Absolute partial electron impact ionization cross sections of Xe from threshold up to 180 eV

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Partial electron ionization cross section ratios and functions of Xe were determined in the low energy regime ($\leqslant$180 eV) using a refined mass spectrometric technique. The experimental results are compared with previous measurements and calculations.

I. INTRODUCTION

Experimental data concerning the electron ionization of atoms and molecules are of great importance in the physics and chemistry of ionized gases.[1,2] The simplicity of the experimental concept does not imply a straightforward approach to determine these data.[3] Until recently, even for the atomic rare gases large differences and uncertainties existed in magnitude and shape of experimentally determined partial ionization cross section functions measured by different authors.[4] There exist, however, some recent studies with improved accuracy, e.g., in the high energy regime data by Nagy *et al.*[5] In the low energy regime (<200 eV) we have recently reported absolute partial electron ionization cross section functions and ratios for He, Ne, Ar, and Kr using a new approach to mass spectrometric technique and analysis.[6,7] The present commmunication[8] is an extension of this study to xenon.

II. EXPERIMENTAL

The experimental setup and technique has been described in detail previously.[6] It consists of a conventional three-electrode type electron impact ion source (FWHM of 500 mV) and a high resolution, reversed geometry, double focusing mass spectrometer. The operating conditions of the ion source-mass spectrometer system have been improved considerably,[6] alleviating the problems of ion extraction from the ion source and the transmission of the extracted ions through the mass spectrometer system. In short, ions produced by electron ionization are drawn out of the collision chamber by means of a penetrating field (and not by a field applied between the repeller and the collision chamber exit slit, as is done usually) produced by electrodes placed outside the collision chamber. It has been demonstrated by Stephan *et al.*[6] that this extraction mode allows complete collection of all rare gas ions produced. In addition, it has been shown, that it is necessary to probe the ion beam shape (ions extracted from the ion source and accelerated towards the mass analyzer) at the mass spectrometer entrance in order to avoid discrimination in the transmission through the mass analyzer. This ion beam shape was determined using two pairs of deflecting electrodes placed between the ion source and the mass spectrometer entrance slit. It has been demonstrated by Stephan *et al.*[6] that the relative cross section functions for a given rare gas ion type can be measured without sweeping the ion beam across the mass spectrometer entrance slit and subsequent integration over the area under the curve of mass-analyzed ion current vs deflecting voltage provided the ion beam shape is flat topped [see Fig. 4(b) in Ref. 6] and is centered approximately on the mass spectrometer entrance slit. Conversely, for the determination of cross section ratios Stephan *et al.*[6] have shown that it is necessary to integrate at least across the mass spectrometer entrance slit in order to avoid serious discrimination effects.

III. RESULTS

Using the above mentioned method, relative partial ionization cross section functions from threshold up to 180 eV have been measured for the processes

$$Xe + e \rightarrow Xe^{+} + 2e,$$

$$Xe + e \rightarrow Xe^{2+} + 3e,$$

$$Xe + e \rightarrow Xe^{3+} + 4e.$$

In addition, cross section ratios between Xe^{2+}, Xe^{3+}, Xe^{4+}, and Xe^{+} have been measured at several electron energies (see Table I). Using these measured cross section ratios the relative partial cross section functions (up to fourfold ionization) were calibrated by normalizing the weighted sum at one particular energy (150 eV) to the value of the absolute total ionization cross section reported by Rapp and Englander-Golden.[12] This normalization factor is found to be indepen-

TABLE I. Partial ionization cross section ratios of the electron impact production of multiply to singly ionized Xe at three different electron energies.

Cross section ratio	Electron energy			Reference
	50 eV	100 eV	150 eV	
$\frac{\sigma(Xe^{2+}/Xe)}{\sigma(Xe^{+}/Xe)}$	0.10	0.17	0.14	Tate and Smith (Ref. 9)
	0.12	0.28	0.28	Fox (Ref. 10)
	0.076	0.15	0.15	Egger and Märk (Ref. 11)
	0.055	0.108	0.113	present
$\frac{\sigma(Xe^{3+}/Xe)}{\sigma(Xe^{+}/Xe)}$	...	0.026	0.063	Tate and Smith (Ref. 9)
	...	0.050	0.089	Fox (Ref. 10)
	...	0.025	0.069	Egger and Märk (Ref. 11)
	...	0.015	0.041	present
$\frac{\sigma(Xe^{4+}/Xe)}{\sigma(Xe^{+}/Xe)}$	...	...	0.004	Tate and Smith (Ref. 9)
	...	...	0.003	Fox (Ref. 10)
	...	...	0.005	Egger and Märk (Ref. 11)
	...	...	0.0023	present

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TABLE II. Absolute partial ionization cross section vs electron energy for the processes $Xe + e \rightarrow Xe^{+} + 2e$, $Xe + e \rightarrow Xe^{2+} + 3e$, and $Xe + e \rightarrow Xe^{3+} + 4e$. Also shown the percentage deviation (Ref. 15) between the total ionization cross section determined in this study $[\sigma_t = \sigma(Xe^{+}/Xe) + 2(Xe^{2+}/Xe) + 3(Xe^{3+}/Xe)]$ and the total ionization cross section reported by Rapp and Englander-Golden (Ref. 12) (see the text).

Electron energy (eV)	$\sigma(Xe^{+}/Xe)$ $(10^{-20}\,m^2)$	$\sigma(Xe^{2+}/Xe)$ $(10^{-20}\,m^2)$	$\sigma(Xe^{3+}/Xe)$ $(10^{-20}\,m^2)$	$\frac{\sigma_t(\text{present})}{\sigma_t(\text{Ref. 12})}$ (%)
15	1.15	...	...	+ 27.2
20	2.42	...	...	+ 6.2
25	3.33	...	...	+ 3.0
30	3.81	...	...	− 1.1
35	4.17	...	...	− 1.7
40	4.30	0.06	...	− 1.1
45	4.31	0.15	...	− 1.4
50	4.29	0.24	...	− 1.6
55	4.27	0.29	...	− 1.9
60	4.37	0.33	...	− 0.2
65	4.47	0.34	...	+ 1.3
70	4.54	0.35	...	+ 2.4
75	4.57	0.36	0.004	+ 2.9
80	4.59	0.38	0.009	+ 3.5
85	4.55	0.40	0.018	+ 2.9
90	4.48	0.43	0.030	+ 2.8
95	4.42	0.45	0.045	+ 2.1
100	4.31	0.47	0.063	+ 0.9
105	4.26	0.48	0.083	+ 1.0
110	4.21	0.49	0.10	+ 0.7
115	4.13	0.49	0.12	+ 0.1
120	4.06	0.49	0.14	− 0.2
125	3.99	0.49	0.15	− 0.7
130	3.97	0.47	0.16	− 0.6
135	3.92	0.47	0.16	− 0.3
140	3.87	0.45	0.16	− 0.5
145	3.85	0.44	0.16	− 0.7
150	3.82	0.43	0.16	− 0.7
155	3.78	0.42	0.16	...
160	3.74	0.41	0.15	− 1.2
165	3.73	0.40	0.15	...
170	3.67	0.39	0.15	...
175	3.63	0.37	0.15	...
180	3.58	0.36	0.14	− 2.2

dent of electron energy within the limits of the combined statistical error (see Table II), except close to threshold.[13] Other consistency checks, electron energy calibration, and error analysis have already been discussed previously.[6]

The present data on partial ionization cross section ratios and functions of Xe are summarized in Tables, I and II, respectively. Furthermore, Table II includes the percentage deviation of the present total cross section (obtained by summing the weighted partial cross sections up to threefold ionization[15]) from the total cross section reported by Rapp and Englander-Golden.[12] Also shown for comparison in Table I are some previously measured cross section ratios, illustrating the discrepancy of the literature values so far. The confidence in the present values stems from our earlier studies of the other rare gases[6] (see above) and from the good agreement between our total ionization cross sections and those of ionization tube measurements.[12]

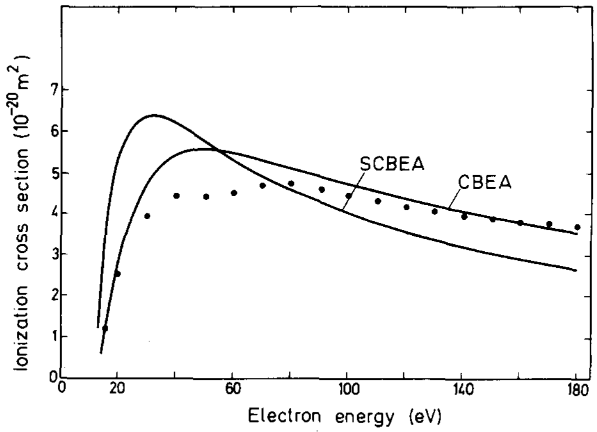

FIG. 1. Partial ionization cross section vs electron energy for the process $Xe + e \rightarrow Xe^{+} + 2e$. Points: present experimental data, curve CBEA: calculated values using the classical binary encounter approximation of Gryzinski (Ref. 16); and curve SCBEA: calculated values using the semiclassical binary encounter approximation of Burgess–Vriens (Ref. 17).

Moreover, Fig. 1 shows a comparison between the present ionization cross sections for the production of singly ionized Xe and calculated cross sections using the classical binary encounter approximation introduced by Gryzinski[16] and the semiclassical binary encounter approximation proposed by Burgess and Vriens.[17] As for the case of the other rare gases[4] classical and semiclassical theory does not provide an accurate description of the ionization function, particular in the low regime.

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