# A theoretical study of the nuclear structure in the even–even Yb isotopes

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## Motivation

The medium–to–heavy mass Ytterbium (Yb, $Z$=70) isotopes located in the rare–earth mass region are well–deformed nuclei that can be populated to very high spin. Spectroscopic information becomes scarcer as the neutron number increases impeding the understanding of nuclear structure in this mass region, where interesting phenomena, such as shape coexistence, have been predicted.

In this work, energy levels, $\beta_2$, B(E2) and transition quadrupole moments $Q_2$ for even–even Yb isotopes with $94 \leq N \leq 108$ have been calculated using different theoretical models. The results are compared to available experimental data [1] and can serve as guide for future experimental studies in the neutron–rich Yb isotopes.

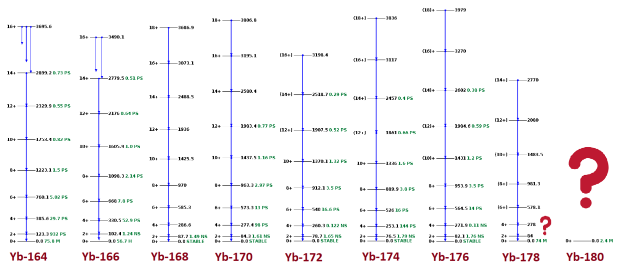


Figure 1: Experimental energy levels and lifetimes for the g.s. bands of $^{164-178}$Yb [2].

## Theoretical Models

The following models have been employed in this study:

- Rotational Model (**ROT**)
- Phenomenological Model (**PhM**) [3]
- Finite–Range Droplet Model (**FRDM**) [4]
- Hartree–Fock BCS Model (**HFBCS**) [5]

## Energy Levels - PhM

The rotating-core energy: $$E_{rot}(I) = \frac{1}{2}\, j_0\, \omega^2_{rot}(I) + \frac{3}{4}\, j_1\, \omega^4_{rot}(I) \qquad (1)$$

where $j_0$ and $j_1$ are the inertial parameters of the rotational core. The rotational frequency of the core $\omega_{rot}(I)$ is found by solving the equation (1) where $\tilde{I} = \sqrt{I(I+1)}$.

$$\omega_{rot} = \left[\frac{\tilde{I}}{2j_1} + [(\frac{j_0}{3j_1})^3 + (\frac{\tilde{I}}{2j_1})^2]^{1/2}\right]^{1/3} + \left[\frac{\tilde{I}}{2j_1} - [(\frac{j_0}{3j_1})^3 + (\frac{\tilde{I}}{2j_1})^2]^{1/2}\right]^{1/3} \qquad (2)$$

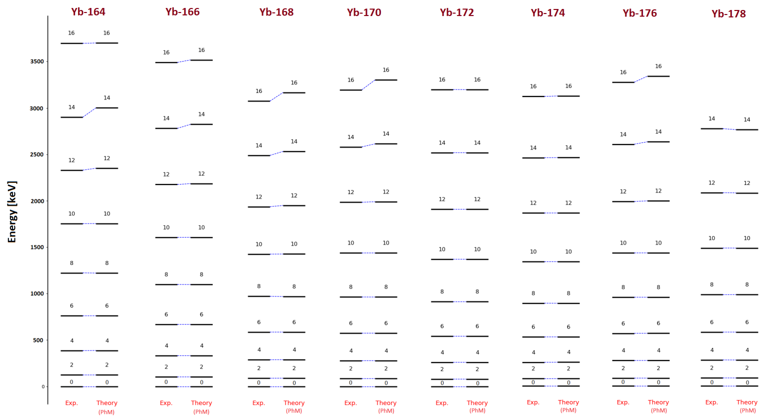


Figure 2: PhM [3] energy levels after fitting the experimental data (Exp) [1].

## Results

| Yb A | $\beta_{2\,(ROT)}$ | $\beta_{2\,PhM}$ | $\beta_{2\,FRDM}$ | $\beta_{2\,HFBCS}$ | $B(E2)_{exp}$ | $B(E2)_{(ROT)}$ | $B(E2)_{PhM}$ | $B(E2)_{FRDM}$ | $B(E2)_{HFBCS}$ | $Q_{(ROT)}$ | $Q_{PhM}$ | $Q_{FRDM}$ | $Q_{HFBCS}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Deformation Parameter $\beta_2$ | | | | Transition Probability B(E2) ($e^2b^2$) | | | | | Quadrupole Moment (b) | | | |
| 164 | 0.289 | 0.289 | 0.262 | 0.270 | 4.330 | 4.356 | 4.351 | 3.568 | 3.790 | 1.891 | 1.890 | 1.711 | 1.764 |
| 166 | 0.315 | 0.315 | 0.274 | 0.280 | 5.200 | 5.241 | 5.230 | 3.966 | 4.142 | 2.074 | 2.072 | 1.804 | 1.844 |
| 168 | 0.328 | 0.322 | 0.286 | 0.280 | 5.750 | 5.792 | 5.574 | 4.391 | 4.209 | 2.180 | 2.139 | 1.898 | 1.858 |
| 170 | 0.325 | 0.325 | 0.287 | 0.280 | 5.721 | 5.768 | 5.743 | 4.492 | 4.276 | 2.176 | 2.171 | 1.920 | 1.873 |
| 172 | 0.333 | 0.333 | 0.300 | 0.320 | 6.090 | 6.134 | 6.152 | 4.985 | 5.672 | 2.244 | 2.247 | 2.023 | 2.158 |
| 174 | 0.324 | 0.322 | 0.289 | 0.310 | 5.850 | 5.898 | 5.828 | 4.698 | 5.406 | 2.200 | 2.187 | 1.964 | 2.106 |
| 176 | 0.302 | 0.300 | 0.289 | 0.290 | 5.189 | 5.225 | 5.157 | 4.770 | 4.803 | 2.071 | 2.057 | 1.979 | 1.985 |
| 178 | 0.299 | 0.302 | 0.278 | 0.280 | - | 5.179 | 5.301 | 4.481 | 4.546 | 2.062 | 2.086 | 1.918 | 1.931 |
| 180 | 0.273 | - | 0.278 | 0.260 | - | 4.379 | - | 4.548 | 3.979 | 1.896 | - | 1.932 | 1.807 |

Table 1: Experimental $B(E2)s$ taken from [1], (ROT) values extracted from experimental energies and lifetimes [1] and extrapolated lifetimes (fig. 3) through equations [1], (PhM) values obtained from theoretical energies (eq. 1), (FRDM) and (HFBCS) values calculated from $\beta_2$ [4,5].

**FRDM**: $\beta_2$ parameters extracted from the radius vector in $\varepsilon$ parameterization via

$$\beta_2 = \sqrt{4\pi}\, \frac{\int r(\theta,\phi)\; Y^0_2(\theta,\phi)\; d\Omega}{\int r(\theta,\phi)\; Y^0_0(\theta,\phi)\; d\Omega} \qquad (3)$$

**HFBCS**: Skyrme MSk7 used for this model and $\beta_2$ calculated from $Q_2, Q_4$.

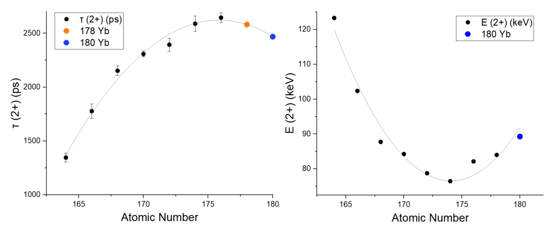


Figure 3: Extrapolated values of $\tau(2^+_1)$ and $E(2^+_1)$ for $^{178,180}$Yb

## Conclusion & Future Directions

An overall good agreement was found between experimental results [1] and theoretical predictions. The latter can prove useful in an upcoming experiment to study the structure of the neutron–rich $^{178}$Yb at IFIN–HH using the fast–timing technique. In addition, calculations with the IBM [6] and the proxy–SU(3) [7] models are in progress.

## Acknowledgments

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