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Projectile electron loss, excitation and de-excitation cross section database in a collision between two hydrogen atoms in the impact energy range between 50 keV–5.0 MeV, Part I: Target is in ground state

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A B S T R A C T

We present projectile electron loss, excitation, and de-excitation cross-sections database for $H(nl) + H(1s)$ collision system. A four-body classical trajectory Monte Carlo (CTMC) and a quasi-classical trajectory Monte Carlo (QCTMC) methods were employed in the projectile energy range between 50 keV to 5.0 MeV.

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Contents

1. Introduction

The atomic collision processes played an important role in fusion energy research [1] and also in astrophysics science, especially in the intermediate to high energy regime. Impurities in the fusion chamber including neutrals undergone a lot of interactions with ions and also with neutral atoms, which originated from the wall tiles composition and from the cooling processes [2–4]. The various aspects of plasma and neutral collisions are given in a few previous works [5–9]. In the fusion reactor, the limiter and divertor act as the main source of neutrals such as hydrogen atoms.

Because both the experimental and theoretical studies are hard to perform for collision between two hydrogen atoms only very limited works are available for the study of this collision system [10–16]. Bailey et al. [12] provided the projectile ionization cross-sections using the convergent close coupling (CCC) method. Bates and Griffing [13] and McLaughlint and Bell [14] calculated the projectile excitation cross sections in a collision between two ground-state hydrogen atoms when the target remains at any state after collisions. Recently, classical trajectory Monte Carlo (CTMC) calculations for determining the ionization and excitation cross-sections in hydrogen–hydrogen collisions were presented [15,16]. It was shown that the CTMC method can be applied with great success in atomic collisions using three, four or more particles [16]. One of the advantages of the CTMC method is that many-body interactions are exactly taken into account during the collisions on a classical level. The quasi-classical trajectory Monte Carlo model of the Kirschbaum and Wilets (QCTMC) is an improved version of the standard CTMC model by including quantum mechanical principles for the description of the classical atomic collisions [17].

In this work, we present a cross-sections database for $H(nl)+H(1s)$ collision system in the energy range between 50 keV to 5.0 MeV using both the CTMC and QCTMC models. This energy range covers the typical energies for astrophysical and plasma researches, including the edge plasmas of thermonuclear fusion devices. The main purpose of the present work is to provide the cross-section data of the inelastic collision processes, like projectile electron loss, excitation, and de-excitation, Atomic units are used throughout unless stated otherwise.

2. The applied theoretical approaches

2.1. The standard four-body CTMC model

In our model, the four particles (the target nucleus, the electron of the target, the electron of the projectile, and the projectile nucleus) are represented by their masses and charges. The projectile nucleus is denoted by P, the electron of the projectile by P_e, the target nucleus by T and the electron of the target by T_e. The electron–electron interaction is explicitly included in our four-body calculation. At the time ($t=-\infty$), we consider four particles as two isolated atoms. We used Coulomb potential [18] for describing all interactions. The Hamiltonian of the system can be expressed as:

$$H_0 = T + V_{coul}, \tag{1}$$

where

$$T = \frac{\vec{P}_p^2}{2m_p} + \frac{\vec{P}_{pe}^2}{2m_{pe}} + \frac{\vec{P}_T^2}{2m_T} + \frac{\vec{P}_{Te}^2}{2m_{Te}}, \tag{2}$$

and

$$V_{coul} = \frac{Z_p Z_{Pe}}{|\vec{r}_p - \vec{r}_{Pe}|} + \frac{Z_P Z_T}{|\vec{r}_P - \vec{r}_T|} + \frac{Z_p Z_{Te}}{|\vec{r}_p - \vec{r}_{Te}|} + \frac{Z_{pe} Z_T}{|\vec{r}_{pe} - \vec{r}_T|} + \frac{Z_{Pe} Z_{Te}}{|\vec{r}_{pe} - \vec{r}_{Te}|} + \frac{Z_T Z_{Te}}{|\vec{r}_T - \vec{r}_{Te}|}, \tag{3}$$

where T and V_{coul} are total kinetic energy and the coulomb potential term. $\vec{r}$, $\vec{p}$, Z, and m are the position vector, momentum vector, the charge, and the mass of the corresponding particles, respectively. From Eq. (1), the Hamilton's equations are determined by:

$$\dot{\vec{r}}_{ij} = \frac{\partial H}{\partial \vec{p}_{ij}}, \qquad \dot{\vec{p}}_{ij} = -\frac{\partial H}{\partial \vec{r}_{ij}}, \tag{4}$$

where $i = P, T, T_e, P_e; \qquad j = x, y, z$.

The equations of motion considering Hamiltonian mechanics are given as follows:

$$\dot{\vec{P}}_p = -\frac{\delta H_0}{\delta \vec{r}_P} = \frac{Z_P Z_{Pe}}{|\vec{r}_p - \vec{r}_{Pe}|^3}(\vec{r}_P - \vec{r}_{Pe}) + \frac{Z_P Z_T}{|\vec{r}_P - \vec{r}_T|^3}(\vec{r}_P - \vec{r}_T) + \frac{Z_P Z_{Te}}{|\vec{r}_P - \vec{r}_{Te}|^3}(\vec{r}_P - \vec{r}_{Te}), \tag{5}$$

$$\dot{\vec{P}}_{Pe} = -\frac{\delta H_0}{\delta \vec{r}_{Pe}} = -\frac{Z_P Z_{Pe}}{|\vec{r}_P - \vec{r}_{Pe}|^3}(\vec{r}_P - \vec{r}_{Pe}) - \frac{Z_T Z_{Pe}}{|\vec{r}_T - \vec{r}_{Pe}|^3}(\vec{r}_T - \vec{r}_{Pe}) - \frac{Z_{Te} Z_{Pe}}{|\vec{r}_{Te} - \vec{r}_{Pe}|^3}(\vec{r}_{Te} - \vec{r}_{Pe}), \tag{6}$$

$$\dot{\vec{P}}_T = -\frac{\delta H_{H_0}}{\delta \vec{r}_T} = -\frac{Z_P Z_T}{|\vec{r}_P - \vec{r}_T|^3}(\vec{r}_P - \vec{r}_T) - \frac{Z_{Te} Z_T}{|Te - \vec{r}_T|^3}(\vec{r}_{Te} - \vec{r}_T) + \frac{Z_T Z_{Pe}}{|\vec{r}_T - \vec{r}_{Pe}|^3}(\vec{r}_T - \vec{r}_{Pe}), \tag{7}$$

$$\dot{\vec{P}}_{Te} = -\frac{\delta H_{H_0}}{\delta \vec{r}_{Te}} = -\frac{Z_P Z_{Te}}{|\vec{r}_P - \vec{r}_{Te}|^3}(\vec{r}_P - \vec{r}_{Te}) - \frac{Z_{Te} Z_T}{|Te - \vec{r}_T|^3}(\vec{r}_{Te} - \vec{r}_T) - \frac{Z_{Te} Z_{Pe}}{|\vec{r}_{Te} - \vec{r}_{Pe}|^3}(\vec{r}_{Te} - \vec{r}_{Pe}). \tag{8}$$

The Runge–Kutta method is employed to numerically integrate the equations of motions with an ensemble of 5.0×10^6

primary trajectories for each energy (a large number of trajectories are usually needed to keep statistical uncertainties less than 5%), it is possible to calculate the total and state selective cross-sections by:

$$\sigma_p = \frac{2\pi b_{max}}{N}\sum_j b_j^{(P)}, \tag{9}$$

where $b_j^{(P)}$ is a given impact parameter satisfying the criteria for process P, N is the total number of calculated trajectories, and $b_{\max}$ is a largest value of the impact parameter in which the processes P can occur. The statistical uncertainty of the cross-section is given by:

$$\Delta\sigma = \sigma_p\left[\frac{N-N_P}{NN_P}\right]^{1/2}. \tag{10}$$

2.2. The four-body QCTMC model

The QCTMC model is a version of the standard CTMC model improved by including quantum mechanical principles [17]. Generally, in the modified Hamiltonian effective potentials (V_H, mimicking the Heisenberg principle and $V_{P,}$ mimicking the Pauli principle) are added to the pure Coulomb inter-particle potentials. Thus:

$$H_{QCTMC} = H_0 + V_H + V_P, \tag{11}$$

where H_0 is the standard Hamiltonian containing the total kinetic energy of all bodies and Coulomb potential terms among all particles. The correction terms are

$$V_H = \sum_{i=1}^{N}\frac{1}{mr_i^2}f\left(r_i\ , p_i; \xi_H; \alpha_H\ \right), \tag{12}$$

and

$$V_p = \sum_{i=1}^{N}\sum_{j=i+1}^{N}\frac{2}{mr_{ij}^2}f\left(r_{ij}\ , p_{ij}; \xi_p; \alpha_p\ \right)\delta_{s_i,s_j}, \tag{13}$$

where the i, j index the electrons. Also, $r_{ij} = r_j - r_i$ and relative momenta are:

$$\vec{P}_{ij} = \frac{m_i\vec{p}_j - m_j\vec{p}_i}{m_i + m_j}, \tag{14}$$

and $\delta_{s_i,s_j} = 1$, if the ith and jth electrons have the same spin and 0 if they are different. Ultimately, the constraining potentials are chosen as:

$$f\left(r_{\lambda\nu}\ , p_{\lambda\nu}; \xi\ ,\ \alpha\right) = \frac{\xi^2}{4\alpha r_{\lambda\nu}^2\mu_{\lambda\nu}}exp\left\{\alpha\left[1-\left(\frac{\vec{r}_{\lambda\nu}\vec{p}_{\lambda\nu}}{\xi}\right)^4\right]\right\}. \tag{15}$$

The equations of motion for four-body collision system including the correction terms can be written as:

$$\begin{aligned}\dot{\vec{P}}_p = -\frac{\delta H_{QCTMC}}{\delta\vec{r}_P} = &\left[\frac{Z_PZ_{Pe}}{\left|\vec{r}_p-\vec{r}_{Pe}\right|^3}\left(\vec{r}_P-\vec{r}_{Pe}\right)\right.\\ &-\left(-\frac{\xi_H{}^2}{2\alpha_H\vec{r}^{\,4}_{P,Pe}\mu_{P,Pe}}-\frac{\left(\vec{P}_{P,Pe}\right)^4}{\mu_{P,Pe}\xi_H{}^2}\right)\\ &\left.\times exp\left\{\alpha_H\left[1-\left(\frac{r_{P,Pe}P_{P,Pe}}{\xi_H}\right)^4\right]\right\}\right]\\ &+\frac{Z_PZ_T}{\left|\vec{r}_P-\vec{r}_T\right|^3}\left(\vec{r}_P-\vec{r}_T\right)+\frac{Z_PZ_{Te}}{\left|\vec{r}_P-\vec{r}_{Te}\right|^3}\left(\vec{r}_P-\vec{r}_{Te}\right),\end{aligned} \tag{16}$$

$$\begin{aligned}\dot{\vec{P}}_{Pe} = -\frac{\delta H_{QCTMC}}{\delta\vec{r}_{Pe}} = -&\left[\frac{Z_PZ_{Pe}}{\left|\vec{r}_P-\vec{r}_{Pe}\right|^3}\left(\vec{r}_P-\vec{r}_{Pe}\right)\right.\\ &+\left(-\frac{\xi_H{}^2}{2\alpha_H\vec{r}^{\,4}_{P,Pe}\mu_{P,Pe}}-\frac{\left(\vec{P}_{P,Pe}\right)^4}{\mu_{P,Pe}\xi_H{}^2}\right)\\ &\left.\times exp\left\{\alpha_H\left[1-\left(\frac{r_{P,Pe}P_{P,Pe}}{\xi_H}\right)^4\right]\right\}\right]-\frac{Z_TZ_{Pe}}{\left|\vec{r}_T-\vec{r}_{Pe}\right|^3}\left(\vec{r}_T-\vec{r}_{Pe}\right)\\ &-\left[\frac{Z_{Te}Z_{Pe}}{\left|\vec{r}_{Te}-\vec{r}_{Pe}\right|^3}\left(\vec{r}_{Te}-\vec{r}_{Pe}\right)\right.\\ &-\left(-\frac{\xi_P{}^2}{2\alpha_P\vec{r}^{\,4}_{Te,Pe}\mu_{Te,Pe}}-\frac{\left(\vec{P}_{Te,Pe}\right)^4}{\mu_{Te,Pe}\xi_H{}^2}\right)\\ &\left.\times exp\left\{\alpha_p\left[1-\left(\frac{r_{Te,Pe}P_{Te,Pe}}{\xi_P}\right)^4\right]\right\}\right],\end{aligned} \tag{17}$$

$$\begin{aligned}\dot{\vec{P}}_T = -\frac{\delta H_{QCTMC}}{\delta\vec{r}_T} = -&\frac{Z_PZ_T}{\left|\vec{r}_P-\vec{r}_T\right|^3}\left(\vec{r}_P-\vec{r}_T\right)\\ &-\left[\frac{Z_{Te}Z_T}{\left|Te-\vec{r}_T\right|^3}\left(\vec{r}_{Te}-\vec{r}_T\right)+\left(-\frac{\xi_H{}^2}{2\alpha_H\vec{r}^{\,4}_{T,Te}\mu_{T,Te}}-\frac{\vec{P}^4_{T,Te}}{\mu_{T,Te}\xi_H{}^2}\right)\right.\\ &\left.\times exp\left\{\alpha_H\left[1-\left(\frac{r_{T,Te}P_{T,Te}}{\xi_H}\right)^4\right]\right\}\right]+\frac{Z_TZ_{Pe}}{\left|\vec{r}_T-\vec{r}_{Pe}\right|^3}\left(\vec{r}_T-\vec{r}_{Pe}\right),\end{aligned} \tag{18}$$

$$\begin{aligned}\dot{\vec{P}}_{Te} = -\frac{\delta H_{QCTMC}}{\delta\vec{r}_{Te}} = -&\frac{Z_PZ_{Te}}{\left|\vec{r}_P-\vec{r}_{Te}\right|^3}\left(\vec{r}_P-\vec{r}_{Te}\right)\\ &-\left[\frac{Z_{Te}Z_T}{\left|Te-\vec{r}_T\right|^3}\left(\vec{r}_{Te}-\vec{r}_T\right)+\left(-\frac{\xi_H{}^2}{2\alpha_H\vec{r}^{\,4}_{T,Te}\mu_{T,Te}}-\frac{\vec{P}^4_{T,Te}}{\mu_{T,Te}\xi_H{}^2}\right)\right.\\ &\left.\times exp\left\{\alpha_H\left[1-\left(\frac{r_{T,Te}P_{T,Te}}{\xi_H}\right)^4\right]\right\}\right]-\left[\frac{Z_{Te}Z_{Pe}}{\left|\vec{r}_{Te}-\vec{r}_{Pe}\right|^3}\right.\\ &\times\left(\vec{r}_{Te}-\vec{r}_{Pe}\right)-\left(-\frac{\xi_P{}^2}{2\alpha_P\vec{r}^{\,4}_{Te,Pe}\mu_{Te,Pe}}-\frac{\left(\vec{P}_{Te,Pe}\right)^4}{\mu_{Te,Pe}\xi_H{}^2}\right)\\ &\left.\times exp\left\{\alpha_p\left[1-\left(\frac{r_{Te,Pe}P_{Te,Pe}}{\xi_P}\right)^4\right]\right\}\right].\end{aligned} \tag{19}$$

2.3. Detection of a trajectory with a particular reaction type

The projectile excitation channel when the electron of the projectile transfers to the higher energy state of the projectile while the target atom remains in the ground state can be written as:

$$\begin{aligned}&H_p\left(n_1\geq 1, l_1 < n_1-1\right)+H_T\left(1s, e_t^-\right)\\ &\quad\rightarrow H_p^*\left(n_2\geq n_1, l_2\geq l_1\right)+H_T(1s, e_t^-).\end{aligned} \tag{20}$$

We also investigated the projectile de-excitation cross-section when the electron of the projectile transfers to the lower energy state of the projectile while the target remains in the ground state. This channel can be defined by Eq. (21):

$$H_p^*\left(n_1\geq 2, l_1 < n_1-2\right)+H_T\left(1s, e_t^-\right)$$

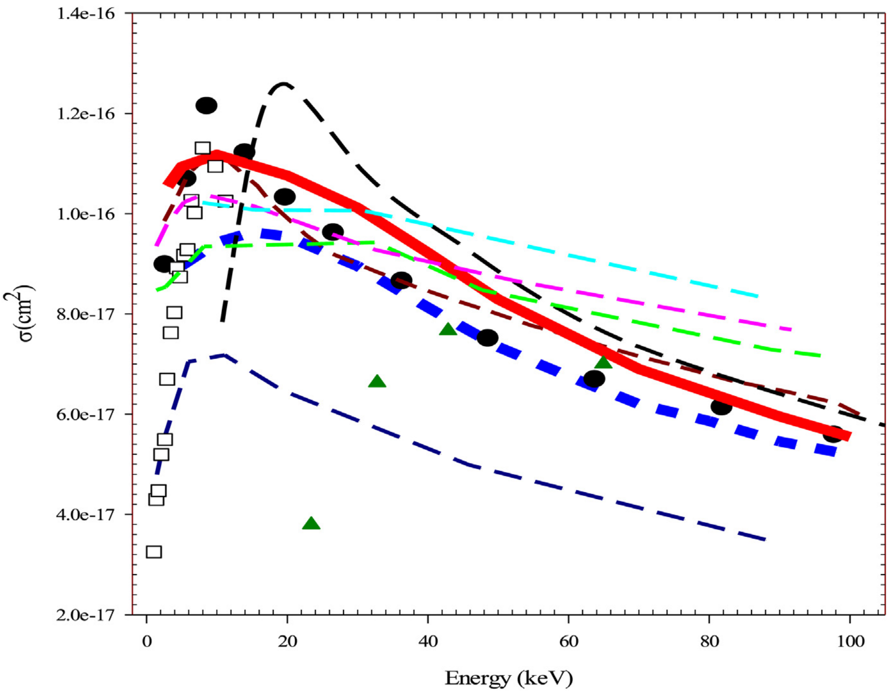

Fig. 1. Projectile ionization cross sections in the H(1s) + H(1s) collision as a function of impact energy. Red solid line: the total ionization cross-sections of the projectile using QCTMC method. Blue dashed line: the total ionization cross-sections of the projectile using CTMC method, Ref. [14]. Black dashed line: theoretical calculation for $H_P\,(1s) + H_T\,(1s) \rightarrow H_P^+ + H_T + e$ by Barnett [11]. Dark brown dashed-line: The CCC calculations by Bailey et al. Ref. [12]. Black solid circle: Experimental data by McClure Ref. [19]. Green dashed lines: CTMC calculations of Olson, Ref. [20]. Pink dashed line: CTMC results of Chen Lan-Fang et al. Ref. [21]. Cyan dashed line: CTMC calculations of Becker and MacKellar, Ref. [22]. Dark blue dashed line: Time-dependent self-consistent-field method of Riley and Ritchie, Ref. [23]. Open squares: experimental results of Hill et al. Ref. [24]. Dark green triangle: experimental results of Wittkower et al. Ref. [25]. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

$$\rightarrow H_P\,(n_2 \leq n_1, l_2 \leq l_1) + H_T\,\left(1s, e_t^-\right). \tag{21}$$

Last but not least, we calculated the cross-sections for projectile electron loss channel. Classically this reaction channel is the sum of the following channels as described below.

The first contribution of the projectile electron loss comes from the direct projectile ionization channel:

$$H_p\,(n_1 \geq 1, l_1 < n-1) + H_T\,\left(1s, e_t^-\right) \rightarrow H_p^+ + H_T\,\left(1s, e_t^-\right) + e_p^-. \tag{22}$$

The projectile can lose the electron after the two step ionization process as described by Eq. (23):

$$H_p\,(n_1 \geq 1, l_1 < n-1) + H_T\,\left(1s, e_t^-\right) \rightarrow H_p^+ + H_T\,\left(1s, e_p^-\right) + e_t^-. \tag{23}$$

The third case is the simultaneous target and projectile ionization channel resulting the complete break of the colliding partners ending with four free particles:

$$H_p\,(n_1 \geq 1, l_1 < n-1) + H_T\,\left(1s, e_t^-\right) \rightarrow H_p^+ + H_T^+ + e_t^- + e_p^-. \tag{24}$$

3. Comparison with experiment and other theories

As it was shown our standard 4-body CTMC calculation between two ground-state hydrogen atoms [15] shows an excellent agreement with experimental data presented by McClure [19]. We present our calculated cross-sections using CTMC and QCTMC model in the tables below. Moreover, as an example, our recent cross-section results are compared with the previous calculations and measured data in Figs. 1 and 2.

Fig. 1 shows the total ionization cross-sections of the projectile obtained by the 4-body CTMC and QCTMC models as a function of impact energy in comparison with the calculation of Barnett [11], Bailey et al. [12], Olson [20], Chen Lan-Fang et al. [21], Becker and MacKellar [22], Riley and Ritchie [23] and with the experimental data of McClure [19], Hill et al. [24], and Wittkower et al. [25]. Chen Lan-Fang et al. [21] calculated the ionization and total collisional destruction cross-section of the H + H system using the four-body classical-trajectory Monte Carlo (CTMC) method over the energy range of 4–100 keV. Becker and MacKellar [22] also investigated the ionization cross-section of H by H impact using the CTMC method. We note that our standard CTMC model provide the lowest cross sections compared to the previous classical results because our cross sections are limited to the cases when the target remained in ground state after the collision. The other CTMC results, however, included also the contributions taken into account the cases of the excited target atoms. Over all, our present CTMC data presents a good agreement with the experimental data, particularly at high energies. At the same time our QCTMC cross sections are higher compared with the results of the standard CTMC model and they are closer to the experimental values especially at lower energies.

To understand in deeper the effect of the correlation term we have to go back why it was developed and applied. As we stated, the QCTMC model is an improved version of the standard CTMC model where the Kirschbaum and Wilets potential [17] ensures mimicking quantum features of the collisions. The QCTMC model has been applied earlier with high success for multi-electronic collisions systems. The method uses momentum-dependent effective potentials ($V_H\,(r, p)$) in a model Hamiltonian to stabilize the multi-electronic atomic and molecular structures, which otherwise would collapse or autoionize in the pure classical description. The potential enforce this condition via the Heisenberg uncertainty principle $r_i p_i \geq \xi_H \hbar$, where r_i and p_i are relative distance and momentum of an electron to the ionic core (nucleus)

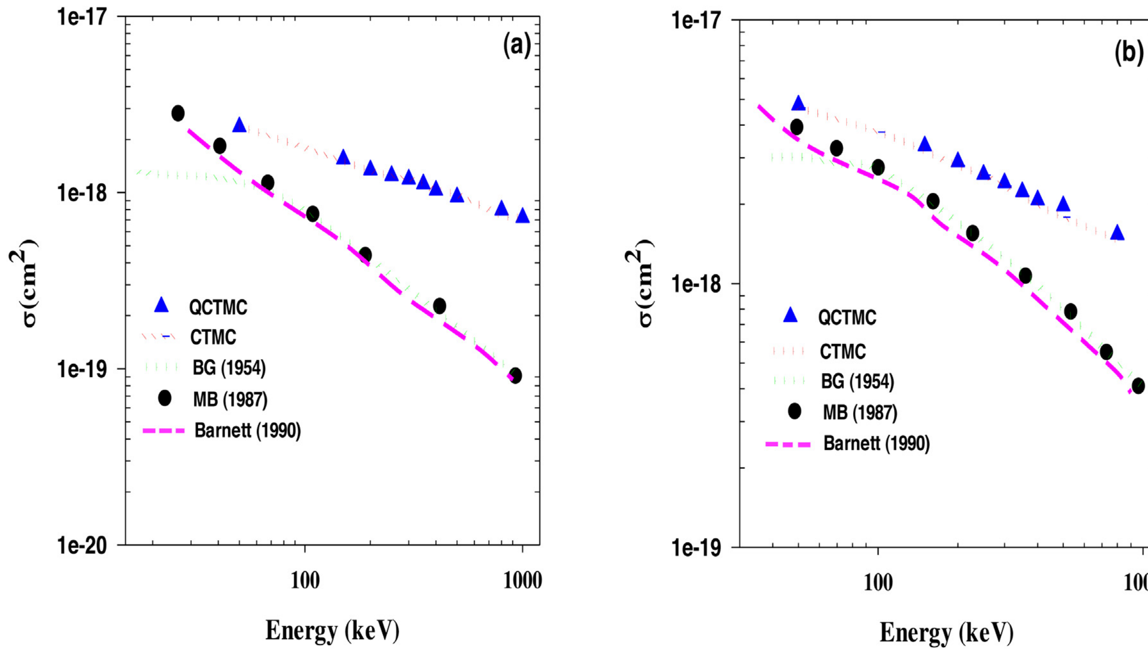

Fig. 2. Excitation cross-sections of the projectile as a function of projectile impact energy. (a) Red dots: present CTMC results for projectile excitation from 1*s* to 3*s*. Blue triangles: present QCTMC results for projectile excitation from 1*s* to 3*s*. Pink dashed line: theoretical calculation for $H_P\,(1s) + H_T\,(1s) \rightarrow H_P^*\,(3s) + H_T$ by Barnett [11]. Green dots: The First Born Approximation for $H_P\,(1s) + H_T\,(1s) \rightarrow H_P^*\,(3s) + H_T^*(nl)$ by Bates and Griffing [13]. Black circles: The first-order exchange theory for $H_P\,(1s) + H_T\,(1s) \rightarrow H_P^*\,(3s) + H_T^*(nl)$ by McLaughlint and Bell [14]. (b) Red dots: present CTMC results for projectile excitation from 1*s* to 3*p*. Blue triangles: present QCTMC results for projectile excitation from 1*s* to 3*p*. Pink dashed line: theoretical calculation for $H_P\,(1s) + H_T\,(1s) \rightarrow H_P^*\,(3p) + H_T$ by Barnett [11]. Green dots: The First Born Approximation for $H_P\,(1s) + H_T\,(1s) \rightarrow H_P^*\,(3p) + H_T^*(nl)$ by Bates and Griffing [13]. Black circles: The first-order exchange theory for $H_P\,(1s) + H_T\,(1s) \rightarrow H_P^*\,(3p) + H_T^*(nl)$ by McLaughlint and Bell [14]. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

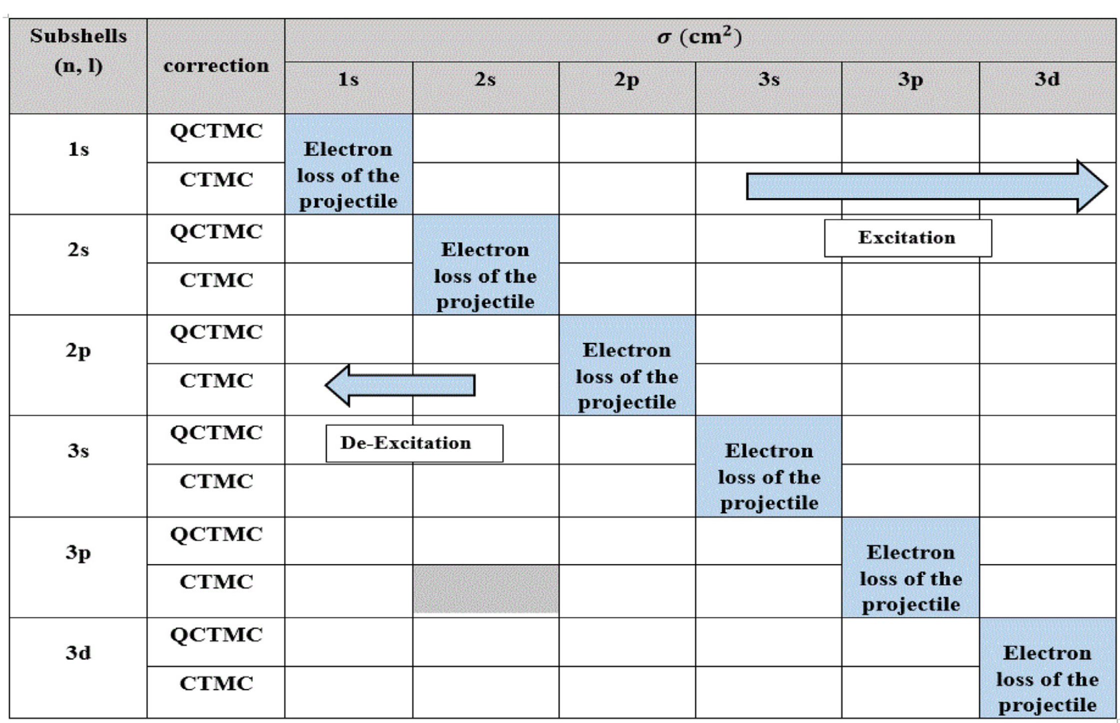

Fig. 3. Schematic diagarm for database table.

and ξ_H is a dimensionless constant. This condition is equivalent to the de Broglie description of the hydrogen atom, the electron treated as a particle on an ellipse with wave-like properties. $V_H\,(r, p)$ may have an effect during the collisions in the vicinity of the target atom, i.e. when the energy (velocity) of incident particle is low compared to the orbital electron velocity ($v \ll v_e$) the $V_H\,(r, p)$ will have an effect for a longer time. So it may modify the trajectory of the particles and thereby can modify the cross sections. At the same time when the energy (velocity) of the projectile is higher than an orbital electron, ($v \gg v_e$), the effect of the V_H (r, p) is less significant and at high energy is negligible. As consequence, the $V_H(r, p)$ potential can influence the trajectory calculations more at low and intermediate energies and can be hardly effect the trajectory calculations at higher energies. So the results of the CTMC and QCTMC can converge each other at higher energies, (see Fig. 1).

Fig. 2 shows the excitation cross-sections of the projectile from 1s to 3s and 3p states as a function of impact energy. Our results were compared with previous results calculated by Barnett [11], Bates and Griffing [13], and McLaughlint and Bell [14]. Bates and Griffing used the First Born approximation to calculate the excited state of the projectile in a collision between two ground state hydrogen atoms. McLaughlint and Bell [14] also recalculated the excited state of the projectile in a collision between two ground state hydrogen atoms when the target remains at any state after collisions using the first-order exchange theory. For these excited states both the standard four-body CTMC and QCTMC model provide higher cross sections compared with the previous results in the entirely energy range. At the same, as it was shown in our previous work [16], our CTMC results are in good agreement with the previous data for the case of 1s–2s and 1s–2p projectile excitations.

Fig. 3 shows the main features of the database tables used in this work. The main column and row represent the (n, l) values of the projectile atoms in a collision with ground state hydrogen atom according to the following equation, $H(nl) + H(1s)$. Our calculations were performed using both the standard four-body CTMC model and the four-body QCTMC model, when the Heisenberg correction term was added to the target atom (see Tables 1–20). The corrected and non-corrected cross-sections data were classified, respectively. While in diagonal positions of the tables the total projectile electron loss cross sections, the right from the diagonal the excitation cross sections and the left from the diagonal the de-excitation cross sections can be seen. We note here, that beside the given cross sections data, we also give the statistical uncertainties of the cross sections. For both CTMC and QCTMC model, the uncertainties were calculated according the Eq. (10).

Data block for each particular reactions contains:

Energy	The Atom collision energy (E) in keV
Cross-Section	Cross-section values $\sigma_p(E)$ of P process in cm^2

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Explanation of Tables

I	Cross-Sections for $H(1s)$ by $(H(n \geq 1, l < n-1)$ for 50 keV impact energy
II	Cross-Sections for $H(1s)$ by $(H(n \geq 1, l < n-1)$ for 100 keV impact energy
III	Cross-Sections for $H(1s)$ by $(H(n \geq 1, l < n-1)$ for 150 keV impact energy
IV	Cross-Sections for $H(1s)$ by $(H(n \geq 1, l < n-1)$ for 200 keV impact energy
V	Cross-Sections for $H(1s)$ by $(H(n \geq 1, l < n-1)$ for 250 keV impact energy
VI	Cross-Sections for $H(1s)$ by $(H(n \geq 1, l < n-1)$ for 300 keV impact energy
VII	Cross-Sections for $H(1s)$ by $(H(n \geq 1, l < n-1)$ for 350 keV impact energy
VIII	Cross-Sections for $H(1s)$ by $(H(n \geq 1, l < n-1)$ for 400 keV impact energy
IX	Cross-Sections for $H(1s)$ by $(H(n \geq 1, l < n-1)$ for 450 keV impact energy
X	Cross-Sections for $H(1s)$ by $(H(n \geq 1, l < n-1)$ for 500 keV impact energy
XI	Cross-Sections for $H(1s)$ by $(H(n \geq 1, l < n-1)$ for 550 keV impact energy
XII	Cross-Sections for $H(1s)$ by $(H(n \geq 1, l < n-1)$ for 600 keV impact energy
XIII	Cross-Sections for $H(1s)$ by $(H(n \geq 1, l < n-1)$ for 700 keV impact energy
XIV	Cross-Sections for $H(1s)$ by $(H(n \geq 1, l < n-1)$ for 800 keV impact energy
XV	Cross-Sections for $H(1s)$ by $(H(n \geq 1, l < n-1)$ for 1000 keV impact energy
XVI	Cross-Sections for $H(1s)$ by $(H(n \geq 1, l < n-1)$ for 1500 keV impact energy
XVII	Cross-Sections for $H(1s)$ by $(H(n \geq 1, l < n-1)$ for 2000 keV impact energy
XVIII	Cross-Sections for $H(1s)$ by $(H(n \geq 1, l < n-1)$ for 3000 keV impact energy
XIX	Cross-Sections for $H(1s)$ by $(H(n \geq 1, l < n-1)$ for 4000 keV impact energy
XX	Cross-Sections for $H(1s)$ by $(H(n \geq 1, l < n-1)$ for 5000 keV impact energy

Table 1
Cross-sections for ionization, excitation, and de-excitation from $H(1s)$ by $H(nl)$.
See pages 9&11 for Explanation of Tables.
Energy (50 keV).

Subshells $(n,\ l)$	Correction	σ (cm^2)							
		1s	2s	2p	3s	3p	3d	4s	4p
1s	QCTMC	(4.16 ± 0.009) (−17)	(1.29 ± 0.005) (−17)	(3.01 ± 0.009) (−17)	(2.39 ± 0.022) (−18)	(4.64 ± 0.034) (−18)	(5.36 ± 0.12) (−19)	(9.08 ± 0.14) (−19)	(1.67 ± 0.021) (−18)
	CTMC	(5.15 ± 0.10) (−17)	(1.31 ± 0.005) (−17)	(3.13 ± 0.009) (−17)	(2.36 ± 0.022) (−18)	(4.75 ± 0.035) (−18)	(4.65 ± 0.11) (−19)	(8.88 ± 0.13) (−19)	(1.70 ± 0.02) (−18)
2s	QCTMC	(7.42 ± 0.021) (−17)	(1.47 ± 0.005) (−16)	(1.07 ± 0.001) (−15)	(4.68 ± 0.027) (−17)	(5.77 ± 0.031) (−17)	(6.04 ± 0.033) (−17)	(8.31 ± 0.10) (−18)	(1.02 ± 0.012) (−17)
	CTMC	(6.96 ± 0.02) (−17)	(1.62 ± 0.005) (−16)	(1.07 ± 0.001) (−15)	(4.74 ± 0.028) (−17)	(5.66 ± 0.032) (−17)	(5.65 ± 0.032) (−17)	(8.05 ± 0.10) (−18)	(1.02 ± 0.013) (−17)
2p	QCTMC	(7.43 ± 0.018) (−17)	(8.70 ± 0.002) (−15)	(1.50 ± 0.004) (−16)	(4.18 ± 0.023) (−17)	(6.32 ± 0.029) (−17)	(6.21 ± 0.029) (−17)	(7.20 ± 0.086) (−18)	(1.07 ± 0.011) (−17)
	CTMC	(6.91 ± 0.019) (−17)	(3.32 ± 0.088) (−16)	(1.63 ± 0.005) (−16)	(5.19 ± 0.083) (−18)	(5.65 ± 0.029) (−17)	(1.14 ± 0.004) (−16)	(1.50 ± 0.041) (−18)	(1.07 ± 0.011) (−17)
3s	QCTMC	(4.69 ± 0.019) (−17)	(7.80 ± 0.044) (−17)	(3.32 ± 0.021) (−17)	(2.79 ± 0.012) (−16)	(2.14 ± 0.003) (−15)	(1.39 ± 0.007) (−16)	(1.02 ± 0.006) (−16)	(9.46 ± 0.067) (−17)
	CTMC	(4.53 ± 0.02) (−17)	(6.86 ± 0.043) (−17)	(2.91 ± 0.021) (−17)	(2.91 ± 0.013) (−16)	(2.48 ± 0.004) (−15)	(1.23 ± 0.008) (−16)	(1.01 ± 0.007) (−16)	(8.82 ± 0.067) (−17)
3p	QCTMC	(4.64 ± 0.02) (−17)	(7.49 ± 0.044) (−17)	(3.61 ± 0.023) (−17)	(3.64 ± 0.001) (−14)	(2.81 ± 0.012) (−16)	(1.49 ± 0.008) (−16)	(8.86 ± 0.061) (−17)	(1.04 ± 0.007) (−16)
	CTMC	(4.68 ± 0.019) (−17)	(3.04 ± 0.026) (−17)	(8.52 ± 0.041) (−17)	(7.43 ± 0.022) (−16)	(2.95 ± 0.012) (−16)	(1.34 ± 0.003) (−15)	(1.06 ± 0.02) (−17)	(1.17 ± 0.007) (−16)
3d	QCTMC	(4.65 ± 0.019) (−17)	(7.25 ± 0.043) (−17)	(4.02 ± 0.025) (−17)	(3.05 ± 0.001) (−14)	(1.47 ± 0.009) (−14)	(2.81 ± 0.012) (−16)	(7.80 ± 0.057) (−17)	(1.14 ± 0.007) (−16)
	CTMC	(5.35 ± 0.019) (−17)	(1.92 ± 0.019) (−17)	(1.14 ± 0.004) (−16)	(2.36 ± 0.03) (−17)	(7.34 ± 0.021) (−16)	(3.01 ± 0.012) (−16)	(1.80 ± 0.075) (−18)	(9.10 ± 0.18) (−18)

$(A \pm B)\,(-a) = (\sigma \pm \Delta\sigma)\,\left(e^{-a}\right)$.

Table 2
Cross-sections for ionization, excitation, and de-excitation from $H(1s)$ by $H(nl)$.
See pages 9&11 for Explanation of Tables.
Energy (100 keV).

Subshells (n, l)	Correction	σ (cm²)							
		1s	2s	2p	3s	3p	3d	4s	4p
1s	QCTMC	(3.94 ± 0.008) (−17)	(1.02 ± 0.004) (−17)	(2.47 ± 0.008) (−17)	(1.79 ± 0.019) (−18)	(3.76 ± 0.03) (−18)	(2.01 ± 0.077) (−19)	(6.60 ± 0.11) (−19)	(1.39 ± 0.018) (−18)
	CTMC	(4.52 ± 0.008) (−17)	(1.03 ± 0.005) (−17)	(2.48 ± 0.008) (−17)	(1.77 ± 0.019) (−18)	(3.86 ± 0.030) (−18)	(2.03 ± 0.076) (−19)	(6.81 ± 0.11) (−19)	(1.38 ± 0.018) (−18)
2s	QCTMC	(2.17 ± 0.011) (−17)	(1.08 ± 0.004) (−16)	(8.52 ± 0.012) (−16)	(3.90 ± 0.023) (−17)	(4.46 ± 0.026) (−17)	(4.21 ± 0.026) (−17)	(6.48 ± 0.09) (−18)	(7.30 ± 0.10) (−18)
	CTMC	(2.18 ± 0.011) (−17)	(1.21 ± 0.004) (−16)	(8.48 ± 0.014) (−16)	(3.89 ± 0.024) (−17)	(4.43 ± 0.027) (−17)	(4.14 ± 0.027) (−17)	(6.72 ± 0.094) (−18)	(7.59 ± 0.10) (−18)
2p	QCTMC	(2.17 ± 0.001) (−17)	(8.97 ± 0.002) (−15)	(1.09 ± 0.003) (−16)	(3.41 ± 0.02) (−17)	(4.94 ± 0.024) (−17)	(4.37 ± 0.024) (−17)	(5.80 ± 0.075) (−18)	(8.07 ± 0.095) (−18)
	CTMC	(2.12 ± 0.009) (−17)	(2.30 ± 0.006) (−16)	(1.25 ± 0.003) (−16)	(3.14 ± 0.061) (−18)	(4.47 ± 0.022) (−17)	(9.07 ± 0.033) (−17)	(8.17 ± 0.29) (−19)	(7.97 ± 0.09) (−18)
3s	QCTMC	(6.69 ± 0.064) (−18)	(5.38 ± 0.037) (−17)	(1.25 ± 0.015) (−17)	(1.96 ± 0.009) (−16)	(1.84 ± 0.003) (−15)	(9.69 ± 0.07) (−17)	(8.56 ± 0.057) (−17)	(7.43 ± 0.058) (−17)
	CTMC	(4.54 ± 0.02) (−17)	(6.86 ± 0.043) (−17)	(2.91 ± 0.021) (−17)	(2.12 ± 0.01) (−16)	(2.50 ± 0.004) (−15)	(1.23 ± 0.0077) (−16)	(1.01 ± 0.007) (−16)	(8.82 ± 0.067) (−17)
3p	QCTMC	(6.45 ± 0.063) (−18)	(5.17 ± 0.036) (−17)	(1.45 ± 0.017) (−17)	(3.69 ± 0.0009) (−14)	(1.96 ± 0.009) (−16)	(1.04 ± 0.007) (−16)	(7.38 ± 0.054) (−17)	(8.43 ± 0.061) (−17)
	CTMC	(7.27 ± 0.068) (−18)	(1.95 ± 0.023) (−17)	(5.40 ± 0.035) (−17)	(5.94 ± 0.02) (−16)	(2.17 ± 0.01) (−16)	(1.07 ± 0.002) (−15)	(8.13 ± 0.19) (−18)	(9.23 ± 0.06) (−17)
3d	QCTMC	(6.10 ± 0.063) (−18)	(5.00 ± 0.036) (−17)	(1.71 ± 0.018) (−17)	(3.08 ± 0.0001) (−14)	(1.47 ± 0.0009) (−14)	(1.97 ± 0.009) (−16)	(6.37 ± 0.05) (−17)	(9.23 ± 0.064) (−17)
	CTMC	(6.95 ± 0.06) (−18)	(9.98 ± 0.16) (−18)	(7.26 ± 0.043) (−17)	(1.72 ± 0.030) (−17)	(5.82 ± 0.018) (−16)	(2.23 ± 0.010) (−16)	(1.07 ± 0.068) (−18)	(6.25 ± 0.17) (−18)

$(A \pm B)(-a) = (\sigma \pm \Delta\sigma)\left(e^{-a}\right)$.

Table 3
Cross-sections for ionization, excitation, and de-excitation from $H(1s)$ by $H(nl)$.
See pages 9&11 for Explanation of Tables.
Energy (150 keV).

Subshells (n, l)	Correction	σ (cm^2)							
		1*s*	2*s*	2*p*	3*s*	3*p*	3*d*	4*s*	4*p*
1*s*	QCTMC	(3.50 ± 0.007) (−17)	(8.74 ± 0.042) (−18)	(2.09 ± 0.006) (−17)	(1.51 ± 0.016) (−18)	(3.19 ± 0.025) (−18)	(1.26 ± 0.058) (−19)	(5.52 ± 0.10) (−19)	(1.15 ± 0.016) (−18)
	CTMC	(4.00 ± 0.008) (−17)	(8.92 ± 0.045) (−18)	(2.11 ± 0.007) (−17)	(1.55 ± 0.018) (−18)	(3.32 ± 0.028) (−18)	(1.18 ± 0.057) (−19)	(5.83 ± 0.11) (−19)	(1.15 ± 0.016) (−18)
2*s*	QCTMC	(1.40 ± 0.009) (−17)	(9.16 ± 0.034) (−17)	(7.15 ± 0.011) (−16)	(3.31 ± 0.02) (−17)	(3.66 ± 0.022) (−17)	(3.31 ± 0.023) (−17)	(5.52 ± 0.077) (−18)	(6.15 ± 0.09) (−18)
	CTMC	(1.40 ± 0.009) (−17)	(1.02 ± 0.004) (−16)	(1.40 ± 0.009) (−17)	(3.43 ± 0.022) (−17)	(3.71 ± 0.024) (−17)	(3.33 ± 0.025) (−17)	(5.50 ± 0.083) (−18)	(6.23 ± 0.10) (−18)
2*p*	QCTMC	(1.40 ± 0.008) (−17)	(9.09 ± 0.002) (−15)	(9.18 ± 0.032) (−17)	(2.87 ± 0.018) (−17)	(4.10 ± 0.022) (−17)	(3.45 ± 0.021) (−17)	(4.74 ± 0.067) (−18)	(6.54 ± 0.085) (−18)
	CTMC	(1.32 ± 0.008) (−17)	(1.93 ± 0.005) (−16)	(1.07 ± 0.0033) (−16)	(2.51 ± 0.054) (−18)	(3.79 ± 0.02) (−17)	(7.65 ± 0.029) (−17)	(6.44 ± 0.26) (−19)	(6.64 ± 0.077) (−18)
3*s*	QCTMC	(2.91 ± 0.045) (−18)	(4.42 ± 0.033) (−17)	(8.27 ± 0.13) (−18)	(1.60 ± 0.009) (−16)	(1.64 ± 0.003) (−15)	(7.66 ± 0.066) (−17)	(7.36 ± 0.052) (−17)	(6.22 ± 0.054) (−17)
	CTMC	(3.22 ± 0.049) (−18)	(4.18 ± 0.034) (−17)	(8.25 ± 0.14) (−18)	(1.78 ± 0.01) (−16)	(1.73 ± 0.003) (−15)	(7.63 ± 0.071) (−17)	(7.06 ± 0.054) (−17)	(6.11 ± 0.0576) (−17)
3*p*	QCTMC	(2.72 ± 0.043) (−18)	(4.17 ± 0.032) (−17)	(1.00 ± 0.015) (−17)	(3.71 ± 0.0008) (−14)	(1.59 ± 0.008) (−16)	(8.20 ± 0.069) (−17)	(6.45 ± 0.05) (−17)	(7.06 ± 0.057) (−17)
	CTMC	(2.82 ± 0.044) (−18)	(1.54 ± 0.021) (−17)	(4.35 ± 0.033) (−17)	(5.47 ± 0.02) (−16)	(1.80 ± 0.009) (−16)	(9.89 ± 0.027) (−16)	(6.91 ± 0.19) (−18)	(8.06 ± 0.058) (−17)
3*d*	QCTMC	(2.75 ± 0.043) (−18)	(4.03 ± 0.032) (−17)	(1.23 ± 0.017) (−17)	(3.10 ± 0.001) (−14)	(1.47 ± 0.0009) (−14)	(1.60 ± 0.008) (−16)	(5.52 ± 0.046) (−17)	(7.80 ± 0.058) (−17)
	CTMC	(1.78 ± 0.027) (−18)	(7.80 ± 0.16) (−18)	(5.75 ± 0.038) (−17)	(1.37 ± 0.027) (−17)	(5.07 ± 0.018) (−16)	(1.86 ± 0.009) (−16)	(7.58 ± 0.64) (−19)	(5.40 ± 0.166) (−18)

$(A \pm B)\,(-a) = (\sigma \pm \Delta\sigma)\,\left(e^{-a}\right)$.

Table 4
Cross-sections for ionization, excitation, and de-excitation from $H(1s)$ by $H(nl)$.
See pages 9&11 for Explanation of Tables.
Energy (200 keV).

Subshells (*n*, *l*)	Correction	σ (cm²)							
		1*s*	2*s*	2*p*	3*s*	3*p*	3*d*	4*s*	4*p*
1*s*	QCTMC	(3.23 ± 0.007) (−17)	(7.84 ± 0.041) (−18)	(1.85 ± 0.006) (−17)	(1.33 ± 0.016) (−18)	(2.80 ± 0.025) (−18)	(9.72 ± 0.53) (−20)	(4.97 ± 0.10) (−19)	(1.01 ± 0.014) (−18)
	CTMC	(3.58 ± 0.007) (−17)	(8.13 ± 0.042) (−18)	(1.86 ± 0.006) (−17)	(1.34 ± 0.016) (−18)	(2.89 ± 0.025) (−18)	(7.53 ± 0.44) (−20)	(5.10 ± 0.10) (−19)	(1.01 ± 0.015) (−18)
2*s*	QCTMC	(1.14 ± 0.008) (−17)	(8.22 ± 0.032) (−17)	(6.49 ± 0.011) (−16)	(3.00 ± 0.019) (−17)	(3.23 ± 0.021) (−17)	(2.85 ± 0.022) (−17)	(4.96 ± 0.073) (−18)	(5.32 ± 0.083) (−18)
	CTMC	(1.17 ± 0.009) (−17)	(9.19 ± 0.004) (−17)	(6.72 ± 0.012) (−16)	(3.05 ± 0.021) (−17)	(3.26 ± 0.023) (−17)	(2.92 ± 0.024) (−17)	(5.18 ± 0.08) (−18)	(5.19 ± 0.088) (−18)
2*p*	QCTMC	(1.15 ± 0.007) (−17)	(9.15 ± 0.002) (−15)	(8.31 ± 0.03) (−17)	(2.58 ± 0.017) (−17)	(3.60 ± 0.02) (−17)	(2.92 ± 0.02) (−17)	(4.25 ± 0.063) (−18)	(5.95 ± 0.081) (−18)
	CTMC	(1.06 ± 0.007) (−17)	(1.76 ± 0.005) (−16)	(9.51 ± 0.031) (−17)	(2.18 ± 0.051) (−18)	(3.35 ± 0.018) (−17)	(6.75 ± 0.027) (−17)	(5.09 ± 0.23) (−19)	(5.79 ± 0.07) (−18)
3*s*	QCTMC	(2.04 ± 0.042) (−18)	(3.81 ± 0.031) (−17)	(6.72 ± 0.13) (−18)	(1.41 ± 0.008) (−16)	(1.52 ± 0.003) (−15)	(6.68 ± 0.064) (−17)	(6.52 ± 0.049) (−17)	(5.34 ± 0.05) (−17)
	CTMC	(2.18 ± 0.042) (−18)	(3.67 ± 0.031) (−17)	(7.19 ± 0.14) (−18)	(1.56 ± 0.009) (−16)	(1.58 ± 0.003) (−15)	(6.57 ± 0.067) (−17)	(6.46 ± 0.052) (−17)	(5.43 ± 0.053) (−17)
3*p*	QCTMC	(1.82 ± 0.037) (−18)	(3.66 ± 0.03) (−17)	(7.85 ± 0.14) (−18)	(3.73 ± 0.0008) (−14)	(1.40 ± 0.008) (−16)	(7.06 ± 0.066) (−17)	(5.70 ± 0.046) (−17)	(6.13 ± 0.052) (−17)
	CTMC	(1.90 ± 0.037) (−18)	(1.31 ± 0.02) (−17)	(3.73 ± 0.029) (−17)	(4.75 ± 0.018) (−16)	(1.59 ± 0.008) (−18)	(8.60 ± 0.023) (−16)	(6.12 ± 0.18) (−18)	(7.13 ± 0.051) (−17)
3*d*	QCTMC	(1.86 ± 0.038) (−18)	(3.54 ± 0.03) (−17)	(9.56 ± 0.15) (−18)	(3.11 ± 0.001) (−14)	(1.47 ± 0.001) (−14)	(1.42 ± 0.008) (−16)	(4.96 ± 0.043) (−17)	(6.77 ± 0.054) (−17)
	CTMC	(7.61 ± 0.17) (−19)	(6.63 ± 0.15) (−18)	(4.95 ± 0.037) (−17)	(1.17 ± 0.025) (−17)	(4.60 ± 0.016) (−16)	(1.63 ± 0.008) (−16)	(7.11 ± 0.64) (−19)	(4.67 ± 0.16) (−18)

$(A \pm B)\,(-a) = (\sigma \pm \Delta\sigma)\,\left(e^{-a}\right)$.

Table 5
Cross-sections for ionization, excitation, and de-excitation from $H(1s)$ by $H(nl)$.
See pages 9&11 for Explanation of Tables.
Energy (250 keV).

Subshells $(n,\ l)$	Correction	σ (cm^2)							
		1s	2s	2p	3s	3p	3d	4s	4p
1s	QCTMC	(2.98 ± 0.006) (−17)	(7.30 ± 0.04) (−18)	(1.67 ± 0.006) (−17)	(1.24 ± 0.016) (−18)	(2.58 ± 0.023) (−18)	(6.07 ± 0.41) (−20)	(4.60 ± 0.097) (−19)	(9.34 ± 0.14) (−19)
	CTMC	(3.30 ± 0.007) (−17)	(7.41 ± 0.04) (−18)	(1.68 ± 0.006) (−17)	(1.24 ± 0.016) (−18)	(2.59 ± 0.024) (−18)	(7.29 ± 0.44) (−20)	(4.44 ± 0.093) (−19)	(9.50 ± 0.14) (−19)
2s	QCTMC	(1.01 ± 0.007) (−17)	(7.62 ± 0.03) (−17)	(5.72 ± 0.01) (−16)	(2.67 ± 0.017) (−17)	(2.90 ± 0.019) (−17)	(2.49 ± 0.019) (−17)	(4.60 ± 0.067) (−18)	(4.64 ± 0.074) (−18)
	CTMC	(1.02 ± 0.008) (−17)	(8.48 ± 0.004) (−17)	(6.25 ± 0.012) (−16)	(2.80 ± 0.02) (−17)	(2.90 ± 0.022) (−17)	(2.54 ± 0.022) (−17)	(4.62 ± 0.075) (−18)	(4.76 ± 0.085) (−18)
2p	QCTMC	(1.00 ± 0.007) (−17)	(9.20 ± 0.002) (−15)	(7.63 ± 0.029) (−17)	(2.33 ± 0.015) (−17)	(3.23 ± 0.02) (−17)	(2.55 ± 0.019) (−17)	(3.92 ± 0.06) (−18)	(5.19 ± 0.075) (−18)
	CTMC	(9.33 ± 0.069) (−18)	(1.62 ± 0.0049) (−16)	(8.66 ± 0.029) (−17)	(1.97 ± 0.049) (−18)	(3.05 ± 0.017) (−17)	(6.04 ± 0.025) (−17)	(4.24 ± 0.22) (−19)	(5.47 ± 0.069) (−18)
3s	QCTMC	(1.74 ± 0.039) (−18)	(3.42 ± 0.029) (−17)	(6.16 ± 0.12) (−18)	(1.30 ± 0.007) (−16)	(1.41 ± 0.003) (−15)	(5.80 ± 0.06) (−17)	(5.90 ± 0.046) (−17)	(4.85 ± 0.047) (−17)
	CTMC	(1.81 ± 0.04) (−18)	(3.29 ± 0.028) (−17)	(6.19 ± 0.13) (−18)	(1.45 ± 0.008) (−16)	(1.39 ± 0.003) (−15)	(5.88 ± 0.062) (−17)	(5.86 ± 0.048) (−17)	(4.87 ± 0.049) (−17)
3p	QCTMC	(1.60 ± 0.036) (−18)	(3.27 ± 0.029) (−17)	(7.16 ± 0.13) (−18)	(3.74 ± 0.0008) (−14)	(1.29 ± 0.007) (−16)	(6.11 ± 0.063) (−17)	(5.12 ± 0.043) (−17)	(5.62 ± 0.051) (−17)
	CTMC	(1.40 ± 0.033) (−18)	(1.19 ± 0.019) (−17)	(3.40 ± 0.027) (−17)	(4.40 ± 0.017) (−16)	(1.46 ± 0.008) (−16)	(7.99 ± 0.022) (−16)	(5.41 ± 0.17) (−18)	(6.47 ± 0.048) (−17)
3d	QCTMC	(1.65 ± 0.038) (−18)	(3.11 ± 0.028) (−17)	(8.97 ± 0.14) (−18)	(3.12 ± 0.001) (−14)	(1.47 ± 0.0009) (−14)	(1.30 ± 0.007) (−16)	(4.39 ± 0.041) (−17)	(6.30 ± 0.052) (−17)
	CTMC	(3.87 ± 0.12) (−19)	(5.81 ± 0.14) (−18)	(4.50 ± 0.035) (−17)	(1.05 ± 0.025) (−17)	(4.24 ± 0.016) (−16)	(1.50 ± 0.008) (−16)	(6.23 ± 0.62) (−19)	(3.99 ± 0.15) (−18)

$(A \pm B)\,(-a) = (\sigma \pm \Delta\sigma)\,\left(e^{-a}\right)$.

Table 6
Cross-sections for ionization, excitation, and de-excitation from $H(1s)$ by $H(nl)$.
See pages 9&11 for Explanation of Tables.
Energy (300 keV).

Subshells (n, l)	Correction	σ (cm^2)							
		1s	2s	2p	3s	3p	3d	4s	4p
1s	QCTMC	(2.85 ± 0.006) (−17)	(6.90 ± 0.039) (−18)	(1.56 ± 0.005) (−17)	(1.20 ± 0.016) (−18)	(2.34 ± 0.022) (−18)	(6.0 ± 0.40) (−20)	(4.41 ± 0.094) (−19)	(8.84 ± 0.13) (−19)
	CTMC	(3.02 ± 0.007) (−17)	(6.98 ± 0.039) (−18)	(1.56 ± 0.006) (−17)	(1.19 ± 0.015) (−18)	(2.41 ± 0.023) (−18)	(6.04 ± 0.38) (−20)	(4.10 ± 0.087) (−19)	(8.52 ± 0.13) (−19)
2s	QCTMC	(9.52 ± 0.073) (−18)	(7.17 ± 0.03) (−17)	(5.38 ± 0.009) (−16)	(2.56 ± 0.017) (−17)	(2.65 ± 0.018) (−17)	(2.32 ± 0.018) (−17)	(4.18 ± 0.063) (−18)	(4.42 ± 0.073) (−18)
	CTMC	(9.31 ± 0.079) (−18)	(7.83 ± 0.034) (−17)	(5.89 ± 0.011) (−16)	(2.54 ± 0.018) (−17)	(2.66 ± 0.02) (−17)	(2.30 ± 0.021) (−17)	(4.41 ± 0.074) (−18)	(4.38 ± 0.08) (−18)
2p	QCTMC	(9.52 ± 0.072) (−18)	(9.23 ± 0.002) (−15)	(7.22 ± 0.028) (−17)	(2.22 ± 0.015) (−17)	(2.98 ± 0.019) (−17)	(2.38 ± 0.019) (−17)	(3.60 ± 0.058) (−18)	(4.88 ± 0.073) (−18)
	CTMC	(8.11 ± 0.064) (−18)	(1.54 ± 0.0048) (−16)	(8.10 ± 0.03) (−17)	(1.73 ± 0.046) (−18)	(2.78 ± 0.016) (−17)	(5.54 ± 0.025) (−17)	(3.94 ± 0.21) (−19)	(4.83 ± 0.064) (−18)
3s	QCTMC	(1.62 ± 0.039) (−18)	(3.10 ± 0.028) (−17)	(5.62 ± 0.13) (−18)	(1.19 ± 0.007) (−16)	(1.33 ± 0.002) (−15)	(5.28 ± 0.058) (−17)	(5.50 ± 0.044) (−17)	(4.46 ± 0.045) (−17)
	CTMC	(1.49 ± 0.037) (−18)	(3.09 ± 0.028) (−17)	(5.29 ± 0.12) (−18)	(1.32 ± 0.008) (−16)	(1.38 ± 0.003) (−15)	(5.28 ± 0.061) (−17)	(5.51 ± 0.047) (−17)	(4.41 ± 0.048) (−17)
3p	QCTMC	(1.47 ± 0.037) (−18)	(3.00 ± 0.027) (−17)	(6.53 ± 0.13) (−18)	(3.75 ± 0.0008) (−14)	(1.20 ± 0.007) (−16)	(5.70 ± 0.061) (−17)	(4.81 ± 0.042) (−17)	(5.16 ± 0.048) (−17)
	CTMC	(1.26 ± 0.035) (−18)	(1.08 ± 0.018) (−17)	(3.10 ± 0.027) (−17)	(4.36 ± 0.018) (−16)	(1.33 ± 0.008) (−16)	(7.91 ± 0.024) (−16)	(5.10 ± 0.18) (−18)	(6.04 ± 0.048) (−17)
3d	QCTMC	(1.48 ± 0.036) (−18)	(2.90 ± 0.027) (−17)	(8.00 ± 0.14) (−18)	(3.12 ± 0.001) (−14)	(1.47 ± 0.0009) (−14)	(1.20 ± 0.007) (−16)	(4.02 ± 0.038) (−17)	(5.74 ± 0.005) (−17)
	CTMC	(2.52 ± 0.10) (−19)	(5.24 ± 0.14) (−18)	(4.02 ± 0.033) (−17)	(9.81 ± 0.23) (−18)	(3.98 ± 0.016) (−16)	(1.40 ± 0.008) (−16)	(5.80 ± 0.65) (−19)	(3.80 ± 0.14) (−18)

$(A \pm B)\,(-a) = (\sigma \pm \Delta\sigma)\,\left(e^{-a}\right)$.

Table 7
Cross-sections for ionization, excitation, and de-excitation from $H(1s)$ by $H(nl)$.
See pages 9&11 for Explanation of Tables.
Energy (350 keV).

Subshells $(n,\ l)$	Correction	σ (cm^2)							
		1*s*	2*s*	2*p*	3*s*	3*p*	3*d*	4*s*	4*p*
1*s*	QCTMC	(2.52 ± 0.006) (−17)	(6.36 ± 0.036) (−18)	(1.39 ± 0.005) (−17)	(1.03 ± 0.014) (−18)	(2.15 ± 0.021) (−18)	(4.68 ± 0.33) (−20)	(3.83 ± 0.087) (−19)	(7.70 ± 0.12) (−19)
	CTMC	(2.84 ± 0.006) (−17)	(6.54 ± 0.038) (−18)	(1.43 ± 0.006) (−17)	(1.12 ± 0.015) (−18)	(2.23 ± 0.021) (−18)	(5.11 ± 0.35) (−20)	(4.18 ± 0.09) (−19)	(7.88 ± 0.13) (−19)
2*s*	QCTMC	(8.54 ± 0.069) (−18)	(6.50 ± 0.027) (−17)	(5.02 ± 0.009) (−16)	(2.31 ± 0.015) (−17)	(2.40 ± 0.017) (−17)	(2.05 ± 0.018) (−17)	(3.82 ± 0.06) (−18)	(4.03 ± 0.07) (−18)
	CTMC	(8.59 ± 0.077) (−18)	(7.41 ± 0.033) (−17)	(5.57 ± 0.011) (−16)	(2.44 ± 0.018) (−17)	(2.53 ± 0.02) (−17)	(2.14 ± 0.02) (−17)	(3.95 ± 0.068) (−18)	(4.03 ± 0.077) (−18)
2*p*	QCTMC	(8.46 ± 0.066) (−18)	(9.26 ± 0.002) (−15)	(6.51 ± 0.026) (−17)	(2.02 ± 0.014) (−17)	(2.70 ± 0.017) (−17)	(2.12 ± 0.017) (−17)	(3.29 ± 0.054) (−18)	(4.33 ± 0.068) (−18)
	CTMC	(7.38 ± 0.062) (−18)	(1.45 ± 0.004) (−16)	(7.59 ± 0.027) (−17)	(1.60 ± 0.044) (−18)	(2.60 ± 0.015) (−17)	(5.04 ± 0.023) (−17)	(3.85 ± 0.22) (−19)	(4.44 ± 0.061) (−18)
3*s*	QCTMC	(1.60 ± 0.04) (−18)	(2.75 ± 0.025) (−17)	(4.81 ± 0.011) (−18)	(1.10 ± 0.007) (−16)	(1.27 ± 0.002) (−15)	(4.83 ± 0.056) (−17)	(5.04 ± 0.042) (−17)	(4.10 ± 0.044) (−17)
	CTMC	(1.51 ± 0.037) (−18)	(2.86 ± 0.026) (−17)	(4.88 ± 0.011) (−18)	(1.24 ± 0.008) (−16)	(1.24 ± 0.002) (−15)	(4.99 ± 0.058) (−17)	(5.27 ± 0.044) (−17)	(4.13 ± 0.044) (−17)
3*p*	QCTMC	(1.36 ± 0.035) (−18)	(2.65 ± 0.025) (−17)	(5.54 ± 0.11) (−18)	(3.75 ± 0.0008) (−14)	(1.11 ± 0.007) (−16)	(5.33 ± 0.06) (−17)	(4.32 ± 0.04) (−17)	(4.80 ± 0.047) (−17)
	CTMC	(1.18 ± 0.032) (−18)	(1.01 ± 0.017) (−17)	(2.90 ± 0.024) (−17)	(3.94 ± 0.016) (−16)	(1.30 ± 0.007) (−16)	(7.17 ± 0.021) (−16)	(4.82 ± 0.16) (−18)	(5.71 ± 0.044) (−17)
3*d*	QCTMC	(1.37 ± 0.035) (−18)	(2.56 ± 0.025) (−17)	(7.00 ± 0.13) (−18)	(3.13 ± 0.0009) (−14)	(1.47 ± 0.0009) (−14)	(1.11 ± 0.007) (−16)	(3.74 ± 0.037) (−17)	(5.31 ± 0.047) (−17)
	CTMC	(1.73 ± 0.083) (−19)	(4.79 ± 0.13) (−18)	(3.70 ± 0.03) (−17)	(8.49 ± 0.22) (−18)	(3.70 ± 0.015) (−16)	(1.28 ± 0.007) (−16)	(5.79 ± 0.66) (−19)	(3.78 ± 0.14) (−18)

$(A \pm B)\,(-a) = (\sigma \pm \Delta\sigma)\left(e^{-a}\right)$.

Atomic Data and Nuclear Data Tables 146 (2022) 101513

Table 8
Cross-sections for ionization, excitation, and de-excitation from $H(1s)$ by $H(nl)$.
See pages 9&11 for Explanation of Tables.
Energy (400 keV)

Subshells (n, l)	Correction	σ (cm^2)							
		1*s*	2*s*	2*p*	3*s*	3*p*	3*d*	4*s*	4*p*
1*s*	QCTMC	(2.40 ± 0.006) (−17)	(5.92 ± 0.035) (−18)	(1.31 ± 0.005) (−17)	(1.02 ± 0.014) (−18)	(1.98 ± 0.02) (−18)	(4.37 ± 0.33) (−20)	(3.79 ± 0.087) (−19)	(7.46 ± 0.12) (−19)
	CTMC	(2.64 ± 0.006) (−17)	(6.23 ± 0.036) (−18)	(1.36 ± 0.054) (−17)	(1.03 ± 0.014) (−18)	(2.08 ± 0.021) (−18)	(4.24 ± 0.31) (−20)	(3.90 ± 0.085) (−19)	(7.40 ± 0.12) (−19)
2*s*	QCTMC	(8.09 ± 0.066) (−18)	(6.29 ± 0.027) (−17)	(4.78 ± 0.009) (−16)	(2.17 ± 0.015) (−17)	(2.23 ± 0.016) (−17)	(1.92 ± 0.017) (−17)	(3.71 ± 0.059) (−18)	(3.50 ± 0.063) (−18)
	CTMC	(8.11 ± 0.074) (−18)	(6.92 ± 0.031) (−17)	(5.33 ± 0.011) (−16)	(2.27 ± 0.017) (−17)	(2.32 ± 0.019) (−17)	(1.97 ± 0.019) (−17)	(3.80 ± 0.067) (−18)	(3.81 ± 0.075) (−18)
2*p*	QCTMC	(7.99 ± 0.064) (−18)	(9.29 ± 0.002) (−15)	(6.28 ± 0.026) (−17)	(1.87 ± 0.014) (−17)	(2.50 ± 0.017) (−17)	(1.99 ± 0.017) (−17)	(3.17 ± 0.054) (−18)	(4.02 ± 0.065) (−18)
	CTMC	(7.04 ± 0.06) (−18)	(1.40 ± 0.005) (−16)	(7.12 ± 0.026) (−17)	(1.40 ± 0.041) (−18)	(2.45 ± 0.015) (−17)	(4.74 ± 0.022) (−17)	(3.31 ± 0.20) (−19)	(4.05 ± 0.057) (−18)
3*s*	QCTMC	(1.31 ± 0.036) (−18)	(2.65 ± 0.025) (−17)	(4.40 ± 0.10) (−18)	(1.05 ± 0.007) (−18)	(1.22 ± 0.002) (−15)	(4.48 ± 0.054) (−17)	(4.76 ± 0.041) (−17)	(3.79 ± 0.042) (−17)
	CTMC	(1.30 ± 0.035) (−18)	(2.70 ± 0.026) (−17)	(4.71 ± 0.11) (−18)	(1.16 ± 0.008) (−16)	(1.26 ± 0.003) (−15)	(4.69 ± 0.059) (−17)	(4.95 ± 0.044) (−17)	(3.93 ± 0.046) (−17)
3*p*	QCTMC	(1.20 ± 0.033) (−18)	(2.54 ± 0.024) (−17)	(5.37 ± 0.12) (−18)	(3.76 ± 0.0008) (−14)	(1.06 ± 0.007) (−16)	(4.77 ± 0.056) (−17)	(4.10 ± 0.039) (−17)	(4.39 ± 0.044) (−17)
	CTMC	(1.04 ± 0.032) (−18)	(9.42 ± 0.17) (−18)	(2.71 ± 0.025) (−17)	(3.98 ± 0.017) (−16)	(1.18 ± 0.007) (−16)	(7.22 ± 0.023) (−16)	(4.45 ± 0.16) (−18)	(5.47 ± 0.05) (−17)
3*d*	QCTMC	(1.18 ± 0.032) (−18)	(2.42 ± 0.024) (−17)	(6.92 ± 0.12) (−18)	(3.14 ± 0.0009) (−14)	(1.47 ± 0.0009) (−14)	(1.05 ± 0.007) (−16)	(3.51 ± 0.036) (−17)	(4.91 ± 0.046) (−17)
	CTMC	(1.52 ± 0.09) (−19)	(4.41 ± 0.12) (−18)	(3.40 ± 0.03) (−17)	(7.80 ± 0.21) (−18)	(3.60 ± 0.015) (−16)	(1.20 ± 0.007) (−16)	(6.44 ± 0.68) (−19)	(3.20 ± 0.13) (−18)

$(A \pm B)\,(-a) = (\sigma \pm \Delta\sigma)\,\left(e^{-a}\right).$

Table 9
Cross-sections for ionization, excitation, and de-excitation from $H(1s)$ by $H(nl)$.
See pages 9&11 for Explanation of Tables.
Energy (450 keV).

Subshells (n, l)	Correction	σ (cm^2)							
		1*s*	2*s*	2*p*	3*s*	3*p*	3*d*	4*s*	4*p*
1*s*	QCTMC	(2.39 ± 0.006) (−17)	(5.88 ± 0.035) (−18)	(1.28 ± 0.005) (−17)	(9.70 ± 0.13) (−19)	(2.0 ± 0.02) (−18)	(4.82 ± 0.35) (−20)	(3.69 ± 0.083) (−19)	(6.94 ± 0.12) (−19)
	CTMC	(2.49 ± 0.006) (−17)	(5.93 ± 0.035) (−18)	(1.30 ± 0.005) (−17)	(9.90 ± 0.13) (−19)	(2.0 ± 0.02) (−18)	(4.70 ± 0.33) (−20)	(3.61 ± 0.083) (−19)	(7.52 ± 0.125) (−19)
2*s*	QCTMC	(7.88 ± 0.066) (−18)	(6.19 ± 0.026) (−17)	(4.65 ± 0.008) (−16)	(2.15 ± 0.015) (−17)	(2.15 ± 0.016) (−17)	(1.84 ± 0.017) (−17)	(3.48 ± 0.057) (−18)	(3.58 ± 0.065) (−18)
	CTMC	(7.86 ± 0.073) (−18)	(6.65 ± 0.031) (−17)	(5.11 ± 0.01) (−16)	(2.12 ± 0.016) (−17)	(2.15 ± 0.018) (−17)	(1.84 ± 0.019) (−17)	(3.51 ± 0.064) (−18)	(3.51 ± 0.071) (−18)
2*p*	QCTMC	(7.85 ± 0.064) (−18)	(9.30 ± 0.002) (−15)	(6.20 ± 0.026) (−17)	(1.84 ± 0.013) (−17)	(2.44 ± 0.016) (−17)	(1.90 ± 0.016) (−17)	(3.06 ± 0.052) (−18)	(4.00 ± 0.064) (−18)
	CTMC	(6.65 ± 0.059) (−18)	(1.33 ± 0.0045) (−16)	(6.80 ± 0.03) (−17)	(1.40 ± 0.042) (−18)	(2.32 ± 0.015) (−17)	(4.51 ± 0.022) (−17)	(3.70 ± 0.22) (−19)	(4.04 ± 0.058) (−18)
3*s*	QCTMC	(1.45 ± 0.039) (−18)	(2.52 ± 0.024) (−17)	(4.68 ± 0.11) (−18)	(1.01 ± 0.006) (−16)	(1.17 ± 0.003) (−15)	(4.18 ± 0.052) (−17)	(4.54 ± 0.039) (−17)	(3.60 ± 0.041) (−17)
	CTMC	(1.27 ± 0.033) (−18)	(2.56 ± 0.024) (−17)	(4.29 ± 0.10) (−18)	(1.12 ± 0.007) (−16)	(1.15 ± 0.028) (−15)	(4.28 ± 0.053) (−17)	(4.59 ± 0.04) (−17)	(3.67 ± 0.042) (−17)
3*p*	QCTMC	(1.26 ± 0.034) (−18)	(2.43 ± 0.024) (−17)	(5.53 ± 0.12) (−18)	(3.76 ± 0.0008) (−14)	(1.02 ± 0.007) (−16)	(4.52 ± 0.055) (−17)	(3.94 ± 0.037) (−17)	(4.19 ± 0.043) (−17)
	CTMC	(1.02 ± 0.031) (−18)	(8.59 ± 0.15) (−18)	(2.58 ± 0.023) (−17)	(3.63 ± 0.015) (−16)	(1.12 ± 0.007) (−16)	(6.65 ± 0.021) (−16)	(4.04 ± 0.15) (−18)	(5.15 ± 0.042) (−17)
3*d*	QCTMC	(1.30 ± 0.034) (−18)	(2.33 ± 0.023) (−17)	(6.80 ± 0.13) (−18)	(3.13 ± 0.0009) (−14)	(1.47 ± 0.0009) (−14)	(1.02 ± 0.006) (−16)	(3.36 ± 0.034) (−17)	(4.69 ± 0.044) (−17)
	CTMC	(1.62 ± 0.10) (−19)	(4.13 ± 0.12) (−18)	(3.20 ± 0.029) (−17)	(7.82 ± 0.21) (−18)	(3.45 ± 0.015) (−16)	(1.14 ± 0.007) (−16)	(4.89 ± 0.62) (−19)	(3.10 ± 0.13) (−18)

$(A \pm B)\,(-a) = (\sigma \pm \Delta\sigma)\,\left(e^{-a}\right)$.

Table 10
Cross-sections for ionization, excitation, and de-excitation from $H(1s)$ by $H(nl)$.
See pages 9&11 for Explanation of Tables.
Energy (500 keV).

Subshells $(n,\ l)$	Correction	σ (cm^2)							
		1*s*	2*s*	2*p*	3*s*	3*p*	3*d*	4*s*	4*p*
1*s*	QCTMC	(2.32 ± 0.006) (−17)	(5.80 ± 0.034) (−18)	(1.24 ± 0.005) (−17)	(9.74 ± 0.14) (−19)	(2.00 ± 0.02) (−18)	(4.12 ± 0.31) (−20)	(3.60 ± 0.083) (−19)	(7.00 ± 0.11) (−19)
	CTMC	(2.40 ± 0.06) (−17)	(5.74 ± 0.034) (−18)	(1.22 ± 0.005) (−17)	(9.46 ± 0.13) (−19)	(1.97 ± 0.02) (−18)	(4.05 ± 0.31) (−20)	(3.39 ± 0.079) (−19)	(7.00 ± 0.11) (−19)
2*s*	QCTMC	(7.43 ± 0.063) (−18)	(6.00 ± 0.026) (−17)	(4.50 ± 0.009) (−16)	(2.09 ± 0.015) (−17)	(2.07 ± 0.016) (−17)	(1.78 ± 0.017) (−17)	(3.49 ± 0.057) (−18)	(3.38 ± 0.062) (−18)
	CTMC	(7.20 ± 0.069) (−18)	(6.37 ± 0.03) (−17)	(4.90 ± 0.01) (−16)	(2.05 ± 0.016) (−17)	(2.10 ± 0.018) (−17)	(1.76 ± 0.018) (−17)	(3.38 ± 0.062) (−18)	(3.38 ± 0.069) (−18)
2*p*	QCTMC	(7.44 ± 0.06) (−18)	(8.49 ± 0.002) (−15)	(6.02 ± 0.025) (−17)	(1.80 ± 0.013) (−17)	(2.36 ± 0.016) (−17)	(1.81 ± 0.016) (−17)	(3.02 ± 0.051) (−18)	(3.80 ± 0.062) (−18)
	CTMC	(6.08 ± 0.056) (−18)	(1.28 ± 0.004) (−16)	(6.55 ± 0.025) (−17)	(1.34 ± 0.042) (−18)	(2.17 ± 0.012) (−17)	(4.22 ± 0.021) (−17)	(3.15 ± 0.20) (−19)	(3.71 ± 0.054) (−18)
3*s*	QCTMC	(1.26 ± 0.034) (−18)	(2.44 ± 0.024) (−17)	(4.18 ± 0.10) (−18)	(9.80 ± 0.066) (−17)	(1.12 ± 0.002) (−15)	(4.19 ± 0.053) (−17)	(4.39 ± 0.039) (−17)	(3.49 ± 0.04) (−17)
	CTMC	(1.15 ± 0.032) (−18)	(2.37 ± 0.023) (−17)	(4.00 ± 0.10) (−18)	(1.08 ± 0.007) (−16)	(1.11 ± 0.0028) (−15)	(4.11 ± 0.053) (−17)	(4.45 ± 0.039) (−17)	(3.48 ± 0.041) (−17)
3*p*	QCTMC	(1.19 ± 0.033) (−18)	(2.37 ± 0.023) (−17)	(5.15 ± 0.11) (−18)	(3.77 ± 0.0008) (−14)	(9.90 ± 0.067) (−17)	(4.28 ± 0.054) (−17)	(3.83 ± 0.037) (−17)	(3.98 ± 0.041) (−17)
	CTMC	(8.50 ± 0.29) (−19)	(8.42 ± 0.16) (−18)	(2.44 ± 0.023) (−17)	(3.62 ± 0.016) (−16)	(1.07 ± 0.007) (−16)	(6.73 ± 0.022) (−16)	(4.13 ± 0.16) (−18)	(4.89 ± 0.043) (−17)
3*d*	QCTMC	(1.21 ± 0.033) (−18)	(2.29 ± 0.023) (−17)	(6.51 ± 0.12) (−18)	(3.14 ± 0.001) (−14)	(1.47 ± 0.001) (−14)	(9.83 ± 0.067) (−17)	(3.24 ± 0.034) (−17)	(4.50 ± 0.043) (−17)
	CTMC	(1.12 ± 0.09) (−19)	(4.03 ± 0.12) (−18)	(3.05 ± 0.03) (−17)	(7.58 ± 0.21) (−18)	(3.30 ± 0.014) (−16)	(1.09 ± 0.007) (−16)	(4.83 ± 0.62) (−19)	(2.71 ± 0.12) (−18)

$(A \pm B)\,(-a) = (\sigma \pm \Delta\sigma)\,\left(e^{-a}\right)$.

Table 11
Cross-sections for ionization, excitation, and de-excitation from $H(1s)$ by $H(nl)$.
See pages 9&11 for Explanation of Tables.
Energy (550 keV).

Subshells (n, l)	Correction	σ (cm^2)							
		1s	2s	2p	3s	3p	3d	4s	4p
1s	QCTMC	(2.17 ± 0.006) (−17)	(5.55 ± 0.034) (−18)	(1.17 ± 0.005) (−17)	(9.20 ± 0.13) (−19)	(1.83 ± 0.019) (−18)	(3.47 ± 0.23) (−20)	(3.45 ± 0.08) (−19)	(6.70 ± 0.11) (−19)
	CTMC	(2.25 ± 0.006) (−17)	(5.55 ± 0.034) (−18)	(1.17 ± 0.005) (−17)	(9.42 ± 0.13) (−19)	(1.81 ± 0.019) (−18)	(3.40 ± 0.26) (−20)	(3.42 ± 0.08) (−19)	(6.64 ± 0.11) (−19)
2s	QCTMC	(7.24 ± 0.062) (−18)	(5.73 ± 0.025) (−17)	(4.33 ± 0.008) (−16)	(2.00 ± 0.014) (−17)	(1.96 ± 0.015) (−17)	(1.68 ± 0.016) (−17)	(3.31 ± 0.055) (−18)	(3.34 ± 0.063) (−18)
	CTMC	(6.77 ± 0.066) (−18)	(6.12 ± 0.029) (−17)	(4.76 ± 0.01) (−16)	(1.92 ± 0.016) (−17)	(1.94 ± 0.017) (−17)	(1.68 ± 0.018) (−17)	(3.44 ± 0.063) (−18)	(3.37 ± 0.071) (−18)
2p	QCTMC	(7.13 ± 0.059) (−18)	(8.50 ± 0.002) (−15)	(5.80 ± 0.024) (−17)	(1.70 ± 0.013) (−17)	(2.20 ± 0.015) (−17)	(1.72 ± 0.015) (−17)	(2.85 ± 0.049) (−18)	(3.59 ± 0.059) (−18)
	CTMC	(5.96 ± 0.054) (−18)	(1.21 ± 0.004) (−16)	(6.30 ± 0.024) (−17)	(1.24 ± 0.04) (−18)	(2.11 ± 0.014) (−17)	(4.03 ± 0.020) (−17)	(3.40 ± 0.20) (−19)	(3.59 ± 0.053) (−18)
3s	QCTMC	(1.30 ± 0.036) (−18)	(2.34 ± 0.023) (−17)	(4.0 ± 0.11) (−18)	(9.58 ± 0.065) (−17)	(1.10 ± 0.0030) (−15)	(3.91 ± 0.051) (−17)	(4.17 ± 0.038) (−17)	(3.28 ± 0.039) (−17)
	CTMC	(1.17 ± 0.034) (−18)	(2.27 ± 0.024) (−17)	(4.06 ± 0.11) (−18)	(1.01 ± 0.007) (−16)	(1.13 ± 0.0029) (−15)	(3.87 ± 0.053) (−17)	(4.19 ± 0.04) (−17)	(3.36 ± 0.042) (−17)
3p	QCTMC	(1.02 ± 0.030) (−18)	(2.25 ± 0.023) (−17)	(4.86 ± 0.11) (−18)	(3.77 ± 0.0008) (−14)	(9.56 ± 0.065) (−17)	(4.11 ± 0.053) (−17)	(3.64 ± 0.036) (−17)	(3.81 ± 0.041) (−17)
	CTMC	(9.19 ± 0.30) (−19)	(7.91 ± 0.15) (−18)	(2.31 ± 0.023) (−17)	(3.52 ± 0.016) (−16)	(1.02 ± 0.007) (−16)	(6.52 ± 0.021) (−16)	(3.60 ± 0.14) (−18)	(4.70 ± 0.042) (−17)
3d	QCTMC	(1.05 ± 0.030) (−18)	(2.19 ± 0.022) (−17)	(5.92 ± 0.11) (−18)	(3.14 ± 0.001) (−14)	(1.47 ± 0.001) (−14)	(9.56 ± 0.066) (−17)	(3.19 ± 0.034) (−17)	(4.28 ± 0.042) (−17)
	CTMC	(1.01 ± 0.083) (−19)	(3.74 ± 0.11) (−18)	(2.90 ± 0.028) (−17)	(6.92 ± 0.20) (−18)	(3.22 ± 0.014) (−16)	(1.03 ± 0.006) (−16)	(4.05 ± 0.60) (−19)	(2.63 ± 0.12) (−18)

$(A \pm B)\,(-a) = (\sigma \pm \Delta\sigma)\left(e^{-a}\right)$.

Table 12
Cross-sections for ionization, excitation, and de-excitation from $H(1s)$ by $H(nl)$.
See pages 9&11 for Explanation of Tables.
Energy (600 keV).

Subshells (n, l)	Correction	σ (cm^2)							
		1*s*	2*s*	2*p*	3*s*	3*p*	3*d*	4*s*	4*p*
1*s*	QCTMC	(2.04 ± 0.006) (−17)	(5.22 ± 0.033) (−18)	(1.10 ± 0.0047 (−17)	(8.59 ± 0.13) (−19)	(1.72 ± 0.018) (−18)	(3.50 ± 0.29) (−20)	(3.10 ± 0.077) (−19)	(6.18 ± 0.11) (−19)
	CTMC	(2.15 ± 0.006) (−17)	(5.29 ± 0.032) (−18)	(1.13 ± 0.005) (−17)	(8.73 ± 0.12) (19)	(1.74 ± 0.018) (−18)	(4.04 ± 0.31) (−20)	(3.32 ± 0.079) (−19)	(6.62 ± 0.11) (−19)
2*s*	QCTMC	(7.00 ± 0.061) (−18)	(5.42 ± 0.025) (−17)	(4.14 ± 0.008) (−16)	(1.83 ± 0.014) (−17)	(1.87 ± 0.015) (−17)	(1.60 ± 0.015) (−17)	(3.11 ± 0.053) (−18)	(3.03 ± 0.059) (−18)
	CTMC	(6.75 ± 0.066) (−18)	(5.89 ± 0.029) (−17)	(4.61 ± 0.01) (−16)	(1.90 ± 0.016) (−17)	(1.87 ± 0.017) (−17)	(1.60 ± 0.018) (−17)	(3.08 ± 0.059) (−18)	(3.10 ± 0.068) (−18)
2*p*	QCTMC	(6.87 ± 0.057) (−18)	(8.52 ± 0.002) (−15)	(5.42 ± 0.023) (−17)	(1.59 ± 0.012) (−17)	(2.08 ± 0.015) (−17)	(1.70 ± 0.015) (−17)	(2.77 ± 0.048) (−18)	(3.56 ± 0.06) (−18)
	CTMC	(5.62 ± 0.052) (−18)	(1.17 ± 0.004) (−16)	(6.05 ± 0.024) (−17)	(1.22 ± 0.04) (−18)	(2.00 ± 0.013) (−17)	(3.83 ± 0.02) (−17)	(3.21 ± 0.20) (−19)	(3.44 ± 0.052) (−18)
3*s*	QCTMC	(1.12 ± 0.031) (−18)	(2.22 ± 0.022) (−17)	(3.88 ± 0.10) (−18)	(8.96 ± 0.063) (−17)	(1.05 ± 0.002) (−15)	(3.80 ± 0.05) (−17)	(4.02 ± 0.037) (−17)	(3.08 ± 0.038) (−17)
	CTMC	(1.05 ± 0.03) (−18)	(2.20 ± 0.022) (−17)	(3.97 ± 0.10) (−18)	(9.68 ± 0.067) (−17)	(1.04 ± 0.0027) (−15)	(3.77 ± 0.051) (−17)	(4.08 ± 0.038) (−17)	(3.21 ± 0.039) (−17)
3*p*	QCTMC	(1.04 ± 0.03) (−18)	(2.14 ± 0.022) (−17)	(4.57 ± 0.01) (−18)	(3.77 ± 0.008) (−14)	(9.00 ± 0.06) (−17)	(3.99 ± 0.052) (−17)	(3.45 ± 0.034) (−17)	(3.53 ± 0.039) (−17)
	CTMC	(8.99 ± 0.31) (−19)	(7.76 ± 0.15) (−18)	(2.22 ± 0.022) (−17)	(3.44 ± 0.016) (−16)	(9.82 ± 0.067) (−18)	(6.32 ± 0.22) (−16)	(4.06 ± 0.16) (−18)	(4.36 ± 0.04) (−17)
3*d*	QCTMC	(1.08 ± 0.03) (−18)	(2.08 ± 0.022) (−17)	(5.65 ± 0.12) (−18)	(3.14 ± 0.001) (−14)	(1.47 ± 0.001) (−14)	(9.00 ± 0.063) (−17)	(2.93 ± 0.032) (−17)	(4.04 ± 0.041) (−17)
	CTMC	(1.08 ± 0.10) (−19)	(3.89 ± 0.12) (−18)	(2.80 ± 0.03) (−17)	(6.60 ± 0.20) (−18)	(3.11 ± 0.014) (−16)	(1.0 ± 0.006) (−16)	(4.99 ± 0.61) (−19)	(2.67 ± 0.12) (−18)

$(A \pm B)\,(-a) = (\sigma \pm \Delta\sigma)\,\left(e^{-a}\right)$.

Table 13
Cross-sections for ionization, excitation, and de-excitation from $H(1s)$ by $H(nl)$.
See pages 9&11 for Explanation of Tables.
Energy (700 keV).

Subshells (n, l)	Correction	σ (cm^2)							
		1s	2s	2p	3s	3p	3d	4s	4p
1s	QCTMC	(1.82 ± 0.005) (−17)	(4.76 ± 0.030) (−18)	(1.00 ± 0.004) (−17)	(7.70 ± 0.11) (−19)	(1.54 ± 0.017) (−18)	(3.41 ± 0.28) (−20)	(2.99 ± 0.074) (−19)	(5.64 ± 0.10) (−19)
	CTMC	(1.96 ± 0.004) (−17)	(4.99 ± 0.029) (−18)	(1.04 ± 0.004) (−17)	(8.30 ± 0.11) (−19)	(1.64 ± 0.016) (−18)	(3.55 ± 0.25) (−20)	(3.03 ± 0.067) (−19)	(6.09 ± 0.099) (−19)
2s	QCTMC	(6.11 ± 0.056) (−18)	(4.89 ± 0.023) (−17)	(3.84 ± 0.008) (−16)	(1.69 ± 0.013) (−17)	(1.64 ± 0.014) (−17)	(1.45 ± 0.015) (−17)	(2.74 ± 0.049) (−18)	(2.82 ± 0.057) (−18)
	CTMC	(6.18 ± 0.063) (−18)	(5.48 ± 0.028) (−17)	(4.35 ± 0.01) (−16)	(1.74 ± 0.015) (−17)	(1.80 ± 0.016) (−17)	(1.50 ± 0.017) (−17)	(3.00 ± 0.058) (−18)	(2.90 ± 0.065) (−18)
2p	QCTMC	(6.08 ± 0.055) (−18)	(1.02 ± 0.0002) (−14)	(4.87 ± 0.023) (−17)	(1.44 ± 0.012) (−17)	(1.88 ± 0.014) (−17)	(1.49 ± 0.015) (−17)	(2.39 ± 0.046) (−18)	(3.00 ± 0.056) (−18)
	CTMC	(5.34 ± 0.051) (−18)	(1.10 ± 0.0039) (−16)	(5.62 ± 0.022) (−17)	(1.20 ± 0.04) (−18)	(1.83 ± 0.012) (−17)	(3.56 ± 0.02) (−17)	(2.72 ± 0.17) (−19)	(3.20 ± 0.049) (−19)
3s	QCTMC	(1.12 ± 0.033) (−18)	(1.98 ± 0.021) (−17)	(3.30 ± 0.095) (−18)	(8.18 ± 0.06) (−17)	(9.96 ± 0.025) (−16)	(3.34 ± 0.047) (−17)	(3.63 ± 0.035) (−17)	(2.70 ± 0.035) (−17)
	CTMC	(1.05 ± 0.031) (−18)	(2.01 ± 0.021) (−17)	(3.55 ± 0.10) (−18)	(9.08 ± 0.065) (−17)	(9.93 ± 0.026) (−16)	(3.55 ± 0.05) (−17)	(3.82 ± 0.036) (−17)	(2.96 ± 0.037) (−17)
3p	QCTMC	(9.52 ± 0.28) (−19)	(1.88 ± 0.02) (−17)	(4.10 ± 0.10) (−18)	(3.78 ± 0.008) (−14)	(8.16 ± 0.06) (−17)	(3.66 ± 0.05) (−17)	(3.11 ± 0.032) (−17)	(3.21 ± 0.037) (−17)
	CTMC	(8.80 ± 0.29) (−19)	(7.21 ± 0.14) (−18)	(2.03 ± 0.02) (−17)	(3.11 ± 0.014) (−16)	(9.21 ± 0.063) (−17)	(5.74 ± 0.019) (−16)	(3.23 ± 0.13) (−18)	(4.17 ± 0.037) (−17)
3d	QCTMC	(9.46 ± 0.28) (−19)	(1.80 ± 0.02) (−17)	(4.76 ± 0.10) (−18)	(3.14 ± 0.0009) (−14)	(1.47 ± 0.0009) (−14)	(8.17 ± 0.06) (−17)	(2.70 ± 0.03) (−17)	(3.65 ± 0.039) (−17)
	CTMC	(8.49 ± 0.93) (−20)	(3.33 ± 0.11) (−18)	(2.60 ± 0.026) (−17)	(6.50 ± 0.19) (−18)	(2.94 ± 0.013) (−16)	(9.32 ± 0.064) (−17)	(3.35 ± 0.50) (−19)	(2.44 ± 0.12) (−18)

$(A \pm B)\,(-a) = (\sigma \pm \Delta\sigma)\,\left(e^{-a}\right)$.

Table 14
Cross-sections for ionization, excitation, and de-excitation from $H(1s)$ by $H(nl)$.
See pages 9&11 for Explanation of Tables.
Energy (800 keV).

Subshells (n, l)	Correction	σ (cm^2)							
		1*s*	2*s*	2*p*	3*s*	3*p*	3*d*	4*s*	4*p*
1*s*	QCTMC	(1.70 ± 0.005) (−17)	(4.47 ± 0.03) (−18)	(9.40 ± 0.043) (−18)	(7.50 ± 0.11) (−19)	(1.47 ± 0.017) (−18)	(2.90 ± 0.25) (−20)	(2.60 ± 0.068) (−20)	(5.40 ± 0.10) (−19)
	CTMC	(1.68 ± 0.005) (−17)	(4.47 ± 0.030) (−18)	(9.38 ± 0.043) (−18)	(7.46 ± 0.12) (−19)	(1.47 ± 0.017) (−18)	(2.89 ± 0.25) (−20)	(2.61 ± 0.068) (−19)	(5.39 ± 0.10) (−19)
2*s*	QCTMC	(5.81 ± 0.054) (−18)	(4.64 ± 0.022) (−17)	(3.65 ± 0.007) (−16)	(1.55 ± 0.012) (−17)	(1.56 ± 0.014) (−17)	(1.33 ± 0.014) (−17)	(2.57 ± 0.05) (−18)	(2.60 ± 0.054) (−18)
	CTMC	(5.90 ± 0.061) (−18)	(5.12 ± 0.26) (−17)	(4.15 ± 0.01) (−16)	(1.64 ± 0.14) (−17)	(1.63 ± 0.016) (−17)	(1.40 ± 0.016) (−17)	(2.70 ± 0.054) (−18)	(2.70 ± 0.062) (−18)
2*p*	QCTMC	(5.74 ± 0.053) (−18)	(1.02 ± 0.0002) (−14)	(4.64 ± 0.022) (−17)	(1.34 ± 0.011) (−17)	(1.75 ± 0.014) (−17)	(1.38 ± 0.014) (−17)	(2.27 ± 0.045) (−18)	(2.90 ± 0.056) (−18)
	CTMC	(4.96 ± 0.048) (−18)	(1.05 ± 0.004) (−16)	(5.24 ± 0.022) (−17)	(1.12 ± 0.037) (−18)	(1.75 ± 0.012) (−17)	(3.31 ± 0.018) (−17)	(2.59 ± 0.17) (−19)	(3.01 ± 0.047) (−18)
3*s*	QCTMC	(9.93 ± 0.30) (−19)	(1.90 ± 0.02) (−17)	(3.15 ± 0.093) (−18)	(7.81 ± 0.058) (−17)	(9.51 ± 0.025) (−16)	(3.23 ± 0.047) (−17)	(3.34 ± 0.033) (−17)	(2.62 ± 0.035) (−17)
	CTMC	(9.04 ± 0.28) (−19)	(1.91 ± 0.021) (−17)	(3.26 ± 0.096) (−18)	(8.76 ± 0.063) (−17)	(9.46 ± 0.025) (−16)	(3.30 ± 0.048) (−17)	(3.48 ± 0.034) (−17)	(2.73 ± 0.036) (−17)
3*p*	QCTMC	(8.82 ± 0.26) (−19)	(1.77 ± 0.019) (−17)	(3.76 ± 0.098) (−18)	(3.78 ± 0.0008) (−14)	(7.83 ± 0.059) (−17)	(3.45 ± 0.048) (−17)	(2.90 ± 0.031) (−17)	(3.06 ± 0.037) (−17)
	CTMC	(7.61 ± 0.27) (−19)	(6.64 ± 0.13) (−18)	(1.90 ± 0.019) (−17)	(2.94 ± 0.014) (−16)	(8.72 ± 0.061) (−17)	(5.49 ± 0.019) (−16)	(3.10 ± 0.13) (−18)	(3.85 ± 0.04) (−17)
3*d*	QCTMC	(8.73 ± 0.27) (−19)	(1.69 ± 0.019) (−17)	(4.55 ± 0.10) (−18)	(3.15 ± 0.0009) (−14)	(1.47 ± 0.0009) (−14)	(7.86 ± 0.059) (−17)	(2.49 ± 0.029) (−17)	(3.39 ± 0.037) (−17)
	CTMC	(6.50 ± 0.80) (−20)	(3.08 ± 0.11) (−18)	(2.37 ± 0.025) (−17)	(5.72 ± 0.18) (−18)	(2.80 ± 0.013) (−16)	(8.80 ± 0.062) (−17)	(4.03 ± 0.53) (−19)	(2.13 ± 0.11) (−18)

$(A \pm B)\,(-a) = (\sigma \pm \Delta\sigma)\left(e^{-a}\right)$.

Table 15
Cross-sections for ionization, excitation, and de-excitation from $H(1s)$ by $H(nl)$.
See pages 9&11 for Explanation of Tables.
Energy (1000 keV).

Subshells $(n,\ l)$	Correction	σ (cm^2)							
		1*s*	2*s*	2*p*	3*s*	3*p*	3*d*	4*s*	4*p*
1*s*	QCTMC	(1.60 ± 0.005) (−17)	(4.30 ± 0.03) (−18)	(9.02 ± 0.042) (−18)	(7.29 ± 0.11) (−19)	(1.41 ± 0.016) (−18)	(2.70 ± 0.24) (−20)	(2.60 ± 0.067) (−19)	(5.18 ± 0.1) (−19)
	CTMC	(1.59 ± 0.0049) (−17)	(4.30 ± 0.029) (−18)	(9.02 ± 0.042) (−18)	(7.29 ± 0.11) (−19)	(1.41 ± 0.016) (−18)	(2.68 ± 0.24) (−20)	(2.60 ± 0.067) (−19)	(5.18 ± 0.10) (−19)
2*s*	QCTMC	(5.55 ± 0.051) (−18)	(4.47 ± 0.021) (−17)	(3.38 ± 0.074) (−16)	(1.49 ± 0.011) (−17)	(1.47 ± 0.013) (−17)	(1.25 ± 0.013) (−17)	(2.54 ± 0.046) (−18)	(2.50 ± 0.053) (−18)
	CTMC	(5.33 ± 0.057) (−18)	(4.61 ± 0.025) (−17)	(3.84 ± 0.009) (−16)	(3.84 ± 0.009) (−16)	(1.47 ± 0.013) (−17)	(1.25 ± 0.016) (−17)	(2.40 ± 0.05) (−18)	(2.48 ± 0.06) (−18)
2*p*	QCTMC	(5.53 ± 0.052) (−18)	(1.02 ± 0.0002) (−14)	(4.49 ± 0.022) (−17)	(1.30 ± 0.011) (−17)	(1.64 ± 0.014) (−17)	(1.32 ± 0.014) (−17)	(2.20 ± 0.044) (−18)	(2.87 ± 0.056) (−18)
	CTMC	(4.49 ± 0.046) (−18)	(9.76 ± 0.037) (17)	(4.71 ± 0.02) (−17)	(9.54 ± 0.34) (−19)	(1.58 ± 0.011) (−17)	(2.97 ± 0.017) (−17)	(2.00 ± 0.15) (−19)	(2.72 ± 0.045) (−18)
3*s*	QCTMC	(8.91 ± 0.27) (−19)	(1.75 ± 0.02) (−17)	(2.99 ± 0.089) (−18)	(7.39 ± 0.057) (−17)	(8.84 ± 0.024) (−16)	(2.87 ± 0.044) (−17)	(3.17 ± 0.033) (−17)	(2.46 ± 0.034) (−17)
	CTMC	(8.51 ± 0.28) (−19)	(1.75 ± 0.02) (−17)	(3.11 ± 0.097) (−18)	(7.69 ± 0.061) (−17)	(9.20 ± 0.026) (−16)	(2.83 ± 0.046) (−17)	(3.08 ± 0.033) (−17)	(2.42 ± 0.035) (−17)
3*p*	QCTMC	(9.03 ± 0.28) (−19)	(1.65 ± 0.019) (−17)	(3.52 ± 0.093) (−18)	(3.78 ± 0.0008) (−14)	(7.40 ± 0.057) (−17)	(3.09 ± 0.046) (−17)	(2.71 ± 0.03) (−17)	(2.84 ± 0.035) (−17)
	CTMC	(6.82 ± 0.25) (−19)	(5.88 ± 0.12) (−18)	(1.69 ± 0.018) (−17)	(2.73 ± 0.013) (−16)	(7.76 ± 0.057) (−17)	(5.07 ± 0.018) (−16)	(2.64 ± 0.12) (−18)	(3.48 ± 0.033) (−17)
3*d*	QCTMC	(8.28 ± 0.26) (−19)	(1.57 ± 0.019) (−17)	(4.34 ± 0.01) (−18)	(3.15 ± 0.001) (−14)	(1.46 ± 0.001) (−14)	(7.40 ± 0.057) (−17)	(2.30 ± 0.028) (−17)	(3.12 ± 0.035) (−17)
	CTMC	(7.22 ± 0.99) (−20)	(2.77 ± 0.10) (−18)	(2.14 ± 0.023) (−17)	(4.95 ± 0.17) (−18)	(2.59 ± 0.013) (−16)	(7.94 ± 0.059) (−17)	(3.40 ± 0.511) (−19)	(1.83 ± 0.10) (−18)

$(A \pm B)\,(-a) = (\sigma \pm \Delta\sigma)\,\left(e^{-a}\right).$

Table 16
Cross-sections for ionization, excitation, and de-excitation from $H(1s)$ by $H(nl)$.
See pages 9&11 for Explanation of Tables.
Energy (1500 keV).

Subshells (n, l)	Correction	σ (cm^2)							
		1*s*	2*s*	2*p*	3*s*	3*p*	3*d*	4*s*	4*p*
1*s*	QCTMC	(1.17 ± 0.0041) (−17)	(3.53 ± 0.025) (−18)	(7.33 ± 0.04) (−18)	(5.64 ± 0.096) (−19)	(1.13 ± 0.014) (−18)	(2.47 ± 0.24) (−20)	(2.08 ± 0.058) (−19)	(4.17 ± 0.087) (−19)
	CTMC	(1.17 ± 0.0041) (−17)	(3.53 ± 0.025) (−18)	(7.33 ± 0.037) (−18)	(5.64 ± 0.096) (−19)	(1.13 ± 0.014) (−18)	(2.47 ± 0.24) (−20)	(2.10 ± 0.058) (−19)	(4.17 ± 0.087) (−19)
2*s*	QCTMC	(4.51 ± 0.045) (−18)	(3.59 ± 0.019) (−17)	(2.85 ± 0.0068) (−16)	(1.22 ± 0.01) (−17)	(1.17 ± 0.011) (−17)	(1.01 ± 0.012) (−17)	(2.07 ± 0.041) (−18)	(2.0 ± 0.046) (−18)
	CTMC	(4.35 ± 0.047) (−18)	(3.73 ± 0.021) (−17)	(3.04 ± 0.007) (−16)	(1.21 ± 0.011) (−17)	(1.20 ± 0.012) (−17)	(1.07 ± 0.013) (−17)	(1.90 ± 0.04) (−18)	(2.01 ± 0.05) (−18)
2*p*	QCTMC	(4.46 ± 0.045) (−18)	(1.02 ± 0.0002) (−14)	(3.56 ± 0.019) (−17)	(1.04 ± 0.009) (−17)	(1.34 ± 0.012) (−17)	(1.08 ± 0.013) (−17)	(1.83 ± 0.04) (−18)	(2.25 ± 0.048) (−18)
	CTMC	(3.69 ± 0.041) (−18)	(8.27 ± 0.034) (−17)	(3.81 ± 0.018) (−17)	(8.49 ± 0.33) (−19)	(1.30 ± 0.01) (−17)	(2.43 ± 0.015) (−17)	(1.90 ± 0.15) (−19)	(2.20 ± 0.040) (−18)
3*s*	QCTMC	(7.20 ± 0.25) (−19)	(1.47 ± 0.017) (−17)	(2.27 ± 0.077) (−18)	(5.96 ± 0.05) (−17)	(7.56 ± 0.022) (−16)	(2.34 ± 0.04) (−17)	(2.55 ± 0.028) (−17)	(2.03 ± 0.03) (−17)
	CTMC	(6.92 ± 0.23) (−19)	(1.40 ± 0.016) (−17)	(2.53 ± 0.082) (−18)	(6.46 ± 0.053) (−17)	(7.34 ± 0.022) (−16)	(2.33 ± 0.039) (−17)	(2.61 ± 0.029) (−17)	(1.97 ± 0.03) (−17)
3*p*	QCTMC	(7.08 ± 0.23) (−19)	(1.40 ± 0.016) (−17)	(2.81 ± 0.082) (−18)	(3.46 ± 0.0007) (−14)	(6.11 ± 0.05) (−17)	(2.57 ± 0.041) (−17)	(2.17 ± 0.026) (−17)	(2.30 ± 0.03) (−17)
	CTMC	(5.72 ± 0.23) (−19)	(4.84 ± 0.11) (−18)	(1.42 ± 0.017) (−17)	(2.33 ± 0.013) (−16)	(6.35 ± 0.051) (−17)	(4.41 ± 0.017) (−16)	(2.37 ± 0.12) (−18)	(2.81 ± 0.029) (−17)
3*d*	QCTMC	(6.70 ± 0.23) (−19)	(1.30 ± 0.017) (−17)	(3.40 ± 0.085) (−18)	(3.15 ± 0.001) (−14)	(1.47 ± 0.001) (−14)	(6.00 ± 0.051) (−17)	(1.83 ± 0.024) (−17)	(2.47 ± 0.031) (−17)
	CTMC	(7.92 ± 1.01) (−20)	(2.34 ± 0.091) (−18)	(1.80 ± 0.022) (−17)	(3.96 ± 0.15) (−18)	(2.18 ± 0.012) (−16)	(6.49 ± 0.053) (−17)	(2.70 ± 0.42) (−19)	(1.84 ± 0.10) (−18)

$(A \pm B)\,(-a) = (\sigma \pm \Delta\sigma)\,\left(e^{-a}\right).$

Table 17
Cross-sections for ionization, excitation, and de-excitation from $H(1s)$ by $H(nl)$.
See pages 9&11 for Explanation of Tables.
Energy (2000 keV).

Subshells (n, l)	Correction	σ (cm²)							
		1*s*	2*s*	2*p*	3*s*	3*p*	3*d*	4*s*	4*p*
1*s*	QCTMC	(9.39 ± 0.033) (−18)	(3.0 ± 0.021) (−18)	(6.14 ± 0.03) (−18)	(4.96 ± 0.081) (−19)	(9.55 ± 0.11) (−19)	(1.74 ± 0.18) (−20)	(1.73 ± 0.047) (−19)	(3.40 ± 0.07) (−19)
	CTMC	(9.40 ± 0.033) (−18)	(2.97 ± 0.021) (−18)	(6.15 ± 0.030) (−18)	(4.96 ± 0.081) (−19)	(9.56 ± 0.12) (−19)	(1.74 ± 0.18) (−20)	(1.73 ± 0.047) (−19)	(3.44 ± 0.078) (−19)
2*s*	QCTMC	(3.78 ± 0.039) (−18)	(2.94 ± 0.017) (−17)	(2.41 ± 0.006) (−16)	(1.02 ± 0.009) (−17)	(1.00 ± 0.01) (−17)	(8.73 ± 0.11) (−18)	(1.73 ± 0.035) (−18)	(1.71 ± 0.041) (−18)
	CTMC	(3.81 ± 0.043) (−18)	(3.15 ± 0.019) (−17)	(2.74 ± 0.007) (−16)	(1.03 ± 0.01) (−17)	(1.05 ± 0.011) (−17)	(9.37 ± 0.13) (−18)	(1.71 ± 0.038) (−18)	(1.87 ± 0.048) (−18)
2*p*	QCTMC	(3.68 ± 0.04) (−18)	(1.03 ± 0.002) (−14)	(2.94 ± 0.017) (−17)	(8.73 ± 0.089) (−18)	(1.14 ± 0.011) (−17)	(9.01 ± 0.11) (−18)	(1.52 ± 0.035) (−18)	(1.90 ± 0.044) (−18)
	CTMC	(3.16 ± 0.037) (−18)	(7.45 ± 0.032) (−17)	(3.20 ± 0.017) (−17)	(6.79 ± 0.29) (−19)	(1.09 ± 0.009) (−17)	(2.13 ± 0.014) (−17)	(1.87 ± 0.16) (−19)	(2.02 ± 0.038) (−18)
3*s*	QCTMC	(5.79 ± 0.21) (−19)	(1.13 ± 0.014) (−17)	(2.06 ± 0.074) (−18)	(5.01 ± 0.045) (−17)	(6.55 ± 0.02) (−16)	(2.03 ± 0.037) (−17)	(2.16 ± 0.025) (−17)	(1.62 ± 0.026) (−17)
	CTMC	(5.30 ± 0.20) (−19)	(1.22 ± 0.017) (−17)	(2.25 ± 0.084) (−18)	(5.50 ± 0.051) (−17)	(7.14 ± 0.023) (−16)	(2.07 ± 0.039) (−17)	(2.19 ± 0.027) (−17)	(1.70 ± 0.029) (−17)
3*p*	QCTMC	(5.58 ± 0.21) (−19)	(1.10 ± 0.014) (−17)	(2.39 ± 0.077) (−18)	(3.80 ± 0.0008) (−14)	(5.11 ± 0.047) (−17)	(2.03 ± 0.037) (−17)	(1.87 ± 0.024) (−17)	(1.91 ± 0.028) (−17)
	CTMC	(4.73 ± 0.20) (−19)	(4.28 ± 0.11) (−18)	(1.20 ± 0.015) (−17)	(2.07 ± 0.011) (−16)	(5.44 ± 0.047) (−17)	(4.01 ± 0.016) (−16)	(1.88 ± 0.10) (−18)	(2.40 ± 0.027) (−17)
3*d*	QCTMC	(5.68 ± 0.21) (−19)	(1.06 ± 0.014) (−17)	(3.10 ± 0.082) (−18)	(3.16 ± 0.001) (−14)	(1.46 ± 0.001) (−14)	(5.08 ± 0.046) (−17)	(1.59 ± 0.022) (−17)	(2.19 ± 0.029) (−17)
	CTMC	(6.05 ± 0.88) (−20)	(1.96 ± 0.083) (−18)	(1.50 ± 0.02) (−17)	(3.95 ± 0.15) (−18)	(1.95 ± 0.011) (−16)	(5.60 ± 0.05) (−17)	(2.74 ± 0.45) (−19)	(1.72 ± 0.10) (−18)

$(A \pm B)\,(-a) = (\sigma \pm \Delta\sigma)\,\left(e^{-a}\right)$.

Table 18
Cross-sections for ionization, excitation, and de-excitation from $H(1s)$ by $H(nl)$.
See pages 9&11 for Explanation of Tables.
Energy (3000 keV).

Subshells $(n,\ l)$	Correction	σ (cm^2)							
		1s	2s	2p	3s	3p	3d	4s	4p
1s	QCTMC	(6.89 ± 0.03) (−18)	(2.57 ± 0.021) (−18)	(5.08 ± 0.03) (−18)	(4.0 ± 0.078) (−19)	(7.60 ± 0.11) (−19)	(8.82 ± 1.24) (−21)	(1.42 ± 0.05) (−19)	(2.77 ± 0.07) (−19)
	CTMC	(6.90 ± 0.031) (−18)	(2.57 ± 0.021) (−18)	(5.08 ± 0.03) (−18)	(4.00 ± 0.078) (−19)	(7.58 ± 0.11) (−19)	(8.82 ± 1.24) (−21)	(1.42 ± 0.047) (−19)	(2.77 ± 0.07) (−19)
2s	QCTMC	(3.09 ± 0.035) (−18)	(2.39 ± 0.015) (−17)	(2.12 ± 0.005) (−16)	(8.47 ± 0.082) (−18)	(8.59 ± 0.095) (−18)	(7.59 ± 0.10) (−18)	(1.55 ± 0.033) (−18)	(1.35 ± 0.036) (−18)
	CTMC	(3.16 ± 0.038) (−18)	(2.40 ± 0.016) (−17)	(2.32 ± 0.006) (−16)	(8.75 ± 0.092) (−18)	(8.84 ± 0.10) (−18)	(7.88 ± 0.11) (−18)	(1.50 ± 0.035) (−18)	(1.52 ± 0.043) (−18)
2p	QCTMC	(2.87 ± 0.034) (−18)	(1.03 ± 0.0002) (−14)	(2.01 ± 0.014) (−18)	(6.76 ± 0.077) (−18)	(8.93 ± 0.097) (−18)	(7.34 ± 0.10) (−18)	(1.06 ± 0.028) (−18)	(1.48 ± 0.038) (−18)
	CTMC	(2.70 ± 0.034) (−18)	(6.34 ± 0.030) (−17)	(2.55 ± 0.014) (−17)	(5.79 ± 0.27) (−19)	(9.04 ± 0.082) (−18)	(1.76 ± 0.013) (−17)	(1.44 ± 0.14) (−19)	(1.62 ± 0.034) (−18)
3s	QCTMC	(5.49 ± 0.20) (−19)	(9.80 ± 0.13) (−18)	(1.74 ± 0.067) (−18)	(4.18 ± 0.041) (−17)	(5.72 ± 0.019) (−16)	(1.66 ± 0.033) (−17)	(1.79 ± 0.023) (−17)	(1.42 ± 0.025) (−17)
	CTMC	(4.56 ± 0.18) (−19)	(1.01 ± 0.014) (−17)	(1.80 ± 0.07) (−18)	(4.42 ± 0.044) (−17)	(5.86 ± 0.02) (−16)	(1.73 ± 0.035) (−17)	(1.75 ± 0.023) (−17)	(1.39 ± 0.025) (−17)
3p	QCTMC	(4.27 ± 0.17) (−19)	(8.81 ± 0.13) (−18)	(1.99 ± 0.067) (−18)	(3.48 ± 0.0007) (−14)	(3.70 ± 0.038) (−17)	(1.61 ± 0.032) (−17)	(1.42 ± 0.02) (−17)	(1.45 ± 0.023) (−17)
	CTMC	(3.58 ± 0.17) (−19)	(3.59 ± 0.097) (−18)	(9.77 ± 0.13) (−18)	(1.80 ± 0.011) (−16)	(4.36 ± 0.042) (−17)	(3.45 ± 0.015) (−16)	(1.70 ± 0.10) (−18)	(1.98 ± 0.024) (−17)
3d	QCTMC	(4.41 ± 0.17) (−19)	(8.59 ± 0.12) (−18)	(2.33 ± 0.068) (−18)	(2.89 ± 0.0008) (−14)	(1.34 ± 0.0008) (−14)	(3.71 ± 0.038) (−17)	(1.21 ± 0.019) (−17)	(1.59 ± 0.024) (−17)
	CTMC	(4.80 ± 0.77) (−20)	(1.77 ± 0.08) (−18)	(1.20 ± 0.017) (−17)	(3.14 ± 0.13) (−18)	(1.66 ± 0.01) (−16)	(4.41 ± 0.044) (−17)	(1.55 ± 0.35) (−19)	(1.10 ± 0.08) (−18)

$(A \pm B)\,(-a) = (\sigma \pm \Delta\sigma)\left(e^{-a}\right)$.

Table 19
Cross-sections for ionization, excitation, and de-excitation from $H(1s)$ by $H(nl)$.
See pages 9&11 for Explanation of Tables.
Energy (4000 keV).

Subshells $(n,\ l)$	Correction	σ (cm^2)							
		1*s*	2*s*	2*p*	3*s*	3*p*	3*d*	4*s*	4*p*
1*s*	QCTMC	(5.50 ± 0.025) (−18)	(2.29 ± 0.017) (−18)	(4.51 ± 0.025) (−18)	(3.62 ± 0.066) (−19)	(6.30 ± 0.094) (−19)	(8.40 ± 1.20) (−21)	(1.32 ± 0.04) (−19)	(2.19 ± 0.055) (−19)
	CTMC	(5.49 ± 0.025) (−18)	(2.29 ± 0.017) (−18)	(4.52 ± 0.025) (−18)	(3.62 ± 0.066) (−19)	(6.27 ± 0.094) (−19)	(8.39 ± 1.20) (−21)	(1.32 ± 0.04) (−19)	(2.19 ± 0.055) (−19)
2*s*	QCTMC	(2.88 ± 0.033) (−18)	(2.05 ± 0.014) (−17)	(1.97 ± 0.005) (−16)	(7.99 ± 0.079) (−18)	(7.92 ± 0.091) (−18)	(7.33 ± 0.10) (−18)	(1.33 ± 0.03) (−18)	(1.35 ± 0.037) (−18)
	CTMC	(2.73 ± 0.037) (−18)	(2.0 ± 0.015) (−17)	(2.23 ± 0.007) (−16)	(7.74 ± 0.092) (−18)	(7.33 ± 0.10) (−18)	(7.06 ± 0.11) (−18)	(1.30 ± 0.035) (−18)	(1.33 ± 0.042) (−18)
2*p*	QCTMC	(2.87 ± 0.034) (−18)	(1.03 ± 0.002) (−14)	(2.01 ± 0.014) (−17)	(6.76 ± 0.077) (−18)	(8.93 ± 0.097) (−18)	(7.34 ± 0.10) (−18)	(1.06 ± 0.028) (−18)	(1.48 ± 0.038) (−18)
	CTMC	(2.27 ± 0.031) (−18)	(5.65 ± 0.03) (−17)	(2.07 ± 0.013) (−17)	(4.88 ± 0.24) (−19)	(7.99 ± 0.077) (−18)	(1.52 ± 0.012) (−17)	(1.50 ± 0.13) (−19)	(1.43 ± 0.032) (−18)
3*s*	QCTMC	(4.58 ± 0.18) (−19)	(9.11 ± 0.13) (−18)	(1.63 ± 0.065) (−18)	(3.73 ± 0.039) (−17)	(5.25 ± 0.018) (−16)	(1.50 ± 0.031) (−17)	(1.62 ± 0.021) (−17)	(1.27 ± 0.023) (−17)
	CTMC	(3.83 ± 0.16) (−19)	(8.68 ± 0.12) (−18)	(1.61 ± 0.066) (−18)	(3.73 ± 0.039) (−17)	(5.24 ± 0.019) (−16)	(1.48 ± 0.032) (−17)	(1.57 ± 0.022) (−17)	(1.21 ± 0.024) (−17)
3*p*	QCTMC	(4.27 ± 0.16) (−19)	(8.81 ± 0.12) (−18)	(1.99 ± 0.067) (−18)	(3.48 ± 0.0007) (−14)	(3.70 ± 0.038) (−17)	(1.61 ± 0.032) (−17)	(1.42 ± 0.02) (−17)	(1.45 ± 0.024) (−17)
	CTMC	(3.40 ± 0.18) (−19)	(3.12 ± 0.092) (−18)	(8.86 ± 0.12) (−18)	(1.58 ± 0.01) (−16)	(3.73 ± 0.04) (−17)	(3.14 ± 0.014) (−16)	(1.42 ± 0.093) (−18)	(1.68 ± 0.021) (−17)
3*d*	QCTMC	(4.41 ± 0.17) (−19)	(8.59 ± 0.12) (−18)	(2.33 ± 0.068) (−18)	(2.89 ± 0.008) (−14)	(1.34 ± 0.008) (−14)	(3.78 ± 0.038) (−17)	(1.21 ± 0.019) (−17)	(1.59 ± 0.023) (−17)
	CTMC	(4.07 ± 0.71) (−20)	(1.45 ± 0.073) (−18)	(1.10 ± 0.017) (−18)	(2.88 ± 0.13) (−18)	(1.44 ± 0.009) (−16)	(3.78 ± 0.04) (−17)	(2.46 ± 0.44) (−19)	(9.78 ± 0.76) (−19)

$(A \pm B)\,(-a) = (\sigma \pm \Delta\sigma)\,\left(e^{-a}\right)$.

Table 20
Cross-sections for ionization, excitation, and de-excitation from $H(1s)$ by $H(nl)$.
See pages 9&11 for Explanation of Tables.
Energy (5000 keV).

Subshells (n, l)	Correction	σ (cm^2)							
		1*s*	2*s*	2*p*	3*s*	3*p*	3*d*	4*s*	4*p*
1*s*	QCTMC	(4.38 ± 0.022) (−18)	(1.98 ± 0.016) (−19)	(3.89 ± 0.023) (−18)	(3.00 ± 0.059) (−19)	(5.19 ± 0.084) (−19)	(6.00 ± 1.00) (−21)	(1.13 ± 0.036) (−19)	(1.86 ± 0.051) (−19)
	CTMC	(4.38 ± 0.022) (−18)	(1.98 ± 0.016) (−18)	(3.89 ± 0.023) (−18)	(3.00 ± 0.059) (−19)	(5.20 ± 0.084) (−19)	(6.00 ± 1.00) (−21)	(1.13 ± 0.036) (−19)	(1.86 ± 0.051) (−19)
2*s*	QCTMC	(2.50 ± 0.031) (−18)	(1.71 ± 0.012) (−17)	(1.79 ± 0.0052) (−16)	(6.92 ± 0.073) (−18)	(7.0 ± 0.085) (−18)	(6.59 ± 0.098) (−18)	(1.16 ± 0.028) (−18)	(1.29 ± 0.036) (−18)
	CTMC	(2.40 ± 0.032) (−18)	(1.67 ± 0.013) (−17)	(1.91 ± 0.006) (−16)	(6.98 ± 0.08) (−18)	(6.98 ± 0.092) (−18)	(6.21 ± 0.10) (−18)	(1.18 ± 0.031) (−18)	(1.17 ± 0.037) (−18)
2*p*	QCTMC	(2.58 ± 0.033) (−18)	(1.03 ± 0.0002) (−14)	(1.69 ± 0.012) (−17)	(5.96 ± 0.071) (−18)	(8.10 ± 0.092) (−18)	(6.70 ± 0.10) (−18)	(9.85 ± 0.27) (−19)	(1.41 ± 0.038) (−18)
	CTMC	(2.00 ± 0.03) (−18)	(5.16 ± 0.027) (−17)	(1.76 ± 0.012) (−17)	(4.80 ± 0.24) (−19)	(7.40 ± 0.073) (−18)	(1.37 ± 0.012) (−17)	(8.53 ± 1.02) (−20)	(1.22 ± 0.029) (−18)
3*s*	QCTMC	(4.04 ± 0.17) (−19)	(8.06 ± 0.12) (−18)	(1.40 ± 0.059) (−18)	(3.25 ± 0.036) (−17)	(4.80 ± 0.017) (−16)	(1.35 ± 0.03) (−17)	(1.46 ± 0.02) (−17)	(1.11 ± 0.022) (−17)
	CTMC	(3.74 ± 0.17) (−19)	(7.97 ± 0.12) (−18)	(1.42 ± 0.061) (−18)	(3.26 ± 0.037) (−17)	(4.80 ± 0.018) (−16)	(1.34 ± 0.03) (−17)	(1.40 ± 0.02) (−17)	(1.08 ± 0.022) (−17)
3*p*	QCTMC	(3.80 ± 0.16) (−19)	(7.74 ± 0.12) (−18)	(1.73 ± 0.063) (−18)	(3.81 ± 0.0008) (−14)	(3.34 ± 0.037) (−17)	(1.40 ± 0.031) (−17)	(1.20 ± 0.018) (−17)	(1.25 ± 0.022) (−17)
	CTMC	(2.92 ± 0.16) (−19)	(2.74 ± 0.083) (−18)	(7.82 ± 0.11) (−18)	(1.43 ± 0.01) (−16)	(3.23 ± 0.036) (−17)	(2.90 ± 0.014) (−16)	(1.24 ± 0.085) (−18)	(1.51 ± 0.022) (−18)
3*d*	QCTMC	(3.60 ± 0.16) (−19)	(7.37 ± 0.11) (−18)	(2.13 ± 0.064) (−18)	(2.90 ± 0.0008) (−14)	(1.34 ± 0.008) (−14)	(3.28 ± 0.035) (−17)	(1.07 ± 0.017) (−17)	(1.45 ± 0.022) (−17)
	CTMC	(4.91 ± 0.88) (−20)	(1.40 ± 0.71) (−18)	(1.01 ± 0.016) (−17)	(2.32 ± 0.11) (−18)	(1.30 ± 0.008) (−16)	(3.22 ± 0.037) (−17)	(1.75 ± 0.36) (−19)	(9.25 ± 0.74) (−19)

$(A \pm B)\,(-a) = (\sigma \pm \Delta\sigma)\left(e^{-a}\right)$.