Structure of the four quasiparticle band in ^{84}Sr

S. Chattopadhyay, H.C. Jain, and M.L. Jhingan
Tata Institute of Fundamental Research, Bombay 400 005, India

C.R. Praharaj
Institute of Physics, Bhubaneswar 751 005, India
(Received 24 January 1994; revised manuscript received 28 February 1994)

The high spin levels in ^{84}Sr have been populated through the ^{59}Co(^{28}Si,3p) reaction using 98 MeV ^{28}Si beam. A regular band structure was found to develop above the 12^+ state with a deformation parameter $\beta = 0.21 \pm 0.04$ and $\gamma = 8° \pm 6°$. The projected Hartree-Fock calculations predict a two proton and two neutron aligned configuration for this band. The predicted quadrupole moment for this configuration is also in good agreement with the experimental values obtained from the lifetime measurements. In addition, a large enhancement in $B(M1)/B(E2)$ transition rates has been observed in the negative parity band above the 11^- state.

PACS number(s): 21.10.Re, 23.20.−g, 21.60.Jz, 27.50.+e

The structure of nuclei in mass-80 region is primarily determined by the $1g_{9/2}, 2p_{1/2}$, $1f_{5/2}$, and $2p_{3/2}$ orbitals of which the $1g_{9/2}$ orbital is predominantly responsible for the observed deformation in this mass range. The neutron deficient even-even nuclei with $Z \sim 36$–40 are the ideal candidates for studying the variation of nuclear deformation as a function of angular momentum and excitation energy because the ground-state configurations with the protons occupying the $1f_{5/2}$ and $2p_{3/2}$ orbitals lead to a low nuclear deformation whereas the alignment of protons in $1g_{9/2}$ orbital gives rise to a substantial deformation at higher excitation energy and angular momentum. The aligned bands with the large deformation parameter $\beta \sim 0.4$ have been observed for a number of nuclei in this mass range, namely ^{74}Br [1] and ^{82}Sr [2]. The alignment of a pair of protons in the low-Ω $g_{9/2}$ orbital also leads to a sudden increase in the $B(E2)$ transition rates. The abruptness of these changes makes these nuclei the ideal testing ground for the nuclear structure models.

The motivation in the present work was to extend the existing level scheme of ^{84}Sr [3] to higher spins and excitation energies and investigate the electromagnetic properties of the high spin states. The positive parity band has been established up to a spin of 20^+ and excitation energy of 11 MeV. This is in agreement with the levels reported by Lister *et al.* [4]. However, the negative parity band has been extended up to $I = 14^-$ for the first time. In addition, the structure of the high spin levels in ^{84}Sr has been probed through a measurement of their lifetimes for the first time.

The high spin states in ^{84}Sr were populated through the ^{59}Co(^{28}Si,3p) reaction using 98 MeV ^{28}Si beam from the 14-UD Pelletron accelerator at Tata Institute of Fundamental Research, Bombay. The γ-γ coincidence data were collected with an array of five Compton suppressed HPGe detectors. Each event was qualified with a two-fold trigger from a multiplicity filter consisting of eight NaI(Tl) detectors to reduce the radioactivity background. The data were collected with two targets: one prepared by evaporating a 250 μg/cm^2 thick Co film on a 6 mg/cm^2 thick Au backing and the other was a thin self-supporting 540 μg/cm^2 thick Co foil. The backed target data had a substantial radioactive contamination due to the decay of the 6^+ isomeric level at an excitation energy $\sim$ 500 keV in ^{84}Y [5]. Therefore, the in-beam γ-ray intensities were estimated from the data obtained with the self-supporting target. The γ-ray energies, their relative intensities, spins and parities of the levels in both the positive and the negative parity bands are listed in Table I.

Figure 1(a) shows the coincidence spectrum with 1040 keV gate for the positive parity band where the γ transitions with energies up to 1635 keV can be identified. Figure 1(b) shows the 415 keV γ-ray gated spectrum. This transition has been placed in the negative parity band. The previously known transitions of the negative parity band with energies 719, 1148, 808, and 625 keV are all clearly visible in this gate. In addition, it shows a strong coincidence with 433 keV transition. These two transitions have been placed above the previously known 12^- state from the intensity considerations. The multipolarities of the new transitions were determined through a measurement of the directional correlation orientation (DCO) ratios. The details of the different experimental facilities are given in Ref. [5]. The deduced level scheme is shown in Fig. 2. The energy levels populated in the radioactive decay of ^{84}Y isomer are not shown.

The aligned quasiparticle angular momentum i_x and the kinematic moment of inertia $J^{(1)}$ for the yrast positive parity high spin band (labeled as band 1 in Fig. 2) have been plotted as a function of the rotational frequency $\hbar\omega$ in Fig. 3. The predominantly two-neutron aligned character of the 3331.5 keV 8^+ state in band 2 and the two-proton aligned character of the 3679.6 keV 8^+ state in band 1 have been established through the g-factor measurements [6]. The irregular behavior of the $J^{(1)}$ and alignment plots at lower frequencies for band 1 primarily indicate quasiparticle alignments. There is also an interaction between the close lying similar spin states of the two bands which is borne out from the presence of the $8_1^+ \rightarrow 8_2^+$ (348 keV), $10_1^+ \rightarrow 10_2^+$ (86 keV), and

0556-2813/94/50(1)/93(6)/$06.00

TABLE I. γ energies and relative intensities, level energies, spins, and parities in ^{84}Sr.

E_I (keV)	E_γ (keV)	I_i^π	I_f^π	I_γ (%)
793.1	793.1(1)	2^+	0^+	100(2)
1767.5	974.4(1)	4^+	2^+	80(2)
2768.7	1001.2(1)	5^-	4^+	19(1)
2807.6	1040.1(1)	6^+	4^+	60(2)
3041	272(1)	5^-	5^-	< 1
3279	510(1)	6^-	5^-	< 1
3279	238(1)	6^-	5^-	< 1
3331.5	523.9(1)	8^+	6^+	31(1)
3487.6	718.9(1)	7^-	5^-	19(1)
3487.6	680.0(2)	7^-	6^+	4.0(4)
3679.6	872.0(1)	8^+	6^+	17(1)
3679.6	347.9(1)	8^+	8^+	5.0(4)
4447.2	1115.7(2)	10^+	8^+	23(2)
4533.6	854.0(1)	10^+	8^+	21(1)
4533.6	86.3(2)	10^+	10^+	3(1)
4635.8	1148.2(2)	9^-	7^-	22(1)
5444.1	808.3(1)	11^-	9^-	24(1)
5444.1	996.9(1)	11^-	9^-	7(1)
5652.9	1119.3(2)	12^+	10^+	15(1)
5652.9	1205.6(3)	12^+	10^+	6(1)
5891	1444(1)	12^+	10^+	5(1)
6069.0	624.9(2)	12^-	11^-	12(1)
6484.1	415.1(2)	13^-	12^-	8(1)
6484.1	830.9(2)	13^-	12^+	< 1
6484.1	830.9(2)	13^-	11^-	< 1
6739.2	1086.3(3)	14^+	12^+	17(2)
6916.6	432.5(3)	14^-	13^-	6(2)
8005.7	1266.5(5)	16^+	14^+	12(2)
9424	1418(1)	18^+	16^+	8(2)
11059	1635(2)	20^+	18^+	5(2)

$12_1^+ \rightarrow 10_2^+$ (1206 keV) transitions. However, it is interesting to note that the rapid variations in $J^{(1)}$ values vanish beyond $\hbar\omega \sim 0.54$ MeV and it remains almost constant at 24.4 MeV$^{-1}\hbar^2$—thereby indicating a near rigid rotor behavior over a frequency interval of about 0.3 MeV. The gain in the aligned quasiparticle angular momentum for $\hbar\omega \sim 0.42$ to 0.54 MeV is $\sim 8\hbar$ which is a characteristic of a four quasiparticle alignment in this mass region.

The structure of the states in the four quasiparticle aligned band has been probed through a measurement of their lifetime through the Doppler shift lineshape analysis for γ rays belonging to the new band. Figure 4 shows the fitted lineshapes at 45° with respect to the beam direction for the 1086, 1267, 1418, and 1444 keV transitions extracted from the γ-γ coincidence data obtained with the backed target. The lineshape of the γ-ray deexciting the topmost 11 059 keV (20+) level was fitted without considering any side feeding or feed from above. This gave an effective lifetime of 0.20±0.06 ps for this level. The lineshapes of γ transitions deexciting lower states were fitted with value of the feeding time equal to the effective lifetime of the level just above the level of interest. The side feeding from unobserved levels was also taken into account and its contribution was determined from

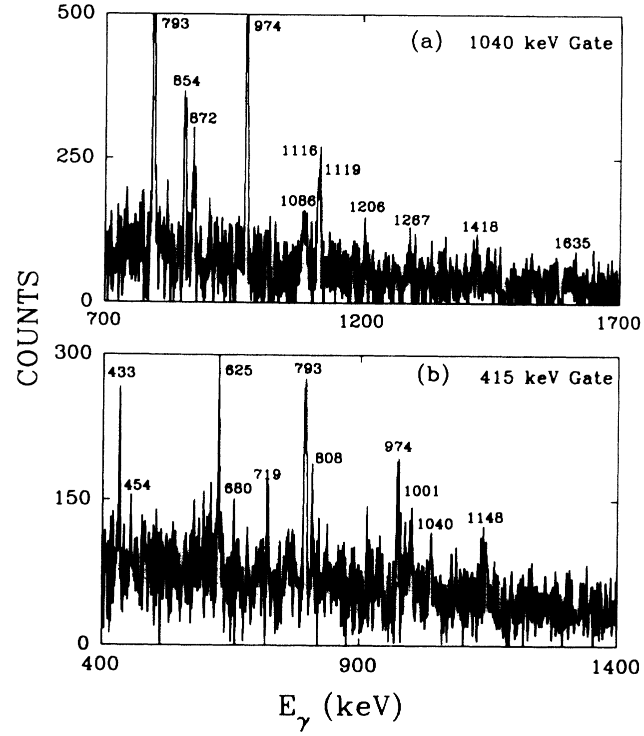

FIG. 1. The γ-ray spectra observed with the self-supporting ^{59}Co target in coincidence with (a) 1040 keV transition which belongs to the positive parity band; (b) 415 keV transition which belongs to the negative parity band of ^{84}Sr.

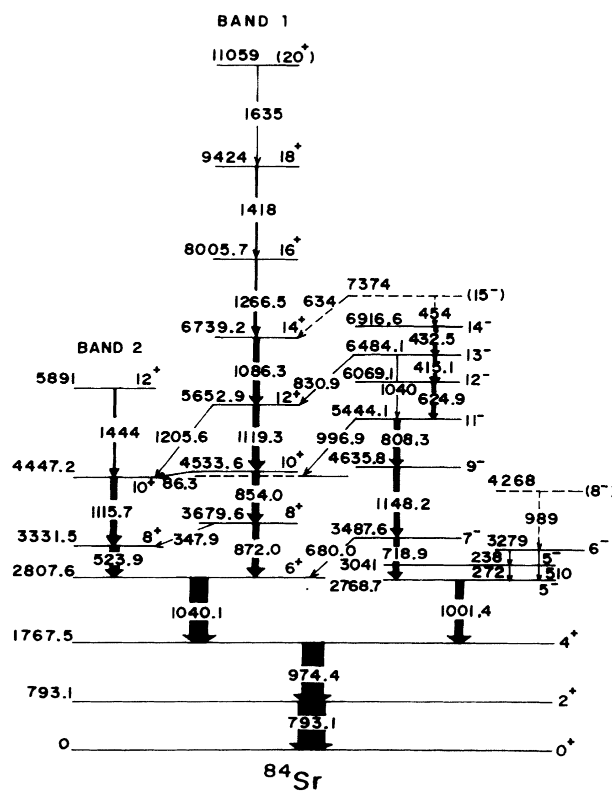

FIG. 2. The partial level scheme for ^{84}Sr. The width of the arrows indicate the transition intensities.

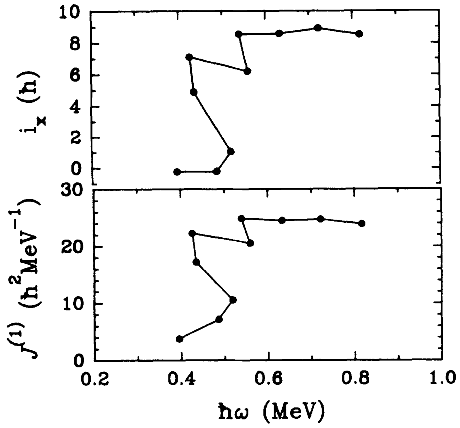

FIG. 3. The aligned angular momentum i_x and kinematic moment of inertia $J^{(1)}$ as a function of rotational frequency $\hbar\omega$ for the positive parity bands in ^{84}Sr.

the measured γ-ray intensities. This side feeding from the unobserved levels was $\sim$ 30% of the total intensity and was assumed to be prompt. However, a side feeding time $\sim$ 0.050 ps does not change the values of the experimental lifetimes within errors. Table II gives the lifetime values for levels in ^{84}Sr measured in the present work and also those obtained from Ref. [3]. It is to be noted that the lifetime value for the 6^+ state estimated through the lineshape analysis is in good agreement with the value quoted in Ref. [3] which was obtained through the recoil distance method. The value for the 12^+ state also matches within the error limits. The data obtained in a recoil distance experiment performed during the present work using the ^{28}Si+^{59}Co reaction did not give useful results for ^{84}Sr due to a large contribution to the intensities of the 793, 974, and 1040 keV γ rays from the decay of the high spin isomer in ^{84}Y. In view of the relatively large $B(E2)$ values reported for the 2^+ and 4^+ states, the RDM data in Ref. [3] was read and reanalyzed. A three level formula was used for the reanalysis. The lifetimes of the top feeding levels and their relative intensities were

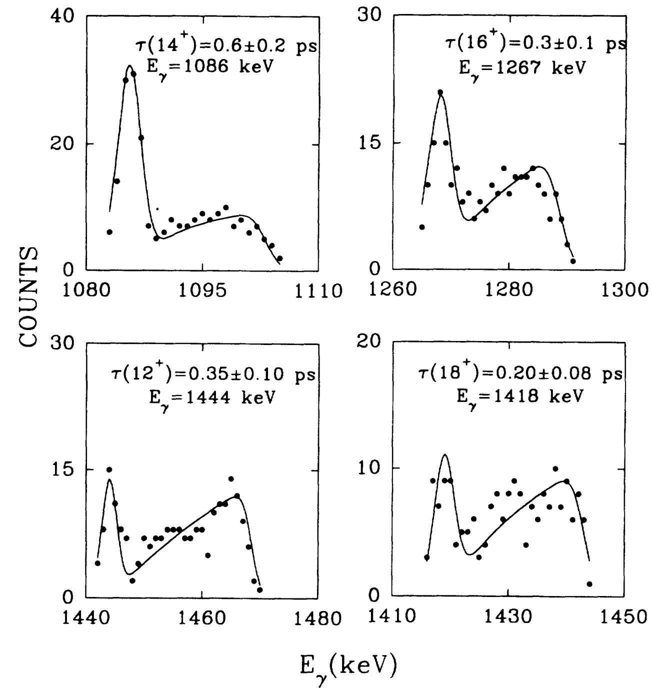

FIG. 4. Lineshapes of γ rays deexciting the 6739 keV (14^+), 8006 keV (16^+), 5891 keV (12^+), and 9424 keV (18^+) states obtained from γ-γ coincidence spectra at 45° with respect to the beam direction. The solid lines are the best fit using Doppler shift attenuation simulations.

TABLE II. Lifetimes, $B(E2)$ and $B(M1)$ values in ^{84}Sr.

$E_x(I^\pi)$ (keV)	E_γ (keV)	τ^a (ps)	τ^b (ps)	$B(E2)$ (fm^4e^2)	$B(E2)$ W.u.	$B(M1)$ $(e\hbar/2mc)^2$	$B(M1)$ W.u.
$793(2^+)$	793	4.6(5)	$9(3)^d$	290(95)	13(4)		
$1768(4^+)$	974	2.5(3)	$6(2)^d$	155(50)	7(2)		
$2808(6^+)$	1040	1.5(3)	1.4(4)	450(90)	20(4)		
$3332(8^+)$	524	266(7)	$235(5)^d$	92(3)	4.2(2)		
$3680(8^+)$	872	4.8(2)		270(10)	12(1)		
$4447(10^+)$	1116	3.2(5)		150(20)	7(1)		
$4534(10^+)$	854	2.4(2)		750(60)	34(3)		
$5653(12^+)$	1119	1.2(4)	0.7(3)	$290(100)^a$	13(4)		
				500(200)b	23(9)		
$5653(12^+)$	1206	1.2(4)	0.7(3)	$62(20)^a$	3(1)		
				105(45)b	5(2)		
$5891(12^+)$	1444		0.35(15)	290(110)	13(6)		
$6739(14^+)$	1086		0.6(2)	885(290)	40(12)		
$8006(16^+)$	1267		0.3(1)	814(270)	37(12)		
$9424(18^+)$	1418		0.20(8)	635(250)	29(12)		
$11059(20^+)$	1635		0.20(6)c				
$6069(12^-)$	625		0.6(2)			0.38(13)	0.23(8)
$6484(13^-)$	415		0.9(4)			0.9(4)	0.5(2)

[a]Reference [3].
[b]Present work.
[c]Effective lifetime.
[d]Reanalysis of data in Ref. [3].

fixed from the values reported in Ref. [3]. Our reanalysis gave an agreement with the reported values for the lifetimes of the 3332 keV (8^+) level and the 2808 keV (6^+) level. However, the reported values for the 4^+ and 2^+ states could not be reproduced. The best fits gave the values of $\tau = 6 \pm 2$ ps and $\tau = 9 \pm 3$ ps for the 4^+ and 2^+ states, respectively. The $B(E2)$ values corresponding to these lifetimes are listed in Table II and also plotted in Fig. 7. These values are relatively smaller compared to the $B(E2)$ values for the 4^+ and 2^+ states as listed in Ref. [3].

The measured lifetimes for the high spin states gave an average value of $Q_t = 1.5 \pm 0.3$ eb for the quadrupole moment for the four quasiparticle band. The measured quadrupole moment, Q_t, and rigid body moment of inertia, $J^{(1)}$, for $\hbar\omega \geq 0.54$ MeV have been used for the determination of the shape parameters β and γ through the simultaneous solution of equations for Q_t and $J^{(1)}$ [7] given by

$$Q_t = [3/(5\pi)^{1/2}]ZeR_0^2\beta\cos(30^\circ + \gamma)/\cos 30^\circ \ , \quad (1)$$

$$J^{(1)} = (2/5)AR_0^2[1 - (5/4\pi)^{1/2}\beta\cos(120^\circ + \gamma)] \ , \quad (2)$$

where $R_0 = 1.2A^{1/3}$. This gave a value of $\beta = 0.21 \pm 0.04$ and $\gamma = 8^\circ \pm 6^\circ$ for the shape parameters thereby establishing a near prolate deformation for the high spin band I in ^{84}Sr.

In the present work we have used the Hartree-Fock and projected Hartree-Fock formalism where the good angular momentum states are projected out from the intrinsic configurations. The details of the model are given in Ref. [8]. The calculations were carried out for 10 protons and 16 neutrons occupying the shell-model configuration space of $2p_{3/2}$, $2p_{1/2}$, $1f_{5/2}$, $1g_{9/2}$, $1g_{7/2}$, $2d_{5/2}$, $2d_{3/2}$, $3s_{1/2}$, and $1h_{11/2}$ with the corresponding single particle energies 0.19, 0.45, 0.0, 3.43, 10.39, 8.83, 12.26, 11.28, and 12.26 MeV, respectively. The surface-delta interaction with the strengths $G_{pp} = G_{nn} = G_{np} = 0.42$ MeV has been used as the two-body nucleon-nucleon interaction. The deformed Hartree-Fock orbits obtained for the lowest prolate solution are shown in Fig. 5. The dotted line in the figure represents the Fermi level for ^{84}Sr. The ground state $K = 0$ configuration was obtained by filling up all the doubly degenerate levels up to the Fermi surface. The other positive parity configurations are obtained by breaking pair(s) of neutrons or/and protons and promoting them to the levels originating from $1g_{9/2}$ orbital. The corresponding bands are obtained by projecting out the good angular momentum states from these intrinsic states using the angular momentum projection operator which is defined for the axially symmetric deformed intrinsic state as

$$P_K^{IM} = \frac{(2I+1)}{2}\int d\beta \sin\beta d_{MK}^I(\beta)e^{i\beta J_y} \ . \quad (3)$$

The projected bands are shown in Fig. 6. The calculations predict that the two-neutron aligned $K = 1$ band ($\Omega_n^\pi = +7/2^+$ and $-5/2^+$) crosses the ground-state

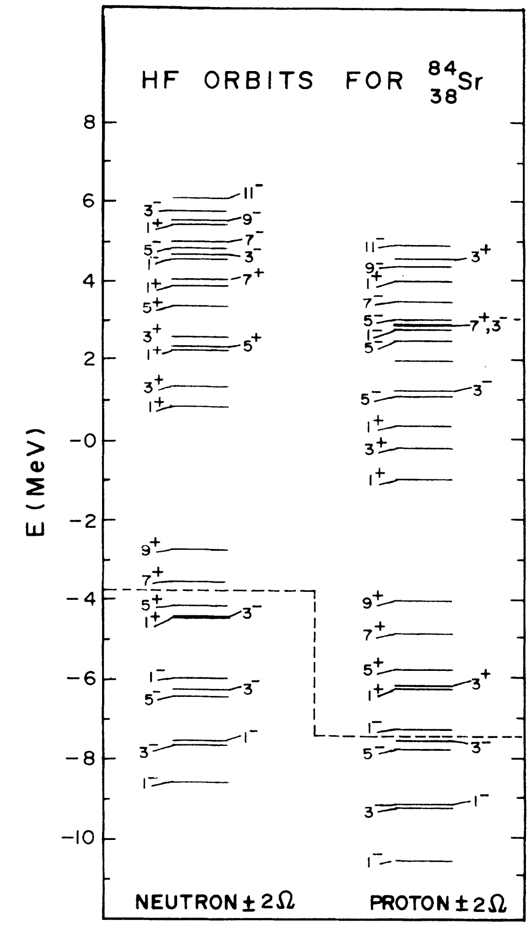

FIG. 5. The lowest prolate HF solutions for ^{84}Sr. Each orbit is doubly degenerate in $\pm\Omega$.

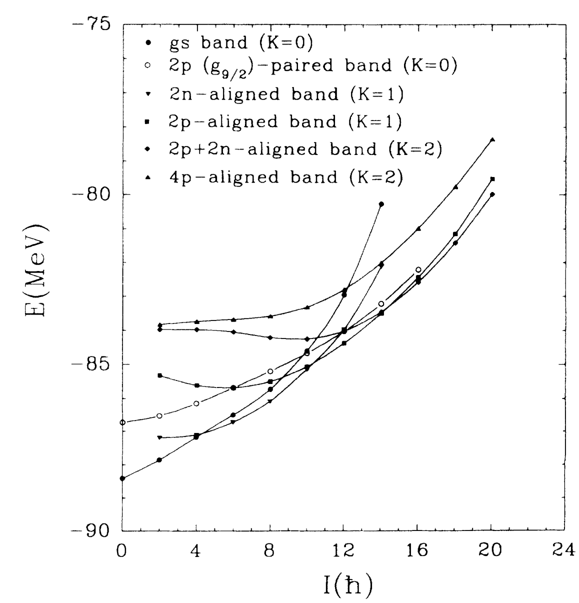

FIG. 6. The signature $\alpha = 0$ component of the lowest bands obtained from the projected Hartree-Fock calculations. The $\alpha = 1$ components are not shown since they are more than an MeV higher in energy.

$K = 0$ band around $I \sim 4\hbar$ while the two-proton aligned $K = 1$ band ($\Omega_p^\pi = +3/2^+$ and $-1/2^+$) becomes yrast beyond $I \sim 10\hbar$. This observation is in reasonable agreement with the experimental situation where, initially, the neutron aligned 8^+ state is lower in energy but at higher spins the proton aligned 12^+ state at 5653 keV state becomes lower in energy compared to the neutron aligned 12^+ state at 5891 keV. An interesting prediction of this calculation is a further band crossing around $I \sim 14\hbar$ corresponding to a two-neutron plus two-proton $K = 2$ band ($\Omega_n^\pi = +7/2^+$ and $-5/2^+$; $\Omega_p^\pi = +3/2^+$ and $-1/2^+$) which matches well with the experimental observation of a four-particle aligned band beyond a spin of $I = 12\hbar$. The lowest four-proton band ($\Omega_p^\pi = -1/2^+, \pm 3/2^+$ and $+5/2^+$) always remains about 2 MeV higher than the $(2p + 2n)$ band as shown in Fig. 6.

As a further check, we have calculated the quadrupole moments for these different configurations. A value of $(e_p)_{\text{eff}} = 1.5e$ and $(e_n)_{\text{eff}} = 0.5e$ has been assumed for the effective charge for protons and neutrons, respectively. The experimental and theoretically predicted $B(E2)$ values are shown in Fig. 7. It is to be noted that the alignment of protons in the low Ω prolate orbitals leads to a sudden increase in the proton contribution to the quadrupole moment from $Q_p = 2.46el^2$ to $7.97el^2$ (where "l" is the harmonic oscillator length parameter given by $A^{1/6}$ fm). This increases the intrinsic quadrupole moment from 0.67 eb to 1.43 eb—thus leading to an increase in the $B(E2)$ transition rates between states belonging to the $2p$-aligned band as compared to the GS band. On the other hand, the alignment of neutrons in the high Ω orbitals reduces the neutron contribution to the quadrupole moment from $2.37el^2$ to $2.00el^2$, thereby slightly reducing the $B(E2)$ transition rates compared to the GS band. This is supported by the experimental observation that the $B(E2)$ values for the $10^+ \rightarrow 8^+$ transition of the $2n$ aligned band is a factor of 5 lower than that of the $2p$ aligned band. In case of the high spin states with $I > 12\hbar$, the $(2p + 2n)$ aligned configuration gives the correct $B(E2)$ values whereas the $4p$

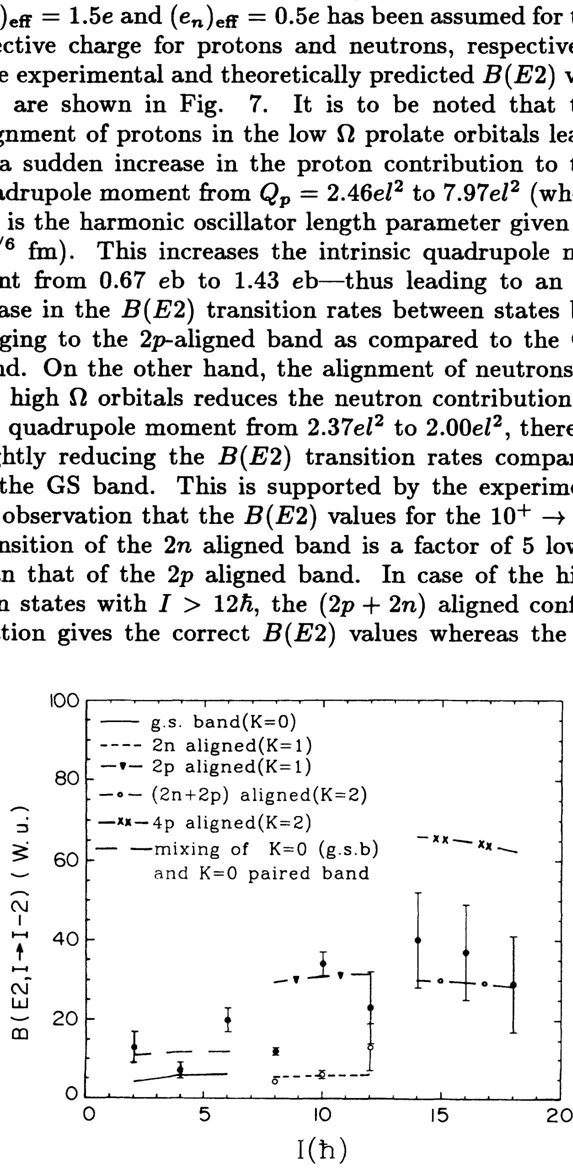

FIG. 7. The $B(E2)$ transition rates in ^{84}Sr in the positive parity bands. The lines show the predictions of PHF calculations for various configurations as mentioned in the figure.

aligned configuration leads to much higher $B(E2)$ values compared to the present measurements. This provides further support for an assignment of $(2p + 2n)$ aligned configuration for the four quasiparticle high spin band in ^{84}Sr. It is seen that there is a drop in the experimental $B(E2)$ value for the $2p$-aligned 8^+ state compared to the 10^+ and 6^+ state. This is due to a difference between the structure of the 8^+ and 6^+ states—the latter being a member of the $K = 0$ GS band. A similar argument provides an understanding for the possible dip in the experimental $B(E2)$ value for the 5653 keV $(12^+) \rightarrow 4534$ keV (10^+) transition since the 12^+ state is a member of the $(2p+2n)$ aligned configuration whereas 10^+ state has the $2p$ aligned configuration.

As discussed earlier, the reanalysis of the lifetime data in Ref. [3] gave a relatively smaller value for the 2^+ and 4+ states of the ground-state band. The $B(E2)$ value for the 4^+ state is in agreement but the value for the 2^+ and 6^+ states are higher compared to the theoretical value (~5 W.u.) obtained by assuming a pure $K = 0$ GS configuration. It is, however, interesting to note that there is a paired ($K = 0$) configuration with the last pair of protons in the $\Omega = \pm 1/2^+$ level which will have a large quadrupole moment and a $B(E2)$ value ~ 35 W.u. This band (shown in Fig. 6) lies about 1.5 MeV higher and can mix with the ground-state band. A simple estimate of this mixing indicates an increase in the calculated $B(E2)$ values for the GS band to about 11 W.u. This is in reasonable agreement with the experimental $B(E2)$ values for the 2^+ and 4^+ states as shown in Fig. 7. The $B(E2)$ value for the 6^+ state, nevertheless, remains relatively higher. This indicates a larger mixing of the $2p$-paired band, giving rise to a higher collectivity for this state.

In a recent communication, Frauendorf *et al.* [9] have shown that an asymmetric filling of neutrons and protons in the high j orbitals can lead to a forking of the proton and neutron aligned bands due to a repulsive neutron-proton correlation energy obtained for these configurations. ^{84}Sr has an asymmetric filling with neutrons in the upper half and protons filling the lower half of the $1g_{9/2}$ orbitals. Therefore, the observation of two bands built on the two 8^+ states with the $2n$ and $2p$ aligned configurations, respectively, is in agreement with the possible presence of n-p interaction in ^{84}Sr. The presence of n-p interaction is also likely to lead to a mixing of $2p$-aligned configuration in the $2n$-aligned configuration. Thus, there should be interband transition between the proton and neutron aligned bands. The experimental data, indeed, support such a possibility. Thus the observation of the $2p$ and $2n$ aligned bands in ^{84}Sr seems to support the presence of n-p interaction in mass-80 region.

The negative parity band has been extended to an excitation energy of 6917 keV and a spin of 14^- with the addition of 415 and 433 keV $M1$ transitions. The $M1$ multipolarity for the 625 keV transition also confirms the 12^- spin for the 6069 keV level. The measured lifetimes (see Table II) indicate $B(M1)$ values lying between 0.15 to 0.7 W.u. for the 12^- and 13^- levels. It should be noted that $M1$ transitions are absent for states between the 11^- and 6^- states. On the other hand, there is a sudden drop in the 13^- to 11^- $E2$ transition intensity and the 14^- to 12^- transition is absent. In other words, the $B(M1)/B(E2)$ ratio shows a sharp increase above the $I = 11^-$ state and the levels also seem to have a regular behavior of a band beyond the 12^- state. The $B(M1)$ values below the 11^- states are expected to be small because of small g factors for these states, e.g., the g factor of the 4636 keV (9^-) state has been experimentally measured to be $g = 0.00(4)$ [6], indicating a predominantly neutron configuration for these states. On the other hand, the large $M1$ transition rates above the 11^- state can be understood in the framework of the semiclassical model by Dönau and Frauendorf [10] as arising due to occupation of high Ω (7/2,9/2) components of the $g_{9/2}$ orbital by two protons. This is possible if the nucleus develops an oblate deformation. Out of the two possible K values ($= \Omega_p \pm \Omega_n$), the $K = 1$ configuration gives a $B(M1)$ value ~ 0.01 $(e\hbar/2mc)^2$, whereas the predicted $B(M1)$ value for $K = 8$ is ~ 1.2 $(e\hbar/2mc)^2$ for the 13^- state. The experimental $B(M1)$ value of 0.9 ± 0.4 $(e\hbar/2mc)^2$ clearly favors the high K configuration. It can be emphasized here that a prolate deformation will lead to an occupation of low $\Omega(1/2, 3/2)$ orbitals and consequently a small $K(= 1$ or $2)$ configuration. Thus, a prolate deformation will predict a much smaller $B(M1)$ compared to the experimental value. The present experimental results, therefore, seem to indicate a high K configuration with an oblate deformation for states above the 12^- level. This conclusion, however, needs further confirmation through an identification of more transitions in this band.

In conclusion, the positive parity band originating at $I = 12\hbar$ in ^{84}Sr has been found to have the shape parameters $\beta = 0.21 \pm 0.04$ and $\gamma = 8° \pm 6°$ from the present lifetime measurements of the levels and the moment of inertia of the band. The microscopic PHF calculations provide a reasonable description for the high spin behavior of ^{84}Sr. They are in good agreement with the observed $B(E2)$ values for the neutron-aligned and the proton-aligned configurations and predict a $(2p+2n)$ aligned configuration with a prolate deformation for the four quasiparticle aligned band in ^{84}Sr. The observed increase in the $B(M1)/B(E2)$ values in the negative parity band can probably be attributed to an alignment of protons in the high Ω components of $g_{9/2}$ orbitals leading to a high K oblate band.

[1] J. W. Holcomb, T. D. Johnson, P. C. Womble, P. D. Cottle, S. L. Tabor, F. E. Durham, and S. G. Buccino, Phys. Rev. C **43**, 470 (1991).

[2] C. Baktash *et al.,* Phys. Lett. B **255**, 174 (1991).

[3] A. Dewald, U. Kaup, W. Gast, A. Gelberg, H. W. Schuh, K. O. Zell, and P. Von Brentano, Phys. Rev. C **25**, 226 (1982).

[4] C. J. Lister, P. Choudhury, and D. Vretenar, Nucl. Phys. **A557**, 361c (1993).

[5] S. Chattopadhyay, H. C. Jain, S. D. Paul, J. A. Sheikh, and M. L. Jhingan, Phys. Rev. C **49**, 116 (1994).

[6] A. I. Kucharska, J. Billowes, and C. J. Lister, J. Phys. G **15**, 1039 (1989).

[7] H. G. Price, C. J. Lister, B. J. Valey, and W. Gelletly, Phys. Rev. Lett. **61**, 1842 (1983).

[8] A. K. Rath, C. R. Praharaj, and S. B. Khadkikar, Phys. Rev. C **47**, 226 (1993).

[9] S. Frauendorf, J. A. Sheikh, and N. Rowley, Phys. Rev. C **50**, 196 (1994).

[10] F. Dönau and S. Frauendorf, in Proceedings of the Conference on High Angular Momentum Properties of Nuclei, Oak Ridge, Tennessee, 1982, edited by N. R. Johnson (Harwood Academic, Chur), p. 143.