frequency of 24,160 Mc, the variations in $\Delta H$ with crystallographic direction were not large enough to be significant.[2] Recently, we have also succeeded in preparing by almost the same method[1,2] single crystals whose composition is approximately $ZnOMnO2Fe_2O_3$. The resulting crystals formed regular octahedra, whose size was 0.6~0.8 mm on the edge. A cone was cut out whose base plane is (100) and ferromagnetic resonance measurements were made at a wavelength of 3.22 cm, with the [110] and [100] directions respectively parallel to the static field. From the experimental data, the line half-widths with crystallographic direction were determined at various temperatures, and considerable difference was found between the [100] and [110] directions.

The experimental procedure and method were given in previous papers.[3,4]

The half-widths were observed from liquid nitrogen temperature to the Curie point *ca* 110°C. All the measurements were made while warming the crystal from the temperature of liquid nitrogen at the rate of 0.5° per minute. The results obtained are shown graphically in Fig. 1; the ordinate gives the half-width in oersteds, and the abscissa gives the temperature in degrees centigrade; open circles denote the [110] direction, and solid circles the [100] direction. For the [100] direction, $\Delta H$ decreases rapidly with rising temperature from −185°C up to *ca* −40°C; then it increases abruptly and afterwards increases slowly. On the other hand, in the case of the [110] direction, $\Delta H$ always decreases continuously with rising temperature and finally vanishes near the Curie point.

The experiment was repeated on the other single crystal having the same composition, and the same tendency was always observed in the same temperature range.

Thus, it was confirmed that the value of $\Delta H$ depends considerably on crystallographic direction and the variation of $\Delta H$ with temperature is quite different for different crystallographic directions. At room temperature, the value of $\Delta H$ is large compared to the result of Galt and his co-workers;[2] the reason for this seems to depend on the crystalline imperfection and the form of the specimen.

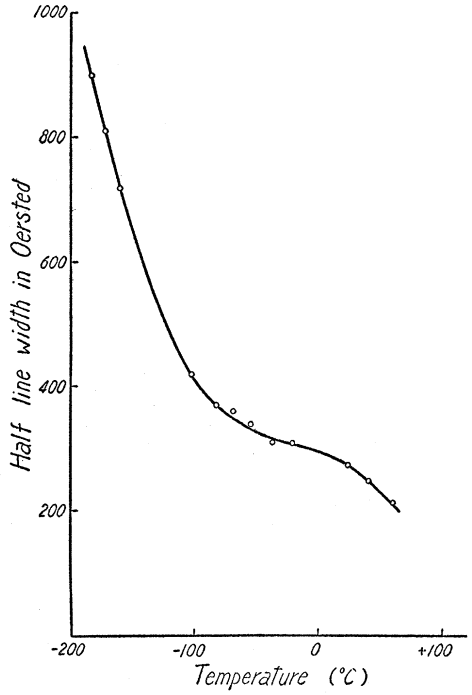


FIG. 2. Temperature dependence of the line half-width for a polycrystalline specimen of $MnOZnO2Fe_2O_3$.

Next, we performed also a resonance experiment on a disk-formed polycrystalline specimen of $ZnOMnOFe_2O_3$, 4.5 mm in diameter and 0.22 mm in thickness, at low temperature and at the same wavelength. The temperature variation of the line half-width is shown in Fig. 2; in the range −95°C to −115°C in which the half-width begins to increase rapidly, double peaks were observed in the resonance curves, which are similar to those found recently by the authors in $MnOFe_2O_3$[5] and $NiOFe_2O_3$[6] at low temperature.

Therefore, the occurrence of double peaks seems to be intimately connected with the change of crystalline anisotropy of the sample at low temperature, as expected.

Experiments on a thin-disk-formed and a sphere-formed specimen of the single crystal are being planned.

Details of this work will be published in the Science Reports of the Research Institute of Tohoku University.

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[2] Galt, Yager, Remeika, and Merritt, Phys. Rev. **81**, 470 (1951); Yager, Merritt, and Guilland, Phys. Rev. **81**, 477 (1951).
[3] Okamura, Torizuka, and Kojima, Sci. Repts. Research Inst. Tohoku University **2**, 663 (1950).
[4] Okamura, Torizuka, and Kojima, Sci. Repts. Research Inst. Tohoku University **3**, 209 (1951).
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## A Steady State Transient Technique in Nuclear Resonance

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THIS title heads two recent Letters to the Editor of this Review.[1] The authors do not seem to have noticed that some previous articles have already described the same effect and given its full theory.[2,3] We wish to draw attention to the fact that this phenomenon was discovered by the late Dr. Gooden.[4] We do not intend to review our previous theory, but will only give its new development concerning the measurement of $T_2$ in liquids in the presence of field inhomogeneities larger than the mean value of the intramolecular field.

When $T_2$ is larger than about $10^{-3}$ sec a well-known transient phenomenon is observed.[2,3] The decay of the oscillations (Fig. 1) is determined by phase shifts produced by both the molecular field $h$ and the inhomogeneities $\delta = H_z - H_0$ of the magnetic field.

After resonance, the molecular field produces a phase shift $\varphi(t) = \int_0^t \gamma h(t)dt$, and we have to integrate over all the values of $\varphi$. These values are distributed according to a Gaussian probability function. The fact that the decay is described by the function $\exp(-t/T_2)$ and not by $\exp(-t^2/T_2)$ as it seems at first, is produced by the fact that $\langle\varphi^2\rangle_{Av}$ is related to $\langle h^2\rangle_{Av}$ not by $\langle\varphi^2\rangle_{Av}$

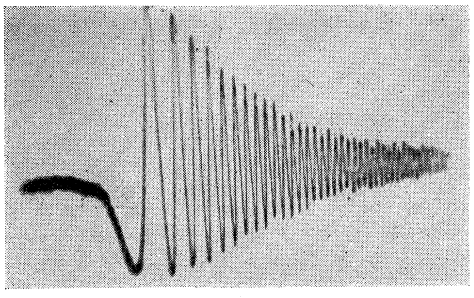

FIG. 1. Decay of oscillations for a Gaussian distribution of field inhomogeneities.

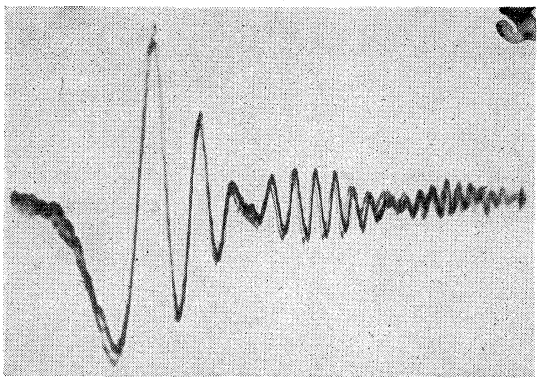

FIG. 2. Decay of oscillations for a "square" distribution of field inhomogeneities.

$=\gamma^2\langle h^2\rangle_{Av}t^2$ but by $\langle\varphi^2\rangle_{Av}=\gamma^2\langle h^2\rangle_{Av}t$ according to the well-known solution of the Gaussian random walk problem.

Field inhomogeneities produce an extra phase shift $\varphi(t)=\gamma\delta t$. In order to obtain the whole signal we have to integrate over all values of $\delta$. An extra decay of the oscillations follows, described by the Fourier transform $F(t)$ of the distribution function $\psi(\delta)$ of $\delta$ over the sample. The envelope amplitude of the signal is the product,

$$A=\exp(-t/T_2)F(t).$$

Discrimination between the two effects is possible for special forms of $F(t)$.

There are two cases of particular interest:

I. We assume that $F(t)$ is a uniformly decreasing function of time. For example, this is the case when $\psi(\delta)$ is a bell-shaped function or a damped oscillation function. Then the signal aspect is that given in Fig. 1 and it is not possible to obtain from its decay curve a measure of $T_2$ if $F(t)$ is an unknown function. But if $F(t)$ is a periodic function of time, it is possible to draw information about $F(t)$ from the position of successive zeros. This is the case when $\psi(\delta)$ is a pulse-like function, and the study of signal decay is a convenient way to measure $T_2$.

For instance, when $\psi(\delta)=1/\Delta$ if $|\delta|\leqslant\Delta$ and $\psi(\delta)=0$ for $|\delta|>\Delta$, then

$$F(t)=\sin\Delta t/\Delta t,$$

and the signal is represented on Fig. 2. Measurement of the first zero time $t$ gives the value of $\Delta$ from $\Delta t=\pi$. Then the amplitude ratio at successive maxima, which is only determined by $T_2$ and $\Delta$, provides a measure of $T_2$. We obtain

$$T_2=\frac{3\pi}{2}\Big/\Delta\log\left(\frac{2}{3\pi}\frac{e_1}{e_2}\right).$$

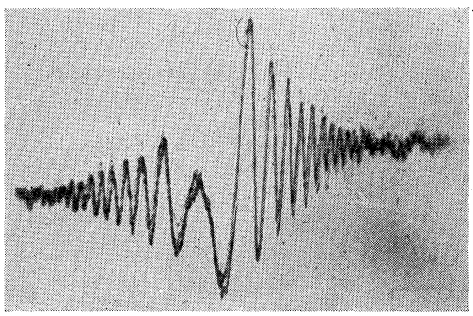

FIG. 3. Preresonance signal for $T_2>T_0$.

II. It is clear that $F(t)=\int_0^\infty\psi(\delta)\cos\gamma\delta t d\delta$ is an even function. On the other hand, $F(t)$ must be a periodic function of time $t$ with a period $T_0$ (half-period of the modulating field). From these two properties it follows that

$$F(T_0-t)=F(t).$$

In the presence of very large inhomogeneities, $F(t)$ drops rapidly to zero in a time $\tau\ll T_2$ and increases again at time before the next resonance according to the even properties of $F(t)$.

Then:

(A) If $T_2<T_0$, the factor $\exp[(T_0-\tau)/T_2]$ is practically zero and there is no observable signal before resonance (Fig. 1 and Fig. 2).

(B) But if $T_2>T_0$, then $\exp[(T_0-\tau)/T_2]$ is an important factor and we can observe a signal before resonance, as seen in Fig. 3. The ratio of the signal amplitudes, $e_1$ after resonance and $e_2$ before resonance, is

$$\frac{e_1}{e_2}=\exp\left(\frac{T_0-t}{T_2}\right)\frac{F(T_0-t)}{\exp(t/T_2)F(t)},$$

and if $t\to0$ (observations of signal near resonance) we get

$$T_2=T_0\log(e_2/e_1).$$

A limit to this method is set by random magnetic field fluctuations produced by the magnet power supplies. These fluctuations produce phase shifts strictly identical to those produced by molecular fields. These phase shifts introduce extra decays which are not generally even functions of time and are not eliminated like $\delta$ by the previous method. In our apparatus this limit occurs for $T_2>0.1$ sec.

Use of a permanent magnet would probably allow the measurement of times $T_2>0.1$ sec, but it is probable that the inhomogeneous magnetic field will set a new limit here.

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## High Energy Nucleon-Deuteron Scattering*

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WE consider the relationship between high energy nucleon-deuteron scattering and elementary nucleon-nucleon scattering. We find that one may, for the case of central potentials of arbitrary exchange character, write the nucleon-deuteron differential cross section in terms of the elementary cross sections. Except for a term which is important only in the backward direction, the reduction is simple and enables one to examine easily the arbitrariness caused by the fact that nucleon-nucleon scattering measurements do not give singlet and triplet cross sections separately nor the phases.

The quartet and doublet Born approximation matrix elements are given by[1]

$$M_q=(3\pi/m)(U_q+L_q+D_q),\quad M_d=(3\pi/m)(U_d+L_d+D_d),\quad(1)$$

and

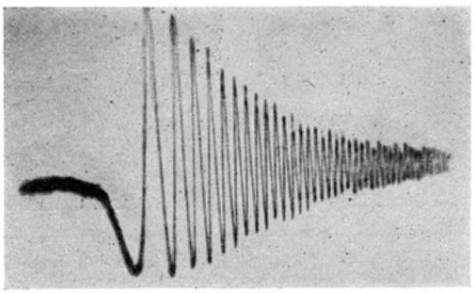
$$d\sigma/d\omega=\tfrac{2}{3}|U_q+L_q+D_q|^2+\tfrac{1}{3}|U_d+L_d+D_d|^2,\quad(2)$$

where

$$U=(m/3\pi)\int\int\chi^*\varphi^*(S)e^{-i\mathbf{k}\cdot\mathbf{X}}V^U(1,3)e^{i\mathbf{k}_0\cdot\mathbf{X}}\varphi(S)\chi d\mathbf{X}d\mathbf{S},$$

$$L=(m/3\pi)\int\int\chi^*\varphi^*(S)e^{-i\mathbf{k}\cdot\mathbf{X}}(1-T_{23})V^L(2,3)\times e^{i\mathbf{k}_0\cdot\mathbf{X}}\varphi(S)\chi d\mathbf{X}d\mathbf{S},\quad(3)$$

$$D=(m/3\pi)\int\int\chi^*\varphi^*(S)e^{-i\mathbf{k}\cdot\mathbf{X}}T_{23}V^U(1,3)\times e^{i\mathbf{k}_0\cdot\mathbf{X}}\varphi(S)\chi d\mathbf{X}d\mathbf{S}.$$



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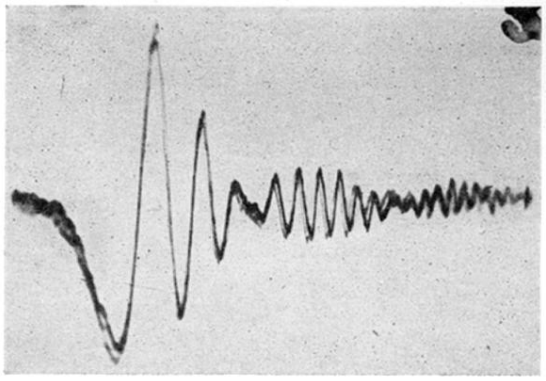

FIG. 2. Decay of oscillations for a "square" distribution of field inhomogeneities.

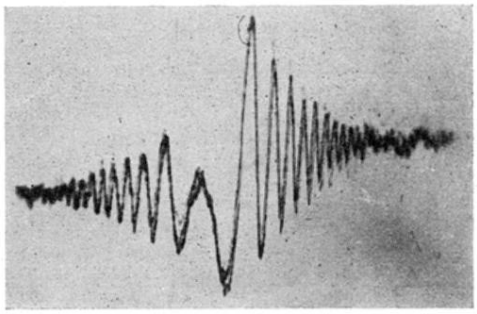

FIG. 3. Preresonance signal for $T_2 > T_0$.