# ON THE MECHANISM OF $^4He(\gamma, pn)^2H$ REACTION

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The interpretation is given on the effect of two "peaks" appearance in the experimental deuteron energy distributions in the $^4He(\gamma,pn)^2H$ reaction with photon energies $E_\gamma$=30...50 MeV. The mechanism of pole $^2H$-diagram determining the first "peak" motion and the mechanism of triangular $^3He(^3H)$-diagrams showing a fixed appearance of the second "peak" with a deuteron energy $E^m_{2H}$=2.22 MeV due to the root singularity in the $p + n \rightarrow {}^2H$ vertex are taken into account. The position of maxima in the calculated distributions by the relative pn-pair energy, going out from the photon vertex, coincides in the diagrams under consideration for $E_\gamma$=45...150 MeV.

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## 1. INTRODUCTION

The interest to the problem of three-particle photodisintegration of $^4He$ nucleus is determined by the possibility of proving the notions about nuclear forces, nucleon-nucleon correlations, cluster configurations and meson exchange currents in nuclei. All these questions are associated with determination of a reaction mechanism. According to the experimental investigations [1] (FIAN, Moscow; Wilson chamber), [2-4] (NSC KIPT; diffusion chamber in the magnetic field), [5] (Turino, Italy; diffusion chamber in the magnetic field) and theoretical research [6-12] carried out in 60-70 years using the photon energies $E_\gamma$=26...150 MeV the main mechanism of $^4He(\gamma, pn)^2H$ reaction is the photon absorption by the pair of nucleons (quasideuteron) being at a short distance from each other. In the 80-th years these investigations were continued at the Kharkov Institute of Physics and Technology using the experimental data obtained by means of a diffusion chamber with an appreciably improved statistics (4.5 thousand of events for the given reaction) [13-15].

A satisfactory fit was obtained for the theoretical estimated values to a pole quasideuteron approximation and the experimental energy distributions of deuterons, protons, neutrons, pair (pn), (pd), (nd) correlations and angular (pn) correlations. In [15] a contribution of triangular $^3H$, $^2H$ and A=3-Feynman diagrams was analyzed and a little importance of the final state interaction (FSI) even with low energies $E_\gamma$ was stated. However, the interpretation of an effect of the appearance of two maxima at $E_\gamma$ ∼50 and 75 MeV in the energy distributions of total cross-sections of the $\sigma_t(E_\gamma)^4He(\gamma, pn)^2H$ reaction should be considered as one of unsolved theoretical problems.

Also, unsolved was a problem of two "peaks" appearance in the experimental $dN/dE_d$ energies distributions of deuterons [14] with $E^m_d(I)$ ≈1.25 MeV and $E^m_d(II)$ ≈2.5 MeV at $E_\gamma$=28...45 and 28...50 MeV, their contributions to the reaction section being changing with $E_\gamma$ increasing (the first "peak" becomes blurry and the second "peak" becomes distinct). The interpretation of this effect is given in Section 2 within the bounds of extension of the mechanism of $^4He(\gamma, pn)^2H$ reaction with taking into account a pole quasi-deuteron mechanism and $^3$He($^3$H)-triangular diagrams which differ markedly from the triangular diagrams [15] by the (np)-pair knocking-out from the photon vertex.

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## 2. MECHANISMS OF $^4$He(γ,pn)$^2$H REACTION IN THE DIAGRAM REPRESENTATION

The pole mechanism of $^4He(\gamma, pn)^2H$ reaction, being discussed in the introduction, corresponds to the Feynman pole diagram (Fig.1) with a quasi-deuteron photodisintegration outside the mass surface in the photon vertex 1 and with a nuclear form-factor in spectator channel 2.

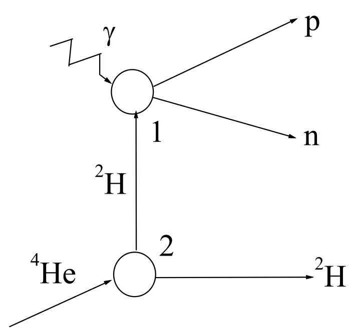


***Fig.1.*** *Pole quasideuteron diagram for the $^4He(\gamma, pn)^2H$ reaction*

In the first approximation, to take into account only the pole mechanism features, vertex 1 and vertex 2 of Fig.1 are replaced by the constants. Then the distributions (being the most sensitive to the reaction mechanism) by the relative energy of (pn) pair, $d\Lambda/dt_{pn}$, and the kinetic energy of deuteron, $d\Lambda/dE_d$, take the following form [13,16]

$$\frac{d\Lambda}{dt_{pn}} = C_1[\frac{\varepsilon'}{E_0} + (1-t_{pn})]^{-2} \cdot \frac{dV}{dt_{pn}}\,, \quad (1)$$

$$\frac{dV}{dt_{pn}} = C_{21}[t_{pn}(1-t_{pn})]^{1/2}\,, \quad (2)$$

$$\frac{d\Lambda}{dE_d} = C_3[\varepsilon'\frac{m_d}{m_{He}} + E_d]^{-2} \cdot \frac{dV}{dE_d}\,, \quad (3)$$

$$\frac{dV}{dE_d} = C_4[E_d(E_0 - E_d\frac{m_d+m_p+m_n}{m_p+m_n})]^{1/2}\,, \quad (4)$$

where $dV/dt_{pn}$ and $dV/dE_d$ are the phase distributions, $\varepsilon' = 2m_d - m_{He}$, $E_0 = E_\gamma - \varepsilon$, $\varepsilon = m_d + m_p + m_n - m_{He}$, $t_{pn} = E_{pn}/E_0$, $E_{pn}$ and $E_d$ are the relative energy of (pn)-pair and the kinetic energy of deuteron in the c.m.s. reaction respectively, $C_1 ... C_4$ are the constants.

The distributions (1) and (3) correspond to the experimental data [14] and [13] at $E_\gamma$=30...45 MeV, 45...75 MeV and $E_\gamma$=28...150 MeV respectively with a normalization performed for the total number of events. The taking into account of triangular diagrams for the $^4He(\gamma,pn)^2H$ reaction is considered in [15] and presented in Fig.2. The calculations of $d\Lambda/dE_p, d\Lambda/dE_n, d\Lambda/dE_d$ in [15] did not allowed one to describe simultaneously, within the theory domain [17], the experimental energy spectra of all the $^4He(\gamma,pn)^2H$ reaction products in the region of $E_\gamma$=26...50 MeV and 50...150 MeV and opened to question the role of FSI in this reaction.

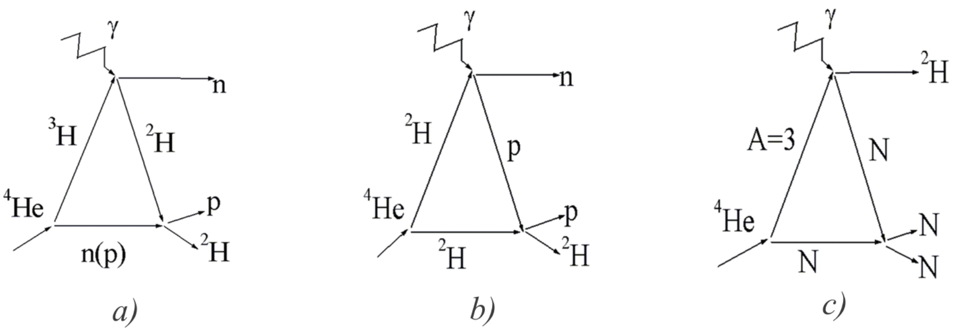


***Fig.2.*** *Triangular diagrams [15] for the $^4He(\gamma,pn)^2H$ reaction*

In [14] one discovered, but did not explained, the effect of two "peaks" appearance in $dN/dE_d$ for $E_d^m$=1.25 and 2.5 MeV at $E_\gamma$= 28...45 MeV and 28...50 MeV the contributions of which to the reaction cross-section was varying depending on $E_\gamma$.

***Table 1.***

| $E_\gamma$ | 28...30 | 30...35 | 35...40 | 40...50 |
|---|---|---|---|---|
| $E_d^m$(I), MeV | 0.66±0.20 | 1.25±0.35 | 1.81±0.26 | 2.39±0.29 |
| $E_d^m$(II), MeV | | 2.22 | 2.22 | 2.22 |

In the present paper this effect was obtained taking into account the pole $^2H$-diagram (Fig.1) with the distribution $d\Lambda/dE_d$ in equation (3) and with taking into account the triangular $^3He(^3H)$-diagrams (Fig.3) (being qualitative different from the triangular diagram of Fig.2) with a root singularity in the $p+n \rightarrow ^2H$ vertex on the mass shell at a deuteron kinetic energy $E_d^*$, according to the theory [17], equal to

$$dE_d^m(II) = m_p + m_n - m_{^2H} = 2.22\,MeV\,. \quad (5)$$

This values of $E_d^*$(II), owing to proper singularity's triangular diagram independence on $E_\gamma$ [17], determines the position of the stable second "peak" (5) at $E_\gamma$ ≥30 MeV. At the same time, the first "peak", unlike the interpretation in [14], moving with $E_\gamma$ changing, is related with the motion of a maximum of $E_d^*$(I) in the distribution $d\Lambda/dE_d$ (3), the position of which is determined by the standard procedure of extremum calculation (3)

$$dE_d^m(I) = \frac{3E_0 + 48 - [9E_0^2 + 96E_0 + (48)^2]^{1/2}}{8}\,. \quad (6)$$

In Table 1 given are the calculation results for $E_d^m$(I) by formula (6) and for $E_d^m$(II) by formula (5) with taken into account the divergances from the average values of $E_0$ for the intervals of energy $E_\gamma$=28...30, 30...35, 35...40 and 40...50 MeV. In whole, a noncontradictory agreement between the model estimates and the experiment takes place.

It is interesting to compare for the diagrams of Fig.1 and Fig.3 the estimated values of $t_{pn}^m$ in the distributions of maxima d$\Lambda$/dt$_{pn}$ in the different energy intervals $E_\gamma$, where $t_{pn} = E_{pn}/E_0$. For the pole $^2H$-diagram formula (1) takes place and for the triangular $^3He(^3H)$-diagrams we use a general equation for the $^4He(\gamma, pn)^2H$ reaction [1,14].

$$\frac{E_{pn}}{E_0} = 1 - \frac{E_d}{E_d^{max}}\,, \qquad (7)$$

where

$$E_d^{max} = E_0 \frac{m_p + m_n}{m_d + m_p + m_n} \qquad (8)$$

Taking into consideration (5) we obtain

$$t_{pn}^m = \frac{E_{pn}^m}{E_0} = 1 - \frac{2E_d^m(II)}{E_0} \qquad (9)$$

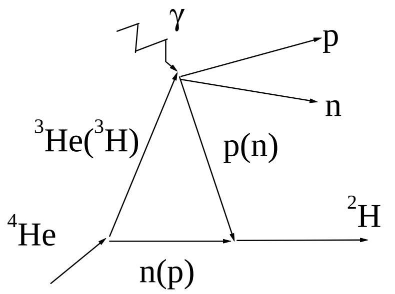


***Fig.3.*** *Triangular $^3He(^3H)$ diagrams for the $^4He(\gamma, pn)^2H$ reaction*

In Table 2 given are the estimated values of $t_{pn}^m(1)$ for the distributions $d\Lambda/dt_{pn}^m$ (1), normalized to all the events, and the estimates of $t_{pn}^m(9)$ by (9) with taking into account the divergences from the average values of $E_0$ for $E_\gamma$=30...45, 45...75 and 75...150 MeV.

***Table 2.***

| $E_\gamma$ | 30...45 | 45...75 | 75...150 |
|---|---|---|---|
| $t_{pn}^m(1)$ | 0.65±0.10 | 0.82±0.05 | 0.92±0.02 |
| $t_{pn}^m(9)$ | 0.61±0.23 | 0.87±0.07 | 0.95±0.03 |

As is obvious from Table 2 the estimates of $t_{pn}^m(1)$ and $t_{pn}^m(9)$ are coinciding for $E_\gamma$=45...150 MeV. For phase distributions (2) $t_{pn}$=0.5. From the experimental analysis of pn-correlations it is practically impossible to single out the mechanisms of $^4He(\gamma, pn)^2H$ reactions presented in Figs.1 and 3.

### 3. DISCUSSION

In the present paper, taking into account the experimental appearance of two "peaks" in the deuteron energy distribution un the range of $E_\gamma$=28...50 MeV, for the first time a conclusion (Table 1) was made about the contribution to the $^4He(\gamma, pn)^2H$ reaction not only from the mechanism of a pole quasideuteron diagram (see Fig.1) with the first "peak" $E_d^m$(I) moving at an energy $E_\gamma$ according to Equation (6), but, also, from the mechanism of triangular $^3He(^3H)$-diagrams presented in Fig.3 with a fixed root singularity $E_d^m$(II)=2.22 MeV in the $p+n \rightarrow ^2H$ vertex. It has been shown that the positions of maxima $t_{pn}^m(1)$ in the distributions $d\Lambda/t_{pn}(1)$ for the pole $^2H$-diagram and $t_{pn}^m(9)$ with $E_d^m$(II), practically, are coinciding in the range of $E_\gamma$=45...150 MeV (Tabl.2). And, therefore, from the experimental analysis of (pn)-correlations one had not succeeded previously to single out the contribution of triangular $^3He(^3H)$-diagram.

Taking into consideration the results obtained upon the mechanisms of $^4He(\gamma, pn)^2H$ reaction, of particular interest is the experimental and theoretical analysis of residual nuclei ($^{10}$B, $^{12}$C and $^{14}$N) energy distributions in the reactions $^{12}C(\gamma, pn)^{10}B$, $^{14}N(\gamma, pn)^{12}C$ and $^{16}O(\gamma, pn)^{14}N$.

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## О МЕХАНИЗМЕ РЕАКЦИИ $^4He(\gamma,pn)^2H$

***В.Н. Гурьев***

Дана интерпретация эффекта возникновения двух "пиков"в экспериментальных энергетических распределениях дейтронов в реакции $^4He(\gamma,pn)^2H$ при энергиях фотонов $E_\gamma$=30...50 МэВ с учетом механизма полюсной $^2H$-диаграммы, определяющим движение первого "пика", и механизма треугольных $^3He(^3H)$ диаграмм с фиксированным проявлением второго пика с энергией дейтрона $E^m_{2H}$=2.22 МэВ из-за корневой особенности в вершине $p+n \rightarrow^2$H. Положение максимумов в расчетных распределениях по относительной энергии pn-пары, выходящих из фотонной вершины, совпадает для рассмотренных диаграмм при $E_\gamma$=45...150 МэВ.

## ПРО МЕХАНІЗМ РЕАКЦІЇ $^4He(\gamma,pn)^2H$

***В.М. Гур'єв***

Надано інтерпретацію ефекту появи двох "піків"в експериментальних енергетичних розподілах дейтронів в реакції $^4He(\gamma,pn)^2H$ при енергіях фотонів $E_\gamma$=30...50 МеВ з урахуванням механізму полюсної $^2H$-діаграми, визначаючим рух першого "піку", і механізму трикутних $^3He(^3H)$-діаграм з фіксованим проявом другого піку з енергією дейтрона $E^m_{2H}$=2.22 МеВ через корневу особливість у вершині $p+n \rightarrow^2 H$. Положення максимумів у розрахункових розподілах по відносній енергії pn-пари, що виходять з фотонної вершини, співпадає для розглянутих діаграм при $E_\gamma$=45...150 МеВ.