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Effect of cross-couplings in nuclear reaction studies using relativistic mean field approach

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Introduction

The Relativistic Mean Field theory (RMF) is well suited for description of finite nuclei and infinite nuclear matter [1]. The RMF motivated Lagrangian approach has proved its applicability for the whole nuclear chart and beyond. For the calculations involving finite nuclei or nuclear matter, nuclear structure properties are primarily determined.

In this work we aim to study the effect of cross coupling terms in the Lagrangian on the ground state properties of the finite nuclei. Further, the obtained information about the nuclear structure (nuclear densities) is used in the Glauber model [2] to calculate the reaction cross sections at high incident energies.

Theoretical formalism

The extension of standard relativistic mean field formalism [1, 3] based on the field theory motivated effective Lagrangian approach is known as E-RMF [4]. The energy density functional of the E-RMF model for finite nuclei [4, 5] is given in (1).

Where the index α runs over all occupied states $\varphi_\alpha(\mathbf{r})$ of the positive energy spectrum and $\Phi \equiv g_s\phi_0(\mathbf{r})$, $W \equiv g_v V_0(\mathbf{r})$, $R \equiv g_\rho b_0(\mathbf{r})$ and $A \equiv eA_0(\mathbf{r})$. The constant g_γ concerns with the electromagnetic coupling, λ is needed to reproduce the magnetic moments of the nucleons. The terms with β_s, β_v contribute to the charge radii of the nucleon. The energy density contains tensor couplings and scalar-vector and vector-vector meson interactions in addition to the standard scalar self interactions κ_3 and κ_4 [1]. This equation of state (EoS) (eq.1) employed with several parameter sets is used for the calculations.

$$
\begin{aligned}
\mathcal{E}(\mathbf{r}) \;=\; & \sum_\alpha \varphi_\alpha^\dagger \Bigg\{ -i\boldsymbol{\alpha}\cdot\boldsymbol{\nabla} + \beta(M-\Phi) + W \\
& + \frac{1}{2}\tau_3 R + \frac{1+\tau_3}{2}A - \frac{i}{2M}\beta\boldsymbol{\alpha}\cdot\big(f_v\boldsymbol{\nabla}W \\
& + \frac{1}{2}f_\rho\tau_3\boldsymbol{\nabla}R + \lambda\boldsymbol{\nabla}A\big) + \frac{1}{2M^2}\big(\beta_s \\
& + \beta_v\tau_3\big)\Delta A\Bigg\}\varphi_\alpha + \Big(\frac{1}{2} + \frac{\kappa_3}{3!}\frac{\Phi}{M} \\
& + \frac{\kappa_4}{4!}\frac{\Phi^2}{M^2}\Big)\frac{m_s^2}{g_s^2}\Phi^2 - \frac{\zeta_0}{4!}\frac{1}{g_v^2}W^4 + \frac{1}{2g_s^2}\Big(1 \\
& + \alpha_1\frac{\Phi}{M}\Big)(\boldsymbol{\nabla}\Phi)^2 - \frac{1}{2g_v^2}\left(1+\alpha_2\frac{\Phi}{M}\right)(\boldsymbol{\nabla}W)^2 \\
& - \frac{1}{2}\left(1+\eta_1\frac{\Phi}{M} + \frac{\eta_2}{2}\frac{\Phi^2}{M^2}\right)\frac{{m_v}^2}{{g_v}^2}W^2 \\
& - \frac{1}{2g_\rho^2}(\boldsymbol{\nabla}R)^2 - \frac{1}{2}\left(1+\eta_\rho\frac{\Phi}{M}\right)\frac{m_\rho^2}{g_\rho^2}R^2 \\
& - \frac{1}{2e^2}(\boldsymbol{\nabla}A)^2 + \frac{1}{3g_\gamma g_v}A\Delta W \\
& + \frac{1}{g_\gamma g_\rho}A\Delta R. \qquad (1)
\end{aligned}
$$

Results and discussions

In the present work we employ $TM1$, $TM1^*$ and $NL3^*$ parameter sets [4, 6] to the EoS for the E-RMF calculations. The ground state

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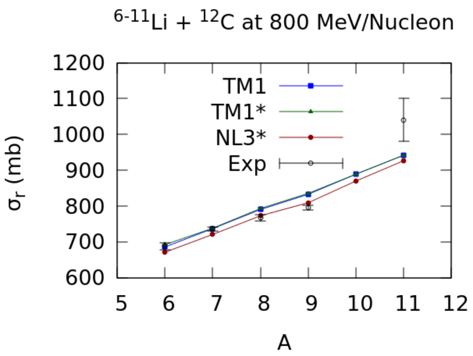

FIG. 1: The total reaction cross-section (σ_r) at 800 MeV/nucleon for Li isotopes as projectile and ^{12}C as target.

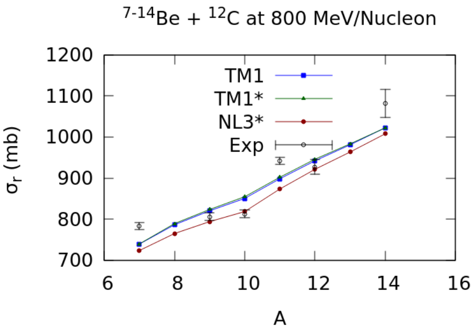

FIG. 2: The total reaction cross-section (σ_r) at 800 MeV/nucleon for Be isotopes as projectile and ^{12}C as target.

properties, namely binding energy and charge radius of the ^{12}C, ^{6-11}Li, ^{7-14}Be and ^{8-17}B nuclei are calculated. The calculated results are in good agreement with the experimental values. The obtained nuclear densities are thus used as an input to the Glauber model to calculate the total reaction cross section, (σ_r). We choose ^{12}C nucleus as the target nucleus and different isotopes of Li, Be and B as the projectile nucleus. Plots between (σ_r) and mass number for isotopes of Li, Be and B are presented in fig. 1-3 respectively. The experimental values for these system [7] are also plotted along with the calculated values. It is observed that the plots are quite similar

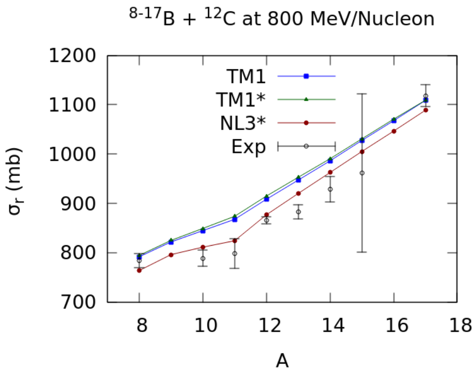

FIG. 3: The total reaction cross-section (σ_r) at 800 MeV/nucleon for B isotopes as projectile and ^{12}C as target.

for the three parameter sets.

It is clear that the $NL3^*$ parameter set produces the best nuclear density. The results shows a good agreement when compared with the observed values and more importantly the cross coupling is not seen to play a major role in this case of finite nuclei. We will extend our work for the the heavy nuclei to see the role of cross couplings for a wider range of nuclei, near and far to the β stability curve.

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