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High-spin structure of yrast-band in ^{78}Kr

P K JOSHI, R PALIT, H C JAIN, S NAGARAJ and J A SHEIKH
Tata Institute of Fundamental Research, Mumbai 400 005, India

Abstract. Lifetime of levels up to 22^+, have been measured in ^{78}Kr and an oblate shape is assigned to the ground state using the CSM and the configuration dependent shell correction calculations. Calculations further show that ^{78}Kr is highly γ-soft nucleus. The experimental $Q_{\rm t}$ values coupled with theoretical calculations indicate an oblate shape for ^{78}Kr at low spins and triaxial shape at higher spins

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High-spin structure in mass-80 region is dominated by the $g_{9/2}$ orbitals and the level density is nearly a factor of 2 smaller compared to nuclei in $A \sim 160$ region. This leads to large variation in nuclear configurations, shape and quasi-particle alignments with small changes in nucleon numbers [1,2]. Nuclei in mass 70–80 region have been predicted to be γ soft with the prolate and oblate configurations coexisting quite close to each other e.g. in ^{76}Kr [3,4]. Recently, E0 transition from 0^+(oblate) to 0^+(prolate) has been reported in ^{74}Kr [5] indicating the mixing of prolate and oblate configurations in this nucleus. The oblate minimum in ^{78}Kr is almost degenerate with the triaxial configuration with $\beta_2 \sim 0.3$ and $\gamma \sim 15^\circ$. The alignment behavior in light Kr isotopes e.g. ^{74,76}Kr differs strongly from ^{78}Kr. It is almost simultaneous alignment of two quasi-protons and two quasi-neutrons in ^{74,76}Kr [4,6] but two well separated bandcrossings are observed in ^{78}Kr [4]. The first bandcrossing was found to arise due to alignment of two quasi-neutrons from a measurement of nuclear g-factors in ^{78}Kr [7] but the high-frequency for the second bandcrossing ($\hbar\omega \sim$ 0.85–0.90 MeV) could not be well understood from the available data. In the present work, the lifetimes have been measured up to the 22^+ state in the yrast positive parity band using recoil distance and lineshape analysis methods in order to study the shape variations with increasing angular momentum and understand the intrinsic structure near the bandcrossing frequencies in ^{78}Kr.

Levels in ^{78}Kr were populated by two reactions, i.e., ^{58}Ni(^{27}Al, $\alpha 3p$) and ^{63}Cu(^{19}F, $2p2n$)^{78}Kr. In the first reaction, 115 MeV ^{27}Al beam from the 14-UD pelletron accelerator at TIFR, Mumbai was bombarded on the ^{58}Ni target. The target was prepared by rolling a 580 μg/cm^2 thick ^{58}Ni foil onto a 9 mg/cm^2 thick gold backing. γ-rays emitted from the nuclear excited states were detected in four CS-HPGe detectors and a Clover detector. γ–γ coincidence data were collected in the list mode when two or more detectors fired simultaneously. In this arrangement, the Clover detector was used in the add-back mode i.e. it was treated as a single detector. Clover was kept at 90° with respect to the beam direction. In the second experiment, 74 MeV ^{19}F beam bombarded a Ta backed Cu target. γ-rays from the excited states were observed by 3 Compton suppressed Clover detectors and a CS-HPGe detector. The background due to radioactivity was reduced with the help of a multiplicity filter consisting of 14 NaI(Tl) detectors. The two fold coincidences in HPGe/Clover detectors were further gated by two(or more) fold coincidences in the NaI(Tl) multiplicity filter.

Lifetimes for levels above 16^+ were measured for the first time in the present work, using the DSAM technique. An effective lifetime $\tau_{\rm eff} = 320(70)$ fs was obtained from the present data at 75° for the 24^+ level. Zeigler's stopping powers have been used for the calculation of the energy loss parameters of the recoiling nuclei. The experimental data along with the theoretical fits for the lifetimes measured can be seen in figure 1. The present lifetime values up to the 14^+ are in good agreement with the earlier measurements [4]. The lifetimes measured and the transition quadrupole measurements can be seen in table 1.

The present measurements show a drop in transition quadrupole moments at high-spins ($> 16\,\hbar$). It is shown that the bandcrossing frequencies and the variation in $Q_{\rm t}$ values with increasing spin can be understood in the framework of the cranked shell model and TRS calculations. These calculations show the γ-soft nature of ^{78}Kr at lower spin. At $\hbar\omega = 0$ MeV, a shallow minimum is present at $\beta_2 = 0.24, \gamma = -60°$. Three more minima (equally favourable) appear along with the first oblate minimum at $\hbar\omega = 0.2$ MeV. However, at higher frequencies i.e. beyond $\hbar\omega = 0.6$ MeV, the shape of the nucleus is driven towards $\beta_2 = 0.24, \gamma = -30°$. Moreover, a non-collective minimum starts building up with $\beta_2 \sim 0.25$, and $\gamma = 60°$. CSM calculations were performed for oblate deformation with $\beta_2 = 0.38$ and $\gamma = -60°$ corresponding to the experimental measured $Q_{\rm t} = 2.57$ eb at low spins. It gives neutron bandcrossing at 0.55 MeV and the proton band crossing at

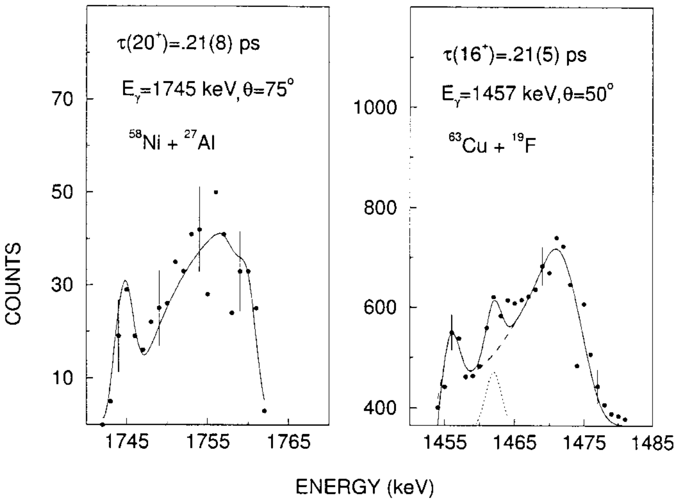

Figure 1. Experimental and theoretical lineshapes for the 20^+ and 16^+ levels in the yrast positive parity band in ^{78}Kr at $\theta = 75°$ and 50°.

Table 1. Experimental values of lifetimes for nuclear excited states in the yrast band of ^{78}Kr

Level energy (keV)	Spin I ($\hbar$)	Transition energy (keV)	τ (ps)				$Q_{\rm t}$ (Expt) (eb)
			Previous work†	^{27}Al + ^{58}Ni	^{19}F + ^{63}Cu	Adopted values	
455.0	2^+	455.0	32(2)	32(2)		32(1.4)	2.55(6)
1119.4	4^+	664.0	3.6(3)	3.4(3)		3.5(2)	$2.51^{+0.08}_{-0.07}$
1977.7	6^+	858.3	1.0(2)	1.4(5)		1.1(2)	$2.25^{+0.23}_{-0.18}$
2993.7	8^+	1016.0	0.38(6)	0.61(20)	0.64(15)	0.48(6)	$2.18^{+0.15}_{-0.13}$
4105.5	10^+	1111.8	0.37(6)	0.30(10)	0.29(6)	0.33(4)	$2.08^{+0.18}_{-0.12}$
5217.3	12^+	1111.8	0.25(15)	0.30(10)	0.31(6)	0.30(5)	$2.15^{+0.21}_{-0.16}$
6479.1	14^+	1261.8	0.22(8)	0.19(10)	0.11(3)	0.16(3)	$2.13^{+0.24}_{-0.17}$
7935.9	16^+	1457.0		0.18(10)	0.21(5)	0.20(5)	$1.33^{+0.20}_{-0.14}$
9567.9	18^+	1632.0		0.26(10)	$<$0.34	0.26(10)	$0.87^{+0.24}_{-0.13}$
11312.9	20^+	1745.0		0.21(8)		0.21(8)	$0.82^{+0.22}_{-0.12}$
13156.9	22^+	1844.0		0.21(11)		0.21(11)	$0.71^{+0.32}_{-0.13}$
15160.0	24^+	2003.0		$<$0.32(7)			

† Values given in ref. [4].

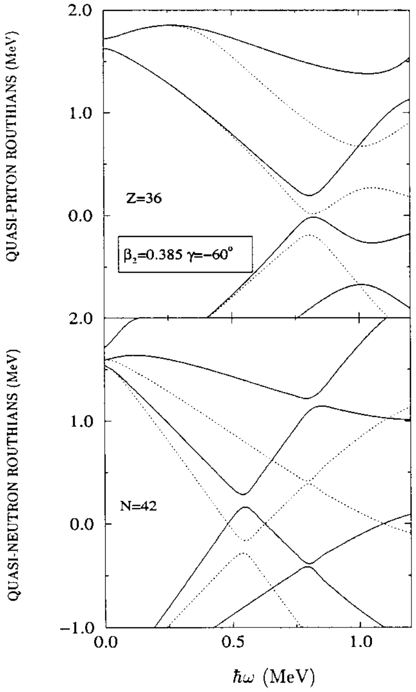

Figure 2. Quasi-proton and quasi-neutron routhians in ^{78}Kr evaluated at β_2 = 0.38 and $\gamma = -60°$. The following convention is used to indicate parities and signature of the routhians: solid curve $(+, +\frac{1}{2})$; dotted curve $(+, -\frac{1}{2})$.

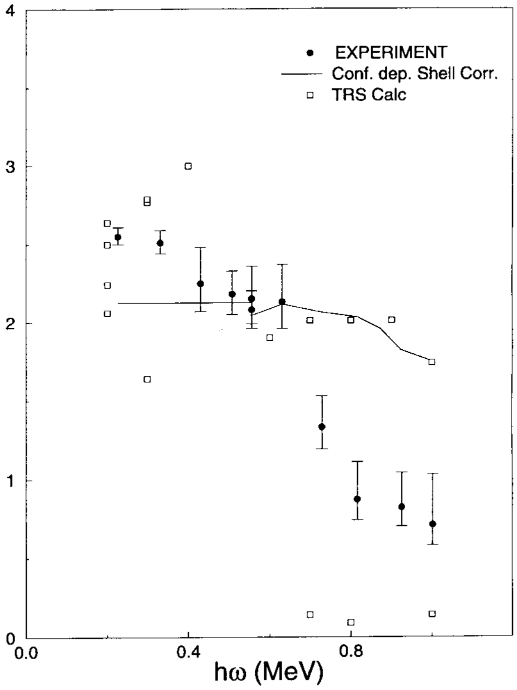

Figure 3. The transition Q_{t} values obtained by experiment, configuration dependent shell correction and TRS calculations, plotted as a function of the rotational frequency.

0.83 MeV in good agreement with the experimentally observed band crossing frequencies (figure 2). Configuration dependent shell corrections, employing Nilsson potential and neglecting pairing correction, have been performed. A configuration based on 2 protons and 4 neutrons (2, 4) in $g_{9/2}$ orbital forms the lowest collective band up to $I = 24\hbar$. A well deformed, oblate shape with ($\epsilon_2 = 0.29, \gamma = -60°$) was predicted for this configuration up to $I = 12\hbar$. This is consistent with the assumption of an oblate shape in the CSM calculations discussed above. Above $I = 12\hbar$, ϵ_2 decreases and shape becomes triaxial. The Q_{t} values for the yrast band calculated using various ϵ_2, γ values, and using the TRS calculations, as a function of frequencies are shown in figure 3. The theoretical values show a decreasing trend with increasing spin, but the decrease is less than that observed experimentally. Q_{t} values corresponding to various energy minima obtained from the TRS calculations are also plotted in figure 3. The calculated values show a spread around the experimental values for $\hbar\omega < 0.6$ MeV. The experimental values lie between the triaxial and the non-collective oblate minima for $\hbar\omega > 0.6$ MeV. This suggests mixing of both the configurations at high spins in ^{78}Kr.

In conclusion, the observed band crossings are understood from the cranked shell model calculations under the assumption of oblate deformation at lower spins. The variation in Q_{t} values is qualitatively understood within the framework of configuration dependent shell correction calculations which predicts the triaxial shape for $I > 12^{+}$. Further support for a triaxial shape at higher spins is also provided by TRS calculations.

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