Effects of the isovector-scalar meson on the softness of the Sn isotopes

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Introduction

The infinite nuclear matter incompressibility K_∞ plays an important role in determining the proper nuclear matter equation of state (EOS). Now-a-days the determination of the correct value of K_∞ remain an active area for both experimentalist and theorist. The K_∞ cannot measured directly by any experimental technique, rather it depends upon the experimental measurement of isoscalar giant monopole resonance (ISGMR), which is a collective phenomena of the nucleons. The excitation energy of the ISGMR for finite nucleus is given by $E_{ISGMR} = \sqrt{\frac{h^2 K_A}{mr^2}}$, where K_A is the incompressibility of the finite nucleus. Then question arises how we get K_∞ from the K_A ?. For that we have taken the help of the theoretical model, which gives best fit to the E_{ISGMR} of various nuclei, the K_∞ of that model suggested to be more appropriate value. Many of the recent report suggest that 220 ± 10 is the best appreciated value for the range of K_∞.

In this report, we have used the relativistic mean field (RMF) theory as to evaluate the E_{ISGMR}. As we know, that the meson exchange is the basic feature in the RMF theory. Various types of the mesons are exchanged between the nucleon. The most important mesons are σ, ρ, and ω. But in principle many other mesons can be exchanged along with these three. In effective theory contribution of some meson are discarded on the basis of symmetry and some meson have a heavy mass so the contribution will not significant in normal nuclear system. But when the asymmetry of the system is very high (like neutron star) some meson contribution become significant. $\delta-$ is the suitable candidate, whose contribution should be added whenever we deal with the highly asymmetric infinite nuclear matter and finite nucleus. Transport properties are very much affected by inclusion of δ meson. We have obtained a new parameter set named NL$-\delta$1 parameter set by including δ meson effects on top of the NL3 like interactions. With this new parameter set we have calculated the excitation energy of various nuclei along with isotopic Sn serise.

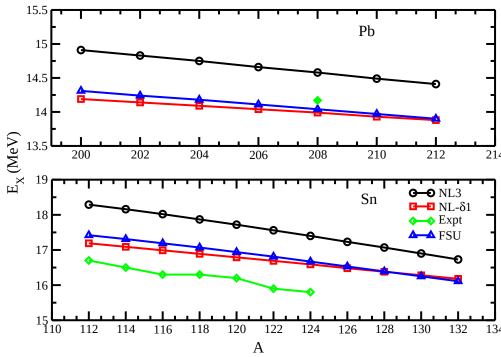

FIG. 1: Variation of excitation energy for Pb ans Sn are given in isotopic series. Results are calculated with various parameter set and compared with experimental data.

Formalism

We have used the semi-classical approaches like relativistic extended Thomas-Fermi (RETF) model to estiomate the excitation energy of GMR. The excitation energy of the ISGMR is calculated by using well established scaling technique. The effective Lagrangian is given by

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$$
\begin{aligned}
\mathcal{H} &= \sum_i \varphi_i^\dagger \Big[-i\vec{\alpha}\cdot\vec{\nabla} + \beta m^* + g_v V + \frac{1}{2} g_\rho R \tau_3 \\
&+ \frac{1}{2} e\mathcal{A}(1+\tau_3) \Big] \varphi_i + \frac{1}{2}\left[(\vec{\nabla}\phi)^2 + m_s^2 \phi^2 \right] \\
&+ \frac{1}{3} b\phi^3 + \frac{1}{4} c\phi^4 - \frac{1}{2}\left[(\vec{\nabla}V)^2 + m_v^2 V^2 \right] \\
&- \frac{1}{2}\left[(\vec{\nabla}R)^2 + m_\rho^2 R^2 \right] - \frac{1}{2}\left(\vec{\nabla}\mathcal{A} \right)^2 + aV^4 \\
&+ \Lambda R^2 V^2 + \frac{1}{2}\left[(\vec{\nabla}\delta)^2 + m_\delta^2 \delta^2 \right]. \qquad (1)
\end{aligned}
$$

In the semi-classical approach the basic variable is the density unlike to the wave function. Semi-classical approach has proved to be very useful for description of the collective property like ISGMR.

TABLE I: The excitation energy (E_x) of various isotopes are calculated with NL-δ1 and compared with other preexisting parameter set along with experimental data .

Nucleus	$(m_3/m_1)^{1/2}$(MeV)				
	NL3	FSUGold	NL1	NL-δ1	Expt.
^{16}O	27.83	26.97	23.31	26.18	21.13±0.49
^{40}Ca	24.01	22.98	20.61	22.61	19.90±0.40
^{48}Ca	22.69	21.72	19.51	21.48	19.90±0.2
^{90}Zr	19.53	18.60	16.91	18.35	17.89±0.2
^{112}Sn	18.29	17.42	15.87	17.19	16.7±0.2
^{114}Sn	18.16	17.31	15.76	17.09	16.5±0.2
^{116}Sn	18.02	17.19	15.63	16.99	16.3±0.2
^{118}Sn	17.87	17.07	15.51	16.89	16.3±0.2
^{120}Sn	17.72	16.94	15.38	16.79	16.2±0.2
^{122}Sn	17.56	16.81	15.24	16.69	15.9±0.2
^{124}Sn	17.40	16.67	15.11	16.59	15.8±0.2
^{208}Pb	14.58	14.04	12.69	13.99	14.17±0.2

Result and discussion

In table we give a comparison between the results obtained with new NL-δ1 parameter and other parameter sets along with the experimental data. The fluffiness of the Sn isotopes remain a major problem in GMR for last one decade. One can see from the data that the difference between the theoretical result (FSU) and experimental data is about 0.8 MEV (average) for Sn isotopes, while this difference is only 0.13 Mev for ^{208}Pb data. Here we want to resolve this problem but this problem is not resolved fully by this new parameter. Our new parameter (NL-δ1) improves the result by 0.2 MeV, keeping the success of the previous parameter set. We have not compromised any finite nuclear property or infinity nuclear matter property in making this parameter. The advantage of this parameter set is that it gives well matched ground state property (Binding energy, charge radius) along with better excitation energy of ISGMR.

Conclusion

We have obtained a new parameter set (NL-δ1), including an extra degree of freedom of meson exchange i.e., $\delta-$ meson. The results of this new parameter set show that the effects of $\delta-$meson can not be overlooked while dealing with an asymmetric nuclear system. The excitation energy of the Sn isotopes get improved with this new parameter set.

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