Phase transitions in neutron stars. Are they non-congruent?

Igor Iosilevskiy

Moscow Institute of Physics and Technology (Moscow, Russia)

Phase transitions (PTs) in neutron stars (NSs) are examined for their non-congruence. Non-congruence (or incongruence) of phase coexistence in chemical mixtures means the ability of a two-phase system to vary the chemical composition ("stoichiometry") of coexisting phases without violating total stoichiometry of the system. Non-congruence leads to an essential change in the topology of inter-phase boundaries and properties of critical point(s). A pressure-temperature phase boundary of a non-congruent phase transition (NPT) is a two-dimensional region with a non-standard critical point, in contrast to the standard one-dimensional $P-T$ curve ending with the critical point of infinite compressibility. Furthermore, isoline behavior in an NPT two-phase region differs from the standard one. Isothermal and isobaric phase transformations do not coincide in NPT. Start and finish of an isothermal phase transition correspond to different pressures and vice versa.

The base for the discussion of non-congruence for phase transitions in an NS is a non-congruent evaporation in high-temperature uranium-oxygen plasma, which has been studied thoroughly in frames of the nuclear reactor safety problem. The main point in application of these results to NSs is the dimensionality of thermodynamic equilibrium in NSs. Phase transitions are definitely non-congruent when chemical composition is an independent variable, for example, for freezing and hypothetical fluid-fluid PTs ("demixing") in multi-nuclear ionic mixture in the outer layers of an accreting NS (Horowitz et al. 2007). In deep NS interior, thermodynamic dimensionality is reduced due to equilibrium nuclear transformations. The limiting situation corresponds to a two-dimensional system with two independent variables: baryon and electron chemical potentials. Phase equilibrium of two macroscopic phases must be forcedly-congruent in this case due to the local electroneutrality conditions. At the same time, the concept of a "mixed phase transition" (Glendening et al.) relaxes the local electroneutrality constraint. The system becomes bi-variant. All phase transitions are proved to be *non-congruent*. Consequences of this non-congruency for NS phase transitions are discussed.