STUDY OF $^4He(\gamma, pn)d$ REACTION MECHANISM FOR E_γ UP TO 100 MeV

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Using a spectrometer based on a diffusion chamber, which is placed in the magnetic field, the $^4He(\gamma, pn)d$ reaction was researched in the energy range from the reaction threshold up to 100 MeV. Nucleons differential cross sections, angular and energy correlation functions of the reaction products were measured. The structure which wasn't observed previously is detected in the deuteron kinetical energies distribution of events. Possible γ-quanta absorbtion by nucleus mechanisms are discussed.

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1. INTRODUCTION

Photonuclear reactions are an instrument to study the nucleon correlations, because an energy and the pulse, which are introduced into nucleolus by γ-quanta with energies below giant resonance, can be absorbed only by correlated nucleon pair. Information on nucleon correlations is an important component of information for understanding the γ-quanta absorption processes at energies below giant resonance. Gotfrid [1] showed, that two-nucleon knockout cross-section can be expressed by two factors $\sigma \sim S_{fi}(P) \cdot f(p_{rel})$, where $S_{fi}(P)$ - is a function, proportional to the probability of finding a nucleon pair in the nucleus with momentum P, equal to the sum of the nucleon pairs momentum, and $f(p_{rel})$ value is a Fourier transform of the correlation function. At energies below the meson production threshold γ-quanta are absorbing by correlated nucleon or by nucleon pair at the time of the meson exchange. In the article [2] Gotfrid model was expanded by nucleons correlation inclusion, which is called by meson exchange currents. It was shown, that, taking into account the meson currents, the cross section factorization remains the form of two factors. The interaction in the final state, which can hide an information about the reaction mechanism, plays the important role.

Two-nucleon reactions in the final state are convenient for nucleon correlations study. ^4He nucleus was selected to study for the following reasons. It consists of $1s$ nucleons only. It has a higher internal density compared to other nuclei, which increases the role of short-range nucleon correlations. Because of the small number of nucleons, interaction effect in the final state is expected to be minimal. ^4He nucleus is the object of the few-nucleon systems theory predictions. Having the small distortions, which are introduced by the interaction in the final state, three-particles kinematic parameters distribution of the $^4He(\gamma, pn)d$ reaction probability is usually used for reaction mechanism identification.

At γ-quantum energies below the threshold meson production the $^4He(\gamma, pn)d$ reaction was studied by the track method: using Wilson chamber [3] and by means of diffusion chamber [4, 5]. The target and detector combining in these chambers allowed to register particles with low energy and to study reaction almost right up to the threshold. It was concluded, that quasideuteron mechanism prevails behind the giant resonance.

In this experiment the deuteron kinetic energy events distribution displays the structure, which has not been observed previously. It can not be explained in a quasideuteron mechanism model.

2. THE DIFFERENTIAL CROSS-SECTIONS

The points in Fig.1,a are the results of the measurement of the proton differential cross-sections in the c.m.s. measured at gamma-quanta energy range from 50 to 70 MeV. Actually the experimental curve is a histogram with a step of 10°. The points placed in the middle of a step, errors are statistical. Differential cross-sections of deuteron photodisintegration [6], measured at γ-quanta energies of 55 MeV and normalized by the area under the experimental curve, are shown with the solid line. Data agreement speaks in favor of quasideuteron mechanism. The dashed curve shows Dedrick calculation within quasideuteron model [7], which is not in agreement with experiment.

The neutron angular distributions for $^4He(\gamma, pn)d$ reaction are shown in Fig.1,b.

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Solid curve is the same curve as in Fig.1a with $0° \rightarrow 180°, 15° \rightarrow 165°$ change. Data agreement can be explained by assuming that γ-quantum is absorbed by nucleon pair. In their rest reference system nucleons are emitted in opposite directions. The third particle does not introduce significant distortions. Deuteron angular distributions do not contradict the quasideuteron mechanism model.

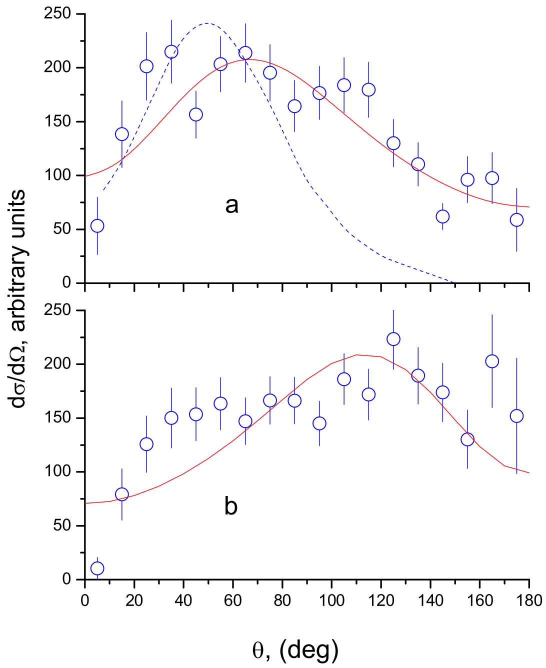

Fig.1. *The differential cross-sections of the nucleons. Points–the results of the experiment, solid line–the cross-section of deuteron photodisintegration* [6]*, dashed line-calculation* [7]

3. RELATIVE MOTION ENERGY

The kinetic energy of the relative motion of the proton and neutron in their c.m.s. is $V_{pn} = \sqrt{(E_p + E_n)^2 - (\vec{p_n} + \vec{p_p})^2} - m_p - m_n$, where $E_p, E_n, \vec{p_p}, \vec{p_n}, m_p, m_n$ total energies, momentums and masses of the nucleons respectively. It forms a part $\eta = V_{pn}/W_0$, of full energy $W_0 = E_\gamma - \varepsilon$, where E_γ - γ-quantum energy, ε - reaction threshold. The η distribution of events for γ-quantum energy in the 50...70 MeV interval is shown in Fig. 2 by triangles. In most cases, pn-pair carries most of the total kinetic energy of the particles, as it can be expected within quasideuteron model. Nevertheless, almost the third of the events pn-pair carries less then a half of the total energy. The energy part $\eta = V_{pd}/W_0$, which is taken by pd-pair, distribution of events is shown by circles. It is nearly symmetrically in relation to a 0.5. The phase distribution for the three-body final state $N \sim (\eta(1-\eta))^{\frac{1}{2}}$ is shown by the dashed curve. It is in a good agreement with pd-pair data and has the disagreement with pn-pair data.

The solid line shows the calculation [9], which is based on the assumption, that ^{4}He nucleus consists of proton-neutron pairs. The γ-quantum interaction with one of them knocks out pn-pair, and the second pair generates deuteron. The calculation results [9], normalized to the area under the experimental curve, are in agreement with pn-pair data.

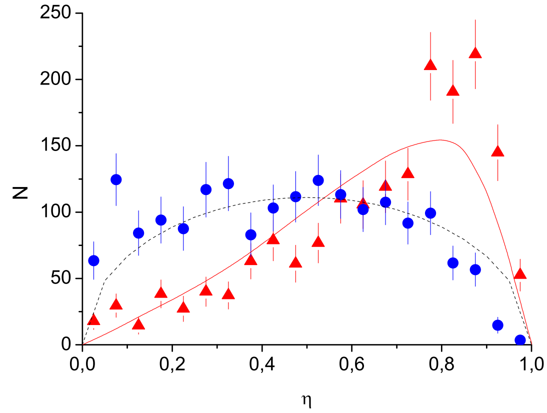

Fig.2. *The events distribution with respect to* η

4. THE AVERAGE MAXIMAL ENERGY OF THE FIRST NUCLEON AND THE AVERAGE MINIMAL ENERGY OF THE SECOND NUCLEON

In the direct mechanism a knocked out nucleon carries most of energy of the final state. The energy of other products of the reaction amounts a smaller portion and weakly increases with the energy of the γ-quantum. Therefore, each event compared proton and neutron energy in c.m.s. Nucleon, which has higher energy was considered the first, and nucleon which has lower energy was considered the second. In the γ-quanta energy interval of 5 MeV the kinetic energies of the first and second nucleon, which fall into this interval, are separately summed. Total energies are divided on number of events which fall into interval. Received average values are shown in Fig. 3,a with circles for the first nucleon, the triangles are for the second nucleon data and the squares are for the deuteron. An average energy divided by the intervals increases with γ-quanta energy increasing. This fact applies not only to the first nucleon but to the rest of nuclear decay products, which is spectator in the direct mechanism model. The nucleon average energies are proportional to the total energy of the reaction product. The average energy of the first nucleon is $T_{av1} = 0,565(E_\gamma - \varepsilon)$ is shown in Fig. 3,a by solid line. The aspect ratio is distinctly lower then 0.75, and direct model mechanism expects exactly it. The average energy of the second nucleon is $T_{av2} = 0,256(E_\gamma - \varepsilon)$ is shown in Fig. 3,a by dashed line. It exceeds the energy, which the rest of nucleus should have according to direct model mechanism.

Instinctively we can expect that γ-quantum energy increasing will cause the increasing of the nucleons average energy difference. The deuteron, which is spectator, average energy would remain nearly constant, in the case of quasideuteron mechanism.

As it follows from figure, the nucleons average energies difference is actually increasing with increasing of γ-quantum energy, which confirms a model of γ-quantum absorption by the nucleon pair. The fact that the deuteron average energy increases can be explained qualitatively on the basis of the final state interaction or the contribution of the mechanism of the γ-quantum absorption by three nucleons.

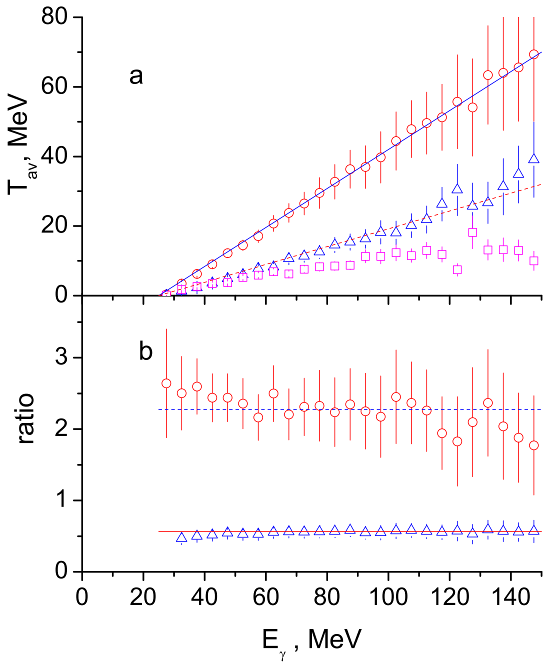

Fig.3. *a) the average kinetic energies; b) the average energies ratio*

The first nucleon average energy portion of the total particles kinetic energy in the final state is shown in Fig. 3,b by triangles. The permanency of this ratio depending of γ-quantum energy should be mentioned. Within the limits of errors it has a value of 0.565. The nucleon should take about a half of energy in the terms of γ-quantum absorption by nucleon pair model. The first nucleon average energy to the second nucleon average energy ratio is shown by circles. Within the limits of errors it remains constant and its average value of 2.27 is shown by dashed line. According to γ-quantum absorption by the nucleon pair model it should be expected this ratio near 1.

5. PARTICLES OPENING ANGLES

Np-pair nucleons angle scattering distribution of events is shown in Fig. 4,a. The measurements were performed at energies of γ-quanta from 50 to 70 MeV. The distribution maximum is in the field of large angles as it can be expected in the γ-quanta nucleon pair absorption model.

But the distribution maximum, which is located at large angles, is also observed in the events distribution by opening angle of pd-pair, which was measured in the same γ-quanta energies interval, as it shown in Fig. 4,b.

The dashed curve shows the phase distribution, normalized to the experimental results. It is in agreement with pd-pair data and is not consistent with the data for pn-pair. The solid curve shows pole mechanism calculation [10] with pn-pair in the top. It is consistent with the data for pd-pair. The pole mechanism model calculation is closer to pn-pair experimental data then the phase distribution. It can be noted that the angle distribution is not critical to the reaction mechanism.

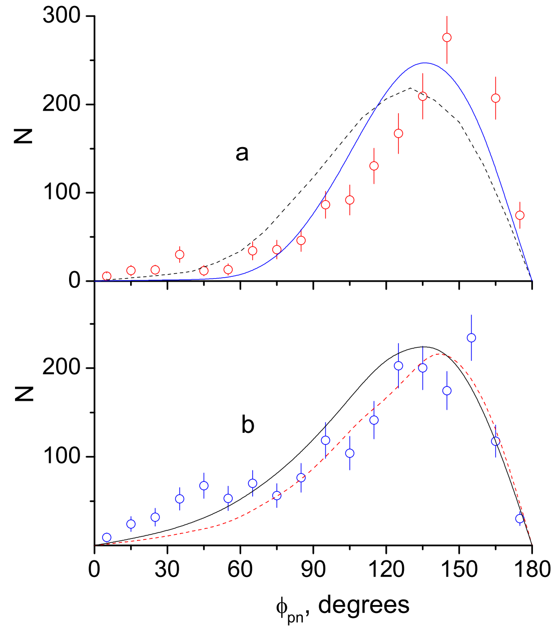

Fig.4. *The particles distribution versus opening angle*

6. THE DEUTERON ENERGY EVENTS DISTRIBUTION

In a terms of quasideuteron model, deuteron is a spectator in the $^4He(\gamma, pn)d$ reaction. Its kinetic energies distribution of events in the absence of interaction in the final state must be determined by quasideuterons momentum distribution in the nucleus. Kinetic energies events distribution which are caused by γ-quanta having energy interval from threshold to 40 MeV is shown in Fig. 5,a. At energies below 5 MeV resonance distribution is observed. At the energy interval from 40 to 50 MeV in the events distribution below 5 MeV resonance distribution is also observed (Fig. 5,b). But in the 5 to 10 MeV interval nonresonance distribution is appeared. With γ-quantum energy increasing tendency remains. The distribution of γ-quantum energies at interval from 60 to 70 MeV is shown in Fig. 5,c. It also has a resonance distribution below 5 MeV, and nonresonance distribution spreads up to 20 MeV. At energy interval from 70 to 80 MeV nonresonance distribution spreads up to 25 MeV (Fig. 5,d).

Such structure in deuteron energies distribution curve wasn't observed previously.

This structure significantly enhances the analysis of experimental data in order to determine the mechanism of the reaction.

Reaction probability dependence of deuteron energy was calculated in quasideuteron pole approximation model [11]. Calculation results, normalized to the maximum of the experimental distributions for γ-quantum energy interval from 60 to 100 MeV are shown in Fig. 6,a. The model predicts wider distribution, than experimental, and it doesn't predicts resonance at deuteron energy below 5 MeV.

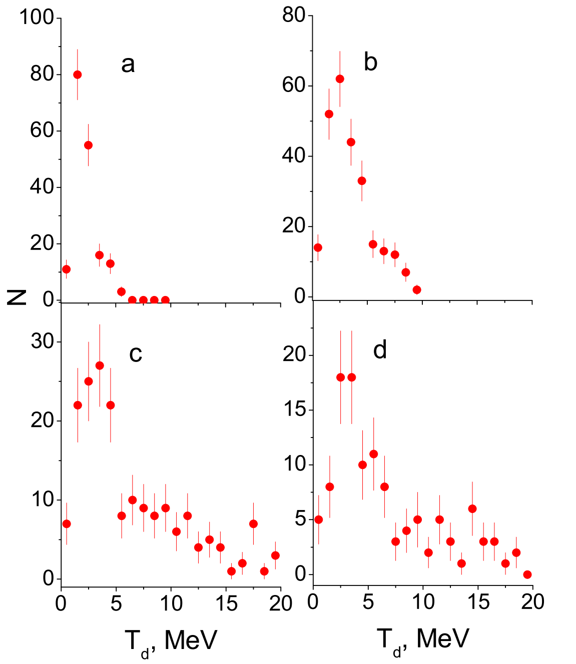

Fig.5. *$^4He(\gamma, pn)d$ reaction events distribution by deuteron kinetic energy*

$^4He(\gamma, pn)d$ reaction deuteron momentum distribution of events for γ-quantum energies interval from 60 to 70 MeV is shown in Fig.6b by black circles. Maximum is observed at 100 MeV/c momentum and at momentum interval from 120 to 240 MeV/c there is a plateau. Experimentally a structure of spectral function distribution of nucleus rebound momentum presence was observed in $^6Li(\gamma, np)X$[11] reaction. For comparison it is shown by triangles in Fig.6b at photon energy from 132 to 157 MeV, normalized at maximum. There is distribution maximum at 50 MeV and there is a plateau at momentum interval from 100 to 250 MeV/c. $^6Li(\gamma, np)\alpha$[11] reaction spectral distribution at energy interval from 55 to 89 MeV is shown by crosses. It also has maximum at 50 MeV/c impulse, but there is no plateau.

Using cluster model the calculation was held for $^6Li(\gamma, np)\alpha$ reaction [13]. It was expected that ^{6}Li nucleus consists of α-core, surrounded by deuteron cluster. The deuteron is absorbing γ-quantum and α-particle is not involved in the interaction. A good agreement with experiment was obtained for $^6Li(\gamma, np)\alpha$[12] reaction at energy interval from 55 to 89 MeV. If the momentum exceeds 120 MeV/c plateau is not predicted by calculation. Plateau presence in experiment at photon energy interval from 132 to 157 MeV is explained by α-core destruction.

At cluster model the ^{4}He nucleus consists of two quasideuterons. One of them is absorbing γ-quantum, and the second is a spectator. Qualitatively events distribution at deuteron momentums of 120 MeV/c can be explained in this model. At a higher momentums second quasideuteron must also be destroyed, this fact is in disagreement with our experiment.

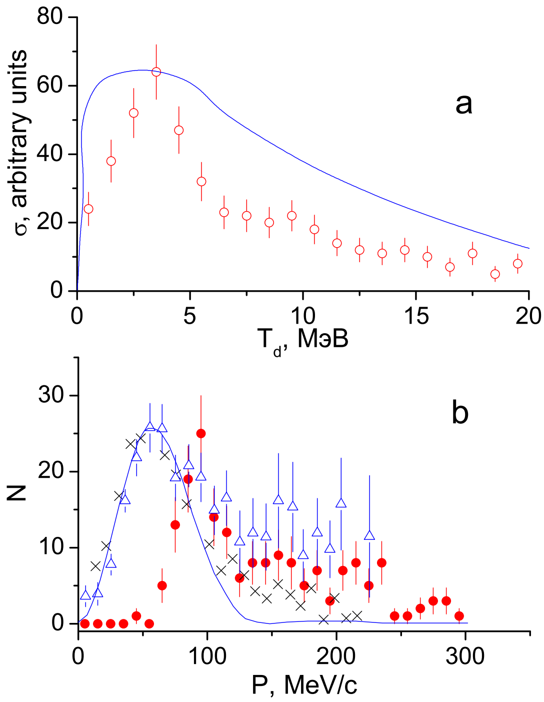

Fig.6. *a) Reaction probability dependence on the deuteron energy; b) The distribution of events versus deuteron momentum from $^4He(\gamma, pn)d$ reaction*

7. CONCLUSIONS

The experimental results could be explained qualitatively at the terms of the one-nucleon absorbtion model. Nucleon correlation with another nucleons is possible before, at the time and after γ-quantum absorbtion. In this case there is np-pair and the deuteron, which momentum is determined by quasideuteron momentum distribution in nucleus.γ-quantum absorbtion is also possible by three-nucleon cluster, which breaks into deuteron and nucleon. In this case there is also np-pair and deuteron in the final state. But deuteron can get large momentum.

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ИССЛЕДОВАНИЕ МЕХАНИЗМА РЕАКЦИИ $^4He(\gamma,pn)d$ ПРИ E_γ ДО 100 МэВ

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С помощью спектрометра на базе диффузионной камеры, расположенной в магнитном поле, исследована реакция $^4He(\gamma,pn)d$ в энергетическом интервале от порога реакции до 100 МэВ. Измерены дифференциальные сечения нуклонов, функции угловых и энергетических корреляций продуктов реакции. В распределении событий по кинетической энергии дейтрона обнаружена структура, которая не наблюдалась ранее. Обсуждаются возможные механизмы поглощения γ-кванта ядром.

ДОСЛІДЖЕННЯ МЕХАНІЗМУ РЕАКЦІЇ $^4He(\gamma,pn)d$ ПРИ E_γ ДО 100 МеВ

М.С. Глазнєв, Є.С. Горбенко, А.Л. Беспалов, Р.Т. Муртазін, А.Ф. Ходячих

За допомогою спектрометра на базі дифузійної камери, розташованої в магнітному полі, досліджено реакцію $^4He(\gamma,pn)d$ в енергетичному інтервалі від порога реакції до 100 МеВ. Обміряні диференційні перерізи нуклонів, функції кутових і енергетичних кореляцій продуктів реакції. У розподілі подій за кінетичною енергєю дейтрона виявлено структуру, що не спостерігалася раніше. Обговорюються можливі механізми поглинання γ-кванта ядром.