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Transition strengths and shapes of 2-qp bands in ^{74}Se and ^{76}Kr

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Abstract. The lifetimes of the states of −ve parity 2-qp bands of $N = 40$ nuclei ^{74}Se and ^{76}Kr were measured. The transition strengths and quadrupole moments, obtained from the lifetimes, show a large collectivity of such bands in both the nuclei. The alignment frequencies were calculated from Woods–Saxon cranking model. Previously suggested quasi proton nature of band 5 and 6 of ^{74}Se were argued to be based on quasi neutron excitations. The total Routhian surface calculations suggest triaxial shapes with large +ve and −ve values of triaxiality parameter γ after proton and neutron alignments in these bands respectively.

Keywords. Heavy ion; γ – γ coincidence; DSAM; Woods–Saxon cranking; TRS.

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1. Introduction

The even–even $N = 40$ nuclei ^{74}Se and ^{76}Kr show interesting structure properties including shape coexistence in the yrast bands [1,2]. In addition to the +ve parity yrast bands, other −ve parity bands with strong E2 transitions have recently been observed in both the nuclei [2–4]. These were interpreted as two quasi particle (2-qp) bands. In ^{76}Kr, two such signature partner bands (band 3 and band 6) were interpreted as two quasi-proton in character [2] and other two signature partner bands (band 4 and band 5) are two quasi-neutron in character [4]. These bands are predicted to have larger deformation than the yrast S-band [2]. Lifetime measurements of these states can test these predictions. Moreover, the quasi particle configuration assigned to these bands can be tested if the deformation is known for these bands. In ^{74}Se, the nature of such two quasi particle bands are not resolved. The close proximity of proton and neutron crossing frequencies makes the interpretation, of whether the bands (band 5 and band 6) are based on two quasi protons or two quasi neutrons, very ambiguous [3]. If the deformation of such bands are known then it might be easier to resolve this ambiguity. This again needs the lifetime measurements of these 2-qp bands.

In the present work, our aim was to study the 2-qp bands of ^{74}Se and ^{76}Kr in detail with lifetime measurements to determine the deformations. The cranking calculations were performed for these bands to interpret the results.

2. Experimental details and data analysis

The nuclei ^{76}Kr and ^{74}Se were populated by heavy ion fusion evaporation reaction, ^{51}V(^{28}Si, $p2n(\alpha,p))^{76}$Kr (^{74}Se) at 115 MeV of beam energy. The beam was delivered from 15UD Pelletron at Nuclear Science Centre (NSC), New Delhi. The target was a self supporting thick ($\sim$ 76 mg/cm^2) vanadium foil. The recoils were stopped in the target itself for the line shape analysis. The maximum recoil velocity of the recoiling nuclei was $\sim$ 3% of the velocity of light. Gamma–gamma coincidence data were taken in the list mode using the gamma detector array (GDA) set up at NSC. GDA consists of 12 Compton suppressed HPGe detectors with 14 element BGO multiplicity filter. The detectors were at three rings at 144°, 98° and 50° angles. There were 4 detectors in each ring. The set up for the similar measurements can been seen in ref. [5].

In the analysis, two 4 K×4 K $\gamma\gamma$-coincidence matrices were constructed separately for forward and backward angle detectors. Most of the transitions in ^{76}Kr reported in refs [2] and [4] and in ^{74}Se reported in refs [1] and [3] have been observed in our experiment. The sum gated spectra were used for line shape analysis. For ^{76}Kr gated spectra with gates put on 424 keV, 611 keV and 825 keV, yrast transitions were added while for ^{74}Se, 635 keV, 728 keV and 868 keV gated spectra were summed up. The computer program LINESHAPE [6] was used to fit the Doppler line shapes. Wherever possible, the lifetimes were obtained by fitting the data from forward and backward matrices separately and the averages were taken. The errors associated with the measured lifetimes were calculated by the MINOS routine in the LINESHAPE program [6]. These were obtained for both backward and forward data. The reported error values are the larger values found between these two measurements.

3. Results

The results are summarized in table 1. It contains the lifetimes (τ) of the levels of band 3 (even spin) and band 6 (odd spin) in ^{76}Kr and band 4 and band 6 of ^{74}Se along with the transition strengths B(E2) and transition quadrupole moments Q_t obtained from the lifetimes. Here we are using the band nomenclatures as given in ref. [4] for ^{76}Kr and in ref. [3] for ^{74}Se. The band 3 and band 6 are the signature partners of the quasi proton band of ^{76}Kr while band 5 and band 6 are the signature partners of quasi proton band of ^{74}Se as interpreted in ref. [3]. However, in the present study it is argued that later bands are quasi neutron in character. The lifetimes of the levels of band 5 of ^{74}Se were previously measured by Cottle *et al* [1] and are not shown in table 1. The measured lifetimes for few levels match quite well with the previous measurements except for the 9^- state of ^{76}Kr. The value obtained by Piercey *et al* for this state was very low compared to our value and this gives an exceptionally high value of Q_t and consequently very large axial deformation. It may be noted, however, that the lifetimes were not known for most of the levels in these bands. The large B(E2) values obtained for these bands indicate highly collective nature of the bands. The quadrupole moments Q_t for both the nuclei remain almost constant at a value of ≈ 2.5 eb for ^{74}Se and ≈ 3.0 eb for ^{76}Kr. These correspond to an axial deformation of $\beta_2 \approx 0.33$ and ≈ 0.38 for ^{74}Se and ^{76}Kr respectively. In the yrast band of ^{76}Kr, it was found that the Q_t decreases from $\sim$ 3 eb for the g-band to ~ 2.2 eb for the S-band [8].

Table 1. Lifetime (τ) for the +ve and −ve parity states in ^{76}Kr and ^{74}Se from previous [7] and present works. 1 w.u = 19.13 and 18.46 e^2fm^4 for ^{76}Kr and ^{74}Se respectively.

I_i^π	E_γ (keV)	τ (ps) (previous)	τ (ps) (present)	τ (ps) (adopted)	B(E2) (w.u)	Q_t (eb)
^{76}Kr						
8^-	725		$1.61^{.41}_{.27}$	$1.61^{.41}_{.27}$	132^{27}_{27}	$2.99^{.29}_{.32}$
10^-	905		$0.80^{.17}_{.23}$	$0.80^{.17}_{.23}$	88^{35}_{16}	$2.34^{.43}_{.22}$
12^-	1066		$0.25^{.05}_{.04}$	$0.25^{.05}_{.04}$	124^{23}_{21}	$2.71^{.25}_{.23}$
14^-	1234		< 0.28	< 0.28	> 53	> 1.75
7^-	604		$2.60^{1.1}_{.64}$	$2.60^{1.1}_{.64}$	204^{67}_{61}	$4.45^{.68}_{.72}$
9^-	784	0.16(6)	$0.81^{.13}_{.11}$	$0.81^{.13}_{.11}$	178^{27}_{25}	$3.66^{.27}_{.27}$
11^-	978	0.18(7)	$0.26^{.05}_{.04}$	$0.22^{.05}_{.04}$	217^{48}_{41}	$3.80^{.41}_{.37}$
13^-	1169	0.34(8)	$0.13^{.04}_{.04}$	$0.13^{.04}_{.04}$	150^{67}_{35}	$3.06^{.62}_{.38}$
15^-	1356		< 0.20	< 0.20	> 46	> 1.67
^{74}Se						
8^-	816		$1.89^{.66}_{.55}$	$1.89^{.66}_{.55}$	65^{26}_{18}	2.28^{43}_{32}
10^-	1011		$0.44^{.17}_{.13}$	$0.44^{.17}_{.13}$	$95^{.40}_{.26}$	$2.55^{.49}_{.40}$
12^-	1044		< 1.07	< 1.07	> 33	>1.43
9^-	1007		$0.57^{.19}_{.16}$	$0.57^{.19}_{.16}$	75^{29}_{18}	$2.32^{.43}_{.30}$
11^-	1080		$0.38^{.10}_{.10}$	$0.38^{.10}_{.10}$	79^{28}_{16}	$2.26^{.38}_{.26}$
13^-	1135		< 1.10	< 1.10	> 21	> 1.11

This indicates that the deformation of the 2-qp band of ^{76}Kr is more deformed than the proton S-band, as conjectured by Gross *et al* [2].

4. Discussion

The results are discussed in the frame work of the cranking model. The protons and neutrons crossing frequencies for different values of deformation parameters β_2 and γ were calculated. These are plotted in figure 1.

Quasi neutron nature of bands 5 *and* 6 *of* ^{74}Se: The bands 5 and 6 were interpreted as quasi proton in nature by Doring *et al* [3]. The band crossing frequencies corresponding to particle alignments in these bands were observed at $\hbar\omega_c \approx 0.5$ MeV. If these bands were quasi proton in nature then this corresponds to neutron crossing frequency, since proton crossing is blocked. The calculated neutron crossing frequency in figure 1(a) shows a value of ≈ 0.5 MeV for $\beta_2 \simeq 0.23$ which is much less than the value obtained from lifetime measurements. In figure 1(b), it can be seen that the neutron crossing frequency never comes closer to 0.5 MeV for any value of triaxiality parameter γ, if the observed deformation of $\beta_2 \approx 0.3$ is assumed. Thus it is very unlikely that the bands 5 and 6 of ^{74}Se are quasi proton bands. However, if quasi neutron nature is assigned to these bands, then the observed crossing frequency

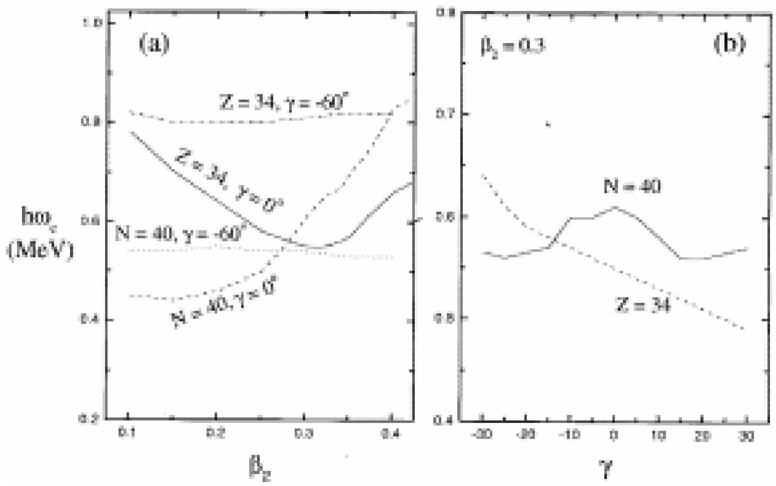

Figure 1. The calculated proton and neutron crossing frequencies for proton and neutrons as a function of β_2 (**a**) and γ (**b**).

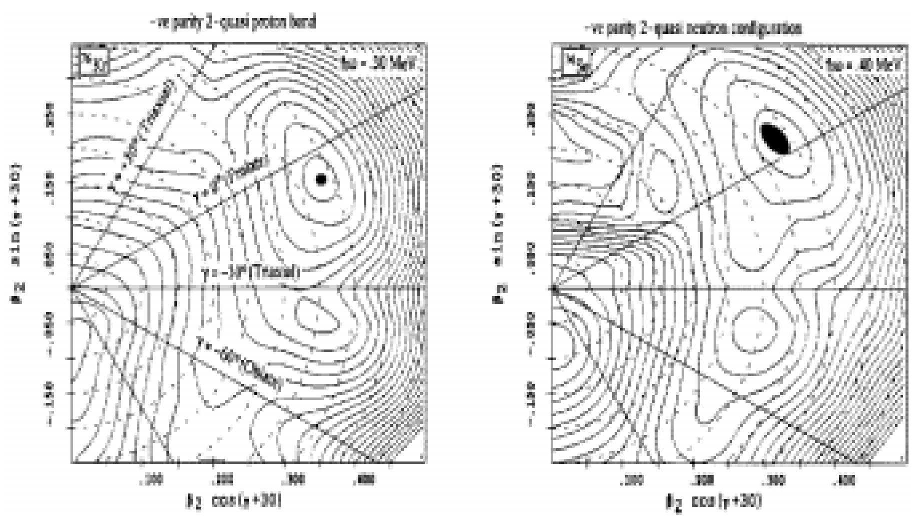

Figure 2. TRS plots for the $-$ve parity 2-qp bands in ^{76}Kr (left) and ^{74}Se (right) calculated at $\hbar\omega = 0.3$ and 0.4 MeV respectively.

agrees well with calculated proton crossing frequency for the deformation $\beta_2 \approx 0.3$, close to the value obtained from lifetimes, with slightly $+$ve γ (see figure 1(a) and (b)).

4.1 Shape calculation

To investigate the shape of the $-$ve parity two quasi particle bands in ^{76}Kr and ^{74}Se, we have carried out the theoretical calculations of total Routhian surfaces in Hartree–Fock–

Bogoliubov cranking model with Woods–Saxon potential and monopole pairing [9]. The total Routhian surfaces (TRS) calculated for the quasi particle bands of ^{76}Kr and ^{74}Se at rotational frequencies $\hbar\omega = 0.3$ and 0.4 MeV respectively are shown in figure 2.

The minimum in the potential energy for ^{76}Kr occurs at $\beta_2 \approx 0.38$ and $\gamma \approx -6°$. The quadrupole moment calculated from these deformation paremeters comes out to be $Q_{\rm th} \approx 3.2$ eb. This is in fair agreement with the experimental values for the even-spin $-$ve parity band (see table 1).

The TRS plot for the two quasi neutron band of ^{74}Se shows a minimum at $\beta_2 \approx 0.36$ and at $+$ve triaxiality $\gamma \approx 7°$. These values are in very good agreement with the values obtained from the experimental observations of crossing frequencies and lifetime data. This provides further support to the quasi neutron nature of the $-$ve parity bands of ^{74}Se, as discussed earlier. The TRS plots calculated at frequencies after the band crossings indicate (not shown) that the alignment of a pair of protons drives the shape towards $+$ve γ value while the neutron pair alignments drives it towards $-$ve γ value.

5. Conclusions

The lifetimes of the $-$ve parity 2-qp bands of ^{76}Kr and ^{74}Se were measured by DSAM. The predicted larger deformation of the 2-qp bands of ^{76}Kr than the proton S-band was confirmed in the present study. The bands 5 and 6 of ^{74}Se were argued to be based on 2 quasi neutron excitations. The TRS calculations were performed with Woods–Saxon potential for these bands in both the nuclei. The results of such calculations are in fair agreement with the measured deformations. The calculations predict a shape change towards $+$ve ($-$ve) γ after proton (neutron) pair alignments.

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