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SPECIFIC FEATURES OF CAPTURE REACTIONS OF REAL AND VIRTUAL *a*-PARTICLES BY ^{6}LI AND ^{7}LI ISOTOPES

The article examines the features of the interaction of virtual and real α-particles with isotopes ^{6}Li and ^{7}Li with the formation of the ground and excited states of ^{10}B and ^{11}B nuclei. The multiparticle shell model is used to describe the structures of nuclei. The significant difference in the excitation spectra of ^{10}B and ^{11}B nuclei in the capture of real and virtual α-particles is explained by the structural features of these nuclei and different mechanisms of capture of α-particles. Real α-particles are captured in reactions (α, γ), and virtual ones – in lithium cluster transfer reactions. In both boron isotopes, the first decay channel is the α-particle, then there is an energy range of several MeV until the next decay channel with the emission of particles. Moreover, in this energy range, the S-factors are anomalously small. If the excited levels lie above the threshold for the breakup of the nucleus with the emission of certain particles α, then the S-factors turn out to be related to the partial widths of the decay Γ_α. In contrast to spectroscopic factors, which do not depend on energy and are determined only by the structure of the initial and final states, the partial Γ-widths depend on the energy which the particles are emitted with. It is shown that, in a narrow energy range from the first threshold for the emission of particles to the second threshold, the cross sections for the excitation of residual nuclei by real and virtual α-particles differ significantly. Narrow beams of γ-quanta formed with large cross sections in reactions of radiative α-capture can be used for diagnostics of thermonuclear plasma.

Keywords: virtual and real α-particles, excitation spectra of ^{6}Li and ^{7}Li, ^{10}B and ^{11}B nuclei, radiative capture, lithium transfer reactions.

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Особенности реакций захвата реальных и виртуальных α-частиц изотопами ^{6}Li и ^{7}Li

В статье рассматриваются особенности взаимодействия виртуальных и реальных α-частиц с изотопами ^{6}Li и ^{7}Li с образованием основных и возбужденных состояний ядер ^{10}B и ^{11}B. Для описания структуры ядер используется многочастичная модель оболочек. Существенное различие в спектрах возбуждения ядер ^{10}B и ^{11}B при захвате реальных и виртуальных α-частиц объясняется структурными особенностями этих ядер и разными механизмами захвата α-частиц. Реальные α-частицы захватываются в реакциях (α,γ), а виртуальные – в литиевых реакциях передачи кластеров. В обоих изотопах бора первым каналом распада является α-частичный, затем имеется область энергий в несколько МэВ до следующего канала распада с вылетом частиц. При этом в данном промежутке энергий S-факторы являются аномально малыми. Если возбуждаемые уровни лежат выше порога развала ядра с вылетом определенных частиц α, то S-факторы оказываются связанными с парциальными ширинами распада Γ_α. В отличие от спектроскопических факторов, не зависящих от энергии и определяемых только структурой начального и конечного состояний, парциальные Г-ширины зависят от энергии, с которой вылетают частицы. Показано, что в узкой области энергий от первого порога для вылета частиц до второго порога сечения возбуждения остаточных ядер реальными и виртуальными α-частицами отличаются существенным образом. Узкие пучки γ-квантов, образующихся с большими сечениями в реакциях радиационного α-захвата, могут быть использованы для диагностики термоядерной плазмы.

Ключевые слова: виртуальные и реальные α-частицы, спектры возбуждения, ядра ^{6}Li и ^{7}Li, ^{10}B и ^{11}B, радиационный захват, литиевые реакции передачи.

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^{6}Li және ^{7}Li изотоптарында нақты және виртуалды α-бөлшектерінің қарпу реакцияларының ерекшеліктері

Мақалада виртуалды және нақты α-бөлшектердің ^{6}Li және ^{7}Li изотоптарымен ^{10}B және ^{11}B ядроларының негізгі және қозған күйлерін түзумен өзара әрекеттесуінің ерекшеліктері қарастырылған. Ядроның құрылымын сипаттау үшін көпбөлшекті қабықша моделі қолданылады. Нақты және виртуалды α-бөлшектерді ұстау кезінде ^{10}B және ^{11}B ядроларының қозу спектрлеріндегі айтарлықтай айырмашылық осы ядролардың құрылымдық ерекшеліктерімен және α-бөлшектерді ұстаудың әр түрлі механизмдерімен түсіндіріледі. Нақты α-бөлшектер реакцияларда (α, γ), ал виртуалды – литий кластерінің берілу реакцияларында ұсталады. Бор изотоптарының екеуінде де алғашқы ыдырау арнасы – α-бөлшек, содан кейін бөлшектердің бөлінуімен келесі ыдырау каналына дейін бірнеше МэВ энергия диапазоны болады. Бұл жағдайда осы энергетикалық диапазонда S-факторлары аномальды түрде аз болады. Егер қоздырылған деңгейлер белгілі бір α бөлшектерінің шығуы кезінде ядроның ыдырау шегінен жоғары тұрса, онда S факторлары парциалдық ыдырау ендеріне Γ_α – мен байланысты боп шығады. Энергияға тәуелді емес және тек бастапқы және соңғы күйлер құрылымымен анықталатын спектроскопиялық факторларға қарағанда парциалдың Γ ені бөлшектер шығаратын энергияға тәуелді. Энергияның тар аймағында, бөлшектер шығарудың бірінші табалдырығынан екінші табалдырыққа дейінгі диапазонда қалдық ядролардың қоздыру қималары нақты және виртуалды α-бөлшектермен айтарлықтай ерекшеленетіні көрсетілген. Радиациялық α-қарпу реакцияларындағы үлкен қималарында пайда болған γ-кванттары термоядролық плазма үшін қолданылуы мүмкін.

Түйін сөздер: виртуалды және нақты α-бөлшектер, ^{6}Li және ^{7}Li, ^{10}B және ^{11}B ядроларының қозу спектрлері, радиациялық түсіру, литий беру реакциялары.

Introduction

The concepts of virtual particles, virtual processes, etc. are firmly embedded in modern physics. So, it is believed that the electrons interact with each other, exchanging virtual photons (γ - quanta). Similarly, according to Yukawa theory, nucleons interact by exchanging virtual π-mesons. It is known that real photons differ from virtual ones. In particular, real photons have only transverse polarization, while virtual photons have both transverse and longitudinal polarization.

The question arises whether there will be a difference in the interaction of real and virtual nuclear particles with nuclei.

To study this question, the cross sections of the capture of real and virtual α-particles by the ^{6}Li and ^{7}Li nuclei with the formation of different excited states of the ^{10}B and ^{11}B nuclei are compared. In this case, real α-particles are observed in radiation (α, γ) – capture reactions on lithium isotopes, and virtual α-particles are observed in lithium transfer reactions on the same targets.

Study of *α*-cluster structure of ^{11}B nucleus

The nucleus ^{11}B is located in the middle of the 1*p*-shell and its structure is well transmitted by the multiparticle shell model [1] .The wave functions of the levels of this nucleus with certain values of the total moment, parity, and isotopic spin (J^π, T) and within the $(1s)^4(1p)^7$ -shells are multi-component. The individual components are characterized by the orbital moment L, the spin moment S and form a complete set of states and satisfy the requirements of fermionic statistics. Due to this, in the multiparticle shell model, based on a single wave function, both nucleon and various cluster degrees of freedom can be considered. The permutation symmetry of the individual components of the wave function is characterized by the Young scheme $\{f\}$. The wave function of the ground state of the ^{11}B nucleus contains 13 components [1]. The total weight of the two main components with the Young scheme {43} is 72 %, the weight of the components with the Young scheme {421} is 22 %, and the remaining components with the Young schemes {331} and {322} account for only 6 %.

If in the atomic nucleus a certain state, ground or excited, is characterized by large values of spectroscopic *S*-factors for the separation or addition of deuterons, tritons, and α-particles, then this state is said to have a corresponding cluster structure.

It is possible that a certain level can simultaneously have large values of *S*-factors for the separation of several clusters; in this case we can talk about the multicluster structure of this state. Thus, the nuclei can have a cluster or multicluster structure not only in the ground, but also in the excited states [2].

Here we study the cluster structure of the nucleus ^{11}B. For this purpose, the cluster spectroscopic factors in the (^{7}Li + α) channels leading to the ground and excited states of the ^{11}B nucleus are calculated in the framework of the multiparticle shell model.

In an experiment, the possibility of establishing the cluster structure of the nucleus is available in the study of lithium reactions of the type (^{6}Li, α), (^{6}Li, *d*), (^{7}Li, *t*) and (^{7}Li, α). Due to the low binding energy of the nucleus of ^{6}Li in the αd –channel (ε = 1.4750 MeV) and ^{7}Li in the αt -channel (ε = 2.4678 MeV) [3], the main mechanism in these processes is the transfer of deuterons, α-particles and tritons, respectively [4]. Triton spectroscopic factors have not been studied, since the ^{8}Be nucleus is not stable and cannot serve as a target. Note that the binding energy of the proton and deuteron in the ^{7}Li nucleus is much greater: ε_p = 9.975 MeV и ε_d = 9.62 MeV. The same situation is in the case of the ^{6}Li nucleus, in which the binding energies of the channels with the escape of protons and tritons are much greater than the binding energy in the αd -channel [4].

In the cross-section σ of transfer reactions, the excitations of the residual core levels (in this case ^{11}B) can be represented, assuming a direct mechanism, by the expression $\sigma \sim (2J + 1)\, \Sigma_L S_L \cdot \Phi$ [5], here S_L – is the corresponding spectroscopic factors, and Φ – is a factor depending on the kinematic characteristics. If we assume that Φ is a more or less smooth value depending on the energy, then the maxima observed in the cross sections must be related to the maxima in the energy distribution of the spectroscopic factors.

Of particular interest is the comparison of the results of calculations of cross-sections in lithium transfer reactions of α-particles with the results of calculations of cross-sections of radiation capture reactions (α, γ) on the ^{7}Li nucleus, especially in the near-threshold region, in which the latter have a resonant character.

Results and discussion

Excitation spectra of ^{11}B nucleus in lithium α-particle transfer reactions

Figure 1 shows the spectroscopic factors for joining of α-particles in (^{6}Li, *d*) reaction to form the ground and excited states of the ^{11}B nucleus. The presented excitation spectra in lithium reactions are obtained by summing these spectroscopic factors in the energy range of 1 MeV and taking into account the multiplier $(2J_i + 1)$, where J_i are the spins of the excited states.

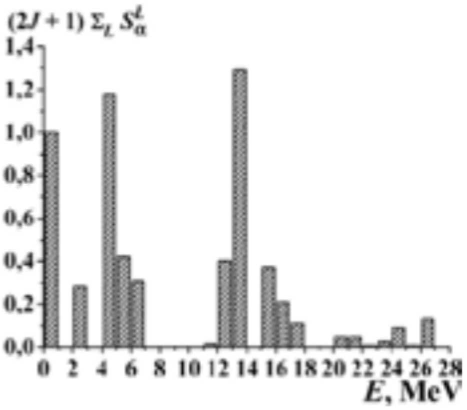

Figure 1 – The excitation spectrum of ^{11}B nucleus in lithium transfer reactions of virtual α-clusters in the ^{7}Li(^{6}Li, d)^{11}B process

To calculate the cross sections of the radiation capture reaction of α-particles, we use the Breit-Wigner formula for a single resonance, since in the case under consideration, the distance between neighboring levels in this energy region is much greater than the total widths of these levels [6]:

$$\sigma = \frac{4\pi}{k^2}\frac{\Gamma\omega_\gamma}{4(E-E_0)^2+\Gamma^2}, \qquad (1)$$

where $k = \frac{\sqrt{2\mu E_\alpha}}{\hbar}$ is the wave number, μ is the reduced mass in the system α-particle is target nucleus, $\omega_\gamma = g\frac{\Gamma_\gamma \Gamma_\alpha}{\Gamma}$ is the strength of resonance, Γ_α и Γ_γ are partial widths for the initial and final channels respectively; $\Gamma = \Gamma_\alpha + \Gamma_\gamma$ is the total width of the level, E_0 is the resonance energy, $g = \frac{2J+1}{(2J_1+1)(2J_2+1)}$ is a factor that takes into account the spins of the particles; J is the spin of the resonance excited in the reaction, J_1 and J_2 are the spins of the interacting particles.

The total cross section in the resonance ($E = E_0$) is determined by the expression:

$$\sigma = \frac{4\pi}{k^2}\omega_\gamma \frac{1}{\Gamma}. \quad (2)$$

Hence, it can be seen that the cross-section for the escaping of γ-quanta during the excitation of resonant states will be the larger the smaller the total width is. This condition will be satisfied if the widths for the α-particles are of the same order as the radiation widths. Note that the partial widths for particle escape are usually several orders of magnitude larger than the radiation widths.

The ^{11}B nucleus has a peculiar structure. For it, as for other strongly clustered nuclei of the type ^{6,7}Li, ^{8}Be, ^{10}B, ^{12}C, cluster decay channels are first opened – namely, α-partial, and other channels lie slightly higher in energy. For example, for ^{11}B nucleus the α-partial threshold is 8.665 MeV, and the next, proton threshold is almost 3 MeV higher [6]. At the same time, in the reaction ^{7}Li(α, γ)^{11}B the α-particles up to 3 MeV lead to the excitation of near-threshold levels of ^{11}B with quantum numbers $J^\pi = 5/2^-$ at an energy of 8.920 MeV, $J^\pi = 7/2^+$ at an energy of 9.185 MeV and $J^\pi = 5/2^+$ at E = 9.275 MeV [6]. In this case, monochromatic γ-quanta with energies of 8.920, 9.185 and 9.275 MeV, as well as with energy $E_\gamma = 4.740$ MeV, are formed from the transition $7/2^+ \rightarrow 5/2^-$ ($E = 4.445$ MeV). It was shown in [7, 8] that the cross sections of the formation of these γ-quanta are resonant and are abnormally large. For all these levels, only 2 decay channels are open: α-partial and radiation. Usually, the widths of the channels with the escape of particles are several orders of magnitude larger than the radiation ones. The full widths for these states are $\Gamma = \Gamma_\gamma + \Gamma_\alpha$.

The Breit-Wigner formulas show that the cross-sections for the escape of the γ-quanta during the excitation of the resonant states will be the larger the smaller the total width Γ of the level is. This condition will be satisfied if the widths for the escape of the α-particles Γ_α are comparable to the radiation widths Γ_γ. Thus, the feature of the γ-transition from the level of ^{11}B at $E = 8.920$ MeV to the ground state of the ^{11}B nucleus ($5/2^- \rightarrow 3/2^-$) is a very small partial width Γ_α. In this case, the total width of the level is $\Gamma = \Gamma_\gamma + \Gamma_\alpha = 4.37$ eV and almost completely coincides with the radiation width. The α-width Γ_α calculated by us in the framework of the multiparticle shell model is ≈ 0.006 eV [8]. The smallness of the partial width for this transition is related to the smallness of the spectroscopic factor S_α proportional to it for this case. This is clearly seen in figure 1. In the region of excitation energies from 8 to 12 MeV, there are generally no levels with large values of α-partial spectroscopic factors. The main components of the wave function of the level $5/2^-$ [1], whose experimental energy is 8.920 MeV, have a permutation symmetry of the spatial part of the wave function with the Young scheme {4421}. The contribution of the latter is 92 % to the total wave function of this state. The wave function of the ground state of the ^{7}Li nucleus has a Young scheme {43}, and its weight is 98 %. According to the quantum selection rules [9], the escape of an α-particle (having symmetry [4]) from the states with the Young scheme {4421} to the ground state of the ^{7}Li nucleus is shown to be strongly suppressed and the transition is possible only due to the small components of the wave function of ^{7}Li with the Young scheme {421}, which leads to the smallness of the spectroscopic factor and the partial width Γ_α proportional to it and, ultimately, the total width Γ.

As can be seen from table 1, the cross-section for the escape of γ-quanta with energy $E_\gamma = 8.920$ MeV is relatively large and equal to $\sigma = 5.2$ mb. Even more intense was the transition from the level of $E = 9.185$ MeV to the level of ^{11}B at $E = 4.445$ MeV ($7/2^+ \rightarrow 5/2^-$). The smallness of the total width Γ of the level, equal to about 3 eV, leads to a large cross-section of the process, equal to $\sigma = 1.3 \cdot 10^5$ μb (130 mb) for the escape of photons with $E_\gamma = 4.740$ MeV. Due to the smallness of the total width of this level, the cross-section of the escape of γ-quanta with $E_\gamma = 9.185$ MeV (for the ground state of ^{11}B) is also significant ($\sigma = 1.3 \cdot 10^3$ μb). An abnormally small value of the α-width for a level with positive parity is also associated with the smallness of the spectroscopic factor. Low-lying levels of positive parity in the ^{11}B nucleus are obtained by transiting of the 1p-nucleon into the next 2s–2d shells. As the calculations in the shell model show, if the cluster is formed by nucleons from different shells, the spectroscopic factor for α-particles in this case is suppressed in comparison with the case when they are formed by nucleons of only one shell [10, 11]. This is what leads to small Γ_α values for these levels.

According to table 1, the cross section of the reaction (α, γ) on the ^{7}Li nucleus for the $7/2^+ \rightarrow 5/2^-$ transition is exactly 2 orders of magnitude larger than the cross section of the $7/2^+ \to 3/2^-$–transition. The orbital moment of the radiated γ-quantum is determined by the ratio $|J_i - J_f| \leq L_\gamma \leq J_i + J_f$. In the transition to the ground state $7/2^+ \to 3/2^-$ according to the rules of spin and parity selection, $E3$ and $M2$-multipoles are dominant. In the $7/2^+ \to 5/2^-$ transition, $E1$ and $M2$ multipoles are dominant. As is known, in light nuclei, the electric dipole multipole is the most intense. The next level of $5/2^+$ considered by us at the energy $E = 9.275$ MeV at the gamma-decay into the ground and excited state with the energy $E = 4.445$ MeV leads to the appearance of resonant photons with the energy $E_\gamma = 9.275$ MeV and $E_\gamma = 4.835$ MeV, respectively. Since the total width of $\Gamma = 4$ keV and is much larger than the radiation one, the cross-section of the formation of γ-quanta for both transitions is somewhat smaller.

Table 1 – Experimental characteristics and cross sections of the formation of resonant γ-quanta in the reaction ^{7}Li(α, γ)^{11}B

№	$E^{\text{lab.}}_{\alpha\,(\text{res.})}$, MeV ($E^{\text{c.m.}}_{\alpha\,(\text{res.})}$, MeV)	$J^\pi_i;T_i \to J^\pi_f;T_f$, $E_i \to E_f$	Multipoles of dominant transitions	E_γ, MeV	ω_γ, eV	Γ, eV	σ_{reaction}, μb
1	0.401 (0.255)	$5/2^- \to 3/2^-$, $8.920 \to$ g.s.	$E2$, $M1$	8.920	$8.8 \cdot 10^{-3}$	4.37	$5.2 \cdot 10^3$
2	0.819 (0.518)	$7/2^+ \to 5/2^-$, $9.185 \to 4.445$	$E1$, $M2$	4.740	$3.1 \cdot 10^{-1}$	3	$1.3 \cdot 10^5$
3	0.819 (0.518)	$7/2^+ \to 3/2^-$, $9.185 \to$ g.s.	$M2$, $E3$	9.185	$3.1 \cdot 10^{-3}$	3	$1.3 \cdot 10^3$
4	0.958 (0.607)	$5/2^+ \to 3/2^-$, $9.275 \to$ g.s.	$E1$, $M2$	9.275	$2.9 \cdot 10^{-1}$	$4 \cdot 10^3$	$7.7 \cdot 10^1$
5	0.958 (0.607)	$5/2^+ \to 5/2^-$, $9.275 \to 4.445$	$E1$, $M2$	4.835	1.2	$4 \cdot 10^3$	$3.21 \cdot 10^2$

Figure 2 shows the full cross-sections of the radiation capture reaction as a function of the energy of the incident α-particles. Comparing figures 1 and 2, we can see that the resonances in the reactions of radiation capture of α-particles by lithium ^{7}Li isotopes with the formation of the ground and excited states of ^{11}B isotopes and the escape of monochromatic γ-quanta are observed precisely at those energies at which the corresponding α-partial S-factor is very small, since the spectroscopic S-factor is included as a multiplier in the formula for the partial level width.

Thus, here we have calculated the excitation spectra of the ^{11}B nucleus in lithium reactions of the transfer of α-particles to the ^{7}Li nucleus. A comparison is made with the spectra in the radiation capture reactions (α, γ) at ^{7}Li. The comparison shows that the excitation spectra in these cases are completely different, especially in the near-threshold region. If in the case when real α-particles are joined in (α, γ)-processes in the energy range from the threshold and up to energies of 10 MeV, the excitation spectra have clearly expressed maxima, then in the case of lithium reactions, when virtual α-particles are transferred, for example, from the process (^{6}Li, d), no maxima are observed in the spectra. This is due to the structural features of the states located here. The results indicate a high yield of monochromatic γ-quanta with energies E_γ = 4.835, 8.920, 9.185 and 9.275 MeV in the radiation capture reaction ^{7}Li(α, γ)^{11}B and confirm the possibility of their use for the diagnosis of thermonuclear dt -plasma [7, 12] by adding a small amount of lithium isotopes to it.

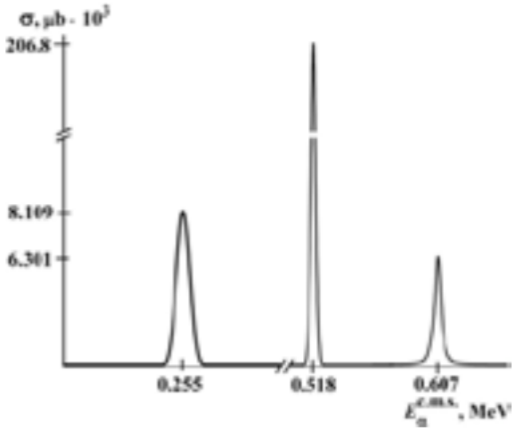

Figure 2 – Energy dependence of the total cross sections of the reaction ^{7}Li(α, γ)^{11}B

Cluster α-structure of ^{10}B nucleus levels

Figure 3 shows the excitation spectrum of the ^{10}B nucleus in the ^{7}Li(^{6}Li, *d*)^{10}B reaction, the main mechanism of which is the transfer of the α-cluster.

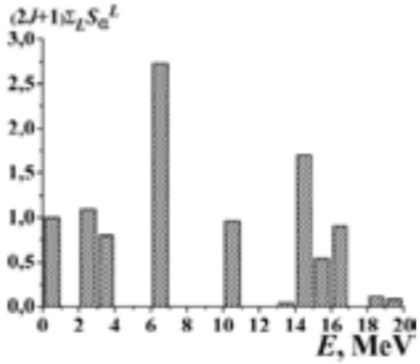

Figure 3 – Excitation spectrum of the ^{10}B nucleus in lithium α-clusters transfer reactions

The figure shows that in the energy range from 4,5 MeV to 6 MeV, in which the only α- partial decay channel is open (the threshold for α-decay is 4,46 MeV in ^{10}B), and the next threshold – the deuteron one is located at E=6,027 MeV [4]), there are no excited levels in the reactions of virtual α-particles.

The Breit-Wigner formula (1) is used to calculate the cross sections of the γ-quanta when capturing real α-particles, for a single resonance, since the distances between adjacent levels in this energy region are greater than the total widths of these levels. The total cross section in the resonance ($E = E_0$) is determined by the expression (2).

Table 2 shows the total cross-sections of the radiation capture reactions ^{6}Li(α, γ)^{10}B (capture of real α-particles), the designations are the same as in the table for the reaction ^{7}Li(α, γ)^{11}B.

Table 2 – Experimental characteristics and cross sections of the formation of resonant γ-quanta in the reaction ^{6}Li(α, γ)^{10}B

№	$E^{\text{lab.}}_{\alpha\text{ (res.)}}$, MeV ($E^{\text{c.m.}}_{\alpha\text{ (res.)}}$, MeV)	$J^\pi_i;T_i \rightarrow J^\pi_f;T_f$, $E_i \rightarrow E_f$	Multipoles of dominant transitions	E_γ, MeV	ω_γ, eV	Γ, eV	σ_{reaction}, μb
1	1.085 (0.651)	2^-; 0 → 3^+; 0, 5.1103 → g.s.	*E*1, *M*2	5.1103	$0.6 \cdot 10^{-1}$	$1.63 \cdot 10^3$	$3.6 \cdot 10^1$
2	1.173 (0.704)	2^+; 1 → 3^+; 0, 5.1639 → g.s.	*M*1, *E*2	5.1639	$0.2 \cdot 10^{-1}$	2.868	$5.78 \cdot 10^3$
3	2.433 (1.459)	2^+; 0 → 3^+; 0, 5.9195 → g.s.	*M*1, *E*2	5.9195	$1.9 \cdot 10^{-1}$	$1 \cdot 10^4$	8.42
4	2.609 (1.565)	4^+; 0 → 3^+; 0, 6.0250 → g.s.	*M*1, *E*2	6.0250	$3.4 \cdot 10^{-1}$	$8 \cdot 10^1$	$1.76 \cdot 10^3$
5	4.022 (2.413)	1^-; 0+1 → 3^+; 0, 6.873 → g.s.	*M*2, *E*3	6.8730	$4.8 \cdot 10^{-1}$	$2 \cdot 10^5$	$6.45 \cdot 10^{-1}$

For the reaction ^{6}Li(α, γ)^{10}B, four resonances are observed. However, in this case, the total Γ widths are usually much larger than in the radiation capture on the ^{7}Li nucleus [4]. The exception is γ-decay from the level (2^+, 1) at *E* = 5.1639 MeV to the ground state. In this case, the smallness of Γ_α and, consequently, the total Γ is related to the smallness of the spectroscopic factor for the α- decay of this level.

Due to the isospin selection rules, the decay is possible only due to the impurity to the wave function of the level (2^+, 1) of the component with *T* = 0, which occurs due to the Coulomb mixing of the levels with *T* = 0 and *T* = 1 [7]. The structural suppression of the α-decay from the state (4^+, 0) [1] leads to a relatively small value of the total width (line 4 in table 2) and, as a result, to a large cross-section of the departure of γ-quanta with energy E_γ = 6.025 MeV. The structural suppression of the α-decay from the (4^+, 0) state in the ^{10}B nucleus is determined the fact that the main component of the wave function of the ^{10}B nucleus with the Young scheme {442}, which gives 70% of the contribution to the total function {442}^{13}F [1], does not contribute to the S_α-spectroscopic factor for the transition to the main state of the ^{6}Li nucleus, the main component of which has the form {42}^{13}S [1]. The contribution to this transition is given by the {442}^{13}G component in the wave function of the (4^+, 0) state of the ^{10}B nucleus. Due to the large value of the orbital moment of the α-particle L_α = 4, the partial Γ_α-width is strongly suppressed due to the permeability factor of the centrifugal barrier. The transition from the state with energy $E = 6.873$ MeV to the ground state (line 5 in table 2) clearly demonstrates how a large value of the total width Γ leads to small cross-section values. In this case, $\Gamma = \Gamma_\gamma + \Gamma_\alpha + \Gamma_d + \Gamma_p$ [13, 14].

Figure 4 [8] shows the full cross-sections of the radiation capture reaction as a function of the energy of the incident α-particles.

Comparing figures 3 and 4, it can be seen that resonances in the reactions of radiation capture of α-particles by lithium ^{6}Li isotopes with the formation of the ground and excited states of ^{10}B isotopes and the escape of monochromatic γ-quanta are observed precisely at those energies at which the corresponding α-partial *S*-factor is very small, since the spectroscopic *S*-factor is included as a multiplier into the formula for the partial level width [8].

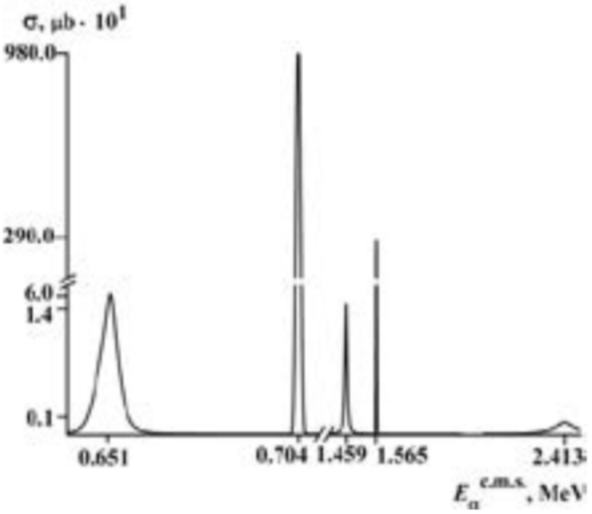

Figure 4 – Energy dependence of the total cross sections of the reaction ^{6}Li(α, γ)^{10}B

Thus, in the reaction (α, γ) on the ^{6}Li nucleus, a resonant cross-section structure is observed. In this case, the resonances are associated with small α-widths of the excited states of the ^{10}B nucleus, which is due to their structural features. So, the cross section for the escape of γ-quanta with energy $E_\gamma = 5.1639$ MeV is particularly large here. In this case, a state with quantum numbers $(J^\pi, T) = (2^+, 1)$ is excited in the process, and the smallness of the α-width is a consequence of the isospin selection rules.

The high yield of resonant monochromatic γ-quanta with $E_\gamma = 5.1639$ and 6.025 MeV in the process on the ^{6}Li nucleus confirms the possibility of using this reaction to diagnose thermonuclear plasma by adding a certain amount of lithium isotopes to it [7, 8].

Conclusion

It is shown that in the reactions of capture of virtual and real α-particles by the ^{6}Li and ^{7}Li nuclei with the formation of the ground and excited states of the ^{10}B and ^{11}B nuclei, respectively, the excitation spectra differ significantly. In a narrow energy range from the first, α-threshold of partial decay, to the next threshold of particle escape, and the width of this region is 3 MeV for ^{11}B and 1.5 MeV for ^{10}B – in the case of capture of real α-particles, the cross sections have a resonant character for both nuclei.

This behavior of the cross sections is related to the different mechanisms of these reactions, as well as to the structural features of the levels of the ^{10}B and ^{11}B nuclei in these energy ranges.

Previously, a similar question was raised for reactions under the action of real and virtual photons [14, 15]. It is the experimental cross sections for the two-particle photo disintegration reactions (α,γ) on the target nuclei ^{6}Li and ^{7}Li that were 25-30% higher for virtual photons, and the shape of the curves did not change. We see that for real and virtual α-particles, the cross-sections can differ dramatically.

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