Asymmetric nuclear matter in a modified quark meson coupling model

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The properties of asymmetric nuclear matter have recently been related to both terrestrial data and star properties from Vela pulsar glitches, which sets the symmetry energy slope value to $L = 88 \pm 25$ MeV [1]. This motivates a study of such effect within a modified quark meson coupling (MQMC) model. In such a picture the bare nucleon are considered to be independently confined by a phenomenological equally mixed scalar and vector potential in harmonic form. In an earlier attempt [2] we have successfully used this model in developing the nuclear equation of state and analysed various other bulk properties of symmetric nuclear matter with the dependence of quark masses. In the present work we want to apply the model to analyze asymmetric nuclear matter with the variation of the asymmetry parameter y_p as well as analyze the effects of symmetry energy and the slope of the symmetry energy L.

The Dirac equation for individual quark in the medium becomes

$$[\gamma^0\ (\epsilon_q - g^q_\omega \omega_0 - \frac{1}{2} g^q_\rho \tau_z \rho_{03}) - \vec{\gamma}.\vec{p} \\ -(m_q - g^q_\sigma \sigma) - U(r)]\psi_q(\vec{r}) = 0 \qquad (1)$$

where g^q_σ, g^q_ω and g^q_ρ are the quark coupling constants with the σ, ω and ρ mesons. In the above, $U(r) = \frac{1}{2}(1+\gamma^0)V(r)$, where $V(r) = (ar^2+V_0)$ with $a > 0$. Here (a, V_0) are the potential parameters which is determined through the nucleon mass and proton charge radius. In the mean field approximation, the meson fields are treated by their expectation values. We can define in the medium,

$$\epsilon'_q = (\epsilon^*_q - V_0/2) \quad \text{and} \quad m'_q = (m^*_q + V_0/2), \quad (2)$$

where the effective quark energy, $\epsilon^*_q = \epsilon_q - g^q_\omega\omega_0 - \frac{1}{2}g^q_\rho\tau_z\rho_{03}$ and effective quark mass, $m^*_q = m_q - g^q_\sigma\sigma_0$. Then the effective mass of the nucleon in the medium is given by [2],

$$M^*_N = E^0_N - \epsilon_{cm} + \delta M^\pi_N + (\Delta E_B)^E_g + (\Delta E_B)^M_g$$

where ϵ_{cm} is the energy associated with the spurious center of mass correction, $(\Delta E_B)^E_g + (\Delta E_B)^M_g$ is the color electric and magnetic interaction energies arising out of the one-gluon exchange process and δM^π_B is the pionic self energy of the baryon due to pion coupling of the non-strange quarks.

The total energy density in the mean field approximation for nuclear matter is given as:

$$\varepsilon = \frac{1}{2}m^2_\sigma\sigma^2_0 + \frac{1}{2}m^2_\omega\omega^2_0 + \frac{1}{2}m^2_\rho\rho^2_{03} \\ + \frac{\gamma}{(2\pi)^3}\sum_{N=p,n}\int^{k^N_f} d^3k\sqrt{k^2 + {M^*_N}^2} \quad (3)$$

where $\gamma = 2$ is the spin degeneracy factor for nuclear matter. The proton or neutron density is given by $\rho_i = \frac{\gamma k^3_f}{6\pi^2}$ so that the total baryon density is $\rho = \rho_p + \rho_n$ and the (third component of) isospin density, $\rho_3 = \rho_p - \rho_n$. The meson fields are determined through $\omega_0 = \frac{g_\omega \rho}{m^2_\omega}$, $\rho_{03} = \frac{g_\rho \rho_3}{m^2_\rho}$ and the sigma field is fixed by $\frac{\partial\varepsilon}{\partial\sigma_0} = 0$.

We fit the quark-meson coupling constants g^q_σ, $g_\omega = 3g^q_\omega$ and $g^q_\rho = g_\rho$ for the nucleons to obtain the correct saturation properties of

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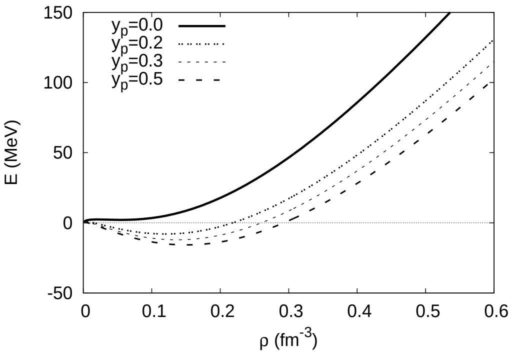

FIG. 1: Binding energy per nucleon at different values of y_p.

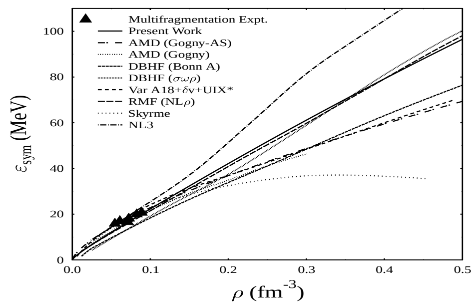

FIG. 2: Symmetry energy versus density.

nuclear matter, $E_B = \varepsilon/\rho - M = -15.7$ MeV at $\rho = \rho_0 = 0.15 fm^{-3}$, $\epsilon_{sym} = 32.$ MeV. For quark mass $m_q = 300$ MeV the couplings are $g_\sigma^q = 4.07$, $g_\omega = 9.09$ and $g_\rho = 8.51$. We take the standard values for the meson masses, namely $m_\sigma = 550$ MeV, $m_\omega = 783$ MeV, and $m_\rho = 770$ MeV.

The symmetry energy is given as,

$$\varepsilon_{sym} = \frac{1}{2}\left[\frac{\partial^2(\varepsilon/\rho)}{\partial y_p^2}\right]_{y_p=0.5} = \frac{k_f^2}{6\epsilon_F} + \frac{g_\rho^2}{4m_\rho^2}\rho \tag{4}$$

where y_p is the asymmetry parameter, $y_p = \rho_p/\rho$, $\epsilon_f = \sqrt{k_f^2 + M_N^{*2}}$. The slope of the symmetry energy is

$$L = 3\rho\left[\frac{\partial \varepsilon_{sym}}{\partial \rho}\right]_{\rho=\rho_0} \tag{5}$$

In Fig 1 we present the binding energy per nucleon calculated at different values of the asymmetry parameter y_p. The knowledge of density dependence of symmetry energy plays a key role in understanding the structure and properties of neutron rich nuclei and neutron stars at densities above and below the saturation density. It is observed that at $\rho < \rho_0$ (the saturation density) the symmetry energy agree with the experimental results (multifragmentation expt.). At $\rho > \rho_0$ there is a wide variation of the symmetry energy and density. Fig 2 represents the dependence of

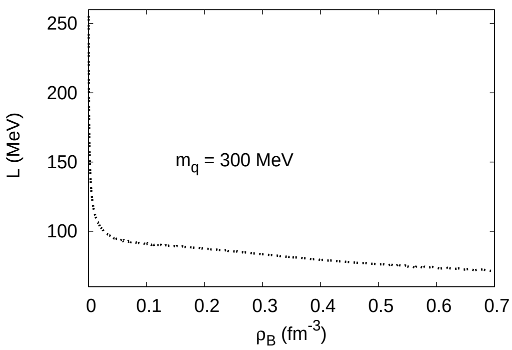

FIG. 3: Slope parameter versus density.

the symmetry energy on density. In Fig. 3 we plot the slope parameter, L versus density. The L value comes around 89 MeV at saturation density.

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