yield from about 20 g/cm^2 of toluene is 0.0030 ± 0.0005 antineutrons per antiproton with the lead glass, and 0.0028 ± 0.0005 with the liquid scintillator. With the assumption that the interaction cross section for antineutrons is the same as for antiprotons, the inefficiency of the detector due to attenuation in S_1, S_2, and the lead converter, and to transmission of the detector can be calculated, and is found to be about 50%. From the observed antineutron yield the mean free path for charge exchange of the type detected is about 2300 g/cm^2 of toluene (C_7H_8); or, in other words, the exchange cross section is about 2% of the annihilation cross section for this material. This corresponds to a cross section of approximately 8 millibarns in carbon for this process.

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Magnetic Moment of the Proton in Bohr Magnetons*

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THIS note is a brief report on a recent measurement of the magnetic moment of the proton in units of the Bohr magneton. The nuclear magnetic resonance frequency, $\omega_p = 2\mu_{p(\text{oil})}H/\hbar$, of protons in mineral oil and the cyclotron frequency, $\omega_e = eH/mc$, of free low-energy electrons are measured in the same magnetic field H. The ratio of these two frequencies yields the proton moment in Bohr magnetons, $\omega_p/\omega_e = \mu_{p(\text{oil})}/\mu_0$, uncorrected for environmental shifts due to the mineral oil.

In the previously reported measurements of the proton moment by the electron-cyclotron method,[1,2] one of the important limitations on accuracy was imposed by shifts in the electron-cyclotron frequency arising from the presence of nonvanishing radial electrostatic fields. These fields can be produced by space charge, externally applied trapping voltages, or stray charges accumulating on the boundaries of the system in which the resonance is studied. The present experiment is specifically designed to correct for these shifts in a fashion that does not require a quantitative knowledge of the electrostatic field distribution.

We make three assumptions which are subjected to experimental verification: (1) The electron orbit radii are small compared to distances in which the electrostatic field varies appreciably. (2) The frequency shift caused by the electrostatic field is small. (3) The electrostatic field is independent of magnetic field in a chosen range of magnetic field variation.

When assumptions (1) and (2) obtain, it follows that the fractional shift of the observed cyclotron frequency ω_e', relative to the unshifted frequency ω_e, is, in Gaussian units,

$$\frac{\omega_e' - \omega_e}{\omega_e} = \frac{c\bar{E}_r}{v_\perp H} = \left[4\pi\rho - \left(\frac{\partial E_z}{\partial z}\right)_0\right]\frac{mc^2}{2eH^2}, \tag{1}$$

wherein $\bar{E}_r = (1/2\pi)\int_0^{2\pi} E_r d\theta$ represents the average radial electric field at the orbit, $v_\perp$ the magnitude of the component of the electron velocity perpendicular to the direction of the magnetic field, and ρ the space charge density. The electric field derivative is evaluated at the orbit center and the direction of H is chosen parallel to the z-axis. We take $e > 0$.

The experimentally observed quantity ω_e'/ω_p can be related to $\mu_0/\mu_{p(\text{oil})}$ by the expression

$$\frac{\omega_e'}{\omega_p} = \frac{\mu_0}{\mu_{p(\text{oil})}}\left\{1 + \left[4\pi\rho - \left(\frac{\partial E_z}{\partial z}\right)_0\right]\frac{mc^2}{2eH^2}\right\}. \tag{2}$$

The absence of any orbit or velocity parameters in (2) suggests the measurement of ω_e'/ω_p as a function of magnetic field. If assumption (3) is satisfied in the range of variation of H, one should observe a linear dependence of ω_e'/ω_p with respect to $1/H^2$. A linear extrapolation to $(1/H^2) = 0$ determines $\mu_0/\mu_{p(\text{oil})}$.

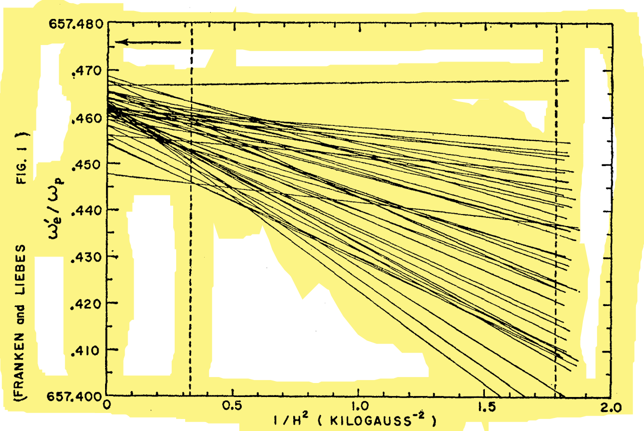

FIG. 1. ω_e'/ω_p, for a spherical sample of mineral oil, is plotted *versus* $1/H^2$ for each run. The straight lines represent least-squares fits to the data of each run. The vertical dashed lines indicate the interval of magnetic field variation in which the data were taken. The heavy horizontal arrow at 657.476 indicates the terminal value of ω_e'/ω_p for zero-energy electrons that should have been obtained in order to yield the theoretical value for the magnetic moment of the free electron.

We have studied ω_e'/ω_p as a function of $1/H^2$ for magnetic fields ranging from 750 to 1700 gauss. For each run, from three to thirteen points were taken in this interval. Deviations from a least-squares straight line fit to the data of each run were less than three parts per million for over half of all points taken. These deviations were primarily due to random errors in tuning the electron microwave cavity at the individual points. We have found, by analysis of all data without rejection, that any systematic deviations from a straight line are less than one part in one million.

The free electrons were produced by photoelectric emission from a film of a few molecular layers of potassium deposited upon the inner surface of a highly evacuated spherical bulb of Pyrex $\sim\frac{1}{2}$ cm in diameter. The resonance was observed by the use of typical microwave techniques. The electron line widths in these measurements varied from one part in 2000 to one part in 35 000. The electrostatic fields, and hence the frequency shifts and line widths, were a function of the intensity and distribution of the light over the surface of the bulb; the lighting conditions were varied from run to run.

Figure 1 summarizes all the data taken. Several different electron bulbs, light sources, and cavities were used. The lines represent least-squares fits to the data of each run.

The average of extrapolated intercepts for all these runs, without rejection of any data, is $\omega_e/\omega_p=657.462\pm0.006$. The limit of error includes 95% of the runs, and is believed to represent a maximum error.[3]

A relativistic correction necessitated by the finite velocities of the electrons is taken to be 0.001 ± 0.001, where the error is again to be regarded as a maximum. Addition of this correction yields

$$\mu_0/\mu_{p(\mathrm{oil})}=657.463\pm0.007 \qquad (3)$$

for a spherical sample of mineral oil, where no magnetic corrections have been applied. This result is to be compared with that of Gardner and Purcell:[1]

$$\mu_0/\mu_{p(\mathrm{oil})}=657.475\pm0.008. \qquad (4)$$

Applying a diamagnetic correction factor[4–6] of $(2.94\pm0.10)\times10^{-5}$ to the field at the proton, we obtain for the final corrected value of the magnetic moment of the free proton in units of the Bohr magneton:

$$\begin{aligned}\mu_p/\mu_0&=(657.444\pm0.007)^{-1}\\&=(1.521042\pm0.000016)\times10^{-3}.\end{aligned} \qquad (5)$$

The present result (3), uncorrected for the spherical sample of mineral oil, when combined with the data[7–9] available for the magnetic moment of the free electron,

$$\mu_e/\mu_{p(\mathrm{oil})}=658.2293\pm0.0010, \qquad (6)$$

also referred to a spherical sample of mineral oil, yields for the magnetic moment of the free electron in Bohr magnetons:

$$\begin{aligned}\mu_e/\mu_0&=1.001165\pm0.000011\\&=1+(\alpha/2\pi)+(0.7\pm2.0)(\alpha^2/\pi^2).\end{aligned} \qquad (7)$$

This is to be compared with the current theoretical estimate[10,11]:

$$\begin{aligned}\mu_e/\mu_0&=1.0011454\\&=1+(\alpha/2\pi)-2.973(\alpha^2/\pi^2).\end{aligned} \qquad (8)$$

A detailed report on this experiment is in preparation.

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Angular Distribution of Nuclear Reaction Products

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In an earlier paper,[1] the author applied the continuum theory of nuclear reactions[2,3] to predict the angular distribution of γ rays following inelastic neutron scattering. Unfortunately the formulas presented there contain an error and a numerical misprint. We wish now to give the corrected formulas, and to generalize them within the S-matrix formalism to include interference between two or more compound nucleus levels. Applications of the incorrect formula to two recent experiments have been published[4,5]; we find that correction of the errors leads to considerably better agreement between experiment and theory.

Let a target nucleus of spin J_0 capture particles with total angular momentum j_1 to form a compound nucleus with spin J_1. This re-emits particles with total angular momentum j_2, leaving an excited nucleus with spin J_2. Consider now the angular distribution (relative to the incident beam) of radiation with total angular momentum j_3, from the decay of J_2 to the final nucleus J_3. We denote the corresponding orbital angular momentum for the particles by l. When the "particles" are photons, j is the multipole order, and $(-)^l$ must be regarded as