Structure studies of nuclei using Self Consistent Mean Fields

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Introduction

Self Consistent Mean Field theory is one of the leading theories which helps in predicting and studying medium and heavy mass nuclei nowadays. The basis of all mean field theory is Hartree-Fock (HF). Pairing correlations are included with the help of BCS theory. HF+BCS theory is well suited for nuclei around the beta stability line but fails towards the drip-line due to their inability to account for the continuum effect there. A generalized version of HF+BCS theory is the Hartree-Fock-Bogoliubov (HFB) theory, in which mean field and pairing part are given equal status [1]. The advantage of HFB theory is that it can successfully describe the nuclei away from beta stability line. In mean field theories, instead of the bare interaction, zero range Skyrme or finite range Gogny effective interactions are used. Pairing correlations play an inevitable role in the case of open shell nuclei. Pairing interaction is included by density dependent delta interaction. The present thesis is devoted to the study of the structural properties of some transitional nuclei with the aid of HFB theory with zero-range Skyrme interaction. Nuclei in the region $A \sim 190$ is found to exhibit a structural change between prolate, oblate and spherical configuration. This made these nuclei an interesting topic of study. We have selected W, Os and Pt isotopes as the representatives of this region. Moreover, these nuclei are near to proton shell closure Z=82. We have studied various structural aspects of these nuclei along the isotopic chain within the framework of Skyrme HFB theory.

Thesis can be divided into three parts. In the first part, we analysed the shape transition of these isotopes using different Skyrme interactions. In the second part, we studied about their decay properties, i.e, alpha and cluster radioactivity. In the third part, we extended the calculation to their isotopes at nuclear drip-lines. Also, we studied the formation of neutron skin in these isotopes, which is a characteristic feature of drip-line nuclei.

Results and Discussion

Shape is one of the fundamental property of the atomic nuclei. Initial studies have been carried out by analysing the shape evolution of these nuclei around the neutron shell closure (N=126). We considered neutron-rich even-even nuclei having neutron number in the range N=110 to 138. Using various Skyrme forces, we analysed the Potential Energy Curves (PEC) by solving the axially symmetric HFB equation. It is observed to exhibit a shape transition from prolate to spherical via oblate configuration [2]. The prolate-oblate shape-phase transition is found to occur around the N=116-118 region. And finally, the isotopes become prolate beyond N=126. Prediction by various Skyrme forces follows a similar trend in almost all cases. As some signatures of triaxiality is found to exist in the region of prolate-oblate shape transition, we have extended our investigation to analyse the role of triaxiality among these nuclei. Triaxial calculations are carried out with UNEDF1 parametrization with the inclusion of Lipkin-Nogami prescription. Potential energy surfaces (PES) are calculated by imposing the constraints Q_{20} and Q_{22} and solving asymmetric HFB equation. We observed that these nuclei pass through a γ-soft region before attaining the spherical configuration.

The second part of the study has been de-

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voted to the decay properties of these nuclei. Because of the high binding energy of alpha particles, alpha radioactivity is one of the most prominent decay modes. We have also studied cluster decay, which is a rare cold nuclear phenomenon. Cluster radioactivity is a spontaneous process, which is intermediate between alpha decay and nuclear fission. This process is not accompanied by any neutron emission. We have analysed the sensitivity of different Skyrme parametrizations in predicting the half-lives of various decay modes. It is observed that, among the selected isotopes, those falling between the proton drip-line and beta stability line are unstable against various decay modes. We have predicted the emission of clusters like ^{8}Be, ^{12}C, ^{16}O, ^{20}Ne and ^{24}Mg from these nuclei. The emission of clusters along an isotopic chain depends on neutron number. i.e, as the neutron number increases, the rate of emission of cluster decreases. Also as the atomic number of the parent increases, we can expect the emission of the massive clusters. In the case of W isotopes, we predicted clusters like ^{8}Be, ^{12}C and ^{16}O [4]. But for Os [3, 5]and Pt [6] isotopes, the emission of ^{20}Ne and ^{24}Mg are predicted. The linear nature of the Geiger-Nuttel plot is also successfully reproduced in the case of all the selected Skyrme forces.

We have extended our investigation to isotopes far from beta stability line. As we move away from beta stability line neutron number increases and n-p interactions are not sufficiently enough to hold the excess neutrons inside the core. This leads to the spatial extension of neutrons around the proton distributions, which results in the formation of a layer of neutrons around the core. We tried to analyse the formation of this layer of neutrons, termed as neutron skin, in these nuclei. The skin thickness is characterised by the difference between neutron and proton rms radii. In the case of normal nuclei, this difference will usually be around 1-2 fm. If the value exceeds this limit, it is expected to form a thin layer of neutrons around the core. In addition to radii, we have analysed the neutron and proton density distributions of these isotopes. By observing the tail of the density distribution, we can identify whether a layer of neutron skin has been formed around the core. It is observed that the distance between the tail of neutron and proton densities increases as we move towards 2n-drip-line, which shows a clear indication of the formation of neutron skin. Our calculations have shown the formation of neutron skin around W, Os [7] and Pt nuclei. We have also predicted N=184 as the magic neutron number next to N=126 based on the 2n-separation energy.

In summary, we have studied the various structural properties of transitional nuclei like W, Os and Pt with the help of Skyrme HFB theory. Sensitivity of various Skyrme forces in predicting the shape evolution, decay properties of the nuclei like alpha and cluster radioactivity and the evolution of neutron skin along the 2n-drip-line have been analysed. All the Skyrme forces follow the same trend in predicting the various properties. It is observed that some properties dominate at neutron deficient region, some at neutron rich region and while some others are prominent near the beta-stability line.

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