made possible by the fact that in the Dirac representation K, and not l, is the good quantum number, and K here changes by one while l changes by two. Thus the shape of the l-forbidden spectra is allowed while the ft value is high (see P^{32}). The transitions which the shell model predicts as l-forbidden appear to be really mixtures of the l-forbidden and the competing allowed configurations from the same shell.

4. The $|M|^2ft$ values obtained for forbidden decays in the axial vector and tensor interactions are throughout consistent with allowed values; the other three interactions sometimes agree, but usually give much too low values. Precise angular correlation work can discriminate between the tensor and axial vector interactions. The only sufficiently clear result published to date (electron-neutrino angular correlation of P^{32} by Sherwin)[4] is consistent with tensor and not with axial vector.

The guidance and assistance of Professor E. Greuling in the research reported here is gratefully acknowledged.

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Erratum: The Theory of Pressure Broadening and Its Application to Microwave Spectra

[Phys. Rev. **83**, 94 (1951)]

MASATAKA MIZUSHIMA
Physics Department, Faculty of Science, Tokyo University, Tokyo, Japan

THERE is an error on page 102 of this paper. The left half of this page should read as follows.

We obtain an approximate eigenvalue of the matrix (66) by solving the problem with a finite matrix, neglecting the lower right-hand part of (66). Obtaining approximate solutions in this way for matrices of rank 3, 5, 7, and 9, we obtain a final approximate solution (69) by extrapolation. The second and higher eigenvalues cannot be obtained at the same time because of convergence difficulties. However, if we neglect the first row and column of (66) and repeat the same procedure as above, we obtain the second solution. Successively following the same procedure, we obtain the approximate eigenvalues (70).

Thermal Destruction of V_1 Centers in Potassium Chloride*

DAVID DUTTON, WILLIAM HELLER, AND ROBERT MAURER
Physics Department, University of Illinois, Urbana, Illinois
(Received August 29, 1951)

SEITZ[1] has suggested that the V_1 absorption band[2,3] is due to centers formed by the trapping of a positive hole by a positive ion vacancy. The following experiments support this model and indicate that the thermal activation energy for release of a hole from a positive ion vacancy is approximately one-tenth of the optical activation energy.

Potassium chloride crystals were irradiated, at liquid nitrogen temperature, with x-rays. An electric field of 500 volts per centimeter was then applied to a crystal and its temperature raised. The current peak shown occurring at -132°C in Fig. 1 indicates the thermal release of trapped charge within the crystal and coincides with the disappearance of the V_1 band. At the same time the F band decreases in height.[2,3] Our optical measurements indicate, assuming the oscillator strengths of the two bands to be the same, that approximately one V_1 center disappears for each F center destroyed.

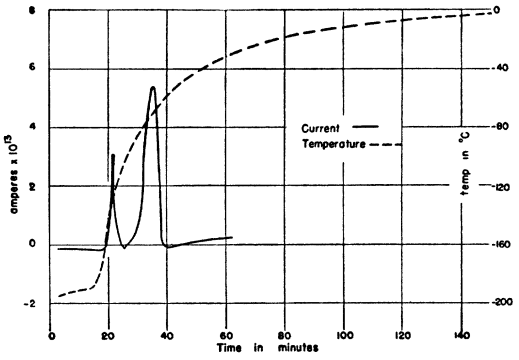

FIG. 1. Release of trapped charge in KCl.

The current peak observed in Fig. 1 at -70°C is the result of the thermal release of electrons from F' centers.

Crystals which have been irradiated at liquid helium temperature exhibit, on warming, a current peak near liquid nitrogen temperature due to release of charge from unidentified traps. The release of charge from V_1 centers at a higher temperature is also observed. F' centers do not appear to be formed on irradiation at liquid helium temperature.

A crystal irradiated at liquid nitrogen temperature exhibits phosphorescence and on warming a burst of luminescence accompanies the disappearance of the V_1 centers. A second much broader glow peak is observed with a maximum near 0°C and appears to correlate with the slow disappearance of F centers in the vicinity of this temperature.

Assuming Seitz's model of the V_1 center, its small thermal activation energy results from the following considerations. The effective mass of the hole is probably three to ten times the electron mass, making its bound orbit smaller than that of the F-center electron. The effective Mott-Littleton radius,[4] for the positive ion vacancy, is undoubtedly smaller than for the negative ion vacancy, tending to give weaker binding by a factor of $\frac{3}{2}$ or more than for an electron in a negative ion vacancy. It should be recognized that Simpson's[5] calculations of polarization energy of F centers show that the continuum approximation gives the expected increase with $1/R$, but underestimates it appreciably. The above two factors affect the optical excitation energy in opposite directions but combine to give a large lattice polarization, which leads to a small thermal activation energy.

* Partially supported by the ONR.
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A Comment on the Validity of the Bloch Formulation for the Interpretation of Nuclear Magnetic Resonance Phenomena*

E. STRICK, R. BRADFORD, C. CLAY, AND A. CRAFT
Physics Staff, University of Wyoming, Laramie, Wyoming
(Received August 13, 1951)

SINCE Bloch's early formulation[1] of the nuclear magnetic resonance radiation in terms of parametric relaxation times, many workers[2–5] have successfully accounted for anomalous observed resonance shapes by referring to Bloch's equations of motion. In the "steady-state," sinusoidal field-sweep technique, "wiggles" which were observed at the higher sweep frequencies were shown by Jacobsohn and Wangsness[2] to be compatible with the proper solution of the Bloch equations. Torrey[3] and Hahn[4] have applied the external resonating field H_1 in the form of a single-shot pulse, Torrey observing the transient effects which occur at

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.

* This work was supported in part by the AEC.

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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)]

A. S. Rao, V. K. Balasubrahmanyam, G. S. Gokhale, and A. W. Pereira
Tata Institute of Fundamental Research, Bombay, India

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

The Specific Fluorescence of Anthracene and Other Organic Materials

J. B. Birks
Department of Physics, Rhodes University, Grahamstown, South Africa
(Received August 23, 1951)

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