"Dineutron" emission from an excited state of the ^{6}He nucleus

O. V. Bochkarev, A. A. Korsheninnikov, E. A. Kuz'min, I. G. Mukha,
A. A. Ogloblin, L. V. Chulkov, and G. B. Yan'kov
I. V. Kurchatov Institute of Atomic Energy, Moscow

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Experiments have been carried out on the decay of the 2^+ excited state of the ^{6}He nucleus, which is formed in the reaction ^{7}Li$(d, {}^3$He$)$ ^{6}He* at a deuteron energy of 30.5 MeV. The mechanism of the emission of a dineutron, ^2n $(T = 1, S = 0)$, explains 45% of the decay events.

The possibility in principle of a dineutron decay of certain specific nuclear states is, like two-proton decay, a consequence of the interaction of two nucleons in an outer shell.[1] The only difference in the dineutron case is that there is no Coulomb barrier, and the decay properties of the unstable level are determined by the centrifugal barrier. The three-particle decay of the 2^+ excited state of ^{6}He is an extremely convenient event for studying the correlations between nucleons in a tunneling decay. The experimental data available indicate that an important role is played by a final-state interaction of two neutrons during the decay of this level.[2] In the present study, the ^{6}He excited state is populated in the reaction ^{7}Li $(d\,^3$He$)$ ^{6}He*. To single out the mechanism of interest, we use a method of ^{3}He-α coincidences. The detection of ^{3}He in the appropriate energy range indicates the production of $^6He^*$, and the spectrum of the α particles of its decay provides information on the nature of the processes that occur.

The present measurements were carried out at the isochronous cyclotron of the Kurchatov Institute of Atomic Energy. Deuterium ions accelerated to 30.5 ± 0.3 MeV were directed at a target of metallic lithium 1.3 mg/cm^2 thick enriched to 99.7% in the isotope ^7Li. The α particles and the ^3He particles are detected and identified by two ΔE-E telescopes (with respective solid angles of 2.2×10^{-4} and 8.7×10^{-4} sr), connected in coincidence. The thicknesses of the ΔE and E silicon detectors are 30 and 500 μm in each telescope. The ^3He particles are detected at an angle of 80°. The α detector is placed along the $^6He^*$ emission direction (− 40°) for some measurements, while for others it is displaced by an azimuthal angle of 9° from the reaction plane. This displacement corresponds to an angle of 5.8° from the emission direction of the nucleus that has decayed (the maximum emission angle of the α particles in the decay is 10°). The positions of the detectors and of the deuterium beam with respect to the reaction plane are monitored by the detection of coincidences of ^3He with the ^6He nucleus in the ground state in the reaction ^7Li $(d, {}^3He){}^6He$. The output signals from the detectors are processed by a data acquisition and processing complex using an ES-1010 computer. The α-^3He coincidences are selected by a technique of fast-slow coincidences. The selected coincidences are recorded in succession on magnetic tape in the form of parametric events, including the specific loss ΔE and the total energy E of the two particles and also the difference (T) in the times at which they are detected. During subsequent processing in terms of the coordinates T-E, true coincidences are identified; a processing in terms of the coordinates ΔE-E identifies α particles and ^3He particles; and a processing in the coordinates E_α-$E_{^3He}$ identifies the reaction mechanism of interest.

Figures 1 and 2 show experimental spectra of α particles from the decay of $^6He^*$ in the laboratory frame (the points, along with the statistical errors). The spectrum in Fig. 1 corresponds to the case in which the detectors are positioned in the plane of the

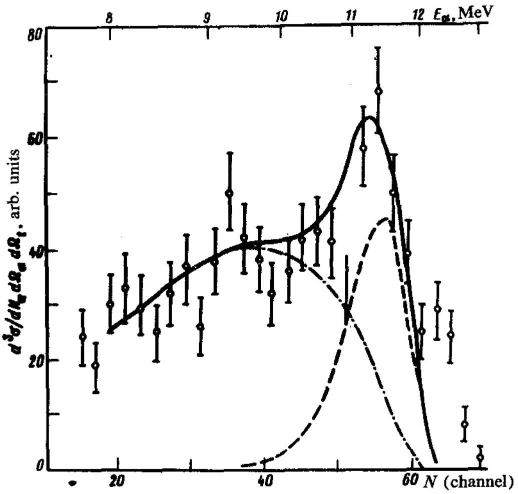

FIG. 1. Spectrum of α particles from the decay of $^6He^*(2^+)$ in the laboratory frame ($\theta_{^3He} = -80°$, $\theta_\alpha = 40°$, $\varphi_\alpha = 0°$).

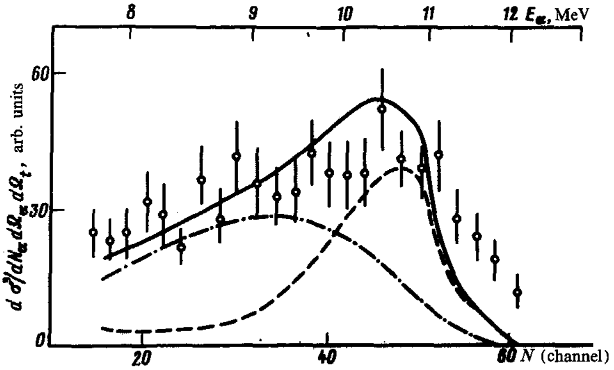

FIG. 2. The same as in Fig. 1, for $\theta_{^3\mathrm{He}} = -80°$, $\theta_\alpha = 40°$, $\varphi_\alpha = 9°$.

reaction. In the hard part of the spectrum, we see a characteristic peak corresponding to the final-state interaction of two neutrons, against the background of a broad distribution.

To analyze the data, we use the formalism of a sequential decay through an unstable system, as developed by Phillips *et al.*[3] We consider two decay mechanisms—one decay going through a ^2n system and one going through the ^{5}He nucleus. The spectrum of recoil nuclei in the first stage of the decay is reproduced by

$$\frac{d\tilde{\sigma}}{dE} \sim k|M|^2 \rho(E),$$

where $|M|$ is the matrix element that determines the decay probability, and $\rho(E)$ is the generalized final-state density, which describes the unstable system that is formed in the first stage of the process.[4] The expression for $\rho(E)$ in the case of the ^2n emission is approximately the same as that derived in the Migdal-Watson theory,[4] while in the case of a one-nucleon decay, the expression is the same as that used in the R-matrix approach.[5] It is assumed in the calculations that the decay probability is proportional to the penetrability of the centrifugal barrier for the separation of the ^{4}He-^2n system with a relative angular momentum of 2 during the decay into the dineutron and of the ^{5}He-n system with a relative angular momentum of 1 for the sequential one-nucleon decay. In the latter case, we assume an isotropic decay of the ^{5}He in calculating the spectrum of α particles. The generalized density of final states is expressed in terms of the scattering phase shift of the particles which make up the unstable system. To calculate the phase shift for the n-n scattering, we use an expansion in the effective radius with the following parameter values: a scattering length of 23.7 fm and $r_0 = 2.65$ fm. The scattering phase shift for the ^{4}He-$n(\delta^1_{3/2})$ system is taken from Ref. 6.

The spectrum of α particles in the laboratory frame is calculated by the Monte Carlo method; the geometric characteristics of the beam, the dimensions of the detectors, and the energy losses of the detected particles in the target material are all taken into account. The normalization parameters (the relation between the decay channels and the absolute value of the cross section) for the calculated distributions are found by approximating the experimental spectrum. We can attribute 45 ± 10% of the decay events to the emission of ${}^2n$. The dashed line in Fig. 1 shows the spectrum of α particles calculated under the assumption of ${}^2n$ emission, while the dot-dashed line corresponds to a sequential one-nucleon decay. The solid line is the sum of the two processes.

To test the approximations of the model, we measured the spectrum with the α detector displaced from the ^{6}He* emission direction. This spectrum is shown in Fig. 2, along with the results calculated on dineutron decay and sequential decay with the normalization parameters found from the fit of the basic spectrum in Fig. 1. It can be seen from these figures that the calculated results are quite successful in reproducing the features of both spectra and their changes with a change in detector position.

In summary, we can say that these results are evidence that the decay of the 2^+ state of the ^{6}He nucleus occurs through the emission of a dineutron in roughly half the cases.

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