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Detailed study of relativistic ^{9}Be → 2α fragmentation in peripheral collisions in a nuclear track emulsion*

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Abstract Recent studies of clustering in light nuclei with an initial energy above 1 A GeV in a nuclear track emulsion are overviewed. The results of investigations of the relativistic ^{9}Be nuclei fragmentation in emulsion, which entails the production of α particles, are presented. It is shown that most precise angular measurements provided by this technique play a crucial role in the restoration of the excitation spectrum of the α particle system. In peripheral interactions $^9\mathrm{Be} \to 2\alpha$ nuclei are dissociated practically totally through the 0^+ and 2^+ states of the ^{8}Be nucleus.

1 Introduction

The peripheral fragmentation of light relativistic nuclei can serve as a source of information about their excitations above particle decay thresholds including few-body final states. Possibilities of the nuclear emulsion technique for the study of the systems of several relativistic fragments produced in the peripheral interactions of relativistic nuclei are discussed [1]. The degree of the dissociation of the relativistic nuclei in peripheral interactions can reach a total destruction into nucleons and singly and doubly charged fragments. In spite of the relativistic velocity of motion of the system of fragments as a whole, the relative motion of fragments is a non-

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relativistic one. The results of investigations of the relativistic ^{9}Be nuclei fragmentation in emulsion, which entails the production of α particles, are presented. The study of the ^{9}Be fragmentation at relativistic energies gives the possibility of observing the reaction fragments, which are the decay products of unbound ^{8}Be nuclei. In this case, the absence of a combinatorial background for ^{9}Be, which is typical for heavier $N\alpha$ nuclei (^{12}C, ^{16}O), makes it possible to observe distinctly this picture.

2 Experiment

Nuclear emulsions were exposed to relativistic ^{9}Be nuclei at the JINR Nuclotron. The beam of relativistic ^{9}Be nuclei was obtained in the ^{10}B $\rightarrow$ ^{9}Be fragmentation reaction using a polyethylene target [2]. Data were obtained at a beam energy of 1.2 A GeV. The ^{9}Be nuclei constituted about 80% of the beam, the remaining 20% fell on Li and He nuclei. Events were sought by microscope scanning over the emulsion plates. In total there were 362 events of the ^{9}Be fragmentation involving the two α-particles production [3]. Emulsions provide the best spatial resolution (about 0.5 μm), which allows one to separate the charged particle tracks in the three-dimensional image of an event within one-layer thickness (600 μm) and ensure a high accuracy of angle measurements (not worse than 1.6×10^{-3} rad. for opening angles). Multiple-particle scattering measurements on the light fragment tracks enable one to separate the H and He isotopes. Irradiation details and a special analysis of interactions in the BR-2 emulsion are presented in refs. [2, 3]. We have no chance to present here a full description of all experimental procedures [1–4].

3 Results

In the opening Θ angle distribution (Fig. 1a) one can see two peaks with mean values 4.4×10^{-3} rad. and 26.8×10^{-3} rad. The ratio of the numbers of the events in the peaks is close to unity. This is the main feature of the ^{9}Be $\rightarrow 2\alpha$ channel. The other angular and transverse momentum characteristics approximately always depend on the opening angle. The Θ distribution entails the invariant energy distribution $Q_{2\alpha}$, which is calculated as a difference between the effective invariant mass $M_{2\alpha}$ of an α fragment pair and the doubled α-particle mass by the equations

$$M^2_{2\alpha} = -\left(\sum_{j=1}^{2} P_j\right)^2,$$

$$Q_{2\alpha} = M_{2\alpha} - 2 \cdot m_\alpha, \qquad (1)$$

where P_j is the α-particle four-momentum.

In the invariant energy distribution $Q_{2\alpha}$ (Fig. 1b) there are two peaks in the ranges 0 to 250 keV and 1.5 to 4.5 MeV. The shape of the distribution does not contradict the suggestion about the ^{9}Be fragmentation involving the production of an unstable ^{8}Be nucleus which decays in the 0^+ and 2^+ states.

The response of the emulsion nuclei includes the multiplicity of strongly ionizing target fragments from α particles up to recoil nuclei n_b and non-relativistic

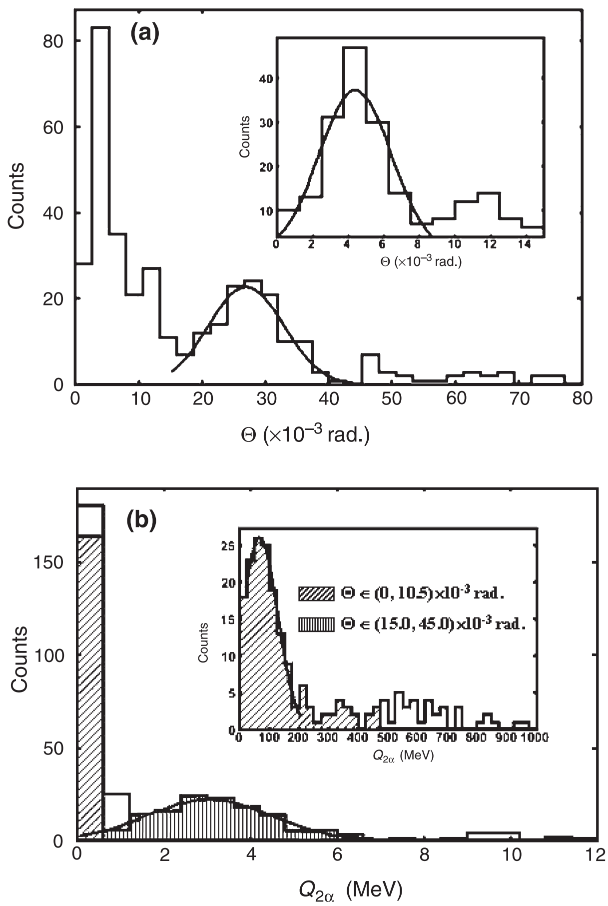

Fig. 1 (**a**) The opening Θ angle distribution of α particles in the $^9Be \to 2\alpha$ fragmentation reaction at 1.2 A GeV energy. On the intersection: the Θ range from 0 to 15×10^{-3} rad. (**b**) The invariant energy $Q_{2\alpha}$ distribution of α-particle pairs in the $^9Be \to 2\alpha$ fragmentation reaction at 1.2 A GeV energy. On the intersection: the $Q_{2\alpha}$ range from 0 to 1 MeV

Table 1 The distribution of the peripheral interactions $^9Be \to 2\alpha$ over intervals of opening angles Θ versus target fragment numbers n_b, n_g ($n_h = n_b + n_g$)

$\Theta \times 10^{-3}$ rad.	$n_g = 0$ $n_b = 0$	$n_g = 1$ $n_b = 0$	$n_g = 0$ $n_b = 3$	$n_g = 0$ $n_b = 4$	$n_g = 0$ $n_b = 5$	$n_g = 0$ $n_b = 6$
$\Theta \leq 10.5$	72	10	1	2	1	–
$10.5 < \Theta \leq 15.0$	26	–	–	1	–	–
$15.0 < \Theta \leq 45.0$	42	12	3	2	–	1
$\Theta \geq 45.0$	4	5	1	2	1	–
Sum	144	27	5	7	2	1

$\Theta \times 10^{-3}$ rad.	$n_g > 1$ $n_b = 0$	$n_g = 0$ $n_b = 1$	$n_g = 0$ $n_b = 2$	$n_g = 1$ $n_b = 1$	$n_h > 2$ $n_g \neq 0$
$\Theta \leq 10.5$	3	17	7	1	18
$10.5 < \Theta \leq 15.0$	–	2	1	–	3
$15.0 < \Theta \leq 45.0$	2	18	4	4	10
$\Theta \geq 45.0$	–	2	1	2	2
Sum	5	39	13	7	33

H nuclei n_g. Besides, the reactions are characterized by the multiplicity of produced mesons n_s. The events in which there are no tracks of the target nucleus belong to the fragmentation on Ag, Br nuclei and are named ‘‘white’’ stars ($n_b = 0$, $n_g = 0$, $n_s = 0$) [4]. Dissociation on a proton (H) must lead to the appearance of its track, that is, $n_b = 0$, $n_g = 1$, and $n_s = 0$. The observations of the ^{9}Be interaction vertices allow one to separate the population of interactions with H, and Ag, Br. Table 1 gives the distribution of the 283 events $^9\mathrm{Be} \to 2\alpha$, with $n_s = 0$ in the major intervals over opening angle Θ and the configurations of accompanying tracks. The principal feature of the distribution consists in an evident dominance of 144 ‘‘white’’ stars ($n_b = 0$, $n_g = 0$) amounting to about 60%. Only 27 events (11%) are ascribed to the stars resulting from ^{9}Be collisions with protons ($n_b = 0$, $n_g = 1$).

Possessing a record space resolution the nuclear emulsion method keeps unique possibilities in studying the structure particularities of light nuclei, first of all, of neutron-deficient nuclei. The presented results of an exclusive study of the interactions of relativistic ^{9}Be nuclei in nuclear emulsion lead to the conclusion that the particular features of their structure are clearly manifested in peripheral fragmentation.

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