ing on the deflection of hydrogen molecules in a very strongly inhomogeneous field. The deflection in their experiments is due to the force exerted directly on the nuclear moment. The moment is evaluated from these deflections after various corrections are made for the moment due to the rotation of the molecule. At present the substantially fair agreement of the two results must be regarded as more important than the difference. There is as yet no sufficient theoretical basis to discuss the far reaching implications of this value of the proton moment. However it can be taken as certain that the proton is not describable by the simple type of Dirac wave equation which describes the electron. An important consequence of these experiments is that we can compare for the first time a measurement made on a nuclear moment directly and one which is fundamentally analogous to the h.f.s. method. The result establishes the h.f.s. method of measuring nuclear moments on firm experimental ground. When both methods are brought to a greater degree of precision we may hope to obtain further tests of the Dirac equation for the electron and perhaps detect other modes of interaction between electron spin and the proton.

The Magnetic Moment of the Deuton[1]

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The magnetic moment of the deuton was measured by the deflection of a beam of neutral deuterium atoms. The magnetic moment of the deuton is found to be 0.75 ± 0.2 nuclear units.

The deuton as the simplest atomic nucleus next to the proton is of particular interest in nuclear investigations. In view of the extreme likelihood that the deuton consists of a proton and a neutron, an evaluation of the magnetic moment of the deuton must yield important information with regard to the magnetic moment of the neutron.

In the experiments to be described the magnetic moment of the deuton was measured by the same method and in the same apparatus which we used for the measurement of the proton moment.[2] A narrow beam of neutral deuterium atoms from a Wood discharge tube is sent through a magnetic field weak enough not to decouple entirely the deuton spin from the electron spin. The field must be sufficiently inhomogeneous to produce easily measurable deflections. As with the H^1 detection was effected on a molybdenum oxide plate. It turned out that the chemical properties of deuterium are not sufficiently different to affect this reaction to any appreciable extent. The traces were measured in the same way as the traces produced by H^1.

The deuton is known to have a spin of 1,[3] consequently there are six magnetic levels corresponding to

$$(m_i,\ m_s)=(1,\ \tfrac{1}{2}),\ (-1,\ -\tfrac{1}{2}),\ (0,\ \tfrac{1}{2}),\ (0,\ -\tfrac{1}{2}),\ (-1,\ \tfrac{1}{2}),\ (1,\ -\tfrac{1}{2}),\quad (1)$$

which have effective magnetic moments of

$$f_1=\pm1,\quad f_2=\pm x+\tfrac{1}{3}/(1+\tfrac{2}{3}x+x^2)^{\frac{1}{2}},\quad f_3=\pm x-\tfrac{1}{3}/(1-\tfrac{2}{3}x+x^2)^{\frac{1}{2}}\quad (2)$$

and x is defined by

$$x=\mu_0 H/hc\Delta\nu.\quad (3)$$

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[1] Estermann and Stern, Phys. Rev. **45**, 761 (1934); Rabi, Kellogg and Zacharias, Phys. Rev. **45**, 769 (1934).

[2] See preceding paper, *The Magnetic Moment of the Proton*, page 157. The deuterium gas as well as a sufficient quantity of heavy water to poison the walls of our discharge tube was generously supplied to us by Professor H. C. Urey.

[3] Murphy and Johnston, Phys. Rev. **45**, 761 (1934).

The quantity $\Delta\nu$ is the energy separation in wave numbers between the state $F=3$ where the electron and deuton spin are parallel and $F=\frac{1}{2}$ where they are opposed. In Fig. 1 is plotted the relation between the values of f and of x. The deuton moment is involved in $\Delta\nu$ through the relation

$$\Delta\nu=\tfrac{3}{4}\cdot(32\pi/3hc)\mu_d\mu_0\psi^2(0), \tag{4}$$

where μ_d is the magnetic moment of the deuton, and $\psi(0)$ the value of the Schrödinger eigenfunction of the normal state at the nucleus, and μ_0 is the Bohr magneton. Expressing μ_d in the customary units of $\mu_0/1838$ we have

$$\mu_d=\Delta\nu/0.0127. \tag{5}$$

The numerical factor in Eq. (5) is different from that for H^1 because of the difference in nuclear spin.

The type of deflection pattern to be expected for deuterium is shown in Fig. 2. The observed traces result from the superposition of 3 patterns, one from each set of moments given in Eq. (2). As with H^1 the images formed on the detector consist of two traces. The moment is evaluated from a measurement of the width and inner separation of these traces. Fig. 3 is a photograph of a typical trace. The theory on which the evaluation of the experimental results is based is the same as with H^1 modified to take account of the fact that there are six magnetic levels of equal *a priori* probability instead of four. The relationship which yields the value of f from which x can be calculated is

$$J(s_1, s_\alpha')+J(s_1, s_\alpha'')+J(s_1, s_\alpha''') = J(s_2, s_\alpha')+J(s_2, s_\alpha'')+J(s_2, s_\alpha'''), \tag{6}$$

where s_α', s_α'' and s_α''' correspond to f_1, f_2 and f_3. By Eq. (2), s_α'' is a function of s_α''' which is therefore determined by Eq. (6).

The conditions for optimum precision are more difficult to attain with H^2 than with H^1 due to the fact that not only is the moment very much smaller, but for a given moment the $\Delta\nu$ is less and the value of x is therefore greater. This necessitates performing the experiment at much lower values of the magnetic field with the consequent small gradients and deflections. Another source of error is due to the fact that however pure the deuterium used may be originally, it is contaminated by H^1 from the electrodes in the discharge tube. It is a matter of common experience that this difficulty is not entirely eliminated even by prolonged flushing of the discharge tube with He and with deuterium. To reduce the effect of protium contamination the discharge tube was run for about an hour and then pumped down to high vacuum. Fresh deuterium was then admitted and the process repeated.

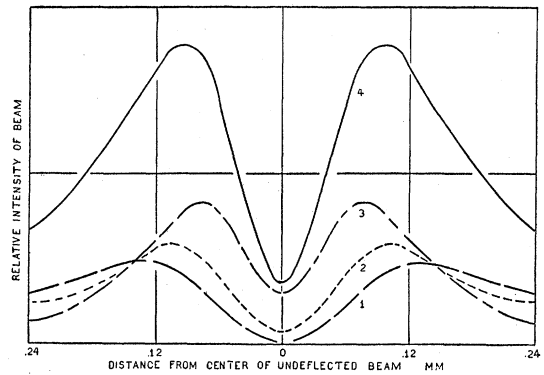

FIG. 2. Deflection pattern with $T=300$, $l_1^2+2l_1l_2=652$, $H=121$, $\partial H/\partial y=984$, and an assumed deuton moment of 1.

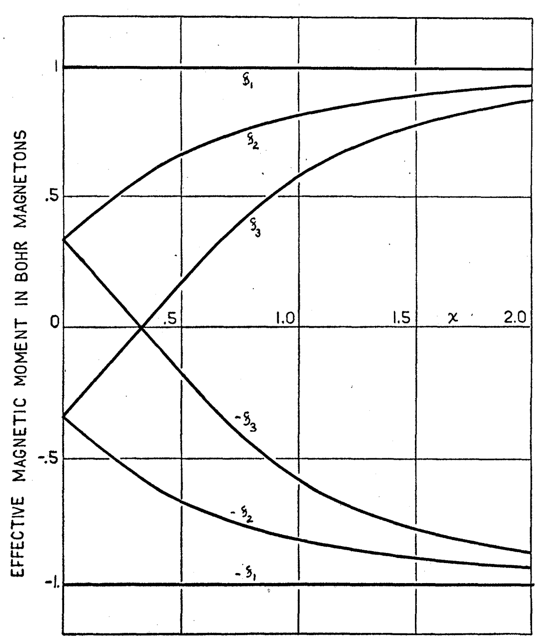

FIG. 1. Variation of the moments of the magnetic levels with magnetic field.

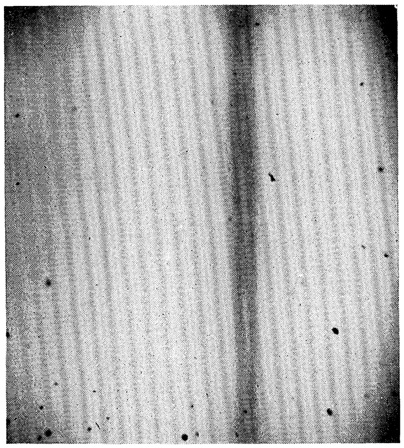

FIG. 3. Photograph of trace. Distance between center of split trace and direct trace is 2.15 mm.

The results of the various runs are given in Table I. The value of the deuton moment is found to be 0.77 ± 0.2. The effect of the protium correction is such that a 5 percent correction results in a moment change of 0.2 of a unit.

TABLE I.

$l_1^2+2l_1l_2=652$ cm^2				$d=0.07$ mm			
H Gauss	$\partial H/\partial y$ Gauss/cm	s_1 mm	s_2 mm	f_3	f_2	μ_d	Estimated H[1] content
98	796	0.03	0.147	0.536	0.802	0.77	5%
121	984	.05	.190	.656	.844	.77	5%
121	984	.045	.190	.683	.855	.73	10%
179	1455	.082	.295	.800	.898	.82	10%

The corrections we have made for H[1] are more likely to be too small than too great.

It should be emphasized that our measurement cannot distinguish the sign of the nuclear moment.[4] It is thus within the realm of possibility that the proton and deuton moments may both or either be negative. On this basis if we assume the deuton to consist of a proton and a neutron which retain their identities in the deuton, and if we further assume no rotational moment, then the magnetic moment of the neutron would be about ± 2.5 or ± 4.0 units.

[4] This is also true in the experiments of Stern, Estermann and Frisch.

The Emission of Ions and Electrons from Heated Sources

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It is found that pin-hole photographs may be made of ions or electrons emitted by a heated source. The crossed paths of the charged particles is explained by the space charges in the immediate neighborhood of the emitting points on the source, which distort the lines of force and allow of accelerations in various directions. Part of the electron emission from an oxide coated filament and the positive ion emission from spodumene is thus found to be concentrated at definite points on the surface.

By means of electric or magnetic fields the electrons emitted by a hot filament may be focused on a photographic plate.[1] These photographs often reveal a difference in the emissions from various parts of the surface. The experiments described in the present paper show that, in addition to the general emission, there are concentrated point sources where the emission is especially intense.

[1] E. Brüche and H. Johannson, Ann. d. Physik **15**, 145 (1932); E. F. Richter, Zeits. f. Physik **86**, 697 (1933); E. Ruska, Zeits. f. Physik **87**, 580 (1934); V. K. Zworykin, J. Frank. Inst. **215**, 535 (1933); C. J. Calbick and C. J. Davisson, Phys. Rev. **45**, 764 (1934).

The source of electrons was a heated Western Electric coated filament F, Fig. 1. The source of positive lithium ions was a strip of platinum on which a small crystal of spodumene had been melted. The source was placed 12 mm in front of the slit S_1, the second slit S_2 was 6 cm from S_1 and the photographic plate P was 22 cm from S_2. Constant accelerating potentials of 10,000 to 20,000 volts were applied between F and the slit system. With $S_1 = 0.5$ mm in width and $S_2 = 0.02$ mm it was noticed with the positive ions that the image on P was not a single line, as was to be expected, but consisted of four lines.

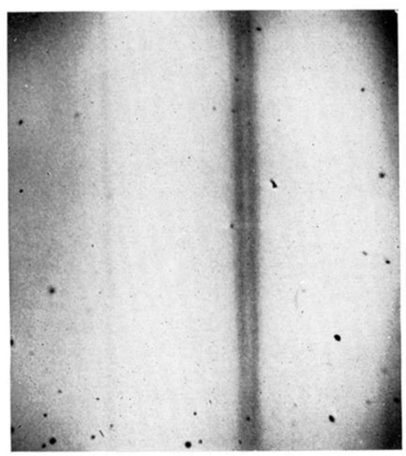

FIG. 3. Photograph of trace. Distance between center of split trace and direct trace is 2.15 mm.