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INTERFERENCE OF FINE-STRUCTURE LEVELS IN HYDROGEN*

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We have observed interference between hydrogen fine-structure levels for $n = 4$, 5, 6, and 7. The experiment was originally designed by Bickel to determine whether excitation equilibrium occurs when energetic ions pass through carbon foils. H_3^+ particles at 200 keV were sent through two successive foils; each foil was ~10 $\mu g/cm^2$ thick. Photographs were taken of the integrated light and of the individual Balmer lines, H_α through H_ϵ, which the foil-excited hydrogen atoms radiated. We then studied the spectrum from excited particles disturbed by electrostatic and magnetostatic fields. The magnetic field appeared between the foils as well as beyond the second one; the electric field, applied between two parallel metal plates which straddled the beam, did not extend between the foils. Experiments were done with H^+, H_2^+, and H_3 particles, and with single, double, and triple foils.

Figure 1(a) shows the integrated light from a beam which passed through two foils. The effect of the second foil is substantially different from that of the first. Hence, the foils do not produce excitation equilibrium. This negates Kay's assumption[1] that such equilibrium is achieved.

Figure 1(b) shows Balmer lines from a single-foil run. The spectrograph slit was wide open. The lines are slanted because of the Doppler effect.

Figure 1(c) shows the lines which resulted from sending the beam through two foils when an 8-G transverse magnetic field was applied. This field gave a motional transverse electric field of 29 V/cm. Figure 1(d) shows the effect of a transverse electric field of 51 V/cm.

Figures 1(c) and 1(d) show regularly spaced bright spots on the spectral lines. The clear-

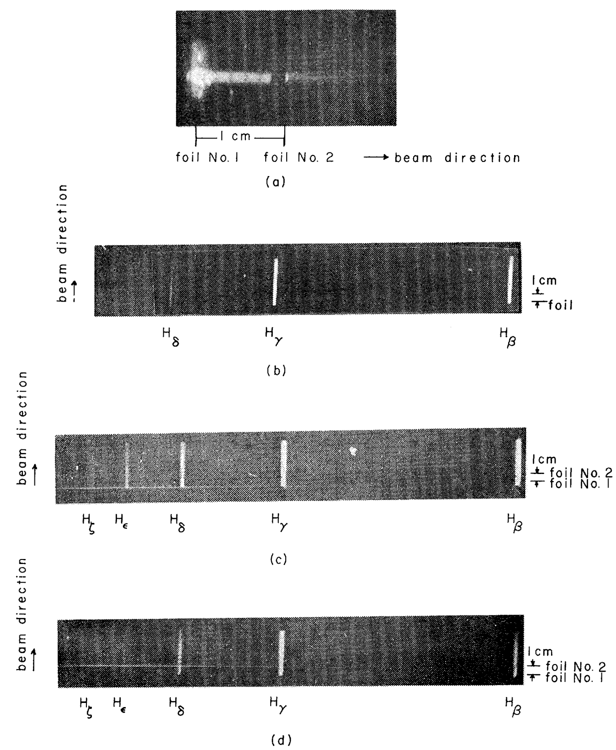

Fig. 1. (a) Photograph of integrated light from 200-keV H_3^+ particles incident on foil no. 1. The particles transmitted through foil no. 1 then pass through a second foil. The bright spot most clearly seen beyond the second foil is believed to be transition radiation. The integrated light exhibits a sharp intensity decrease after the second foil. (b) Resolved Balmer lines. The incident beam of 200-keV H_3^+ particles passed through a single foil. (c) Resolved Balmer lines when two foils were used with the 200-keV H_3^+ incident beam and an 8-G transverse magnetic field was present. Note the spots beyond the second foil. These spots are not present between the foils. (d) As in (c), with the magnetic field replaced by a transverse electric field of 51 V/cm.

est spots are on H_δ and H_ϵ, but they are certainly present on H_β and H_γ. None was seen on H_α. The spot spacing decreases for successively higher Balmer lines and for increasing field intensity. The spots disappeared for electric fields greater than 80 V/cm or less than 10 V/cm.

We interpret the spots as arising from Stark-induced interference of hydrogen fine-structure levels. With the field present, the probability amplitude of a level has admixed into it contributions depending on the initial probability amplitudes of nearby levels of opposite parity. These contributions are such that the probability of a given level includes a term proportional to $\sin^2(2\pi ct\Delta k)$, where Δk is the wave-number difference of the levels's energies. Our experiment converts these temporal variations into spatial variations along the beam. The periodic light intensification arises because the mixing of s or d levels with p levels allows radiative decay to occur with the relatively fast transition rate characteristic of the latter. For example, the decay rates for the s, p, and d levels for $n=6$ are in the ratio 1:13.6:4.5.

We verified this interpretation quantitatively by using Schlapp's[2] and Rojansky's[3] theory of the weak-field Stark effect of the hydrogen fine structure to calculate the level shifts, neglecting the quadratic term. From these level spacings, we found beat frequencies $f=c\Delta k$, which were compared with those determined from the spacing of adjacent spots and the speed of the beam particles. Spot spacings were measured to ±10% on H_δ and H_ϵ, but to ±25% on H_β and H_γ.

Results appear in Table I. Column 1 lists the Balmer lines, column 2 lists the frequencies deduced from the spots produced in the 8-G field, and the remaining columns give the frequencies calculated for particular transitions between levels designated by $L_{j|m|}$ and the $S_{1/2,1/2}$ level. These calculations omitted possible contributions from the mixing of levels other than P and S. In principle, such contributions should be considered, but it appears[4] that the s levels in hydrogen are preferentially populated in the beam-foil collisions.

For H_α, the theoretical frequencies are either too short or too long for us to have seen spots, given the poor intensity response of photographic emulsions. For H_β, the periods due to the $P_{3/2}$-$S_{1/2}$ mixture add light to alternate spots from the $P_{1/2,1/2}$-$S_{1/2,1/2}$ mixing and the detector plates (Eastman 103a-o) could not reveal so detailed an intensity fluctuation. For H_γ, all theoretical periods are close to that observed. For H_δ, the dominant yield seems to come from the $P_{3/2,1/2}$-$S_{1/2,1/2}$ combination. For H_ϵ, the $P_{1/2,1/2}$-$S_{1/2,1/2}$ pair merges in its effect with that of the $P_{3/2,1/2}$-$S_{1/2,1/2}$ pair. It thus appears that interference of closely spaced levels in hydrogen has been identified. The electric-field data also agree with the calculations. He lines showed no spots.

Table I. Comparison of experimental and theoretical beat frequencies. The frequencies are given in units of 10^7 sec^{-1}.

Line	f(exp)	f(calc) $P_{1/2,1/2}$	$P_{3/2,1/2}$	$P_{3/2,3/2}$
H_β	52	48	116	112
H_γ	76	86	88	72
H_δ	84	130	90	63
H_ϵ	96	184	108	70

Several problems remain. The role of the second foil is not understood. Figure 1(c) shows that the spots are not present after one foil. Extensive tests verified this. A third foil, however, gave the same spot pattern as two foils. A second, possibly related, matter is that the spots occurred with incident beams of H_2^+ and H_3^+, but not with H^+. Further work is in progress.

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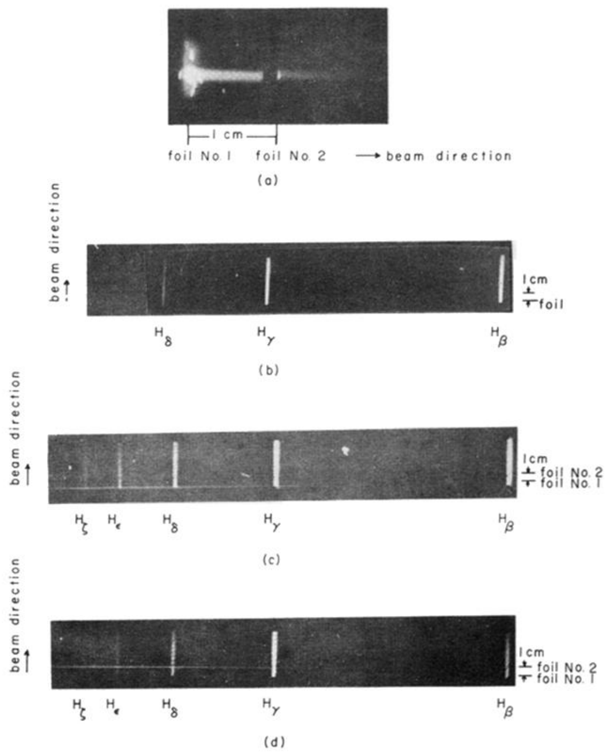

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