Shape evolution and coexistence in Hg isotopes

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1. Introduction

Nuclear shape results from the interplay between the single particle energy and the collective degrees of freedom. Many theoretical, as well as experimental studies, have been carried out in recent years to explore the structural evolution of atomic nuclei. Investigation of the evolution of nuclear shape as a function of nucleons is gaining much interest nowadays. Rapid change in nuclear shape at zero temperature limit as a function of nucleon number is termed as quantum phase transition[1]. Nuclei exhibit various phases like spherical, axially deformed and triaxial configurations. Moreover, the identification of the nuclei at critical point of phase transition, where the sudden change in shape occurs is also very important.

Shape coexistence is a phenomenon in which spherical configuration competes with the deformed one and more than one stable state exists at different deformations[2]. In other words, nuclei can exist in different shapes having degenerate energy states. Experimental signatures for shape coexistence is the presence of excited 0^+ states lying close to 0^+ ground state. This phenomenon is found to appear throughout the nuclear landscape spanning from light to heavy nuclei[3]. Atomic nuclei in the transitional region near to Z=82 is rich with a variety of shapes. So this region has much importance in studying the structural evolution of nuclei. We have selected Hg isotopes as a representative of this region. Many experimental results show evidence for the occurrence of shape coexistence in Hg isotopes.

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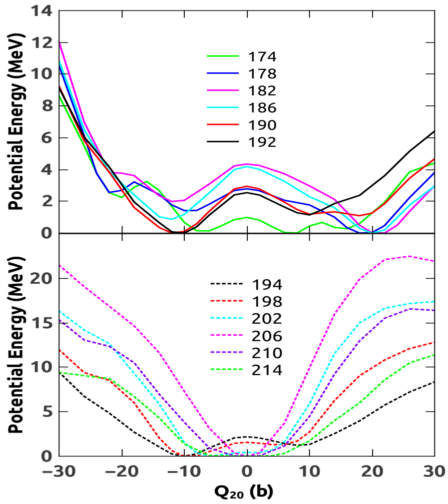

FIG. 1: Potential energy curves of ^{174}Hg-^{214}Hg.

2. Theoretical formalism

The calculations have been done using Skyrme Hartree Fock Bogoliubov (HFB) formalism[4]. The matrix form of HFB equation is given by,

$$\begin{pmatrix} h-\lambda & \Delta \\ -\Delta^* & -h^*+\lambda \end{pmatrix} \begin{pmatrix} U_n \\ V_n \end{pmatrix} = E_n \begin{pmatrix} U_n \\ V_n \end{pmatrix} \tag{1}$$

Constraint HFB equations are solved for extracting the potential energy curves with quadrupole moment Q_{20} as the deformation degree of freedom.

For the mean field part, we have used the recent UNEDF2[5] parametrizaton and for the pairing part, we adopted the density dependent delta interaction (DDDI)[6] in their mixed form.

3. Result and discussions

We have carried out a systematic analysis of the ground state shape transition and shape coexistence of Mercury isotopes. The study has been carried out for even-even isotopes in the mass range A=174 to 214. HFB equations are solved with the aid of axially deformed harmonic oscillator basis. In fig.1, we have shown the potential energy curves of the Hg isotopes (each line corresponds to mass number(A)) as a function of Q_{20}. The minimum energy corresponds to the ground state and other local minima are the intrinsic excited states. From the figure, we can see a shape transition from prolate(^{174}Hg-^{186}Hg) to oblate(^{188}Hg-^{202}Hg) and then becomes spherical at N=126(^{206}Hg). Then it becomes flat minima and a slow transition to the prolate configuration is observed as neutron number is increased. In fig.2 we have plotted the ground state binding energy per nucleon of Hg isotopes and compared with the experimental values[7].

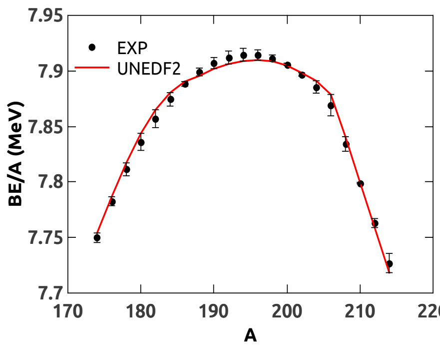

FIG. 2: Ground state binding energies

From a theoretical point of view, if the energy between the ground and first intrinsic excited state is very less, nuclei are said to have co-existing shapes. Quantitatively, shape coexistence can be expressed as the difference between the ground state and excited state energies. ($\Delta E = E_{gs} - E_{exc}$). Fig.3 shows the calculated values of ΔE. From the figure, we can observe that the energy difference between oblate and prolate minima is in the range 0-2 MeV. As this value comes in the required range, we can say that some of these isotopes exhibit the phenomena of shape coexistence. For a more detailed study regarding shape-coexistence, we have to carry out triaxial calculations.

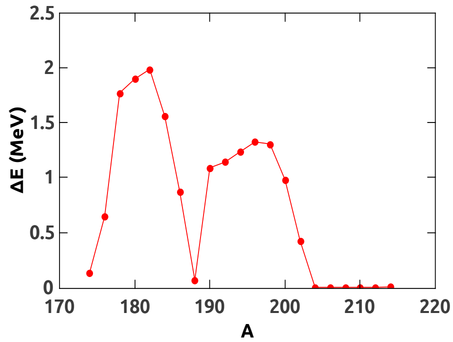

FIG. 3: Shape coexistence of Hg isotopes.

In short, with the help of axially deformed HFB theory, we studied the evolution of the shape of ^{174}Hg-^{214}Hg. It is observed that light isotopes are prolate and as neutron number increases they change to the oblate configuration and finally becomes spherical at N=126 and again deviate towards prolate deformation. We also observed some signatures of shape coexistence in the selected isotopes.

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