КОМЕНТАРІ
COMMENTS

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Comments on the article:

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EXPERIMENTAL OBSERVATION OF NEUTRON-NEUTRON CORRELATIONS IN NUCLEUS ^{6}He FROM ^{3}H(α, pα)nn REACTION

Original article: Yaderna Fizyka ta Energetyka (Nucl. Phys. At. Energy) 20 (4) (2019) 357.

Energy distributions of protons and alpha particles from ^{3}H(α, pα)nn reaction at alpha particles beam energy of 27.2 MeV are discussed in the commented article. Energy distributions of protons were obtained by projecting two-dimensional pα coincidence spectra on the proton energy axes. A few resonances were found out which were assumed to be resonances of ^{6}He nucleus formed in the sequential decay reaction $\alpha + {}^3H \to p + {}^6He^* \to p + \alpha + n + n$, namely, the well-known 2^+ excited state at the energy of 1.8 MeV above the ground state and two new previously unknown levels at energies of 2.4 and 3.0 MeV.

In my opinion, the hypothesis of the existence of these new levels needs to be tested in independent experiments. No doubt, reactions of alpha particles with tritium nuclei are promising for the study of light nuclei and for testing the nuclear structure theories, but such interpretation of the resonances is not convincing enough. These new hypothetical resonances lie in a continuum on the tail of the much more intense peak, so the procedure of adequate simulation of the instrumental spectral line is important to identify new levels and determine their parameters correctly. Besides, a priori at such energies contributions from other processes to spectra are also possible. They are statistical three-body break-up of the triton

$$\alpha + {}^3H \to p + \alpha + n + n,$$

nn and np final-state interaction (FSI) in the case neutron-neutron or neutron-proton pairs are formed with small relative energies in the final state and they interact for a while, being already outside the influence of the other fragment

$$\alpha + {}^3H \to p + \alpha + (nn) \to p + \alpha + n + n,$$

$$\alpha + {}^3H \to p + \alpha + (np) \to p + \alpha + n + p,$$

sequential decay via ^{5}He* resonance, in which the resonant state of the ^{5}He nucleus is first formed and then it decays into an alpha particle and a neutron

$$\alpha + {}^3H \to p + {}^5He^* + n \to p + \alpha + n + n.$$

Besides, contributions of random pα coincidences are also possible.

Some samples of such two-dimensional pα coincidence spectra are shown in Fig. 1.

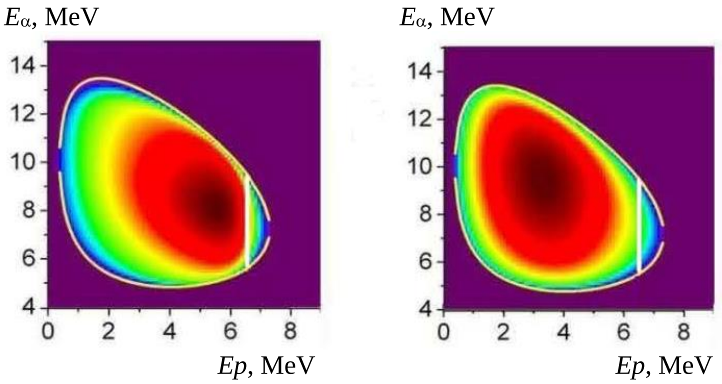

Fig. 1. Two-dimensional pα coincidence spectra from the ^{3}H(α, pα)nn reaction, calculated for sequential decay via resonances ^{5}He*. Boundaries of allowed four-body regions for pα pairs [1] and loci of events from the decay of the ^{6}He*(2 + 1.8 MeV) resonance are shown with light lines.

They were calculated for sequential decay via resonances ^{5}He* with parameters: resonances energy, $E_{\alpha n}$ = E_R = 0.798 MeV, width Γ = 0.578 MeV (left), $E_{\alpha n}$ = E_R = 2.068 MeV, Γ = 3.18 MeV (right). ^{4}He beam energy is 27.2 MeV, escape angles of protons and alpha particles are 28.5 and 16.5 degrees, respectively. The Breit - Wigner parametrization was adopted to define the distributions:

$$N(E_p,E_\alpha) \sim \rho(E_p,E_\alpha)\frac{(\Gamma/2)^2}{\left(E_{\alpha n}(E_p,E_\alpha)-E_R\right)^2+(\Gamma/2)^2},$$

$$\rho(E_p,E_\alpha) \sim \sqrt{E_p E_\alpha E_{nn}}.$$

I do not argue that the above-mentioned new excited states of ^{6}He* cannot exist, but it should be ensured that there are no contributions from other sources in the pα coincidence spectra. It should also be borne in mind that in practice the analysis of spectra is performed using simple theoretical models, even without taking into account interference effects, which can also simulate a resonant structure [2].

To understand the structure of excited ^{6}He states it is important to investigate the alpha particles spectra from the decay of these resonances and mechanisms of their decay as well. Such spectra from decay of the first ^{6}He* (1.8 MeV) resonance was published in the Refs. [3, 4]. Again, they are presented in the commented paper along with simulated distributions calculated using the Monte Carlo method. However, these distributions were calculated strangely under the assumption that in excited nuclei two neutrons with relative energy $E_{n\alpha}$ = 0 or 1 MeV revolve around the alpha particle (“as a whole”) and keep these two energy values $E_{n\alpha}$ unchanged in the final state. In such a way three-particle decay ^{6}He* → α + n + n was reduced to the binary one ^{6}He*→ α + ^{2}n. This primitive and quite artificial construction of decay has nothing to do with reality and therefore leads the authors to incorrect conclusions about the configuration of nuclei.

I made other calculations of these spectra. Experimental alpha particle distribution was obtained by projecting the strip in the two-dimensional αp coincidence spectra along the corresponding locus on the E_α axis (Fig. 2).

Differential cross-sections of the four-particle reaction b + t → a1 + a2+ a3 + a4 are written in the form [5]

$$d\sigma = \frac{(2\pi)^4}{\upsilon_0}\delta^3\left(\vec{P}-\sum_{i=1}^{4}\vec{P}_i\right)\delta\left(E-\sum_{i=1}^{4}E_i\right)\,|F|^2\prod_{i=1}^{4}d\vec{P}_i,$$

where υ_0, $\vec{P}$, E are velocity, momentum, and energy of the beam particles, $\vec{P}_i$, E_i are momenta and energies of the particles in the final state respectively, F is the matrix element. The cross-section of the ^{3}H(α, pα)nn reaction has been obtained by integration over the momenta for undetected particles 3 and 4:

$$\frac{d^4\sigma(E_1,E_2,\theta_1,\varphi_1,\theta_2,\varphi_2)}{d\Omega_1 d\Omega_2 dE_1 dE_2} = \frac{(2\pi)^4}{\upsilon_0}\int\rho|F|^2\,d\omega_{34}.$$

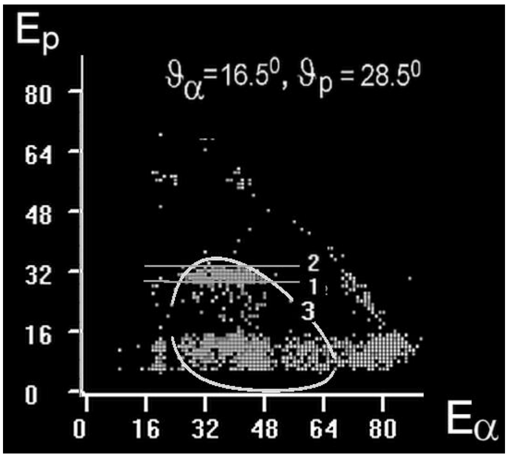

Fig. 2. Two-dimensional αp coincidence spectrum from the ^{3}H(α, αp)nn reaction, obtained when irradiating a tritium-titanium target with alpha particles beam at energy 27.2 MeV. Cell sizes are $\Delta E_\alpha \times \Delta E_p$ = 0.2 MeV × 0.2 MeV. Symbols: 1, 2 are lower and upper boundaries of the strip projected on the E_α axis, 3 is the boundary of the allowed four-body region for αp pairs.

Here ω_{34} represents the solid angle variables for relative motion in the nn subsystem, E_1, E_2, ϑ_1, φ_1, ϑ_2, φ_2, $d\Omega_1$, $d\Omega_2$ are the energies, polar, azimuthal, and the solid angle variables of protons and alpha particles, respectively, $\rho \sim \sqrt{E_1 E_2 E_{34}}$ is the four body phase space factor [1]

$$\rho\,|F|^2 = c_1\rho + c_2\rho\,|F_{nn}|^2 + c_3\rho\,|F_R|^2.$$

The first term determines the statistical distribution of events in the break-up ^{6}He* → α + n + n in which matrix element is assumed to be a constant [6].

F_{nn} is a Watson - Migdal amplitude [7, 8] for nn final-state interaction (in other words, for decay into an alpha particle and a dineutron)

$$^6\mathrm{He}^* \to \alpha + (nn) \to \alpha + n + n,$$

$$F_{nn}(q) = \frac{r(q^2+\eta^2)}{2(-1/a + rq^2/2 - iq)},$$

$$\eta = \frac{1}{r}\left(1+\sqrt{1-\frac{2r}{a}}\right), \qquad q = \sqrt{m_n E_{nn}},$$

r = 2.84 Fm and a = –18.7 Fm are the nn effective radius and scattering length, respectively [9].

F_R is a contribution of the sequential decay via the $^5He^*_{gs}$ resonance

$$^6He^* \to {}^5He^* + n \to \alpha + n + n,$$

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

with parameters E_R = 0.89 MeV. Γ = 0.60 MeV.

Calculated in such a way spectrum is shown in Fig. 3. It should be noticed that statistical distribution and that of the sequential decay via $^5He^*$ resonance are almost indistinguishable.

For a more detailed comparison, energy distributions were also simulated by the Monte Carlo method taking into account effects of the experimental set-up: beam spot size on the target, sizes, and distances of the detectors from the target, their energy resolutions, the beam energy, and its dispersion, energy losses in the target. The experimental spectrum and its approximation, obtained by fitting in the ranges of 5 - 10 MeV, are shown in Fig. 4.

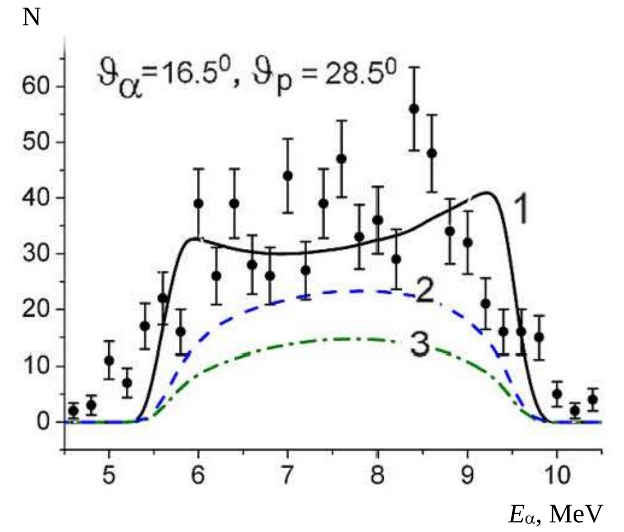

Fig. 3. Experimental and calculated αp coincidence spectra from the reaction $\alpha + {}^3H \to p + {}^6He^* \to \alpha + p + n + n$. Errors are statistical. Symbols: *1* – Watson - Migdal distribution; *2* – distribution calculated for the sequential decay via the resonance $^5He^*$ (E_{nn} = 0.89 MeV, Γ = 0.60 MeV); *3* – statistical distribution. Normalizations of the curves are arbitrary.

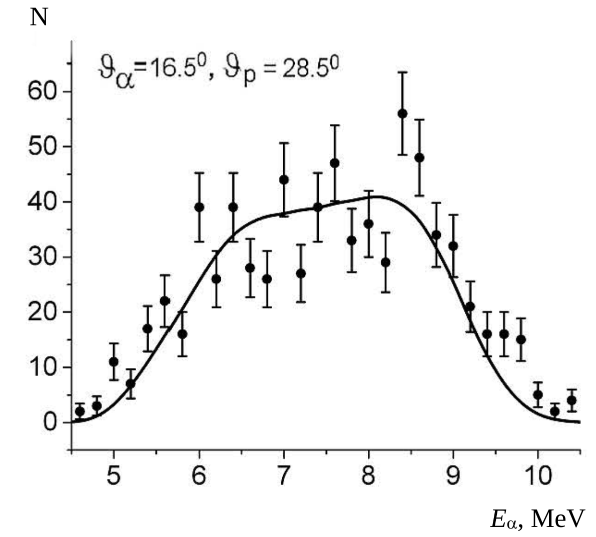

Fig. 4. Experimental αp coincidence spectrum from the reaction $\alpha + {}^3H \to p + {}^6He^* \to \alpha + p + n + n$ and simulated one calculated taking into account effects of the experimental set-up. Curve shows the Watson - Migdal distribution for nn FSI with a_{nn} = –18.7 Fm.

Thus, the experimental spectrum of alpha particles can be fitted up properly, taking into account only nn FSI. This result is predictable if the $^6He^*$ resonance is formed in the $^3H(\alpha, p)^6He^*$ reaction via the 2-neutron transfer. Such a mechanism was considered for the $^1H(^8He, t)^6He^*$ reaction in the Ref. [10].

REFERENCES

1. M. Furič, H.H. Forster. Two-particle coincidence measurement of four-body break-up: Kinematics, phase space, and the detection of possible resonances. Nucl. Instrum. Meth. 98 (1972) 301.
2. B. Struzhko. Do excited states of dineutrons really exist? Ukr. J. Phys. 45(58) (2000) 901; Interpretation of ^3He inclusive spectra from the $^3H(d, {}^3He)$ reaction at 31 MeV. Journal of Physical Studies 3(2) (1999) 144.
3. O.K. Gorpinich et al. Investigation of the first excited level's decay of ^6He with α + t interaction. Yaderna Fizyka ta Energetyka (Nucl. Phys. At. Energy) 3(5) (2001) 53. (Ukr)
4. O.K. Gorpinich et al. On the decay mechanism of the first excited level of ^6He formed at α+ t interaction. Uzhhorod University Scientific Herald. Series Physics 10 (2001) 107.
5. R.O. Newton. *Scattering theory of waves and particles* (New York: McGraw-Hill, 1966) p. 219.
6. G.G. Ohlsen. Kinematic relations in reactions of the form a + b → c + d + e. Nucl. Instr. and Meth. 37 (1965) 240.
7. K.M. Watson. The effect of final-state interactions on reaction cross section. Phys. Rev. 88 (1952) 1163.

8. A.B. Migdal. The theory of nuclear reactions with production of slow particles. JETP USSR 28 (1955) 3.
9. W. Tornow et al. Scattering length measurements from radiative pion capture and neutron-deuteron breakup. Nucl. Phys. A 631 (1998) 421.
10. X. Mougeot et al. New excited states in the halo nucleus ^{6}He. Phys. Lett. B 718 (2012) 441.

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ЕКСПЕРИМЕНТАЛЬНЕ СПОСТЕРЕЖЕННЯ НЕЙТРОН-НЕЙТРОННИХ КОРЕЛЯЦІЙ У ЯДРІ ^{6}He З РЕАКЦІЇ ^{3}H(α, pα)nn

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