Isentropic Equation of State of Supernova Matter

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Introduction

It is believed that prototype of neutron star is formed in central part of collapsing supernova core as a result of the bounce and successful supernova explosion. This star contracts rapidly within (0.1-1) second and its radius drops from 100 km to 10 km. Temperature falls to Fermi energy of the constituent particles. At this stage, star is supposed to be composed of nuclear matter with degenerate neutrinos as well as electrons under extreme conditions called supernova matter. This matter is charecterised by almost constant entropy per baryon S=(1.0-1.5) [1] and constant lepton fraction y_l=(0.3-0.4) [1, 2] with respect to nuclear matter density. The Knowledge of properties of isentropic equation of state (EOS) may provide better insight to understand the physical mechanism of iron core collapse of massive star. In this article we have tried to investigate how the generation of pressure is varied with density during adiabatic collapse for lepton fractions y_l=0.3 and 0.4.

Formalism

We assume that our system consists of protons, neutrons and electrons and it is charge neutral. A microscopic calculation has been performed for supernova matter in frame work of Brueckner Goldstone expansion using density dependent effective two body Sussex interaction [3]. The starting point of our formalism is to calculate grand thermodynamic potential per unit volume as it can be expressed as a linked cluster expansion analogous to zero temperature Brueckner Goldstone expansion i.e.

$$\Omega = \Omega_0 + \Omega_1 + \Omega_2 + \cdots \qquad (1)$$

where Ω_0, Ω_1 and Ω_2 are the contributions to the thermodynamical potential due to unperturbed part, one body part and two body part of Hamiltonian. In our formalism, chemical potential is calculated from number-density constraint and double self consistency is satisfied with respect to single particle potential and chemical potential. Taking into considerations upto two body part, the pressure of the nuclear matter is calculated using the formula

$$P_N = \frac{1}{\pi^2}\sum_\tau \int_o^\infty dk k^2 n_\tau(k)\left(\frac{1}{3}k\frac{d\epsilon_\tau}{dk} + \frac{1}{2}U_\tau(k)\right) \qquad (2)$$

where

$$\begin{aligned} \tau &\rightarrow stands\ for\ isospin \\ n_\tau(k) &\rightarrow Fermi\ distribution\ function \\ \epsilon_\tau &\rightarrow single\ particle\ energy \\ U_\tau(k) &\rightarrow single\ particle\ potential \end{aligned}$$

Electrons are treated as relativistic free particles and its contribution to pressure is calculated using the formula:

$$P_e = \frac{1}{3\pi^2}\int_0 \infty \frac{k^2}{(k^2+m_e^2)^{\frac{1}{2}}} n_e(k) k^2 dk \qquad (3)$$

Where $n_e(k)$ is the distribution function of the electron. Pressure of the supernova matter is given by:

$$P = P_N + P_e \qquad (4)$$

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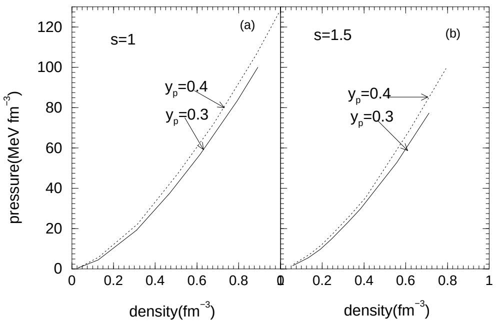

FIG. 1: Pressure versus density of supernova matter at entropy S=1.0 and 1.5 for lepton fraction y_l=0.3 and 0.4.

We have introduced, $y_p = \frac{n_p}{n}$ as proton fraction in our asymmetric nuclear matter calculation. Where n_p is the proton density and n is nuclear matter density. In order to impose charge neutrality condition, we assume that lepton fraction y_l is equal to proton fraction y_p. In our earlier publications [4, 5] we have discussed isothermal EOS of supernova matter. Isentropic EOS is obtained by converting isothermal EOS using ρ-T relation.

Results and Discussion

In fig.1, pressure is plotted at various values of densities at two adiabates S=1.0 and 1.5 for lepton fractions y_l=0.3 and 0.4. It is observed that for a given value of entropy, say for S=1.0 and lepton fraction y_l=0.3, generation of pressure increases with density. On increasing lepton fraction from 0.3 to 0.4, more pressure is generated. This excess pressure is due to contribution of additional number of particles. When adiabate is enhanced to S=1.5, generation of pressure is enhanced. But this enhancement is very less. This increase in pressure at higher adiabate may be due to effect of thermal energy. It discussed by Muto etal. [6] that for a given density, higher adiabate corresponds to higher temperature. However density has the maximum contribution for the generation of pressure on comparison to that of lepton fraction and thermal energy. The trend of our calculation is similar to the calculation made by Muto etal. [6]. They performed the calculation in frame work of finite temperature Hartree-Fock approach with RSC potential at S=1 for lepton fraction y_l=0.3 and 0.4.

References

[1] H.A. Bethe, G.E.Brown, J.Applegate and J.M.Lattimer, Nucl.Phys.**A324**,487 (1979)

[2] J.M.Lattimer, C.J.Pethick, D.G.Ravenhall and D.Q.Lamb, Nucl.Phys.**A432**,646 (1985)

[3] R.K.Tripathi, J.P.Elliot and E.A.Sanderson, Nucl.Phys.**A380**, 483 (1982)

[4] C.Das, R.Sahu and A.Mishra, Phys. Rev.**C75**, 015807-1 (2007)

[5] C.das, A.Mishra, S.Mishra and P. panda, Int. Jour. Mod. Phys.**D19**, 2135-2150 (2010)

[6] Takumi Muto, T. Takatsuka, R.Tamagaki and T.Tatsumi, Prog. Theo. Phys. Supp.**112**, 260 (1993)