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LETTER TO THE EDITOR

Measurements of cross sections for the production of protons by collisions between electrons and vibrationally de-excited H_3^+ ions

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Abstract. The results of two experiments are reported. In the first, cross sections were measured for the production of protons by collisions between electrons and vibrationally de-excited H_3^+ ions for interaction energies between 29 and 611 eV. This experiment employed electron and ion beams which intersected at right angles ($\theta = 90°$). In the second experiment inclined beams ($\theta = 10°$) were used to investigate lower interaction energies (19·2 to 29·5 eV) because it was found that the cross section increased rapidly with energy between 20 and 30 eV. The cross section reached a maximum value of $7{\cdot}6 \times 10^{-16}$ cm^2 at 79 eV and the systematic errors were assessed to be less than $\pm 6\%$. There is excellent accord between the present results and our earlier measurements (Peart and Dolder 1974) at near-threshold energies.

A recent paper (Peart and Dolder 1974, to be referred to as I) described the development of a source of vibrationally de-excited H_3^+ ions and its application to an experiment in which cross sections were measured for the production of protons by collisions between electrons and H_3^+. This experiment employed inclined beams of electrons and ions so that accurate results could be obtained at energies close to threshold (approximately 15 eV). From these results it was possible to deduce approximate values for the energies of the $^3E'$ and $^1E'$ electronically excited states of H_3^+ and so verify the theoretical predictions of Kawaoka and Borkman (1971).

No calculation has yet been made of the dissociation of H_3^+ by electron impact although the results should be particularly interesting because H_3^+ is the simplest polyatomic system. Such a calculation would probably employ Born's approximation and so it seemed worthwhile to extend our earlier measurements to higher energies where this approximation ought to be valid. Dissociation by fast electrons might also provide some check for calculations of the photodissociation of H_3^+ (which is of astrophysical interest) because, in the limit of Bethe's approximation, the two processes are related.

The apparatus and method of the first experiment were the same as described in I, except that a different electron gun (see Dolder *et al* 1961) was used and the ion and electron beams intersected perpendicularly.

Measurements of cross sections for proton production (σ) were made for interaction energies between 34 and 611 eV. The results are listed, with their 90% confidence limits of random error (see I), in the upper section of table 1, which also records the energies, in laboratory coordinates, of the ion (E_i) and electron (E_e) beams. Systematic errors of the experiment were assessed to be less than $\pm 6\%$.

Table 1.

Interaction energy (eV)	Cross section (10^{-16} cm^2)	Ion lab energy (keV)	Electron lab energy (eV)	90% confidence limits (%)
29	6·32	60	18	17
34	6·52	60	23	7
49	6·54	60	38	7
59	7·16	60	48	12
69	6·90	60	58	13
79	7·60	60	68	5
94	7·09	60	83	9
109	7·19	60	98	8
124	6·46	60	113	7
139	5·99	60	128	4
159	5·49	60	148	8
169	5·52	60	158	6
189	5·62	60	178	6
211	5·08	60	200	8
241	4·50	60	230	4
261	4·83	60	250	7
281	4·36	60	270	6
311	4·15	60	300	5
331	3·94	60	320	6
361	3·78	60	350	4
411	3·62	60	400	5
461	3·41	60	450	8
511	3·12	60	500	5
611	2·99	60	600	4
19·2	2·80	40	49	5
20·4	3·08	40	51	7
21·0	2·98	40	52	13
22·9	3·83	40	55	8
24·8	4·54	40	58	16
26·1	5·34	40	60	13
28·1	6·04	40	63	15
29·5	6·14	40	65	10

Our apparatus used a proton detector which did not distinguish between the almost simultaneous arrival of one or more protons. Consequently, $\sigma = \sigma_1 + \sigma_2 + \sigma_3$ where σ_1, σ_2 and σ_3 respectively represent cross sections for the formation of one, two or three protons by a single collision between an electron and an H_3^+ ion.

With perpendicular beams it was found that the accuracy of the measurements deteriorated significantly when the interaction energy was less than about 29 eV but the cross sections measured at these energies were about twice those reported in I for energies around 22 eV. This suggested a rapid increase in the cross section with energy between 22 and 29 eV. To check this, the inclined beam experiment described in I was repeated for energies up to 29·5 eV. The results of the new experiments with inclined beams are presented in the lower part of table 1 and it can be seen that their energy range overlaps those reported in I and those obtained with perpendicular beams.

The results of all three experiments and their 90% confidence limits of random error are illustrated by figure 1. The full curve summarizes the results already presented

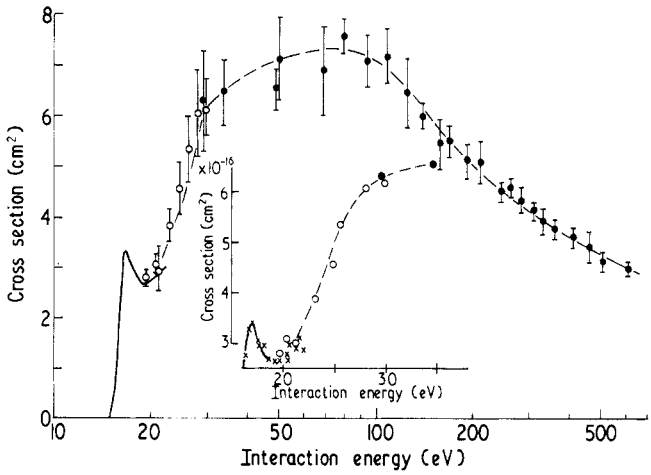

Figure 1. Measured cross sections for the production of protons by collisions between electrons and H_3^+ ions. The full curve and crosses refer to results previously reported. The open and full circles respectively denote new measurements with inclined and perpendicular electron and ion beams.

in I whilst the open and full circles respectively refer to the new measurements with inclined and perpendicular beams. The insert illustrates in greater detail the results obtained for the range of energies in which the three experiments overlap; the crosses in the insert refer to measurements previously presented in I.

The rapid increase observed in the cross section between 20 and 30 eV is consistent with the calculations of Kawaoka and Borkman which indicate several unstable states of H_3^+ with energies about 20 eV above the ground state.

The following values were typical of the experiment with perpendicular beams: ion beam current 5×10^{-10} A, ion beam energy 60 keV, electron beam current 0·5 mA (at 100 eV), count rate of protons produced by electron impact approximately $30\ s^{-1}$, count rate due to extraneous processes approximately $7000\ s^{-1}$. It is estimated that the residual gas pressure where the beams intersected was about 2×10^{-9} Torr.

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