Letters to the Editor

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The Magnetic Moments of the Neutron and the Deuteron

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ON the basis of the measurement of the quadrupole moment of the deuteron by Rabi and his co-workers,[1] Rarita and Schwinger[2] calculated that the predominantly $^3S_1$ ground state of the deuteron must contain an admixture of 3.9 percent $^3D_1$ state. On the simple assumption that the proton and the neutron retain, when combined in the deuteron, the magnetic moments they possess when free, these authors predicted from the known magnetic moments of the proton and the deuteron that the magnetic moment of the free neutron should be -1.911 nuclear magneton. Because of the contribution of the orbital angular momentum of the ^3D state, this is different from the simple numerical difference between the proton and deuteron moments, which is -1.933 nuclear magneton. The predicted value is not inconsistent with the experimental value for the magnetic moment of the neutron obtained by Alvarez and Bloch,[3] which is -1.935 ± 0.03. It is clear, however, that greater precision in the measurement of the neutron magnetic moment is desirable.

Recently, Purcell, Torrey, and Pound,[4] and Bloch, Hansen, and Packard[5] have described closely-related radiofrequency resonance methods for measuring the gyromagnetic ratios of nuclei in matter in the solid or liquid state. We have now taken advantage of the method of Purcell, Torrey, and Pound, the technique of Bloch *et al*,[6] in polarizing and analyzing neutron beams by passage through ferromagnets, and the availability of an intense source of well-thermalized neutrons in the Argonne heavy water pile, to measure carefully the ratios of the deuteron magnetic moment and the neutron magnetic moment to the magnetic moment of the proton.

In the case of the neutron, the magnetic field was adjusted for proton resonance, using an arbitrary radiofrequency near 30 Mc/sec. Without changing the magnetic field, the water sample used for proton resonances was removed from the r-f coil in the magnetic field, a neutron beam sent through the coil, and the neutron resonance found by varying the radiofrequency applied to the coil. The drop in intensity of the neutron beam at resonance was between five and eight percent. The ratio of the magnetic moments, since the spins of both proton and neutron are one-half, is then the ratio of the two radiofrequencies.

For the deuteron, the magnetic field was adjusted to resonance at a fixed frequency with a heavy water sample. Ordinary water was then substituted and the frequency varied until the proton resonance was found.

The mean of seventeen observations of the neutron-proton ratio gives the value 0.68479. Four observations on the deuteron-proton ratio give the value 0.30702. The internal consistency of these observations alone yields the probable errors 0.0002 and 0.00002, respectively. A search for possible systematic error in the proton resonance was made. The proton resonances in tap water, distilled water, benzene, paraffin, and 1.5 percent $FeCl_3$ solution could not be separated and were all within 0.01 percent in frequency. The magnetic field was homogeneous to better than 0.05 percent, and to a first approximation the inhomogeneity introduces no error in the ratios. Since the possibility of systematic error cannot be excluded, however, we regard the final values as 0.68479 ± 0.0004 for the neutron-proton ratio and 0.30702 ± 0.0001 for the deuteron-proton ratio. Taking the magnetic moment of the proton as *exactly* 2.7896 nuclear magnetons, since the theory depends only upon relative values, we obtain for the neutron, inserting a minus sign, -1.9103 ± 0.0012 nuclear magneton, and for the deuteron 0.85647 ± 0.0003. Rabi and his co-workers[7] give for the deuteron-proton ratio 0.30703 ± 0.0001, and for the absolute value of the magnetic moment of the deuteron 0.8565 ± 0.0004.

Rarita and Schwinger's predicted value for the neutron moment, corrected to use Rabi's latest values, is -1.9108. Conversely, using our measured values for the neutron-proton and deuteron-proton ratios, we find in the ground state of the deuteron an admixture of 4.0 percent $^3D_1$ state, as compared with 3.9 percent deduced from the quadrupole moment.

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The Maximum Inversion Temperatures of Helium, Hydrogen, and Neon

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J. R. ROEBUCK and H. Osterberg in their work on the Joule-Thomson effect of helium[1] estimate the maximum inversion temperature of helium as 23.6°K by using their experimental value for air and assuming that the