divergent beam of x-rays originated at the specimen as secondary Co or Fe radiation which had been excited by the incident beam. The white arcs are quite prominent, while the dark lines are somewhat difficult to distinguish from the background. Fewer dark lines are expected since all reciprocal lattice points within the volume of reflection diffract corresponding rays from the scattered beam to leave the white lines, whereas only those rays diffracted in the forward direction reach the flat film and are detected as black lines. Black diffraction lines have been observed best where they fall in a region of the film remote from the center where background scattering is slight.

The technique which we used offers the advantage that the line pattern is supplemented by the normal Laue pattern on the same film and that the exposures are made with the sealed-off x-ray tubes which are so widely used today. The obvious disadvantages are the relatively long exposure times (8 to 16 hours) and possibly the limitation of materials which can be investigated directly; however, a technique probably could be developed for the examination of single crystals of other materials in which a piece of iron foil is placed in front of the sample as the source of divergent Fe radiation. Work is in progress to determine the utility of this new kind of x-ray diffraction analysis in the study of the solid-state reactions in the above alloys.

[1] Annual Meeting, American Society for X-Ray and Electron Diffraction, June 23-26, 1947, Ste. Marguerite Sta., P. Q. Philosophical Transactions of the Royal Society of London **240**, 219 (A) (1947).

Does the Electron Have an Intrinsic Magnetic Moment?

G. Breit
Yale University, New Haven, Connecticut
September 29, 1947

The hyperfine structure of the ground term of H^1 and H^2 is greater[1] than expected from nuclear magnetic moments by, respectively, 0.26 and 0.31 percent. The difference between these values is less certain than the approximate value 0.28 percent and will be assumed to be insignificant.[2] If the electron had a small, Pauli-type, intrinsic magnetic moment[3] μ_e the observed and calculated values would differ.

The effect of $\mu_e\rho_3(\mathbf{H\sigma})$ in the Hamiltonian (Dirac's notation) is to change the hfs interval factor to

$$A=\frac{2e\mu_N}{ij(j+1)}\,Im\int_0^\infty\left[-k+\frac{\mu_e p_0}{e\hbar}\right]F^*G dr, \tag{1}$$

where $k=l,\ -l-1$, respectively, for $j=l-\frac{1}{2},\ l+\frac{1}{2}$. The functions F, G are, respectively, $-iF$, G of Roess.[4] Azimuthal, inner, and nuclear-spin quantum numbers are l, j, i. The magnetic field of nucleus at the electron is H, the nuclear magnetic moment is μ_N. The molecular-beam experiment gives $\mu_N/(\mu_0-\mu_e)$, where $\mu_0>0$ is the Bohr magneton. The atomic-beam experiment determines,[5] according to Eq. (1), the quantity $\mu_N(\mu_0+\mu_e/2)$. The theoretical ratio of the hfs to the molecular-beam value of μ_N contains, therefore, $1-\mu_e/2\mu_0$ as a factor. To explain the observed discrepancy one needs $\mu_e/\mu_0=-0.0056$, a small value which could have escaped detection. According to Eq. (1) the interval factors of s, $p_{1/2}$, $p_{3/2}$ terms contain μ_e in the factors $1+\mu_e/2\mu_0$, $1-\mu_e/2\mu_0$, $1+\mu_e/4\mu_0$ apart from factor $1-\mu_e/\mu_0$ which is needed in (1) if the apparent μ_N is substituted for the true value. In principle, ratios of interval factors for these terms could determine μ_e/μ_0.

One expects the following additional effects of μ_e: (a) A modification of the Landé g factor through factor $1-2\mu_e/\mu_0$ in $g-1$. (b) The term $(-\mu_e)\rho_2(\mathbf{E\sigma})$ caused by nuclear electric field contributes to the energy

$$\Delta E=-2\mu_e Im\int_0^\infty F^*G dr\cong\frac{2\mu_e(1+k)Z^4Rch\alpha^2}{\mu_0(l+1)l(2l+1)n^3}, \tag{2}$$

where n is the principal quantum number of a hydrogenic term, R is the Rydberg, and α is the fine structure constant. For $n=2$, $Z=1$ Eq. (2) gives

$$\Delta E=(-4,\ 4/3)(\mu_e/\mu_0)(Rch\alpha^2/16)$$

for $2s$, $2p_{1/2}$, respectively. The displacement of $2s$ with respect to $2p_{1/2}$ of hydrogen is $(-16/3)(\mu_e/\mu_0)(Rch\alpha^2/16)$, which is about 1/33 of the $2p_{3/2}$, $2s$ doublet separation for $\mu_e/\mu_0=-0.0056$. The Lamb-Retherford $-2s+2p_{1/2}$ separation is roughly 3 times the above value. It is doubtful that Bethe's[6] electrodynamic shift theory of the Lamb-Retherford effect[7] is as yet quantitative enough to exclude the possibility of about $\frac{1}{3}$ of the effect arising from another cause.

The presence of the Coulomb energy in p_0 in Eq. (1) makes the integral diverge for s terms. The integral converges, however, if the Coulomb energy is made finite at small distances. A cut-off of the integral at $r\sim e^2/mc^2$ makes the contribution of the Coulomb energy to the integral of the negligible order $\alpha^2\log\alpha^{-2}$ of the term containing p_0. The quantity p_0 has accordingly been replaced by mc in the estimates.

It is not claimed that the electron has an intrinsic magnetic moment. Aesthetic objections could be raised against such a view. The only object of this note is to point out that the evidence considered above does not disprove a small μ_e of the order $\alpha\mu_0$.

If the discrepancy is due to an interaction between the electron and the nucleus of a local type, it is hard to see why it should have the same fractional value for the proton and the deuteron. In this case the effect would be practically confined to s terms, and one could, in principle, distinguish between it and the hypothesis of the intrinsic magnetic moment by comparing hfs interval factors for different spectroscopic terms.

[1] J. E. Nafe, E. B. Nelson, and I. I. Rabi, Phys. Rev. **71**, 914 (1947).

[2] Verbal communication from Professor I. I. Rabi. The writer is very grateful to Professors Rabi and Ramsey for this and other discussions of the subject.

[3] W. Pauli, *Handbuch der Physik* (Verlag Julius Springer, Berlin, 1933), Vol. 24/1, p. 211.

[4] C. G. Darwin, Proc. Roy. Soc. **A118**, 654 (1928); L. C. Roess, Phys. Rev. **37**, 532 (1931).

[5] G. Breit and F. W. Doermann, Phys. Rev. **36**, 1732 (1930), see p. 1737.

[6] H. A. Bethe, Phys. Rev. **72**, 339 (1947).

[7] Willis E. Lamb and Robert C. Retherford, Phys. Rev. **72**, 241 (1947).