Fragmentation of positronium in collision with singly ionized lithium

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Abstract. Fragmentation of ground state ortho Positronium (Ps) in collision with Li ion (Li+) including the electron loss to the continuum (ELC) are studied in the framework of post collisional coulomb distorted eikonal approximation (CDEA) for the target elastic case. The present model takes account of the two center effect on the ejected e which is crucial for a proper description of the projectile ionization involving an ionic target, particularly for the explanation of the shifting of the ELC DDCS peak.

1. Introduction

Electron emission process in atom – atom or ion - atom collisions becomes particularly interesting at the same time complex when a structured projectile loses electron in collision with the target. Most of the earlier experiments [1, 2] and consequently theories [3] on the projectile ionization concentrated on bare , partially stripped or neutral heavy projectiles [1] for which a distinct signature of a cusp / peak was observed in the emitted electron energy spectrum at around $\nu_e$ ( velocity of the electron ) $\approx \nu_p$ ( velocity of the positron ). This peak was attributed to the electron loss from the projectile ion / atom into its low - lying continuum, usually referred to as the electron loss peak (ELP). With the advent of mono energetic energy tunable positronium (Ps) beams [4], attention is also being focused both experimentally [5] and theoretically [6,7] on the breakup process of the projectile Ps atom.

The present work addresses the extension of our earlier work [6] to a more complex system, e.g., the two electron ( helium like ) ionic target , Li+ for the target elastic case ; i.e.,

$$\text{Ps} \ (1s) + \text{Li}^+ (\vec{r}_3, \vec{r}_4) \rightarrow e^+ (\vec{r}_1) + e^- (\vec{r}_2) + \text{Li}^+$$

(1)

One major advantage of the Li+ target (over He+) is that the electrons of the former are much more tightly bound than the electron of the Ps atom and as such the probability of the electron loss from the projectile Ps is expected to be much higher than the ionization of the target. Further, in view of the large excitation energy of Li+ as compared to the projectile Ps, we have neglected any virtual or real excitation of the Li+ target during the fragmentation, i.e., only the target elastic case is considered.

2. Theory:

The prior form of the ionization amplitude for the process (1) is given as [6]:

$$T_{\text{prior}} = \langle \Psi_f (\vec{r}_1, \vec{r}_2, \vec{r}_3, \vec{r}_4) | H - E | \Psi_i (\vec{r}_1, \vec{r}_2, \vec{r}_3, \vec{r}_4) \rangle$$

(2)

The prior interaction $V_i$ is given by;

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The initial asymptotic state \( \psi_i \) in Eq. (1) is given as:

\[
\psi_i = \phi_{Ps} \left( 1 - \frac{1}{r_2} + \frac{1}{r_3} \right) e^{i \tilde{k}_i \tilde{R}} \phi_{Li^+} \left( \tilde{r}_2, \tilde{r}_3 \right)
\]

where \( \tilde{R} = \frac{\tilde{r}_2 + \tilde{r}_3}{2} \) and \( \tilde{k}_i \) is the initial momentum of Ps atom with respect to the target nucleus. The wave function of Li\(^+\) \( (\phi_{Li^+}) \) is chosen to be due to Morse et al [8] as well as due to Clementi & Roetti [9].

The final channel wavefunction \( \Psi_f \) in Eq. (1) satisfying the incoming wave boundary condition is constructed taking into consideration that the ejected electron is in the combined (attractive) fields of the two positive ions, e.g., its parent ion \( (e^-) \) and the target ion Li\(^+\) and is approximated by the following ansatz in the framework of Coulomb modified eikonal approximation [6]:

\[
\Psi_f(\tilde{r}_2, \tilde{r}_3, \tilde{r}_4) = (2\pi)^{\frac{3}{2}} \phi_{Li}(\tilde{r}_2, \tilde{r}_3) e^{i k_i \tilde{r}_1} e^{i k_2 \tilde{r}_2} F_1(-i\alpha_2, 1, -i(k_2 r_2 + \tilde{k}_2, \tilde{r}_2)) \exp \left\{ i \eta \left( \frac{1}{r_2} - \frac{1}{r_{12}} \right) d\zeta \right\}
\]

with \( \alpha_2 = -\frac{(Z_i - 2)}{k_2} \) and \( \eta = \frac{(Z_i - 2)}{k_1} \) \( \tilde{k}_1, \tilde{k}_2 \) being the final momenta of the scattered positron and the ejected electron respectively with respect to the target nucleus.

Following our earlier work [6], the break up amplitude \( T_\theta \) can be finally reduced to a two dimensional numerical integral [6, 10]. The triple (TDCS) and double (DDCS) differential cross sections for the process (1) are given as:

\[
\frac{d^3\sigma}{dE_2 d\Omega_1 d\Omega_2} = \frac{k_1 k_2}{k_i} \left| T_\theta \right|^2;
\]

\[
\frac{d^2\sigma}{dE_2 d\Omega_1 (d\Omega_2)} = \frac{k_1 k_2}{k_i} \int d\Omega_2 \left| T_\theta \right|^2 d\Omega_2 (d\Omega_1)
\]

3. Results and Discussions

The fully (triple) differential (TDCS) and the double differential cross sections (DDCS) are computed for the process (1).

The TDCS in figure 1 exhibits a broad electron loss peak (ELP) for forward emission (0\(^0\)) of both the \( e^- \) & the \( e^+ \) in contrast to the sharp ELP cusp around 0\(^0\) for heavy ion impact [1]. This could be attributed to the probability of deflection of the light particle (\( e^- \)) to higher angles in contrast to the heavy projectile which is predominantly scattered in the forward direction (0\(^0\)). A prominent secondary peak appears particularly at \( \theta_2 = 45^0 \), that could be associated with the famous Thomas (p – n – e) mechanism [11] in charge transfer problems. The peak becomes more and more prominent with increasing incident energy, indicating the importance of the higher order effects at higher incident energies.
Figure 1. TDCS against the ejected $e^-$ angle ($\theta$) for different values of the scattered $e^+$ angle ($\theta_1$). The incident energy ($E_i$) = 50 eV, ejected $e^-$ energy $E_i$ = scattered $e^+$ energy $E_2 = 21.6$ eV. Solid curve for $\theta_1 = 0^\circ$, dashed curve for $\theta_1 = 20^\circ$, dashed dot-dot curve for $\theta_1 = 30^\circ$, and the dotted curve for $\theta_1 = 45^\circ$.

In figure 2, the DDCS ($\Sigma \theta_1, \phi_1$) exhibits a broad peak, slightly shifted towards higher ejection energy with respect to half of the residual energy ($E_{\text{res}}/2$, $E_{\text{res}} = E_i - E_1 - 6.8$). However, this shift decreases and moves towards $E_{\text{res}}/2$ with increasing $\theta_2$ and could be attributed to the post collisional two center effect [10,11].

Figure 2. The electron DDCS ($\Sigma \theta_1, \phi_1$) against the ejected $e^-$ energy for different values of $\theta_2$ at an incident energy $E_i = 56$ eV. The solid curve is for $\theta_2 = 0^\circ$, dashed curve is for $\theta_2 = 20^\circ$ and the dotted curve is for $\theta_2 = 30^\circ$.

Figure 3. The positron DDCS ($\Sigma \theta_2, \phi_2$) against the ratio of $R = \bar{\theta}_e / \bar{\theta}_p$ for three different incident energies and for $\theta_2 = 0^\circ$. The solid curve is for $E_i = 50$ eV, dashed curve is for $E_i = 75$ eV and the dotted curve is for $E_i = 100$ eV.
Figure 3 demonstrating the $e^+$ DDCS ($\sum \theta_1, \phi_2$) against the ratio $R = \tilde{u}_x / \tilde{u}_p$ indicates that the shifting of the peak arising due to the post collisional two center effect moves gradually towards $R=1$ with increasing incident energy.

4. Conclusions
The angular distribution (TDCS) of the $e$ exhibits a broad ELP at around $E_{\text{res}}/2$, unlike the sharp ELP cusp around $0^\circ$ for heavy ion impact. The notable shift of the electron DDCS peak (towards higher momenta) from its standard position ($\tilde{u}_e = \tilde{u}_p$) could be attributed to the post collisional two center effect. The $e^+$ DDCS shows exactly the reverse behaviour as is expected. The position of the $e^+$ ($e$) DDCS peak shifts gradually towards higher (lower) value of the ratio $R = \tilde{u}_x / \tilde{u}_p$ with increasing incident energy.

5. References

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