Study of newly appeared γγ band in $^{104\text{-}108}$Mo

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Introduction

The neutron rich molybdenum isotopes around A ≈ 100 are found to exhibit different kind of nuclear structure. Thus it has always been a subject of keen interest for experimentalists and theoreticians to see whether the nucleus under consideration is axial, γ - soft or γ – rigid. Sometimes back spontaneous fission of ^{252}Cf with Gamma sphere detector array has yielded many high states in Mo nuclei including a fresh appearance of $K^{\pi} = 4^{+}$, γγ band besides the usual $K^{\pi} = 0^{+}$, yrast band and $K^{\pi} = 2^{+}$, γ band spectrum [1-3]. Modified soft rotor formula has been found successful in reproducing the energies of these various levels [4].

In the present work, we shall investigate whether a half century old predictions on the existence of $K^{\pi} = 4^{+}$, γγ band has become a reality [5]. According to ref. 2 the violation of axial symmetry of even nuclei generates two energy states for I = 2 (2_1^+, 2_2^+) one for I = 3 (3_1^+) three for I = 4 (4_1^+, 4_2^+, 4_3^+), two for I = 5 (5_1^+, 5_2^+), four for I = 6 (6_1^+, 6_2^+, 6_3^+, 6_4^+) etc corresponding to the rotation of the nucleus. 2_1^+, 4_1^+, 6_1^+ …… make yrast band, 2_2^+, 3_1^+, 4_2^+, 5_1^+, …… make gamma band while 4_3^+, 5_2^+, 6_3^+ …… make γγ band. Yrast band is normal while the other to bands i.e. γ band and γγ band are anomalous bands. We shall evaluate the values of energy of the levels of observed spectrum within the framework of Asymmetric Rotor Model (ARM) and compare them with experiment just to explore whether the nucleus under consideration are rigid or not. Since the energy predicted in ARM is large, the relative displacement of the odd spin levels with respect to even spin levels (odd – even staggering OES) will be taken as signature of nucleus being γ-rigid, γ soft or axial [6]. The staggering indices S(I) for the experimental as well as asymmetric rotor energy levels of γ – band and for γγ – band is expressed as –

$$S(I) = \frac{(E_I - E_{I-1}) - (E_{I-1} - E_{I-2})}{E2_1^+}$$

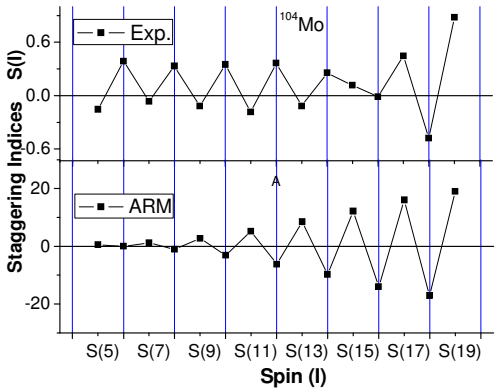

Fig. 1 (a)

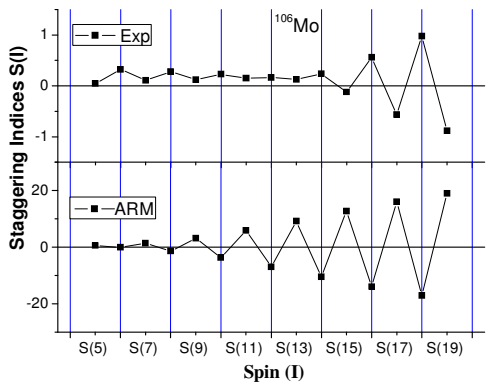

Fig. 1 (b)

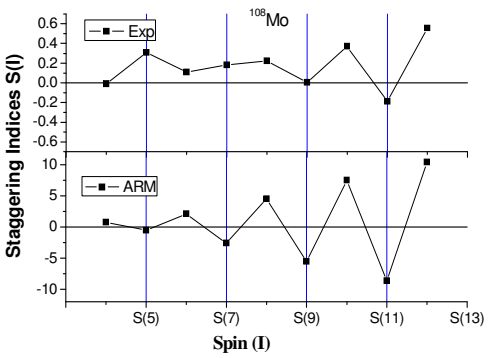

Fig 1 (c)

Fig 1(a-c) Energy staggering S (I) vs Spin (I) in γ – band for $^{104-108}$Mo nuclei

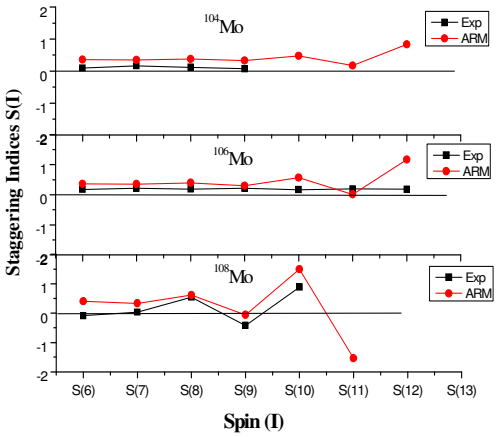

Fig. 2 Energy staggering S(I) vs spin (I) in γγ – band for $^{104-106}$Mo nuclei

For axially symmetric rotor, S (I) does not show any variation in phase and remain small in magnitude. The pattern of S (I) vs. spin (I) in asymmetric rotor if found similar with that of experiment then nucleus is taken γ – rigid and opposite pattern in theory and experiment may be predicted as γ – soft.

Fig 1 (a–c) are drawn in favors of $^{104-108}$Mo nuclei for γ and γγ – bands separately in S (I) vs spin (I) for the values found in theory and experiment respectively. In ^{104}Mo, the values of S(I) are +ve for odd spin and –ve for even spin in γ – band for experiment while for rigid rotor there is an opposite trend and thus the shape of nucleus is γ – soft. This trend continues up to spin I = 13 and the trend get reversed after the spin I = 16 and correctly match with the prediction of rigid rotor model. At spin I = 13 – 14 the shape of the nucleus changed to γ – rigid from the γ – soft i.e. the shape phase transition takes place at this spin.

In ^{106}Mo, S (I) values in γ – band are +ve and small in magnitude up to I = 12^+ in experiment and rigid rotor values does not match being zig – zag in nature so the nucleus is axial in nature. Later experimental trend of S (I) is opposite to the rigid rotor trend reflects the γ – soft nature of the nucleus.

In ^{108}Mo, S (I) values are small in experiment up to spin I = 9^+ and does not match with the rigid rotor values so the nucleus is axial. Later the experimental and rigid rotor values of S (I) match in phase, thus the nucleus becomes triaxial.

In γγ – band for all the $^{104-108}$Mo nuclei there is an interesting situation that S (I) values are smaller in both the experiment and rigid rotor model and have same phase. There is no phase change either in experiment or in rigid rotor model at any known spin. This similar trend makes all these three nuclei to be rigid triaxial.

The above study infers that γγ – band observed in experiment in $^{104-108}$Mo nuclei are generated due to the rotation of γ – rigid nucleus and follows the rigid rotor predictions.

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