Letters to the Editor

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Transition Effect for Neutron Production in Lead*

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THE production rate of cosmic-ray stars in photographic emulsions placed under various thicknesses of lead has been studied by a number of investigators,[1–8] and the existence of a transition maximum, occurring within the first few centimeters of lead, has been observed. A similar result has been obtained for single protons in emulsions.[9] In this note we report on a set of measurements dealing with a closely related problem: The absorption in lead of the neutron-producing radiation. This problem has been investigated at airplane altitudes by Simpson,[10] and a transition maximum at 15–18 g/cm² of lead has been observed. The measurements reported here were performed at Chicago (750 mm Hg average pressure).

The experimental arrangement is shown in Fig. 1. The aim of the experiment was to measure the production rate of neutrons in a fixed thickness ($\frac{1}{2}$ in.) of lead "producer," as a function of lead absorber thickness. The neutron detector consisted of a tray of three BF_3 proportional counters connected in parallel and embedded in a large block of paraffin (19×30×48 in.), which serves as a neutron moderator. We denote the counting rates by $R(x, p)$ and $R(x, 0)$, where x is the thickness of absorber and where the symbols p and 0 signify, respectively, the presence or absence of producer. The counting rates were normalized to a constant counting rate on a monitoring apparatus similar to the absorption apparatus shown in Fig. 1, but with a different (and fixed) arrangement of lead. The pressure coefficients for the two sets of apparatus were found to be the same, irrespective of absorber (or producer) thickness. This normalization procedure also corrects for possible time variations in cosmic-ray intensity.

In the absence of producer, the total counting rate $R(x, 0)$ contains a term $A(x)$ due to neutrons produced in the absorber, a term $W(x)$ due to neutrons produced in the paraffin block, and a term B due to "background" (e.g., alpha-contamination):

$$R(x, 0) = A(x) + W(x) + B. \quad (1)$$

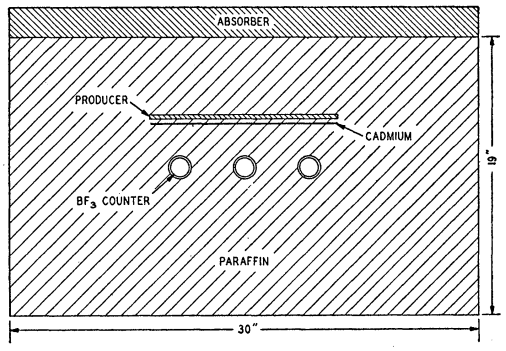

FIG. 1. Sketch of apparatus used to measure neutron production rate in half-inch lead "producer," as a function of lead absorber thickness. The cadmium sheet reduces the contribution to the counting rate from neutrons produced in the absorber.

Because of the large size of the paraffin block, the contribution from neutrons produced outside the block is negligible. The background rate was measured by covering the counters with cadmium shields, and the value $B=3.1\pm0.1$ counts/min was obtained. Within this accuracy B was independent of absorber and producer thickness. When the producer is inserted, there is an additional contribution $P(x)$ due to neutrons coming from the producer. Also, a certain fraction f of the neutrons from the absorber is scattered by the producer and is no longer detected. (The contribution from the paraffin, however, is assumed to remain unchanged, because of the approximately symmetric distribution of the paraffin with respect to the BF_3 counters.) Thus,

$$R(x, p) = P(x) + (1-f)A(x) + W(x) + B. \quad (2)$$

From Eqs. (1) and (2) we obtain

$$P(x) = R(x, p) - R(x, 0) + f[R(x, 0) - W(x) - B]. \quad (3)$$

The last term in this equation is only a small correction term, particularly for small values of x. A sufficiently accurate estimate of f is obtained by assuming that the energy distribution of the neutrons produced in lead can be approximated by a Ra+Be source.[11] A 5-mC source was placed on top of the paraffin block and the reduction in counting rate, due to the insertion of the producer, was noted. The value $f=0.060$ was obtained. The function $W(x)$, which represents the counting rate due to neutrons produced in the paraffin, is proportional to the flux of neutron-producing radiation which emerges from the absorber of thickness x. Except at small thicknesses where a transition effect occurs, we can anticipate from the results of other investigators that the flux of neutron-producing radiation varies exponentially with x and that the absorption mean free path has the value $L=320$ g/cm². This will be confirmed by our own results. We therefore write

$$W(x) = W(0)\exp(-x/L), \quad (4)$$

where, from Eq. (1), $W(0)=R(0, 0)-B$. This assumption breaks down at small thicknesses, but at small thicknesses the last term in Eq. (3) is negligible in any case.

TABLE I. Counting rate resulting from neutrons produced in half-inch thickness of lead producer, as a function of absorber thickness.

Absorber thickness (inches)	Counting rate (counts/min) $R(x, p)$	$R(x, 0)$	$P(x)$
0	17.91±0.14	11.36±0.10	6.55±0.17
0.25	19.13±0.14	13.03±0.11	6.21±0.17
0.50	19.09±0.16	14.08±0.08	5.19±0.18
1.0	20.17±0.16	15.33±0.13	5.12±0.18
2.0	23.11±0.19	18.81±0.14	4.83±0.24
4.0	28.20±0.20	25.30±0.19	3.89±0.29

The results of the absorption experiment are summarized in Table I, where the indicated errors are standard deviations due to

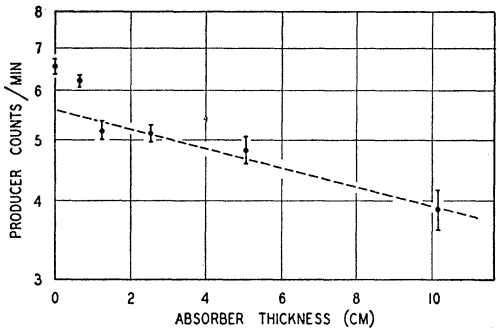

FIG. 2. Neutron production rate in half-inch thickness of lead placed under various thicknesses of lead absorber. The dotted line represents an exponential function with $L=320$ g/cm².

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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Neutron Diffraction Investigation of the Atomic Magnetic Moment Orientation in the Antiferromagnetic Compound CrSb

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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 10.97×10^{-6} at 450°C to 3.3×10^{-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 ± 0.2, 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.

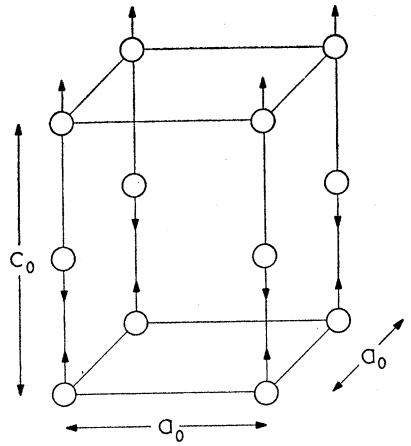

FIG. 1. Unit cell of CrSb. Arrows indicate the relative alignments of atomic magnetic moments. Only chromium atoms are shown.

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.

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Nutational Resonance*

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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