ample, by very low pressures. At very high temperatures or very high values of E/p_0, at which equilibrium would be shifted toward the left side, the H_2^+ ion would still not be found as the dissociation of H_2^+ would then prevail. It may be noted that the binding energy of H_2^+ at 2.65 ev is appreciably less than that of H_3^+ quoted as 4.18 ev by Stevenson.

The structure of H_3^+ seems necessarily to be H - H - H. Since H_2 is simply H = H, the exchange of the proton is not surprising. The binding energy of H_2 is very nearly the same as for H_3^+, 4.48 and 4.18 ev, respectively, so that the proton exchange is virtually a resonance phenomenon. The H_3^+ ion passing through H_2 gas is, in effect, the "normal" ion of the parent gas consisting of the parent molecule with an attached proton instead of the parent molecule with a detached electron. The size of the charge-exchange cross section should drastically lower the ionic mobility.

The writer is much indebted to Dr. Stevenson for pointing out the experimental evidence he had obtained and for extensive discussions in which the analysis above was formulated.

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[1]A. M. Tyndall, The Mobility of Positive Ions in Gases (Cambridge University Press, New York, 1938), p. 70.

[2]D. J. Rose, J. Appl. Phys. 31, 643 (1960).

[3]L. M. Chanin, Thirteenth Annual Gaseous Electronics Conference, October 12-15, 1960 (unpublished).

[4]N. E. Bradbury, Phys. Rev. 40, 508 (1932).

[5]K. B. Persson, Phys. Rev. 106, 191 (1957).

[6]E. A. Mason and J. T. Vanderslice, Phys. Rev. 114, 497 (1959).

[7]D. P. Stevenson, J. Chem. Phys. 29, 282 (1958).

DISSOCIATION OF H_2^+ AND He^- BY ELECTRIC FIELDS

A. C. Riviere and D. R. Sweetman
United Kingdom Atomic Energy Authority, Aldermaston, Berkshire, England
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Processes leading to the dissociation of molecular ions have assumed some importance recently in connection with injection into thermonuclear devices. In particular, the dissociation of molecular ions by electric fields (or the equivalent $\vec{v}\times\vec{B}$ field), provides an attractive method of injection of high-energy particles which avoids the use of dense low-temperature plasmas or carbon arcs.

Recent theoretical studies by Hiskes et al.[1-3] have shown that the upper vibrational states of molecular ions may dissociate in electric fields of a few hundred kilovolts/cm. In this paper we describe experiments in which this dissociation has been observed and also an experiment in which the He^- ion was dissociated by an electric field.

The experimental arrangement was basically that described by Sweetman[4] for measuring the H_2^+ dissociation cross section in hydrogen. For the present measurements the gas target chamber was replaced by an electrode system so designed that the ion beam would pass through an electric field of known strength. Figure 1 shows the details of the high-field gap and the field distribution as seen by a particle on the axis and on the periphery of the beam. The ions passed through the gap and the high-voltage electrode,

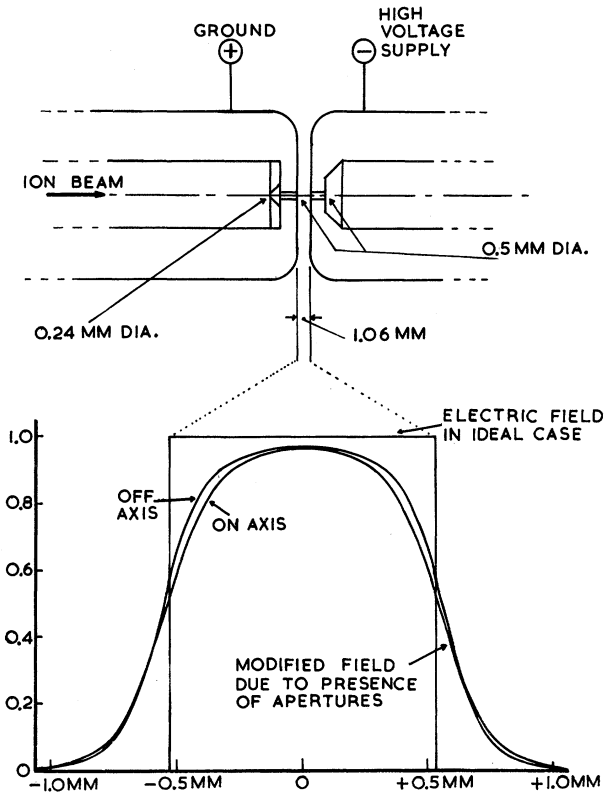

FIG. 1. Details of the high-field gap and electric field distribution.

and then returned to ground potential through a region in which the field was everywhere less than 2% of that in the gap. The ion beam was magnetically analyzed and the individual components were detected by CsI scintillation counters. Coincidences between H^0 and H^+ particles and also between two H^+ particles were recorded so that both modes of dissociation could be studied under low-background conditions.

In the first experiments, H_2^+ ions emerging from an rf ion source were accelerated to 2 Mev in a Van de Graaff electrostatic accelerator before passing into the apparatus. The fraction of the beam dissociated by electric fields up to 5×10^5 volts/cm is shown in Figure 2. The number dissociated increases steadily for fields above 0.70×10^5 volts/cm. The rate of ionizing dissociation (to $H^+ + H^+$) remains constant over this range. This is to be expected since the field strength required to ionize hydrogen atoms is of the order of 10^8 volts/cm,[1] whereas the maximum field strength achieved here was 5×10^5 volts/cm. This result also removes any doubt about possible dissociation due to the deflection of the ion beam on to stops by the applied electric field. No such effect is observed.

In order to increase the population of the uppermost vibrational levels, H_2^+ ions were obtained from H_3^+ ions which had been accelerated to 2.0 Mev and then dissociated by collision with gas molecules. It can be seen that the H_2^+ ions formed by the breakup of H_3^+ ions were dissociated by the field to a much greater extent than those obtained directly from the ion source. This mode of formation evidently results in a considerably greater population of the upper vibrational states.

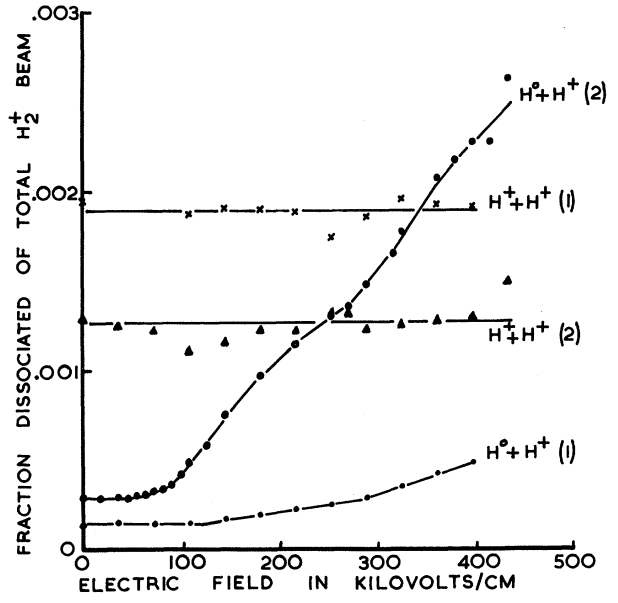

FIG. 2. Dissociation of H_2^+ ions as a function of electric field. Curves (1): H_2^+ ions direct from source. Curves (2): H_2^+ ions obtained from the breakup of H_3^+ ions.

The calculations of Hiskes[1] show that the uppermost vibrational levels ($v = 17$, 18) with zero rotational energy should be completely dissociated by fields of 6×10^5 and 2×10^5 volts/cm, respectively. A steep rise in the fraction dissociated would be expected at 2×10^5 volts/cm followed by a plateau. In fact the dissociation fraction is seen to rise almost linearly from fields of about 0.7×10^5 volts/cm. According to Hiskes,[1] the presence of rotational energy probably has the effect of reducing the field required for dissociation, and this may account for the lack of distinct steps due to the discrete vibrational states.

The dissociation of HD^+, D_2^+ and other molecular ions is of great interest for thermonuclear experiments and will be investigated in future work.

The effect of an electric field was also tried on He^- and H^- ions at energies of 1.0 Mev and 0.33 Mev, respectively. The results are shown in Fig. 3. The He^- ion has an estimated binding energy of 0.075 ev,[5] and was completely dissociated by a field of 4.5×10^5 volts/cm. The H^- ion has a binding energy of 0.75 ev,[6] and no effect was observed up to the maximum field of 5.4×10^5 volts/cm. Holøien and Midtdal[5] have shown that

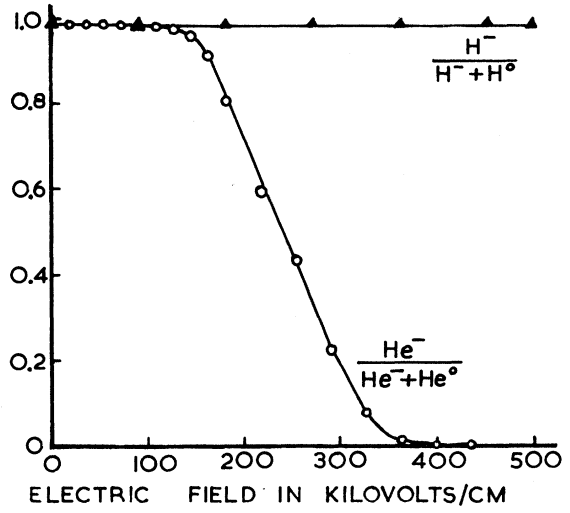

FIG. 3. Dissociation of He^- and H^- as a function of electric field.

the probable configuration of He^- is $(1s\ 2s\ 2p)^4P$, and that autoionization from this state is not allowed. In the absence of an electric field the lifetime of this state is known to be greater than 10^{-5} second.[7] The dissociation of this ion in the electric field may be due to breakdown of the selection rules for autoionization or due to field emission of the electron leaving the He^0 in the $(1s\ 2s)$ metastable state. Further experimental investigations are under way to elucidate this point.

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[1]J. R. Hiskes, University of California Radiation Laboratory Report UCRL-9182, May, 1960 (unpublished).
[2]J. R. Hiskes and J. L. Uretsky, University of California Radiation Laboratory Report UCRL-8255, April, 1958 (unpublished).
[3]J. R. Hiskes, Bull. Am. Phys. Soc. 5, 340 (1960).
[4]D. R. Sweetman, Proc. Roy. Soc. (London) A256, 416 (1960).
[5]E. Holøien and J. Midtdal, Proc. Phys. Soc. (London) A68, 815 (1955).
[6]E. A. Hylleraas and J. Midtal, Phys. Rev. 103, 829 (1956).
[7]D. R. Sweetman, Proc. Phys. Soc. (London) (to be published).

SEARCH FOR A SMALL CHARGE CARRIED BY MOLECULES*

John G. King
Department of Physics and Research Laboratory of Electronics, Massachusetts Institute of Technology, Cambridge, Massachusetts
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The suggestion by Lyttleton and Bondi[1] that hydrogen atoms might carry a charge of approximately 2×10^{-18} of an elementary charge has stimulated a number of investigators to undertake experiments designed to measure this charge. At least two methods have been used: atomic beam deflection experiments,[2,3] and the method of Piccard and Kessler.[4] The results published thus far[2-6] are listed in Table I. In this paper preliminary results of a Piccard-Kessler experiment are reported in which hydrogen molecules (and also helium atoms) exhibit a charge that is approximately 40 times less than that required by the hypothesis of Lyttleton and Bondi.

In our experiment the gas whose charge is to be measured is allowed to escape from an electrically insulated metal container connected to an electrometer. While the gas is escaping, a current that can be measured will flow to the container if the gas is charged. The charge on each atom can then be computed, although it is essential to distinguish charge carried by each of the hypothetically charged atoms from charge carried by ions, electrons, and charged dust particles. By passing the escaping gas through a de-ionizer consisting of a coaxial capacitor charged by a

Table I. Upper limit on the charge carried by various molecules.

Molecule	Charge (elementary charge/molecule)	Experimental method
CO_2	$\leq 2\times10^{-19}$	Piccard-Kessler [a]
CsI	$\leq 4\times10^{-13}$	Molecular beam [b]
A	$< 8\times10^{-20}$	Piccard-Kessler [c]
N_2	$< 12\times10^{-20}$	Piccard-Kessler [c]
CsF	$\leq 2\times10^{-14}$	Molecular beam [d]
KF	$\leq 1\times10^{-13}$	Molecular beam [d]
n	$< 6\times10^{-12}$	Molecular beam [e]

[a]See reference 4.
[b]See reference 2.
[c]See reference 5.
[d]See reference 3.
[e]See reference 6.