THE ^{8}BE GROUND STATE FORMATION IN $^{12}C(\gamma,3\alpha)$-REACTION

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The energy dependence of the total cross section the ^{8}Be ground state formation at the energies up to 40 MeV is measured. Angular distributions at three energy intervals are obtained. Results are compared with predictions of a direct knockout α-cluster mechanism.

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1. INTRODUCTION

The investigation of the α–disintegration reactions is of the great interest because it is widely used to prove the predictions of the α–cluster nuclear model, quasi-α-particle mechanisms of nuclear reactions and to investigate the characteristics of the αα–interactions. When the initial and final nuclei have zero isotopic spin, the dipole transitions are suppressed. In this case it is possible to verify the validity of the isospin violation law.

The $^{12}C(\gamma,3\alpha)$-reaction was investigated with a help of nuclear emulsions, which were exposed to monochromatic photons from the reaction of a radiation capture of proton by the nucleus of Lithium [4,5] and by the bremsstrahlung photons [5-9]. The quality agreement between the experimental data in the sense of the excitation curve form is observed, while the value of total cross-section has a large discrepancy. This discrepancy may be caused by the large amount of the three-particle background reactions on the nuclei of nuclear emulsions, which are difficult to distinguish only by the transverse momentum conservation law. The multiple scattering causes a large inaccuracy in particle momentum measurements.

The ground state formation of the ^{8}Be was observed only in the experiments with monochromatic photons where the $^{12}C(\gamma,3\alpha)$-reaction was surely singled out. The α_1-particle is easy to identify in the channel of the ^{8}Be ground state production. The analysis of the angular distributions of α_1-particles has shown [4,5] that in this channel electrical dipole transitions, which are prohibited by the law of the isospin conservation, are preferable. Further experiments didn't show this channel.

There are some advantages of the $^{12}C(\gamma,3\alpha)$-reactions investigation by means of the diffusion chamber. In this case one can obtain an admixture-free target. Owing to low gas density an inaccuracy in the momentum measurement greatly diminished because of a multiple scattering decreasing. An ionization density and its change along a track length make it possible to identify a particle charge. The comparison of momentum values that were obtained by curvature and length measurements for every track was used as a final criterion to identify a α-particle.

2. EXPERIMENTAL METHOD

The experiment was performed by the method of a diffusion chamber in a magnetic field with the strength of 1.5 T.

The chamber, filled with a mixture of methane (13%) and helium, was exposed to a beam of bremsstrahlung photons with end point energy of 150 MeV. Owing to the gas filling, the tracks of slow residual nuclei had measurable lengths and their images on a photographic film were sufficiently clear at pressures close to an atmospheric one. A large angular coverage and low density of the medium made it possible to measure the angular distributions of charged products of multiparticle photonuclear reactions in a broad energy range. This experimental method makes possible a charge identification of particles by analysis of the ionization density and its change along the track. A primary selection of events of thee-pronged stars was carried out on the base of the conclusion that all the tracks were left only by twice charged particles and those tracks were almost complanar. The inaccuracy in the momentum measurement was increasing when the angle between the particle momentum and the median plane was growing because of the track length diminishing. An event was not taken into account if the directing cosine exceeds 0.64 and two or three particles escaped from the chamber volume. The geometrical correction for not scored events was calculated by Monte-Carlo simulation of the reaction.

After a momentum measurement for every track was done, a sum of momentum projections onto axes was obtained for each event. Because of a measurement inaccuracy this sum was not equal to zero. An imbalance onto axis, along which a γ-quanta was directional, came to a difference between this sum and a γ-quanta momentum.

A γ-quantum energy was equal to the sum of kinetic energies of three α-particles and the reaction threshold.

In Fig.1 dot line shows the absolute value of the momentum imbalance projection distribution onto a transverse axis. The distribution at momentum imbalance projections up to 15 MeV/c was fitted by a gaussian-shape curve and its half-width (FWHM) was equal to 5.8 MeV/c. For comparison, the solid line represents the data of the experiment with monochromatic photons [4] with a half-width equal 16 MeV/c. The discrepancy may be explained by a large

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inaccuracy of the angle measurements because of a multiple scattering in nuclear emulsion experiments. Only a quarter of selected three-track stars satisfied a requirements of the momentum-balance analysis and were scored as a $^{12}C(\gamma,3\alpha)$-reaction. The energy-momentum conservation law makes it possible to calculate the energy of the γ-quanta forming a star and to define more accurately a α-particle momentum. This was done in a following way: when two particles stop in the chamber volume the kinematical parameters of the third particle, which didn't stop, were calculated. And when momentum of two particles that were extracted from a curvature measurement did not have large values of the directing cosines along the vertical axis then the third particle momentum that has large directing cosine was calculated.

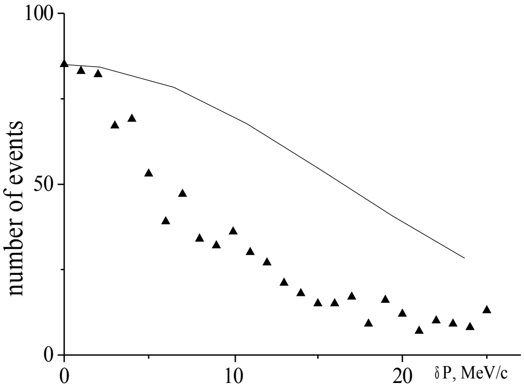

***Fig. 1.** The module projection imbalance distribution of events. Dots – this experiment, curve –[4]*

This results in a sufficient inaccuracy diminishing. The width of the excitation energy distribution of the ^{8}Be ground state, which is shown in Fig. 2, is an apparatus value. The inaccuracy in the momentum measurement extracted from this distribution is equal to the 1.4 MeV/c.

The main background reaction is the $^{12}C(\gamma,n)^{3}He2\alpha$ because the experimental method is unable to distinguish ^{4}He from ^{3}He. The $^{12}C(\gamma,n)^{3}He2\alpha$-reaction yield is 3.5 times higher then the one of the $^{12}C(\gamma,3\alpha)$-reaction, but its admixture does not exceed 3 %. The three-α-prong events are emitted by the $^{4}He(\gamma,n)^{3}He$-reaction that is accompanied by the ^{3}He scattering on the ^{4}He nuclei. Here three rays are always complanar, but a vertex of an event was often outside of the beam volume. When the chamber was filled with pure helium 200 of three-tracks events with the vertex inside of the beam volume were selected. All these events were treated as $^{12}C(\gamma,3\alpha)$ stars but all of them were later rejected because of the momentum balance non-fulfillment.

3. EXPERIMENTAL RESULTS

In Fig. 2 a histogram shows an in- pair relative energy distribution W for the energy region between 0.0 and 0.5 MeV. The maximum of the distribution is located near the value of 0.09 MeV. The half-width of the distribution is about of 0.026 MeV. The dots show the result [4] obtained by the nuclear emulsion method, which were irradiated by monochromatic photons [4]. The results were normalized by the equal amount of events and are in a good agreement

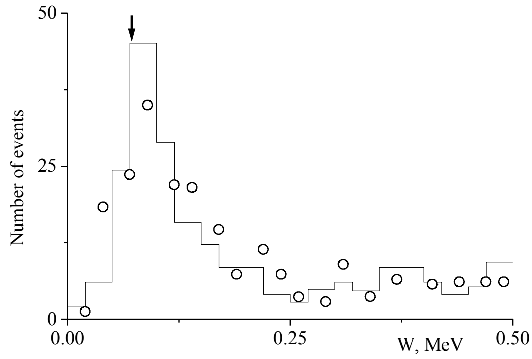

***Fig. 2**. In-pair relative energy distribution. The histogram – this experiment, dots – [4]*

The position of maximum in the energy distribution for the ^{8}Be ground state decay obtained from the spectrometric measurements is marked with the arrow. The distribution [8] has following parameters: the maximum is located at 0.078 MeV and the half-width is equal to 6.8±1.7 eV. It means that the concentration of events near 0.09 MeV may be explained by the ^{8}Be ground state formation. The width being observed in our experiment is the apparatus one.

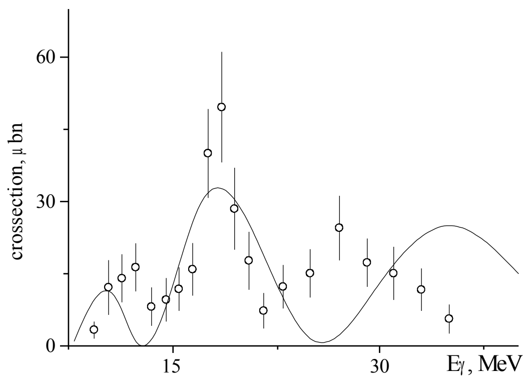

***Fig. 3.** The total cross section as a γ-quanta energy function. Dots – this experiment, the curve – [1]*

Fig. 3 shows the total cross section of the $^{12}C(\gamma,\alpha)$ ^{8}Be-reaction as a function of the energy. All errors are statistical. The integral cross sections are equal to 0.38± 0.03 MeV mb. One can see a structure in the excitation curve. The clearest maximum is located near 18 MeV. One can notice the irregularities near 12.5 and 26 MeV. In the previous works of the carbon 3-alfa-particle brake-up the ^{8}Be ground state was observed only with the energies up to 20 MeV. The total cross section is measured here for the first time. The relative yield of this channel amounts 11 % of total cross section of the $^{12}C(\gamma,3\alpha)$-reaction in the whole energy interval. At the energies of 10.3 and 19.4 MeV the ^{12}C nuclei has exited states of high width and the isospin T=0 [8]. The decay of these states into three α-particles is permitted. Probably, the curve structure up to 20 MeV reflects the ^{12}C ground state generation.

There are three maxims in the total cross section predicted by the α-cluster direct knockout mechanism and in the nuclear shell model frames [1]. Coulomb and nuclear final-state interactions do not change the quality picture. The model predicts the value of the cross section in maximum, which is close to the experimental data. The position of the maximum near 18 MeV is predicted satisfactory, while the other two are shifted in comparison with the experiment.

Fig. 4 shows angular distributions of α_1-particles for three energy intervals. Dots represent data [4] that have been obtained by means of the nuclear emulsion method. The data are normalized. At the energies below 15.6 MeV the angular distributions are almost symmetrical relative to 90° and that's why the statistics of symmetrical intervals was summed.

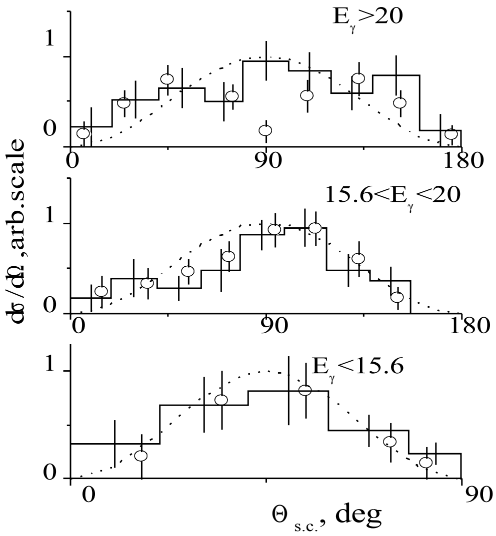

Fig. 4. *The α_1-particle angular distributions. The histogram – this experiment, dots – [3]. The curves are explained in the text*

If in this reaction a ^{12}C compound nucleus is formed the angular distributions should have the form of $\sin^2\theta$ or $\sin^2\theta\cos^2\theta$ for the pure E1- and E2- transitions respectively. The angular distributions in the energy interval 9-15.6 MeV are the evidence of the quadruple transition predominance. The same result one should expect also in the model of direct α-cluster knockout mechanism [1]. While the ^8Be nuclei transits to 0^+ level, the Coulomb and nuclear final state interactions do not distort vastly the angular distributions, and the initial state with l=0 plays the main role in the (γ,α) reaction. In the compound nuclei formation limit one can draw a conclusion that electrical dipole transitions dominate in the other two energy intervals. However, E1-transitions are prohibited by the rule of selection of the isospin $\Delta T = \pm 1$ for even-even nucleus. This is also confirmed by the small value of the reaction cross section being measured. But the conclusion about the dipole transition domination is not considered to be definitive. The model of the direct knockout of the α-particle from the state with the orbital moment of l=2 and transition of the ^8Be to the 2^+ level [1] shows that the angular distributions are strongly distorted by the Coloumb and nuclear final state interactions. The result of this calculation for the quadruple transitions with taking into account only the Coulomb final state interaction is shown on Fig. 4 by the dotted line. Calculations predict the $\sin^2\theta$-like form of distribution. Final state nuclear interactions increase substantially the isotropic part of the angular distributions. The model supposes that simultaneously with the knockout of the α-particle from the state with the l=2 the transition of the ^8Be from the 2^+ to 0^+ level is possible.

In conclusion, the channel of photo-generation of the ^8Be nucleus from the reaction C(γ,3α) is identified. The total cross section of the reaction channel in the energetic region between 10 and 35 MeV and angular distributions in three energy intervals were measured. With the energies of 15 to 35 MeV the angular distributions have a $\sin^2\theta$-like form. According to a ^{12}C compound nuclei formation there is a good agreement with E1-absorption, which is prohibited in this reaction by the rule of the isospin selection. The contradiction is removed by the model of the direct α-particle knock-out mechanism, which takes into account the Coulomb and nuclear final state interactions.

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