J. Phys. B: At. Mol. Phys. **17** (1984) L621–L624. Printed in Great Britain

LETTER TO THE EDITOR

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

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Received 18 July 1984

Abstract. A new absolute measurement of the cross section for the process $Ne^+ + e \rightarrow Ne^{2+} + 2e$ has been made at electron energies from threshold to 2 keV using the crossed electron and ion beams technique. The total error at a 90% confidence level is estimated to be ±5%, increasing to ±7% at energies greater than about 1 keV. The present cross section is about 6% greater than that measured by Dolder *et al* near the peak, increasing to 11% at higher energies. The cross section of Müller *et al* has the same shape as the present data from threshold to 400 eV, but is about 20% lower in magnitude. Above this energy it falls more rapidly with increasing energy and is more than 30% lower at 800 eV. The recent measurement of Achenbach *et al* is in excellent agreement with the present data.

A knowledge of the absolute cross section for the electron impact ionisation of neon is of timely interest for two particular reasons. Firstly, neon gas may be introduced as a controlled impurity into a fusion reactor in order to lower the temperature of the plasma boundary region. Secondly, the cross section has been used as a standard for normalisation of some crossed beams measurements of ionisation phenomena.

The ionisation cross section of Ne^+ has been measured previously at the Culham Laboratory by Dolder *et al* (1963) using the crossed electron–ion beams technique, but the technique and the apparatus have been much improved since that time. Müller *et al* (1980) at Giessen have measured this cross section using a significantly different crossed beams technique, but their values are some 15% smaller than those of Dolder *et al.* Although this difference is within the combined errors claimed for these two sets of measurements, a further study was obviously desirable. We have therefore remeasured the cross section and the results are reported in this Letter. Recently the Giessen group have reported a new measurement using a modified technique (Achenbach *et al* 1984).

The apparatus and technique used for our measurement are as described by Montague and Harrison (1983), except that a new electron gun has been used. This gun utilises a tungsten dispenser cathode and produces a narrower electron energy distribution; at 60 eV and 0.5 mA the energy spread is about 0.6 eV FWHM. To enhance the current carried by a beam of acceptable dimensions the gun incorporates electrostatic focusing.

The Ne^+ ions were produced in an ion source usually used to produce sputtered metal ions, but in this experiment no voltage was applied to the sputter electrode. The

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ion-beam energy was 2 or 4 keV with typical currents between 2.0 and 3.5×10^{-9} A. The efficiency of the electron multiplier used for detecting Ne^{2+} ions was measured as 0.73 ± 0.04 at 2 keV and 0.92 ± 0.04 at 4 keV. The cross section at the two ion energies differed by about 5% but this is within the error range of the efficiency measurements so the data sets have been normalised to the mean value at 200 eV.

Most of the data were taken at single electron currents ranging from 150 to 300 μA, but linearity of signal with electron current was demonstrated at a number of electron energies. To minimise any effects due to drifting of the Ne^{2+} detector efficiency, frequent measurements of the cross section were made at 200 eV and used to normalise the cross section at other energies. In the near-threshold region some measurements were made by stepping the electron beam through a range of energies in a time that was short compared with any drift in the detector efficiency. To obtain adequate statistics for the relative shape of the cross section several such scans were made over the same energy range. No structure was detected.

To make the observed threshold agree with the known ionisation energy of Ne^+ of 41.1 eV, a correction of 1.7 V has been added to the measured cathode voltage to give the electron energy. At the peak of the cross section the Ne^{2+} count rates were

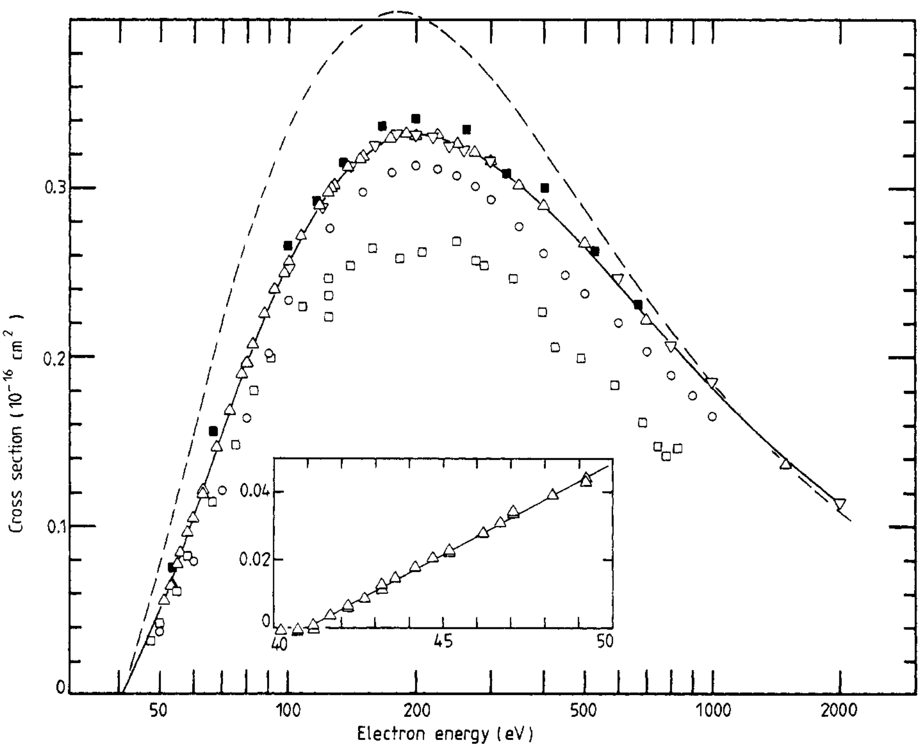

Figure 1. Cross section for the ionisation process $Ne^++e\rightarrow Ne^{2+}+2e$ plotted against incident electron energy. △, present data for an incident ion energy of 2 keV; ▽, present data for an incident ion energy of 4 keV; ○, data of Dolder *et al* (1963); □, data of Muller *et al* (1980); ■, data of Achenbach *et al* (1984). The full curve is the best line than can be drawn through the present data points. The cross section values in table 1 are taken from this line. The broken curve is the Coulomb–Born approximation of Moores (1972). The inset shows the near-threshold region on an expanded scale.

typically 200 s^{-1} with a signal-to-background ratio of 4:1 at 4 keV and 8:1 at 2 keV at an electron current of 150 μA averaged over the duty cycle.

The present results are shown in figure 1. Ninety per cent confidence limits due to the counting statistics do not exceed the size of the symbols. The near-threshold data are shown separately in the inset of figure 1. Neon has no low-lying metastable states and consequently the near-threshold region shows no structure or non-linearity. Also shown in the figure are the experimental results of Dolder *et al*, Müller *et al* and Achenbach *et al*.

The present cross section is about 6% greater than that measured by Dolder *et al* near the peak increasing to 11% at higher energies, but nevertheless there is agreement within the combined quoted errors. Below 100 eV the shape of the cross section of Dolder *et al* differs slightly from the present measurement. In contrast, the cross section of Müller *et al* has the same shape from threshold to 400 eV, but is about 20% lower in magnitude. Above this energy it decreases more rapidly with increasing energy than the present cross section and is more than 30% lower at 800 eV. A similar situation exists in the case of argon where the Ar^+ cross section of Müller *et al* is 20% to 34% lower than that of Woodruff *et al* (1978) measured in this laboratory. The more recent

Table 1. Measured cross section for electron impact ionisation of Ne^+ ions taken from a smooth curve drawn through the experimental points.

Mean electron energy (eV)†	Measured cross section Q (10^{-18} cm^2)	Total error in Q (±% of Q)‡	Mean electron energy (eV)†	Measured cross section Q (10^{-18} cm^2)	Total error in Q (±% of Q)‡
42	0.50	7	150	31.87	5
43	1.05	6	160	32.38	5
44	1.61	5	170	32.80	5
45	2.16	5	180	33.08	5
46	2.72	5	190	33.25	5
47	3.27	5	200	33.27	5
48	3.83	5	210	33.22	5
49	4.38	5	220	33.12	5
50	4.94	5	230	32.97	5
52	6.04	5	250	32.60	5
55	7.71	5	270	32.18	5
57	8.92	5	300	31.60	5
60	10.48	5	350	30.20	5
65	13.20	5	400	28.96	5
70	15.42	5	500	26.50	5
75	17.62	5	600	24.33	5
80	19.65	5	700	22.46	5
85	21.40	5	800	20.81	5
90	22.90	5	900	19.42	5
95	24.16	5	1000	18.20	6
100	25.38	5	1200	16.18	6
110	27.48	5	1400	14.60	6
120	29.19	5	1600	13.31	7
130	30.26	5	1800	12.26	7
140	31.17	5	2000	11.40	7

† ±0.5 eV.

‡ 90% confidence limits. This is a combination of systematic and random errors (see text).

work of Achenbach *et al* using a modified apparatus includes measurements of the cross sections for Ne^+ and Ar^+. Using the Ar^+ data of Woodruff *et al* for normalisation they find the cross section for Ne^+ slightly higher than that of Dolder *et al* and in excellent agreement with our present data.

The broken curve in figure 1 is the Coulomb–Born approximation (without exchange) of Moores (1972). The theory overestimates the cross section at intermediate energies but at higher energies it is in good agreement with experiment.

Values of the measured cross section are listed in table 1. The values are obtained from a smooth curve drawn through the experimental points of figure 1. Systematic errors arise from the calibration of the apparatus; the largest uncertainties occur in the measurement of the multiplier efficiency (±4%) and the effective beam height (±2%), and there is a further uncertainty of about ±2% arising from the measurements of the beam currents. These errors are compounded in quadrature to give the overall systematic error estimated to be ±5% at a 90% confidence level. The total error in the cross section given in table 1 is compounded from the systematic error and an error calculated from the deviations of the experimental points from the smooth curve.

The authors are grateful to Mr R G Montague for his advice on crossed beams techniques and Mr P R White for his skilled assistance. One of us (MJD) acknowledges receipt of a Science and Engineering Research Council CASE Studentship.

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