LETTERS TO THE EDITOR

Prompt publication of brief reports of important discoveries in physics may be secured by addressing them to this department. Closing dates for this department are, for the first issue of the month, the twentieth of the preceding month; for the second issue, the fifth of the month. The Board of Editors does not hold itself responsible for the opinions expressed by the correspondents.

The Magnetic Moment of the Proton

O. Stern[1] by his method of molecular rays obtained the surprising result that a proton has a magnetic moment of about $2\frac{1}{2}$ nuclear magnetons with a possible error of 10 percent. It seems now that the same result of an extraordinarily large magnetic moment of the proton can be derived from the magnetic properties of higher nuclei, although instead of Stern's value $2\frac{1}{2}$, the value 2 seems to account best for the observations.

There are four types of nuclei belonging to even and odd charge-number Z and mass number M, namely: (1) Z even, M even; (2) Z even, M odd; (3) Z odd, M even; (4) Z odd, M odd. In type 1 the nucleus consists of α-particles and an even number of neutrons. It is known from experiments that nuclei of this type have no mechanical moment j and no magnetic moment $g\cdot j$. The even arrangements of neutrons and the α-particles seem to form closed shells. They give us no information about the magnetic properties of their elements. Type 4 differs from type 1 only by one additional proton. Hence we suppose that, as a rule, the mechanical and magnetic moment of such a nucleus is due only to the orbit and spin of this one additional proton. Nuclei belonging to type 2 (α-particles and an odd number of neutrons) give us no information about the proton. Type 3 (one additional proton besides α-particles and an odd number of neutrons) does not exist, as a rule, due to an instability that was explained, together with some exceptions of this rule, in a previous paper.[2] So we are left only with type 4 (Z odd and M odd) where the quantum number j (total angular moment) and the magnetic moment $g\cdot j$ is due to the orbit and the spin of one proton only. Since the mechanical spin of the proton is $s=\frac{1}{2}$, its orbital quantum number l is combined with the spin to give one of the two values $j=l\pm\frac{1}{2}$ forming doublet-terms. Their g-values can be calculated according to the general formula of Goudsmit:

$$g=g_l\frac{l(l+1)+j(j+1)-s(s+1)}{2j(j+1)}+g_s\frac{s(s+1)+j(j+1)-l(l+1)}{2j(j+1)},$$

where $s=\frac{1}{2}$, $g_l=1$ and where g_s is the magnetic factor of the proton. According to Stern we should take $g_s\sim 5$. It turns out however that $g_s=4$ agrees better with the observed nuclear data of j and g than any other choice. Table I gives the g-values for various j and l, putting $g_s=4$ according to the above formula. Next we reproduce a table of Goudsmit[3] (Table II) containing the observed values of j and g for various nuclei of type 4. Although the values of j can be said to be observed, the values of g are obtained by rather indirect conclusions and extrapolations. Goudsmit himself classified his results under grades A, B, and C of reliability. Even the accuracy of the g-values graded B may not be considered more than qualitative. The last column gives the theoretical values of g taken from our Table I and selected as close as possible to the observed g. This choice is made in every case between two possibilities only, since j is observed and only l may be either $j+1$ or $j-1$. Thus there is almost no arbitrariness. The case of Ga is omitted from the comparison; apparently it cannot be

TABLE I. $s=\frac{1}{2}$, $g_s=4$.

l	$j=\frac{1}{2}$	$1\frac{1}{2}$	$2\frac{1}{2}$	$3\frac{1}{2}$	$4\frac{1}{2}$
0	4				
1	0	2			
2		2/5	8/5		
3			4/7	10/7	
4				2/3	4/3
5					8/11

TABLE II.

Nuclei	j (obs.)	g (obs.)	g (theor.)
Li^7 (3)	$1\frac{1}{2}$	2.19 (A)	2 ($l=1$)
Al^{27} (13)	$\frac{1}{2}$	4.2 (B)	4 ($l=0$)
$Cu^{63,\,65}$ (29)	$1\frac{1}{2}$	1.7 (B)	2 ($l=1$)
$Ga^{69,\,71}$ (31)	$1\frac{1}{2}$	1.34 (A)	?
		1.70 (A)	
As^{75} (33)	$1\frac{1}{2}$	0.6 (C)	0.4 ($l=2$)
$Rb^{85,\,87}$ (37)	$2\frac{1}{2}$	0.5 (C)	0.57 ($l=3$)
	$1\frac{1}{2}$	1.8 (C)	2.0 ($l=1$)
In^{115} (49)	$4\frac{1}{2}$	1.2 (B)	1.33 ($l=4$)
$Sb^{121,\,123}$ (51)	$2\frac{1}{2}$	1.1 (B)	1.6 ($l=2$)
	$3\frac{1}{2}$	0.6 (B)	0.57 ($l=3$)
$Tl^{203,\,205}$ (81)	$\frac{1}{2}$	3.6 (A)	4 ($l=0$)
Bi^{209} (83)	$4\frac{1}{2}$	0.89 (A)	0.73 ($l=5$)

[1] O. Stern, Helv. Phys. Acta **6**, 426 (1933).
[2] A. Landé, Phys. Rev. **43**, 620 (1933).
[3] S. Goudsmit, Phys. Rev. **43**, 636 (1933).

subordinated to our simple model, since the two isotopes $M=69$ and 71 of Ga with equal j differ only by 2 neutrons. Thus they should not, but do, differ in their values of g. Of course we do not pretend to give here an exact theory of the magnetic properties of nuclei. But we think that at least in first approximation the one proton is responsible for the mechanical and magnetic moment of the whole nucleus of type 4. From this simplified model we infer that *the magnetic moment of a proton is about 2 magnetons* differing from Stern's value by 20 percent. It is quite interesting that the values of the orbital quantum number l assigned to the proton in Table II indicate: *The proton circles around inside or on the surface of the neutron shells only*, and never far outside them. Indeed $l=2$ appears in Table II first with $Z=33$, $l=3$ first with $Z=37$, $l=4$ with $Z=49$, and $l=5$ with $Z=83$, in accordance with a scheme of neutron shells suggested in a previous paper.[2]

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Ohio State University,
November 9, 1933 at Zurich.

The Electronic Atomic Weight and e/m Ratio

The atomic weight of the electron, determined from measurements of the interval between corresponding components of the $H^1\alpha$ and $H^2\alpha$ lines, has been found to be $(5.491\pm0.002)\times10^{-4}$. Combining this value with that of the Faraday a value of $(1.757\pm0.001)\times10^7$ e.m.u/gram has been obtained as the e/m ratio for the electron.

The desired radiation was secured by passing an electrical discharge through a modified Wood's tube immersed in liquid air and filled with water vapor that contained both isotopes of hydrogen in about the same order of abundance. This "heavy" water was generously supplied by Professor G. N. Lewis.

Interference patterns of the "doublets" of both the $H^1\alpha$ and $H^2\alpha$ lines, formed by a prism spectrometer and an etalon, were photographed on very fine-grained plates. With a 3 mm etalon spacing the $H^2\alpha$ fringes were displaced about two and one-half interference orders from the corresponding fringes of $H^1\alpha$. The exact displacement in orders was computed from measurements of the positions of maxima on large-scale microphotometer curves of these fringes. The isotopic interval in cm^{-1} between the low frequency members of the doublets was then determined from the etalon equation, not neglecting the cosine factor, for each of the thus computed displacements (22 in all, taken from three different plates). This yielded an average interval, when reduced to vacuo, of 4.148 ± 0.0015 cm^{-1}. The measurements were confined to this member of the doublet in order to eliminate any possible discrepancy that might result, if the separation of the microphotometer peak from the component chiefly responsible for the peak were not the same for the two isotopes. In the first place analyses had shown that this separation was the smaller for the low frequency peak, being of the order of 0.002 cm^{-1} for both isotopes. Furthermore, neither of the two components which are measurably responsible for the position of this peak involves levels that are likely to be affected by any departure from a coulomb field such as probably exists very close to the H^2 nucleus or deuton. The measured isotopic interval may thus be safely considered equal to that between the components in the two isotopes arising from the transition $3d\ ^2D_{5/2}\rightarrow 2p\ ^2P_{3/2}$.

The ratio of the wave numbers for such a transition for the two isotopes is the same as the ratio of the corresponding Rydberg numbers, since, for the component selected, all quantities involving quantum numbers are the same for both isotopes and accordingly cancel out. This cancellation would occur even if these quantities were in error (evidence for which is accumulating), since any correction would in all probability be the same for both isotopes.

Thus:

$$\frac{\nu(H^1\alpha)}{\nu(H^2\alpha)}=\frac{R_{H^1}}{R_{H^2}}=\frac{M^+{}_{H^1}/(m+M^+{}_{H^1})}{M^+{}_{H^2}/(m+M^+{}_{H^2})},$$

where $M^+{}_{H^1}$, $M^+{}_{H^2}$ and m may be taken to represent the atomic weight of the proton, deuton and electron, respectively.

The atomic weights of H^1 and H^2 reported by Bainbridge[1] were obtained by adding an electronic atomic weight of 0.00055 to his experimentally determined results for ionized atoms. Hence a subtraction of this amount from his published results[2] for neutral atoms yields the values of $M^+{}_{H^1}$ and $M^+{}_{H^2}$. Using these, Houston's[3] value for $\nu(H^1\alpha)$, and the measured isotopic interval, the atomic weight of the electron was found to be $(5.491\pm0.002)\times10^{-4}$. Since the other quantities involved have been measured to a higher percent accuracy than the isotopic interval the uncertainty in this result is due chiefly to the uncertainty in the value of the interval.

Dividing the value of the Faraday, as given by Birge,[4] by this value of the electronic atomic weight, we obtain $(1.757\pm0.001)\times10^7$ e.m.u./gram for the ratio of e/m for the electron. This ratio is in excellent agreement with those obtained by magnetic deflection methods as recently reported by Dunnington[5] and by Kretschmar.[6]

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November 21, 1933.

[1] Bainbridge, Phys. Rev. **41**, 115 (1932).
[2] Bainbridge, Phys. Rev. **43**, 103 (1933); **44**, 57 (1933).
[3] Houston, Phys. Rev. **30**, 608 (1927).
[4] Birge, Phys. Rev. Sup. **1**, 1 (1929).
[5] Dunnington, Phys. Rev. **43**, 404 (1933).
[6] Kretschmar, Phys. Rev. **43**, 417 (1933).