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 successfully 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 \( m_\sigma \approx 480 \text{ MeV} \). In the process, the masses and coupling strengths of the fields were also extracted, 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 \( v_{\text{eff}}(r) \) is given by

\[
v_{\text{eff}}(r) = 7999 e^{-4r} - 2134 e^{-2.5r/2.5r}.
\]

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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the coupling constants $g_\omega$, $g_\sigma$ and masses $m_\omega$ and $m_\sigma$. The fitted masses and strength parameters of the fields are presented in Table I (marked Present Fit) for the choices ($A_\sigma$ and $B_\omega=1$) and ($A_\sigma$ and $B_\omega\neq1$), compared with the results obtained for use of the RMF model [2] with the linear parameter set L1 [for both ($A_\sigma$ and $B_\omega=1$) and ($A_\sigma$ and $B_\omega\neq1$), keeping the masses and coupling constants same] and the ones fitted in Ref. [3] (Fit 1 and Fit 2, both for ($A_\sigma$ and $B_\omega\neq1$)).

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 $A_\sigma$ and $B_\omega=1$. However, the $m_\sigma$ mass seems to be more favourable (close to 550 for RMF-L1) for $A_\sigma$ and $B_\omega\neq1$. Also, the $m_\omega$ mass is exactly equal to the experimental value of 783 MeV for $A_\sigma$ and $B_\omega\neq1$. The results of all other calculations deviate considerably from the effective M3Y interaction. Also, the $m_\sigma=480$ MeV in [3] is farther from the RMF-L1 result. Apparently, it is relevant as well as interesting to study further the observed differences in order to understand the link between the RMF phenomenology and the effective NN interaction.

**References**


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**TABLE I:** The values of $m_\sigma$ and $m_\omega$ (in MeV) alongwith $g_\omega$ and $g_\sigma$ from different works, and the present fits to the Eq. (2).

<table>
<thead>
<tr>
<th>Work</th>
<th>$m_\sigma$ (MeV)</th>
<th>$m_\omega$ (MeV)</th>
<th>$g_\omega$</th>
<th>$g_\sigma$</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1 (RMF) [2]</td>
<td>550</td>
<td>783</td>
<td>10.30</td>
<td>12.60</td>
</tr>
<tr>
<td>Fit 1 ($A_\sigma$ and $B_\omega\neq1$) [3]</td>
<td>480</td>
<td>716</td>
<td>10.12</td>
<td>13.41</td>
</tr>
<tr>
<td>Fit 2 ($A_\sigma$ and $B_\omega\neq1$) [3]</td>
<td>480</td>
<td>738</td>
<td>09.07</td>
<td>13.06</td>
</tr>
<tr>
<td>Present Fit ($A_\sigma$ and $B_\omega=1$)</td>
<td>403</td>
<td>789</td>
<td>7.374</td>
<td>11.287</td>
</tr>
<tr>
<td>Present Fit ($A_\sigma$ and $B_\omega\neq1$)</td>
<td>542</td>
<td>783</td>
<td>09.59</td>
<td>11.30</td>
</tr>
</tbody>
</table>

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**FIG. 1:** Comparison of phenomenological M3Y effective interaction [Eq. (1)] with one from relevant ($\sigma$, $\omega$) RMF fields, [Eq. (2)], and other calculations stated in the text.