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Cross Sections for Electron Capture and Ionization in Collisions of Fusion Plasma Impurity Ions with Atomic Hydrogen

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Abstract

Systematic electron capture and ionization cross section calculations are performed for the systems $A^{q+} + H(1s)$, A=Be, B, Al, Ti, V, Kr, Mo, W and q = 3-10. The method applied in these calculations is based on the Keldysh non-stationary approach to the collision dynamics, and the energy range covered is from 6.25 keV/amu to 600 keV/amu. For the heavier ions (Ti to W), partial electron capture cross sections are also calculated. The data are presented in tabular form; for some cross sections a graphical representation is also given.

1 Introduction

Impurities in a fusion plasma, through their collision and radiative processes, have a strong influence on the plasma properties and the overall performance of the fusion device. The knowledge of collisional properties of fusion plasma impurities is required in the studies of their transport, both in the central and plasma edge region, their radiative plasma cooling effects, and in various plasma diagnostic schemes [1,2]. Impurity radiation has particularly strong impact on the plasma parameters and performance. In the plasma core, the radiation of high-q impurities may be detrimental for achieving or maintaining the plasma burn conditions. In the plasma edge region, however, the impurity radiation may be highly beneficial for exhausting the thermal plasma power before it reaches the plasma facing components (walls, limiters, divertor plates), thus reducing the thermal loads on them. The impurity radiation in the plasma edge keeps the plasma temperature in this region rather low, which supports existence of plasma impurities in low charge states and high densities of neutral hydrogen atoms. Such plasma composition and physical parameters makes the plasma edge region extremely reach in atomic collision phenomena, the most important of which are those associated with the interactions of ionized impurities with the electrons and neutral hydrogen. The collision processes taking place in the plasma edge have been subject of numerous studies (see e.g. [3] and the references therein).

For the impurity and hydrogen atom transport studies in the plasma edge, and for the calculation of attenuation kinetics of diagnostic neutral hydrogen beams in the edge plasma region, of significant importance are the charge exchange and ionization processes in collisions between impurity ions and hydrogen atoms. The information about the cross sections of these processes, particularly for the incompletely stripped ions, is still far from complete. Particularly scarce is the cross section information for the state-selective electron capture, which is required in both radiation loss calculations and in charge exchange spectroscopy diagnostics.

In the present work, we undertake systematic cross section calculations for the chrage exchange process,

$$A^{q+} + H(1s) \rightarrow A^{(q-1)+}(nl) + H^{+} \tag{1}$$

and the ionization process

$$A^{q+} + H(1s) \rightarrow A^{q+} + H^{+} + e \tag{2}$$

where A = Be, B, Al, Ti, V, Kr, Mo, W, q = 3-10 and n,l are the principal and angular momentum quantum numbers of the final state. The limitation to ion charge states below q = 10 implies that we are interested mainly in the plasma edge region. The selected impurities are the ones which are expected to be present in the next step fusion devices, with Kr being considered as deliberately added diagnostic impurity.

The theoretical methods which are usually applied in the treatment of charge exchange and ionization processes are discussed in detail in Ref. [4]. The theoretical description of charge exchange and ionization processes is most difficult in the intermediate energy region (20 - 200 keV/amu) due to the strong coupling of many states (including the continuum) involved in the collision dynamics.

In the present work we shall apply a non-stationary approach to collision dynamics which has proved in the past to be effective in the intermediate energy region.

The basic elements of the method are described in Section 2. In the subsequent sections we give some details of the performed cross section calculations in the considered systems, the last section describing the obtained results. Atomic units are used throughout, unless otherwise explicitly stated.

2 Non-Stationary Theory for Charge-Transfer and Ionization in Ion-Atom Collisions

The calculations presented here are based on the theory of ion-atom collisions [5,6] developed as a generalization of the Keldysh [7] theory of multiphoton ionization The basis of the theory can be summarized as follows. The one-electron removal from a neutral atom occurs at large internuclear distances where the high-q ion field can be described as a pure dynamical Coulomb field. The dynamical part of the problem has an exact analytic solution if we expand the electron-projectile interaction potential over multipoles and retain the monopole and dipole terms. Thus, the physical mechanism of charge transfer and ionization is formulated as under- and over-barrier electron transitions in the non-stationary potential created by the ion moving in the vicinity of the atom. In this approach, the binding energy of the neutral atom acquires an imaginary part related to the decay of the initial state during the collision, and the wave function is a wave packet of Volkoff-Keldysh states The stationary-phase three-dimensional calculations enable us to express all the elements of the theory [5,6] (the imaginary part of the binding energy, the transition amplitudes, the unitarity of the transition probabilities) in terms of the reduced transition amplitudes given by

$$h(\vec{p}) = \int_{-\infty}^{\infty} dt \left\langle \phi_{\vec{p}}(\vec{r},t) | \vec{r}\vec{F}(t) | \phi_0(\vec{r}) e^{-i\epsilon_0 t} \right\rangle . \tag{3}$$

Here $\vec{p}$ and $\vec{r}$ are the momentum and coordinate of the active electron, $\phi_0(\vec{r})$ is the unperturbed wave function of the neutral atom, and ϵ_0 is the real part of the binding energy The magnitude of the ion field,

$$\vec{F}(t) = q\frac{\vec{R}(t)}{[R(t)]^3} \tag{4}$$

depends on the ion charge, q, and on the time-dependent internuclear distance $\vec{R}(t)$ Note that the monopole term has the same value and opposite sign as the internuclear repulsion one, thus they cancel each other and do not contribute to the equations below This internuclear repulsion itself can influence the trajectory in the final reaction channels, however, this effect is important at collision energies much lower than those considered here. The Volkoff-Keldysh states,

$$\phi_{\vec{p}}(\vec{r},t) = (2\pi)^{-3/2} exp[i\vec{k}(t)\cdot\vec{r} - \frac{i}{2}\int_0^t k^2(\tau)d\tau], \quad (5)$$

$$\vec{k}(t) = \vec{p} - \vec{A}(t), \quad \vec{A} = -\int_0^t \vec{F}(\tau)d\tau, \quad (6)$$

describe the motion of the unbound electron with definite values of momentum $\vec{p}$ in the time-dependent field of the ion and satisfy the non-stationary Schrödinger equation

$$\left[i\frac{\partial}{\partial t} + \frac{1}{2}\Delta_r + \vec{r}\cdot\vec{F}(t)\right]\phi_{\vec{p}}(\vec{r},t) = 0 \quad (7)$$

Following Keldysh [7], we omit here the Coulomb interaction of the active electron with the proton and include it later on with the help of the so-called Coulomb factor introduced by Keldysh [7] and further investigated by Ritus and Nikishov [8] (see also [5,6]).

The solution of the non-stationary Schrödinger equation,

$$\left[i\frac{\partial}{\partial t} + \frac{1}{2}\Delta_r + \frac{1}{r} + \frac{q}{|\vec{R}(t)-\vec{r}|} - \frac{q}{|\vec{R}(t)|}\right]\Psi(\vec{r},t) = 0, \quad (8)$$

under the initial condition H(1s) + ion has the following form

$$\Psi(\vec{r},t) = \phi_0(\vec{r})e^{-i\epsilon_0 t - \frac{1}{2}\int_{-\infty}^t \Gamma(\tau)d\tau} + \Psi_f(\vec{r},t), \quad (9)$$

where ϕ_0 and ϵ_0 are defined in Eq. (3) for the reduced amplitude, and $\Gamma(t)$ is the decay width Ψ_f corresponds to the final channels and has the form

$$\Psi_f(\vec{r},t) = \int d\vec{p}\, a_{\vec{p}}(t)\,\phi_{\vec{p}}(\vec{r},t); \quad (10)$$

It is important to note that after performing analytic calculations in the complex t-plane, all elements of Eq. (9) can be expressed in terms of the reduced amplitude h(p) given by Eq. (3). The decay width of the initial state is, for instance, equal to [5,6]

$$\Gamma(t) = \int d\vec{p}\,|h(\vec{p})|^2\,\delta(t - t_0(\vec{p}))f_k, \quad (11)$$

where f_k is the Coulomb factor described below, and the value $t_o(\vec{p})$ is real and has the physical meaning of the time when the electron emerges from the non-stationary barrier created by the ion filed. The amplitude a_p is given by

$$a_{\vec{p}} = f_k\, h(\vec{p})\, exp[-\frac{1}{2}\int_{\{t_0(\vec{p'}) \leq t_0(\vec{p})\}} d\vec{p'}|h(\vec{p'}|^2]. \quad (12)$$

$$\{t_0(\vec{p'}) \leq t_0(\vec{p})\} \quad (13)$$

The Coulomb factor introduced by Keldysh [7] and discussed by many authors (see, for example [5,6 and 8]) is equal to

$$f_k = \left[\frac{2vb/q}{\left(\frac{v}{b}\right)\left[1+\left(\frac{vb}{q}\right)^2\right]^{1/2}} \right], \tag{14}$$

where v is the relative velocity, b is the impact parameter and q is the ion charge respectively.

In order to calculate ionization and charge transfer cross sections separately including distributions over the principal and orbital quantum number of the final ion, we express the amplitude a_p of Eq. (12) in the form

$$|a_{\vec{p}}|^2 = \nu(\vec{p}) = |G(\vec{p})|^2 exp\left[-2S(\vec{p}) - \int_{-\infty}^{t_0(\vec{p})} \Gamma(t)dt\right]. \tag{15}$$

Here we used the three-dimensioned stationary phase approach described in Refs. [5,6]. The quantity $\nu(\vec{p})$ corresponds to the electron-flux density in momentum space We need the results as function of the following variables. the ejected electron energy in the ion frame system (E_ϵ), the total orbital momentum (L) and its projection onto the direction of the relative velocity of colliding particles (M). The flux density ν_{E_ϵ} in the configuration space [E_ϵ, L, M] is related to $\nu(\vec{p})$ as

$$\nu_{E_\epsilon} = \nu(\vec{p}) \left| \frac{\partial(E_\epsilon, L, M)}{\partial(p_x, p_y, p_z)} \right|^{-1}. \tag{16}$$

For calculating the partial charge-transfer probabilities, $W_{nL} = W_1$, and the total ones, $W_{ch} = \sum_{nL} W_{nL} = W_2$, and with the ionization probabilities $W_{ion} = W_3$, we have to partition the configuration space [E_ϵ, L, M] into three regions, $\Lambda_1, \Lambda_2 = \sum \Lambda_1$ and Λ_3, corresponding to the reaction channels, and to define the number of electrons going to each Λ-region. The probabilities discussed are equal to

$$W_\alpha = \int_{\Lambda_\alpha} \nu_{E_\epsilon}\, dE_\epsilon\, dL\, dM,\ \ \alpha = 1, 2, 3. \tag{17}$$

It is important to note that the processes of charge transfer and ionization are defined completely from the energy analysis $E_\epsilon < 0$ defines the discrete spectrum (charge transfer) whereas $E_\epsilon > 0$ corresponds to continuum (ionization) The region Λ_1 is defined as

$$n - 1 \ < \ \left(\frac{2q^2}{|E_\epsilon|}\right)^{1/2} < n, \tag{18}$$

$$n - L - 1 \ < \ \left(\frac{2q^2}{|E_\epsilon|}\right)^{1/2} - M < n - L \tag{19}$$

The procedure for obtaining the classical values of the electron energies and orbital momenta in the presence of the ion field is described in [5,6] jointly with details of the flux calculations.

The cross sections in different channels (charge transfer to given nL-states, $\alpha = 1$; total charge transfer, $\alpha = 2$; and ionization, $\alpha = 3$) are given by

$$\sigma_\alpha = 2\pi \int_0^\infty b\,db \int_{\Lambda_\alpha} dE_e\,dL\,dM\,\nu_E. \tag{20}$$

The results of numerical calculations for He^{2+}, Li^{2+}, C^{q+} (q=2-4), N^{q+} (q=2-4), O^{q+} (q=2-6), and Ar^{q+} (q=6-7) [5,6] are in good quantitative agreement with the experimental data of Gilbody and co-workers [9- 12]. At the same time, the scaling law for the total removal of an electron from the neutral atom (charge transfer + ionization) in collisions with highly charged ions was confirmed,

$$\sigma_{\rm tot} = qQ(E/q). \tag{21}$$

Here E is the collision energy per atomic mass unit, and the function Q depends on the parameters of target atom only. This scaling law was established semi-empirically [13] and compares favorably with experimental data [14]. It is important to note that the Keldysh-type theory [5,6] leads to the parametrization (21) because of analytic properties of the Volkoff-Keldysh states (5) and the general form of the non-stationary wave function (9).

3 Applications of the Theory to Charge Exchange and Ionization of Impurity Ions in Fusion Plasmas

We now consider the charge transfer and ionization processes for the H(1s) + A^{q+} collision systems (A=Be, B, Al, Ti, V, Kr, Mo, and W with q=3-10) by using the computational scheme described above. There are certain specific features which should be taken into account when considering these systems. Firstly, all the projectile ions, except Be and B, contain many electrons, even being highly ionized. Secondly, their ionization potentials (except Be, B and Al) are comparatively lower than the ionization potentials of ions with just a few electrons. Therefore, the energy structure of the excited states in the multiply charged ions of Ti, V, Kr, Mo and W is very important for analysing capture into excited states. At comparatively low energies, $q^{-1}\times$ E(keV/amu) ≤ 5, the charge transfer is more effective than ionization. The most populated ionic levels have the effective principal quantum numbers given by

$$q/2 < n_{eff} \leq q^{3/4}, \tag{22}$$

which means that (for $q < 16$)

$$\frac{q^{1/2}}{2} \leq E_e < 2, \tag{23}$$

where E_ϵ is defined in Eqs. (15) and (16) and is measured in atomic units. These excited states are vacant in all ions under consideration At larger collision energies, electron capture usually goes to deeper energy levels, which in many-electron ions, like Ti, V, Kr, Mo and W, are alredy occupied. For this reason, the total charge-transfer cross sections in collisions involving these heavy ions are smaller than those for collisions involving Be, B and Al when the impact energy increases.

At the intermediate energies considered here, ionization does not depend on the spectroscopic structure of multiply charged ions and is mainly defined by the value of the ion charge. Here we do not consider the region of high collision energies. We note, however, that the Keldysh method leads to the Bethe-Born asymptotics at high energies [5,6] and can be easily corrected in order to describe the rigorous Born asymptotics in the energy range where the perturbation theory is valid.

In our numerical calculations, we divide the considered multiply charged ions into two groups The first group consists of the light elements with relatively small number of electrons: Be, B and Al. The second group includes more heavy elements with open p- and d-electron shells: Ti, V, Kr, Mo and W. For the reason given above, the ionization cross sections of both projectile groups depend on the ion charge and the collision energy only. The charge transfer cross section for the light and heavy projectiles differs, however, by 20% with increasing the collision energy For all projectiles considered here, the principal quantum number should be regarded as the effective quantum number describing the values of E_ϵ for captured electrons The ionization potentials and additional spectroscopic information are derived from the systematic calculations of Ref. [15]. The distributions over orbital quantum numbers are given in the form

$$\tilde{\sigma}_{nL} = \frac{\sigma_{nL}}{\sum_L \sigma_{nL}} \tag{21}$$

Based on previous experience [5,6], we estimate that the accuracy of the present calculations is within 15%

4 The Cross Section Data

The results of the present numerical calculations for ionization and charge transfer in collisions of A^{q+} (A = Be, B, Al, Ti, V, Kr, Mo and W; q=3-10) with H(1s) atoms are presented in Tables 1-3 and in Figures 1-3 at collision energies from 6.25 to 625 keV/amu

Table 1 contains the ionization cross section as function of the collision energy and of the ion charge For the reasons discussed in Sec 3, the cross sections do not depend on the ion structure Table 2 shows the total charge transfer cross sections for Be, B and Al In this case, the excited ionic levels which are mostly populated can be considered as hydrogenic (except for the first few) For these excited levels, the partial cross sections describing distributions of captured electrons over the principal and orbital momentum quantum numbers are close to those for the collisions of H(1s) with fully stripped ions The latter were computed and published elsewhere [5,6]

Table 3 contains the values of total and partial charge transfer cross sections for Ti, V, Kr, Mo and W ions. The principal quantum numbers n this Table refer to the effective quantum numbers which define the middle of the energy interval,

$$E_e^{(n)} = \frac{-q^2}{2n^2}, \; n = \text{integer}, \tag{25}$$

$E_e^{(n)}$ being defined by the condition (18). The effective principal quantum number n = 1 corresponds to all values of $E_\epsilon < E_e^{(n=2)}$ (if any). For the highly excited states (e.g. $n > 6$), the effective quantum numbers coincide with the spectroscopic ones.

The orbital quantum numbers l correspond to the orbital momenta of the captured electron located in the energy band with the center defined by Eq. 25. Since we consider charge transfer into comparatively wide energy intervals, the quantum defect values are not important for $l \geq 1$, and population of s-levels is comparatively small with respect to the higher values of the orbital momentum.

In the case of Ti^{q+}, there are calculations for the total charge transfer and ionization cross sections (q=4-10 [16]) and for the partial and total charge transfer cross sections (q=3 [17]). The comparison of the present results with those of Refs. [16,17] is within 20%.

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Table 1: Total ionization cross section (in units of 10^{-16} cm^2, lower number) for ions with charge state q as a function of E (in keV/amu, upper number)

q = 3	6 25	16.00	30 30	49 00	72.30	100.00	132.00	169 00	210 00	256.00	306 00
	1 06	1.87	3 95	6.47	7.37	6 81	5.60	4.46	3.46	2 67	2 07
q = 4	9 00	20 70	37 20	58 50	84.60	116.00	151 00	192.00	237 00	287 00	342 00
	1.05	2.36	5 61	9.55	10.90	10.40	8.94	7.25	5 78	4 61	3 63
q = 5	9 00	22 10	41.00	65 60	96 00	132 00	174.00	222.00	276 00	335 00	400 00
	.92	2 51	6.55	12 60	14 80	14.20	12.40	10.10	8.08	6.39	5 07
q = 6	16 00	31 40	51.80	77 40	108 00	144.00	185.00	231.00	282.00	339.00	400 00
	1 24	4.06	10.30	16.60	19 30	18 80	16 50	14 10	11 70	9 55	7 80
q = 7	16 00	34 20	59 30	91 20	130.00	176.00	228.00	287 00	353.00	426 00	506 00
	1.02	4 51	13 00	21.80	23 70	22 30	19 10	15 80	12 80	10 30	8 24
q = 8	25 00	49 00	81 00	121 00	169.00	225 00	289 00	361.00	441.00	529.00	625 00
	2 09	9 16	21.70	28 30	27.80	24.80	20.40	16 60	13 40	10 70	8 52
q = 9	25 00	49 00	81 00	121 00	169 00	225 00	289 00	361 00	441 00	529 00	625 00
	1 85	9 01	23 40	32.70	32 90	30 10	25.70	21 20	17 30	14 00	11 30
q = 10	25 00	49 00	81 00	121.00	169 00	225 00	289.00	361 00	441 00	529.00	625 00
	1 73	8 79	24 70	36 60	38 40	35 60	31 30	26.20	21 60	17 70	14 50

Table 2: Total capture cross section (in units of 10^{-16} cm^2, lower number) for Be and B (q = 3 - Z) and Al (q=3 - 10), as a function of E (in keV/amu, upper number)

q = 3	6 25	16 00	30 30	49 00	72.30	100 00	132 00	169 00	210.00	256 00	306 00
	23 40	19 70	14 50	8 63	4 45	2 20	1 17	61	34	.20	11
q = 4	9 00	20.70	37 20	58 50	84.60	116 00	151.00	192 00	237 00	287 00	342 00
	31 30	26 50	19 70	11 70	6 37	3 28	1 68	96	55	29	18
q = 5	9 00	22 10	41 00	65 60	96 00	132 00	174 00	222 00	276 00	335 00	400 00
	40.50	34 60	26 20	15 30	8 11	4.10	2 04	1.12	61	36	19
q = 6	16 00	31 40	51 80	77 40	108 00	144 00	185 00	231.00	282 00	339 00	400 00
	46 30	39 20	28 40	17 10	9 25	4 91	2 84	1.56	93	57	35
q = 7	16 00	34 20	59 30	91 20	130 00	176 00	228 00	287.00	353 00	426 00	506 00
	55 50	46 50	32 40	17 40	9 09	4 52	2.38	1 28	76	39	25
q = 8	25 00	49 00	81 00	121 00	169 00	225 00	289 00	361 00	441.00	529 00	625 00
	60.20	46.80	27 50	13 60	6 75	3 16	1 83	96	51	31	19
q = 9	25 00	49 00	81 00	121 00	169 00	225 00	289 00	361 00	441 00	529 00	625 00
	69 20	55 40	34 00	17.10	9 00	4 39	2 33	1 27	75	.39	26
q = 10	25 00	49 00	81 00	121 00	169 00	225 00	289.00	361 00	441 00	529 00	625 00
	78 20	64 10	41 00	21 20	11 00	5 76	2 84	1 66	99	57	28

Table 3a: Total and partial electron capture cross section (in uints of 10^{-16} cm^2) for Ti^{3+}, V^{3+}, Kr^{3+}, Mo^{3+} and W^{3+}. Partial cross sections for nl substates are relative.

E(keV)	6 25	16 00	30 30	49 00	72.30	100.00	132.00	169 00	210 00	256.00	306 00
σ_{CT}	23 40	19 60	14 10	8 17	4 21	2 07	1.11	.58	32	.19	11
n= 1	2 100	1 140	691	458	260	125	087	046	030	020	013
l= 0	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1.000
n= 2	20 500	10 300	4 900	2 540	1 390	722	429	.239	143	088	054
l= 0	260	130	080	.050	030	020	020	010	001	010	000
l= 1	740	870	920	950	970	980	.980	990	1 000	990	1 000
n= 3	450	6 750	5 130	2.620	1 200	.595	296	143	080	045	021
l= 0	010	000	000	000	001	000	001	001	001	001	001
l= 1	170	200	110	050	030	030	020	020	020	030	020
l= 2	820	800	880	950	970	970	980	980	980	970	980
n= 4	181	.852	1 830	1 270	614	285	139	071	030	017	009
l= 0	010	000	000	000	001	001	001	001	001	001	001
l= 1	070	080	030	010	010	010	010	010	030	001	070
l= 2	240	380	210	210	230	260	.330	420	280	390	400
l= 3	680	530	770	780	760	730	660	560	690	610	520
n= 5	093	274	743	640	348	141	065	042	019	009	005
l= 0	030	001	001	001	001	001	001	001	001	001	001
l= 1	030	060	020	010	000	010	001	010	020	030	001
l= 2	130	310	120	120	130	200	230	270	370	410	500
l= 3	740	500	480	520	630	590	650	640	470	530	500
l= 4	080	130	380	360	230	200	130	080	140	030	001
n= 6	034	116	421	328	183	102	047	020	009	006	003
l= 0	001	001	000	001	001	001	001	001	001	001	001
l= 1	070	070	030	010	001	001	010	001	040	001	001
l= 2	210	350	100	100	100	190	110	200	320	500	330
l= 3	430	330	430	550	540	560	590	700	560	410	580
l= 4	290	240	370	290	350	250	270	050	080	090	080
l= 5	001	001	070	060	010	010	010	050	001	001	001
n= 7	010	088	205	195	118	058	031	012	006	003	001
l= 0	001	020	001	001	001	001	001	001	001	001	001
l= 1	001	020	020	010	010	020	001	001	001	001	200
l= 2	250	.270	080	080	210	110	220	170	310	400	400
l= 3	500	560	480	510	460	480	420	630	500	400	400
l= 4	250	120	340	320	280	390	330	210	190	200	001
l= 5	.001	001	080	090	040	001	020	001	001	001	001
l= 6	001	001	.001	001	001	001	001	001	001	001	001
n= 8	015	041	155	122	101	039	021	006	005	002	000
l= 0	001	001	020	001	001	001	001	001	001	001	001
l= 1	001	110	020	001	001	070	001	001	080	001	001
l= 2	170	110	110	100	140	070	160	450	330	170	500
l= 3	670	630	400	470	460	510	450	450	580	830	001
l= 4	170	160	360	360	330	330	390	090	001	001	500
l= 5	001	001	070	070	060	020	001	001	001	001	001
l= 6	001	001	010	001	010	001	001	001	001	001	001
l= 7	001	001	001	001	001	001	001	001	001	001	001

Table 3b: Total and partial electron capture cross section (in uints of 10^{-16} cm^2) for Ti^{4+}, V^{4+}, Kr^{4+}, Mo^{4+} and W^{4+}. Partial cross sections for nl substates are relative.

E(keV)	9 00	20 70	37.20	58 50	84.60	116.00	151 00	192.00	237 00	287 00	342 00
σ_{CT}	31.20	26.20	18.70	10 70	5 82	2.99	1.53	88	51	27	17
n= 1	.902	.610	470	319	.193	087	.044	.027	.020	013	008
l= 0	1.000	1.000	1.000	1.000	1.000	1 000	1.000	1.000	1 000	1.000	1 000
n= 2	10 500	5.150	3 170	1.960	1.200	678	420	.263	.162	.082	068
l= 0	170	150	120	.100	.070	.050	040	030	.020	020	020
l= 1	830	.850	.880	.900	.930	.950	.960	.970	.980	.980	980
n= 3	19 200	13.400	6.370	3.170	1 680	886	.455	.257	156	.084	046
l= 0	030	020	.010	000	.000	.000	.001	001	001	001	001
l= 1	.500	260	.130	100	.030	020	.010	010	020	010	020
l= 2	480	730	.860	900	960	.970	.990	.990	980	990	980
n= 4	385	4 980	4.440	2 330	1 180	.573	.284	142	080	040	022
l= 0	001	000	000	000	001	001	001	001	001	001	001
l= 1	050	040	010	010	.010	001	010	010	010	010	001
l= 2	180	230	140	.080	.090	090	110	110	190	210	230
l= 3	760	.730	.850	910	890	910	.880	.880	800	780	770
n= 5	142	1 140	2 180	1 300	660	343	160	088	.053	023	010
l= 0	020	001	.000	001	001	001	.001	001	001	001	001
l= 1	020	020	010	001	001	.001	001	001	001	001	040
l= 2	020	170	.060	020	050	070	.060	140	100	130	150
l= 3	.390	360	250	330	410	450	.540	470	570	570	620
l= 4	550	450	680	650	540	.480	400	.390	.340	300	190
n= 6	049	494	1 050	815	423	186	084	.052	020	015	010
l= 0	001	001	.000	.001	001	001	001	001	001	001	001
l= 1	001	020	.000	.010	010	001	001	001	001	001	040
l= 2	001	.130	040	040	020	030	040	100	090	100	080
l= 3	130	370	.200	230	290	320	340	460	470	600	650
l= 4	870	.400	480	510	500	510	540	430	440	300	230
l= 5	001	080	280	210	180	140	080	020	001	001	001
n= 7	052	231	639	504	292	134	056	039	014	009	006
l= 0	001	001	001	001	001	001	001	001	001	001	001
l= 1	060	040	000	001	001	.001	001	001	.001	001	001
l= 2	001	150	060	000	020	030	060	210	001	060	060
l= 3	.060	.210	130	190	240	280	400	330	590	440	560
l= 4	810	430	.430	500	490	530	450	420	360	440	380
l= 5	060	140	320	.280	250	150	090	.040	050	060	001
l= 6	001	.040	060	030	.010	010	001	.001	001	001	001
n= 8	032	159	323	.311	183	104	027	014	009	006	003
l= 0	001	020	.001	001	001	001	001	001	001	001	001
l= 1	001	020	001	001	001	.001	001	.001	001	001	001
l= 2	001	070	050	020	010	.070	080	060	070	080	001
l= 3	200	310	170	210	230	180	120	530	270	460	570
l= 4	500	420	360	360	380	540	760	290	600	460	430
l= 5	300	110	.350	360	350	210	040	120	070	001	001
l= 6	001	040	070	040	030	001	001	001	001	001	001
l= 7	001	020	001	010	010	001	001	001	001	001	001

Table 3c: Total and partial electron capture cross section (in uints of 10^{-16} cm^2) for Ti^{5+}, V^{5+}, Kr^{5+}, Mo^{5+} and W^{5+}. Partial cross sections for nl substates are relative.

E(keV)	9 00	22 10	41 00	65 60	96 00	132 00	174.00	222.00	276.00	335 00	400 00
σ_{CT}	40 40	34 10	24 40	13 60	7 24	3 67	1 84	1 04	57	33	17
n= 1	691	541	354	218	145	070	037	019	014	004	.005
l= 0	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000
n= 2	4 820	3 290	2 160	1 310	941	587	328	236	126	098	053
l= 0	130	140	140	130	130	080	090	030	030	060	050
l= 1	870	860	.860	870	870	920	910	970	970	940	950
n= 3	30 900	11 600	5 790	3 290	1 660	1 000	508	282	195	102	047
l= 0	090	030	010	000	000	001	000	001	001	001	001
l= 1	480	290	.180	120	060	050	020	020	030	001	001
l= 2	430	680	800	880	930	950	970	980	970	1 000	1 000
n= 4	3 630	13 300	6 620	3 220	1 670	747	353	187	093	053	026
l= 0	000	000	001	000	001	001	001	001	001	001	001
l= 1	140	050	020	000	001	000	001	001	001	001	001
l= 2	650	300	160	090	050	020	090	050	050	050	020
l= 3	200	650	820	910	950	970	910	950	950	950	980
n= 5	178	3 440	4 530	2 180	1 110	501	245	138	056	036	016
l= 0	020	001	001	001	001	001	001	001	001	001	001
l= 1	020	010	000	000	001	001	001	001	001	001	030
l= 2	050	090	030	020	010	010	040	050	050	040	160
l= 3	050	270	210	190	200	230	330	310	490	470	450
l= 4	860	630	760	790	790	770	640	640	460	490	350
n= 6	087	1 080	2 360	1 510	757	308	147	081	027	017	008
l= 0	001	001	000	001	001	001	001	001	001	001	001
l= 1	001	010	000	000	001	001	001	001	001	001	001
l= 2	050	080	020	010	010	010	030	040	001	080	130
l= 3	050	180	110	070	130	130	250	150	420	360	330
l= 4	480	400	360	460	460	570	540	640	520	480	530
l= 5	430	340	510	460	400	300	180	170	060	080	001
n= 7	050	419	1 320	829	422	209	107	053	031	007	008
l= 0	001	001	001	001	001	001	001	001	001	001	001
l= 1	001	020	000	001	001	001	001	001	001	001	001
l= 2	001	060	020	010	020	001	001	040	030	090	070
l= 3	080	220	090	060	130	110	200	190	190	180	600
l= 4	170	320	240	340	380	360	500	430	670	640	270
l= 5	750	290	430	420	390	470	270	320	110	090	070
l= 6	001	090	220	170	090	060	030	020	001	001	001
n= 8	050	260	805	625	326	134	069	028	013	007	006
l= 0	001	001	001	001	001	001	001	001	001	001	001
l= 1	001	010	010	001	001	001	001	001	001	001	001
l= 2	001	040	010	001	001	010	001	040	070	300	090
l= 3	001	210	070	050	090	080	150	160	270	200	270
l= 4	250	430	170	230	360	400	330	480	530	400	550
l= 5	750	230	400	400	390	400	460	320	130	100	090
l= 6	001	040	280	290	150	110	060	001	001	001	001
l= 7	001	030	050	030	010	001	001	001	001	001	001

Table 3c: cont.

n= 9	021	126	.504	455	202	.117	.047	.019	014	.005	003
l= 0	001	.001	001	001	001	.001	.001	.001	001	001	001
l= 1	001	001	.001	001	001	.001	001	.001	001	001	001
l= 2	001	001	010	010	001	.020	.001	.060	130	250	.200
l= 3	001	210	.060	.030	.050	.080	.120	.120	.250	250	200
l= 4	400	290	160	220	420	310	.360	.470	310	380	600
l= 5	400	.210	400	410	340	480	.420	.290	310	001	001
l= 6	200	260	270	280	.170	110	.090	.060	001	130	001
l= 7	001	030	.090	060	020	001	.001	.001	001	001	.001
l= 8	001	001	.001	001	001	001	.001	.001	001	001	001

Table 3d: Total and partial electron capture cross section (in uints of 10^{-16} cm^2) for Ti^{6+}, V^{6+}, Kr^{6+}, Mo^{6+} and W^{6+}. Partial cross sections for nl substates are relative.

E(keV)	16 00	31 40	51 80	77 40	108 00	144 00	185 00	231 00	282 00	339.00	400 00
σ_{CT}	46 10	37 70	25 10	14 50	7 81	4 25	2.50	1 40	84	52	32
n= 1	471	320	263	186	157	064	052	020	005	011	003
l= 0	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 000
n= 2	2 540	1 960	1 340	1 030	678	410	312	180	142	.090	068
l= 0	090	130	110	110	120	130	110	100	100	040	020
l= 1	910	870	890	890	880	870	890	900	900	960	980
n= 3	11 100	6 640	4 250	2 630	1 560	1 010	664	379	215	145	091
l= 0	070	040	020	010	010	000	000	001	001	.010	001
l= 1	320	260	200	150	090	090	070	060	030	010	040
l= 2	610	700	780	840	900	910	930	940	970	980	960
n= 4	25 600	11 500	6 070	3 120	1 790	880	488	319	189	101	057
l= 0	010	000	000	001	001	001	001	001	001	001	001
l= 1	140	060	020	010	000	001	001	001	001	010	001
l= 2	430	280	150	080	050	040	040	030	050	010	090
l= 3	430	660	820	910	950	960	960	970	950	980	910
n= 5	5 340	9 720	5 280	2 580	1 320	650	391	181	106	072	047
l= 0	001	001	000	001	001	001	001	001	001	001	001
l= 1	010	010	010	001	001	001	001	001	001	001	001
l= 2	130	060	020	010	000	010	010	001	040	010	070
l= 3	400	240	160	090	120	150	110	160	230	230	340
l= 4	460	690	810	900	870	830	880	840	740	760	590
n= 6	619	4 210	3 460	2 050	958	496	273	125	074	041	024
l= 0	001	001	001	001	001	001	001	001	001	001	001
l= 1	001	000	000	001	001	001	001	001	001	001	001
l= 2	040	020	010	000	000	000	001	010	020	001	070
l= 3	160	100	060	030	050	080	090	130	070	120	240
l= 4	400	260	270	330	370	370	480	470	710	730	590
l= 5	400	620	660	640	570	550	430	360	200	150	100
n= 7	205	1 940	2 210	1 250	581	318	176	091	045	022	017
l= 0	001	001	001	001	001	001	001	001	001	001	001
l= 1	001	001	001	001	001	001	001	001	001	001	001
l= 2	020	010	010	001	000	001	020	050	001	050	050
l= 3	120	050	030	030	030	050	070	070	080	090	330
l= 4	260	190	140	230	230	230	420	360	580	550	480
l= 5	510	330	440	460	550	590	440	400	280	320	140
l= 6	090	410	390	280	180	130	050	120	060	001	001
n= 8	138	917	1 360	938	446	225	081	073	035	021	005
l= 0	001	001	001	001	001	001	001	001	001	001	001
l= 1	001	001	001	001	001	001	001	001	001	001	001
l= 2	001	010	010	001	001	010	001	001	001	050	001
l= 3	070	090	030	010	010	050	050	090	001	140	001
l= 4	140	180	090	130	220	220	260	430	430	620	670
l= 5	660	270	310	390	440	490	570	130	500	190	330
l= 6	100	330	450	380	310	200	120	060	070	001	001
l= 7	030	120	110	090	030	020	001	001	001	001	001

Table 3d: cont.

n= 9	100	537	887	708	309	192	.068	033	.026	014	010
l= 0	001	001	.001	.001	001	.001	001	001	.001	001	.001
l= 1	001	001	001	.001	001	001	.001	001	001	001	001
l= 2	001	020	020	001	001	.001	.001	050	001	001	001
l= 3	.001	.060	.010	.000	.030	.020	.060	100	.050	140	170
l= 4	.240	230	.070	.080	.190	190	.260	240	290	500	420
l= 5	620	.230	.300	.440	390	370	.490	480	570	360	420
l= 6	140	250	.360	340	300	350	.140	140	100	001	001
l= 7	001	200	.190	120	060	070	.060	001	001	001	001
l= 8	001	.010	.060	010	040	001	.001	001	001	001	.001

Table 3e: Total and partial electron capture cross section (in uints of 10^{-16} cm^2) for Ti^{7+}, V^{7+}, Kr^{7+}, Mo^{7+} and W^{7+} Partial cross sections for nl substates are relative.

E(keV)	16 00	34 20	59 30	91 20	130 00	176 00	228 00	287 00	353 00	426.00	506 00
σ_{CT}	55 00	44 20	27.80	14 40	7 61	3 82	2 04	1.13	68	35	23
n= 2	1 760	1 300	1 140	745	449	302	.172	104	087	051	043
l= 0	080	060	.100	090	150	110	160	.130	030	020	060
l= 1	920	940	900	910	850	890	.840	870	970	.980	940
n= 3	7 440	4.780	3 300	2 200	1 300	717	485	265	164	.091	068
l= 0	080	070	020	010	010	010	.000	010	001	001	001
l= 1	320	270	240	190	140	100	080	060	070	020	030
l= 2	600	660	740	790	860	900	920	930	930	980	980
n= 4	24 100	10 200	5 340	2 750	1 580	814	440	290	143	061	043
l= 0	020	010	000	000	001	001	001	001	001	001	001
l= 1	200	100	020	010	010	000	001	001	001	001	001
l= 2	370	280	190	120	060	050	020	020	050	020	040
l= 3	410	610	780	870	940	950	980	980	950	980	960
n= 5	19 400	12 500	5 650	2 510	1 310	677	311	167	103	050	028
l= 0	000	001	001	001	001	001	001	001	001	001	001
l= 1	030	010	000	001	001	001	001	001	001	001	001
l= 2	200	080	020	010	000	001	010	001	010	020	001
l= 3	450	290	130	090	070	080	080	090	170	190	300
l= 4	320	620	840	900	930	920	920	910	820	790	700
n= 6	1 540	7 980	4 380	2 120	1 030	418	217	106	062	043	019
l= 0	001	001	001	001	001	001	001	001	001	001	001
l= 1	001	001	001	001	001	001	001	001	001	001	001
l= 2	020	020	010	010	000	010	001	030	040	050	090
l= 3	160	080	040	020	020	010	050	050	040	080	180
l= 4	400	250	200	180	210	220	300	440	460	520	450
l= 5	420	660	750	790	770	760	650	480	460	350	270
n= 7	412	3 940	3 240	1 530	823	343	174	065	047	016	011
l= 0	001	001	001	001	001	001	001	001	001	001	001
l= 1	010	001	001	001	001	001	001	001	001	001	001
l= 2	010	010	010	001	001	001	001	001	001	001	001
l= 3	080	050	010	000	040	020	050	080	001	070	001
l= 4	230	140	090	110	130	160	220	240	430	470	310
l= 5	480	280	360	420	490	540	510	680	540	470	620
l= 6	180	520	530	470	350	270	220	001	030	001	080
n= 8	170	1 890	2 160	1 110	522	254	092	068	035	013	009
l= 0	001	001	001	001	001	001	001	001	001	001	001
l= 1	001	001	001	001	001	001	001	001	001	001	001
l= 2	030	000	001	000	001	010	001	001	001	080	001
l= 3	030	020	020	000	010	040	070	030	040	001	270
l= 4	130	140	060	070	060	150	120	220	270	580	270
l= 5	400	190	230	320	290	440	470	600	580	330	180
l= 6	330	310	430	410	520	320	300	150	120	001	270
l= 7	070	320	260	190	120	040	050	001	001	001	001

Table 3e: cont.

n= 9	107	.960	1 530	.870	.358	169	.105	041	024	014	005
l= 0	.001	.001	.001	001	.001	.001	001	001	001	.001	001
l= 1	.001	001	.001	001	.001	001	001	001	.001	.001	001
l= 2	.001	.010	.001	001	.001	.001	001	001	060	.001	001
l= 3	001	050	.000	.010	.020	030	060	001	001	150	001
l= 4	110	100	.060	.050	.070	100	120	170	390	380	500
l= 5	370	240	180	250	290	400	470	540	440	380	500
l= 6	470	240	.330	.400	370	400	.240	250	110	080	000
l= 7	050	.250	340	.240	.250	080	100	040	001	001	.000
l= 8	001	110	090	.050	001	001	001	001	001	001	000
n= 10	073	720	1 060	.525	243	126	043	022	015	006	.004
l= 0	001	.001	.001	001	001	001	001	001	001	001	000
l= 1	001	010	001	001	.001	001	001	001	001	001	000
l= 2	001	001	001	001	001	001	001	001	.001	001	000
l= 3	001	030	000	.001	010	001	001	080	090	170	000
l= 4	080	140	030	030	040	090	050	150	360	001	000
l= 5	150	110	140	200	280	300	650	380	270	670	000
l= 6	620	370	290	340	320	450	250	310	270	170	000
l= 7	150	210	360	310	320	130	050	080	001	001	000
l= 8	001	110	150	.130	010	040	.001	001	001	001	.000
l= 9	001	020	030	001	001	001	001	001	001	001	000

Table 3f: Total and partial electron capture cross section (in uints of 10^{-16} cm^2) for Ti^{8+}, V^{8+}, Kr^{8+}, Mo^{8+} and W^{8+}. Partial cross sections for nl substates are relative.

E(keV)	25 00	49.00	81.00	121 00	169 00	225.00	289 00	361 00	441 00	529 00	625 00
σ_{CT}	59 00	40 90	22 00	10 70	5 56	2 72	1 57	86	46	28	17
n= 2	1 310	.907	.689	402	.301	173	145	076	050	041	021
l= 0	.050	.070	060	110	.140	080	110	.070	110	080	040
l= 1	950	.930	940	890	.860	920	890	.930	.890	920	960
n= 3	4 730	3 320	2 060	1.410	.861	.466	329	180	115	067	.049
l= 0	060	050	030	020	.010	001	.001	001	001	001	001
l= 1	290	290	210	190	170	.200	120	.100	080	070	040
l= 2	650	.660	760	790	820	800	880	.900	920	930	960
n= 4	11 500	6 310	3 720	2 080	1 040	623	347	183	093	062	047
l= 0	020	010	001	001	001	001	001	001	001	001	001
l= 1	150	070	030	020	000	001	001	001	010	001	001
l= 2	320	230	150	100	040	040	010	020	010	050	040
l= 3	520	690	820	890	960	960	990	980	970	950	960
n= 5	20 600	8 180	4 080	1 900	1 040	461	271	136	071	036	021
l= 0	000	001	001	001	001	001	001	001	001	001	001
l= 1	030	010	000	001	001	001	001	001	001	001	001
l= 2	160	050	010	000	000	001	.010	010	060	001	040
l= 3	350	240	100	060	050	060	070	050	080	180	170
l= 4	450	700	890	940	950	940	920	940	860	820	790
n= 6	14 100	8 000	3 790	1 660	774	304	180	099	045	031	014
l= 0	001	001	001	001	001	001	001	.001	001	001	001
l= 1	000	000	001	001	001	001	001	001	001	001	001
l= 2	030	010	000	001	001	001	001	040	001	001	001
l= 3	150	050	020	010	.010	060	040	090	001	180	060
l= 4	340	200	130	170	140	240	310	270	410	640	690
l= 5	470	740	840	830	850	710	650	610	590	180	250
n= 7	4 340	6 220	2 550	1 210	598	271	111	077	036	011	009
l= 0	001	001	001	001	001	001	001	001	001	001	001
l= 1	001	000	001	001	001	001	001	001	001	001	001
l= 2	010	000	000	001	001	001	020	001	001	001	001
l= 3	060	020	010	010	001	020	040	050	040	200	100
l= 4	190	100	050	050	080	120	180	070	230	300	300
l= 5	280	250	320	390	430	530	540	770	650	400	600
l= 6	460	630	620	560	490	330	220	110	080	100	001
n= 8	1 490	3 680	2 240	913	391	195	087	051	022	015	005
l= 0	001	001	001	001	001	001	001	001	001	001	001
l= 1	001	001	000	001	001	001	001	001	001	001	001
l= 2	010	000	000	000	001	010	001	001	001	001	001
l= 3	050	020	000	001	010	040	001	001	001	070	001
l= 4	160	050	030	020	070	060	001	100	190	360	500
l= 5	230	140	160	190	240	530	380	620	690	570	330
l= 6	300	360	400	460	540	290	540	280	130	001	170
l= 7	250	430	410	320	140	070	080	001	001	001	001

Table 3f: cont.

n= 9	635	2 620	1.690	.678	290	123	058	037	017	010	003
l= 0	001	001	001	.001	.001	001	001	001	001	001	001
l= 1	001	.001	.001	.001	001	001	001	001	001	001	001
l= 2	001	.001	.001	001	001	.001	001	001	080	001	.001
l= 3	070	.010	001	001	.001	.020	.080	050	080	001	250
l= 4	150	020	010	010	050	090	150	001	.500	220	001
l= 5	.180	100	.140	.200	200	230	.350	.480	170	560	500
l= 6	.280	270	340	.460	460	500	310	.430	.170	.220	250
l= 7	210	380	360	290	290	160	120	050	001	001	.001
l= 8	120	.230	.150	040	001	001	001	001	001	001	001
n= 10	317	1 620	1 120	494	.256	101	.040	018	010	005	002
l= 0	001	001	.001	001	001	001	001	001	001	001	001
l= 1	001	001	001	.001	001	001	001	001	001	001	001
l= 2	020	001	001	001	001	001	001	.001	001	001	001
l= 3	001	.000	001	001	030	001	060	001	290	001	001
l= 4	100	040	010	010	010	030	170	200	140	200	500
l= 5	290	080	.070	080	160	310	390	400	430	600	500
l= 6	290	210	.310	340	460	560	280	400	140	200	001
l= 7	140	290	350	420	270	.110	.110	.001	001	001	.001
l= 8	140	290	240	140	070	001	001	001	001	001	001
l= 9	020	080	020	001	001	001	001	001	001	001	001

Table 3g: Total and partial electron capture cross section (in units of 10^{-16} cm^2) for Ti^{9+}, V^{9+}, Kr^{9+}, Mo^{9+} and W^{9+}. Partial cross sections for nl substates are relative.

E(keV)	25 00	49 00	81 00	121 00	169 00	225.00	289 00	361 00	441 00	529 00	625 00
σ_{CT}	67 10	48 40	26 60	13 20	7.07	3 53	1 92	1 07	62	30	21
n= 3	3 570	2 560	1 920	1 450	855	566	322	.187	153	076	064
l= 0	070	060	040	.010	000	.020	001	001	001	001	001
l= 1	280	230	240	230	.200	180	160	110	080	060	090
l= 2	650	.700	720	750	790	.800	.840	890	920	940	910
n= 4	9 180	5 800	3 660	2 120	1 290	.673	.453	232	124	073	046
l= 0	040	010	001	001	000	.001	001	001	001	001	001
l= 1	170	130	050	030	010	.010	.010	010	001	001	001
l= 2	310	260	230	150	100	060	.040	050	010	040	030
l= 3	490	600	720	830	890	930	940	940	990	960	980
n= 5	17 800	8 360	4 430	2 320	1 270	604	297	238	088	065	031
l= 0	000	000	001	001	.001	001	001	001	001	001	001
l= 1	060	020	000	001	001	001	001	001	001	001	001
l= 2	200	090	010	000	001	001	001	001	001	001	001
l= 3	320	270	160	100	060	050	040	090	060	180	070
l= 4	410	620	820	890	940	950	960	910	940	820	930
n= 6	22 500	9.500	4 350	1 840	980	.524	297	121	074	024	025
l= 0	000	001	001	001	001	001	.001	001	001	001	001
l= 1	010	000	001	001	001	001	001	001	001	001	001
l= 2	060	010	001	001	001	001	001	001	001	060	001
l= 3	200	080	030	010	010	020	060	040	050	001	090
l= 4	350	250	110	100	090	130	.180	190	240	350	410
l= 5	390	660	860	890	900	860	760	780	710	590	500
n= 7	9 790	8 320	3 700	1 670	813	400	171	103	068	016	015
l= 0	001	001	001	001	001	001	001	001	001	001	001
l= 1	000	001	001	001	001	001	001	001	001	001	001
l= 2	020	010	001	000	001	001	001	040	001	001	001
l= 3	070	010	000	000	001	001	001	001	110	001	150
l= 4	180	080	020	030	060	100	080	110	160	180	080
l= 5	330	230	220	250	240	340	330	570	500	730	770
l= 6	410	670	750	710	700	550	590	280	240	090	001
n= 8	2 550	5 910	2 960	1 410	620	290	115	074	049	003	013
l= 0	001	001	001	001	001	001	001	001	001	001	001
l= 1	000	001	001	001	001	001	001	001	001	001	001
l= 2	010	001	001	001	001	001	001	001	001	001	001
l= 3	030	020	000	001	001	001	070	060	040	001	001
l= 4	130	040	010	010	070	050	070	090	150	500	180
l= 5	230	120	100	110	160	190	170	390	260	500	640
l= 6	270	280	410	440	480	570	540	450	520	001	180
l= 7	330	550	480	430	300	190	150	001	040	001	001

Table 3g: cont.

n= 9	959	3.710	2 380	1 080	.461	190	126	052	032	.020	009
l= 0	001	001	001	001	.001	001	.001	001	.001	.001	001
l= 1	001	001	.001	001	001	001	001	001	.001	001	001
l= 2	001	001	001	001	001	001	001	001	001	001	001
l= 3	030	001	.000	001	001	.040	001	040	.060	.001	130
l= 4	.100	030	000	010	020	.040	090	001	170	.001	.380
l= 5	.190	070	090	.100	100	130	.200	.350	220	.640	130
l= 6	240	170	240	280	390	450	490	.520	280	290	380
l= 7	260	.360	370	410	390	290	200	.090	280	070	.001
l= 8	180	370	290	210	100	050	020	001	001	001	001
n= 10	462	2 670	1 720	651	390	138	078	036	018	010	005
l= 0	001	001	001	001	001	001	001	001	001	001	.001
l= 1	001	001	001	001	001	001	001	001	001	001	.001
l= 2	001	001	001	001	001	001	001	001	.001	001	001
l= 3	020	000	001	001	001	050	001	001	001	.001	.001
l= 4	060	030	010	001	020	.100	001	001	100	140	500
l= 5	200	070	020	080	080	001	140	380	400	140	.250
l= 6	.340	140	180	190	280	430	570	500	500	710	250
l= 7	230	280	.350	440	480	300	290	130	001	001	001
l= 8	090	310	330	240	130	.100	001	001	.001	001	001
l= 9	060	170	110	050	010	030	001	001	001	.001	001
n= 11	206	1 550	1 450	651	394	.148	059	027	011	012	.006
l= 0	001	001	001	001	001	001	001	001	001	.001	001
l= 1	.001	001	.001	001	.001	.001	001	.001	001	001	001
l= 2	001	001	001	001	001	001	001	001	001	001	001
l= 3	001	000	000	001	001	001	001	001	170	130	.001
l= 4	070	030	000	010	020	001	001	080	170	250	200
l= 5	170	060	020	030	100	090	190	250	330	001	400
l= 6	310	130	140	170	280	300	430	500	170	500	400
l= 7	310	220	310	360	380	490	290	080	170	130	001
l= 8	140	290	350	330	160	120	100	080	001	001	001
l= 9	.001	220	.170	100	060	.001	001	001	001	001	001
l= 10	001	040	010	010	001	001	001	001	001	001	001

Table 3h: Total and partial electron capture cross section (in uints of 10^{-16} cm^2) for Ti^{10+}, V^{10+}, Kr^{10+}, Mo^{10+} and W^{10+}. Partial cross sections for nl substates are relative

E(keV)	25 00	49 00	81 00	121 00	169 00	225 00	289 00	361 00	441 00	529 00	625 00
σ_{CT}	76 40	55 30	29 80	15 70	8 22	4 62	2 32	1 37	81	48	24
n= 3	2 950	2 480	1 780	1 010	736	472	321	237	151	133	067
l= 0	060	070	040	050	.020	020	.030	010	001	010	001
l= 1	270	250	250	290	300	.250	160	150	100	080	130
l= 2	670	680	700	660	680	730	810	.840	900	900	870
n= 4	7 310	5 380	3 110	2 030	1 430	911	443	314	151	106	049
l= 0	030	020	010	000	001	.001	001	001	001	001	001
l= 1	190	140	070	030	040	000	010	001	001	001	001
l= 2	320	260	270	230	.170	090	040	050	001	050	030
l= 3	470	580	660	740	800	900	950	.950	1 000	950	970
n= 5	15 000	7 840	4 380	2 800	1 260	832	382	228	135	075	040
l= 0	010	001	001	001	001	001	001	001	001	001	001
l= 1	080	010	001	001	001	001	001	001	001	001	001
l= 2	210	090	030	010	000	001	001	001	020	001	070
l= 3	290	270	200	110	.060	040	030	060	080	050	040
l= 4	410	620	760	880	940	960	970	940	900	950	890
n= 6	24 300	9 960	4 950	2 390	1 330	700	365	220	124	049	022
l= 0	000	001	001	001	001	001	001	001	001	001	001
l= 1	020	000	000	001	001	001	001	001	001	001	001
l= 2	090	010	000	000	001	001	001	001	001	040	001
l= 3	210	100	010	000	010	010	020	010	001	001	001
l= 4	350	270	150	090	120	090	090	150	070	260	330
l= 5	340	620	830	910	870	890	890	840	930	700	670
n= 7	18 700	10 000	4 540	2 310	914	493	273	122	093	049	022
l= 0	001	001	001	001	001	001	001	001	001	001	001
l= 1	000	001	001	001	001	001	001	001	001	001	001
l= 2	010	000	001	001	001	001	001	001	001	001	001
l= 3	080	020	000	001	001	001	010	001	020	040	001
l= 4	210	090	020	000	030	030	080	090	070	110	330
l= 5	330	240	180	190	220	210	290	410	560	590	530
l= 6	370	640	800	810	760	760	630	500	340	260	130
n= 8	5 650	7 600	3 700	1 810	954	493	191	086	065	024	019
l= 0	001	001	001	001	001	001	001	001	001	001	001
l= 1	001	000	001	001	001	001	001	001	001	001	001
l= 2	000	001	001	001	001	001	001	001	001	001	001
l= 3	030	000	001	001	001	001	020	001	001	080	001
l= 4	090	030	010	001	020	070	110	030	030	230	080
l= 5	210	100	060	070	060	080	200	160	310	230	620
l= 6	310	270	310	350	370	400	.520	770	480	460	310
l= 7	360	590	620	580	540	450	160	030	170	001	001

Table 3h: cont.

n= 9	1 550	5 880	3 160	1 410	647	282	143	064	041	018	012
l= 0	001	001	001	001	001	001	001	001	001	001	001
l= 1	001	001	001	001	001	001	001	001	001	001	001
l= 2	001	001	000	001	001	001	001	001	001	001	001
l= 3	010	010	000	001	001	001	070	040	001	001	001
l= 4	060	010	010	010	020	010	.050	040	060	001	.001
l= 5	190	070	040	060	080	.090	.210	260	220	300	500
l= 6	200	140	160	220	.300	350	310	300	610	600	380
l= 7	260	300	380	400	400	400	260	260	110	100	130
l= 8	290	460	400	310	200	150	100	090	001	001	001
n= 10	663	3 600	2 230	1 130	544	203	130	042	027	018	007
l= 0	001	001	001	001	001	001	001	001	001	001	.001
l= 1	001	001	001	001	001	001	001	001	001	001	001
l= 2	001	001	001	001	001	001	001	001	001	001	.001
l= 3	020	000	000	001	001	001	050	001	001	001	.001
l= 4	040	020	000	010	010	020	001	130	001	100	001
l= 5	110	050	010	010	060	040	080	130	500	200	600
l= 6	360	110	100	190	220	370	420	400	330	600	200
l= 7	280	180	340	350	360	390	340	330	170	100	200
l= 8	120	350	330	290	280	160	110	001	001	001	.001
l= 9	070	290	210	150	060	020	001	001	001	001	001
n= 11	264	2 570	1 970	791	410	232	075	053	018	011	000
l= 0	001	001	001	001	001	001	001	001	001	001	000
l= 1	001	001	001	001	001	001	001	001	001	001	000
l= 2	001	001	001	001	001	001	001	001	001	001	000
l= 3	001	000	001	001	001	001	050	001	001	001	000
l= 4	030	020	000	001	001	020	001	050	130	001	000
l= 5	150	040	010	010	070	090	140	110	001	330	000
l= 6	270	100	090	090	140	290	180	470	500	670	000
l= 7	240	190	260	310	280	360	550	210	380	001	000
l= 8	180	300	280	370	390	210	090	160	001	001	000
l= 9	120	240	290	190	110	040	001	001	001	001	000
l= 10	001	120	060	030	010	001	001	001	001	001	000

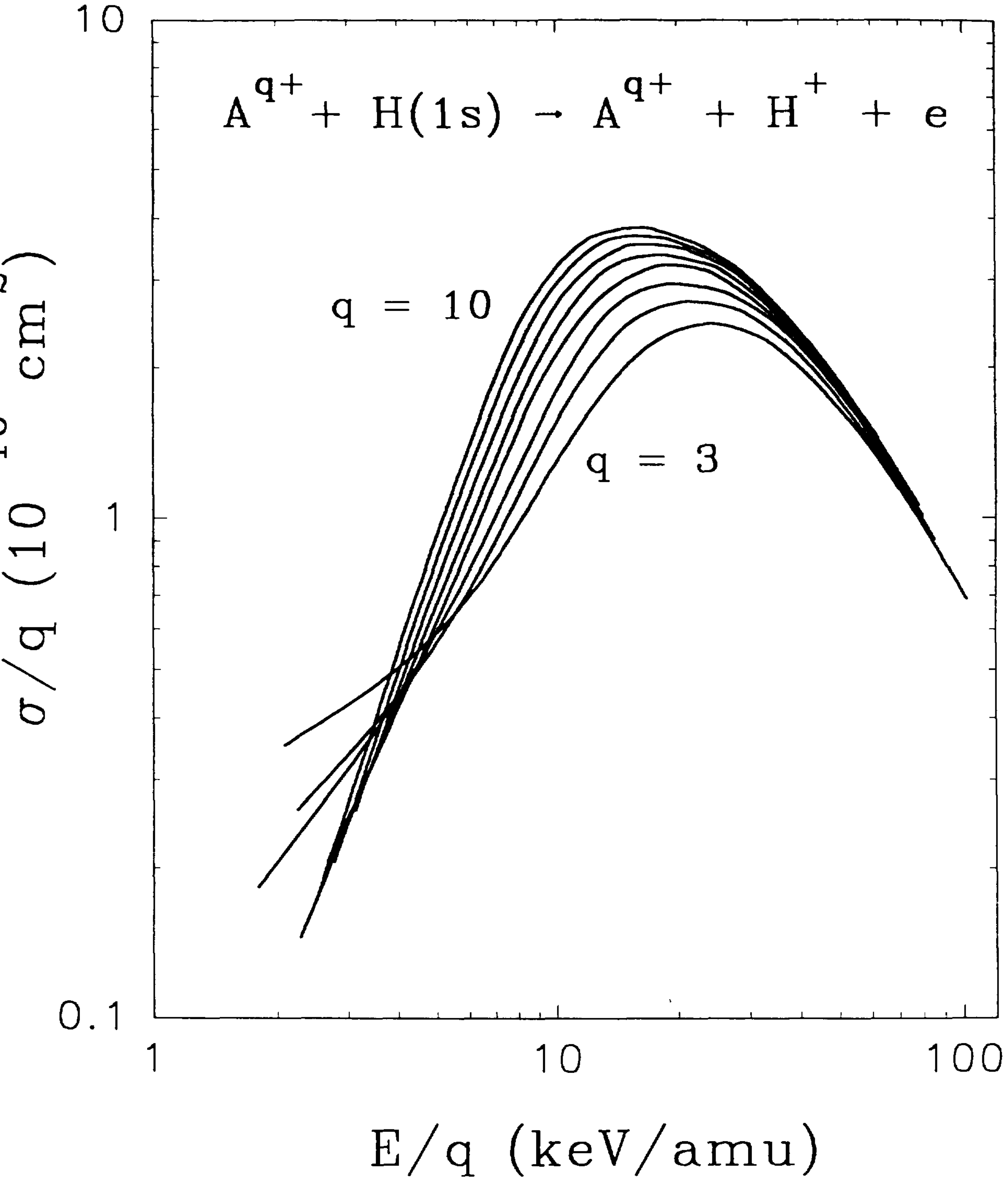

Figure 1 Reduced ionization cross section (in units of 10^{-16} cm^2) of H(1s) by impact of A^{q+}, (A= Be, B, Al, Ti, V, Kr, and W; q=3-10)

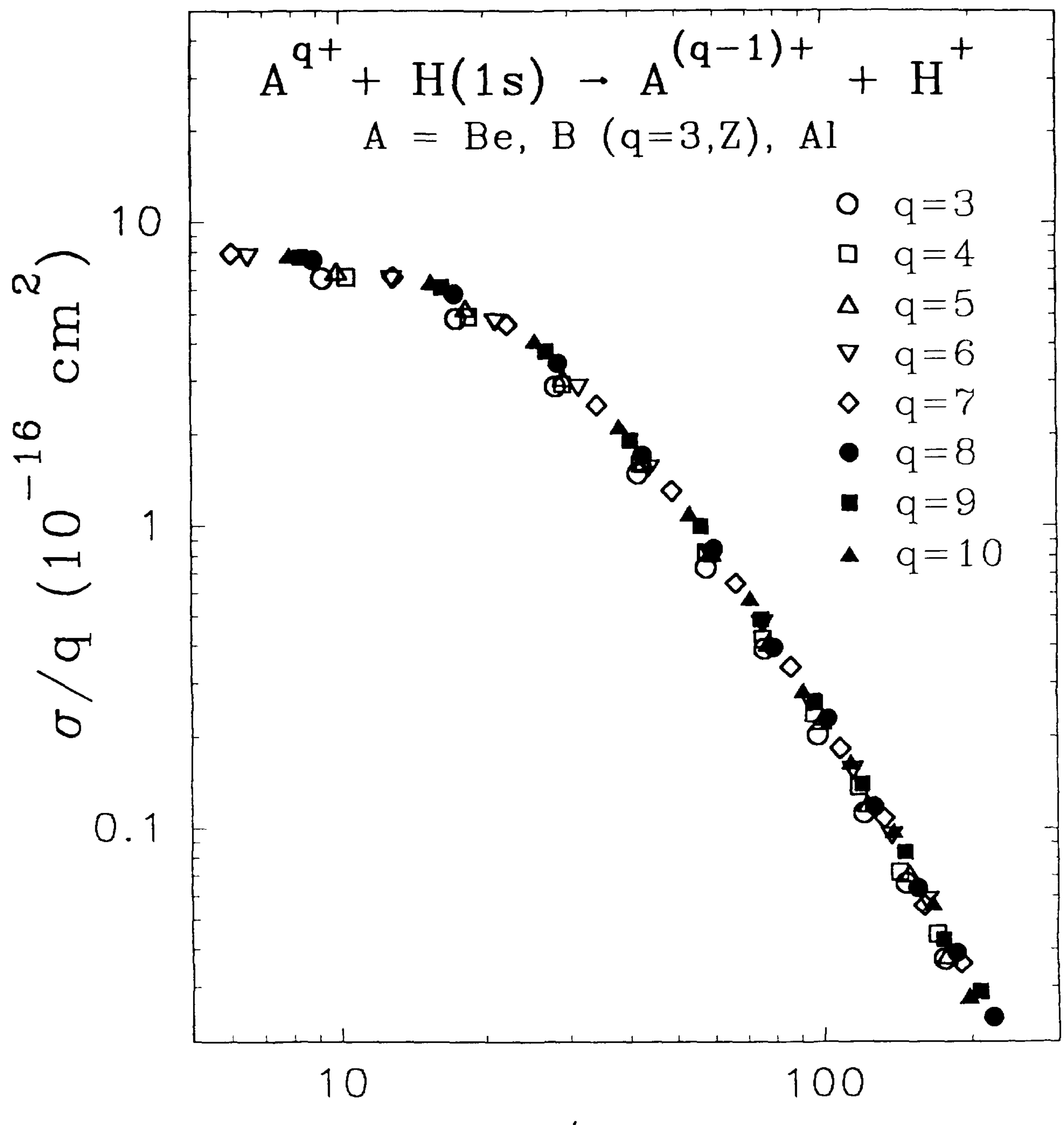

Figure 2 Reduced charge transfer cross section (in units of 10^{-16} cm^2) of H(1s) by impact of A^{q+}, (A= Be, B (q=3-Z), Al q=3-10).

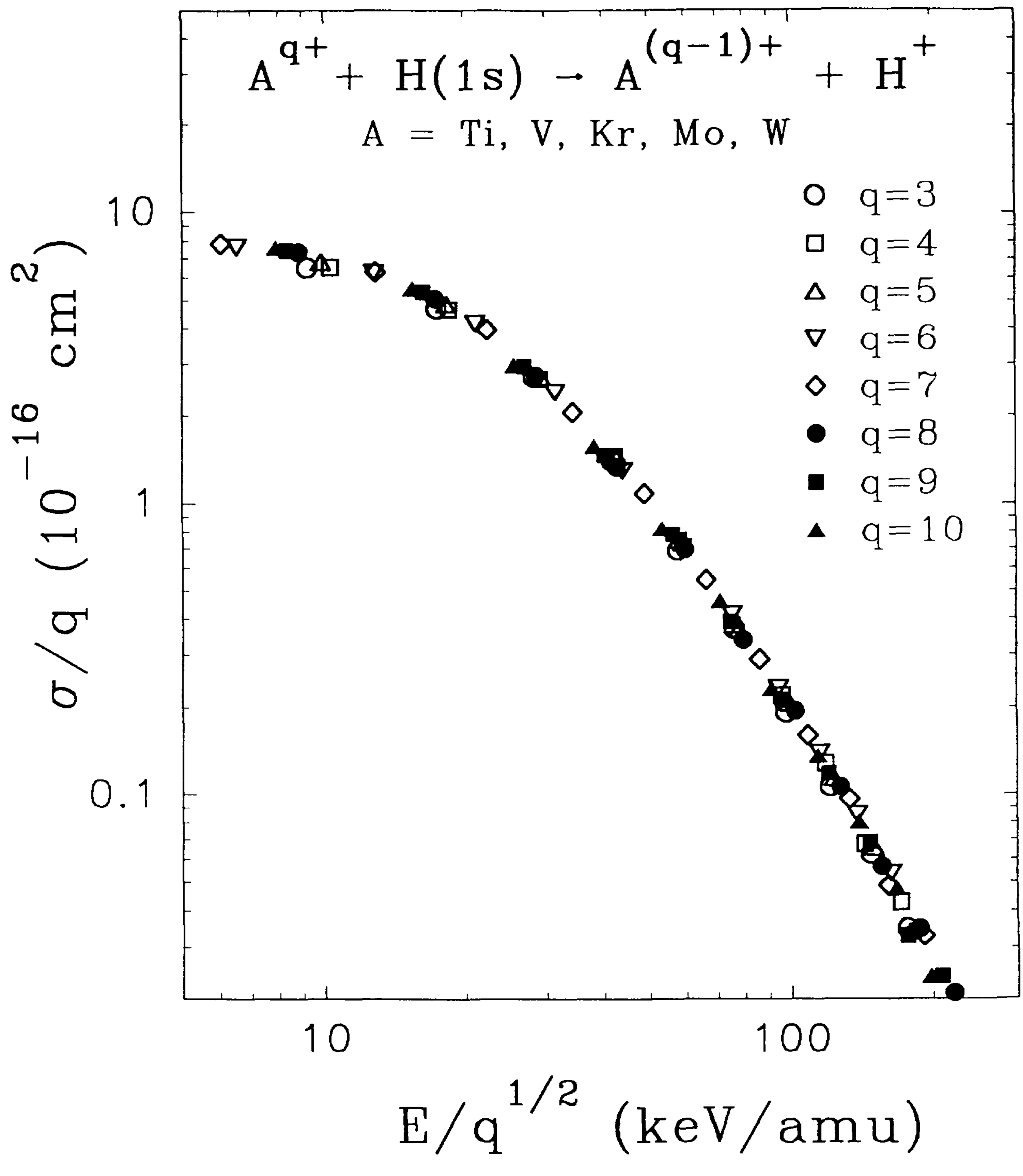

Figure 3 Reduced charge transfer cross section (in units of 10^{-16} cm^2) of H(1s) by impact of A^{q+}, (A= Ti, V, Kr, and W; q=3-10)