Asymmetry in the cross sections for photodisintegration of a helium-4 nucleus by linearly polarized γ rays

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The angular distribution of the asymmetry of the cross sections in the reaction $\gamma^4\mathrm{He}\to p^3\mathrm{T}$ at energies in the range 120–250 MeV was measured for the first time in a linearly polarized photon beam. The results are compared with the calculations carried out using a gauge-invariant covariant approach.

In addition to the usual problems of nuclear physics, problems such as meson exchange currents, isobaric configurations in nuclei, and quark degrees of freedom have recently become important in the study of photodisintegration of very light nuclei. The study of these phenomena in photonuclear reactions requires the development of relativistic theoretical approaches which would satisfy the basic requirements of covariance and gauge invariance and which would take into account in a consistent way the internal structure of atomic nuclei. From the experimental standpoint, measurement of the various types of polarization characteristics of the processes with use of polarized γ-ray beams and polarized targets and measurement of the polarization of the reaction products play an important role in solving these problems.

In the present letter we report the results of an experimental study of the asymmetry of the cross sections

$$\Sigma=(d\sigma^{\parallel}-d\sigma^{\perp})/(d\sigma^{\parallel}+d\sigma^{\perp}) \tag{1}$$

in the reaction $\gamma^4\mathrm{He}\to p^3\mathrm{T}$ in the energy interval 120–250 MeV and angles of emission of protons 60°–14° in the c.m. frame in a linearly polarized γ-ray beam of the Khar'kov 2-GeV electron linear accelerator. The Σ asymmetry of the cross sections in the γ, p and γ, n photodisintegration of helium-4 nuclei was previously studied using a magnetic spectrometer with a streamer chamber only at the energy of linearly polarized 40-MeV γ-rays.[1]

The experimental hardware consisting of systems which produce and monitor the electron and γ-ray beams, a goniometric apparatus with diamond single crystal, a liquid-helium target and detecting apparatus was previously used in the study of polarization parameters in the photodisintegration of deuterium and helium-3 nuclei.[1-3]

A linearly polarized quasimonochromatic γ-ray beam was produced as a result of coherent bremsstrahlung of 1.2-GeV electrons in a 1-mm-thick diamond single crystal. A system of collimators and magnets was used to produce the γ-ray beam aimed at the liquid-helium target. The target with a 90-μm-thick stainless-steel neck had the shape of a cylinder 25 mm in diameter and 130 mm long along the beam axis.

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The channel for the reaction $\gamma^4\text{He}\to p^3\text{T}$ under study was isolated by measuring the $p,^3\text{T}$ coincidences. The protons and tritons emitted from the liquid-helium target were analyzed in terms of their momenta by two magnetic spectrometers and detected by the scintillation-counter telescopes. The energy resolution of the experiment, which was determined by the angular and momentum capture of the magnetic spectrometers, varied in the experimental energy range from $\Delta E_\gamma/E_\gamma = 0.08$ to 0. 14 MeV, with allowance for the energy loss of particles in the target and in the foil of the frame.

The time-to-amplitude converters with a resolution of 0.8 ns were used to detect the $p,^3\text{T}$ coincidences. The experiment, carried out with use of the M-6000 computer, involved the collection of data for two directions of the γ-ray polarization vectors: parallel to the reaction plane ($C^{\parallel}$) and perpendicular to it ($C^{\perp}$).

The asymmetry of the cross sections, in accordance with (1), was calculated in the following way:

$$\Sigma = \frac{1}{\overline{P}_\gamma} \frac{C^{\parallel} - C^{\perp}}{C^{\parallel} + C^{\perp}}, \qquad (2)$$

where $\overline{P}_\gamma$ is the effective polarization of the γ-ray beam found directly from the yield of the $p,^3\text{T}$ coincidences $C^{\parallel(\perp)}$, using the method described in Ref. 4.

Figure 1 compares the experimental data obtained by us with the results of a calculation of the Σ asymmetry in the reactions $^4\text{He}(\gamma,p)^3\text{T}$ and $^4\text{He}\ (\gamma,n)^3\text{He}$, which was carried out using a gradient-invariant covariant method. By exactly matching the pole parts and the regular parts with the help of the generalized Ward–Takahashi identities we were able to render gauge invariant the total amplitudes of the processes under study, with allowance for the internal structure of the nuclei.

In the two-particle processes $\gamma^4\text{He}\to NT$ ($N=p,n$; $\text{T} = {}^3\text{T},{}^3\text{He}$) the basis upon which the amplitude is determined[5] is the selection in the four-point connected Green's function of the reducible single-particle (pole) contributions which contain the familiar, strongly coupled, three-point Green's functions—the vertices of γNN, γTT, and $^4\text{He}\to N\text{T}$—of the irreducible, single-particle, four-tail contributions (the contact blocks) (Fig. 2).

For the vertex function G_λ ($\lambda = s, t, u$) we used the following parametrization:

$$G(-k_\lambda^2) = (\alpha_1^2 - k_\lambda^2) \sum_{i=1}^{4} c_i (\alpha_i^2 - k_\lambda^2)$$
$$\alpha_1^2 = m m_T - \eta_1 \eta_2 M_H^2; \quad \sum_{i=1}^{4} c_i = 0, \qquad (3)$$

where m, m_I, and M_H are the masses of the N, T, and ^4He particles, $\eta_1 = m_\text{T}/(m+m_\text{T})$, and $\eta_2 = m/(m+m_\text{T}/)$.

The argument of the covariant vertex function $G(-k_\lambda^2)$ of the virtual decay $^4\text{He}\to N$, T is defined as follows: $k_s = \eta_1 p - \eta_2 p_\text{T}$, $k_\text{T} = k_s - (\eta_{12}/m)k$, and $k_u = k_s + (\eta_{12}/m_\text{T})k$, where $\eta_{12} = m m_\text{T}/(m+m_\text{T})$, and k, p, and p_T are the mo-

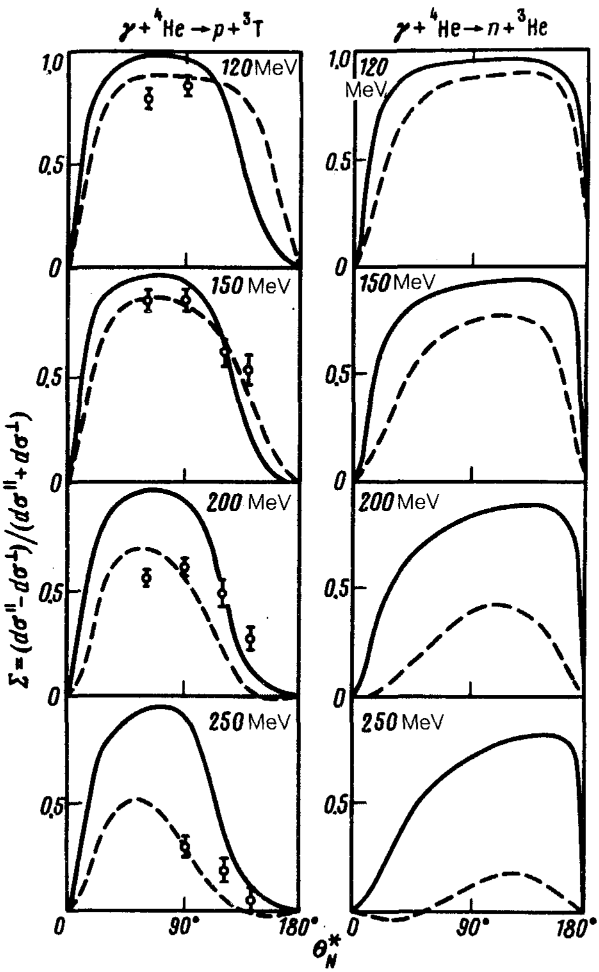

FIG. 1. Angular distribution of the asymmetry of the cross sections. Solid curves—Calculation in which the Roper resonance is ignored; dashed curves—calculation in which the Roper resonance is taken into account.

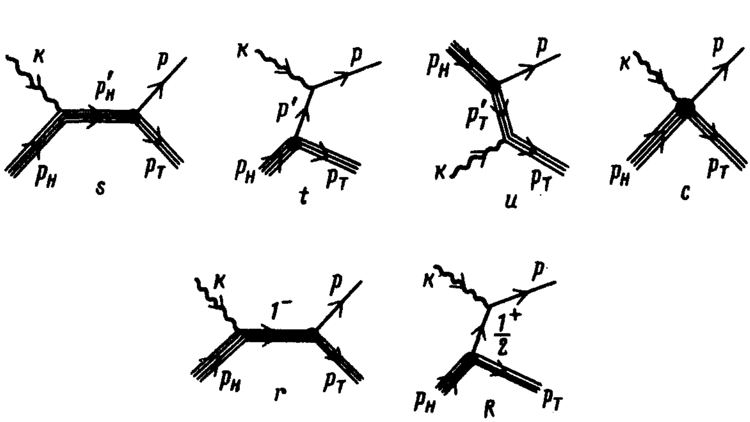

FIG. 2. Covariant diagrams used in the calculations.

menta of the γ ray and of the N and T particles, respectively. The parameters α_i and c_i ($i = 2, 3, 4$) were determined by fitting the differential cross sections $d\sigma/d\Omega^*$ to the experimental energy dependence[6] for $\theta_N^* = 90°$ and $E_\gamma = 30$–120 MeV.

It can be seen from Fig. 1 that as the energy of γ rays is increased, the angular distributions of the Σ asymmetry become asymmetric with respect to $\theta_p^* = 90°$, in contrast with the results obtained in Ref. 1 at low energies. We might add that the contribution of the resonance I^- (Fig. 2r) to the asymmetry of the cross sections is small.

A better agreement with the experimental data can be obtained by taking into account the Roper resonance N^* $(1^+/2, 1440)$ (Fig. 2R) in the calculations of the Σ asymmetry at $E_\gamma > 150$ MeV (the dashed curves in Fig. 1). This suggests that the study of polarization phenomena in the reactions ^{4}He $(\gamma,p)^3$T and ^{4}He $(\gamma,n)^3$He may yield information on the nonnucleon degrees of freedom of nuclei.

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