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Investigation of the dissociation of ^{10}B nuclei in a nuclear track emulsion

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The structural features of ^{10}B are studied by analyzing the dissociation of nuclei of this isotope at energy of 1 *A* GeV in a nuclear track emulsion. The fraction of the $^{10}B \rightarrow 2He + H$ channel in the charge state distribution of fragments is 78%. It was determined, based on the measurements of fragment emission angles, that unstable $^{8}Be_{g.s.}$ nuclei appear with a probability of (26 ± 4)%, and (14 ± 3)% of them are produced in decays of a unstable $^{9}B_{g.s.}$ nucleus. The Be + H channel was suppressed to approximately 1%.

Keywords: nuclear emulsion, relativistic nuclei, clusters.

INTODUCTION

The cluster model of the atomic nucleus appeared in the early 1930s as an α-partial model of light nuclei with an even and equal number of protons and neutrons (^{12}C, ^{16}O, etc.) In the concept of this model, clusters in nuclei are virtual nucleons in the lightest nuclei that do not have excited states, such as: ^{4}He (α-particle), ^{3}He, ^{3}H (triton) and ^{2}H (deuteron), which have no excited states. In recent decades, the phenomenon of nucleon clustering has been well established experimentally [1, 2]. The presence of clusters in the nucleus leads to experimentally observed phenomena: increase in the probability of decays with cluster emission, increase in cross sections with the transfer of these clusters, observation of quasi-free nucleon scattering on substructures in the target nucleus.

Distinct cluster structure has a nucleus located at the beginning of the table of isotopes. The possible virtual nucleon and cluster configurations including unstable isotopes (for example: ^{5}He, ^{5}Li, ^{8}Be and ^{9}B) can play the role of the nucleus base in heavier isotopes. The balance of possible superpositions in states with suitable spin and parity determines the fact of connectedness and the parameters of the ground state of the corresponding nucleus. The clustering of the ground state of the lung nucleus determines the structure of its excitations and the initial conditions for reactions with its participation. The concepts of clustering of nuclei are necessary for applications in cosmic-ray physics, nuclear astrophysics, nuclear medicine and for nuclear geology as well.

Traditionally, studies of the clustering of light nuclei belong to low-energy physics [3]. However, experiments studying clustering in beams of relativistic nuclei have several advantages for detection and allow investigating a whole class of short-lived radioactive isotopes. At the same time, they provide an opportunity to select the most peripheral interactions, since in such events the configurational overlapping of the structure of the studied nuclei with final states is manifested. The most peripheral events ("white" stars) occurring without overlapping of nuclear densities are especially valuable for cluster physics (example in Figure 1). The contribution of such events is a few percent of all inelastic interactions. The term "white" star reflects the breakdown of the ionization density at the top of the interaction. In the "white" stars, the projectile nucleus interacts with the target nucleus without transfer of angular momentum, the target nucleus is not visibly destroyed and there are no tracks of fragments and produced charged mesons at the interaction vertex.

Indeed, "white" star events are quite difficult to register with standard electronic detectors. At the same time, channels with a higher multiplicity that contain He and H fragments are skipped. However, such channels are important due to the fact that isotopes are the decay products of unbound ^{8}Be and ^{9}B nuclei. In the case of ^{10}B nuclei, identification of decays of unstable ^{8}Be and ^{9}B nuclei is fundamental.

On the other hand, NTE has no momentum resolution. Longitudinally irradiated NTE layers provide an opportunity to fully analyze the fragment ensembles in 4π-geometry.

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EXPOSURE OF NTE BY RELATIVISTIC ^{10}B NUCLEI

Stack of NTE layers was exposed to secondary beam of ^{10}B nuclei with a momentum of 1.7 *A* GeV/*c* at the Nuclotron of the Joint Institute for Nuclear Research (JINR, Dubna) (Figure 2) in 2002. The geometry of the beam corresponded to the NTE stack profile with a uniform distribution. The beam was controlled by multiwire proportional chambers and the total flow was monitored by a monitor counter. NTE layers had a size of 10×20 cm^2, the thickness before development was about 500 µm (Figure 3). The beam was directed parallel to the emulsion plane along its long side.

SEARCH EVENTS OF ^{10}B INTERACTION IN NTE

The layers were scanned in order to search for interactions of ^{10}B nuclei with emulsion nuclei by tracing along the track. Microscope of the MBI-9 type with ×900 optical magnification was used. Tracking the required track was carried out from its entry into the plate to the interaction or exit from the layer.

This scanning type makes it possible to register all types of interactions without discrimination. It also makes possible to determine the average lengths λ of nuclei with high accuracy. In this paper, 1664 inelastic interactions ^{10}B + *Em* were found on the total scanned length of 241 m, length

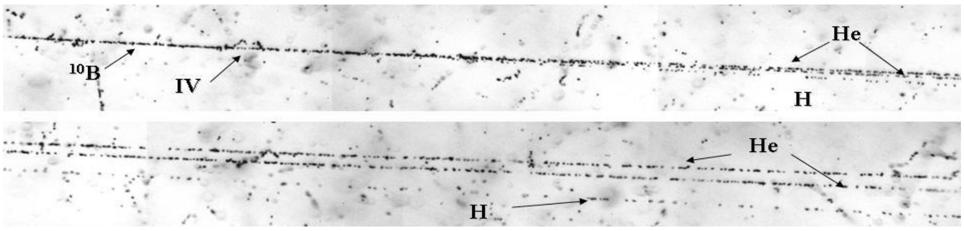

Fig. 1. Macrophotograph of the event ("white" star) of dissociation of a ^{10}B nucleus into He and H fragments (IV is the approximate position of the interaction vertex). This event has the following parameters: $\Theta_{2\alpha}$ = 5.3 mrad, $Q_{2\alpha}$ = 87 keV, and $Q_{2\alpha p}$ = 352 keV. Grain size 0.5 µm

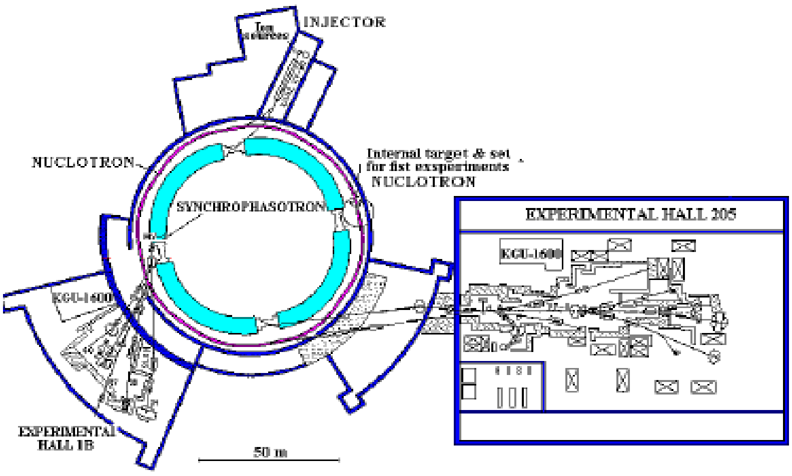

Fig . 2. Scheme of the accelerator complex of the Laboratory of High Energy Physics of JINR

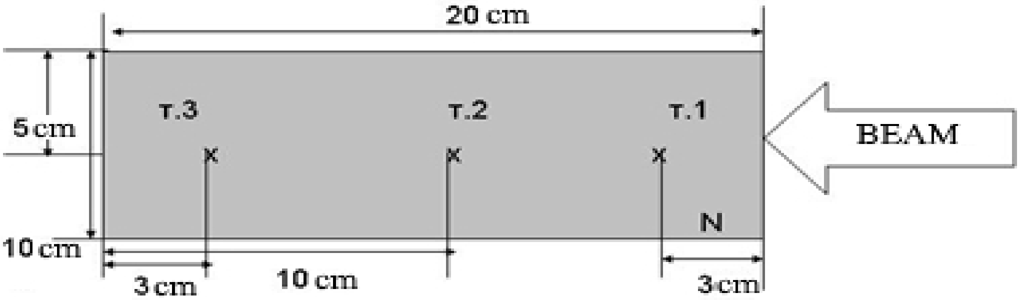

Fig. 3. A schematic representation of the emulsion layer, where N is the plate number, T.1, T.2, T.3 are the points at which the thickness of the emulsion is measured before and after the chemical development. Emulsion width - 10 cm, length - 20 cm, thickness 500 µm.

for ^{10}B nuclei in NTE was (14.5 ± 0.2) cm and for including 127 “white” stars. Thus, the average the “white” stars - λ= (1.5 ± 0.2) m. The value of λ for all statistics has a good agreement with calculated value (14.2 ± 0.2) cm. The calculated length λ for the ^{10}B nucleus in the NTE was calculated according to relation (1):

$$\overline{\qquad} , \qquad (1)$$

where N is the projectile nucleus, N' is the target nucleus, $\sigma_{N+N'}$ is the cross section of $N + N'$ interaction, and P_i is the concentration of N' nuclei in the NTE. Cross sections are calculated within the framework of the overlapping geometric model of Bradt-Peters [5] (2):

$$, \quad - \quad \sqrt{3} \qquad (2)$$

where r_0 = 1.23 fm and b = 1.56 - 0.2 ($N^{1/3} + N'^{1/3}$) is the overlap parameter. Such approximation satisfactorily describes the experimental data in a wide range of mass numbers of projectile nuclei.

The information on the composition of the charged fragments in the front cone (angle of the cone is 6°) and on the fragmentation channels of the ^{10}B nucleus is presented in Table 1. The dominant modes of dissociation of ^{10}B nuclei are channels with only He and H fragments (90%), with dominance of the 2He + H (78%) channel. For 1% of ^{10}B dissociation events, there is a complete destruction of the ^{10}B nucleus into 5H fragments. In this channel is the collapse of all α clusters.

Table 1. Distribution of events of ^{10}B dissociation over the charge configurations of fragments

Channels	Number of events with target fragments	Number of events of “white” stars
Li + He	21 (5%)	5 (4%)
Li + 2H	32 (8%)	5 (4%)
He + 3H	120 (32%)	18 (13%)
2He + H	182 (48%)	103 (76%)
5H	24 (6%)	2 (1%)
Be + H	1(< 1%)	2 (1%)

The next step for investigation of the dissociation of ^{10}B nuclei is connected with the study of the mechanism of the formation of relativistic He and H fragments in the ^{10}B → 2He + H channel. Sources of this effect have not been studied previously. This effect can determine the possible presence of cluster structure like $^{9}B_{g.s.}$ + n as well as 9Be + p. In the ^{10}B nucleus, the ^{9}Be virtual core may exist in the superposition either as $^{8}Be_{g.s.}$ + n or as $^{8}Be_{2+}$ + n [6]. The cluster configuration, including the deuteron, can be a source of decays of the $^{8}Be_{2+}$ nucleus.

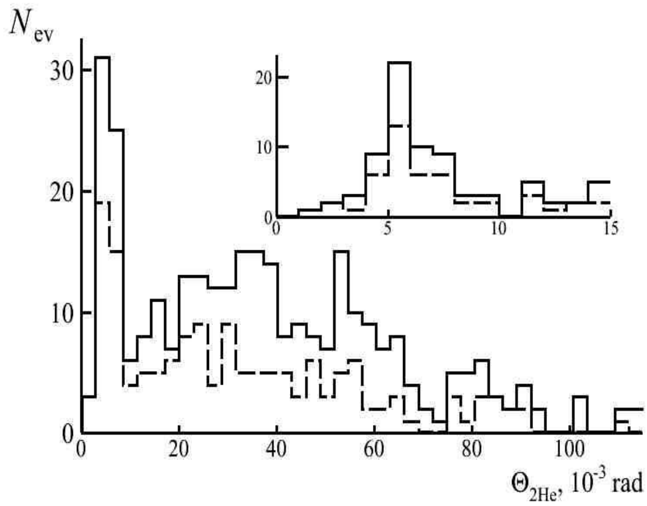

Fig. 4. Distribution of events over the opening angle Θ between two He fragments formed in channel ^{10}B → 2He + H: solid line for all statistics, dotted line represents “white” stars. Inset, the enlarged area of $\Theta_{2\alpha}$ less to 15 mrad.

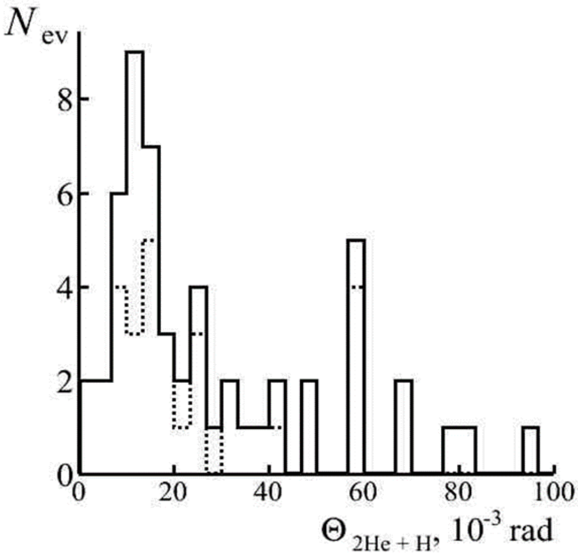

Fig. 5. Distribution over the opening angle $\Theta_{(2He+H)}$ between the direction of emission of a narrow pair of He fragments (Θ_{2He} <10.5 mrad) and the track of a single-charged particle H in all events $^{10}B \rightarrow 2He + H$ (solid histogram) and in "white" stars (dotted line)

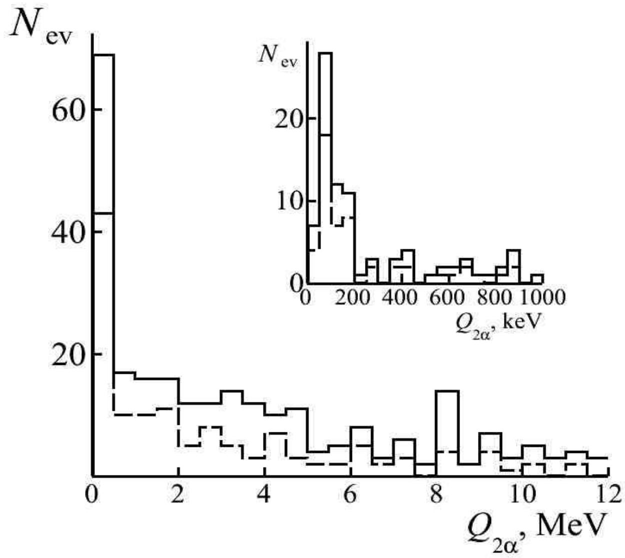

Fig. 6. Distribution over the invariant mass $Q_{2\alpha}$ of a system of two α-particles in events $^{10}B \rightarrow 2He + H$, the dotted line - events of the "white" star.

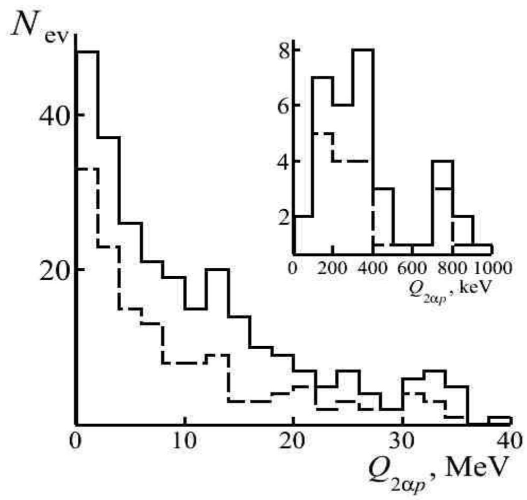

Fig. 7. Distribution over the invariant mass $Q_{2\alpha p}$ of triples 2He + H; the inset shows an increased distribution of $Q_{2\alpha p}$. Solid - all measured events, dotted line - "white" stars.

MANIFESTATION OF ^{8}Be AND ^{9}B IN DISSOCIATION OF ^{10}B

Distributions according to the magnitude of the effective invariant mass of a system of fragments will make it possible to interpret such events. The decays of relativistic ^{8}Be and ^{9}B nuclei can be reconstructed based on the excitation energy $Q = M^* - M$, which is the difference between invariant mass of fragments M^*, $M^{*2} = \sum(P_i P_k)$, and total fragment mass M. $P_{i,k}$ are 4-momenta determined in the approximation of conservation of the initial momentum of fragments per nucleon. In the region of small opening angles, it is reasonable to assume that the H isotope corresponds to protons and the He isotope corresponds to α-particles. In the distribution over the invariant mass Q of α-particle pairs (Figure 6) for 68 events the value $Q_{2\alpha}$ does not exceed 200 keV and has an average value of $\langle Q_{2\alpha}\rangle = (101 \pm 6)$ keV with RMS 46 keV, for 39 "white" stars $\langle Q_{2\alpha}\rangle = (102 \pm 8)$ keV with RMS 51 keV. The obtained values are in good agreement with the decay energy of the unstable ^{8}Be nucleus from the ground state into 2 α-particles with energy $Q = 91$ keV. In turn, the distribution over the effective invariant mass $Q_{2\alpha p}$ of triples 2α + p (Figure 7) in the $Q_{2\alpha p} < 400$ keV region for 23 events has an average value of $\langle Q_{2\alpha p}\rangle = (249 \pm 19)$ keV with RMS 91 keV. For 15 "white" stars $\langle Q_{2\alpha p}\rangle = (227 \pm 24)$ keV with RMS 96 keV, which corresponds to the decay energy of the ^{9}B nucleus in ground state $Q(^9B_{g.s.}) = 185$ keV.

CONCLUSION

The predominance of "white" stars over the 2He + H channel with a probability of 76% was established since the suppression of the Be + H channel was <1%. The event statistics in the other channels were distributed as follows: He + 3H - 13%, Li + He - 4% and Li + 2H - 4%. It was revealed that the unstable ^{8}Be and ^{9}B nuclei manifest themselves in dissociation *via* the ^{10}B → 2He + H channel with a probability of (24 ± 3)% and (12 ± 2)%, respectively. However, events with the formation of ^{9}B nuclei are explained only by 50% of $^8Be_{g.s}$ decays.

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