

Excitation Plus Ionization in Electron-Atom Collisions to He^+ ($n=2$): $(e,2e)$, $(e, e\gamma)$ and $(e, 2e\gamma)$ Studies

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Abstract

Simultaneous excitation-ionization of helium atoms by electron impact is observed by the coincidence detection of the outgoing particles. The relationship between $(e,2e)$, $(e,e\gamma)$ and $(e,2e\gamma)$ experiments is discussed.

Key Words: Ionization-Excitation, Helium, Electron, Triple Coincidence, Correlation

1. Introduction

There is now considerable effort aimed at understanding two active atomic electron processes in helium to the same extent as single active electron processes. Simultaneous excitation-ionization forms an important component of these two active electron processes. These processes, apart from being interesting themselves, are also important for the description of auroral and other upper atmospheric phenomena. Knowledge of these processes in other atoms can also be important for understanding plasma characteristics [1].

A schematic diagram for excitation-ionization processes is shown in Figure 1. Until recently, experimental studies have been limited to emission cross section measurements from the optical decay to lower energy state ions. The $\text{He}^+(2p)$ emission cross section as a function of energy from threshold to 300 eV has been observed by Dogan et al. [2] and compared with previous absolute cross sections and theoretical excitation cross sections. Information is not available from observation of single outgoing electrons since they are generally small indistinguishable components of a continuum dominated by ground state

ionization. Hence information from the scattered and ejected electrons only became available through the (e,2e) method, some time after it had been developed and applied to a large number of ground state ionization studies.

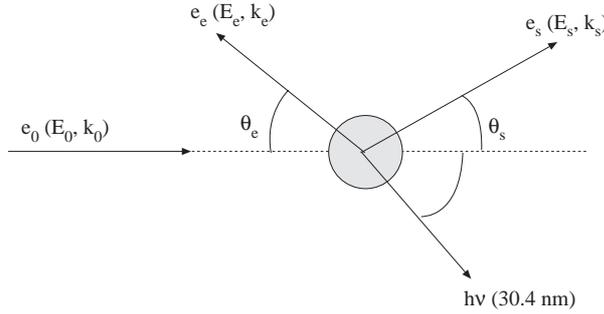


Figure 1. Schematic diagram for excitation-ionization processes.

So far, only (e,2e) and electron-photon correlation experiments have been reported. In both cases one particle is undetected. The (e,2e) measurements have been carried out for the combined $\text{He}^+(2s,2p)$ states while the photon correlation measurements have the advantage that the $\text{He}^+(2p)$ state can be isolated. Moreover, the emitted photon has the potential to provide more detailed information on the excitation-ionization process. Although non-detection of the second electron leads to a loss of coherence, the results provide a very valuable test of theory. The combination of (e,2e) and (e,e γ) methods provides an important stepping stone on the way to an (e,2e γ) study [3]. The study of an excited ion using a triple scattered electron-ejected electron-polarized photon coincidence technique raises the possibility of a complete ionization experiment.

The first correlation studies of the ionization-excitation process used the (e,2e) method. For $\text{He}^+(n = 2)$ only four groups have presented data: (i) The Rome group [4]; (ii) the Paris group [5]; (iii) the Newcastle group [6]; and (iv) the Manchester group [7]. Apart from the symmetric geometry data of Murray and Read [7] at an incident electron energy of 145 eV, the Rome and Paris studies have been carried out in highly asymmetric geometries at incident energies in the range 10-85 times the threshold energy. In this approach the emitted photon has been ignored and the dynamics of the process probed using the two outgoing electrons in (e,2e) experiments. Since the energies of all free electrons are determined in an (e,2e) experiment, there is no problem with cascade effects but there is a problem with degenerate ion states which cannot be separated on the basis of energy analysis alone: for example, $\text{He}^+(2s)$ and $\text{He}^+(2p)$. Recently, (e,2e) calculations using an R-matrix final-state have been made by Marchalant et al [8]. They obtained good agreement with the experimental data given by Avaldi et al. [4]. For their second order calculation, they also obtained much better agreement with the Dupre et al. [5] data than for first Born R-matrix final-state calculations.

A second type of experiment for looking at simultaneous ionization and excitation of neutral helium atoms is the electron-photon correlation method. The first measurement

of electron-photon angular correlations for ionization-excitation was reported recently [2,9], while a general analysis of such experiments, together with some calculations for $\text{He}^+(2p)$, was given by Schwienhorst et al. [10]. They have developed the general theory of correlation experiments for simultaneous excitation-ionization. Their predictions of the differential cross sections and correlation parameters using a combined DWBA-R-matrix method provide experimentalists with a helpful guide to conditions likely to lead to a measurable signal.

Another type of experiment can be done using the electron-photon coincidence technique for ionization-excitation [2,6]. The coincidence rate as a function of the energy of the outgoing detected electron gives the shape of a double-differential cross section (DDCS).

2. Experimental Arrangement

The experimental apparatus has been described in previous publications [2,11]. Essentially, it consists of fairly conventional $(e,2e)$ and $(e,e\gamma)$ spectrometers sharing a single fast-scatter electron analyzer. Energy analysis is performed using electrostatic hemispherical analyzers. The 30.4 nm radiation is detected directly by a channel electron multiplier preceded by a broad-band filter to eliminate most or all of the much more intense helium atom resonance lines in the VUV [2].

3. Results

3.1. $\text{He}^+(n=2)$ - $(e,2e)$ studies

Studies of $(e,2e)$ angular distributions have been carried out on the $\text{He}^+(n=1)$ state under various kinematic conditions in order to demonstrate that accurate relative triple-differential cross sections (TDCS) can be measured by comparison with previous data. $(n=2)$, $(e,2e)$ data have been obtained for different incident energies and kinematics.

Comparisons with previous $n=1$ data are made for an incident electron energy of $E_o=200$ eV, scattered electron angle of $\theta_s = -12^\circ$ and ejected electron energy of 33.5 eV. The ejected electron angular range reported here spanned 50 to 120° in the forward direction and 70 to 120° in the backward direction. In Figure 2a the present results are compared with the measurements of Lower and Weigold [12] and McDonald and Crowe [13] (using a different apparatus than in the present study).

The results all display good agreement in the region of the binary peak ($\sim 50^\circ$). However, there is pronounced disagreement in the recoil region where Lower and Weigold [12] suggest the TDCS is effectively constant between 110° and 150° , in contrast to the rise in the TDCS as the $-\mathbf{K}$ direction is approached, observed in both the present work and by McDonald and Crowe [13].

The measurements for the $\text{He}^+(n=2)$ state excitation-ionization have been made for an incident electron energy, $E_o=570$ eV, ejected electron energy, $E_e=10$ eV, and fixed scattering angle, $\theta_s=-4^\circ$. In Figure 2b the present results are compared with experimental

data of Avaldi et al. [4] and theoretical calculations of Marchalant et al. [8] at an incident energy of 645.4 eV. The present data have been normalized at an ejected electron angle of 75° to Avaldi et al. [4]'s data. The form of the cross sections in the forward direction are qualitatively similar. At the time of measuring this data, the backward angular range was restricted. Unusually the recoil peak is larger than the binary peak and the recoil peak is not a simple maximum as for the $n=1$ state. The measured binary peak is well displaced from the momentum transfer direction. The theoretical calculations of Marchalant et al. [8] and Avaldi et al. [4] do not agree with the experimental data or even with themselves both in shape and magnitude. Both first Born calculations show the expected symmetry about the θ_K , and $-\theta_K$ directions (in the case of Marchalant et al. after we corrected their data). The second Born results of Marchalant et al. show good agreement in shape at large ejected electron angles but the magnitude is a factor of 2.75 higher than the absolute experimental values of Avaldi et al.

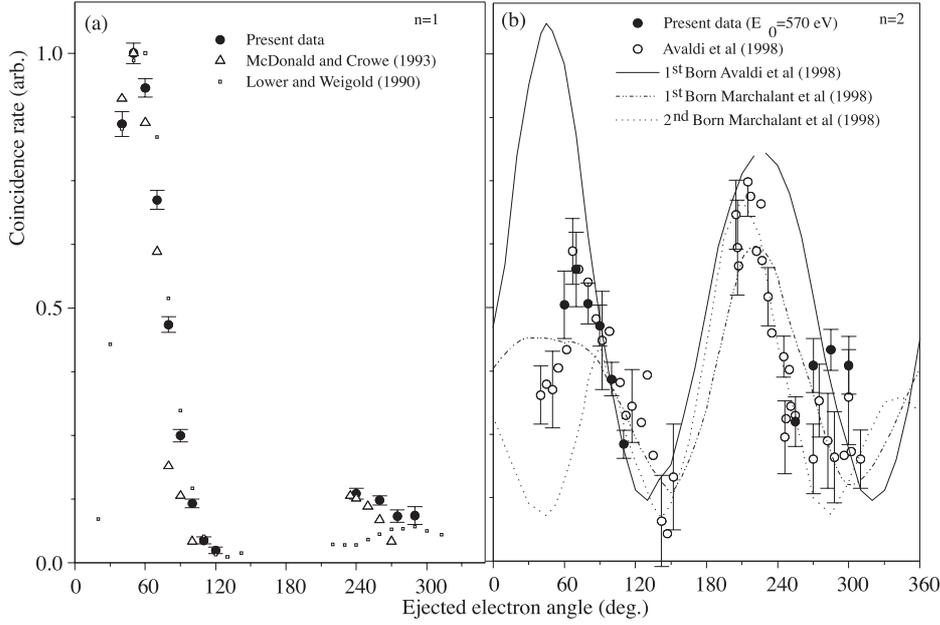


Figure 2. TDCS for (a) $\text{He}^+(n=1)$ $E_o=200$ eV, $E_e=34$ eV and $\theta_s = -12^\circ$ and (b) $\text{He}^+(n=2)$ at $E_o=570$ eV compared with the $E_o=645$ eV data of Avaldi et al. with $E_e=10$ eV and $\theta_s = -4^\circ$.

3.2. He^+ (2p) - Electron-photon angular correlations

We have measured correlations at 200 eV for an ejected electron energy of 1.2 eV and scattered electron angles in the range $5-30^\circ$. A single angular correlation can only yield two independent parameters, amplitude and phase, and hence cannot uniquely determine

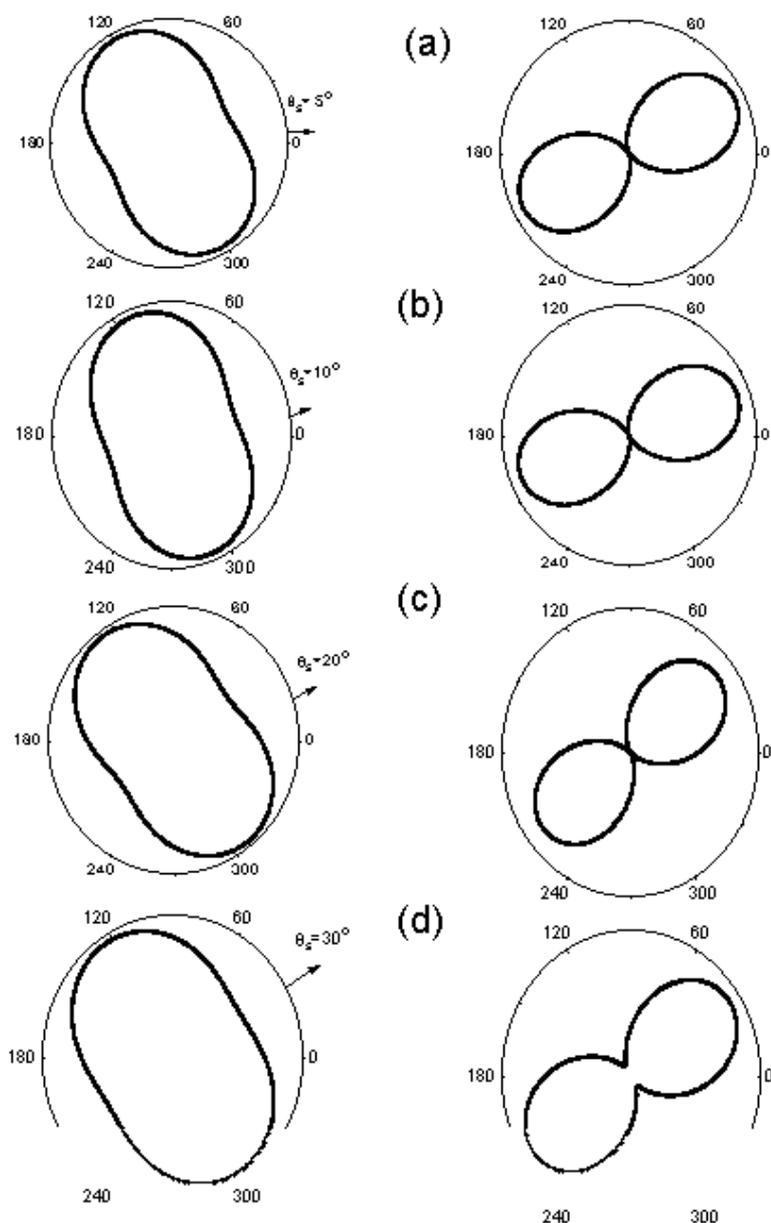


Figure 3. The measured angular correlations (left row) and corresponding charge cloud shapes in the scattering plane (right row) for excitation-ionization of the helium 2p ion state excited by 200 eV incident electrons and corresponding 1.2 eV ejected electron energy for scattering angles of (a) 5° , (b) 10° , (c) 20° and (d) 30° .

the three alignment parameters of the excited ion state. The observed coincidence signal N_c can be written in the form

$$N_c = B[1 - A \cos(2(\theta - \gamma))],$$

where B is a normalization constant, A is the amplitude of the correlation, θ is the photon emission angle and γ is the alignment angle of the excited state. From our values of A and γ , Figure 3 shows the measured angular correlations and corresponding charge cloud shapes in the scattering plane for $\text{He}^+(2p)$ states.

The realization of a triple coincidence ($e, 2e\gamma$), quantum mechanically complete experiment for ionization [14,15] is an exciting prospect and is significantly enhanced by the present complementary ($e, 2e$) [6,16] and ($e, e\gamma$) [2,17] studies. It is hoped that the current work will further stimulate experimental and theoretical efforts in this field.

Acknowledgements

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