Compact Stars in the QCD Phase Diagram IV (CSQCD IV)
September 26-30, 2014, Prerow, Germany
http://www.ift.uni.wroc.pl/~csqcdiv

Towards a Beth-Uhlenbeck EoS for Compact Stars

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1 Introduction

The quest for a better understanding of the properties of nuclear matter under extreme conditions as, e.g. in relativistic heavy ion collisions or in the cores of neuron stars has led to the investigation of equations of state (EOS) allowing for a transition to quark matter. However, these developments of theory have been performed only within the so called two phase approaches, where the nuclear and the quark matter branches were modeled by separate equations of state, respectively. In the present paper, we want to propose an approach, where nucleons appear as bound states of their quark constituents and we will study the effects of surrounding dense nuclear matter on the possibility of the formation of these bound states. In particular, we want to study the effect that at a critical density or temperature a bound state merges the continuum of scattering states, which is well–known, e. g. from solid state physics as the metal–insulator transition or pressure ionisation effect (Mott effect). For the problem under consideration, the disappearance of the nucleon pole in the three–quark propagator and the occurence of a resonance in the continuum will be described. The appropriate theory is the Green–function approach, which was recently developed in order to generalize the so called Beth–Uhlenbeck approach [1], such that medium effects on the formation of bound as well as scattering states in a many particle system can be treated on an equal footing. However, in quark matter systems a special feature due to Quantum Chromodynamics in the low energy regime,

V_0 [GeV^{-2}]	β [fm^{-1}]	C [GeV]	E_B [GeV]	$n_{\mathrm{Mott}}[n_0]$; SNM	$n_{\mathrm{Mott}}[n_0]$; PNM
250	2.73902	0.143152	0.204252	4.46062	2.23005
500	2.08783	0.262325	0.323425	5.96763	2.65924
650	1.91431	0.324144	0.385244	5.61316	2.80667

Table 1: Parameter set for the quark-diquark potential model of a nucleon with mass $M_N = 938.9$ MeV and r.m.s. radius $< r^2 >= 0.7$ fm^2. The quark mass is $m_q = 350$ MeV, the diquark mass is $m_d = 650$ MeV

is the confinement property of effective quark interactions which prevents the quark constituents from appearing as free particles. Therefore, an appropriate description of bound state formation in quark matter in the low–energy (confinement) regime has to be formulated including correlations in the surrounding medium. This confining property of strong interactions can be modeled by a confinement potential. We show for a confining model potential in momentum space representation, that the free one–particle states cannot be occupied. The quarks do appear only in correlated states such as hadronic bound or resonant states. The treatment within the thermodynamic Green–function approach is based on the analysis of the thermodynamic T–matrix which can be obtained from a solution of the Bethe–Goldstone equation. Since our aim is to study the effect of thermodynamic quark deconfinement, we concentrate ourselves on the treatment of the bound–resonance transition within a nonrelativistic constituent quark–diquark model of nuclear matter. The generalization of the presented approach to the treatment of the nucleon as a three–quark bound state and the consideration of effects due to chiral symmetry restoration is possible along the lines of the present approach.

2 Beth-Uhlenbeck EoS and nucleonic Mott effect

Fig. 1 shows the importance of Pauli blocking for the occurrence of a Mott effect for nucleons (left panel). In the right panel of that figure it is shown how the Mott dissociation of nucleons is depending on the asymmetry: for neutron star matter the phase transition to quark matter shall occur at lower densities than in symmetric nuclear matter. This statement is quite independent of the parametrization of the potential (see Tab. 1) used to describe the nucleons as bound states of quarks.

Acknowledgement

We express our thanks to the organizers of the CSQCD IV conference for providing an excellent atmosphere which was the basis for inspiring discussions with all participants. We have greatly benefitted from this.

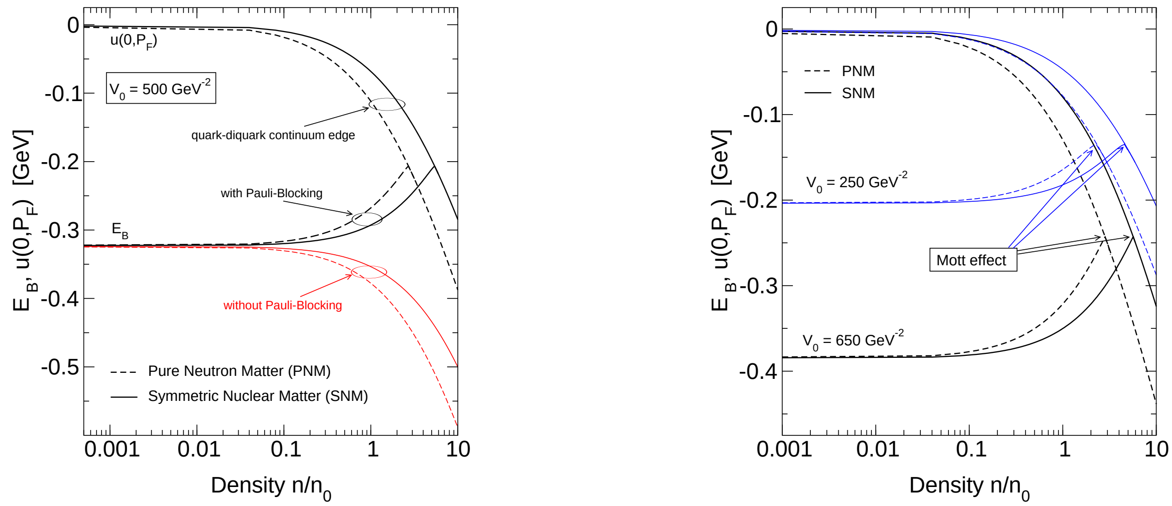

Figure 1: Binding energy E_B and continuum edge $u(p = 0, P_F)$ for nucleons in symmetric nuclear matter (solid lines) and pure neutron matter (dashed lines) as a function of the density at $T = 0$. The nucleon dissociation (Mott transition) occurs at the densities where the binding energy merges the corresponding continuum edge. Left panel: The role of the Pauli blocking for the Mott effect is shown. Right panel: The Mott densities are almost independent of the choice of the potential parameter V_0, see also Table 1.

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