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Searches for alpha condensate states in relativistic nuclear fragmentation

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The BECQUEREL experiment is aimed at solving topical problems in nuclear clustering physics [1]. The used method of nuclear track emulsion (NTE) makes it possible, due to its unique sensitivity and spatial resolution, to study by means of the unified approach multiple final states arising in dissociation of relativistic nuclei. Currently, the research has been focused on the theoretical concept of α-particle Bose- Einstein condensate (αBEC) – the ultra cold state of several S-wave α-particles near coupling thresholds. The unstable 8Be nucleus is described as 2αBEC, and the 12C(0+2) excitation or Hoyle state (HS) as 3αBEC. Decays 8Be ⟶ 2α and 12C(0+2) ⟶ 8Beα can serve as signatures for more complex αBEC decays. Thus, the 0+6 state of the 16O nucleus at 660 keV above the 4α threshold, considered as 4αBEC, can sequentially decay 16O(0+6) ⟶ α12C(0+2) or 16O(0+6) ⟶ 28Be(0+). Confirmation of the existence of this and more complex forms of αBEC could provide the basis to expand scenarios for the synthesis of medium and heavy nuclei in nuclear astrophysics. The consideration of αBEC as an invariant phenomenon indicates an opportunity of its search in the relativistic fragmentation. A practical alternative is provided by NTE layers longitudinally exposed to relativistic nuclei. In them, the invariant mass of ensembles of He and H fragments can be determined from emission angles in the approximation of conservation of momentum per nucleon of a parent nucleus. Due to extremely small energies and widths, the 8Be and HS decays, as well as 9B ⟶ 8Bep, are identified in light nucleus fragmentation by an upper constraint on the invariant mass [2]. Having been tested, this approach has been used to identify 8Be and HS and search for more complex states of αBEC in fragmentation of medium and heavy nuclei. Recently, based on the statistics of dozens of 8Be decays, we have found more probability of detecting 8Be in the event with increasing the number of relativistic α-particles. It has been concluded that contributions of 9B and HS decays also grow [3]. The exotically large sizes and lifetimes of 8Be and HS allow us to assume an opportunity of synthesizing αBEC by successively connecting the emerging α-particles 2α ⟶ 8Be, 8Beα ⟶ 12C(0+2), 12C(0+2)α ⟶ 16O(0+6), 28Be ⟶ 16O(0+6) and further, with a decreasing probability at each step, when γ-quanta or recoil particles are emitted. The main task of the forthcoming stage of the project is to clarify the relation between the appearance of 8Be and HS and α-ensemble multiplicities and on this basis search for decays of the 16O(0+6) state. In this regard, the purpose is to measure multiple channels of 84Kr fragmentation below 1 GeV per nucleon. There is a sufficient number of NTE layers, whose transverse scanning by means of the motorized microscope Olympus BX63 makes it possible to achieve the required statistics. A status of the searches is overviewed.

[1] P.I. Zarubin, Lect. Notes in Phys. 875, Clusters in Nuclei, Volume 3. Springer Int. Publ., 51 (2013); arXiv: 1309.4881. [2] D.A. Artemenkov et al., Eur. Phys. J. A 56 (2020) 250; arXiv: 2004.10277. [3] A.A. Zaitsev et al., Phys. Lett. B 820 (2021) 136460; arXiv: 2102.09541.

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