: Equation 4-4, $E_R = 99.27$ keV.
Values of a_i ($i = 1, 2, 3, 4$) are as follows.

a_1	a_2	a_3	a_4
7.130E−02	1.274E+00	1.122E+02	1.192E+00

The expression represents the recommended data with an rms deviation of 2.0%.
The maximum deviation is 4.5% at 5.0×10^2 keV/amu.
See Graph 69.

$$\mathbf{He^* + H_2 \rightarrow He \text{ or } He^+}$$

Range of recommended data: 1.8 keV/amu $\leq E \leq 1.2\times10^2$ keV/amu.
Accuracy: 50%.
Analytic expression: Equation 4-4, $E_R = 99.27$ keV.
Values of a_i ($i = 1, 2, 3, 4$) are as follows.

a_1	a_2	a_3	a_4
2.559E+02	1.029E+00	6.115E+00	6.257E−01

The expression represents the recommended data with an rms deviation of 1.3%.
The maximum deviation is 2.0% at 4.0 keV/amu.
See Graph 70.

$$\mathbf{He^* + H_2 \rightarrow He^+ + H_2 + e}$$

Range of recommended data: 2.5 keV/amu $\leq E \leq 1.3\times10^2$ keV/amu.
Accuracy: 50%.
Analytic expression: Equation 4-4, $E_R = 99.27$ keV.
Values of a_i ($i = 1, 2, 3, 4$) are as follows.

a_1	a_2	a_3	a_4
1.603E+03	1.722E+00	4.952E+00	4.753E−01

The expression represents the recommended data with an rms deviation of 1.8%.
The maximum deviation is 2.6% at 4.0 $\times10^2$keV/amu.
See Graph 71.

$$\mathbf{He^* + H_2 \rightarrow He + H_2}$$

Range of recommended data: 6.3 keV/amu $\leq E \leq 1.2\times10^2$ keV/amu.
Accuracy: 50%.
Analytic expression: Equation 6-6, $E_R = 99.27$ keV.
Values of a_i ($i = 1, 2, \ldots, 6$) are as follows.

a_1	a_2	a_3	a_4	a_5	a_6
5.049E+00	2.558E−01	1.809E+01	1.311E+00	5.071E+01	3.402E+00

The expression represents the recommended data with an rms deviation of 0.1%.
The maximum deviation is 0.3% at 70 keV/amu.
See Graph 72.

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

Range of recommended data: 5.0×10^{-2} keV/amu $\leq E \leq 5.0\times10^2$ keV/amu.
Accuracy: 20% for $E >$ 1keV/amu; 100% for $E \leq 1$ keV/amu.
Analytic expression: Equation 7-9, $E_R = 99.27$ keV.
Values of a_i ($i = 1, 2, \ldots, 9$) are as follows.

a_1	a_2	a_3	a_4	a_5
2.924E+02	1.808E+00	3.088E+00	−3.861E−01	1.413E+01

a_6	a_7	a_8	a_9
8.150E−01	5.462E−04	8.810E−03	3.741E+00

The expression represents the recommended data with an rms deviation of 3.1%.
The maximum deviation is 6.0% at 4.0 keV/amu.
See Graph 73.

$$\mathbf{He + He \rightarrow He^{2+} + He + 2e}$$

Range of recommended data: 50 keV/amu $\leq E \leq 1.0\times10^3$ keV/amu.
Accuracy: 100%.
Analytic expression: Equation 4-4, $E_R = 99.27$ keV.
Values of a_i ($i = 1, 2, 3, 4$) are as follows.

a_1	a_2	a_3	a_4
1.241E−01	1.467E+00	9.416E+01	1.287E+00

The expression represents the recommended data with an rms deviation of 1.7%.
The maximum deviation is 3.1% at 70 keV/amu.
See Graph 74.

$$\mathbf{He^+ + H \rightarrow He^{2+} + H + e}$$

Range of recommended data: 12 keV/amu $\leq E \leq 9.0\times10^2$ keV/amu.
Accuracy: 20%.
Analytic expression: Equation 6-8, $E_R = 99.27$ keV.
Values of a_i ($i = 1, 2, \ldots, 8$) are as follows.

a_1	a_2	a_3	a_4
6.103E+02	6.018E+00	1.738E+01	−7.496E−01

a_5	a_6	a_7	a_8
1.951E+01	7.506E−01	8.118E+00	2.272E+00

The expression represents the recommended data with an rms deviation of 0.9%.
The maximum deviation is 1.9% at 1.0×10^2 keV/amu.
See Graph 75.

$$\mathbf{He^+ + H_2 \rightarrow He^{2+} + H_2 + e}$$

Range of recommended data: 5.0 keV/amu $\leq E \leq 9.5\times10^2$ keV/amu.
Accuracy: 20% for $E > 30$keV/amu; 40% for $E \leq 30$ keV/amu.
Analytic expression: Equation 4-6, $E_R = 99.27$ keV.
Values of a_i ($i = 1, 2, \ldots, 6$) are as follows.

a_1	a_2	a_3	a_4	a_5	a_6
5.625E−01	2.498E+00	8.362E+01	7.287E−01	6.328E−03	7.117E−02

The expression represents the recommended data with an rms deviation of 3.1%.
The maximum deviation is 6.9% at 40 keV/amu.
See Graph 76.

$$\mathbf{He^+ + He \rightarrow He^{2+} + He + e}$$

Range of recommended data: 3.5 keV/amu $\leq E \leq 4.0\times10^3$ keV/amu.
Accuracy: 20%.
Analytic expression: Equation 6-6, $E_R = 99.27$ keV.
Values of a_i ($i = 1, 2, \ldots, 8$) are as follows.

a_1	a_2	a_3	a_4	a_5	a_6
8.412E+04	4.906E+00	3.198E+00	−1.249E+00	1.354E+01	9.611E−01

The expression represents the recommended data with an rms deviation of 2.0%.
The maximum deviation is 4.5% at 70 keV/amu.
See Graph 77.

Electron Detachment Collisions

$$\mathbf{H^- + H \rightarrow H + H + e}$$

Range of recommended data: 0.11 keV/amu $\leq E \leq 4.0\times10^3$ keV/amu.
Accuracy: 30%.
Analytic expression: Equation 6-8, $E_R = 25.0$ keV.
Values of a_i ($i = 1, 2, \ldots, 8$) are as follows.

a_1	a_2	a_3	a_4
1.094E+02	1.261E+00	4.449E+00	2.287E−01

a_5	a_6	a_7	a_8
8.877E+00	9.779E−01	2.280E+00	4.848E−02

The expression represents the recommended data with an rms deviation of 1.3%.
The maximum deviation is 2.9% at 7.0 keV/amu.
See Graph 78.

$$\mathbf{H^- + H \rightarrow (H + H + e) \text{ or } (H + H^-)}$$

Range of recommended data: 6.0×10^{-2} keV/amu $\leq E \leq 4.0\times10^{3}$ keV/amu.
Accuracy: 30%.
Analytic expression: Equation 4-6, $E_R = 25.0$ keV.
Values of a_i ($i = 1, 2, \ldots, 6$) are as follows.

a_1	a_2	a_3	a_4	a_5	a_6
7.636E+00	2.193E−01	2.572E+01	9.341E−01	1.380E+01	1.143E−02

The expression represents the recommended data with an rms deviation of 1.7%.
The maximum deviation is 6.3% at 4.0 keV/amu.
See Graph 79.

$$\mathbf{H^- + H \rightarrow H^+ + H + 2e}$$

Range of recommended data: 1.8 keV/amu $\leq E \leq 3.0\times10^{2}$ keV/amu.
Accuracy: 20%.
Analytic expression: Equation 6-6, $E_R = 25.0$ keV.
Values of a_i ($i = 1, 2, \ldots, 6$) are as follows.

a_1	a_2	a_3	a_4	a_5	a_6
2.175E+01	2.331E+00	2.605E+00	−6.206E−01	6.820E+00	9.935E−01

The expression represents the recommended data with an rms deviation of 1.7%.
The maximum deviation is 3.0% at 3.0×10^{2} keV/amu.
See Graph 80.

$$\mathbf{H^- + H^+ \rightarrow H + H^+ + e}$$

Range of recommended data: 2.8 keV/amu $\leq E \leq 70$ keV/amu.
Accuracy: 40%.
Analytic expression: Equation 4-4, $E_R = 25.0$ keV , $E_{th} = 2.594$ keV. The parameter E_{th} was used as an additional adjustable parameter.
Values of a_i ($i = 1, 2, 3, 4$) are as follows.

a_1	a_2	a_3	a_4
1.354E+02	7.333E−01	1.319E+01	6.433E−01

The expression represents the recommended data with an rms deviation of 0.5%.
The maximum deviation is 1.2% at 4.0 keV/amu.
See Graph 81.

$$\mathbf{H^- + H_2 \rightarrow H + H_2 + e}$$

Range of recommended data: 2.3×10^{-3} keV/amu $\leq E \leq 1.7\times10^{4}$ keV/amu.
Accuracy: 25%.
Analytic expression: Equation 11-10, $E_R = 25.0$ keV.
Values of a_i ($i = 1, 2, \ldots, 10$) are as follows.

a_1	a_2	a_3	a_4	a_5
1.234E+02	6.273E−01	1.683E+00	3.473E−01	1.920E+01

a_6	a_7	a_8	a_9	a_{10}
1.209E+00	7.105E+00	4.202E−03	1.916E+00	5.117E−01

The expression represents the recommended data with an rms deviation of 2.5%.
The maximum deviation is 4.8% at 4.0×10^{2} keV/amu.
See Graph 82.

$$\mathbf{H^- + H_2 \rightarrow H^+ + H_2 + 2e}$$

Range of recommended data: 1.0 keV/amu $\leq E \leq 1.0\times10^{4}$ keV/amu.
Accuracy: 30%.
Analytic expression: Equation 6-6, $E_R = 25.0$ keV.
Values of a_i ($i = 1, 2, \ldots, 6$) are as follows.

a_1	a_2	a_3	a_4	a_5	a_6
1.397E+02	1.838E+00	7.574E−01	−2.575E−01	5.713E+00	1.074E+00

The expression represents the recommended data with an rms deviation of 2.6%.
The maximum deviation is 4.8% at 2.0×10^{2} keV/amu.
See Graph 83.

$$\mathbf{H^- + He \rightarrow H + He + e}$$

Range of recommended data: 1.0×10^{-3} keV/amu $\leq E \leq 1.5\times10^{4}$ keV/amu.
Accuracy: 25%.
Analytic expression: Equation 11-10, $E_R = 25.0$ keV.
Values of a_i ($i = 1, 2, \ldots, 10$) are as follows.

a_1	a_2	a_3	a_4	a_5
1.177E+01	3.420E−01	1.662E+01	7.778E−01	5.906E+02

a_6	a_7	a_8	a_9	a_{10}
1.958E+00	4.980E−01	1.556E−04	2.286E+00	9.363E−03

The expression represents the recommended data with an rms deviation of 1.8%.
The maximum deviation is 5.1% at 7.0×10^{-3} keV/amu.
See Graph 84.

$$\mathbf{H^- + He \rightarrow H^+ + He + 2e}$$

Range of recommended data: 0.40 keV/amu $\leq E \leq 2.3\times10^4$ keV/amu.
Accuracy: 30%.
Analytic expression: Equation 6-6, $E_R = 25.0$ keV.
Values of a_i ($i = 1, 2, \ldots, 6$) are as follows.

a_1	a_2	a_3	a_4	a_5	a_6
7.524E+02	2.519E+00	1.189E+00	−4.094E−01	3.513E+00	1.079E+00

The expression represents the recommended data with an rms deviation of 2.1%.
The maximum deviation is 5.3% at 40 keV/amu.
See Graph 85.

$$\mathbf{He^- + H \rightarrow He + H + e}$$

Range of recommended data: 3.7×10^2 keV/amu $\leq E \leq 9.0\times10^3$ keV/amu.
Accuracy: 40%.
Analytic expression: Equation 4-4, $E_R = 99.27$ keV.
Values of a_i ($i = 1, 2, 3, 4$) are as follows.

a_1	a_2	a_3	a_4
1.560E+01	1.466E−01	1.982E+02	9.228E−01

The expression represents the recommended data with an rms deviation of 0.4%.
The maximum deviation is 0.7% at 7.0×10^3 keV/amu.
See Graph 86.

$$\mathbf{He^- + H_2 \rightarrow He + H_2 + e}$$

Range of recommended data: 0.13 keV/amu $\leq E \leq 8.0\times10^2$ keV/amu.
Accuracy: 30%.
Analytic expression: Equation 4-4, $E_R = 99.27$ keV.
Values of a_i ($i = 1, 2, 3, 4$) are as follows.

a_1	a_2	a_3	a_4
2.022E+01	−1.194E−02	3.539E+01	9.182E−01

The expression represents the recommended data with an rms deviation of 0.6%.
The maximum deviation is 1.2% at 0.13 keV/amu.
See Graph 87.

$$\mathbf{He^- + H_2 \rightarrow He^+ + H_2 + 2e}$$

Range of recommended data: 26 keV/amu $\leq E \leq 8.0\times10^2$ keV/amu.
Accuracy: 30%.
Analytic expression: Equation 4-4, $E_R = 99.27$ keV.
Values of a_i ($i = 1, 2, 3, 4$) are as follows.

a_1	a_2	a_3	a_4
5.580E−01	2.089E−01	1.753E+02	9.985E−01

The expression represents the recommended data with an rms deviation of 0.5%.
The maximum deviation is 1.1% at 90 keV/amu.
See Graph 88.

$$\mathbf{He^- + He \rightarrow He + He + e}$$

Range of recommended data: 0.12 keV/amu $\leq E \leq 7.0\times10^2$ keV/amu.
Accuracy: 25%.
Analytic expression: Equation 4-4, $E_R = 99.27$ keV.
Values of a_i ($i = 1, 2, 3, 4$) are as follows.

a_1	a_2	a_3	a_4
1.835E+01	5.316E−02	1.831E+01	8.616E−01

The expression represents the recommended data with an rms deviation of 0.5%.
The maximum deviation is 0.9% at 2.0×10^2 keV/amu.
See Graph 89.

$$\mathbf{He^- + He \rightarrow He^+ + He + 2e}$$

Range of recommended data: 27 keV/amu $\leq E \leq 8.0\times10^2$ keV/amu.
Accuracy: 25%.
Analytic expression: Equation 4-4, $E_R = 99.27$ keV.
Values of a_i ($i = 1, 2, 3, 4$) are as follows.

a_1	a_2	a_3	a_4
9.101E−01	2.719E−01	5.499E+01	6.178E−01

The expression represents the recommended data with an rms deviation of 0.5%.
The maximum deviation is 1.0% at 5.0×10^2 keV/amu.
See Graph 90.

$$\mathbf{Li^- + H_2 \rightarrow Li + H_2 + e}$$

Range of recommended data: 1.5 keV/amu $\leq E \leq 4.0\times10^2$ keV/amu.
Accuracy: 25%.
Analytic expression: Equation 4-4, $E_R = 172.1$ keV.
Values of a_i ($i = 1, 2, 3, 4$) are as follows.

a_1	a_2	a_3	a_4
6.442E+01	1.935E−01	6.048E+00	5.585E−01

The expression represents the recommended data with an rms deviation of 0.5%.
The maximum deviation is 0.8% at 1.5 keV/amu.
See Graph 91.

$$\mathbf{Li^- + H_2 \rightarrow Li^+ + H_2 + 2e}$$

Range of recommended data: 15 keV/amu $\leq E \leq 1.8\times10^2$ keV/amu.
Accuracy: 25%.
Analytic expression: Equation 4-6, $E_R = 172.1$ keV.
Values of a_i ($i = 1, 2, \ldots, 6$) are as follows.

a_1	a_2	a_3	a_4	a_5	a_6
2.103E−01	−2.095E−01	1.787E+01	2.870E+00	8.525E−01	1.E+02

The value of a_6 was assumed.
The expression represents the recommended data with an rms deviation of 0.2%.
The maximum deviation is 0.3% at 1.8×10^2 keV/amu.
See Graph 92.

$Li^- + He \rightarrow (Li + He + e)$ or $(Li^+ + He + 2e)$

Range of recommended data: 0.18 keV/amu $\leq E \leq$ 60 keV/amu.
Accuracy: 25%.
Analytic expression: Equation 6-6, E_R = 172.1 keV.
Values of a_i (i = 1, 2, ..., 6) are as follows.

a_1	a_2	a_3	a_4	a_5	a_6
6.615E+06	1.9021E+00	1.082E−01	−3.160E−01	4.445E−01	4.738E−01

The expression represents the recommended data with an rms deviation of 0.2%.
The maximum deviation is 0.5% at 40 keV/amu.
See Graph 93.

5 Explanation and List of Graphs

Explanation of Graphs

Graphs. Cross section vs Energy

Ordinate	Cross section (in cm^2)
Abscissa	Projectile energy (in eV/amu)

The curve represents the analytic expression, and points, recommended data given by Barnett [1]. The curve is shown, when possible, over the range of projectile energy from $E_{min}/10$ to $10E_{max}$, where E_{min} and E_{max} are the minimum and the maximum energy of the recommended data.

List of Graphs

Ionization and Production of Charged Particles

$H + H_2 \rightarrow$ Total Slow Positive Ion Production
$H + H_2 \rightarrow$ Total Slow Electron Production
$H + H_2 \rightarrow H + H_2{}^+ + e$
$H^+ + H \rightarrow H^+ + H^+ + e$
$H^+ + H^- \rightarrow H_2{}^+ + e$
$H^+ + H_2 \rightarrow$ Total Slow Electron Production
$H^+ + H_2 \rightarrow H^+ + H_2^+ + e$
$H^+ + H_2 \rightarrow$ Total Production of $H_2{}^+$
$H^+ + H_2 \rightarrow$ Total Production of H^+
$H^+ + He \rightarrow$ Electrons and H^-
$H^+ + He \rightarrow H^+ + He^+ + e$
$H^+ + He \rightarrow (H + He^+)$ or $(H^+ + He^+ + e)$
$H^+ + He \rightarrow H^+ + He^{2+} + 2e$
$H^+ + He \rightarrow (H^- + He^{2+})$ or $(H^+ + He^{2+} + 2e)$
$H^+ + He^+ \rightarrow H^+ + He^{2+} + e$
$H^+ + He^+ \rightarrow (H^+ + He^{2+} + e)$ or $(H^0 + He^{2+})$
$H^+ + Li \rightarrow H^+ + Li^+ + e$
$He(2^1S) + H \rightarrow He + H^+ + e$
$He(2^1S) + H \rightarrow HeH^+ + e$
$He(2^1S) + H \rightarrow (He + H^+ + e)$ or $(HeH^+ + e)$
$He(2^3S) + H \rightarrow He + H^+ + e$
$He(2^3S) + H \rightarrow HeH^+ + e$
$He(2^3S) + H \rightarrow (He + H^+ + e)$ or $(HeH^+ + e)$

$He(2^3S) + H_2 \rightarrow$ Total Ionization
$He(2^3S) + H_2 \rightarrow$ Rearrangement Ionization
$He(2^1S) + H_2 \rightarrow$ Total Ionization
$He(2^1S) + H_2 \rightarrow$ Rearrangement Ionization
$He + H_2 \rightarrow$ Total Slow Positive Ion Production
$He + H_2 \rightarrow$ Total Slow Electron Production
$He + H_2 \rightarrow He + H_2^+ + e$
$He + H_2 \rightarrow$ Total H^+ Production
$He + He \rightarrow$ Total Slow Positive Ion Production
$He + He \rightarrow$ Total Slow Electron Production
$He + He \rightarrow He + He^+ + e$
$He + He \rightarrow He + He^{2+} + 2e$
$He^+ + He^+ \rightarrow He^+ + He^{2+} + e$
$He^+ + He^+ \rightarrow (He + He^{2+})$ or $(He^+ + He^{2+} + e)$
$He^+ + H \rightarrow He^+ + H^+ + e$
$He^+ + H_2 \rightarrow$ Total Slow Positive Ion Production
$He^+ + H_2 \rightarrow$ Total Slow Electron Production
$He^+ + H_2 \rightarrow (He + H_2^+)$ or $(He^+ + H_2^+ + e)$
$He^+ + H_2 \rightarrow$ Total H^+ Production
$He^+ + H_2 \rightarrow He^+ + 2H^+ + 2e$
$He^+ + He \rightarrow$ Total Slow Positive Ion Production
$He^+ + He \rightarrow$ Total Slow Electron Production
$He^+ + He \rightarrow He^+ + He^+ + e$
$He^+ + He \rightarrow He^+ + He^{2+} + 2e$
$He^+ + Li \rightarrow He^+ + Li^+ + e$
$He^{2+} + H \rightarrow He^{2+} + H^+ + e$
$He^{2+} + H_2 \rightarrow$ Total Slow Positive Ion Production
$He^{2+} + H_2 \rightarrow$ Total Slow Electron Production
$He^{2+} + H_2 \rightarrow$ Total H_2^+ Production
$He^{2+} + H_2 \rightarrow H_2^+$ Production by Single Ionization
$He^{2+} + H_2 \rightarrow$ Total H^+ Production
$He^{2+} + H_2 \rightarrow H^+$ Production by Ionization Collisions
$He^{2+} + He \rightarrow$ Total Slow Positive Ion Production
$He^{2+} + He \rightarrow$ Total Slow Electron Production
$He^{2+} + He \rightarrow He^{2+} + He^+ + e$
$He^{2+} + He \rightarrow He^{2+} + He^{2+} + 2e$
$He^{2+} + Li \rightarrow He^{2+} + Li^+ + e$

Electron Loss or Stripping Collisions

$H + H \rightarrow H^+ + H + e$
$H(2s) + H(1s) \rightarrow H^+ + H + e$
$H + H_2 \rightarrow H^+ + H_2 + e$
$H(2s) + H_2 \rightarrow H^+ + H_2 + e$
$H + He \rightarrow H^+ + He + e$
$H(2s) + He \rightarrow H^+ + He + e$
$He + H \rightarrow He^+ + H + e$
$He + H_2 \rightarrow He^+ + H_2 + e$
$He + H_2 \rightarrow He^{2+} + H_2 + 2e$
$He^* + H_2 \rightarrow He$ or He^+
$He^* + H_2 \rightarrow He^+ + H_2 + e$
$He^* + H_2 \rightarrow He + H_2$
$He + He \rightarrow He^+ + He + e$
$He + He \rightarrow He^{2+} + He + 2e$
$He^+ + H \rightarrow He^{2+} + H + e$
$He^+ + H_2 \rightarrow He^{2+} + H_2 + e$
$He^+ + He \rightarrow He^{2+} + He + e$

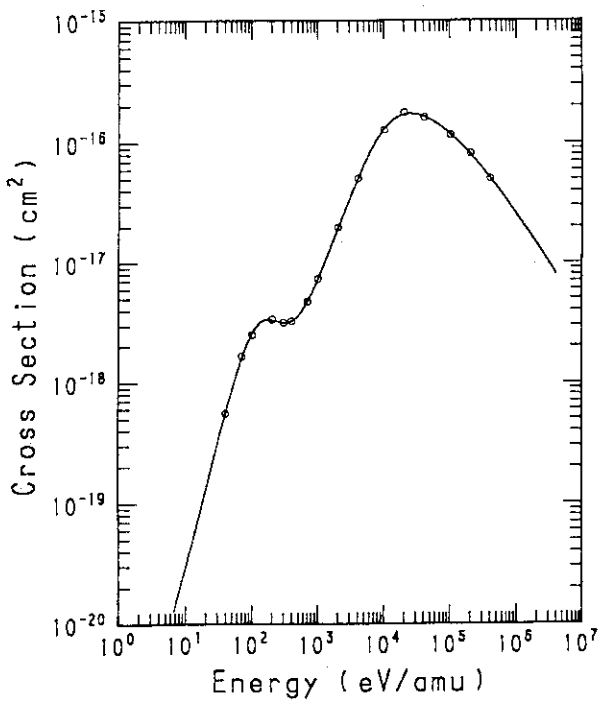
Electron Detachment Collisions

$H^- + H \rightarrow H + H + e$
$H^- + H \rightarrow (H + H + e)$ or $(H + H^-)$
$H^- + H \rightarrow H^+ + H + 2e$
$H^- + H^+ \rightarrow H + H^+ + e$
$H^- + H_2 \rightarrow H + H_2 + e$
$H^- + H_2 \rightarrow H^+ + H_2 + 2e$
$H^- + He \rightarrow H + He + e$
$H^- + He \rightarrow H^+ + He + 2e$
$He^- + H \rightarrow He + H + e$
$He^- + H_2 \rightarrow He + H_2 + e$
$He^- + H_2 \rightarrow He^+ + H_2 + 2e$
$He^- + He \rightarrow He + He + e$
$He^- + He \rightarrow He^+ + He + 2e$
$Li^- + H_2 \rightarrow Li + H_2 + e$
$Li^- + H_2 \rightarrow Li^+ + H_2 + 2e$
$Li^- + He \rightarrow (Li + He + e)$ or $(Li^+ + He + 2e)$

6 Graphs of Cross Sections

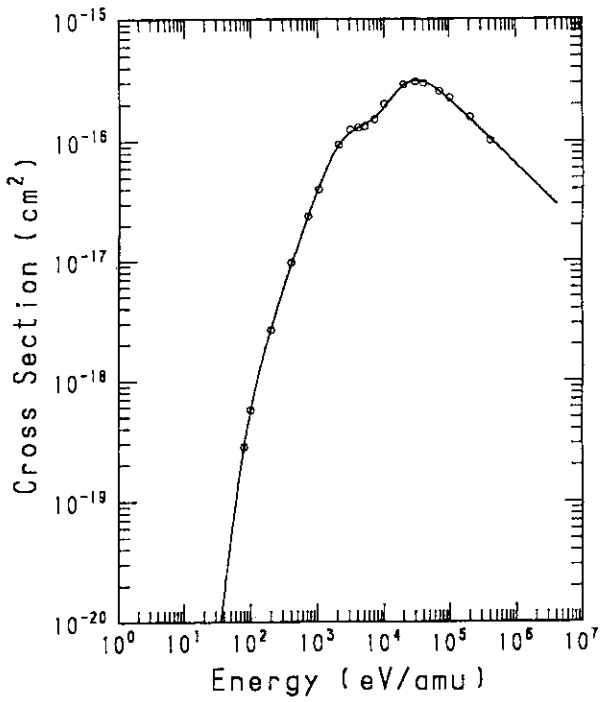
GRAPH 1

H + H_2 → Sum of Slow Positive Charges



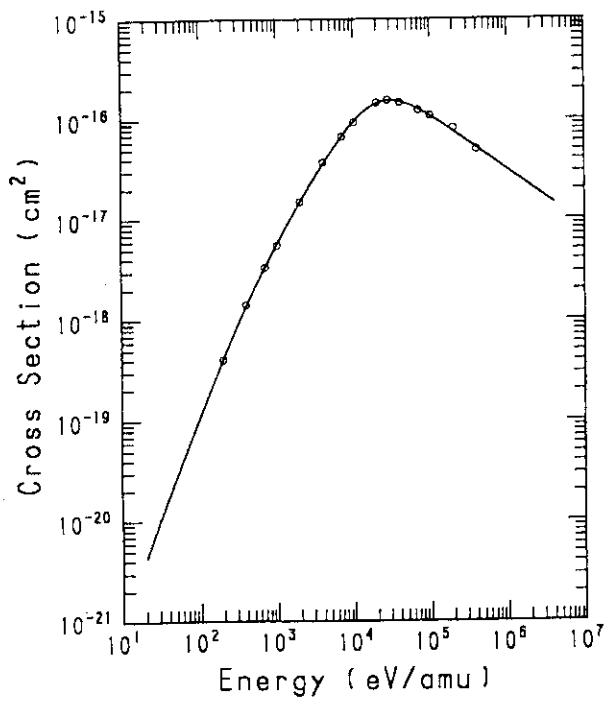
GRAPH 2

H + H_2 → Sum of Electrons Produced



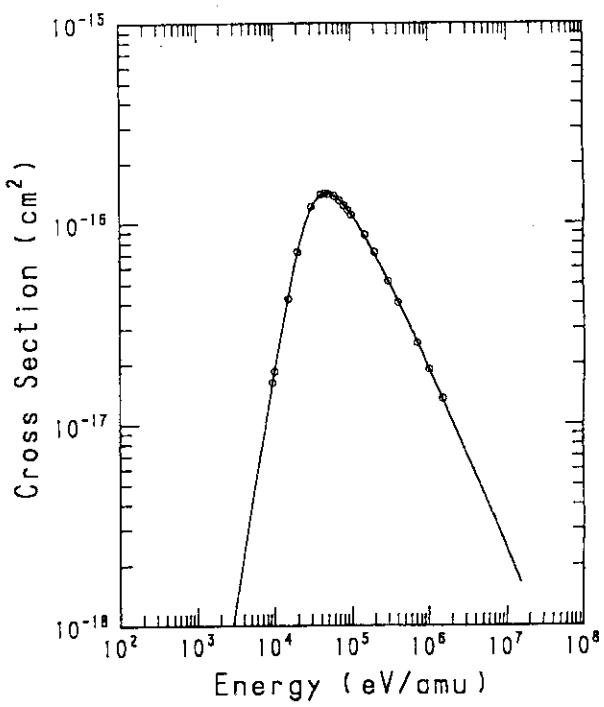
GRAPH 3

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



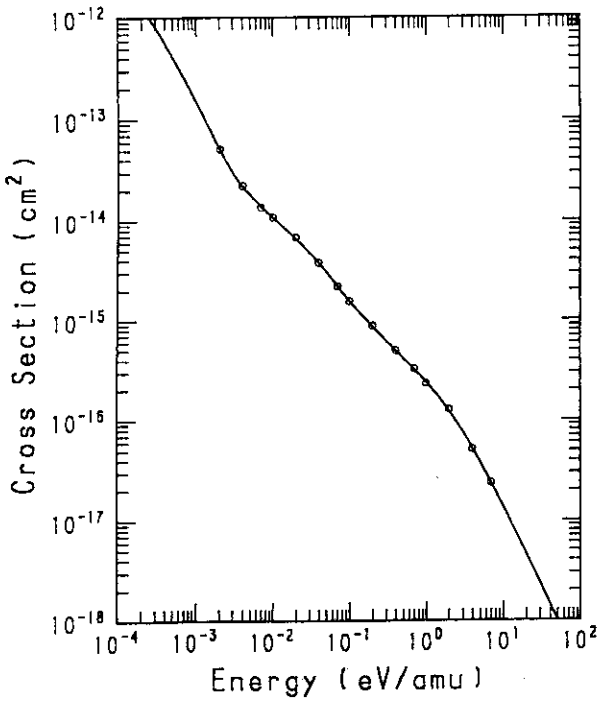
GRAPH 4

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



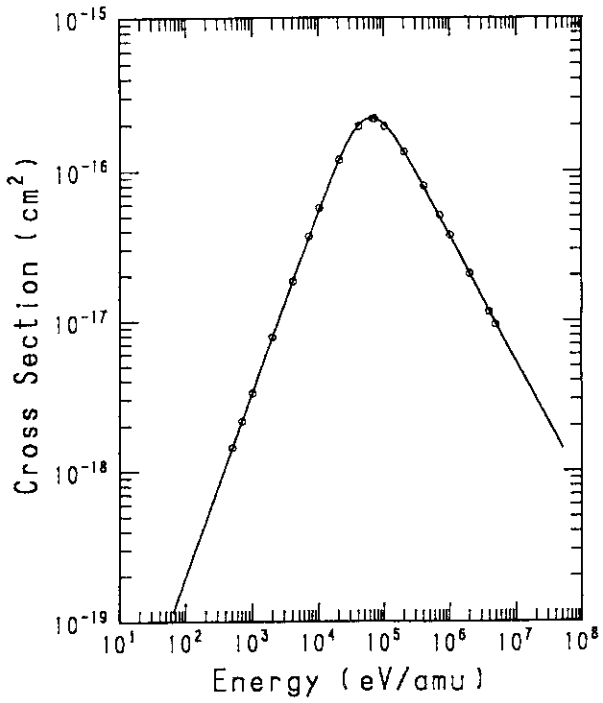
GRAPH 5

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



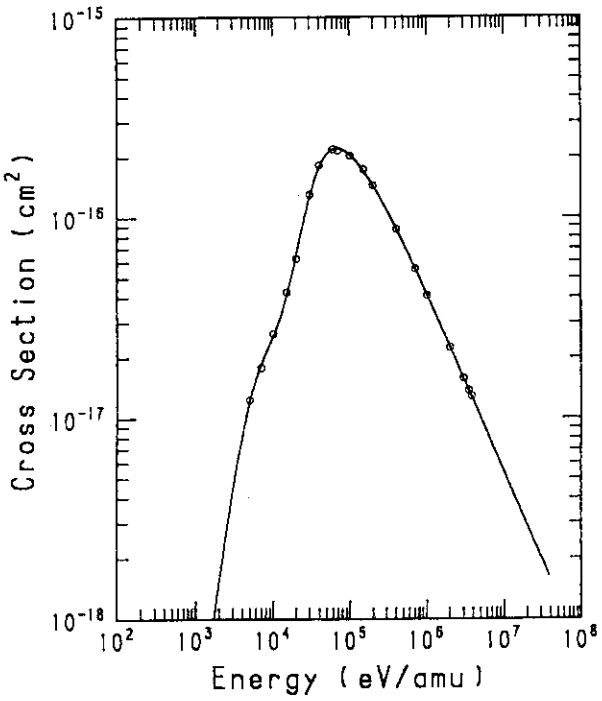
GRAPH 6

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



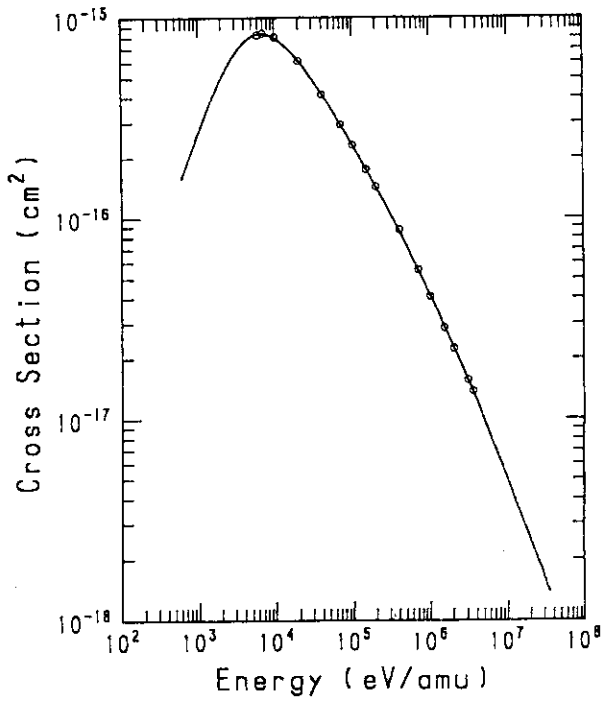
GRAPH 7

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



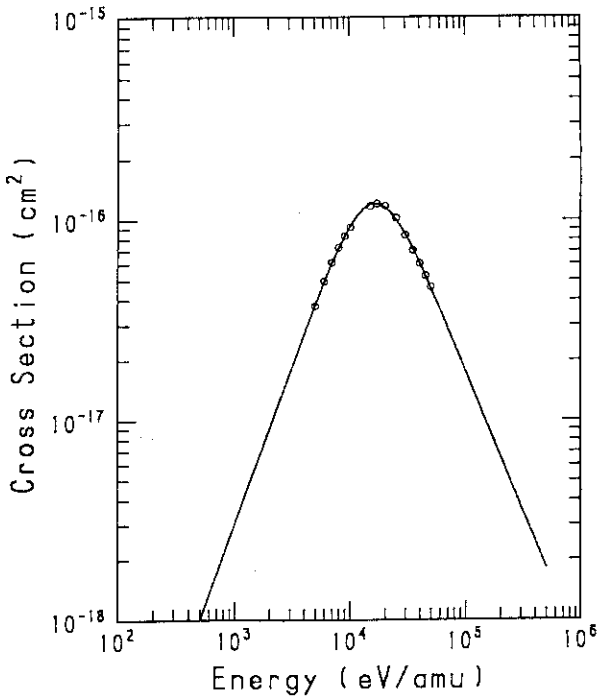
GRAPH 8

$H^+ + H_2 \rightarrow$ Total H_2^+ Production



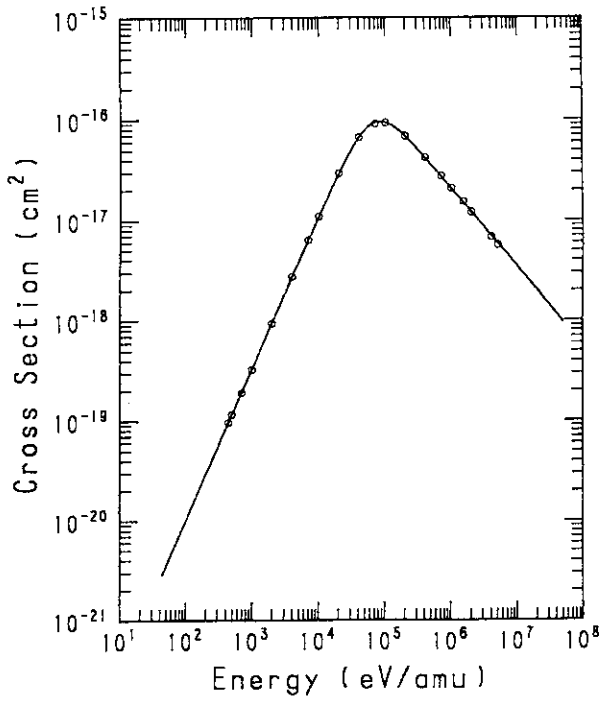
GRAPH 9

$H^+ + H_2 \rightarrow$ Total H^+ Production



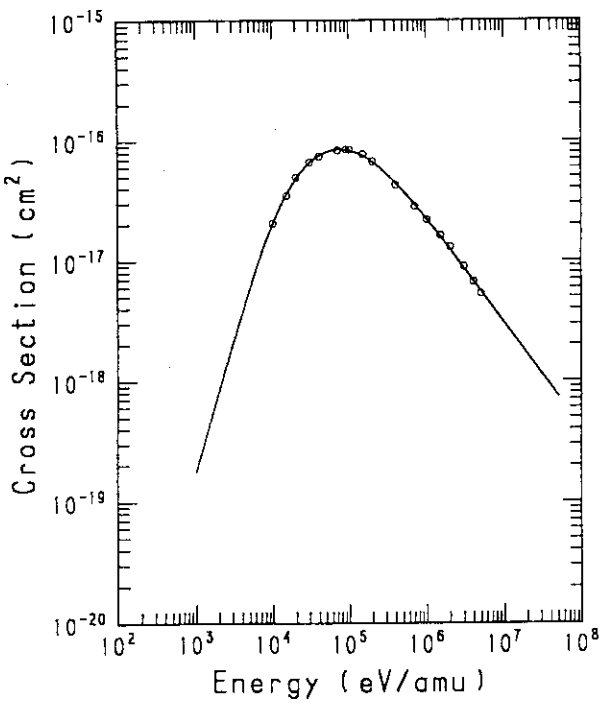
GRAPH 10

$H^+ + He \rightarrow$ electrons + H^-



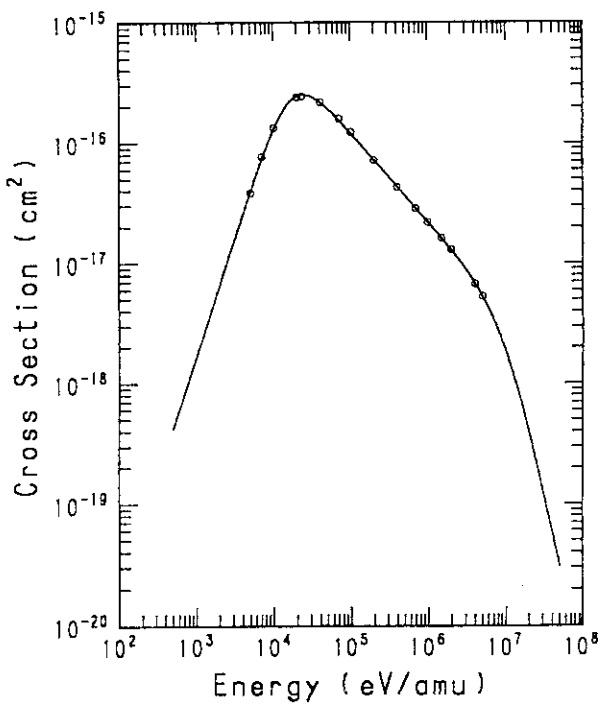
GRAPH 11

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



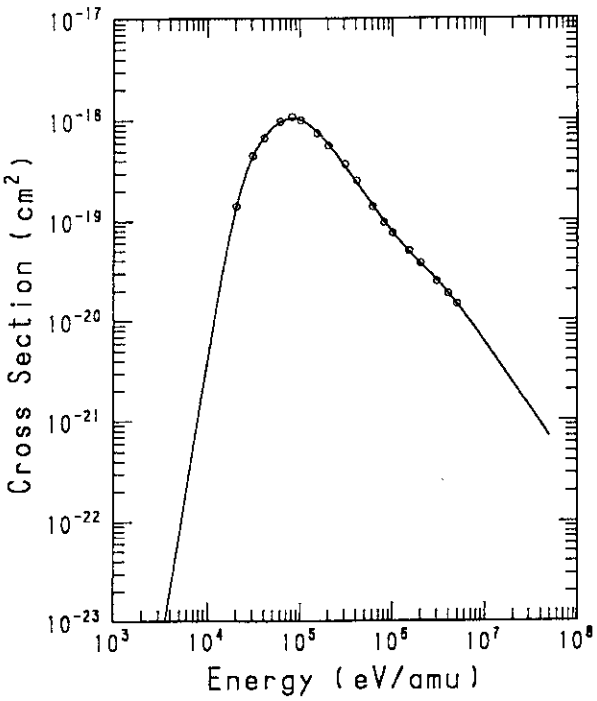
GRAPH 12

$H^+ + He \rightarrow (H + He^+)$ or $(H^+ + He^+ + e)$



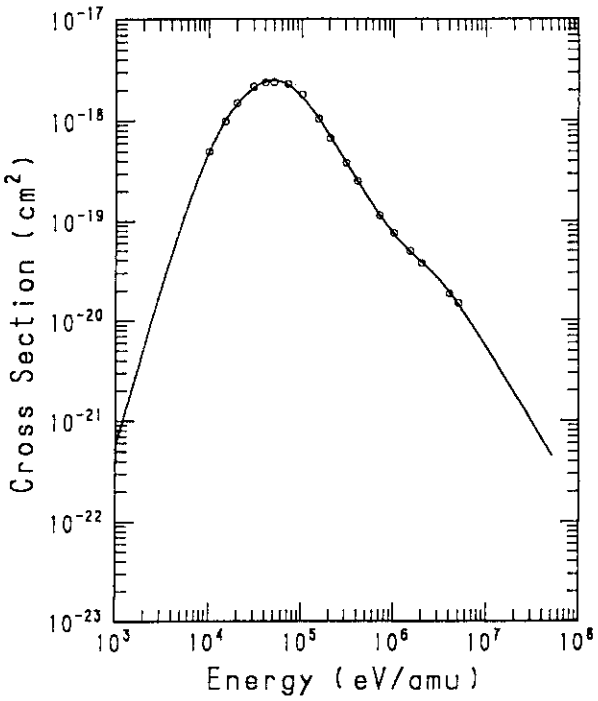
GRAPH 13

$H^+ + He \rightarrow H^+ + He^{2+} + 2e$



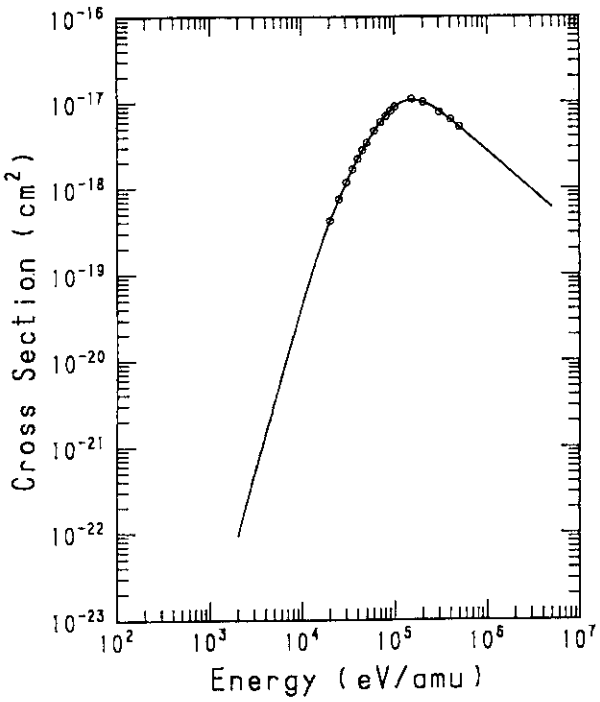
GRAPH 14

$H^+ + He \rightarrow (H^- + He^{2+})$ or $(H^+ + He^{2+} + 2e)$



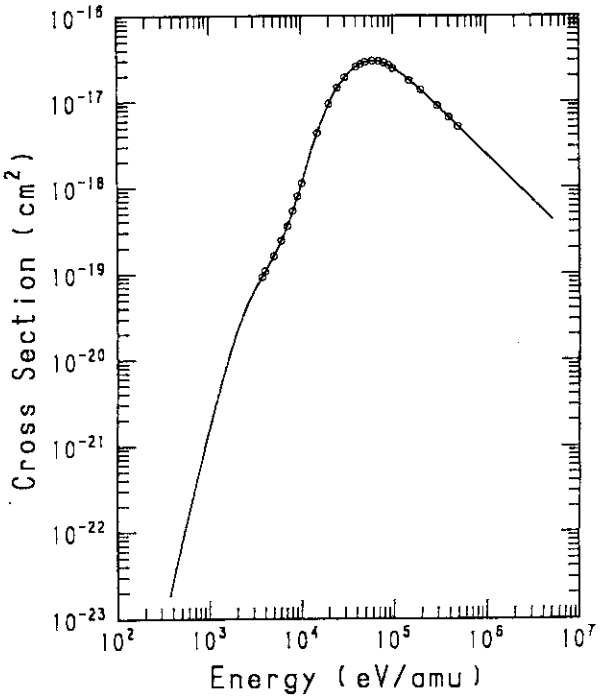
GRAPH 15

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



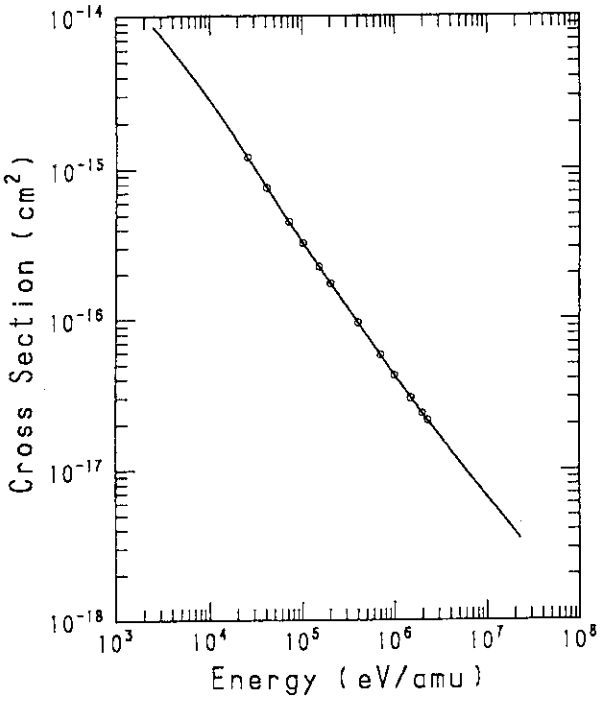
GRAPH 16

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



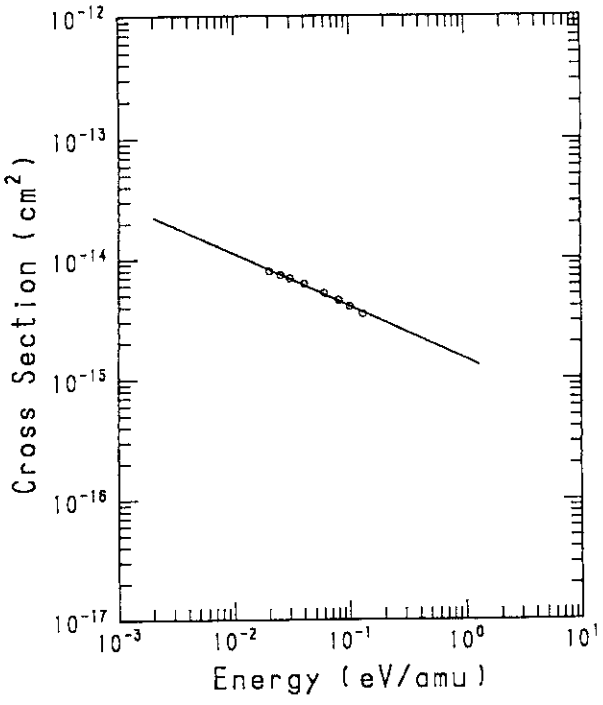
GRAPH 17

$H^+ + Li \rightarrow H^+ + Li^+ + e$



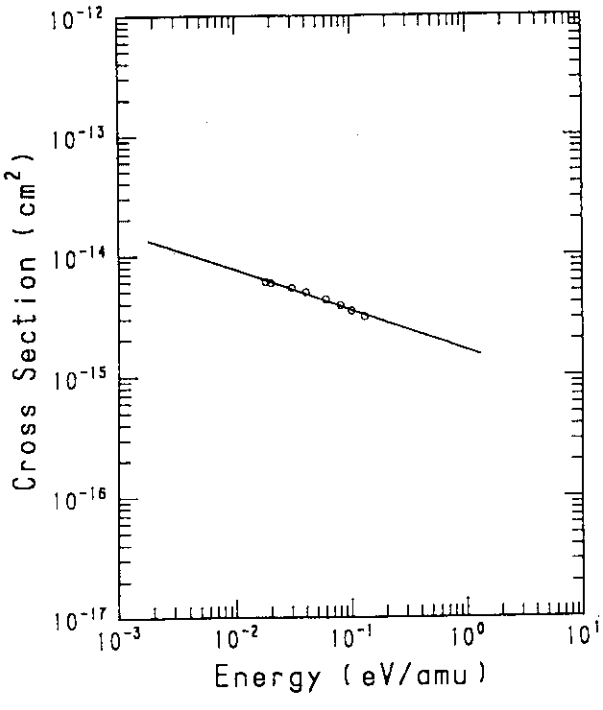
GRAPH 18

$He(2^1S) + H \rightarrow$ Total Ion. ($\sigma_{PI}+\sigma_{AI}$)



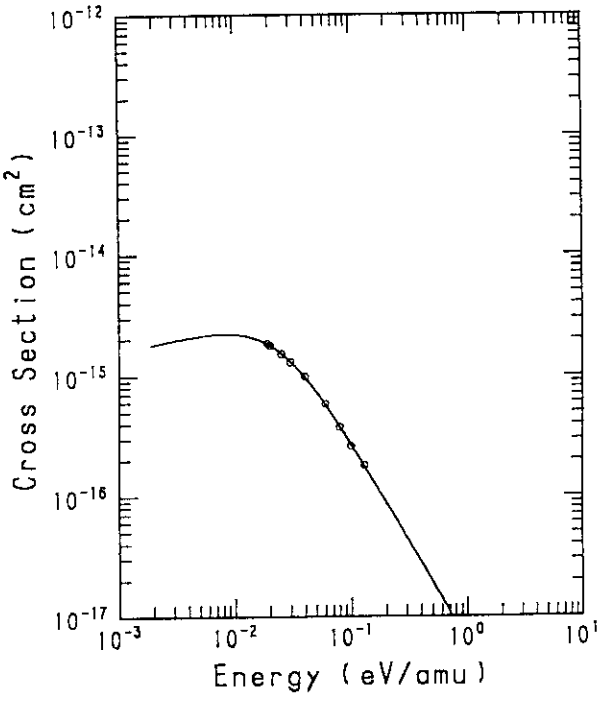
GRAPH 19

$He(2^1S) + H \rightarrow He + H^+ + e$ (σ_{PI})

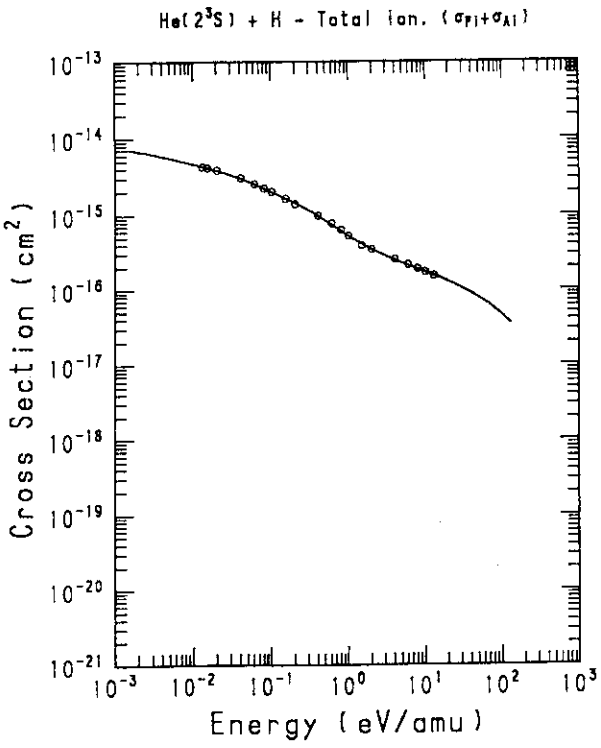


GRAPH 20

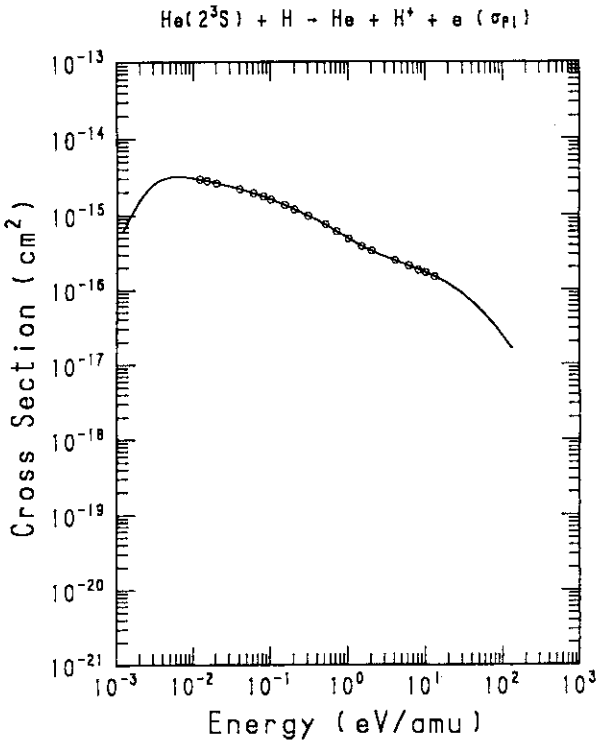
$He(2^1S) + H \rightarrow HeH^+ + e$ (σ_{AI})



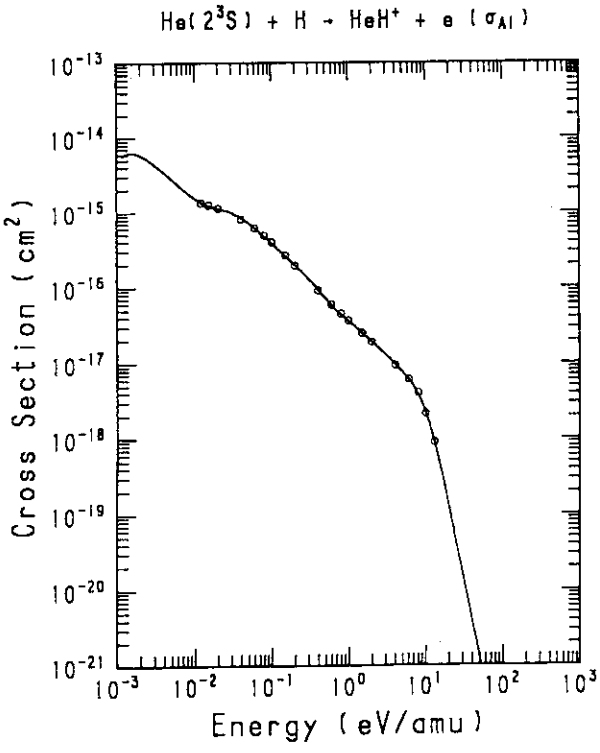
GRAPH 21



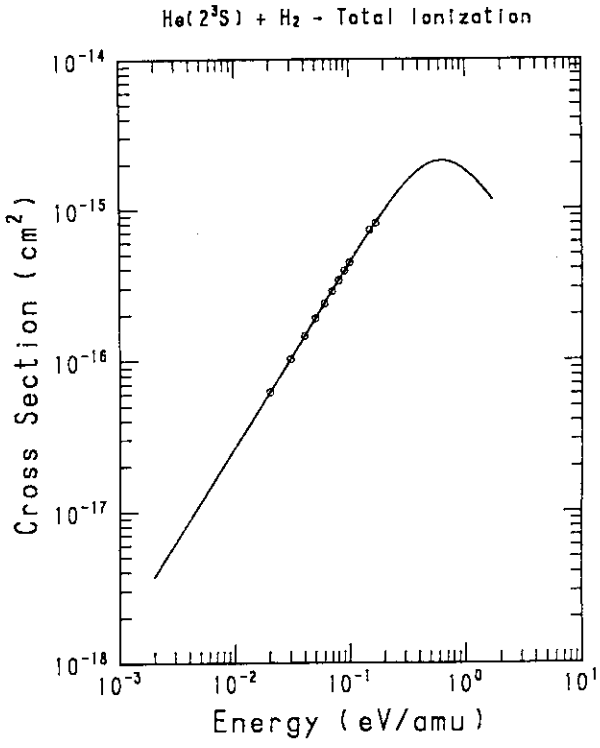
GRAPH 22



GRAPH 23

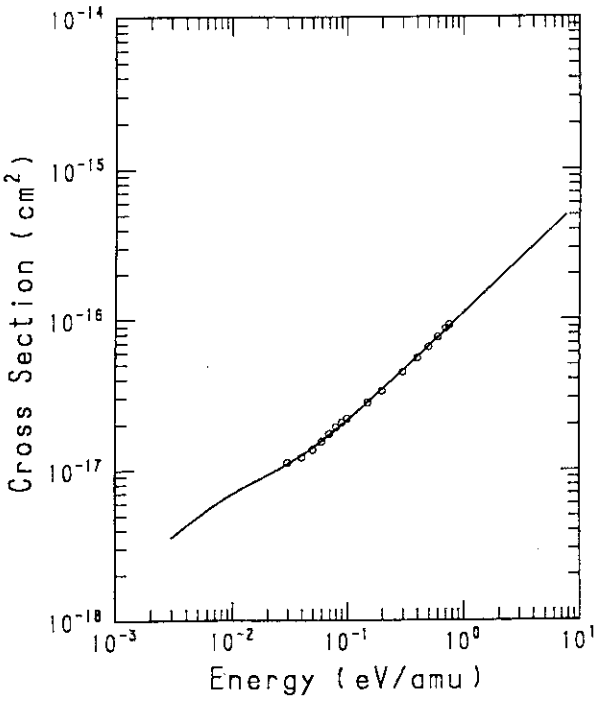


GRAPH 24



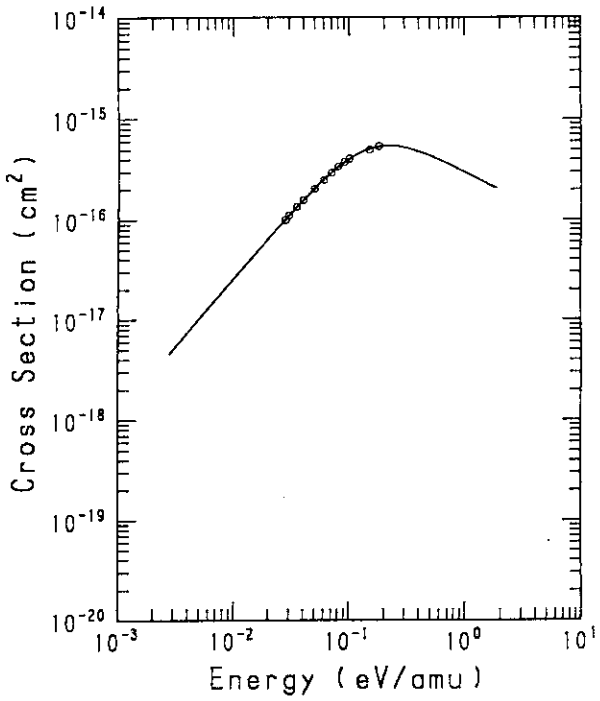
GRAPH 25

He(2³S) + H₂ → Rearrangement Ion.



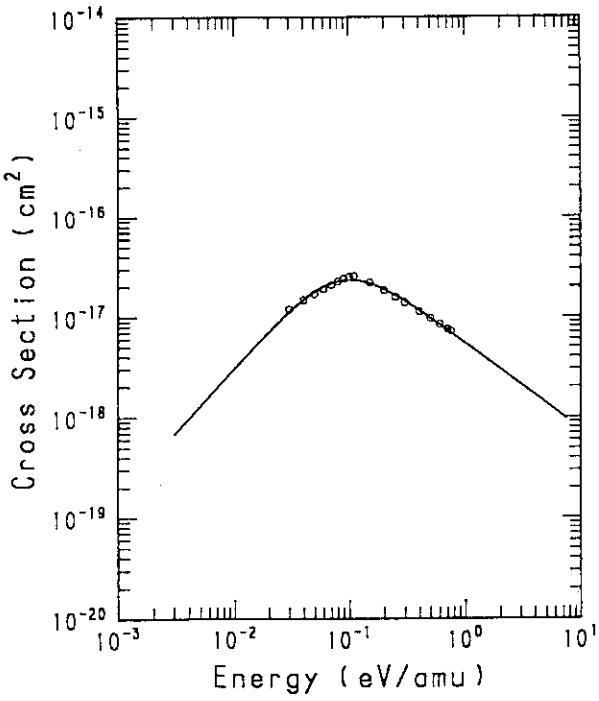
GRAPH 26

He(2¹S) + H₂ → Total Ionization



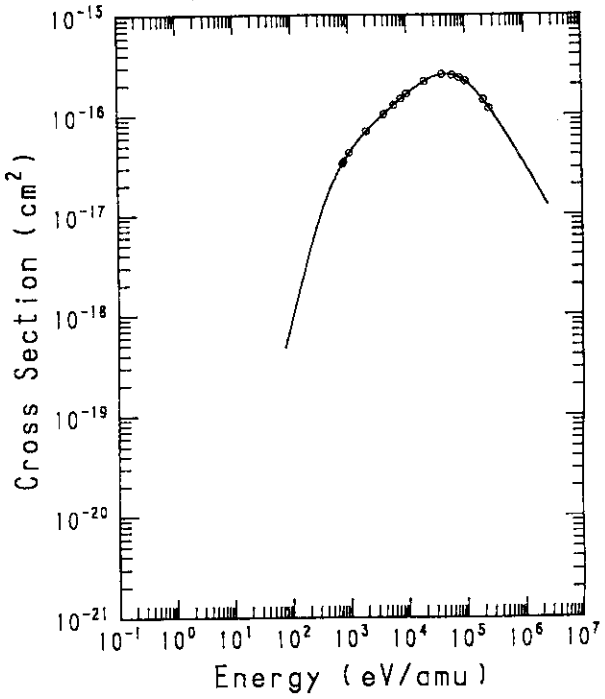
GRAPH 27

He(2¹S) + H₂ → Rearrangement Ion.



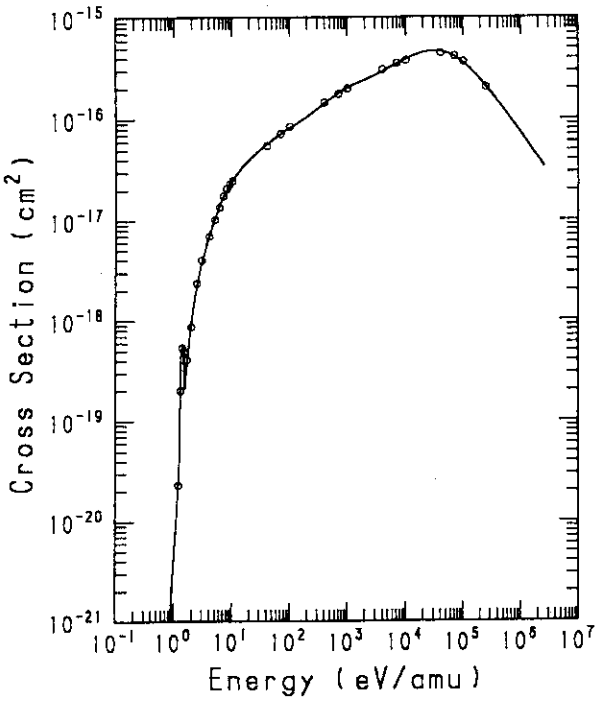
GRAPH 28

He + H₂ → Σ Slow Ions (σ⁺)



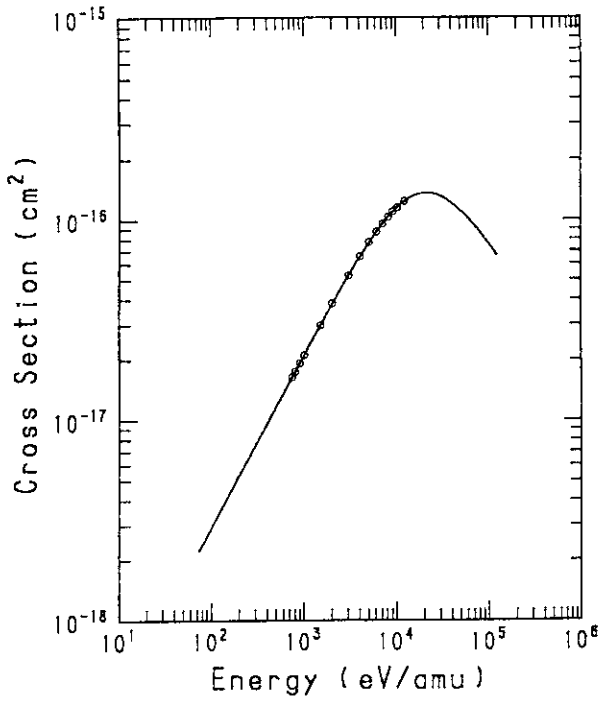
GRAPH 29

He + H_2 → Σ Slow Electrons (σ^-)



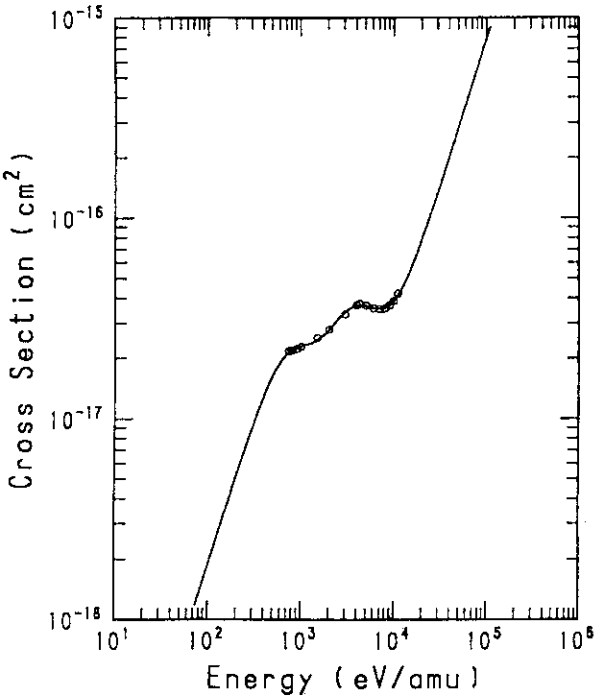
GRAPH 30

He + H_2 → He + H_2^+ + e



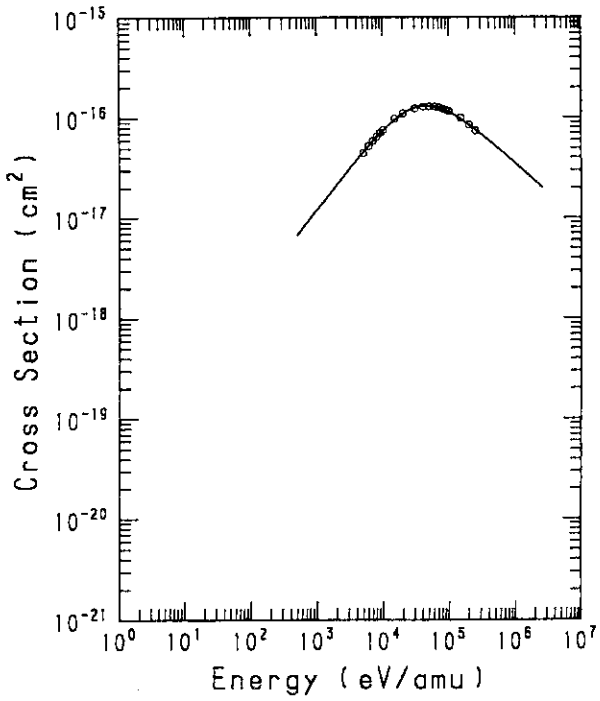
GRAPH 31

He + H_2 → ΣH^+



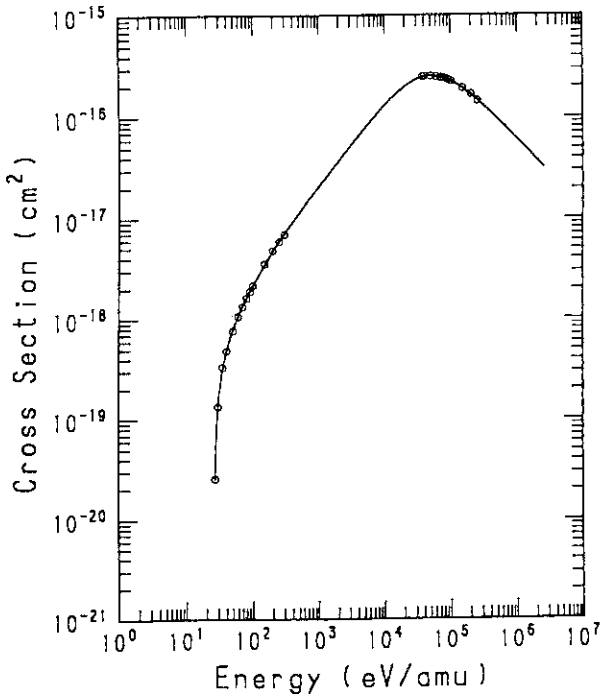
GRAPH 32

He + He → Σ Slow Ions (σ^+)



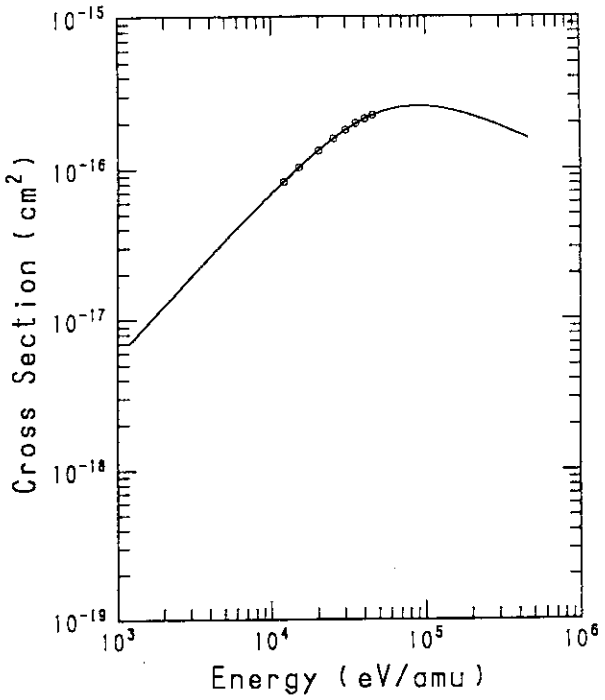
GRAPH 33

He + He → Σ Slow Electrons (σ^-)



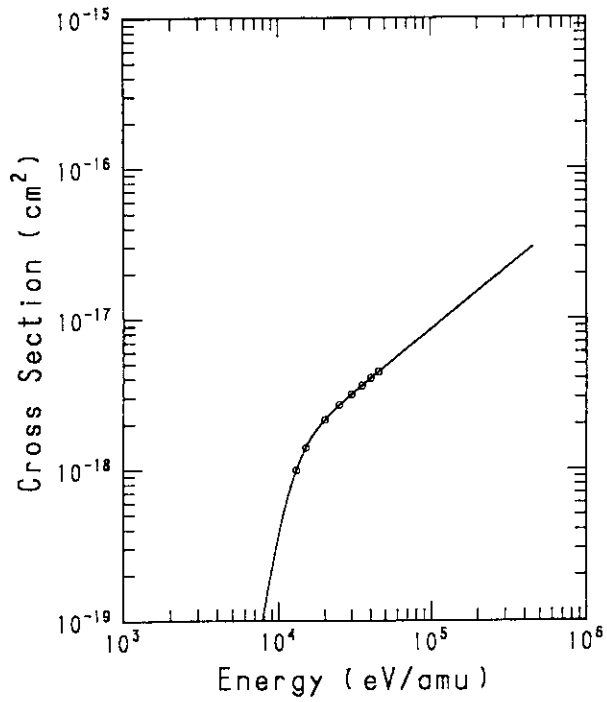
GRAPH 34

He + He → He + He$^+$ + e



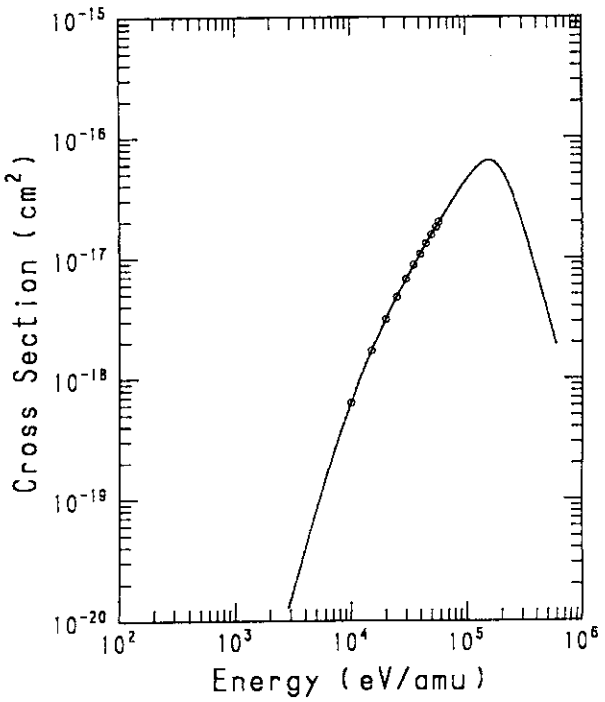
GRAPH 35

He + He → He + He^{2+} + 2e

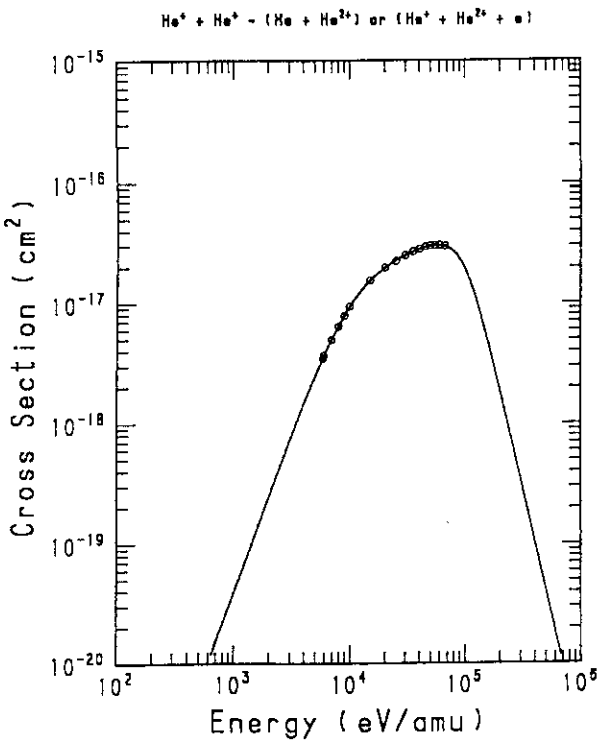


GRAPH 36

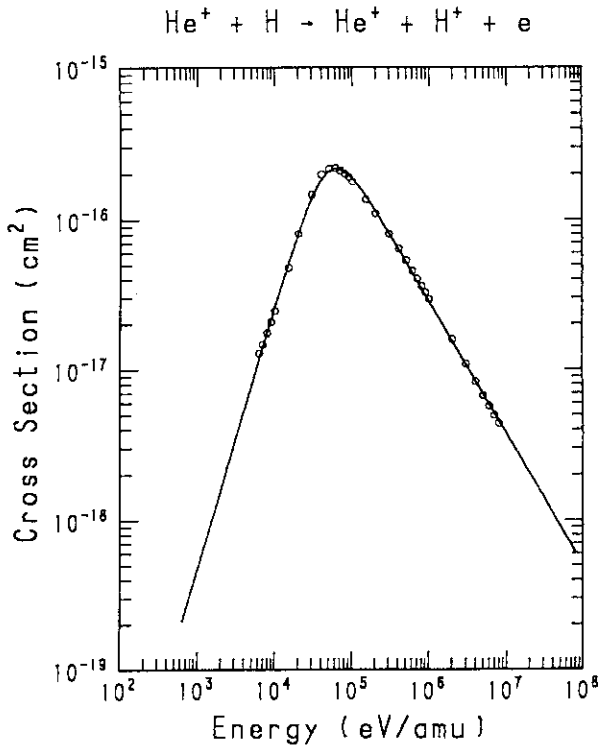
He$^+$ + He$^+$ → He$^+$ + He^{2+} + e



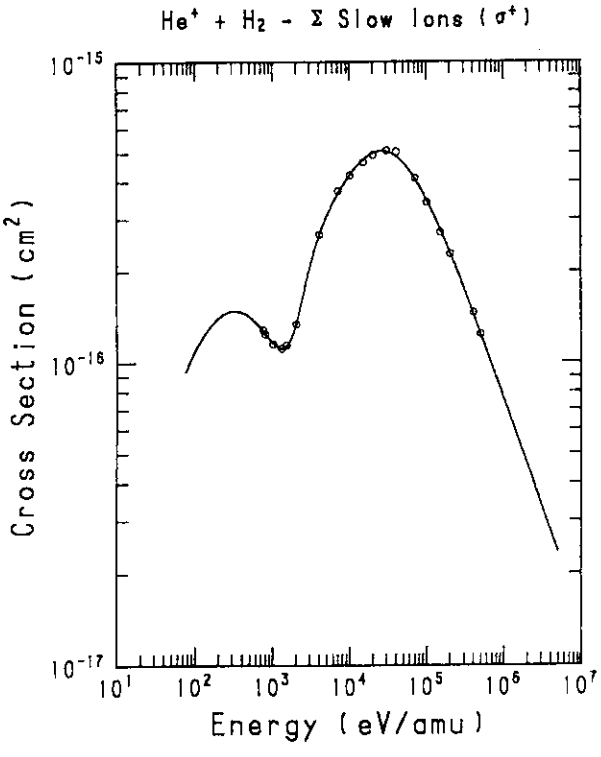
GRAPH 37



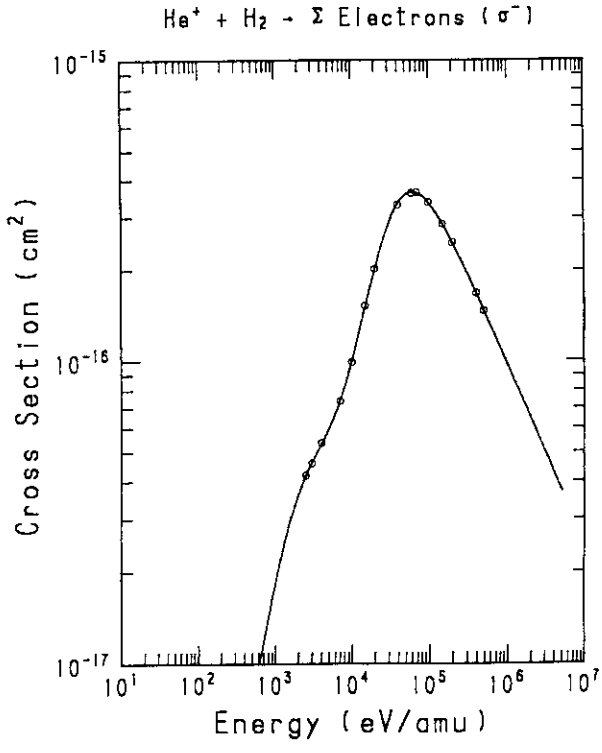
GRAPH 38



GRAPH 39

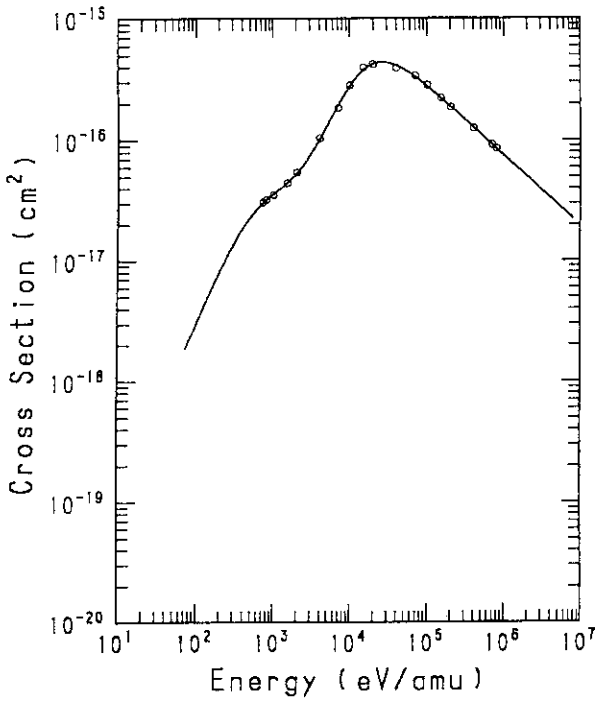


GRAPH 40



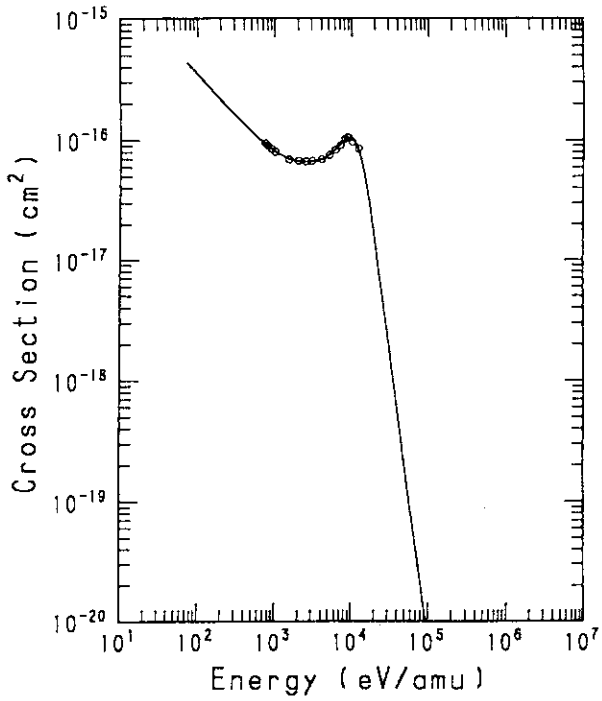
GRAPH 41

$He^+ + H_2 \rightarrow \sigma(H_2^+)$



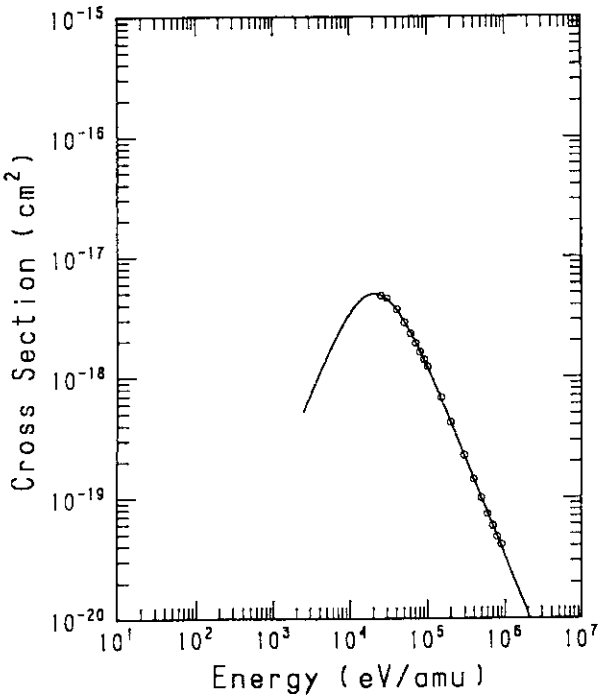
GRAPH 42

$He^+ + H_2 \rightarrow \sigma(H^+)$



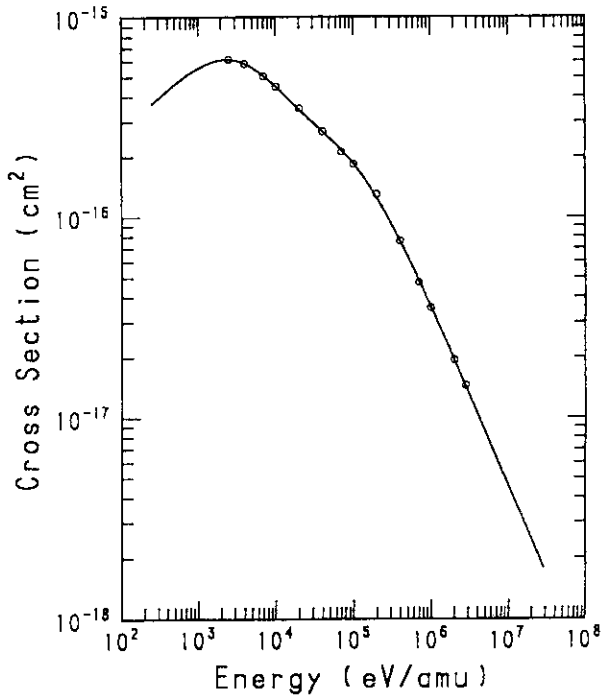
GRAPH 43

$He^+ + H_2 \rightarrow He^+ + 2H^+ + 2e$



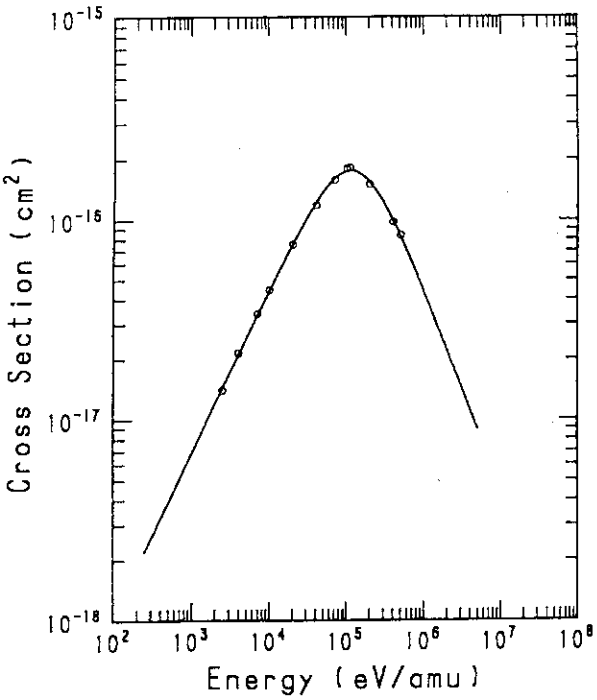
GRAPH 44

$He^+ + He \rightarrow \sigma^+$



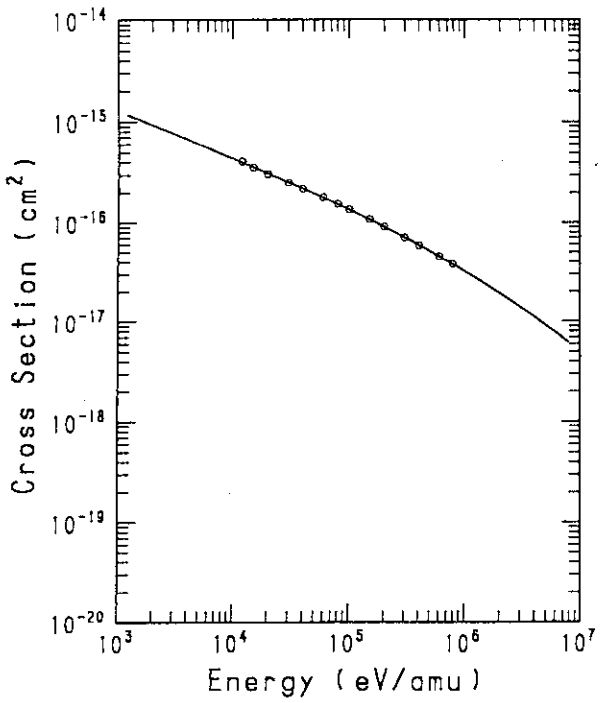
GRAPH 45

$He^+ + He \rightarrow \sigma^-$



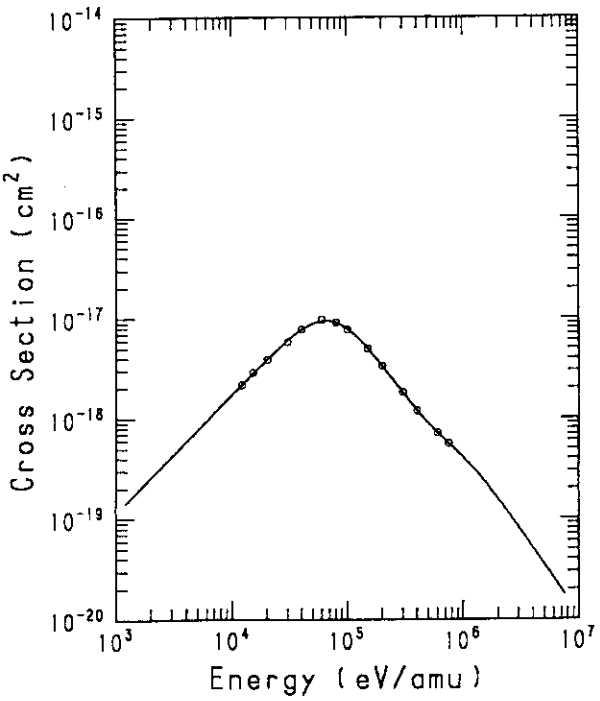
GRAPH 46

$He^+ + He \rightarrow He^+ + He^+ + e$



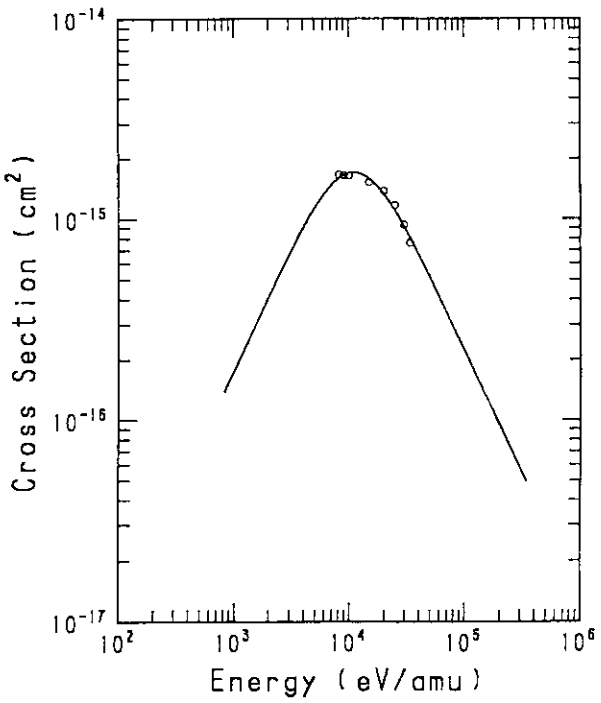
GRAPH 47

$He^+ + He \rightarrow He^+ + He^{2+} + 2e$



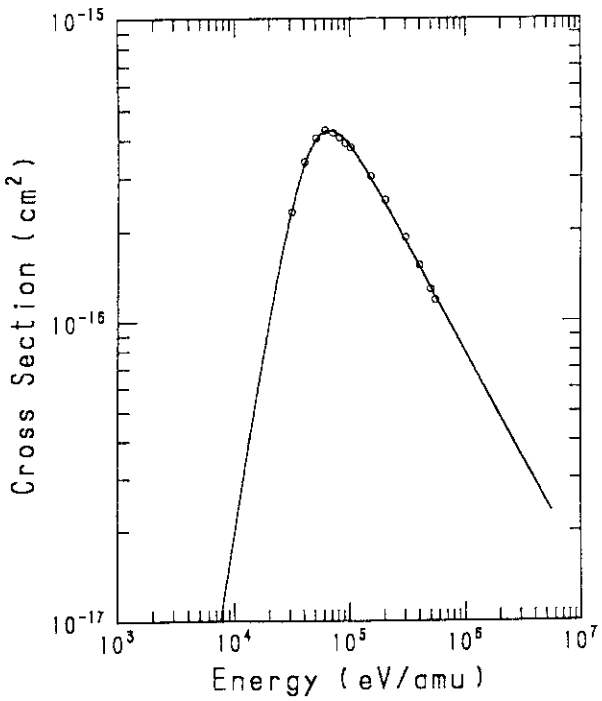
GRAPH 48

$He^+ + Li \rightarrow He^+ + Li^+ + e$



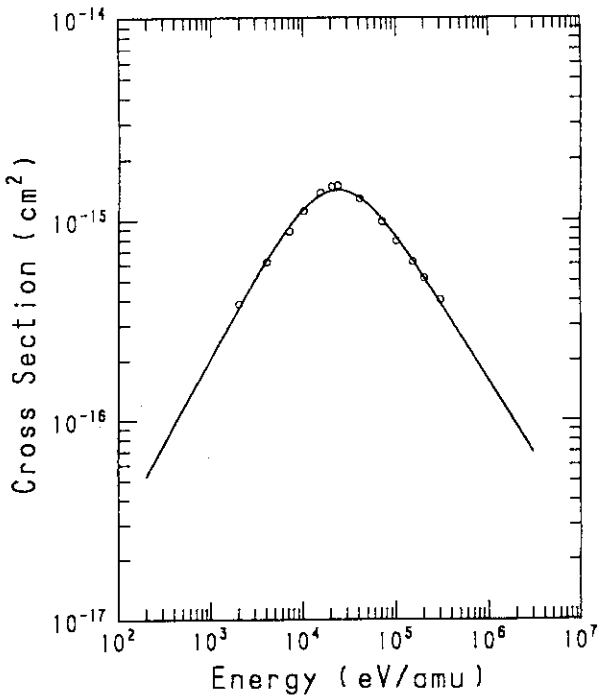
GRAPH 49

$He^{2+} + H \rightarrow He^{2+} + H^{+} + e$



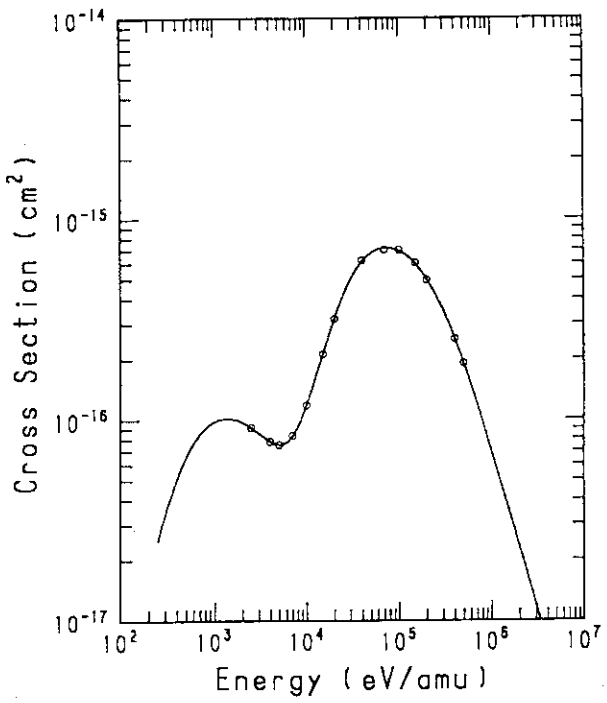
GRAPH 50

$He^{2+} + H_2 \rightarrow \Sigma(H^{+} + H^{+})\ (\sigma^{+})$



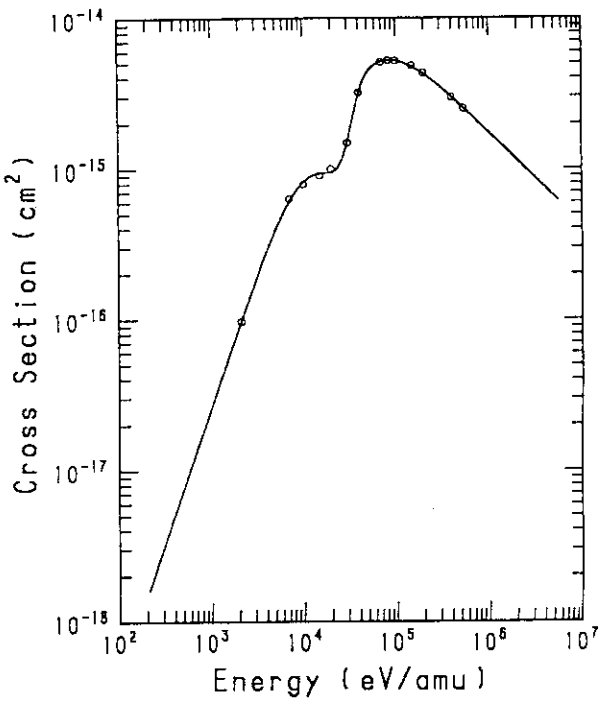
GRAPH 51

$He^{2+} + H_2 \rightarrow \Sigma e\ (\sigma^{-})$



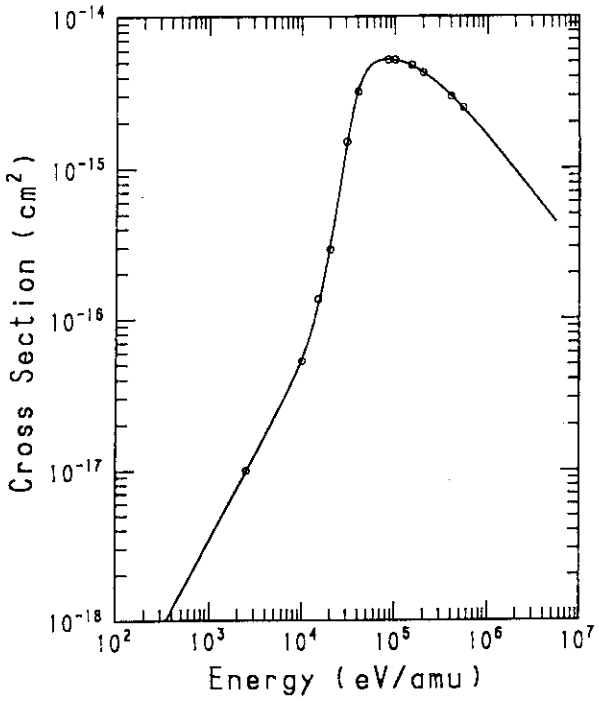
GRAPH 52

$He^{2+} + H_2 \rightarrow$ Total $\sigma(H_2^{+})$



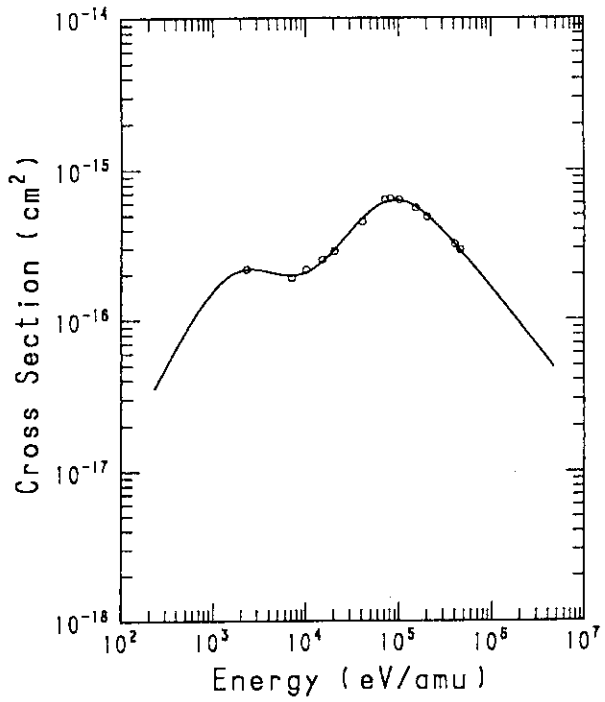
GRAPH 53

$He^{2+} + H_2$ - Single Ion. $\sigma(H_2^+)$



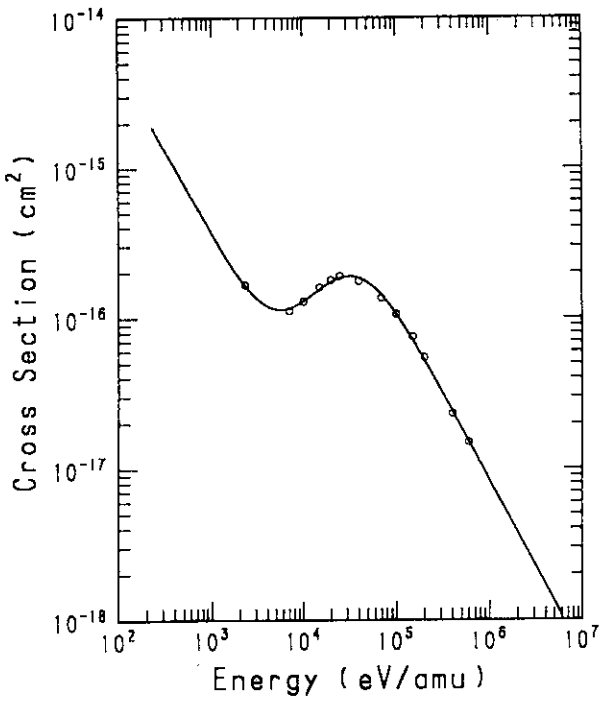
GRAPH 54

$He^{2+} + H_2$ - Total $\sigma(H^+)$



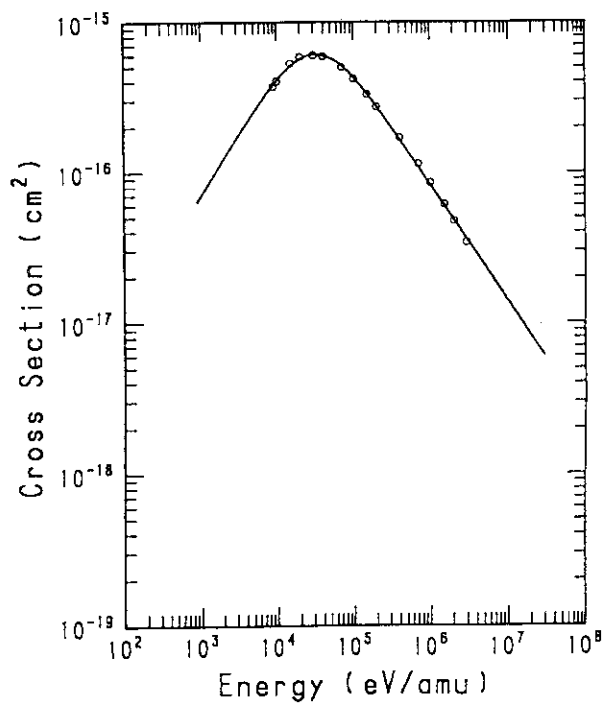
GRAPH 55

$He^{2+} + H_2$ - Single Ion. $\sigma(H^+)$



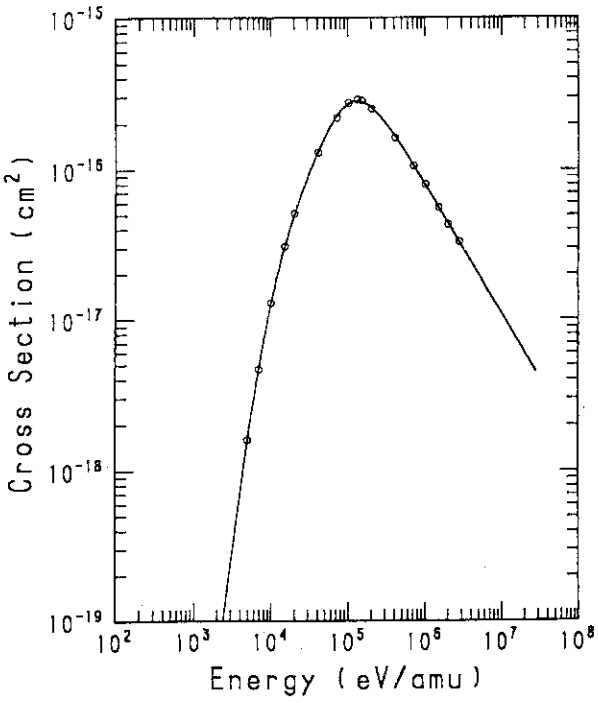
GRAPH 56

$He^{2+} + He \rightarrow \sigma^+$



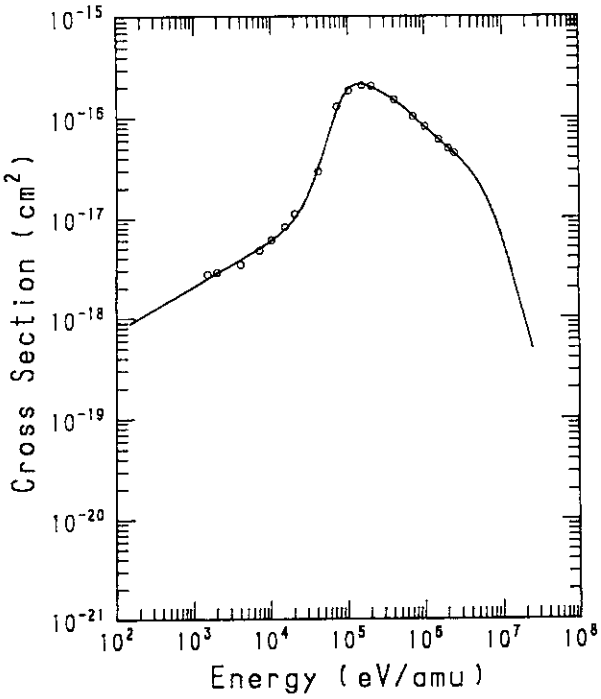
GRAPH 57

$He^{2+} + He \rightarrow \sigma^{-}$



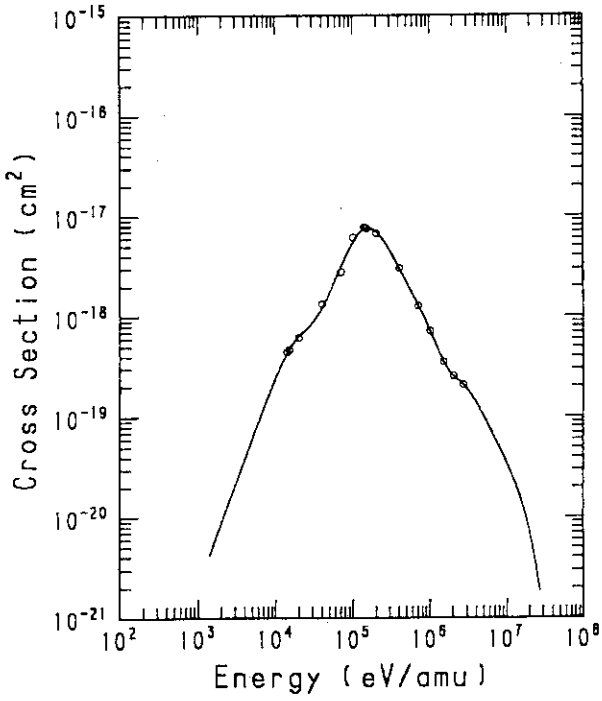
GRAPH 58

$He^{2+} + He \rightarrow He^{2+} + He^{+} + e$



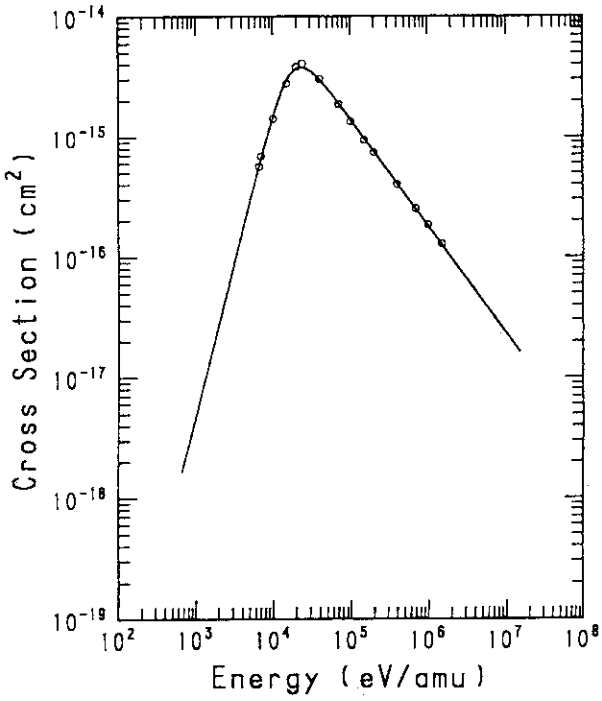
GRAPH 59

$He^{2+} + He \rightarrow He^{2+} + He^{2+} + 2e$



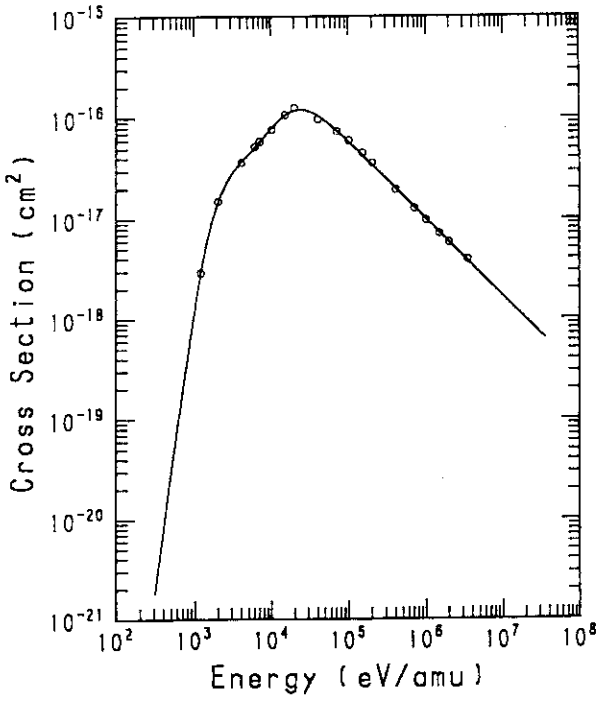
GRAPH 60

$He^{2+} + Li \rightarrow He^{2+} + Li^{+} + e$



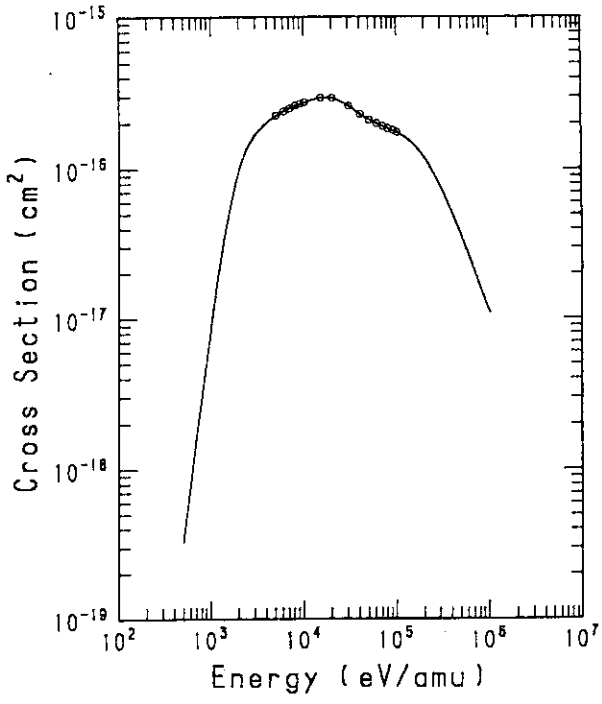
GRAPH 61

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



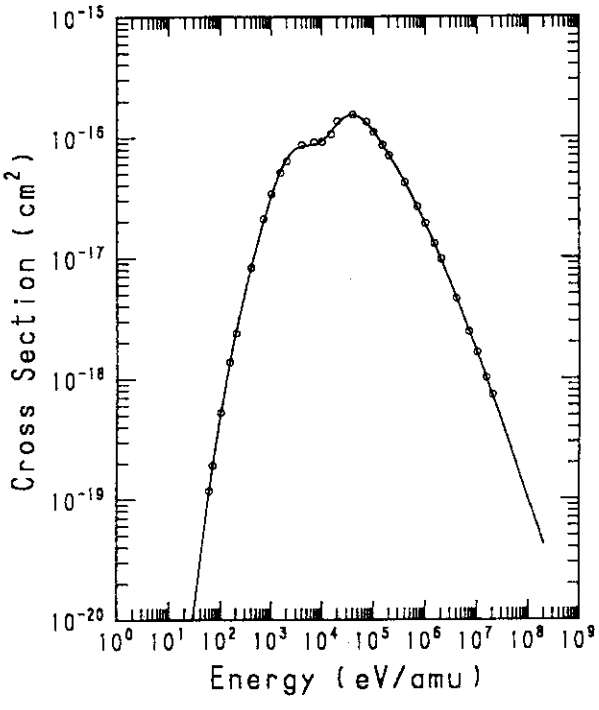
GRAPH 62

$H(2s) + H(1s) \rightarrow H^+ + H + e$



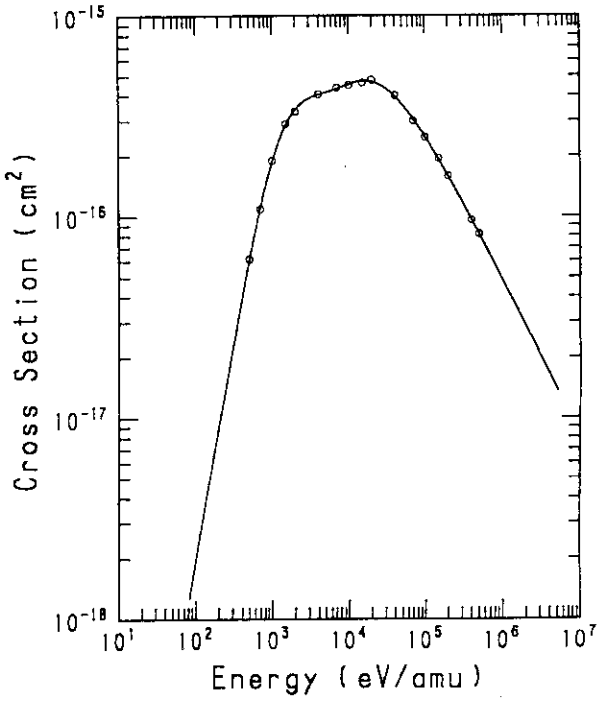
GRAPH 63

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



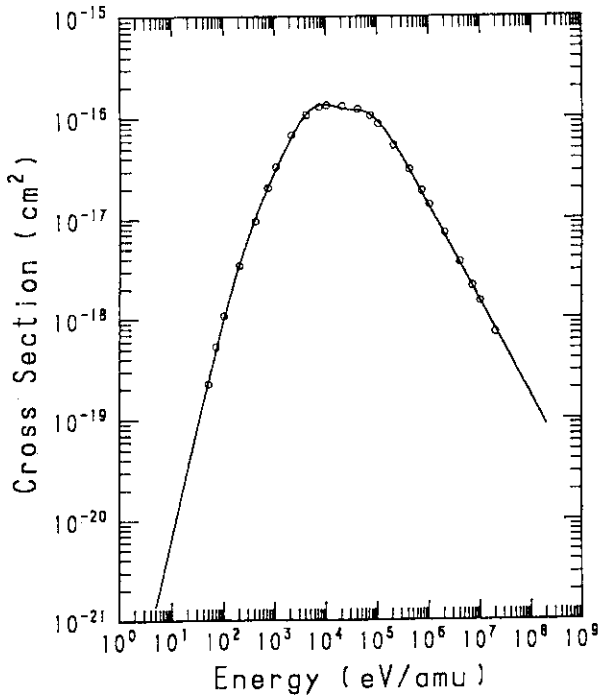
GRAPH 64

$H(2s) + H_2 \rightarrow H^+ + H_2 + e$



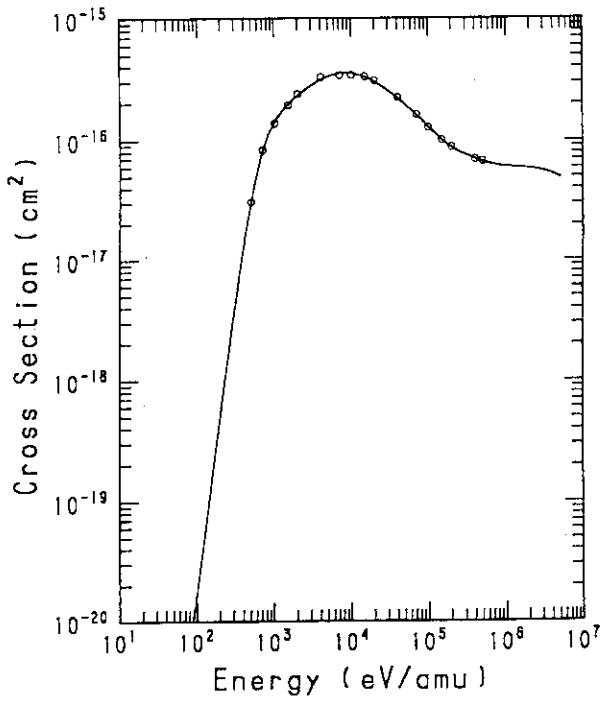
GRAPH 65

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



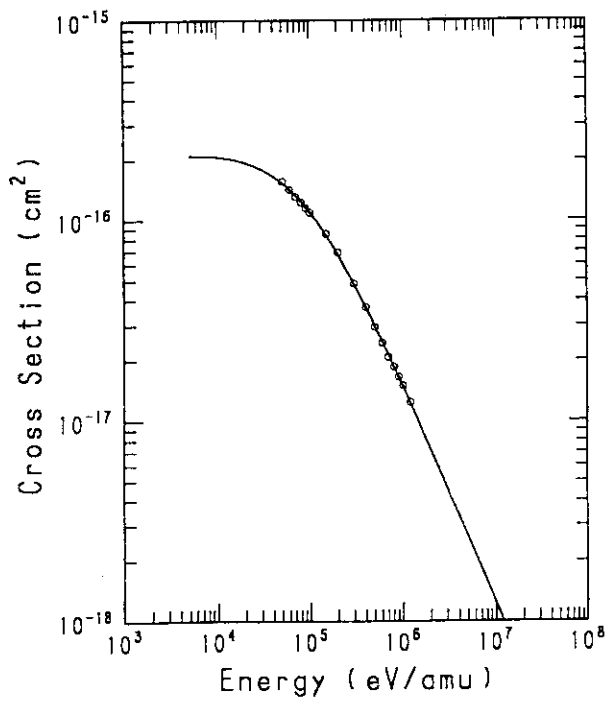
GRAPH 66

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



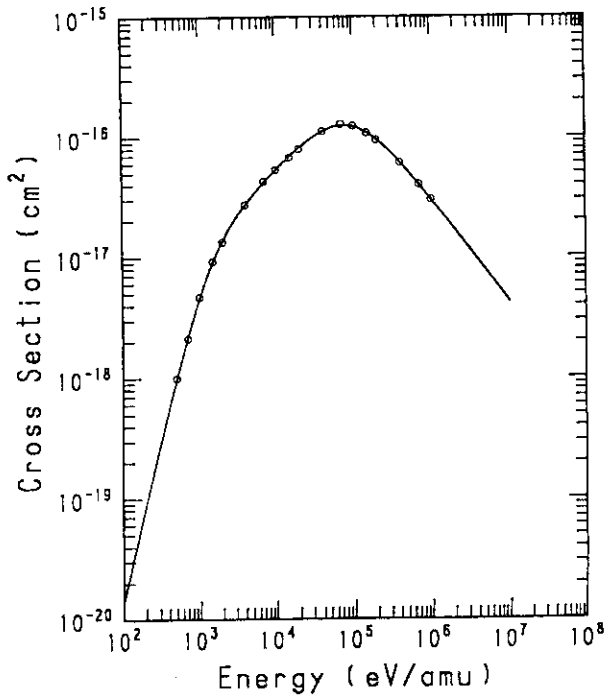
GRAPH 67

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



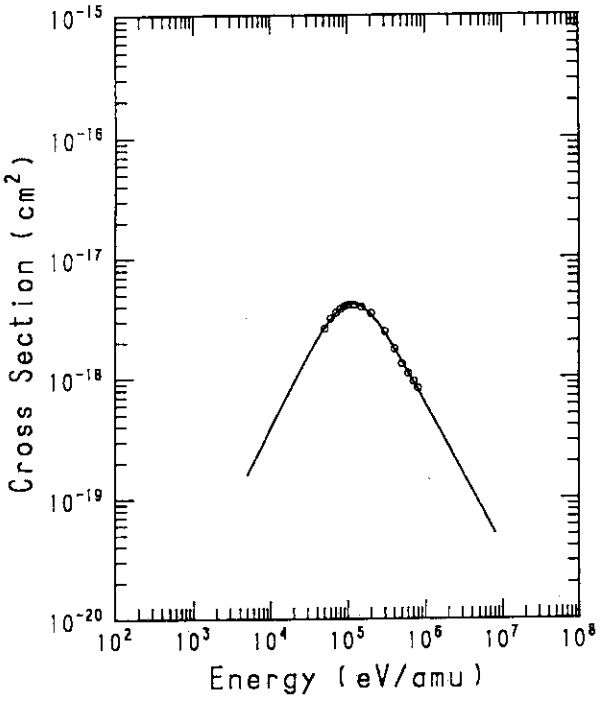
GRAPH 68

$He + H_2 \rightarrow He^+ + H_2 + e \ (\sigma_{01})$



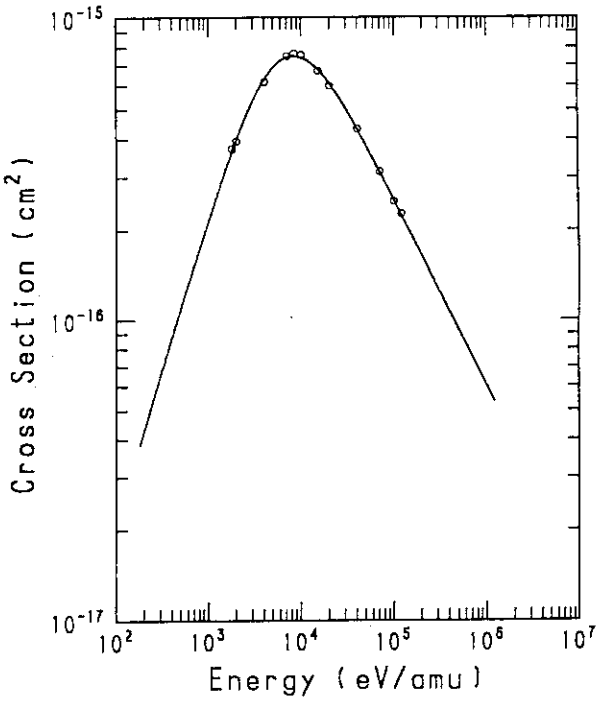
GRAPH 69

$He + H_2 \rightarrow He^{2+} + H_2 + 2e$ (σ_{02})



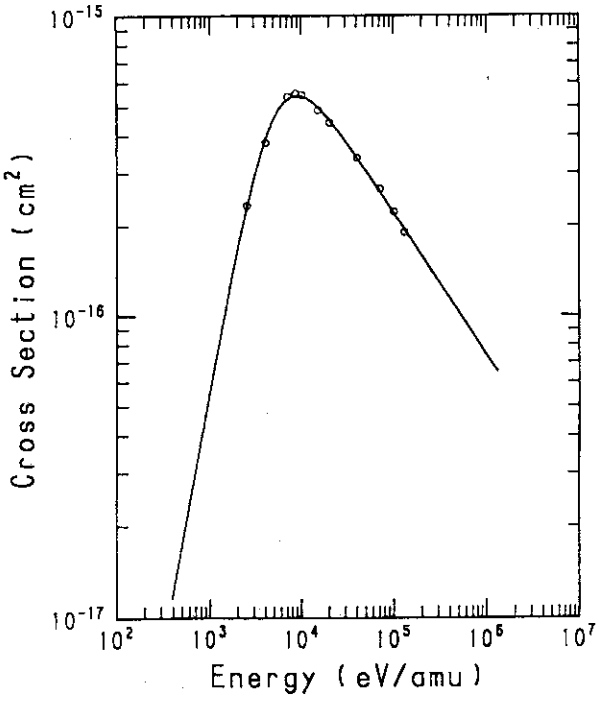
GRAPH 70

$He^* + H_2 \rightarrow He$ or He^+ (σ_T)



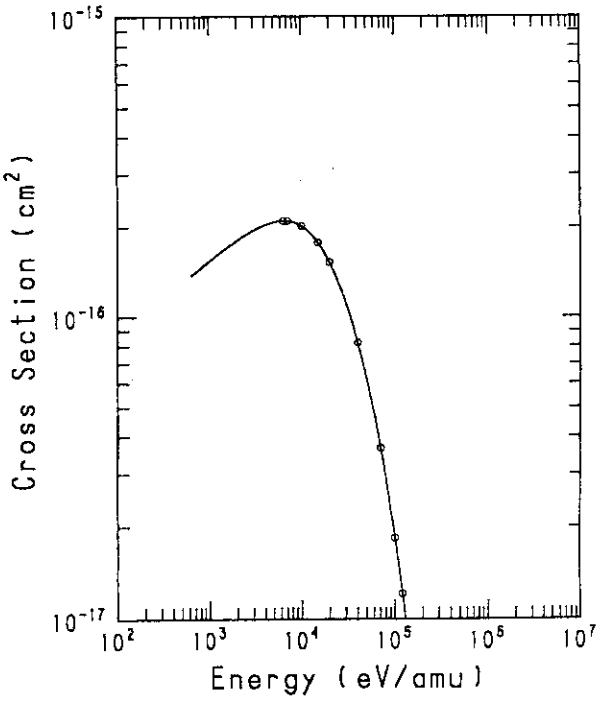
GRAPH 71

$He^* + H_2 \rightarrow He^+ + H_2 + e$



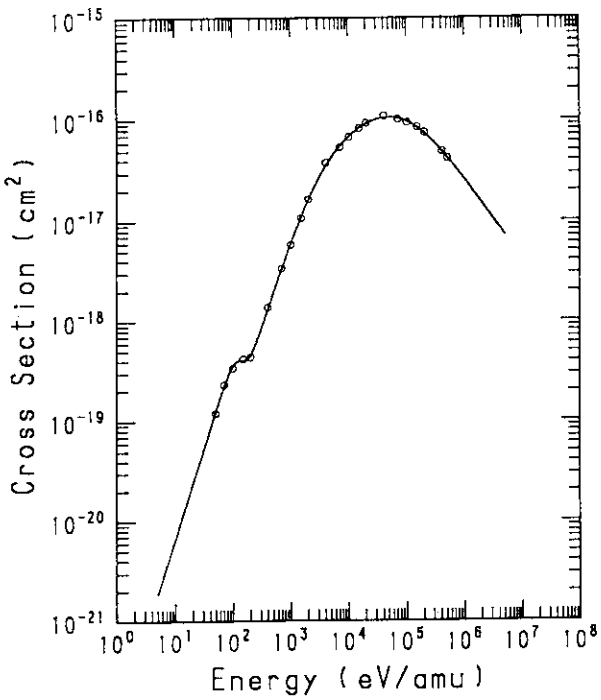
GRAPH 72

$He^* + H_2 \rightarrow He + H_2$



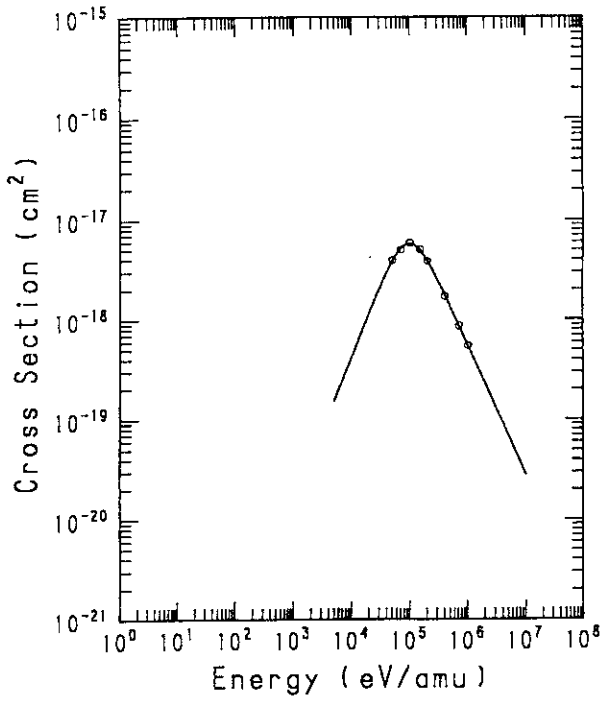
GRAPH 73

$He + He \rightarrow He^{+} + He + e$ (σ_{01})



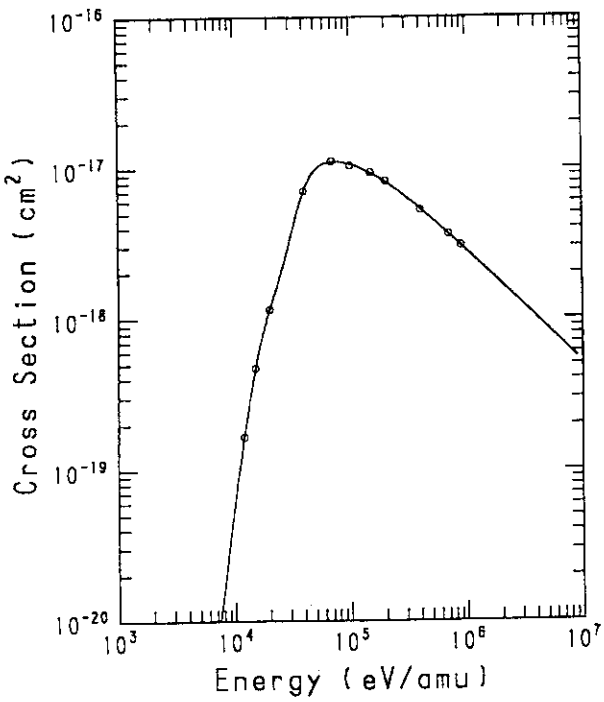
GRAPH 74

$He + He \rightarrow He^{2+} + He + 2e$ (σ_{02})



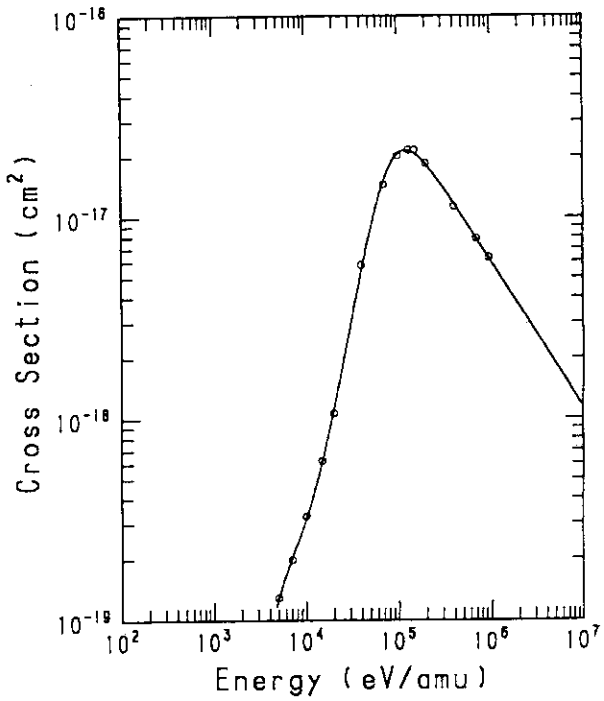
GRAPH 75

$He^{+} + H \rightarrow He^{2+} + H + e$



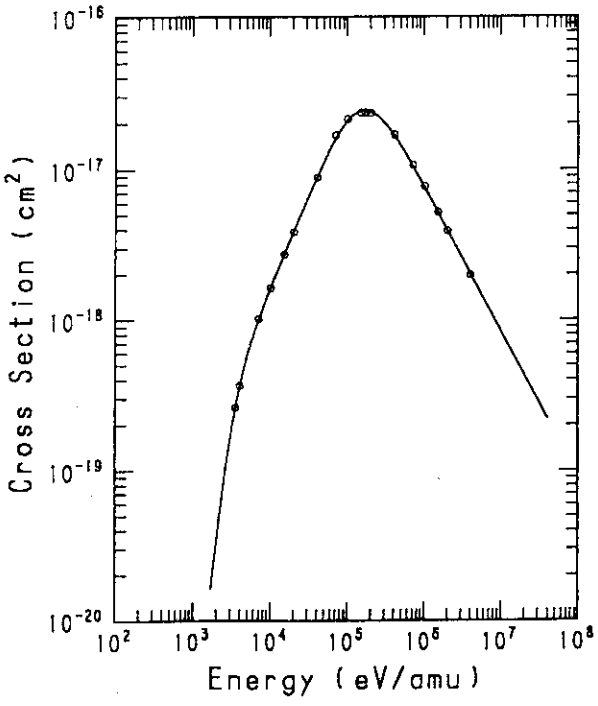
GRAPH 76

$He^{+} + H_2 \rightarrow He^{2+} + H_2 + e$



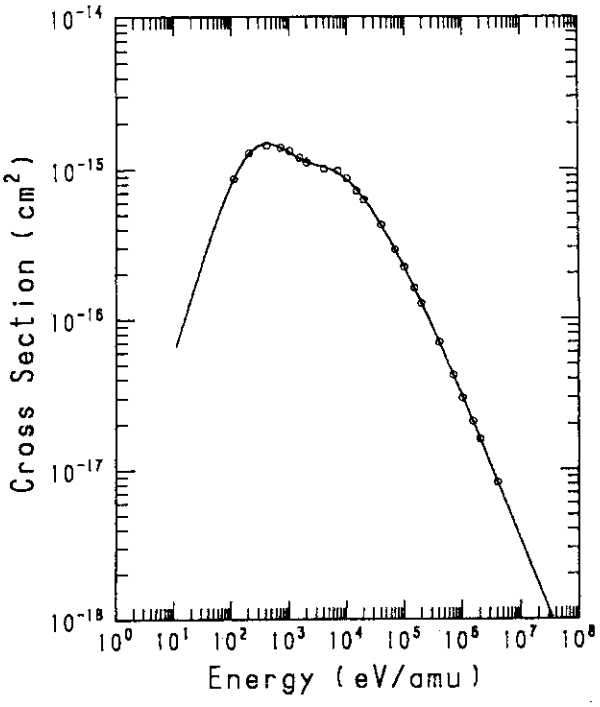
GRAPH 77

$He^+ + He \rightarrow He^{2+} + He + e$



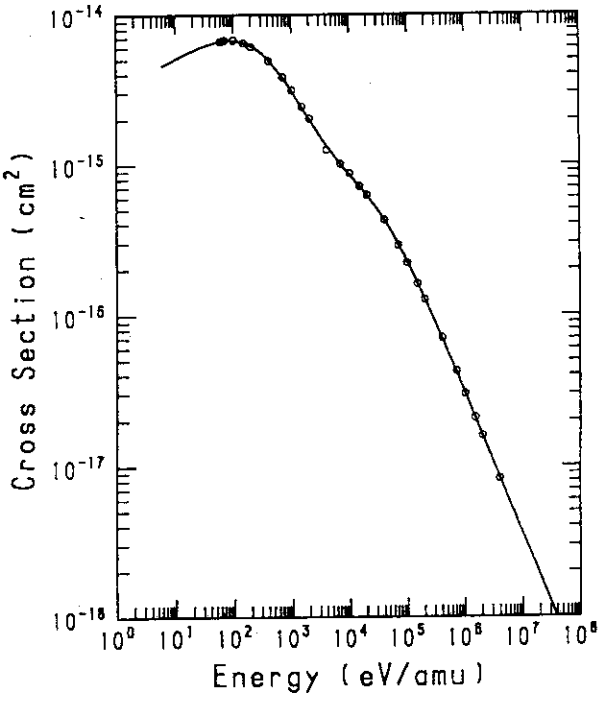
GRAPH 78

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



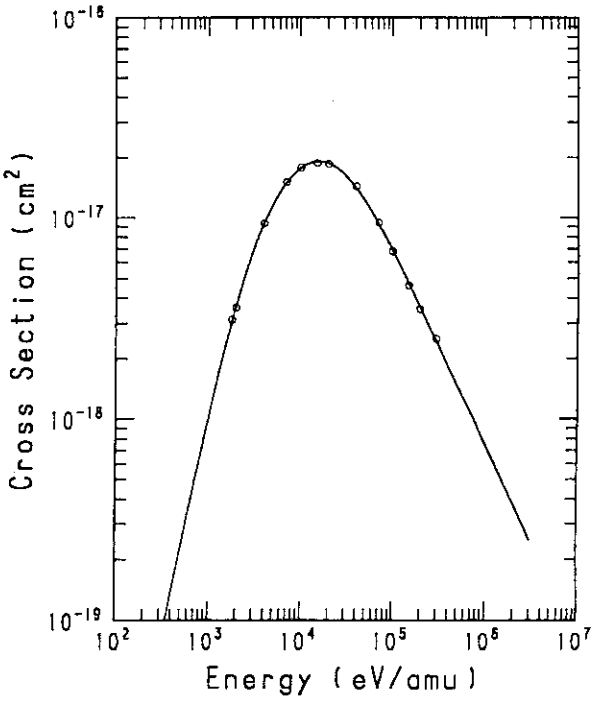
GRAPH 79

$H^- + H \rightarrow (H + H + e)$ or $(H + H^-)$



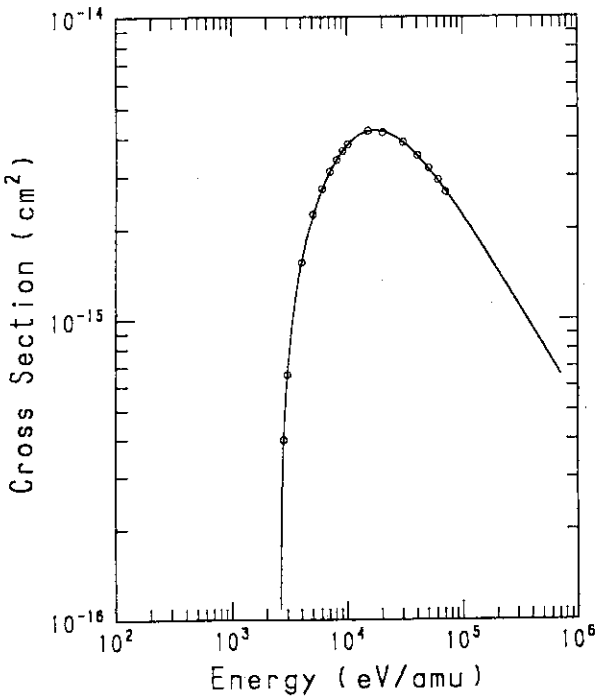
GRAPH 80

$H^- + H \rightarrow H^+ + H + 2e$



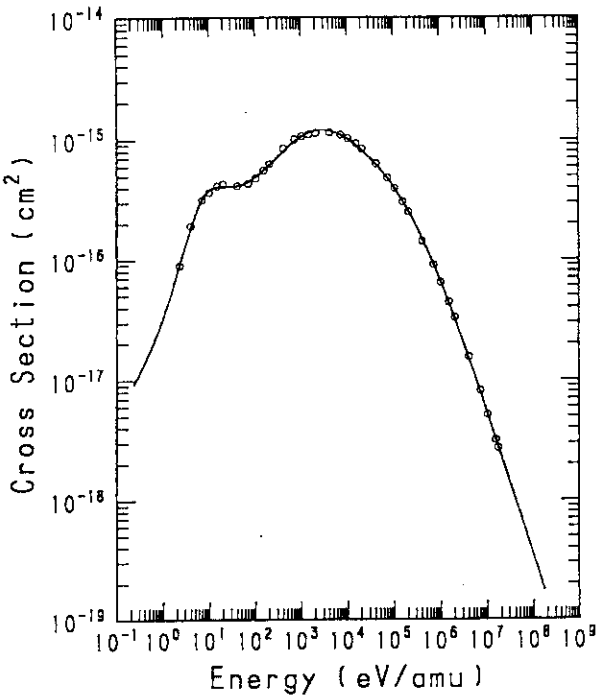
GRAPH 81

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



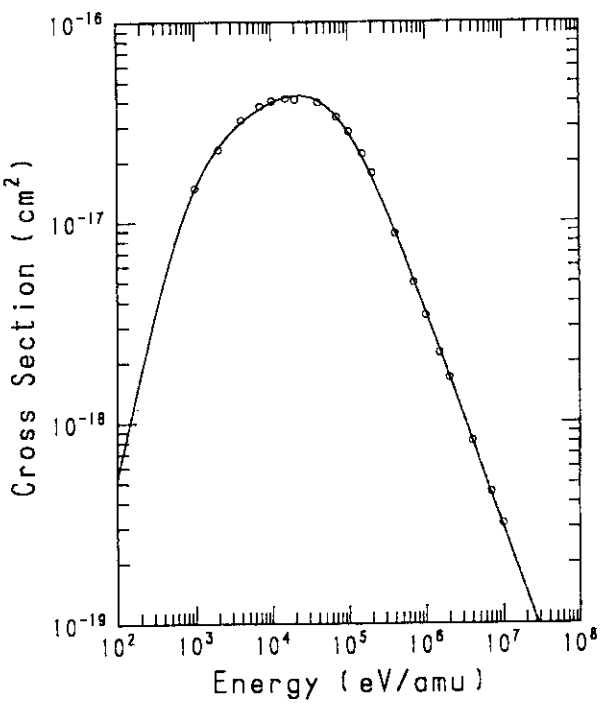
GRAPH 82

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



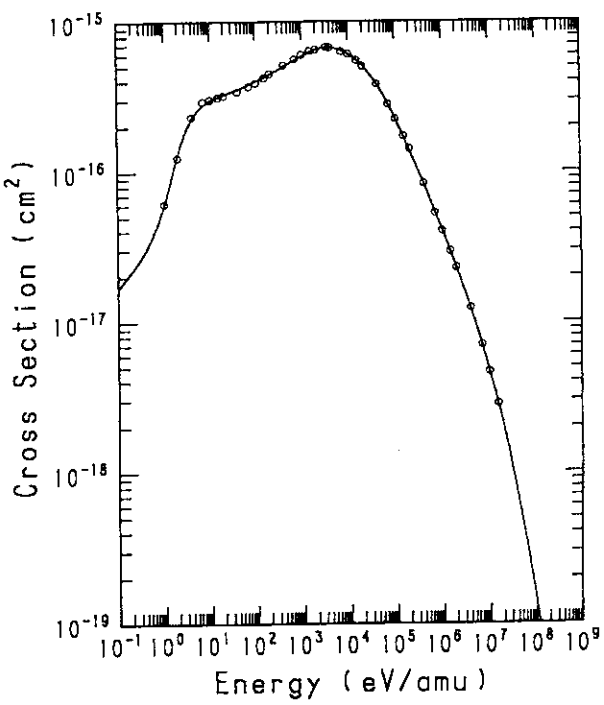
GRAPH 83

$H^- + H_2 \rightarrow H^+ + H_2 + 2e$



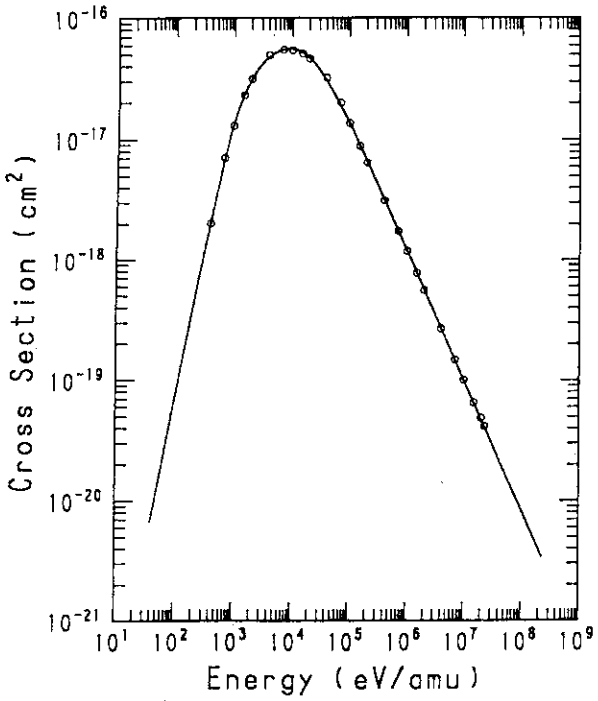
GRAPH 84

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



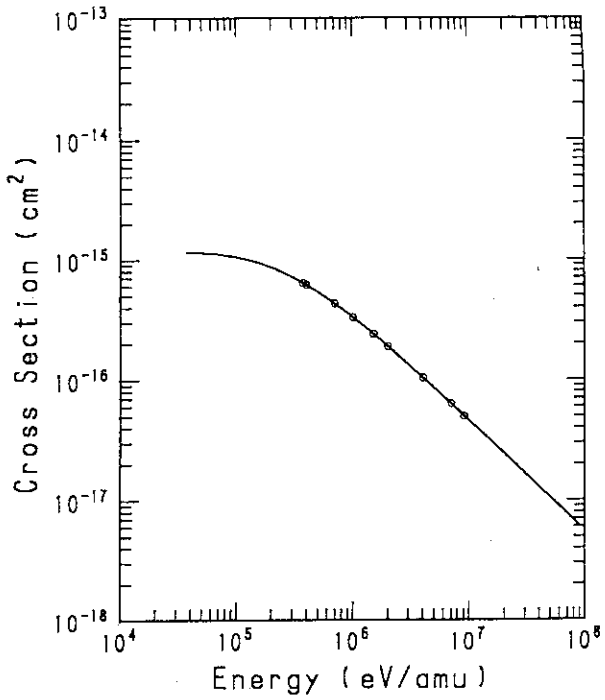
GRAPH 85

$H^- + He \rightarrow H^+ + He + 2e$



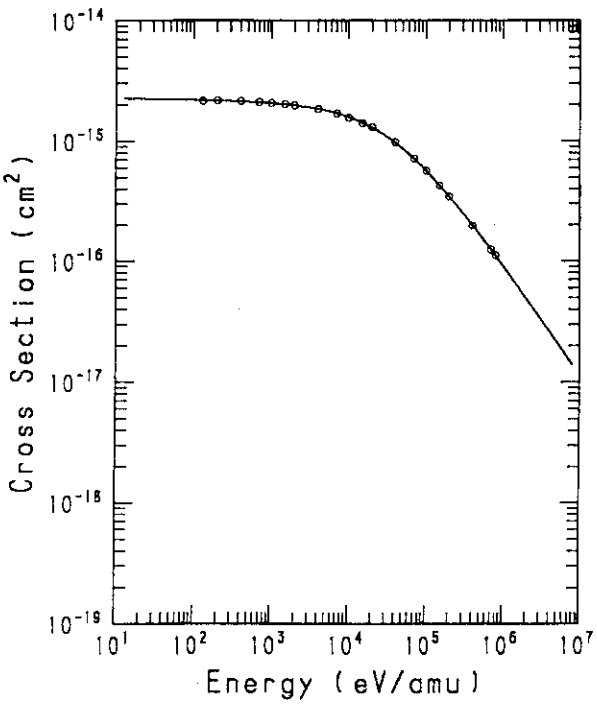
GRAPH 86

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



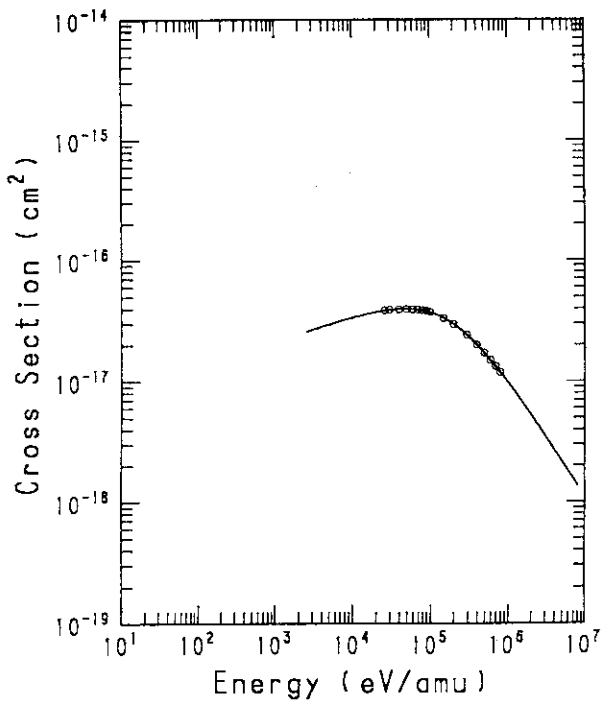
GRAPH 87

$He^- + H_2 \rightarrow He + H_2 + e$



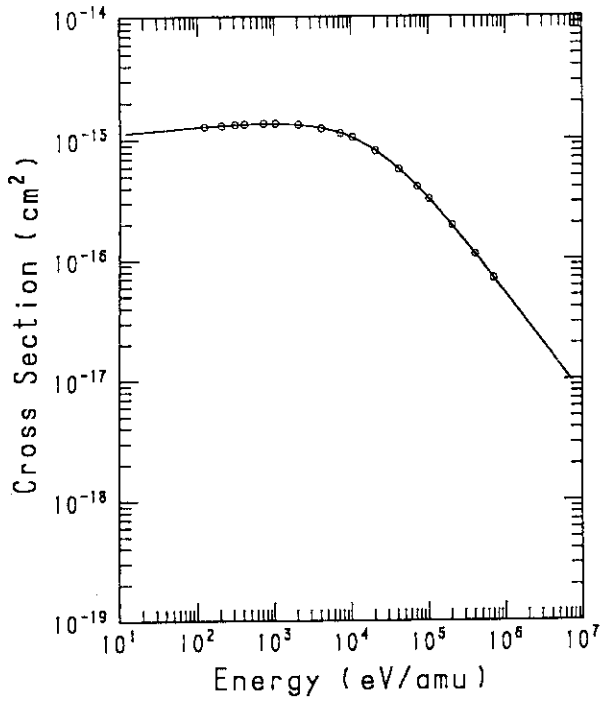
GRAPH 88

$He^- + H_2 \rightarrow He^+ + H_2 + 2e$



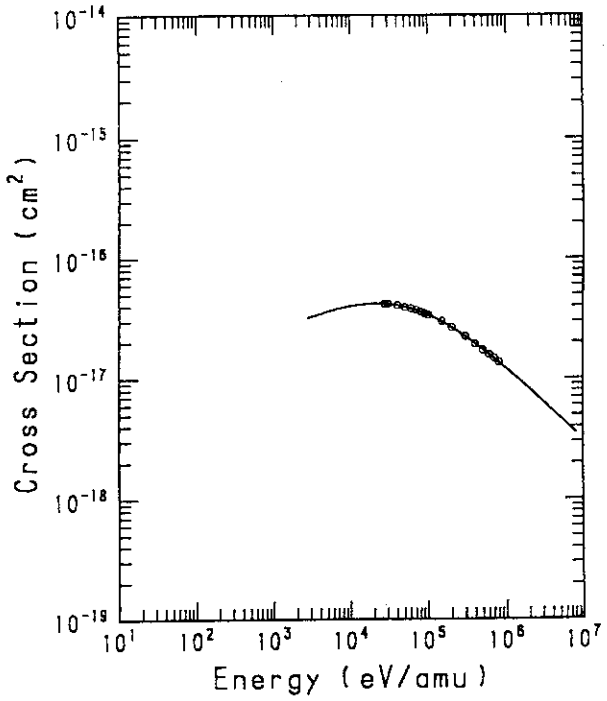
GRAPH 89

$He^- + He \rightarrow He + He + e$



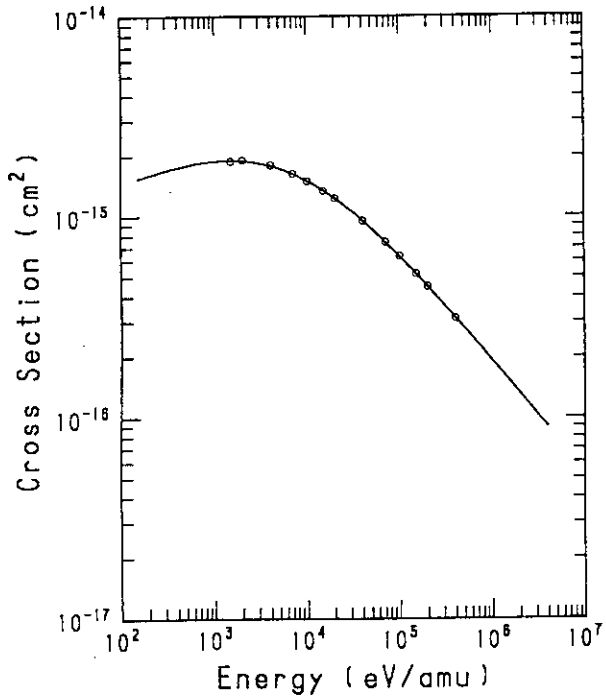
GRAPH 90

$He^- + He \rightarrow He^+ + He + 2e$



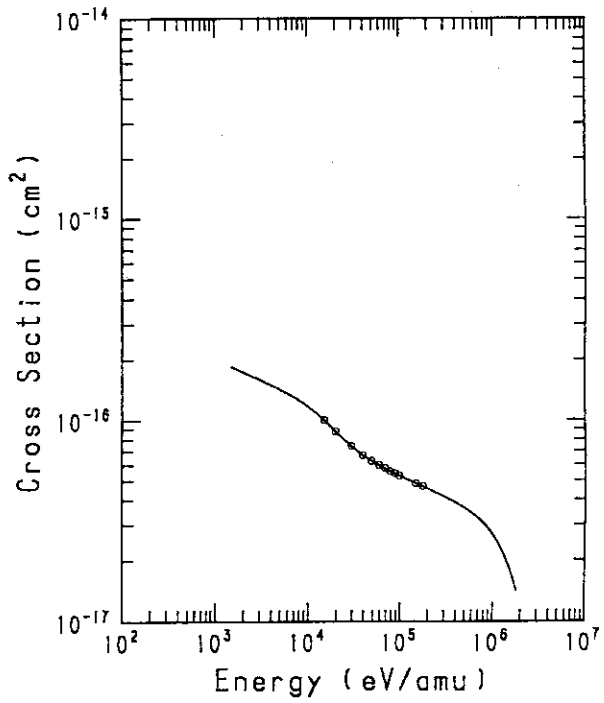
GRAPH 91

$Li^- + H_2 \rightarrow Li + H_2 + e$



GRAPH 92

$Li^- + H_2 \rightarrow Li^+ + H_2 + 2e$



GRAPH 93

$Li^- + He \rightarrow Li/Li^+$