Asymmetry of the cross section for the inclusive photodisintegration of the lithium-6 nucleus by linearly polarized γ rays

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The asymmetry of the cross sections for the inclusive process $\gamma^6\text{Li}\to px$ has been measured at a proton emission angle of 90° in the laboratory frame in beams of linearly polarized, monochromatic γ rays with energies of 60, 140, and 300 MeV. A significant asymmetry has been observed. The energy dependence of this asymmetry agrees with that of the asymmetry for the reaction $\gamma d\to pn$.

Inclusive photoprocesses involving light nuclei at intermediate energies have recently attracted increased research interest. The progress in this research and the interest in it stem from the production of intense beams of monochromatic γ rays with an energy resolution $\sim$1–2% at many electron accelerators. Such beams make it possible to determine more precisely the mechanism by which the γ rays are absorbed by nuclei and to obtain information on the nuclear structure, the nucleon wave functions, the wave functions of clusters of nucleons in the nuclei, etc.

The information obtained to date indicates that the yield of protons and proton-neutron pairs at γ-ray energies above the giant dipole resonance but below the threshold for the photoproduction of pions can be explained by Levinger's model,[1] which assumes that the γ ray is absorbed in the nucleus by a bound (p, n) pair. The kinematic criteria, while indicating a definite photoproduction mechanism, e.g., that of Ref. 1, generally do not determine the spin state of the nucleon correlation, which may, in general, vary. A new and sensitive tool for determining the mechanism for the absorption of γ rays by nuclei—and which furthermore allows a study of the state of the nucleon cluster—is the symmetry of the cross sections for the inclusive process:

$$\Sigma=(\sigma_{\parallel}-\sigma_{\perp})/(\sigma_{\parallel}+\sigma_{\perp}), \tag{1}$$

where $\sigma_{\parallel(\perp)}=d\sigma_{\parallel(\perp)}(\theta,p,E_{\gamma})/d\Omega dP$ is the differential reaction cross section due to linearly plarized γ rays with polarization vector directed parallel (or perpendicular) to the reaction plane, and P and θ are the momentum and emission angle of the detected particle. There have been no previous experimental studies of this sort.

In this letter we report measurements of the asymmetry of the cross sections of the reaction

$$\gamma^6\text{Li}\to px \tag{2}$$

for a proton emission angle $\theta=90°$ in the laboratory frame in a linearly polarized beam of monochromatic γ rays. The experiments were carried out at the Khar'kov LUÉ-2000 linear electron accelerator at γ-ray energies $E_\gamma = 60$, 140, and 300 MeV. The kinematic range studied includes the region corresponding to the emission of protons from the deuteron photodisintegration reaction $\gamma d \rightarrow pn$.

The monochromatic γ-ray beam was obtained from the coherent bremsstrahlung of electrons with energies of 600, 1000, and 1200 MeV, respectively, in a diamond single crystal 0.3 mm thick. The crystal was oriented in the goniometer in such a way that a single reciprocal-lattice site, (2,0), contributed most of the coherent bremsstrahlung. The spectrum of coherent-bremsstrahlung γ rays has a characteristic interference maximum, against the background of an incoherent (Schiff) bremsstrahlung. To single out the interference component, we measured the energy distributions of γ rays at deuterium and lithium targets for three orientations of the crystal under identical kinematic conditions. In one orientation of the crystal, the polarization vector of the beam was directed parallel to the reaction plane. In the second orientation, it was directed perpendicular to the reaction plane. In the third orientation, the crystal was not oriented (the situation was equivalent to an amorphous target). Taking the difference between the proton spectra for the oriented crystals, $C_{\parallel(\perp)}(\theta,P,E_\gamma)$, and for the disoriented crystal, $C_0(\theta,P,E_\gamma)$ we obtained the spectra of protons due to the monochromatic γ rays. The spectrum of these γ rays is shown in Fig. 1a. It corresponds to that part of the coherent-bremsstrahlung spectrum which is shown above the dashed line in this figure. The solid line shows results calculated from the theory for coherent bremsstrahlung with the experimental parameter values on the collimation, multiple

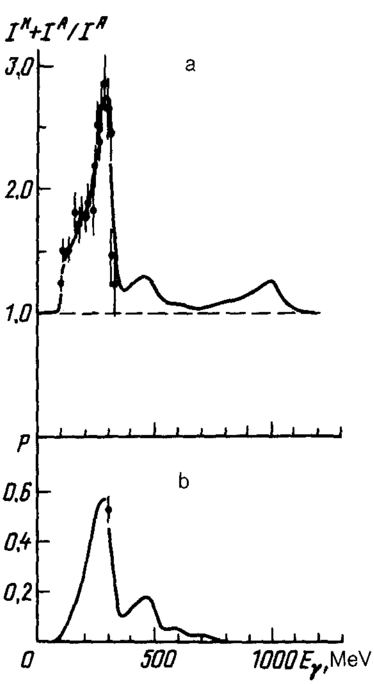

FIG. 1. a: Energy distribution of the intensity ratio of the coherent and incoherent components of the bremsstrahlung. Here I^K and I^A are respectively the interference and noninterference components of the coherent bremsstrahlung ($E_0 = 1200$ MeV, $E_\gamma = 300$ MeV). Points—experimental spectrum of the coherent bremsstrahlung; curve—calculated from the theory of coherent bremsstrahlung. b: Theoretical energy dependence of the polarization of the coherent bremsstrahlung. Point—experimental polarization value found by the method of Ref. 2.

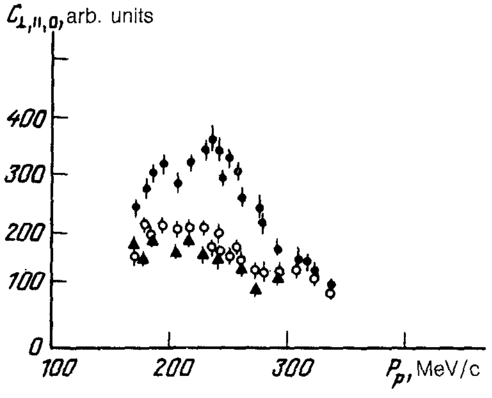

FIG. 2. Spectra of protons from reaction (2) ($E_\gamma = 60$ MeV, $E_0 = 600$ MeV). ●— $C_\parallel(\theta,P,E_\gamma)$; ○—$C_\perp(\theta,P,E_\gamma)$; ▲— $C_0(\theta,P,E_\gamma)$.

scattering, and divergence of the electron beam. The effective values of these parameters were found by fitting the theory to the experimental data. The width at half-maximum of the interference part of the coherent-bremsstrahlung peak is $\sim 25\%$. The flux density of γ radiation was measured within an error of no worse than 2% by a total-absorption quantameter. The energy dependence of the polarization was calculated theoretically (Fig. 1b). To test the calculation, we determined the magnitude of the polarization at the maximum of the coherent-bremsstrahlung spectrum experimentally, from the yields $C_{\parallel,\perp,0}$ measured for the reaction $\gamma d \to pn$, by the method of Ref. 2.

The deuterium target was a cylinder 20 mm in diameter, whose axis was oriented perpendicular to the beam. The thickness of the lithium target was 3 mm. Protons were identified by a two-channel telescope of scintillation counters by means of magnetic analysis and the dE/dx method. The momentum capture of each channel was 2.7%. The background particles (π^+, e^+) amounted to no more than 2–3% of the measured proton yields.

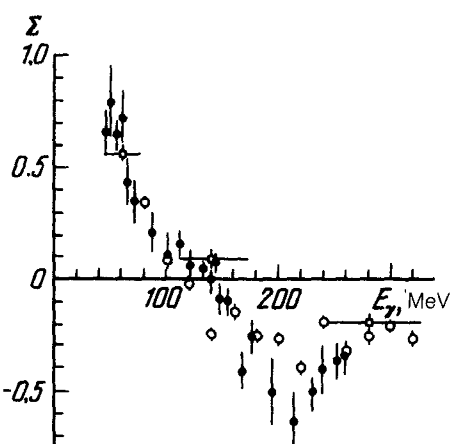

FIG. 3. Energy dependence of the asymmetry. □—The reaction $\gamma ^6\mathrm{Li} \to px$; ●—the reaction $\gamma d \to pn$, ○—results of the measurements of Ref. 2 for $\theta = 105°$ in the c. m. frame, $\gamma d \to pn$.

The proton spectra $C_{\parallel,\perp}(\theta,P,E_\gamma)$ found in inclusive reaction (2) turned out to be sensitive to the direction of the beam polarization vector (Fig. 2). After integrating these distributions in the proton momenta, we can express the asymmetry of reaction (2) in terms of the integrated yields $C_{\parallel,\perp}(\theta,E_\gamma)$

$$\Sigma(\theta,E_\gamma)=\frac{1}{\mathcal{P}}\frac{C_\parallel(\theta,E_\gamma)-C_\perp(\theta,E_\gamma)}{C_\parallel(\theta,E_\gamma)+C_\perp(\theta,E_\gamma)},$$

where $\mathcal{P}$ is the mean value of the polarization of the interference part of the coherent-bremsstrahlung beam, found by taking an average of the calculated polarization spectrum. Figure 3 shows values found for the asymmetry along with the asymmetry of the reaction $\gamma d\to pn$ which we measured under the same kinematic conditions, and also data from Ref. 2. We see that the asymmetries in the two processes have an identical energy dependence and are approximately the same in magnitude. This agreement indicates that under these particular kinematic conditions the emission of protons is apparently due to the absorption of γ rays by bound nucleon pairs, which are primarily in the $^3S_1$ state, and that the wave function of these pairs is approximately that of the real deuteron. Rescattering effects play no important role in this case.

[1]J. S. Levinger, Phys. Rev. **84**, 13 (1951).
[2]V. G. Gorbenko *et al.*, Yad. Fiz. **35**, 1073 (1982) [Sov. J. Nucl. Phys. **35**, 627 (1982)].

Translated by Dave Parsons