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SHEARS EFFECT WITH PAC CORE ROTATION FOR DIPOLE BANDS IN ^{142}Gd AND ^{130,132}La*

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Experimental B(M1) and B(E2) values as well as level energy structures of dipole bands in ^{142}Gd and ^{130,132}La are compared with calculations in the framework of SPAC (Shears mechanism with Principal Axis Cranking) model. All observed dipole bands in these nuclei can indeed be considered as magnetic rotational bands with different planar symmetries and remarkable contribution of collectivity.

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1. Introduction

The magnetic rotational bands result when the angular momentum vectors of the involved particles and holes $\vec{j_1}$ and $\vec{j_2}$ are initially oriented approximately perpendicular to each other. In the limiting case, when $\vec{j_1}$ is aligned along the symmetry (z) axis and $\vec{j_2}$ along the rotation (x) axis, considered in the framework of the principal axis cranking (PAC) coupling scheme, the angular momentum vector $\vec{R}$ of the collective rotation is parallel to the x-axis. In the case when the total spin is produced solely by the shears effect (the angular momentum of the band is increased by the gradual alignment of the individual nucleon spins along the total angular momentum vector) and the collective rotation is absent, only the angle between the angular momentum vectors $\vec{j_1}$ and $\vec{j_2}$ is considered and a semiclassical description is possible. Subsequently, collective rotation has been added to this model in the framework of a core rotation coupling scheme, when the vectors $\vec{R}$ and $\vec{I} = \vec{j_1} + \vec{j_2}$ are parallel to each other, corresponding to the tilted axis crancing (TAC) model [1]. In the case of triaxial nuclei not planar mutual orientation of $\vec{j_1}$, $\vec{j_2}$ and $\vec{R}$ is possible and, due to a chiral symmetry braking, chiral band pairs with close energy structures and reduce transition probabilities should be observed. But, as turned out to be, in many cases

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B(E2) and B(M1) extracted from lifetime measurements contradict to the known theoretical predictions. In particular it related to dipole bands in ^{141}Eu [2], ^{142}Gd [3], and ^{132}La, which originally regarded as chiral candidate [4,5]. For the explanation of experimental data we have proposed the planar semiclassical approach, in which the shears mechanism is combined with PAC (SPAC model [2,3]). In case of ^{141}Eu, ^{142}Gd and ^{139}Sm [6] the SPAC model reproduces the experimental data very well. In the present work the SPAC model is applied for the interpretation of dipole band properties in ^{132}La as well as for new DSAM lifetime measurement results in ^{142}Gd [7] and ^{130}La [8].

2. The SPAC model

Similar to Ref. [1] the total energy contains collective and quasiparticle contributions:

$$\begin{aligned}
E(I,\theta_1,\theta_2) &= E_{\mathrm{coll}}(I,\theta_1,\theta_2) + E_{\mathrm{qp}}(I,\theta_1,\theta_2) \\
&= C(I)R^2(I,\theta_1,\theta_2) + V_2\frac{3\cos^2(\theta_2-\theta_1)-1}{2} + \mathrm{const.}\,, \\
C &= \frac{1}{2J(I)}; \qquad \vec{R} = \vec{I} - \vec{j}\,, \\
R(I,\theta_1,\theta_2) &= \sqrt{I^2 - (j_1\sin\theta_1 + j_2\sin\theta_2)^2} - j_1\cos\theta_1 - j_2\cos\theta_2\,,
\end{aligned}$$

where θ_1 and θ_2 are the angles between the x-axis and the vectors $\vec{j_1}$ and $\vec{j_2}$, respectively. The collectivity of the core $J(I)$ is assumed to be I dependent. For each I the angles θ_1 and θ_2 can be found from the minimization conditions:

$$\left(\frac{\partial E}{\partial\theta_1}\right)_I = 0\,, \qquad \left(\frac{\partial E}{\partial\theta_2}\right)_I = 0\,.$$

Subsequently, the total energy $E(I)$ and transition probabilities can be calculated as functions of I. Taking into account the classical approximation for Clebsch–Gordon coefficients the reduced M1 and E2 transition probabilities are

$$B(M1; I\rightarrow I-1) = \frac{3}{8\pi}\mu_\perp^2; \mu_\perp^2 = g_1^* j_1\sin(\theta_1-\theta_I) - g_2^* j_2\sin(\theta_I-\theta_2)\,,$$

where $g_1^* = g_1 - g_{\mathrm{R}}$, $g_2^* = g_2 - g_{\mathrm{R}}$, $g_{\mathrm{R}} = Z/A$ and

$$B(E2; I\rightarrow I-2) = \frac{15}{128\pi}\left[Q_{\mathrm{eff}}\sin^2\theta_{1j} + Q_{\mathrm{coll}}\cos^2\theta_I\right]^2\,,$$

where Q_{eff} and Q_{coll} are quasiparticle and collective quadrupole moments. Generally, any initial orientation of the angular momentum vectors $\vec{j_1}$ and $\vec{j_2}$ can be considered. Particularly, the two symmetric initial orientations of $\vec{j_2}$, resulting from a rotation by $\Re_z(\pi)$, can generate three different dipole bands. The corresponding alignment schemes can be labeled as "normal" and "inverse" initial alignment, moreover the "inverse" case can result in two bands corresponding to the clockwise (ICW)and counterclockwise (ICCW) rotation of the $\vec{j_2}$ vector in the x–z plane. Parameters of SPAC model are found from the comparison with experimental data (see Appendix A).

3. Comparison with experimental data

3.1. Dipole band DB5 in ^{142}Gd

In Ref. [3] four dipole bands of ^{142}Gd have been interpreted in the framework of SPAC as corresponded to the ICW quasiparticle alignment. Lifetimes for DB5 with configuration $\pi h_{11/2} \otimes (\pi d_5/2)^{-1}(\nu h_{11/2})^{-2}$ have been published in Ref. [7]. In the present work the SPAC analysis of corresponding B(M1) and B(E2) values confirmed the "normal" orientation for this band. Results are presented in Fig. 1 together with TAC calculations.

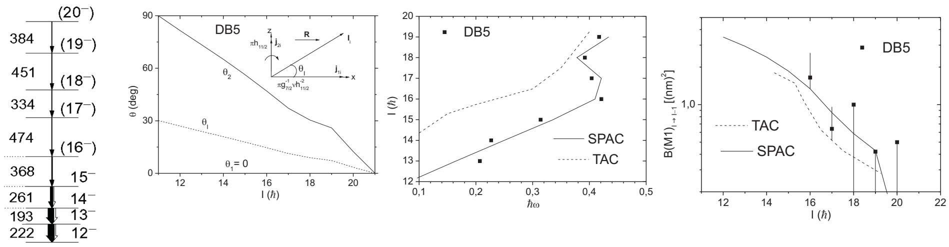

Fig. 1. Results for DB5 in ^{142}Gd. Left: Angles of vectors $\vec{j_1}$, $\vec{j_2}$ and $\vec{I}$ *versus* spin. Middle: Experimental I *versus* $\hbar\omega$ plots are compared with TAC and SPAC model calculations. Right: The corresponding B(M1) values.

3.2. Dipole bands in ^{132}La

The results of the lifetime measurements of the excited states in ^{132}La and ^{128}Cs [5] show that these nuclei, in spite of the similar levels schemes, have essentially different electromagnetic properties. Whereas the properties of the $\pi h_{11/2} \otimes (\nu h_{11/2})^{-1}$ bands in ^{128}Cs exhibit the main features expected for chiral partner bands the reduced transition probabilities for ^{132}La are not consistent with the chiral hypothesis. In the framework of the SPAC model all three bands can be described as corresponding to the same structure $\pi(h_{11/2})^1\nu \otimes (h_{11/2})^{-1}$ but for the different symmetries mentioned above. Results of SPAC analysis presented in Fig. 2 indicate that the dipole bands in ^{132}La can indeed be considered as magnetic rotational bands with different planar symmetries and remarkable contribution of collectivity.

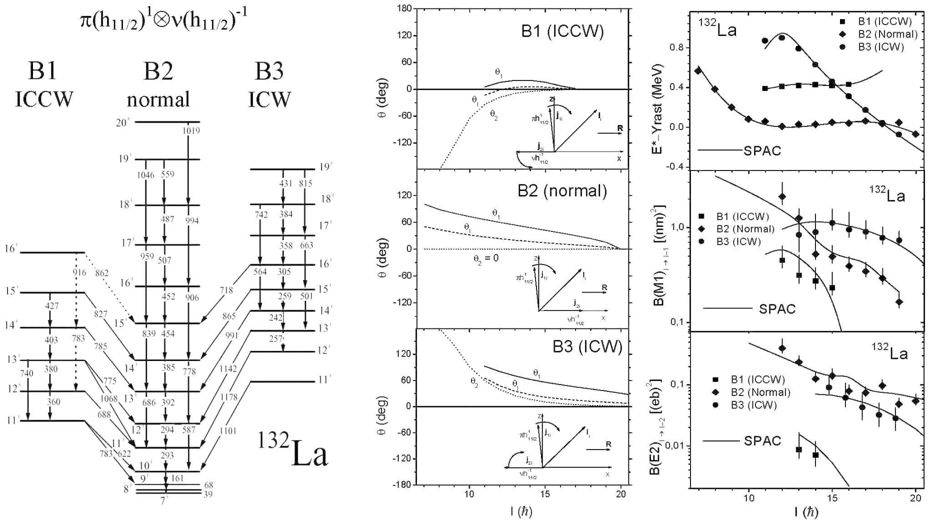

Fig. 2. Results for dipole bands in ^{132}La. Left: Three dipole bands in ^{132}La [4]. Middle: Calculated evolutions of quasiparticle and total spin vector directions θ_1, θ_2 and θ_I. Right: The comparison of experimental energies, B(M1) and B(E2) values with calculations.

3.3. Dipole bands in ^{130}La

In case of ^{130}La experimental energies, B(M1) and B(E2) for the yrast dipole band [8] as well as corresponding calculated values are compared with those for the B2 of ^{132}La. For both nuclei the parameters of the calculations are the same, excluding slight difference in $Q_{\rm coll}$ (see Fig. 3).

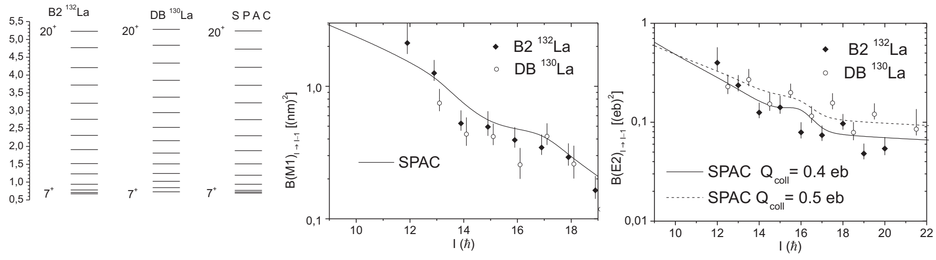

Fig. 3. Results for dipole bands in ^{130}La in comparison with ^{132}La. Left: Experimental and calculated energies. Middle: Experimental and calculated B(M1) values at the same SPAC parameters. Right: The corresponding B(E2) values with different collective Q-values.

4. Summary and conclusions

In the SPAC model the magnetic rotation with shears effect is described in the main ellipsoid system of coordinates. In this case the magnetic rotation of quasi-particles coexists with the collective (electrical) core rotation. SPAC model regards normal and inverse (relative to the collective rotation axis) initial orientations of quasiparticle angular momenta and can explain the appearance of two or three bands with same head configuration but different spin dependencies of level energy, $B(\mathrm{E2})$ and $B(\mathrm{M1})$. Predictions of $B(\mathrm{M1})$ and $B(\mathrm{E2})$ are based on the analysis of the experimental energy band structure. Energy structures and electromagnetic transition probabilities in dipole bands of ^{142}Gd and ^{130,132}La have been successfully described with SPAC model.

Appendix A

SPAC parametrization

In SPAC model the spin dependence of the core collectivity are described by the Hill $C(I) = C_i + \frac{(C_f - C_i)(x-1)^n}{1+(x-1)^n}$ or Boltzmann $C(I) = C_f + (C_i - C_f)/(1 + \exp(x))$ functions, where $x = (I - I_{\mathrm{tr}})/(\mathit{\Delta})$. In case of the normal initial alignment $\theta_2 = 0$ and $\theta_1(I)$ can be found applying the one-dimensional minimization condition: $(\frac{dE}{d\theta_1})_I = 0$. For the inverse initial alignment the required two-dimensional search of the energy minimum is replaced by the one-dimensional minimization condition. In this work a model function $\theta_2(I) = \theta_2^i \exp[(1 - I/I_i)\alpha_2]$ was used, where α_2 is a parameter describing how fast full alignment is achieved [3]. Corresponding parameters, which have been obtained by the fitting of band energies and used for $B(\mathrm{M1})$ and $B(\mathrm{E2})$ calculations, are presented in Table I and Fig. 4. Herewith for $B(\mathrm{M1})$ no additional fitting parameters are required, since j_1, j_2, g_1, g_2 are defined by quasiparticle configurations. For all considered bands $j_1 = 5.5\ \hbar$ and $g_1 = 1.21$ being corre-

TABLE I

SPAC parameters deduced from energies and $B(\mathrm{E2})$ values.

Band	I_{tr} $\hbar$	$\mathit{\Delta}_{\mathrm{tr}}$ $\hbar$	C_i MeV/$\hbar^2$	C_f MeV/$\hbar^2$	Model*	α_2 $\hbar$	Q_{coll} eb	Q_{eff} eb
DB5 ^{142}Gd	22	0.8	0.037	0.027	B	—	1.0	0.5
B1 ^{132}La	10	1.8	2.08	0.05	H3	2.0	0.2	7
B2 ^{132}La	12.5	6.5	0.1	0.02	B	—	0.4	7
B3 ^{132}La	10.6	3.6	0.115	0.023	H2	2.8	0.2	7

* Model: B — Boltzmann; H3 — Hill with $n = 3$; H2 — Hill with $n = 2$.

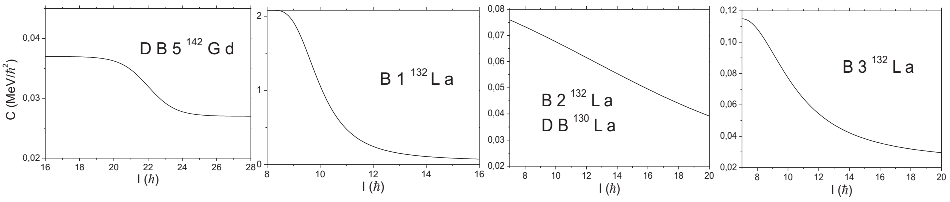

Fig. 4. Collectivity parameter $C = 1/J$ *versus* spin value for dipole bands in ^{142}Gd and ^{130,132}La.

sponded to the $\pi(h_{11/2})^1$. For dipole bands in ^{130,132}La $j_2 = 5.5\ \hbar$ and $g_2 = -0.21$ $[\nu(h^{-1}_{11/2})]$, while for the DB5 in ^{142}Gd $j_2 = 9.5\ \hbar$ and $g_2 = -0.014$ $[(\pi d_{5/2})^{-1}(\nu h_{11/2})^{-2}]$. Parameters Q_{eff} and Q_{coll}, which are needed for the calculation of B(E2) values, have been obtained from experimental B(E2) and B(M1)/B(E2) data are also presented in Table I. In case of DB2 in ^{132}La and DB in ^{130}La a band mixing of a $2qp$ $\pi(h_{11/2})^1 \otimes \nu(h_{11/2})^{-1}$ and a $4qp$ $\pi(h_{11/2})^1 \otimes \nu(h_{11/2})^{-3}$ configurations with $Q_{\text{coll}} = 1.3$ eb at high spins has been carried out similarly to [9], which gives a better description of the experimental B(M1) and B(E2) values. In this case the band mixing amplitude $\alpha(I)$ of $2qp$ and $4qp$ is approximated by a Hill function with $\alpha_i = 1$, $\alpha_f = 0$ and $I_{\text{tr}} = 16.5$, $\mathit{\Delta} = 3$, $n = 7$. The corresponding values of $E(I)$ and B(M1) are calculated as: $E(I) = \alpha^2(I)E_{2qp}(I) + [1 - \alpha^2(I)]E_{4qp}(I)$; $B(M1; I \to I-1) = \frac{3}{8\pi}(\alpha\mu_{\perp 2qp} + \sqrt{1-\alpha^2}\mu_{\perp 4qp})^2$.

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