Quest for Research Excellence On Computing, Mathematics and Statistics

Editors
Kor Liew Kee
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Faculty of Computer and Mathematical Sciences

iCMS 2015

Quest for Research Excellence on Computing, Mathematics and Statistics

Chapters in Book

The 2nd International Conference on Computing, Mathematics and Statistics (iCMS2015)

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The 2nd International Conference on Computing, Mathematics and Statistics
(iCMS2015)

4-5 November 2015
Langkawi Lagoon Resort
Langkawi Island, Kedah
Malaysia

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Publication by
Faculty of Computer & Mathematical Sciences
UiTM Kedah

ISBN 978-967-0314-26-6

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International Scientific Committee

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CHAPTER 14
Octupole Vibrations in Even–Even Isotopes of Dy

A.A. Okhunov, G.I. Turaeva, and M. Jahangir Alam

Abstract. The phenomenological model is used for the study of the characteristics of low – lying states of negative parity in Dy. The spectra of octupole bands and reduced probability of E1– transitions are discussed. Calculated level energies and B(E1) values are compared with experimental data. Within this phenomenological model firstly introduced for actinides, it is possible to obtain good results for rare earth region as well.

Keywords: Nuclei; isotopes; model; even –even; vibration; energy levels.

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1 Introduction

Odd collective oscillation with the least energy should carry octupole character $\left(\lambda = 3\right)$. In even - even nucleus one phonon excited states of this type has two phonon excited states have $I = 0^{+}, 2^{+}, 4^{+}$ and 6^{+}. Levels with one quadrupole and one octupole phonons have $I = 1^{-}, 2^{-}, \cdots, 5^{-}$.

The comparatively low-lying states 3^{-} was observed ^{152}Gd, $^{156,160}Dy$ and also in 164Er and apparently, can represent the oscillatory excited states with $\left(\lambda = 3\right)$. Such interpretation actuate to probability of Coulomb excitation of type *E3* considerably large, than one–partial probability. It is interesting that odd state roughly at the same energy were observed in the neighboring deformed nucleus; in such cases coupling between oscillations quadrupole and octupole deformations can actuate to low odd levels with $I = 1^{-}$.

In present work the phenomenological model [1] is used for the study of the characteristics of low–lying states of negative parity in isotopes Dy. The spectra energy of octupole band state is discussed. Calculations have carried out for the deformed nuclei of rare–earth area in isotopes Dy.

2 Model

The nuclear rotational components of Hamiltonian choose as

$$H = H_{\text{int}}\left(q, p\right) + H_{rot}\left(R^{2}\right) \tag{1}$$

where $H_{\text{int}}\left(q, p\right) = \sum_{K} \omega_{K} b_{K}^{+} b_{K}$ – is intrinsic part of Hamiltonian, b_{K}^{+} and b_{K} – are operators of phonon. The nuclear rotational energy described $H_{rot}\left(R^{2}\right)$ and its dependent from collective angular moment is

$$R^{2} = \left(I - j\right) \tag{2}$$

where I – total and j - intrinsic angular moments. wave function of the total Hamiltonian's (1) follow

$$\begin{aligned}\Psi\left(I, M\right) = \left[\frac{2I+1}{16\pi^{2}}\right]^{\frac{1}{2}} \sum_{K=0}^{3} \tilde{\Psi}_{\nu}^{I}\left(K\right)\Big\{D_{M,K}^{I}\left(\theta\right) \\ + \left(-1\right)^{I+K} D_{M,-K}^{I}\left(\theta\right) R_{y}\left(\pi\right)_{b-K}\Big\}\left|b_{K}^{+}\right|0\rangle\end{aligned} \tag{3}$$

where $\tilde{\Psi}^I_\nu(K)$ – the mixture states amplitude, $D^I_{M,K}(\theta)$ – Viegner's functions, R_y – toner operator to angle π around axis y, ν – number of bands including to the basis state of hamiltonian.

High spins approximations is used for the $H_{rot}(R^2)$ following

$$H(R) = H_{rot}(I(I+1)) - \omega_{rot}(I)\, j_x \tag{4}$$

where $\omega_{rot}(I)$ – rotational frequency of core, its described as

$$\omega_{rot}(I) = dE(I)/dI \tag{5}$$

where $I = \sqrt{I(I+1)}$, $E(I) = H_{rot}(I(I+1))$.

For the matrix elements $(j_x)^\sigma_{K,K'}$ between phonon states and its have following

$$(j_x)^\sigma_{K,K'} = (j_x)^\sigma_{K',K} = -\sqrt{\frac{(3-K)(3+K+1)}{1+\delta_{K,0}}}\left\{\frac{1+(-1)^{(I+1)\delta_{K,0}}}{2}\right\}\tau_K\,\delta_{K,K'-1} \tag{6}$$

where $\sigma = +1$– signature of state. From the symmetrical properties of wave function (3) we have $(-1)^I\sigma = 1$ parameters τ_K shows Coriolis mixture between phonon states. where under squat expression in (6) corresponded to the rotational spherical surface of phonon state with $\lambda = 3$.

Hamiltonian eq. 1 has following form

$$H - E_{rot}(I)\,\delta_{K,K'} + H^\sigma_{K,K'} \tag{7}$$

where

$$H^\sigma_{K,K'} = \omega_K\,\delta_{K,K'} - \omega_{rot}(I)(j_x)^\sigma_{K,K'} \tag{8}$$

We calculated energy E^σ_ν and wave functions $\tilde{\Psi}^I_\nu(K)$ of odd parity states, Diagnolized the matrix eq. (8). Total energy of states described following:

$$E^\sigma_\nu(I) = E_{core}(I) + E^\sigma_\nu(\omega_{rot}(I)) = E_{core}(I) - \omega_{rot}(I)\cdot\left\langle\Psi^\sigma_\nu(K)\middle|j_x\middle|\Psi^\sigma_\nu(K)\right\rangle$$
$$+\left\langle\Psi^\sigma_\nu(K)\middle|\sum_{K=-3}^{3}\omega_{|K|}b^+_K b_K\middle|\Psi^\sigma_\nu(K)\right\rangle \tag{9}$$

The first part of the formula (9) have function $E_{cor}\left(I\right)$ and as well as dependent from $\omega_{rot}\left(I\right)=dE_{cor}\left(I\right)/dI$ too. Formula (10) possible look like differential equation, which possible obtained $E_{cor}\left(I\right)$ if known E_{ν}^{σ} from the experiment. Differentia formula (9) by I, we will take next differential equation for the rotational core angular frequency $\omega_{\nu}^{\sigma}\left(I\right)$.

$$\frac{d\omega_{rot}\left(\tilde{I}\right)}{dI}=\frac{\omega_{rot}\left(\tilde{I}\right)-\omega_{eff}^{\nu}\left(\tilde{I}\right)}{\left(j\right)_{\nu}^{\sigma}} \qquad (10)$$

and

$$\omega_{eff}^{\nu}\left(\tilde{I}\right)=\frac{dE_{eff}^{\nu}\left(\tilde{I}\right)}{dI}=\frac{1}{2}\left\{E_{\nu}^{\exp}\left(I+1\right)-E_{\nu}^{\exp}\left(I-1\right)\right\}$$

and built angular moment is defined as

$$\left(j_{x}\right)_{\nu}^{\sigma}=-\frac{dE_{\nu}^{\sigma}\left(\omega_{rot}\left(\tilde{I}\right)\right)}{d\omega_{rot}\left(\tilde{I}\right)}=\left\langle\Psi_{\nu}^{\sigma}\left|\cap j_{x}\right|\Psi_{\nu}^{\sigma}\right\rangle=-2\left\{\sqrt{6}\,\tau_{0}\tilde{\Psi}_{\nu}^{\sigma}(0)\Psi_{\nu}^{\sigma}(1)\right.$$

$$\left.+\sqrt{\frac{5}{2}}\,\tau_{1}\tilde{\Psi}_{\nu}^{\sigma}(1)\Psi_{\nu}^{\sigma}(2)+\sqrt{\frac{3}{2}}\,\tau_{2}\tilde{\Psi}_{\nu}^{\sigma}(2)\Psi_{\nu}^{\sigma}(3)\right\} \qquad (11)$$

The correct choice of the initial condition for the $\omega_{rot}\left(\tilde{I}\right)$ corresponded solving equation (9) and (10) the same time with the same function $\omega_{rot}\left(\tilde{I}\right)$ and with function $E_{cor}\left(\tilde{I}\right)$, are equal

$$E_{cor}\left(\tilde{I}\right)=E_{0}-\int_{\tilde{I}_{0}}^{\tilde{I}}\omega_{ror}\left(\tilde{I}\right)d\tilde{I} \qquad (12)$$

For the several initial values of $\omega_{rot}\left(\tilde{I}\right)$ by at least value of $I\ \left(I_{0}=2\right)$ was calculated. We will search decision equation (10) with initial value of $\omega_{rot}\left(I_{0}\right)$, which are function $\Im_{cor}\left(\tilde{I}\right)=\tilde{I}/\omega_{rot}\left(\tilde{I}\right)$ is linear by $\omega_{rot}^{2}\left(\tilde{I}\right)$.

3 Electric Octupole Transitions

Reduced probability of $E1-$ transitions from the octupole state IK^{π} to the $\left(I\pm1\right)gr$ ground rotational band states [3] is

$$B\left(E1;IK^{\pi}\to\left(I\pm1\right)gr\right)=\left(2I+1\right)\Big[\tilde{\Psi}_{0}^{IK}\left\langle I010\,|\left(I\pm1\right)0\right\rangle\left(-m_{0}\sin\zeta_{0}\right)$$
$$+\tilde{\Psi}_{1}^{IK}\left\langle I1\left(1-1\right)|\left(I\pm1\right)0\right\rangle\left(-m_{0}\sin\zeta_{1}\right)\Big]^{2} \tag{13}$$

Using obvious expressions for the Clebsch – Gordan coefficient [4] possible write next ratio for (13):

$$R_{IK}^{phen}=\frac{B\left(E1;IK^{\pi}\to\left(I+1\right)gr\right)}{B\left(E1;IK^{\pi}\to\left(I-1\right)gr\right)}=\frac{\left|\tilde{\Psi}_{0}^{IK}\sqrt{I+1}-\tilde{\Psi}_{0}^{IK}\sqrt{I}\times Z\right|^{2}}{\left|\tilde{\Psi}_{0}^{IK}\sqrt{I}+\tilde{\Psi}_{0}^{IK}\sqrt{I+1}\times Z\right|^{2}} \tag{14}$$

where $Z=\dfrac{\sin\zeta_{1}}{\sin\zeta_{0}}$ and its have relation with easing coefficient of Coriolis interaction (6) following

$$\theta_{0}=\cos\zeta_{0}\cdot\cos\zeta_{1}+\frac{1}{6}\sin\zeta_{0}\cdot\sin\zeta_{1},\quad\theta_{1}=\cos\zeta_{1},\quad\theta_{2}=1 \tag{15}$$

Possible to calculate parameters of Z from the tacked value of θ_{i} by fitting the experimental data for the energies of negative states, which are appears equal to $Z_{E}=0.9666$ for ^{158}Dy within the model.

4 Numerical Results

The calculations are performed for Dy isotopes. For the octupole rotational band with $K^{\pi}=1^{-}$ has solved of differential equation (10). We have use the following procedure for the parameters of determination. Unperturbed excited energy of phonon state ω_{K} and attenuation coefficient of Coriolis interaction τ_{n}. They are determined chosen from the condition of the best reproduction of the negative parity states with the experimental data (See Table 1).

Table 1. The Parameters.

ω_K				η_n			$\Im_i$	
0^-	1^-	2^-	3^-	η_0	η_1	η_2	$\Im_0$	$\Im_1$
1.590	1.440	1.318	2.313	0.49	0.35	1.00	49.0	237.5

Table 2. Reduced probabilities of E1 – transitions in ^{158}Dy.

$I_i K_i^\pi$	$I_f K_f^\pi$	$R_{IK}^{\exp.}$	R_{IK}^{theory}
$1^- 0^-_I$	$0^+ 0^+_I$	4.587	1.045
$3^- 0^-_I$	$2^+ 0^+_I$	--	0.211
$1^- 1^-_I$	$0^+ 0^+_I$	1.052	1.003
$3^- 1^-_I$	$2^+ 0^+_I$	0.689	3.743
$3^- 2^-_I$	$2^+ 0^+_I$	0.537	1.910

5 Conclusion

In the paper we introduced a theoretical framework. For the understanding of properties of collective states, we use the phenomenological model. That results taking in this model give good agreement with the experimental data, then microscopic model. Though, utilized model described ratio R_{IK} is worse for the rare-earth regions, then in case antinodes (actinides). Its possible have link therewith that we take into account only lowest bands with $K^\pi = 0^-, 1^-, 2^-$ and 3^-, whereas in experimentally obtained several band with $K^\pi = 0^-, 1^-, 2^-$ and 3^-, in rare-earth region which its have very closer each other. With such case possible the Coriolis mixture is effected of the calculation results of ratio R_{IK}. Therefore to define exact describe of R_{IK} must be into account all common knowledge bands from the experiment on nuclear in rare-earth region.

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iCMS
2015

ISBN 978-967-0314-26-6