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Experimental studies of nuclear clusters via the dissociation of relativistic nuclei

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The existence of spin-paired proton and neutron quartets in light nuclei is a key factor that drives the formation of alpha particles in nuclear reactions and decays [1]. The investigations of ensembles with several alpha particles can clarify the ^{8}Be and ^{9}B and their analogues states and it make possible to study the 3α Hoyle state (HS). In this prospects, the BECQUEREL experiment is devoted to answer the topical problems of nuclear physics. The phenomenon is dissociation of relativistic nuclei observed in the Nuclear Track Emulsion (NTE) with a unique completeness and making it a valuable tool for studying ensembles of nucleons and lightest nuclei [1]. The current focus of theoretical research is on the α-particle Bose-Einstein Condensate (αBEC), an ultra-cold state of several S-wave α-particles near coupling thresholds [see ref [3] and references herein]. The nα-tuple nuclei that are excited to states just above the α-particle binding energies may exhibit αBEC behaviour. The unstable ^{8}Be nucleus and the ^{12}C(0_2^+) or Hoyle state are described as 2αBEC and 3αBEC. The decay of ^{8}Be $\rightarrow 2\alpha$ and ^{12}C(0_2^+) $\rightarrow$ ^{8}Beα can be viewed as signatures of more complicated decays of nαBEC states.

The consideration of αBEC as an invariant phenomenon makes it a promising candidate for search in relativistic fragmentation [1]. To address these challenges, the NTE longitudinally exposed to relativistic nuclei and the invariant mass ensembles H and He are produced within very narrow cone. Owing to extremely low energy and widths, ^{8}Be, ^{9}B and Hoyle state decays manifest themselves as pairs and triples of He and H relativistic fragments with smallest opening angles. This approach has been used to identify ^{8}Be and HS, and to search for more complex states of αBEC in the fragmentation of medium and heavy nuclei. Moreover, these fragments release neutrons, which manifest themselves as secondary neutron stars. The frequency of these neutron stars should increase with the number of lightest nuclei in the fragmentation cone [2]. Recently, an increase in the probability of detecting ^{8}Be in an event with an increase in the number of relativistic α-particles was found, based on the statistics of dozens of ^{8}Be decays. This suggests that the contributions of ^{9}B and HS decays also increase. The exotically large sizes and lifetimes of ^{8}Be and HS allow us to suggest the possibility of synthesizing αBEC by successively connecting the emerging α-particles [3]. In the near future, the BECQUEREL experiment will focus on the analysis of ^{84}Kr-Emulsion interactions at 950 MeV per nucleon, to their unstable states of 4αBEC and induced neutron events. In addition to understand the mechanism of nuclear dissociation, it is proposed to analyse the fragmentation of NTE nuclei by relativistic muons until they are completely destroyed.

References
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