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ARTICLE

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AN INVESTIGATION ON NEUTRON SKIN THICKNESS OF FINITE NUCLEI BY STUDYING DIPOLE POLARIZABILITY USING FINITE RANGE EFFECTIVE INTERACTION

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The dipole polarizability ‘α_D’ is analyzed by using Droplet Model (DM) in finite range effective interaction for two different splitting of exchange strength parameters $E_{ex}^{l} = E_{ex}/2$ and $E_{ex}^{ul} = E_{ex}/2$ where E_{ex} is the exchange parameter of the interaction. The role of density derivatives of symmetry energy and neutron skin thickness on α_D is studied and the value of α_D is found to be 24.10 fm^3 and 26.43 fm^3 for E_{ex}^{l} and E_{ex}^{ul} respectively.

Introduction

The density-dependent symmetry energy is a key ingredient for the study of many aspects of astrophysics and nuclear physics in both theoretical and experimental fields[1-4]. But we cannot measure the fundamental quantities like the nuclear symmetry energy directly. So, it is essential to gather some measurable observables to extract information about the fundamental quantity. The Research Centre of Nuclear Physics (RCNP), Osaka, Japan measured the dipole polarizability, α_D of the ^{208}Pb with the help of polarized proton inelastic scattering (p, p′) at very forward angles. The value of dipole polarizability in this experiment is found to be α_D= (20.1±0.6) fm^3 for ^{208}Pb [5]. Using several EDFs, Roca-Maza et. al[6] showed that dipole polarizability varies as 18 fm$^3 < \alpha_D <$ 24fm^3. In this paper, we calculate the dipole polarizability α_D with the help of finite range effective interaction by using very well-known DM and then extract skin thickness to compare our previous results for two types of splitting[7,8].

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Electric Dipole Polarizability

We have used a simple finite-rage effective interaction in this work in a non-relativistic manner and the potential is defined as[8,9]

$$V_{eff}(r) = t_0\left(1 + x_0 P_\sigma\right)\delta\left(\vec{r}\right) + \frac{t_3}{6}\left(1 + x_3 P_\sigma\right) \times \left[\frac{\rho\left(\vec{R}\right)}{1 + b\rho\left(\vec{R}\right)}\right]^\gamma \delta\left(\vec{r}\right) + \left(W + BP_\sigma - HP_\tau - MP_\sigma P_\tau\right) f(r) \tag{1}$$

Using the droplet model (DM) approach of Myers and Swiatecki[10] the dipole polarizability α_D^{DM} can be expressed in terms of symmetry energy coefficient $a_{sym}(A)$ of finite nuclei as[11,12]

$$\alpha_D^{DM} = \frac{\pi e^2}{54}\frac{A\left\langle r^2\right\rangle}{E_{sym}\left(\rho_0\right)}\left(1 + \frac{5}{3}\frac{E_{sym}\left(\rho_0\right) - a_{sym}(A)}{a_{sym}(A)}\right) \tag{2}$$

We know that $a_{sym}(A) \approx E_{sym}(\rho_A)$ and using a local density approximation $E_{sym}(\rho_A) = E_{sym}(\rho_0) + L\chi$, where $\chi = (\rho_A - \rho_0)/3\rho_0$, we can write the dipole polarizability as

$$\alpha_D^{DM} = \frac{\pi e^2}{54} \frac{A\langle r^2 \rangle}{E_{sym}(\rho_0)} \left(1 - \frac{5}{3} \frac{L}{E_{sym}(\rho_0)} \chi\right) \quad (3)$$

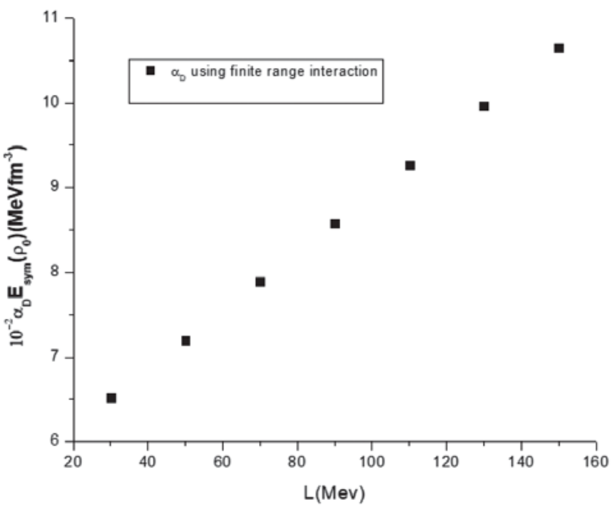

Fig.1. Variation of $10^{-2}\alpha_D E_{sym}(\rho_0)$ with respect to slope parameter *L* using finite range effective interaction.

Using finite range effective interaction in equation (3) we have plotted the variation of $10^{-2}\alpha_D E_{sym}(\rho_0)$ as a function of the slope of symmetry energy at saturation density within a range of 30 MeV< *L*<150 MeV in Fig.1. A linear increasing trend of dipole polarizability with the slope of symmetry energy *L* is observed, which is consistent with other observations[6]. From the above figure, it is observed that for $E_{ex}^l = \frac{E_{ex}}{2}$, corresponding to the slope of symmetry energy = 41.38 MeV the value of dipole polarizability α_D = 23.01 fm^3 and for $E_{ex}^{ul} = \frac{E_{ex}}{2}$, corresponding to the slope of symmetry energy *L* = 75.204 MeV, the value of dipole polarizability α_D =26.90 fm^3.In Fig.2, we have represented the values of $10^{-2}\alpha_D E_{sym}(\rho_0)$ against corresponding values of the slope of symmetry energy at saturation density obtained by using our interaction and in the same figure, the same quantities for other interactions like FSU, Skyrme, DD-ME are also shown for comparison. The equation obtained from the linear fit with correlation coefficient *r* = 0.91 is given by

$10^{-2}\alpha_D E_{sym}(\rho_0)$ = (0.02942 ± 0.01408)*L* + (5.122 ± 1.040) MeV fm^3 .

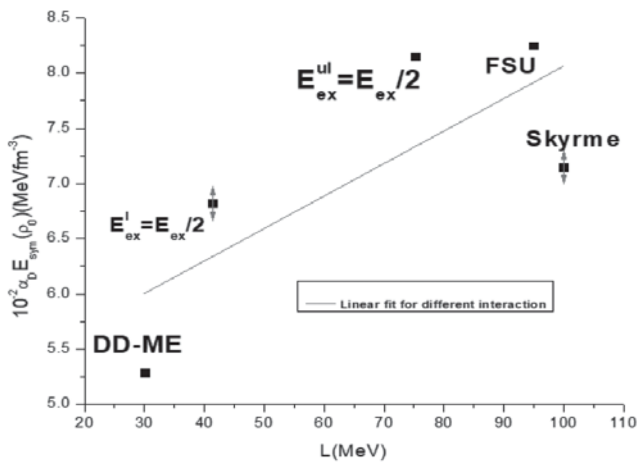

Fig.2. The values of $10^{-2}\alpha_D E_{sym}(\rho_0)$ correspond to *L* for the $E_{ex}{}^l = E_{ex}/2$, $E_{ex}{}^{ul} = E_{ex}/2$, DD-ME, FSU and Skyrme and their linear fit.

Using the linear fit equation, we get 15.73 fm^3< α_D <26.54 fm^3 for $E_{ex}{}^l = E_{ex}/2$ and 17.45 fm^3< α_D <31.42 fm^3 for $E_{ex}{}^{ul} = E_{ex}/2$.

In our previous work, we have studied the correlation between neutron skin thickness *S* of ^{208}Pb with the slope of symmetry energy *L*[11]. Hence, it is interesting to study the correlation between dipole polarizability α_D and neutron skin thickness *S* of ^{208}Pb. The dipole polarizability α_D can be written in terms of neutron skin thickness *S* in DM as[10-12]

$$\alpha_D^{DM} = \frac{\pi e^2}{54} \frac{A\langle r^2 \rangle}{E_{sym}(\rho_0)} \left(1 + \frac{5}{2} \frac{S}{I\langle r^2 \rangle}\right) \quad (4)$$

The dipole polarizability $10^{-2}\alpha_D E_{sym}(\rho_0)$ is plotted as a function of *S* for ^{208}Pb (0.12fm < *S* < 0.34 fm) for finite range effective parameters[13,14] in Fig.3. A linear increasing trend of $10^{-2}\alpha_D E_{sym}(\rho_0)$ with *S* is observed and the result is consistent with other studies[6,15,16]. It is found that for $E_{ex}^l = \frac{E_{ex}}{2}$, the value of dipole polarizability α_D = 23.10 fm^3 corresponding to the skin thickness *S* = 0.13 fm and for $E_{ex}^l = \frac{E_{ex}}{2}$, the value of dipole

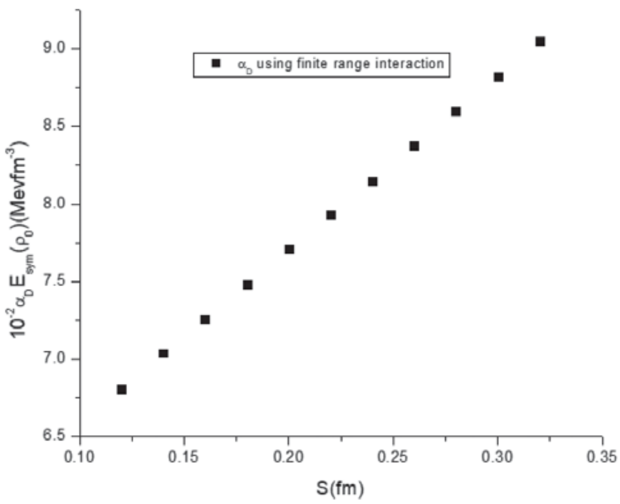

Fig.3. Study of$10^{-2}\,\alpha_D\,E_{sym}(\rho_0)$ as a function of neutron skin thickness S with the using finite range effective interaction.

polarizability α_D = 26.10 fm^3 corresponding to the skin thickness S = 0.21 fm for $E_{ex}^{ul} = \frac{E_{ex}}{2}$. It is further observed that the values of α_D for both the splitting of our interaction obtained by using from the correlation between dipole polarizability with the slope of symmetry energy L as well as with the neutron skin thickness S are consistent with each other.

The values of dipole polarizability $10^{-2}\,\alpha_D\,E_{sym}(\rho_0)$ obtained by using our interaction corresponding to skin thickness S for two different strength parameters are represented in Fig. 4. Our results are compared with the

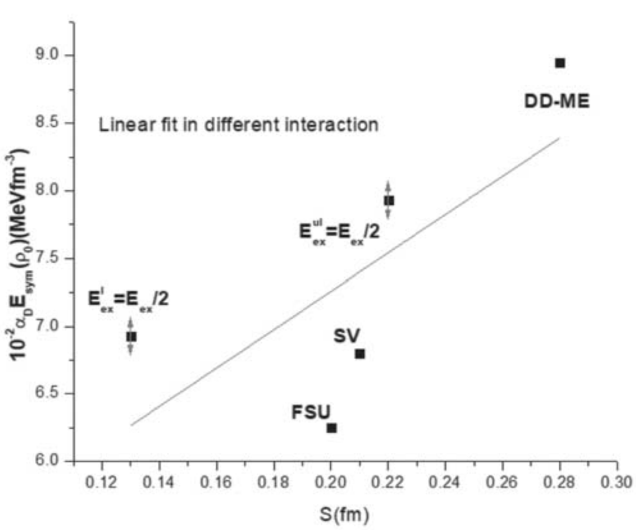

Fig.4. Comparison of dipole polarizability corresponding to neutron skin thickness S for $E_{ex}{}^{l} = E_{ex}/2$, $E_{ex}{}^{ul} = E_{ex}/2$, SV, FSU and DD-ME and their linear fit in the same graph.

results obtained from other interactions like DDME, FSU, and SV, which gives the linear fit equation $10^{-2}\,\alpha_D\,E_{sym}(\rho_0)$ = (14.17 ± 8.135)S + (4.426 ± 1.736) MeV fm^3 with correlation coefficient, in this case, is =0.85. The values of dipole polarizability using the linear fit equation are found to be 11.72 fm^3< α_D <30.18 fm^3 for $E_{ex}{}^{l} = E_{ex}/2$ and 13.41 fm^3< α_D <36.69 fm^3 for $E_{ex}{}^{ul} = E_{ex}/2$.

Conclusion

In this paper, we have studied the variation of $10^{-2}\,\alpha_D\,E_{sym}(\rho_0)$ concerning slope parameter L and drawn a linear fit $10^{-2}\,\alpha_D\,E_{sym}(\rho_0)$ = (0.02942 ± 0.01408)L + (5.122 ± 1.040) of ^{208}Pb which consistent with other results[11]. In our result, the value of dipole polarizability, α_D is larger for $E_{ex}{}^{ul} = E_{ex}/2$ that $E_{ex}{}^{l} = E_{ex}/2$. We compared our results with other interactions like FSU, Skyrme, DD-ME and our results obtained by using finite range effective interaction agree quite well with the results obtained from other interactions. Next, we studied the variation of $10^{-2}\,\alpha_D\,E_{sym}(\rho_0)$ with neutron skin thickness S of ^{208}Pb and found the value of α_D = 24.10 fm^3 for $E_{ex}{}^{l} = E_{ex}/2$ which is smaller compared to $E_{ex}{}^{ul} = E_{ex}/2$ for which α_D = 26.43 fm^3. In this case, a linear fit was also drawn and found $10^{-2}\,\alpha_D\,E_{sym}(\rho_0)$ = (14.17 ± 8.135) S + (4.426 ± 1.736) MeV. ❐

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