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LETTER TO THE EDITOR

A measurement of the cross section for electron impact ionisation of Ar^+

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Abstract. The crossed-beam technique has been used to measure the absolute cross section for the process $Ar^+ + e \rightarrow Ar^{2+} + 2e$ at electron energies ranging from below threshold to 1000 eV. The cross section differs in shape from the trapped-ion data of Hasted and Awad, but is in good absolute agreement with the semi-empirical calculation of Lotz.

Electron impact ionisation of rare-gas ions is an important process in many areas of applied physics. In recent years there has been particular interest in argon ions because bremsstrahlung radiation from these provides a possible route to temperature control in a conceptual Tokamak fusion reactor (Tenney 1974). Crossed-beam measurements for rare-gas ions have been restricted to an absolute measurement of the ionisation cross section of Ne^+ by Dolder *et al* (1963) and to single values of some peak cross sections quoted by Latypov *et al* (1964). Trapped-ion mass spectrometry measurements for Ar^+, Ar^{2+} and Ar^{3+} have been made by Hasted and Awad (1972), but these data are relative and have been normalised to the peak values of Latypov *et al*. The cross section for Ne^+ has been calculated by McGuire (1977) using scaling laws derived from Born-approximation calculations for neutral atoms. The cross sections for Ar^+ and Kr^+ can also be obtained in this way. The only other calculation available for the rare-gas ions is the semi-empirical approach of Lotz (1968). In order to provide less ambiguous data, at least for the lower stages of ionisation, the cross section for the process $Ar^+ + e \rightarrow Ar^{2+} + e + e$ has been measured absolutely by the crossed ion and electron beam technique. The energy range studied is from below threshold up to 1000 eV.

The apparatus used, apart from minor modifications, was the same as that described by Dixon *et al* (1975) for measuring the ionisation cross section of metastable hydrogen atoms. Since the present experiment dealt solely with ions, the caesium charge-exchange cell was removed and the parent ion beam was collected in a Faraday cup in a manner similar to that described by Aitken and Harrison (1971). The product Ar^{2+} ions were detected by a Johnston Laboratories MM1 electron multiplier. This was calibrated by comparing the counting rates for known currents of Ar^{2+} ions measured using a Faraday cup and a Carey Model 401 electrometer.

The experiment was performed using a pulsed electron beam (240 μs pulse length; 48% duty cycle) and a DC ion beam. Values of the cross section, $Q(E)$, were obtained from the expression

$$Q(E) = \frac{R}{IJ} \frac{vV}{(v^2 + V^2)^{1/2}} \frac{e^2 h'}{\Omega} \tag{1}$$

where R is the signal count rate, I and J are the instantaneous electron and ion beam currents, v and V are the electron and ion beam velocities, Ω is the signal detector efficiency and h' is the effective height of the beams (see Harrison 1968). For most electron energies it was shown that the signal count rate was proportional to the electron beam current, although at energies within 15 eV of threshold, data were obtained using single values of electron current.

A duoplasmatron ion source was used to give Ar^+ ions with an energy of 4 keV and currents that were typically $1{\cdot}6 \times 10^{-8}$ A. The multiplier efficiency was found to be 75·8 ($\pm$1·3)% and this value remained constant to within the experimental error during the time taken to accumulate the data. The electron currents used ranged from 20 μA to 600 μA. At the peak of the cross section, count rates were typically 2000 s^{-1} for an electron current of 150 μA (averaged over the duty cycle) and a signal to background ratio of 4:1. Count rates close to threshold dropped to about 100 s^{-1} for an averaged electron current of 30 μA. No significant difference in signal was observed when the pulsing frequency was increased by a factor of 10.

The present data are shown in figure 1. The 90% confidence limits on the random errors do not exceed the size of the symbols. The maximum systematic error is given in table 1, together with the numerical values of the cross section. Ar^+ does not have any low-lying metastable states and the ionisation thresholds for the formation of the first five states of Ar^{2+} from the ^2P ground state of Ar^+ are shown in figure 1. The lower thresholds correspond to the removal of a 3p electron while the two higher thresholds correspond to the removal of a 3s electron. There is some

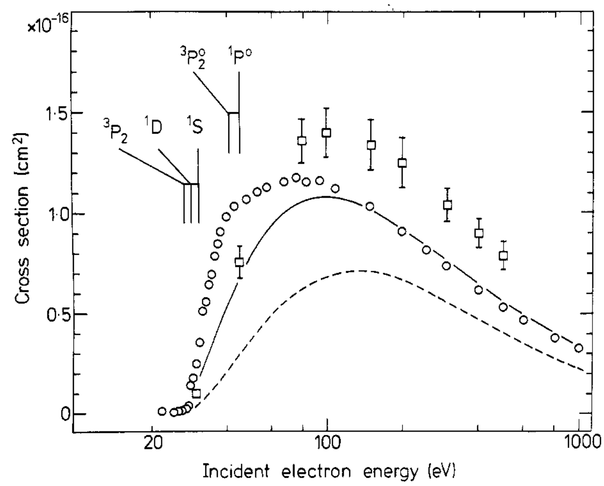

Figure 1. The cross section for $Ar^+ + e \rightarrow Ar^{2+} + 2e$. ○: present data; 90% confidence limits on the random errors do not exceed the size of the symbol. □: data from Hasted and Awad (1972). The full curve is a semi-empirical calculation from Lotz (1968). The broken curve is the scaled Born-approximation calculation from McGuire (1977). The thresholds shown are for ionisation to different states of Ar^{2+}. The lower group correspond to the configuration $3s^2 3p^4$; the higher group correspond to the configuration $3s3p^5$.

Table 1. The cross section for $Ar^{+} + e \rightarrow Ar^{2+} + e + e$.

Incident electron energy[a] (eV)	Cross section (10^{-16} cm^2)	Random error[b] (%)	Systematic error ($\pm$%)
19	0·005	10	11·4
22	0·013	5	8·8
24·5	0·008	8	6·3
25·5	0·010	12	9·6
26	0·009	8	9·5
26·5	0·011	2	9·1
27 }[c]	0·013	2	8·1
27·5 }	0·025	3	9·1
28	0·034	3	10·4
28·5	0·125	5	8·1
29	0·184	3	8·1
30	0·255	2	7·8
31	0·366	3	10·6
32	0·522	2	8·1
33	0·571	4	9·1
34	0·655	2	10·4
35	0·712	2	8·5
36	0·808	2	10·1
37	0·868	2	11·1
38	0·929	2	8·9
40	0·999	2	5·9
43	1·054	1	6·8
48	1·104	2	6·4
53	1·120	2	5·6
58	1·149	1	5·7
68	1·178	1	6·1
76	1·198	0·5	7·1
83	1·178	1	5·1
94	1·164	0·5	5·8
108	1·141	0·5	5·1
148	1·054	1	4·6
198	0·926	1	4·1
248	0·834	1	4·1
298	0·754	0·5	4·1
398	0·629	0·5	4·1
498	0·543	0·5	4·1
598	0·478	2	4·1
798	0·389	0·5	4·1
998	0·334	1	4·1

[a] $\pm$ 0·6 eV.
[b] 90% confidence limits.
[c] Lowest ionisation potential = 27·44 eV ($Ar^{+}\ {}^2P_{1/2} + e \rightarrow Ar^{2+}\ {}^3P_2 + 2e$).

evidence of structure, particularly above the $^3P^o$ threshold. The experimental data of Hasted and Awad are also shown. Their data were normalised at the peak of the cross section to the single value of 1·4 ($\pm$0·4) $\times$ 10^{-16} cm^2 obtained by Latypov *et al* (1964) and so the difference in absolute magnitude at the peak is understandable. However, the disagreement with the present data at low energies probably reflects the uncertainties involved in the trapped-ion beam technique.

The full curve in figure 1 is the semi-empirical calculation of Lotz (1968) which agrees well with the present data above 200 eV electron energy. The broken curve is the scaled Born-approximation calculation from McGuire (1977). The neglect of the Coulomb interaction may partly explain the poor agreement at low energies. However, the presence of autoionisation, neglected in both calculations, will also contribute to the discrepancy.

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