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Directional Correlation of Gamma Rays from Sn^{116}

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The directional correlations of successive gamma rays from Sn^{116} have been measured. Sn^{116} decays via 1.09-Mev—1.27-Mev, 1.49-Mev—1.27-Mev, 0.80-Mev—1.27-Mev and 0.40-Mev—2.09-Mev gamma cascades following beta decay from 54-minute In^{116m}. The measured directional correlation functions are in agreement with those expected for $4(Q)2(Q)0$, $4(Q)2(Q)0$, $2(10\%\ D, 90\%\ Q, 0°\text{ phase})2(Q)0$ and $2(4\%\ D, 96\%\ Q, 0°\text{ phase})\ 2(Q)0$ spin sequences, respectively.

INTRODUCTION

THE complex decay of 54-minute In^{116m} has been studied by many authors. Slätis *et al.*[1] confirmed the existence of the 0.137-Mev, 0.406-Mev, 1.09-Mev, 1.27-Mev, 1.49-Mev, and 2.09-Mev gamma rays by studying the internal conversion electron and photoelectron spectra. A consistent decay scheme was proposed and is shown in Fig. 1.

The scintillation spectrum of In^{116m} is shown in Fig. 2. The above named gamma rays are in evidence. The photopeak at 0.80 Mev corresponds to the transition between the 2.09-Mev and 1.27-Mev levels. The scintillation sum spectrum[2] shown in Fig. 3 supports the decay scheme of Slätis *et al.*, including the 0.80-Mev gamma ray. The measurement of the directional correlation of the various gamma cascades would give information about the spins of these excited states and the multipolarity of the associated gamma radiation.

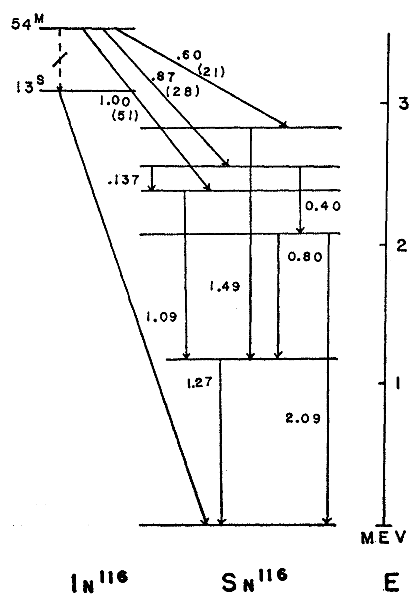

FIG. 1. Decay scheme of In^{116} including the 0.80-Mev gamma ray.

PROCEDURE

The apparatus used has been described in a previous article.[3] For these measurements the counters were shielded by $\frac{1}{16}$ inch of aluminum. The discrimination level of each counter was set to select the cascade of interest. The sources were prepared by irradiating a 0.25-gram bead of natural indium metal (embedded in a paraffin block) with the stray neutron flux from the University of Michigan cyclotron. The data was collected in the double-quadrant sequence 90°–120°–150°–180°–180°–210°–240°–270°, running 100 seconds at a position. The coincidence rate was normalized using both single counting rates. The method of data collection reduced source lifetime effects to less than 1% of the coincidence counting rate. The resolving time of the coincidence circuit ($2\tau = 2\times10^{-8}$ sec) was measured at intervals and used to correct for accidental coincidences. The effect of finite angular resolution was computed by the Rose[4] method. $(J_2/J_0)^2 = 0.85$, $(J_4/J_0)^2 = 0.60$. A least squares fit of the data was made

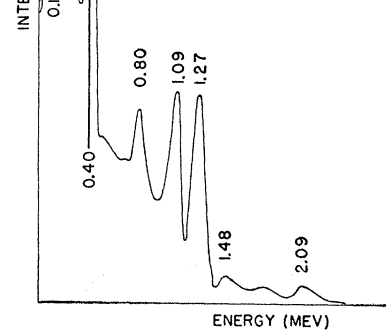

FIG. 2. Scintillation spectrum of the gamma rays from Sn^{116}.

* Present address: Massachusetts Institute of Technology, Cambridge, Massachusetts.
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[1] Slätis, Dutoit, and Siegbahn, Arkiv. Fysik 2, 321 (1950).
[2] D. C. Lu (private communication).
[3] Stewart, Scharenberg, and Wiedenbeck, Phys. Rev. 99, 691 (1955).
[4] M. E. Rose, Phys. Rev. 91, 610 (1953).

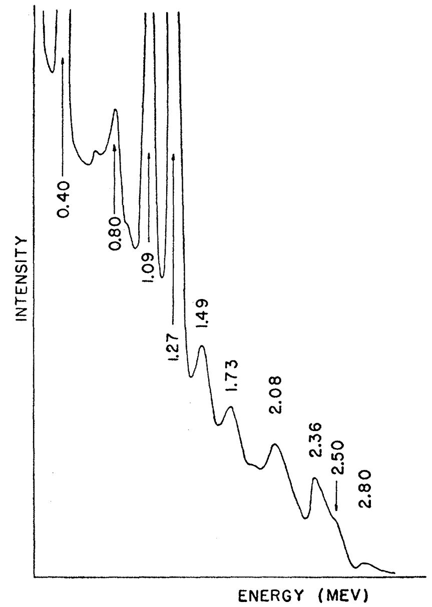

FIG. 3. Scintillation sum spectrum[2] of the gamma rays from Sn^{116}.

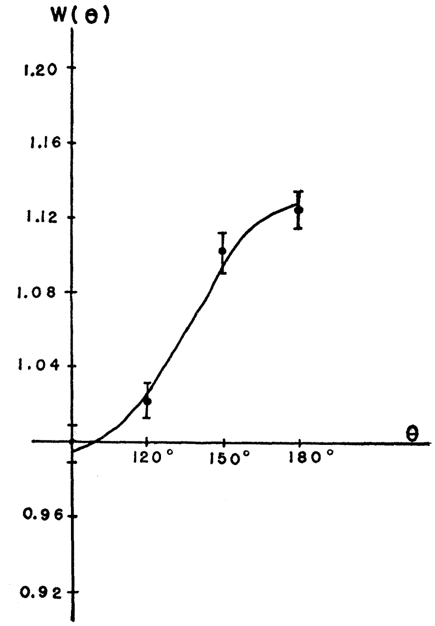

FIG. 5. 1.09-Mev—1.27-Mev correlation.

to the function

$$F(\theta)=A_0'+A_2'P_2(\cos\theta)+A_4'P_4(\cos\theta),$$

where $P_k(\cos\theta)$ is the Legendre polynomial of order k. The Rose correction was applied to the normalized expansion coefficients A_2 and A_4.

RESULTS

To obtain a clean selection of the 1.49-Mev—1.27-Mev cascade, the discrimination level of the first counter was set integrally at 0.90 Mev and the discrimination level of the second counter was set integrally at 1.3 Mev. The experimental points are shown in Fig. 4. A least squares fit of the data to the function $F(\theta)$, corrected for solid angle, gives, $A_2=0.120\pm0.045$, $A_4=0.033\pm0.018$. Table I lists several possible "pure" correlation functions. We conclude that the measured correlation is in agreement with that expected for a $4(Q)2(Q)0$ spin sequence.

To obtain a preferential selection of the 1.09-Mev—1.27-Mev cascade the discrimination level of each counter was set integrally at 0.90 Mev. The 1.49-Mev—1.27-Mev cascade will now contribute only about one tenth of the coincidence rate. The experimental points are shown in Fig. 5. The error flags represent root mean square statistical errors. A least squares fit of the data to the function $F(\theta)$, corrected for solid angle, gives $A_2=0.099\pm0.015$, $A_4=0.000\pm0.018$. This composite correlation is in good agreement with that expected for a $4(Q)2(Q)0$ spin sequence.

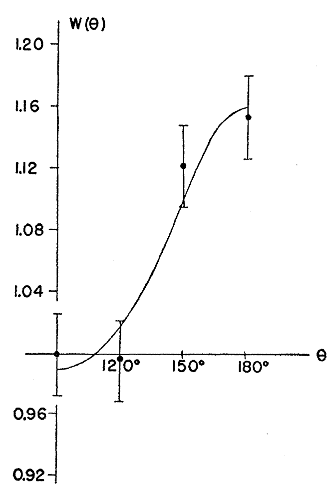

FIG. 4. 1.49-Mev—1.27-Mev correlation.

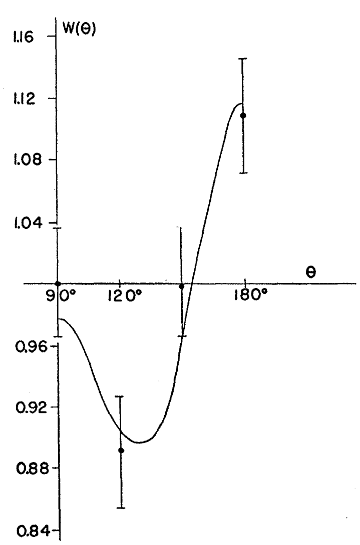

FIG. 6. 0.40-Mev—2.09-Mev correlation.

TABLE I. "Pure" correlation functions.

Correlation function	A_2	A_4
$Q-Q$ basic	0.1020	0.0091
$D-Q$ basic	−0.0714	...
$O-Q$ basic	0.1786	−0.0043
$2(D)2(Q)0$	0.2500	...
$2(Q)2(Q)0$	−0.0766	0.3264

To cleanly select the 0.40-Mev—2.09-Mev cascade the discrimination level of the first counter was set integrally at 1.90-Mev and the differential discriminator of the second counter was set to straddle the 0.40-Mev photopeak. The experimental points are shown in Fig. 6 The error flags represent root mean square statistical errors. A least squares fit of the data to the function $F(\theta)$, corrected for solid angle, gives $A_2=0.038\pm0.039$, $A_4=0.234\pm0.067$. The expansion coefficients can be simultaneously fit by a $2(D,Q)2(Q)0$ mixed correlation function as shown in Fig. 7. The error lines show the range of δ, the mixing parameter, required to fit each expansion coefficient. $\delta=5$ lies within both these regions. This means the 0.40-Mev gamma ray is a mixture of 96% quadrupole and 4% dipole radiation. The ratio of the matrix elements δ and its phase ($\pm$) are defined according to Biedenharn and Rose.[5]

The three directional correlation measurements are sufficient to assign spins to the five excited states of Sn^{116}. Measurement of the 0.80-Mev—1.27-Mev cascade would give information about the 0.80-Mev gamma ray. Only a partial selection of this cascade is possible. The discrimination level of the first counter was set at 1.1 Mev. The differential discrimination of the second counter was set to straddle the 0.80-Mev photopeak. The experimental points are shown in Fig. 8. The error flags represent root mean square statistical errors. A least squares fit of the data to the function $F(\theta)$, corrected for solid angle, gives $A_2=0.120\pm0.060$, $A_4=0.139\pm0.070$. To roughly estimate the multipolarity of the 0.80-Mev gamma ray we assume the measured correlation is a composite of $2(D,Q)2(Q)0$ and $4(Q)2(Q)0$ correlation functions. The measured expansion coefficients determine the mixing parameter δ and γ the fraction of the $4(Q)2(Q)0$ correlation function present in the composite correlation. The range of δ is shown in Fig. 9. The most probable value is $\delta=3.5$, which corresponds to a $\gamma=0.5$, a value which agrees with estimates based on the scintillation spectrum. This means the 0.80-Mev gamma ray is 90% quadrupole and 10% dipole in phase radiation.

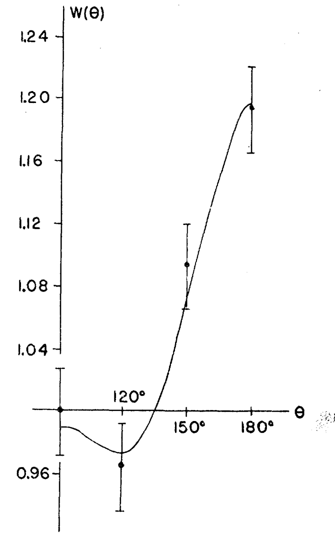

FIG. 8. 0.80-Mev—1.27-Mev correlation.

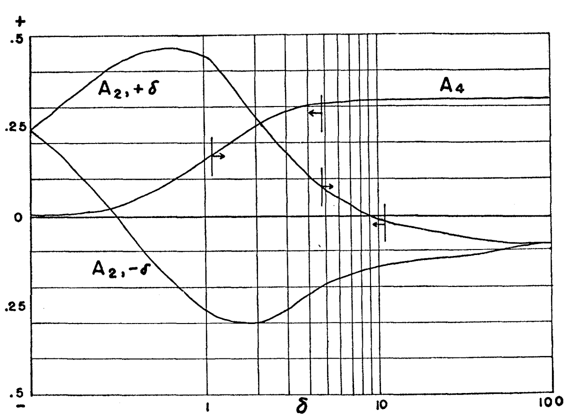

FIG. 7. Graph of the expansion coefficients of a $2(D,Q)2(Q)0$ correlation function as a function of the mixing parameter σ. The errors lines indicate the range of δ for the 0.40-Mev—2.09-Mev correlation.

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SUMMARY

We have assumed, of course, that the ground state of Sn^{116} (50 protons, 66 neutrons) is a 0^+ level. On the basis of the above directional correlation measurements

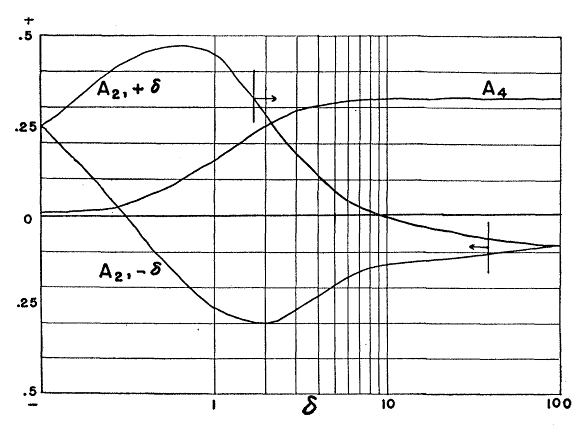

FIG. 9. Graph of the expansion coefficients of a $2(D,Q)2(Q)0$ correlation function as a function of the mixing parameter σ. The error lines indicate the range of δ for the 0.80-Mev—1.27-Mev correlation.

we make the following spin assignments: 1.27-Mev level spin 2, 2.09-Mev level spin 2, 2.36-Mev level spin 4, 2.49-Mev level spin 2, and 2.75-Mev level spin 4. We further classify the 1.09-Mev, 1.27-Mev, 1.49-Mev, 2.09-Mev gamma rays as quadrupole, the 0.40-Mev transition as a 96% quadrupole, 4% dipole 0° phase, and the 0.80-Mev gamma ray as a 90% quadrupole, 10% dipole 0° phase radiation.

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Nuclear Elastic Scattering of Photons*

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A NaI(Tl) scintillation spectrometer biased to detect only photons in the upper energy tip of a betatron-produced bremsstrahlung spectrum is used to measure the differential nuclear elastic scattering cross section at 120 degrees as a function of photon energy from 4 to 40 Mev. The targets ranged in Z from Na to U. Total cross sections are calculated by assuming a dipole angular distribution. The scattering cross sections tend to exhibit two maxima, one below the particle threshold that corresponds to the scattering by separate levels, and one that follows the giant resonance for photon absorption. Both the maximum cross section and the energy of the giant resonance vary smoothly with A from Na to U and are roughly proportional to $(NZ/A)^2$ and $A^{-1/3}$, respectively. The dipole dispersion relation is used to compare the scattering data with the neutron yield data in the giant resonance region.

I. INTRODUCTION

THE absorption of gamma rays by nuclei has been the subject of numerous investigations. The most recent compilations of experimental data are those given by the Saskatchewan[1] and Pennsylvania[2] groups. Most of this work has involved the measurement of neutron emission cross sections which, when integrated over the "giant resonance," have been compared to the predictions of the dipole sum rule. The elastic scattering process associated with the nuclear absorption of photons presents an alternative way of studying the basic interaction. This paper is an account of an experimental study of the elastic scattering cross section as a function of both energy and atomic number.[3] The results are compared with the neutron yield cross sections.

The scattering of photons in the region of the "giant resonance" was probably first observed by Gaerttner and Yeater[4] and Dressel, Goldhaber, and Hanson.[5] In a more refined experiment[6] Stearns studied the scattering of the Li(p,γ) photons by various nuclei using a NaI(Tl) scintillation counter which detected only the elastically scattered photons. The results indicated that the cross section for the elastic scattering of 17-Mev photons by heavy nuclei is of the order of a few millibarns.

II. EXPERIMENTAL METHOD

The present experiment is an extension of the Stearns experiment. The discrimination level of a large NaI(Tl) scintillation spectrometer is set to detect only the photons in the upper energy tip of the betatron bremsstrahlung spectrum. The spectrometer is first calibrated at a given energy by observing the number of counts, C_1, produced when the spectrometer is placed in the direct beam from the betatron (see Fig. 1). Simultaneously a charge, Q_1, is collected from a transmission ionization chamber in the direct beam. With the detector rotated to the 120° position the number of counts, C_2, produced by scattered photons is recorded while a charge, Q_2, is collected from the ionization chamber. On the assumption that the shape of the bremsstrahlung spectrum is the same for both the high and low intensity beams, the elastic scattering cross section is then given by:

$$\langle\sigma_s\rangle_{\mathrm{Av}}=K(C_2/Q_2)\cdot(Q_1/C_1), \qquad (1)$$

where K includes geometrical factors as well as a correction for the absorption of photons in the target. The scattering cross section was determined as a function of energy from 4 to 40 Mev by changing both the peak energy of the betatron and the gain of the amplifier so as to keep the end of the bremsstrahlung spectrum at the same discrimination level. The measured cross

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