

Materials of Conferences

 ${}^7\text{Li} \rightarrow {}^5\text{He}\{dt\}$ FRAGMENTATION CHANNEL IN THE POTENTIAL CLUSTER MODEL

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Within the two-body at -model for ${}^7\text{Li}$ nucleus the relative motion wave functions in ${}^5\text{He} + d$ channel have been built by using the projecting method in the dynamic potential cluster model. It is necessary to note, that in this calculations the $\{dt\}$ configuration of ${}^5\text{He}$ nucleus has been taken into account. The graphs of obtained ${}^5\text{He} + d$ relative motion wave functions at the various values of the oscillatory parameter of α -particle are presented. S -wave of the relative $d^5\text{He}$ motion wave function, obtained in this work within the $\{dt\}$ configuration of ${}^5\text{He}$ nucleus, doesn't have a node in contrast to the corresponding one obtained earlier within the $\{an\}$ configuration of ${}^5\text{He}$ nucleus. Obtained functions have been used for calculation of the spectroscopic S_d -factors of the deuteron separation from ${}^7\text{Li}$ nucleus. Also the comparative analysis of the obtained spectroscopic S_d -factors with corresponding ones calculated earlier within the $\{an\}$ configuration of this nucleus has been performed.

$$\Phi_{7\text{Li}} = \Phi_{000}^\alpha(1,2,3,4) \sum_{m_s, m_p} C_{1/2 m_s, 1/2 m_p}^{00} C_{1/2 -1/2, 1/2 1/2}^{00} \chi_{1/2 m_s}^{(\sigma)} \chi_{1/2 m_p}^{(\sigma)} \chi_{1 -1}^{(\tau)}(1,2,3) \chi_{1 -1}^{(\tau)}(4) \times \\ \times \Phi_{000}^t(5,6,7) \cdot \sum_{M, m_t} \chi_{1 -1}^{(\sigma)}(5,6,7) \chi_{1 -1}^{(\tau)}(5,6,7) \cdot C_{1M 1/2 m_t}^{3/2 M_t} Y_{1M}(\vec{R}) \sum_k A_k e^{-\gamma_k \vec{R}^2}, \quad (2)$$

where $\Phi_{000}^\alpha(1,2,3,4)$, $\Phi_{000}^t(5,6,7)$ are the internal WF of α -particle and tritium correspondingly, $\chi_{1/2 m_p}^{(\sigma)}$, $\chi_{1 -1}^{(\tau)}(4)$ are the spin and isospin functions of proton, $\chi_{1 -1}^{(\sigma)}(5,6,7)$, $\chi_{1 -1}^{(\tau)}(5,6,7)$ are the spin

$$\Phi_{000}^\alpha(1,2,3,4) = \Phi_{000}(\vec{\xi}_1, \vec{\xi}_2) \sum_n D_n e^{-\omega_n \vec{\xi}_3^2} Y_{00}(\Omega_{\vec{\xi}_3}), \quad (3)$$

where $\Phi_{000}(\vec{\xi}_1, \vec{\xi}_2)$ is the internal function of tritium being in the α -particle structure, which has been

In the present work the construction of relative motion wave functions (WF) in ${}^5\text{He} + d$ channel with taking into account dt -configuration of ${}^5\text{He}$ nucleus is performed within the dynamic potential cluster model (DPCM) on the basis of projecting technique described in detail in Refs [1–3]. Below, the main stages of construction of mentioned above WF are presented.

To construct ${}^5\text{He}\{dt\}$ relative motion WF it is necessary to calculate the overlap integral:

$$\Phi(\vec{\rho}) = \langle \Phi_{5\text{He}}(\vec{\rho}_3), \Phi_d(\vec{\rho}_5) | \Phi_{7\text{Li}}(\vec{R}) \rangle, \quad (1)$$

where $\Phi_{5\text{He}}(\vec{\rho}_3)$, $\Phi_d(\vec{\rho}_5)$, $\Phi_{7\text{Li}}(\vec{R})$ are the WF of ${}^5\text{He}\{dt\}$, d and ${}^7\text{Li}\{at\}$ nuclei, \vec{R} is the relative motion coordinate of α and t clusters, $\vec{\rho}_3$ is the relative motion coordinate of d and t clusters, $\vec{\rho}_5$ is the np relative motion coordinate, $\vec{\rho}$ is the relative motion coordinate of ${}^5\text{He}$ and d nuclei. The integration with respect to $\vec{\rho}_3$ and $\vec{\rho}_5$ leads to the corresponding ${}^5\text{He}\{dt\}$ relative motion WF as a function of $\vec{\rho}$ variable.

Next, let us comment the model functions used in calculations. For description of ${}^7\text{Li}\{at\}$ nucleus state the following WF is used:

and isospin functions of tritium, $C_{\alpha\alpha\beta}^{c\gamma}$ are the Clebsch-Gordan coefficients, $Y_{1M}(\vec{R})$ is the angular spherical function.

It is obvious that in this case the projecting of ${}^7\text{Li}\{at\}$ nucleus WF on ${}^5\text{He} + d$ channel affects the internal structure of α -particle, so for our calculation the WF of α -particle is also needed:

obtained in Refs [4, 5] within the resonating group method (RGM).

The state of tritium in ${}^7\text{Li}\{at\}$ structure is described by WF:

$$\Phi_t(\vec{\xi}_4, \vec{\xi}_5) = \sum_{m_2} B_{m_2} e^{-\frac{1}{4} \delta_{m_2} \vec{\xi}_4^2} e^{-\frac{1}{3} \delta_{m_2} \vec{\xi}_5^2} Y_{00}(\Omega_4) Y_{00}(\Omega_5). \quad (4)$$

The WF of ${}^5\text{He}\{dt\}$ nucleus with the total momentum j and its projection m_j may be formally presented in the form:

$$\Phi_{{}^5\text{He}} = \Phi_{000}^t(1,2,3)\Phi_{000}^d(5,6) \sum_{\substack{S_d, M_{S_d}, m'_d \\ M_L, S, M_S}} C_{S_d M_{S_d} 1/2 m'_d}^{SM_S} C_{1 M_L S M_S}^{j m_j} \chi_{S_d M_{S_d}}^{(\sigma)}(5,6) \times \chi_{\frac{1}{2} m'_d}^{(\sigma)}(1,2,3) \chi_{T_d M_{T_d}}^{(\tau)}(5,6) \chi_{\frac{1}{2}, -\frac{1}{2}}^{(\tau)}(1,2,3) Y_{1 M_L}(\bar{\rho}_3) \sum_j C_j e^{-\alpha \eta^{-2/3}}, \quad (5)$$

where $\Phi_{000}^t(1,2,3)$, $\Phi_{000}^d(5,6)$ are the internal WF of tritium and deuteron in ${}^5\text{He}\{dt\}$ structure correspondingly.

The state of deuteron is described by the following WF:

$$\Phi_{J_d M_d} = \sum_{S'_d, M'_{S'_d}} C_{S'_d M'_{S'_d} 00}^{J_d M_d} \cdot \chi_{S'_d M'_{S'_d}}^{(\sigma)}(4,7) \chi_{T'_d M'_{T'_d}}^{(\tau)}(4,7) \cdot \sum_{i_1} G_{i_1} e^{-\beta_{i_1} \rho^2} Y_{00}(\Omega_{\rho S}), \quad (6)$$

where J_d, M_d are the total angular momentum and its projection.

To calculate integral (1) it is necessary to perform the direct transformations of relative Jacobi coordinates at the transition from ${}^7\text{Li}\{\alpha t\}$ system to $d + {}^5\text{He}\{dt\}$ system, i.e.

$$\{\bar{R}, \bar{\xi}_1, \bar{\xi}_2, \bar{\xi}_3, \bar{\xi}_4, \bar{\xi}_5\} \Rightarrow \{\bar{\rho}, \bar{\rho}_1, \bar{\rho}_2, \bar{\rho}_3, \bar{\rho}_4, \bar{\rho}_5\},$$

$$\Psi_{\kappa}(\bar{\rho}) = \sum_{\substack{s_c, m_c, \\ \kappa m_{\kappa}}} Y_{\kappa m_{\kappa}}^*(\Omega_{\rho}) \cdot C_{3/2 M_{\kappa} m_{\kappa}}^{s_c m_c} C_{S_d M_{S_d} j m_j}^{s_c m_c} R_{d^5\text{He}}(\rho), \quad (7)$$

where κ, m_{κ} are the orbital momentum of $d^5\text{He}$ relative motion and its projection, s_c, m_c are ${}^5\text{He}\{dt\} + d$

and, similarly, back transformations. It is fairly easy to do, so we shall not give these transformations explicitly.

Next, using the projection technique presented in [1–3], we obtain the final form of the clusters relative motion wave function in the channel:

channel spin and its projection, $R_{d^5\text{He}}(\rho)$ is the radial part of the relative motion WF which has the form:

$$R_{d^5\text{He}}(\rho) = \sum_{i, i_j, j, k, m_2, n} G_i G_{i_j} C_j A_k B_{m_2} D_n (-1)^{2s_c} \frac{3}{4} \frac{\sqrt{(2j+1)} \cdot I_{\kappa}(\rho)}{(\beta_i + \delta_{m_2}/4)^{3/2}} C_{1010}^{\kappa 0} \times \begin{Bmatrix} S & S_d & 1/2 \\ s_c & 1 & j \end{Bmatrix} \begin{Bmatrix} 1 & 1/2 & 3/2 \\ s_c & \kappa & 1 \end{Bmatrix} \begin{Bmatrix} 1 & 1/2 & 1/2 \\ 1 & S & 1/2 \end{Bmatrix}. \quad (8)$$

In expression (8) the integral $I_{\kappa}(\rho)$ at $\kappa = 0$ (S-component) has the following form:

$$I_S(\rho) = \frac{(3\pi)^{3/2} e^{-d_i \bar{\rho}^2}}{16(d_2 d_3)^{3/2}} \left[\frac{f_1}{d_2} + \frac{\alpha f_2}{d_3} \right] + \frac{\sqrt{3} \pi^{3/2} \xi f_3}{8(d_2 d_3)^{3/2}} \cdot e^{-d_i \bar{\rho}^2} \cdot \rho^2, \quad (9)$$

and at the value $\kappa = 2$ (D-component) it takes the form:

$$I_D(\rho) = \frac{\sqrt{3} \pi^{3/2} \xi f_3}{8(d_2 d_3)^{3/2}} \cdot e^{-d_i \bar{\rho}^2} \cdot \rho^2. \quad (10)$$

The obtained relative motion WF in ${}^5\text{He}\{dt\} + d$ channel (7) are plotted in Fig. 1 and 2 at the various values of the oscillatory parameter of α -particle. As it seen from Fig. 1, S-wave of the relative $d^5\text{He}$ motion WF, obtained in this work within the $\{dt\}$ configuration of ${}^5\text{He}$ nucleus, doesn't have a node in contrast to the corresponding one obtained earlier within the $\{\alpha n\}$ configuration of ${}^5\text{He}$ nucleus [6].

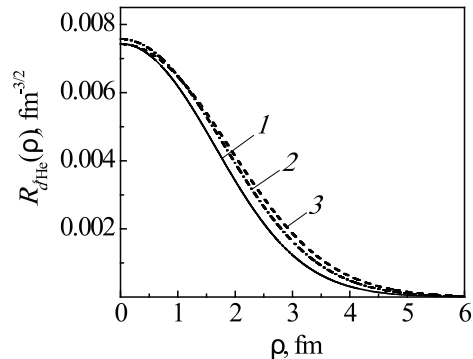


Fig. 1. Relative motion wave functions in ${}^5\text{He}\{dt\} + d$ channel (S-wave), obtained at the various values of the oscillatory parameter r_0 of α -particle: 1 – $r_0 = 1,7$ fm; 2 – $r_0 = 2$ fm; 3 – $r_0 = 2,2$ fm

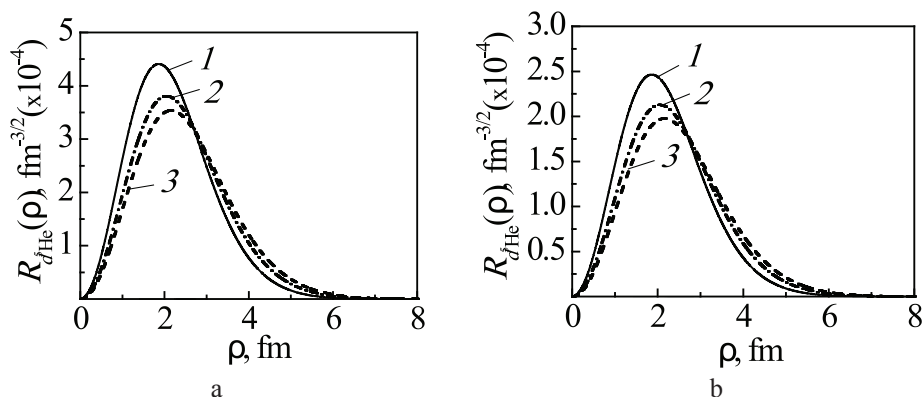


Fig. 2. Relative motion wave functions in ${}^5\text{He}\{dt\} + d$ channel: $D_{1/2}$ – wave (a) and $D_{3/2}$ – wave (b). Curve denotations are the same as in Fig. 1

On the basis of formula (7) it is easy to obtain the formula for calculation of the spectroscopic

S_d -factors of the separation of deuterons from ${}^7\text{Li}$ nucleus:

$$S = \int |\Psi(\vec{\rho})|^2 d\vec{\rho} = (2s_c + 1) \int \left| \sum_{i,j,k,m_2,n} G_i G_j C_k A_k B_{m_2} D_n \cdot \frac{3}{4} \cdot \frac{\sqrt{(2j+1)}}{(\beta_i + \delta_{m_2}/4)^{3/2}} \right|^2 \times \quad (11)$$

$$\times I_\kappa(\rho) \left\{ \begin{matrix} S & S_d & 1/2 \\ s_c & 1 & j \end{matrix} \right\} \left\{ \begin{matrix} 1 & 1/2 & 3/2 \\ s_c & \kappa & 1 \end{matrix} \right\} \left\{ \begin{matrix} 1 & 1/2 & 1/2 \\ 1 & S & 1/2 \end{matrix} \right\} C_{1010}^{\kappa 0} \Big| \rho^2 d\rho.$$

The results of theoretical calculations of the spectroscopic S_d -factors in ${}^5\text{He}\{dt\} + d$ channel are presented in Table.

It is necessary to note that presented in Table values of the spectroscopic S_d -factors for ${}^5\text{He}\{dt\} + d$ channel, obtained with taking into account $\{dt\}$ configuration of ${}^5\text{He}$ nucleus, are very small in comparison with the values obtained earlier for ${}^5\text{He}\{an\} + d$ channel in Refs. [7, 8]. As it seen in the present calculations S -wave is dominating,

and weight of D -wave is about $\sim 1\%$. Apparently, this situation is due to the fact that ${}^5\text{He}$ nucleus in the ground state exists only in $\{an\}$ configuration. $\{dt\}$ configuration of this nucleus is more probable only in the first excited state of ${}^5\text{He}$ nucleus ($j^\pi, T = 3/2^+, 1/2$) [9]. Thus, in future it would be urgent to calculate the spectroscopic S_d -factors for ${}^5\text{He}_{exc}^*\{dt\} + d$ channel, when ${}^5\text{He}\{dt\}$ nucleus is in the first excited state.

The results of calculations of the spectroscopic S_d -factors for ${}^5\text{He}\{dt\} + d$ channel, depending on the oscillatory parameter r_0 of α -particle

r_0 , fm	S_0	S_2	$P_S, \%$	$P_D, \%$
1,7	$4,01 \cdot 10^{-4}$	$4,84 \cdot 10^{-6}$	98,8	1,2
2,0	$5,23 \cdot 10^{-4}$	$4,70 \cdot 10^{-6}$	99,1	0,9
2,2	$5,89 \cdot 10^{-4}$	$4,71 \cdot 10^{-6}$	99,2	0,8

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ONE-NUCLEON SPECTROSCOPY OF NUCLEI WITH $A = 7$

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One-nucleon spectroscopic S -factors and types of nuclei clusterization are discussed. There is carried out a comparative analysis of the spectroscopic proton S_p - and neutron S_n -factors for transition to both the ground and the excited states of the corresponding nuclei-residues ${}^6\text{Li}$ - ${}^6\text{He}$ calculated within the two-body at -model of ${}^7\text{Li}$ nucleus with new accurate results of theoretical calculations of the spectroscopic S -factors for ${}^7\text{Li} \rightarrow {}^6\text{He} + p$ channel obtained within the shell model and also by using of variation methods of Monte-Carlo. For construction of the virtual tritium cluster ${}^3\text{H}$ the following models of wave functions have been used: the translational-invariant shell model which corresponds to the symmetric wave function of the relative coordinates, which has a free variable oscillatory parameter r_0 , and also «realistic» wave functions which are variation functions the parameters of which are chosen to reproduce the observable form-factor of tritium nucleus ${}^3\text{H}$.

The important problem in the theoretical analysis of the nuclear-physical processes is the finding of the correct form of the wave functions of the nuclei participating in the interaction being considered. Since it is possible only in the framework of the definite models, then it is preferably to use the model representations reproducing as much as possible wide spectroscopic information about nuclei. Now the many-particle shell model (MSM) is the more complete and developed one for the light nuclei [1]. The experience of MSM use showed that its application was justified when considering the processes covering the interior of nuclei. At investigating of the peripheral processes, particularly, the reactions of nuclei photodisintegration, the disadvantages of the MSM use appear to be obvious and they are connected with an incorrect asymptotics of the wave functions, i.e. with too fast decrease at large distances.

When considering the peripheral processes the more acceptable are the potential cluster models (PCM), the wave functions of which have a correct asymptotics [2]. In addition, exactly the peripheral processes dominate in the range of low and super-low energies of interaction, which are paid still an increasing attention now, for example, the problem of nucleosynthesis of neutron-deficient p -nuclei. In a whole, a study of the structure of the light nuclei including low-energetic near-threshold photonucleon (γ, N) reactions has a connection to the nuclear astrophysics, and also to the applied thermonuclear physics.

One-nucleon characteristics of nuclei such as the spectroscopic S -factors, reduced widths θ^2 , partial widths Γ , and impulse distribution of nucleons are the important element for investigation of reactions, where one nucleon's separation or joining to target-nucleus occurs. Such ones are the direct nuclear reactions of stripping and pickup, the reactions of elastic and inelastic scattering of nucleons on the nuclei, the resonance reactions with an excitation of the high levels of the compound nucleus and with their consequent decay by one-nucleon channel.

Nowadays for the nuclei of $1p$ -shell the various experimental data are accumulated. The study of the one-nucleon characteristics in the light nuclei was began with reactions of deuteron stripping and nucleon pickup as (d, p) , (d, n) , (p, d) . The mechanism of these reactions is well established: this is either the nucleon transfer from the slightly bound deuteron to the target-nucleus, i.e. stripping reaction, or a pickup of the proton or neutron by the projectile nucleon from the target-nucleus, for example (p, d) and (n, d) . It was further shown that the similar simple polar mechanism is the dominant on a series of other direct processes as $({}^3\text{He}, \alpha)$, (d, t) , $(\alpha, {}^3\text{He})$, (t, d) and etc. The fundamental structural characteristic in all these reactions is the spectroscopic S -factor establishing a connection between different states of the neighboring nuclei. The similar structural information can be obtained in the reactions of quasi-elastic knockout of nucleons by the projectile protons such as $(p, 2p)$ and (p, pn) , and also by electrons $(e, e'p)$. The experiments on quasi-elastic knockout of nucleons from nucleus by electrons, carried out on the Holland accelerator NIKHEV last years, are characterized with high energetic resolution ($E \approx 0,1$ MeV), that allows to study transitions to the separate levels of the nuclei-residues (see, for example, review [3] and the literature cited in this ref.).

During the 80–90th a group of theorists created the dynamic model of the light nuclei [4–8], which the first time allowed to describe the structure of ${}^6,7\text{Li}$, ${}^6\text{He}$, ${}^7,9\text{Be}$, ${}^9\text{B}$ nuclei, and properties of their excited states and probabilities of the different processes on them. For the first time the characteristic geometric forms were predicted, and these