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Total and partial ionization cross sections of NH_3 by electron impact

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Abstract. Values of cross sections for the production of positive ions resulting from electron collisions with NH_3 at impact energies ranging from threshold to 1 keV have been measured using a crossed-beams apparatus. These cross sections have been normalized by using the relative flow technique and the previously determined cross sections of He and Ne. The measured values are compared with previous data available in the literature. The threshold energy for the production of each ion has been measured. Total ionization cross sections as a function of electron impact energies have been deduced from the measured partial ionization cross sections.

1. Introduction

Ammonia is present in cometary, planetary and astrophysical atmospheres (Allen *et al* 1987, Prasad and Huntress 1980). It is also used as a carrier gas for the generation of various low temperature plasmas (Manos and Flamm 1989). The determination of quantitative cross section data for ionization and fragmentation of NH_3 by electron impact has, therefore, been a subject of extensive investigation for the last two decades. By using various methods, several investigators (Gomet 1975, Crowe and McConkey 1977, Märk *et al* 1977, Bederski *et al* 1980, Syage 1988) have measured ionization cross sections. However, in general, the agreement is rather poor among their results. Other studies are concerned with the measurement of total ionization cross sections (Djuric *et al* 1981), ionization thresholds (Frost and McDowell 1958, Lifshitz and Long 1964), appearance potentials (Mann *et al* 1940, Reed and Snedden 1959, Morrison and Traeger 1973, Proulx and Marmet 1983, Locht *et al* 1989) and total ionization cross section at one particular energy (Mann *et al* 1940, Melton 1966). Crowe and McConkey (1977) and Bedereski *et al* (1980) obtained the absolute values of cross sections by normalizing their total ionization cross section data to the semi-empirically derived cross section of Jain and Khare (1976) at 100 eV. However, the two experimental sets of data are in complete disagreement with each other in regard to the shapes, magnitudes and positions of cross section maxima. The accuracy of their data depends on the validity of the results of Jain and Khare (1976). In a subsequent paper, Khare and Meath (1987) have presented some improvements to Jain and Khare's (1976)

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original semi-empirical formula and recalculated the cross section values for NH_3^+, NH_2^+ and NH^+ resulting from electron impact ionization of NH_3. Their new values are higher than their previous data. In their most recent paper, Khare *et al* (1989) have further improved the cross section values for NH_2^+ and NH^+ fragments from NH_3.

In view of the above disagreements among various data, we undertook a systematic study of the ionization processes of NH_3 by electron impact and measured the cross sections, both total and partial, for electron impact energies ranging from threshold to 1000 eV.

In section 2 details on the experiment and method are discussed and in section 3 our results are presented and compared with previous data.

2. Experimental procedure

2.1. Apparatus and data acquisition

A schematic diagram of the apparatus used in the present measurements is shown in figure 1. Since a detailed description of the present experimental set-up has already been given in two earlier publications (Khakoo and Srivastava 1984, Krishnakumar and Srivastava 1988), only the salient features are discussed here. It is a crossed-beams apparatus, and consists of an electron source, a Faraday cup, a quadrupole mass spectrometer (QMS), a time-of-flight mass spectrometer (TOFMS) and two parallel extraction grids for extracting ions. A beam of magnetically collimated and nearly monoenergetic electrons (FWHM ~300 meV) collides with a beam of the target gas of interest, which flows into the interaction region through a capillary array, at right angles to each other. The ions produced in the interaction region are extracted by the

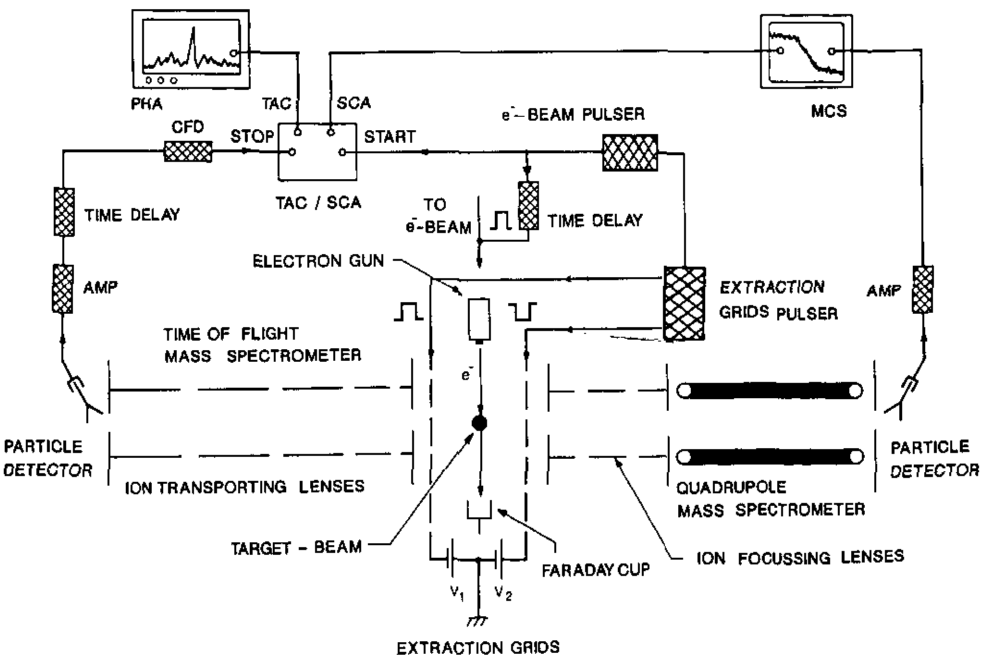

Figure 1. A schematic diagram of the experimental set-up.

pair of grids and are then focused by the ion optics either at the entrance of the QMS or into the TOFMS. A field of $100\ V\ cm^{-1}$ was set up between the extraction grids to ensure complete collection of ions born with energies ranging from thermal to as high as 5 eV. The electron energy is controlled by a ramp signal generated by a MCA (multichannel analyser). In the present measurements, the formation and extraction of ions are accomplished by using a pulsed technique which has been successfully employed in the past (Krishnakumar and Srivastava 1988). The heavier ions NH_3^+, NH_2^+, NH^+, N^+ and NH_3^{2+} have been mass analysed by the QMS whereas the lighter ions H^+ and H_2^+ have been separated by the TOFMS. In the following sections, the method of data acquisition by the QMS and by the TOFMS will be discussed.

2.1.1. Quadrupole mass spectrometer. Ions reaching the entrance of the QMS are selected for m/e (m and e are the mass and the charge of an ion, respectively) and are transported along its axis to a channel electron multiplier (CEM) which is placed off-axis at the end of the QMS in order to avoid counting photons coming from the interaction region. The CEM converts each ion into an electrical pulse which is then fed to an amplifier whose output is sent to the MCA. The detected ion intensity is recorded in the MCA as a function of incident electron energy. The above procedure is repeated for each ion species produced in the interaction region to obtain the ionization efficiency curve.

2.1.2. Time-of-flight mass spectrometer. The TOFMS is mounted directly opposite the QMS. When the TOFMS is operated, the polarities of the extraction grids are reversed such that the ions are extracted towards the TOFMS. Figure 1 shows the various components of the TOFMS. It consists of five equi-spaced cylindrical lenses of the same diameter but of different lengths. It transports ions along its axis onto the CEM, which is mounted off-axis for the same reason as in the case of the QMS. Each detected ion gives rise to an electrical pulse of about 20 mV amplitude which is increased by a fast amplifier to about 2 V. This pulse is then fed to a time delay unit which can delay it from 1 ns to 1 ms. The delayed pulse passes through a constant fraction discriminator (CFD) whose output is then fed to the stop terminal of a time-to-amplitude converter/single channel analyser (TAC/SCA). A start pulse to the TAC/SCA is provided by the pulser employed for pulsing the electron beam. The time difference (ΔT) between the start and the stop pulses is equal to the time-of-flight of the ion from the collision region to the detector. For a particular ion this time-of-flight depends on its kinetic energy. The ΔT is converted by the TAC into an electrical pulse whose amplitude is proportional to ΔT. These pulses of varying amplitudes are then stored in a PHA (pulse height analyser) mode of MCA which displays them as a function of ΔT. The trajectories of various ions through the ion transport lenses are calculated by utilizing a computer program called SIMION (EGG-cs-7233 Rev. 2 prepared by EG&G Idaho Inc., PO Box 1625, Idaho Falls, ID 83415, USA) which also provides the values of ΔT for ions of different energies. The voltages on various lenses are varied in such a way that most ions travel very close to the axis of the TOFMS, which is a desirable condition to improve the time resolution. For the measurement of the ionization efficiency curve of each ion, the lower and the upper levels of the single channel analyser are set on a selected ion such that the SCA gives a constant TTL pulse output. The output of the SCA is then fed to the MCA in the multichannel scaling mode to record the ionization efficiency curve as a function of electron impact energy.

2.2. *Data analysis*

2.2.1. Normalized values of ionization cross sections. The measured relative cross sections represented by the ionization efficiency curves of NH_3^+, NH_2^+, NH^+, N^+, H^+, H_2^+ and NH_3^{2+} were placed on an absolute scale by a normalization procedure which employs the relative flow technique. This technique utilizes the accurately known values of ionization cross sections, such as for He, to calibrate the apparatus. Details on the procedure are given in our papers published previously by Srivastava *et al* (1975) and Krishnakumar and Srivastava (1988). Briefly, the gas, for which accurate values of ionization cross sections are known, flows into the interaction region through a capillary array. At a fixed electron impact energy E_0, the intensity $I_0(E_0)$ of the ionic species is recorded. This gas is then replaced by the gas for which the cross sections have to be measured. The intensities $I_u(E_0)$ of various ionic species are once again recorded under the same experimental conditions. The intensities and the respective cross sections can then be related to each other through the following relation:

$$\sigma_u(E_0) = \sigma_0(E_0)[I_u(E_0)/I_0(E_0)](M_0/M_u)^{1/2}(F_0/F_u)(K_0/K_u) \tag{1}$$

where $\sigma_u(E_0)$ and $\sigma_0(E_0)$ are ionization cross sections at electron impact energy E_0 for the gas under study and the standard gas respectively, M_u and M_0 their atomic or molecular weights, F_u and F_0 their flow rates and K_u and K_0 the mass transmission efficiencies of the whole mass analysis and detection system for the two species. In the past, as standard practice, we have used accurately known values of ionization cross sections of He for normalization. However, in addition to He, we have also chosen the well known cross sections of Ne (Krishnakumar and Srivastava 1988) for the present measurements. Cross sections for the ionization of Ne were used to normalize the data obtained for NH_3^+, NH_2^+, NH^+, N^+ and NH_3^{2+} ions, whereas the ionization cross sections of He were employed for the normalization of H^+ and H_2^+ data. This choice of two separate cross sections was influenced by the fact that the atomic mass of Ne is closer to the first group of ions and the mass of He is very similar to the second group. Thus, any error caused by mass-dependent transmission efficiencies, K_0 and K_u, of the mass analyser was reduced.

2.2.2. Total cross sections. The values of total ionization cross sections σ_t as a function of electron impact energy E_0 were obtained by summing the partial ionization cross sections of each ionic species by the following relation:

$$\sigma_t(E_0) = \Sigma_p \sigma_p(E_0) + \Sigma_i \sigma_p^i(E_0) \tag{2}$$

where $\sigma_p(E_0)$ is the partial cross section for single ionization of a species and $\sigma_p^i(E_0)$ is the cross section for doubly and multiply ionized atoms or molecules and 'i' is the stage of ionization.

2.3. *Error estimation*

The total error in the present values of the cross sections can be estimated by considering the uncertainties involved in the measurement of individual quantities in equation (1). We have used the helium cross section value at 100 eV electron impact energy recommended by Bell *et al* (1983), which is accurate to within ±5%, and those of neon reported by Krishnakumar and Srivastava (1988), which are accurate to within ±10%. As a routine we repeat the measurements on the ratios of intensities and the flow rates several times, and also accummulate enough signal to avoid uncertainties related to the count rates. Therefore, they are estimated to be measured with an accuracy of about 2% each. Our procedure for measuring the flow rates has been described by Trajmar and Register (1984). The determination of the ratio K_0/K_u is estimated to be accurate to within ±2%. Therefore, the cross section values reported in this paper for NH_3^+, NH_2^+, NH^+, N^+, NH_3^{2+} and total are at most uncertain by about ±16% which is a direct sum of all the estimated errors. For H^+ and H_2^+, we have used the cross sections of He. Therefore, for these species the uncertainty in the cross section values is about ±11%. However, since the nature of all errors mentioned above is statistical, a better estimate of uncertainty is obtained by calculating the square root of the sum of the squares of individual errors. Thus, the overall uncertainty of the cross section for NH_3^+, NH_2^+, NH^+, N^+, NH_3^{2+} and total is about ±11%, and for H^+ and H_2^+ it is approximately ±6%.

3. Results and discussion

The threshold for the production of NH_3^+ and appearance potentials for the production of ionic fragments resulting from the dissociation of NH_3 by electron impact have been measured several times. They consistently appeared at 10.25 eV for NH_3^+, 15.70 eV for NH_2^+, 22.80 eV for NH^+, 26.60 for N^+, 27.50 eV for H^+, 22.40 eV for H_2^+ and 35.50 eV for NH_3^{2+}. The energy of the electron beam was calibrated with the well known onsets of rare gases and was estimated to be accurate to within ±0.20 eV. Ionization energy curves near threshold region are shown in figure 2. The cross section data for various ionic species are presented in figures 3–10 along with previously published results. Normalized values of ionization cross sections for parent and fragment ions are given in table 1. In the following we will discuss the present results.

3.1. Total ionization cross sections

Figure 3 shows a comparison of our results with other previous measurements and semi-empirical values of Khare and Meath (1987). Our results agree very well, except the position of cross section maximum, with the absolute values reported by Djurič *et al* (1981). Crowe and McConkey (1977) and Bederski *et al* (1980) performed relative measurements and normalized their values at 100 eV with the cross section of semi-empirical calculations of Jain and Khare (1976). The normalized values of the above two groups were very different from the present ones. Therefore, we renormalized their published data with respect to ours at 70 eV electron impact energy, where the cross section is a maximum, by multiplying the data of Crowe and McConkey (1977) by 1.22 and those of Bederski *et al* (1980) by 1.26. The new values are presented in figure 3. It is clear from the figure that the agreement is excellent among us within the combined errors. The new semi-empirical results of Khare and Meath (1987) also agree well with the present data which are accurate to within 16%. The cross sections of Gomet (1975), although lying in the neighbourhood of the present ones, have a very different energy dependence. The maximum in his total ionization efficiency curve is at a much higher energy than that obtained by others. We suspect that the author made an error in calibrating the energy of the incident electrons.

Our results are higher by about a factor of 1.5 than those of Märk *et al* (1977). Such a large difference between the two measurements is very difficult to explain. The

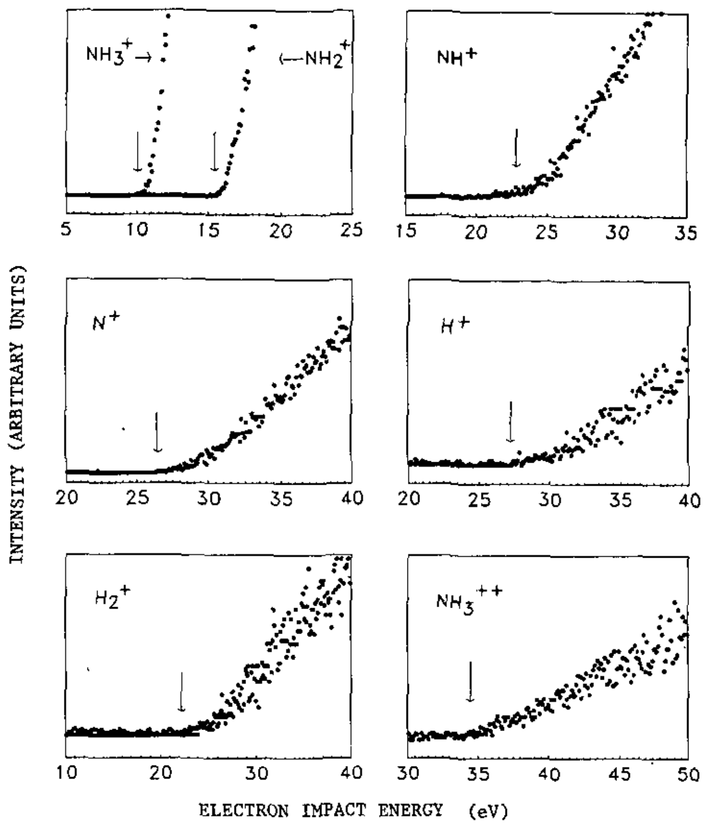

Figure 2. Measured thresholds of various ionic species from NH_3 as a function of electron impact energy: NH_3^+ and NH_2^+; NH^+; N^+; H^+; H_2^+; NH_3^{2+}. *Arrows pointing downward* indicate the threshold values (see text).

ion source design of Märk *et al* seriously discriminates energetic fragments (Märk and Castleman 1980) and, therefore, may have contributed large errors to the measurement of their intensities resulting in lower values of the total cross sections.

Besides the above mentioned results, there are three other measurements at one electron impact energy. They are by DeMaria *et al* (1963) at 70 eV, Melton (1966) at 100 eV, and Lampe *et al* (1957) at 75 eV. The results of DeMaria *et al* and Melton are much lower than the present one whereas the value of Lampe *et al* is in good agreement with ours.

3.2. NH_3^+, NH_2^+ and NH^+

Figures 4, 5 and 6 show the present results along with the previous data. The same normalization factors which were obtained for Crowe and McConkey (1977) and Bederski *et al* (1980) for the total ionization cross sections as explained in the previous section, have been employed here to generate the new values of cross sections for NH_3^+, NH_2^+ and NH^+ from their old ones. There is a good agreement between the present results and those of Crowe and McConkey (1977) for NH_3^+ but the agreement is not so good for NH_2^+. For NH^+ their values are larger by a factor of four, however

Table 1. Partial and total ionization cross sections of NH_3 by electron impact (in units of 10^{-18} cm^2). The values of NH_3^+, NH_2^+, NH^+, N^+ and NH_3^{2+} are accurate to within ± 11% and the values of H^+ and H_2^+ are within ±6% (see text).

Energy E_0 (eV)	NH_3^+	NH_2^+	NH^+	N^+	H^+	H_2^+	NH_3^{2+}	NH_3 (total)
15	0.5	—	—	—	—	—	—	0.5
20	32.5	13.2	—	—	—	—	—	45.7
25	63.7	47.1	—	—	—	—	—	110.8
30	84.5	71.4	0.97	—	—	—	—	156.9
35	100.9	92.8	2.67	0.46	0.17	0.082	—	197.0
40	123.6	104.6	4.90	0.91	0.53	0.140	0.003	234.7
45	140.0	110.9	6.70	1.45	1.02	0.171	0.010	260.2
50	149.8	116.2	7.66	2.04	1.48	0.192	0.021	277.4
55	153.8	120.2	8.26	2.43	1.90	0.213	0.039	286.8
60	156.4	122.8	8.72	2.71	2.18	0.226	0.064	293.1
65	157.9	125.2	9.04	2.88	2.35	0.230	0.086	297.7
70	158.7	127.2	9.27	3.05	2.46	0.240	0.114	301.0
75	158.8	128.6	9.37	3.20	2.60	0.245	0.132	302.9
80	158.4	129.2	9.47	3.32	2.70	0.247	0.145	303.5
85	157.8	129.5	9.51	3.39	2.79	0.250	0.154	303.4
90	157.2	130.0	9.54	3.44	2.83	0.252	0.164	303.4
95	155.8	129.9	9.51	3.49	2.86	0.253	0.173	302.0
100	154.8	129.6	9.47	3.53	2.89	0.254	0.178	300.7
105	153.2	129.4	9.42	3.56	2.90	0.253	0.183	298.7
110	151.9	128.7	9.32	3.58	2.91	0.252	0.187	296.8
115	150.3	128.3	9.22	3.59	2.92	0.250	0.191	294.7
120	149.0	127.4	9.11	3.59	2.91	0.249	0.195	292.4
125	147.5	126.8	9.00	3.58	2.88	0.246	0.198	290.2
130	146.0	125.7	8.87	3.56	2.86	0.243	0.201	287.4
135	144.6	124.9	8.76	3.53	2.83	0.240	0.202	285.0
140	143.0	123.9	8.68	3.51	2.80	0.237	0.204	282.3
145	141.8	123.1	8.55	3.47	2.76	0.233	0.205	280.1
150	140.4	122.4	8.44	3.41	2.72	0.229	0.205	277.8
155	139.0	121.4	8.32	3.34	2.68	0.225	0.205	275.2
160	137.6	120.4	8.21	3.30	2.63	0.222	0.204	272.5
165	136.4	119.5	8.09	3.24	2.60	0.219	0.203	270.2
170	135.3	118.6	7.96	3.19	2.56	0.216	0.202	268.0
175	133.5	117.5	7.85	3.15	2.52	0.213	0.200	264.9
180	132.3	116.8	7.76	3.12	2.48	0.209	0.199	262.8
185	130.9	116.0	7.65	3.06	2.45	0.205	0.197	260.4
190	129.5	114.9	7.54	3.02	2.40	0.203	0.196	257.7
195	128.0	114.0	7.43	2.97	2.36	0.199	0.194	255.1
200	126.6	112.9	7.32	2.93	2.33	0.195	0.192	252.4
210	124.0	111.0	7.11	2.84	2.24	0.187	0.188	247.5
220	121.0	108.9	6.90	2.75	2.15	0.183	0.184	242.0
230	118.4	107.0	6.72	2.67	2.09	0.178	0.180	237.2
240	116.0	105.0	6.52	2.59	2.02	0.173	0.177	232.5
250	114.0	103.4	6.35	2.50	1.96	0.168	0.173	228.5
260	111.6	101.4	6.17	2.43	1.90	0.162	0.169	223.8
270	109.7	99.8	5.98	2.35	1.83	0.158	0.166	220.0
280	107.7	97.9	5.81	2.29	1.78	0.154	0.163	215.8
290	105.6	96.1	5.66	2.21	1.72	0.150	0.159	211.6
300	104.0	94.5	5.52	2.14	1.67	0.146	0.156	208.1
320	100.1	91.3	5.25	2.00	1.60	0.142	0.150	200.5
340	96.0	88.9	5.02	1.87	1.53	0.136	0.144	193.6
360	92.9	86.2	4.79	1.78	1.47	0.132	0.139	187.4
380	90.0	83.7	4.59	1.68	1.41	0.126	0.133	181.6

Table 1. (continued)

Energy E_0 (eV)	NH_3^+	NH_2^+	NH^+	N^+	H^+	H_2^+	NH_3^{2+}	NH_3 (total)
400	87.5	80.9	4.45	1.60	1.38	0.121	0.128	176.0
420	85.0	78.6	4.29	1.54	1.34	0.117	0.122	171.0
440	82.7	76.2	4.17	1.49	1.30	0.112	0.118	166.1
460	79.9	73.9	4.05	1.41	1.27	0.108	0.114	160.7
480	77.8	71.9	3.95	1.36	1.22	0.105	0.111	156.4
500	75.0	69.8	3.84	1.32	1.19	0.102	0.107	151.3
525	72.4	68.1	3.71	1.28	1.15	0.100	0.103	146.9
550	70.2	65.7	3.60	1.24	1.12	0.098	0.100	142.0
575	68.0	63.6	3.54	1.19	1.09	0.096	0.097	137.6
600	66.2	62.1	3.46	1.16	1.06	0.094	0.093	134.1
625	64.5	60.4	3.38	1.12	1.04	0.092	0.090	130.6
650	62.6	58.6	3.30	1.08	1.01	0.089	0.087	126.7
675	61.2	57.3	3.24	1.05	0.99	0.086	0.084	124.0
700	60.0	55.8	3.17	1.02	0.97	0.083	0.081	121.1
750	57.0	53.6	3.07	0.97	0.93	0.079	0.078	115.7
800	55.0	52.1	2.95	0.91	0.89	0.076	0.075	112.0
850	53.0	50.4	2.86	0.88	0.85	0.073	0.072	108.1
900	51.5	48.7	2.77	0.84	0.82	0.070	0.069	104.7
950	50.3	47.2	2.65	0.81	0.79	0.067	0.066	101.9
1000	49.4	45.5	2.57	0.78	0.77	0.064	0.063	99.1

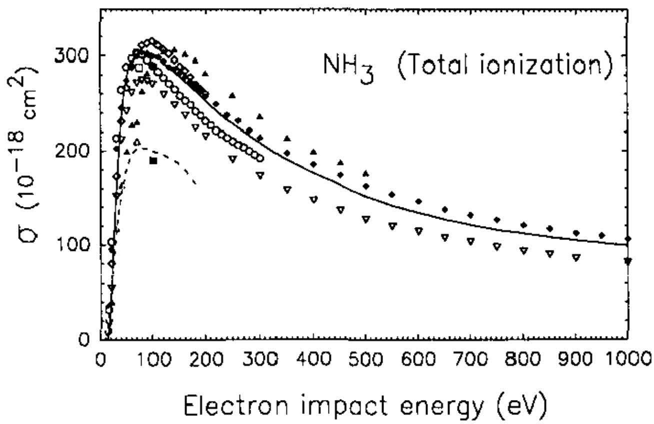

Figure 3. Total ionization cross sections of NH_3 as a function of electron impact energy. □, Lampe *et al* (1957); △, DeMaria *et al* (1963); ■, Melton (1966); ▲, Gomet (1975); ○, Crowe and McConkey (1977), renormalized (see text); — —, Märk *et al* (1977); ◆, Bederski *et al* (1980), renormalized (see text); ◇, Djuric *et al* (1981); ▽, semi-empirical formula, Khare and Meath (1987); ——, present data (uncertainty ≃ 11%).

the shape appears to be in excellent agreement with the present one. On the other hand, the agreement of the present results with Bederski *et al* is excellent for NH_2^+ over the entire electron impact energy range. However, the same is not true for NH_3^+ and NH^+.

Data reported by Gomet (1975) are higher by a factor of two than the present ones for NH_3^+ and NH^+, and also the shapes of their ionization efficiency curves differ

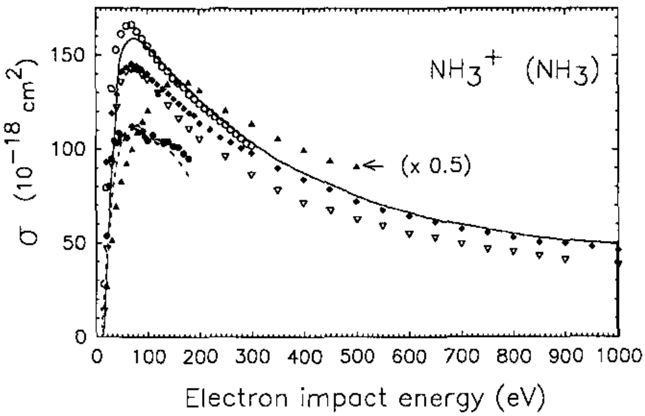

Figure 4. Ionization cross sections of NH_3 to produce NH_3^+ as a function of electron impact energy. ▲, Gomet (1975), multiplied by 0.5; ○, Crowe and McConkey (1977), renormalized (see text); — —, Märk *et al* (1977); ◆, Bederski *et al* (1980), renormalized (see text); ▽, semi-empirical formula, Khare and Meath (1987); ●, Syage (1988); ——, present data (uncertainty ≃ 11%).

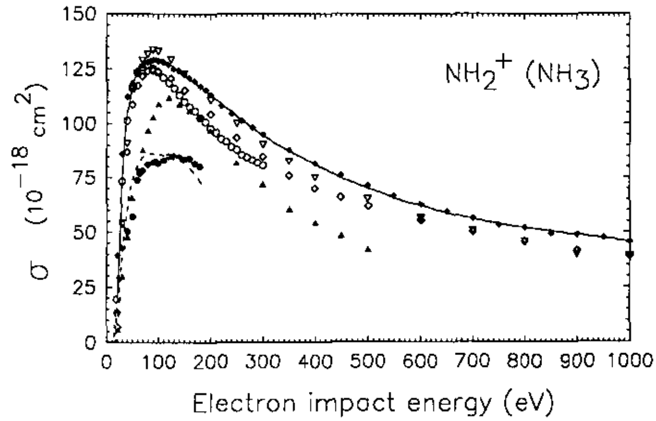

Figure 5. Partial ionization cross sections of NH_3 to produce NH_2^+ as a function of electron impact energy. ▲, Gomet (1975); ○, Crowe and McConkey (1977), renormalized (see text); — —, Märk *et al* (1977); ◆, Bederski *et al* (1980), renormalized (see text); ▽, semi-empirical formula, Khare and Meath (1987); ●, Syage (1988); ◇, semi-empirical formula, Khare *et al* (1989); ——, present data (uncertainty ≃ 11%).

considerably from everyone elses. In contrast, the data of Märk *et al* (1977) and Syage (1988) are much lower than the others. The most recent measurements of Syage (1988), except for NH^+, are in excellent agreement with those of Märk *et al* (1977). The ionization efficiency curves of Märk *et al* and of Syage show distinct structures which have not been reported by any of the previous measurements. If their curves are extrapolated to higher electron impact energies, they will show a tendency to fall off very rapidly with energy.

The semi-empirical calculations of Khare and Meath (1987) and Khare *et al* (1989) are quite satisfactory, considering the fact that they are based on high energy collision approximations.

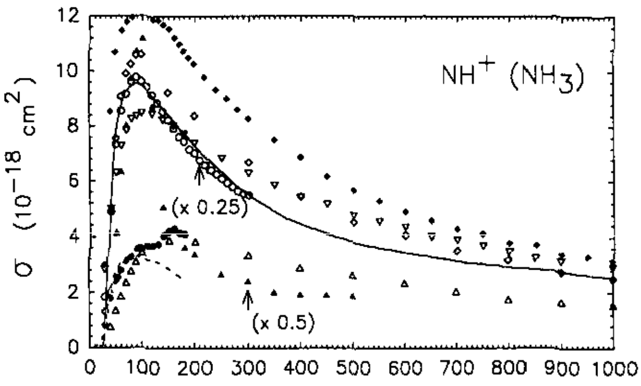

Figure 6. Partial ionization cross sections of NH_3 to produce NH^+ as a function of electron impact energy. ▲, Gomet (1975), multiplied by 0.5; ○, Crowe and McConkey (1977), multiplied by 0.25 and renormalized (see text); — —, Märk *et al* (1977); ◆, Bederski *et al* (1980), renormalized (see text); ∇, semi-empirical formula, Khare and Meath (1987); ●, Syage (1988); ◇, semi-empirical formula, Khare *et al* (1989); ——, present data (uncertainty = 11%).

3.3. N^+, H^+, H_2^+ and NH_3^{2+}

Figures 7-10 present the various cross section data on these species. The previous measurements for N^+, H^+ and H_2^+ are from Gomet (1975), Märk *et al* (1977) and Bederski *et al* (1980). For NH_3^{2+}, the only available data are of Märk *et al* (1977) and Bederski *et al* (1980). The renormalized results of Bederski *et al* (see section 3.1) are consistently higher than the present ones over the entire energy range for N^+, H^+ and H_2^+. In contrast, their values are considerably lower than the present ones for NH_3^{2+}. The data of Märk *et al* are much lower than others for all species. Gomet's results are not only higher than the present ones but also differ in the shapes of the ionization efficiency curves.

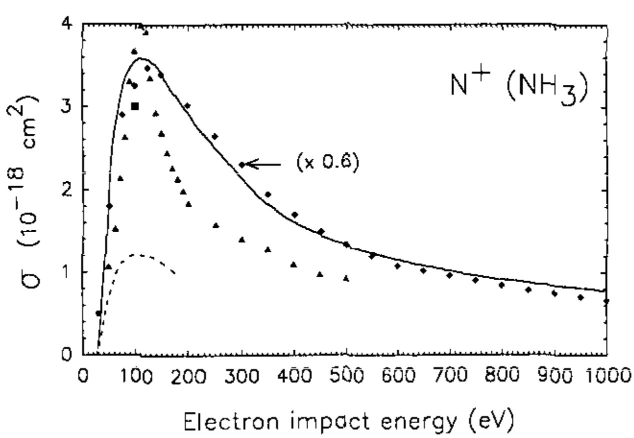

Figure 7. Partial ionization cross sections of NH_3 to produce N^+ as a function of electron impact energy. ▲, Gomet (1975), multiplied by 0.6; — —, Märk *et al* (1977); ◆, Bederski *et al* (1980), renormalized (see text); ——, present data (uncertainty = 11%).

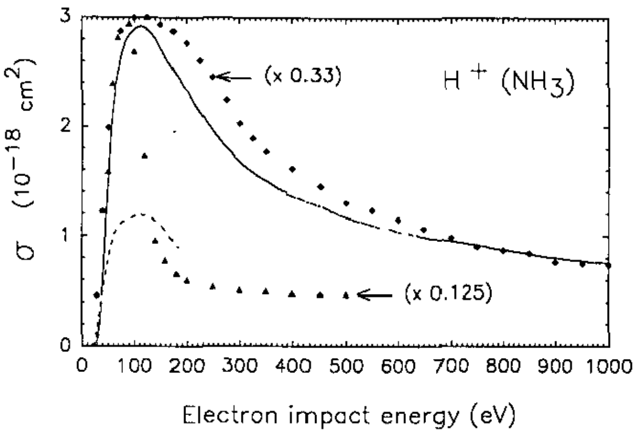

Figure 8. Partial ionization cross sections of NH_3 to produce H^+ as a function of electron impact energy. ▲, Gomet (1975), multiplied by 0.125; — —, Märk *et al* (1977); ◆, Bederski *et al* (1980), multiplied by 0.33 and renormalized (see text); ——, present data (uncertainty ≃ 6%).

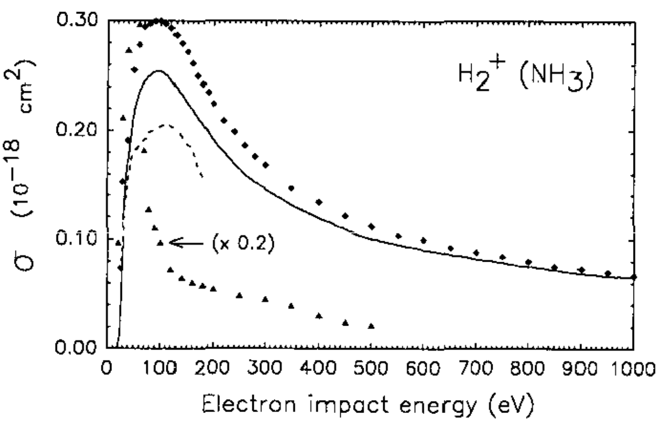

Figure 9. Partial ionization cross sections of NH_3 to produce H_2^+ as a function of electron impact energy. ▲, Gomet (1975), multiplied by 0.2; — —, Märk *et al* (1977); ◆, Bederski *et al* (1980), renormalized (see text); ——, present data (uncertainty ≃ 6%).

In summary, although quite a number of measurements on the electron impact ionization of this molecule have been reported in the past, there are disagreements among themselves. The main reason for these differences lies in the fact that the methods of normalization are quite different from each other. After renormalizing the data of Crowe and McConkey (1977) and Bederski *et al* (1980) we find a good agreement between our results and theirs for the main constituents NH_3^+, NH_2^+ and NH^+ of NH_3 and the total. On the other hand, differences in cross sections for lighter fragments N^+, H^+, H_2^+ and NH_3^{2+}, as reported by different groups, are rather large. This discrepancy may come mainly from the fact that these fragments may be born with an appreciable amount of kinetic energy. Therefore, incomplete collection of these energetic ions will result in a lowering of the cross section values. Since our ion source has been designed to eliminate this source of error, we believe that our results are accurate to within the stated errors given in section 2.2.2.

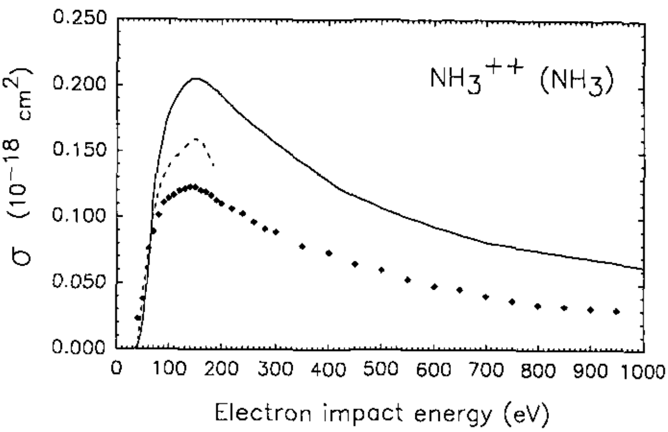

Figure 10. Partial ionization cross sections of NH_3 to produce NH_3^{2+} as a function of electron impact energy. — —, Märk *et al* (1977); ◆, Bederski *et al* (1980), renormalized (see text); ——, present data (uncertainty ≈ 11%).

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