New source of charge symmetry breaking

Subhrajyoti Biswas, Pradip K. Roy, and Abhee K. Dutt-Mazumder
High Energy Physics Division, Saha Institute of Nuclear Physics,
1/AF Bidhannagar, Kolkata 700 064, INDIA

Introduction

The study of charge symmetry breaking (CSB) is always an interesting area of activities in nuclear physics. The general goal of the research in this area is to find small but observable effects of CSB which might provide significant insight into the strong interaction dynamics.

At the fundamental level, CSB is caused by the finite mass difference between u-d quarks. As a consequence, at the hadronic level, charge symmetry (CS) is broken due to non-degenerate mass of hadrons of the same isospin multiplet.

There are several experimental data such as non-zero difference between pp and nn scattering lengths at $^1\mathrm{S}_0$ state, binding energy difference of mirror nuclei etc. which indicate CSB in NN interaction.

In vacuum, the charge symmetry is broken explicitly due to the non-degenerate nucleon masses. In matter, there can be another source of symmetry breaking if the ground state contains unequal number of neutrons (n) and protons (p) giving rise to ground state induced mixing of various charged states like ρ-ω mesons even if neutron-proton masses are same *i.e.* $M_n = M_p$. This additional source of symmetry breaking for the construction of CSB potential has, to the best of our knowledge, not been considered before.

We consider both of these mechanisms to construct the CSB potential.

Formalism

In matter, intermediate mesons might be absorbed and re-emitted from the Fermi spheres. Inclusion of this process is depicted by the second diagram in Fig.1 represented by V^{NN}_{med}.

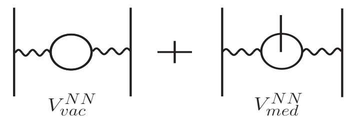

FIG. 1: Feynman Diagrams contribute to CSB potential in matter. Solid lines represent nucleons and wavy lines stand for vector mesons.

The following matrix element is required for the construction of CSB potential.

$$\mathcal{M}^{NN}_{\rho\omega}(q) = [\bar{u}_N(p_3)\Gamma^\mu_\rho(q)u_N(p_1)]\Delta^\rho_{\mu\alpha}(q)\,\Pi^{\alpha\beta}_{\rho\omega}(q^2)\Delta^\omega_{\beta\nu}(q)[\bar{u}_N(p_4)\Gamma^\nu_\omega(-q)u_N(p_2)]. \quad (1)$$

In the limit $q_0 \to 0$, Eq.(1) gives the momentum space CSB NN potential. Here $\Gamma^\mu_\omega(q) = \mathrm{g}_\omega\gamma^\mu$, $\Gamma^\nu_\rho(q) = \mathrm{g}_\rho\left[\gamma^\nu - \frac{C_\rho}{2M} i\sigma^{\nu\lambda}q_\lambda\right]$ denote the vertex factors, u_N is the Dirac spinor and $\Delta^i_{\mu\nu}(q)$, $(i = \rho, \omega)$ is the meson propagator.

$$\Pi^{\mu\nu}_{\rho\omega}(q^2) = \Pi^{\mu\nu(p)}_{\rho\omega}(q^2) - \Pi^{\mu\nu(n)}_{\rho\omega}(q^2). \quad (2)$$

Note that $\Pi^{\mu\nu}_{\rho\omega}(q^2)$ contains a vacuum and a density dependent parts as the in-medium nucleon propagator consisting of a free and a density dependent parts. $\Pi^{\mu\nu}_{\rho\omega}(q^2)$ can be decomposed as follows

$$\Pi^{\mu\nu}_{\rho\omega}(q^2) = \Pi^L_{\rho\omega}(q^2)A^{\mu\nu} + \Pi^T_{\rho\omega}(q^2)B^{\mu\nu} \quad (3)$$

$A^{\mu\nu}$ and $B^{\mu\nu}$ are the longitudinal and transverse projection operators; $\Pi^L_{\rho\omega} = -\Pi^{00}_{\rho\omega} + \Pi^{33}_{\rho\omega}$ and $\Pi^T_{\rho\omega} = \Pi^{11}_{\rho\omega} = \Pi^{22}_{\rho\omega}$.

We, in the present calculation, use the average of longitudinal and transverse components of the polarization tensor instead of $\Pi^L_{\rho\omega}$ and $\Pi^T_{\rho\omega}$. The average mixing amplitude is denoted by

$$\bar{\Pi}(q^2) = \tfrac{1}{3}\left[\Pi^L_{\rho\omega}(q^2) + 2\Pi^T_{\rho\omega}(q^2)\right] = \bar{\Pi}_{vac}(q^2) + \bar{\Pi}_{med}(q^2). \quad (4)$$

After some algebra, one finds the following three momentum dependent average mixing amplitudes which are relevant for the construction of the potential.

$$\bar{\Pi}_{vac}(\mathbf{q}^2) = -\mathcal{A}\mathbf{q}^2,$$
$$\bar{\Pi}_{med}(\mathbf{q}^2) = \Delta' - \mathcal{A}'\mathbf{q}^2.$$

Explicit expressions for $\mathcal{A}$, $\mathcal{A}'$, Δ' and the derivation of momentum space CSB potential can be found in [5].

It is to be mentioned here that most of the earlier calculations performed to construct CSB potential considered the on-shell or constant ρ-ω mixing amplitude [1, 2, 3]. Recent calculations show that ρ-ω mixing has strong momentum dependence and even changes its sign as one moves away from the ρ (or ω) pole to the space-like region [4]. These observations suggests that the off-shell corrections should be included to construct CSB potential.

We, in the present paper, focus on Class III force only; though full CSB potential contains both Class III and IV forces [5]. The Fourier transform of Class III momentum space force gives the following potential in coordinate space.

$$\begin{aligned} V^{NN}_{med}(\mathbf{r}) &= \\ -\ &\frac{g_\rho g_\omega}{4\pi} T_3^+ \left[\Delta' \left\{ \frac{m_\rho Y_0(x_\rho) - m_\omega Y_0(x_\omega)}{m_\omega^2 - m_\rho^2} \right.\right. \\ +\ &\frac{1}{M_N^2}\left(\frac{m_\rho^3 V_{vv}(x_\rho) - m_\omega^3 V_{vv}(x_\omega)}{m_\omega^2 - m_\rho^2}\right) \\ +\ &\left.\frac{C_\rho}{2M_N^2}\left(\frac{m_\rho^3 V_{tv}(x_\rho) - m_\omega^3 V_{tv}(x_\omega)}{m_\omega^2 - m_\rho^2}\right)\right\} \\ +\ &(\mathcal{A} + \mathcal{A}')\left\{\frac{m_\rho^3 Y_0(x_\rho) - m_\omega^3 Y_0(x_\omega)}{m_\omega^2 - m_\rho^2}\right. \\ +\ &\frac{1}{M_N^2}\left(\frac{m_\rho^5 V_{vv}(x_\rho) - m_\omega^5 V_{vv}(x_\omega)}{m_\omega^2 - m_\rho^2}\right) \\ +\ &\left.\left.\frac{C_\rho}{2M_N^2}\left(\frac{m_\rho^5 V_{tv}(x_\rho) - m_\omega^5 V_{tv}(x_\omega)}{m_\omega^2 - m_\rho^2}\right)\right\}\right], \end{aligned}$$

where T_+, $Y_0(x)$, $V_{vv}(x)$ and $V_{tv}(x)$ are given in [5]; $x_i = m_i\ r$.

Result and Discussion

In this section we present numerical results. we show $\Delta V = V^{nn}_{CSB} - V^{pp}_{CSB}$ in Fig.2.

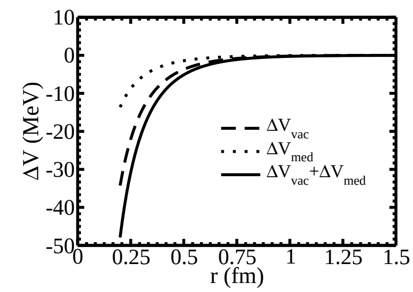

FIG. 2: ΔV for ^{1}S$_0$ state at $\rho_B = 0.148$ fm^{-3} and $\alpha = 1/3$.

In this work we have constructed the CSB NN potential in dense matter using asymmetry driven momentum dependent ρ^0-ω mixing amplitude. The correction to the central part of the CSB potential due to external nucleon legs are also considered.

We have shown that the vacuum mixing amplitude and the density dependent mixing amplitude are of similar order of magnitude and both contribute with the same sign to the CSB potential. The contribution of density dependent CSB potential is not negligible in comparison to the vacuum CSB potential.

References

[1] P. G. Blunden and M. J. Iqbal, Phys. Lett. **B 198**, 14 (1987).

[2] S. A. Coon and R. C. Barrett, Phys. Rev. **C 36**, 2189 (1987).

[3] R. Machleidt and H. Mther, Phys. Rev. **C 63**, 034005 (2001).

[4] J. Piekarewicz, Phys. Rev. **C 47**, R2462 (1993).

[5] S. Biswas, P. Roy and A. K. Dutt-Mazumder, Phys. Rev. **C 78**, 045207 (2008).