PHASE TRANSITIONS OF SUPERDENSE MATTER AND SUPERNOVA EXPLOSION

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Abstract Effects of the phase transitions of superdense matter on supernova explosions are investigated with the aid of an idealized model of phase transition. It is found that in the case of strong phase transitions explosions become weaker, while in the case of weak phase transitions explosions become stronger, but the increment of the ejectecd energy is less than 20 percent and is not large as suggested by Migdal et al.

1. INTRODUCTION

Recently, it has been suggested that many types of phase transitions might occur in high density matter, for example, transitions to the pion condensed state, to the quark matter and to the abnormal nuclear state. It is then very natural to question that if such transitions occur, what happens in the collapsing stellar cores? Migdal et al.(1979) suggested that the release of energy due to phase transitions may result in a violent explosion. If this is the case, it will be a new mechanism of the formation of the neutron stars. This is very important because the formation of neutron stars from the massive stars ($M > 10\ M_\odot$) is difficult in current theories of supernova explosions. The purpose of the present work is to make clear the effects of the phase transitions on supernova explosions by simulations of collapsing stellar cores.

2. MODEL OF PHASE TRANSITION

In order to treat the phase transitions in a general form, we adopted the following idealized EOS. The total pressure P is assumed to be the sum of the cold pressure P_C which is originated from the degenerate leptons and nuclear force, and the thermal pressure P_T,

$$P=P_C(\rho)+P_T(\rho,\varepsilon_T),$$

where ρ and ε_T describe the density and the specific thermal energy,

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respectively. We assumed that P_C changes as shown in Fig. 1; the critical density, ρ_{cr}, and ρ_h at which phase transitions terminate are treated as the parameters because they are not confirmed yet. As for the EOS at the density lower than ρ_n, we adopted an idealized one described by Takahara and Sato (1984).

After the core bounce, the shock dissipation significantly increase P_T which is connected by γ_T by the following equation,

$$P_T=(\gamma_T-1)\varepsilon_T \ ,$$

where γ_T is the thermal stiffness and assumed to be 4/3.

We simulated the collapse of the Fe-core of 1.4 $M_\odot$ considering the effects of general relativity on the assumption of adiabatic collapse. This assumption is based on the neutrino trapping phenomenon and a good approximation before neutrinos diffuse out from the core. As for the trapped lepton fraction Y_L, we adopted 0.39.

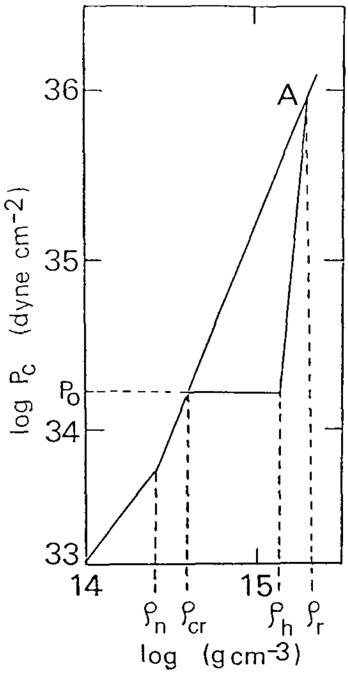

Fig. 1. Equation of state (EOS) of cold matter. The upper solid line represents the normal EOS (Model I of Bethe and Johnson) and the lower solid lines the EOS with phase transitions which start at ρ_{cr} and terminate at ρ_h. The nuclear density is shown by ρ_n.

3. RESULTS

Results are summarized in Fig. 2. Figure 2 shows that Strong phase transitions make the explosions weaker, while weak transitions make them stronger. However, the increment of the ejected energy is only 18 percent and not so large as suggested by Migdal et al. Especially in the case of strong phase transitions the collapsing core is difficult to explode, which is in contrast to the suggestion by Migdal et al. Therefore the difficulty of explosion cannot be solved by the phase transitions of superdense matter.

Since strong phase transitions suppress the supernova explosions, it is very important to research the EOS of the hot superdense matter. It might be carried out by the heavy ion collisions.

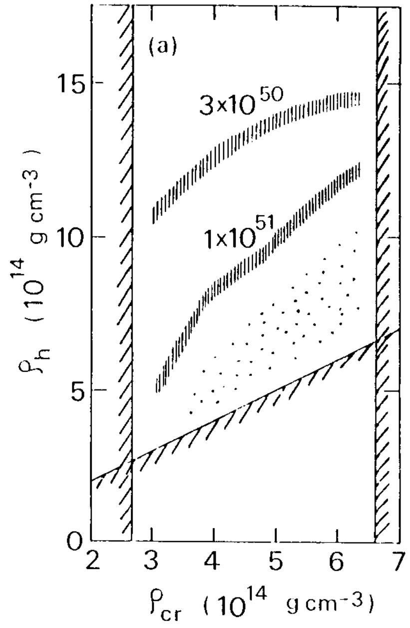

Fig. 2. Iso-contours of the ejected energy in parameter plane(ρ_{cr}-ρ_h), where ρ_{cr} is the beginning density of phase transition and ρ_h, the finishing density, see Fig. 1. This shows that the ejection energy decreases when phase transition is strong (upper regions in this plane). On the other hand, if the transition is weak(the dotted regions) explosions become stronger than the case neglecting the phase transitions.

The left and lower shaded regions are not considered in our calculations because we assumed $\rho_{cr}>\rho_n$ and $\rho_h>\rho_{cr}$. The right shaded-region corresponds to the case in which the central density never exceeds the critical density, hence, the phase transitions do not affect the dynamics.

References

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