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Nuclear Clustering Quest in Relativistic Multifragmentation

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Abstract. The status of nuclear clustering studies performed by nuclear emulsion irradiations in beams of light relativistic nuclei is briefly reviewed. Thank to the best spatial resolution and full solid angle acceptance provided by nuclear emulsions, such an approach allow one to obtain unique and evident observations reflecting cluster-like features in light nuclear structures. Future investigations are suggested in relativistic beams of He, Be, B, C, and N isotopes.

We give a short overview of the results and prospects of nuclear clustering studies on the grounds of the observations of interactions of light nuclei with initial energy above 1·A GeV in nuclear emulsions. The discussed explorations are provided by beams of the JINR Synchrophasotron and Nuclotron in Dubna.

The track detection is performed in emulsion layers measuring $100\times200\times0.5$ mm^3. The layers are assembled in few cm thick stacks. The stacks are exposed to a beam in the longitudinal direction. They provide multiple track visualization over the total solid angle with spatial resolution of about 0.5 micron. Their sensitivity extends from slow fragments down to relativistic single charge particles. A mean range of light relativistic nuclei in emulsion is defined by the cross section of their inelastic interaction with emulsion nuclei. It varies from 14 cm for ^{6}Li nuclei to 9 cm for ^{24}Mg in a BR-2 type emulsion.

Nuclear clustering manifests itself in the isotope composition of projectile nucleus fragments. They are collimated mostly in a narrow forward cone limited by an angle $0.2/\mathrm{P}_o$, where P_o is the momentum per nucleon of a projectile nucleus in GeV/c. Their tracks stay within a single emulsion layer long enough to be identified. The projectile fragment charge can be measured by ionization density. Tracks of double charge relativistic fragments are recognized most easily. This is an advantage for α clustering studies. Measurements of a track multiple scattering allow one to identify relativistic hydrogen and helium isotopes due to sufficient discreteness of their total momenta accepted in projectile nucleus fragmentation. The isotope composition of projectile nucleus fragmentation is independent of a target nucleus in accordance with the established concept of limiting fragmentation. This circumstance makes the question about the emulsion composition unimportant for the discussed application.

To disclose a clustering picture we select events preserving the total charge of relativistic fragments in the forward cone equal to a projectile nucleus value. This leads to a correlated reduction or even absence of accompanying multiplicity. The excitation scale of a fragmenting system in a projectile nucleus rest frame is of the order of few MeV per fragmenting nucleon. In the considered case of the projectile nucleus fragmentation perfect angular measurements play the determinative role in the estimation of the excitation energy scale while their momentum per nucleon may be taken the same as for an incoming nucleus. Thus, emulsions provide an excellent opportunity of a complete observation and study of light nucleus multifragmentation in flight.

For the first time a coherent multifragmentation was observed and explored in emulsion for ^{12}C nucleus dissociation into three α particles at an initial momentum 4.5·A GeV/c [1]-[3]. The mean free path in emulsions for such events is equal to 5 m, i. e. this study demanded a visual scanning over a long track path to find the statistics of about 100 events. This scale of the statistics is a practical limit of the described approach. Relativistic multifragmentation was also explored for ^{16}O, ^{24}Mg, and ^{28}Si nuclei at an initial momentum 4.5·A GeV/c by means of nuclear emulsion [4]-[7] and hydrogen bubble chamber techniques [8]-[10].

Nowadays we have resumed searches of events for straightforward multifragmentation of a ^{24}Mg nucleus as a natural development of α particle clustering searches. One may expect that this study will clarify a question about relative probabilities of fragmentation into multiple and binary channels and, in particular, the symmetric one [11]. As example, the figure shows one of the multifragmentation events initiated by a quasinucleonic collision. A three dimensional image is reconstructed as a projection by means of a scanning CCD microscope. It can be seen (from top to bottom) how a ^{24}Mg nucleus dissociate into five double and two single charged nuclei. An interaction vertex with a nuclear fragment jet and a single charge relativistic particle (the dotted track going down) directed beyond a fragmentation cone is seen on the top photo. Most probably this track is due to a produced pion. A distict separation of two single charged fragments (tracks going up and down) from a major jet is seen on the middle photo. The bottom photo demonstrates a clear track separation of five double charged fragments.

Exotic nuclei present a bright extention of nuclear clustering. The lightest one among them is a ^{6}Li nucleus. Relativistic fragmentation of 4.5·A GeV/c ^{6}Li nuclei was explored by means of nuclear emulsion [12]-[16]. It was found that ^{6}Li

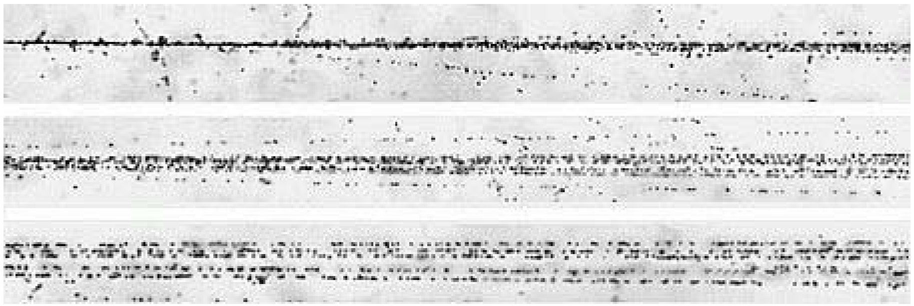

Figure 1. 4.5·A GeV/c ^{24}Mg nucleus dissociation into five double and two single charged fragments in sequential evaluation (top to bottom).

nuclei have a reduced mean path in emulsion. The obtained value would rather correspond to a nucleus with mass number equal to 11 under the assumption of a uniform nucleon density. The fragmentation channel ^{6}Li→ α points to a lower value of the mean transverse momentum of α particles, $<p_T>=0.13\pm0.1$ GeV/c when compared with the case ^{12}C→ α having $<p_T>=0.24\pm0.01$ GeV/c. This also points to an unusually large radius of the nucleon distribution in the ^{6}Li nucleus. Using the geometric overlapping model, its value was estimated to be 2.7±0.1 fm, which is in reasonable agreement with the known data on elastic scattering of protons on a ^{6}Li target. Another distinctive feature of the ^{6}Li nucleus fragmentation is an unusually enhanced yield of relativistic deuterons which is equal to the proton one. In the sample of about 1000 events ^{6}Li nucleus inelastic interactions found in [16] 31 events of ^{6}Li nucleus dissociation aren't accompanied by the target nucleus excitation. Among them 23 events correspond to the dissociation channel α+d, four of them to ^{3}He+t, four to t+d+p and none of them to d+d+d. This topology explains an increased yield of deuterons as a reflection of the structure of weakly bound clusters of the α particle and the deuteron. As extention, we formed a ^{6}He nucleus beam using a charge exchange process ^{6}Li→^{6}He. Results can be found in [17].

In the framework of researches with neutron-deficient isotopes, we irradiated emulsions by 1·A GeV ^{10}B nuclei. The value of the mean free path was found to be in good agreement with the expected one for a nuclei with homogeneous nucleon density. 90 events of ^{10}B total frgmentation without charged meson production have been observed. Their distribution over the final charged fragments is as follows: 62% - 2+2+1, 16% - 2+1+1+1, 12% - 3+2, 1% - 3+1+1, 2% - 1+1+1+1+1, 3% - 4+1, and 3% - 4+1+1. This distribution clearly points to the dominant role of a three-body dissociation. A interesting feature of the ^{10}B nucleus fragmentation is that a yield of deuterons in the first channel is equal to the proton one like in the ^{6}Li case. This indicates on the possible role of a deuteron clustering. As the next step it is important to verify such a clustering in a ^{14}N nucleus by the same technique.

We irradiated emulsions by 1.2·A GeV ^{7}Be nuclei obtained via a charge exchange process ^{7}Li→^{7}Be and a corresponding analysis is in progress now. It is particularly important to determine the cluster structure of this nucleus for clarification of the problem of the existence of a proton halo in ^{8}B and understand the role of the ^{7}Be as a core. Future irradiations are foreseen with ^{14}N, ^{8}B, ^{10}C, ^{9}C, and nuclei to establish existence and relative intensities of various fragmentation options. The problem of our special interest is a possible role of deuterons and ^{3}He nuclei as structural clusters in these nuclei. We expect that forthcoming studies of multifragmentation of light relativistic nuclei in emulsions will allow one to obtain evident information on nuclear clustering.

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