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ELECTRON IMPACT IONIZATION OF Ar^{8+}

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ABSTRACT

Absolute electron impact ionization cross-sections have been measured for the Neon-like Ar^{8+} in the energy range from below the threshold for the metastable state to 2500 eV. No contribution of metastable states is observed. The results are well reproduced by the Distorted Wave Born Approximation.

INTRODUCTION

Argon gas is frequently introduced in small amount as an impurity in high temperature laboratory plasmas (1). Ionic densities in these plasmas are determined by a lot of processes, essentially ionization, radiative, dielectronic and three-body recombination and charge-exchange.

For these reasons, it is not surprising that great attention has been given to the various ionization stages of argon in those processes. This is particularly valid for the Neon-like Ar^{8+}. See for instance the long list of papers of this Conference.

In this paper, the first absolute electron impact ionization cross-section measurements are reported for Ar^{8+}. Results are discussed and compared with theoretical predictions.

METHODS AND APPARATUS

In this experiment, the animated beam method (2) is used in a crossed electron-ion beam set-up.

In the method the electron beam is swept across the ion beam in a linear see-saw motion at constant velocity. The cross-section is related to the measured quantities in the following way :

$$\sigma = \frac{v_e v_i}{(v_e^2 + v_i^2)^{1/2}} \quad \frac{uK}{(\frac{I_e}{e})(\frac{I_i}{q})} \tag{1}$$

In this formula u is the scanning velocity, K is the total number of events produced during one passage across the ion beam, e, v_e, I_e, $q, v_i I_i$ are the charge, velocity and beam current of the electrons and ions respectively. The main advantage of the method is that it does not require the knowledge of beam density profiles.

The experimental set up has been described previously (3). Briefly, the ion beam is extracted from the new ECR Ion Source OCTOPUS (4) under a voltage of 6 kV. After analysis by means of a Wien filter, the beam is purified and focused before crossing the electron beam at right angle. In a subsequent magnetic change state analyser, product ions are separated from the primary beam which is collected by means of a Faraday cup. Product ions are detected by a channelplate detector.

Typical working conditions are : I_e = 3.4 mA, I_i = 20 nA, u = 0.4 M/sec and K = 0.12 event/crossing.
Systematic errors are estimated to be ± 2.9 % and the statistical uncertainties are estimated to ± 8.7 % at the peak cross-section.

The quadrature sum of those figures is ± 9.2 %.

RESULTS

The results are listed in table I. They extend over a wide energy range, from 50 eV to 2500 eV.
The listed relative energies have been corrected for the contact potentials (-2.8 eV) and for the ion kinetic energy term (+ 0.65 eV). The listed uncertainties are the statistical uncertainties on the count rate only.

Some important features must be mentionned concerning the low energy data.

First of all, below the ionization threshold of ions in the ground state (422.44 eV) a significant signal has been observed. By taking into account the four lowest points, this signal appeared and a smooth decreasing curve. This effect has sometimes been observed in various crossed electron-ion beam experiments and it is attributed (5) to the background modulation due to the electrical interaction between both charged particle beams. The subsequent apparent cross-section σ_a depends mainly on the electron density and may be represented by the form :

$$\sigma_a = A \frac{I_e}{E_e^{1/2}} \qquad (1)$$

By fitting the data below the threshold, A has been given a value of :
$A = (4.65 \pm 0.90) 10^{-19}\ cm^2\ eV^{1/2} / mA$.
The data presented in Table I are obtained after substracting that contribution. That correction is of order of 6 % of the true cross-section at its maximum.

The second effect is the possible presence of ions in metastable states formed in the source. This presence has been observed for Ar^{8+} ions produced by an ECR Ion Source. See for instance the papers of A. Bordenave-Montesquieu and M. Druetta in this Conference.

In ionization cross-section measurements, the presence of a proportion α of ions in a defined metastable state affects the experimental result because that state has a different cross-section from the ground state. The measured cross-section σ is given by :

$$\sigma = \sigma_g (1-\alpha) + \sigma_m \alpha \qquad (2)$$

where σ_g and σ_m are the ionization cross-sections for the ground-state and the metastable state respectively. Below the ionization threshold for the ground state, the metastable component only contributes to the signal. This signal has a threshold corresponding to the metastable state ionization potential. In cases where σ_g and σ_m are known, from other experiments, from theoretical or semi-empirical predictions, a value can be given to α by formula (2).

Although ionization cross-sections are not well-known, at least the semi-empirical Lotz formula (6) may be used with an acceptable precision.

Examples have shown a metastable proportion of 0.03 for the heliumlike N^{5+} ion (3). In the case of Fe^{9+} a proportion as high as 0.74 is estimated from the experimental results of D.C. Gregory et al (7) and from the full set of theoretical data by M. Pindzola et al (8).

In the present case, the metastable effect should be seen for electron energies between the ionization potential of the metastable state (170 eV) and the ground state (421.44 eV). From inspection of table I, it is clearly demonstrated that α is negligeable.

Results are shown in figure 1 together with the measurements of Donets (6) at 2.2 keV. This point has been estimated from the time evolution of the charge state spectra extracted out of an Electron Beam Ion Source. According to the large difference between both experimental methods, the agreement is quite satisfactory.

In figure 1, results are compared to the theoretical data by Younger (10) obtained in the Distorted Wave Born Approximation. The agreement with his results is very good. As Younger pointed out excitation-autoionization is of low importance in the Neon-like isoelectronic sequence. In this case, excitation autoionization may take place through some of the states $2s\ 2p^6\ n\ell$. In the absence of detailed information, the energy of those levels can be estimated by considering that an electron is ejected out of the 2s-shell of an Ar^{7+} ion in the $(1s^2 2s^2 2p^6 n\ell)$ state. Assuming that orbitals are froozen, the Ar^{8+} ion is left in the $(1s^2 2s 2p^6 n\ell)$ state. Excited states energies $\Delta E(Ar^{7+}(3s-n\ell))$ are found in the tables of Bashkin and Stoner (11) and the inner-shell ionization potential $I_{2s}(Ar^{7+})$ and $I_{3s}(A_r^{7+})$ are given by Clementi and Roetti (12).

Finally, the energy of the considered level $E(Ar^{8+}(1s^2 2s 2p^6 n\ell)$ is given by :

$$E(Ar^{7+}(1s^2 2s 2p^6 n\ell)) = I_{2s}(Ar^{7+}) - I_{3s}(Ar^{7+}) + \Delta E(Ar^{7+}(3s-n\ell))$$

From this simple calculation, it is seen that the first excited states higher than the ionization threshold is the 5s state. So that, only states with $n \geq 5$ shall contribute to autoionization.

Excitation cross-sections scale as $(n^*)^{-3}$ where n^* is the effective quantum number. In the same isoelectronic sequence, for Al^{3+} the n=3 state is autoionizing and its contribution to the cross-section is estimated at less than 2% (11). According to these considerations, the contribution of the 5s state should appear at about 7 eV higher than the ground state threshold, but its importance is probably much less than 1% so that, it is well understood that this process do not appear in our measurements.

In figure 1 is also shown the semi-empirical Lotz formula prediction. That prediction shows a surprisingly satisfactory agreement in the whole experimental energy range. In spite of its poor basis, that formula underestimate the cross-section by less than 15 % only over the whole energy range.

TABLE I

E_e (eV)	σ (10^{-19} cm^2)	$\pm\ \Delta\sigma$ (10^{-19} cm^2)
47.8	0.00	0.59
147.8	0.10	0.43
247.8	0.03	0.36
397.8	- 0.09	0.28
447.8	0.80	0.43
497.8	3.39	1.02
547.8	4.05	0.45
597.8	4.97	1.27
697.8	5.39	0.49
797.8	6.20	0.53
897.8	7.21	0.51
997.8	7.56	0.71
1098	8.12	0.45
1198	8.04	0.72
1298	7.00	0.58
1398	7.64	0.71
1498	7.18	1.07
1598	7.11	0.58
1698	7.36	0.48
1798	7.07	0.46
1898	6.93	0.96
1998	7.06	1.06
2098	7.18	0.46
2198	6.67	0.75
2298	6.87	0.50
2398	6.57	0.79
2498	6.47	0.54

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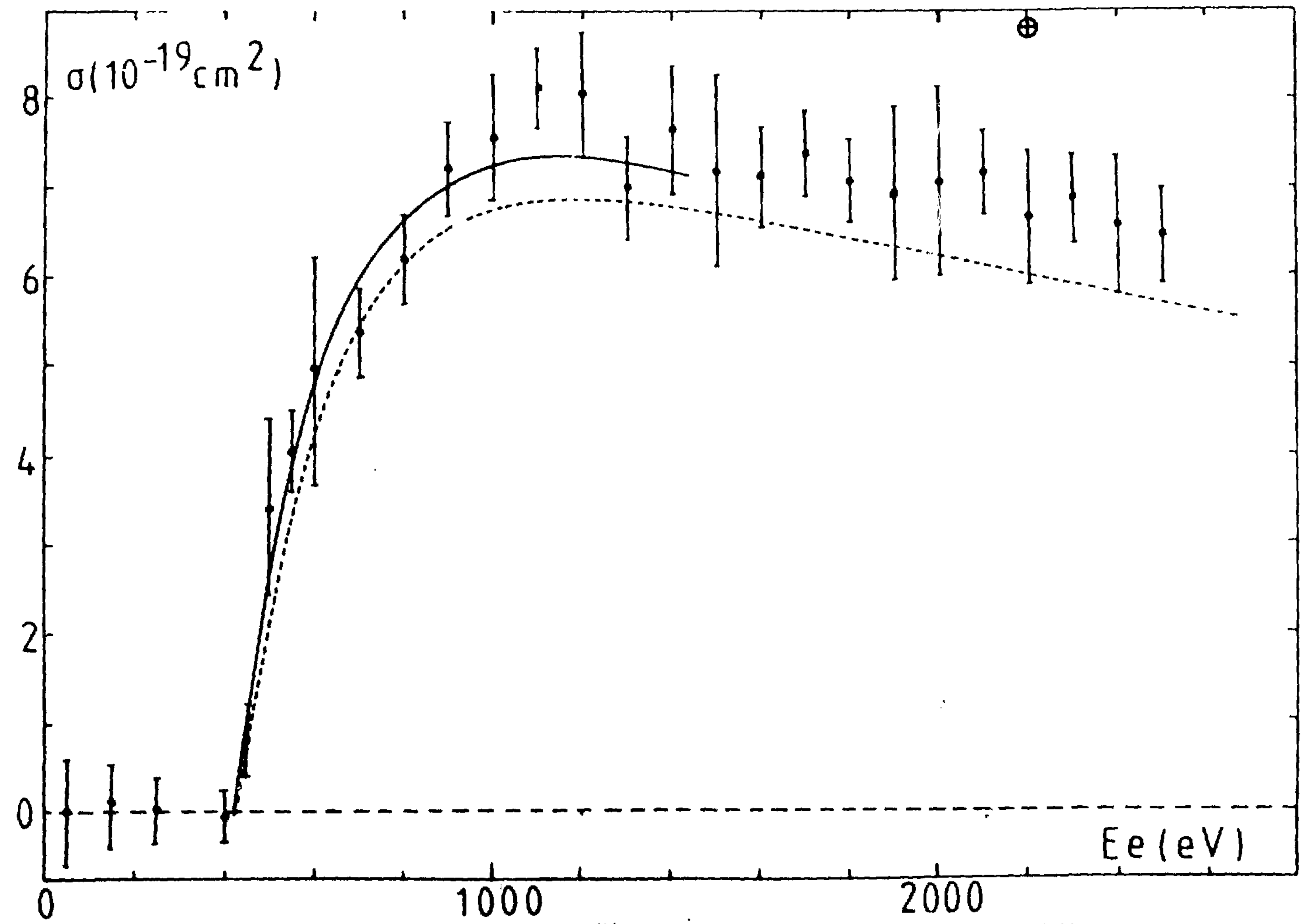
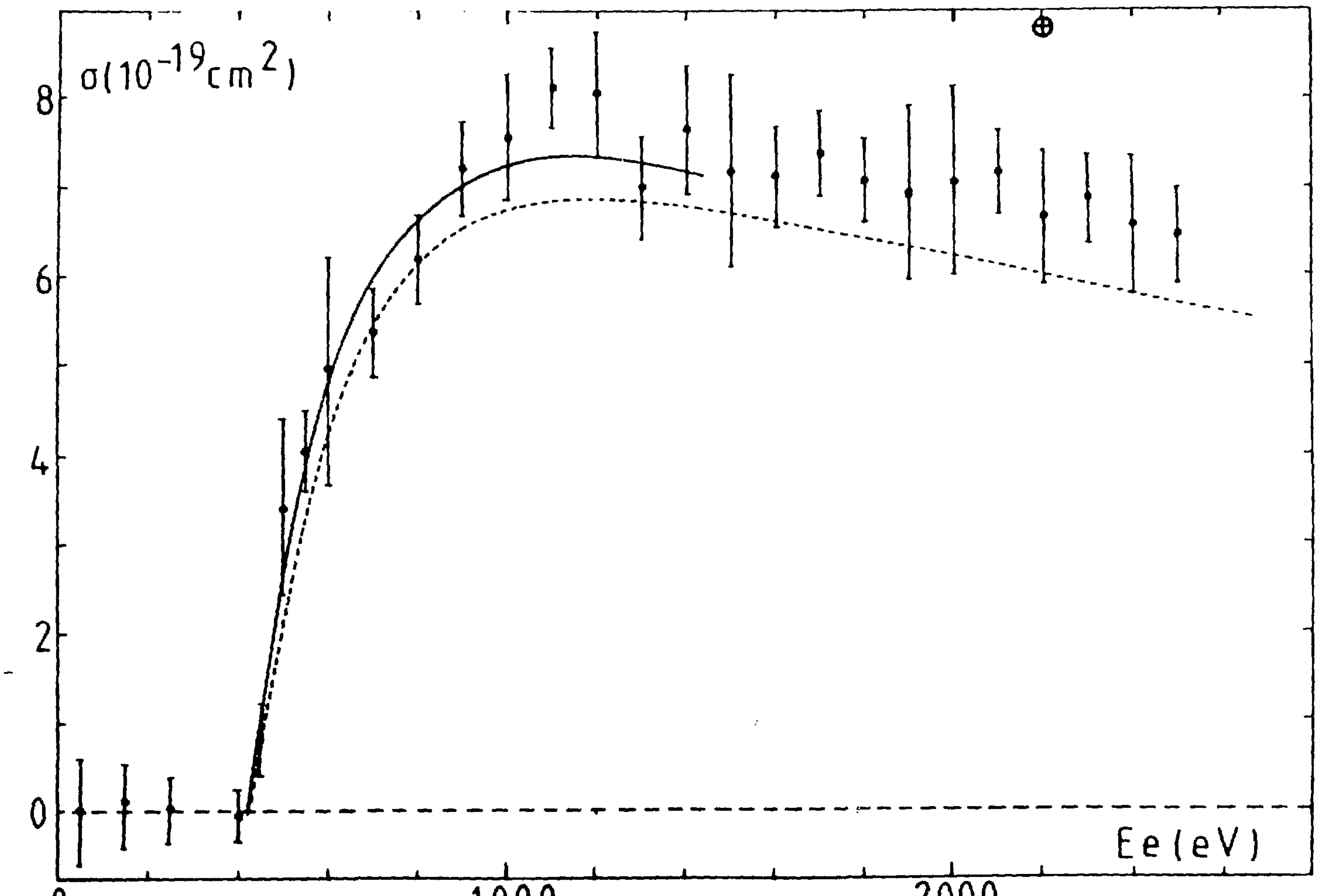
FIGURE CAPTION

Fig. 1. Absolute cross-section for electron-impact ionization of Ar^{8+} : full circles, our results; ⊕ E.D. Donets (9); —— S.M. Younger (10) and ---, W. Lotz (6).



σ(10^-19 cm^2)
8
6
4
2
0
0
1000
2000
Ee(eV)


σ(10^-19 cm^2)
8
6
4
2
0
0
1000
2000
Ee(eV)