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CROSS SECTIONS FOR THE PRODUCTION OF N_2^+, N^+ AND N_2^{2+} FROM NITROGEN BY ELECTRONS IN THE ENERGY RANGE 16–600 eV

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ABSTRACT

Cross sections were determined for the production of N_2^+, N_2^{2+} by electrons from molecular nitrogen in the energy range from 16 through 600 eV, using a cycloidal mass spectrometer with total ion transmission. The investigation of the reaction $N_2+e \rightarrow N_2^{2+}+3e$ was made possible by using isotopically enriched nitrogen. At 430 eV electron energy a sudden increase in the cross section for N_2^{2+} was found, due to an Auger process.

INTRODUCTION

In many publications ionization and dissociation cross sections of nitrogen with electrons have been reported[1-5]. In refs. 2 and 3, absolute values for the total cross sections determined by the condenser method were given: in the other publications[1,4,5], partial cross sections had been measured using a mass spectrometer.

For these measurements it is not appropriate to take nitrogen in the natural isotopic composition, as it is then impossible to distinguish between N_2^{2+} and N^+ as both ions will occur at the same peak, $m/e = 14$. Hagstrum and Tate[1] were the first to determine the appearance potential of N_2^{2+} from a break in the curve representing the ionization as a function of the electron energy. Dorman and Morrison[4] determined the appearance potential of N_2^{2+} from measurements on $^{14}N^{15}N$.

In the present investigation we also used isotopically enriched nitrogen for the determination of the ionization cross sections of N_2^{2+} as well as for those of N_2^+ and N^+. We applied the cycloidal mass spectrometer, because of its ability to transmit the full ion intensity from the source to the collector[5-7]. In this way all mass discrimination is avoided and the apparatus provides accurate relative cross sections. Absolute measurements are not possible, as the gas pressure in the source is not known, nor is the effective length of the ionization region. For this reason a normalization of our results with literature data on the total ionization cross section[3] was performed.

EXPERIMENTAL AND RESULTS

The composition of the nitrogen used in our experiments was nearly 25 % $^{14}N_2$, 50 % $^{14}N^{15}N$, and 25 % $^{15}N_2$. The electron energy ranged from 16 through 600 eV and the ion currents I_{14}, $I_{14.5}$, I_{15} as well as I_{28}, I_{29} and I_{30} were measured.

In relative measure

$$\sigma(N_2^+) = c\,(I_{28}+I_{29}+I_{30})$$

$$\sigma(N^+)+2\sigma(N_2^{2+}) = c\,(I_{14}+I_{14.5}+I_{15})$$

$$\sqrt{2}\sigma(N_2^{2+}) = c\,\overline{[(I_{28}+I_{29}+I_{30})/I_{29}]}I_{14.5}$$

where c is a proportionality constant and the bar means the average taken over all measurements.

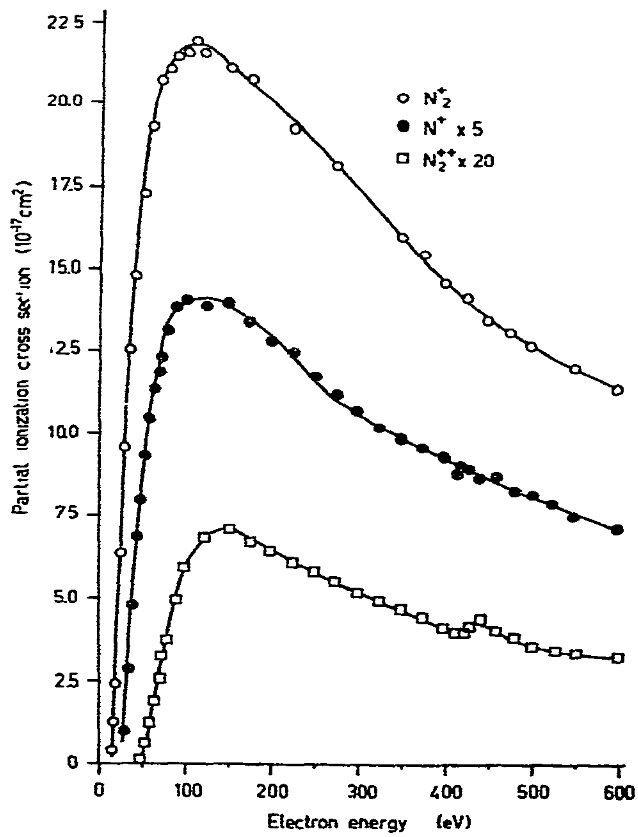

Fig. 1. Partial ionization cross sections of nitrogen.

TABLE 1

PARTIAL IONIZATION CROSS SECTIONS OF NITROGEN IN 10^{-17} cm^2/molecule

E_{el} in eV	N_2^+	N^+	N_2^{2+}
16	0.4	—	—
18	1.2	—	—
20	2.5	—	—
25	6.3	—	—
30	9.5	0.18	—
35	12.5	0.57	—
40	14.8	0.93	—
45	—	1.37	—
50	17.2	1.60	0.006
55	—	1.87	0.029
60	19.3	2.08	0.063
65	—	2.27	0.094
70	20.7	2.38	0.131
75	—	2.47	0.164
80	21.1	2.63	0.187
90	21.5	2 76	0.248
100	21.6	2.81	0.294
110	21.8	—	—
120	21.6	—	—
125	—	2.78	0.34
150	21.1	2.79	0.36
175	20.7	2.68	0.33
200	—	2.56	0.32
225	19.3	2.49	0.31
250	—	2.34	0.291
275	18.1	2.22	0.276
300	—	2.12	0.260
325	—	2.03	0.248
350	16.0	1.96	0.229
375	15.4	1.91	0.225
400	14.6	1.86	0.208
415	—	1.77	0 202
420	—	1.80	0.202
425	14.2	1.80	0.203
440	—	1.75	0.219
450	13.4	—	—
460	—	1.74	0.202
475	13.1	—	—
480	—	1.66	0.190
500	12.7	1.64	0.179
525	—	1.57	0.175
550	12.0	1.50	0.167
600	11.4	1.44	0.165

The relative values obtained were normalized on the absolute total ionization cross sections for N_2 as obtained by Rapp and Englander-Golden[3]. The condition of attaining such a normalization is the validity of the equation:

$$\frac{\sigma_T}{I_{14}+I_{14.5}+I_{15}+I_{28}+I_{29}+I_{30}} = \text{constant}$$

over the whole range of electron energies, where σ_T is the absolute total cross section of Rapp and Englander-Golden. Indeed the value of this ratio was constant within $\pm 3\,\%$ in the range from 30 through 600 eV.

Figure 1 and Table 1 give the observed and normalized values for the cross sections for the production of N_2^+, N^+ and N_2^{2+} ions.

AUGER PROCESS

At about 430 eV electron impact energy we observed a hump in the ionization curve of N_2^{2+} due to an Auger process: one inner-shell electron of the nitrogen molecule is ionized and a second electron is ejected from the excited N_2^{+*} ion when an electron from the outer shell jumps back into the vacancy in the inner shell:

$$N_2 + e \rightarrow N_2^{+*} + 2e$$

$$N_2^{+*} \rightarrow N_2^{2+} + e$$

The appearance potential of the first process was calculated by Nesebet[8] to be 427 eV which corroborates our experimental value.

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