Nuclear structure properties of Os isotopes

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Introduction

Self Consistent Mean Field (SCMF) models describe the nuclear structure properties using different effective interactions [1]. These methods are closely related to the Energy Density Functional (EDF) theory in electronic systems. The Hartree-Fock-Bogoliubov (HFB) theory is essentially a self consistent framework unifying the Hartree-Fock (HF) theory that describes the nuclear mean field and the Bardeen-Cooper-Schrieffer (BCS) theory that explains nuclear pairing correlations [2]. In this work, we studied the nuclear structure properties of Os isotopes using the code HFBTHO v2.00d that solves the Skyrme HFB equations in the deformed harmonic oscillator basis [3].

Theoretical Framework

The Hamiltonian of a system of fermions can be written in second quantized notation as

$$H = \sum_{mn} e_{mn} a_m^\dagger a_n + \frac{1}{4} \sum_{mnpq} \bar{v}_{mnpq} a_m^\dagger a_n^\dagger a_p a_q \tag{1}$$

where $a^\dagger$ and a are the particle creation and annihilation operators respectively and $\bar{v}_{mnpq} = \langle mn|V|pq - qp\rangle$ are the anti-symmetrized two-body interaction matrix elements [4].

The HFB approach is based on the linear Bogoliubov transformation that mixes the creation and annihilation operators to define the quasiparticle creation and annihilation operators in the form

$$\begin{pmatrix} \eta^\dagger \\ \eta \end{pmatrix} = \begin{pmatrix} U^T & V^T \\ V^* & U^* \end{pmatrix} \begin{pmatrix} a^\dagger \\ a \end{pmatrix} \tag{2}$$

U and V are the coefficients that transform the single-particle states (n) into quasiparticle states (μ).

The state of the system is specified by two operators - the one-particle density matrix ρ and the pairing density matrix κ that describes the Cooper pairing effect.

$$\begin{aligned} \rho_{mn} &= \langle\phi|a_n^\dagger a_m|\phi\rangle = \sum_\mu V_{n\mu} V_{m\mu}^* \\ \kappa_{mn} &= \langle\phi|a_m a_n|\phi\rangle = \sum_\mu U_{m\mu} V_{n\mu}^* \end{aligned} \tag{3}$$

Variation of the expectation value of Hamiltonian in eq. (1) with respect to ρ and κ gives the HFB equations [4]:

$$\begin{pmatrix} e + \Gamma - \lambda & \Delta \\ -\Delta^* & -(e + \Gamma)^* + \lambda \end{pmatrix} \begin{pmatrix} U \\ V \end{pmatrix} = E \begin{pmatrix} U \\ V \end{pmatrix} \tag{4}$$

where

$$\Gamma_{ij} = \sum_{kl} \bar{v}_{ikjl} \rho_{lk} \quad \text{and} \quad \Delta_{ij} = \frac{1}{2} \sum_{kl} \bar{v}_{ijkl} \kappa_{lk} \,. \tag{5}$$

The finite temperature HFB equations has a similar form except for the density matrices that now depend on the Fermi - Dirac occupation factor f_μ [3].

$$\begin{aligned} \rho &= U f U^T + V(1 - f) V^T \\ \kappa &= U f V^T + V(1 - f) U^T \end{aligned} \tag{6}$$

Results

We employ two Skyrme parameter sets SLY4 and UNE0 for our calculation of the ground and excited state properties of the Os isotopes. The binding energy per nucleon obtained at different temperatures 0 MeV, 2 MeV and 4 MeV are shown in figure 1 along with the experimental results. The theoretical results obtained with both parameter sets

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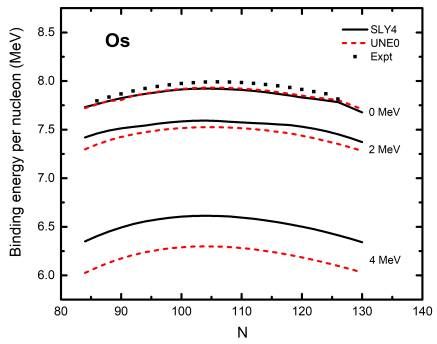

FIG. 1: The binding energy per nucleon calculated at different temperatures for the even-even isotopic chain $^{160-206}$Os as a function of neutron number along with the experimental values are presented [5].

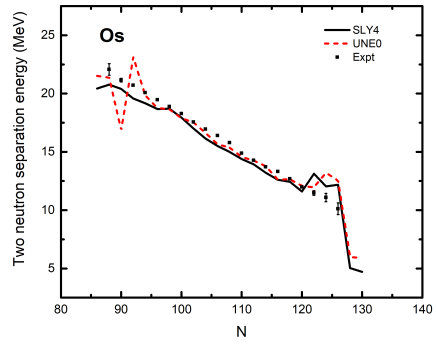

FIG. 2: Two neutron separation energies calculated for the even-even isotopic chain $^{160-206}$Os as a function of neutron number along with the experimental values are presented [5].

show a fair agreement with the experimental results obtained at $T = 0$ MeV. The discrepancy between the theoretical results obtained with two parameter sets SLY4 and UNE0 increases with temperature.

We have also calculated the two neutron separation energy of Os isotopes. It is the energy required to separate two neutrons from the nucleus. The two neutron separation energy of different Os isotopes obtained with the parameter sets SLY4 and UNE0 are presented in figure 2. They are found to be in good agreement with the experimental results.

We have also calculated the charge radii, proton and neutron radii, the neutron skin thickness and quadrupole deformation of different Os isotopes within this framework.

Conclusion

We have calculated nuclear structure properties of the Os isotopic chain in the self-consistent framework of the Skyrme-Hartree-Fock-Bogoliubov theory. These calculations provide the results with reasonable accuracy for nuclei close to the driplines and can effectively study exotic nuclei.

References

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