Influence of the functional form of the Finite range interaction in the predictions of finite Nuclei

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Introduction

The finite range Simple effective interaction (SEI) has been used in the studies of various aspects of nuclear matter (NM) [1-3]. Nine parameters from the combinations of altogether eleven parameters of SEI required for complete study of asymmetric nuclear matter (ANM) have been adjusted carefully using minimum number of experimental/empirical constraints. The predictions of SEI in the areas of the momentum and density dependence of the mean field in NM are in conformity with the trend predicted by microscopic calculations. The use of SEI has been extended to the finite nuclei study with the Gaussian form for its finite range part. The two open parameters of SEI, taken to be t_0 and x_0 along with the additional spin-orbit (SO) interaction strength parameters W_0 (in case of finite nucleus) are to be fixed for the study of finite nuclei. Out of the three open parameters, t_0, x_0 and W_0, the parameter x_0 has been fixed from the spin-polarization property of pure neutron matter (PNM), and the rest two parameters t_0 and W_0 are fixed from the fits to the binding energies (BEs) of doubly closed nuclei Ca^{40} and Pb^{208} [4]. All the eleven plus the W_0 – parameters fixed from the NM and finite nuclei, could reproduce the BEs of 161 and charge radii of 86-spherical even-even nuclei within root mean square deviations (rms) ~ 1.5 MeV and ~ 0.015 fm, respectively, with the Gaussian form of SEI [4,5]. The SEI with its Gaussian form has also been used in the study of fission dynamics [6]. In this work we present some results of finite nuclei study with SEI having Yukawa form for its finite range part. The study will show the influence of the functional form of the interaction in the predictions of finite nuclei properties.

Formalism

The finite range Simple effective interaction is given by,

$$V(\vec{r}) = t_0(1 + x_0P_\sigma)\delta(\vec{r}) + \frac{t_3}{16}(1 + x_3P_\sigma)\left(\frac{\rho(\vec{r})}{1 + b\rho(\vec{r})}\right)^\gamma \delta(\vec{r}) + (W + BP_\sigma - HP_\tau - MP_\sigma P_\tau)f(r) \quad (1)$$

where, $f(r) = \frac{e^{-r/\alpha}}{r/\alpha}$ is the finite range part taken to be of Yukawa form. The procedure of determination of eleven parameters b, α, γ , t_0, x_0, t_3, x_3, W, B, H and M plus the SO strength parameter W_0 is similar to that of the Gaussian form of SEI discussed in [4, 5]. The finite nuclei study has been carried out in the framework of Density Functional Theory (DFT) where the non-local density matrix $\rho\left(\vec{r},\vec{r}'\right)$ has been localized by using the Semi-Classical $\hbar^2$-expansion. The SO interaction has been taken similar to the Skyrme case. The pairing interaction has been taken in the BCS framework by using a contact interaction whose parameter has been adjusted to the energy gap in PNM. The general expression of the localized density matrix $\rho\left(\vec{r},\vec{r}'\right)$ under $\hbar^2$-expansion, that is applicable to both Gaussian and Yukawa form of finite range interactions, is given in equation (A1) of [7].

Result and Discussions

The Equation of State (EOS) of SEI used for calculations of finite nuclei results is for γ=1/2 that predicts NM incompressibility K (ρ_0) ~ 240 MeV. The open parameters t_0 and W_0 are determined from fits to the BEs of Ca^{40} and Pb^{208}. The BEs of 161- and charge radii of 86-

even-even spherical nuclei have been calculated. It is worth mentioning that for a given stiffness of NM, i.e., given γ, in order to get the best prediction in terms of minimum rms deviation, the NM saturation properties, namely, the saturation density ρ_0 and the symmetry energy at saturation density $E_s(\rho_0)$ are to be varied with in their accepted range. For the EOS γ=1/2 the NM saturation properties for which minimum rms deviations in the results of BE and charge radii are obtained, is given in Table1. It has been noticed that in the predictions BE and charge radii, the values of $E_s(\rho_0)$ and ρ_0 play dominant role, whereas the influence of energy per particle is minimum. The results of the BEs of 161- and charge radii of 86- spherical even-even nuclei for the EOS γ=1/2 of SEI having Yukawa form have been given in the panels (a) and (b) of Fig.1. The rms deviations for the BE is ΔE= 1.9 MeV, whereas, that of charge radii, Δr = 0.04 fm.

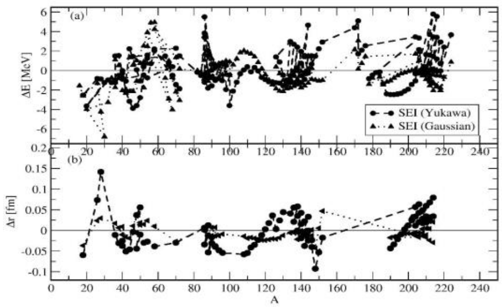

Fig.1 rms deviation of BE of 161 even-even spherical nuclei in panel (a) and rms deviation of charge radii of 86-spherical even-even nuclei in panel (b) for Yukawa and Gaussian form of SEI.

Form of SEI	$e(\rho_0)$ (MeV)	ρ_0 (fm^3)	$E_s(\rho_0)$ (MeV)	$L(\rho_0)$ (MeV)
Yukawa	-16.05	0.163	34	72.66
Gaussian	-16	0.158	35.5	76.71

Table1. Nuclear matter Saturation properties of the two sets of EOS of SEI having Yukawa and Gaussian form.

In order to examine the influence of the functional form of the finite range part, we have made the calculation for the equivalent EOS of SEI having Gaussian form. The equivalent EOS of SEI with Gaussian form has been obtained by matching the NM incompressibility values, and this has been obtained for the value of γ=0.42. The results of BEs and charge radii for the Gaussian form are also given in the respective panels of Fig.1. The comparison between the predictions of BEs and charge radii under DFT formulation for Yukawa and Gaussian forms of SEI shows that the later one is more competent for the bulk properties of nuclei. In order to explore the consequence of the finding we have computed the results of BEs in the isotopic of Ni-isotopes using both forms of SEI. The results of BE/A along with the NL3 and experimental values are given in the Fig.2.

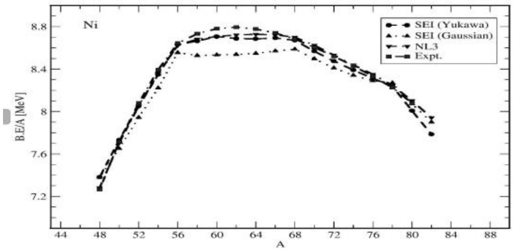

Fig.2 BEs in the isotopic chain of Ni-isotopes using both forms of SEI compared with NL3 and experimental data.

Conclusion

It is found that under DFT formulation where the density matrix is localized by using the semi-classical ħ - expansion up to second order i.e., up to $\hbar^2$– term, the Gaussian form of SEI reproduces the BEs and charge radii of spherical nuclei quite well. However, under the same formulation the Yukawa form of SEI fails to reproduce charge radii well as compared to its Gaussian counterpart, whereas, the BEs are reproduced with rms deviation in close proximity with that of the Gaussian form.

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