Ground state properties of Dy even-even Isotopes under HFB approach

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Introduction

Stable rare-earth nuclei are very well known for their large deformation in their ground states. The rare-earth neutron-rich nuclei remains a region of the nuclear chart which has been seldom studied. A recent article by Rodríguez et. al.[1] have explored the the emergence and stability of (static) octupole deformation effects in Dy isotopes from dripline to dripline ($72 \leq N \leq 142$). This encouraged us to study the ground state properties i.e binding energy, quadrupole deformation, hexadecapole deformation and nuclear charge radius of Dysprosium even-even isotopes. In this work our aim is to study the ground state properties and low lying states of Dysprosium (Dy) isotopes, in the region $82 < N < 126$, using the Hartree-Fock-Bogoliubov approach with Skyrme energy functional SLY6 for stable nuclei as well as neutron-rich nuclei far away from the stability line.

Calculation

Normal Bardeen-Cooper-Schrieffer(BCS) pairing is suitable for study of the ground state of nuclei near the valley of stability but it is not suitable for nuclei far away from stability line. The Hartree-Fock-Bogoliubov (HFB) approach is well known to be suitable for the study of nuclei near dripline where data are scarce. Therefore, Hartree-Fock-Bogoliubov (HFB) approach is suitable for our calculation. The calculation has been done using the publicly available code HFODD (ver 2.49T) by Schunck et. al. This code solves the HFB equations in a three dimensional deformed cartesian harmonic oscillator basis.

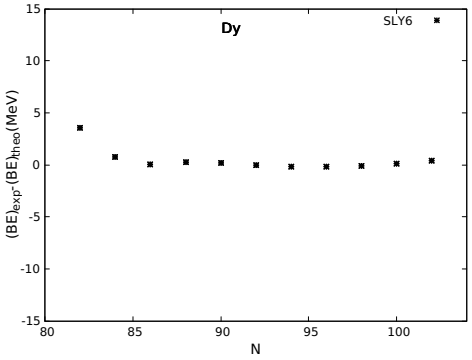

FIG. 1: Difference between theoretical and experimental binding energy values.

We do not expect that the pairing strength will be constant throughout the large range of neutron numbers. Therefore, we have used following formula for the neutron and proton pairing strengths (in MeV) which we have obtained by comparing our results for the binding energy and quadrupole deformation values with experimental measurements.

$$V_P = V_N = 182.6 + 3.08 * (N - 82) \qquad (1)$$

Results

Binding Energy

We have calculated the binding energy and deformation of even-even Dy isotopes and compared with experimental values wherever available. From FIG. 1 It is seen that binding energy difference between theory and experimental is less than 1 MeV except in the case for N=82. Our results are in good agreement with experimental results.

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Potential Energy Surface (PES) and Quadrupole Deformation

The quadrupole deformation is also an important property in nuclear physics which gives information about the shape of the nucleus. In FIG. 2 we have plotted the potential energy surface as a function of quadrupole deformation β_2 for some representative nuclei. We have not obtained any prolate to oblate transformation. All the isotopes are reasonably prolate. We obtained zero deformation for Magic nuclei of N=82,126. The quadrupole deformations are given in TABLE-II. Experimental values are from the NNDC website. We have also calculated hexadecapole moments for the ground state solutions. Calculated hexadecapole deformation starts from a small positive value, first increases and then decreases to become negative at N=112 as shown in TABLE-I.

TABLE I: Hexadecapole deformation of Dy isotopes.

N	β_4	N	β_4	N	β_4	N	β_4
84	0.006	92	0.109	100	0.080	108	0.019
86	0.070	94	0.106	102	0.063	110	0.011
88	0.074	96	0.102	104	0.048	112	-0.000
90	0.089	98	0.092	106	0.032	114	-0.002

Charge Radius

One other important property of the ground state that has been measured is the charge radius. The charge radii (r_{ch}), in fm have been obtained from the root mean square point proton radius (r_p) using the formula

$$r_{ch} = \sqrt{r_p^2 + 0.64} \qquad (2)$$

In TABLE II, we have shown our results for the charge radius of Dysprosium (Dy) isotopes and compared with experimental measurements. Experimental values are from the compilation by Angeli[2].

Energy Ratio

A number of Dysprosium isotopes near N=100 have deformation values $\beta_2 \geq 0.3$. They are expected to be very good rotors. For a purely rotational excitation, collective model predicts the ratio $R_{42} = E(4^+)/E(2^+)$ to be 3.33. We have calculated it and from TABLE III one can see that a number of nuclei come very close to this limit.

TABLE II: Quadrupole deformation and charge radius of Dy isotopes.

Isotopes	β_2(Exp)	β_2(Th)	r_c(Exp)	r_c(Th)
154	0.235	0.213	5.127	5.115
156	0.294	0.269	5.163	5.155
158	0.327	0.301	5.181	5.185
160	0.336	0.310	5.193	5.204
162	0.341	0.320	5.206	5.225
164	0.349	0.324	5.220	5.241
166	-	0.323	-	5.256

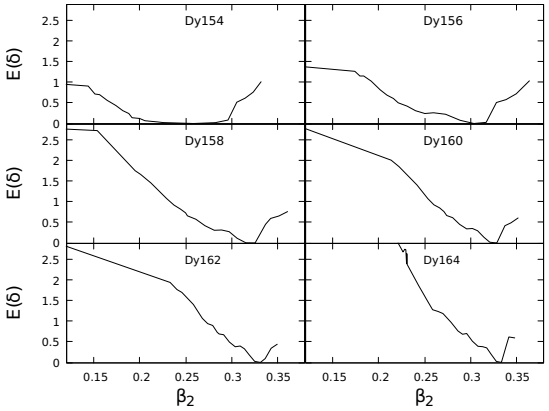

FIG. 2: Potential energy surface of some selected Dy nuclei.

TABLE III: Rotational energy levels in strongly deformed Dy isotopes.

Isotopes	$2^+(^a)$	$4^+(^a)$	R_{42}	$2^+(^b)$	$4^+(^b)$
160	86.78	283.820	3.270	95.7	308.4
162	80.661	265.664	3.293	64.6	252.0
164	73.393	242.234	3.300	73.4	283.6
166	76.587	253.527	3.310	126.8	471.0

[a]Experimetal Energy values in (keV)
[b]Theoretical Energy Values in (keV)

Acknowledgments

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References

[1] R. Rodríguez-Guzmán et.al. Phys. Rev.C **108**, 024301 (2023).

[2] I. Angeli Atom. Data Nucl. Data Tables **87**, 185-260 (2004).