Ground State Properties and Shape Evolution of Hg Isotopes within Covariant Density Functional Theory

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Introduction

Density functional theories (DFT's) have been tremendously effective in understanding nuclear many-body dynamics. Especially the covariant density functional theory (CDFT) [1, 2] is widely popular because of its satisfactory description of ground and excited states of nuclei throughout the periodic table. The transitional nuclei around Z=80, exhibit a variety of intriguing phenomena such as shape coexistence, change of shape in an isotopic chain, and so on. [3, 4] In this work, we investigated the ground state characteristics and shape evolution of mercury (Hg) isotopes using CDFT.

Formalism

The density-dependent point-coupling (DD-PC) model and the density-dependent meson-exchange (DD-ME) model are the two types of covariant density functional models employed in this work. The former has a finite range of interaction and has been fitted to binding energies and radii of spherical nuclei; while the has a zero-range interaction and has been fitted to nuclear matter data and for finite nuclei only to binding energies of a large range of deformed nuclei. In the present work, we have used two density-dependent meson-exchange relativistic energy functionals DD-ME1 [5], and DD-ME2 [2] and two very successful density-dependent point-coupling interaction DD-PC1 [6], and DD-PCX [7].

Results and Discussion

In Fig. 1 we display the potential energy curves for even-even Hg nuclei from A = 160 to A = 264 using CDFT with density-dependent effective interactions DD-ME1, DD-ME2, DD-PC1, and DD-PCX. The ground states nears of ^{162}Hg, ^{206}Hg, and ^{264}Hg are found to be spherical, which indicates the magicity of N = 82, N = 126, and N = 184. We observe a periodic shape transition from spherical to prolate then oblate again back to spherical between two consecutive neutron magicity. We also notice prolate and oblate shape coexistence in $^{178-190}$Hg, and $^{238-252}$Hg nuclei.

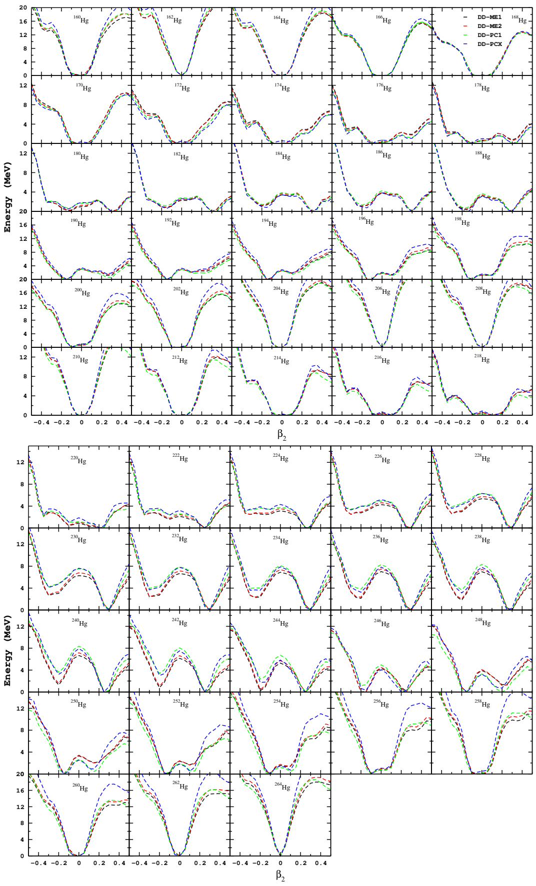

FIG. 1: The potential energy curves for even-even $^{160-218}$Hg (top), and $^{220-264}$Hg (bottom) as a function of the axial quadrupole deformation parameter β_2.

The binding energies per nucleon (BE/A) of ground states for mercury isotopes, $^{160-270}$Hg, are presented in Fig. 2 as a function of the neutron number N. The available experimental data [8] as well as the predictions of the RMF(NL3) [9], FRDM [10], and HFB(SKP, and SLy4) [11] theories are also shown for comparison. The Fig.2 clearly shows that the theoretical predictions accurately reflect the experimental data and that all curves have similar qualitative characteristics.

As one can see from Fig. 3, s_{2n} gradually decreases with N, and there are sharp drops at N = 82, 126, and 184 in both experimental and theoretical curves, which corresponds to the closed shell at this magic neutron number. The s_{2n} goes negative

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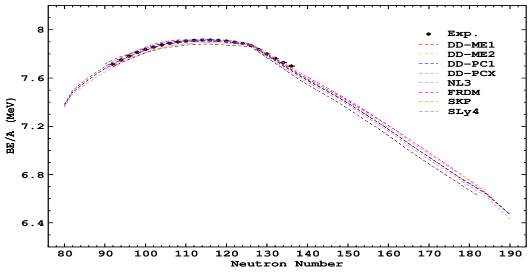

FIG. 2: The binding energies per nucleon for even-even Hg isotopes.

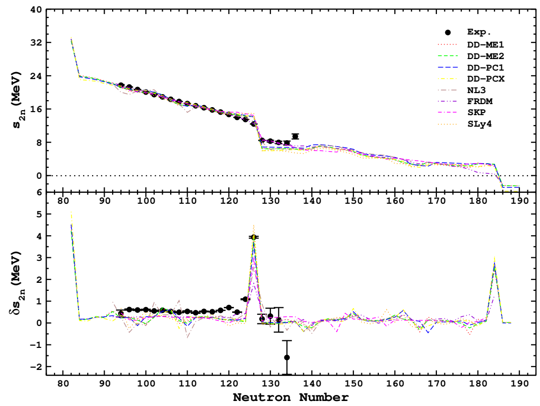

FIG. 3: The two-neutron separation energies, s_{2n}, (top panel) and two-neutron shell gap, δ_{2n}, (bottom panel) for Hg isotopes.

after N = 184 indicating N = 184 as the neutron dripline for Hg. A more accurate observable for detecting the shell closure is the two-neutron shell gap $\delta_{2n} = [s_{2n}(N,Z) - s_{2n}(N+2,Z)]/2$. δ_{2n} is also shown in Fig. 3 as a function of the neutron number N. The high spiking in the two-neutron shell gap

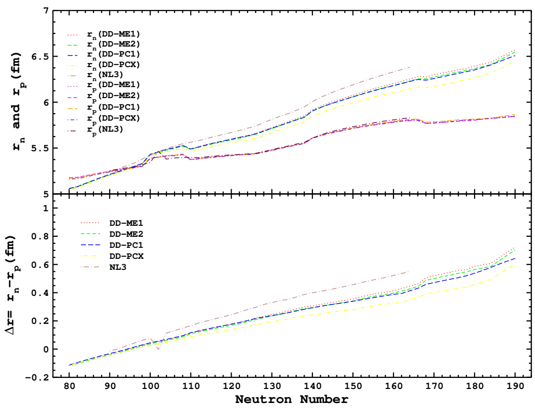

FIG. 4: The neutron and proton radii of Hg isotopes (top panel) and the neutron skin thicknesses ($\Delta r = r_n$ r_p)(bottom panel).

(δ_{2n}) clearly seen at N = 82, 126, and 184 further confirms the shell closure at these neutron magic number.

The computed neutron and proton radii, r_n and r_p, of Hg isotopes are shown in Fig. 4. The neutron rms radii produced by employing the density-dependent effective interactions DD-ME1, DD-ME2, DD-PC1, and DD-PCX are nearly identical across the isotope chain, but the NL3 findings are exaggerated, as seen in the top panel of Fig. 4. The lacking density-dependence in in the iso-vector channel of NL3 is the source of this difference. All of the formalisms, CDFT(DD-ME2, DD-ME2, DD-PC1, and DD-PCX), and RMF(NL3), provide very identical proton rms radii. We can also see in Fig. 4 that increasing the neutron number raises the difference between the rms radii of neutrons and protons ($\Delta r = r_n - r_p$) in favor of building a neutron skin.

Conclusion

We used CDFT with density dependent effective interactions DD-ME1, DD-ME2, DD-PC1, and DD-PCX to investigate the ground state characteristics and shape evolution of even-even Hg isotopes from the proton-rich side up to the neutron dripline. In the range of isotopes studied, we found a good number of shape phase transitions and shape coexistence. Our calculations accurately recreate the bulk ground state parameters and are in good agreement with the experimental results. At N = 82,126, and 184, a strong shell closure can be seen. Hg is projected to have a neutron dripline at N = 184.

Acknowledgments

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[11] see *http://www.fuw.edu.pl/dobaczew/thodri/thodri.html.*