The Magnetic Moment of the Neutron

In spite of our knowledge of electrons, positrons and possibly other light particles one can try to establish a preliminary theory of the nucleus by using heavy particles only. The scheme "nucleus = α-particles + neutrons + one or no proton" first suggested by D. Iwanenko[1] accounts indeed for a number of facts concerning the presence and absence of isotopes and their mass defects.[2] The same scheme gives an independent way for calculating, from the observed magnetic moments of higher nuclei, the magnetic moment of the proton.[3] Although the resulting value of about 2 nuclear magnetons deviates from Stern's value 2.5±10 percent from Rabi's value 3.2±10 percent, this does not necessarily mean a failure of our scheme of the nucleus. For in spite of the excellent experimental observations of hyperfine structure and of molecular ray deflections a number of rather crude theoretical assumptions about the orbits of external electrons are used to infer the values of nuclear magnetic moments from the observations in all three cases. Indeed the accuracy claimed by either one is far beyond the discrepancy of the results. The following method for getting information about the magnetic moment of the neutron from observed values for higher nuclei is likewise dependent on the accuracy of the "observed" g-values of Table I.

TABLE I.

Z	M	j	μ	g	
48	Cd^{111}	1/2	−0.67	−1.33	B
48	Cd^{113}	1/2	−0.67	−1.33	B
80	Hg^{199}	1/2	0.55	+1.10	B
80	Hg^{201}	3/2	−0.62	−0.41	B
82	Pb^{207}	1/2	0.60	+1.20	A

According to our scheme one has four distinct 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. Nuclei of this type, of which the α-particle itself is an outstanding example, prove to have no mechanical moment j and no magnetic moment $\mu = g \cdot j$ at all. The even arrangements of neutrons seem to form closed shells and thus they give us no information about the magnetic properties of their constituents. Type 4 differs from type 1 only by one additional *proton* and was used to determine the above-mentioned value of its magnetic moment. Type 2 differs from the closed shell type 1 only by one additional *neutron*. We suppose then, that this one neutron alone is responsible for the mechanical and the magnetic moment of the whole nucleus. Hyperfine-structure measurements of isotopes of this type have been made in a few instances only. According to Goudsmit's calculations[4] one has the following nuclear data (Table I). The letters A and B mean grades of reliability of these data. Our interpretation starts with the fact, that the orbit of the neutron furnishes no magnetic moment, since the neutron is uncharged. Hence there is no magnetic coupling force between the orbit and the spin of the neutron. Both are completely uncoupled, and the smallest external magnetic field will produce a complete Paschen-Back effect. The spin of the neutron is known to be $\frac{1}{2}$. Hence if l is the quantum number of its orbit, then the total mechanical moment j will be $l+\frac{1}{2}$ or $l-\frac{1}{2}$. If μ_0 is the unknown magnetic moment of the neutron, then there are two cases:

For $j = l+\frac{1}{2}$ one has $g = (0+\mu_0)/(l+\frac{1}{2}) = +\mu_0/j$.

For $j = l-\frac{1}{2}$ one has $g = (0-\mu_0)/(l-\frac{1}{2}) = -\mu_0/j$.

From this g-formula one obtains the following Paschen-Back g-tables carried out for the two cases $\mu_0 = 1$ and $\mu_0 = -0.6$.

TABLE II. $\mu_0 = 1$.

l \ j	1/2	3/2	5/2
0	2		
1	−2	2/3	
2		−2/3	2/5

TABLE III. $\mu_0 = -0.6$.

l \ j	1/2	3/2	5/2
0	−1.2		
1	+1.2	−0.4	
2		+0.4	−0.24

The latter case is taken because $\mu_0 = -0.6$ seems to fit best with the "measured" g-values of Table I. It is quite striking that the three first values of the g-Table III in its upper left hand corner alone check perfectly with the observed data in their j-values and their signs and almost perfectly in their numerical values giving due allowance to Goudsmit's grades of accuracy. Our result is:

In addition to its angular moment of $\frac{1}{2}$, the neutron has a magnetic moment of $\mu_0 = -0.6$ nuclear magnetons approximately. The minus sign means that the neutron is a rotator, in which a negative charge is fixed to a light mass and an equal positive charge is fixed to a heavier mass. This would seem to decide the question whether the neutron is or is not an elementary particle.

In our opinion it is much more reliable to use for the determination of μ_0 elements of type 2 than to use for instance the *deuton*, since the latter belongs to type 3 and represents a much more problematic compound than the isotopes of the other three types. Fortunately this complicated type is stable in only 4 cases that are easily understandable exceptions of a general rule that this type decomposes by β-emission and formation of an α-particle out of 2 neutrons and 2 protons in the remainder of the nucleus.

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[1] D. Iwanenko, Comptes Rendus **195**, 439 (1932).
[2] E. N. Gapon, Zeits. f. Physik **79**, 676 (1932); A. Landé Phys. Rev. **43**, 620 (1933).
[3] A. Landé, Phys. Rev. **44**, 1028 (1933).
[4] S. Goudsmit, Phys. Rev. **43**, 636 (1933).