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Dissociation of Relativistic ^{10}C Nuclei in Nuclear Track Emulsion

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Abstract Dissociation of 1.2 A GeV ^{10}C nuclei in nuclear track emulsionis is studied. 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 $2\alpha + 2$p system. Strong contribution of the cascade process $^{10}\mathrm{C} \rightarrow ^{9}\mathrm{B} \rightarrow ^{8}\mathrm{Be}$ identified.

1 Introduction

The phenomenon of multiple fragmentation of relativistic nuclei can serve as a source of coherent ensembles of the lightest nuclei and nucleons. In this respect only nuclear track emulsion providing 0.5 μm spacial resolution allow one to follow tracks of all relativistic fragments in forward cone defined by a nucleon Fermi motion. The most peripheral collisions accompanied by neither "black"nor "gray"tracks of target nucleus fragments are few percents among inelastic interactions [1]. They are referred to as the "white"stars what also aptly reflects the short drop of ionization from primary to secondary tracks. Such events occur as a result of electromagnetic and nuclear diffraction on heavy nuclei of emulsion composition (i.e., Ag and Br). Minimal perturbation of a projectile make them the most valuable sample for nuclear cluster physics. Excitation energy of a fragment ensemble is estimated as $Q = M^{*} - M$, where M^{*} is the ensemble invariant mass and M—a projectile mass. The value M^{*} is defined as $M^{*2} = \left(\sum P_j\right)^2 = \sum(P_i \cdot P_k)$, where $P_{i,k}$ are 4-momenta of the fragments. Assumption of projectile speed conservation by relativistic fragments is sufficient to compensate the lack of momentum measurements. Already it is established that final states of relativistic He fragments effectively correlate with the clustering in the nuclei ^{12}C [2], ^{6}Li [3], and ^{9}Be [4–6]. The described approach is used in the BECQUEREL Project [7] to study the dripline nuclei ^{7}Be [5,8], ^{8}B [5,9], ^{9}C [10], ^{10}C [11], and ^{12}N [11] by means emulsion stacks exposed to secondary beams of the JINR Nuclotron [12]. The status of the ^{10}C investigation, which entails the production of two α particles and two protons, is presented.

2 Experiment

Nuclear track emulsion is exposed to a mixed beam of ^{12}N, ^{10}C and ^{7}Be nuclei formed by means of primary 1.2 A GeV ^{12}C nucleus beam[11,12]. The scanning along the total length of primary tracks in emulsion layers that was equal to 924.7 m revealed 6,144 inelastic interactions, including 516 "white"stars. For "white"stars with charge topology $\sum Z_{fr} = 6$ the most probable channel is represented by 159 events 2He+2H as expected for the ^{10}C isotope. Example of such event is shown in Fig. 1. The channel He+4H is found to be suppressed (16 events) since it has higher threshold for an α-cluster break up.

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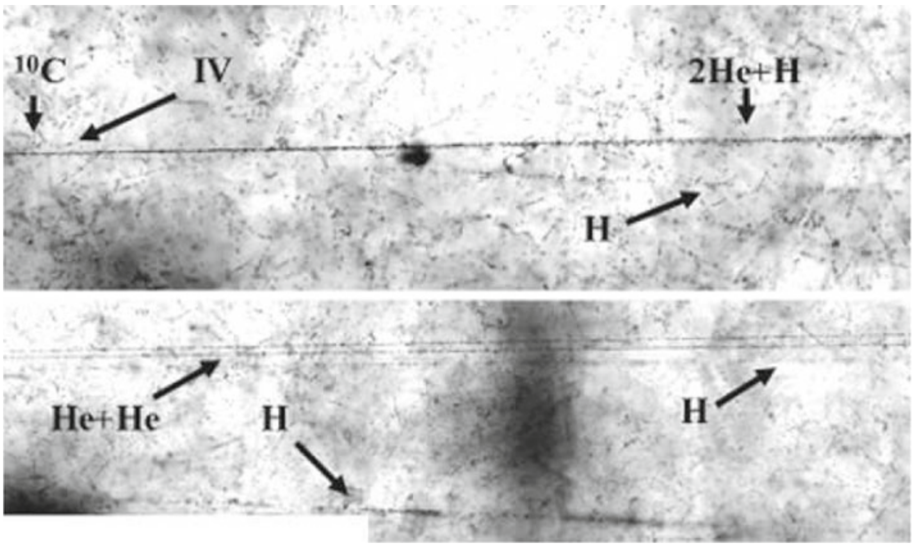

Fig. 1 Dissociation ^{10}C $\rightarrow$2He+2H in a nuclear track emulsion ("white" star). The interaction vertex is indicated as *IV* and secondary tracks as H and He

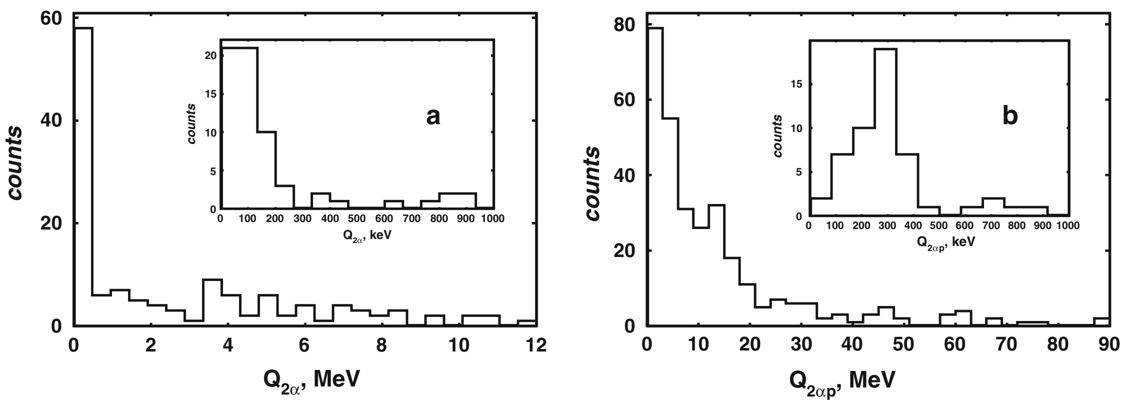

Fig. 2 **a** Distribution of the number of "white"stars $2\alpha + 2$p versus excitation energy $Q_{2\alpha}$ of the α-pairs. In the *inset* a zoom over the $Q_{2\alpha}$ distribution is shown. **b** Distribution of the number of "white"stars 2α + 2p versus excitation energy $Q_{2\alpha p}$ of triples 2α + p. In the *inset*l a zoom over the $Q_{2\alpha p}$ distribution is shown

The core role of the unbound ^{8}Be nucleus in the ^{10}C structure is manifested in intensive fragmentation via $^{10}\mathrm{C} \rightarrow ^{8}$ Be+2p. Distribution of α-pairs in the 156 "white"stars $2\alpha + 2$p on the excitation energy $Q_{2\alpha}$ is presented in Fig. 2 a. In 63 events the $Q_{2\alpha}$ value does not exceed 1 MeV (inset in Fig. 2 a). For them, the average value is $< Q_{2\alpha} > \approx 63 \pm 30\,\mathrm{keV}$ and the mean-square scattering $\sigma = 83\,\mathrm{keV}$, which agrees well with the decay of the ^{8}Be0^{+} ground state. The ^{8}Be0^{+} contribution is approximately the same as for the neighboring cluster nuclei [2,5].

The unbound ^{9}B nucleus can be another major product of the ^{10}C coherent dissociation. Figure 2 b shows the distribution of "white"stars $2\alpha + 2$p on the excitation energy $Q_{2\alpha p}$, defined by the difference of the invariant mass of the three fragments 2α+p and the mass of the proton and the doubled α-particle masses. The $Q_{2\alpha p}$ values for one of two possible 2α+p triples do not exceed 1 MeV in 58 events (inset in Fig. 2 b). The average value for these triples is $< Q_{2\alpha p} >= 254 \pm\ 18\,\mathrm{keV}$ with rms $\sigma = 96\,\mathrm{keV}$. These values correspond well to the ^{9}B ground state decay via the channel p+^{8}Be (0^{+}) with energy 185 keV and width (0.54 ± 0.21) keV. In the region limited by $Q_{2\alpha} < 1$ MeV and $Q_{2\alpha p} < 1$ MeV there is a clear correlation in the ^{8}Be and ^{9}B production. One can note the formation of a single event $2\alpha + 2$p with $Q_{2\alpha p}$ equal to the values 0.23 and 0.15 MeV, i.e., at the same time both triples correspond to the decay of the nucleus ^{9}B (Fig. 2 b). In all other ^{9}B cases one of $Q_{2\alpha p}$ is above 1 MeV. Excitation channel $\alpha + 2$p is studied on the remaining statistics of "white"stars $2\alpha + 2$p beyond ^{9}B decays. There is no clear signal of ^{6}Be decays.

To conclude, contribution of ^{8}Be nuclei is about one-third in relativistic ^{10}C dissociation. The production of ^{8}Be nuclei shows strong correlation with cascade decay $^{10}C \to ^{9}B \to ^{8}Be$. There is no significant contribution of decays $^{8}Be \to 2\alpha$ through the first excited state 2^{+}, which differs qualitatively the ^{10}C and ^{9}Be nuclei [4–6]. It can be assumed that the ^{8}Be 2^{+} state does not contribute to the ground state of the ^{10}C nucleus, and its core is formed of the 0^{+} state. Paired protons can have the meaning of a covalent pair in the ^{10}C molecular-like system with two-center potential $\alpha + 2p + \alpha$. Verification of these assumptions will be made in the correlation analysis of the pairs of 2p and 2α is foreseen with the rest two-thirds of statistics.

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