counting statistics only. The function $P(x)$ is plotted in Fig. 2. The dotted line represents an exponential function with $L=320$ g/cm² and is seen to provide a good fit to the data for absorber thicknesses greater than ~1.2 cm. A transition maximum for zero absorber thickness is clearly indicated. Since $P(x)$ represents an integrated value for neutron production over a half-inch of lead, the transition maximum for neutron production per unit volume of lead must occur within the first 1.25 cm (half-inch) of lead.

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† AEC Predoctoral Fellow.
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## Neutron Diffraction Investigation of the Atomic Magnetic Moment Orientation in the Antiferromagnetic Compound CrSb

A. I. Snow
*University of Chicago, Chicago, Illinois*
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THE atomic magnetic moment orientation in the antiferromagnetic compound CrSb has been investigated at room temperature by neutron diffraction. The crystal structure and magnetic properties of this compound have been previously determined by Haraldsen, Rosenqvist, and Grønvold.[1] This compound has the nickel arsenide structure and shows a marked decrease in magnetic susceptibility as the temperature is lowered from the antiferromagnetic Curie point (450°C). The magnetic mass susceptibility falls from $10.97\times10^{-6}$ at 450°C to $3.3\times10^{-6}$ at 20°C. Lattice constants are $a_0=4.127$A and $c_0=5.451$A.

Calculation showed that all antiferromagnetic magnetic moment orientations which lead to a magnetic unit cell, one side of which is a multiple of the atomic (x-ray) unit cell, would cause the presence of strong new diffraction maxima at low angles in a neutron diffraction pattern. Such new maxima were not observed, although they were looked for carefully. Experimental data showed that the (101) maximum had twice the intensity of the (102) and (110) maxima, respectively. On the basis of nuclear scattering, with no magnetic scattering, these three maxima would be essentially equal in magnitude. This doubling in intensity of (101) relative to (102) and (110), respectively, is consistent with the atomic magnetic moments being aligned perpendicular to (001) planes, i.e., along the $c$ axis, in such a manner that they are aligned in the same direction (ferromagnetically) in any one (001) plane but oppositely directed (antiferromagnetically) in adjacent (001) planes. Nearest neighbor chromium atoms (2.726A apart) are thus aligned antiferromagnetically whereas second nearest neighbors (4.127A apart) are aligned ferromagnetically. One unit cell is shown in Fig. 1. The possibility that the magnetic moments may be aligned parallel to the (001) planes may be eliminated since this arrangement would lead to an unobserved strong maximum at low angles.

On the basis of the relative intensity data, a conservative estimate for the average number of electrons per atom whose magnetic moments are aligned in the manner described above is $2.7\pm0.2$, if the assumption is made that the orbital angular momentum contribution is completely quenched and the magnetic amplitude form factor of manganese[2] is used in the calculation.

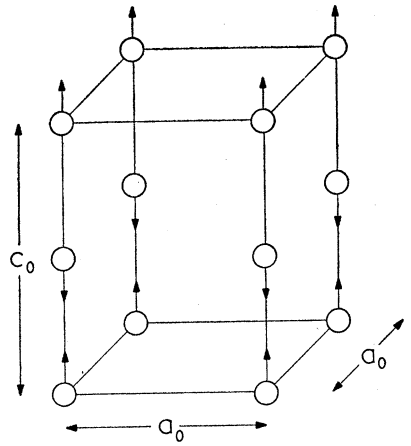


FIG. 1. Unit cell of CrSb. Arrows indicate the relative alignments of atomic magnetic moments. Only chromium atoms are shown.

The atomic magnetic moment orientation found above differs from that found in $MnF_2$ which is body-centered tetragonal with respect to the manganese atoms, where nearest neighbors (3.31A apart)[3] are ferromagnetically arranged and next nearest neighbors (3.82A apart)[3] are antiferromagnetically arranged.[4] The CrSb arrangement is somewhat similar to the arrangement in some of the (111) planes of the face-centered cubic compound FeO[2] since in FeO the moments are aligned perpendicular to some of the (111) planes and are aligned in opposite directions in adjacent (111) planes[4] of the particular sets considered.

Thanks are due to Dr. T. Rosenqvist for preparation of the compound and to Dr. G. R. Ringo and other members of the Argonne National Laboratory staff for their cooperation. The neutron diffraction work was performed by the author at the heavy water nuclear reactor of the Argonne National Laboratory.

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## Nutational Resonance*

H. C. Torrey
*Department of Physics, Rutgers University, New Brunswick, New Jersey*
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APPLICATION of repeated radiofrequency pulses to proton-containing liquids in a magnetic field results in transient nuclear resonance absorption effects which we have reported[1] previously.

Recently we have observed an additional effect which results when both the time between pulses (off-time) and a pulse duration (on-time) are short compared with the relaxation times $T_1$ and $T_2$. Under these circumstances one might expect the nuclear resonance signal to be small in the case of power levels normally sufficient to saturate the sample. However, if a radiofrequency pulse contains an integral number of nutational periods it is possible for the signal to maintain a relatively large value as a result of a nutational resonance process. In case the magnetic field is homogeneous over the sample, the nutational frequency will be uniform and after an initial rf pulse lasting for an integral number of nutational periods the sample's magnetic moment will be left oriented along the magnetic field in its original condition except for some attenuation due to the net effect of the transverse and longitudinal relaxation processes. During the succeeding off-time, the moment's orientation will be undisturbed while its amplitude increases due to longitudinal relaxation. After a sufficient number

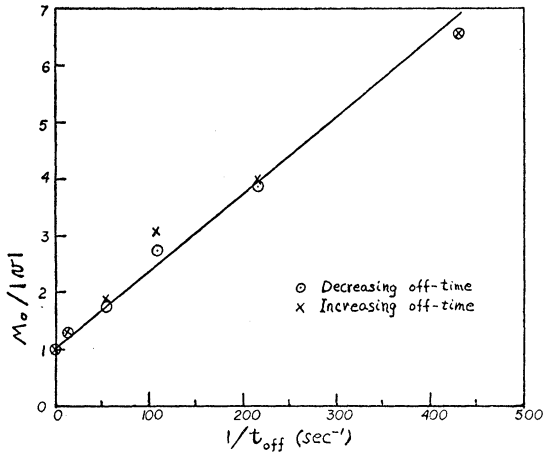


FIG. 1. Nutational resonance in distilled water.

of pulses a steady state results in which there is considerable signal strength even if the off-time is short compared with $T_1$ and $T_2$.

It is clear that this is a resonance process since, if the condition on the nutational frequency is not exactly fulfilled, the moment will make increasing angles with the magnetic field on succeeding pulses and in the steady state the signal will be small. It is not necessary, however, for the rf resonance condition $\omega=\gamma H_0$ to be exactly satisfied.

To explain the effect quantitatively we have solved the Bloch equations for the case of an infinite succession of radiofrequency pulses. This was done by first solving the Bloch equations for a single pulse with undetermined initial conditions and then applying the condition that the components of magnetic moment at the end of an off-time should be the same as at the start of an on-time. The general steady-state solution is somewhat involved, but the special case of radiofrequency resonance, $\omega=\gamma H_0$, yields for the amplitude

$$|v|/M_0=[1+(t_1/2t_2)(1+T_1/T_2)]^{-1}\times(1+A^2\sin^2\tfrac{1}{2}\theta)^{\frac{1}{2}}(1+AB\sin^2\tfrac{1}{2}\theta)^{-1},$$

where

$$A=2[\tfrac{1}{2}t_1(1/T_1+1/T_2)+t_2/T_2]^{-1}$$
$$B=2[\tfrac{1}{2}t_1(1/T_1+1/T_2)+t_2/T_1]^{-1}$$
$$\theta=\gamma H_1 t_1$$

and $t_1$ and $t_2$ are the on-time and off-time, respectively. It is assumed that both $t_1$ and $t_2$ are small compared with $T_1$ and $T_2$ so that $A$ and $B$ are very large. If then $\sin\frac{1}{2}\theta$ is not small we have

$$|v|/M_0\simeq\tfrac{1}{2}(t_2/T_1)\,|\csc\tfrac{1}{2}\theta|\ll 1.$$

If, however, $\theta=2n\pi$ where $n$ is an integer (the nutational resonance condition), we get

$$|v|/M_0=[1+(t_1/2t_2)(1+T_1/T_2)]^{-1}, \qquad (1)$$

which may be of the order of unity.

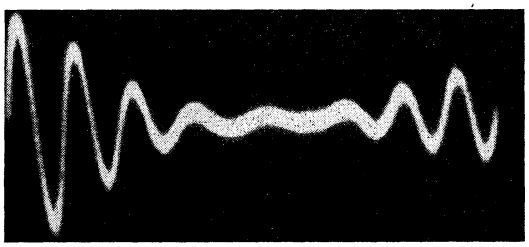

FIG. 2. Effect of an inhomogeneous field.

We have tested this result for distilled water with the result shown in Fig. 1, where we plot $M_0/|v|$ *versus* the reciprocal of the off-time holding $t_1$ fixed. The points fall well on a straight line in accord with Eq. (1). In this case the on-time contained one complete nutational period. From the slope of the line we obtain $T_2=0.63T_1$. Taking[2] $T_1=2.3$ sec we find $T_2=1.4$ sec. This is much the longest $T_2$ yet measured and confirms the conjecture[2] that the line width in distilled water is of the order of $10^{-4}$ oersted.

We believe that this phenomenon explains another effect first observed in this laboratory by Thomas.[3] If the magnetic field is sufficiently inhomogeneous the nutational frequency varies over the sample. The net signal is then the result of superposed sine waves from those parts of the sample obeying the nutational resonance condition. These sine waves will have different frequencies but all begin and end in the same phase. Thus there will be constructive interference at the start and at the end of a rf pulse but destructive interference in the center. A typical signal is shown in Fig. 2. This effect appears to be similar to one recently reported by Bradford, Clay, and Strick.[4]

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## A Solar Component of the Primary Cosmic Radiation*†

J. A. SIMPSON, W. FONGER, AND L. WILCOX
*Institute for Nuclear Studies, University of Chicago, Chicago, Illinois*
(Received November 26, 1951)

THE time-dependent changes of intensity of the low energy primary cosmic radiation as observed by changes in the nucleonic component intensity have been investigated further to determine the extent to which these changes may identify the origin of at least a small fraction of the low energy end of the primary particle intensity spectrum. Continuous observations are made at different geomagnetic latitudes and altitudes by measuring the disintegration product neutrons[1] from the local production of small stars in lead. The geometries are similar to those described earlier.[2] We report here preliminary results selected as typical samples of the behavior of the low energy primary radiation with time and restrict our present discussion to large world-wide changes which persist for the order of days.

The total number of events registered for successive twelve-hour intervals has been plotted for three of the monitor stations in Fig. 1. For example, each point for the Climax, Colorado, monitor (11,000 feet) represents more than $4\times10^5$ events. All monitors are normalized periodically with Ra-Be standard neutron sources. Hence, the principal error is the barometric correction. In spite of the differences in atmospheric temperature changes between Climax and Sacramento Peak, there appears a remarkable similarity of details of intensity changes among the three monitors.

By observing the change of intensity with latitude, $\lambda$, at 30,000 ft pressure altitude from $\lambda=40°$ to 63° N in aircraft on August 7, 18, and 25, 1951 we have been able to show the following:

a. The changes of intensity observed in Fig. 1 are of the type reported earlier,[1] and, hence, represent near the maxima in Fig. 1 additional primary radiation arriving at latitudes at least up to $\lambda=56°$ N.

b. Changes in the dipole magnetic field of the earth do not account for the observed changes of intensity.

Hence, these changes of cosmic-ray intensity are reasonably certain of being extra-terrestrial in origin.

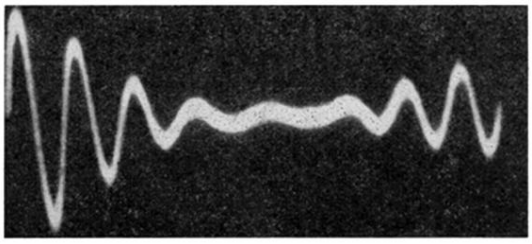

FIG. 2. Effect of an inhomogeneous field.