Exotic decay modes of ^{6}Be in a kinematically complete experiment

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A kinematically complete experiment on the three-particle decay of the 0^+ and 2^+ states of the ^{6}Be nucleus has been carried out. The resulting distributions have a clearly defined structure. Specific decay modes—a "dinucleon" mode and a "cigar" mode—which stem from a particle focusing effect in the ^{6}Be nucleus have been observed in clear, nonintegrated form for the first time.

Experiments designed to learn about the spectra of α particles and protons from the decay into $\alpha + p + p$ of the 0^+ and 2^+ states of the ^{6}Be nucleus[1,2] and an analysis of the experimental data available[3–5] have made it possible to explain the nature of the ^{6}Be decay. Data have been obtained on the existence of the following three unusual decay mechanisms; a "dinucleon" decay, in which the pair of emitted protons is highly correlated in terms of the energy of its relative motion, $E_{p\text{-}p}$ (i.e., $E_{p\text{-}p}$ is close to 0); a "cigar" decay, in which the protons are anticorrelated ($E_{p\text{-}p}$ approaches the maximum possible value); and a "helicopter" decay, characterized by a weak correlation of the products. In this third decay mode,the resultant spin of the protons is $S = 1$, in contrast with the $S = 0$ of the first two decay modes.

Processes of the dinucleon and cigar types have not been seen clearly in experiments; instead they have been seen in a summation with the helicopter mode, which washes out the presumed sharp structure of the $S = 0$ component, particularly in the case of ^{6}Be(0^+). The reason is that although these experiments have been correlation experiments, they have been of an inclusive nature with respect to measurements of the decay products.

In a kinematically complete experiment, which provides the most-detailed information, it is possible to distinguish the components with $S = 0$ from that with $S = 1$ and thus to directly study the nature of the decays with $S = 0$. The reason is that the correlation parts of the amplitudes with $S = 0$ and $S = 1$, which reflect the conservation of angular momentum, have different angular dependences [intermediate angular momenta which are combined into the total angular momentum, which is equal to the spin of the decay nucleus ("decaylet"), are different]. In a kinematically complete experiment, it would thus be possible to choose an arrangement of detectors such that (for example) the angular part of the amplitude excludes the term with $S = 1$.

In this letter we are reporting a kinematically complete experiment on the decays of ^{6}Be(0^+) and ^{6}Be(2^+). The beryllium levels were populated in the reaction ^{6}Li(^{3}He, ^{3}H)^{6}Be(0^+;2^+) at $E_{^3He} = 40$ MeV. We detected the ^{3}H nuclei, which indicate a filling of the state of interest, and also the α and p from the decay of ^{6}Be at the

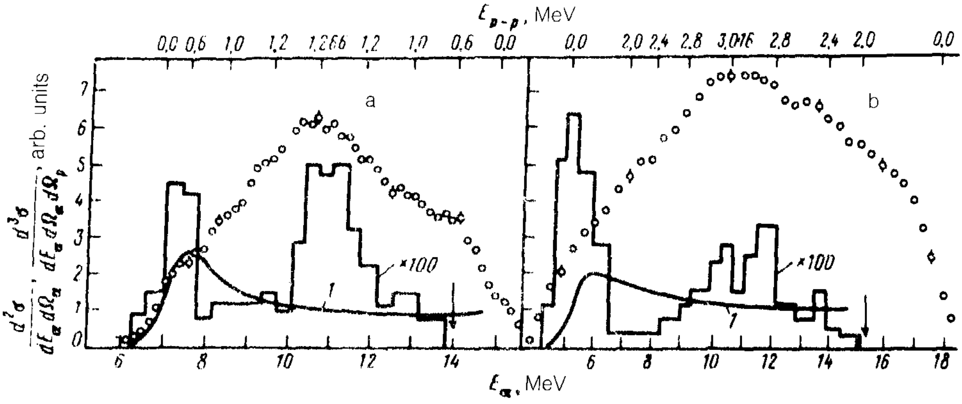

FIG. 1. Inclusive spectra (circles) and correlation spectra (histograms) of the α particles from the decay of two states (a—0^+; b—2^+) of the ^{6}Be nucleus into three particles. Line 1 shows a phase-volume calculation.

angles − 60°, 40°, and 56°, respectively (the solid angles of the detectors were 2.3, 20.5, and 20.5 msr). In addition to the t-α and t-p coincidences, which correspond to measurements of the inclusive spectrum of the decay product, we detected t-α-p triple coincidences, which correspond to the kinematically complete formulation of the experiment. The detectors were positioned in such a way that the contribution of the $S=1$ component could be suppressed in the three-particle coincidences, so the "pure" spectrum of the decay with $S=0$ could be obtained.

Figure 1, a and b, shows the resulting inclusive α spectra from the decay of the 0^+ and 2^+ states (the circles; the error bars show the statistical errors), along with the projections of the E_α-E_p distributions from the kinematically complete experiment onto the E_α axis (the histogram) in the laboratory frame of reference. The values of $E_{p\text{-}p}$ are plotted along the upper abscissa. The shape of the correlation spectra is seen to be defined vastly better than that of the inclusive spectra; the shape of the correlation spectra is radically different from the results of the phase-volume calculations for the case of an independent emission of the three particles (the solid line).[1)] The experimental histogram demonstrates the presence of two sharp peaks: at $E_{p\text{-}p}$ values close to 0 and at $E_{p\text{-}p}$ values close to the maximum value for the given decay. The positions and small widths of these peaks cannot be explained on the basis of conventional final-state p-p and α-p interactions. The peaks are separated clearly by a deep dip, whose appearance reflects the suppression of the $S=1$ contribution in the given experimental geometry. On the whole, the observation of characteristic peaks is direct experimental confirmation of the existence of exotic dinucleon and cigar processes.

The experimental data were analyzed (first) with the help of models based on an interpolation by means of binary amplitudes from the cases of two-particle decays to a three-particle decay.[3] The spectra of the decay α particles measured previously made it possible to fix all the parameters of the models and to generate unambiguous model-based predictions of, in particular, the results of a kinematically complete experiment. Such predictions, shown by the dashed lines in Fig. 2, a and b, are in complete agree-

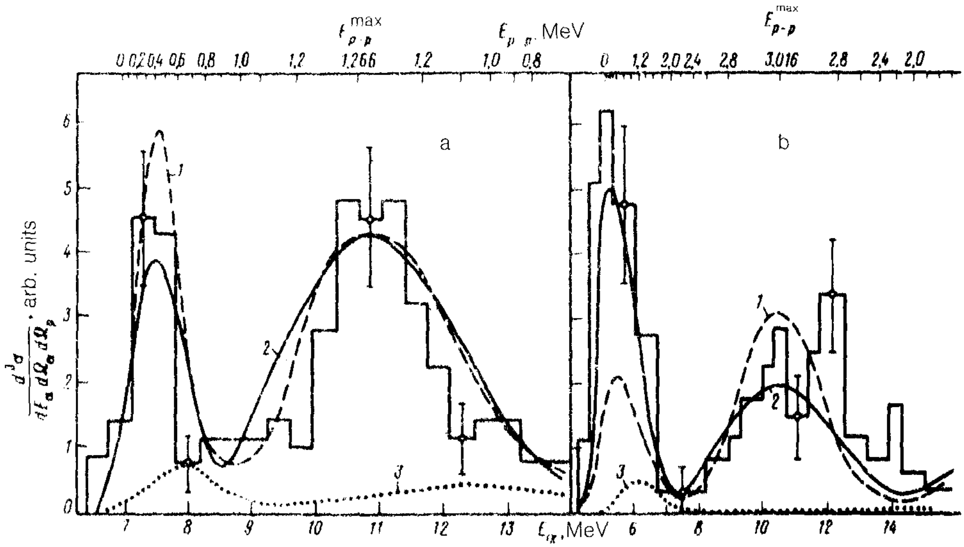

FIG. 2. Correlation α spectra from the decay of (a) $^6Be(0^+)$ and (b) $^6Be(2^+)$. Calculations: 1—on the basis of an interpolation model; 2—fitting by a method of hyperspherical harmonics; 3—contribution of a triplet state of protons.

ment with the experimental data. This agreement is a vote in support of the interpolation which we just mentioned; it would be desirable to strengthen this support with a theoretical basis, since the models which were used might serve as a simple tool for analyzing three-particle processes.

Second, the data were analyzed by an approach which starts from an expansion of the decay amplitude in a series in hyperspherical harmonics.[4] This basis is a generalization of the basis of spherical harmonics from the two-body problem to the three-body problem. An analog of the orbital angular momentum from the two-particle problem here is then the hypermoment K. An analysis of the inclusive α and p spectra from the decay of $^6Be(0^+)$ carried out by this method generated an unambiguous prediction of the results of the correlation measurements (the solid line in Fig. 2a); this prediction agrees with the experimental results. The corresponding prediction for the decay of $^6Be(2^+)$ is ambiguous, since the α and p spectra are not sufficient for fixing the weight of the helicopter component. A fit of the measured correlation spectra (the solid line in Fig. 2b) made it possible to estimate the probability for decays with $S=1$: $25 \pm 20\%$. We might add that this analysis provides evidence that the single hypermoment value $K=2$ is playing a governing role in the decay of both of these ^6Be levels and is thereby serving as a sort of "good" quantum number.

The switch to a coordinate representation made it possible to study the spatial characteristics of the amplitudes found for the decay of the 0^+ and 2^+ states. In particular, it was found that the spatial correlation of protons as well corresponds to a dinucleon, while in the case of the cigar the protons are on opposite sides of the α particle. Since a final-state interaction cannot explain these decay modes, it might be suggested that they are a consequence of the existence of corresponding spatial configurations in the wave function of the decaylet. This conclusion is in complete agreement with an elementary calculation from Ref. 6, where the existence of a spatially compact dinucleon and a formation of a cigar type in the wave function of nuclei with $A = 6$ ($T = 1$) was first predicted. This conclusion is also in complete agreement with a calculation carried out by another method[7] (a hyperspherical-harmonic method). The K-harmonic method provides a transparent explanation for such phenomena. The dinucleon and cigar structures and the corresponding decay modes arise in the case $K \neq 0$ because of a kinematic focusing of particles. This focusing generalizes to the case of several bodies an effect known in the two-body problem: a characteristic angular dependence in the scattering of a pair of particles through a state with $l \neq 0$.

In summary, this study has resulted in the first direct observation of exotic decay modes of ^{6}Be caused by a kinematic focusing of particles in the nucleus.

[1)]The detector apertures, the thickness of the ^{6}Li target, and the energy spread of the beam of ^{3}He ions were all taken into account in all of the calculations.

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[1]O. V. Bochkarev *et al.*, Pis'ma Zh. Eksp. Teor. Fiz. **40**, 204 (1984) [JETP Lett. **40**, 969 (1984)]; Pis'ma Zh. Eksp. Teor. Fiz. **42**, 305 (1985) [JETP Lett. **42**, 377 (1985)].

[2]O. V. Bochkarev *et al.*, in: Proceedings of the 37th Conference on Nuclear Spectroscopy and Nuclear Structure, Nauka, Leningrad, 1987, p. 394.

[3]O. V. Bochdarev *et al.*, Yad. Fiz. **46**, 12 (1987) [Sov. J. Nucl. Phys. **46**, 7 (1987)].

[4]B. V. Danilin *et al.*, Yad Fiz. **46**, 427 (1987) [Sov. J. Nucl. Phys. **46**, 225 (1987)].

[5]B. V. Danilin *et al.*, in: Proceedings of the 38th Conference on Nuclear Spectroscopy and Nuclear Structure, Nauka, Leningrad, 1988, p. 399.

[6]V. I. Kukulin *et al.*, Nucl. Phys. **A453**, 365 (1986).

[7]B. V. Danilin *et al.*, Yad. Fiz. **47**, No. 8 (1988) [Sov. J. Nucl. Phys. (to be published)].

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