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Autoionization Resonances in the Simultaneous Excitation-Ionization of Helium

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Abstract

The effect of autoionizing states on excitation-ionization processes has been investigated experimentally by observation of the electron impact ionization process leading to $He^+(2p)$ with the excitation energy region in helium corresponding to doubly excited states above the second ionization threshold. Also, the process arising from the decay of the doubly excited 'parity unfavoured' $(2p^2)^3P$ state of helium, is studied.

Key Words: Autoionization, Ionization-Excitation, Coincidence Detection, Angular Correlation, Helium

1. Introduction

Atoms, molecules and ions can be excited to certain discrete states which spontaneously decay by the emission of electrons rather than photons. This radiationless process is called double excitation-autoionization and was first noted by Auger in 1925 by observation of the ejected electrons in a cloud chamber. An autoionizing atomic state is one in which the atomic excitation energy is in excess of the first ionization limit of the atom, but the atom is not in an ionized state. The study of the electrons ejected through the autoionization decay of these excited states is expected to provide important information on their properties. Resonances and the phenomenon of autoionization present interesting challenges to the quantum theory of the structure and dynamics of many-electron systems. Their rigorous and quantitative understanding requires the application of many-electron approaches to the discrete as well as to the continuous spectrum. The autoionization of atoms excited by electron impact involves the interference between the direct-ionization amplitude and the resonance or autoionization amplitude. This interference depends on the momenta of the scattered and ejected electrons. A critical characteristic of these resonances, aside from the actual resonant energy is Γ, the spectral linewidth proportional to the inverse lifetime, typically $10^{-12}-10^{-16}$ sec. The radiative decay channel is generally too slow (10^{-8} sec.) to compete with autoionization.

Two electron atoms are the simplest systems which autoionize. For this reason their resonances above the first ionization threshold have been studied extensively both experimentally and theoretically. Considering now the case of helium, atomic excitation to an energy in excess of the ionization potentials will arise only through the simultaneous excitation of both atomic electrons.

Autoionizing levels excited in the photoabsorption spectrum of helium by Madden and Codding [1] were classified by Cooper et al. [2] in a quite useful manner. The observed series of autoionizing levels, lying in the 60 to 65 eV energy region converge to the n=2 level of He^+. First calculations on the autoionizing levels between the n=2 and n=3 levels of He^+ have been carried out by Ormonde et al. [3]. Because of recent experimental and the theoretical interest, we have carried out an investigation of the resonance states in helium atoms between the n=2 and n=3 He^+ thresholds.

'Parity unfavoured' transitions are characterized by the property L + ΔΠ odd, where L is the orbital angular momentum transfer and ΔΠ(=0 or 1) is the change of parity. An important consequence of that property is that the doubly excited states concerned are stable against autoionization. In general they cannot be excited from the ground state by photoabsorption and are therefore unobserved in the absorption experiments of Madden and Codling [1]. In electron impact experiments parity unfavoured transitions can in principle occur and they are expected to exhibit a number of interesting properties.

2. Double Excitaion-Autoionization Effects in the Excitation-Ionization Process

The influence of high lying autoionizing states on $He^+(2p)$ production has been observed in four separate experiments. In the first we measure the $He^+(2p)$ excitation function by observing the 30.4 nm $He^+(2p\text{-}1s)$ radiation [4]. We observe structure in the incident electron energy range 69-70 eV (figure 1a). The two-electron excited states ($3l$,$3l'$) fall in this energy range. The structure can be attributed to interference between the direct excitation-ionization process and indirect population of the $He^+(2p)$ state due to autoionization of the He ($3l3l'$) states. Note that the angle-integrated alignment parameter measured by Gotz et al. [5] also showed substantial energy dependence close to the threshold for excitation of the ($3l$,$3l'$) states. Figure 1b also shows evidence of the n=3 autoionizing states in an ejected electron spectrum measured in our laboratory.

In a third experiment we observe an outgoing electron in coincidence with the 30.4 nm photon as a function of the detected electron energy for a fixed photon angle [6]. This gives the double differential cross section (DDCS) for the $He^+(2p)$ state. In this study, we see two main structures around ejected electron energies of 4.3 eV and 7.5 eV at 200 eV incident electron energy (figure 2). A careful study of the DDCS for ejected electron energies in the range 3.2-6.3 eV shows a resonance shaped structure arising from decay of the n=3 autoionization states through the $He^+(2p)$ state at incident electron energies of 200 eV and 400 eV [7] (figure 1c, and 1d respectively). The maximum around an ejected electron energy of 7.5 eV may be evidence of further interference from higher lying autoionizing states in figure 2. However, it corresponds in energy with the threshold for production of $He^+(n=3)$ states which will also be observed in this experiment.

In the fourth experiment we observe a scattered electron in coincidence with the 30.4 nm photon as a function of the photon angle for an incident electron energy of 200 eV, corresponding to ejected electron energies of 1.2, 4.3 and 15 eV and an electron scattering angle of 5^0 [7]. In figure 3, we see a significantly reduced amplitude in the region of the $(3l,3l')$ autoionizing resonances, i.e., for an ejected electron energy of 4.3 eV. In all cases the amplitudes of the measured correlations are small [8]. This could be expected due to the amplitude reduction associated with fine-structure depolarization and the effect of integration over the angles of the undetected electron.

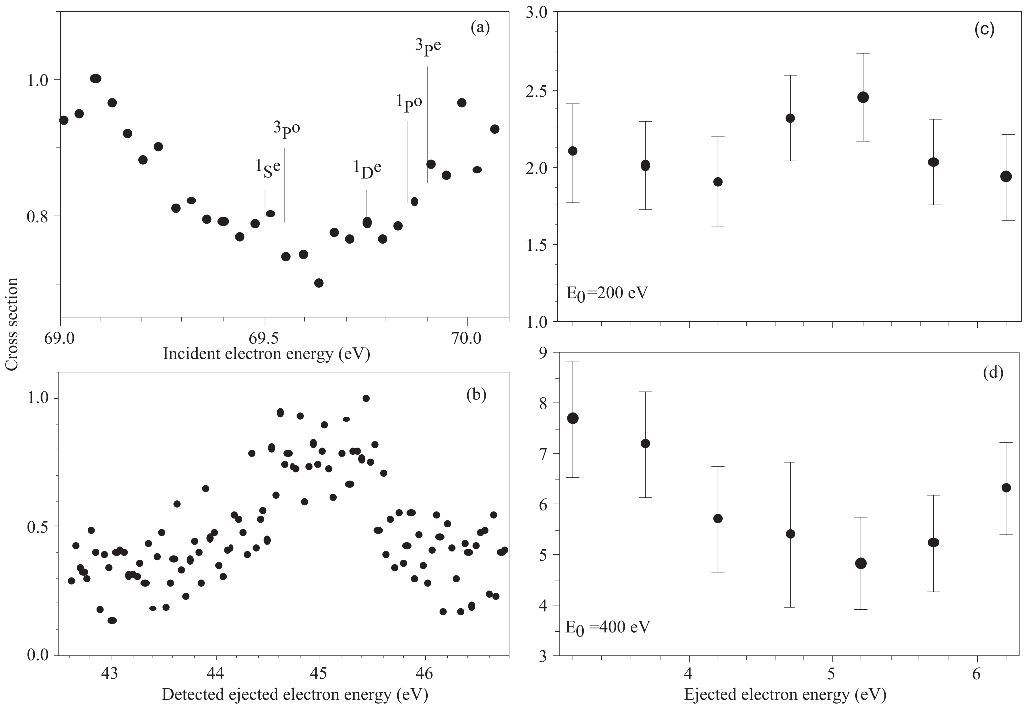

Figure 1. He $(3l3l')$ resonance effects

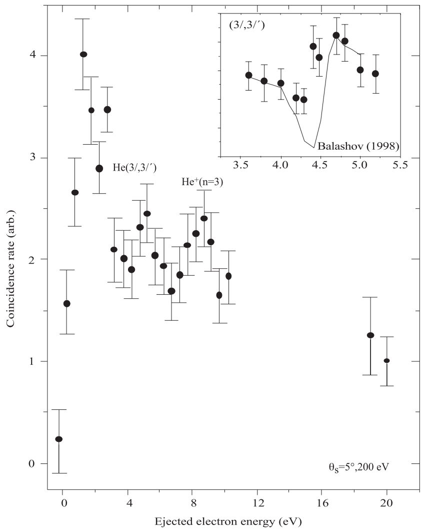

Figure 2. DDCS for $He^{+}(2p)$ at an incident energy of 200 eV, for a scattered electron angle of 5^{o} and photon angle of 90^{o}.

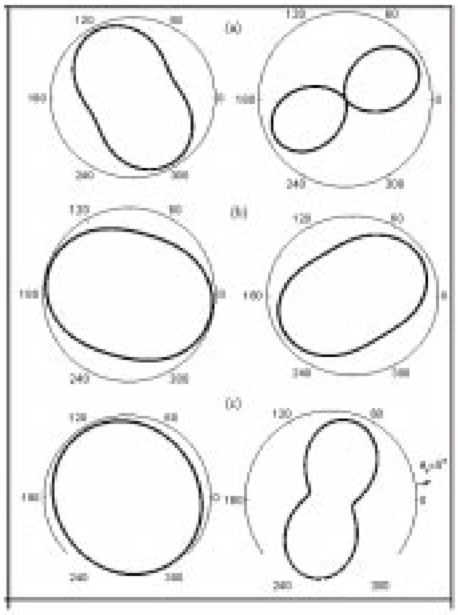

Figure 3. The measured angular correlations (left row) and corresponding charge cloud shapes in the scattering plane (right row) for $He^{+}(2p)$ at E_o=200 eV. (a) E_e=1.2 eV, (b) E_e=4.3 eV, (c) E_e=15 eV.

3. Double Excitation- Radiative Decay Effects

A process of this unusual type has been observed in the present work and so it is appropriate to discuss it here, even through it is not related to an excitation-ionization process. The $(2p^2)^3P$ decays with the emission of a 32 nm photon to the $(1s2p)^3P$ state. To the best of our knowledge the present observations of radiation from this transition have only been made by one other electron scattering group [9,10]. Figure 4 shows the excitation function of the $(2p^2)^3P$ state close to its threshold energy of 59.7 eV. There is good agreement in shape between the data of Westerveld et al. [9] and that of our data. In both experiments strong structures are observed in the excitation functions. These are most likely due to triply excited negative ion states with configurations of the type $(2s3l3l')$. The calculations performed up until now on the electron impact excitation of doubly excited states (including parity-unfavoured states), are unable to describe the present experimental results. In a second observation, the Utrecht group [10] have attempted to get information on the polarization of the radiation. We believe that the time is now right to pursue new experiments and calculations aimed at gaining a better understanding of these unusual states.

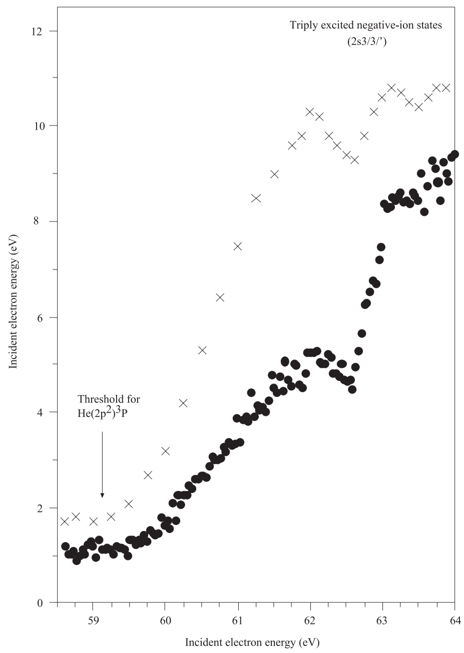

Figure 4. Near threshold excitation function for the $(2p^2)^3P$ state. •, present data; +, Westerveld et al. (1979).

Acknowledgements

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