Study of the Involvement of $^8$Be and $^9$B Nuclei in the Dissociation of Relativistic $^{10}$C, $^{10}$B, and $^{12}$C Nuclei

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Abstract—The results obtained by estimating the contribution of $^8$Be and $^9$B nuclei to the coherent dissociation of $^{10}$C, $^{10}$B, and $^{12}$C relativistic nuclei in nuclear track emulsions (“white” stars) are presented. The selection of white stars accompanied by $^9$B leads to a distinct peak appearing in the distribution of the excitation energy of $2\alpha 2p$ ensembles and having a maximum at $4.1 \pm 0.3$ MeV. A $^8$Be nucleus manifests itself in the coherent–dissociation reaction $^{10}$B $\rightarrow$ $2\alpha$He + H with a probability of $(25 \pm 5)\%$, $(14 \pm 3)\%$ of it being due to $^9$B decays. The ratio of the branching fractions of the $^9$B $+$ n and $^9$B $+$ p mirror channels is estimated at $6 \pm 1$. An analysis of the relativistic dissociation of $^{12}$C nuclei in a nuclear track emulsion revealed nine $3\alpha$ events corresponding to the Hoyle state.

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INTRODUCTION

A relativistic approach to studying nucleon clustering on light nuclei was developed within the BECQUEREL project [1] (for an overview, see [2, 3]). The project was aimed at an analysis of layers of nuclear track emulsion that were exposed to primary and secondary beams of nuclei accelerated to an energy of about 1 GeV per nucleon at the nuclotron of the Joint Institute for Nuclear Research (JINR, Dubna). The accelerator facility at the Institute for High Energy Physics (IHEP, Protvino), which may provide beams of $^{12}$C nuclei whose energy ranges from a few hundred MeV units (booster) to several tens of GeV units (main ring), opens new possibilities in this respect. In this context, we present below the results and prospects of studies of multiparticle states involving $^8$Be and $^9$B unstable nuclei originating from the dissociation of a $^{10}$C radioactive nucleus and $^{10}$B and $^{12}$C stable nuclei.

Observations of events of the multiparticle fragmentation of relativistic nuclei by means of nuclear track emulsions are unique in completeness and in angular resolution. In order to deduce conclusions on the structure of nuclei being studied, one analyzes the observed interactions, focusing on coherent–dissociation events, which do not involve slow fragments or charged mesons (“white” stars). This event selection gives grounds to assume that respective collisions have a tangential character and that colliding nuclei are minimally perturbed. White stars emerge upon nuclear diffractive dissociation without an overlap of the densities of colliding nuclei. The probability for final states of fragments in white stars provides an estimate of their contribution to the structure of nuclei being studied.

Unstable nuclei of $^8$Be and $^9$B may play a key role in a general picture of nuclear clustering. Although attempts at respective observations run into serious difficulties, the contribution of these nuclei deserves investigation over the whole available range of nuclei. On the basis of measuring emission angles for...
helium and hydrogen isotopes, one reconstructs the decays of \(^{8}\text{Be}\) and \(^{9}\text{B}\). The relativistic decays of \(^{8}\text{Be}\) and \(^{9}\text{B}\) nuclei can be identified in the distributions of the variable \(Q = M^* - M\), where \(M^* = \sum (P_i \cdot P_k)\), \(M^*\) is the invariant mass of the system of fragments, and \(P_{i,k}\) stands for their 4-momenta determined in the approximation where the fragments conserve the primary momentum per nucleon.

**POSSIBLE 2\(\alpha\)2\(p\) RESONANCE**

The structure of the \(^{10}\text{C}\) radioactive nucleus was studied by the method of coherent dissociation at an energy of 1.2 GeV per nucleon \([4]\). It was found that events of the \(2\text{He} + 2\text{H}\) channel saturate 82\% of white stars. The assumption that helium nuclei correspond to \(^4\text{He}\), while hydrogen isotopes correspond to proton is justified for \(^{10}\text{C}\) \(\rightarrow 2\text{He} + 2\text{H}\) white stars. In analyzing the distributions of \(2\alpha p\) three-particle combinations with respect to the energy \(Q_{2\alpha}\), it was found that \(^9\text{B}\) manifests itself in \(^{10}\text{C}\) with a probability of \((30 \pm 4)\%\), while \(^8\text{Be}\)\(_{g.s.}\) originates from \(^9\text{B}\) decays exclusively.

A feature missed in \([4]\) was found recently in the energy \((Q_{2\alpha 2p})\) distribution of \(2\alpha 2p\) four-particle combinations (Fig. 1a). This is a distinct peak (RMS is 2.0 MeV) at \(Q_{2\alpha 2p} = 4.1 \pm 0.3\) MeV for white stars featuring \(^9\text{B}\) decays. The number of events forming this peak is \((17 \pm 4)\%\) of the total number of \(^{10}\text{C}\) white stars and \((65 \pm 14)\%\) of events involving \(^9\text{B}\) decay. The distribution of all \(2\alpha 2p\) ensembles with respect to the total transverse momentum \(P_{T_{2\alpha 2p}}\) (see Fig. 1b) is described by the Rayleigh function specified by the parameter value of \(\sigma = 175 \pm 10\) MeV/c. In the presence of \(^9\text{B}\), this distribution is substantially narrower—\(\sigma = 127 \pm 16\) MeV/c.

An indication that such a resonance is present in the \(^{9}\text{B} + p\) system was obtained in \([5]\) by employing \(^{10}\text{C}\) nuclei at the energy of 35 MeV per nucleon, but this was not confirmed in a different experiment \([6]\) where the energy of these nuclei was 10 MeV per nucleon. Later, the authors of \([5]\) disavowed their original result, referring to insufficient resolution and supporting their statement by a simulation \([7]\). Nevertheless, a strong energy dependence of the inevitably peripheral excitation of this resonance may underlie the contradiction between \([5]\) and \([6]\).

In low-energy experiments involving the detection of all projectile fragments, the condition of its peripheral character cannot be strengthened by the requirement of the absence of target fragments. At the energy threshold for the dissociation reaction, such a resonance may either prove to be unobservable under conditions of an intricate reaction mechanism or not arise in principle. Our observation is based on a totally different implementation. It is maximally reliable and boasts the highest angular resolutions in measuring tracks of \(2\alpha 2p\) four-particle combinations. In order to confirm the existence of such a resonance, which may prove to be a \(2\alpha 2p\) nuclear-molecule system, it is highly desirable to obtain a vaster data sample on the basis of a new irradiation run and to apply a faster method of searches for jets of \(2\text{He} + 2\text{H}\) fragments.

**ASYMMETRY IN MIRROR CHANNELS OF DISSOCIATION OF \(^{10}\text{B}\)**

An irradiation of a nuclear track emulsion with \(^{10}\text{B}\) nuclei accelerated to an energy of 1 GeV per