Study of ground state properties of Germanium isotopes using Skyrme-Hartree-Fock-Bogoliubov approach

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Introduction

Exotic nuclei, which exist near the nuclear drip line, play a vital role in nuclear physics as they provide valuable insights into nuclear structure. The development of theoretical and computational methods has enhanced the study on exotic nuclei [1]. The nuclei approaching the dripline become increasingly unstable, resulting in low binding and neutron separation energy. Mean field approximation is a technique used to simplify the complex interactions or many body interactions between nucleons by taking an average field experienced by all other nucleons. Self-consistent mean field theory plays a crucial role in the understanding of medium and heavy mass nuclei [2].

In this work, we studied the ground state properties of Germanium isotopes (Z=32) with mass number ranging from 58 to 92. Skyrme Hartree-Fock Bogoliubov calculations were done for all odd and even isotopes of Ge by using the Skyrme function SLY4. The calculated values of binding energy per nucleon, one- and two-neutron separation energies are then compared with the available experimental data from mass table [3].

Formalism

The nuclear shell model suggests that there exist a number of energy states which allows the nucleons to move independently inside the nucleus. Here each particle is assumed to move in an average potential created by all other particles and this average potential is called mean field. In mean field approximation, many-body interaction is replaced with an effective one-body interaction. A single particle wave function is considered as a trial wave function and it is treated with Hamiltonian operator to obtain an eigen value of energy. Using variational principle we solve the Slater determinant, which is an antisymmetric product of trial wave function or single particle wave function, and minimize the total energy of the system to formulate Hartree-Fock equation. The resulting equation includes a density dependent self-consistent field along with kinetic energy term, which can be solved iteratively.

Hartree-Fock-Bogoliubov (HFB) theory is a combination of Hartree-Fock theory which falls under mean-field approximation and Bogoliubov transformation to incorporate mean field and pairing correlation. This theory describes the system in terms of quasiparticles, which is a combination of particle and hole state. The HFB equation is given by:

$$\begin{pmatrix} h & \Delta \\ -\Delta^* & -h^* \end{pmatrix} \begin{pmatrix} U_k \\ \nu_k \end{pmatrix} = \begin{pmatrix} U_k \\ \nu_k \end{pmatrix} \cdot E_k \qquad (1)$$

The analysis is conducted using the code HFBTHO v2.00d. This solves the nuclear Skyrme-Hartree-Fock (HF) or Skyrme-Hartree-Fock-Bogoliubov (HFB) problem using the cylindrical transformed deformed harmonic oscillator basis [1].

The pairing interaction is given by:

$$V_{\mathrm{pairing}}^{(n,p)}(r) = V_0^{(n,p)} \left(1 - \alpha \frac{\rho(r)}{\rho_n}\right) \delta(r - r') \qquad (2)$$

The mixed surface-volume pairing force is set to be 0.5 and quasi particle energy cutoff is taken as 60 MeV. The principle number of shells N was chosen to be 20 and oscillator length was taken as 2.2 fm. The pairing strength of neutron and protons was set to 300 MeV. Quasiparticle states were blocked in order to calculate odd isotopes.

Results and discussion

In the present work, the ground state binding energy per nucleon of Ge isotopes ranging from A = 58 to 92 are calculated. The results obtained are then compared with the available experimental data and plotted as in Fig 1. The calculated BE/A values are in good agreement with the experimental values. At A = 72 binding energy is at its peak because of the completely filled neutron subshell $2p^{1/2}$.

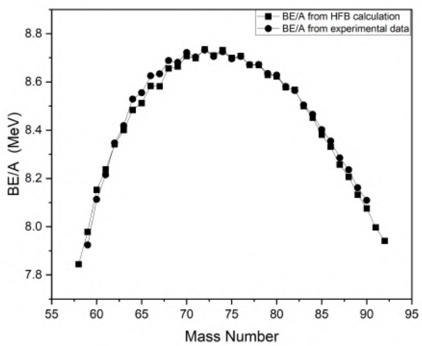

Fig. 1 Binding energy per nucleon curve for Ge isotopes

One-neutron and two-neutron separation energy are also calculated.
The one-neutron separation energy is given by:

$$S_n = BE(Z, N) - BE(Z, N-1) \quad (3)$$

The two-neutron separation energy is given by:

$$S_{2n} = BE(Z, N) - BE(Z, N-2) \quad (4)$$

The obtained results are compared with experimental data and are plotted in figure 2 and 3 respectively. From the graph we can see that, separation energy decreases as the neutron number increase, i.e., as the neutrons approach the dripline they become less tightly bound to the nucleus.

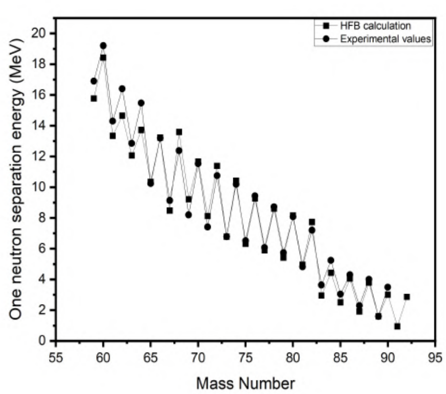

Fig. 2 One-neutron separation energy plotted against mass number

From Fig 2 it is evident that theoretically calculated one-neutron separation energy is in good agreement with the experimental value. Also odd even staggering, i.e., the even numbered neutrons more stable than odd numbered neutrons, is well reflected.

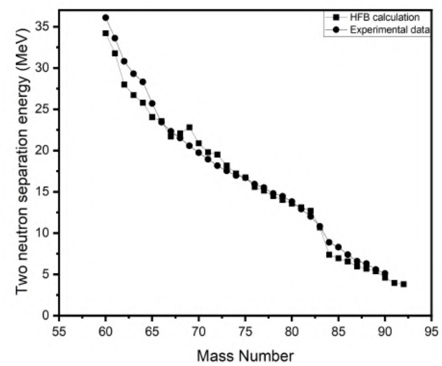

Fig. 3 Two-neutron separation energy plotted against mass number

The plot for two-neutron separation energy (Fig 3) clearly depicts that the theoretically calculated values are well aligned with the experimental data.

References

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