0^+-STATES OF THE ^{8}Be AND ^{12}C NUCLEI ABOVE THE α-DECAY THRESHOLD

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The distributions over the excitation energies of the systems of two α-particles in the ^{14}N(γ,np)3α reaction have been analyzed and a channel of the ^{8}Be nucleus formation in the ground state (GS, $J^\pi = 0^+$) is revealed and resolved. In addition, a resonance structure with a maximum located at E_0 = 0.75 MeV, possessing the width Γ= 0.75 MeV, identified as a ghost anomaly (GA) was revealed between the ground state and the first excited state of the ^{8}Be nucleus. For events corresponding to GS and GA, the excitation energy distribution of three α-particles is determined. Maxima corresponding to the Hoyle state (E_0 = 7.654 MeV) and the broad state at E_0 = 10.3 MeV of the ^{12}C nucleus have been detected. A physical analysis has been performed and it has been found that the spin and parity of these states are $J^\pi = 0^+$. Events corresponding to the partial channel of the ^{14}N(γ,np)^{12}C*(0+) reaction with the subsequent two-particle decay $^{12}C^* \rightarrow \alpha + {}^8Be(0^+)$ are separated.

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The structure of the 0^+_2 state at E_0 = 7.654 MeV nucleus ^{12}C (Fig. 1, [1]), known as the Hoyle state, is in the energy range slightly above the threshold of 3α-particle decay of the nucleus ^{12}C (7.275 MeV) and is considered a typical 3α-cluster structure. Numerous experimental and theoretical studies refine both the configuration of α-clusters and various energy and angular correlations of α-particles.

Shortly after the existence of the Hoyle state was experimentally confirmed, something resembling a broad resonance at E_0 = 10.3 MeV with a width of Γ = 3.0 MeV was discovered (see Fig. 1). The structure of this state has long been one of the most interesting unsolved problems in nuclear physics. It is believed that it also has an α-cluster structure due to its large α-decay width. According to calculations, the spin and parity J^π should be 2^+ as in the second member of the rotational band starting from the 0^+ state of the Hoyle state. However, recent studies [2, 3] have shown that the spin of this state is J^π = 0+.

E_x in ^{12}C (MeV ± keV)	J^π : T	$\Gamma_{c.m.}$ (keV)	Decay
7.65407 ± 0.19 c	0^+ : 0	9.3 ± 0.9 eV	π, γ, α
9.641 ± 5	3^- : 0	46 ± 3 b	γ
9.870 ± 60	2^+ : 0	850 ± 85	γ
(9.930 ± 30) b	0^+	2710 ± 80	
(10.3 ± 300) a	(0^+); 0	3000 ± 700	α
10.847 ± 4	1^- : 0	273 ± 5 c	γ

Fig. 1. Levels of the ^{12}C nucleus

Recently, several experimental works have been published with the detection of level 2^+ (for example, E_0 = 9.87 MeV in Fig. 1) in this area [4, 5]. However, all these 2^+ states overlap with a broad 0^+ component in the energy range from 8 to 12 MeV, so a unified picture has not yet been formed.

This paper presents the results of a study of the ^{14}N(γ,np)3α reaction [6, 7]. The experimental data were obtained using a diffusion chamber in a magnetic field, installed in the path of a photon beam with a maximum energy of 150 MeV.

The excitation energy for a pair of α-particles was determined according to the formula

$$E_x(2\alpha) = M^{e\phi}(^8Be) - 2m_\alpha, \quad (1)$$

where $M^{e\phi}(^8Be)$ is an effective mass equal to the total energy of a pair of α-particles in their rest coordinate frame, and m_α is the mass of α-particle.

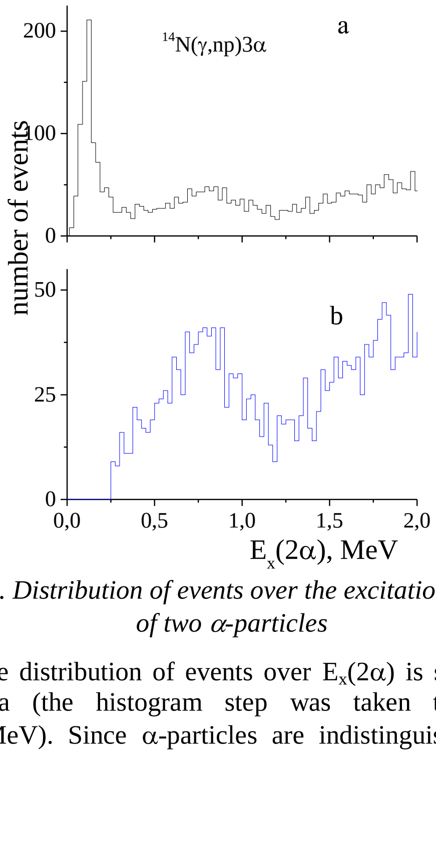

Fig. 2. Distribution of events over the excitation energy of two α-particles

The distribution of events over $E_x(2\alpha)$ is shown in Fig. 2,a (the histogram step was taken to equal 0.25 MeV). Since α-particles are indistinguishable, a preliminary selection of α-particles forming a pair as a result of the ^8Be nucleus decay is impossible. Therefore, all possible combinations of $E_x(2\alpha)$ were calculated for every event, and all obtained values are presented in the figure.

The concentration of events around an energy of $E_x(\alpha\alpha) < 0.25$ MeV can be explained by the formation of ^8Be nucleus in the ground state (GS) [7].

After highlighting the OS (see Fig. 2,b), one can see the manifestation of a resonant structure with $E_0 \sim 0.75$ MeV, which can be intuitively identified as a ghost anomaly (GA) [8]. The feature GA are explanation in the framework of the R-matrix theory of nuclear reactions: the modulation of the ground state resonance of the ^8Be nucleus by the probability for an α-particles through the potential barrier gives rise to the appearance of the resonance – ghost anomaly. Events corresponding to GA can also be highlighted – $0.25 < E_x(\alpha\alpha) < 1.25$. The study of angular distributions in the center of mass system of GS and GA allowed us to conclude that $J^\pi = 0^+$ for both levels.

Fig. 3 shows the distribution according to $E_x(3\alpha)$ in the channel $^{14}N(\gamma,np)\alpha^8Be$. The solid histogram shows the distribution of events for the GS ^8Be nucleus formation channel, while the dotted histogram shows the distribution for the GA ^8Be nucleus channel.

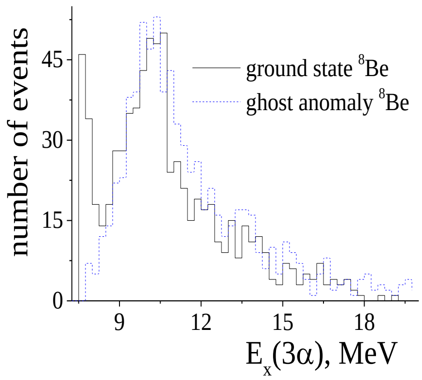

Fig. 3. Distribution of events over the excitation energy of three α-particles

The position of the first maximum (at $E_x(3\alpha) < 8.0$ MeV) is consistent with data on the narrow 0^+ state of the ^{12}C nucleus with $E_0 = 7.654$ MeV (see Fig. 1), which is referred to in the literature as the Hoyle state. The resonance width observed in this experiment is instrumental. The figure shows that the contribution to the Hoyle state is mainly due to the channel of formation of the GS ^8Be nucleus. On the other hand, the broad maximum at $E_0 = 10.3$ MeV corresponds with almost equal probability to both the GS and the GA.

For events corresponding to the maximum at E_0 = 10.3 MeV, the differential cross-section dN/dθ in the rest coordinate frame of the system $\alpha+^8Be_0$ is determined. The obtained results were fitted with a linear function, and it was found that its slope almost equals zero within the error limits. This fact made it possible to conclude that the quantum characteristics $J^\pi = 0^+$ is also valid for ^{12}C nucleus. Thus, a partial channel of the reaction $^{14}N(\gamma,np)^{12}C^*(0^+)$ with the subsequent two-particle decay of $^{12}C^*$ into $\alpha + ^8Be(0^+)$ is distinguished.

An explanation for the broad resonance at $E_0 = 10.3$ MeV can be found within the framework of a single-level approximation model with a single decay channel.

In this case the spectral density looks like:

$$\rho(E_x) \propto \frac{\frac{1}{2}\Gamma_0}{(E_0 - \Delta_0 - E_x)^2 + (\frac{1}{2}\Gamma_0)^2}, \qquad (2)$$

where the given width of α-particle decay Γ_0 and offset of the resonance Δ_0 are associated with the regular, F_0, and irregular, G_0, Coulomb functions. These functions include the probability for an α-particles through the potential barrier and if the numerator of the fraction (2) grows faster than the denominator, the excitation curve becomes asymmetrical and a satellite peak may even appear within its limits.

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0^+-СТАНИ ЯДЕР ^{8}Be І ^{12}C ВИЩЕ ПОРОГУ α-ЧАСТИНКОВОГО РОЗПАДУ

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При дослідженні розподілу енергій збудження системи двох α-частинок у реакції $^{14}N(\gamma,np)3\alpha$ було виявлено і виділено канал утворення ядра ^{8}Be в основному стані (ОС, $J^\pi = 0^+$). Крім того, між основним станом і першим збудженим станом ядра ^{8}Be виявлено резонансну структуру з максимумом, розташованим при E_0 = 0,75 МеВ і шириною Γ = 0,75 МеВ, яку ідентифіковано як аномалію-привид (АП). Для подій, що відповідають ОС та АП, отримано розподіл енергій збудження трьох α-частинок. Виявлено максимуми, що відповідають стану Хойла з E_0 = 7,654 МеВ та широкому стану при E_0 = 10,3 МеВ ядра ^{12}C. Проведено фізичний аналіз і встановлено, що спін і парність цих станів $J^\pi = 0^+$. Виділено події, що відповідають парціальному каналу реакції $^{14}N(\gamma,np)^{12}C^*(0^+)$ із подальшим двочастинковим розпадом $^{12}C^* \rightarrow \alpha + {}^8Be(0^+)$.