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Color superconductivity and neutron star structure†

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[MATTER AT HIGH DENSITY, Compact stars]

Effective quark theories enable us to incorporate the quark structure of hadrons into the description of nuclear matter (NM) at normal densities, and at the same time to investigate the structure of compact stars, where a phase transition to quark matter (QM) may take place at high baryon densities. In this paper, we report on our recent calculations on the equation of state (EOS) of 2-flavor matter and compact star structure in the Nambu-Jona-Lasinio (NJL) model.

The single nucleon is constructed as a quark-diquark bound state, where both the scalar and the axial vector diquark channels are included. We also include the pion cloud effect on the nucleon mass, which typically leads to mass shifts (Σ_π) of 200 - 400 MeV. In this work we will consider the following cases: (A): $\Sigma_\pi = 0$ (no pion cloud); (B): $\Sigma_\pi = -200$ MeV; (C): $\Sigma_\pi = -300$ MeV; (D): $\Sigma_\pi = -400$ MeV. For each case, the strengths of the scalar and axial vector diquark interactions are adjusted so as to reproduce the experimental nucleon and delta masses.

The EOS of charge neutral NM in beta-equilibrium is then described in the mean field approximation, where the mean scalar-isoscalar, vector-isoscalar and vector-isovector fields couple to the quarks inside the nucleons, rather than to point nucleons. The most important effect of the quark substructure at normal densities is summarized in the scalar polarizability of the nucleon, which is very important for saturation[1)].

By using the same effective quark theory, we also calculate the EOS of QM, including the possibility of quark pairing (color superconductivity) in the scalar diquark channel. The Gibbs conditions (equality of pressure and chemical potentials for baryon number and isospin) are then used to investigate the transition from NM to QM[2)]. The key point in our present work is to equate the pairing strength for the color superconducting pairs in QM with the scalar diquark interactions inside the nucleons in NM. From our above discussion, it is clear that the scalar pairing strength will decrease as we go (A) $\rightarrow$ (B) $\rightarrow$ (C) $\rightarrow$ (D). Since for case (A) (no pion cloud) the scalar diquark pairing is so strong that QM would become the ground state even at normal densities, we consider this case only for the pure NM EOS.

In Fig.1 we show the pressure as a function of the baryon density for the 4 cases, and in Fig.2 we show the corresponding star masses vs. central baryon density. We see that decreasing the pairing strength has 2 effects: The phase transition moves to higher densities, and the EOS on the NM side becomes softer. The phase transition to QM leads to plateaus in the star masses, which correspond to hybrid stars with a small region of QM in the center. For the cases (B) and (C) we also get "twin" solutions at high central densities, which correspond to quark stars with radii of about 8 km.

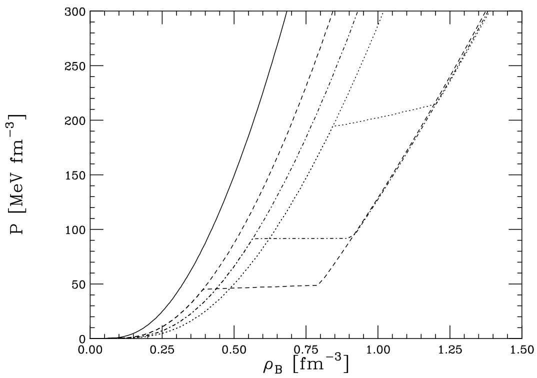

Fig. 1. Pressure vs. baryon density for the cases (A) (solid line), (B) (dashed line), (C) (dash-dotted line) and (D) (dotted line) discussed in the text.

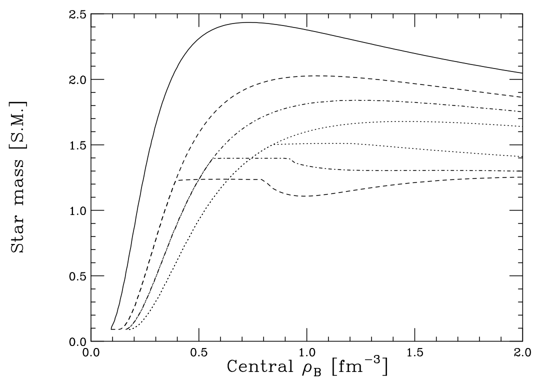

Fig. 2. Star masses vs. central density for the same cases as in Fig.1.

References
1) W. Bentz and A.W. Thomas, Nucl. Phys. **A 696**, 138 (2001).
2) S. Lawley, W. Bentz and A.W. Thomas, Phys. Lett. **B 632**, 495 (2006).

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