USE OF A LARGE-VOLUME NE-213 SCINTILLATOR FOR INVESTIGATIONS OF THE $tt\mu^- \rightarrow {}^4He + 2n + \mu^-$ REACTION

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Use of a large-volume NE-213 scintillator for investigations of the mechanism of the nuclear synthesis reaction $tt\mu^- \rightarrow {}^4He + 2n + \mu^-$ is discussed. The investigations are supposed to be performed by comparison of the measured amplitude distributions of registered neutrons with the calculated neutron distributions obtained for an assumed form of the matrix element of the reaction.

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By now the reaction

$$\begin{array}{l} t+t \rightarrow {}^4He + 2n \\ \quad\searrow \\ \qquad {}^5He + n \\ \qquad\quad \searrow \\ \qquad\qquad {}^4He + n \end{array} \tag{1}$$

is not studied well. Only two kinematically complete experiments have been carried out at the energies 1.39 MeV [1] and 40 keV [2] with ambiguous results as to interpretation of the role of n-n and α-n interactions between reaction products in the final state. It is noteworthy that this reaction starts with the orbital momentum of the system $L = 0$. In this case three reaction channels are possible:

1) production of the ${}^6He$ compound nucleus followed by its break-up into an α-particle and two neutrons;

2) production of ${}^5He$ in the ground state $P_{3/2}$ and a neutron;

3) production of ${}^5He$ in the excited state $P_{1/2}$ and a neutron.

For the triton energy 0.5 MeV and $\theta = 90°$ the branching ratio for those channels is 0.7 : 0.2 : 0.1 [3].

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The theoretical investigation of the ttμ-molecule formation followed by the synthesis in it

$$t\mu^- + t \rightarrow tt\mu^- \rightarrow 4He + 2n + \mu^- \qquad (2)$$

showed that, unlike reaction (1), reaction (2) starts from the state $L = 1$ and, consequently, the relation between the reaction channels may change. However, it is possible to obtain information on contributions of n-n and α-n interactions between the reaction products in the final state. We believe it is possible by comparison of amplitude spectra of registered neutrons with the simulated distributions obtained with the help of assumed matrix element which describes reaction (2).

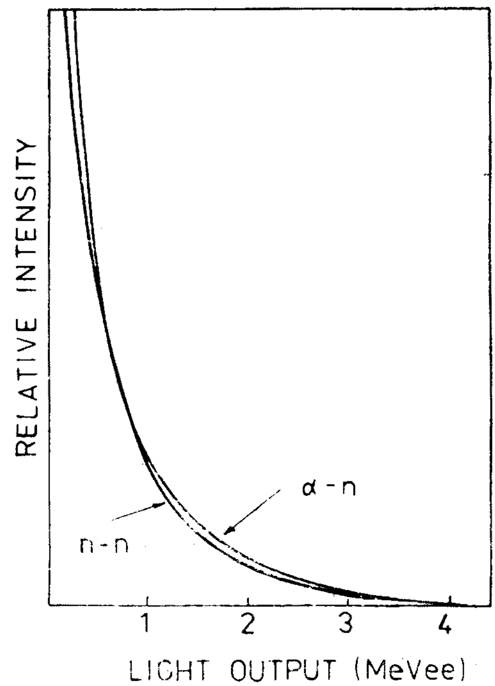

Fig. 1. Amplitude distributions of neutrons for reaction (2), calculated for the detector with 1 l of the NE-213 scintillator. Curves are normalised to the same area (equal to unity); total statistics is $5 \cdot 10^4$

In Ref. [4] the neutron registration efficiency has been calculated for reaction (2) using a 1-litre detector with the NE-213 scintillator, and amplitude distributions have been plotted with allowance for "pure" n-n and α-n interactions in the final state (chosen as extreme cases). They are given in Fig. 1. As is seen, arriving at a definite conclusion on the relation between n-n and α-n interactions is rather doubtful in this case To answer the question, whether the amplitude distributions of registered neutrons allow in general information on the mechanism of reaction (2), we have performed the necessary calculations using a neutron detector of practically full absorption with 200 l of the NE-213 scintillator.

Fig. 2 shows the distributions of the total energy of two neutrons produced in reaction (2) for n-n and α-n interactions. In Fig. 3 one can see the calcalated amplitude distributions obtained with the help of a 200 l detector for those two variants of reaction (2) product interactions in the final state. The calculations were performed using the Monte-Carlo method. The algorithm for the calculations and the geometric dimensions of the neutron detector are given in Ref. [5].

The differential cross section for reaction (2) where two particles i, j interact strongly in the final state can be written in a simplified form:

$$d\sigma = \text{const} \cdot F_{ij}^2(k_{ij})dR, \tag{3}$$

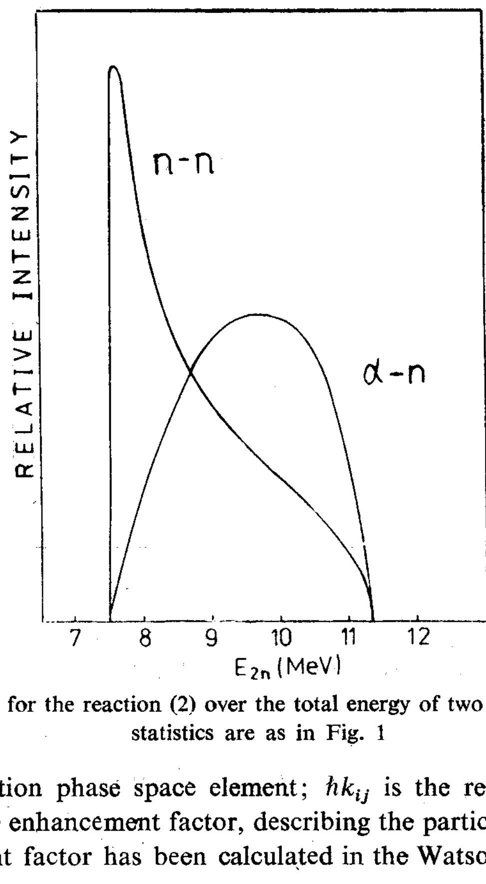

Fig. 2. Event distributions for the reaction (2) over the total energy of two neutrons. Normalization and statistics are as in Fig. 1

where dR is the reaction phase space element; $\hbar k_{ij}$ is the relative momentum of the particles i, j; F_{ij}^2 is the enhancement factor, describing the particle interaction in the final state. The enhancement factor has been calculated in the Watson-Migdal approximation

$$F_{ij}^2 = k_{ij}^{-2} \sin^2 \delta_{ij}, \tag{4}$$

where δ_{ij} is the scattering phase shift.

For the n-n interaction the scattering phase shift has been parametrized using the effective radius approximation with the scattering length $a_{nn} = -17$ fm and the effective radius $r_0 = 2.65$ fm. For the α-n interaction the phase shift parametrization was taken from Ref. [6]. The channel ratio $P_{3/2}:P_{1/2} = 1$ was arbitrarily chosen, as its value is not critical for the form of calculated (α-n)-curves.

Comparison of Figs 1 and 3 makes it obvious that the difference of hypotheses of n-n and α-n interactions becomes significant when a large-volume neutron detector is used. Besides, attention should be paid to the following fact: when the experimental spectrum coincides with the simulated one, the energy distribution of α-particles becomes known, what is important for determination of the probability of the muon shaking-off from $^4He\mu^-$ produced in reaction (2). This is significant for the efficiency of the μ-catalyzed fusion.

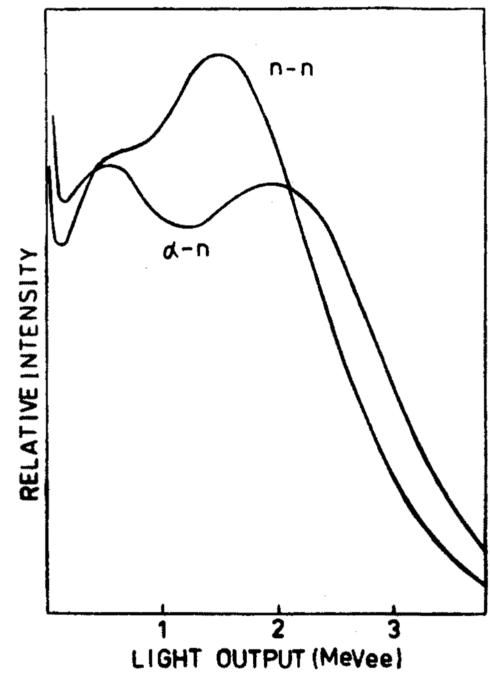

Fig. 3. Amplitude distributions of neutrons for reaction (2), calculated for the detector with 200 l of the NE-213 scintillator. The n-γ pulse-shape discrimination is taken into account, so the escape peak (as result of inelastic n-C scattering) appears in the lower energy channels. Normalization and statistics are as in Fig. 1

In conclusion we note that a large-volume scintillator detector can be employed for checking the theoretical description of reaction (2) mechanism.

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