Anharmonicity in the non-rotational region of rare earths

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For the non-deformed nuclei (2.05< $R_{4/2}$ <3.0), a plot of $E(4_1)$ versus $E(2_1)$ yields a linear relation with a slope of 2.0 [1]. For the varying energy E_2, the intercept ε_4 is constant (Fig. 1). This can be expressed as

$$E_4 = 2 E_2 + \varepsilon_4, \qquad (1)$$

A constant ε_4 was ascribed to a constant anharmonicity. In terms of the anharmonic model expression [2]

$$E_I = a I + bI(I-2) \qquad (2)$$

ε_4 is 8b. In the absence of a cubic term, denoting rotation vibration interaction, 'a' and 'b' stay constant for all I in a given nucleus. Also, $\varepsilon_4=E_{\gamma(2)}-E_{\gamma(1)}=\Delta E_\gamma$, which is related to dynamic moment of inertia $J^{(2)}=4/\Delta E_\gamma$ according to rotation model. So ε_4 is inverse dynamic moment of inertia in RM. We study constancy of ε_4 (or b or $J^{(2)}$) with E_2. Rewrite Eq. 1 as

$$R_4 = 2.0 + \varepsilon_4/E(2_1). \qquad (3)$$

a) If one assumes a constant ε_4 =160 keV, for E_2= 160 keV, E_4 would be 320+160 =480, so that Eq. (2) yields $R_{4/2}$ =3.0.
b) For E_2=800 keV, it yields $R_{4/2}$= 2.2.

Thus a constant value of residual energy ε_4 is in principle possible for the whole region of E_2=160-800 keV. The variation of $R_{4/2}$ and E_4 is absorbed in E_2. A varying $R_{4/2}$ can yield constant ε_4. But the arithmetic for the deformed region is different [1, 2]. At E_2 =70 keV, $R_{4/2}$ =10/3 and ε_4 should be about 90 keV only. Just below the deformed region, defined by $R_{4/2}$>3.0 and E_2=120-130 keV, ε_4 would be 120-130 keV. This sets the lower limit on the deformed side, ε_4 varying 90-130 keV.

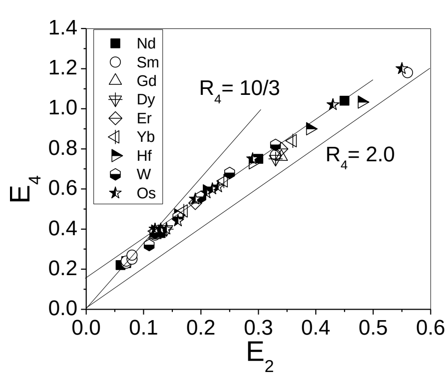

Fig. 1. Plot of E_4 versus E_2. Lines from the origin have slope of 2 and 10/3.

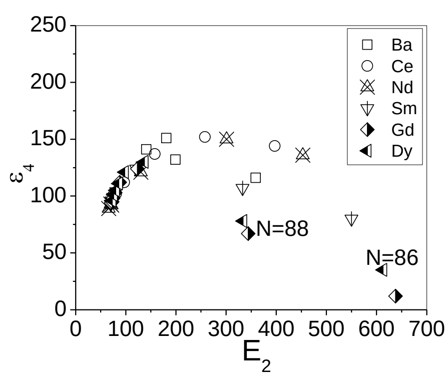

Fig. 2. Plot of residual energy ε_4 for Q-I.

Real nuclei

A mean value of ε_4=(160 ± 50) keV is indicated for the whole range of E_2 from about 120-700 keV. For a search of the systematics of ε_4 we study the data quadrant wise. In Quad-1 (N<104, Z=54-66) (Fig. 2), for N=86 (E_2~600 keV) data of Sm, Gd and Dy, the value of.ε_4 is very low, off the general trend on the right. In the middle, also N= 88 data of Z=62, 64, 66 (E_2=300 keV) lie off downwards. Next, on the deformed side (on the left) also ε_4 falls below 125, reflecting saturation effect. Excluding these data, others lie at about 125-150 keV In Quadrant-II (N<104, Dy-Pt)(Fig. 3) again ε_4 is below 125 keV on deformed side, (E_2 <150 keV). Next Pt data on left are also off, (E_2 <250 keV). Six data on right, of Dy, Er, Yb, Hf also lie low below 100 keV (non-collective effect). Data on smooth curve lie at 140 to 175 keV

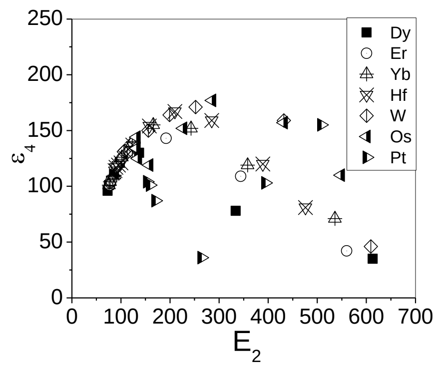

Fig. 3. Plot of residual energy ε_4 Quad. II.

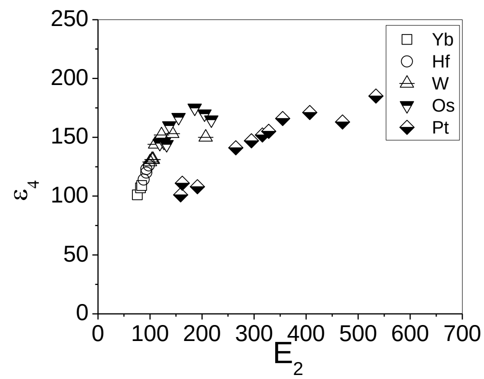

Fig. 4. Plot of residual energy ε_4 Quad. III.

In Quadrant-III (N>104,Yb-Pt)(Fig. 4), excluding data of deformed nuclei (E_2<130 keV), and 3 other points, ε_4 lies at 125-175 keV. This study illustrates how the residual energy varies with N, Z quadrant wise

Discussion

A constant gradient=$\Delta E_4/\Delta E_2$ holds good approximately for non-deformed region, in spite of the varying structure. But in Eq. (1), a constant intercept has differing effect on nuclei of different E_2. The Eq. (1) also holds good for higher spin I, with slope of (I/2), which implies the application of phonon rule in the spectrum of all non-deformed nuclei, before the phase transition, from anharmonic to deformed, at X(5) symmetry point [4]. The differing range of ε_4 in different quadrants arises on account of the fact that for same E_2 energy, E_4 is different, reflecting the different underlying microscopic structure.

The anharmonicity represents either a symmetric change in the width of a harmonic oscillator potential well due to the quadratic term, or the asymmetry of the well due to the cubic term. This is not constant with varying R_4. Moreover, the split in the 2 phonon triplet states varies continuously. Other attributes of structure vary with E_2. *It highlights the fact that the near constancy of ε_4 is related to the rotational invariance of the angular moment projected states in the ground sate band from an intrinsic state, and not to the vibrational states*.

Reference

[1] R. F. Casten et al, Phys. Rev. Lett. **71**, 227 (1993).
[2] T.K. Das et al. Phys. Rec. C2, 632 (1970)
[3] R. V. Jolos et al., Phys. Rev. C**54**, R2146 (1994).
[4] F. Iachello, Phys. Rev. Lett. 87, 2502 (2001).