A study of influence of nuclear matter parameters on finite nuclei properties

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Introduction

The study of nuclear matter (NM) and finite nuclei in a given model is a promising area of current nuclear research. The use of effective models have been quite successful in this regard. The relativistic mean field (RMF) theory uses exchange of mesons to account for the interaction part. On the other hand, the non-relativistic mean field models uses two body effective interactions for the purpose. The Skyrme type, Gogny and *M3Y* interactions are the ones those have been successful in the application to the studies of NM as well as finite nuclei in the non-relativistic model. Most recently, we have also accomplished successfully the similar studies by using our simple effective interaction (SEI) [1]. It has been found in the work that the variation of NM parameters, namely, energy per particle $e(\rho_0)$, saturation density ρ_0 and the symmetry energy $E_s(\rho_0)$ in normal NM within the range of their accepted empirical values, has substantial influence on the finite nuclei properties although the change in the predictions of NM bulk properties are not of much significance. This motivates one to search for constraining the range of the NM parameters from the studies of finite nuclei.

Formalism

The SEI that has a single finite range term along with a density dependent zero-range part is

$$v_{eff}(\vec{r}) = t_0(1+x_0P_\sigma)\delta(\vec{r}) + \frac{t_3}{6}(1+x_3P_\sigma)\left[\frac{\rho(\vec{R})}{1+b\rho(\vec{R})}\right]^\gamma \delta(\vec{r})$$
$$\left(W+BP_\sigma-HP_\tau-MP_\sigma P_\tau\right)f(r) \qquad ..(1)$$

where, $f(r)$ is the form factor of the finite range interaction containing the range parameter α and the other symbols have their usual meaning. In the present work, the Gaussian form, e^{-r^2/α^2} for $f(r)$ is used. The energy density, $H(\rho)$, and mean field, $u(k,\rho)$, in isospin asymmetric NM (ANM) at zero-temperature can be obtained in analytical form. These expressions contain 09-parameters, namely, α, b, γ, ε_0^l, ε_0^{ul}, ε_γ^l, ε_γ^{ul}, ε_{ex}^l and ε_{ex}^{ul} in terms of the 11-interaction parameters of Eq.(1), keeping two parameters open to be determined from the study of finite nuclei [1]. The systematic determination of these 09-parameters of ANM is discussed in Ref.[1]. The extension of the formulation to the finite nuclei is based on Kohn-Sham method where the exchange part of the energy density functional is built up with the help of the semi-classical $\hbar$-expansion of the density matrix. The spin-orbit (SO) contribution is taken as in case of Skyrme or Gogny. Both direct and exchange Coulomb contributions along with the center of mass correction are also considered. The BCS pairing is used to account for open shell nuclei. The two open parameters, t_0, x_0 along with the SO strength parameter, W_0, are determined from fitting to the experimental results of energies, and splitting of single particle levels in the three closed shell nuclei, O^{16}, Ca^{40} and Pb^{208}. Under the procedure used in extending the study to finite nuclei in the present model has the definite advantage that the predictions in ANM remain unchanged. On the other hand, one can make a variation in the NM constraints used in the determination of the parameters in ANM and can make a systematic study of their influence on finite nuclei properties. The empirical values of NM parameters, namely, $e(\rho_0)$, ρ_0 and $E_s(\rho_0)$ are -16.0±0.2 MeV, 0.17±0.3 fm^{-3} and 32.5±2.5 MeV, respectively [2].

Results and discussions

We shall, at first, show the strong correlation of the charge radii of nuclei over the nuclear chart with the NM saturation density, ρ_0. The charge radii of 88 even-even nuclei from A=16 to A=224, whose experimental values are available [3], are calculated for the three equation of states (EOS) of NM with same $e(\rho_0)$=-16.0 MeV, T_{f0}=37 MeV (corresponding to ρ_0=0.161 fm^{-3}) and $E_s(\rho_0)$=33 MeV, but having different values of incompressibility, $K(\rho_0)$=220, 225, 245 and 265 MeV (corresponding to γ =1/6,1/3,1/2 and 2/3). The results of the deviation from experimental value, $\delta r_{ch} = (r_{ch})_{Th} - (r_{ch})_{expt}$, as function of mass number A is given in Fig.1. The root mean square (*rms*) deviations are 0.0363fm, 0.0171fm, 0.0386fm and 0.0573 fm for the four cases of γ

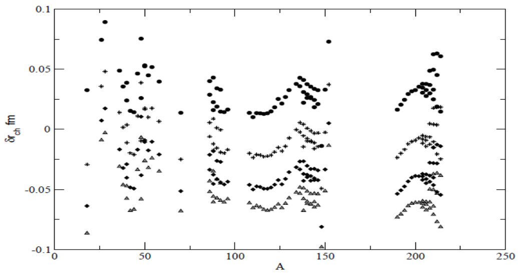

Fig.1: *rms* deviations of charge radii of even-even nuclei for A=16-224 with the EOSs having γ=1/6(filled circles),1/3(stars),1/2(filled diamond) and 2/3(triangles). See text for details.

in increasing order. The overall trend shows that the charge radii are predicted undervalued as the incompressibility increases for given $e(\rho_0)$, ρ_0 and $E_s(\rho_0)$. This conclusion is verified to remain valid for the variations of $e(\rho_0)$ and $E_s(\rho_0)$ within their ranges. It can be, therefore, concluded that for a given value of $K(\rho_0)$ there corresponds a typical value of ρ_0 for which the nuclear EOS predicts best results for charge radii over the nuclear chart with minimum *rms* deviation. Once the saturation density corresponding to the incompressibility of the EOS is ascertained from the study of the charge radii, that results into minimum *rms* deviation, the binding energy (BE) of all the 161 even-even nuclei [4] in the mass region, A=16 −224, were examined for the variation of symmetry energy $E_s(\rho_0)$. It is found that for the characteristic value of ρ_0=0.1597 fm^{-3} obtained for γ=1/3, the *rms* deviation in BE, ΔE, was found to be minimum for $E_s(\rho_0)$=32.0 MeV. The results of ΔE and δr_{ch} as function of A are shown in Fig.2. The *rms* values are 2.048 MeV and 0.0158 fm, respectively.

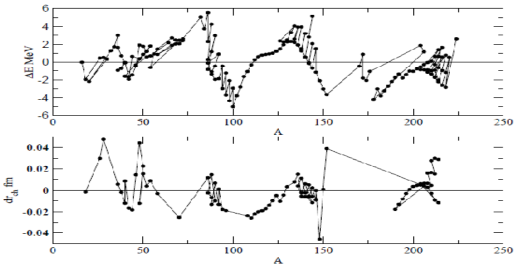

Fig.2: *rms* deviations of energy (upper) and charge radii (lower) of even-even nuclei for A=16-224. For details see text.

In this calculation, we have considered only the variation for $E_s(\rho_0)$ for a given γ. The variation of $e(\rho_0)$ can also be included together with $E_s(\rho_0)$. The parameters in NM and the parameters t_0 , x_0 and W_0 in finite nuclei are to be determined following the procedure, discussed in Ref.[1], each time once a variation in the empirical value of any of the NM parameter is made, so that the characteristic predictions of momentum and density dependence of the nuclear mean field in ANM do not change in an arbitrary unknown fashion. Hence the procedure can be considered as a consistent way of studying the finite nuclei using the effective force in Eq.(1) with controlled variation in the NM predictions. The study can also be extended for different values of NM incompressibility. This formidable task of finite nuclei calculation including the deformation part and performing variations in all the NM parameters may provide the advantage of narrowing down the range of uncertainties in their empirical values.

References

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