ANGULAR DISTRIBUTION OF ELASTICALLY SCATTERED 14.5-Mev NEUTRONS

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The differential cross sections for elastic scattering of 14.5-Mev neutrons on silver, mercury, and bismuth were measured. Neutrons from the T(d, n)α reaction were scattered from spherical targets and counted in coincidence with the accompanying α particles by means of a pulse height-time analyzer with a resolving time of 5×10^{-9} sec. The experimental differential cross sections are compared with cross sections calculated on the basis of the optical model.

1. INTRODUCTION

IN the last few years, a large number of measurements of differential cross sections for elastic scattering of protons and neutrons by nuclei have been published. These measurements have been performed over a wide energy range for the scattered nucleons and for a substantial number of nuclei. Aside from its purely practical purposes (neutrons in the fission energy range), this subject has become interesting because of the success of the optical model of the nucleus,[1] particularly its later modifications,[2,3] which agree quite well with experiment. For comparison with the optical model, neutron experiments are preferable because there is no Coulomb interaction with the nucleus. The 14.5-Mev neutrons from the T(d, n)He^4 reaction have often been used for this purpose,[4-9] because, on the one hand, the reaction is easy to realize experimentally and the neutrons are monoenergetic and are accompanied by α particles (which are utilized in a considerable number of the experiments), and, on the other hand, theoretical considerations lead one to expect that at this neutron energy processes involving compound nucleus formation should make a very small contribution to the total scattering. However, the data on angular distributions from elastic scattering of 14.5-Mev neutrons are as yet available for a limited number of nuclei.

2. APPARATUS

The technique known as electronic collimation of the neutrons was applied for the measurements. This collimation technique is based on the correlation of the neutron with its accompanying α particle and is accomplished by means of a pulse height-time analyzer.[10]

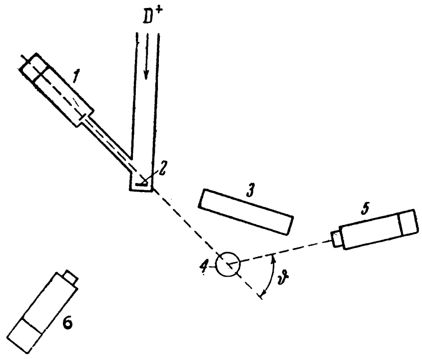

FIG. 1. Experimental arrangement: 1 – α particle counter, 2 – tritium target, 3 – shield, 4 – scatterer, 5 – detector, 6 – monitor.

The experimental arrangement is shown in Fig. 1. The neutrons were produced from the T(d, n)α reaction in a neutron generator.[11] A scintillation counter with a stilbene crystal (diameter 3.5 cm, length 2.4 cm) and an FÉU-33 photomultiplier was used as the neutron detector. The output of the photomultiplier, on which an amplitude resolution of 7% was attained with good output pulse shape, was sent through a fast electronic gate into a pulse-height analyzer.

The accompanying α particles were recorded by a thin stilbene crystal (0.04 cm) on the photocathode of an FÉU-33. An aluminum foil (0.9 mg/cm^2) was between the crystal and the target.

The neutrons detected in coincidence with particles are in a solid angle determined by the angle subtended by the α particle counter. The "collimation curve," Fig. 2, obtained by measuring the neutron intensity as a function of angle around the tritium target, gives 9° for the half-width of the collimated neutron beam. In addition, a copper shield was placed between the target and the neutron detector.

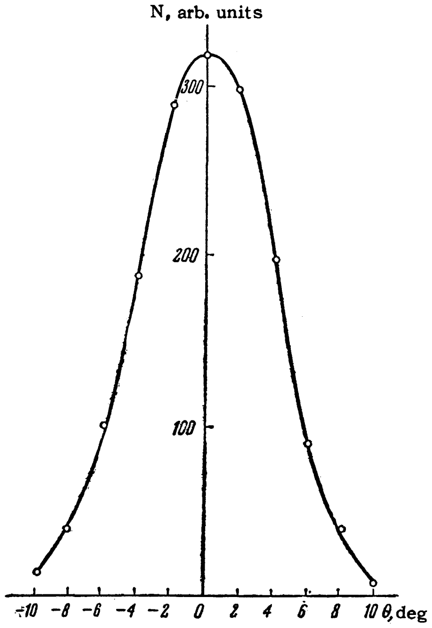

FIG. 2. Collimation curve (N is the number of counts).

The scatterers were spheres, 4 cm in diameter (the mercury was in a thin-walled container).

A block diagram of the pulse height-time analyzer is shown in Fig. 3. The pulses from the anode of the photomultiplier are limited by a 6Zh5P pentode, clipped by a short-circuited coaxial cable, and then go to the coincidence diode. A delay line ensures that the neutron pulses coincide with the pulses from the accompanying α particles.

The pulses for the pulse height analyzer are taken from the tenth dynode of the photomultiplier and after going through an amplifier and a discriminator are fed into a triple coincidence circuit with a resolution of 5×10^{-7} sec. The slow coincidence circuit is useful for eliminating counts due to inelastic neutrons, γ rays, and photomultiplier noise.

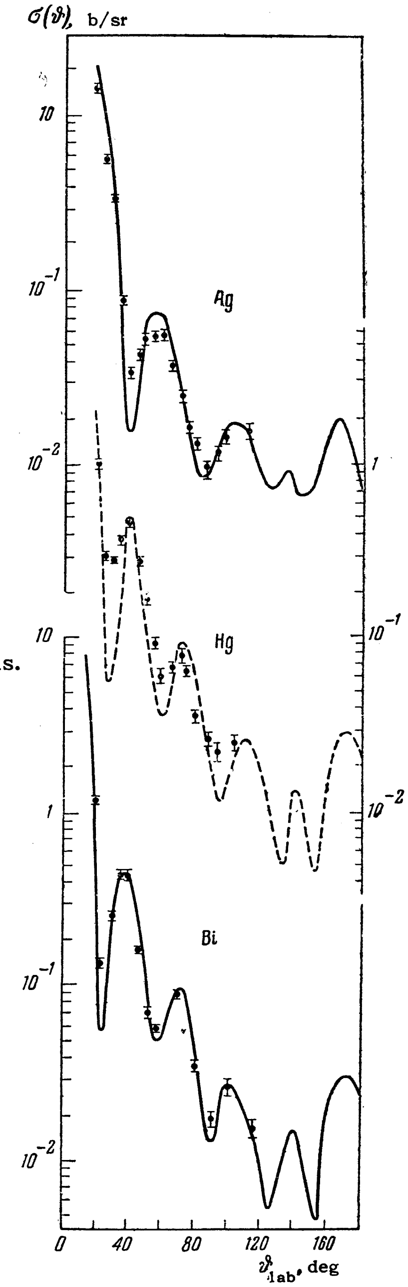

FIG. 4. Elastic scattering differential cross sections for 14.5-Mev neutrons on silver, mercury, and bismuth. The curves are the results of optical-model calculations.

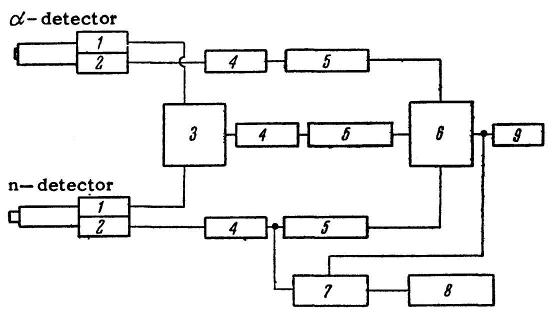

FIG. 3. Block diagram of the pulse height-time analyzer. 1 – limiting pentode, 2 – cathode follower, 3 – fast coincidence circuit, 4 – amplifier, 5 – discriminator, 6 – triple coincidence circuit, 7 – amplitude-preserving gate, 8 – pulse height analyzer, 9 – counter.

The resolving time of the analyzer can be controlled by a retarding voltage on the coincidence diode and also by changing the setting of the discriminator in the time channel. In the present experiment it was a 4×10^{-9} sec. By increasing the discriminator setting, a resolving time of 1×10^{-9}sec can be attained, but the efficiency of the circuit is then strongly decreased.

3. MEASUREMENTS AND COMPUTATIONS

Measurements were carried out on silver, mercury, and bismuth for scattering angles, ϑ, from 20° to 110°.

In order to compute the absolute differential cross section, it is necessary to determine experimentally the ratio

$$S(\vartheta) = (N_s - N_b)/N_d, \quad (1)$$

where N_s is the number of counts due to neutrons elastically scattered through the angle ϑ, N_b is the number of counts due to noise, and N_d is the number of counts in a measurement in the direct neutron beam.

N_s, N_b, and N_d are normalized by the monitor. The differential cross section is calculated from the formula

$$\sigma_{el}(\vartheta) = S(\vartheta)\,[R_1R_2/(R_1+R_2)]^2 \times \exp\{n\sigma_{in}\,d\}[NB(E_n)\eta]^{-1}, \quad (2)$$

Where R_1 is the distance from source to scatterer, R_2 is the distance from scatterer to detector, n is the number of nuclei per cubic centimeter in the scatterer, σ_{in} is the inelastic cross section, d is the thickness of the scatterer, N is the number of scattering nuclei, $B(E_n)$ takes into account the energy sensitivity of the detector, η takes into account the collimation configuration of the neutron beam, and $[R_1R_2/(R_1+R_2)]^2$ is the coefficient which reduces the ratio $S(\vartheta)$ to unit solid angle.

The threshold for discriminating against inelastically scattered neutrons was taken to be 11 Mev.

The configuration of the collimated neutron beam was taken into account in computing the cross section; this allowed the absolute value of $\sigma_{el}(\vartheta)$ to be obtained and eliminated the necessity of normalizing the experimental results to the theoretical curve, as was done, for example, in the work of Berko et al.[5]

The experimental data were corrected for depletion of the beam in the scatterer; the use of σ_{in} instead of the total cross section σ_t in these corrections partially takes into account multiple scattering. Corrections for finite geometry were made by a method similar to that used in the work of Meier et al.[12]

4. RESULTS

The experimental results are shown in Fig. 4 along with theoretical curves. The angles are given in the laboratory coordinate system. The statistical errors, varying from 4% at scattering angles less than 50° to 7 or 8% at larger angles, are shown in the figure. The results in bismuth are in good agreement with those of several other experiments.[5,7,9] For silver, the data for scattering angles less than 90° are the first that have been obtained. Nauta's measurements on mercury are less accurate than the present ones.

The theoretical curves shown in Fig. 4 are taken from references 5 and 6. These curves were calculated with the potential proposed by Bjorklund and Fernbach:[2]

$$V = V_{CR}\,p(r) + iV_{CJ}\,q(r) + V_{SR}(\hbar/mc)^2\frac{1}{r}\frac{dp}{dr}(\sigma l),$$

where

$$p(r) = [1 + \exp\{(r - R_0)/a\}]^{-1},$$
$$q(r) = \exp[-(r - R_0)^2/b^2], \qquad R_0 = r_0A^{1/3}. \quad (3)$$

The parameters which give the best fit for 14.5 Mev neutrons are V_{CR} = 44 Mev, V_{CJ} = 11 Mev, V_{SR} = 8.3 Mev, a = 0.65 f, b = 0.98 f, r_0 = 1.25 f.

Since there were no theoretical curves for mercury at our disposal, the experimental points in this case are compared with the curve for lead. Such a comparison is reasonable, since mercury and lead do not differ much in atomic weight.

The agreement of the calculated curves and the experimental points is sufficiently good.

[1] Feshbach, Porter, and Weisskopf, Phys. Rev. **96**, 448 (1954).

[2] F. E. Bjorklund and S. Fernbach, Phys. Rev. **100**, 1295 (1958).

[3] Luk'yanov, Orlov, and Turovtsev, JETP **35**, 750 (1958), Soviet Phys. JETP **8**, 521 (1959).

[4] H. Nauta, Nuclear Phys. **2**, 124 (1956).

[5] Berko, Whitehead, and Groseclose, Nuclear Phys. **6**, 210 (1958).

[6] Anderson, Gardner, Nakada, and Wong, Phys. Rev. **110**, 160 (1958).

[7] Coon, Davis, Felthauser, and Nicodemus, Phys. Rev. **111**, 250 (1958).

[8] K. Yuasa, J. Phys. Soc. Japan **13**, 1248 (1958).

[9] L. A. Rayburn, Phys. Rev. **116**, 1571 (1959).

[10] Bobyr', Grona, and Strizhak, Ukr. Fiz. Zhurn. **5**, 591 (1960).

[11] V. I. Strizhak and N. S. Nazarov, Приборы и техника эксперимента (Instrum. and Meas. Techniques) **2** (1960).

[12] Meier, Scherrer, and Trumpy, Helv. Phys. Acta **27**, 577 (1954).

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