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Structure of ^{72,74}Se at high spin

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Abstract. Lifetimes of high spin states up to $I^{\pi}=22^{+}$ in the yrast positive parity bands have been measured to investigate the shape evolution with increasing spin in ^{72,74}Se. The $Q_{\rm t}$ values derived from these measurements indicate that prolate shape stabilizes for ^{72}Se, while a triaxial shape develops for ^{74}Se at higher spins. Comparison of the observed trend in $Q_{\rm t}$ with spin for ^{72,74}Se with that of the corresponding kryptones isotones emphasizes the stability provided by $N = 38$ prolate shell gap even at high rotational frequency.

Keywords. Alignment; projected shell model; lifetime; shell gap.

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1. Introduction

Nuclei in mass 70–80 region show variety in their behaviour because of characteristic properties of $f-p-g$ shell nuclei. In comparison to the rare-earth region where the change in nuclear structure properties is quite smooth with respect to particle number, the structure of the proton-rich mass-80 nuclei shows considerable variation in going from one nucleus to another. This is mainly due to the fact that the available shell model configuration space in the mass-80 region is much smaller than in the rare-earth region. There are also prominent shell gaps at $N, Z =$ 34, 36 and 38 at large deformation. The total energy surface calculations [1] of the light Se, Kr and Sr isotopes show either more than one minima with small barrier between them or they are gamma soft in nature. Thus, the prolate-oblate mean field coexistence dominates the low-spin states structure of many nuclei in this region. The study concerning the competition of these two mean fields at higher angular momentum and the role of deformed shell gaps in this process are of vital interest for better understanding of nuclei in this region.

More recently, the yrast bands of ^{70,72,74}Se were investigated [3,4] up to spins of $I^{\pi} =$ 16^{+}, 28^{+} and 22^{+}, respectively. In the case of ^{70}Se, a well deformed minimum competes with a non-collective structure for high spins with $I \geq 8$ and both the structures persist up to $\hbar\omega \approx 1.2$ MeV. This result can be associated with the fact that many non-collective states have been observed in the vicinity of and above the 8^{+} level. Earlier experiments [2] on ^{72}Se include lifetime measurements up to $I = 14^{+}$ state along the yrast band. A systematic increase of the B(E2) values for spins up to $I = 14\hbar$ has been observed [2] in ^{72}Se contrary to the trend found in ^{74}Se. This behaviour is better understood by a soft triaxial rotor with large rotation-vibration coupling rather than a rigid axially symmetric or triaxial rotor. A recent study of ^{74}Se [4] shows a deformed shape for the excited states with a considerable softness towards triaxiality. With these varying predicted shape evolutions at higher excited states in even-even Se isotopes, the study of structure of high spin states through measurements of transition strengths in ^{72,74}Se would be of considerable interest.

2. Experimental procedure and results

Levels in ^{72}Se(^{74}Se) were populated in the ^{54}Fe(^{24}Mg, $\alpha 2p(4p)$) reaction where an ^{54}Fe target was bombarded with 104 MeV ^{24}Mg beam from the 14-UD pelletron accelerator at TIFR, Mumbai. The target was prepared by rolling a 540 μg/cm^2 thick ^{54}Fe foil onto a 9 mg/cm^2 thick gold backing used for stopping the recoiling ions produced in various reaction channels. Gamma rays emitted from the nuclear excited states were detected in 5 CS-HPGe detectors and a CS-Clover detector. The background due to radioactivity was reduced with the help of a multiplicity filter consisting of 14 NaI(Tl) detectors. Gamma–gamma coincidence data were collected in the list mode when two or more CS-HPGe/CS-Clover detectors fired simultaneously and multiplicity of NaI(Tl) filter is more than one.

The energy calibration for all the detectors was matched to 0.5 keV/Channel. Data were sorted into $4k \times 4k$ $\gamma\gamma$ matrices with one of the detectors along x-axis and any of the other detectors along y-axis. The transitions reported in ref. [3,4] were identified in our experiment. To get the lineshape spectra of the concerned transitions, their lower gamma transitions were used as gates and these gated spectra were added.

Lifetimes of levels were obtained from the analysis of lineshapes in the detectors at 45° and 75°. Lineshapes of the transitions obtained were fitted with the program developed by Wells [5]. The lifetimes of the 16$^+$ to 22$^+$ states in ^{72}Se and 18$^+$ to 22$^+$ states in ^{74}Se are found for the first time. The experimental data along with theoretical fits for γ-rays de-exciting 16$^+$ state of ^{72}Se and 18$^+$ state of ^{74}Se are shown in figure 1a and 1b. The lifetimes obtained for the lower states in the present work are in good agreement with earlier measurements [2,6]. The transitional quadrupole moments $Q_{\rm t}$ derived from the adopted lifetimes for high spin states up to $I = 22^+$ are shown in figure 1c and 1d.

3. Discussion

The $J^{(2)}$ plots for the yrast bands of ^{72,74}Se are shown in figure 2. Apart from the low spin anomaly, the $J^{(2)}$ of ^{72}Se shows a smooth behavior at higher frequencies. On the other hand, that of ^{74}Se shows irregularities at $\hbar\omega = 0.50$, 0.67 and 0.80 MeV, corresponding to the quasi-particle alignments.

The total routhian surface calculations [3] for the yrast positive parity band of ^{72}Se predict three minima – two oblate and one prolate at low spin with $\hbar\omega \le 0.3$ MeV. But only the prolate minimum with $\beta_2 = 0.33$ and $\gamma = -4^\circ$ persists at higher spins. This is consistent with the measured $Q_{\rm t} \sim 2$ eb for most of the high spin states except for $I = 22^+$ state. For ^{74}Se, at moderate spin (i.e., $I = 6-10$) with frequency $\hbar\omega = 0.4$ MeV, a prolate shape appears at $\beta_2 = 0.33, \gamma = -12^\circ$ which is in agreement with the measured $Q_{\rm t}$ values ~ 2.4 eb. At higher frequency $\hbar\omega = 0.8$ MeV, two triaxial shapes appear – one with $\beta_2 = 0.29^\circ, \gamma = -26^\circ$ giving

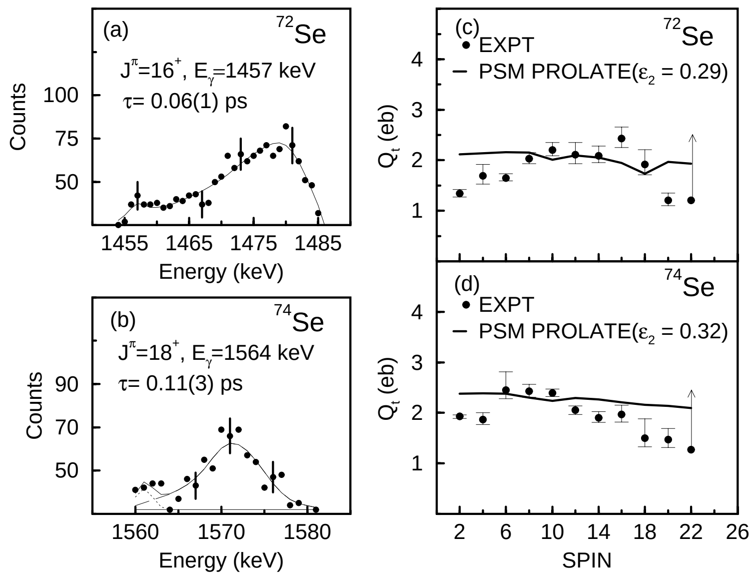

Figure 1. (**a**) and (**b**) show the lineshapes of transitions from 16^+ state of ^{72}Se and 18^+ state of ^{74}Se, respectively. (**c**) and (**d**) depict the comparison of experimental and calculated $Q_{\rm t}$ values for ^{72,74}Se.

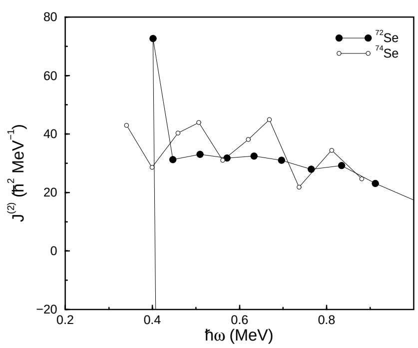

Figure 2. Comparison of $J^{(2)}$ values for the yrast positive parity bands of ^{72,74}Se.

$Q_{\rm t} = 2.12$ eb, the second with $\beta_2 = 0.29, \gamma = 40°$ giving $Q_{\rm t} = 0.73$ eb. However, experimental $Q_{\rm t}$ values lie between these values corresponding to the two minima.

It is interesting to examine the behavior of $Q_{\rm t}$ at high spin through a model beyond the usual mean field approach like projected shell model [7]. The PSM is a spherical shell model truncated in a Nilsson-BCS single particle basis. Projected shell model calculations for the positive parity yrast bands of ^{72,74}Se have been carried out assuming prolate deformations with $\epsilon_2 = 0.29$ and 0.32, respectively. The variation of $Q_{\rm t}$ with spin for ^{72,74}Se is shown in figure 1 and compared with the experimental data. The agreement is qualitatively fairly well for higher spin states. The discrepancy between experimental data and present calculations at low spin has been attributed to the more favorable oblate shape at lower frequency as discussed in detail [8,9].

4. Conclusion

The $Q_{\rm t}$ values for the high spin states of ^{72,74}Se derived from the lifetime measurements have been reported. The observed variation of $Q_{\rm t}$ with spin is understood in terms of TRS and PSM calculations. At low spin, these nuclei show the shape co-existence feature. But at moderate spin, the prolate shape becomes more favorable. In the case of ^{72}Se even after particle alignment the prolate shape persists, while in ^{74}Se, nucleus becomes triaxial after particle alignment. The same feature is observed in ^{74,76}Kr isotopes [10,6]. This shows that $N = 38$ prolate shell gap helps the nuclei remain axially symmetric even at high spin.

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