M3Y effective nucleon-nucleon interaction and the relativistic mean field theory

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Introduction

The microscopic heavy-ion scattering potential of interest is obtained in double folding model [1], by using an effective nucleon-nucleon (NN) interaction (say, M3Y plus a zero-range pseudo-potential) folded over the matter densities of the interacting nuclei. In the following, we dwell on the simplified (spin- and isospin-independent, S=T=0) M3Y effective NN interaction [1], which is widely and succesfully used in a number of applications.

The relativistic mean field (RMF) theory [2] is now established to be one of the most successful approaches for the accurate description of nuclear properties. The basic ansatz of the RMF theory is a Lagrangian density whereby nucleons are described as free Dirac particles, which interact via the exchange of sigma (σ), omega (ω), and rho (ρ) mesons, and also the photons (A). The σ (ω) meson produces long-range attraction (short-range repulsion), whereas the ρ meson is required for the isospin dependence of the nuclear properties.

In a recent study, starting from a non-relativistic bare potential and by employing a G-matrix formalism, Serra *et al.* [3] derived an effective interaction in the nuclear medium that depends on its density, and established a connection between the RMF models and bare NN interaction. Interestingly, the medium- and long-range components of the above derived effective interaction can be described to a good extent by an effective, density-dependent, relativistic one-boson-exchange potential (OBEP). For a good fit of the OBEP to the G-matrix potential, it is found essential to include the σ, ω, δ, ρ and π meson fields. Also, the tensor force of the bare NN interaction, though through renormalization, is shown essential for explaining the dominance of the σ-field for attraction, with the σ-mesons mass $m_\sigma \approx 480$ MeV. In the process, the masses and coupling strengths of the fields were also exrtacted, which are found consistent with the available RMF parameterizations. In the light of this work [3], in this paper, we look for a comparison between the well known M3Y effective NN interaction [1] and one obtained from the RMF-based relevant fields with its fitted masses (ranges) and coupling constants (strength parameters).

Methodology

The M3Y effective NN interaction, obtained from a fit of the G-matrix elements based on Reid-Elliott soft-core NN interaction [1], in an oscillator basis, is the sum of three Yukawa's (M3Y) with ranges 0.25 fm for a medium-range attractive part, 0.4 fm for a short-range repulsive part and 1.414 fm to ensure a long-range tail of the one-pion exchange potential (OPEP). The widely used form of the M3Y effective interaction $v_{eff}(r)$ is given by

$$v_{eff}(r) = 7999\frac{e^{-4r}}{4r} - 2134\frac{e^{-2.5r}}{2.5r}. \qquad (1)$$

Note that Eq. (1) represents the spin- and isospin-independent parts of the central component of the effective NN interaction, and that the OPEP contribution is absent here.

Similarly, following Ref. [3], the spin- and isospin-independent (i.e., pure central) part of the total OBEP can be written from Eq. (22) and Table II in [3] on the basis of the σ- and

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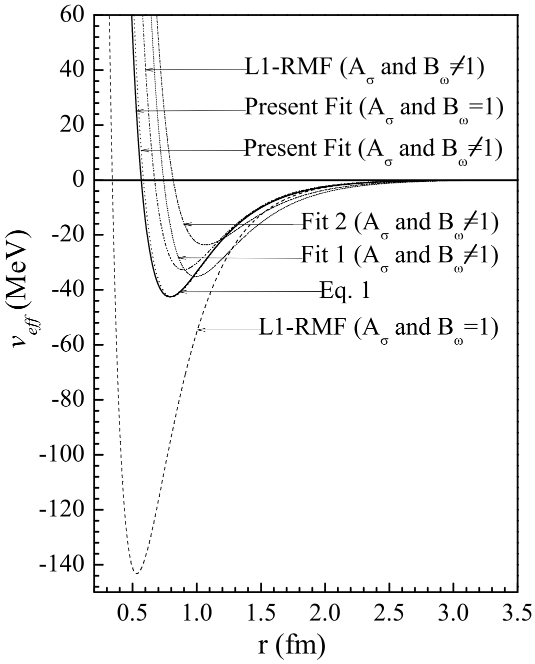

FIG. 1: Comparison of phenomenological M3Y effective interaction [Eq. (1)] with one from relevant (σ, ω) RMF fields, [Eq. (2)], and other calulations stated in the text.

ω-meson fields of the RMF Lagrangian, as

$$v_{eff}(r) = \frac{g_\omega^2}{4\pi} B_\omega \frac{e^{-m_\omega r}}{r} - \frac{g_\sigma^2}{4\pi} A_\sigma \frac{e^{-m_\sigma r}}{r}. \quad (2)$$

Note that Eq. (2) can be related to the phenomenological M3Y effective NN interaction in Eq. (1). In Eq. (2), m_ω, m_σ and g_ω, g_σ are, respectively, the masses and coupling constants of the ω and σ mesons. The coefficients $B_\omega = (1+\frac{1}{2}(\frac{m_\omega}{M})^2)$ and $A_\sigma = (1-\frac{1}{4}(\frac{m_\sigma}{M})^2)$ are dependent on relativistic corrections $(\frac{m_i}{M})^2$, $i = (\omega, \sigma)$, which is important for the field masses m_i becoming comparable to nucleon mass M.

Calculations and Discussions

Fig. 1 illustrates the comparison between the M3Y effective NN interaction (Eq. (1), solid line) and its equivalent presentation, Eq. (2), based on RMF considerations involving the coupling constants g_ω, g_σ and masses m_ω and m_σ. The fitted masses and strength parameters of the fields are presented in Table I (marked Present Fit) for the choices (A_σ and B_ω=1) and (A_σ and B_ω≠1), compared with the results obtained for use of the RMF model [2] with the linear parameter set L1 [for both (A_σ and B_ω=1) and (A_σ and B_ω≠1), keeping the masses and coupling constants same] and the ones fitted in Ref. [3] (Fit 1 and Fit 2, both for (A_σ and B_ω≠1)).

TABLE I: The values of m_σ and m_ω (in MeV) alongwith g_σ and g_ω from different works, and the present fits to the Eq. (2).

Work	m_σ	m_ω	g_σ	g_ω
L1 (RMF) [2]	550	783	10.30	12.60
Fit 1 (A_σ and B_ω≠1) [3]	480	716	10.12	13.41
Fit 2 (A_σ and B_ω≠1) [3]	480	738	09.07	13.06
Present Fit (A_σ and B_ω=1)	493	789	7.374	11.287
Present Fit (A_σ and B_ω≠1)	542	783	09.59	11.30

It is evident from Fig. 1 that the phenomenological M3Y effective interaction [Eq. (1)] can be best fitted only to its equivalent RMF-based representation [Eq. (2)], and that too better for the case of A_σ and B_ω=1. However, the m_σ mass seems to be more favourable (close to 550 for RMF-L1) for A_σ and B_ω ≠1. Also, the m_ω mass is exactly equal to the experimental value of 783 MeV for A_σ and B_ω ≠1. The results of all other calculations deviate considerably from the effective M3Y interaction. Also, the m_σ=480 MeV in [3] is farther from the RMF-L1 result. Apparently, it is relevant as well as intersting to study further the observed differences in order to understand the link between the RMF phenomenology and the effective NN interaction.

References

[1] G. R. Satchler and W. G. Love, *Phys. Reports* **55** (1979) 183.

[2] See, e.g., S. K. Patra and C. R. Prahraj, *Phys. Rev. C* **44** (1991) 2552.

[3] M. Serra *et al.*, *Prog. Theo. Phys.* **113** (2005) 1009.