ON $^{12}C(\gamma, N)^{11}B$ REACTION MECHANISM IN THE INTERMEDIATE ENERGY RANGE

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The experimental research results for two reactions of photodisintegration of a carbon nucleus which proceed with the knocking out the nucleons from different shells are considered. The total cross-section dependence with respect to energy and dependence of expansion coefficients of the nucleon angle distributions by trigonometric functions on energy are compared. Both reactions have dependence non-regularities within the 34...44 MeV energy interval, it can be explained as a change of mechanism the nucleus absorbs a photon. It is shown that a joining of the quasideuteron mechanism has a identical energy threshold if nucleons are detached from the different shells of a carbon nucleus.

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1. INTRODUCTION

The mechanism of a knocking out the single nucleon from the nucleus within an area of giant resonance and out of it is an object for numerous experimental and theoretical studies [1-3]. At the same time virtual and actual photons can be used as the test particles. At the energies above the giant resonance one can mainly discuss the role of a two mechanisms: direct nucleon knockout and photon absorption by nucleon pair. The model of the direct neutron and proton knockout expects different response of the differential cross-sections. It is expected that asymmetry coefficient of the neutron angle distributions will be small and negative since this particle has no electric charge. Conversely a proton asymmetry coefficient is positive and noticeably differs from a zero. The pair absorption model predicts equal value of the asymmetry coefficients for both nucleons. We researched $\gamma +^{12}C \rightarrow n + ^3He + 2\alpha$ reaction earlier in the giant resonance region and very close to resonance area [4], hereinafter this reaction will be designated as (γ, n). It was shown reaction runs through two-particle phase and the conclusion is a neutron is separated from the s-shell of ^{12}C nucleus. The irregularities in total cross-section and in angle distributions parameters were found out in the range of 40 MeV, it is clarified as opening the channel when nucleon pair absorbs the photon. It is interesting to research the reaction for comparison in case nucleon is detached from the p-shell. For this purpose the $\gamma +^{12}C \rightarrow p + ^{11}B$ reaction was chosen, in what follows it will be indicated as (γ, p). In our experiment this reaction was studied without a separation by the excited states of a final nucleus. The fact final nucleus does not split into hadrons is an evidence it sits in the low excited state, so one can consider nucleon detachment comes from p-shell. We investigated this reaction sooner [5]. In present experiment the measurements were carried out because of processing system gets modernized and this improves energy resolution.

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2. EXPERIMENTAL RESULTS

a. (γ,n)- reaction

There is a dependence of the reaction total cross-section on the photon energy [4] is shown on a Fig.1,a.

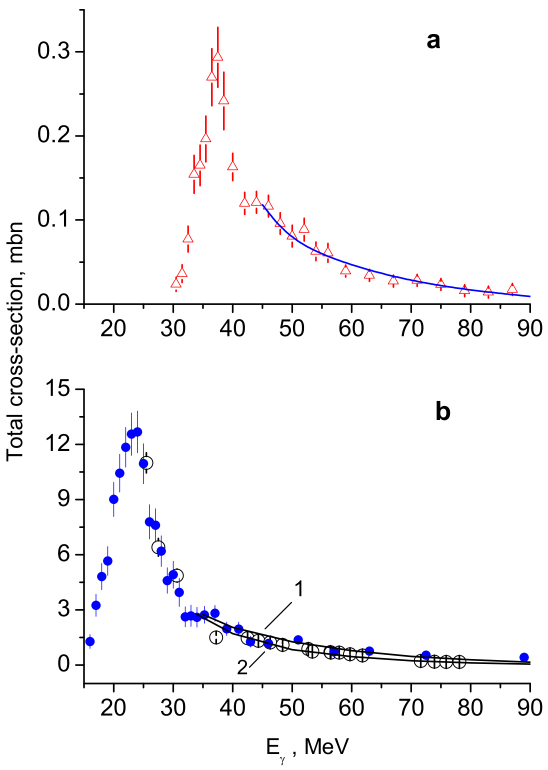

Fig.1. *The total-cross section dependence on energy*

The cross-section shows the wide resonance which has a peak in the area of 37 MeV. Beyond the maximum the cross-section has a rapidly decreasing. There is non-regularity near the 43 MeV. The speed of a cross-section decreasing is diminished after this irregularity. The event distribution of the effective mass of $^3He + 2\alpha$ particles was obtained and it has the narrow resonance shape. Making a comparison with a phase distribution we can see that the particles are decay products of the $^{11}C^*$ excited state. Therefore the reaction goes through two-particle stage. Neutron gets knocked out first and then intermediate nucleus of $^{11}C^*$ having excitation energy with a maximum at $E_x = 14.7 \pm 0.3\, MeV$, disintegrates in three particles. Wide detector's solid angle allowed measuring the angle distribution of the neutrons in range from 0 up to π. The angle distributions asymmetry coefficient of β is defined as a ratio difference of the outputs to the front and rear half-spheres correspondingly to integrate output:

$$\beta = \frac{\int_0^{\frac{\pi}{2}} (d\sigma/d\Omega) d\theta - \int_{\frac{\pi}{2}}^{\pi} (d\sigma/d\Omega) d\theta}{\int_0^{\pi} (d\sigma/d\Omega) d\theta} \quad (1)$$

the $d\sigma/d\Omega$ - differential cross-sections which depend on polar angle of θ. There is a asymmetry coefficient dependence on energy [4] is shown on the Fig.2,b. The value of coefficient is small at the energies below 40 MeV and direct knock-out model explains it: one can expects a symmetric angle distribution [7] relative 90° since neutron does not have negative effective quadrupole charge. At the $38.0 \pm 1.5\, MeV$ we can see the discontinuity. The rapid change of asymmetry coefficient and total cross-section irregularity were illustrated as a change of the reaction mechanism. The mechanism of the direct knockout is prevailed below the 40 MeV. In the range above 40 MeV photon gets absorbed by the np-pair. The neutron leaves a nucleus and the proton stays in it. A solid line shows a result of calculation bye the phenomenological quasi-deuteron model [4] and this calculation is conformed to an experiment. High excitation energy of a ^{11}C and the shape of the neutron angle distributions in the c. m. system indicate that a $^{11}C^*$ has $I^\pi = \frac{1}{2}^+$ state. Therefore one can conclude neutron gets detached from the s-shell of the ^{12}C nucleus.

b. (γ,p)- reaction

The experiment was carried out with an aid of the diffusion chamber which was placed in the magnetic field, a chamber was irradiated bye the bremsstralung γ-quanta with a peak energy of 150 MeV. The ^{11}B tracks are short and wide, this fact is an inconvenience to determine the pulse direction. On the contrary proton's pulse direction are determined with a good precision but to determine pulse module with necessary precision the track projection on the median plane not always has enough length. Thus, energy of the γ - quantum was evaluated using proton direction cosines and ^{11}B kinetic energy which was obtained using the value of range. The ^{11}B track length was calculated bye its projection on the plane laying via γ-quantum and proton pulses. There is a dependence of the (γ, p)-reaction total cross-section on the photon energy is shown on a Fig.1,b. The cross-section has a giant resonance with a maximum at 23 MeV. Beyond the maximum the cross-section is quickly diminished. At the energy of 30 MeV and above this speed is slumped. One can see that cross-section is non-monotonically diminished at the $36 \pm 1.5\, MeV$. For comparison empty circles represent the experimental data [2], it was obtained using labeled photons beam with a high energy resolution and big statistical supply in the reaction of formation of the ^{11}B ground state during the proton registration angularly 60°. The results were normalized in the point placed at $E_\gamma = 25\, MeV$. There is total cross-sections accordance during the energy change. The curve of 1 shows a calculation in the context of a phenomenological quasideuteron model [4]. The curve 2 is a calculation using the shell model. The photon interacts with a two correlated nucleons. The meson exchange currents are taken into account [6]. The curves are normalized at the 35 MeV. The quasideuteron mechanism describes energy dependence of the total cross-section satisfactorily. The differential cross-sections are plotted in the center-of-mass system for the energy intervals of different width. For the 32...36 MeV and 42...46 MeV they are shown on the Fig.2.

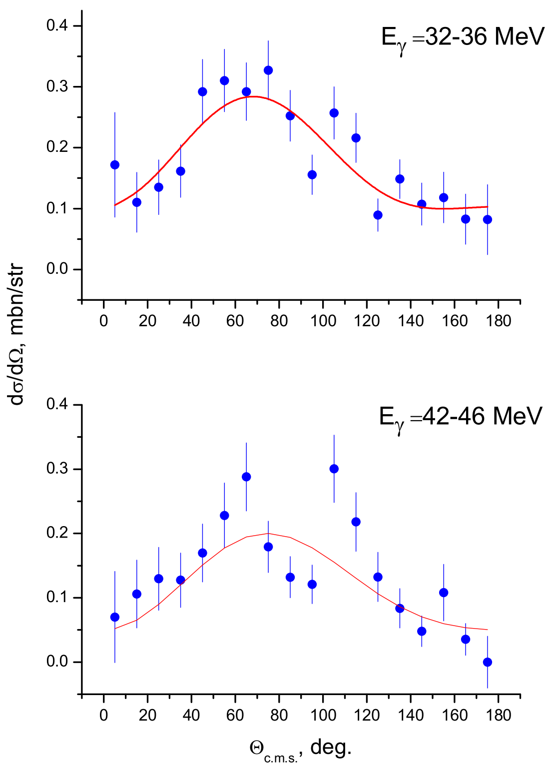

Fig.2. *Differential cross-section of the* $^{12}C(\gamma,p)^{11}B$ *reaction*

The differential cross-sections of the all intervals were fitted with the least square method by function (2):

$$d\sigma/d\Omega = a + bsin^2\theta + csin^2\theta cos\theta\,. \qquad (2)$$

The solid line is a fitting result. The asymmetry coefficient β of the angle distributions, which is calculated by (1), with respect to energy is shown on a Fig.3,a. From the reaction threshold its value is increased and at the 35 MeV considerably exceeds the asymmetry coefficient of the (γ, n) reaction which is shown on a Fig.3,c. In the area of a giant resonance an asymmetry arises because of interference of the dipole and quadrupole transitions.

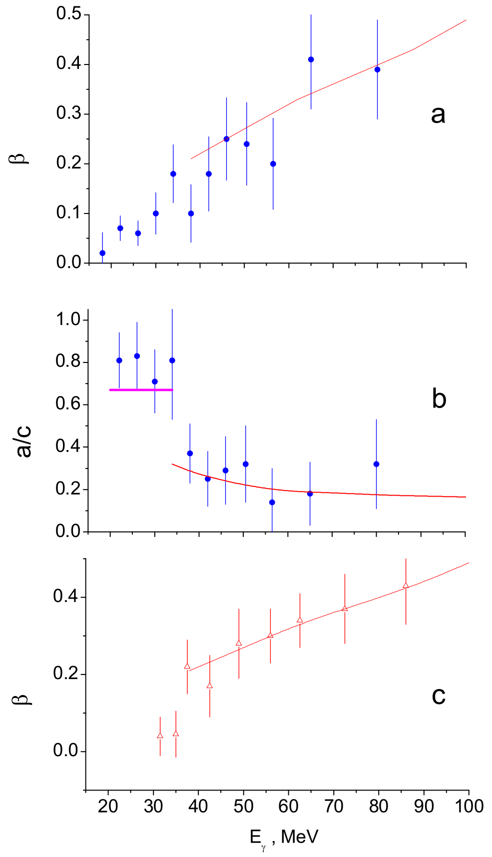

Fig.3. *Dependence of the angle distribution coefficients on energy*

One can see a difference in the response of the asymmetry coefficients for reactions with a proton and neutron output as the direct knockout model does predict it. At the energy above 40 MeV asymmetry coefficients of the both reactions are almost the equal and have the same energy dependence. The asymmetry rise can be qualitatively explained using kinematic approach: γ-quantum interacts with a pair of the nucleons. The passage to the center of inertia of the reaction causes angle distributions asymmetry of the nucleons leaving nucleus. The Fig.3,b shows the a/b ratio with respect to photon's energy. Coefficients of a and b were obtained under fitting of the angle distributions by a function (2). The dots are placed in the middle of a energy intervals the differential cross-sections plotted for. In the giant resonance region this ratio are uniform within the errors. The dotted line - ratio the electric dipole approach expects, it is $\frac{2}{3}$ for the transition to ground state of the final nuclei [8]. An elevation of this value can be explained as contribution of the excited states forming. At the energy above than 34 MeV the ratio is decreased in discrete steps. The change limit is $36 \pm 2\,MeV$. 2 MeV error is equal to the half of a width of the interval within cross-sections are plotted. The solid line is result in the context of a phenomenological quasideuteron model [4]. There is agreement with an experiment. The energy dependence of the asymmetry coefficient which is shown on the Fig.3,c for (γ, n) reaction has a discontinuous changing as well. Changing energy which was determined analogously to (γ, p) reaction, is $36.3 \pm 22\,MeV$. Hence the energy coefficients drastically changing at are the same for both reactions within the errors. Previously the quasideuteron mechanism was theoretically investigated more than once in the context of a shell model taking into account nucleon-nucleon correlation [9]. The different contribution was predicted to the total cross-section of the interaction processes with nucleon pairs whose partners are in same or different shell. The not equal contribution dependence on γ-quantum energy was also expected. The Fig.4 compares dependence of the total cross-sections of the (γ, n) and (γ, p) on energy and and the dependence of the photoproduction total cross-section of the ^{11}B ground state on energy.

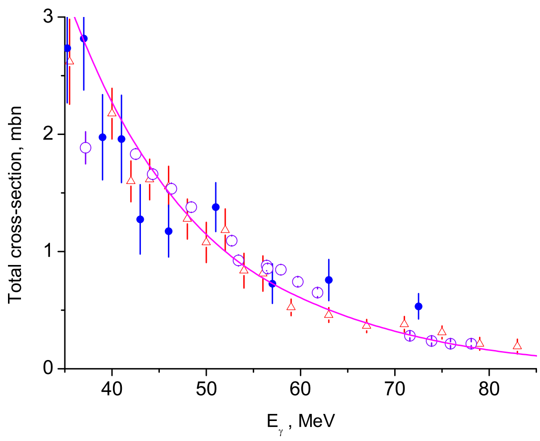

Fig.4. *Energy dependence comparison of the total cross-sections for both reactions*

The photoproduction total cross-section of ^{11}B ground state [2] was registered angularly 60° and it is designated as the empty circles. The data was normalized at γ-quantum energy of 40 MeV. The total cross-sections have practically equal dependence on energy.

3. SUMMARY

The measurement of the total cross-section and angle distributions of the $\gamma +^{12} C \rightarrow p +^{11} B$ reaction which proceeds with a nucleon detachment from p-shell are performed. The total cross-section dependence on energy at $34.0 \pm 1.5\, MeV$ has a non-monotonous subsiding. The a/c ratio has discontinuous changing at energy of $36 \pm 2\, MeV$. The comparison with the same dependences concerning $\gamma +^{12} C \rightarrow n +^{3} He + 2\alpha$ reaction which runs with a detachment of a nucleon from s-shell is carried out. For this reaction one can see the total cross-section monotony at $43.0 \pm 2.0\, MeV$ and discontinuous changing of the angle distributions asymmetry at $36 \pm 2\, MeV$. These irregularities were explained as the two-particle absorption channel was opened. Above giant resonance the relative changing of the total cross-sections with respect to energy change is same. The results are in concordance with calculations of the model which depicts nucleon pair absorbs a photon considering meson exchange currents.

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О МЕХАНИЗМЕ РЕАКЦИЙ $^{12}C(\gamma, N)^{11}B$ В ПРОМЕЖУТОЧНОЙ ОБЛАСТИ ЭНЕРГИЙ

Е.С. Горбенко, Р.Т. Муртазин, А.Ф. Ходячих

Обсуждаются результаты экспериментального исследования двух реакций фоторасщепления ядра углерода, идущих с отделением нуклонов из разных оболочек. Сравниваются зависимости полных сечений и коэффициентов разложения угловых распределений нуклонов по тригонометрическим функциям от энергии. В обеих реакциях обнаружены нерегулярности в зависимостях при энергиях в интервале от 34 до 44 МэВ, которые объяснены изменением механизма поглощения фотона ядром. Найдено, что включение квазидейтронного механизма имеет одинаковый энергетический порог при отделении нуклонов из разных оболочек ядра углерода.

ПРО МЕХАНІЗМ РЕАКЦІЙ $^{12}C(\gamma, N)^{11}B$ У ПРОМІЖНІЙ ОБЛАСТІ ЕНЕРГІЙ

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Обговорюються результати експериментального дослідження двох реакцій фоторозщеплення ядра вуглецю, що йдуть з відокремленням нуклонів з різних оболонок. Порівнюються залежності повних перерізів та коефіцієнтів розкладання кутових розподілів нуклонів за тригонометричними функціями від енергії. В обох реакціях виявлено нерегулярності в залежностях при енергіях в інтервалі від 34 до 44 МеВ, які пояснено зміною механізму поглинання фотона ядром. Знайдено, що включення квазидейтронного механізму має однаковий енергетичний поріг при відділенні нуклонів з різних оболонок ядра вуглецю.