

On the stability of spherical nuclei in the inner crust of neutron stars

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The inner crust of neutron stars contains nuclei with large neutron excess. Furthermore, in the deepest layers they can take a substantially non-spherical shape (this region is typically referred to as mantle) [1]. The stability of spherical nuclei in inner crust with respect to fission was considered in [2]. The authors apply the fission instability criterion for spherical nuclei, derived by Bohr and Wheeler for terrestrial conditions [3]. It was predicted that spherical nuclei should lose stability when the ratio of nucleus volume to Wigner-Seitz cell volume (filling factor) reaches a value of 0.125 [2], as a result authors suggest that this instability can be a mechanism of transition to the mantle. However, according to our calculations within compressible liquid drop model, the spherical nuclei remain energetically favorable for filling factors up to 0.2 [4]. Obviously, this contradiction have two possible solutions: A) complex nuclear structures (e.g., [5]), which stays beyond scope of [4], correspond to the true thermodynamic equilibrium for filling factors 0.125-0.2; B) the fission instability is suppressed in the inner crust, as it was argued qualitatively in [6]. Here we demonstrate that the proposition B) holds true. Similar result was obtained in [7], but, as we argue here, it was based on incorrect conditions at Wigner-Seitz cell boundary.

In inner crust of a neutron star, the nuclei are immersed into degenerate electrons, which provides background charge density of the same order of magnitude as charge density inside the nucleus. This background creates an electrostatic potential, which supports spherical shape of the nuclei. As a result, spherical nuclei becomes stable with respect to quadrupole deformations for all values of the filling factor, if their number density correspond to the optimal value. However, if the number of atomic nuclei per unit volume is much lower than the equilibrium value, instability may arise and leading to nuclear fission and increase of nuclei number density. This phenomenon may be important in the formation of the crust in the early evolutionary stages of neutron stars.

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Section

1. Neutrino physics and nuclear astrophysics

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