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State-Selective and Total Electron Capture, Excitation and Ionization Cross Sections in Slow Collisions of H(2s) and $He^+(2s)$ with H^+, He^{2+}, Li^{3+}, Be^{4+} and B^{5+}

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Abstract

The results of systematic calculations by the hidden crossing method for the state-selective and total cross sections for electron capture, excitation (de-excitation) and ionization processes in slow collisions of H(2s) and He^{+}(2s) with H^{+}, He^{2+}, Li^{3+}, Be^{4+} and B^{5+} ions are presented. The data for selected energies in the overall range of 0.05-20 keV/amu are presented in tabular form. The total and n-selective cross sections are also shown in graphical form.

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1. INTRODUCTION

Atomic and ion species in metastable excited states are known to have significant effects on the kinetics of partially ionized plasmas. In the edge and divertor plasmas of magnetic confinement fusion devices the existence of H(2s) and $He^+(2s)$ metastables is expected to result from the complex collisional physics of these plasmas [1]. Radial fluxes of multiply charged impurity ions coming from the hot plasma regions travels towards the edge plasma and thereby undergo inelastic collisions with the H(2s) and $He^+(2s)$ metastables. The most prominent of the collision processes involving H(2s), $He^+(2s)$ and plasma impurity ions are those leading to collisional excitation or de-excitation of the metastables, or to the removal (i.e. electron capture or ionization) of the electron from the metastable target. In the case of H(2s), these processes are also important in the context of neutral hydrogen beam penetration in fusion plasmas [2].

In this report we present the results of cross section calculations for the excitation, de-excitation, electron transfer (or capture) and ionization processes in collisions of H(2s) and $He^+(2s)$ metastables with fully stripped ions of the elements with atomic number $Z \leq 5$. The calculations were performed by using the advanced adiabatic (or hidden crossing) method [3,4] which provides an adequate description of the collision dynamics of one-electron ion-atom(ion) systems in the adiabatic energy region.

The processes considered in the present report include:

$$B(2s) + A^{q+} \rightarrow B(n\ell) + A^{q+} \quad , \; n\ell \neq 2s \, , \tag{1}$$

$$\rightarrow B^+ + A^{(q-1)+}(n\ell) \tag{2}$$

$$\rightarrow B^+ + A^{q+} + e \tag{3}$$

where B = H, He^+ and $A^{q+} = H^+$, He^{2+}, Li^{3+}, Be^{4+} and B^{5+}. Some of these processes have previously been investigated within the framework of hidden crossing theory. For instance, the processes (1)-(3) for H(2s) were studied in Refs. [5] (for H^+), [6] (for He^{2+}) and [7] (for Li^{3+}) with a varying number of states included in the basis.

In the present work the cross section calculation for processes (1)-(3) were carried out in a systematic manner with a fixed basis containing all the adiabatic states having united atom principal quantum number $N \leq 10$. This ensures uniformity of the accuracy of obtained cross sections, at least for low-lying inelastic channels. The present work also reports a complete set of ℓ-resolved electron capture cross sections for the considered collision systems.

2. BRIEF DESCRIPTION OF COMPUTATIONAL METHOD

The advanced adiabatic (or hidden crossing) method applied in the present calculations is described elsewherre [4-7]. The method is based on the analytic continuation of adiabatic electron energies of the one-electron — two-Coulomb centre system in the complex plane of

internuclear distance R, where the potential energy surfaces (for the states of a given symmetry) are connected with a square-root branching point (hidden crossing). These branching points sequentially and pairwise couple all potential energy surfaces (of a given symmetry) and form series along which the system evolves during the collision. Each of the hidden crossings represents a point at which the system may smoothly pass from one surface to another by just going around that point. This signifies that the system has made a transition between the two adiabatic states represented by the crossing potential surfaces. The transition probability between two adiabatic electronic states $|\alpha>$ and $|\beta>$ having a hidden crossing at $R_c = R_{\alpha\beta}$ in the complex R-plane is give by [4] (in atomic units)

$$p_{\alpha\beta} = \exp\left(-\frac{2}{v}\,\Delta_{\alpha\beta}\right) \tag{4}$$

where v is the collision velocity and $\Delta_{\alpha\beta}$ is the generalized Massey parameter defined by

$$\Delta_{\alpha\beta} = \left| \mathrm{Im} \int_{\mathrm{Re}\,X(Rc)}^{X(Rc)} \Delta E_{\beta\alpha}(R(x))dx \right| \tag{5}$$

where

$$\Delta E_{\alpha\beta} = E_{\beta}(R) - E_{\alpha}(R) \tag{6}$$

is the difference of the considered adiabatic surfaces and $x = vt$. In the straight-line approximation for the classical trajectory, $x=(R^2-b^2)^{1/2}$, where b is the impact parameter.

The knowledge of the distribution of the hidden crossings in the complex R-plane allows following the complete dynamical evolution of a one-electron — two-Coulomb centre collision system. All series of hidden crossings end up at the continuum edge, which allows the description of the ionization process as well. Apart from the (radial) couplings of adiabatic states at the hidden crossings, the states with different m within the same (N,ℓ)-manifold (N,ℓ,m are the united atom spherical quantum numbers) are rotationally coupled in the united atom region, and these couplings should also be included in the construction of the evolution matrix. Finally, at large internuclear distances, there are also rotational couplings between the states caused by the long-range dipole interaction. These couplings control the population of ℓ-sublevels in the exit channels. The combination of all these types of couplings allows construction of the evolution (or the S-) matrix for the collision system for a given trajectory (or impact parameter value). In practical calculations one has to make a truncation of the basis at certain value N_0. In the present calculations N_0 was taken to be 10. Transitions to states with N higher than N_0 (=10) were treated in the present calculations as ionization. (This introduces an error in the ionization cross sections for the considered systems of not larger than 5%).

3. COLLISIONS OF H(2s) WITH H^+, He^{2+}, Li^{3+}, Be^{4+} AND B^{5+}

The cross sections for the processes (1)-(3) for the H(2s) - H^+, He^{2+}, Li^{3+}, Be^{4+} and B^{5+} collision systems in the energy range (in general) 0.1-10 keV/amu are given in Tables 1-5 and Figs. 1a,b-5a,b. The specific energy range for each collision system in which the calculations have been performed was determined on the basis of the expected validity of the hidden crossing method.

In the case of charge-symmetric system H(2s) + H^+, there is a strong interference of the excitation and electron transfer channels, the description of which requires inclusion of dynamical and topological phases in the treatment. Since the existing codes do not allow for inclusion of phase interference effects, the cross sections for excitation and electron transfer to a given $n\ell$-state are given in Table 1 as a sum. (Exception from this interpretation are the data for $n\ell$=1s(de-exc+ct) and $n\ell$=2s (only ct). In the considered energy range, the contribution of each of these processes to their total cross section amounts to approximately 50%.

The summed excitation and electron capture cross sections for production of a product atom in a shell *n* are given in Fig. 1a, from where it is apparent that the production of a neutral atom in the n=2 state is dominant. The ionization cross section for this collision system is given in Fig. 1b. For the charge - asymmetric systems H(2s) + Z ($2 \leq Z \leq 5$). Tables 2-5 contain state-selective and total electron capture cross section data, cross section data for the de-excitation (n=1) and excitation ($n > 2$) processes, and cross section data for ionization. Figures 2a-5a show the n-selective electron capture cross sections, while Figs. 2b-5b show the total excitation, de-excitation and ionization cross sections. (For Li^{3+} and Be^{4+}, the excitation cross sections are not shown because of their high uncertainties.

4. COLLISIONS OF He^+(2s) WITH He^{2+}, Li^{3+}, Be^{4+} AND B^{5+}

The cross section data for the processes (1)-(3) in He^+(2s) + He^{2+}, Li^{3+}, Be^{4+}, B^{5+} collision system are given in Tables 6-9 and Figures 6a,b - 9a,b. The method of data presentation is the same as in the preceding case for H(2s). The He^+(2s) + He^{2+} system is charge-symmetric and the data for excitation (de-excitation) and electron transfer are given as a sum, for the same reason as discussed in the H(2s) + H^+ case.

5. REFERENCES

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Table 1: Cross sections (in units of 10^{-16} cm^2) for state-specific and total charge transfer+excitation and for ionization in $H(2s) + H^+$ collisions as a function of energy (in units of keV/u).

E(keV/u)	.10	.20	.50	.70	1.00	2.00	3.00	5.00
σ_{ct+ex}								
n= 1	3.86E-21	1.80E-20	5.10E-20	7.03E-20	1.00E-19	3.15E-19	8.69E-19	2.85E-18
l= 0	3.86E-21	1.80E-20	5.10E-20	7.03E-20	1.00E-19	3.15E-19	8.69E-19	2.85E-18
n= 2	1.71E-15	1.88E-15	2.08E-15	2.26E-15	2.56E-15	3.72E-15	4.79E-15	6.53E-15
l= 0	7.93E-16	8.51E-16	9.09E-16	9.61E-16	1.05E-15	1.46E-15	1.96E-15	3.03E-15
l= 1	9.18E-16	1.03E-15	1.18E-15	1.29E-15	1.51E-15	2.26E-15	2.83E-15	3.50E-15
n= 3	1.04E-15	1.08E-15	1.09E-15	1.18E-15	1.35E-15	1.99E-15	2.49E-15	3.17E-15
l= 0	2.36E-17	3.10E-17	6.50E-17	9.45E-17	1.40E-16	2.71E-16	3.80E-16	5.47E-16
l= 1	2.08E-16	2.13E-16	2.21E-16	2.57E-16	3.25E-16	5.46E-16	7.08E-16	9.62E-16
l= 2	8.05E-16	8.32E-16	8.07E-16	8.27E-16	8.88E-16	1.17E-15	1.40E-15	1.66E-15
n= 4	4.36E-16	4.42E-16	4.52E-16	4.67E-16	5.01E-16	6.67E-16	8.40E-16	1.11E-15
l= 0	4.04E-19	1.73E-18	7.40E-18	1.16E-17	1.87E-17	4.23E-17	6.28E-17	9.57E-17
l= 1	5.36E-18	1.03E-17	2.43E-17	3.33E-17	4.76E-17	1.00E-16	1.47E-16	2.21E-16
l= 2	3.55E-18	1.38E-17	4.58E-17	6.47E-17	9.15E-17	1.73E-16	2.33E-16	2.94E-16
l= 3	4.27E-16	4.16E-16	3.75E-16	3.58E-16	3.43E-16	3.52E-16	3.97E-16	4.96E-16
n= 5	1.54E-17	4.54E-17	1.12E-16	1.44E-16	1.86E-16	3.55E-16	5.69E-16	1.03E-15
l= 0	3.32E-20	1.89E-19	1.32E-18	2.57E-18	5.17E-18	1.82E-17	3.43E-17	6.89E-17
l= 1	3.29E-19	1.44E-18	5.82E-18	9.19E-18	1.53E-17	4.63E-17	8.50E-17	1.64E-16
l= 2	2.19E-19	1.36E-18	7.93E-18	1.38E-17	2.42E-17	7.21E-17	1.27E-16	2.20E-16
l= 3	7.34E-18	2.10E-17	4.74E-17	5.76E-17	6.93E-17	1.13E-16	1.72E-16	2.96E-16
l= 4	7.48E-18	2.14E-17	4.92E-17	6.04E-17	7.25E-17	1.05E-16	1.50E-16	2.82E-16
n= 6	1.62E-18	9.40E-18	4.00E-17	5.80E-17	8.02E-17	1.29E-16	1.57E-16	1.88E-16
l= 0	7.61E-21	5.19E-20	4.56E-19	8.54E-19	1.51E-18	3.59E-18	5.27E-18	7.72E-18
l= 1	5.24E-20	3.67E-19	2.04E-18	3.22E-18	4.74E-18	8.06E-18	9.92E-18	1.20E-17
l= 2	4.11E-20	3.20E-19	2.27E-18	3.98E-18	6.59E-18	1.37E-17	1.85E-17	2.41E-17
l= 3	4.72E-19	2.71E-18	1.08E-17	1.50E-17	1.98E-17	2.93E-17	3.48E-17	4.09E-17
l= 4	5.82E-19	3.23E-18	1.31E-17	1.86E-17	2.52E-17	3.88E-17	4.60E-17	5.34E-17
l= 5	4.66E-19	2.72E-18	1.14E-17	1.64E-17	2.24E-17	3.52E-17	4.24E-17	5.00E-17
n= 7	2.36E-19	2.27E-18	1.53E-17	2.51E-17	3.88E-17	7.44E-17	9.83E-17	1.26E-16
l= 0	2.58E-21	1.86E-20	1.78E-19	3.28E-19	5.67E-19	1.31E-18	1.94E-18	2.86E-18
l= 1	1.30E-20	1.14E-19	7.25E-19	1.13E-18	1.64E-18	2.72E-18	3.29E-18	3.87E-18
l= 2	1.07E-20	9.25E-20	7.29E-19	1.31E-18	2.22E-18	4.99E-18	7.10E-18	9.94E-18
l= 3	5.69E-20	5.55E-19	3.64E-18	5.74E-18	8.38E-18	1.38E-17	1.65E-17	1.86E-17
l= 4	4.23E-20	3.89E-19	2.50E-18	4.11E-18	6.45E-18	1.30E-17	1.76E-17	2.31E-17
l= 5	4.77E-20	4.53E-19	3.00E-18	4.97E-18	7.90E-18	1.64E-17	2.25E-17	2.99E-17
l= 6	6.31E-20	6.50E-19	4.56E-18	7.51E-18	1.16E-17	2.23E-17	2.94E-17	3.79E-17
n= 8	5.80E-20	6.14E-19	4.49E-18	7.48E-18	1.17E-17	2.27E-17	3.00E-17	3.88E-17
l= 0	9.77E-22	6.07E-21	5.82E-20	1.06E-19	1.79E-19	3.95E-19	5.66E-19	8.24E-19
l= 1	3.86E-21	2.93E-20	1.90E-19	3.02E-19	4.45E-19	7.42E-19	8.93E-19	1.03E-18
l= 2	4.51E-21	3.47E-20	2.18E-19	3.59E-19	5.67E-19	1.18E-18	1.65E-18	2.31E-18
l= 3	9.12E-21	9.65E-20	7.32E-19	1.21E-18	1.86E-18	3.28E-18	3.98E-18	4.50E-18
l= 4	1.17E-20	1.28E-19	9.34E-19	1.55E-18	2.41E-18	4.60E-18	5.95E-18	7.27E-18
l= 5	9.87E-21	1.06E-19	7.06E-19	1.15E-18	1.79E-18	3.64E-18	5.12E-18	7.26E-18
l= 6	1.18E-20	1.38E-19	1.03E-18	1.72E-18	2.67E-18	5.00E-18	6.43E-18	8.00E-18
l= 7	6.15E-21	7.51E-20	6.19E-19	1.08E-18	1.77E-18	3.83E-18	5.44E-18	7.60E-18
n= 9	1.24E-20	1.50E-19	1.15E-18	1.97E-18	3.16E-18	6.36E-18	8.60E-18	1.13E-17
l= 0	5.60E-24	1.78E-22	3.56E-21	8.00E-21	1.66E-20	5.01E-20	8.24E-20	1.37E-19
l= 1	3.54E-22	3.86E-21	2.37E-20	3.92E-20	6.16E-20	1.22E-19	1.64E-19	2.20E-19
l= 2	9.34E-22	9.49E-21	4.71E-20	7.28E-20	1.10E-19	2.14E-19	2.96E-19	4.09E-19
l= 3	1.66E-21	1.80E-20	1.09E-19	1.78E-19	2.77E-19	5.49E-19	7.45E-19	1.01E-18
l= 4	2.84E-21	3.42E-20	2.57E-19	4.32E-19	6.75E-19	1.25E-18	1.57E-18	1.85E-18
l= 5	3.38E-21	4.25E-20	3.48E-19	5.96E-19	9.47E-19	1.82E-18	2.34E-18	2.83E-18
l= 6	2.32E-21	2.97E-20	2.55E-19	4.44E-19	7.28E-19	1.54E-18	2.14E-18	2.90E-18
l= 7	8.35E-22	1.08E-20	9.59E-20	1.72E-19	2.93E-19	6.94E-19	1.05E-18	1.62E-18
l= 8	1.23E-22	1.61E-21	1.48E-20	2.72E-20	4.85E-20	1.30E-19	2.14E-19	3.72E-19
$\sigma_{ct+ex;tot}$	3.20E-15	3.46E-15	3.79E-15	4.14E-15	4.73E-15	6.96E-15	8.98E-15	1.22E-14
σ_{ion}	2.76E-19	3.22E-18	3.18E-17	6.01E-17	1.08E-16	2.87E-16	4.70E-16	8.13E-16

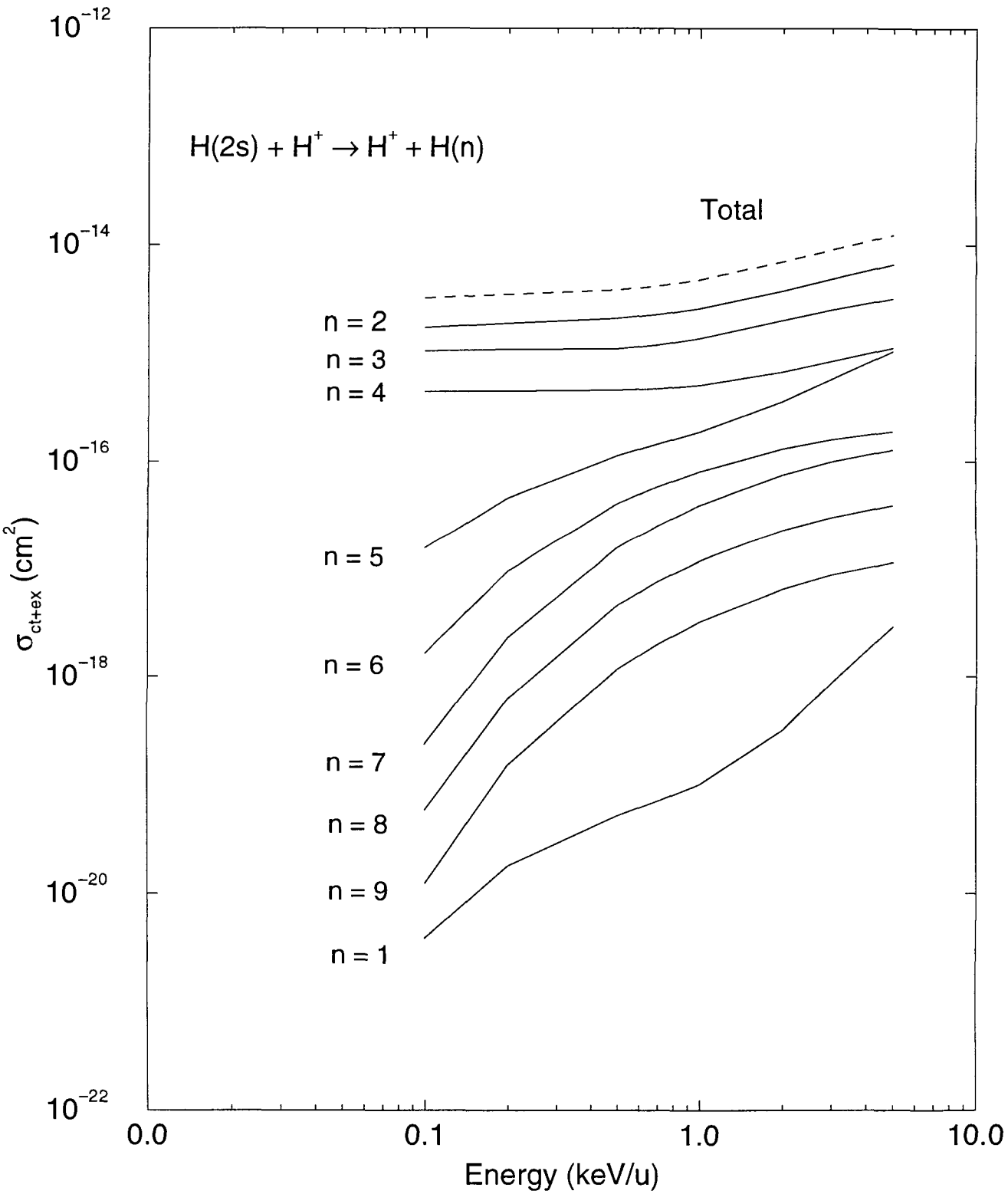
10^{-12}
10^{-14}
10^{-16}
10^{-18}
10^{-20}
10^{-22}
σ_{ct+ex} (cm^2)
H(2s) + H$^+$ → H$^+$ + H(n)
Total
n = 2
n = 3
n = 4
n = 5
n = 6
n = 7
n = 8
n = 9
n = 1
0.0
0.1
1.0
10.0
Energy (keV/u)

Fig. 1a

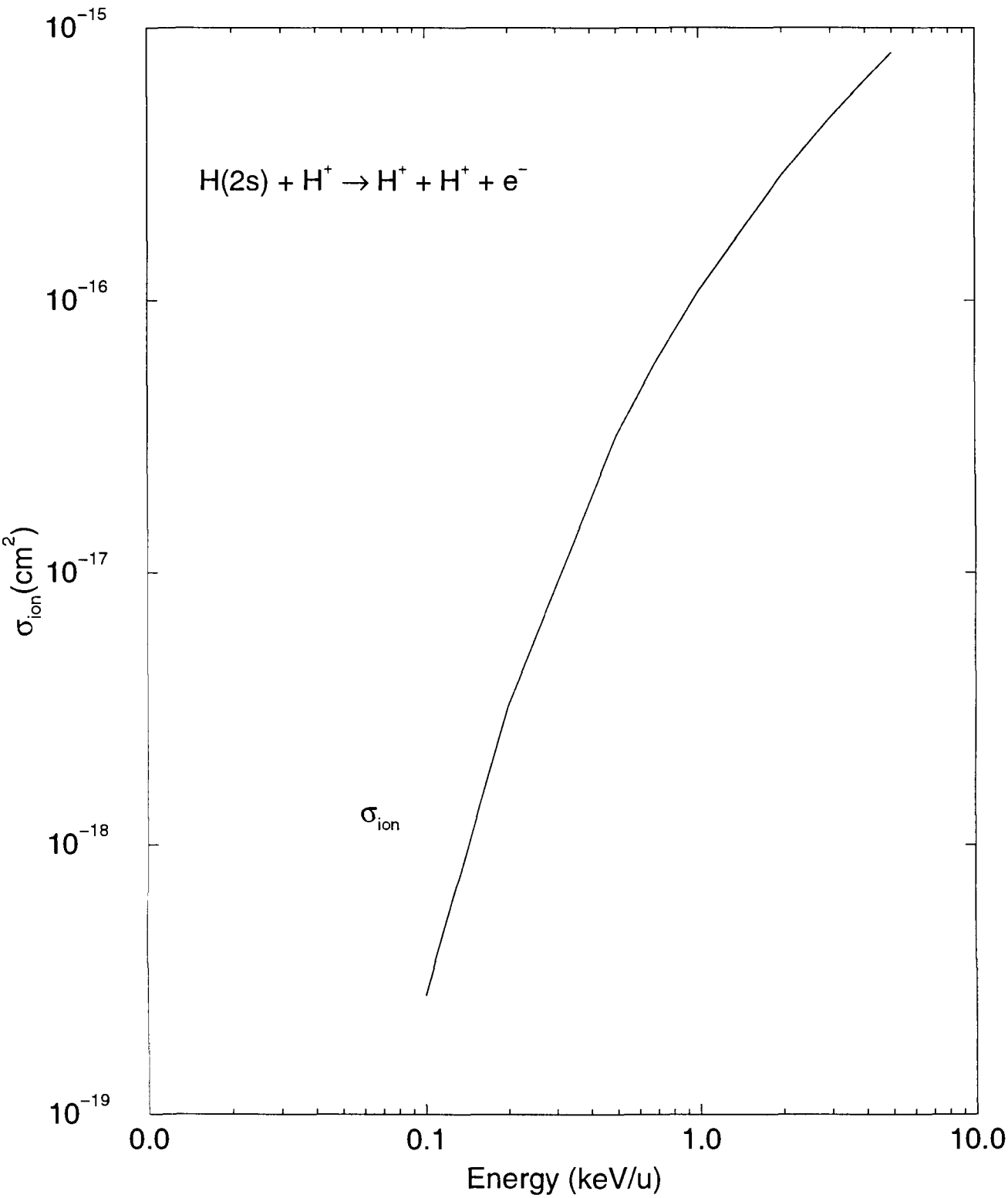
10^{-15}
10^{-16}
10^{-17}
10^{-18}
10^{-19}
$\sigma_{ion}(cm^2)$
$H(2s) + H^+ \rightarrow H^+ + H^+ + e^-$
σ_{ion}
0.0
0.1
1.0
10.0
Energy (keV/u)

Fig. 1b

Table 2: Cross sections (in units of 10^{-16} cm^2) for state-specific and total charge transfer, excitation and de-excitation, and ionization for the $H(2s) + He^{+2}$ collision system as a function of energy (in units of keV/u).

E(keV/u)	.05	.10	.20	.50	1.00	2.00	5.00	10.00
σ_{ct}								
n= 2	3.40E-22	1.26E-20	1.08E-19	6.67E-19	1.97E-18	5.61E-18	2.28E-17	4.94E-17
l= 0	1.70E-22	6.25E-21	5.35E-20	3.24E-19	9.04E-19	2.13E-18	7.57E-18	2.08E-17
l= 1	1.70E-22	6.30E-21	5.45E-20	3.43E-19	1.07E-18	3.48E-18	1.53E-17	2.87E-17
n= 3	1.15E-16	4.58E-16	1.27E-15	2.96E-15	3.97E-15	4.19E-15	3.41E-15	2.51E-15
l= 0	3.23E-17	1.18E-16	2.83E-16	5.31E-16	6.96E-16	7.92E-16	6.37E-16	3.90E-16
l= 1	1.54E-17	1.04E-16	3.86E-16	1.01E-15	1.32E-15	1.44E-15	1.53E-15	1.43E-15
l= 2	6.70E-17	2.36E-16	6.05E-16	1.42E-15	1.95E-15	1.96E-15	1.25E-15	6.82E-16
n= 4	4.27E-16	5.48E-16	9.67E-16	2.62E-15	4.54E-15	6.16E-15	6.65E-15	5.79E-15
l= 0	3.86E-18	2.02E-17	7.50E-17	2.35E-16	4.29E-16	5.52E-16	3.96E-16	2.14E-16
l= 1	1.29E-16	1.52E-16	2.65E-16	6.54E-16	1.12E-15	1.63E-15	1.66E-15	1.15E-15
l= 2	1.90E-16	2.28E-16	3.66E-16	8.35E-16	1.13E-15	1.42E-15	2.46E-15	3.08E-15
l= 3	1.04E-16	1.47E-16	2.61E-16	9.01E-16	1.87E-15	2.56E-15	2.14E-15	1.34E-15
n= 5	8.34E-16	9.60E-16	9.29E-16	8.17E-16	7.87E-16	8.34E-16	8.77E-16	8.21E-16
l= 0	8.69E-18	7.38E-18	8.07E-18	1.21E-17	2.21E-17	3.93E-17	4.54E-17	3.23E-17
l= 1	8.36E-18	1.01E-17	1.33E-17	2.95E-17	5.52E-17	8.21E-17	9.60E-17	8.84E-17
l= 2	4.54E-17	4.01E-17	4.30E-17	6.19E-17	9.93E-17	1.43E-16	1.82E-16	1.80E-16
l= 3	2.26E-16	2.67E-16	2.54E-16	2.11E-16	1.95E-16	1.88E-16	2.11E-16	2.59E-16
l= 4	5.45E-16	6.35E-16	6.11E-16	5.02E-16	4.15E-16	3.81E-16	3.43E-16	2.61E-16
n= 6	1.21E-18	1.31E-17	6.41E-17	2.25E-16	4.15E-16	7.09E-16	1.18E-15	1.36E-15
l= 0	2.15E-20	2.06E-19	1.10E-18	4.26E-18	9.88E-18	2.08E-17	2.80E-17	2.20E-17
l= 1	1.62E-20	1.91E-19	1.12E-18	6.99E-18	2.14E-17	4.66E-17	7.38E-17	6.30E-17
l= 2	8.28E-20	8.00E-19	4.28E-18	1.76E-17	4.36E-17	9.20E-17	1.52E-16	1.45E-16
l= 3	2.25E-19	2.45E-18	1.10E-17	3.46E-17	6.58E-17	1.17E-16	2.17E-16	2.80E-16
l= 4	3.83E-19	4.01E-18	1.88E-17	6.20E-17	1.09E-16	1.79E-16	2.50E-16	2.97E-16
l= 5	4.79E-19	5.47E-18	2.78E-17	9.94E-17	1.66E-16	2.54E-16	4.62E-16	5.51E-16
n= 7	3.37E-20	1.02E-18	1.07E-17	7.52E-17	1.93E-16	4.48E-16	1.39E-15	2.70E-15
l= 0	8.35E-22	2.01E-20	2.23E-19	1.67E-18	5.25E-18	1.74E-17	4.65E-17	4.84E-17
l= 1	8.82E-22	2.61E-20	2.86E-19	2.42E-18	1.02E-17	4.10E-17	1.21E-16	1.39E-16
l= 2	2.12E-21	5.47E-20	6.18E-19	5.23E-18	1.87E-17	6.35E-17	2.03E-16	2.74E-16
l= 3	5.72E-21	1.67E-19	1.69E-18	1.09E-17	2.63E-17	6.25E-17	2.65E-16	5.03E-16
l= 4	9.94E-21	2.90E-19	2.89E-18	1.81E-17	3.90E-17	6.02E-17	1.87E-16	6.16E-16
l= 5	8.35E-21	2.55E-19	2.64E-18	1.88E-17	4.73E-17	9.43E-17	1.36E-16	2.24E-16
l= 6	5.88E-21	2.02E-19	2.36E-18	1.81E-17	4.64E-17	1.09E-16	4.32E-16	8.95E-16
n= 8	1.39E-21	8.96E-20	1.73E-18	2.20E-17	7.16E-17	1.47E-16	2.38E-16	2.69E-16
l= 0	3.56E-23	1.44E-21	2.48E-20	2.93E-19	1.28E-18	4.09E-18	4.46E-18	1.08E-17
l= 1	3.84E-23	2.34E-21	4.40E-20	7.07E-19	2.30E-18	3.65E-18	1.77E-17	1.11E-17
l= 2	9.98E-23	4.54E-21	8.34E-20	1.02E-18	4.06E-18	1.21E-17	1.30E-17	3.00E-17
l= 3	1.42E-22	9.07E-21	1.66E-19	2.12E-18	6.90E-18	1.31E-17	3.02E-17	3.41E-17
l= 4	2.06E-22	1.66E-20	3.26E-19	3.82E-18	1.11E-17	2.14E-17	3.44E-17	4.75E-17
l= 5	2.84E-22	1.94E-20	3.76E-19	4.75E-18	1.48E-17	2.80E-17	4.54E-17	5.04E-17
l= 6	3.19E-22	1.92E-20	3.56E-19	4.55E-18	1.55E-17	3.40E-17	5.05E-17	4.47E-17
l= 7	2.69E-22	1.71E-20	3.52E-19	4.76E-18	1.57E-17	3.10E-17	4.20E-17	4.04E-17
$\sigma_{ct;tot}$	1.38E-15	1.98E-15	3.25E-15	6.75E-15	1.01E-14	1.28E-14	1.46E-14	1.46E-14
$\sigma_{ex,de-ex}$								
n= 1	8.20E-30	2.12E-26	3.27E-24	3.09E-22	6.66E-21	1.58E-19	2.62E-18	7.95E-18
l= 0	8.20E-30	2.12E-26	3.27E-24	3.09E-22	6.66E-21	1.58E-19	2.62E-18	7.95E-18
n= 3	1.71E-19	1.65E-18	9.06E-18	4.36E-17	1.56E-16	5.04E-16	1.30E-15	1.71E-15
l= 0	8.47E-21	1.17E-19	8.02E-19	6.64E-18	3.16E-17	9.53E-17	1.87E-16	2.10E-16
l= 1	5.35E-21	1.12E-19	9.56E-19	1.06E-17	5.71E-17	2.05E-16	4.90E-16	5.72E-16
l= 2	1.57E-19	1.42E-18	7.31E-18	2.63E-17	6.76E-17	2.04E-16	6.24E-16	9.26E-16
σ_{ion}	2.81E-21	1.62E-19	3.41E-18	6.91E-17	3.70E-16	1.26E-15	3.52E-15	5.46E-15

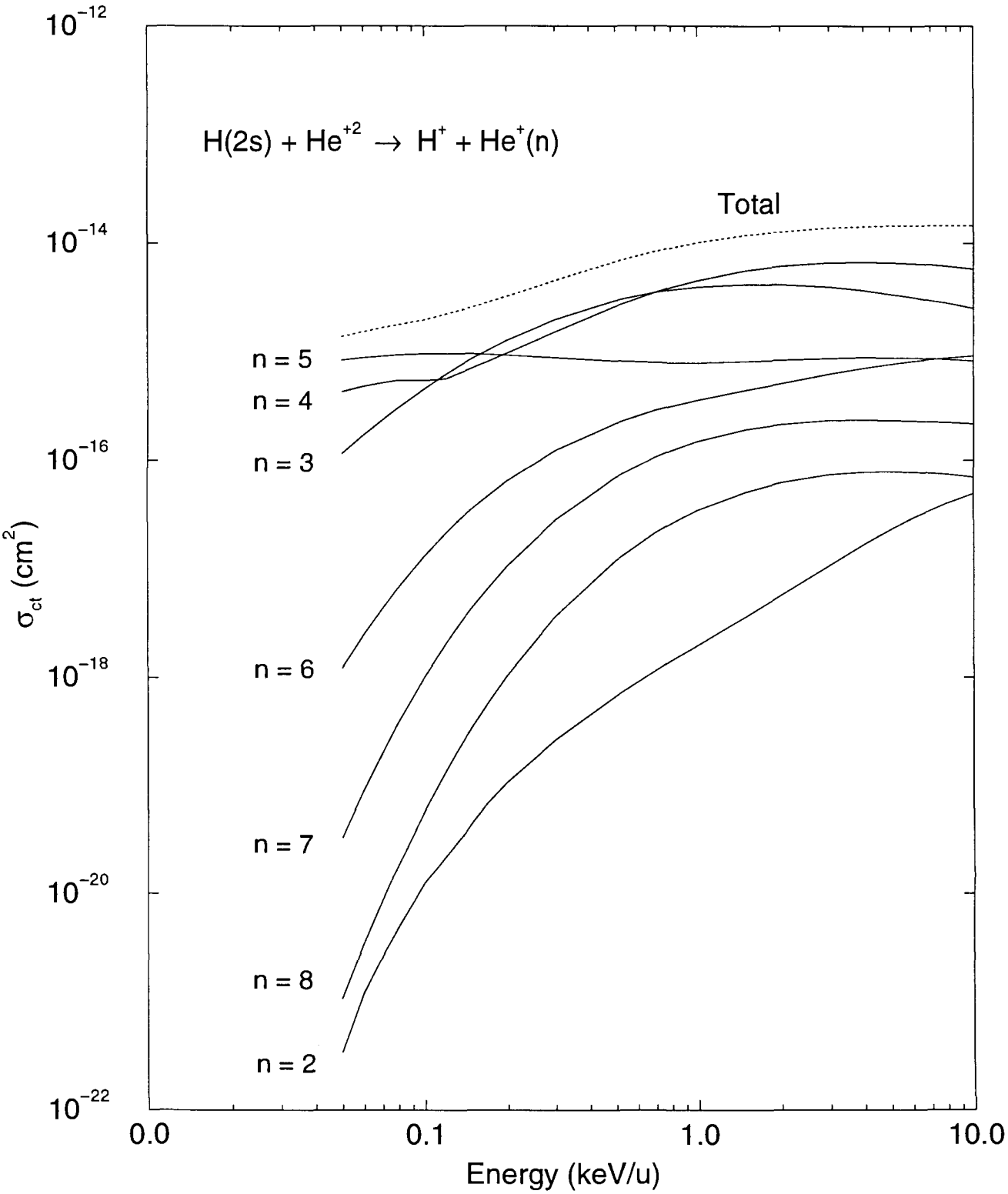
10^{-12}
10^{-14}
10^{-16}
10^{-18}
10^{-20}
10^{-22}
σ_{ct} (cm^2)
H(2s) + He^{+2} → H^+ + He^+(n)
Total
n = 5
n = 4
n = 3
n = 6
n = 7
n = 8
n = 2
0.0
0.1
1.0
10.0
Energy (keV/u)

Fig. 2a

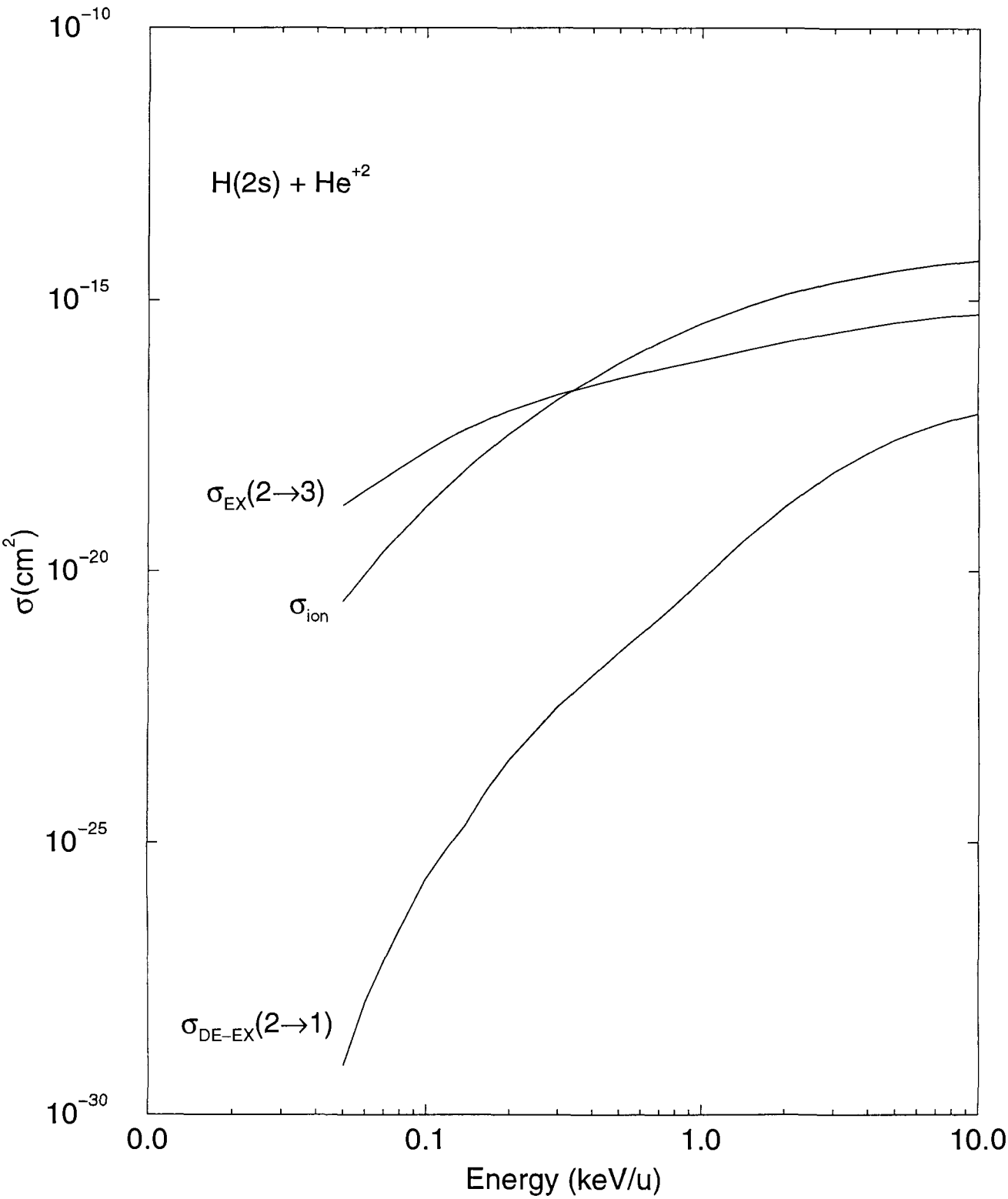
10^{-10}
10^{-15}
10^{-20}
10^{-25}
10^{-30}
$\sigma(cm^2)$
H(2s) + He^{+2}
$\sigma_{EX}(2\rightarrow3)$
σ_{ion}
$\sigma_{DE-EX}(2\rightarrow1)$
0.0
0.1
1.0
10.0
Energy (keV/u)

Fig. 2b

Table 3: Cross sections (in units of 10^{-16} cm^2) for state-specific and total charge transfer, de-excitation, and ionization for the $H(2s) + Li^{+3}$ collision system as a function of energy (in units of keV/u).

E(keV/u)	.10	.20	.50	.70	1.00	2.00	3.00	5.00
σ_{ct}								
n= 1	1.82E-80	5.54E-62	1.03E-45	2.10E-41	1.54E-37	1.04E-31	4.01E-29	1.54E-26
l= 0	1.82E-80	5.54E-62	1.03E-45	2.10E-41	1.54E-37	1.04E-31	4.01E-29	1.54E-26
n= 2	6.77E-29	1.72E-25	1.58E-22	7.66E-22	3.26E-21	3.24E-20	9.77E-20	3.38E-19
l= 0	3.37E-29	8.48E-26	7.58E-23	3.63E-22	1.51E-21	1.40E-20	3.86E-20	1.10E-19
l= 1	3.41E-29	8.70E-26	8.17E-23	4.03E-22	1.75E-21	1.84E-20	5.91E-20	2.28E-19
n= 3	3.64E-20	3.96E-19	3.65E-18	7.11E-18	1.39E-17	4.53E-17	7.93E-17	1.34E-16
l= 0	1.18E-20	1.24E-19	9.99E-19	1.75E-18	3.02E-18	8.05E-18	1.33E-17	2.16E-17
l= 1	1.81E-20	1.88E-19	1.48E-18	2.69E-18	4.99E-18	1.56E-17	2.75E-17	4.93E-17
l= 2	6.49E-21	8.27E-20	1.18E-18	2.67E-18	5.89E-18	2.16E-17	3.85E-17	6.37E-17
n= 4	4.12E-16	1.18E-15	2.82E-15	3.39E-15	3.82E-15	3.95E-15	3.63E-15	3.00E-15
l= 0	5.65E-17	1.29E-16	2.66E-16	3.16E-16	3.49E-16	3.13E-16	2.44E-16	1.50E-16
l= 1	8.78E-17	3.12E-16	7.82E-16	9.22E-16	1.01E-15	9.83E-16	8.52E-16	6.26E-16
l= 2	1.17E-16	3.37E-16	7.53E-16	8.63E-16	9.36E-16	1.03E-15	1.08E-15	1.11E-15
l= 3	1.51E-16	4.00E-16	1.02E-15	1.29E-15	1.52E-15	1.62E-15	1.45E-15	1.11E-15
n= 5	4.95E-15	6.06E-15	1.10E-14	1.30E-14	1.47E-14	1.59E-14	1.52E-14	1.32E-14
l= 0	3.86E-16	5.24E-16	9.04E-16	9.24E-16	8.37E-16	4.96E-16	3.12E-16	1.61E-16
l= 1	1.04E-15	1.29E-15	2.49E-15	2.74E-15	2.71E-15	1.93E-15	1.33E-15	7.33E-16
l= 2	1.35E-15	1.25E-15	2.53E-15	3.38E-15	4.21E-15	4.69E-15	4.15E-15	3.04E-15
l= 3	1.33E-15	1.34E-15	1.13E-15	1.27E-15	1.85E-15	4.19E-15	5.63E-15	6.71E-15
l= 4	8.34E-16	1.66E-15	3.91E-15	4.69E-15	5.13E-15	4.61E-15	3.72E-15	2.52E-15
n= 6	1.54E-15	1.66E-15	1.69E-15	1.74E-15	1.84E-15	2.19E-15	2.39E-15	2.52E-15
l= 0	1.98E-17	2.23E-17	3.28E-17	4.18E-17	5.31E-17	6.17E-17	5.58E-17	4.88E-17
l= 1	2.46E-17	3.23E-17	6.76E-17	9.19E-17	1.19E-16	1.43E-16	1.33E-16	1.06E-16
l= 2	7.07E-17	8.02E-17	1.34E-16	1.74E-16	2.25E-16	3.06E-16	3.13E-16	2.79E-16
l= 3	2.31E-16	2.54E-16	2.49E-16	2.56E-16	2.96E-16	4.78E-16	5.80E-16	6.17E-16
l= 4	4.75E-16	5.22E-16	4.74E-16	4.34E-16	3.87E-16	3.82E-16	5.02E-16	7.62E-16
l= 5	7.23E-16	7.51E-16	7.34E-16	7.39E-16	7.63E-16	8.22E-16	8.07E-16	7.07E-16
n= 7	1.40E-16	1.36E-16	2.10E-16	2.56E-16	3.09E-16	3.99E-16	4.36E-16	4.63E-16
l= 0	8.34E-19	1.39E-18	3.64E-18	5.21E-18	7.35E-18	1.04E-17	1.06E-17	1.07E-17
l= 1	1.22E-18	2.12E-18	6.47E-18	8.84E-18	1.10E-17	1.40E-17	1.54E-17	1.59E-17
l= 2	3.37E-18	5.15E-18	1.36E-17	1.91E-17	2.57E-17	3.54E-17	3.74E-17	3.76E-17
l= 3	9.35E-18	1.19E-17	2.19E-17	2.73E-17	3.48E-17	5.29E-17	5.95E-17	6.00E-17
l= 4	2.23E-17	2.32E-17	3.69E-17	4.50E-17	5.31E-17	6.95E-17	8.18E-17	9.63E-17
l= 5	4.30E-17	3.87E-17	5.22E-17	6.13E-17	7.06E-17	8.23E-17	8.84E-17	1.03E-16
l= 6	5.98E-17	5.35E-17	7.51E-17	8.97E-17	1.06E-16	1.34E-16	1.43E-16	1.40E-16
n= 8	5.16E-17	9.03E-17	1.92E-16	2.28E-16	2.60E-16	2.97E-16	3.04E-16	3.05E-16
l= 0	2.13E-18	3.53E-18	7.08E-18	8.07E-18	8.75E-18	8.64E-18	8.20E-18	8.27E-18
l= 1	2.68E-18	4.73E-18	9.95E-18	1.17E-17	1.31E-17	1.45E-17	1.45E-17	1.41E-17
l= 2	2.87E-18	5.29E-18	1.16E-17	1.37E-17	1.55E-17	1.85E-17	2.03E-17	2.09E-17
l= 3	9.68E-18	1.55E-17	2.92E-17	3.25E-17	3.46E-17	3.43E-17	3.28E-17	3.16E-17
l= 4	1.54E-17	2.47E-17	4.65E-17	5.26E-17	5.73E-17	6.03E-17	5.73E-17	4.96E-17
l= 5	1.21E-17	2.11E-17	4.32E-17	5.03E-17	5.60E-17	6.23E-17	6.45E-17	6.55E-17
l= 6	5.19E-18	1.08E-17	2.81E-17	3.57E-17	4.32E-17	5.30E-17	5.59E-17	5.92E-17
l= 7	1.51E-18	4.53E-18	1.67E-17	2.37E-17	3.16E-17	4.52E-17	5.09E-17	5.62E-17
$\sigma_{ct;tot}$	7.10E-15	9.13E-15	1.59E-14	1.86E-14	2.10E-14	2.28E-14	2.20E-14	1.96E-14
σ_{de-ex}								
n= 1	2.82E-30	5.19E-27	8.07E-24	1.24E-22	1.79E-21	1.12E-19	6.88E-19	4.00E-18
l= 0	2.82E-30	5.19E-27	8.07E-24	1.24E-22	1.79E-21	1.12E-19	6.88E-19	4.00E-18
σ_{ion}	2.35E-16	1.05E-15	8.51E-15	1.73E-14	3.39E-14	9.70E-14	1.54E-13	2.39E-13

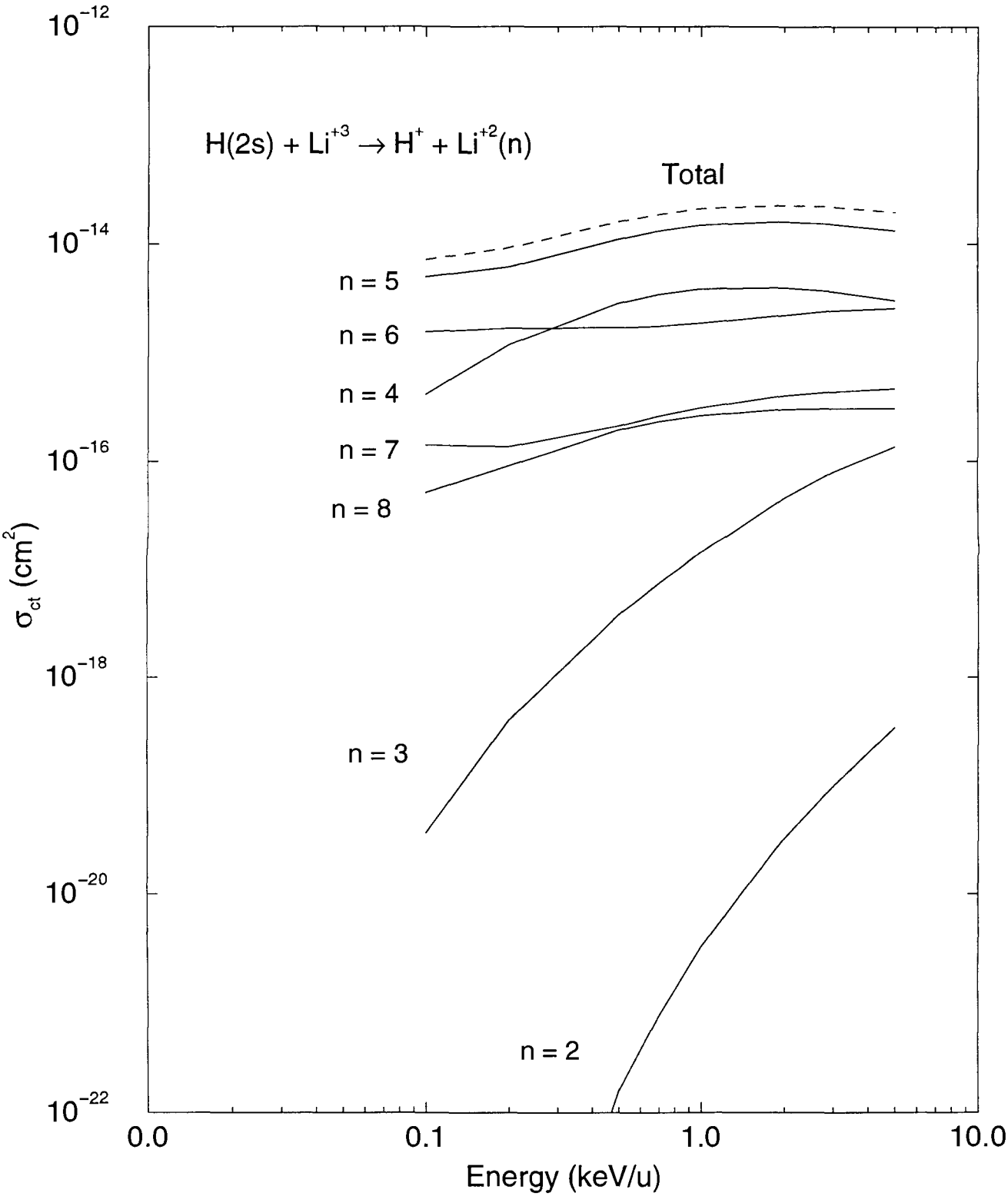
10^{-12}
10^{-14}
10^{-16}
10^{-18}
10^{-20}
10^{-22}
σ_{ct} (cm^2)
H(2s) + Li^{+3} → H$^+$ + Li^{+2}(n)
Total
n = 5
n = 6
n = 4
n = 7
n = 8
n = 3
n = 2
0.0
0.1
1.0
10.0
Energy (keV/u)

Fig. 3a

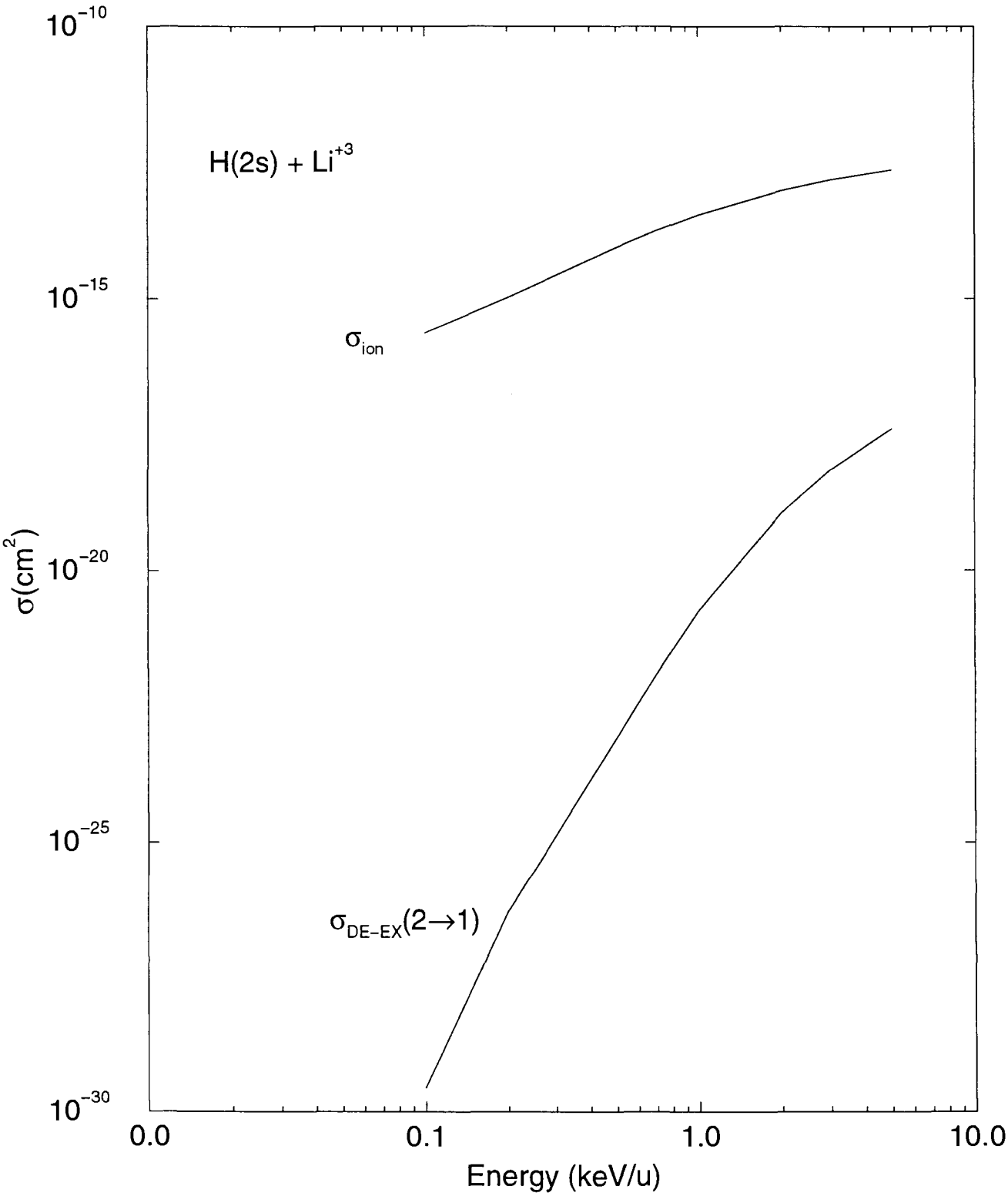
10^{-10}
10^{-15}
10^{-20}
10^{-25}
10^{-30}
$\sigma(cm^2)$
H(2s) + Li^{+3}
σ_{ion}
$\sigma_{DE-EX}(2\rightarrow1)$
0.0
0.1
1.0
10.0
Energy (keV/u)

Fig. 3b

Table 4: Cross sections (in units of 10^{-16} cm^2) for state-specific and total charge transfer, de-excitation and ionization for the $H(2s) + Be^{+4}$ collision system as a function of energy (in units of keV/u).

E(keV/u)	.10	.15	.20	.30	.50	.70	1.00	1.50
σ_{ct}								
n= 2	4.95E-51	1.45E-44	9.70E-41	2.93E-36	1.10E-31	2.62E-29	3.38E-27	3.16E-25
l= 0	2.43E-51	7.04E-45	4.68E-41	1.38E-36	5.01E-32	1.14E-29	1.40E-27	1.22E-25
l= 1	2.52E-51	7.42E-45	5.01E-41	1.55E-36	5.99E-32	1.47E-29	1.98E-27	1.94E-25
n= 3	6.94E-27	5.62E-25	3.17E-24	8.14E-23	2.88E-21	1.23E-20	4.47E-20	1.63E-19
l= 0	2.29E-27	1.82E-25	1.02E-24	2.53E-23	8.39E-22	3.41E-21	1.17E-20	3.89E-20
l= 1	3.47E-27	2.81E-25	1.58E-24	4.06E-23	1.43E-21	6.07E-21	2.19E-20	7.70E-20
l= 2	1.18E-27	9.91E-26	5.61E-25	1.55E-23	6.06E-22	2.77E-21	1.11E-20	4.66E-20
n= 4	2.73E-20	1.91E-19	2.44E-19	1.31E-18	6.93E-18	1.64E-17	4.12E-17	1.07E-16
l= 0	6.57E-21	4.40E-20	5.46E-20	2.66E-19	1.25E-18	2.79E-18	6.56E-18	1.51E-17
l= 1	1.21E-20	8.34E-20	1.04E-19	5.19E-19	2.40E-18	5.15E-18	1.23E-17	3.26E-17
l= 2	7.07E-21	5.16E-20	6.69E-20	3.78E-19	1.94E-18	4.00E-18	8.23E-18	1.88E-17
l= 3	1.52E-21	1.23E-20	1.92E-20	1.51E-19	1.34E-18	4.49E-18	1.41E-17	4.09E-17
n= 5	1.48E-16	4.07E-16	7.32E-16	1.47E-15	2.83E-15	3.90E-15	5.06E-15	6.22E-15
l= 0	1.74E-17	4.69E-17	8.15E-17	1.52E-16	2.42E-16	2.75E-16	2.71E-16	2.28E-16
l= 1	3.63E-17	9.45E-17	1.64E-16	3.21E-16	5.97E-16	7.81E-16	9.15E-16	9.37E-16
l= 2	3.86E-17	9.46E-17	1.54E-16	2.80E-16	5.47E-16	8.31E-16	1.23E-15	1.70E-15
l= 3	3.68E-17	1.03E-16	1.83E-16	3.34E-16	5.09E-16	5.87E-16	6.90E-16	9.72E-16
l= 4	1.88E-17	6.81E-17	1.50E-16	3.83E-16	9.37E-16	1.43E-15	1.96E-15	2.38E-15
n= 6	1.80E-14	1.63E-14	1.49E-14	1.30E-14	1.07E-14	9.40E-15	8.22E-15	7.05E-15
l= 0	1.13E-15	8.41E-16	6.55E-16	4.41E-16	2.58E-16	1.85E-16	1.34E-16	9.54E-17
l= 1	3.00E-15	2.34E-15	1.93E-15	1.42E-15	9.00E-16	6.48E-16	4.59E-16	3.13E-16
l= 2	3.98E-15	3.22E-15	2.80E-15	2.32E-15	1.78E-15	1.44E-15	1.10E-15	7.87E-16
l= 3	4.27E-15	3.56E-15	3.05E-15	2.51E-15	2.20E-15	2.12E-15	2.00E-15	1.76E-15
l= 4	3.80E-15	3.78E-15	3.49E-15	2.81E-15	1.93E-15	1.61E-15	1.55E-15	1.72E-15
l= 5	1.86E-15	2.54E-15	3.00E-15	3.48E-15	3.62E-15	3.41E-15	2.98E-15	2.37E-15
n= 7	1.42E-15	1.67E-15	1.75E-15	1.93E-15	2.12E-15	2.18E-15	2.17E-15	2.02E-15
l= 0	2.06E-17	3.12E-17	2.90E-17	3.70E-17	3.90E-17	3.67E-17	3.40E-17	3.12E-17
l= 1	4.26E-17	5.28E-17	4.92E-17	5.90E-17	5.95E-17	5.64E-17	5.21E-17	4.59E-17
l= 2	7.82E-17	8.59E-17	8.55E-17	9.38E-17	1.01E-16	1.02E-16	9.99E-17	9.35E-17
l= 3	1.63E-16	1.84E-16	1.84E-16	2.03E-16	2.26E-16	2.22E-16	2.04E-16	1.75E-16
l= 4	2.59E-16	3.06E-16	3.21E-16	3.60E-16	3.98E-16	3.94E-16	3.64E-16	3.03E-16
l= 5	3.59E-16	4.46E-16	4.84E-16	5.38E-16	5.99E-16	6.25E-16	6.19E-16	5.55E-16
l= 6	4.97E-16	5.65E-16	5.95E-16	6.37E-16	6.98E-16	7.47E-16	7.98E-16	8.21E-16
n= 8	4.34E-15	4.72E-15	4.82E-15	4.83E-15	4.42E-15	3.90E-15	3.26E-15	2.54E-15
l= 0	5.86E-17	1.04E-16	1.33E-16	1.69E-16	1.59E-16	1.25E-16	8.42E-17	4.86E-17
l= 1	1.32E-16	2.06E-16	2.69E-16	3.40E-16	3.32E-16	2.70E-16	1.90E-16	1.15E-16
l= 2	2.55E-16	3.30E-16	3.62E-16	3.95E-16	4.15E-16	3.88E-16	3.22E-16	2.30E-16
l= 3	3.66E-16	4.41E-16	4.50E-16	4.33E-16	3.97E-16	3.87E-16	3.70E-16	3.13E-16
l= 4	4.25E-16	4.95E-16	5.46E-16	5.82E-16	5.01E-16	4.12E-16	3.44E-16	3.05E-16
l= 5	6.74E-16	6.79E-16	6.45E-16	6.29E-16	6.42E-16	5.97E-16	4.90E-16	3.52E-16
l= 6	1.07E-15	1.07E-15	1.01E-15	8.70E-16	6.72E-16	5.88E-16	5.46E-16	5.08E-16
l= 7	1.36E-15	1.39E-15	1.41E-15	1.41E-15	1.30E-15	1.13E-15	9.12E-16	6.62E-16
$\sigma_{ct;tot}$	2.39E-14	2.31E-14	2.22E-14	2.12E-14	2.01E-14	1.94E-14	1.88E-14	1.79E-14
$\sigma_{ex,de-ex}$								
n= 1	3.51E-28	1.87E-26	8.04E-26	1.49E-24	3.69E-23	1.44E-22	7.87E-22	8.53E-21
l= 0	3.51E-28	1.87E-26	8.04E-26	1.49E-24	3.69E-23	1.44E-22	7.87E-22	8.53E-21
σ_{ion}	4.96E-16	9.99E-16	1.48E-15	2.45E-15	3.80E-15	4.59E-15	5.19E-15	5.51E-15

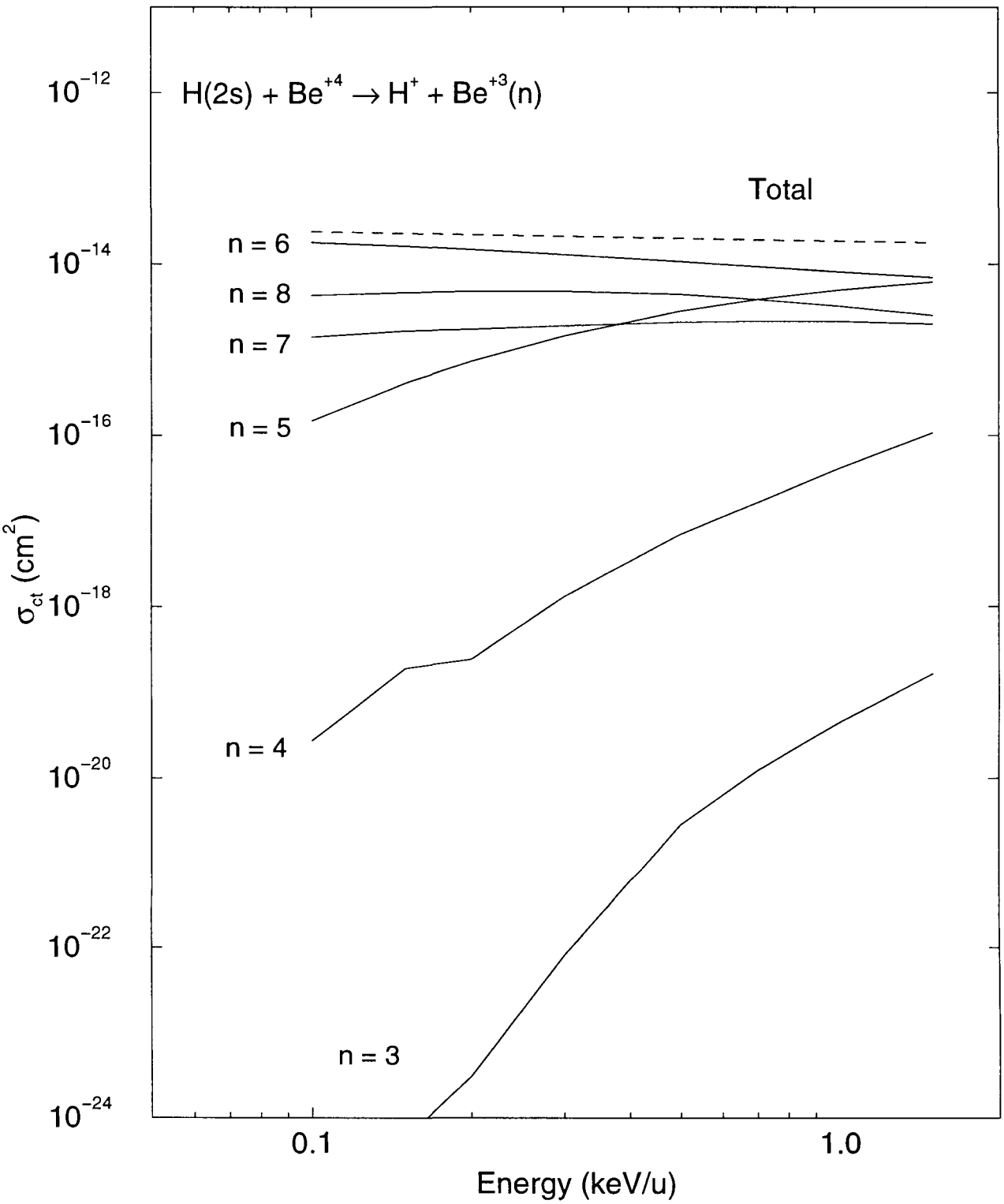
H(2s) + Be+4 → H+ + Be+3(n)
Total
n = 6
n = 8
n = 7
n = 5
n = 4
n = 3
10−12
10−14
10−16
10−18
10−20
10−22
10−24
σct (cm2)
0.1
1.0
Energy (keV/u)

Fig. 4a

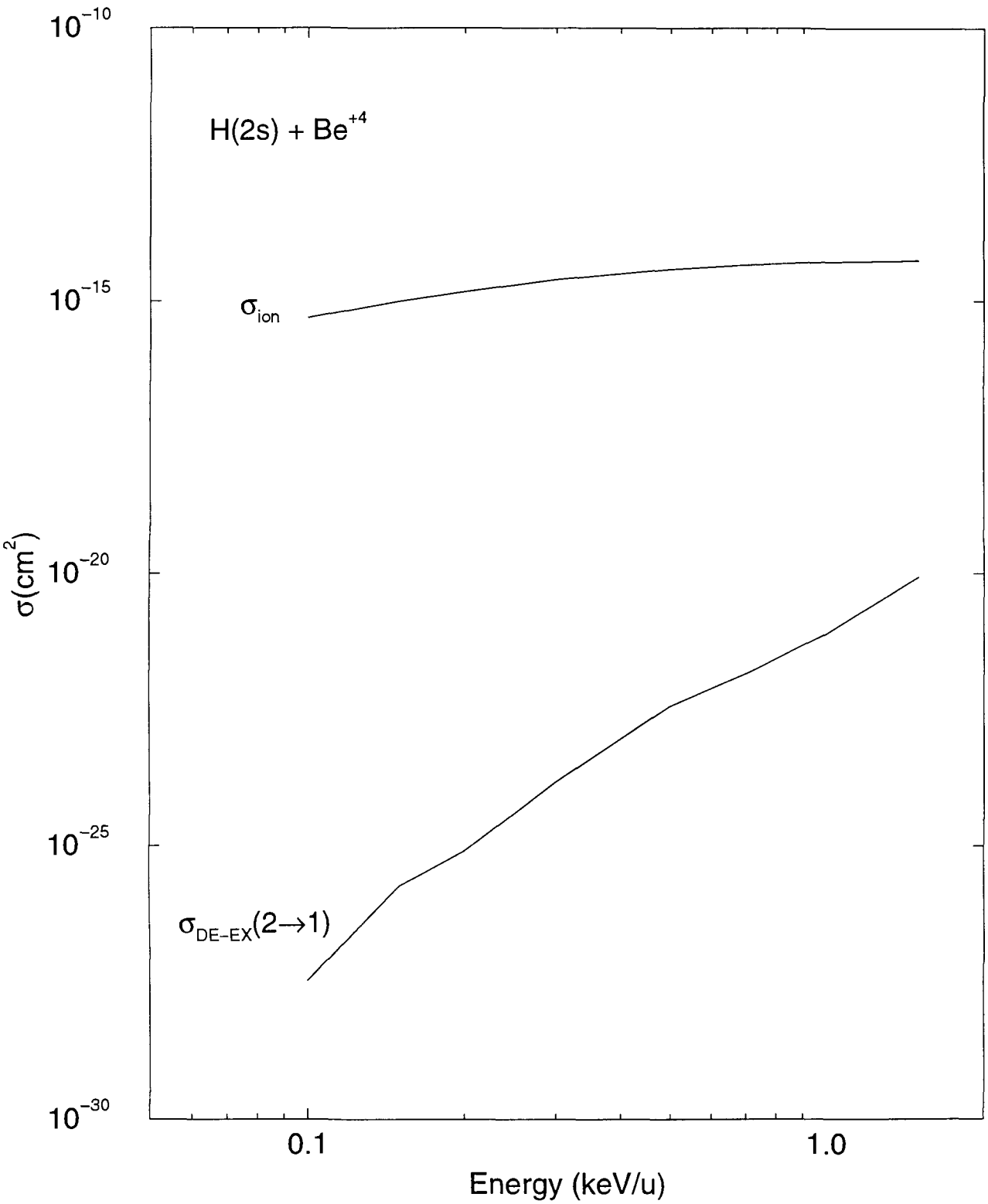
10^{-10}
10^{-15}
10^{-20}
10^{-25}
10^{-30}
$\sigma(cm^2)$
H(2s) + Be^{+4}
σ_{ion}
$\sigma_{DE-EX}(2\rightarrow1)$
0.1
1.0
Energy (keV/u)

Fig. 4b

Table 5: Cross sections (in units of 10^{-16} cm^2) for state-specific and total charge transfer, excitation, de-excitation and ionization for the $H(2s) + B^{+5}$ as a function of energy (in units of keV/u).

E(keV/u)	.05	.10	.20	.50	1.00	2.00	5.00	10.00
σ_{ct}								
n= 2	1.05E-61	4.94E-49	4.52E-40	3.58E-32	3.86E-28	4.23E-25	2.05E-22	3.70E-21
l= 0	5.27E-62	2.47E-49	2.26E-40	1.52E-32	1.07E-28	1.62E-25	8.80E-23	1.51E-21
l= 1	5.27E-62	2.47E-49	2.26E-40	2.05E-32	2.79E-28	2.61E-25	1.16E-22	2.18E-21
n= 3	1.29E-19	5.70E-19	1.60E-18	4.46E-18	8.91E-18	2.29E-17	6.11E-17	8.04E-17
l= 0	4.28E-20	1.88E-19	5.20E-19	1.38E-18	2.42E-18	4.40E-18	5.94E-18	4.61E-18
l= 1	6.44E-20	2.85E-19	8.00E-19	2.23E-18	4.36E-18	1.02E-17	2.09E-17	2.08E-17
l= 2	2.16E-20	9.68E-20	2.80E-19	8.58E-19	2.12E-18	8.24E-18	3.42E-17	5.50E-17
n= 4	2.43E-21	8.15E-21	5.60E-20	1.84E-18	1.23E-17	4.80E-17	1.72E-16	3.20E-16
l= 0	6.06E-22	1.99E-21	1.12E-20	2.92E-19	1.61E-18	5.66E-18	2.23E-17	3.74E-17
l= 1	1.09E-21	3.45E-21	1.13E-20	2.88E-19	2.50E-18	1.24E-17	5.48E-17	1.08E-16
l= 2	6.09E-22	2.08E-21	1.55E-20	5.13E-19	3.28E-18	1.13E-17	2.84E-17	5.96E-17
l= 3	1.23E-22	6.30E-22	1.80E-20	7.48E-19	4.87E-18	1.87E-17	6.69E-17	1.16E-16
n= 5	1.36E-16	2.00E-16	2.51E-16	4.09E-16	7.53E-16	1.19E-15	1.51E-15	1.40E-15
l= 0	3.12E-19	2.79E-18	6.24E-18	2.10E-17	4.37E-17	7.51E-17	8.68E-17	5.64E-17
l= 1	2.72E-17	3.62E-17	4.07E-17	7.21E-17	1.49E-16	2.34E-16	2.51E-16	1.74E-16
l= 2	5.78E-17	7.11E-17	7.12E-17	1.02E-16	1.83E-16	2.71E-16	3.61E-16	3.59E-16
l= 3	4.09E-17	5.15E-17	7.26E-17	1.10E-16	1.82E-16	2.39E-16	2.37E-16	3.01E-16
l= 4	9.91E-18	3.81E-17	6.04E-17	1.04E-16	1.95E-16	3.73E-16	5.75E-16	5.12E-16
n= 6	2.65E-16	4.31E-16	5.20E-16	5.92E-16	6.14E-16	6.14E-16	5.53E-16	4.69E-16
l= 0	4.81E-18	6.00E-18	6.67E-18	8.98E-18	1.12E-17	1.41E-17	1.86E-17	1.58E-17
l= 1	5.43E-18	6.53E-18	7.45E-18	1.13E-17	1.78E-17	2.65E-17	3.36E-17	3.16E-17
l= 2	1.50E-17	1.95E-17	2.29E-17	3.05E-17	4.05E-17	5.17E-17	5.49E-17	5.48E-17
l= 3	6.68E-17	7.73E-17	8.25E-17	9.94E-17	1.03E-16	1.01E-16	9.39E-17	8.32E-17
l= 4	1.12E-16	1.41E-16	1.68E-16	1.88E-16	1.86E-16	1.74E-16	1.34E-16	1.07E-16
l= 5	6.18E-17	1.81E-16	2.33E-16	2.54E-16	2.55E-16	2.46E-16	2.18E-16	1.76E-16
n= 7	1.46E-21	8.84E-20	1.55E-18	2.07E-17	8.06E-17	2.21E-16	5.66E-16	8.29E-16
l= 0	2.20E-23	1.24E-21	2.41E-20	4.19E-19	1.91E-18	5.95E-18	1.45E-17	1.38E-17
l= 1	7.30E-23	3.43E-21	5.44E-20	7.17E-19	3.82E-18	1.35E-17	3.26E-17	3.59E-17
l= 2	1.34E-22	6.55E-21	1.12E-19	1.49E-18	6.45E-18	1.99E-17	5.71E-17	7.78E-17
l= 3	1.61E-22	8.62E-21	1.50E-19	2.36E-18	9.96E-18	2.90E-17	7.69E-17	1.20E-16
l= 4	2.67E-22	1.31E-20	2.56E-19	3.45E-18	1.42E-17	4.15E-17	9.64E-17	1.35E-16
l= 5	3.30E-22	2.43E-20	4.02E-19	5.25E-18	1.94E-17	5.09E-17	1.31E-16	1.67E-16
l= 6	4.69E-22	3.11E-20	5.53E-19	7.01E-18	2.49E-17	5.98E-17	1.57E-16	2.79E-16
n= 8	9.95E-25	5.26E-22	4.08E-20	1.88E-18	1.29E-17	5.14E-17	2.17E-16	5.28E-16
l= 0	2.47E-26	1.20E-23	9.04E-22	3.92E-20	2.66E-19	1.43E-18	7.45E-18	1.01E-17
l= 1	3.60E-26	1.78E-23	1.54E-21	7.92E-20	6.62E-19	3.32E-18	1.66E-17	2.91E-17
l= 2	8.07E-26	3.67E-23	3.02E-21	1.40E-19	9.55E-19	4.26E-18	2.65E-17	5.63E-17
l= 3	8.42E-26	4.44E-23	3.46E-21	1.67E-19	1.21E-18	5.02E-18	2.63E-17	8.02E-17
l= 4	1.43E-25	5.99E-23	4.91E-21	2.30E-19	1.64E-18	6.17E-18	2.27E-17	8.16E-17
l= 5	1.23E-25	7.69E-23	5.92E-21	2.83E-19	1.99E-18	8.12E-18	2.52E-17	5.06E-17
l= 6	1.65E-25	1.15E-22	8.68E-21	3.80E-19	2.55E-18	1.01E-17	4.33E-17	7.39E-17
l= 7	3.38E-25	1.63E-22	1.23E-20	5.57E-19	3.67E-18	1.30E-17	4.90E-17	1.46E-16
$\sigma_{ct;tot}$	4.02E-16	6.31E-16	7.75E-16	1.04E-15	1.54E-15	2.39E-15	3.66E-15	4.33E-15
$\sigma_{ex,de-ex}$								
n= 1	0.00E+00	3.96E-34	8.23E-30	5.74E-26	4.28E-24	1.92E-22	4.57E-21	2.21E-20
l= 0	0.00E+00	3.96E-34	8.23E-30	5.74E-26	4.28E-24	1.92E-22	4.57E-21	2.21E-20
n= 3	5.77E-19	3.54E-18	1.69E-17	1.03E-16	2.95E-16	5.88E-16	1.01E-15	1.25E-15
l= 0	3.42E-21	1.52E-19	2.26E-18	2.40E-17	7.24E-17	1.42E-16	2.12E-16	2.31E-16
l= 1	2.83E-19	1.52E-18	4.76E-18	1.29E-17	3.18E-17	7.07E-17	1.92E-16	3.34E-16
l= 2	2.91E-19	1.87E-18	9.89E-18	6.65E-17	1.91E-16	3.75E-16	6.03E-16	6.87E-16
σ_{ion}	2.97E-25	4.13E-22	6.78E-20	5.88E-18	4.92E-17	1.83E-16	3.84E-16	3.70E-16

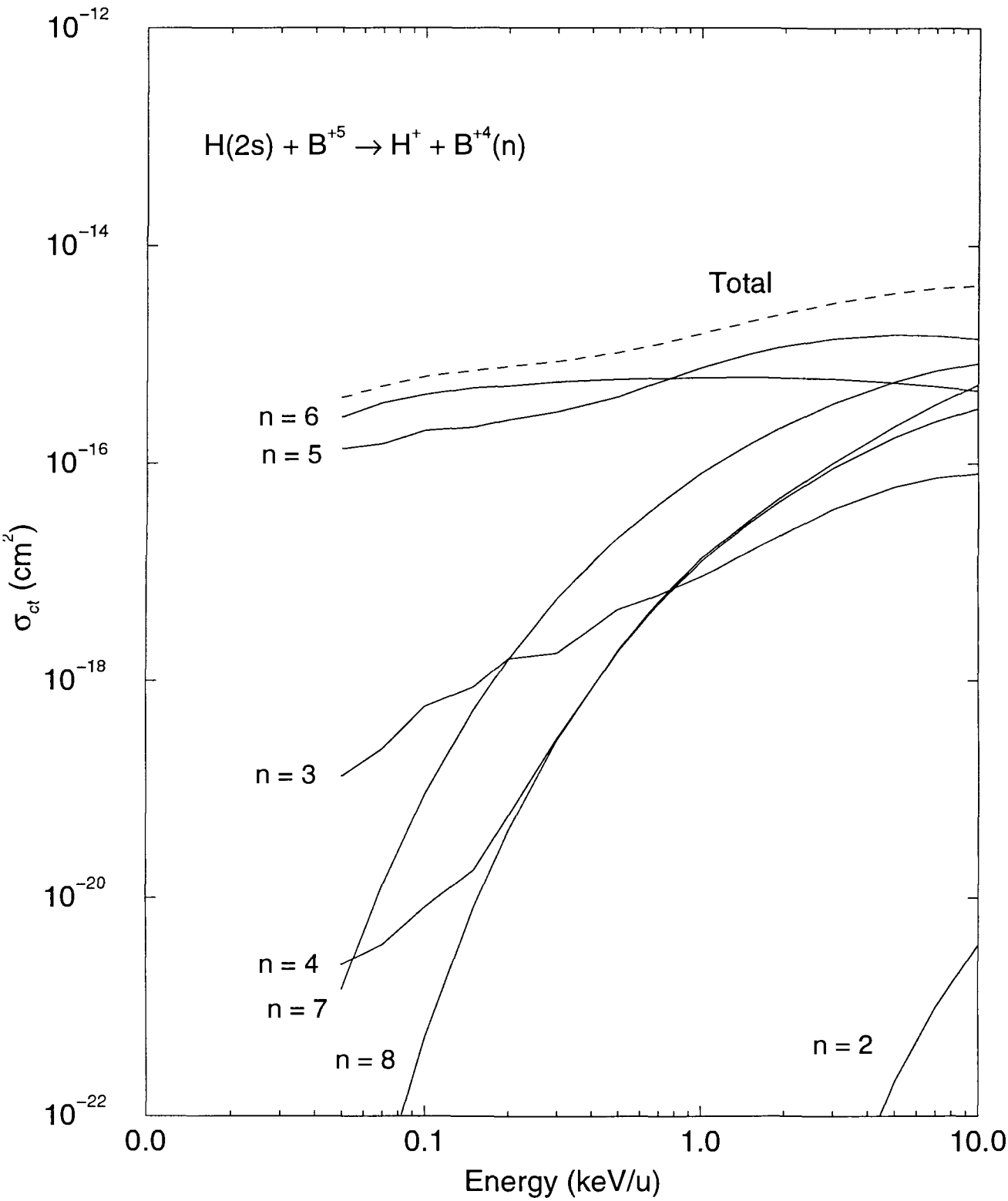
10^{-12}
10^{-14}
10^{-16}
10^{-18}
10^{-20}
10^{-22}
σ_{ct} (cm^2)
H(2s) + B^{+5} → H$^+$ + B^{+4}(n)
Total
n = 6
n = 5
n = 3
n = 4
n = 7
n = 8
n = 2
0.0
0.1
1.0
10.0
Energy (keV/u)

Fig. 5a

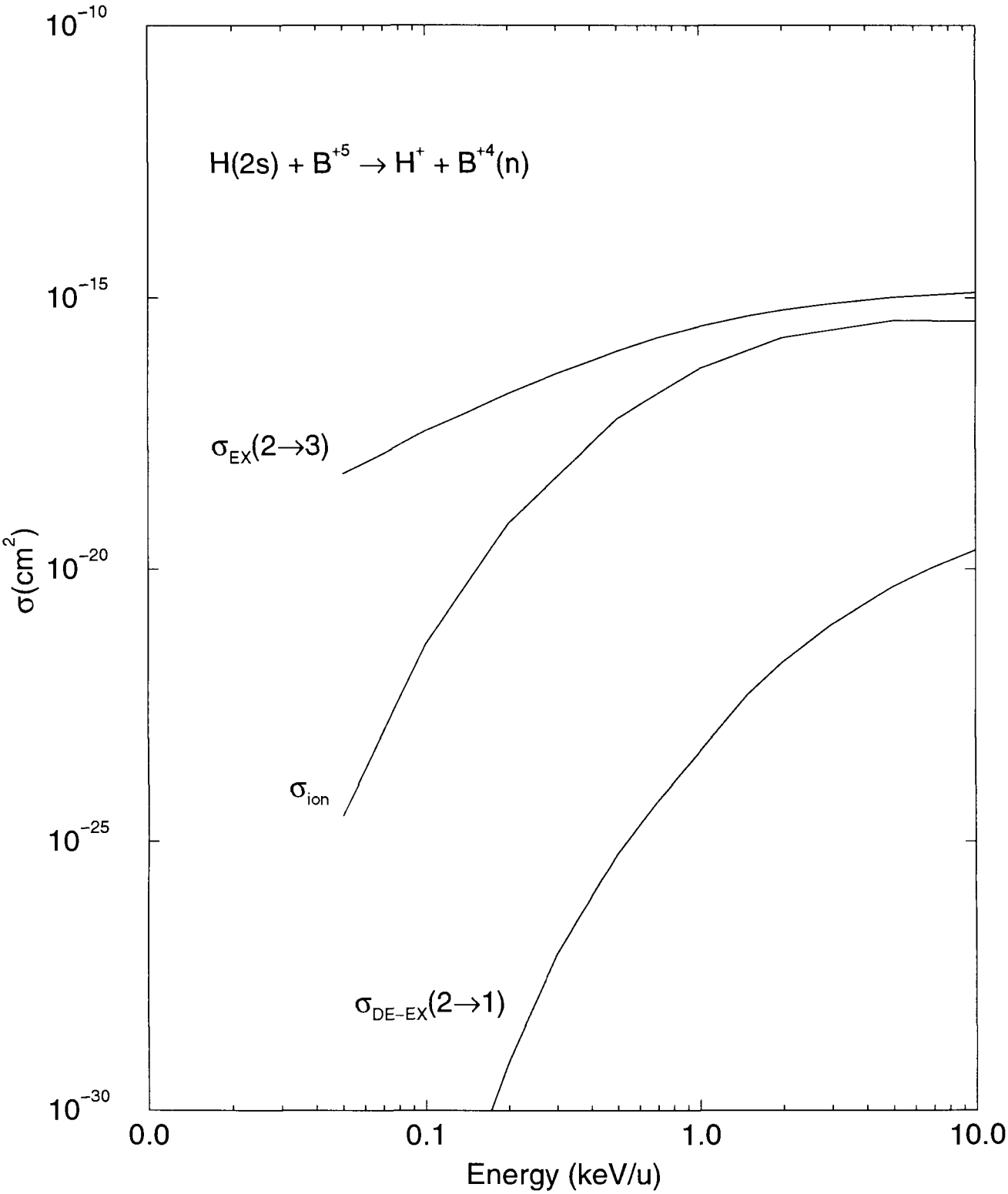
10^{-10}
10^{-15}
10^{-20}
10^{-25}
10^{-30}
$\sigma(cm^2)$
$H(2s) + B^{+5} \rightarrow H^+ + B^{+4}(n)$
$\sigma_{EX}(2\rightarrow3)$
σ_{ion}
$\sigma_{DE-EX}(2\rightarrow1)$
0.0
0.1
1.0
10.0
Energy (keV/u)

Fig. 5b

Table 6: Cross sections (in units of 10^{-16} cm^2) for state-specific and total charge transfer+excitation, and ionization for the $He^+(2s) + He^{+2}$ collision system as a function of energy (in units of keV/u).

E(keV/u)	.10	.20	.50	1.00	2.00	5.00	10.00	20.00
σ_{ct+ex}								
n= 1	7.02E-51	3.38E-22	2.69E-21	6.15E-21	1.24E-20	3.23E-20	1.36E-19	7.12E-19
l= 0	7.02E-51	3.38E-22	2.69E-21	6.15E-21	1.24E-20	3.23E-20	1.36E-19	7.12E-19
n= 3	2.01E-16	2.59E-16	2.71E-16	2.67E-16	2.77E-16	3.79E-16	5.64E-16	7.93E-16
l= 0	3.15E-18	4.90E-18	6.20E-18	8.73E-18	1.63E-17	4.39E-17	8.20E-17	1.37E-16
l= 1	5.11E-17	5.58E-17	5.64E-17	5.41E-17	5.77E-17	9.64E-17	1.58E-16	2.40E-16
l= 2	1.47E-16	1.98E-16	2.08E-16	2.04E-16	2.03E-16	2.39E-16	3.24E-16	4.16E-16
n= 4	8.40E-17	1.00E-16	1.08E-16	1.10E-16	1.13E-16	1.34E-16	1.89E-16	2.77E-16
l= 0	1.56E-21	1.42E-20	1.58E-19	6.41E-19	1.82E-18	6.22E-18	1.33E-17	2.40E-17
l= 1	7.13E-19	9.16E-19	1.66E-18	3.28E-18	6.26E-18	1.51E-17	3.12E-17	5.53E-17
l= 2	2.80E-20	1.85E-19	1.51E-18	4.83E-18	1.15E-17	2.83E-17	5.16E-17	7.35E-17
l= 3	8.32E-17	9.90E-17	1.04E-16	1.01E-16	9.37E-17	8.46E-17	9.30E-17	1.24E-16
n= 5	7.25E-20	7.59E-19	5.63E-18	1.47E-17	2.82E-17	5.60E-17	1.15E-16	2.58E-16
l= 0	3.42E-23	6.28E-22	1.28E-20	8.26E-20	3.51E-19	2.01E-18	6.52E-18	1.72E-17
l= 1	1.02E-21	1.25E-20	1.41E-19	5.44E-19	1.53E-18	5.44E-18	1.63E-17	4.10E-17
l= 2	2.97E-22	6.13E-21	1.10E-19	5.52E-19	2.04E-18	8.66E-18	2.50E-17	5.49E-17
l= 3	3.52E-20	3.66E-19	2.66E-18	6.69E-18	1.19E-17	1.97E-17	3.53E-17	7.41E-17
l= 4	3.59E-20	3.73E-19	2.71E-18	6.86E-18	1.24E-17	2.02E-17	3.14E-17	7.05E-17
n= 6	6.62E-22	2.97E-20	7.65E-19	3.60E-18	1.01E-17	2.39E-17	3.62E-17	4.71E-17
l= 0	6.56E-24	1.19E-22	2.84E-21	2.47E-20	1.20E-19	5.27E-19	1.13E-18	1.94E-18
l= 1	2.41E-23	9.05E-22	2.65E-20	1.53E-19	5.28E-19	1.45E-18	2.28E-18	2.99E-18
l= 2	1.69E-23	7.73E-22	2.22E-20	1.38E-19	5.75E-19	2.17E-18	4.10E-18	6.03E-18
l= 3	1.84E-22	8.56E-21	2.22E-19	1.02E-18	2.71E-18	5.71E-18	8.10E-18	1.02E-17
l= 4	2.57E-22	1.11E-20	2.70E-19	1.22E-18	3.28E-18	7.39E-18	1.07E-17	1.34E-17
l= 5	1.73E-22	8.21E-21	2.20E-19	1.04E-18	2.88E-18	6.63E-18	9.82E-18	1.25E-17
n= 7	2.71E-23	2.36E-21	1.35E-19	9.88E-19	3.82E-18	1.23E-17	2.19E-17	3.16E-17
l= 0	2.01E-24	3.78E-23	9.15E-22	9.16E-21	4.58E-20	1.93E-19	4.13E-19	7.15E-19
l= 1	4.80E-24	1.75E-22	7.05E-21	4.96E-20	1.80E-19	4.95E-19	7.60E-19	9.70E-19
l= 2	4.30E-24	1.84E-22	5.92E-21	4.09E-20	1.80E-19	7.41E-19	1.53E-18	2.48E-18
l= 3	5.42E-24	5.47E-22	3.26E-20	2.41E-19	9.06E-19	2.53E-18	3.84E-18	4.66E-18
l= 4	3.65E-24	4.35E-22	2.42E-20	1.66E-19	6.24E-19	2.07E-18	3.88E-18	5.78E-18
l= 5	3.34E-24	4.55E-22	2.75E-20	1.95E-19	7.47E-19	2.56E-18	4.92E-18	7.48E-18
l= 6	3.62E-24	5.23E-22	3.70E-20	2.86E-19	1.13E-18	3.67E-18	6.53E-18	9.47E-18
n= 8	7.74E-24	5.80E-22	3.47E-20	2.72E-19	1.11E-18	3.71E-18	6.66E-18	9.69E-18
l= 0	7.88E-25	1.53E-23	2.82E-22	2.99E-21	1.48E-20	5.95E-20	1.21E-19	2.06E-19
l= 1	1.87E-24	5.95E-23	1.83E-21	1.28E-20	4.76E-20	1.35E-19	2.07E-19	2.57E-19
l= 2	1.87E-24	7.81E-23	2.39E-21	1.47E-20	5.40E-20	1.82E-19	3.57E-19	5.77E-19
l= 3	1.37E-24	9.53E-23	5.31E-21	4.32E-20	1.82E-19	5.77E-19	9.21E-19	1.12E-18
l= 4	8.43E-25	1.07E-22	7.20E-21	5.68E-20	2.32E-19	7.62E-19	1.34E-18	1.82E-18
l= 5	4.55E-25	9.43E-23	6.36E-21	4.56E-20	1.74E-19	5.71E-19	1.10E-18	1.81E-18
l= 6	3.72E-25	8.94E-23	7.46E-21	6.16E-20	2.57E-19	8.39E-19	1.45E-18	2.00E-18
l= 7	1.76E-25	4.06E-23	3.84E-21	3.44E-20	1.54E-19	5.81E-19	1.17E-18	1.90E-18
n= 9	2.07E-25	1.29E-22	8.63E-21	6.66E-20	2.86E-19	1.01E-18	1.89E-18	2.83E-18
l= 0	7.82E-30	1.06E-26	4.84E-24	1.01E-22	8.76E-22	6.13E-21	1.66E-20	3.43E-20
l= 1	2.66E-27	5.94E-24	2.79E-22	1.56E-21	5.76E-21	1.95E-20	3.60E-20	5.49E-20
l= 2	4.31E-27	1.79E-23	7.63E-22	3.61E-21	1.13E-20	3.42E-20	6.41E-20	1.02E-19
l= 3	1.40E-26	2.70E-23	1.29E-21	7.27E-21	2.65E-20	8.77E-20	1.63E-19	2.52E-19
l= 4	4.59E-26	3.05E-23	1.98E-21	1.51E-20	6.35E-20	2.12E-19	3.57E-19	4.63E-19
l= 5	6.82E-26	2.65E-23	2.22E-21	1.94E-20	8.66E-20	3.01E-19	5.27E-19	7.06E-19
l= 6	5.05E-26	1.54E-23	1.48E-21	1.38E-20	6.34E-20	2.38E-19	4.65E-19	7.25E-19
l= 7	1.88E-26	5.14E-24	5.29E-22	5.06E-21	2.39E-20	9.87E-20	2.20E-19	4.05E-19
l= 8	2.81E-27	7.28E-25	7.78E-23	7.58E-22	3.69E-21	1.69E-20	4.30E-20	9.29E-20
$\sigma_{ct+ex;tot}$	2.85E-16	3.60E-16	3.86E-16	3.93E-16	4.34E-16	6.10E-16	9.35E-16	1.42E-15
σ_{ion}	2.87E-23	2.24E-21	1.58E-19	1.55E-18	8.04E-18	3.79E-17	9.48E-17	2.03E-16

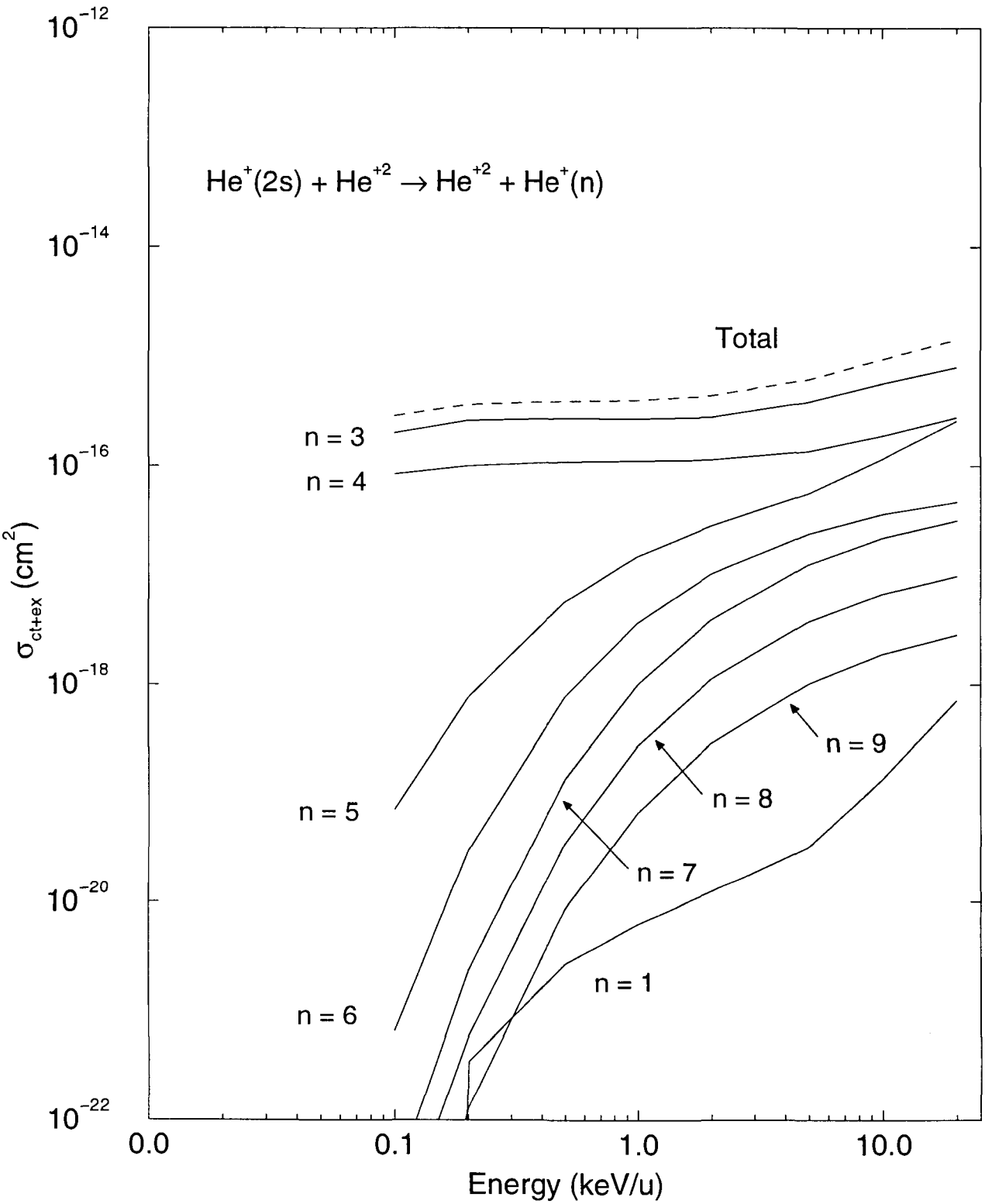
$He^+(2s) + He^{+2} \rightarrow He^{+2} + He^+(n)$
Total
n = 3
n = 4
n = 5
n = 6
n = 7
n = 8
n = 9
n = 1
σ_{ct+ex} (cm^2)
10^{-12}
10^{-14}
10^{-16}
10^{-18}
10^{-20}
10^{-22}
0.0
0.1
1.0
10.0
Energy (keV/u)

Fig. 6a

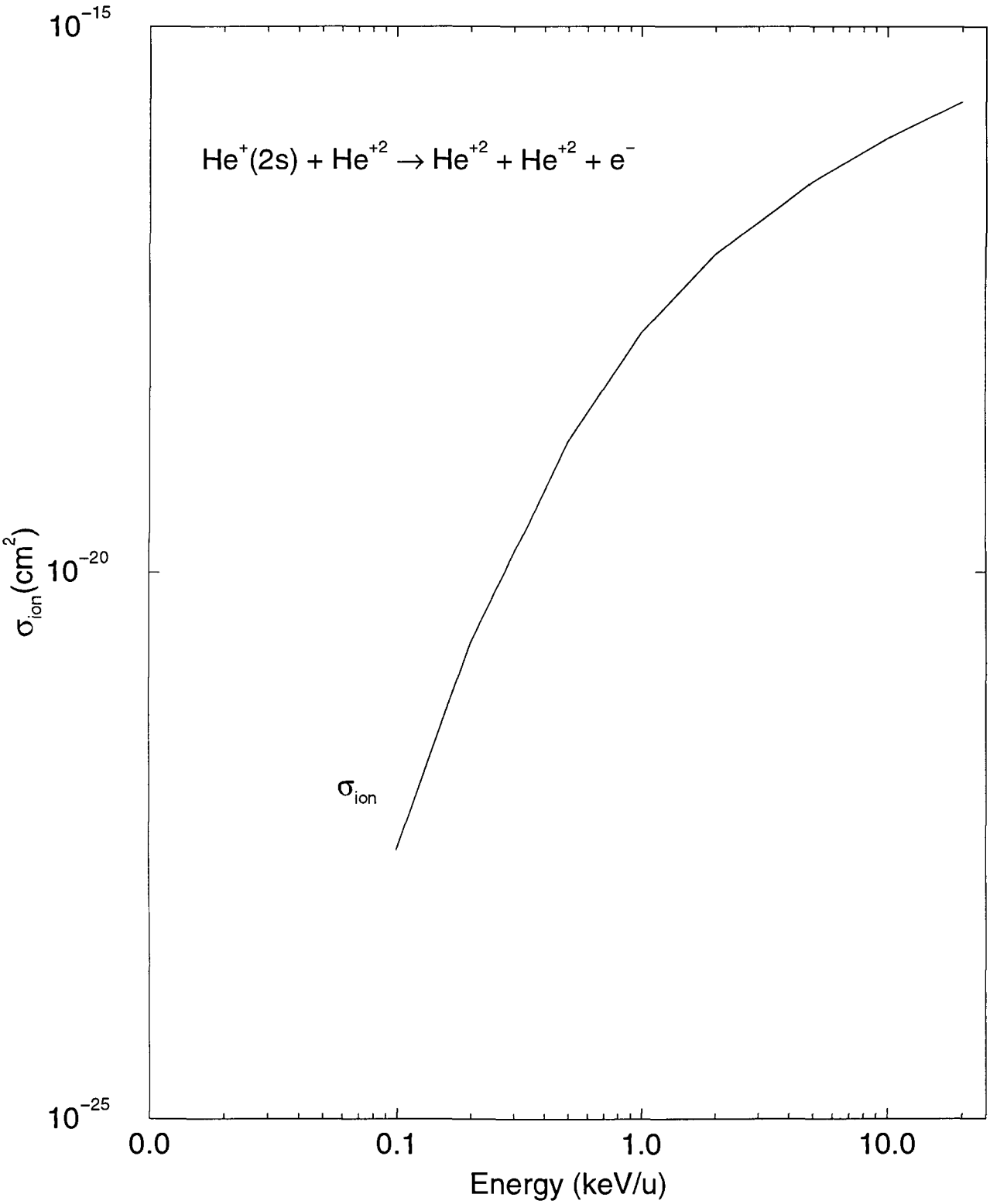
10^{-15}
$He^{+}(2s) + He^{+2} \rightarrow He^{+2} + He^{+2} + e^{-}$
$\sigma_{ion}(cm^2)$
10^{-20}
σ_{ion}
10^{-25}
0.0
0.1
1.0
10.0
Energy (keV/u)

Fig. 6b

Table 7: Cross sections (in units of 10^{-16} cm^2) for state-specific and total charge transfer, excitation, de-excitation and ionization for the $He^+(2s) + Li^{+3}$ collision system as a function of energy (in units of keV/u).

E(keV/u)	.05	.10	.20	.50	1.00	2.00	5.00	10.00
σ_{ct}								
n= 2	3.36E-27	1.63E-20	6.05E-20	2.29E-19	1.16E-18	5.92E-18	2.78E-17	5.35E-17
l= 0	1.68E-27	8.12E-21	3.02E-20	1.13E-19	5.38E-19	2.43E-18	9.24E-18	1.66E-17
l= 1	1.68E-27	8.13E-21	3.03E-20	1.16E-19	6.20E-19	3.50E-18	1.85E-17	3.69E-17
n= 3	6.84E-17	9.28E-17	1.91E-16	6.92E-16	1.33E-15	1.96E-15	2.31E-15	2.14E-15
l= 0	5.10E-19	6.43E-18	3.78E-17	1.56E-16	2.67E-16	3.39E-16	4.05E-16	4.07E-16
l= 1	3.41E-17	4.53E-17	8.73E-17	2.98E-16	5.42E-16	7.24E-16	7.57E-16	7.61E-16
l= 2	3.38E-17	4.11E-17	6.54E-17	2.38E-16	5.26E-16	8.94E-16	1.14E-15	9.70E-16
n= 4	2.09E-17	6.73E-17	9.31E-17	1.00E-16	1.06E-16	1.20E-16	1.52E-16	1.66E-16
l= 0	9.38E-19	1.48E-18	1.50E-18	1.66E-18	2.51E-18	4.71E-18	8.38E-18	1.07E-17
l= 1	1.97E-19	6.65E-19	1.14E-18	2.30E-18	4.40E-18	9.02E-18	2.03E-17	2.75E-17
l= 2	9.27E-18	1.47E-17	1.51E-17	1.66E-17	2.02E-17	2.76E-17	3.93E-17	4.24E-17
l= 3	1.05E-17	5.05E-17	7.54E-17	7.95E-17	7.86E-17	7.83E-17	8.36E-17	8.56E-17
n= 5	1.83E-20	4.13E-19	3.04E-18	1.57E-17	3.45E-17	5.71E-17	8.74E-17	1.10E-16
l= 0	2.56E-24	1.61E-22	2.80E-21	4.88E-20	2.32E-19	7.88E-19	2.50E-18	4.54E-18
l= 1	1.83E-22	2.66E-21	2.08E-20	1.45E-19	5.35E-19	1.67E-18	6.00E-18	1.10E-17
l= 2	1.08E-22	4.03E-21	3.91E-20	4.10E-19	1.54E-18	4.18E-18	1.08E-17	1.72E-17
l= 3	6.85E-21	9.79E-20	7.21E-19	3.36E-18	7.04E-18	1.15E-17	1.93E-17	2.58E-17
l= 4	1.12E-20	3.08E-19	2.25E-18	1.17E-17	2.52E-17	3.90E-17	4.88E-17	5.15E-17
n= 6	1.58E-24	4.41E-22	2.73E-20	9.35E-19	5.25E-18	1.62E-17	4.15E-17	7.88E-17
l= 0	2.20E-27	8.42E-25	7.96E-23	5.80E-21	5.32E-20	2.54E-19	1.21E-18	3.72E-18
l= 1	2.36E-26	5.92E-24	3.67E-22	1.60E-20	1.22E-19	5.31E-19	2.82E-18	9.67E-18
l= 2	1.65E-26	6.29E-24	5.45E-22	3.40E-20	2.72E-19	1.16E-18	4.60E-18	1.25E-17
l= 3	4.07E-25	9.98E-23	5.84E-21	1.78E-19	9.38E-19	2.80E-18	7.16E-18	1.17E-17
l= 4	7.37E-25	1.96E-22	1.14E-20	3.63E-19	1.94E-18	5.64E-18	1.27E-17	1.92E-17
l= 5	3.91E-25	1.33E-22	9.05E-21	3.38E-19	1.93E-18	5.77E-18	1.30E-17	2.19E-17
n= 7	2.99E-27	3.53E-24	8.51E-22	1.10E-19	1.17E-18	5.49E-18	1.74E-17	2.58E-17
l= 0	2.34E-28	1.12E-25	1.20E-23	1.28E-21	1.67E-20	9.78E-20	4.19E-19	7.58E-19
l= 1	2.27E-28	1.21E-25	1.73E-23	2.38E-21	3.10E-20	1.77E-19	6.68E-19	1.05E-18
l= 2	1.34E-28	1.43E-25	3.56E-23	5.81E-21	6.97E-20	3.74E-19	1.36E-18	2.15E-18
l= 3	6.42E-28	5.93E-25	1.31E-22	1.51E-20	1.51E-19	6.78E-19	2.18E-18	3.47E-18
l= 4	8.04E-28	7.07E-25	1.57E-22	2.17E-20	2.39E-19	1.15E-18	3.67E-18	5.29E-18
l= 5	6.17E-28	9.77E-25	2.39E-22	3.04E-20	3.22E-19	1.52E-18	4.79E-18	6.86E-18
l= 6	3.32E-28	8.72E-25	2.59E-22	3.37E-20	3.41E-19	1.49E-18	4.34E-18	6.18E-18
n= 8	5.20E-28	3.84E-25	1.12E-22	2.93E-20	4.70E-19	3.08E-18	1.42E-17	2.74E-17
l= 0	4.14E-29	2.28E-26	2.64E-24	4.12E-22	6.90E-21	4.90E-20	2.45E-19	5.27E-19
l= 1	4.82E-29	2.62E-26	3.24E-24	6.20E-22	1.04E-20	7.59E-20	4.55E-19	1.07E-18
l= 2	1.92E-29	1.76E-26	5.95E-24	1.62E-21	2.54E-20	1.73E-19	8.47E-19	1.76E-18
l= 3	7.99E-29	5.28E-26	1.36E-23	3.24E-21	4.83E-20	2.99E-19	1.32E-18	2.58E-18
l= 4	1.50E-28	9.28E-26	1.93E-23	4.49E-21	6.94E-20	4.37E-19	1.85E-18	3.24E-18
l= 5	1.20E-28	8.20E-26	2.02E-23	5.20E-21	8.57E-20	5.74E-19	2.68E-18	5.08E-18
l= 6	4.97E-29	5.66E-26	2.61E-23	7.38E-21	1.18E-19	7.59E-19	3.45E-18	6.75E-18
l= 7	1.20E-29	3.35E-26	2.07E-23	6.31E-21	1.06E-19	7.15E-19	3.34E-18	6.41E-18
$\sigma_{ct:tot}$	8.93E-17	1.61E-16	2.87E-16	8.09E-16	1.48E-15	2.17E-15	2.67E-15	2.66E-15
$\sigma_{ex,de-ex}$								
n= 1	4.44E-64	1.40E-43	4.15E-31	1.45E-26	1.28E-24	3.31E-23	4.31E-21	7.23E-20
l= 0	4.44E-64	1.40E-43	4.15E-31	1.45E-26	1.28E-24	3.31E-23	4.31E-21	7.23E-20
n= 3	7.18E-18	2.03E-17	3.39E-17	5.49E-17	7.06E-17	9.96E-17	2.00E-16	3.03E-16
l= 0	2.19E-19	6.20E-19	1.03E-18	1.74E-18	3.19E-18	9.64E-18	3.19E-17	4.93E-17
l= 1	1.64E-21	4.58E-20	3.66E-19	2.80E-18	8.62E-18	2.16E-17	6.40E-17	1.02E-16
l= 2	6.96E-18	1.97E-17	3.25E-17	5.04E-17	5.88E-17	6.83E-17	1.04E-16	1.52E-16
σ_{ion}	1.28E-26	1.21E-23	1.92E-21	1.94E-19	2.44E-18	1.59E-17	9.21E-17	2.37E-16

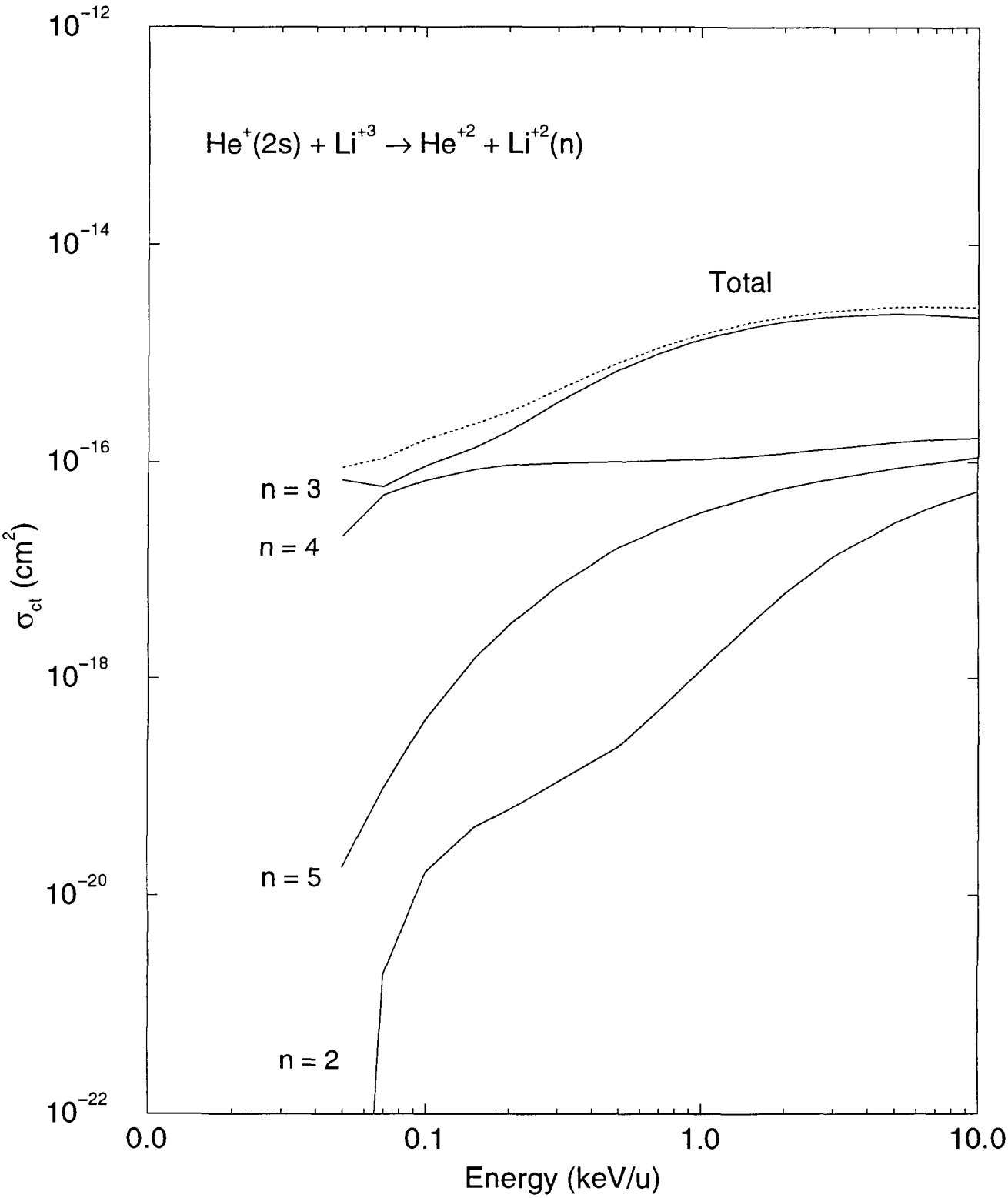
$He^{+}(2s) + Li^{+3} \rightarrow He^{+2} + Li^{+2}(n)$
Total
n = 3
n = 4
n = 5
n = 2
σ_{ct} (cm^2)
10^{-12}
10^{-14}
10^{-16}
10^{-18}
10^{-20}
10^{-22}
0.0
0.1
1.0
10.0
Energy (keV/u)

Fig. 7a

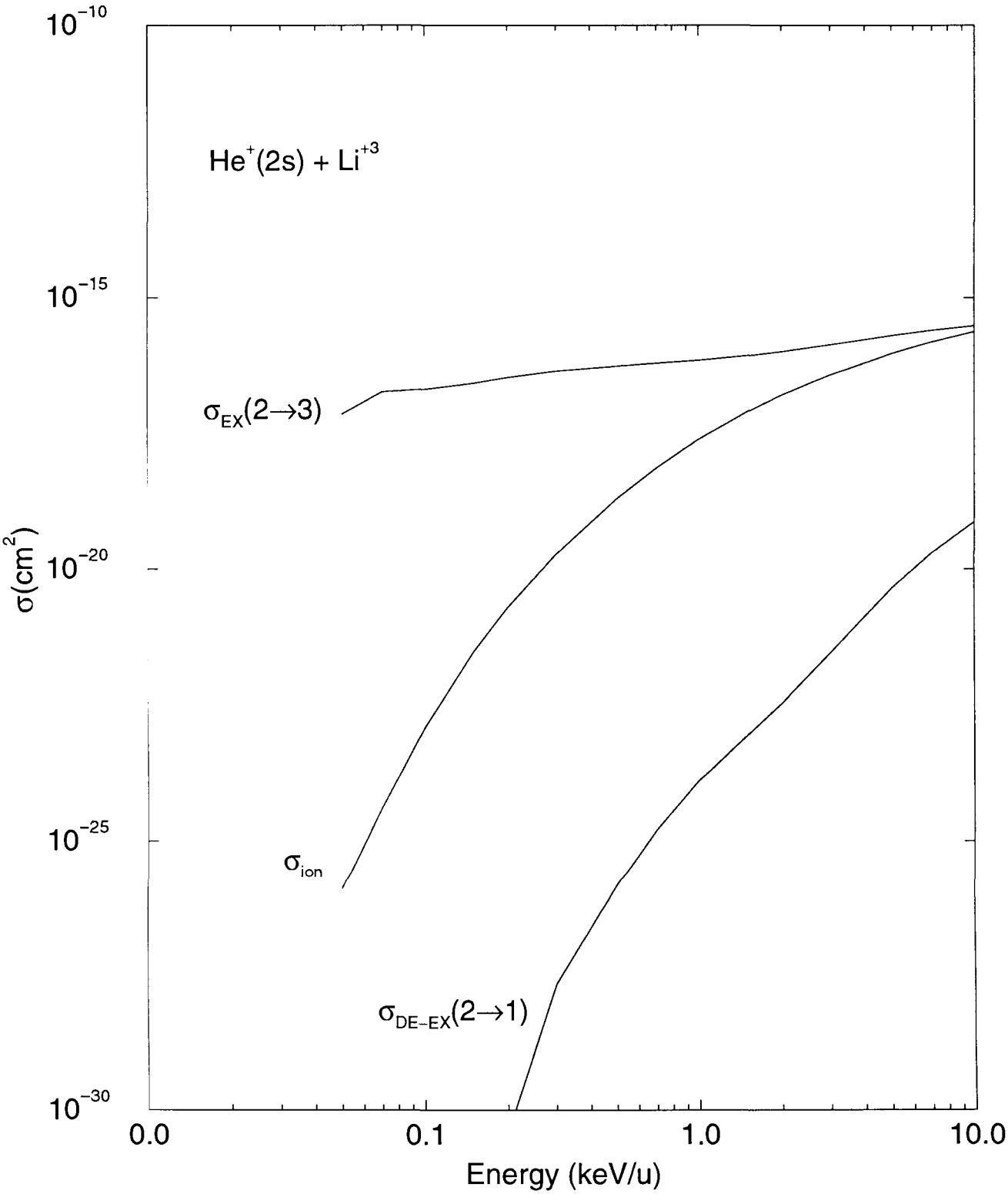
10^{-10}
10^{-15}
10^{-20}
10^{-25}
10^{-30}
$\sigma(cm^2)$
$He^+(2s) + Li^{+3}$
$\sigma_{EX}(2\rightarrow3)$
σ_{ion}
$\sigma_{DE-EX}(2\rightarrow1)$
0.0
0.1
1.0
10.0
Energy (keV/u)

Fig. 7b

Table 8: Cross sections (in units of 10^{-16} cm^2) for state-specific and total charge transfer, excitation, de-excitation, and ionization for the $He^+(2s) + Be^{+4}$ collision system as a function of energy (in units of keV/u).

E(keV/u)	.30	.50	.70	1.00	1.50	2.00	3.00	5.00
σ_{ct}								
n= 2	5.99E-22	6.67E-21	2.08E-20	5.41E-20	1.22E-19	1.89E-19	3.32E-19	6.77E-19
l= 0	2.99E-22	3.32E-21	1.03E-20	2.67E-20	5.99E-20	9.19E-20	1.57E-19	2.95E-19
l= 1	3.00E-22	3.35E-21	1.05E-20	2.73E-20	6.20E-20	9.70E-20	1.75E-19	3.82E-19
n= 3	6.84E-17	1.66E-16	2.70E-16	4.14E-16	6.04E-16	7.40E-16	9.08E-16	1.03E-15
l= 0	1.84E-17	4.12E-17	6.21E-17	8.71E-17	1.15E-16	1.33E-16	1.58E-16	1.85E-16
l= 1	1.28E-17	4.24E-17	7.85E-17	1.32E-16	2.03E-16	2.52E-16	3.06E-16	3.43E-16
l= 2	3.71E-17	8.28E-17	1.29E-16	1.95E-16	2.86E-16	3.56E-16	4.45E-16	5.06E-16
n= 4	8.12E-17	1.45E-16	2.02E-16	2.88E-16	4.80E-16	6.52E-16	9.31E-16	1.28E-15
l= 0	2.03E-18	7.22E-18	1.46E-17	2.55E-17	4.34E-17	5.91E-17	8.63E-17	1.22E-16
l= 1	2.42E-17	4.35E-17	5.76E-17	7.79E-17	1.23E-16	1.62E-16	2.27E-16	3.25E-16
l= 2	3.81E-17	5.79E-17	7.77E-17	1.05E-16	1.64E-16	2.07E-16	2.57E-16	2.97E-16
l= 3	1.69E-17	3.68E-17	5.23E-17	7.94E-17	1.50E-16	2.24E-16	3.61E-16	5.41E-16
n= 5	1.91E-16	2.23E-16	2.32E-16	2.27E-16	2.15E-16	2.06E-16	1.99E-16	2.00E-16
l= 0	1.91E-18	1.59E-18	1.66E-18	1.98E-18	2.53E-18	3.10E-18	4.30E-18	6.79E-18
l= 1	1.93E-18	2.33E-18	2.92E-18	3.66E-18	5.33E-18	7.19E-18	1.08E-17	1.62E-17
l= 2	9.91E-18	8.71E-18	9.03E-18	1.04E-17	1.29E-17	1.56E-17	2.08E-17	2.86E-17
l= 3	5.10E-17	5.55E-17	6.06E-17	6.03E-17	5.63E-17	5.32E-17	5.02E-17	4.83E-17
l= 4	1.26E-16	1.55E-16	1.58E-16	1.51E-16	1.37E-16	1.27E-16	1.13E-16	1.00E-16
n= 6	1.14E-18	5.19E-18	1.14E-17	2.20E-17	3.83E-17	5.19E-17	7.22E-17	9.89E-17
l= 0	2.09E-20	7.23E-20	1.52E-19	3.14E-19	5.75E-19	8.26E-19	1.34E-18	2.63E-18
l= 1	1.53E-20	7.98E-20	1.93E-19	4.16E-19	8.84E-19	1.44E-18	2.69E-18	5.54E-18
l= 2	7.60E-20	2.77E-19	5.88E-19	1.20E-18	2.27E-18	3.32E-18	5.38E-18	9.81E-18
l= 3	2.01E-19	8.79E-19	1.95E-18	3.67E-18	6.08E-18	7.91E-18	1.04E-17	1.34E-17
l= 4	3.52E-19	1.60E-18	3.46E-18	6.52E-18	1.11E-17	1.47E-17	1.97E-17	2.49E-17
l= 5	4.75E-19	2.28E-18	5.06E-18	9.82E-18	1.74E-17	2.37E-17	3.27E-17	4.26E-17
n= 7	7.19E-20	5.72E-19	1.78E-18	4.73E-18	1.10E-17	1.73E-17	2.78E-17	4.06E-17
l= 0	2.15E-21	1.27E-20	3.61E-20	9.78E-20	2.28E-19	3.58E-19	5.77E-19	8.70E-19
l= 1	1.63E-21	1.41E-20	4.31E-20	1.10E-19	2.56E-19	4.01E-19	6.31E-19	8.97E-19
l= 2	5.60E-21	3.60E-20	1.03E-19	2.76E-19	6.45E-19	1.02E-18	1.66E-18	2.50E-18
l= 3	1.15E-20	8.91E-20	2.78E-19	7.28E-19	1.63E-18	2.48E-18	3.76E-18	5.15E-18
l= 4	1.81E-20	1.45E-19	4.50E-19	1.18E-18	2.66E-18	4.09E-18	6.32E-18	8.66E-18
l= 5	1.86E-20	1.52E-19	4.76E-19	1.26E-18	2.93E-18	4.64E-18	7.51E-18	1.09E-17
l= 6	1.43E-20	1.23E-19	3.96E-19	1.08E-18	2.63E-18	4.31E-18	7.36E-18	1.16E-17
n= 8	2.97E-21	3.79E-20	1.48E-19	4.81E-19	1.39E-18	2.51E-18	4.81E-18	8.37E-18
l= 0	8.84E-23	6.40E-22	2.29E-21	7.40E-21	2.02E-20	3.52E-20	6.51E-20	1.14E-19
l= 1	5.29E-23	8.95E-22	3.16E-21	8.57E-21	2.24E-20	3.70E-20	6.09E-20	8.70E-20
l= 2	2.16E-22	2.13E-21	7.40E-21	2.33E-20	6.79E-20	1.24E-19	2.39E-19	4.28E-19
l= 3	2.98E-22	3.74E-21	1.50E-20	4.68E-20	1.23E-19	2.06E-19	3.53E-19	5.46E-19
l= 4	3.72E-22	5.19E-21	2.09E-20	6.88E-20	1.96E-19	3.50E-19	6.49E-19	1.07E-18
l= 5	5.12E-22	6.95E-21	2.67E-20	8.68E-20	2.55E-19	4.68E-19	9.06E-19	1.56E-18
l= 6	7.14E-22	9.10E-21	3.48E-20	1.11E-19	3.20E-19	5.83E-19	1.14E-18	2.06E-18
l= 7	7.21E-22	9.20E-21	3.76E-20	1.28E-19	3.84E-19	7.10E-19	1.40E-18	2.51E-18
$\sigma_{ct;tot}$	3.42E-16	5.40E-16	7.17E-16	9.56E-16	1.35E-15	1.67E-15	2.14E-15	2.66E-15
$\sigma_{ex,de-ex}$								
n= 1	4.03E-30	1.67E-26	2.44E-25	1.88E-24	2.00E-23	7.85E-23	4.54E-22	4.95E-21
l= 0	4.03E-30	1.67E-26	2.44E-25	1.88E-24	2.00E-23	7.85E-23	4.54E-22	4.95E-21
n= 3	5.49E-17	5.62E-17	6.33E-17	7.70E-17	9.10E-17	1.04E-16	1.38E-16	2.20E-16
l= 0	1.95E-18	2.45E-18	3.25E-18	4.95E-18	7.85E-18	1.18E-17	2.13E-17	3.98E-17
l= 1	2.48E-19	7.87E-19	1.53E-18	2.96E-18	7.33E-18	1.38E-17	3.05E-17	6.72E-17
l= 2	5.27E-17	5.29E-17	5.85E-17	6.91E-17	7.58E-17	7.89E-17	8.62E-17	1.13E-16
σ_{ion}	1.17E-20	1.44E-19	5.94E-19	2.22E-18	7.75E-18	1.68E-17	4.33E-17	1.15E-16

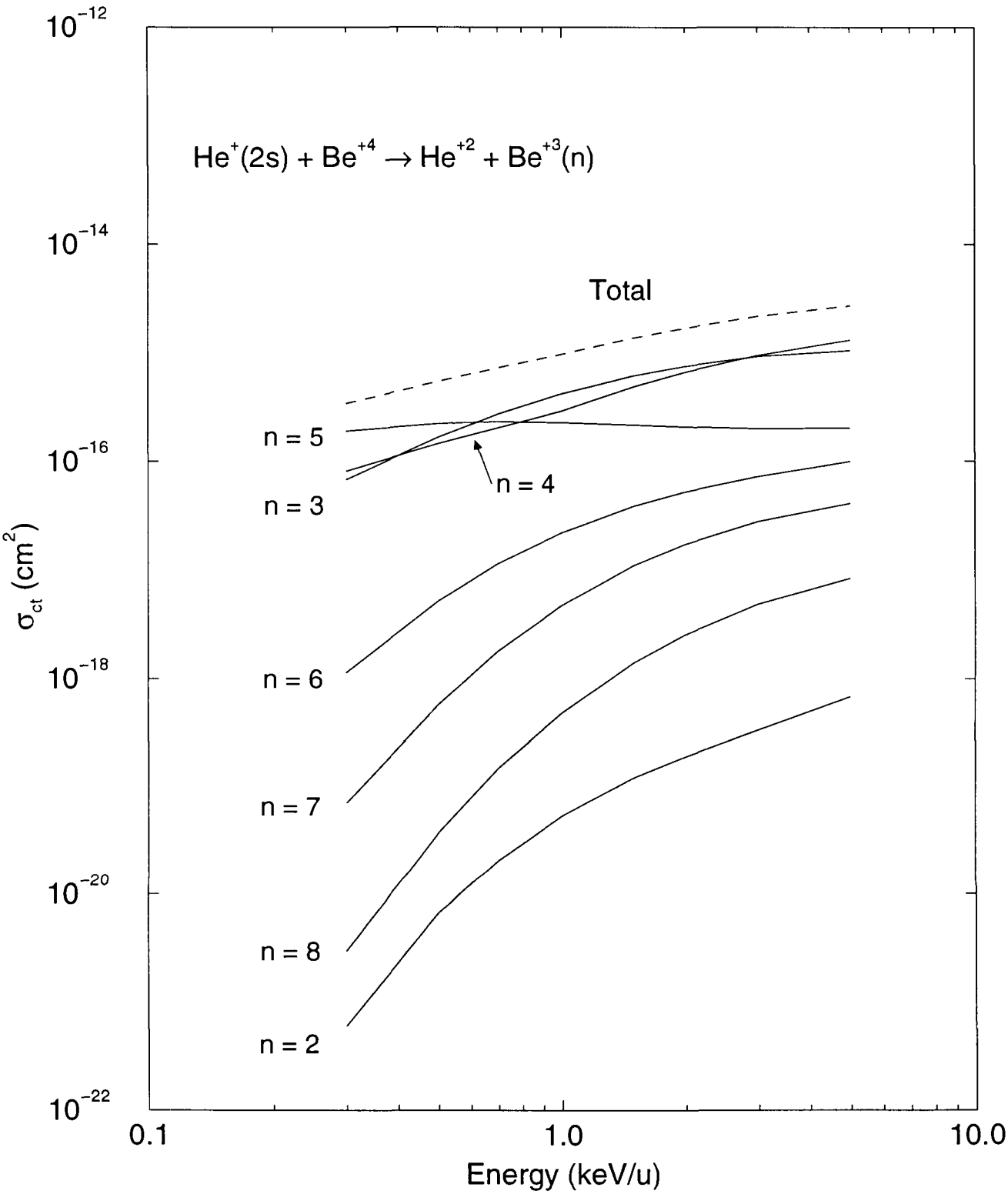
$He^{+}(2s) + Be^{+4} \rightarrow He^{+2} + Be^{+3}(n)$
Total
n = 5
n = 4
n = 3
n = 6
n = 7
n = 8
n = 2
10^{-12}
10^{-14}
10^{-16}
10^{-18}
10^{-20}
10^{-22}
σ_{ct} (cm^2)
0.1
1.0
10.0
Energy (keV/u)

Fig. 8a

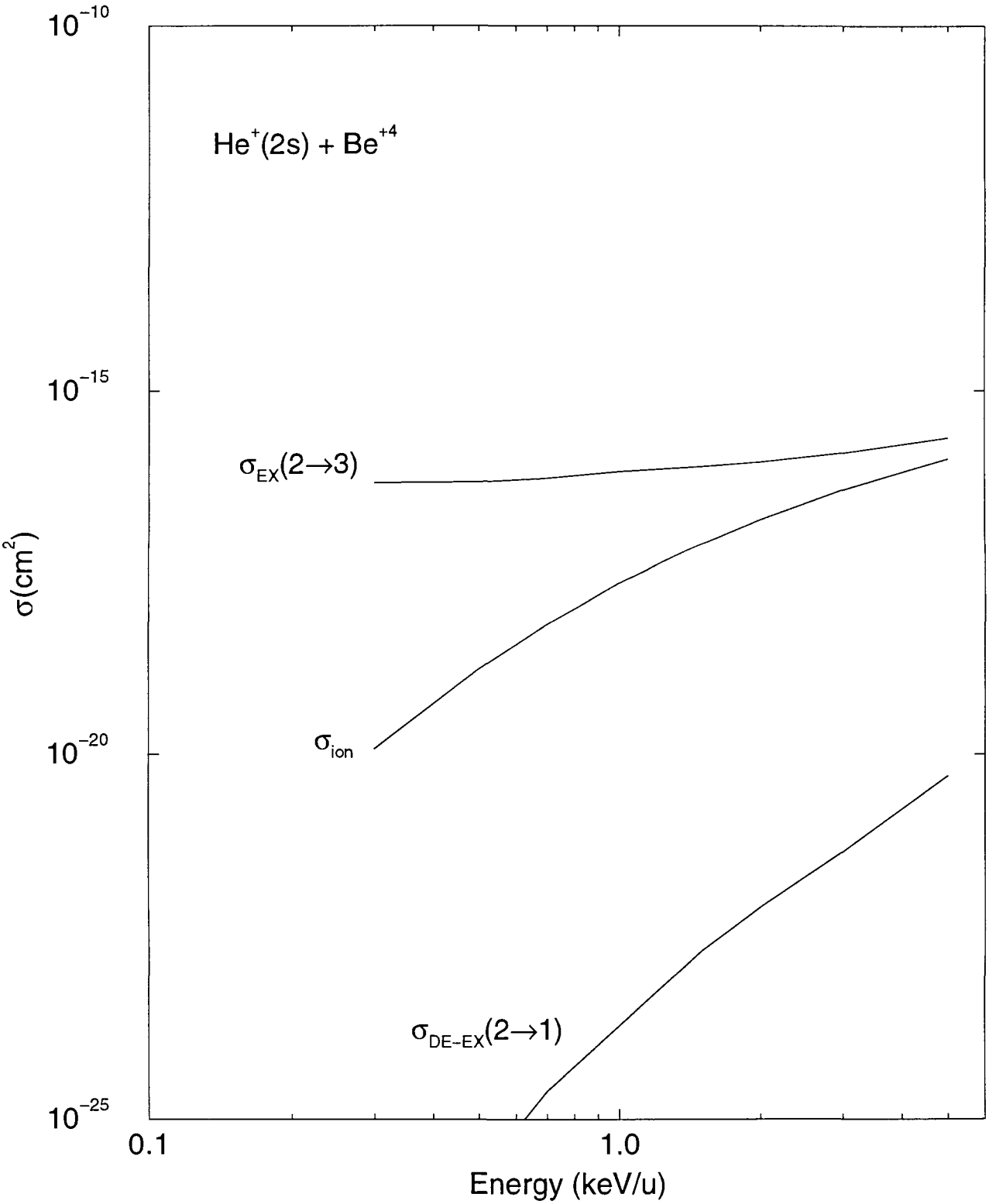
10^{-10}
10^{-15}
10^{-20}
10^{-25}
$He^{+}(2s) + Be^{+4}$
$\sigma_{EX}(2\rightarrow3)$
σ_{ion}
$\sigma_{DE-EX}(2\rightarrow1)$
$\sigma(cm^2)$
0.1
1.0
Energy (keV/u)

Fig. 8b

Table 9: Cross sections (in units of 10^{-16} cm^2) for state-specific and total charge transfer, excitation, de-excitation and ionization for the $He^+(2s) + B^{+5}$ collision system as a function of energy (in units of keV/u).

E(keV/u)	.05	.10	.20	.50	1.00	2.00	5.00	10.00
σ_{ct}								
n= 2	2.26E-36	1.09E-30	6.49E-27	9.45E-24	3.40E-22	5.70E-21	8.21E-20	3.13E-19
l= 0	1.13E-36	5.46E-31	3.24E-27	4.70E-24	1.68E-22	2.78E-21	3.84E-20	1.33E-19
l= 1	1.13E-36	5.47E-31	3.25E-27	4.75E-24	1.72E-22	2.91E-21	4.37E-20	1.80E-19
n= 3	9.05E-26	1.36E-20	7.74E-20	7.35E-19	4.69E-18	2.33E-17	1.07E-16	2.19E-16
l= 0	2.74E-26	4.53E-21	2.53E-20	2.16E-19	1.18E-18	4.89E-18	2.02E-17	4.34E-17
l= 1	3.97E-27	6.79E-21	3.56E-20	1.91E-19	1.06E-18	6.50E-18	3.38E-17	7.47E-17
l= 2	5.91E-26	2.32E-21	1.64E-20	3.28E-19	2.45E-18	1.20E-17	5.34E-17	1.01E-16
n= 4	1.37E-15	2.10E-15	2.87E-15	3.55E-15	3.56E-15	3.17E-15	2.32E-15	1.66E-15
l= 0	2.66E-16	3.83E-16	4.63E-16	4.46E-16	3.86E-16	3.29E-16	2.09E-16	1.08E-16
l= 1	2.21E-16	4.92E-16	8.23E-16	1.07E-15	1.00E-15	8.37E-16	6.15E-16	4.21E-16
l= 2	3.93E-16	6.03E-16	8.56E-16	1.12E-15	1.08E-15	8.29E-16	5.72E-16	5.50E-16
l= 3	4.93E-16	6.18E-16	7.28E-16	9.17E-16	1.09E-15	1.17E-15	9.26E-16	5.83E-16
n= 5	1.33E-16	1.67E-16	1.96E-16	1.98E-16	2.32E-16	3.49E-16	7.55E-16	1.17E-15
l= 0	3.28E-19	1.78E-18	2.75E-18	5.23E-18	8.49E-18	1.67E-17	3.83E-17	4.42E-17
l= 1	2.63E-17	2.94E-17	2.91E-17	2.06E-17	2.27E-17	4.21E-17	1.11E-16	1.47E-16
l= 2	5.62E-17	5.96E-17	5.82E-17	4.46E-17	4.50E-17	6.34E-17	1.61E-16	2.95E-16
l= 3	4.01E-17	4.62E-17	5.77E-17	6.00E-17	7.08E-17	9.64E-17	1.41E-16	2.37E-16
l= 4	9.82E-18	3.02E-17	4.85E-17	6.71E-17	8.52E-17	1.30E-16	3.04E-16	4.44E-16
n= 6	2.18E-16	3.36E-16	3.61E-16	3.10E-16	2.42E-16	1.87E-16	1.70E-16	2.04E-16
l= 0	2.72E-18	2.61E-18	2.12E-18	1.71E-18	1.61E-18	2.21E-18	5.06E-18	7.38E-18
l= 1	3.70E-18	3.54E-18	3.09E-18	3.02E-18	3.14E-18	4.29E-18	9.58E-18	1.48E-17
l= 2	9.27E-18	9.89E-18	9.44E-18	8.43E-18	8.42E-18	1.03E-17	1.73E-17	2.57E-17
l= 3	5.00E-17	4.88E-17	4.27E-17	3.69E-17	2.77E-17	2.28E-17	2.66E-17	3.73E-17
l= 4	9.55E-17	1.10E-16	1.17E-16	9.94E-17	7.44E-17	5.32E-17	4.06E-17	4.24E-17
l= 5	5.65E-17	1.61E-16	1.87E-16	1.61E-16	1.27E-16	9.39E-17	7.09E-17	7.63E-17
n= 7	3.96E-17	5.92E-17	6.92E-17	8.41E-17	9.11E-17	1.09E-16	2.32E-16	5.59E-16
l= 0	1.86E-18	2.77E-18	3.22E-18	3.69E-18	3.39E-18	3.46E-18	9.52E-18	1.68E-17
l= 1	1.86E-18	2.78E-18	3.28E-18	4.14E-18	4.93E-18	7.19E-18	2.32E-17	4.58E-17
l= 2	3.15E-18	4.68E-18	5.43E-18	6.60E-18	7.90E-18	1.16E-17	3.41E-17	8.05E-17
l= 3	1.10E-17	1.64E-17	1.89E-17	2.14E-17	2.00E-17	1.89E-17	3.49E-17	1.06E-16
l= 4	1.35E-17	2.01E-17	2.34E-17	2.73E-17	2.65E-17	2.54E-17	2.90E-17	7.65E-17
l= 5	6.92E-18	1.04E-17	1.24E-17	1.59E-17	1.85E-17	2.39E-17	4.35E-17	5.68E-17
l= 6	1.32E-18	2.01E-18	2.60E-18	5.16E-18	9.71E-18	1.86E-17	5.81E-17	1.76E-16
n= 8	1.52E-24	3.07E-22	1.69E-20	6.71E-19	3.95E-18	1.38E-17	4.51E-17	8.32E-17
l= 0	2.16E-26	5.92E-24	3.68E-22	1.49E-20	7.54E-20	2.67E-19	1.14E-18	2.06E-18
l= 1	2.55E-26	5.91E-24	3.90E-22	2.23E-20	1.79E-19	6.48E-19	1.73E-18	3.45E-18
l= 2	6.04E-26	1.44E-23	9.17E-22	3.88E-20	2.29E-19	8.51E-19	3.16E-18	6.42E-18
l= 3	1.69E-25	3.44E-23	1.84E-21	7.52E-20	4.12E-19	1.30E-18	4.52E-18	8.69E-18
l= 4	3.49E-25	5.96E-23	2.94E-21	1.09E-19	6.39E-19	2.18E-18	6.50E-18	1.17E-17
l= 5	4.55E-25	7.85E-23	3.60E-21	1.27E-19	7.12E-19	2.44E-18	7.72E-18	1.38E-17
l= 6	3.13E-25	6.32E-23	3.29E-21	1.26E-19	7.47E-19	2.65E-18	8.84E-18	1.65E-17
l= 7	1.23E-25	4.48E-23	3.51E-21	1.58E-19	9.57E-19	3.44E-18	1.15E-17	2.06E-17
$\sigma_{ct:tot}$	1.76E-15	2.66E-15	3.50E-15	4.14E-15	4.14E-15	3.86E-15	3.68E-15	4.00E-15
$\sigma_{ex,de-ex}$								
n= 1	2.02E-71	1.73E-49	1.71E-28	2.55E-25	6.78E-24	7.11E-23	2.23E-21	5.38E-20
l= 0	2.02E-71	1.73E-49	1.71E-28	2.55E-25	6.78E-24	7.11E-23	2.23E-21	5.38E-20
n= 3	3.17E-23	2.98E-21	6.63E-20	1.04E-18	4.20E-18	1.93E-17	1.53E-16	4.49E-16
l= 0	1.08E-24	1.33E-22	4.51E-21	1.18E-19	7.21E-19	4.69E-18	3.68E-17	8.79E-17
l= 1	1.77E-25	6.86E-23	3.94E-21	1.24E-19	8.53E-19	6.82E-18	6.46E-17	1.88E-16
l= 2	3.05E-23	2.78E-21	5.79E-20	8.02E-19	2.63E-18	7.78E-18	5.13E-17	1.73E-16
σ_{ion}	2.25E-33	6.76E-28	4.91E-24	1.28E-20	6.70E-19	1.09E-17	1.20E-16	3.50E-16

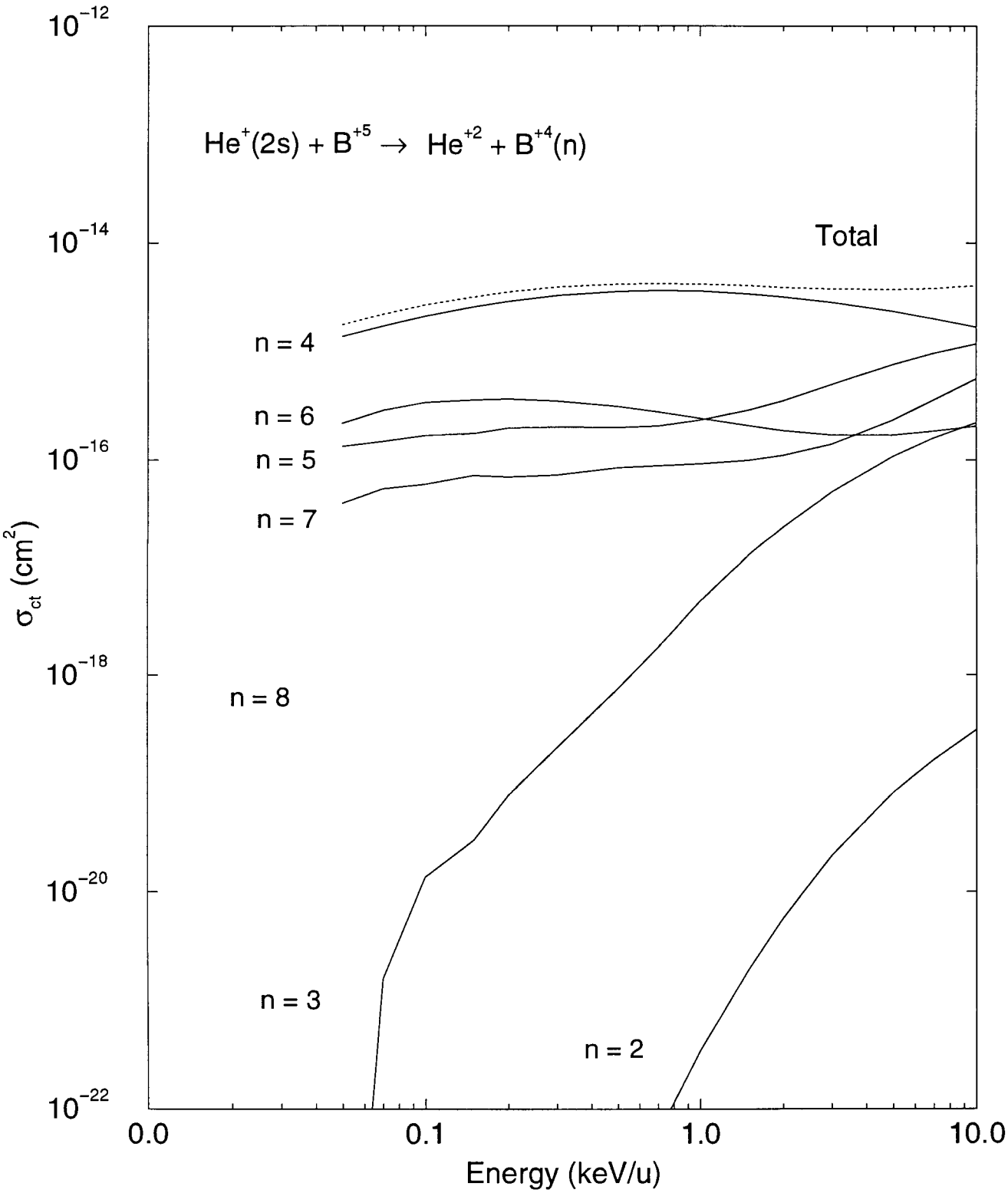
$He^{+}(2s) + B^{+5} \rightarrow He^{+2} + B^{+4}(n)$
Total
n = 4
n = 6
n = 5
n = 7
n = 8
n = 3
n = 2
10^{-12}
10^{-14}
10^{-16}
10^{-18}
10^{-20}
10^{-22}
σ_{ct} (cm^2)
0.0
0.1
1.0
10.0
Energy (keV/u)

Fig. 9a

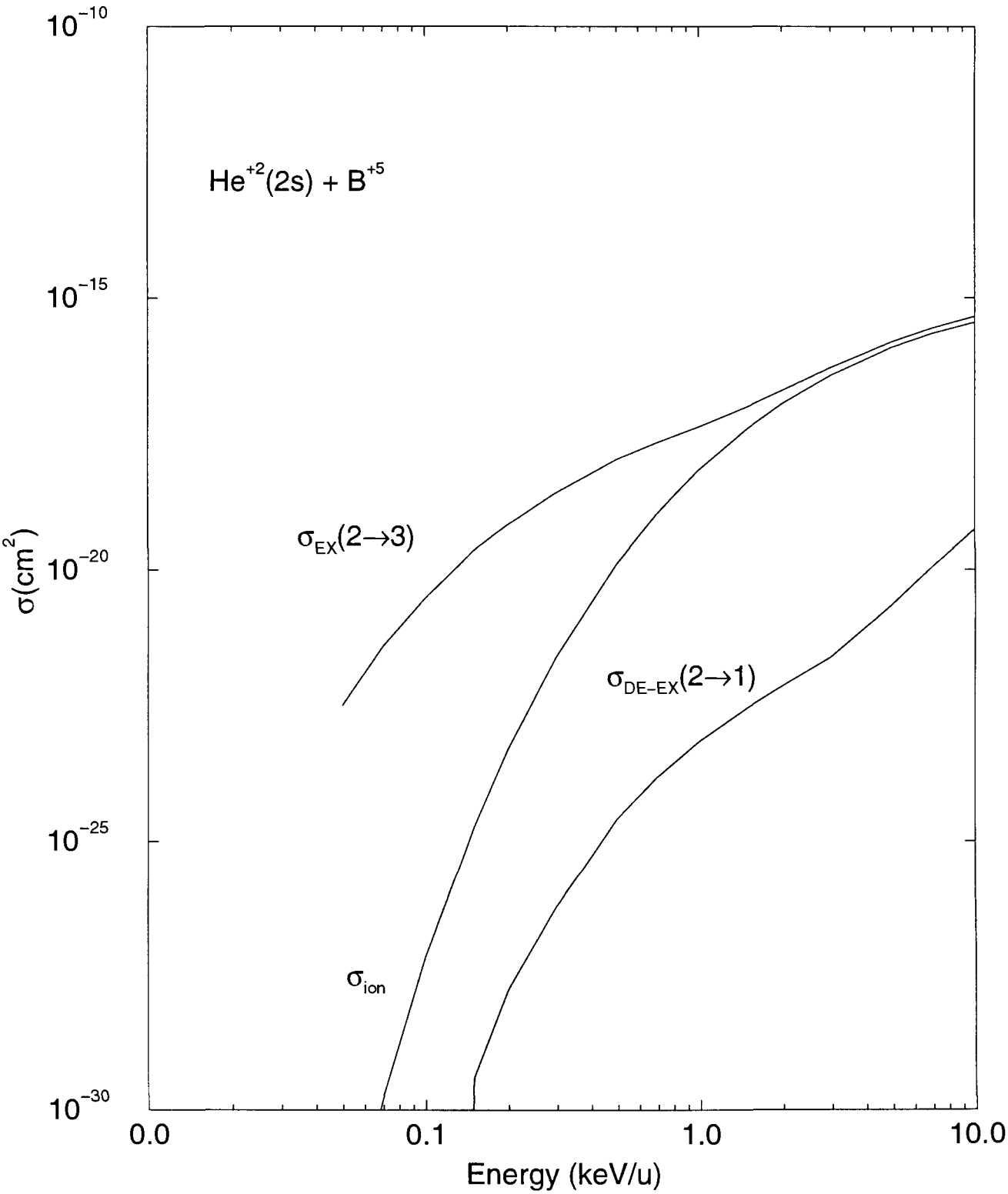
10^{-10}
10^{-15}
10^{-20}
10^{-25}
10^{-30}
$\sigma(cm^2)$
$He^{+2}(2s) + B^{+5}$
$\sigma_{EX}(2\rightarrow3)$
$\sigma_{DE-EX}(2\rightarrow1)$
σ_{ion}
0.0
0.1
1.0
10.0
Energy (keV/u)

Fig. 9b