27th Summer School and International Symposium on the Physics of Ionized Gases

August 26-29, 2014, Belgrade, Serbia

CONTRIBUTED PAPERS

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ABSTRACTS OF INVITED LECTURES, TOPICAL INVITED LECTURES, PROGRESS REPORTS AND WORKSHOP LECTURES

Editors:
Dragana Marić
Aleksandar R. Milosavljević
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Institute of Physics, Belgrade
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HIGH RESOLUTION EJECTED ELECTRON SPECTRA OF ARGON AT ELECTRON IMPACT ENERGIES OF 303, 505, 809 AND 1000 eV AND EJECTION ANGLE OF 90°

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Abstract. We present high resolution ejected electron spectra of argon at several high impact electron energies from 303 to 1000 eV and the ejection angle of 90^o. The spectra cover autoionization region of excitation energies from 21.26 to 38.26 eV. These spectra have been obtained by using high resolution electron spectrometer with a hemispherical analyzer and a high energy electron gun. The features have been identifed as autoionizing states and resonances and their assignments and energy positions have been compared with those found in literature.

1. INTRODUCTION

Autoionizing states and resonances in argon have been studied in the past by different experimental techniques; photons [1], high energy ions [2], high energy electrons [3,4] and low energy electrons [5,6]. The studies of resonances are cited in [7]. Here we present results of our measurements of autoionizing states and resonances in argon at electron impact energies of 303, 505, 809 and 1000 eV in the region of excitation energies from 21.26 to 38.26 eV (5.50 to 22.50 eV of ejection energy), and the ejection angle of 90°. The aim of this study is to improve the understanding of a very important role of the resonances in the behavior of the autoionization states at the higher electron impact energies. This was possible due to the very high resolution obtained in the measured spectra, as demonstrated by resolving the triplet and singlet states.

2. EXPERIMENTAL SETUP

The apparatus represents a typical crossed electron-atom experiment already described earlier [8]. Here we will give a short outline. It is consisted of a high energy electron gun, high resolution hemispherical analyzer, hypodermic needle as a source of an effusive beam of target gas, a Faraday cup as a collector for incident electron beam and 7 channeltrons for detection of ejected electrons.

The background pressure was 10^{-8} mbar, while the working pressure with argon was 10^{-6} mbar. The estimated energy resolution of ejected electron spectra was below 0.080 eV. The calibration of the ejected electron energy scale was done in a mixture of argon and helium at high impact energy of 303 eV using the position of the double excited 2s2p(^{1}P) state at 60.130 eV (35.55 eV of ejected energy) [9]. The incident electron energy scale was calibrated through the elastic channel.

3. RESULTS AND DISCUSSION

Figure 1 shows four ejected electron spectra measured at the incident energies of 303, 505, 809 and 1000 eV and the ejection angle of 90°. The spectra are shown with subtracted background without normalisation. They cover energy region of ejected electrons from 5.50 to 22.50 eV i.e. the region of excitation energy from 21.26 to 38.26 eV (ionization potential for Ar is 15.76 eV). All spectra show identical form with small differences in intensities of the features

The ejected energy domain presented in the figure can be divided into three regions. In the first one from 5.5 to 9 eV, an isolated well defined peak marked “a” at the energy of 6.22 eV (21.98 eV) and two small peaks marked “b” at 7.70 eV (23.46 eV) and “c” at 8.63 eV (24.39 eV) at the impact electron energies of 303 and 505 eV are present. The first peak has been already reported previously [2,3,5,10], however only Hicks et al [5] give its energy position at 6.24 eV and propose that it comes as a result of the excitation above the second ionization potential at 40.74 eV. The present measurement gives the energy of 6.22 eV, which is in excellent agreement with reference [5]. Other two peaks “b” and “c” with low intensities are seen for the first time in the present experiment, according to our knowledge and they can be due to similar type of excitation.

The second region of ejected energies from 9 to 14 eV (24.76 to 29.76 eV of excited energies) was the subject of many experimental studies mentioned in the Introduction. It is abundant with the features in the form of well define peaks and deeps. Under these experimental conditions the figure shows double peaks and deeps separated by 0.180 eV which correspond to the triplet-singlet splitting in argon ion. The autoionizing states in this energy region have the configuration $3s3p^6(ns,np,nd)$ and not all of them are present in the previously reported experiments with electrons, depending on the experimental conditions and the resolution.

The members of the $3s3p^6np$ series are not seen in the present experiment. The first two features marked as “d” and “d’” correspond to the $3s3p^64s$ (^{3,1}S) states respectively, which are present with low intensities because they represent optically forbidden transitions. The next two well defined features marked as “e” and “e’ ” at 11.54 eV (27.30 eV) and 11.72 eV (27.48 eV) should belong to the $3s3p3d$ (^{3,1}D) series.

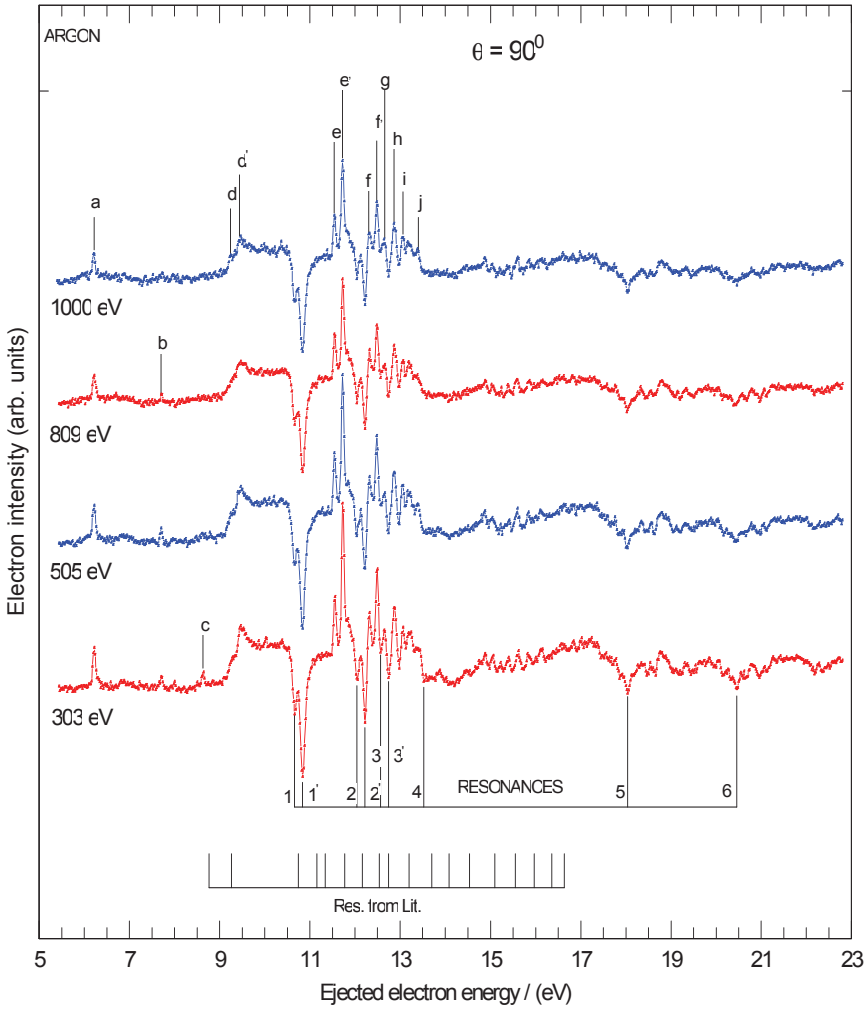

Figure 1. Ejected electron spectra of argon obtained at the ejection angle of 90°. The incident electron energies labeled on the left hand side of the figure were: 1000, 809, 505, and 303 eV respectively. The energy region for ejected electrons is from 5.50 to 22.50 eV corresponding to the region from 21.26 to 38.26 eV of excitation energies. The energy width per channel was 0.020 eV. The short vertical lines above the peaks denoted with small letters from "a" to "j" mark the position of excited states, while the vertical lines below the spectrum of 303 eV show the positions of minima or resonances marked with numbers 1 to 6. The short vertical lines at the bottom of the figure mark positions of resonances taken from the literature [7].

The next two less pronounced features in the spectra marked as “f” and “f’ ” at energies 12.30 eV (28.06 eV) and 12.48 eV (28.24 eV) belong to the $3s3p^6 4d$ (^{3,1}D) series. Again, the energy separation between two peaks is 0.18 eV. The two small not identified features “i” at 13.06 eV (28.82 eV) and “j” at 13.40 eV (29.16 eV) belong to the $3s3p^6$ series are the last features belonging to the single excitation from 3*s* shell. The energy region above 14 eV (29.76 eV) is due to the decay of doubly excited states $3s^2 3p^4$ *nln’l’* to the ground state of argon ion. Under the present experimental condition the later states appear in the form of large number of features with low intensity.

Temporary negative ions (resonances) in the autionization region of argon have been studied in the past [7]. In the present experiment they appear in the form of double resonances separated by 0.180 eV, indicating that they are formed at the threshold or very close to the threshold of singlet and triplet states. Three pairs of this type of resonances are visible on the figure. The first pair 1-1’ has energy positions of 10.66 eV (26.42 eV) and 10.84 eV (26.60 eV), which correspond to $3s3p^6 4p$ (^{3,1}P) states, in good agreement with references [1,4]. The second resonance pair 2-2’ has energy positions of 12.04 eV (27.80 eV) and 12.22 eV (27.98 eV), respectively with the energy splitting of 0.180 eV. The position of 2’ (27.98 eV) is in a good agreement with the previously reported 5*p* (^{1}P) state [1,4] (27.996 eV and 27.994 eV, respectively), whereas the resonance 2 (27.80 eV) has not been reported in the literature.The third pair 3-3’ at 12.56 eV (28.32 eV) and 12.74 eV (28.50 eV) is present with much lower intensity, but with the same splitting of 0.180 eV. The position of 3’ (28.50 eV) is in a good agreement with the 6*p*(^{1}P) state from references [1, 4] (28.509 eV). The triplet state 6*p* (^{3}P) has not been seen in previous measurements. These two resonances coincide in energies with two resonances from literature [7] shown at the bottom of the figure 28.30 and 28.50 eV respectively.

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