than the theoretical one. The experimental coefficients of the second and fourth Legendre polynomials are, respectively, smaller than the theoretical ones by the factors $G_2=0.42$ and $G_4=0.50$.

Such a weakening can be produced by the interaction of the quadrupole moment in the intermediate state with the gradient of the electric field at the nucleus. If we assume that the field has axial symmetry and that all directions of its axis are equally probable (as for a crystalline powder), it can be shown that for a nucleus of spin 2,

$$G_2^{\text{theor}}=(1/35)[8(1+16x^2)^{-1}+12(1+9x^2)^{-1}+2(1+x^2)^{-1}+13],$$
$$G_4^{\text{theor}}=(1/63)[6(1+16x^2)^{-1}+16(1+9x^2)^{-1}+12(1+x^2)^{-1}+29].$$

In this formula $x=2\pi\nu\tau$, where τ is the lifetime of the intermediate state and $h\nu$ the energy difference between the states $M_b=0$ and $M_b=\pm1$ of the quadrupole moment in the axial field.

G_2 and G_4 are decreasing functions of x which vary very slowly for $x>1$.

$$G_2(0)=G_4(0)=1;$$
$$G_2(1)=0.45,\quad G_4(1)=0.59,$$
$$G_2(\infty)=0.37,\quad G_4(\infty)=0.46.$$

If we take $\tau=10^{-8}$ sec,[1,2] $x=1$ corresponds to a frequency ν of 15 Mc/sec. Much higher quadrupole interactions have been observed in nuclear resonance experiments, and values of x much higher than 1 are by no means unlikely.

It follows from this that G_2 and G_4, and therefore the correlation, are practically independent of the value of the gradient of the electric field as long as it is large enough (ν higher than 15 Mc/sec). This is particularly important in view of the fact that after the α-emission, the nucleus, which has a recoil energy higher than 100 kev, can occupy any position with respect to the surrounding atoms or molecules. Such circumstances are favorable for large electric field gradients with considerable variation in magnitude and direction from one radioactive nucleus to another. For $x>1$ the agreement with experiment is very good.

The near constancy of the G's for $x>1$ explains why both experimental groups obtain almost identical results using different source materials. A departure of the electric field from axial symmetry is not likely to affect the previous results drastically.

The fact that G_4 is larger than G_2, theoretically and experimentally, suggests very strongly that the influence of atomic magnetic fields on the correlation is very small. It can be shown[3] that a magnetic field, whether atomic or applied, affects the higher harmonics most strongly and would lead to $G_4 \ll G_2$.

The nuclear electric quadrupole interaction in the intermediate state appears to offer explanation of discrepancies observed in many other angular correlation experiments. Other examples will be discussed in the later paper.

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Neutron Capture Cross Sections for Production of Sc^{46} and Sr^{85}†

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CONSIDERABLE uncertainty exists in the literature concerning the thermal neutron capture cross section for production of both 85-day Sc^{46} and 65-day Sr^{85}. Tabulated nuclear data[1] give conflicting values for Sc^{46} and none for Sr^{85}.

Bethe[2] has reported >13 barns for the reaction $Sc^{45}(n,\gamma)Sc^{46}$. Seren *et al.*[3] report 22 b. Recently Pomerance[4] has measured the capture cross section for pile neutrons using the pile oscillator. He finds 23±1.5 barns.

Samples of spectroscopically pure Sc_2O_3 together with weighed pieces of Al—Mn alloy of known Mn concentration were irradiated in the Oak Ridge National Laboratory graphite reactor for eight hours. Upon removal from the reactor the decay of the monitor metal was followed in a calibrated high pressure ionization chamber, and the activity of the product 2.59-hour Mn^{56} was determined. The neutron flux was then calculated using the expression

$$A=Nf\sigma(1-e^{-\lambda t}),$$

where $\sigma=13$ barns.

Samples of the irradiated Sc_2O_3 were then weighed on an analytical balance, and the activity of the daughter Sc^{46} determined from ion chamber measurements. After correction for decay from pile discharge time, the pile neutron cross section for Sc^{46} was calculated as above and found to be 21.6±2 barns. Goldhaber and Muehlhause[5] have reported a 20-sec isomer of Sc^{46} which has an activation cross section of 10±4 barns. Thus the cross section for direct production to the ground state 85-day activity is 12 barns, and the value of 22 barns is the "effective" production cross section for the longer-lived activity.

Sr^{85} is a K electron capturing nuclide whose decay scheme has only recently been completely elucidated by Sunyar *et al.*[6] These workers have established that Sr^{85m}, which is the 70-min excited state initially produced, decays to Sr^{85} (65-day) in 86 percent of the disintegrations. Recently Harrison and Seymour[7] have reported an "effective" production cross section of Sr^{85} of 0.3±0.1 measured relative to the 5-mb cross section for the Sr^{89} 53-day activity.

The thermal neutron cross section for production of Sr^{85} has been obtained by use of $SrCO_3$ enriched to a Sr^{84} concentration of 45.95 percent.[8] Samples of $SrCO_3$ together with cobalt monitor metal were irradiated in the Oak Ridge National Laboratory graphite reactor for two weeks. After cooling one week, the $SrCO_3$ and Co metal were weighed, and the activity produced in them was read on the calibrated high pressure ionization chamber. By use of the decay scheme noted above, the activity of product Sr^{85} was calculated. The "effective" isotopic capture cross section for the production of Sr^{85} was then calculated and found to be 1.2±0.1 barns.

To establish that the γ-activity observed was due solely to radiation from the primary product nuclides, portions of the irradiated material were examined on a NaI(Tl) crystal γ-ray spectrometer equipped with a linear amplifier and differential and integral pulse-height selector. The γ-spectra so obtained indicated the activities to be pure Sc^{46} and Sr^{85}.

Table I is a summary of the results.

TABLE I. Capture cross sections for pile neutrons.

Target atom	Product atom	"Effective" isotopic capture cross section (barns)	Atomic capture cross section (barns)
Sc^{45}	Sc^{46}	21.6±2	21.6±2
Sr^{84}	Sr^{85}	1.2±0.1	0.0066±0.0006

† Based on work performed by the U. S. Atomic Energy Commission.
[1] K. Way *et al.*, *Nuclear Data*, National Bureau of Standards Circular 499, and Supplements 1, 2, 3 (1951).
[2] W. Bothe, Z. Naturforsch. **1**, 179 (1946).
[3] Seren, Friedlander, and Turkel, Phys. Rev. **72**, 88 (1947).
[4] H. Pomerance, private communication, November, 1952.
[5] M. Goldhaber and C. O. Muehlhause, Phys. Rev. **74**, 1877 (1948).
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[7] G. E. Harrison and F. D. Seymour, Proc. Phys. Soc. (London) **A65**, 958 (1952).
[8] Electromagnetically enriched isotope supplied by the Isotope Research and Production Division, Y-12 Plant, Carbide and Carbon Chemicals Corporation, Oak Ridge, Tennessee.

Angular Distribution of Particles from Stars*

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IN our recent communications[1,2] we have described the experimental arrangement and some preliminary results obtained on stars induced by high energy neutrons in 200-μ Ilford G5 plates.

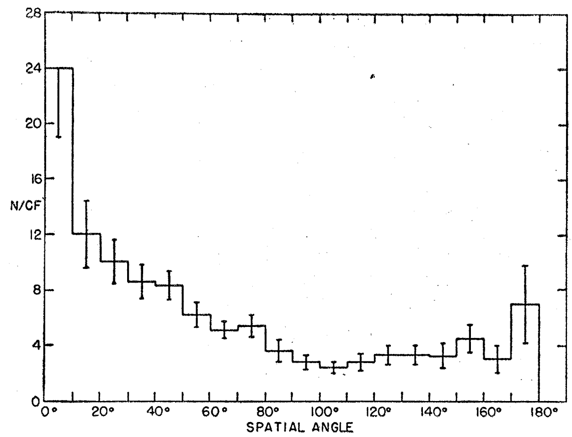

FIG. 1. Number of prongs *vs* spatial angle in 10° intervals. (Plate exposed at 0°.)

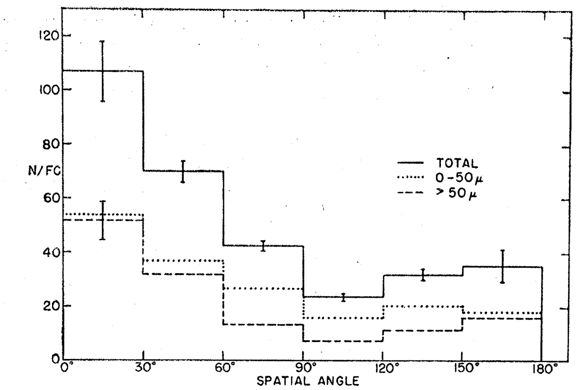

FIG. 3. Number of prongs *vs* spatial angle, in 30° intervals, with range subdivisions from all types of events. (Plate exposed at 0°.)

We intend to report here on the angular distribution of the particles emitted.

To our knowledge similar studies so far have been made only on the distribution projected onto the plane of the emulsion. However, this can be regarded only as an approximation to the three-dimensional phenomenon, and consequently, what is of interest is the distribution in space.

We have carried out the measurement of about 1000 stars for the two plates exposed[2] determining the angular distribution in space for each prong. This was obtained in the conventional way by observing the angle of dip together with the projected angle. Particular care was taken in determining the shrinkage factor which affects the angle of dip and hence could be a source of possible distortion of the distribution.

The results obtained from the plate exposed to the higher effective neutron energy[2] are given in Fig. 1. The width of the channels is selected as 10° because the intrinsic angular resolution, taking into account all possible sources of error (range, dip, shrinkage factor), is estimated to be about ±2°.

The forward tendency in the emission of the prongs is apparent. This spatial angular distribution includes all types of events (1 to 5 prongs) and particles of all energies. The discrimination between $n-p$ scattering events due to the interaction of the neutrons with the hydrogen in the emulsion and *bona fide* one-prong events is made difficult by the uncertainties in the flux determination, shape of the spectrum, and effective cross section. Therefore in Fig. 2, we show results obtained by excluding all one-prong events, together with the results in which the two and three prongs respectively are excluded. The channel has been widened to 30° in order to avoid large statistical fluctuations. The forward trend is seen to prevail up to three-prong events. As for the larger types of events, a conclusive answer cannot be provided due to the lack of statistics, although the distribution seems to be nearly isotropic. One might expect that the peak in the forward direction is due to the high energy knock-on particles. In order to investigate this point we have plotted the angular distribution of Fig. 1 subdivided into prongs with actual ranges over and under 50 microns (Fig. 3).

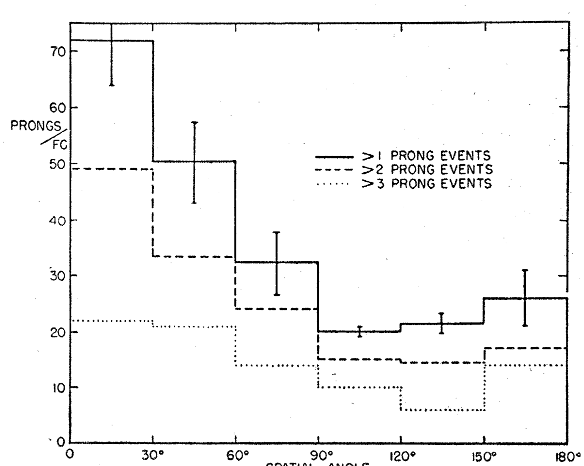

FIG. 2. Number of prongs *vs* spatial angle, in 30° intervals, for different classes of events. (Plate exposed at 0°.)

It turns out that not only the high energy particles but also the low energy ones are peaked to an appreciable extent in the forward direction, a fact which remains true for at least up to three-prong events. This is not easy to interpret if the stars examined originate in the heavier elements because the low energy particles are normally attributed to the evaporative component of the star generating process. From consideration of the measured cross sections it seems unlikely that the light elements are contributing to a very appreciable extent, although direct confirmation is still lacking.

This anomaly is less pronounced in the plate exposed to the lower effective neutron energy, which seems to indicate that this phenomenon is caused mainly by the high energy peak of the neutron spectrum.

We wish to express our indebtness to Mr. Sang C. Kim for his valuable assistance in scanning the plates.

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[1] R. W. Waniek and T. Ohtsuka, Bull. Am. Phys. Soc. 27, No. 1, 26 (1953).

[2] R. W. Waniek and T. Ohtsuka, Phys. Rev. 89, 882 (1953).

Errata

An Application of the Cellular Method to Silicon, D. K. HOLMES [Phys. Rev. 87, 782 (1952)]. The following acknowledgement should have been included: "This work was suggested by Prof. F. Seitz, and its completion was made possible by his constant help and advice."