Title
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DISSOCIATION OF $\text{H}_2^+$ IONS BY A MAGNETIC FIELD

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The dissociation of molecular ions by an externally applied electric field, 
$E$, or an equivalent electric field, $E' = v \times B$, due to motion through a magnetic 
field has been calculated by Hiskes. Qualitatively, it is predicted that the external 
fields warp the nuclear potential in such a way that the higher vibrational states 
become unstable and dissociation results. This effect has been observed recently 
by Riviere and Sweetman, who dissociated $H_2^+$ and $H_3^+$ ions of approximately 
2 Mev energy with electric fields of up to $5 \times 10^5$ v/cm. The measurements 
presented here demonstrate the break-up of molecular hydrogen ions of 10 Mev 
per nucleon by static magnetic fields.

The experimental arrangement is shown in Fig. 1. Ions produced in a 
PIG discharge were accelerated in the Berkeley heavy-ion linear accelerator 
(Hilac). $H_2^+$ and $H_3^+$ ions were continuously accelerated to full energy, and, 
alternatively, full-energy $H_2^+$ ions were obtained by partially stripping 3-Mev 
$H_3^+$ ions in a jet of Hg vapor and then accelerating the resulting $H_2^+$ ions to 20 Mev. 
The reason for producing $H_2^+$ by the latter technique is that such ions might be left 
in more highly excited states than those which came directly from the ion source, 
as demonstrated by Riviere and Sweetman. The ions emerged from the Hilac 
accompanied by other particles formed by break-up on the residual gas in the 
vacuum system. The beam was collimated to 3/16 x 3/16 in., and the various 
particles were then separated by bending the useful beam by 15 deg in a dc 
magnetic field. No further collimation was required, thus eliminating background 
from break-up at slit edges.
The dissociation and analysis were obtained in a dc magnet with a 4-in. gap. The gap in the first 1.5 in. of the magnet could be reduced to 1 in., thereby producing a maximum magnet field of about 19 kilogauss. The beam required about $10^{-9}$ second to traverse this region.

The results reported here were obtained by activating 0.010-in.-thick Cu foils, placed in the analyzing magnet perpendicular to the direction of the incident beam. The foil holder was built to serve as a Faraday cup, and was used in the beam-monitoring system. The spatial distribution and the relative intensities of the beam particles (i.e., $H_0^0$, $H_1^+$, $H_2^+$, etc.) were determined by counting the Zn$^{63}$ activity ($T_{1/2} = 38$ min) produced in the foil.

Briefly, the scanning was done as follows: the bombarded Cu foil was wrapped around a rotating wheel whose instantaneous position was synchronized with the voltage of a linear ramp. A NaI crystal viewed the wheel through a slit in a W and Pb shield. Whenever a 0.51-Mev annihilation $\gamma$ ray from Zn$^{63}$ decay was detected in the crystal, a pulse of height equal to the ramp voltage was generated. These pulses were put into a Penco 100-channel pulse-height analyzer, and a presentation of count rate vs position on the foil was obtained.

The dissociation caused by the residual gas in the vacuum system at our base pressure of about $6 \times 10^{-6}$ mm Hg was determined by raising the pressure in several steps by adding $N_2$, measuring the dissociation, and extrapolating to the base pressure.

The $H_2^+$ ions obtained by stripping $H_3^+$ were partially dissociated by the magnetic field, with a rapid rise at about 12 kilogauss. This magnetic field corresponds to approximately $5 \times 10^5$ V/cm (Fig. 2). Our result is consistent with the dissociation of the $v = 17$ vibrational state as calculated by Hiskes for nonrotating molecules. The vertical bands marked $10^{-8}$ sec and $10^{-14}$ sec indicate the calculated
fields necessary for barrier penetration in these times, with the widths of the bands corresponding to the uncertainties. The field in the 15-deg bending magnet was sufficiently high to have already dissociated the \( v = 18 \) vibrational state if it were populated. Conversely, the maximum stripping field was somewhat too low to affect the \( v = 16 \) state.

No indication of magnetic field dissociation was obtained for the directly accelerated \( \text{H}_2^+ \) and \( \text{H}_3^+ \) ions. We have no theoretical information concerning the \( \text{H}_3^+ \) ion. The absence of dissociation of directly accelerated \( \text{H}_2^+ \) ions is assumed to be due to the method of formation and to possible de-excitation in the ion source.

With more suitable choices of the kind of ion, energy, and magnetic field strength, dissociation by a magnetic field might provide a mechanism for trapping ions in a highly evacuated controlled thermonuclear device, and provide a diagnostic tool for the study of molecular ion formation and excitation. We are extending this investigation to other molecular ions and to neutral atoms in similar and higher magnetic fields.

We wish to express our appreciation to Dr. C. M. Van Atta for supporting and encouraging this research, J. Warren Stearns and Henry F. Rugge for helping with the measurements, Dr. Edward L. Hubbard, Duane A. Spence, and other members of the Hilac staff, for their assistance, John R. Meneghetti for much of the mechanical construction, and Dr. John R. Hiskes for many interesting and useful theoretical discussions. One of the authors (S. K.) would like to thank Professor Burton J. Moyer for the support and interest that enabled him to participate in this work.
Notes and References

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Figure Captions

Fig. 1. Experimental arrangement.

Fig. 2. Fraction of the beam dissociated by magnetic fields (present experiment) and electric fields (Riviere and Sweetman). Δ, magnetic, $H_2^+$ from $H_3^+$; о, magnetic, $H_2^+$ direct; Ω, electric, $H_2^+$ from $H_3^+$; o, electric, $H_2^+$ direct. A background-gas break-up corresponding to a fractional dissociation of $(0.26\pm0.04)\times10^{-3}$ has been subtracted from the magnetic dissociation data. The standard deviations shown include counting statistics, an estimated uncertainty of 15% in the extrapolated dissociation by the residual gas in the vacuum system, and an uncertainty of 5% in the calibrations of foil activity vs. ion current.