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# ECC study in positron impact ionization of helium

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**Abstract**

A 3C approximation which was employed in the study of the ECC phenomenon in positron impact ionization of $H_2$ is now applied to positron impact ionization of helium. Our absolute triple differential cross sections are used to calibrate the existing experimental data.


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*Keywords:* Positron collisions; Ionization of helium

## 1. Introduction

Experimental triple differential cross sections (TDCS) for the ionization of helium by positrons have been obtained in a relative scale by Arcidiacono et al. [1]. These measurements focused on the electron capture to the continuum (ECC) phenomenon, a special ionization case in which the ejected electron is captured by the projectile to a low-lying continuum state.

There are no theoretical results for this experiment. The only similar theoretical work was focused on obtaining TDCS for the ionization of $H_2$ by positron impact [2,3]. The BBK model used by both these papers was applied originally for the ionization of the atomic hydrogen by electron impact [4]. Both papers on the ionization of $H_2$ assumed that the target is comprised of two non-interacting hydrogen atoms and obtained theoretical TDCS in good agreement with the measurements for 100 eV positrons. However, for 50 eV positrons the experimental ECC peak appeared at an energy which was about 1.6 eV lower than the energy of the theoretical ECC peak obtained by Fiol et al. [3] after the convolution with the experimental angular and energy resolution. More recent calculations using the molecular model MBBK [5] improved the agreement with the experiment but did not resolve the disagreement in the ECC position for 50 eV positrons.

In this letter we shall use the BBK model of [4] in the study of the ECC phenomenon in positron impact ionization of helium. We shall study the ECC phenomenon only for 59.16 eV, the impact energy for which the experiment of Arcidiacono et al. [1] was performed. This impact energy in the case of helium ionization leads to the same residual energy as the 50 eV impact energy in the $H_2$ ionization.

## 2. Theory

We chose the initial state wave function as

$$\Psi_i = \frac{e^{i\mathbf{k}_i\cdot\mathbf{R}}}{(2\pi)^{3/2}}\phi_i(r_1, r_2), \tag{1}$$

where $\mathbf{R}$ is the position vector of the incident positron, while $\mathbf{r}_1$ and $\mathbf{r}_2$ are the position vectors of the two electrons of the helium atom, which is represented by the following ground-state wave function:

$$\phi_i(r_1, r_2) = u(r_1)\,u(r_2), \tag{2}$$

where $u(r)$ are one electron orbitals. Our calculations were done with $u(r)$ taken as the analytic fit to the Hartree-Fock wave function of Byron and Joachain [6]:

$$u(r) = c_1 e^{-1.41\cdot r} + c_2 e^{-2.61\cdot r}, \tag{3}$$

with $c_1 = 0.73485$, $c_2 = 0.58715$.

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We also did calculations with $u(r)$ represented as a hydrogenic type wave function

$$u(r) = 1.2371\mathrm{e}^{-1.6875\cdot r}. \quad (4)$$

The final state wave function was chosen as

$$\Psi_f = \frac{\mathrm{e}^{\mathrm{i}\mathbf{k}_e\cdot\mathbf{r}_1}\mathrm{e}^{\mathrm{i}\mathbf{k}_s\cdot\mathbf{R}}}{(2\pi)^3} C(\mathbf{k}_e, \mathbf{r}_1, \gamma_e) C(\mathbf{k}_s, \mathbf{R}, \gamma_s) C(\mathbf{k}_{1p}, \mathbf{r}_{1p}, \gamma_{ep}) \phi_f(r_2), \quad (5)$$

where the Coulomb distortion factors $C(\mathbf{k}, \mathbf{r}, \gamma)$ are defined as

$$C(\mathbf{k}, \mathbf{r}, \gamma) = \Gamma(1 - \mathrm{i}\gamma)\mathrm{e}_1^{-\pi\gamma/2} F_1(\mathrm{i}\gamma; 1; -\mathrm{i}(kr + \mathbf{kr})). \quad (6)$$

In Eq. (5) it is assumed that electron 1 is ionized, $\phi_f$ stands for the $He^+$ ground-state wave function and the Sommerfeld parameters $\gamma_e, \gamma_s$ and $\gamma_{ep}$ are given by

$$\gamma_s = 1/k_s, \quad \gamma_e = -1/k_e, \quad \gamma_{ep} = \frac{-1}{2k_{1p}}, \quad (7)$$

where $\mathbf{k}_{1p} = \frac{1}{2}(\mathbf{k}_s - \mathbf{k}_e)$ is the momentum conjugate to $\mathbf{r}_{1p}$, $\mathbf{k}_e$ and $\mathbf{k}_s$ are the vector momenta of the emerging electron and positron, respectively.

## 3. Results and discussion

In Fig. 1 we present our TDCS results for 59.16 eV impact energies and zero ejected and scattering angles. The ECC peak corresponds to the emerging electron and positron having exactly the same momentum. Actually the ECC peak should be infinite, but the resolution of our points along the ejected electron axis makes it look finite. Fig. 1 shows that there is significant difference between the results corresponding to the two representations of the helium target.

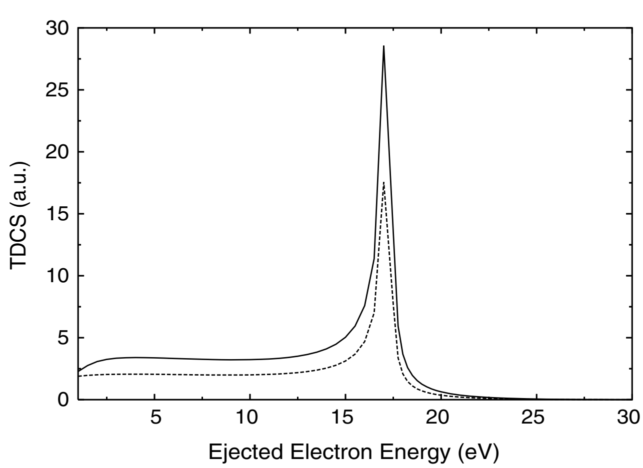


Fig. 1. TDCS as a function of the ejected electron energy for helium ionization with 59.16 eV positrons. Both emerging particles are detected in the forward direction. The solid curve corresponds to the BBK results corresponding to an analytic fit to the Hartree-Fock representation of [6], while the dashed curve corresponds to the hydrogenic representation of helium.

A comparison with experiment can be done only after the convolution with the experimental angular and energy resolution, which we assumed as being the same as communicated by Kövér et al. [7] in the $H_2$ case. By convolution the position of the peak shifts to a lower ejected electron value (from 17.3 to 16.6 eV).

Fig. 2 compares our convoluted BBK data for 59.16 eV impact energy with the experimental data of Arcidiacono et al. [1]. Two adjustments were made to facilitate this comparison. First, our theoretical data were shifted by 2.66 eV towards lower ejected electron energies. Secondly, the experimental data, which were produced in a relative scale, were made to match our peak sizes. The agreement between our shifted theoretical curves and the experiment is quite good.

The 2.66 eV shift between our theoretical data and the experiment illustrates that our BBK model is unable to correctly reproduce the experiment. The most likely phenomenon responsible for the shift of the theoretical peak is the interaction between the direct ionization and other open channels like positronium formation, or helium excitation.

The fact that the interaction between the ionization channel and the Ps formation channel is very important is supported by our finding that the shift in the He case (2.66 eV) is larger than in the $H_2$ case (1.6 eV). As the Ps formation maximum occurs at around 45 eV in the He case and at around 25 eV in the $H_2$ case (see [8]), one could expect that the interaction with the Ps formation channel is more important for the 59 eV positron impact ionization of helium than for the 50 eV positron impact ionization of $H_2$.

Helium excitation channels can also have some influence on the ionization channel. However, based on Fig. 4 of Campeanu et al. [9], at 59 eV positron impact energy the sum of all helium excitation cross sections equals about a third of the Ps formation cross section. This observation gives support to future theoretical work using only the coupling between the ionization and Ps formation channels.

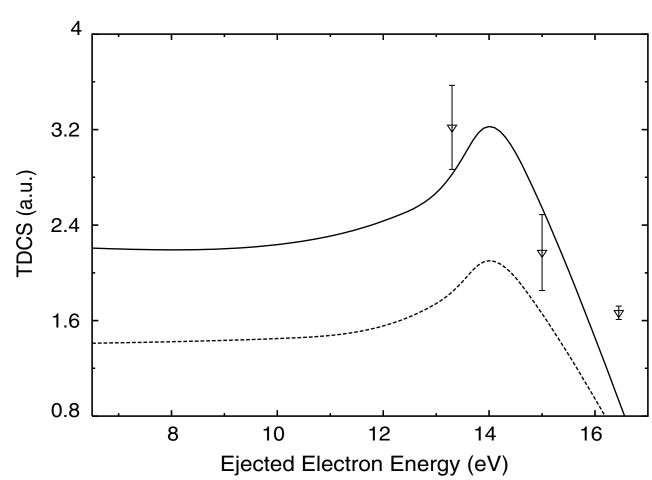


Fig. 2. Convoluted TDCS as a function of the ejected electron energy for helium ionization with 59.16 eV positrons. The theoretical curves, explained in Fig. 1, were shifted by 2.66 eV for comparison with the experimental data of Arcidiacono et al. [1].

## 4. Conclusions

Our paper presents for the first time absolute TDCS values for positron impact ionization of helium in the ECC range.

We find that our 59.16 eV impact energy ECC peak is shifted relative to the experimental peak by 2.66 eV. Based on the analysis of the existing data for Ps formation and He excitation, we conclude that the shift is most likely due to the absence in the theory of the interaction between the ionization and the positronium formation channels.

## Acknowledgement

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