The effect of exchange and absorption potential in the distorted wave calculation of electron impact excitation of the autoionizing state of caesium

Ochieng A. A.¹, Okumu J.¹, Singh C. S.^{1*}

^{1,1*}Department of Physics, Kenyatta University, P.O Box 43844-0100, Nairobi, Kenya

^{1*} Corresponding Author. Email: singh.chadra@ku.ac.ke

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ABSTRACT

We have calculated the differential and integral cross sections for electron impact excitation of the lowest autoionizing level of caesium atoms in the energy range 13 – 500 eV using the distorted wave method. In this study we have used a complex distortion potential as the distortion potential both at the initial and the final channels. Our results are compared amongst themselves to establish the effect of exchange and imaginary absorption potentials. We also compared with other available theoretical and experimental results to determine the suitability of our present method. From the results it is seen that when an absorption potential is included in the distortion potential, the integral cross section moves closer to the experimental result in the intermediate energy range 19 – 40 eV.

Key Words: Differential cross section, Integral cross section, Absorption potential, Autoionizing state, Electron impact excitation, Lambda and Alignment parameters.

INTRODUCTION

The study of electron impact excitation of autoionizing states of alkali atoms has been of interest for a long time (Roy and Rai, 1973; Nygaard, 1975; Srivastava et al., 1982; Pangantiwar and Srivastava, 1987; Borovik et al., 1999, 2005, 2008, 2009, 2011, 2012, 2013; Jobunga et al., 2012) because it can help in the explanation of the peaks observed in the ionization curves of the alkali atoms (Nygaard, 1975) and also in explaining the near threshold structures observed in the excitation-autoionization curves (Borovik et al., 2005). Some theoretical (Pangantiwar

and Srivastava, 1987; Kaur and Srivastava, 1999) and experimental (Borovik et al., 2011) studies have been made on electron impact excitation of lowest autoionizing state of caesium, but no calculation on this process has been made using the distorted wave method with a complex distortion potential. In the work of Pangantiwar and Srivastava (1987) they have used the distorted wave method with a real potential (static) and Kaur and Srivastava (1999) used a relativistic distorted wave method with a real (static) potential. So, a study on electron impact excitation of the lowest autoionizing state of caesium is of interest.

In the present work we have calculated the differential and integral cross sections for electron impact excitation of the lowest autoionizing state of caesium ($5p^66s\ ^2S_{1/2} - 5p^56s^2\ ^2P_{1/2, 3/2}$) in the energy range 13 – 500 eV using the distorted wave method with static (real), static plus exchange (real) and static plus exchange plus absorption (complex) potentials as the distortion potentials both in the initial and final channels. We have compared our results amongst themselves to establish the effect of exchange and absorption potentials and compare our results with the theoretical results of Pangantiwar and Srivastava (1987) and Kaur and Srivastava (1999) and the experimental results of Borovik et al. (2011) to determine the suitability of our present method.

For our numerical calculation of the cross sections and alignment parameters, we have modified the Fortran computer program DWBA1 developed by Madison and Bartschat (1996) for electron- hydrogen with a real distortion potential. We have modified it for electron-caesium scattering using a complex distortion potential.

THEORY

The Distorted Wave Method

The Hamiltonian of the electron-caesium scattering system is expressed as (Madison & Bartschat, 1996)

$$H = H_o + V \quad (1)$$

where H_o , the unperturbed Hamiltonian describing a free motion of the electron and atom, is given by

$$H_o = h_a + K \quad (2)$$

where K is the kinetic energy operator of the projectile electron and h_a is the Hamiltonian of the N -electron target atom.

V is the interaction potential between the projectile electron and the target atom given by the relation

$$V = -\frac{Z}{r_o} + \sum_{i=1}^N v_i \quad (3)$$

where

$$v_i = \frac{1}{r_{oi}}, \quad (4)$$

with r_o the position vector of the projectile electron (taking the nucleus of the atom as the origin) and r_{oi} the separation between the projectile electron and the i^{th} atomic electron.

The first order T-matrix in the two potential approach is given by (Madison & Bartschat, 1996)

$$T_{i,f} = (N+1) \langle x_f^-(0) \psi_f(1 \dots N) | V - U_f(0) | A \Psi_i^+(0 \dots N) \rangle + \langle x_f^-(0) \psi_f(1 \dots N) | U_f(0) | \psi_i(1 \dots N) \beta_i(0) \rangle \quad (5)$$

where $\psi_{i,f}$ are the initial/final state atomic wave functions, U_f is the final channel complex distorting potential, A is the antisymmetrization operator given by

$$A = \frac{1}{N+1} (1 - \sum_{i=1}^N P_{i0}) \quad (6)$$

where P_{i0} is the operator that exchanges electrons 0 and i , β_i is the initial state plane wave and x_f^- is the distorted wave in the final channel with incoming boundary conditions.

For inelastic collisions that we are considering, the second term of equation (5) vanishes due to the orthogonality of the initial and final state wave functions. We have taken the potential U_f in equation (5) as a complex distortion potential in the final channel which includes static, exchange, and absorption potentials. This complex distortion potential is used to calculate the final distorted wave x_f^- by solving the Schrödinger equation

$$(\nabla_o^2 + 2k_f^2 - 2U_f)x_f^- = 0 \quad (7)$$

The superscript $-$ indicates incoming wave boundary conditions, k_f is the final state wave vector and its corresponding energy is given as $E_f = k_f^2$ (in atomic units).

In the first order distorted wave Born approximation, Ψ_i^+ in equation (5) is replaced by the product of the initial state distorted wave x_i^+ and the initial state atomic wave function ψ_i and then it takes the following form (for excitation process). (Expressing Ψ_i^+ in terms of the product of an initial state distorted wave x_i^+ times an initial state atomic wavefunction ψ_i and making a power series expansion for the interaction potential, one gets it as the first order term.) (Madison & Bartschat, 1996)

$$T_{i,f} = (N+1) \langle x_f^-(0) \psi_f(1 \dots N) | V - U_f(0) | \frac{1}{N+1} (1 - \sum_{i=1}^N P_{i0}) x_i^+(0) \psi_i(1 \dots N) \rangle \quad (8)$$

The initial state distorted wave x_i^+ is a solution of the Schrödinger equation

$$(\nabla_o^2 + 2k_i^2 - 2U_i)x_i^+ = 0 \quad (9)$$

where U_i is an arbitrary complex distorting potential in the initial channel, k_i is the incident wave vector which is connected to the incident particle energy as $E_i = k_i^2$ (in atomic units).

Distortion Potentials U_i and U_f

The distortion potential we have used is complex in nature both in initial and final channels. The complex distortion potential includes static, exchange, and absorption potentials, and is given by

$$U_{i,f} = V_{i,f}^{st}(r) + V^{exch}(r) + iV^{abs}(r) \quad (10)$$

Thus, the distortion potentials in the initial and final channels respectively are given by

$$U_i = \langle \psi_i | V | \psi_i \rangle + V^{exch}(r) + iV^{abs}(r) \quad (11)$$

$$U_f = \frac{1}{2} \langle \psi_i | V | \psi_i \rangle + \frac{1}{2} \langle \psi_f | V | \psi_f \rangle + V^{exch}(r) + iV^{abs}(r) \quad (12)$$

where, V is as given in equation (3) and

$$V^{exch}(r) = \frac{1}{2} [E - V^{st}(r)] - \frac{1}{2} \{ [E - V^{st}(r)]^2 + 4\pi\rho(r) \}^{\frac{1}{2}} \quad (13)$$

is the exchange potential (Furness and McCarthy, 1973), E is the incident particle energy, and $\rho(r)$ is the target electron charge density. The exchange potential accounts for exchange effects between the projectile electron and bound atomic electron.

$$V^{abs}(r) = \frac{1}{2} T_{loc} \rho(r) \sigma_b \quad (14)$$

is the absorption potential (Staszewska et al., 1984), where

$T_{loc} = [2(E - V_{se})]^{\frac{1}{2}}$ is the local kinetic energy of the incident electron, V_{se} is the static + exchange potential and σ_b is the average binary collision cross section. This absorption potential accounts for the removal of the incident projectile from the channel being considered. $V_i^{st}(r) = \langle \psi_i | V(r, r_i) | \psi_i \rangle$ is the initial channel static potential since in the initial state the projectile only 'sees' the static potential of the target atom in its initial state. In the final state, the final state static potential is taken as

$$V_f^{st}(r) = \frac{1}{2} \langle \psi_i | V(r_0, r_i) | \psi_i \rangle + \frac{1}{2} \langle \psi_f | V(r_0, r_i) | \psi_f \rangle$$

We have taken the average of the initial and final state potential, since in the final channel, when the energy of the projectile is transferred to the atom, it takes some time (relaxation time) before the atom goes to its final state. As a result, the projectile in its final state 'sees' an intermediate potential between the initial and final state static potentials of the target.

Atomic wave functions

We have used multi zeta (MZ) wavefunctions as given by McLean and McLean (1981). They are based on the Roothan-Hartree-Fock (RHF) expansion technique. The total wave function for an N-electron atom is a Slater determinant given by

$$\Psi = \frac{1}{\sqrt{N}} \begin{vmatrix} \varphi_1(\mathbf{r}_1) & \varphi_2(\mathbf{r}_1) \cdots & \varphi_N(\mathbf{r}_1) \\ \vdots & \vdots & \vdots \\ \varphi_1(\mathbf{r}_N) & \varphi_2(\mathbf{r}_N) \cdots & \varphi_N(\mathbf{r}_N) \end{vmatrix} \quad (15)$$

where,

$$\varphi_{i\eta\lambda} = \sum_p \chi_{p\eta\lambda} C_{i\eta p} \quad (16)$$

where p refers to the p^{th} basis function of symmetry η . $C_{i\eta p}$ is the expansion coefficients which depends on η , p and i but not λ .

The basic functions $\chi_{p\eta\lambda}$ are Slater-type orbitals with integer quantum numbers given as

$$\chi_{p\eta\lambda}(r, \theta, \varphi) = R_{\eta p}(r) Y_{\eta\lambda}(\theta, \varphi) \quad (17)$$

where $R_{\eta p}(r)$ is the radial Slater-type basis function given by

$$R_{\eta p}(r) = N_n r^{n-1} e^{-\xi r} \quad (18)$$

The normalization factor N_n , takes the form

$$N_n = \frac{(2\xi)^{n+\frac{1}{2}}}{\sqrt{(2n)!}} \quad (19)$$

Evaluation of the static potentials U_i and U_f

The mathematical formulation of static potentials experienced by the projectile electron in the field of a caesium atom both in the initial and final channels is given as (Joachain, 1975)

$$U_s = \langle \varphi_s | V | \varphi_s \rangle \quad (20)$$

where $s = i$ or (f) for initial or (final) state respectively. The initial atomic wave function is given as

$$\varphi_i = \varphi(5p) = \sum_p \chi_i C_i \quad (21)$$

The final wave function (excited state) is given as

$$\varphi_f = \varphi(6s) = \sum_p \chi_f C_f \quad (22)$$

V is the interaction potential between the target atom (caesium) and the projectile (electron) and is given (in atomic units) as

$$V = \left(\frac{1}{r_{0,1}} - \frac{1}{r_0} \right) \quad (23)$$

treating the target as a one-electron atom.

Considering the 5p electron being excited to the 6s orbital, the initial and final state static potentials are given by

$$U_{i,f} = \sum_n \sum_{n'} C_{i,f} C_{i,f} \langle \chi_{i,f} | V | \chi_{i,f} \rangle, \quad (24)$$

obtained by substituting equations (21) and (22) in (20). When we substitute for the interaction potential V given in equation (23) in equation (24) and expand the term $\frac{1}{r_{0,1}}$ in terms of spherical harmonics as

$$\frac{1}{r_{0,1}} = \sum_{l=0}^{\infty} \sum_{m=-1}^{+l} \frac{4\pi}{2l+1} \frac{r_{<}^l}{r_{>}^{l+1}} Y_{l,m}(\hat{r}_0) Y_{l,m}^*(\hat{r}_1) \quad (25)$$

where $r_{<}(r_{>})$ is the lesser (greater) between r_0 and r_1 , only the term associated with $l = 0$ and $m = 0$ contributes and since the non-spherical term contribution is very small and hence negligible (Madison et al., 1991), the static potential takes the form, after substituting $Y_{00} = \frac{1}{\sqrt{4\pi}}$,

$$U_{i,f} = 2 \sum_n \sum_{n'} C_{i,f} C_{i,f} \langle \chi_{i,f} | \frac{1}{r_{>}} - \frac{1}{r_0} | \chi_{i,f} \rangle \quad (26)$$

Substituting the Slater-type wave function as constructed from the McLean and McLean (1981) tables in equation (22) we obtain the static potentials both in the initial and final channels as

$$U_{i,f} = 2 \sum_n \sum_{n'} N_n N_{n'} C_n C_{n'} \int_0^{\infty} r_1^{\mu_n + \mu_{n'}} e^{-(\xi_n + \xi_{n'})r_1} \left| \frac{1}{r_{>}} - \frac{1}{r_0} \right| dr \quad (27)$$

where N_n is the normalization factor, μ_n is the principal quantum number, ξ_n is the orbital exponent, and C_n is the expansion coefficient.

Splitting the integral appearing in equation (27) as $\int_0^{r_0}$ and $\int_{r_0}^{\infty}$, and noting that $r_0 > r_1$ for the integral from 0 to r_0 and $r_1 > r_0$ for the integral from r_0 to ∞ , the static potential takes the form

$$U_{i,f} = 2 \sum_n \sum_{n'} N_n N_{n'} C_n C_{n'} \int_{r_0}^{\infty} r_1^{\mu_n + \mu_{n'}} e^{-(\xi_n + \xi_{n'})r_1} \left| \frac{1}{r_1} - \frac{1}{r_0} \right| dr_1 \quad (28)$$

since

$$\int_0^{r_0} r_1^{\mu_n + \mu_{n'}} e^{-(\xi_n + \xi_{n'})r_1} \left| \frac{1}{r_0} - \frac{1}{r_0} \right| dr_1 = 0$$

Letting $\zeta = \xi_n + \xi_{n'}$, we can write the static potential as

$$V_{i,f} = 2 \sum_n \sum_{n'} N_n N_{n'} C_n C_{n'} \int_{r_0}^{\infty} r_1^{\mu_n + \mu_{n'}} e^{-\zeta r_1} \left| \frac{1}{r_1} - \frac{1}{r_0} \right| dr_1 \quad (29)$$

The problem reduces to analytically calculating the integrals with respect to r_1 which was done for both the initial and final states static potentials.

Evaluation of direct and exchange T-matrix elements

The system is taken as a one-electron atom excited from initial state $5p$ to final state $6s$. After neglecting terms associated with $U_f(0)$ because of the orthogonality of the atomic wave functions and orthogonality of bound and continuum wavefunctions, the transition matrices for direct and exchange processes are expressed as

$$T^{dir} = \langle x_f^-(r_0) \psi_f(r_1) | V(r_0 r_1) | x_i^+(r_0) \psi_i(r_1) \rangle \quad (30)$$

$$T^{exc} = \langle x_f^-(r_0) \psi_f(r_1) | V(r_0 r_1) | x_i^+(r_1) \psi_i(r_0) \rangle \quad (31)$$

where $V(r_0 r_1) = \left(\frac{1}{r_{01}} - \frac{1}{r_0} \right)$ is the interaction potential between the projectile electron and target atom. To evaluate the scattering amplitudes (30) and (31), the distorted waves x_i^+ and x_f^- are expanded in terms of partial waves (Singh, 2004; Madison and Bartschart, 1996), giving

$$|x_i^+ \rangle = \sqrt{\frac{2}{\pi}} \frac{1}{k_i r} \sum_{l_i m_i} i^{l_i} x_{l_i}(k_i r) Y_{l_i m_i}(r) Y_{l_i m_i}^*(k_i) \quad (32)$$

$$|x_f^- \rangle = \sqrt{\frac{2}{\pi}} \frac{1}{k_f r} \sum_{l_f m_f} i^{l_f} x_{l_f}^*(k_f r) Y_{l_f m_f}(r) Y_{l_f m_f}^*(k_f) \quad (33)$$

Substituting (32) and (33) in the Schrodinger equations (9) and (7) respectively we obtain radial distorted waves x_{l_i}, x_{l_f} which are the solutions of the equation

$$x_{l_s}''(r) + \left[k_s^2 - \frac{l_s(l_s+1)}{r^2} - U_s(r) \right] x_{l_s}(r) = 0 \quad (34)$$

where $s = i, f$.

We have calculated the differential cross section summed over magnetic sub levels using the formula

$$\left(\frac{d\sigma}{d\Omega} \right)_{5p \rightarrow 6s} = (4\pi)^4 \frac{k_f}{k_i} \left[\frac{1}{4} |T_{5p \rightarrow 6s}^{dir} + T_{5p \rightarrow 6s}^{exc}|^2 + \frac{3}{4} |T_{5p \rightarrow 6s}^{dir} - T_{5p \rightarrow 6s}^{exc}|^2 \right] \quad (35)$$

The integral or total cross section is obtained by summing up the differential cross section given by the relation

$$\sigma = \int_0^{2\pi} \int_0^{\pi} \sin\theta \frac{d\sigma}{d\Omega} d\theta d\varphi. \quad (36)$$

We have also calculated λ and alignment parameter A_{20} using the relations

$$\lambda = \frac{\sigma_0(\theta, \varphi)}{\sigma_0(\theta, \varphi) + 2\sigma_1(\theta, \varphi)} \quad 0 \leq \lambda \leq 1 \quad (37)$$

where $\sigma_0(\theta, \varphi)$ and $\sigma_1(\theta, \varphi)$ are the differential cross sections for $np_m \rightarrow (n+1)s$ transition where $m = 0$ or 1 , and

$$A_{20} = \frac{\sigma_1 - \sigma_0}{\sigma} \quad (38)$$

where σ_0 and σ_1 are integral cross sections for magnetic sublevels $m = 0$ and $m = 1$ respectively.

RESULTS AND DISCUSSION

We have calculated the differential and integral cross sections and angular correlation parameters for electron-caesium scattering using a complex distortion potential both in the initial and final channels. The impact energy ranges between 13 – 500 eV. Our results are shown in Figure 1 for integral cross section, in Figures 2 – 7 for differential cross section, in Figure 8 for the alignment parameter and in Figures 9 – 12 for λ parameters.

In Figure 1 the present integral cross section results obtained using static potential and static plus absorption potential experience a sharp increase in the cross section just around the excitation threshold (12.9 eV) (negative ion resonances), a phenomenon that is attributed to the formation of a negative ion when the projectile electron is left with very little energy after exciting the target atom. When we include the absorption potential (Staszewska et al., 1984), the results are brought closer to the experimental results between 19 – 40 eV.

Integral cross section

Figure 1. Integral cross section results for electron impact excitation of the lowest autoionizing state of caesium using different distortion potentials (static only; static plus exchange; static plus absorption; static plus exchange plus absorption).

Differential cross section

Figure 2. Differential cross section results for electron impact excitation of the lowest autoionizing state of caesium at 16 eV using different distortion potentials (static only; static plus exchange; static plus absorption; static plus exchange plus absorption). The graph of our present static plus absorption potential is mounted on the graph of our present static only potential while the graph of our present static, exchange plus absorption potential is mounted on the graph of our present static plus exchange potential.

Figure 3. Differential cross section results for electron impact excitation of the lowest autoionizing state of caesium at 20 eV using different distortion potentials (static only; static plus exchange; static plus absorption; static plus exchange plus absorption). The graph of our present static plus absorption potential is mounted on the graph of our present static only potential while the graph of present static, exchange plus absorption potential is mounted on the graph of our present static plus exchange potential.

Figure 4. Differential cross section results for electron impact excitation of the lowest autoionizing state of caesium at 30 eV using different distortion potentials (static only; static plus exchange; static plus absorption; static plus exchange plus absorption).

Figure 5. Differential cross section results for electron impact excitation of the lowest autoionizing state of caesium at 40 eV using different distortion potentials (static only; static plus exchange; static plus absorption; static plus exchange plus absorption).

Figure 6. Differential cross section results for electron impact excitation of the lowest autoionizing state of caesium at 70 eV using different distortion potentials (static only; static plus exchange; static plus absorption; static plus exchange plus absorption).

Figures 2 – 7 present the differential cross section (DCS) results at different electron impact energies. The DCSs have maximum value at small scattering angles and they reduce as the angles increase except at very low impact energy. This means that more particles are scattered at small scattering angles and less at large angles. As the projectile energy increases, the particle encounters less interaction with the target atom, hence it is scattered at a small angle. The inclusion of the exchange and absorption potential lowers the DCS across the energy range of the study but does not change the trend. As the impact energy increases, the agreement between our present results improves. This is because as the impact energy increases, the difference in the distortion potentials become less important. At lower impact energies, the absorption potential has little effect on the DCS. This is because very few other channels are open at this energy. That explains why the inclusion of an absorption potential at impact energies 16 eV and 20 eV (Figures 2 and 3) does not change the DCS at these energies. But as the impact energy increases, more channels are open and the inclusion of absorption potential shows its effect as we see at 30 and 40 eV electron impact energies. The present DCS results are in qualitative agreement amongst themselves and with those of Pangantiwar and Srivastava (1987) at all impact energies considered. Though there are few discrepancies which are attributed to different distortion potentials used at both the initial and final channels and also the different method of calculation of the transition matrix.

Our alignment parameter results for static and static plus absorption as the distortion potentials are in very close agreement with the relativistic distorted wave (without exchange) results (RDWD) of Kaur and Srivastava (1999). From the formula of alignment parameter, when A_{20} is negative indicates that σ_0 is greater than σ_1 . This means that most of the excitations are taking place from the magnetic substate $m = 0$ and when A_{20} is positive, it means that σ_1 is greater than σ_0 and most of the excitations are taking place from $m = 1$ magnetic substate. In our study, Figure 8, from just above excitation threshold up to around 350 eV, the alignment parameter is negative indicating that most of the incident electrons are scattered from the magnetic substate $m = 0$, compared to magnetic substate $m = 1$. Inclusion of absorption potentials slightly reduces the alignment parameter across the projectile impact energy range. Further inclusion of exchange potentials gives a slight reduction of the alignment parameter at intermediate energy range. Between 60 – 150 eV, our results for static and static plus absorption as the distortion potentials are in perfect agreement with the results of Kaur and Srivastava (1999).

Figure 7. Differential cross section results for electron impact excitation of the lowest autoionizing state of caesium at 100 eV using different distortion potentials (static only; static plus exchange; static plus absorption; static plus exchange plus absorption).

Alignment parameter

Figure 8. Alignment parameter results for electron impact excitation of the lowest autoionizing state of caesium using different distortion potentials (static only; static plus exchange; static plus absorption; static plus exchange plus absorption).

Lambda parameter

Figure 9. λ parameter results for electron impact excitation of the lowest autoionizing state of caesium at 16 eV using different distortion potentials (static only; static plus exchange; static plus absorption; static plus exchange plus absorption). The graph of present static plus absorption potential is mounted on the graph of our present static only potential, while the graph of our present static, exchange plus absorption potential is mounted on the graph of our present static plus exchange potential.

Figure 10. λ parameter results for electron impact excitation of the lowest autoionizing state of caesium at 30 eV using different distortion potentials (static only; static plus exchange; static plus absorption; static plus exchange plus absorption).

Figure 11. λ parameter results for electron impact excitation of the lowest autoionizing state of caesium at 40 eV using different distortion potentials (static only; static plus exchange; static plus absorption; static plus exchange plus absorption).

Figure 12. λ parameter results for electron impact excitation of the lowest autoionizing state of caesium at 70 eV using different distortion potentials (static only; static plus exchange; static plus absorption; static plus exchange plus absorption).

Our results show that most of the particles are scattered from the magnetic substate $m = 0$ as indicated in lower and upper scattering angles in our present λ parameter results for all the impact energies. We see from Figures 9 – 12 that as the impact energy increases most of the particles scattered at intermediate angles are scattered from $m = 1$ magnetic sublevel, since $\lambda < 0.3$. When $\lambda = 0.3$, then the particles are evenly scattered from the two states.

At 16 eV which is closer to the excitation energy, our results are in perfect agreement with the results of Pangantiwar and Srivastava (1987) at lower and upper scattering angles, with disparity at intermediate scattering angles ($30^\circ - 140^\circ$). At 30, 40 and 70 eV, our present λ results are in good qualitative and quantitative agreement at lower scattering angles, while in upper scattering angles there is disparity which is associated to different distortion potential used in the initial and final channels. Also, in the present study we have calculated the λ parameter for the unresolved state while Pangantiwar and Srivastava (1987) studied the λ parameter only for the fine structure state ($^2P_{3/2}$) of the caesium atom.

CONCLUSION

In conclusion our present results for integral cross section compares well with the experimental results of Borovik et al. (2011) around excitation threshold when we use real distortion potentials but with disparity at the intermediate energy region. When the imaginary absorption potential (Staszewska et al., 1984) is included, the results are improved at the intermediate energies (our present results are brought closer to the experimental results). The exchange potential drastically reduces the integral cross section around the excitation threshold (Furness & McCarthy, 1973). The change is very big, and this suggests that this model of exchange potential is not suitable for heavy alkali metals such as caesium. The present DCS results are in qualitative agreement with those of Pangantiwar and Srivastava (1987) at all impact energies considered. Though there are few discrepancies which are attributed to different distortion potentials used in both the initial and final channels, the present alignment parameter results are in good qualitative agreement with the theoretical work of Kaur and Srivastava (1999). It is seen from the present results for the λ parameter that, as the impact energy increases, most of the particles scattered at intermediate angles are scattered from the $m = 1$ substate.

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