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INTERPRETATION OF THE ^{3}H(d,^{3}He) INCLUSIVE SPECTRA AT 31 MeV

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An inclusive spectrum of the ^{3}He ions from the ^{3}H(d,^{3}He)$2n$ reaction at the deuteron beam energy $E_d = 31$ MeV has been simulated taking into account neutron–neutron final state interaction and sequential decay of the 21.2 MeV state ^{4}He*. It is shown that the interference effects must be considered for obtaining a satisfactory agreement between experimental and theoretical spectra. All distinctive features of the experimental spectrum at 10^0 have been reproduced with only three free parameters in fitting procedure. No confirmation has been found about the existence of neutron–neutron excited states.

Key words: deuteron, 31 MeV, ^{3}H target, ^{3}He spectra, dineutron, resonances.

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Recently inclusive spectra of the ^{3}He ions from the ^{3}H(d,^{3}He) reaction have been measured at small angles using the 31 MeV deuteron beam [1]. Shapes of spectra are typical for such cases, with intensive peaks from the final state interaction (FSI) of neutrons on the upper edges and long tails having wide resonances on them (fig. 1). According to the authors, such a structure should be perceived as confirmation of their hypothesis about the existence of neutron–neutron excited states, because they could not get satisfactory fitting using conventional methods such as FSI and sequential decay models. Therefore they fitted their spectra with three Gaussian functions and derived parameters of hypothetical resonances (positions and widths). The considered hypothesis seems to be a bit drastic, because there is no confirmation of it in direct (rather exact) experiments on a proton–proton (pp) and neutron–proton (np) scattering and in numerous researches of three–body systems.

On the contrary, I have found reasonable fitting of the spectrum, taking into account only FSI of neutrons and sequential decay of the ^{4}He* states. Some results of the calculations are presented below. If only one particle is observed in the three–body reaction (kinematically incomplete experiment), the momenta of the detected particle $\mathbf{p}_1$ and of the center of mass of $2-3$ subsystem $\mathbf{p}_{23}$ are determined. In addition magnitude of the relative momentum $\mathbf{k}_{23}$ in the $2-3$ subsystem can be defined. Direction of the vector $\mathbf{k}_{23}$ is not defined so the differential cross–section is calculated by integration over appropriate angles:

$$\frac{d^2\sigma(\vartheta_1, E_1)}{d\Omega_1 dE_1} = \frac{8\pi^2}{h^2 v}\int \rho \mid F \mid^2 d\Omega \qquad (1)$$

Here ϑ_1 and E_1 are the emission angle and energy of the registered particle in the laboratory system, v is a velocity of beam particles, ρ is a density of final states [2],

$$\mid F \mid^2 = \mid c_S F_S + c_R F_R \mid^2, \qquad (2)$$

F_S and F_R are FSI and sequential decay amplitudes, c_S and c_R are free parameters. The Watson–Migdal approximation is used for calculating F_S [3, 4]:

$$F_S(k) \sim \frac{r(k^2+\alpha^2)}{2(-1/a + rk^2/2 - ik)},$$

$$\alpha = \frac{(1+\sqrt{1-2r/a})}{r}$$

with $k = \mid \mathbf{k}_{23} \mid$, $a = -18.5$ fm, $r = 2.80$ fm [5], and F_R is taken in the Breit–Wigner form:

$$F_R(E) \sim \frac{\Gamma/2}{(E - E_R + i\Gamma/2)},$$

where E is the relative energy in the n^3He subsystem, E_R and Γ are the energy level and width of the ^{4}He* state. Expression (2) can be rewritten as follows:

$$|F|^2 = |c_S F_S|^2 + |c_R F_R|^2 + 2|c_S F_S||c_R F_R|\cos(\varphi_S - \varphi_R),$$

$$\cos\varphi_R = \frac{(E-E_R)}{\sqrt{(E-E_R)^2+\Gamma^2/4}},$$

$$\sin\varphi_R = -\frac{\Gamma/2}{\sqrt{(E-E_R)^2+\Gamma^2/4}}.$$

In the real calculations changes of φ_S along the spectrum are neglected and $\varphi_S = const$ is used as the third free parameter. Resolution and, to a certain extend, target and detector dimensions are taken into account by using the spectral line in the form of the symmetric Gaussian function

$$dN(E,E_0)/dE \sim exp\{(-ln2)(E_0-E)^2/H^2\}$$

with the value of a half- width parameter $H = 0.25$ MeV. This value is defined by simulating the ^3He recoil peak from the elastic deuteron — ^{3}He scattering.

The experimental spectrum [1] and the calculated one with only the first term in the used sum (2) are shown in fig. 1b. It is necessary to agree that the Watson–Migdal approximation surprisingly well reproduces the experimental spectrum (with the exception of resonance structure, naturally) on such a wide interval of energies. Curves 1–4 show the possible contributions from a sequential decay of the ^{4}He* states (E_x=21.2, 22.0, 25.3, Γ = 0.7, 1.8, 2.4 MeV) and from a space phase factor ρ (statistical distribution). At the first sight it seems that they can not explain the resonance structure, as contributed just at those energies, where the minimum in the experimental spectrum is observed. However as usual in such calculations angular distributions of ^{4}He* systems and their decay on neutrons and ^{3}He nuclei are not taken into account, though, as it is known, these distributions are non–isotropic [6]. In the fig. 1c (dashed line) the contribution from the state of 25.3 MeV is shown. It is calculated with an angular distribution in the chosen form of $(0.01 + sin\theta)^{-1}cos^2\varsigma$ where θ is the emission angle of the ^{4}He* nuclei in the lab. system and ς is the angle between $\mathbf{p}_{23}$ and $\mathbf{k}_{23}$ vectors. Even incoherent contribution in such a form improves fitting to the experimental data (solid line in the fig. 1c).

On fig. 1d an interference effect in the sum (2) is shown. Only the 21.2 MeV state is taken into account, and all angular relations are ignored. The quality of fitting obtained with only three free parameters is, at least, not worse, than in Ref. [1], taking into consideration a careless fitting of the FSI peak in it because of incorrect use of Gaussian function (fig. 1a). Again nine free parameters must have been used in calculations in Ref. [1]. So, apparently, the experimental data under consideration should not be regarded as a confirmation of a hypothesis about the existence of the excited states of the dineutron.

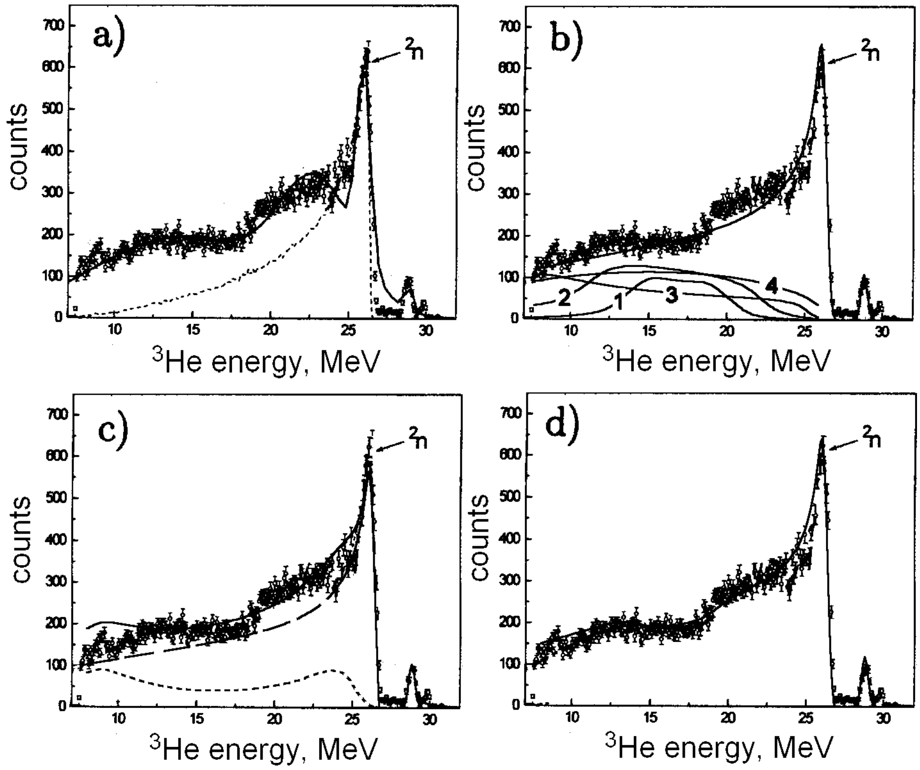

Рис. 1. Experimental [1] and calculated spectra of the ^{3}He ions from the ^{3}H(d,^{3}He)$2n$ reaction at 10° in lab. system: a) Watson–Migdal approximation with $a_{nn} = -16$ fm (dotted line) and fitting with three normal distributions (solid line) [1]; b) Watson–Migdal approximation with $a_{nn} = -18.5$ fm, $r = 2.80$ fm (the upper line) and contributions from sequential decay of the ^{4}He* states with E_x=21.2, 22.0, 25.3 MeV and statistical distribution (curves 1–4 respectively); c) contribution from sequential decay of the 25.3 MeV state ^{4}He* with angular distributions taken into account (dotted line), Watson–Migdal approximation (dashed line) and their incoherent sum (solid line); d) coherent sum of Watson–Migdal and sequential decay of the 21.2 MeV ^{4}He* state amplitudes.

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ІНТЕРПРЕТАЦІЯ ІНКЛЮЗИВНИХ СПЕКТРІВ ^{3}H(d,^{3}He) РЕАКЦІЇ ПРИ ЕНЕРҐІЇ ПУЧКА 31 МеВ

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Модельовано інклюзивний спектр йонів ^{3}He з реакції ^{3}H(d,^{3}He)$2n$ при енергії пучка дейтронів E_d = 31 МеВ. Модель ураховує взаємодію нейтронів у кінцевому стані й послідовний розпад через резонанс ^{4}He* (21.2 МеВ). Як виявилось, для задовільного узгодження з експериментальними даними слід ураховувати інтерференцію амплітуд. З трьома вільними параметрами вдалося відтворити всі особливості експериментального спектра під кутом 10°. Гіпотеза про наявність резонансів у системі двох нейтронів не знаходить підтвердження.