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THE MIT BAG MODEL IN NUCLEAR MEDIUM FROM EQMC AND QHD DESCRIPTIONS ^a

MARTIN SCHVELLINGER

*Department of Physics, Universidad Nacional de La Plata, C.C. 67 (1900),
La Plata, Argentina*

Recent developments in the density dependence of the MIT bag radius and parameters in nuclear matter are discussed. Starting from the MIT bag lagrangian density, the calculations are specialized for symmetric homogeneous isotropic nuclear matter. A simultaneous description of the density dependence of MIT bag model is derived from the Quantum Hadrodynamics and an extended Quark Meson Coupling model. Results are in agreement with those derived from Scaling Model.

1 Introduction

As it is well known, the Quantum Chromodynamics (QCD) is the most accepted candidate for a theory of strong interactions. Although QCD has been successful in describing the high energy domain, its application seems difficult in the energy range associated to nuclear phenomena. Several QCD-inspired models have been developed to sort up the non-perturbative character of QCD at the nuclear energy range. For instance, there are the so-called bag models. Although these kind of models are made up to describe hadron properties, in general they have a set of parameters which must be fixed in order to reproduce certain specific hadron or nuclear properties. In order to describe hadrons in nuclear medium it is very interesting to know the density dependence of the parameters of the specific model. In this presentation we want to do that for the MIT bag model. In this sence, we have used an extended version of the Quark Meson Coupling model (EQMC). In the present case we assume the validity of the nuclear matter predictions derived from an effective hadronic lagrangian, looking for the implications that this description has for a picture with deals with subnuclear degrees of freedom, like that EQMC.

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2 Formalism

The MIT bag lagrangian density is

$$\begin{aligned} \mathcal{L}^{MIT}(x) = & \sum_{\alpha=1}^3 [\bar{q}_\alpha(x)(i\gamma_\mu\partial^\mu - m_q + g_\sigma^q\sigma(x) \\ & - g_\omega^q\gamma_\mu\omega^\mu(x))q_\alpha(x) - \frac{B}{3}]\Theta_V - \sum_{\alpha=1}^3 \frac{1}{2}\bar{q}_\alpha(x)q_\alpha(x)\Delta_S \\ & + \frac{1}{2}(\partial^\mu\sigma(x)\partial_\mu\sigma(x) - m_\sigma^2\sigma^2) + \frac{1}{2}m_\omega^2\omega_\mu(x)\omega^\mu(x) - \frac{1}{4}F^{\mu\nu}(x)F_{\mu\nu}(x), \end{aligned}$$

where the degrees of freedom are the quark fields $q_\alpha(x)$ (up or down), the scalar-isoscalar meson field $\sigma(x)$ and the vector-isoscalar field $\omega_\mu(x)$. $F^{\mu\nu}(x)$ is defined as $\partial^\mu\omega^\nu(x) - \partial^\nu\omega^\mu(x)$. The bag boundary conditions are used and the Euler-Lagrange eqs. for quarks, and mesons are derived. g_σ^q and g_ω^q are the quark-meson coupling constants. The continuity of the fields through the bag surface is assumed. The Mean Field approximation is used, and in this form we have the MIT bag energy

$$\begin{aligned} E_b = & \int d^3x T_{MFA}^{00} = \frac{4}{3}\pi R^3 B + \\ & \frac{i}{2} \sum_{\alpha=1}^3 \int_V d^3x \langle \bar{q}_\alpha^\dagger \partial^0 q_\alpha - \partial^0 \bar{q}_\alpha^\dagger q_\alpha \rangle + \frac{2}{3}\pi R^3 (m_\sigma \bar{\sigma}^2 - m_\omega \bar{\omega}^2), \end{aligned}$$

where $T^{\mu\nu}$ is the energy momentum tensor, $q_\alpha(\vec{r}, t)$ is the normalized ground-state quark wave function for a spherical bag of radius R expressed in terms of the y -variable calculated from the boundary conditions for the bag, the bag radius R , the effective quark mass given by $m_q^* = m_q - g_\sigma^q \bar{\sigma}$ and the effective energy eigenvalue $\epsilon_q = \Omega/R + g_\omega^q \bar{\omega}$, where $\Omega = \sqrt{y^2 + (Rm_q^*)^2}$.

The bag energy is $E_b = \frac{3\Omega - z_0}{R} + \frac{4}{3}\pi BR^3$ where B is the energy per unit of volume and z_0 takes into account the zero point energy of the bag. The nucleon mass (including the correction due to the spurious center of mass motion) is $M_b^* = \sqrt{E_b^2 - 3(y/R)^2}$. Here M_N^* is the nucleon mass entering in QHD and M_b^* is the nucleon mass generated by the bag model M_b^* . The pressure inside the bag is $P_b = -\partial E_b / \partial V$.

Always the bag parameters at zero baryon density are calculated to reproduce the experimental nucleon mass $M_b = 939$ MeV. Simultaneously it is required the equilibrium condition for the bag $dM_b(\sigma)/dR = 0$, evaluated at

$\sigma = \bar{\sigma}$. By using the bag radius at zero baryon density R_0 , and the quark mass m_q as free parameters, one can obtain the values shown in reference ¹. In the present case, since the bag is immersed in the nuclear medium, the bag is not isolated, we need calculate the nucleon mass and the bag pressure extracted from the nuclear medium ^{2,3}, i.e., using the Quantum Hadrodynamics (QHD) ⁴. In QHD, nucleons ψ and mesons $\sigma, \omega_\mu, \pi, b_\mu$ are the relevant degrees of freedom. In the simplest version (the so-called QHD-I model) nucleons and only scalar (σ) and vector (ω_μ) neutral mesons are used. We have used the lagrangian density corresponding to the Zimanyi-Moszkowski model (ZM) ⁵. We have used the MFA and calculated the effective nucleon mass $M_N^* = M_N - V(\bar{\sigma})$ and the hadronic pressure for uniform nuclear matter $P_h = -\frac{1}{3}T^{ii}$ (where T^{ii} is the trace over the spatial components of the energy-momentum tensor $T^{\mu\nu}$).

If EQMC and QHD produce coherent descriptions, the following condition must be fulfilled $M_N^*(\sigma) = M_b^*(\sigma)$, together with $g_\sigma = 3g_\sigma^q$, $g_\omega = 3g_\omega^q$. The stability of the bags in the nuclear medium with respect to volume changes is imposed by $P_b(\sigma) = P_h(\sigma)$, where $P_b(\sigma)$ is the internal pressure generated by the quark dynamics and $P_h(\sigma)$ is the external hadronic pressure. The last equation is a statistical equilibrium condition on the bag surface which ensures a direct relation between nuclear matter bulk properties and the stability of the confining volume. These relations have been used to get the density variation of the bag parameters. They can be expanded in power series and by equating coefficient to coefficient additional relations can be obtained. Since in our approach only the linear contributions have been retained, we have additional equations $\left. \frac{dM_b^*(\sigma)}{d\sigma} \right|_{\bar{\sigma}} = - \left. \frac{dV(\sigma)}{d\sigma} \right|_{\bar{\sigma}}$ and $\left. \frac{dP_b(\sigma)}{d\sigma} \right|_{\bar{\sigma}} = \left. \frac{dP_h(\sigma)}{d\sigma} \right|_{\bar{\sigma}}$ for each $\bar{\sigma}$ at a given density. Since the σ -dependence is contained in the bag parameters R , B and z_0 , the hypothesis is equivalent to assume that the derivatives $\lambda = dB/d\bar{\sigma}$ and $\mu = dz_0/d\bar{\sigma}$ are constant values.

3 Results and conclusions

To search for appropriate values of λ and μ we have explored the (λ, μ) plane at zero baryon density. R, B and z_0 at zero baryon density as a function of λ for several values of μ and using the ZM model of QHD. We have selected two sets of values set I ($\lambda = -5.28 \text{ fm}^{-3}$, $\mu = -0.50 \text{ fm}$); set II ($\lambda = 0$, $\mu = 1.6 \text{ fm}$) which places the ZM model in the regions I and II, respectively. The bag radius as a function of the density has been calculated. We have compared our results with those obtained by Jin and Jennings ⁶. In ref. ⁶ the density dependence of the bag constant has been modeled in two different forms: the so-called Direct Coupling Model (DCM) and the Scaling Model (SM). The bag constant

is parametrized by $\frac{B}{B_0} = \left[1 - 4\frac{g_\sigma^B \bar{\sigma}}{\delta M_N}\right]^\delta$, for the DCM and $\frac{B}{B_0} = \left[\frac{M_N^*}{M_N}\right]^k$ for the SM. g_σ^B , δ and k are positive parameters and B_0 is the bag parameter at zero density. The table shows a comparison between our results by using ZM model with the set II and the ones of ref. ⁶ with the DCM. The last row corresponds to our calculations with ZM model and set II, the remaining rows display the DCM results corresponding to the model parameters indicated. This density dependence was fitted with a quadratic polynomial $B = A_0 + A_1\bar{\sigma} + A_2\bar{\sigma}^2$. The best fit has been obtained for $A_0 = 184,723$ MeV, $A_1 = -186.42$ MeV and $A_2 = 112.37$ MeV. These values correspond to $g_\sigma^q = 4.8$ and $\delta = 20.5$ for the DCM in the same degree of approximation. The best fit of our results is for the value of $k = 3.16$ for the SM. Our results are in good agreement with the SM model and they coincide with the DCM model only for small values of $\bar{\sigma}$.

To conclude, I want to remark that we have studied the coherence of the QHD and QMC descriptions by using the equilibrium conditions for the MIT bag in nuclear matter. The density dependence of the bag parameters and the bag radius have been evaluated by using two dynamical quantities, i.e. the derivatives $dB/d\bar{\sigma}$ and $dz_0/d\bar{\sigma}$, as parameters and we have explored their possible variation range ^{2,3}. We have found two different dynamical regimes for these parameters. We have chosen the Zimanyi-Moszkowski model to study the EMC effect because it is the more adequate to describe bulk properties of nuclear matter in the MFA.

δ	g_σ^q	g_σ^B	g_ω	M_N^*/M_N	κ [MeV]	B/B_0	R/R_0
3.6	2	6.30	10.04	0.70	431	0.36	1.27
4		6.13	9.65	0.72	398	0.39	1.25
8		5.65	8.54	0.77	336	0.48	1.18
12		5.53	8.29	0.76	324	0.50	1.17
set II	2.61		6.67	0.78	224	0.54	1.12

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