Relativistic Equation of State for Supernova Explosion

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We construct the equation of state (EOS) of nuclear matter at finite temperature and density with various proton fractions for the use in the supernova simulations. The calculation is based on the relativistic mean field (RMF) theory with the parameter set TM1, which has been demonstrated to provide good accounts of the ground and the excited state properties of finite nuclei [1,2,3]. We work out consistent calculations for uniform matter and non-uniform matter. The Thomas-Fermi approximation is adopted to describe non-uniform matter, which can be modeled as a mixture of free neutrons, free protons, alpha-particles, and a single species of heavy nuclei [4]. Here the phase of heavy nuclei formed together with free nucleons and alpha-particles is referred to as non-uniform matter while the phase of nucleons mixed with alpha-particles without heavy nuclei is referred to as uniform matter. For each T, Y_p, and ρ_B, we have to determine the thermodynamically favorable state of nuclear matter, which has the lowest free energy in this model. At low density, the thermodynamically favorable state is homogeneous nucleon gas with a small fraction of alpha-particles, the heavy nuclei are formed at some medium densities where the system can lower the free energy by forming heavy nuclei, then it becomes uniform matter as density increases beyond $\rho_B \sim 10^{14.2}$g/cm^3. As temperature increases, the density range of the non-uniform matter phase becomes narrower. The non-uniform matter phase disappears completely as temperature increases beyond 15MeV [5,6]. We tabulate the outcome for various densities as the pressure, the free energy, entropy etc, at enough mesh points in the density range $\rho_B = 10^{5.1} \sim 10^{15.4}$g/cm^3 and the temperature range $T = 0 \sim 100$MeV and the proton fraction range of $Y_p = 0 \sim 0.56$ to be used for the supernova simulations.

References

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