# PHOTONEUTRON ANGULAR DISTRIBUTIONS FROM LEAD AND BISMUTH*

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The angular distributions of photoneutrons emitted from lead and bismuth under irradiation by 17·5 MeV bremstrahlung have been measured. This work was part of a program aimed at understanding systematic features of photoneutron angular distributions as the target atomic mass number is varied.

The photoneutrons were detected in this experiment by observing neutron-proton recoils in a stilbene crystal of 1 in. diameter and 1 in. long. The use of a scintillation counter to measure fast neutron angular distributions is complicated by the large flux of background $\gamma$-radiation which is naturally present during such an experiment. It is not possible to separate by simple pulse-height analysis those pulses produced by neutrons (recoil protons) from those produced by $\gamma$-radiation (Compton electrons). In this experiment a separation was achieved using the technique of pulse-shape discrimination in the manner described by Owen (1959, 1962), and uses the fact that the neutron-produced pulses have a longer decay time than those produced by $\gamma$-radiation.

A display system of the type discussed by Brooks (1959) was used during the initial adjustment of circuit parameters to obtain maximum efficiency of discrimination. The performance of a pulse-shape discrimination circuit is a function of the count rate, including those finally rejected as due to $\gamma$-rays. Thus considerable care was taken with the shielding of the scintillation counter.

The energy response of the crystal was calibrated using monoenergetic neutrons of known energies from the $^{3}H(p,n)^{3}He$ and $^{2}H(d,n)^{3}He$ reactions. Eight calibration points were obtained for neutrons with energies between 2·6 and 8·5 MeV. Following this the energy bias was set to count only those neutrons whose energy was above 4·5 MeV.

Extensive shielding protected the scintillation counter unit from bremstrahlung coming directly from the synchrotron. Two inches of lead was placed in front of the scintillation counter to shield it from $\gamma$-rays scattered from the target. It was shown that the lead had a negligible effect on the measured angular distribution. Data were taken at 15° intervals between 45° and 135°, and the counting statistics were approximately 3% at each point. The bremstrahlung dose delivered to the targets was monitored by a Victoreen thimble. The stability of the electronic and photomultiplier tube systems was checked frequently using a precision sliding pulser or by taking standard counts with a Po-$\alpha$-Be neutron source.

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The experimental data were fitted by a least-squares method to a function of the form

$$Y = k(1+a_1 \cos\theta+a_2 \cos^2\theta).$$

These fits gave $a_1 = -0{\cdot}01\pm0{\cdot}03$, $a_2 = -0{\cdot}58\pm0{\cdot}08$ for bismuth and $a_1 = 0{\cdot}03\pm0{\cdot}03$, $a_2 = 0{\cdot}39\pm0{\cdot}05$ for lead. Thus, within experimental error, there is no asymmetry of the distributions about 90°. The distributions are shown in Figure 1.

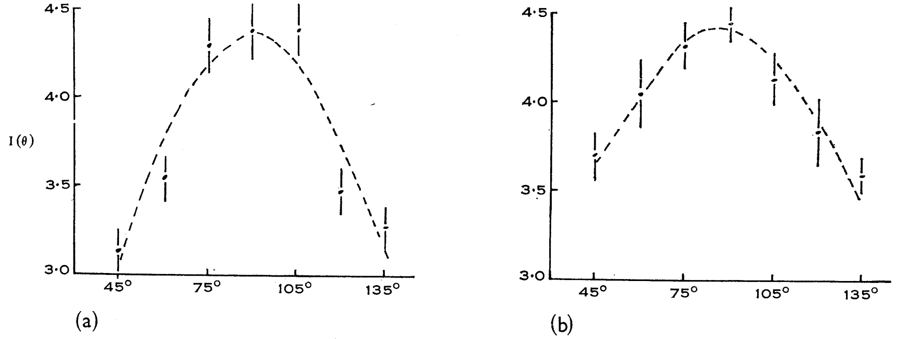


Fig. 1.—Fast photoneutron (>4·5 MeV) angular distributions from bismuth and lead. (*a*) Bismuth, $I(\theta) = 4{\cdot}36-0{\cdot}04\cos\theta-2{\cdot}52\cos^2\theta$ (dotted line); (*b*) lead, $I(\theta) = 4{\cdot}40+0{\cdot}14\cos\theta+1{\cdot}71\cos^2\theta$ (dotted line).

A theory has been proposed (Quirk and Spicer 1964) which ascribes the forward peaking of fast photoneutron angular distributions to the occurrence of proton-neutron collisions within the nucleus where the photon was absorbed. If the mean free path of a nucleon in nuclear matter is greater than the nuclear radius, such collisions are improbable, and the angular distributions are expected under those circumstances to be symmetric about 90°. In the cases of lead and bismuth, the mean free path must be less than 7 fermi for there to be a 50% chance of a proton-neutron collision. According to Quirk and Spicer (1964), this equality occurs for a proton energy of 13 MeV, which implies a photon energy greater than 21 MeV. Thus the present experiment, using 17·5 MeV bremstrahlung, should show no detectable asymmetry about 90°, and this is indeed the case.

## *References*

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