Positron Impact Excitation ($n = 2$ states) of Hydrogen at 20 eV

M. Z. M. Kamali*

Center for Foundation Studies in Science, University of Malaya, Kuala Lumpur, 50603, Malaysia

Kuru Ratnavelu

Institute of Mathematical Sciences, University of Malaya, Kuala Lumpur, 50603, Malaysia

(Received 17 November 2010, in final form 15 February 2011)

The calculation of accurate differential cross sections (DCS) has always posed a litmus test for theoretical models. Among the positron-atom scattering systems, the positron-hydrogen ($e^+ - H$) atom system is the fundamental prototype. Thus, the present work utilizes 12- and 15-states coupled-channel optical method (CCOM) calculations to study the DCS $H(2s + 2p)$ excitation, together with the angular correlation parameters ($\lambda(2p)$), for the $e^+ - H$ system at 20 eV, but up to now, there have been no measurements yet on the DCS for this system. A comparison is done with other theoretical and experimental works, including the electron case.

I. INTRODUCTION

Since the theoretical prediction of the positron [1] and the experimental verification by Anderson [2], the positron has had a big impact on the world of atomic and molecular physics. Furthermore, the birth of the positron unintentionally triggered the idea of the physics of antimatter. In particle physics, the combinations of matter and antimatter can lead to annihilation, thus giving rise to high-energy photons (gamma rays) or other particle-antiparticle pairs. Although, the positron is just a simple anti-electron with a positive charge, it is still an interesting subject to be studied.

In this paper, we present the coupled-channel optical method (CCOM) calculation for $N = 2$ (H(1s-2s or 2p)) differential cross sections (DCS) for $e^+ - H$ systems and angular correlation parameters ($\lambda(2p)$). Due to the unavailability of experimental measurements for the inelastic DCS and the angular correlation parameters in the $e^+ - H$ systems, comparisons are made with measurements [3,4] in the corresponding electron case. Such comparisons may provide some insight into these two different systems.

II. THEORY AND DISCUSSION

The theoretical details of the coupled-channel optical method (CCOM) for the $e^+ - H$ collision system has been discussed in a previous work [5]. Basically, the Schrodinger equation can be transformed into a coupled set of momentum space Lippmann-Schwinger (L-S) equations for a positron with the momentum $k$ incident on a hydrogen atom in state $\psi$:  

$$
\langle k' \psi_{\alpha'} \mid T \mid k \psi_{\alpha} \rangle = \langle k' \psi_{\alpha'} \mid V^{(Q)} \mid k \psi_{\alpha} \rangle + \sum_{\alpha''} \int d^3 k'' \langle k' \psi_{\alpha'} \mid V^{(Q)} \mid k'' \psi_{\alpha''} \rangle \langle k'' \psi_{\alpha''} \mid T \mid k \psi_{\alpha} \rangle \left( E^{(+)} - \epsilon_{\alpha''} - \frac{1}{2} k''^2 \right) + \sum_{\beta''} \int d^3 k'' \langle k' \psi_{\alpha'} \mid V \mid k'' \psi_{\beta''} \rangle \langle k'' \psi_{\beta''} \mid T \mid k \psi_{\alpha} \rangle \left( E^{(+)} - \epsilon_{\beta''} - \frac{1}{2} k''^2 \right)
$$

$$
\langle k' \phi_{\beta'} \mid T \mid k \psi_{\alpha} \rangle = \langle k' \phi_{\beta'} \mid V \mid k \psi_{\alpha} \rangle + \sum_{\alpha''} \int d^3 k'' \langle k' \phi_{\beta'} \mid V^{(Q)} \mid k'' \psi_{\alpha''} \rangle \langle k'' \psi_{\alpha''} \mid T \mid k \psi_{\alpha} \rangle \left( E^{(+)} - \epsilon_{\alpha''} - \frac{1}{2} k''^2 \right) + \sum_{\beta''} \int d^3 k'' \langle k' \phi_{\beta'} \mid V \mid k'' \psi_{\beta''} \rangle \langle k'' \psi_{\beta''} \mid T \mid k \psi_{\alpha} \rangle \left( E^{(+)} - \epsilon_{\beta''} - \frac{1}{2} k''^2 \right)
$$

where $\phi_{\beta}$ represent the Ps states and $V^{(Q)}$ is the optical potential. The $E^{(+)}$ denotes the total energy of the system. In this work, the following calculations were performed: (a) CCO(9,6) – this CC model includes 9 hydrogen states (1s, 2s, 2p, 3s, 3p, 3d, 4s, 4p, 4d) and 6 positronium states Ps(1s, 2s, 2p, 3s, 3p, 3d) states, together with 3 continuum optical potentials for 1s-1s, 1s-2s, and 1s-2p; (b) CCO(9,3) – this is similar to (a)

*E-mail: mzmk2000@yahoo.com; Fax: 603-79576478
The present results are depicted in Fig. 1, where a comparison is made with experimental data [3,4] and other theoretical data [6,7] from the electron case. Similar qualitative shapes are observed in Fig. 1(a) for both collision systems except for the small maxima that can be seen in the positron case in the angular range from 45° to 110°. The magnitudes of the $e^-$ DCS are larger at backward scattering angles compared to the positron case. This might be due to the exchange effect, which is absent in the positron case. In Fig. 1(b), there is limited agreement between the positron and the electron cases at lower angles. The CCO(9,6) and CCO(9,3) predict a very deep minima at about 40° for the electron. Generally, there are similarities, as well as differences, between these two collision systems throughout the whole angular range.

### III. CONCLUSION

We have extended the CCOM calculations by using larger states, CCO(9,6) and CCO(9,3), on the $e^-\text{-H}$ scattering at 20 eV. The continuum optical potentials were used in both calculations. It is interesting to find that the qualitative DCS are quite similar for both scattering systems. As expected, the $\lambda$ parameter for the 2p excitation of hydrogen by positron impact shows some significant differences from the electron case. This is plausibly due to the contribution of $Ps$ formations. Further work is still in progress.

### ACKNOWLEDGMENTS

MZMK and KR acknowledge research grants No.: RG089/10AFR and No.: RG134/10AFR, respectively, from the University of Malaya (UM) for support of this work. MZMK also thanks UM for travel support.

### REFERENCES