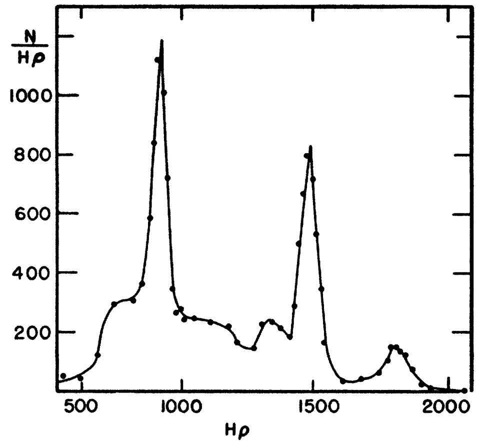

FIG. 1. Cd^{111m} photoelectron spectrum from a 1.1-mg/cm² gold radiator.

As the evidence for spin 13/2 even parity was not conclusive, it was decided to reinvestigate this assignment.

Cd^{111m} decays by the emission of a 149-kev γ-ray followed by a 247-kev γ. The latter is known to be electric quadrupole and 6.0 percent internally converted. The ground state of Cd^{111} is $s_{\frac{1}{2}}$, and this first excited state is $d_{5/2}$. On this basis, spin and parity are assigned to the 396-kev level, row 1, Table I, assuming a multipole order for the 149-kev γ listed in row 2. The possible ratios 149/247-kev γ-rays, row 5, were computed on the basis of the latter being 6 percent internally converted; and the percent the 149-kev γ is converted was computed from the measured K/L ratio, 2.0, and the theoretical K internal conversion coefficients.[4] In a similar manner the possible ratios of 149/247 conversion electrons, row 4, were calculated. It is seen from Table I that the γ-ray ratio is more sensitive to the character of the 149-kev γ than is the ratio of conversion electrons.

This γ-ray ratio was measured by observing the Cd^{111m} photoelectron spectrum from a 1.1 mg/cm² gold radiator, Fig. 1. The measured ratio of 149/247 of photoelectrons was 0.9 ± 0.1. The correction for absorption[5] in an 0.4 mg/cm² Nylon window of the spectrograph increased the ratio to 1.0 and estimating the loss in the gold foil makes the ratio 1.2 ± 0.2. According to the experimental data of Jones[6] a 149-kev γ is 3.67 times more efficient photoelectrically than a 247-kev γ. Hence the γ-ray ratio is 0.33 ±0.06.

This ratio eliminates the possibility that the 396-kev level has spin 13/2 even parity and favors the assignment $h_{11/2}$. The previously measured[1] ratio of conversion electrons, 14.5, is considered to be in error because of the difficulties in making the corrections for scattering and self-absorption in the measurement of such a large ratio.

The $g_{9/2}$ ground state of In^{111} decays by allowed K-capture to the $g_{7/2}$ level of Cd^{111} at 419 kev. The possible ratios (In^{111} transitions to the 396-kev level)/(In^{111} transitions to the 419-kev level), are listed in row 6. The theoretical ratios are those of the Fermi theory f values. The experimental ratio is, within a factor of two, 1×10^{-4}, which was determined by extracting chemically the 48-min Cd from the 2.84-day In. This measurement is consistent with the assignment $h_{11/2}$ to the 396-kev level and is not consistent with the previously assigned spin 13/2 and even parity.

Hence, it is concluded that the 396-kev level of Cd^{111} is $h_{11/2}$. This places the nine levels of the 111-isobars in agreement with the predictions of the shell model.

The usual γ-ray half-life formula assigns a multipole order of four to the 149-kev γ rather than the measured three. This result indicates that such a formula cannot be relied upon to assign a multipole order, despite the apparent correlation with energy and half-life as is shown by the plot of Axel and Dancoff.[3] Sunyar and Goldhaber[7] find that this formula yields spin differences one unit too high for electric 2^3 and 2^4 transitions. The description of the 149-kev γ-ray as electric 2^3 agrees with their conclusion.

I wish to express my appreciation to Professor A. C. Helmholz for his continued guidance.

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The Anomalous Spin Gyromagnetic Ratio of the Electron*

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PRELIMINARY results of a new measurement of the anomalous spin gyromagnetic ratio[1] of the electron will be presented in this letter.

By a measurement of transitions between Zeeman levels of the hfs of atomic hydrogen in a fixed magnetic field, and a measurement of the precession frequency of protons in a water sample placed in the same magnetic field, it has been possible to find an experimental value for $g_J(^2S_{\frac{1}{2}}, H)/g_I$. Here g_J is the Landé g factor of the electron configuration of the $^2S_{\frac{1}{2}}$ state of hydrogen, and g_I that of the proton, except for small corrections due to diamagnetic effects.

Inasmuch as the ground state of hydrogen is pure to considerably better than a part in a million, it is apparent that g_J equals g_S', the spin g value of the bound electron in atomic hydrogen. It can be shown that application of the correction for the relativistic mass change due to binding yields[2] for the g value of a free electron, g_S:

$$g_S = g_S'(1+\alpha^2/3).$$

Essentially, then, what is measured is the ratio of the spin magnetic moment of the electron to that of the proton.

The recent measurement by Gardner and Purcell[3] of the ratio of the cyclotron frequency of the electron and the nuclear resonance frequency of the proton in a magnetic field establishes the ratio of the orbital gyromagnetic ratio, g_L, of the electron, and g_I, the nuclear g value, of the proton, again within the limits of the internal diamagnetic effects of the hydrogen bearing molecule. A combination of the two results yields a value for g_S/g_L, or effectively the spin magnetic moment of the electron in units of the Bohr magneton.

Preliminary results for the value of g_S/g_I have been obtained. They depend essentially on the measurement of the frequency of the transition $(F=1, m=0 \leftrightarrow F=1, m=-1)$ in a field of 1500 gauss, on a prior knowledge[4] of the hyperfine separation, $\Delta\nu(H)$, of hydrogen, and on the measurement of the proton resonance frequency in the same magnetic field. A mechanism is provided in the present experiments for interchanging the positions of the water sample together with the associated rf coil mount and the uhf circuit in which the atomic transitions occur. A crucial point of the experiment is, of course, the accuracy with which the interchange may be made.

A cylindrical water sample is used in the experiment to insure optimum coincidence of water sample and atomic beam. This requires a correction[5] of +1.5 parts in 10^6 to the measured value of g_J/g_I, due simply to the bulk diamagnetism of the water. No such correction is necessary for the spherical sample of mineral oil used by Gardner and Purcell. A correction of -0.4 in 10^6 must be applied because of the presence of a known concentration of paramagnetic ions in the water sample. Finally, to combine our result with that of Gardner and Purcell, the known discrepancy between the resonant frequency of the proton in mineral oil and water requires an additional correction of +2.2 parts in 10^6.

After the application of the total correction of 3.3 parts in

10^6, we obtain

$$g_J(^2S_{\frac{1}{2}}, H)/g_I = 658.2163,$$

where g_I is the proton g value measured in oil. After applying the relativistic correction, $g_S/g_I = 658.2280$. The probable error of this result from statistical sources alone is about 0.0004. The stated result may, however, be subject to systematic errors of unknown magnitude, presumably arising from effects associated with any inhomogeneity of the magnetic field. We believe that an upper limit to the total uncertainty is about ± 0.0030.

Gardner and Purcell give

$$2g_L/g_I = 657.475 \pm 0.008.$$

A combination of the two results yields

$$g_S/g_L = 2(1.001145 \pm 0.000013).$$

Theoretical calculations of this quantity have been carried out to second order by Schwinger,[6] and more recently to fourth order by Karplus and Kroll.[7] The result is

$$g_S/g_L = 2[1 + (\alpha/2\pi) - 2.973\alpha^2/\pi^2] = 2(1.0011454).$$

The rather startling agreement of experiment and theory can only be considered fortuitous at this point, in view of the experimental uncertainties. However, even in their present state the results give very strong evidence of the validity of the higher order quantum electrodynamical calculations. This work is being continued to increase the precision with which g_S/g_I is known.

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The Electron-Neutron Interaction*

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THE existence of a weak attractive interaction between electrons and neutrons has recently been reported by two groups of workers.[1,2] It was immediately recognized that such an interaction is to be expected on the basis of current meson theories of nuclear forces as a consequence of the partial dissociation of a neutron into a proton and virtual negative meson. Explicit calculations[3] have shown that an electron-neutron interaction of the required character and order of magnitude is indeed obtained on the basis of this assumption.

We wish to show first that an electron-neutron interaction of the desired character and magnitude can also be obtained as a direct consequence of attributing to a neutron an anomalous magnetic moment in the manner suggested by Pauli[4] without any further assumptions. The relativistic (one-particle) hamiltonian for such a neutron in an external electromagnetic field is

$$H = \beta M + \boldsymbol{\alpha}\cdot\mathbf{p} - \mu_N(e/2M)[\beta\boldsymbol{\sigma}\cdot\mathbf{H} - i\beta\boldsymbol{\alpha}\cdot\mathbf{E}],$$

where μ_N is the magnetic moment of the neutron measured in nuclear magnetons. On reducing this by a canonical transformation to the corresponding nonrelativistic hamiltonian by the method of Foldy and Wouthuysen[5] one obtains

$$H = \beta M + (\beta p^2/2M) - \mu_N(e/4M^2)\beta\,\mathrm{div}\mathbf{E} + \mu_N(e/4M^2)\beta\boldsymbol{\sigma}\cdot[\mathbf{p}\times\mathbf{E} - \mathbf{E}\times\mathbf{p}],$$

where we have retained terms up to order $(1/M)^2$. For the coulomb field of an electron located at the point $\mathbf{x}_e$, the above hamiltonian becomes

$$H = \beta M + (\beta p^2/2M) + 4\pi\mu_N(e^2\beta/4M^2)\delta(\mathbf{x}-\mathbf{x}_e) + \cdots.$$

The term[6] containing the delta-function $\delta(\mathbf{x}-\mathbf{x}_e)$ is exactly of the form of the electron-neutron interaction. Expressing the interaction in terms of the well-depth V_0 of an equivalent[7] square well of radius e^2/mc^2, one obtains for V_0

$$V_0 = \pi\mu_N(e^2/M^2)[(4\pi/3)(e^2/mc^2)^3]^{-1} = \tfrac{3}{4}\mu_N(\hbar c/e^2)^2(m/M)^2\,mc^2 = 3900 \text{ ev},$$

where we have taken $\mu_N = -1.9$ nuclear magnetons. The above figure is to be compared with the experimental value:[2] $V_0 = 5300 \pm 1000$ ev.

We do not wish to imply that this is the correct explanation of the interaction, but we do wish to point out an important bearing of the above result on meson-theory calculations of the interaction. When one calculates the electromagnetic properties of nucleons according to meson theory by canonical transformations which remove the coupling of the mesons to the nucleon to any given order in the meson coupling constants, one obtains interaction terms representing the anomalous magnetic moment of the nucleon interacting with the magnetic field, together with its relativistic complement expressing the interaction of an electric dipole moment for the nucleon with the electric field, plus an additional term which gives rise to a direct electron-neutron interaction. In the calculations employing this method (Case, and Borowitz and Kohn) only the last term has been compared with the experimental interaction. Actually, the electric dipole moment term gives in second order an additional contribution which is exactly that found above[8] and which must be added to the direct term before the comparison with experiment is made. In the calculations performed by direct computation of neutron scattering by an external coulomb field (Slotnick and Heitler, and Dancoff and Drell) the extra term is automatically included in the computation. We believe that this extra term may account for the discrepancy between the results of Slotnick and Heitler and of Borowitz and Kohn which was noted in a footnote to the paper of the latter authors.

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[8] In this respect we disagree with the remarks of K. M. Case given at the beginning of Sec. VI of his paper referred to in footnote 3 above. A careful investigation is necessary before discarding terms proportional to the Dirac matrix $\boldsymbol{\alpha}$ on the grounds that they are velocity proportional, since they may give rise to velocity independent contributions in higher order.

4.4-Minute Radiations from Zr^{89}

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THE recent findings of Shure and Deutsch[1] regarding 79.3-hour Zr^{89} have been confirmed in this laboratory employing a 180° magnetic spectrometer. The sources were 1-mil foils of zirconium which had been irradiated by means of the probe method[2] in the 22-Mev betatron here. Our results indicate a simple positron spectrum with an allowed shape (at least to 450 kev, where the unfavorable source thickness is apparent), having a Kurie end point at 890 ± 10 kev, and in addition a single K-conversion line at 896 ± 5 kev.[3] The presence of the corresponding gamma-ray was established also by means of a scintillation spectrometer. The ratio of conversion electrons to positrons is 0.023. Deutsch[4] has obtained a conversion coefficient of 8×10^{-3} for this transition and, in addition, has measured the half-life of the ex-