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

[Phys. Rev. **83**, 173 (1951)]

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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

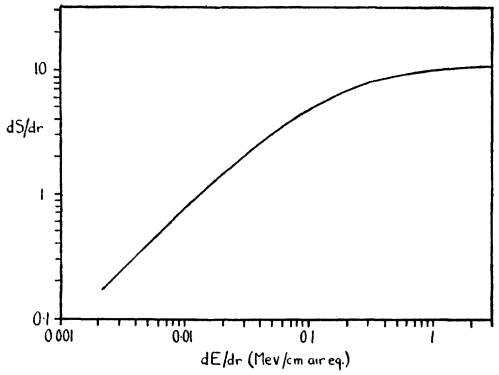

FIG. 1. Specific fluorescence *vs* specific energy loss for anthracene.

act as quenching agents. A similar effect may be assumed to occur with individual ionizing particles. The passage of the particle through the crystal produces a local concentration of damaged molecules along its path, which act as quenching agents for the excitons produced by it. If the number of excitons produced per unit path length is $A\ dE/dr$, the local concentration of damaged molecules is $B\ dE/dr$ molecules per undamaged molecule, and the exciton capture probability of a damaged molecule relative to an undamaged molecule is k, then the specific fluorescence

$$dS/dr=(A\ dE/dr)/(1+kB\ dE/dr). \quad (1)$$

The values for anthracene of $A=82.5$, $kB=7.15$ have been calculated from the observations[1] on α-particles and electrons. The variation of dS/dr with dE/dr from (1), plotted in Fig. 1, is in excellent agreement with the experimental curve of Jentschke *et al.*[6] Their anomalous results for electrons of $E<10$ kev must be due to errors in either the observational or range-energy data, or to some other effect.

The relative scintillation response of anthracene to an ionizing particle of any energy can be computed from (1) and the range-energy relation for the particle. $(dS/dr, r)$ curves have been plotted for different particles, and the variation of S with r (and hence with E) obtained by integration. The response curves calculated in this manner are plotted in Fig. 2, and they are in excellent agreement with those obtained experimentally.

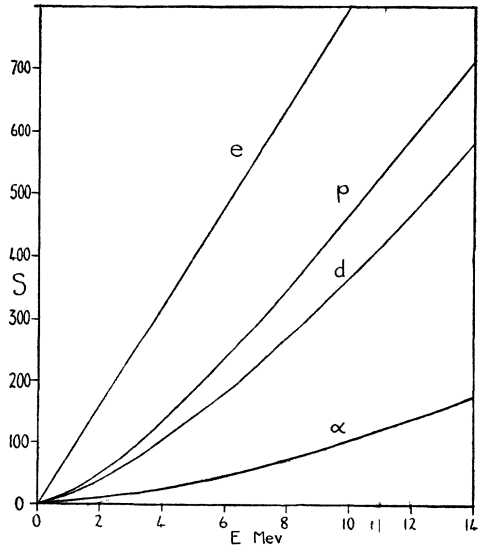

FIG. 2. Calculated scintillation response of anthracene to electrons, protons, deuterons, and α-particles.

Measurements of the relative response of other organic crystals, naphthalene,[1] stilbene,[3] terphenyl,[10] etc., and of organic solutions,[11] to different particles show that their behavior is similar to that of anthracene. Complete response curves for these materials, similar to Fig. 2, can therefore be obtained by the experimental determination of A and kB, and the subsequent computation described above for anthracene. It is also probable that the nonlinear response of inorganic crystals, like sodium iodide,[3] to heavy particles is due to a similar quenching effect, which is less marked because of the reduced radiation damage. A fuller account of this work is being published.[12]

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Some New Isotopes of Antimony and Tin*

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IN the course of an investigation of Sn and Sb isotopes occurring in U^{235} fission, several new activities have been found.

A 1.5-hr Sn activity has been identified as Sn^{127}, the parent of known 93-hr Sb^{127}. Sb milked from fission product Sn was shown to be Sb^{127} by its decay and absorption curves and by the half-life of its daughter, 9.3-hr Te^{127}. From the amount of Sb activity obtained from the Sn as a function of time, the half-life of Sn^{127} was calculated; three experiments gave 83 min, 86 min, and 94 min, respectively.

A 9-hr Sb was discovered by $\beta-\gamma$ and $\gamma-\gamma$ coincidence counting of fission product Sb. Subsequently, the same activity was observed in the decay of Sb grown from fission product Sn. Timed separations of Sb from fission product Sn gave, in two experiments, 49 min and 52 min for the half-life of the Sn parent of the 9-hr Sb activity. Observation of the 9-hr Sb is difficult in decay curves of Sb obtained from thermal fission because the 9-hr Sb is partially masked by 4.2-hr Sb^{129}. However, the ratio of 9-hr Sb to 4.2-hr Sb^{129} is much greater when fission is caused by 14-Mev neutrons. This fact suggested a means of determining the mass assignment for the 9-hr Sb and its 50-min Sn parent. It has been established that fission of U^{235} becomes more symmetrical as the energy of the neutron causing fission is increased.[1] Fission products in the valley of the familiar yield-*vs*-mass number curve are affected most; the change in fission yield with neutron energy becomes smaller as one climbs from the valley to the peaks. A convenient way to measure the change in yield for a fission product, X, is to compare the ratio of X activity to Mo^{99} activity as observed in fast fission to the same activity ratio as observed in thermal fission. Thus, the Cd^{115}/Mo^{99} activity ratio increases by a factor 101 in going from thermal fission to fission with 14-Mev neutrons. Similarly the increases in the Sn^{121}/Mo^{99}, Sn^{125}/Mo^{99}, Sb^{127}/Mo^{99}, and I^{131}/Mo^{99} activity ratios are 100, 75, 20.5, and 1.65, respectively.[2] The increase in the 9-hr Sb/Mo^{99} activity ratio in going from thermal to 14-Mev fission was 38. Since this increase lies between that observed for Sn^{125} and that observed for Sb^{127}, we conclude that the 9-hr Sb should be assigned to mass 126.

Coincidence counting experiments have shown that 9-hr Sb^{126} has at least one beta- and two gamma-rays all in coincidence (the resolving time of the coincidence counter used in this work was