Study of Beta Equilibrated 2+1 Flavor Quark Matter in PNJL Model

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Introduction

We present a first case study of the phase diagram of 2+1 flavor strongly interacting matter in $\beta-$equilibrium, using the Polyakov$-$Nambu$-$Jona-Lasinio model. This condition is relevant for the study of physics of neutron star. Physical characteristics of a number of thermodynamic observables have been presented, and their variation with the changing environmental conditions discussed. Comparative analysis with the corresponding situation in the Nambu-Jona-Lasinio model is presented.

Formalism

The thermodynamic potential Ω of PNJL model [1, 2] is extremised with respect to the scalar fields under the condition μ_d=μ_u+μ_e and μ_s=μ_d. The equations of motions for the mean fields σ_u, σ_d, σ_s, Φ and $\bar{\Phi}$ for any given values of temperature T, quark chemical potential μ_q and electron chemical potential μ_e are determined through the coupled equations,

$$\frac{\partial \Omega}{\partial X_i} = 0, \qquad (1)$$

Where, X_i stands for the mean fields $\sigma_u, \sigma_d, \sigma_s, \Phi$ and $\bar{\Phi}$. With these values of the mean fields all thermodynamic quantities are obtained. Electrons are considered as free non-interacting fermions [3].

Results and Discussions

The phase diagrams for NJL and PNJL models are obtained from the behavior of the mean fields, and are shown in Fig.1 for $\mu_e = 40$ MeV. As is evident from the figures, the differences between the NJL and PNJL models arise mainly due to the Polyakov loop, whose presence is primarily responsible for raising the transition/crossover temperature in the PNJL model.

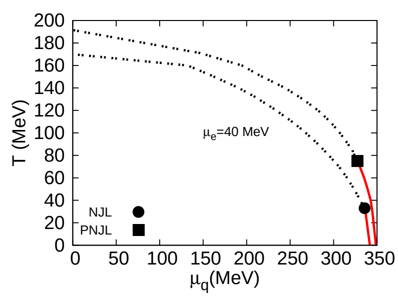

FIG. 1: Comparison of phase diagram in NJL and PNJL model at $\beta-$equilibrium for μ_e=40.

We now look into the net charge density given by $n_Q = \frac{2}{3}n_u - \frac{1}{3}n_d - \frac{1}{3}n_s - n_e$. For $\mu_e = 0$, $n_e = 0$ and we have $n_u = n_d$. When μ_q is large, the number density n_s of strange quarks become almost equal to the light quark number densities as the constituent masses of strange quarks are reduced significantly. For non-zero μ_e, charge neutral configuration is possible even at non-zero moderate values of μ_q. Given that one may be interested in the charge neutral condition *e.g.* in the case of neutron stars, in Fig.2 the charge neutral trajectories for NJL model are compared with those of PNJL model along with the phase diagrams. The trajectories are quite interesting in that they are closed ones pinned on to the μ_q axis. They start off close to $\mu_q = M_{vac}$, the constituent quark mass in the model in vacuum, makes an exploration in the $T - \mu_q$ plane and joins back at a higher μ_q. There

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is a maximum temperature T_Q up to which the trajectory goes. Beyond this temperature no charge neutrality is possible. Below this temperature we have essentially two values of μ_q where charge neutrality occurs. There are significant differences between the contours of NJL and PNJL model in the hadronic phase. However close to the transition and inside the deconfined region, the differences subside as the Polyakov loop relaxes the confining effect leading to the PNJL model behaving in a similar way to that of the NJL model.

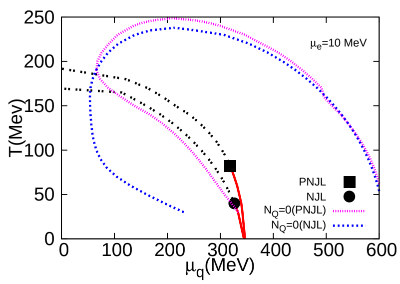

FIG. 2: Comparison of charge neutral trajectory in NJL and PNJL model at μ_e=10

The system under investigation can be characterized primarily by the behavior of EOS. In Fig. 3, the variation of the isentropic speed of sound squared $c_s^2 = \partial P/\partial \epsilon$ is plotted against μ_q at $T = 50$ MeV. In the NJL model the c_s^2 starts from a non-zero value, steadily decreases and then shows a sharp fall around the crossover region at $\mu_q \sim 320$ MeV. This

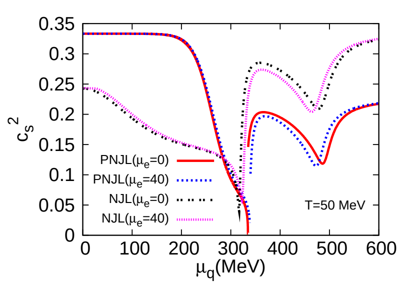

FIG. 3: Isentropic speed of sound, for NJL and PNJL models at $T = 50$ MeV.

is followed by a sharp rise, a dip and then approaches the ideal gas value of 1/3. In contrast the c_s^2 in the PNJL model starting from the ideal gas value remains almost constant up to $\mu_q \sim 200$ MeV and then falls sharply to almost zero. This is followed by a discontinuous jump, a similar dip at $\mu_q \sim 500$ MeV and a gradual approach to a non-zero value quite different from the ideal gas limit. The difference at $\mu_q = 0$ MeV occurs specifically due to the Polyakov loop which suppresses any quark-like quasi-particles. As a result the c_s^2 is completely determined by the ideal electron gas. On the other hand those quasi-particles with heavy constituent mass tend to lower the c_s^2 in the NJL model. The difference at the transition region is again mainly due to the discontinuous phase transition in PNJL model which leads to c_s^2 almost going down to zero, and a crossover in the NJL model where c_s^2 is small but non-zerof the EOS.

Acknowledgments

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References

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