

DWBA double differential ionization cross sections for positron impact on argon

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Abstract

The ionization of the 3p orbital of argon by 60 and 100 eV incident positrons is studied with the DWBA approximation. The variation of our double differential ionization cross sections with scattered positrons energy is found to be in reasonable agreement with the experiment.

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1. Introduction

Differential cross section measurements provide a more stringent test of theory than do their integral counterparts. Accordingly, much effort, both theoretical and experimental, has been devoted to studies of double and triple differential cross sections (DDCS and TDCS respectively) in electron–atom collisions with the aim of elucidating the mechanisms underlying the ionization process. For positron impact, much fewer measurements of DDCS and TDCS have been undertaken, mainly due to the serious intensity limitation of the beams available in most laboratories. This is also the reason why many of the positron impact studies dealt with the argon-gas target, where the larger cross section can partially offset the low positron flux.

Double differential cross sections for positron impact ionization of argon have been measured by Moxom *et al* [1], Kover *et al* [2] and Schmidt *et al* [3]. The only theoretical results available for comparison with these experimental data were provided by Sparrow and Olson [4] with a classical-trajectory Monte Carlo (CTMC) method. The data of Sparrow and Olson agreed with the experimental data of Kover *et al* for the case in which the positrons were scattered at 2° . However for the cases when positrons were scattered at 30° and 45° a serious discrepancy between theory and experiment was noted for high scattered positron energies. This discrepancy was studied more recently by Kover *et al* [5] but the new experimental results confirm the accuracy of those published in [2] showing that the decrease of the DDCS when the scattered positron energy increases from 70 to 80 eV is a genuine feature of the scattering process and not an instrumental effect. The paper by Kover *et al* [5] also presents new experimental results for 60 eV impact energy.

This paper provides new theoretical results for the discussion around the discrepancy between the CTMC data and the experimental results in the study of the variation of the DDCS with high scattered positron energies. Unlike in the theoretical work of Sparrow and Olson [4], which utilized a classical-trajectory Monte Carlo (CTMC) method, our paper employs the Distorted Wave Born Approximation (DWBA).

2. Theory

The triple differential cross-section for the ionization of argon by positron impact may be written as

$$\frac{d^3\sigma}{d\hat{k}_f d\hat{k}_e dE_e} = \sum_r \frac{(2\pi)^4}{E_i} |f_r|^2 . \quad (1)$$

Here E_i is the energy of the incident positron, E_e the energy of the ejected electron, while \hat{k}_e and \hat{k}_f stand for the direction of the momenta of the ejected electron and scattered positron, respectively. The summation over r is done over all occupied atomic orbitals. The DWBA results presented in this paper correspond to the ionization of the 3p orbital of argon. The contributions coming from the ionization of the 3s orbital were negligible for the impact energies considered in our calculations.

The amplitude can be written as

$$f_r = \langle \phi_f(\vec{r}_1) \phi_e(\vec{r}_2) | V(r_{12}) | \phi_i(\vec{r}_1) \phi_r(\vec{r}_2) \rangle , \quad (2)$$

where ϕ_i and ϕ_f stand for the wavefunction of the incident and scattered positron respectively, ϕ_e is the wavefunction of the ejected electron, while ϕ_r describes the initial state of the active electron. In the above amplitude \vec{r}_1 is the position vector of the positron, while \vec{r}_2 stands for the position vector of the active electron.

Our quantum model included the distortion of the positron and ejected electron waves in various fields seen by these particles. For the incident positron we considered the static field of Ar and the atomic polarization potential. The final state channels description depends on the energies of the outgoing leptons.

For the energies considered in this work it was very important to correctly describe the situation when the scattered positron is faster than the ejected electron. For the scattered positron channel we considered the static potential of the Ar^+ ion and a polarization potential corresponding to the Ar^+ and the slow ejected electron system. We used as a polarization potential the same potential as the one used in the incident channel. For the ejected electron channel we considered the static potential of the Ar^+ ion and a Furness-

McCarthy exchange potential, where we assumed that the exchange is triplet for all bound electrons.

For the case of ejected electrons faster than the scattered positron we used simple Coulomb potentials. We assumed that the scattered positron “sees” a single positive charge, while the ejected electron “sees” two positive charges. For the ejected electron channel we also added the Furness-McCarthy exchange potential.

For the post-collision interaction (PCI) between the scattered positron and the ejected electron we used the low energy approximation of Ward and Macek [6]. This approximation produces the external factor:

$$|C_{proj-eject}|^2 = G \left| {}_1F_1 \left(\frac{i\gamma}{2\pi}, 1, \frac{i2\pi}{\gamma} r_{ab}^{ave} \right) \right|^2 \quad (3)$$

where the last parameter of the hypergeometric function ${}_1F_1$ includes:

$$r_{ab}^{ave} = \frac{\pi^2}{16\varepsilon_t} \left(1 + \frac{0.627}{\pi} \sqrt{\varepsilon_t} \ln \varepsilon_t \right)^2. \quad (4)$$

ε_t is the total energy of the scattered positron and ejected electron and G is the Gamow factor:

$$G = \frac{\gamma}{\exp(\gamma) - 1}$$

with

$$\gamma = \frac{-\pi}{|\mathbf{k}_f - \mathbf{k}_e|}. \quad (5)$$

Madison and Al-Hagan [7] found that in many cases the Ward-Macek PCI approximation produces better TDCS values than the Gamow factor. In our work we found that the use of the Ward-Macek external factor produces higher DDCS than the use of the Gamow factor but the shape of the DDCS variation with the scattered positron energies is about the same in both cases.

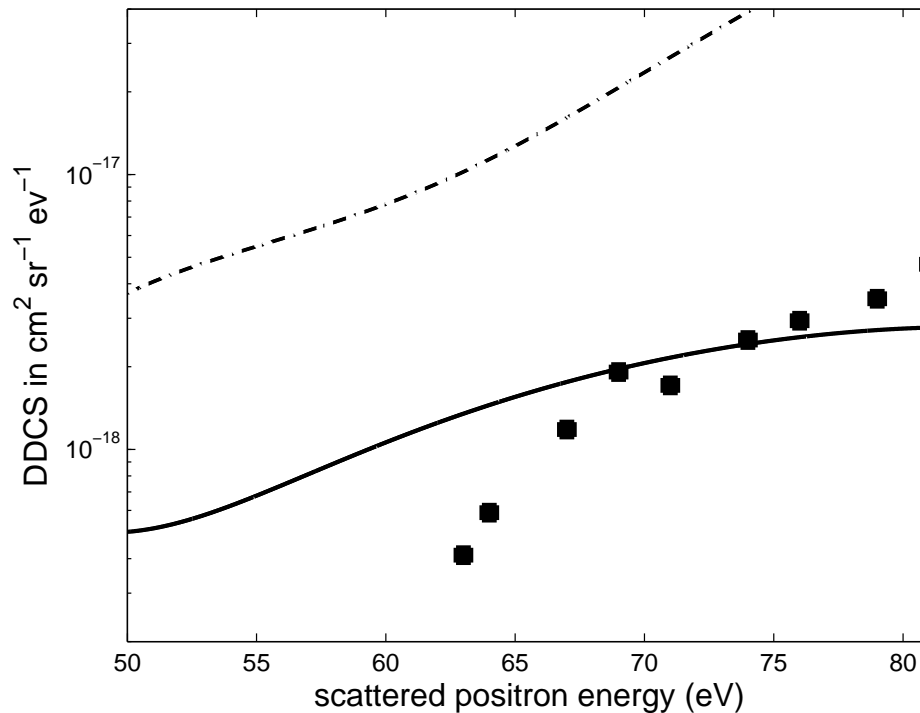
In this paper we obtained DDCS by integrating the TDCS over the ejected electron angles. In addition we performed a Gaussian convolution with the experimental angular resolution, which was 8° for the case of positrons scattered at 30° and 45° and 2° for the positrons scattered at 2° .

3. Results and Discussion

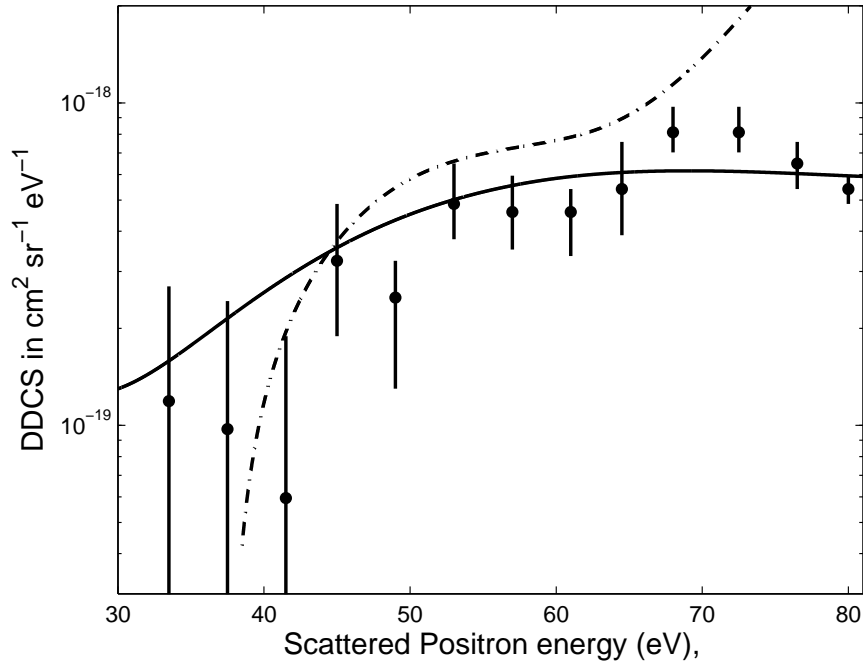
Figure 1 presents our DDCS for 100 eV positron impact energy. They are compared with the CTMC data and the experimental cross sections. The experimental data of Kover *et al* [5] were relative and were adjusted to match our DWBA data at the middle of the range of scattered positron energies considered in the experiment.

Figure 1 shows that our DWBA cross sections are in general lower than the CTMC results. The other observation is that the variation of our results is in better agreement with the experimental variation than the CTMC results. The agreement with the experimental data is particularly good at high scattered positron energies, while at low energies the experimental cross sections are typically below the DWBA curves. At low scattered positron energies the experimental uncertainties are very large in figures 1b and 1c.

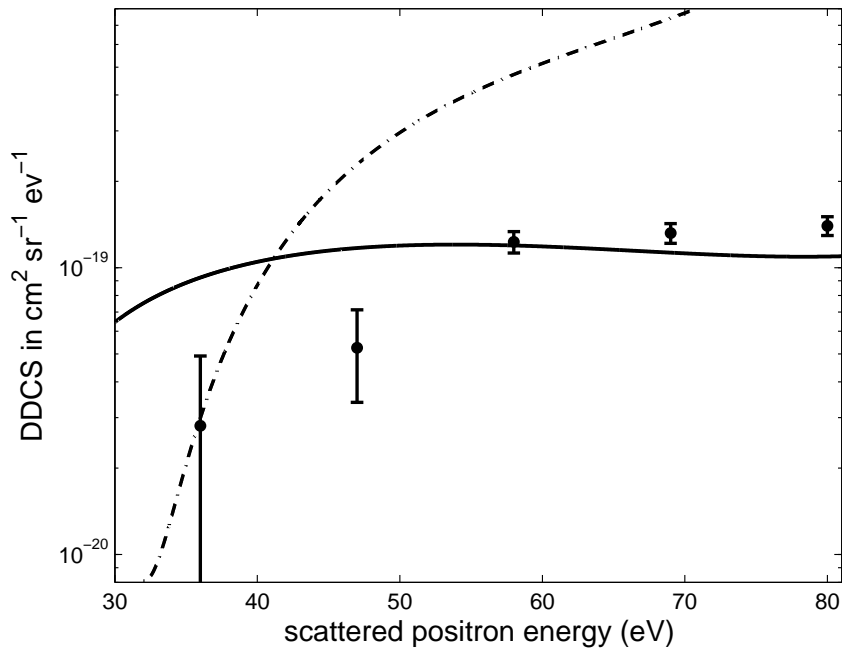
For the 2° case the difference between the size of the DWBA and CTMC cross sections is the largest, but their variation with the scattered positron energies is quite similar. Only at energies higher than around 70 eV the CTMC data increase faster than our DDCS results and the experimental data.



(a)



(b)



(c)

Figure 1. Double-differential cross sections for Ar ionization by 100 eV positrons. The continuous curve corresponds to our DWBA model and the dotted dashed curve to the CTMC data of Sparrow and Olson [4]. The experimental results are the relative measurements of Kover *et al* [5] scaled to fit our DWBA results. Figures (a), (b), (c) correspond to positrons scattered at 2° , 30° and 45° respectively.

For the 30° case the disagreement between the variation of our DWBA data and of the CTMC data is larger than in the 2° case. For scattered positron energies at over 70 eV the CTMC model predicts a sharp increase in the DDCS values, which is in clear disagreement with the experiment and our DWBA data. For very low scattered positron energies the CTMC model predicts a sharp drop in the cross sections in contrast with the results of our study.

The theoretical curves for the 45° case behave similarly to those in the 30° case but the difference between the two curves increases relative to the 30° case. The peak of our DWBA curve is at 70 eV in the 30° case and at 50 eV in the 45° case.

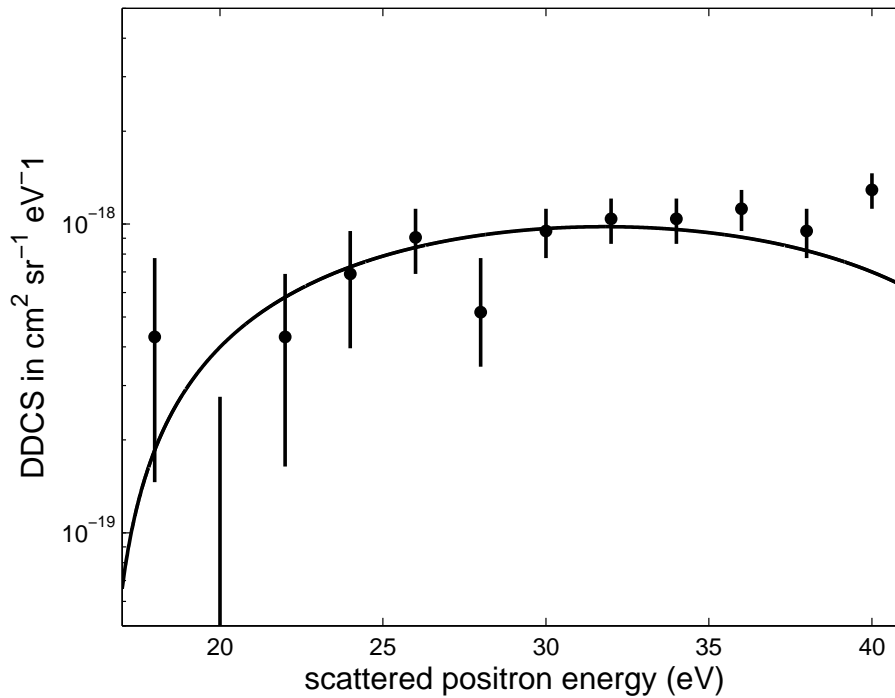


Figure 2. Double-differential cross sections for 60 eV positrons scattered at 30° after Ar ionization. The continuous curve corresponds to our DWBA model. The experimental results are the relative measurements of Kover *et al* [5] normalized to fit our theoretical results at 30 eV.

In Figure 2 we compare our DDCS for 60 eV impact energy with the relative experimental data of Kover *et al* [5], which were normalized to fit our DWBA results at the middle of the energy range considered. For this case there are no CTMC calculations.

The shape of our DWBA DDCCS variation with the scattered positron energies is in good agreement with the experiment.

3. Conclusions

We conclude that our DWBA model produces a variation of the DDCCS with the scattered positron energies which agrees quite well with the experimental findings of Kover *et al* [2,5] for all cases studied in this paper. Our theoretical data agree with the experiment better than the CTMC data [4], particularly at high scattered positron energies.

Our DWBA model included the distortion of the positron and ejected electron waves in the static field of Ar or Ar⁺, the argon polarization in the incident and fast scattered positron channels, and a Furness-McCarthy exchange potential in the ejected electron channel. In this work we found that the addition of the post-collision interaction between the scattered positron and the ejected electron through the Ward-Macek PCI approximation does not significantly change the shape of the DDCCS variation with the scattered positron energy. However, the PCI inclusion increases the magnitude of the DDCCS making them similar to those predicted by the CTMC model.

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