High spin states in ^{78}Rb

G. C. Hicks,* C. J. Gross, U. J. Hüttmeier, Xi-Ting Lu,† G. Neuschaefer, and S. L. Tabor
Department of Physics, Florida State University, Tallahassee, Florida 32306
(Received 27 February 1984)

High spin states have been studied in ^{78}Rb using the ^{54}Fe(^{28}Si,3pn)^{78}Rb and ^{56}Fe(^{28}Si,αpn)^{78}Rb reactions at laboratory energies of 103.5 and 108 MeV. γ-γ coincidence and γ-ray angular distribution measurements were performed. New states were found at 1511[$10^{(-)}$], 1908[$11^{(-)}$], 2929[$13^{(-)}$], 4143[(15^-)], and 1004[$8^{(-)}$] keV above the bandhead state. The latter state is probably the $4^{(-)}$, 5.74 min isomeric state whose excitation energy lies somewhat above 103 keV. The states populated in this reaction group into two decay sequences which appear to be rotational bands. The moment-of-inertia parameter $\hbar^2/2\mathscr{I}$ is about 20 keV. There is a close similarity to the level structure of ^{76}Br.

I. INTRODUCTION

This investigation of the yrast levels in ^{78}Rb is part of a continuing study[1–5] of the collective properties of nuclei in the mass 80 region using heavy-ion fusion-evaporation reactions. There is increasing evidence[1–10] that the neutron deficient nuclei with about 40 protons and neutrons are strongly deformed and can provide new information about rotational motion in nuclei. For example, band crossings involving a change of signature splitting have recently been reported in ^{81}Kr (Ref. 10) and ^{81}Sr.[3]

Some evidence of band structure has been reported[11] in ^{78}Rb. A sequence of states was observed up to five units of angular momentum above the bandhead. The bandhead is believed to be a 6 min isomer with $J=4$. The sequence of levels is rather similar to one seen in ^{76}Br,[12,13] another nearby odd-odd nucleus. It has also been compared to the $K^\pi=\frac{5}{2}^+$ band in ^{77}Kr.

^{78}Rb was produced in the present work using the ^{56}Fe(^{28}Si,αpn)^{78}Rb and ^{54}Fe(^{28}Si,3pn)^{78}Rb reactions at 103.5 and 108 MeV. γ-ray angular distributions and decay curves and γ-γ coincidence spectra were measured with both reactions. Because ^{78}Rb was produced strongly in two different reactions, we have analyzed the two data sets separately to provide a consistency check and a means of estimating uncertainties. Our results on ^{78}Rb agree with those of Mariscotti *et al.*[11] and extend the two sequences of levels they reported up to probable spins of 8 and 15.

II. EXPERIMENTAL PROCEDURE

^{28}Si beams were accelerated to energies of 103.5 and 108 MeV with the Florida State University Super FN tandem accelerator. The negative ^{28}Si ions were stripped to a charge state of 9^+ in the terminal of the tandem. Midway down the high-energy column they were stripped again[14] to a charge state of 12^+ or 13^+ for the 103.5- or 108-MeV beams, respectively. Typical beam currents on target were 5–15 nA. The targets consisted of about 400 μg/cm^2 of iron evaporated onto a gold foil. Natural iron (92% ^{56}Fe) was used for the ^{56}Fe target, while isotopically enriched iron (93% ^{54}Fe) was used for the ^{54}Fe target.

TABLE I. The relative yields of coincident γ rays in the yrast decay sequences in ^{78}Rb measured with the ^{54}Fe(^{28}Si,3pn)^{78}Rb reaction at 108 MeV. These values have been corrected for the relative efficiencies of both γ detectors.

Gate	E_γ (keV)													
(keV)	153	155	186	245	308	366	398	406	430	552	773	805	1021	1214
153		126	27	66		60	37	23	59	23	38	27	45	
155	116		48	83		79	44	16	74	20	68	29	81	
186	23	50		63	12	a	30	19			47	52	21	
245	66	68	43		24	26	19	12		20	20	23	39	
308			30	32		30	11	9	29		22	15	22	
366	67	48	a	50	28		33	28	54			88	54	
398	a	a	18	18	10	26		13	34	14	63			
406	5	7	3			7	2							
430	54	45			51	46	18	9			48	37		
552	12	8		27	8									
773	34	32	17	20		21	59		46				13	
805	25	25	32	26		62			21	24				
1021	81	77	25	73	25	73	47		142	94	72	40		
SUM[b]	268	191	205	200	72	332	117	48	124	87	184	197	298	87

[a]Obscured by false coincidences due to Compton scattering between the detectors.
[b]Sum of the 155, 186, 245, 366, and 430 keV gates.

The γ rays were detected with two lithium-drifted germanium [Ge(Li)] detectors with energy resolutions of 2—3 keV and relative efficiencies [compared to a 7.6×7.6 cm NaI(Tl) detector] of 19% and 27% for 1.33 MeV γ rays. Conventional fast-slow timing techniques were used for the γ-γ coincidence measurements, and the results were recorded event by event on magnetic tape for subsequent off-line analysis. The detectors were placed at 90° to the beam direction and the real to random coincidence ratio was greater than 25.

To sort the γ-γ coincidence data, digital gates were set on each detector for a given γ ray, and the resulting coincidence spectra were added together, after compensating for small differences in the energy calibrations. In addition, spectra in coincidence with equal-width background gates were subtracted to approximately remove the background from Compton-scattered events.

The γ-ray angular distributions were measured by moving the 27% efficient detector to angles of 0°, 35°, 55°, and 90° relative to the beam. The measured angular distributions were least-squares fitted to the series of Legendre polynomials:

$$Y(\theta)=A_0[1+a_2P_2(\cos\theta)+a_4P_4(\cos\theta)]\ .$$

γ spectra were also measured at various time intervals after the beam was removed from the target to construct decay curves of the β-decay activities.

III. γ-γ COINCIDENCE MEASUREMENTS

As mentioned before, we have treated the ^{78}Rb data from the two reactions separately. The results of the γ-γ coincidence measurements on ^{78}Rb from the ^{54}Fe + ^{28}Si reaction are summarized in Tables I and II, while those from the ^{56}Fe + ^{28}Si reaction are given in Tables III and IV. The coincidence yields in these tables have been corrected for the energy dependence of the relative efficiencies of both detectors—the one in which the gate was placed and the one in which the coincident peak yield was integrated. The absence of an entry in these tables indicates the absence of a convincing peak. In some cases, poor statistics or contaminant lines may have obscured peaks which would be expected to be present.

All of the entries in Tables I—IV are based on individual coincidence spectra, except the lines labeled "SUM." The latter come from spectra summed from the

TABLE II. The relative yields of coincident γ rays in the yrare decay sequence in ^{78}Rb measured with the ^{54}Fe(^{28}Si,3pn)^{78}Rb reaction at 108 MeV. These values have been corrected for the relative efficiencies of both γ detectors.

Gate	E_γ (keV)						
(keV)	153	225	278	348	377	503	626
153		69	32	12		29	12
225	69		41	59			17
278	23	48		21	33		
348	14	9	10				
377			33				
626	7	11					

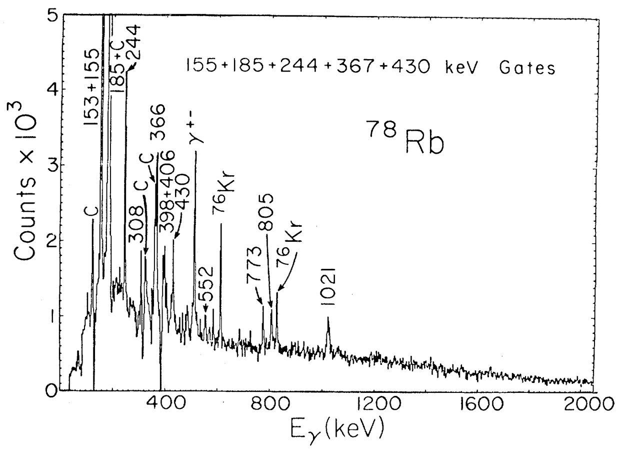

FIG. 1. The spectrum of γ rays in coincidence with other γ rays of 155, 186, 244, 366, and 430 keV produced in the bombardment of ^{54}Fe with ^{28}Si at 108 MeV. γ rays in ^{78}Rb are labeled with their energy in keV. Those in other nuclei are labeled by the nucleus. The lines labeled "C" result from Compton scattering of strong singles γ rays from one detector into the other.

155, 186, 245, 366, and 430 keV coincidence gates. This sum improves the statistical accuracy for determining intensities, energies, and branching ratios as well as for displaying the data. These summed coincidence spectra for the yrast cascade are shown in Figs. 1 and 2 for the ^{54}Fe and ^{56}Fe targets, respectively. Similar sums were not useful for the yrare cascade because fewer gates are involved and one, the 278 keV gate, is dominated by γ rays from Coulomb excitation of the Au backing.

The ^{78}Rb level and decay scheme implied by these coincidence measurements is shown in Fig. 3. The lower portion of this decay scheme is in agreement with that deduced by Mariscotti et al.[11] They have reported states up to $1105+x$ keV in the yrast sequence and up to $656+x$ keV in the yrare sequence. We have observed all the γ rays which they reported, as well as ones at 503 and 552 keV. A possible 400 keV transition between the $553+x$

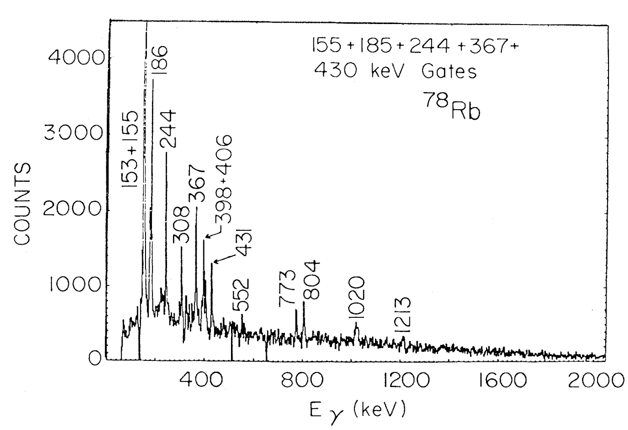

FIG. 2. The spectrum of γ rays in coincidence with other γ rays of 155, 186, 244, 366, and 430 keV produced in the bombardment of ^{56}Fe with ^{28}Si at 108 MeV.

TABLE III. The relative yields of coincident γ rays in the yrast decay sequence in ^{78}Rb measured with the ^{56}Fe(^{28}Si,αpn)^{78}Rb reaction at 108 MeV. These values have been corrected for the relative efficiencies of both γ detectors.

Gate (keV)	153	155	186	245	308	366	E_γ (keV) 398	406	430	552	773	805	1021	1214
153		68	22	39		38	29	11	38	3	28	11	51	
155	74		29	51		45	34	18	36	12	21	41	34	25
186	20	30		36	7	32	19				30	16	11	
245	63	85	61		38	35	26			24	30	37	22	
308			16	25		15			28		39			
366	60	86	46	38	26		11	34				60	59	
398	32	55	19	16		18			25		19		51	
430	47	62			57	62	33	10			47	85	32	
773	26	53	26	26		28	86		77					
805	15	26	24	19	17	27	14		24					
1021	36	45	9	22			24		55	16				
SUM	230	243	136	170	115	244	179	108	144	43	145	181	304	188

and $153+x$ keV states has not been drawn in Fig. 3 because the evidence for it is weak. Its energy it too close to be adequately resolved from the 398 keV γ ray and it appears to be present in the 805 keV coincidence gate in only one of the two measurements (Tables I and II). In addition, we have observed a number of transitions from energy levels higher than those reported by Mariscotti *et al.*[11] The question of the spin and excitation energy of the bandhead will be discussed in Sec. V.

The new levels are generally well supported by the observed coincidence relations. There is a small possibility that the 1021 keV transition ends on the 10^- rather than the 11^- level. A 1021 keV peak was seen in the 398 keV gate in the reaction on ^{56}Fe (Table III), but not clearly for the ^{54}Fe target (Table I). Hence, we cannot be certain whether the two transitions are in coincidence. If the 1021 keV transition ended on the 10^- state, a 623 keV $M1$ transition would be possible and would be consistent with the decays of the other states. No evidence has been seen for a 623 keV γ ray in coincidence with other ^{78}Rb lines.

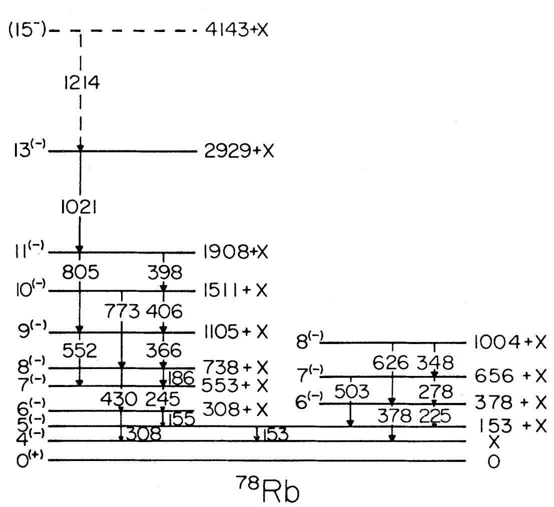

FIG. 3. The level scheme of ^{78}Rb as deduced from the present work and that of Ref. 11. The energies of the states and transitions are listed in keV. The state of unknown energy "x" is discussed in Sec. V.

The 1214 keV transition and $4143+x$ keV level are probable, but not certain. A 1214 keV γ ray is seen clearly in the summed coincidence spectrum on the ^{56}Fe target (Fig. 2), but weakly, if at all, on the ^{54}Fe target (Fig. 1). The 1214 keV γ ray is too weak to be seen in most of the individual coincidence gates and too weak to be used as a coincidence gate. Hence, this transition and the level that it implies are drawn as dashed lines in Fig. 3.

Table V presents a comparison of the γ-ray energies measured in the two parts of this experiment with the earlier results of Mariscotti *et al.*[11] Where possible, the present γ energies were determined from the summed coincidence spectra of Figs. 1 and 2. Yrare γ energies were determined from individual coincidence spectra. The γ-ray energies determined from the two reactions on ^{54}Fe and ^{56}Fe are quite consistent and there is excellent agreement between our averaged values and the results of Mariscotti *et al.*[11] In the latter work γ rays at 397.5 and 405.7 keV were reported, but not placed in the decay scheme. They were unambiguously placed in the present decay scheme because of the observation of crossover transitions.

The branching ratios measured in the present work are listed in Table VI. The γ-ray intensities were determined from the coincidence spectra, especially the summed coincidence spectra where possible. The branching ratios re-

TABLE IV. The relative yields of coincident γ rays in the yrare decay sequence in ^{78}Rb measured with the ^{56}Fe(^{28}Si,αpn)^{78}Rb reaction at 108 MeV. These values have been corrected for the relative efficiencies of both γ detectors.

Gate (keV)	153	225	278	E_γ 348	377	503	626
153		40	16	11		21	9
225	72		35	7			15
278	23	41		7	54		
348	13	9	11			13	
626	12	15					

TABLE V. A comparison of γ-ray energies.

E_γ (keV)			
^{54}Fe target	^{56}Fe target	Average	Previous[a]
152.9	152.7	152.8±0.2	152.6±0.2
155.3	155.0	155.2±0.2	155.2±0.2
185.7	185.8	185.8±0.2	185.6±0.2
225.3	224.8	225.1±0.2	225.0±0.2
244.5	244.6	244.6±0.2	244.4±0.2
278.5	278.1	278.3±0.2	278.5±0.2
308.2	307.9	308.0±0.2	307.7±0.2
347.5	347.7	347.6±0.2	
366.6	366.1	366.4±0.3	366.8±0.2
377.2	376.8	377.0±0.3	377.6±0.2
397.7	397.4	397.6±0.3	397.5±0.2
406.1	405.3	405.7±0.4	405.7±0.2
430.7	429.4	430.2±0.6	429.7±0.2
503.0	503.5	503.2±0.4	
551.7	552.2	552.0±0.4	
625.8	625.5	625.7±0.4	
772.7	773.5	773.1±0.5	
804.5	805.2	804.9±0.7	
1020.4	1021.2	1020.8±0.7	
1212.6	1215.8	1214.2±2.0	

[a]Reference 11.

ported are the averages of those obtained from the two reactions.

IV. ANGULAR DISTRIBUTIONS

The angular distributions of the γ rays were measured at angles of 0°, 35°, 55°, and 90° at a beam energy of 103.5 MeV. The results for some of the ^{78}Rb γ rays obtained using the ^{56}Fe target are shown in Fig. 4. Also shown in this figure are Legendre polynomial fits to the data, as described in Sec. II. The resulting Legendre coefficients averaged from the measurements on the ^{54}Fe and ^{56}Fe targets are listed in Table VII. It was not possible to measure the angular correlations of all of the ^{78}Rb γ rays because some were too weak to stand out clearly in the singles spectra or were overlapped by other, stronger lines.

Because of the alignment produced in heavy-ion fusion-evaporation reactions,[14] the angular distributions of stretched $E2$ transitions have positive a_2 coefficients

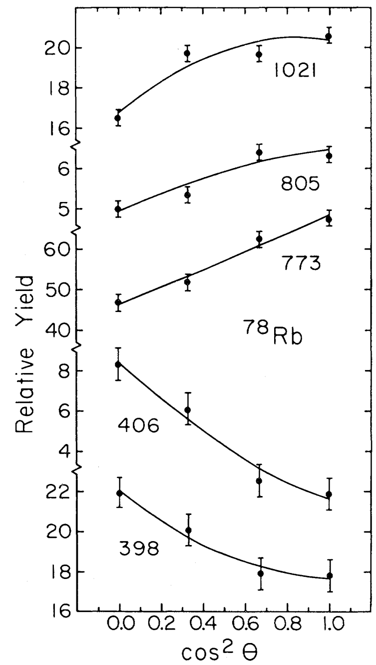

FIG. 4. Angular distributions of some of the ^{78}Rb γ rays measured in the ^{56}Fe + ^{28}Si reaction. The smooth lines represent Legendre polynomial fits.

in the range of 0.2—0.4, while those of predominantly stretched $M1$ transitions have negative a_2 coefficients. The signs of the a_2 coefficients in Table VII agree with those of Mariscotti et al.[11] for all of the transitions they reported. The spin assignments implied by these results are shown in the level scheme of Fig. 3. A reliable angular distribution could not be obtained for the weak 1214 keV γ ray. The tentative spin assignment of 15^- shown in Fig. 3 is based upon the energy vs $J(J+1)$ systematics (see Sec. VI). The uncertainties in the a_4 coefficients are probably larger than the statistical uncertainties listed in Table VII. It is difficult to estimate the nonstatistical errors introduced by the subtraction of the Compton scattering background under peaks. Such errors introduce

TABLE VI. Branching ratios in ^{78}Rb.

E_x (keV)[a]	E_γ (keV)	Branching ratio (%)	E_γ (keV)	Branching ratio (%)
308.0	155.2	70±5	308.0	30±5
377.9	225.1	51±10	377.0	49±10
656.2	278.3	55±12	503.2	45±12
738.4	185.8	55±10	430.2	45±10
1003.8	347.6	28±5	625.7	72±5
1104.8	366.4	82±5	552.0	18±5
1510.5	405.7	32±13	773.1	68±13
1908.1	397.6	44±10	804.9	56±10

[a]Excitation energy above the bandhead.

TABLE VII. Legendre polynomial coefficients for the angular distributions of ^{78}Rb γ rays measured with the ^{54}Fe + ^{28}Si and ^{56}Fe + ^{28}Si reactions at 103.5 MeV.

E_γ (keV)	a_2	a_4
153	−0.37±0.10	−0.01±0.05
155	−0.23±0.10	0.07±0.05
225	−0.46±0.08	0.06±0.07
245	−0.25±0.07	0.02±0.07
308	0.24±0.09	0.15±0.09
366	−0.15±0.08	0.10±0.09
398	−0.16±0.06	0.04±0.06
406	−0.84±0.17	0.13±0.15
430	0.20±0.11	0.08±0.11
773	0.24±0.08	0.06±0.08
805	0.30±0.17	−0.11±0.17
1021	0.14±0.07	0.11±0.07

TABLE VIII. Relative intensities of γ rays from the decay of ^{78}Rb.

E_γ (keV)	I(17.66 m)[a]	I^*(5.74 m)[a]	I(present work)
455	10 000[b]	10 000[b]	10 000[b]
562	1815±15	35±10	c
664	186± 6	4734±45	4850±250

[a]Reference 14.
[b]Normalized to 10 000 counts.
[c]No peak observed.

fluctuations in the angular distributions which affect the higher order Legendre coefficients much more than the lower ones.

The implication that all of the observed levels have the same parity comes from the $\Delta J=2$ crossover transitions. For example, if the $378+x$ keV state had a parity opposite to that of the x keV state, the 378 keV transition would have $M2+E3$ character. If the $M2$ transition strength were as much as 1 W.u., the upper state would have a lifetime[15] in excess of 300 ns and the 378 keV γ ray would have been well outside the coincidence time window. Parentheses have been placed on the parity values of the states in Fig. 3 because the parity assignment of the bandhead is not firm (see Sec. V).

V. THE BANDHEAD STATE

A major question remaining is the nature of the state at the bottom of the observed decay chains, which is probably the bandhead of the yrast rotational band. ^{78}Rb is known[16–18] to have an isomeric state with a half-life ($t_{1/2}$) of 5.74 min, while the ground state (g.s.) has $t_{1/2}=17.66$ min. Mariscotti *et al.*[11] have identified the bandhead with the 5.74 min isomeric state.

To test this identification, we have measured the decay curves and relative intensities of some of the γ rays from the β decay of ^{78}Rb. The following results were obtained from the ^{28}Si + ^{56}Fe reaction at 103.5 MeV, and similar results were observed with the ^{28}Si + ^{54}Fe reaction. Decay curves for the two strongest γ rays are shown in Fig. 5,

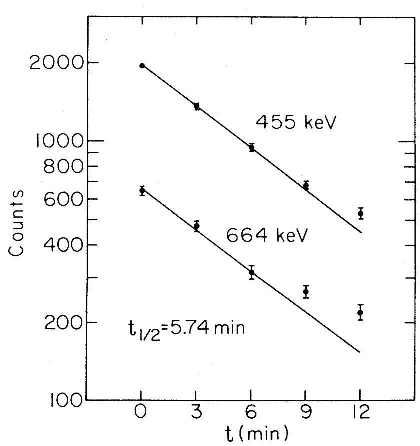

FIG. 5. Decay curves of transitions in ^{78}Kr produced by the β decay of ^{78}Rb. The straight lines represent the expected decay of a single activity with a half-life of 5.74 min.

along with lines representing a decay half-life of 5.74 min. The data agree well with the 5.74 min activity, except at longer times after bombardment. The departures from these lines are more likely to be due to γ rays of similar energies from other nuclei, rather than to a 17.66 min ^{78}Rb component. This is especially true for the 664 keV γ ray which is produced very weakly in the decay of the 17.66 min g.s.

Further evidence that the heavy-ion reactions used in the present work populate predominantly the 5.74 min isomer comes from the relative intensities of the decay γ rays. Table VIII compares the relative intensities of the 455-, 562-, and 664-keV lines immediately after bombardment in the ^{28}Si + ^{56}Fe reaction at 103.5 MeV with the results of Bavaria *et al.*[16] for the two ^{78}Rb activities. We conclude (in agreement with Ref. 11) that the present reactions populate predominantly the 5.74 min isomer and that the observed γ decays in ^{78}Rb must end on that state.

Spins of 0 for the 17.66 min g.s. and 4 for the 5.74 min isomer have been assigned[19,20] in atomic beam measurements. The β-decay measurements[16] strongly favor parity assignments of 0^+ and 4^- for these states. These parity assignments are in agreement with the Nilsson model configurations proposed by Ekström *et al.*[20] These authors have suggested predominant configurations of $0^+\{\pi[422\frac{5}{2}]\nu[422\frac{5}{2}]\}$ and $4^-\{\pi[422\frac{5}{2}]\nu[301\frac{3}{2}]\}$ for the ^{78}Rb g.s. and isomer, based on the active particles in the $\frac{5}{2}^+$ g.s. of ^{79}Rb and the $\frac{5}{2}^+$ g.s. and $\frac{3}{2}^-$ excited state of ^{77}Kr. The measured magnetic moment of the ^{78}Rb 4^- state ($\mu_I=2.56\ \mu_N$) is in close agreement with the theoretical value implied by the proposed configuration.

The remaining question is the excitation energy of the bandhead. A 103 keV transition is known to be associated[16–18] with the ^{78}Rb isomer. Two arguments show that this could not be an $M4$ transition between the 4^- and 0^+ states. First, the internal conversion coefficient[16] for the 103 keV transition is about 0.3, which is consistent with an $M1+E2$ transition, rather than $M4$. Second, the 5.74 min half-life and 8% branching ratio would imply[15] an $M4$ transition strength of 5×10^6 W.u., which is unrealistically large. Even if one of the parity assignments were incorrect, the 103 keV transition would have an unreasonably large $E4$ strength of 10^5 W.u.

Hence, an intermediate state must be involved in the γ decay of the 4^- level, which then lies somewhat above 103 keV. We have followed the convention of Mariscotti *et al.*[11] by labeling the excitation energy of the bandhead as "x." The value of x is probably[15] somewhat larger than 103 keV. A 46.8 keV γ ray has also been observed[14] in the decay of the 4^- isomer, but its placement remains uncertain.

VI. DISCUSSION

Our results for ^{78}Rb are in good agreement with those of Mariscotti *et al.*[11] and extend the level structure to higher spins. Some uncertainty remains about the nature of the bandhead state, but it appears to be the $J=4$, 5.74 min isomeric state which lies somewhat above 103 keV. Its parity is probably odd.

The level scheme of Fig. 3 is relatively simple for an odd-odd nucleus in this region and probably results from the selectivity inherent in the reaction process. The excitation energies of the two independent sequences of decay cascades have been plotted as a function of $J(J+1)$ in Fig. 6. The relative linearity of the graphs suggest a rotational band interpretation of the sequences and a tentative assignment of $J=15$ for the $4143+x$ keV state. The evidence for a yrare rotational band built on the $378+x$ keV state is weaker since only three members of this possible band have been seen. The slope of the curve for the yrast band implies a moment-of-inertia parameter $\hbar^2/2\mathscr{I}$ of about 20 keV. This represents somewhat more deformation than some nearby odd nuclei, such as ^{79}Rb (Refs. 4 and 8) (24 keV), ^{81}Sr (Refs. 1 and 3) (25 keV), ^{77}Kr (Ref. 21) (29 keV), and ^{79}Kr (Ref. 22) (30 keV). A similarity between the level schemes of ^{78}Rb and ^{76}Br has already been pointed out.[11] If the ^{76}Br bandhead also has a spin of $4\hbar$, then the $\hbar^2/2$ value[13] of 21 keV is very close to that of ^{78}Rb.

A number of the even J states lie somewhat below the average line on the $J(J+1)$ plot of Fig. 6, showing a weak signature splitting in the yrast band. A similar effect is seen[13] in ^{76}Br and stronger signature splitting is seen in the positive parity yrast bands of many odd nuclei in this region.

It is not clear why $M1$ transitions were not seen above the 11^- state, although a similar effect may occur[13] in ^{76}Br. Increasing transition energies and collectivity may simply favor $E2$ decays more. It is also possible that the signature splitting changes so as to raise the 12^- and 14^- energy levels, which would reduce the decay probabilities to them. The signature splitting could change as a result of a band crossing, such as has been seen in ^{81}Sr (Ref. 3) and ^{81}Kr (Ref. 10). More evidence is needed to choose between these or other possibilities.

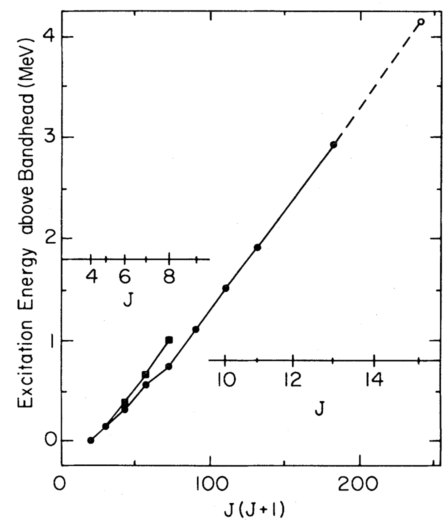

FIG. 6. Excitation energies above the bandhead of the states observed in the present experiment as a function of $J(J+1)$. For convenience, a scale of J is also indicated. The straight line segments merely connect the points.

This work was supported in part by the National Science Foundation.

*On leave from James Cook University, Townsville, Qld 4811, Australia.

†On leave from Peking University, Beijing, China.

[1]L. V. Theisen, S. L. Tabor, L. R. Medsker, G. Neuschaefer, L. H. Fry, Jr., and J. S. Clements, Phys. Rev. C **25**, 1325 (1982).

[2]L. V. Theisen, L. R. Medsker, and S. L. Tabor, Phys. Rev. C **27**, 2679 (1983).

[3]G. C. Hicks, C. J. Gross, U. J. Hüttmeier, Xi-Ting Lu, G. Neuschaefer, and S. L. Tabor, Phys. Rev. C **29**, 1345 (1984).

[4]J. S. Clements, L. R. Medsker, L. H. Fry, Jr., L. V. Theisen, and L. A. Parks, Phys. Rev. C **20**, 164 (1979).

[5]J. S. Clements, L. R. Medsker, L. H. Fry, Jr., and L. V. Theisen, Phys. Rev. C **21**, 1285 (1980).

[6]R. B. Piercey, A. V. Ramayya, J. H. Hamilton, X. J. Sun, Z. Z. Zhao, R. L. Robinson, H. J. Kim, and John C. Wells, Phys. Rev. C **25**, 1941 (1982).

[7]H. P. Hellmeister, U. Kaup, J. Keinonen, K. P. Lieb, R. Rascher, R. Ballini, J. Delaunay, and H. Dumont, Phys. Lett. **85B**, 34 (1979).

[8]J. Panqueva, H. P. Hellmeister, F. J. Bergmeister, and K. P. Lieb, Phys. Lett. **98B**, 248 (1981).

[9]C. J. Lister, B. J. Varley, H. G. Price, and J. W. Olness, Phys. Rev. Lett. **49**, 308 (1982).

[10]L. Funke, F. Dönau, J. Döring, P. Kemnitz, E. Will, G. Winter, L. Hildingsson, A. Johnson, and Th. Lindblad, Phys. Lett. **120B**, 301 (1983).

[11]M. A. J. Mariscotti, G. Garcia Bermudez, J. C. Acquadro, A. Lepine, M. N. Rao, W. Seale, E. der Mateosian, and P. Thieberger, Phys. Rev. C **19**, 1301 (1979).

[12]M. Behar, A. Filevich, G. Garcia Bermudez, and M. A. J. Mariscotti, Nucl. Phys. **A282**, 331 (1977).

[13]J. C. Wells, R. L. Robinson, H. J. Kim, R. O. Sayer, R. B. Piercey, A. V. Ramayya, J. H. Hamilton, C. F. Maguire, K. Kumar, R. W. Eastes, M. R. Barclay, and A. J. Caffrey, Phys. Rev. C **24**, 171 (1981).

[14]R. M. Diamond, E. Matthais, J. O. Newton, and F. S. Stephens, Phys. Rev. Lett. **16**, 1205 (1966); J. O. Newton, F. S. Stephens, R. M. Diamond, K. Kotajima, and E. Matthais, Nucl. Phys. **A95**, 357 (1967).

[15]M. A. Preston, *Physics of the Nucleus* (Addison-Wesley, Reading, Mass., 1962), p. 333.

[16]G. K. Bavaria, J. E. Crawford, S. Calamawy, and J. E. Kitching, Z. Phys. A **302**, 329 (1981).

[17]E. Nolte and Y. Shida, Z. Phys. **256**, 243 (1972).

[18]N. E. Sanderson, J. C. Lisle, and J. C. Willmott, J. Phys. A **7**, 1156 (1974).

[19]C. Thibault, F. Touchard, S. Buttgenbach, R. Klapisch, M. de Saint Simon, H. T. Duong, P. Jacquinot, P. Juncar, S. Liber-

man, P. Pillet, J. Pinard, J. L. Vialle, A. Pesnelle, and G. Huber, Phys. Rev. C **23**, 2720 (1981).
[20]C. Ekström, S. Ingelman, G. Wannberg, and M. Skarestad, Nucl. Phys. **A311**, 269 (1978).
[21]E. Nolte and P. Vogt, Z. Phys. A **275**, 33 (1975).
[22]G. Kajrys, S. Landsberger, R. Lecomte, and S. Monaro, Phys. Rev. C **27**, 983 (1983).