the top of the pulse and Hahn in the interim thereafter. Both these authors showed that one can obtain the relaxation times from measurements on the transient signal shape and Hahn showed the experimental values to be compatible with and extending the range of measurement of the earlier sinusoidal technique.

Recently, Uehling and Bradford[5] have developed a technique using periodically repeated pulses for the determination of the relaxation times of a system. Here, the pulse width τ' is taken to be much less than the relaxation times, so that a rather violent test of the validity of the Bloch formulation is to be expected. In our laboratory, utilizing this technique, we have observed four distinct transient effects: (1) an exponential decay of the form $e^{-\tau/T_2}(A\cos\Delta t+B\sin\Delta t)$, (2) the decay in (1) modified by magnetic field inhomogeneities,[6] (3) the existence of a mirror signal[5] and (4) the existence of signals on each side of the resonance signal (side bands). The first effect would be expected of almost any transient decay, and thus does not constitute as strong a test of the theory as do (2), (3), and (4). The second effect was initially observed in our laboratory,[6] while the third was first described by Bradford[5] and Uehling[7] using the Bloch formulation.

The fourth effect, that of the existence of side bands, was observed recently in our laboratory. In order to describe these side bands, we have carried out the solution of the Bloch equations of motion without making severe limitations on the size of the off-resonance frequency $\Delta\equiv\gamma H_0-\omega$. Neglecting the effect of magnet inhomogeneities which were made purposely small, we have arrived at the following expression for the y-component of the magnetization in the rotating system:

$$V(t,\Delta)=C(1-e^{-\tau/T_1})e^{-t/T_2}(\gamma H_1/\beta)[\{\sin\beta\tau'(1-e^{-\tau/T_2}\cos\Delta\tau)+(\Delta/\beta)(1-\cos\beta\tau')e^{-\tau/T_2}\sin\Delta\tau\}\cos\Delta t-\{\sin\beta\tau'e^{-\tau/T_2}\sin\Delta\tau+(\Delta/\beta)(1-\cos\beta\tau')(1+e^{-\tau/T_2})\}\sin\Delta t], \quad (1)$$

where τ' and τ are the pulse width and repetition period, respectively, $\beta^2\equiv(\gamma H_1)^2+\Delta^2$, and C is a constant very weakly dependent upon Δ and the relaxation times. Our experimental conditions will be such that $T_2\ll\tau$; therefore, the time-free dependence of v on Δ is given by

$$V(\Delta)\sim(\gamma H_1/\beta)[\sin^2\beta\tau'+(\Delta/\beta)^2(1-\cos\beta\tau')^2]^{\frac{1}{2}}, \quad (2)$$

or, rewriting,

$$V(\Delta)\sim\gamma H_1\tau'(\sin x/x)[1-(\tfrac{1}{2}\gamma H_1\tau')^2(\sin x/x)^2]^{\frac{1}{2}}\sim\sin x/x, \quad (3a)$$

where

$$x\equiv\tfrac{1}{2}\beta\tau'=\tfrac{1}{2}\tau'[(\gamma H_1)^2+\Delta^2]^{\frac{1}{2}}. \quad (3b)$$

Thus, the extrema of the side bands correspond to those of

$$\sin x/x \quad (4a)$$

and the nulls occur for $\sin x=0$ or for

$$x\equiv\tfrac{1}{2}\beta\tau'=n\pi, \quad n>0. \quad (4b)$$

Equation (3) may be written in the form

$$V(\Delta)\sim[1+(\Delta/\gamma H_1)^2]^{-\frac{1}{2}}\sin\{\tfrac{1}{2}\gamma H_1\tau'[1+(\Delta/\gamma H_1)^2]^{\frac{1}{2}}\}. \quad (5)$$

The factor $[1+(\Delta/\gamma H_1)^2]^{-\frac{1}{2}}$ is just the $\sin(\arctan\Delta/\gamma H_1)$ which one finds in Eq. (20) of the original Bloch paper.[1] There the signal amplitude is calculated under the assumption that $T_1=T_2=\infty$, (i.e., that H_1 is large enough so that lattice fields may be ignored). The side bands we have observed demonstrate this same independence of "line width" upon the time constants when H_1 is sufficiently large. The sinusoidal factor in Eq. (5) provides a structure to the simple resonance curve. It is this structure which we have designated as the side bands.

Within the limitations in accuracy imposed by those commercially calibrated components in our equipment, we have been able to obtain experimental confirmation of Eq. (4). For example, 0.03 molar $MnSO_4$ yielded an average of 6.8 kc between nulls ($\tau'=140$ μsec, $\tau=0.01$ sec, $\sin\gamma H_1\tau'\sim1$, and the magnet field control calibrated as in Thomas, Driscoll, and Hipple[8]). Calculations using Eq. (4b) resulted in nulls spaced at 7.1 kc intervals; thus we have agreement in this case well within 5 percent.

Although Torrey[3] has stated that he felt the Bloch macroscopic theory to be only semiquantitative, transient solutions of the Bloch equations have described the signals observed by other investigators as well as ourselves. In particular, our investigations of the mirror signal, effect of magnetic field inhomogeneity, and side bands have shown these effects can be described by appropriate solutions of the Bloch equations. These results should add support to use of the Bloch formulation in describing transient nuclear resonance phenomena.

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Erratum: High Altitude Measurements of the Penetrating Component Intensity of Cosmic Radiation near the Geomagnetic Equator

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THE ordinate of Fig. 1 should be labeled "Quadruple coincidences per minute."

The Specific Fluorescence of Anthracene and Other Organic Materials

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THE scintillation response S of anthracene to an ionizing particle of energy E, range r, depends on the nature of the particle, and it is not in general proportional to E. The author previously[1] showed that this behavior was due to the nonlinear variation of the specific fluorescence dS/dr (expressed in arbitrary units per cm air equivalent) with the specific energy loss dE/dr. It was also suggested that dS/dr depended only on dE/dr, and was otherwise independent of the nature of the particle. From the limited measurements then available, for α-particles[1] of $E\leq5.3$ Mev and electrons[2] of $E\leq1$ Mev, a graph was drawn of the variation of dS/dr with dE/dr, predicting the behavior for particles of intermediate dE/dr.

Further experimental data are now available for α-particles[3] of $E\leq21$ Mev, deuterons[3] of $E\leq11$ Mev, protons[3-5] of $E\leq17$ Mev, and for electrons[6,7] of E from 1 kev to 3 Mev. Jentschke *et al.*[6] have correlated these observations, and they have plotted the (dS/dr, dE/dr) curve. It is found that, with the exception of their own measurements on electrons of $E<10$ kev, the results for each of the different particles lie on a single smooth curve, similar to that predicted by the author.[1]

The variation of dS/dr with dE/dr may be explained, using the exciton theory. On this theory, the electronic energy excited by the ionizing particle is transferred from molecule to molecule within the crystal, until it is captured by a single molecule, which then either fluoresces or quenches the exciton, depending on the nature of the molecule. The theory has been successfully applied to mixed naphthalene-anthracene crystals,[8] where both molecular components fluoresce, and also to the deterioration of the fluorescent efficiency of anthracene under prolonged α-particle irradiation,[9] where the molecules damaged by the preceding irradiation