Cross Section Ratios for the Electron Impact Production of Singly and Multiply Ionized Rare Gas Ions

F. Egger and T. D. Märk

Institut für Atomphysik der Universität Innsbruck, Österreich

Electron impact ionization of He, Ne, Ar, Kr and Xe has been studied with a double focussing mass spectrometer Varian MAT CH5. Ratios of various multiple ionization cross sections with respect to single ionization cross sections for He, Ne, Ar, Kr and Xe at electron energies of 50, 100 and 150 eV are given. These cross section ratios are compared with previous determinations.

Experimental data on electron impact ionization of gaseous species are of great interest for predicting and understanding the properties of nonequilibrium plasmas, cf. e.g. ref. [1]. However, even for the rare gases discrepancies between published partial ionization cross section ratios amount to more than a factor of 2. The present paper is devoted to precise measurements of partial cross section ratios in He, Ne, Ar, Kr and Xe.

Experimental

The experimental arrangement was identical with that previously described [2, 3]. In short, it consists of a molecular type electron impact source Varian MAT Intensitron M, a high resolution double focussing mass spectrometer Varian MAT CH5, and a gas handling system. The working conditions of the ion source have been improved, i.e.: The electron trap collector potential was raised to 24 V to ensure saturation of electron currents at all electron energies. The range of the continuously selectable electron accelerating voltage was expanded up to 185 eV and the voltage of the electron beam focussing Wehnelt cylinder was maintained proportional to the electron accelerating voltage in order to improve electron current collimation over the whole electron energy range. Thus stray electron currents could be reduced to $< 20\%$ of the electron trap current and were allowed for in the calibration. Consistency checks necessary in electron impact studies and the energy scale calibration have been carried out and discussed previously [2, 3].

In order to obtain the relevant information for the present study, ionization efficiency curves have been measured as a function of applied extraction and focussing potentials [4]. It has been found that these curves depend on the extraction potential applied, and only a relatively small range of extraction potentials can be used [4]. The measured cross section ratios had a maximum deviation from each other of $\pm 10\%$ in this extraction voltage range. The reported cross section ratios are averages over repeated measurements under various extraction potentials in this range.

In all normalization procedures the ion currents have been measured with a Faraday collector cup, and electron currents of 50 μA have been used. The gas temperature in the collision chamber has been stabilized at 400 K during measurements. The pusher electrode, which for measurements of mass spectra is usually operated positive with respect to the collision chamber potential, was put at the same potential as the collision chamber. The rare gases used were obtained from Air Reduction Company and Fa. Linde with a purity of better than 99.995%. The reproducibility of measured ion currents was in general better than $\pm 2\%$. However, for very low ion currents, e.g. as in case of He^{++}, Ar^{+++}, Kr^{+++}, and Xe^{++++}, the statistical error could be as large as 5 to 10%. The estimated maximum possible error is for cross section ratios > 0.01 about 10 to 20% and for cross section ratios < 0.01 about 20 to 40%.

In order to demonstrate the reliability of the presently measured cross section ratios it is interesting to make a comparison with two previous studies [5, 6], in wich either by virtue of the apparatus used [5] or by virtue of the method applied [6] reliable cross section ratios have been obtained. Adamczyk et al. [5] have used a cycloidal mass spectrometer, which does not suffer the drawback of charge dependent collection efficiency, because without slits it is possible to attain complete collection of all ions produced in the source. Comparison of $q(He^{++}/He)/q(He^{+}/He)$ and $q(Ne^{++}/Ne)/q(Ne^{+}/Ne)$ reported by those authors with the present values (see Table I) shows fairly good agreement within the experimental error bars. Drewitz [6] has used a magnetic sector field mass spectrometer eliminating initial energy discrimination by means of a deflection method. Comparison of $q(Ar^{++}/Ar)/q(Ar^{+}/Ar)$ at 100 eV reported by Drewitz with the present value also shows agreement within the experimental error bars. Thus it is con-

Table I. Ionization cross section ratios of the electron impact production of multiply to singly ionized rare gas ions at three different electron energies.

Energy in eV	50	100	150	Author	Apparatus
$\dfrac{q(\mathrm{He^{++}/He})}{q(\mathrm{He^{+}/He})}$	—	—	0,0025	Bleakney et al. 1936 [7]	not mentioned
	—	0,0007	0,0031	Harrison 1956 [8]	thesis not available
	—	0,00037	0,0020	Adamczyk et al. 1966 [5]	cycloidal mass spectrometer
	—	0,0025	0,0040	Gaudin et al. 1967 [10]	90° magnetic sector field m.s., Nier type ion source
	—	0,0003	0,0023	present study	—
$\dfrac{q(\mathrm{Ne^{++}/Ne})}{q(\mathrm{Ne^{+}/Ne})}$	—	0,017	0,041	Bleakney 1930 [11]	Bleakney type m.s.
	—	0,010	0,034	Adamczyk et al. 1966 [5]	see above
	—	0,022	0,039	Gaudin et al. 1967 [10]	see above
	—	0,013	0,038	present study	—
$\dfrac{q(\mathrm{Ar^{++}/Ar})}{q(\mathrm{Ar^{+}/Ar})}$	0,014	0,101	0,113	Bleakney 1930 [11]	see above
	0,007	0,102	0,104	Stevenson et al. 1942 [12]	180° magnetic sector field m.s.
	0,009	0,101	0,087	Fox 1960 [13]	90° magnetic sector field m.s.
	—	0,079	—	Melton et al. 1967 [14]	60° magnetic field m. s., dual electron beam radiolysis source
	—	0,050	0,066	Gaudin et al. 1967 [10]	see above
	0,004	0,050	—	Morrison et al. 1970 [15]	quadrupole mass filter with electron multiplier
	0,005	0,070	0,073	Crowe et al. 1972 [16]	quadrupole mass filter with chaneltron multiplier pulse counting, field free ion source
	—	0,070	—	Drewitz 1975 [6]	60° magnetic field m.s. in connection with deflection method
	0,008	0,084	0,086	present study	—
$\dfrac{q(\mathrm{Ar^{+++}/Ar})}{q(\mathrm{Ar^{+}/Ar})}$	—	0,0003	0,00144	Fox 1960 [13]	see above
	—	0,0035	—	Melton et al. 1967 [14]	see above
	—	0,0009	0,0022	Gaudin et al. 1967 [10]	see above
	—	0,00028	—	Drewitz 1975 [6]	see above
	—	0,00059	0,0037	present study	—
$\dfrac{q(\mathrm{Kr^{++}/Kr})}{q(\mathrm{Kr^{+}/Kr})}$	0,03	0,125	0,125	Tate et al. 1934 [17]	180° magnetic sector field m.s., Bleakney type ion source
	0,04	0,151	0,136	Fox 1960 [13]	see above
	0,03	0,130	0,120	Ziesel 1967 [18]	not mentioned
	0,030	0,118	0,114	present study	—
$\dfrac{q(\mathrm{Kr^{+++}/Kr})}{q(\mathrm{Kr^{+}/Kr})}$	—	0,0025	0,0102	Tate et al. 1934 [17]	see above
	—	0,0037	0,0132	Fox 1960 [13]	see above
	—	0,0025	0,0102	Ziesel 1967 [18]	see above
	—	0,0027	0,0103	present study	—
$\dfrac{q(\mathrm{Xe^{++}/Xe})}{q(\mathrm{Xe^{+}/Xe})}$	0,102	0,172	0,138	Tate et al. 1934 [17]	see above
	0,076	0,146	0,155	present study	—
$\dfrac{q(\mathrm{Xe^{+++}/Xe})}{q(\mathrm{Xe^{+}/Xe})}$	—	0,026	0,063	Tate et al. 1934 [17]	see above
	—	0,025	0,069	present study	—
$\dfrac{q(\mathrm{Xe^{++++}/Xe})}{q(\mathrm{Xe^{+}/Xe})}$	—	—	0,004	Tate et al. 1934 [17]	see above
	—	—	0,005	present study	—

cluded that all of the presently reported cross section ratios can be regarded as reliable determinations within the experimental error range discussed above.

Results

Table I gives the ratio of the measured partial cross section values of multiply to singly ionized rare gas ions at three different electron energies, 50, 100 and 150 eV. Also shown in Table I are all available literature values as given in Ref. [4]. It can be seen that the agreement between the different authors is generally quite poor. The big differences for instance in case of $q(\mathrm{He^{++}/He})/q(\mathrm{He^{+}/He})$ at 100 eV or $q(\mathrm{Ar^{+++}/Ar})/q(\mathrm{Ar^{+}/Ar})$ at 50 eV are probably due to uncertainties in the electron

energy scales of the different authors. Results of Stuber [19] are not included in Table I, because a secondary electron multiplier was used to measure the ion signal.

A detailed appraisal of the previous data is difficult, because of lack of experimental detail given by some of the authors. However, in general it can be stated that all data reported from measurements with a magnetic sector field will suffer in accordance with Drewitz [6] from considerable initial-energy discrimination even for thermal ions leading to an overestimation of multiply ionized species. As has been found in the present study, extraction potentials in the ion source may also strongly influence measured cross section ratios, i.e. leading to smaller fractions of multiply ionized particles at too low or too high extraction potentials [20].

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