Possibility of magnetic rotation in ^{85}Zr

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Being a few-body quantum mechanical system, observation of the rotation motion in a spherical atomic nucleus is quite unexpected. Therefore, the observation of rotational-like sequence of magnetic dipole ($M1$) transitions in weakly deformed nuclei has attracted an immense interest in the nuclear physics since last few decades. One of the first evidences of such $\Delta I = 1$ rotational bands was found in ^{199}Pb [1]. Generation of higher angular momentum in this kind of motion was interpreted under the framework of shears mechanism [2]. Symmetry breaking by the current distributions of a few high spin particles and holes outside a nearly spherical core and the magnetic moments associated with these currents are considered as the main reason behind the origin of this phenomena. As the magnetic moment breaks the symmetry and rotates around the angular momentum vector, this mode of nuclear excitation is called as "magnetic rotation" (MR) [3, 4]. Magnetic rotational bands were reported in many nuclei through out the Segrè chart [5]. However, the abundance of such bands in $A \lessapprox 100$ is rather less [6, 7, 8, 9, 10]. Experimental fingerprints of this phenomena are follows:

(i) Excitation energy of the levels follow $I(I + 1)$ rotational pattern.

(ii) Low magnitude of dynamic moment of inertia. Remains constant with spin.

(iii) Large $B(M1)$, small $B(E2)$ strengths.

Odd-A zirconium isotopes with protons in $Z = 40$ sub-shell closure and the valance neutrons in the middle of $Z = 40 - 50$ (sub) shell gaps are the ideal laboratory to understand the interplay between single-particle and collective excitations. However, in spite of having favourable configurations to generate magnetic rotational band, evidence of such bands was found only in ^{87}Zr [7]. A similar looking band was also reported in neighbouring ^{85}Zr, for which the semi-classical model calculation is carried out in this work [11].

Macchiavelli and Clark proposed the semiclassical description of the shears mechanism, where, the energy states of a shears band were generated from the interaction of particles and holes [12, 13]. This interaction is proportional to $P_2(\theta)$. The shears angle (θ) between j_π and j_ν is defined as:

$$cos\ \theta = \frac{\vec{j_\pi}.\vec{j_\nu}}{|\ \vec{j_\pi}\ |\ .\ |\ \vec{j_\nu}\ |}$$

$$= \frac{I_{sh}(I_{sh}+1) - j_\pi(j_\pi+1) - j_\nu(j_\nu+1)}{2\sqrt{(j_\pi(j_\pi+1)j_\nu(j_\nu+1))}}$$

The $\vec{I}_{sh} = \vec{j_\pi} + \vec{j_\nu}$ is the shear contribution to the total angular momentum $\vec{I}$. The total spin of the band $\vec{I} = \vec{I}_{sh} + \vec{R}_{core}$. $\vec{R}_{core}$ is the core contribution.

The effect due to the contribution of core angular momentum towards the total angular momentum can be estimated as,

$$R_{core} = \frac{\Delta R}{\Delta I}(I - I_{bh})$$

$$= \frac{I_{max} - j_\pi - j_\nu}{I_{max} - I_{bh}}(I - I_{bh})$$

Where, I_{max} represents the maximum observed spin and I_{bh} is the band-head of the shear band. The magnitude of $B(M1)$ is proportional to the square of the perpendicular component magnetic moment vector ($\mu_\perp$) [12]. The $B(M1)$ can be estimated by:

$$B(M1, I \to I-1) = \frac{3}{8\pi}\ g_{\rm eff}^2\ j_\pi^2\ \sin^2\theta_\pi\ [\mu_N^2]$$

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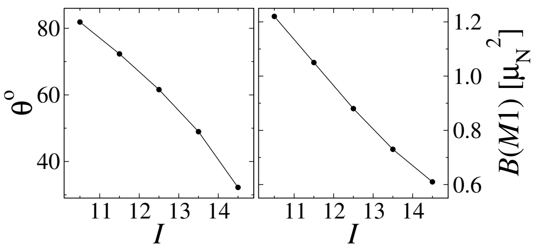

FIG. 1: Plots of (right) $B(M1)$ and (left) shears angle (θ°), calculated using the semiclassical particle rotor model, as function of spin (I) for the states belonging to the possible MR band in ^{85}Zr.

Where, j_{π} is the proton angular momentum, θ_{π} is the proton angle between j_{π} and total angular momentum I. The magnitude of θ_{π} is given by:

$$\theta_{\pi} = tan^{-1}\frac{j_{\nu}sin\theta}{j_{\pi} + j_{\nu}cos\theta}$$

g_{eff} is the effective gyromagnetic factor and is given by $g_{\pi} - g_{\nu}$. The values of g_{π} and g_{ν} depend on the orbital involved at the configuration of the band.

Utilising this semi-classical formalism the dipole band in ^{85}Zr is investigated. As shown in the FIG. 1, both the shears angle [θ] and the reduced $M1$ transition probability [$B(M1)$] are showing a decreasing trend with increasing spin as expected for a MR band. Therefore, the band above $I^{\pi} = (21/2^{+})$ state in ^{85}Zr is found to be a possible candidate for magnetic rotation.

To summarise, the semiclassical particle rotor model calculation has been carried out for the magnetic dipole band in ^{85}Zr. The calculated $B(M1)$ values are found decreasing as a function of increasing spin. This indicates that the shears mechanism is possibly responsible to generate the higher angular momentum states belonging to the band of present interest. Detailed results obtained from this calculation will be presented.

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References

[1] Nucl. Phys. A **574**, 521 (1994).
[2] Nucl. Phys. A **557**, 259 (1993).
[3] Prog. Part. Nucl. Phys. **90**, 241 (2016).
[4] Annu. Rev. Nucl. Part. Sci. **50**, 1 (2000).
[5] At. Data Nucl. Data Tab. **74**, 283 (2000).
[6] Phys. Rev. C **83**, 024316 (2011).
[7] Phys. Rev. C **98**, 034320 (2018).
[8] Int. J. Pure Appl. Phys. **6**, 295 (2010).
[9] Nucl. Phys. A **768**, 43 (2006).
[10] Acta Phys. Pol. B **51**, 473 (2020).
[11] Phys. Rev. C **65**, 054307 (2002).
[12] Phys. Rev. C **57**, 1073(R) (1998).
[13] Phys. Rev. C **58**, 3746 (1998).