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Decay of ^{83}Zr and the low-energy level structure of ^{83}Y

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Decay studies of on-line mass-separated low-spin ^{83}Zr and ^{83}Y sources were carried out. γ, x-ray, conversion-electron singles and time-multiscale, and γ-γ-t measurements were used to deduce the ^{83}Zr decay scheme with 18 levels up to 1250 keV. The investigations establish the decay properties of $^{83}\mathrm{Y}^m(\frac{3}{2}^-)$ and do not confirm the previously proposed high-spin $^{83}\mathrm{Zr}^m(T_{1/2}=6\ \mathrm{s})$. The low lying structure of ^{83}Y is compared with published theoretical calculations in terms of collective models.

I. INTRODUCTION

Systematic studies of isotopes in the $N \sim Z \sim 40$ region have revealed the evolution of nuclear-level structure from spherical to deformed nuclei. The onset of nuclear deformation, indicated by the drop of the 2_1^+ level energies and the corresponding increase in the 4_1^+ to 2_1^+ level energy ratios, was observed for the even-even neutron-deficient Sr ($Z=38$) and Zr ($Z=40$) nuclei. The isotones ^{82}Sr and ^{84}Zr, with quite similar complex level structures, are situated at the edge of the deformed region and are characterized as transitional nuclei. The structure of the $^{83}_{39}$Y isotope, which is of interest in this work, is expected to be related to the coupling of single particle states to a ^{82}Sr or ^{84}Zr core, and it might indicate the onset of deformation.

The neutron-deficient Y isotopes, ^{85,87,89}Y, were investigated through radioactive decay and particle reactions.[1–4] Recently, ^{81}Y was investigated by the latter technique.[5] The applicability of different nuclear models to the neutron-deficient Y isotopes was tested[6–9] with the aid of experimental results.

Very little experimental data on the decay of ^{83}Zr to ^{83}Y exist at present. Several γ rays were assigned and a half-life value of 44 s was determined[10,11] for the radioactive decay of ^{83}Zr. A decay scheme incorporating seven γ rays and a Q_β measurement was proposed and the presence of an isomeric state in ^{83}Zr ($T_{1/2}=8$ s) was also reported.[12] In that report, the low spin isomer of Y ($T_{1/2}=2.8$ min) was deduced to be located 233±99 keV above the high spin isomer ($T_{1/2}=7.1$ min). By following the time decay of the $K\alpha$ yttrium x rays the relative positions of the ^{83}Y isomers were confirmed.[13] In another study,[14] ^{83}Zr was shown to be a β-delayed proton precursor ($T_{1/2}=38$ s). A 6.0±1.5 s proton-emitting activity was observed in the same experiment, but its origin could not be uniquely assigned. It should be noted that in the above studies only the work reported in Ref. 13 was carried out with on-line mass-separated sources.

The present paper describes the experimental study of the low-energy levels of ^{83}Y populated in the decay of mass separated ^{83}Zr. The isomers $^{83}\mathrm{Zr}^m$ and $^{83}\mathrm{Y}^m$ were searched for and the decay of the latter was observed and studied.

II. EXPERIMENT

A target of 10 μm thick natural Mo foil rolled into a cylindrical container was bombarded with a 280 MeV ^{3}He beam from the Orsay synchrocyclotron. The beam intensity was in the range of 1–2 μA. Activity was extracted and mass separated at the ISOCELE-2 facility, operating on line to the synchrocyclotron. In the reaction the ^{83}Zr or ^{83}Y activities were produced either directly or through decay in the target. Continuous fluorination of the target by CF_4 gas permitted, through chemical selectivity (i.e., the formation of $NbF_4{}^+$, $ZrF_3{}^+$, $YF_2{}^+$, SrF^+, and Rb^+ ion beams), the extraction of $^{83}ZrF_3{}^+$ or $^{83}YF_2{}^+$ free from the other isobars.[13] The mass-separated activity was collected on the aluminized Mylar tape of a fast modular transport system. Each source was collected for a preset time and moved to a counting station where its decay was recorded for another preset time.

Gamma-ray measurements in the singles, time-multiscale, and three-parameter γ-γ-t coincidence modes were performed using large-volume intrinsic-Ge coaxial detectors and an intrinsic-Ge planar detector with a thin Be window. In order to reduce background, some of the singles and multiscale data were recorded as β^+-gated spectra. A plastic scintillator provided the β-coincidence gate. The energy range 10–1100 keV was covered in the present study.

Conversion electrons, singles and time multiscale, were recorded by means of a Si(Li) detector located inside a magnetic selector. The detector was shielded from the source, and the selector, in order to record electrons in the energy range 20–400 keV, was operated at two different magnetic fields. The simultaneous recording of γ rays was performed by means of a Ge detector placed 4 cm away from the source. Energy and efficiency calibrations of the different detectors were performed with calibrated sources. The geometrical factor required for the conversion-coefficient determinations was calculated from the measurements of the 259.1 keV $E3$ transition following the β decay of $^{83}Y^m$.

III. RESULTS

A. Search for an ^{83}Zr isomeric state

A search for an isomeric state was carried out by measuring γ and x rays following the decay of ^{83}Zr. Each measurement consisted of recording eight sequential γ and x-rays spectra detected in a Ge(Li) and a planar detector in fixed time cycles. The cycles consisted of a 5, 15, 40, or 150 s collection period followed by an 8×2, 8×5, 8×10, or 8×30 s counting period, respectively. The analysis of the time decay behavior of these γ rays was consistent with $T_{1/2}=44$ s. Also, Zr K x rays were not observed, indicating the absence of a highly converted transition with energy greater than 18 keV. The same result was obtained from the conversion-electron singles spectra of ^{83}Zr, where the electron lines ($E_e > 19$ keV) were identified with transitions in ^{83}Y. Here the time cycles consisted of a 15 s (or 120 s) collection period and a 15 s (or 120 s) counting period.

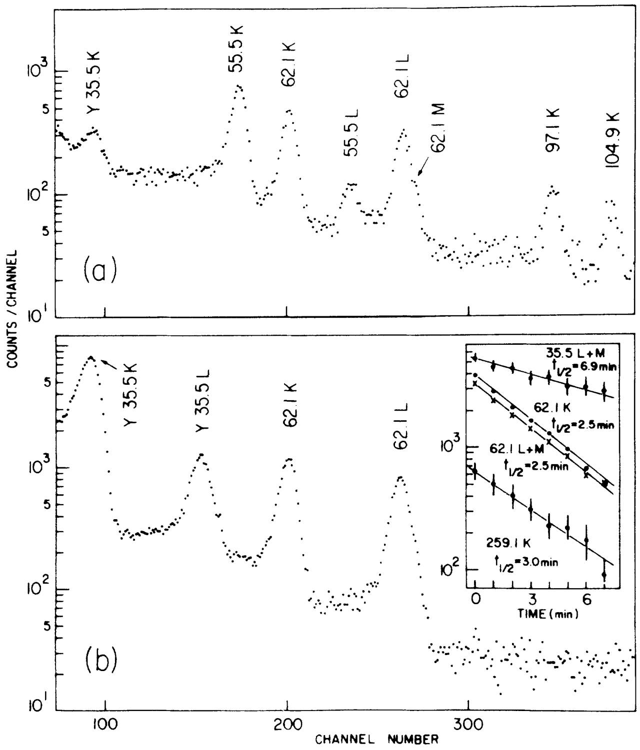

FIG. 1. Low-energy parts of the electron spectra. (a) ^{83}Zr and (b) ^{83}Y decay measurement. The inset in (b) shows the decay curves of the 62.1 keV internal transition in the decay of $^{83}Y^m$ and of the 35.5 and 259.1 keV transitions in the decay of $^{83}Y^g$.

B. Search for an ^{83}Y isomeric state

Two isomeric states are known in ^{83}Y. Through their β decay to ^{83}Sr, the 7.1 and 2.85 min isomers were identified as the high- and low-spin isomers, respectively.[1] The total β-decay energies of the ^{83}Y isomers were measured and the low spin isomer (taken as $\frac{1}{2}^-$) was placed (at 233 ± 99 keV) above the $\frac{9}{2}^+$ isomer.[12] This placement was confirmed by a study of the time decay of Y $K\alpha$ x rays.[13] In addition to the 44 s component, a 2.8 min component, due to an internal transition in ^{83}Y, was measured.

Several measurements were carried out, identifying an $^{83}Y^m$ internal transition of 62.1 keV. Shown in Fig. 1 are the low-energy parts of the ^{83}Zr and ^{83}Y conversion-electron spectra. The $^{83}ZrF_3{}^+$ and $^{83}YF_2{}^+$ beams were collected and measured for 120 and 20 s, respectively. Common to both spectra are the 45.1 and 60.2 keV electron peaks identified as 62.1 K and L transitions. The measured ratio $K/(L+M)=1.06$ indicated either $E3$ or $M4$ multipolarity.[15] The measured half-life of 2.5 ± 0.3 min is in agreement with that reported for $^{83}Y^m$. The 62.1 keV γ ray was observed in the $^{83}YF_2{}^+$ activity (collection and counting time of 20 s) with a planar Ge detector. The γ-ray intensity was too weak for half-life determination, but permitted a calculation of its conversion coefficient ($\alpha_K=73$) corresponding to an $E3$ multipolarity.

C. ^{83}Y level scheme

The sums of the various multiscale spectra described above were used for energy and intensity determinations of γ rays following the ^{83}Zr decay. These results and the placements of the γ rays in the ^{83}Y level scheme are summarized in Table I.

Two γ-γ-t coincidence experiments were carried out. Activity of ^{83}Zr (or ^{83}Y) was collected for 60 s (150 s) and coincidences were recorded for 60 s (150 s). The event-by-event mode data were later scanned for the desired energy and time gates, and the coincident relationships are shown in Table II.

Conversion-electron spectra recorded simultaneously with γ-ray spectra were used for the characterization of transition multipolarities. The deduced multipolarities are presented in Table III.

On the basis of transition-intensity balances and an electron-capture Q value of 5.804 ± 0.050 MeV (recalculated from the data given in Ref. 12), the β feedings and $\log ft$ values were determined and are presented in Table IV. Due to the restricted energy range of the experimental setup, no information was obtained on the energy levels above 1250 keV. However, the β feedings and $\log ft$, being upper and lower limit values, respectively, are not expected to change drastically with additional information pertaining to the high-energy part of the level scheme.

The level scheme of ^{83}Y from the decay of ^{83}Zr is shown in Fig. 2. Two groups of levels, one decaying mainly to the low-spin isomeric state and the other mainly to the high-spin ground state, were deduced for ^{83}Y. Based on direct measurements of the spins of high-spin isomers of Y ($A\geq87$), spin and parity values of $\frac{9}{2}^+$ were assigned to the high-spin odd Y isotopes ($A\geq85$). In the

TABLE I. Energies and relative intensities of the γ rays observed in the decay of ^{83}Zr and their placements in the ^{83}Y level scheme.

This work		Haustein *et al.*[c]		Della Negra *et al.*[d]		*E* level
E (keV)	I^e	*E* (keV)	*I*	*E* (keV)	*I*	(keV)
55.5	100	55		55.5	100	117.6
62.1	5.5[a]					62.1
70.0	1.1[b]					167.1
97.1	21.4					97.1
104.9	85.0	105		105.0	76	167.1
114.5	<1					536.4
133.0	<1					855.7
144.8	4.7					144.8
164.5	<1					331.6
186.7	<1					331.6
213.3	4.7					855.7
220.6	5.1	221				642.5
234.5	12.6					331.6
238.9	<1					570.3
254.9	50.4	255	38	254.8	63	422.0
269.8	3.8					436.9
285.3	<1					722.3
290.0	1.3[b]					855.7
291.0	1.0[b]					855.7
304.3	54.2	304	54	304.2	54	422.0
310.5	2.2					642.5
319.2	6.2					855.7
324.6	8.5					483.9
359.8	39.5	360		359.8	36	422.0
370.1	<1					536.4
374.8	9.2					436.9
397.6	4.0[b]					564.7
398.5	4.0[b]					565.7
418.7	2.1[b]					855.7
425.5	<1					570.3
433.7	2.1					855.7
448.0	8.9					565.7
474.4	57.5[b]	474	23	474.4	68	536.4
475.4	11.2[b]					642.5
502.5	8.2[b]					564.7
503.5	12.4[b]					565.7
524.8	7.4[b]					855.7
534.1	<1[b]					642.5
550.8	2.2					882.4
580.3	4.4					642.5
		617				
660.2	6.8					722.3
688.4	3.9					855.7
713.4	3.0					1249.8
758.5	2.6					855.8
793.5	36.8					855.8
		828	11			
		1133	11	1132.8	~ 1	
		1602				
		1644				
		1917				

[a] Corrected for $T_{1/2}=2.8$ min decay.

[b] Relative intensity determined from coincidence data.

[c] Reference 11.

[d] Reference 12.

[e] Gamma ray intensities normalized to 100 for the 55.1 keV γ ray.

TABLE II. Gamma-gamma coincidence relationships in ^{83}Y.

Gate	Coincidences[a]
55.5	213.3, 220.6, 304.3, 448.0, 524.8
70.0	97.1, 254.9
97.1	70.0, 234.5, 324.6, (758.5)
104.9	164.5, 213.3, 220.6, 269.8, 290.0, 291.0, 370.1, 398.5 (433.7), 475.4, 688.4
114.5	(319.2)
133.0	660.2
144.8	186.7, 425.5
164.5	104.9
186.7	144.8
213.2	55.5, (97.1), 104.9, 220.6, (310.5), 475.4, 524.8
220.6	55.5, 104.9, 213.2, 254.9, 304.3, 359.8
234.5	97.1, (238.9), 310.5, 524.1, 550.8
238.9	(234.5)
254.9	70.0, 104.9, 220.6, 433.7
269.8	104.9
285.3	(374.8)
290.0+291.0	55.5, 104.9, (397.6), 502.5, 503.5
304.3	55.5, 220.6
310.5	234.5
319.2	474.4
324.6	97.1
359.8	220.6, (433.7)
370.1	104.9
374.8	(418.7)
397.6+398.5	104.9, 290.0, 291.0
418.7	(374.8)
425.5	144.8
433.7	104.9, (254.9), (304.3)
448.0	55.5, (290.0)
474.4+475.4	104.9, 213.2, 319.2, 713.4
502.5+503.5	290.0, 291.0
524.1+524.8	55.5, 213.2, 234.5
550.8	234.5
580.3	213.2
660.2	133.0
688.4	104.9
713.4	474.4
758.5	97.1
793.5	

[a] Parentheses indicate an uncertain coincident relationship.

TABLE III. Experimental and theoretical conversion-coefficient values and deduced multipolarities.

Electron line[a]		α_{expt}[b]	α_{theory}[c]								Multipolarity
			*E*1	*E*2	*M*1	*M*2	*E*3	*E*4	*M*3	*M*4	
55.5	*K*	1.2	0.527	6.74	0.854	14.3					
	L	0.13	0.075	2.28	0.121	3.1					*M*1 + (6% *E*2)
62.1	*K*	73					45.1	424	112	1295	
	L	69					46.3	1364	44	1035	
	K/*L*	1.06					0.95	0.31	2.55	1.25	*E*3
97.1	*K*	1.0	0.104	0.980	0.176	1.86					
	L	0.31	0.013	0.21	0.025	0.28					*E*2
104.9	*K*	0.5	0.083	0.746	0.142	1.37					
	L	0.017	0.011	0.151	0.019	0.24					*M*1

[a] The conversion electron lines are denoted by the γ ray energy and electron shell considered (where $L = L + M + N$).

[b] Typical errors are about 25%.

[c] Theoretical conversion coefficients (Ref. 15).

TABLE IV. β feedings and log*ft* values for ^{83}Zr decay.

Level energy (keV)	Branching (%)	log*ft*[a]
0	b	
62.1	56.7	5.2
97.1	1.8	6.7
117.6	10.4	5.9
144.8	0.2	7.6
167.1	1.8	6.6
331.6	0.7	7.0
422.0	11.3	5.7
436.9	0.8	6.9
483.9	0.7	6.9
536.4	4.2	6.1
564.7	0.9	6.8
565.7	2.0	6.4
570.3	0.2	7.4
642.5	2.3	6.3
722.3	0.6	6.9
855.7	5.0	5.9
882.4	0.2	7.3
1249.8	0.2	7.1

[a] log*ft* value calculated as if β transition is allowed.
[b] A 0% branching to the g.s. was assumed.

present work the same values were adopted for ^{83}Y^{g}. Thus, from the measured $E3$ multipolarity (Table III) of the transition populating the ground state, spin and parity of $\frac{3}{2}^-$ were deduced for ^{83}Y^{m}. Based on J^{π} values of the low-spin isomers of Zr isotopes,[1-3] ^{83}Zr probably has, and so it was assumed in the present work, a spin and parity of $\frac{1}{2}^-$. The measured log*ft* value of 5.2 for the β transition to the 62.1 keV level indicates its allowed character and is in accordance with the J^{π} assignment.

Relative total conversion-electron intensities were determined for the 62.1 (^{83}Y^{m} decay, $T_{1/2}=2.8$ min) and 259.1 (^{83}Sr^{m} decay, $T_{1/2}=5$ s) keV $E3$ transitions from the measured 62.1 K and 259.1 K electron lines. The EC-β^+ decay of ^{83}Y^{m} ($\frac{3}{2}^-$) is known[1] to feed, directly and through intermediate levels, ^{83}Sr^{m} ($\frac{1}{2}^-$), which, in turn, decays 100% by internal transition. It was assumed that only minute feeding of ^{83}Sr^{m} through intermediate levels follows the decay of ^{83}Y^{g} ($\frac{9}{2}^+$). The branching ratio for EC-β^+ of ^{83}Y^{m} was thus found to be (60 ± 5) %.

Using the values $T_{1/2}=2.85$ min, $\alpha=92.4$, and the branching ratio for the $E3$ isomeric transition, the probability for the isomeric γ-ray transition was calculated. The result of 1.7×10^{-5} s^{-1} is equal to 0.020 Weisskopf single-particle units (W.u.).

The spin and parity for the level at 97.1 keV were established from the deduced $E2$ multipolarity of the 97.1 keV

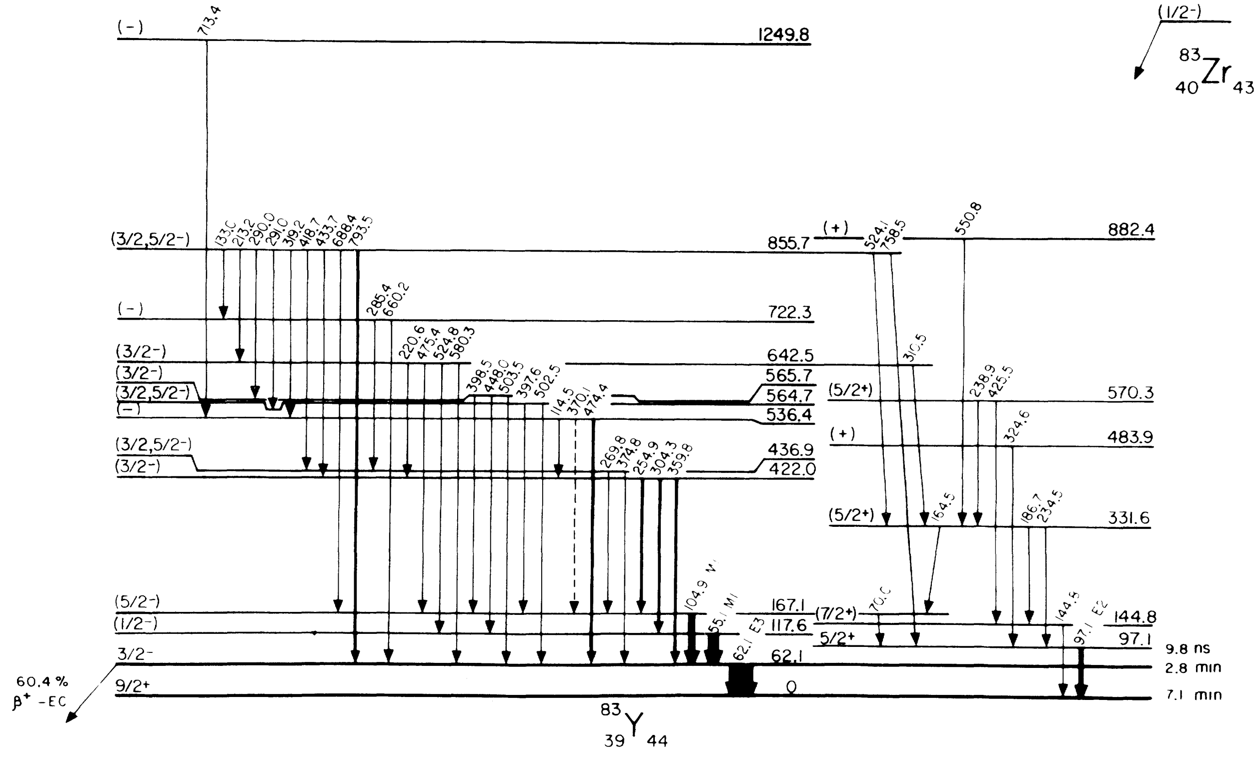

FIG. 2. Decay scheme for ^{83}Zr. The relative total transition intensities are indicated by the black arrows.

transition to the g.s. ($\frac{9}{2}^+$) to be $\frac{5}{2}^+$. For the same level the half-life was determined by comparing the centroid position of the time distribution in the $\gamma(234)$-$\gamma(97)$ delayed-coincidence measurement with that of two prompt γ,γ pairs. The prompt γ,γ pairs used were the Compton continuum adjacent to the above two γ rays and the $\gamma(255)$-$\gamma(105)$ pair. The measurement yielded a $T_{1/2}$ value of 9.8 ± 1.0 ns and a transition probability of 154 W.u.

The level at 117.6 keV populates the $\frac{3}{2}^-$ isomeric state by a 55.5 keV $M1$ transition and thus is limited to J^π values of $\frac{1}{2}$, $\frac{3}{2}^-$, or $\frac{5}{2}^-$. The logft of 5.9 for β feeding to this level is of an allowed character and favors either $\frac{1}{2}^-$ or $\frac{3}{2}^-$. Further restriction to a J^π value of $\frac{1}{2}^-$ is derived from the level systematics for odd-A Y isotopes (Fig. 3).

The level at 144.8 keV populates only the $\frac{9}{2}^+$ g.s. Conversion electrons were not observed for the 144.8 keV transition, but calculation shows that they should have been observed if the transition multipolarity was $E2$ or $M2$ but not $M1$ or $E1$. Since this level is fed by levels not related to the ones established to have negative parities, a $M1$ multipolarity is proposed for the 144.8 keV transition and thus a J^π value of $\frac{7}{2}^+$ for the level.

Negative parity is deduced for the level at 167.1 keV, which populates the $\frac{3}{2}^-$ level by a 104.9 keV $M1$ transition. For the same level a transition to the $\frac{5}{2}^+$ level of an undetermined multipolarity was observed. Assuming for the latter transition that $M2$ does not compete with $E1$, the J^π of the 167.1 keV level is limited to $\frac{3}{2}^-$ or $\frac{5}{2}^-$. A J^π of $\frac{5}{2}^-$ is favored from the systematic behavior of odd mass Y isotopes.

The lack of electron-conversion data for the transitions of higher energies does not allow exact additional J^π assignments. However, suggestions concerning J^π values for some of the levels, besides the six mentioned above, are included in the level scheme, the bases for these suggestions being logft values and deexcitation modes.

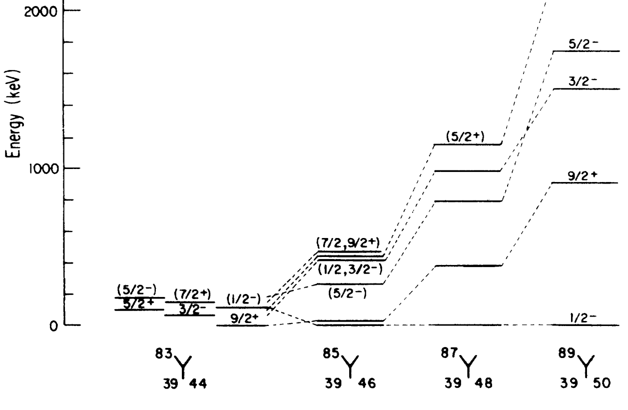

FIG. 3. Low-energy-level systematics in $^{83-89}$Y. Data for $^{85-89}$Y are taken from Refs. 1–4.

IV. DISCUSSION

Each of the ^{85,87,89}Zr isotopes is known to have an isomeric state, and, as mentioned above, in previous studies an isomeric state was reported for ^{83}Zr.[12,14] In one experiment,[12] Zr activity was produced by the reaction ^{54}Fe(^{32}S,2pn), and a β-recoil time-of-flight mass spectrometer was utilized. In addition to the known 44 s decay period an 8 s decay period was observed for the $A = 83$ mass, but no γ rays were found to follow the latter half-life. Since the cross section for the production of ^{83}Nb by (^{32}S,p2n) is small, this half-life was attributed to ^{83}Zr^m. In the other experiment,[14] the time behavior of β-delayed proton activity following the same reaction was recorded, and a short-lived component with a 6.0 s half-life calculated. The origin of this activity could not be assigned but was preferably attributed to ^{83}Zr^m, the other possibility being ^{81}Zr ($T_{1/2} = 5.9$ s).

The results of the present study, the absence of a highly converted transition and Zr K x rays, a single time component (44 s) in the decay of ^{83}Zr, and a measured value for the β feeding of the ^{83}Y ($\frac{7}{2}^+$) level close to zero, do not support the previous evidence for a 6 or 8 s high-spin ^{83}Zr isomeric state. A possible explanation for the disagreement between the present and the two previously reported studies is the lack of selective mass and Z separation and thus the misassignment of A in the latter. However, the present study does not rule out the possibility of a high-spin ^{83}Zr isomer having $T_{1/2}$ less than 1 or much greater than 44 s. An attempt, in the present study, to identify this isomer through ^{83}Nb decay was unsuccessful due to the very low intensity of the mass separated ^{83}Nb beam.

On the other hand, the location and decay modes of ^{83}Y^m were well characterized in the present study. ^{81}Rb^m and ^{79}Br^m, which are isotones of ^{83}Y^m, decay via $\frac{9}{2}^+ \rightarrow \frac{3}{2}^-$ $E3$ IT, the inverse transition of ^{83}Y^m. The hindrance factor (F_w) value of 50 calculated for ^{83}Y^m is close to the $F_w = 33$ of ^{79}Br^m but is smaller than the corresponding value of $F_w = 415$ of ^{81}Rb^m.[16,17] From the above data, a trend for the hindrance factors cannot be established. The retarded transitions, however, indicate the single particle character of the states involved.

The results of the present study have extended the systematics of the neutron-deficient odd-mass Y isotopes. The low-energy-level systematics is shown in Fig. 3. It is characterized, as A decreases, by a gradual decrease in level energies, showing a relatively high level density for ^{83}Y. The six different J^π values of the first six levels in $^{89}_{39}$Y$_{50}$ are interpreted as the shell-model configuration ($2p_{1/2}$, $1g_{9/2}$, $2p_{3/2}$, $1f_{5/2}$, and $2d_{5/2}$). A more elaborate model is required for ^{83}Y.

Nazarewicz *et al.*[9] included in their theoretical study of the high-spin configurations in the $A = 80$ region the calculated deformation and energy of low-lying bandheads in ^{83}Y. In the calculation the single-particle energy levels were generated by the deformed Woods-Saxon potential. A BCS procedure with blocking was applied and the bandhead energies were minimized with respect to the quadrupole and hexadecapole deformations. The calculation correctly predicts the presence at low energy of six

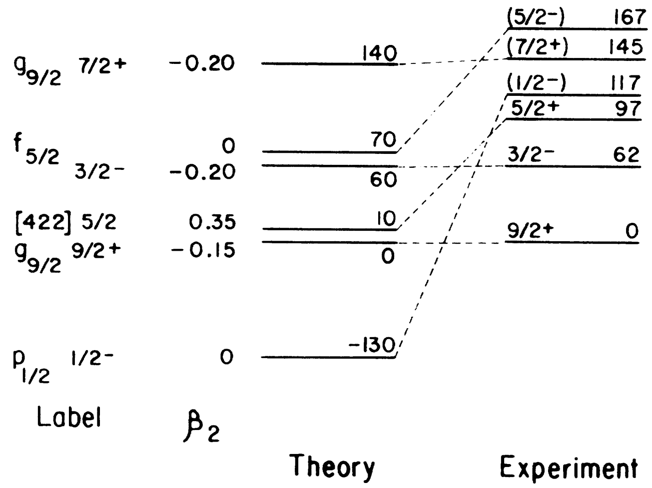

FIG. 4. Comparison of experimental results concerning the six lowest energy levels and theoretical results taken from Ref. 9.

levels with unique J^{π} values, but fails to reproduce their correct ordering. The levels are predicted to be spherical (two levels), prolate (one), and oblate (three). Thus, the transition connecting the $\frac{5}{2}^{+}$ ($\beta_2=0.35$) and $\frac{9}{2}^{+}$ ($\beta_2=-0.15$) levels is expected to be retarded. The measured $E2$ transition probability of 154 W.u. does not support such shape coexistence. The comparison of experimental results and theoretical results is shown in Fig. 4.

An alternative approach to describe odd-A nuclei is the interacting boson fermion model (IBFM).[18,19] The collective states are obtained from the interaction of an odd fermion with a given even-even core. The core is characterized by the interacting-boson model (IBM) and the interaction between the single particle and core consists of monopole, quadrupole, and exchange terms.

Several studies have applied the IBFM to odd-A nuclei in the region of interest in the present work. Bucurescu *et al.*[8] have employed the IBM-1 and IBMF-1 versions (versions which do not distinguish between proton and neutron degrees of freedom in the description of the core) and calculated the energy spectra of even-even neutron deficient isotopes of Sr and Zr and the positive-parity energy spectra of several odd-A neighboring nuclei. Unfortunately, ^{83}Y was not included in the calculation. However, the calculation seems to reproduce successfully the sequence of positive states in ^{85}Y. This nucleus was described by an ^{84}Sr core coupled to a proton occupying the $1g_{9/2}$ or $2d_{5/2}$ shell. The model parameters were obtained from the yrast states. The calculation predicts the sharp decrease in energy of the $\frac{7}{2}^{+}$ states which at that time was not known in $^{85-87}$Y. On ^{85}Y, the $\frac{7}{2}^{+}$ state was calculated at ~440 keV and was later located[4] at 474 keV. On ^{83}Y, the $\frac{7}{2}^{+}$ state was located at 145 keV, establishing the trend for the $\frac{7}{2}^{+}$ states in the neutron-deficient Y isotopes (Fig. 3). Kaup *et al.*[20] have employed the IBMF-1 and reproduced the positive parity energy spectra of ^{81}Rb. The core was ^{80}Kr, and $1g_{9/2}$, $2d_{5/2}$, and $2g_{7/2}$ proton shells were considered. ^{81}Rb is an isotone of ^{83}Y but exhibits an energy spectra similar to that of ^{85}Y. Panqueva *et al.*[21] have applied this theoretical treatment to ^{79}Rb (a ^{78}Kr core coupled to a $f_{9/2}$ proton). Though the calculations reproduced the high-energy spectra and $B(E2)$ values, they did not reproduce the low energy spectra of ^{79}Rb.

In general, the IBFM is helpful in describing the odd-mass nuclei at $A\sim80$. Clearly, a detailed study of the positive and negative parity states and their electromagnetic properties, for the neutron-deficient Y isotopes, will be useful. If successful, such a study should be extrapolated and the nuclear structure of ^{81}Y predicted.

Experimentally, the studies of the neutron deficient Y isotopes should be continued. Further information on the nuclear structure of ^{83}Y could be obtained through in-beam or β-decay studies. Additional information is required on the level structure of ^{85}Y, which could be obtained through β decay of low- and high-spin ^{85}Zr isomers. Lastly, the analysis of the β decay of ^{81}Zr, not yet experimentally studied, would probably display the complex nuclear structure of ^{81}Y.

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