ANGULAR DISTRIBUTION OF PHOTONEUTRONS FROM Bi^{209}

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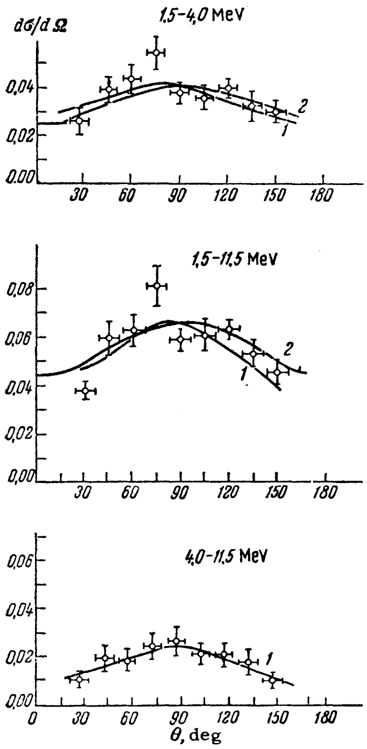
Angular distributions are obtained for 1.5 to 4.0 and 4.0 to 11.5 MeV photoneutrons emitted from Bi^{209} irradiated by bremsstrahlung γ-rays with $E_{\gamma max} = 85$ MeV. The neutrons are registered with NIKFI-Ya2 photographic emulsions $400\,\mu$ thick. The contribution of the anisotropically distributed part to the total photoneutron yield is ~ 20%. In absolute units the total photoneutron yield for energies between 1.5 and 11.5 MeV is $(3.7 \pm 0.8) \times 10^{-3}$ neutrons/mole-MeV-cm^{-2}.

MEASUREMENTS of the spectrum of Bi^{209} photoneutrons produced by bremsstrahlung irradiation of a bismuth plate were previously [1] reported. In the following we increase the statistics of the measurements, which were made at the same conditions of the experiment and by the same method of particle registration. We obtained the angular distributions of the photoneutrons at energies 1.5—4 and 4.0—11.0 MeV (see the figure). The maximum energy of the bremsstrahlung spectrum obtained was 85 MeV.

We have measured 8989 tracks of recoil protons. The error in the determination of the number of neutrons, which is given in the figure, is the result of the statistical error, the error in the determination of the correction to the probability of escape of the proton from the emulsion, the uncertainty in the cross-section of the scattering of neutrons by emulsion protons, the error in the determination of the solid angle, and the error in measuring the observed volume. The angular resolution in the figure is ±4°.



The angular distribution of the photoneutrons is anisotropic. According to the data obtained by us, the contribution of the anisotropically distributed part of the photoneutrons to the total emission at 1.5—11.5 MeV is 20%. The absolute magnitude of the total emission of the photoneutrons was measured by us by the same method. For the energy-interval 1.5—11.5 MeV it is $(3.7 \pm 0.8)10^{-3}$ neutrons/mole-MeV-cm^{-2}.

According to the statistical model, the angular distribution from the nucleus Bi^{209} ($s_0 = 9/2$) should be practically isotropic. [2] The curve 2 in the figure corresponds to our evaluation of the angular distribution of the direct resonance photoneutrons, using the independent particle model [3] and taking into account only the electric dipole transitions in the nucleus. The relative probabilities of the principal transitions are the following

$3p_{1/2} \to d_{3/2}$	$3p_{3/2} \to d_{5/2}$	$2f_{5/2} \to d_{3/2}$	$3p_{3/2} \to s_{1/2}$
0.29	0.13	0.18	0.24

The curves 1 in the figure correspond to least-square fitting. It is possible to represent them by the following formulas:

$$1.5 - 4.0\ \text{MeV}: (1.00 \pm 0.08) + (0.10 \pm 0.08)\cos\theta - (0.4 \pm 0.1)\cos^2\theta,$$

$$4.0 - 11.5\ \text{MeV}: (1.00 \pm 0.08) + (0.02 \pm 0.08)\cos\theta - (0.7 \pm 0.2)\cos^2\theta,$$

$$1.5 - 11.5\ \text{MeV}: (1.00 \pm 0.05) + (0.07 \pm 0.05)\cos\theta - (0.5 \pm 0.1)\cos^2\theta.$$

It can be seen that the curves are slightly asymmetric about 90°.

The asymmetry in the angular distribution of the photoneutrons from Bi^{209} was previously observed in [4,5] at $E_{\gamma max}$ = 20 MeV and $E_{\gamma max}$ = 30 MeV, in [6] at $E_{\gamma max}$ = 22 MeV, and in [7] at $E_{\gamma max}$ = 55 MeV. In our work it was measured at considerably higher maximum bremsstrahlung energy. However, the magnitude of the shift of the maximum of the angular distribution in the direction of small angles did not increase.

Calculations that take only the electric dipole excitation of the nucleus into account do not reflect in any way the observed asymmetry in the character of the photoneutron angular distribution. In the case of electric dipole transitions the asymmetry might appear only as a result of the shift in the angular distribution, due to the transformation from the barycentric to the laboratory system, which turns out to be very small ($\sim 20'$) for heavy nuclei.

It is therefore possible to attribute the asymmetry to the addition of non-dipole transitions of the nucleus. Since the E2 interaction appears to be the most probable, the interference of the interaction of E1 and E2 γ-quanta with the nucleus might explain the character of the angular distribution. For a quantitative explanation, however, it is necessary to regard the effective charge of the neutron in quadrupole interaction, as being increased to the order of the proton charge.

If one accepts such an explanation, then the aggregate of the results on the angular distribution of photoneutrons from Bi^{209} [4-7] (which the results of this work do not contradict) and the investigations by Shevchenko and Yur'ev [8] of the photoneutron angular distribution as well as the work of Balashov [9] [which explains the magnitude of the cross-section of the reaction $(\gamma\gamma')$], confirm the supposition of quadrupole resonance absorption (20—25 MeV) directly beyond the "giant resonance" for dipole absorption.

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[9] V. V. Balashov, JETP **43**, 2199 (1962), Soviet Phys. JETP **16**, 1553 (1963).

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