# THE REACTION $^4He(\gamma,\, p)^3H$, CAUSED BY POLARIZED PHOTONS IN THE GIANT RESONANCE RANGE

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The reaction of $^4He(\gamma,\, p)^3H$ in the range of giant resonance was studied by a streamer chamber method in a magnetic field irradiated with polarized photons obtained by plane channeling of electrons by a diamond crystal. The angular and energetic dependences of the asymmetry of the cross section have been measured. The results are explained by the mechanism of direct knock out of nucleons.

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## 1. INTRODUCTION

An experimental investigation of the $^4He(\gamma,\, p)^3H$ reaction in the low-energy range is of interest both for determining the structure of the wave function of the ground state of the initial nucleus and for the contribution of various reaction mechanisms. A small number of nucleons makes it possible to produce more detailed theoretical calculations by including a smaller number of model assumptions about the observables. The reaction was extensively studied on beams of bremsstrahlung and tagged unpolarized photons, using track chamber [1, 2] and spectrameter [3] methods of particles detection. Analysis of the differential cross sections made it possible to estimate the cross sections of the electric and magnetic transitions of different spin states of finite particles.

Polarized experiments give information on reaction observables, which are determined by interference of the amplitudes. They are more sensitive to the details absorption mechanism of the photon and the structure of nucleus. In this reaction, the use of polarized photons gives additional information of transitions with spin S = 1 of the particles final state.

The detailed study of the $^4He(\gamma,\, p)^3H$ reaction was carried out by means of the streamer chamber in a magnetic field, which was after an electron accelerator at $2\,GeV$ in the KIPT [4]. The chamber was irradiated by linearly polarized photons obtained by coherent bremsstrahlung of high-energy electrons in a thin diamond crystal. An analysis of the results obtained in the energy range from 40 to $100\,MeV$ was carried out in the model of direct knockout the nucleon. But in the intermediate energy range the contribution of the quasi-deuteron mechanism in appreciable [5]. Therefore, it is of interest to investigate the reaction at giant resonance energies, where the mechanism of direct knockout of the nucleon predominates.

The experiment was performed with the help of a streamer chamber irradiated with linearly polarized photons obtained by plane channeling of electrons with energy of $1200\,MeV$ in a diamond crystal of $0.3\,mm$ thick. The photon beam had a maximum intensity and almost 90% degree of polarization at energies below $40\,MeV$, which ensured effective investigation of the reaction in the region of its giant resonance.

## 2. EXPERIMENTAL METHOD

The scheme of the experimental setup is shown in Fig.1. Electrons 1 with an energy of $1200\,MeV$ fell on a diamond crystal 2 of $0.3\,mm$ thick, forming polarized photons, and deflected by the magnet 4 into the beam dump 5. The photon beam 3 was formed by the system of collimators 6. The soft component of the spectrum was extracted out of the beam by an $LiH$ filter of 3.7 rad. units thick. Low energy photons would create in the chamber a significant electronic background, making it difficult detecting events. The polarization vector of the beam was directed at an $\pi/4$ angle to the magnetic field strength vector.

The spectral distribution of photons and the degree of its polarization are measured with the $\gamma + d \to p + n$ reaction [6]. Polarization decreased from 88% in the range of the reaction threshold to 58% at $E_\gamma = 50\,MeV$. The possible depolarization of the beam due to Compton scattering into small angles, when the scattered photon enters the chamber, according to the estimate of [4], was negligibly small. In the experiment, the alignment of the electron and collimated photon beams was strictly controlled in order to avoid additional uncontrolled polarization arising from their misalignment.

A two-gap streamer chamber 8 with a working volume of $60 \times 60 \times 24\,cm^3$, was filled with pure helium to a pressure of $101325\,Pa$. The large working

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volume of the camera allowed the particles to leave long tracks, according to which their kinematic parameters were determined with the necessary accuracy. The chamber was placed in an axially symmetric magnetic field 9 with intensity $\sim 1\,T$, known with an accuracy of 0.2%. The working volume of the camera was photographed with a three-lens camera and which made it possible to reconstruct events with high accuracy. The coordinates of the tracks were measured by means of semi-automat of the type "PUOS". The complex of programs made it possible to reconstruct the kinematic parameters of the particles. The average error of pulse measurement is 5%, polar and azimuth angles, 2° and 3° respectively.

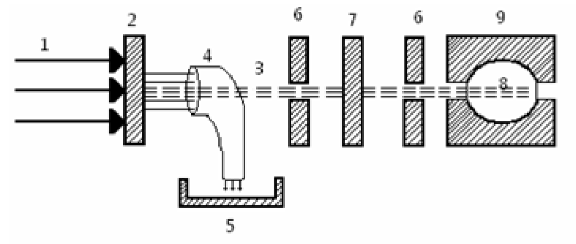


***Fig.1.*** *The scheme of the experimental setup*

With $^4He$ photodisintegration, the formation of four reactions with two tracks is possible:

$$\gamma + {}^4\boldsymbol{He} \longrightarrow \begin{array}{rr} p+t\,, & (1) \\ p+n+d\,, & (2) \\ 2p+2n\,, & (3) \\ 2d\,. & (4) \end{array}$$

The reaction (1) is separated from the background (2) and (3), using the criterion of complanarity: the final particles momenta and the photon must lie in one plane. Error of noncomplanarity measurement is 5°. It follows from kinematics that the angle of particles scattering should be more then 160°. Pulses of finite particles are close in magnitude. Therefore, because of the large difference of the velocities, the tracks density of the proton and the tritium differ a lot. While in the reaction (4) the track densities practically the same because of the equality of the particle masses. The photon energy $E_\gamma$ is equal to the sum of the kinetic energies of the proton and the tritium and the threshold energy of the reaction. Using the conservation laws, the values of $E_\gamma$ can be determined independently by the kinematic parameters of the photon and the tritium. The residual between them $\delta E_\gamma$ is due to measurement errors and multiple particles scattering. The average measurement error is $\delta E_\gamma = 1\,MeV$. The 2420 events of this reaction were measured. Their distribution in the energy of the $\gamma$-quantum was constructed with a $2\,MeV$ step. After dividing into the total reaction cross section taken from the literature [2] due to energy, the spectrum of photons that caused this reaction was obtained.

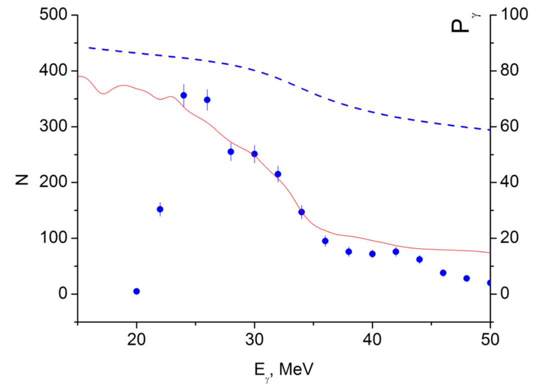


***Fig.2.*** *The spectrum of photons*

It is presented in Fig.2 at the energies from the reaction threshold to $50\,MeV$. The solid line shows the calculated spectrum for the planar channeling method [6], taking into account the removal of the soft component by the impeller. It is normalized to the experiment at the maximum. The accordance of the curves in form confirms that in this experiment the beam was obtained with planar channeling. The dashed curve shows the dependence of the polarization degree of the beam $P_\gamma$ on the energy of the $\gamma$-quantum, measured in [6], the scale of which is shown on the right. The degree of polarization decreases from 88% at the reaction threshold energy to 58% at $50\,MeV$. Data on the degree of polarization will be used to determine the asymmetry of the cross section.

## 3. ANGULAR DEPENDENCE OF THE CROSS SECTION ASYMMETRY

The maximum yield of the reaction is in the energy interval $20 < E_\gamma < 30\,MeV$, which provides the necessary accuracy of the cross section asymmetry measurement at the polar angles from 20° to 160°. Figure 3 shows the distribution of events along the azimuthal angle of protons falling within the range of polar angles from 60 to 80 degrees.

The azimuthal angle is measured beginning from the polarization vector with a step of 10°. The number of events at each step is indicated by the point, set in the middle of the step.The error is statistical.

In the case of linearly polarized photons, the distribution of reaction products along the azimuthal angle $\varphi$ has the form [7]:

$$d\sigma_\phi/d\Omega = d\sigma_0/d\Omega(1 + p\cdot\cos 2\varphi)\,, \qquad (5)$$

where $d\sigma_0/d\Omega$ – cross section of the reaction upon absorption of unpolarized photons. Parameter $p = P_\gamma\Sigma$. The asymmetry of the cross-section, depending on the energy and the polar angle, is determined by the relation $\Sigma(\Theta, E_\gamma) = (\sigma_\parallel - \sigma_\perp)/(\sigma_\parallel + \sigma_\perp)$, $\sigma_\parallel$ and $\sigma_\perp$ – cross sections when the polarization vector lies in the plane of the reaction or is perpendicular to it.

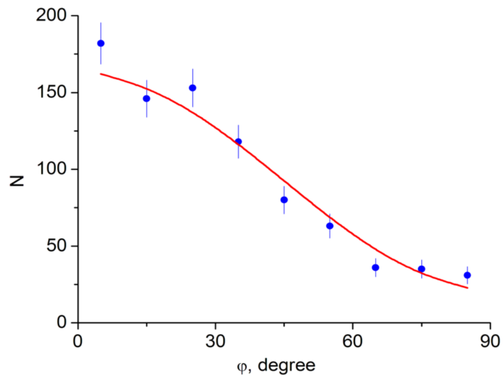


***Fig.3.*** *Protons distribution along the azimuthal angle*

In our experiment, the measurements were performed at different angles of orientation of the polarization vector to the reaction plane.

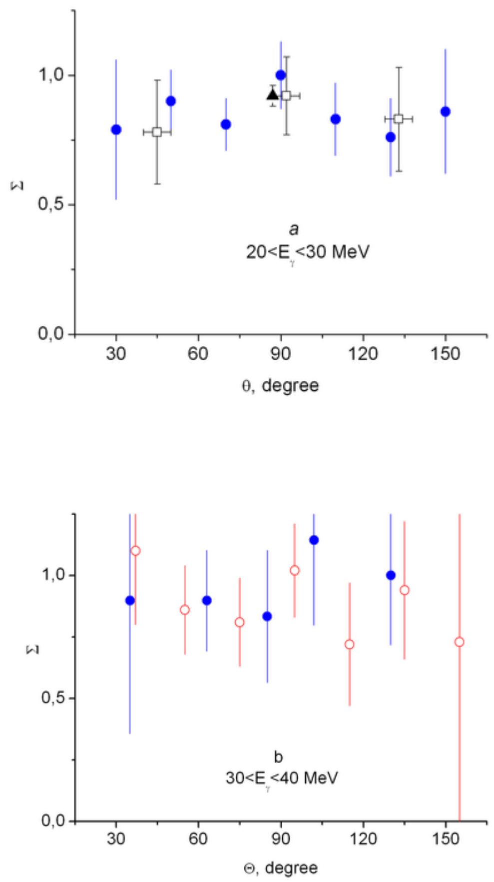


***Fig.4.*** *Dependence of* $\Sigma$ *on the polar angle*

Approximation the distribution function

$$F(\phi) = a + b \cdot \cos 2\phi \tag{6}$$

increases the accuracy of determining the parameter $p = a/b$ in comparison with the variant if only the first and last points were used. The solid line in Fig.3 shows the result of fitting by the method of least squares function (6). The values $a = 95.28 \pm 2.86$, $b = 72 \pm 3.64$ and their ratio $p = 0.76 \pm 0.04$ were obtained. The cross section asymmetry $\Sigma = 0.89 \pm 0.05$. A similar procedure is performed for seven intervals with a step of 20° polar angle. In the intervals 0°...20° and 160°...180° the statistical supply is insufficient to determine $\Sigma$.

Dependence of $\Sigma$ on the proton polar angle is shown in Fig.4,a by circles. Within the error limits, the asymmetry does not depend on the polar angle. For comparison, the squares exhibit the neutron cross section asymmetry in the $^4He(\gamma, n)^3He$ reaction generated by coherent bremsstrahlung with a maximum at 45 $MeV$ [7], and triangles - asymmetry for the reaction $\gamma + d \to p + n$ [8]. The results are conformed.

In Fig.4,b, the close circles represent the asymmetry distribution for photon energy interval from 30 to 40 $MeV$. It is measured at polar angles from 40° to 140° and compared with the data [4] represented by open circles. There is some conformation. Within the limits of errors, the asymmetry does not depend on the polar angle.

In Fig.5, the angular dependence of $\Sigma$ is compared with theoretical predictions.

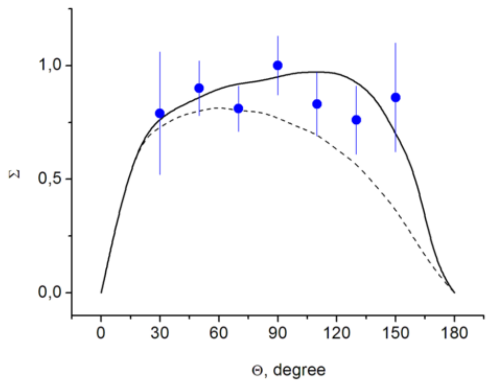


***Fig.5.*** *Comparison with the theory*

The dashed curve is the calculation of [9] using the gradient-invariant series of Feynman diagrams for the process of two-particle photodisintegration of the $^4He$ nucleus. It is possible to note a value close to the experiment $\Sigma$ in magnitude, but its variation with increasing angle does not agree. The solid curve shows the calculation of [10] in the plane wave pulse approximation, taking into account the mechanism of nucleons direct knock out and exchange diagrams. The interaction in the final state was not taken into account. The calculation is consistent with the experiment.

Since $\Sigma$ does not depend on the polar angle, we can integrate from it and construct the azimuthal distribution of all events that falling within the energy interval. In this assumption, the asymmetry is determined with better statistical security. The value of $\Sigma$ is found in five energy intervals. The result is shown in Fig.6 by solid circles. Points are placed in the middle of intervals. Open circles show the cross section asymmetry for the deuteron photodisintegration [11], when the proton emits at a polar angle 90° in the c.m. system. Within the limits of errors, the results are consistent.

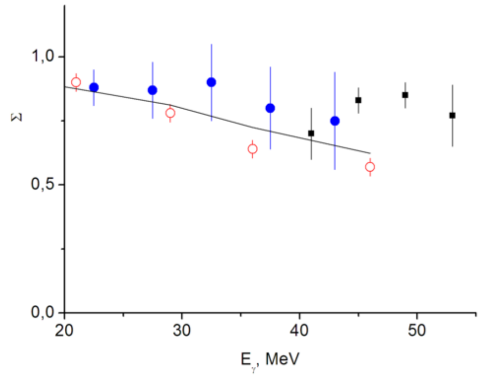


***Fig.6.*** *Σ dependence on the photon energy*

But the data for the deuteron are systematically lower and noticeably decrease with increasing energy. In our experiment, the asymmetry does not vary much. The squares show the asymmetry of the proton photoproduction cross section at an angle of 90° in the $^{12}C(\gamma,\,p)^{11}B$ reaction, when the residual nucleus is in the ground state [12]. The result agrees with our data on both the magnitude of the asymmetry and the absence of a noticeable change in it with energy increasing. The line shows the calculation of the asymmetry of the cross section for a deuteron at the proton escape at a polar angle of 90° in the c.m. system [13]. Within the limits of errors, the calculation is consistent with the experiment.

### 4. SUMMARY

The reaction $^4He(\gamma,\,p)^3H$ was studied with the help of a streamer chamber in the magnetic field irradiated with linearly polarized photons obtained by plane channeling of electrons by a diamond.The cross section asymmetry dependence on polar angle was measured in the energy intervals of 20...30 $MeV$ and 30...40 $MeV$. An asymmetry value is close to the one and within errors limits does not depend on polar angle. The dependence of asymmetry on energy in interval of 20...45 $MeV$ has no energy increasing which exceeds errors limits. It is shown that the energetic and angular dependences of Σ are consistent with the analogous data in the $^4He(\gamma,\,n)^3He$, $^2H(\gamma,\,p)n$ and $^{12}C(\gamma,\,p)^{11}B$ reactions, where the residual nucleus is in the ground state, in the range of close energies. The results can be explained within the framework of the mechanism of direct knock out of nucleons.

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## РЕАКЦИЯ $^4He(\gamma, p)^3H$, ВЫЗВАННАЯ ПОЛЯРИЗОВАННЫМИ ФОТОНАМИ В ОБЛАСТИ ГИГАНТСКОГО РЕЗОНАНСА

***А. А. Перетятько, Р. Т. Муртазин, А. Ф. Ходячих***

Методом стримерной камеры в магнитном поле, облученной поляризованными фотонами, полученными при плоскостном каналировании электронов в кристалле алмаза, исследована реакция $^4He(\gamma, p)^3H$ в области ее гигантского резонанса. Измерены угловая и энергетическая зависимости асимметрии сечения. Результаты объясняются механизмом прямого выбивания нуклонов.

## РЕАКЦІЯ $^4He(\gamma, p)^3H$, ВИЗВАНА ПОЛЯРИЗОВАНИМИ ФОТОНАМИ В ОБЛАСТІ ГІГАНТСЬКОГО РЕЗОНАНСУ

***О. О. Перетятько, Р. Т. Муртазін, О. Ф. Ходячих***

Методом стримерної камери в магнітному полі, яка опромінювалась поляризованими фотонами, отриманими при площинному каналюванні електронів в кристалі діаманта, досліджено реакцію $^4He(\gamma, p)^3H$ в області її гігантського резонансу. Виміряно кутову та енергетичну залежності асиметрії перерізу. Результати пояснюються механізмом прямого вибивання нуклонів.