Effect of Isospin on compressibility of drip line and superhero nuclei

S.K.Biswal* and S.K. Patra†
Institute of physics, Sachivalya marg, Bhubaneswar-751005, India.

Introduction

Compression modulus is a key word of the equation of state (ESO) for astrophysical object like neutron star. But there is no direct method to measure the compressibility. On the other hand uncertainty in the astrophysical measurements are very much. So it is very hard to get any conclusive result from these measurements. The only method to calculate the compressibility for infinite nuclear systems like neutron star is to study of finite nuclear compressibility. That is the reason why now-a-days the study of Isoscalar giant monopole resonance (IGMR) increasing day by day. In Isoscalar monopole resonance(commonly known as breathing mode) the proton and neutron oscillate in same phase. It mostly like to the density oscillation. Excitation energy of the IGMR is directly related to the compressibility of the nucleus by the formula $E_m = \sqrt{\frac{AK}{B_m}}$, where E_m and B_M are the excitation energy and mass parameter respectively. But extraction of infinite nuclear matter compressibility from finite nuclear compressibility is not easy task. There are well defined theory for this prescribed job. In leptodermous expansion the compressibility of the finite nucleus can be written as $K_A = K_\infty + K_{surf}A^{-\frac{1}{3}} + K_\tau I^2 + K_{coul}Z^2A^{-\frac{4}{3}}$, where $I = \frac{N-Z}{A}$. K_∞ is the infinite nuclear matter compressibility. In the limit A approaches to infinite the finite nuclear matter compressibility can be approximated to infinite nuclear matter compressibility. Isospin has also large effect on the ESO. So it is very instructive to study variation of compressibility with isotopic chain both in light and super heavy region. For the study, we have taken here O, Ca, Sn and Zr as light nuclei and $Z = 114$ and $Z = 120$ as super-heavy element and calculated the compressibility of these nuclei starting from neutron to proton drip-lines.

Formalism

For effective nuclear interaction we have taken relativistic mean field (RMF) theory with NL3 parameter set to reproduces the ground state properties of the nucleus. Density is calculated in semiclassical approximation like Thomas-Fermi (TF) and Extended Thomas-Fermi (ETF) approaches. In extended Thomas-fermi calcuation there is an extra $\hbar^2$correction to the Thomas-fermi calculation which takes care the surface correction of the density. For the calculation we have used the Relativistic Extended Thomas-Fermi (RETF) Hamiltonian. The RETF Hamiltonian is written as [1, 2]

$$\mathcal{H} = \mathcal{E} + \frac{1}{2}g_s\phi\rho_s^{eff} + \frac{1}{3}b\phi^3 + \frac{1}{4}c\phi^4 + \frac{1}{2}g_v V\rho + \frac{1}{2}g_\rho R\rho_3 + \frac{1}{2}e\mathcal{A}\rho_p. \quad (1)$$

In order to study the monopole vibration of the nucleus, we have scaled the baryon density. The normalized form of the scaled baryon density is given by

$$\rho_\lambda(\mathbf{r}) = \lambda^3 \rho(\lambda r). \quad (2)$$

With this scaled density we can write the RETF Hamiltonian in scaled form. The compressibility can be obtained from the derivative of the scaled Hamiltonian with respect to the scaled co-ordinate λ. After some algebric manupulation, the restoring force $C_m$is writ-

*Electronic address: sbiswal@iopb.res.in
†Electronic address: patra@iopb.res.in

ten as

$$C_m = \int dr\Big[- m\frac{\partial\tilde{\rho}_s}{\partial\lambda} + 3\Big(m_s{}^2\phi^2 + \frac{1}{3}b\phi^3 - m_v{}^2V^2 - m_\rho{}^2R^2\Big) - (2m_s{}^2\phi + b\phi^2) \frac{\partial\phi_\lambda}{\partial\lambda} + 2m_v{}^2V\frac{\partial V_\lambda}{\partial\lambda} + 2m_\rho{}^2R\frac{\partial R_\lambda}{\partial\lambda}\Big]_{\lambda=1} \quad (3)$$

The detail formalism can be found [3].

Result and Discussion

The calculated results of compressibility are depicted in fig.1 and fig.2. From fig.1 it is clear that the compressibility for light mass nuclei deceases in an isotopic chain both in proton and neutron drip-line region. But the compressibility has a higher value in a region where N=Z. This shows that the nucleus with certain combination of proton and neutron are more compressible than other. From the leptodermous expansion we can get some basic ideas about this decreseness in the vicinity of drip-line. In the drip line region the asymmetry between the proton and neutron number is more. As the coefficient of the asymmetry term is negative, this decreases the compressibility when the $N - Z$ value increase. But the compressibility of super-heavy nuclei in the isotopic chain do not follow this trend. For these nuclei the compressibility decreases monotonically starting from proton drip line to neutron drip line. This discrepancy between super-heavy and light nuclei may be due to Coulomb interaction and large value of isospin difference. For lighter value of Z, proton drip-line occurs at a combination of proton and neutron where the neutron number is less than or nearer to the proton number. But in case of super heavy nucleus due to large Coulomb interaction proton drip-line occurs where neutron number is greater than proton number. For Ca isotopic chain, the compressibility from scaling and constraint method are compared with same obtained from Hartee-Fock with RPA. Semiclassical results deviate from RPA in light isotopes but excellently matches in heavier Ca isotopes.

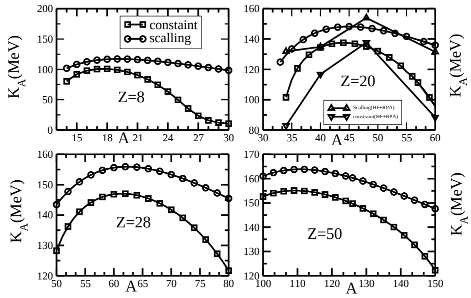

FIG. 1: Variation of compressibility in Isotopic chain of light nuclei.

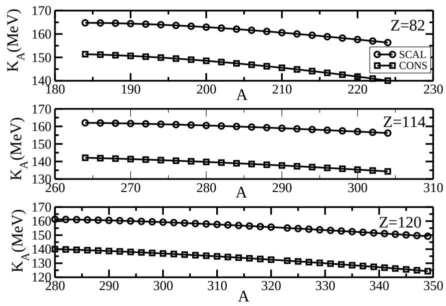

FIG. 2: Variation of compressibility in Isotopic chain of superhaevy nuclei.

Summary and Conclusion

We have analyzed the variation of compressibility in case of light and superhaevy nuclei starting from proton drip-line to neutron drip-line. From our analysis it is well understood that the compressibility decreases in proton and neutron drip-line regions.

The author thanks to porfs. X.viñas and M.Centelles for his valuable guidance and care full reading of the manuscript.

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