Two-proton decay of ^{6}Be

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Experiments are reported on the decay of the ground state of the ^{6}Be nucleus produced in the reaction ^{6}Li(^{3}He,*t*)^{6}Be induced by 40-MeV ^{3}He ions. The peak found in the energy spectrum of α particles in coincidence with the *t* nuclei can be explained qualitatively in terms of the simultaneous emission of two protons.

The emission of a pair of correlated nucleons from a nucleus may be one of the primary decay modes of nuclei at the stability boundary, and it is the physical cause of several new effects, e.g., two-proton radioactivity.[1] This simultaneous emission of two nucleons has heretofore been observed in only two cases: in the decay of 2^+ excited states of ^{6}He nuclei (the emission of a dineutron)[2] and of ^{6}Li (the emission of a singlet deuteron).[3] The results which have been obtained on the decay of the ^{6}Be nucleus are ambiguous.[4] The two-proton decay of ^{6}Be is of particular interest in view of a recent report[5] of the observation of a delayed emission of two protons.

Figure 1 shows the ^{6}Be decay scheme. The ground state (0^+) and the excited state (2^+) of the nucleus can decay either through the simultaneous emission of a pair of

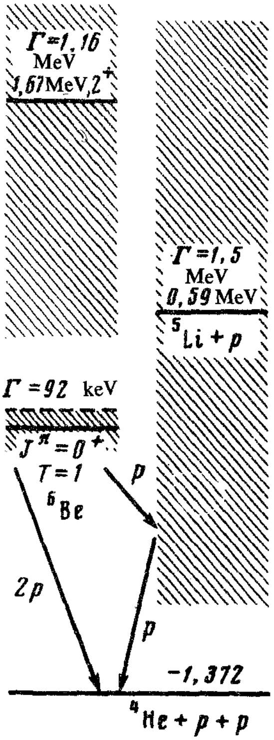

FIG. 1. Decay scheme of the ^{6}Be nucleus.

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protons, resulting in the production of ^{4}He, or through the sequential emission of two protons through an intermediate state: the ^{6}Li nucleus. Because of the large width of the ^{5}Li ground state, the difference between these two decay branches may be somewhat arbitrary. In a model-based description of the α spectrum in the former case, the spectrum should be reproduced by a Migdal-Watson formula[6] with the appropriate Coulomb corrections, while in the latter case it should be described in the R-matrix theory of a sequential decay (see Ref. 7, for example). Our calculation of the partial decay width of the beryllium ground state through the ^{5}Li system yields the value of about 50 keV. Since the experimentally observed width of the state is 92 keV, the probabilities for the decay through the two channels should be comparable.

In the present letter we report experiments on the decay of the ground state of ^{6}Be produced in the reaction $^6\text{Li}(^3\text{He},t)^6\text{Be}$ induced by 40-MeV ^{3}He ions.

The tritium nuclei and the α particles are detected in coincidence by telescopes of silicon detectors (with respective solid angles 1.3×10^{-3} sr and 3.9×10^{-4} sr); a ΔE–E method is used to distinguish the particles of a particular species. The tritium nuclei are detected at an angle of 90°, which corresponds to a ^{6}Be velocity of 4.2 MeV/nucleon; taking into account the decay energy ($Q = 1.37$ MeV), we find that this velocity corresponds to an energy range from 11.7 to 22.8 MeV for the α particles. The α detection threshold is 12.5 MeV. The α detector is placed at the angle corresponding to the emission of beryllium nuclei in the ground state ($-27.1°$). In the measurements we used a metallic lithium target 0.67 mg/cm^2 thick enriched to $\sim$91% in the ^{6}Li isotope.

Figure 2 shows the spectrum of α particles from the decay of the ^{6}Be ground state in the laboratory coordinate system. The arrow marks the threshold for the detection

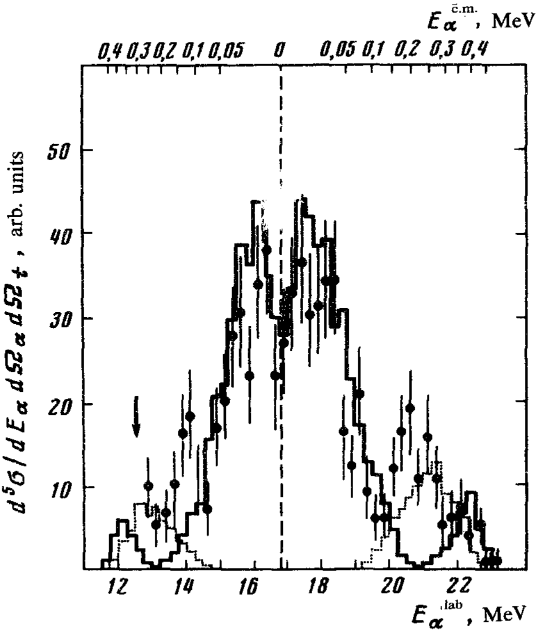

FIG. 2. Analysis of the spectrum of α particles from the decay of the ^{6}Be ground state.

of α particles. The upper scale has the energy of the α particle in the ^{6}Be system (c.m.). A zero energy in the c.m. system corresponds to an energy of 16.8 MeV in the laboratory coordinate system (shown by the vertical dashed line in Fig. 2). To the right of this dashed line the α particles are emitted along the direction in which the beryllium is moving, while to the left they are emitted in the opposite direction. The structural features in the spectrum to the right and left of the dashed line should be repeated. In Fig. 2 we see an increase in the emission in the region corresponding to low c.m. energies (0–100 keV), due primarily to a kinematic enhancement. We see a peak on the right side of the spectrum at a laboratory energy of 20–21 MeV, where we would expect to see evidence of a two-proton interaction.

To identify the sequential decay through the ^{5}Li system we use a formalism which successfully reproduces the experimental data on an analogous sequential decay.[7] The expression for the probability amplitude for the decay in the c.m. system incorporates the angular correlations between the emission directions of the first and second protons and the final-state interaction between the second proton and the α particle. This interaction is chosen as a simple Breit-Wigner p resonance. The decay amplitude is rendered antisymmetric in the coordinates of the two protons. The expression derived for the square amplitude is summed over the spin projections of the emitted protons and integrated over the variables not observable in the experiment. As integration variables we use the azimuthal angle and the momentum of the first proton. The calculations show that the two protons are emitted preferentially either in the same direction or in opposite directions. As a result, we find peaks in the α spectrum in the c.m. system at energies of about 420 and about 50 keV. For comparison with the experimental data, we convert the calculated spectrum to the laboratory coordinate system, using the Monte Carlo method. This approach allows us to take into account the finite dimensions of the detectors and of the beam at the target. The results of this calculation are shown by the histogram in Fig. 2. We see that the calculations give a satisfactory description of the α spectrum at low c.m. energies (0–100 keV). The peak at high energies is not reproduced. Taking into account the kinematic factor, we conclude that about 50% of the decay events can be attributed to decay through the ^{5}Li system, in agreement with our estimate of the decay branching.

We attempted to describe the remainder of the spectrum under the assumption that two protons cross a potential barrier as a single particle (a diproton) and that the accessible phase space is determined by the distribution calculated from the Migdal-Watson formula.[8] The results of these calculations (the dotted histogram in Fig. 2) predict peaks shifted about 1 MeV from the experimental peaks. This discrepancy is significant.

In summary, we can say that only half of the decays of the ^{6}Be ground state can be described by the mechanism of a sequential decay through the ^{5}Li system. This fraction of sequential decay can be attributed to a competition from a channel involving the simultaneous emission of two protons. However, calculations based on the assumption that two protons are emitted as a correlated pair are only qualitatively successful in reproducing the spectrum. The obvious discrepancies may be due to imperfections of the models used here. It may be possible to cast some light on the situation by carrying out a joint analysis of the decay of the 2^+ states ($T = 1$) in the isobaric triplet of ^{6}He, ^{6}Li, and ^{6}Be. In these nuclei, with identical nuclear structures, the decay occurs through the emission of different pairs of interacting nucleons, for which the potential barriers are different.

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