Asymmetry of the cross sections for inclusive (γ, p) and (γ, π) reactions induced by helium-3 and helium-4 nuclei

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(Submitted 14 March 1988)
Pis'ma Zh. Eksp. Teor. Fiz. **47**, No. 9, 438–441 (10 May 1988)

The asymmetry of the cross sections for the inclusive processes $\gamma\, ^{3,4}\text{He} \to px$, $\gamma\, ^3\text{He} \to \pi^\pm x$, and $\gamma^4\text{He} \to \pi^- x$ has been measured in a beam of linearly polarized monochromatic photons for a particle emission angle of 90° in the laboratory frame, for photon energies of 60, 140, and 350 MeV for the (γ, p) reaction and 350 MeV for the (γ, π) reaction. The asymmetry value turns out to be close to that for the elementary processes $\gamma d \to pn$ and $\gamma N \to N\pi$.

Intense beams of monochromatic photons in the intermediate energy region with a small energy spread ($\sim$1–2%) have recently been produced at many electron accelerators. This capability is spurring further progress in research on photonuclear reactions. In particular, it has revived interest in research on inclusive processes,[1,2] since beams of this sort make possible a clearer determination of the mechanisms by which photons are absorbed by nuclei and allow the acquisition of new information on the structure of the nuclei, the state of the nucleons and their clusters, etc.

The information currently available indicates that two absorption mechanisms are possible at intermediate energies: Over the photon interval from the giant dipole resonance to the threshold for pion photoproduction, the yield of protons and of proton-neutron pairs can be explained on the basis of Levinger's model,[3] which assumes that the photons are absorbed by bound (p, n) pairs. At energies above the pion photoproduction threshold, the primary photoabsorption mechanism is believed to involve the quasifree production of pions by nucleons of the nucleus. While the kinematic criteria do indicate a definite absorption mechanism, they generally do not determine the quantum state of the nucleon or of the nucleon correlation, which may in general be different. A new and sensitive method for determining the mechanism by which photons are absorbed by nuclei, which would also make it possible to study the state of nucleons and of nucleon clusters, may be the asymmetry of the cross sections for an inclusive process, $\Sigma = (\sigma_\parallel - \sigma_\perp)/(\sigma_\parallel + \sigma_\perp)$, where $\sigma_{\parallel(\perp)} = [d\sigma_{\parallel(\perp)}(\theta, P, E_\gamma)/d\Omega dp]$ is the differential cross section for the reaction which is determined by linearly polarized photons with a polarization vector directed parallel (perpendicular) to the scattering plane, and P and θ are the momentum and emission angle of the detected particle. There has been no previous study of this sort.

In this letter we are reporting measurements of the asymmetry of the cross sections for the reactions

$$\begin{aligned} &\gamma^3\text{He} \to px \\ &\gamma^4\text{He} \to px \end{aligned} \quad (1)$$

 0021-3640/88/090519-04$01.00

in a linearly polarized monochromatic photon beam at the LU-2000 Khar'kov Linear Electron Accelerator at photon energies $E_\gamma = 60$, 140, and 350 MeV and also the asymmetry of the cross sections for the reactions

$$\begin{aligned} &\gamma^3\text{He} \rightarrow \pi^{\pm} x \\ &\gamma^4\text{He} \rightarrow \pi^{-} x \end{aligned} \tag{2}$$

for a photon energy of 350 MeV. The particles were detected at an angle $\theta = 90°$ in the laboratory frame. The particular kinematic region which was studied included regions corresponding to the emission of protons from the photodisintegration of the deuteron, $\gamma d \rightarrow pn$, for processes (1) and to the emission of pions from the reaction $\gamma N \rightarrow \pi N$ for processes (2). The monochromatic photon beam was produced through the coherent bremsstrahlung of electrons in a diamond single crystal with a thickness of 0.3 mm. The experimental conditions and the data acquisition procedure were the same as in Ref. 4. The pions were detected after a magnetic analysis on the basis of their range by means of a telescope of scintillation counters.

In the experiments we measured the momentum dependence of the particle yields $(p,\pi) C_{\|,\perp,0} (\theta,P,E_\gamma)$ from a target[5] filled with liquid helium-3 or helium-4, for three orientations of the crystal, with the beam polarization vector directed parallel (perpendicular) to the scattering plane, and also for an unoriented crystal (an analog of an

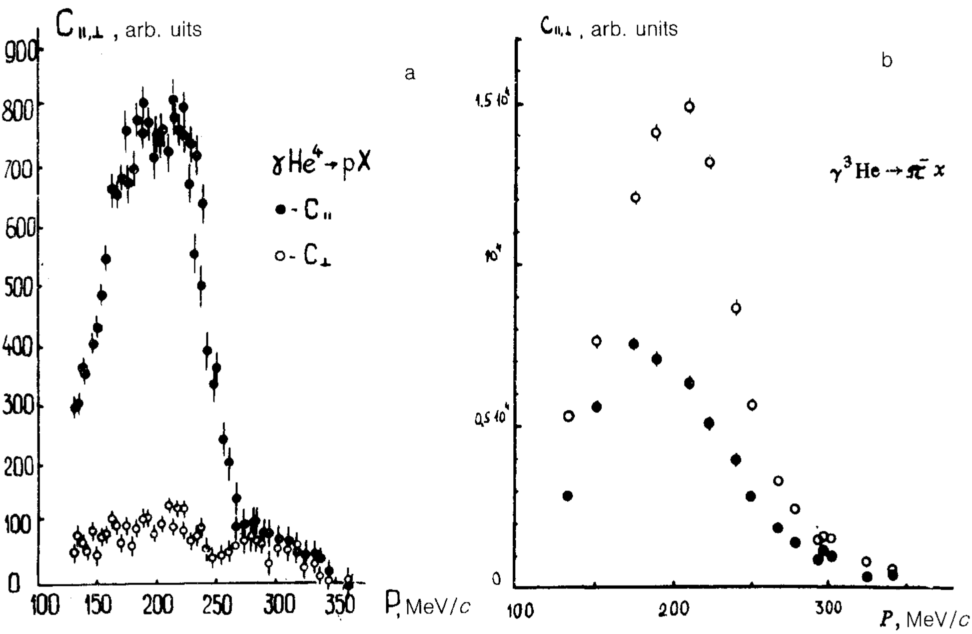

FIG. 1. a: Spectra of protons from the reaction $\gamma^4\text{He} \rightarrow px$ at $E_\gamma = 60$ MeV found by taking the difference between the spectra for oriented and unoriented crystals. ⧫—The polarization vector of the beam is parallel to the reaction plane; ♁—the polarization vector of the beam is perpendicular to the reaction plane. b: Spectra of pions from the reaction $\gamma^3\text{He} \rightarrow \pi^- x$ for $E_\gamma = 350$ MeV (the notation is the same).

amorphous target of the same thickness). Particle spectra due to monochromatic photons were found by subtracting the spectra obtained from the oriented crystal, $C_{\parallel,\perp}$, and the unoriented crystal, C_0. Figure 1 illustrates the results with spectra found by this subtraction procedure for protons from the reaction $\gamma^4\text{He}\to px$ at $E_\gamma = 60$ MeV and for π^+ mesons from the reaction $\gamma^3\text{He}\to\pi^+x$ for $E_\gamma = 350$ MeV. We see that the reaction yields depend strongly on the direction of the polarization vector.

The magnitude of the asymmetry was found, as in Ref. 4, in terms of the yields $\overline{C}_{\parallel,\perp}(\theta,E_\gamma)$, found after an integration of the proton and pion spectra (Fig. 1) over the momentum:

$$\Sigma(\theta,E_\gamma) = \frac{1}{\mathscr{P}}\,\frac{\overline{C}_\parallel(\theta,E_\gamma)-\overline{C}_\perp(\theta,E_\gamma)}{\overline{C}_\parallel(\theta,E_\gamma)+\overline{C}_\perp(\theta,E_\gamma)}\,,$$

where $\mathscr{P}$ is the mean value of the polarization of the interference part of the coherent bremsstrahlung, found by taking an average of the calculated polarization spectrum. Figure 2 shows the values of the asymmetry for reactions (1), along with the asymmetry for the reactions $\gamma d\to pn$ and $\gamma^6\text{Li}\to px$, measured in Ref. 4 under the same kinematic conditions. We see that the asymmetries of the inclusive processes in which protons are emitted have an energy behavior which is the same as that of the asymmetry of the reaction $\gamma d\to pn$. This agreement seems to indicate that the proton production mechanism under these conditions is governed by the absorption of photons by nucleon pairs with a wave function which is close to that of a real deuteron. This mechanism is also dominant at energies above the pion production threshold in the kinematic region in which the yield from pion photoproduction processes is forbidden kinematically (at angles $\theta \geqslant 90°$).

Figure 3 shows the asymmetry for reactions (2). Also shown here is the asymme-

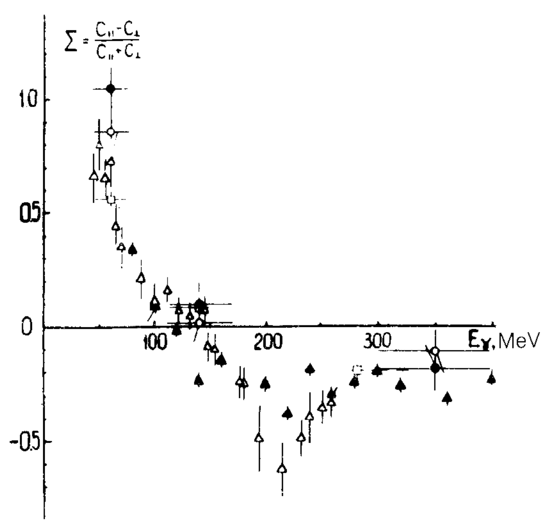

FIG. 2. Energy dependence of the asymmetry of reaction (1). ●—The reaction $\gamma^3\text{He}\to px$; ○—the reaction $\gamma^4\to px$; □—the reaction γ^6 Li$\to px$ (Ref. 4); △—the reaction $\gamma d\to pn$ (Ref. 4); ▲—the reaction $\gamma d\to pn$ (data of Ref. 8 for $\theta = 105°$ c.m.).

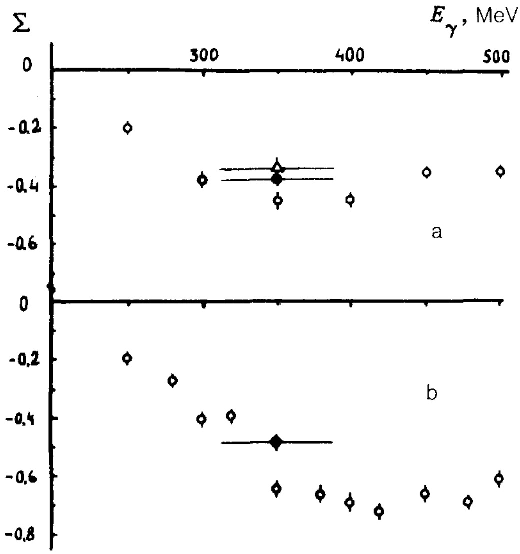

FIG. 3. Asymmetry of reactions (2). a: ♦— The reaction $\gamma^3\text{He}\to\pi^- x$; ▲—the reaction $\gamma^4\text{He}\to\pi^- x$; ◊—the reaction $\gamma n\to p\pi^-$ (data of Ref. 6). b: ♦—The reaction $\gamma^3\text{He}\to\pi^+ x$; ◊—the reaction $\gamma p\to n\pi^+$ (data of Ref. 7).

try for the elementary processes $\gamma p\to n\pi^+$ and $\gamma n\to p\pi^-$, according to the measurements of Refs. 6 and 7. We see that the asymmetry of inclusive processes (2) is large and is essentially the same as the asymmetry for pion photoproduction at free nucleons. There is a slight difference, which can apparently be explained on the basis that the asymmetry of the inclusive processes refers to a broader energy interval. The experimental results indicate that the single absorption of photons occurs through a quasifree production of pions at nucleons of the nucleus. The effects which stem from the binding of nucleons or the final-state interaction are slight, or they cancel out to a large extent in such a relative quantity as the asymmetry.

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Translated by Dave Parsons