Levels in ^{43}K and ^{44}K excited by the β decay of ^{43}Ar and ^{44}Ar

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The nuclides ^{43}Ar and ^{44}Ar have been produced by spallation reactions on vanadium targets at $E_p = 600$ MeV. The subsequent β decays to ^{43}K and ^{44}K have been studied via delayed γ-ray singles and γ-γ coincidence techniques. In ^{43}K, excitation energies and γ-branching fractions have been determined for 19 levels. The log*ft* values imply $J^\pi = 3/2^-, 5/2^\pm$ for the ground state of ^{43}Ar. For ^{44}Ar, evidence is found for four new β branches and $J^\pi = 1^+$ is assigned to the levels at 2326 and 2574 keV on the basis of the β decay selection rules. The proposed decay scheme accounts for γ transitions between 10 levels, the first excited state being located at 182.6 keV. The structure of these nuclei is discussed in the weak coupling scheme.

[RADIOACTIVITY ^{43,44}Ar| from ^{50,51}V$(p, 6pxn)$, natural target, mass separated| measured delayed E_γ, I_γ, γ-γ coincidences, deduced decay schemes, log ft, J, π.]

I. INTRODUCTION

The neutron-rich nuclei ^{43}Ar and ^{44}Ar have been identified for the first time by Larson and Gordon[1] using the ^{48}Ca$(\gamma, \alpha n)$ and ^{48}Ca(γ, α) reactions. Producing these isotopes by spallation with high energy protons and taking advantage of the on-line mass separation technique, Hudis *et al.*[2] performed the first detailed investigation of the decay scheme. Since then, the nuclear structure of odd potassium isotopes has been extensively studied by proton pickup reactions on even calcium targets. For ^{43}K an analysis of ^{44}Ca$(d, {}^3$He) at 13 MeV (Ref. 3) and especially at 52 MeV (Ref. 4) as well as the study of ^{44}Ca(t, α) (Refs. 5 and 6) has led to a good description of positive parity states. Additional information has been obtained with the ^{40}Ar$(\alpha, p\gamma)^{43}$K (Refs. 7 and 8) and the ^{41}K$(t,p)^{43}$K (Ref. 7) reactions. In particular the measurement of the lifetime[9-11] and of the g factor[11,12] of the $\frac{7}{2}^-$ level at 738 keV have revealed the single particle nature of this state. For the description of ^{44}K, only one charged particle reaction has been reported, namely $(t, {}^3$He) at 13 MeV.[6]

Recently the mass excess of ^{44}Ar has been measured as -32.27 ± 0.02 MeV via the ^{48}Ca(^{3}He, ^{7}Be)^{44}Ar reaction.[13] For ^{43}Ar, a mass excess of -31.98 ± 0.07 MeV was determined in the ^{48}Ca$(\alpha$, ^{9}Be)^{43}Ar reaction.[14] According to these results a Q_β value respectively equal to 4.60 ± 0.07 and 3.53 ± 0.04 MeV for the β decay of ^{43}Ar and ^{44}Ar could be calculated.

The improved performance of the on-line device ISOLDE 2 (Ref. 15) afforded an opportunity to produce these β unstable nuclei with a good yield and a negligible level of parasitic activity. A reexamination of the ^{43}Ar and ^{44}Ar decay was therefore undertaken in order to corroborate the charged particle results with data from radioactivity and to extend the spectroscopic knowledge on ^{43,44}K. New information on ^{43,44}K levels and their electromagnetic decay is presented and conclusions regarding the structure of some levels are discussed. This work is part of a continuing study of $A \simeq 40$ nuclei far from stability.[16,17]

II. EXPERIMENTAL PROCEDURES

The ^{43}Ar and ^{44}Ar isotopes have been produced in the spallation reaction ^{50,51}V $(p, 6pxn)$ by the protons from the 600 MeV external beam of the CERN synchrocyclotron bombarding a vanadium carbide target. Argon nuclides diffuse selectively to a plasma ion source[15] and are isotopically separated in the ISOLDE on-line mass separator. For a selected mass, the beam was then intercepted either by a collector foil or by a Mylar tape associated with a tape transport system. Singles γ-ray spectra were obtained with a 53 cm^3 Ge(Li) detector associated with an Intertechnique Plurimat 20 computer used in a multianalysis mode (2×4096 channels). Attributions of all transitions to the relevant decays are based on the intensity ratios in the two successive spectra, the counting time for each sequence being of the order of the half-life of the argon isotope under study. In the ^{43}Ar experiment, the short half-life [$T_{1/2} = 5.37$ min (Ref. 2)] allowed all the measurements to be performed without contribution of the ^{43}K decay ($T_{1/2}$ =22.3 h). For ^{44}Ar [$T_{1/2}$ =11.87 min (Ref. 2)] most of the rays associated with the ^{44}K radioactivity ($T_{1/2}$ =22.13 min) could be identified on the basis of half-life. No activity other than ^{43}Ar, ^{44}Ar, or their radioactive filiation was detected in samples for mass positions 43 and 44.

For the γ-ray coincidence experiments, two Ge(Li) detectors (relative efficiency 9.5% and 13%) were used in a γ-γ-t measurement. The relative time between events in both counters was determined by conventional electronics using constant fraction discriminators and was investigated over a 1 μs range in order to take into account the contribution of long lived excited states. The data were analyzed in a 2048×2048×1024 channel configuration and recorded on magnetic tape with the Plurimat 20 computer working in a microprogramed buffer mode allowing coincidence rates of 1000 events per second. Their fast classification was performed off-line with a CII 10070 computer by means of the code TRITON.[18] True and random coincidences were obtained by summing up the energy spectra gated by the appropriate portion of the time spectrum.

To investigate the existence of lifetimes in the nanosecond range in the decay of ^{44}Ar, fast γ-γ coincidences were measured. The detectors used were cylindrical NE 102 *A* plastic scintillators (5 cm long, 4 cm diam, for $E_\gamma > 1$ MeV and 1.5 cm long, 2 cm diam for $E_\gamma < 200$ keV) associated to RTC XP 2230 B photomultiplier tubes. The efficiency of the Ge(Li) counters was determined off line with radioactive standards. Internal energy calibration during the experiment was provided by well defined lines in the decay of ^{44}K and ^{43}K.[19,20]

Since no direct measurement of the β transitions has been made in the two decays under study, an estimation of the ground state transition intensity is deduced from the comparison of the observed parent and daughter activities with the ones expected from the laws of radioactive series. Our calculations are based on the assumption that no significant γ activity escapes the study. Target tests have shown that there is no daughter species in the mass separated beam.[21]

III. RESULTS AND DISCUSSION

A. ^{43}Ar

The singles γ ray spectrum, shown in Fig. 1, was obtained in the first counting period of the multianalysis experiment (2×5 min). In this spectrum, all the lines could be attributed to γ rays following ^{43}Ar or ^{43}K β emission, on the basis of their decay rate. The relatively high intensity of the sources overshadows background activities. For the same reason, the spectrum appears more

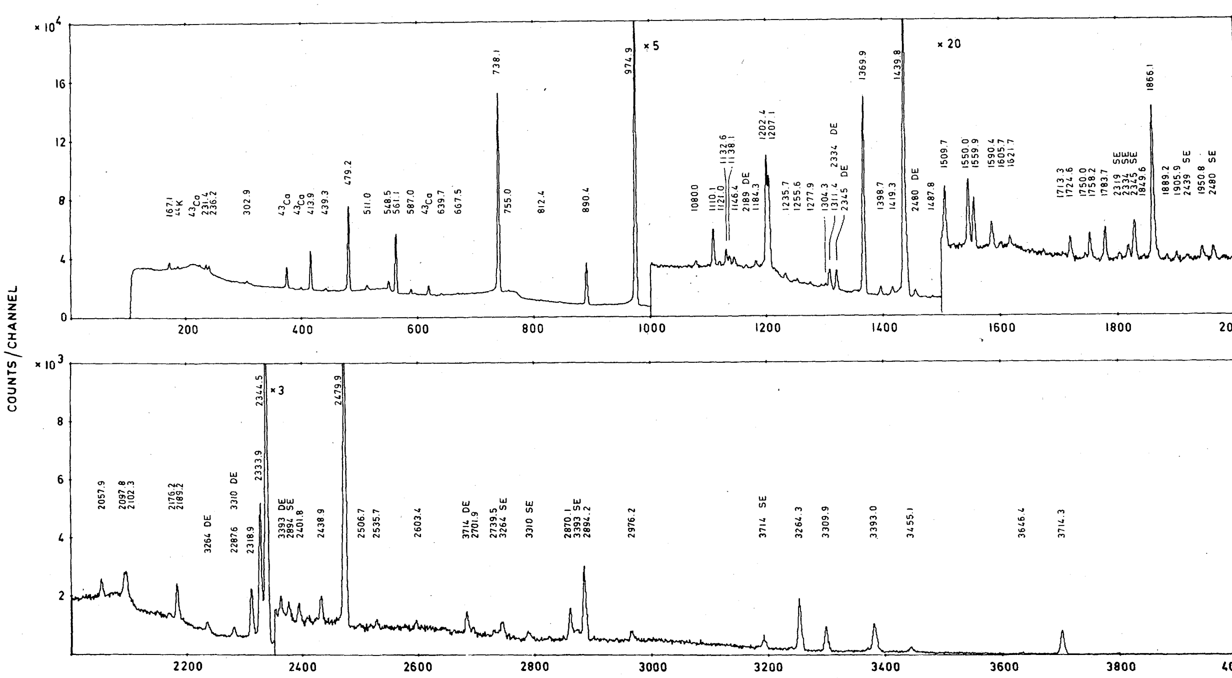

FIG. 1. Singles γ-ray spectrum following ^{43}Ar β decay, recorded during five minutes after collection. The single-and double-escape peaks are noted SE and DE, respectively.

complex than in the experiment of Ref. 2 where 17 transitions were observed as compared with 85 in the present one. About 10^7 events have been accumulated in a γ-γ-t coincidence measurement and were analyzed with a time window of 400 ns to take into account the long lifetime of the second excited state of ^{43}K (E_x = 738 keV, $T_{1/2} \simeq 280$ ns). Energy and intensity of γ rays following the β decay of ^{43}Ar are listed in Table I. From these results, γ-ray branching ratios in ^{43}K have been evaluated and are presented in Table II. The comparison with other experiments indicates a good agreement in the few cases where previous results are available.

The ^{43}K level scheme (Fig. 2) includes 19 excited states. Among these, only one, located at 3608.1 ±0.7 keV on the basis of six different cascades, has no possible correspondent in the level list established from previous work.[20] In addition, it clearly appears from our results that the level proposed at 2892.7 ±1.2 keV by Hudis *et al.*[2] does not exist, the corresponding γ ray being unambiguously coincident with the 561 keV transition. It is a member of one of the seven cascades origi-

TABLE I. Energy and relative intensity of γ rays following β decay of ^{43}Ar.

E_γ (keV)	I_γ	E_i (MeV)	E_f (MeV)	E_γ (keV)	I_γ	E_i (MeV)	E_f (MeV)
167.1 ± 0.1	2.5	2.34	2.18	1559.9 ± 0.1	15.9		
231.4 ± 0.1	2.8			1590.4 ± 0.2	10.6	3.45	1.87
236.2 ± 0.1	3.4			1605.7 ± 0.8	2.6		
302.9 ± 0.2	1.9	1.51	1.21	1621.7 ± 0.5	5.5		
413.9 ± 0.1	42.9	0.97	0.56	1713.3 ± 0.6	3.2		
439.3 ± 0.2	2.8	1.55	1.11	1724.6 ± 0.2	9.3		
479.2 ± 0.1	116.0	2.34	1.87	1750.0 ± 0.5	2.0		
548.5 ± 0.1	13.4	1.11	0.56	1758.2 ± 0.2	10.2		
561.1 ± 0.1	94.0	0.56	0	1783.7 ± 0.2	12.6	2.34	0.56
587.0 ± 0.1	9.0			1849.6 ± 0.8	2.5		
639.7 ± 0.3	2.7	2.19	1.55	1866.1 ± 0.1	70.4	1.87	0
667.5 ± 0.2	1.9	2.18	1.51	1889.2 ± 0.7	3.0		
738.1 ± 0.1	454.8	0.74	0	1905.9 ± 0.6	3.9		
755.0 ± 0.3	1.8	1.87	1.11	1950.8 ± 0.3	10.0		
812.4 ± 0.4	1.3			2057.9 ± 0.3	10.7	3.61	1.55
878.2 ± 0.8	0.9			2097.8 ± 0.5	9.8	3.61	1.51
890.4 ± 0.1	118.3	1.87	0.97	2102.3 ± 0.5	9.8	3.31	1.21
910.5 ± 0.9	1.0			2176.2 ± 0.7	2.5	2.18	0
922.5 ± 0.5	1.7			2189.2 ± 0.3	20.4	2.19	0
974.9 ± 0.1	1000	0.97	0	2287.6 ± 0.2	4.7	3.26	0.97
1080.0 ± 0.2	4.6	2.19	1.11	2318.9 ± 0.2	31.0	3.06	0.74
1110.1 ± 0.1	31.2	1.11	0	2333.9 ± 0.2	81.9	3.31	0.97
1121.0 ± 0.2	3.2	3.31	2.19	2344.5 ± 0.2	217.3	2.34	0
1132.6 ± 0.1	12.2	3.31	2.18	2345	1.2	3.45	1.11
1138.1 ± 0.1	8.7	2.34	1.21	2401.8 ± 0.3	2.8	3.61	1.21
1146.4 ± 0.2	9.1			2438.9 ± 0.5	6.4	3.65	1.21
1184.3 ± 0.3	5.1			2479.9 ± 0.1	65.5	3.45	0.97
1202.4 ± 0.3	98.3	2.18	0.97	2506.7 ± 1.5	1.0	3.71	1.21
1207.1 ± 0.3	75.8	1.21	0	2535.7 ± 0.7	1.2	3.65	1.11
1235.7 ± 0.2	6.3	2.34	1.11	2603.4 ± 0.4	0.9	3.71	1.11
1255.6 ± 0.3	3.2			2701.9 ± 0.5	1.3	3.26	0.56
1277.9 ± 0.5	2.5	3.45	2.18	2739.5 ± 0.7	2.1	3.71	0.97
1304.3 ± 0.7	3.1	1.87	0.56	2870.1 ± 0.2	7.5	3.61	0.74
1311.4 ± 0.1	22.7			2894.2 ± 0.2	17.9	3.45	0.56
1369	0.4	3.71	2.34	2976.2 ± 0.3	2.8		
1369.9 ± 0.1	200.0	2.34	0.97	3264.3 ± 0.2	14.7	3.26	0
1398.7 ± 0.1	9.5	3.26	1.87	3309.9 ± 0.2	7.4	3.31	0
1419.3 ± 0.1	12.9	3.61	2.19	3380.6 ± 0.7	0.8		
1439.8 ± 0.1	369.0	2.18	0.74	3393.0 ± 0.2	11.2	3.39	0
1443	48.0	3.31	1.87	3455.1 ± 0.4	2.0	3.45	0
1487.8 ± 0.5	2.7			3646.4 ± 0.5	0.5	3.65	0
1509.7 ± 0.1	20.7	1.51	0	3714.3 ± 0.2	9.5	3.71	0
1550.0 ± 0.1	22.9	1.55	0				

TABLE II. γ-ray branching ratios in ^{43}K.

E_i (MeV)	E_f (MeV)	Branching ratios (%) This work	Hudis et al.[a]	Merdinger et al.[b]
0.56	0	100	100	100
0.74	0	100	100	100
0.97	0	95.9 ±0.3	96 ± 2	92 ± 5
	0.56	4.1 ±0.3	4 ± 2	8 ± 5
1.11	0	70 ±3	100	60 ± 10
	0.56	30 ±3		40 ± 10
1.21	0	100	(100)	100
1.51	0	92 ±2		93 ± 4
	1.21	8 ±2		7 ± 4
1.55	0	89 ±2		100
	1.11	11 ±2		
1.87	0	36 ±2	45 ± 25	
	0.56	1.6 ±0.3		
	0.97	61 ±2	55 ± 25	
	1.11	0.9 ±0.3		
2.18	0	0.6 ±0.1		
	0.74	76 ±4	70 ± 16	
	0.97	23 ±4	30 ± 16	
	1.51	0.4 ±0.1		
2.19	0	74 ±3		
	1.11	16 ±3		
	1.55	10 ±1		
2.34	0	38.7 ±2.5	48 ± 12	
	0.56	2.2 ±0.2		
	0.97	35.4 ±1.9	33 ± 10	
	1.11	1.1 ±0.2		
	1.21	1.5 ±0.3		
	1.87	20.5 ±1.3	17 ± 5	
	2.18	0.44 ±0.05	2 ± 2	
3.06	0.74	100		
3.26	0	49 ±3		
	0.56	4 ±1		
	0.97	16 ±3		
	1.87	31 ±2		
3.31	0	4.6 ±0.6		
	0.97	50.4 ±6.2	100	
	1.21	6.0 ±1.5		
	1.87	29.5 ±6.3		
	2.18	7.5 ±1.2		
	2.19	2.0 ±0.9		
3.39	0	100		
3.45	0	1.9 ±1.1		
	0.56	17.3 ±1.3		
	0.97	63.1 ±1.9		
	1.11	1.2 ±0.4		
	1.55	3.8 ±0.7		
	1.87	10.2 ±1.0		
	2.18	2.4 ±0.4		
3.61	0.74	12.0 ±1.4		
	1.21	4.5 ±1.0		
	1.51	15.6 ±3.1		
	1.55	17.0 ±1.9		
	2.19	20.6 ±1.9		
	unknown	30.2 ±4.6		
3.65	0	5.8 ±1.3		
	1.11	14.4 ±3.6		
	1.21	79.7 ±3.7		
3.71	0	68.3 ±4.3		

TABLE II. (*Continued*).

E_i (MeV)	E_f (MeV)	Branching ratios (%) This work	Hudis *et al.*[a]	Merdinger *et al.*[b]
3.71	0.97	15.1 ±3.3		
	1.11	6.5 ±2.7		
	1.21	7.2 ±2.4		
	2.34	2.9 ±1.7		

[a] Reference 2.
[b] Reference 7.

nating in the 3454.9 ±0.5 keV state which can be related with the 3460 ± 30 keV level reported in Ref. 6.

For the most part, the ^{43}K level scheme is built up on coincidence data except for very weak low energy transitions whose contributions to such a measurement are negligible compared to those of Compton distributions from other γ rays. In that case, the assignments are based only on energy matching in a roughly 1 keV limit. The 1310 +1560 keV cascade is obviously in coincidence with the 738 keV γ ray and corresponds therefore to a deexcitation of the 3608 keV state. However, no previously quoted level allows the emission order to be established. Nevertheless, this cascade was taken into account for the in-out balance calculations of the 738 and 3608 keV levels. Another difficulty is encountered with the 587 +1758 keV cascade for which two interpretations can be given. It may be a two-step deexciting

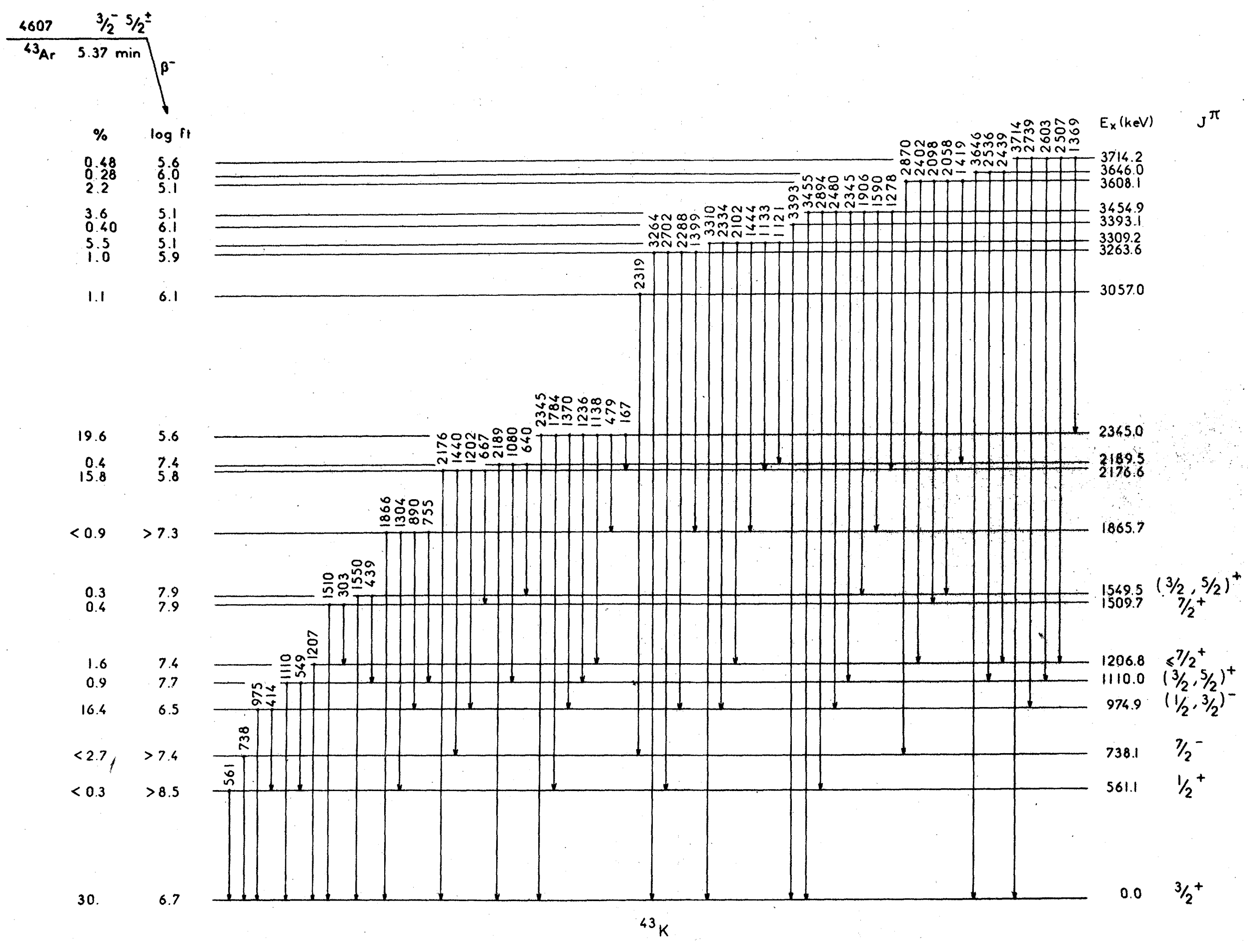

FIG. 2. Proposed decay scheme for ^{43}Ar. Spin values for ^{43}K levels are from Refs. 3, 4, 8, and 20.

process either of the 2345 keV level to the ground state or of the 3455 keV level to the 1110 keV level. Moreover, no suitably located state is known from previous work[20] for consideration as the intermediate level. This cascade has therefore to be ignored in further calculations and its two γ rays ranked among those not placed in the decay scheme. On the whole, 24 out of 85 γ transitions have not been interpreted, their energy lying between 231.5 and 3380.6 keV and their intensity relative to the 975 keV line being less than 1% in all cases and for the most part much less.

The intensity of the β transition to the ground state of ^{43}K, $I_{\beta_0} = (30 \pm 10)\%$, has been inferred as described above from the rate of the daughter relatively to the parent activity. Its uncertainty is reduced to 7% by taking into account the correlated kind of such errors. The $\log ft$ values listed in Table III were deduced from the Gove and Martin's $\log f$ tables,[22] together with the values $T_{1/2} = 5.37$ min (Ref. 2) and $Q_\beta = 4607$ keV.

An expectation based on the simplest form of the shell model would give $J = \frac{7}{2}^-$ for the ground state of ^{43}Ar, as this nucleus has an odd number of neutrons in the $f_{7/2}$ shell. The β^- transition to the state at 975 keV with $\log ft$ value of 6.5 is too fast for a unique first-forbidden transition. As this level is populated with an $l = 1$ transfer in the $(d, {}^3\mathrm{He})$ reaction,[4] its J^π value is restricted to $(\frac{1}{2}, \frac{3}{2})^-$. From its β feeding we are able to set an upper limit of $\frac{5}{2}$ on the spin value of ^{43}Ar ground state. As the level at 1.51 MeV has been established as $\frac{7}{2}^+$,[8] the β transition to this state ($\log ft = 7.8$) implies $\Delta J = 0, 1$ $\Delta\pi = \pm$ or $\Delta J = 2$ $\Delta\pi = -$. We must then conclude $J_{\mathrm{g.s.}}(^{43}\mathrm{Ar}) = \frac{3}{2}^-, \frac{5}{2}^\pm$, the value $\frac{5}{2}$ being suggested by the nonobservation of transitions to the $J^\pi = \frac{1}{2}^+$ states at $E_x = 0.56$ MeV ($\log ft > 8.5$) and $E_x = 2.45$ MeV. A first-forbidden transition to the ground state of ^{43}K is consistent with $J^\pi = \frac{5}{2}^-$ for ^{43}Ar and with the $\log ft$ value deduced from our measurements ($\log ft = 6.7 \pm 0.1$).

A nuclear spin $\frac{5}{2}$ for ^{43}Ar, if related to five neutrons in the $f_{7/2}$ subshell, must result from the $(j)^n_J = (f_{7/2})^5{}_{5/2}$ configuration. The occurrence of low lying states with seniority number $v = 3$ and $J = j - 1$ has been reported by Talmi.[23] Such states have been identified in other $N = 25$ isotones (^{45}Ca, ^{47}Ti, and ^{49}Cr). Using a $(\pi d_{3/2})^{-2}$ $(f_{7/2}, p_{3/2})^n$ model, Gloeckner *et al.*[24,25] have shown that the binding energies of the argon isotopes calculated for ^{39}Ar, ^{41}Ar, ^{42}Ar, ^{43}Ar, and ^{44}Ar are in qualitative agreement with experiment. From these calculations a ground state doublet is predicted in ^{43}Ar with the $\frac{5}{2}^-$ state lying approximately 150 keV below the $\frac{7}{2}^-$ level. A detailed comparison of this theoretical work with experimental level scheme is not yet possible due to lack of data, but the ground state energy is well predicted (the calculated value differs only by 35 keV).

It should also be noted that a $J^\pi = \frac{5}{2}^-$ ground state with $v = 3$ would explain the lack of an observed β transition to the $E_x = 0,74$ MeV, $J^\pi = \frac{7}{2}^-$, ^{43}K level. The single particle nature of this state being established by the g-factor measurement,[11,12] a strong feeding from a state with higher seniority is therefore not expected.

TABLE III. β branching and $\log ft$ values in the ^{43}Ar decay.

Final state in ^{43}K (keV)	I_β (%)	$\log ft$
0	30 ±7	6.7 ± 0.1
561.1 ± 0.2	<0.3	>8.5
738.1 ± 0.1	<2.7	>7.4
974.9 ± 0.1	16.4 ±2.4	6.5 ± 0.1
1110.0 ± 0.3	0.9 ±0.1	7.7 ± 0.1
1206.8 ± 0.4	1.6 ±0.6	7.4 ± 0.2
1509.7 ± 0.3	0.4 ±0.1	7.9 ± 0.1
1549.5 ± 0.3	0.3 ±0.1	7.9 ± 0.1
1865.7 ± 0.5	<0.9	>7.3
2176.6 ± 0.5	15.8 ±2.1	5.8 ± 0.1
2189.5 ± 0.5	0.4 ±0.1	7.4 ± 0.1
2345.0 ± 0.6	19.6 ±2.1	5.6 ± 0.1
3057.0 ± 0.5	1.1 ±0.1	6.1 ± 0.1
3263.6 ± 0.9	1.0 ±0.1	5.9 ± 0.1
3309.2 ± 0.5	5.5 ±0.9	5.1 ± 0.2
3393.1 ± 0.5	0.40 ± 0.05	6.1 ± 0.2
3454.9 ± 0.5	3.6 ±0.4	5.1 ± 0.1
3608.1 ± 0.7	2.2 ±0.3	5.1 ± 0.2
3646.0 ± 0.4	0.28 ± 0.03	6.0 ± 0.2
3714.2 ± 0.6	0.48 ± 0.05	5.6 ± 0.2

B. ^{44}Ar

The γ-ray spectrum obtained in the first counting period of the multianalysis experiment (2×10 min) is given in Fig. 3. In order to improve the statistical quality of the data, 54 cycles were summed up. Contrary to what is observed for ^{43}Ar, the ^{44}Ar γ spectrum is strongly contaminated with the daughter activity of ^{44}K, due to the comparable half-lives. The lines from ^{44}K decay are well known from Ref. 19. A list of γ-ray intensities and energies assigned to ^{44}Ar decay is given in Table IV and the deduced branching ratios in ^{44}K are reported in Table V. The level scheme established on the basis of our γ-γ measurements (10^6 events) is shown in Fig. 4 and is built on nine excited states in ^{44}K. The main feature of the γ decay is the strong cascade 1886 → 183 → 0 involving two transitions of 1703 and 183 keV. As the (t, p) experiment of Ajzenberg-Selove and Igo[6] indicated no level below 385 keV, this cascade was previously interpreted as the depopulation of the

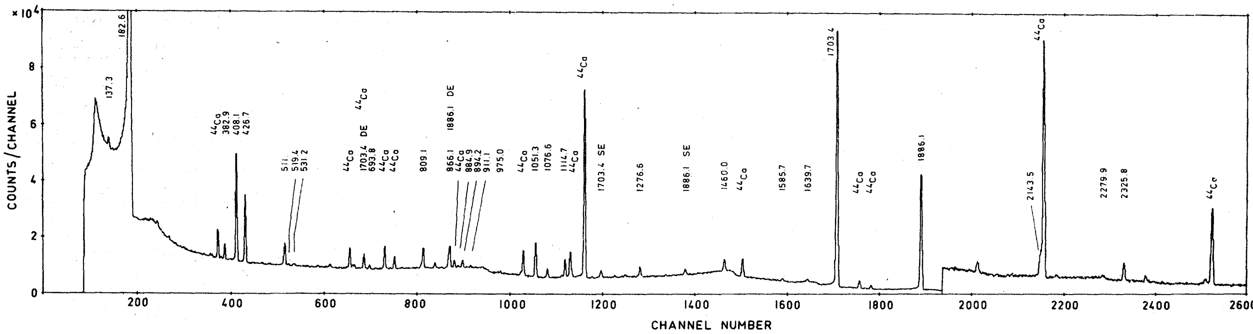

FIG. 3. Singles γ-ray spectrum following ^{44}Ar β decay, recorded during 10 minutes after collection. The single-and double-escape peaks are noted SE and DE, respectively.

level at 1886 keV via a 1704 keV level.[20] A detailed discussion of the ^{44}K excited states populated in this work is presented below.

182.6 keV level. The 183 keV line is the most intense of the spectrum. The level at 183 keV is established by the 183-1703, 183-1277, and 183-2143 keV coincidences combined with the presence of the 1886, 1460, and 2326 keV crossover transitions. Of particular interest is the spectrum in coincidence with the 2143 keV γ ray, shown in Fig. 5, which cannot be interpreted with the previous assignment of the 183 keV transition.[2] In the same figure, the spectrum resulting from chance coincidences and from Compton continuum under the 183 keV gated peak is also represented. A limit for the lifetime of the 183 keV level has been determined using the fast γ-γ coincidence set up with two plastic scintillators. From the obtained limit ($T_{1/2} < 0.9$ ns) we can conclude that the transition (183 → 0) is either $M1$ or $E1$. Multipolarities of higher order would imply unrealistic enhancements.[26]

382.9 keV level. This excitation energy is within the value measured in the (t, ^{3}He) experiment,[6] 383 ±20 keV. The decay takes place 100% to the ground state.

519.8 keV level. A level was also observed by (t, ^{3}He) at 520 ±20 keV. In addition to a ground state transition its γ decay proceeds via the 383

TABLE IV. Energy and relative intensity of gamma rays following β decay of ^{44}Ar.

E_γ (keV)	I_γ	E_i (MeV)	E_f (MeV)
137.3 ± 0.3	2.0	0.52	0.38
182.6 ± 0.1	1000	0.18	0
382.9 ± 0.1	7.8	0.38	0
408.1 ± 0.1	62.4	1.46	1.05
426.7 ± 0.1	39.8	1.89	1.46
519.4 ± 0.4	0.7	0.52	0
531.2 ± 0.3	1.9	1.05	0.52
693.8 ± 0.2	3.5	1.08	0.38
809.1 ± 0.1	29.5	1.89	1.08
866.1 ± 1.0	24.7	2.33	1.46
884.9 ± 0.7	0.5		
894.2 ± 0.1	10.1	1.08	0.18
911.1 ± 0.2	2.3		
975.0 ± 0.4	3.3		
1051.3 ± 0.1	59.8	1.05	0
1076.6 ± 0.1	14.7	1.08	0
1114.7 ± 0.1	33.0	2.57	1.46
1276.6 ± 0.1	23.3	1.46	0.18
1460.0 ± 0.1	33.0	1.46	0
1585.7 ± 0.2	7.8		
1639.7 ± 0.2	10.2		
1703.4 ± 0.1	856.4	1.89	0.18
1765.4 ± 0.8	1.7		
1886.1 ± 0.1	476.5	1.89	0
2143.5 ± 0.4	11.8	2.33	0.18
2279.9 ± 0.3	2.6		
2325.8 ± 0.2	12.3	2.33	0

TABLE V. γ-ray branching ratios in ^{44}K.

E_i (MeV)	E_f (MeV)	Branching ratios (%)
0.18	0	100
0.38	0	100
0.52	0	30.2 ± 0.5
	0.38	69.8 ± 0.5
1.05	0	96.9 ± 0.6
	0.52	3.1 ± 0.6
1.08	0	52.0 ± 2.8
	0.18	35.6 ± 2.5
	0.38	12.8 ± 2.0
1.46	0	27.8 ± 1.8
	0.18	19.6 ± 1.4
	1.05	52.6 ± 2.0
1.89	0	34.0 ± 1.1
	0.18	61.1 ± 2.3
	1.08	2.1 ± 0.2
	1.46	2.8 ± 0.1
2.33	0	25.5 ± 1.5
	0.18	24.3 ± 1.5
	1.46	50.2 ± 2.8
2.57	1.46	100

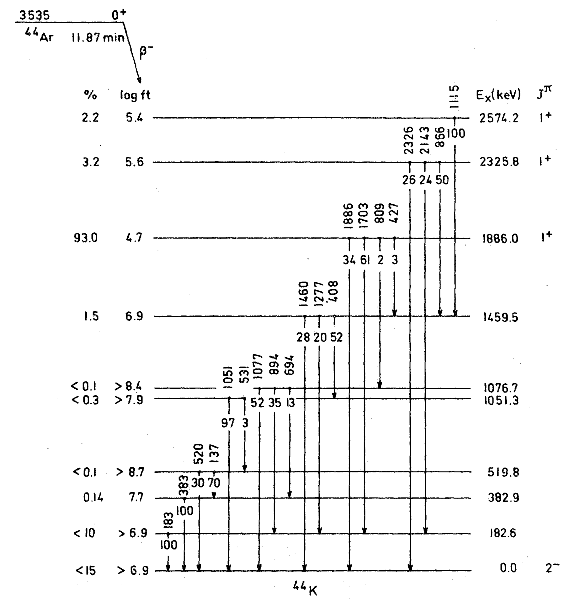

FIG. 4. Proposed decay scheme for ^{44}Ar. Spin values are from Refs. 2, 20, and from this work.

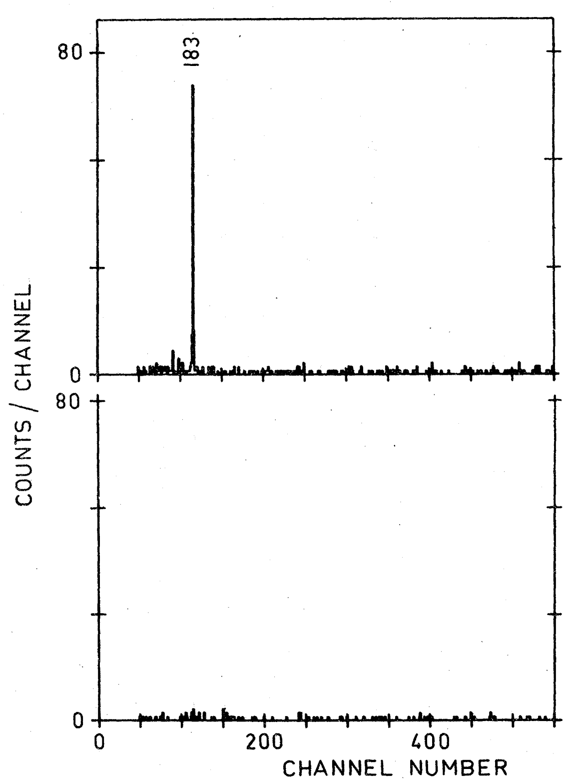

FIG. 5. γ-ray spectrum in coincidence with the 2143 keV transion in ^{44}K (upper portion). Corresponding background spectrum (lower portion).

keV level as indicated by the 137-383 keV coincidence.

1051.3 keV level. This level is established by the coincidences between the 531 keV γ ray and both the 137 and 383 keV lines combined with a strong 1051 keV crossover transition.

1076.7 keV level. A state at 1070 ± 30 keV has been observed by (t, ^{3}He). The 894-183 and 694-383 keV coincidences along with the presence of the 1077 keV crossover transition allow the characterization of the γ decay of this level.

1459.5 keV level. This excitation energy is significantly lower than the value of 1494 ± 20 keV observed in (t, ^{3}He) work and which may correspond to unresolved states.[6] In addition to the ground state transition, two cascades depopulate the level via the 1051 and 183 keV states. This results from the 408-1051 and 1277-183 keV coincidences (Fig. 6).

1886.0 keV level. This level was quoted in the previous ^{44}Ar β decay study and its deexcitation was reported with a 182-1704 keV cascade and a crossover transition. We have proved in this experiment the inverse order for the cascade. In addition two new decay modes were discovered populating the levels at 1460 and 1077 keV via the 427 and 809 keV γ rays. The members of the first of these cascades appear clearly on the spectrum gated by the 408 keV transition given in Fig. 6.

2325.8 keV level. The existence of this new level is inferred from the 2143-183 keV coinci-

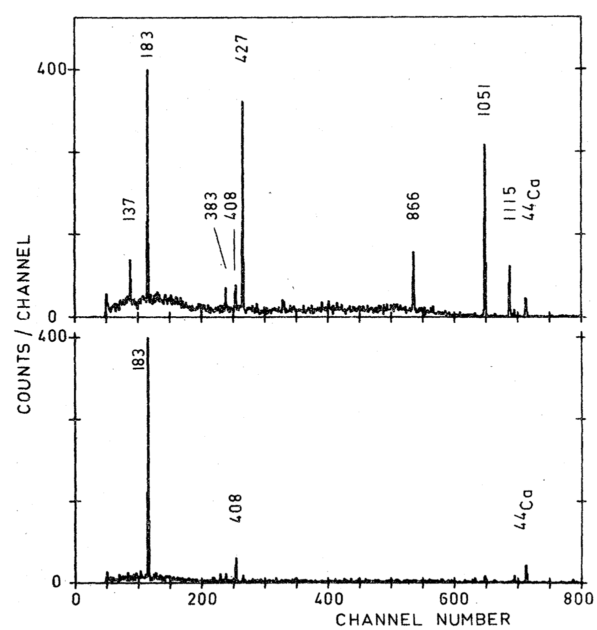

FIG. 6. γ-ray spectrum in coincidence with the 408 keV transition in ^{44}K (upper portion). Corresponding background spectrum (lower portion).

dences and the 2326 keV crossover transition.

2574.2 keV level. The coincidence experiment establishes a level at 2574 keV from the observation of the 1115 keV γ ray cascading with 408, 1051, 1277, and 1460 keV transitions (see Fig. 6).

The β branches and their relative intensity were deduced from the γ-in γ-out balance calculation for each level in the direct γ spectrum. An estimation of the intensity of a possible ground state transition based as in the case of ^{43}Ar on the comparison of the mother and daughter γ activity yields an upper limit of 15%. By taking into account the relatively large uncertainties quoted by Ing[19] in the ^{44}K decay this limit is shifted up to 30%, a value which is probably strongly overestimated. Indeed, the β_0 transition ($0^+ \to 2^-$) related to the lower limit of $\log f_1 t$ for unique first-forbidden β transitions[27] yields in that case an upper limit of only 12%. The $\log ft$ values calculated from our measured β branchings with $T_{1/2} = 11.87$ min (Ref. 2) and $Q_\beta = 3535$ keV are reported in Table VI. The transitions to the levels at 1886, 2326, and 2574 keV are allowed β decays, assigning positive parity to these states with $J = 1$.

IV. WEAK-COUPLING PREDICTIONS

A. $(sd)^{-1}(f)^n$ configurations

The low energy excited states of ^{43,44}K may be viewed as particle-hole states around the closed-shell core of ^{40}Ca. Sherr *et al.*[28] have given a description of $d_{3/2}^{-1}f_{7/2}^{\,n}$, $J = \frac{3}{2}^+$ levels in the $1f_{7/2}$ shell by using the weak-coupling model. In their work, good agreement is found between experimental and computed values of the proton removal energy $R_\pi(A,Z)$ required to remove a proton in a particular configuration, resulting in a state of the nucleus (A,Z). In a recent paper, Paul *et al.*[29] showed that the experimental values of R_π for the lowest $\frac{3}{2}^+$ and $\frac{1}{2}^+$ levels in odd-even potassium and scandium isotopes fit with the theoretical predictions[28] derived from the weak-coupling model:

$$R_\pi(A,Z) = R_\pi(^{39}\mathrm{K}) - (a - \tfrac{1}{4}b)(A-39) - (\tfrac{1}{2}b - c)(Z-19)\,, \qquad (1)$$

the parameters a, b, and c being defined by the usual Bansal-French-Zamick formulation[30] for computing the energy of particle-hole states. The quantity $(a - \frac{1}{4}b)$, deduced from the experimental values of R_π in the odd potassium nuclei is, respectively, equal to -0.92 and 0.76 MeV for the $d_{3/2}$ and $s_{1/2}$ hole states. The value for $(\frac{1}{2}b - c)$, 1.60 MeV, is obtained by fitting the experimental and theoretical results for ^{43}Sc. The R_π dependence on A and Z according to Eq. (1) and corresponding experimental data are compared in Fig. 7. For odd-odd nuclei, it has been shown[31] that proton removal energies corresponding to centroids of $(2J+1)$-weighted states should fall into the same straight line as the proton removal energies for the neighboring odd-even nuclei. With the parameters quoted above, the difference between the calculated and the experimental value[29] for $(d_{3/2}^{-1}f_{7/2}^{\,3})$ centroid is found equal to 93 keV for ^{42}K. The corresponding difference for ^{40}K is

TABLE VI. β branching and $\log ft$ values in the ^{44}Ar decay.

Final state in ^{44}K (keV)	I_β (%)	$\log ft$
0	<15	>6.9
182.6 ± 0.1	<10	>6.9
382.9 ± 0.1	0.14 ± 0.1	$7.7^{+0.4}_{-0.2}$
519.8 ± 0.4	<0.1	>8.7
1051.3 ± 0.1	<0.3	>7.9
1076.7 ± 0.1	<0.1	>8.4
1459.5 ± 0.3	1.5 ± 0.4	$6.9^{+0.3}_{-0.1}$
1886.0 ± 0.1	93.0 ± 0.6	4.66 ± 0.05
2325.8 ± 0.2	3.2 ± 0.2	5.6 ± 0.1
2574.2 ± 0.3	2.2 ± 0.1	5.4 ± 0.1

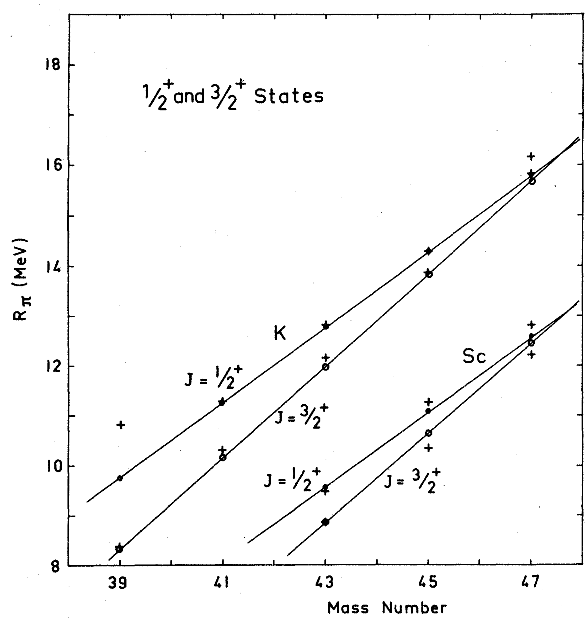

FIG. 7. Proton removal energy for $(d_{3/2}^{-1}f_{7/2}^{\,n})J^\pi = \frac{3}{2}^+$ and $(s_{1/2}^{-1}f_{7/2}^{\,n})\,J^\pi = \frac{1}{2}^+$ levels in K and Sc isotopes. Open circles account for the calculated values from Eq. (1). Experimental values (+) are from Refs. 19 and 32.

20 keV for the $(d_{3/2}^{-1}f_{7/2}^{1})$ configuration. The excitation energy of the $(d_{3/2}^{-1}f_{7/2}^{5})$ configuration in ^{44}K is predicted at 692 keV (213 keV higher than for ^{42}K). Unfortunately such states are not yet identified so that the detailed comparison with experimental values cannot be made.

B. $(sd)^{-2}(f)^n$ configurations

We turn now to the systematics of states with two proton holes in the sd shell and an odd number n of $f_{7/2}$ particles. We define $R_{2\pi}(A,Z)$ as the energy required to remove two protons from a nucleus to reach $M^*(A,T_Z)$ and obtain a simple expression for the binding energy of these states with respect to core plus n particles:

$$R_{2\pi}(A,Z)=R_{2\pi}(^{38}\mathrm{Ar})-(2a-\tfrac{1}{2}b)(A-38)-(b-2c)(Z-18). \qquad (2)$$

We compare in Fig. 8 calculated values with data for the lowest $\frac{7}{2}^-$ states in odd K and Ar isotopes. For ^{43}Ar, no experimental excitation energy for the lowest $\frac{7}{2}^-$ state is known, as the only presumed $\frac{7}{2}^-$ state is assigned $J^\pi=\frac{3}{2}^-$, $\frac{5}{2}^\pm$ from our work. The value reported on the diagram corresponds to the first excited level in ^{43}Ar ($J^\pi=\frac{7}{2}^-$) located in the shell model calculation by Gloeckner *et al.*[25] at 150 keV. In odd potassium nuclei, these $\frac{7}{2}^-$ states have been identified up to $A=45$ and their single particle nature is suggested by magnetic moment measurements[11,12] for $A=39$, 41, and 43. The experimental values of $R_{2\pi}$ display the regularities predicted by Eq. (2). The lines in Fig. 8 represent the calculated values obtained by taking for $(a-\frac{1}{4}b)$ the mean of the values fitted previously for $d_{3/2}$ and $s_{1/2}$ hole states. It appears that the interaction parameter, which shows large variations when a single hole in different subshells interacts with particles, is replaced successfully by a mean value, as the number of holes increases.

From the weak-coupling model, an estimate for the excitation energy of the lowest positive parity state corresponding to an n-particle–2-hole configuration can be calculated for even K isotopes. This value for ^{44}K ($E_x\simeq 1.4$ MeV) suggests a negative parity for the lowest five excited states observed in this work, in good agreement with the related logft values.

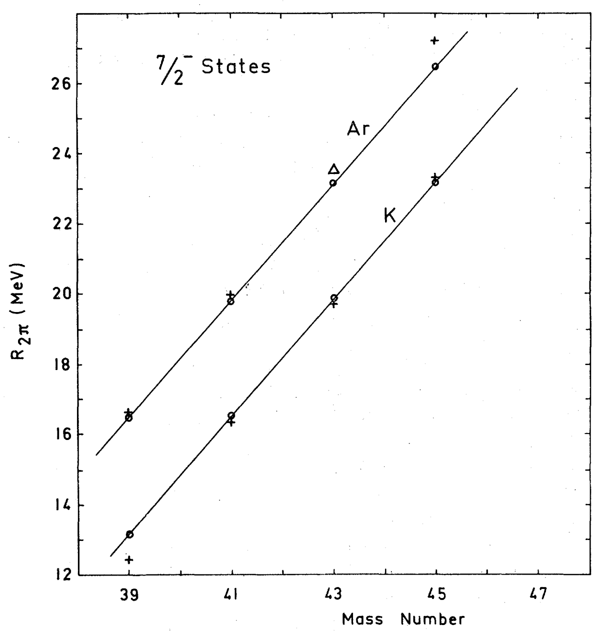

FIG. 8. Two-proton removal energy for $(s_{1/2}d_{3/2})^{-2}(f_{7/2})^n$ $J^\pi=\frac{7}{2}^-$ levels in Ar and K isotopes. Calculated values are obtained from expression (2) (open circles). Experimental values (+) are from Refs. 19 and 32. The triangle represents the value calculated by Gloekner (Ref. 25) for ^{43}Ar.

V. CONCLUSION

The most significant results of this study are as follows:

The limitation of the spin of the ground state of ^{43}Ar to $J^\pi=\frac{3}{2}^-,\frac{5}{2}^\pm$, which makes possible a comparison between ^{43}Ar and other $N=25$ isotones.

The identification of two new $J^\pi=1^+$ states in ^{44}K at 2326 and 2574 keV on the basis of low values of log ft for the β transitions populating them.

The location of the first excited state of ^{44}K at 183 keV resulting from the detailed investigation of γ transitions subsequent to ^{44}Ar β decay.

Finally, it can be noted that there is reasonable agreement between the predictions of the weak-coupling model and the position, spin, and parity of some low lying levels in heavy K and Ar isotopes.

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