PHYSICAL REVIEW C VOLUME 23, NUMBER 5 MAY 1981

High spin states in ^{74}Br

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(Received 23 December 1980)

States of ^{74}Br excited through the ^{60}Ni(^{16}O,np) reaction at $E = 40$ to 55 MeV were studied. From the excitation function, γ-ray angular distribution, γ-γ coincidences, and decay measurements three groups of γ rays depopulating states with probable spin values ranging up to $I = (11)$ were found. A half-life of 49.5 min and $I = (4)$ for the high spin isomeric state at $E \approx 200$ keV were determined at variance with previous values of 41.5 min and $I = (4^-)$. The group of γ rays feeding the $I = (4)$ isomer shows similarities with a recently reported band built on a 4^+ isomer in both ^{76}Br and ^{78}Br. The interpretation of these states as members of the $\tilde{\pi} g_{9/2} \otimes \tilde{\nu} g_{9/2}$ structure is discussed.

[NUCLEAR REACTIONS ^{60}Ni(^{16}O,$np\gamma$)^{74}Br, E=40–55 MeV. Measured E_γ, I_γ, $I_\gamma(t)$, $I_\gamma(\theta)$, γ-$\gamma(t)$. ^{74}Br deduced levels, I^π. Enriched Ni target. Ge(Li) detectors.]

I. INTRODUCTION

In recent years there have been many studies of the properties of high spin states in nuclei in the $A = 60-80$ region. As a consequence of these investigations[1,2] several interesting phenomena have been reported such as the observation of decoupled bands and the coexistence of spherical and deformed shapes. A general feature of this region is the predominant role played by the $g_{9/2}$ orbit in the structure of high spin states.

For those moderately deformed nuclei in this region the influence of the $g_{9/2}$ orbit gives rise to important Coriolis effects. In the particular case of doubly odd nuclei, one expects the yrast states to involve the $\tilde{\pi} g_{9/2} \otimes \tilde{\nu} g_{9/2}$ configuration. Such an intrinsic configuration in which both valence proton and neutron lie in the same orbit is not usually encountered in other regions of the Periodic Table and therefore this case may provide a useful tool for the study of p-n interactions.

The $\tilde{\pi} g_{9/2} \otimes \tilde{\nu} g_{9/2}$ configuration has been identified[3] in ^{76}Br. The 4^+ member of the corresponding multiplet lies lowest and becomes the head of a Coriolis distorted band which has been successfully described[4] by a two-nonintereacting quasiparticle plus rotor model. This calculation confirmed an earlier suspicion[5] (based on the observed parallelism between the first states of this band and those of the ground state band in ^{77}Kr) that there is a common parentage for the positive parity states in ^{76}Br and ^{77}Kr and that the odd proton in the doubly odd nucleus remains considerably inert for the lowest excitations. The agreement obtained with this model implies that the p-n interactions in this system are weak or at least that they do not significantly distort the predicted spectrum.

Another result of this calculation is the prediction of the possible occurrence of a change of phase in the level staggering above the state whose spin value equals that corresponding to the maximum alignment of the proton and neutron, in this case $I = 9$. This prediction which has not been checked until now for ^{76}Br, has been borne out in the case of ^{108}In as pointed out in Ref. 6. Other results concerning this configuration have been obtained for ^{78}Br (Ref. 7) and ^{78}Rb (Ref. 8) although in the latter case the character of the band head remains in doubt.

The nucleus ^{74}Br is an interesting case for extending the study of these systematic features. Coban *et al.*[9] observed a 41.5 min activity in ^{74}Br using the ^{63}Cu(^{14}N, $2np$)^{74}Br and ^{65}Cu(^{12}C, $3n$)^{74}Br reactions. From the subsequent decay into levels of ^{74}Se they tentatively assigned $I = (4^-)$ to the ^{74}Br parent state. Most of the information about ^{74}Br available to date refers to low-spin states.

The ground state of ^{74}Br was found to have $I = (0, 1^-)$ and a half-life of 25.3 min from the decay studies of ^{74}Kr to levels of ^{74}Br (Ref. 10) and from ^{74}Se$(p,n)^{74}$Br reaction studies (Ref. 11).

The 41.5 min activity observed by Coban *et al.*[9] was shown[11] to correspond to an isomeric state with an energy between 135 and 255 keV above the ground state. Recently Piercey *et al.*,[12] bombarding ^{60}Ni with 46 MeV ^{16}O, reported a band structure tentatively assigned to decay into the (4^-) isomer of ^{74}Br. Preliminary results of the present work can be found in Ref. 13.

II. EXPERIMENTAL PROCEDURE AND RESULTS

The decay of high spin states in ^{74}Br was studied using the reaction ^{60}Ni(^{16}O,*np*)^{74}Br produced with an ^{16}O beam from the Brookhaven National Laboratory Tandem accelerator at energies between 40 to 55 MeV. To stop the recoiling nucleus, thick enriched Ni foils (3 mg/cm^2) were used. The spectra were obtained with two Ge(Li) detectors at 90° with respect to the beam axis. Figure 1 shows a singles spectrum at 50 MeV beam energy in which the origins of the strongest peaks are indicated. Robinson *et al.*,[14] in their study of the ^{60}Ni(^{16}O,*xpynzα*) cross sections between 38–46 MeV energy, showed that the strongest channels were *np* and 2*p* and, to a lesser extent, *αp*, 2*pn*, 2*n*, and *αn*. The high spin study of ^{60}Ni(^{16}O, 2*p*)^{74}Se (Ref. 15) established that the cascade of 967.0, 868.2, 728.4, and 634.8 keV transitions form the main path of deexcitation for ^{74}Se. From the intensity of the 967.0 keV γ ray the relative cross section for the 2*p* channel can be obtained. A large part of the intensity of the two lowest members of the cascade, the 782.4 and 634.8 keV transitions, come from the ^{74}Br decay populated in this reaction. The relative cross sections of the *αp* and 2*pn* reaction channels are proportional to the strengths of the 147.6 and 125.6 keV lines (see Fig. 1), the strongest transitions in ^{71}As (Ref. 16) and ^{73}Se (Refs. 17, 18), respectively. A 455.6 keV γ ray, corresponding to the 2*n* reaction, leading to levels of ^{74}Kr (Ref. 19) is observed with a smaller cross section. The Ta x rays in Fig. 1 come from stray radiation hitting the target holder. Finally there are several strong additional transitions (e.g., 188.5, 194.9, and 72.0 keV), some of which have been tentatively[12] identified with transitions in ^{74}Br. In order to establish their origin coincidence and decay measurements, described in the following sections, were performed.

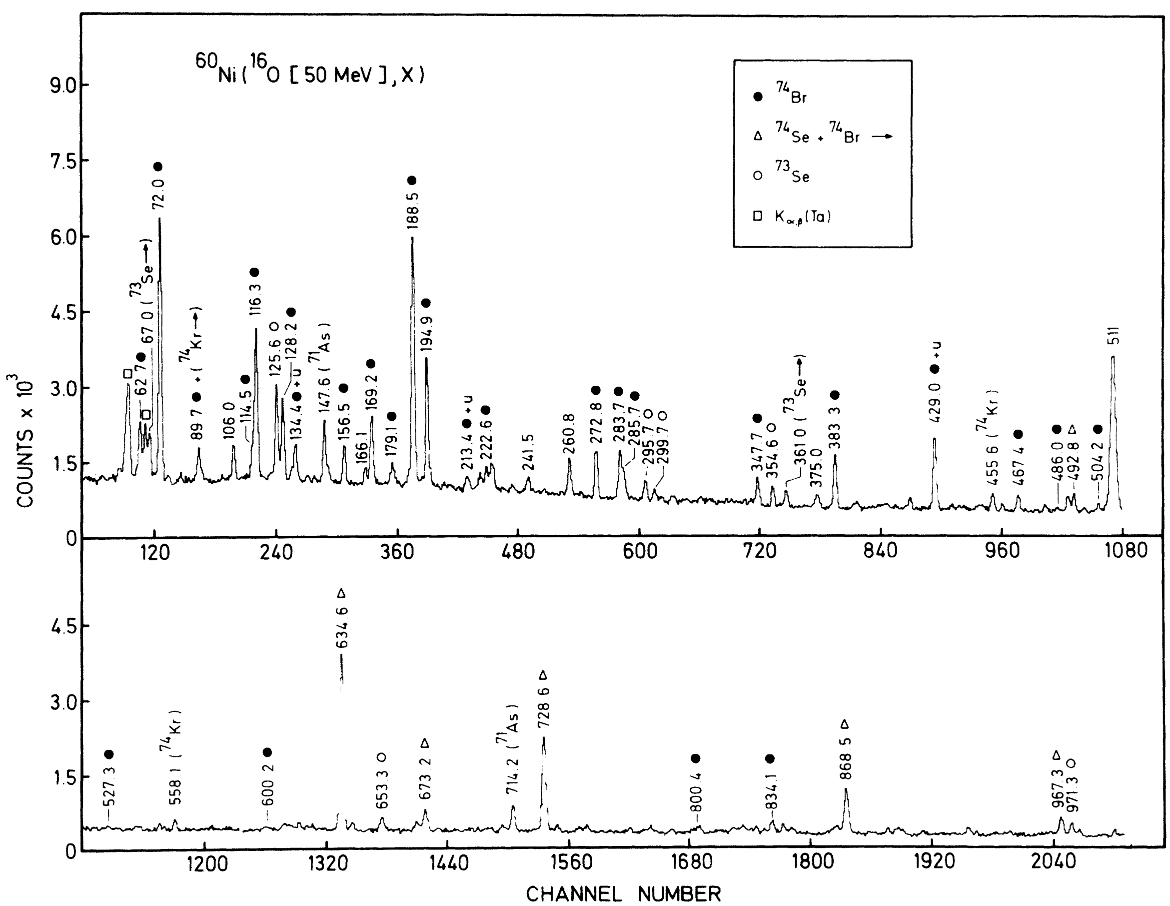

FIG. 1. Singles gamma-ray spectrum from the ^{60}Ni(^{16}O, *X*) reaction at 50 MeV beam energy. Several reaction channels are labeled. Arrows show the transitions originating from the decay of the nuclei indicated. The letter *u* stands for unidentified lines.

A. Coincidence and angular distribution results

The γ-ray coincidence run was performed at 50 MeV beam energy using a pair of Ge(Li) detectors at a distance of 8 cm and at 90° with respect to the beam axis. The data were collected in the event by event mode. After analyzing the gated spectra, three groups of γ rays were found. These groups from now on will be identified by the energies of the strongest transitions feeding the lowest states, namely 188.5, 72.0, and 62.7 keV.

The coincidence results for each group of γ rays are shown in Tables I, II, and III for the three cascades. These tables report the experimental intensities of the transitions observed in each gate and, in parentheses, the expected intensities assuming the level scheme shown in Fig. 2. A search for intergroup transitions proved unsuccessful. Some of the gated spectra are shown in Fig. 3.

The γ-ray angular distributions were measured at 50 MeV beam energy using a cylindrical chamber and a pair of detectors at a distance of 15 cm from the target. One of the detectors was held fixed for normalization purposes. The measurement angles were 90°, 105°, 120°, 140°, and 160°. The resulting A_2 and A_4 coefficients for the angular distribution measurements, together with the intensities of the γ transitions, are shown in Table IV. The level scheme will be discussed in Sec. III.

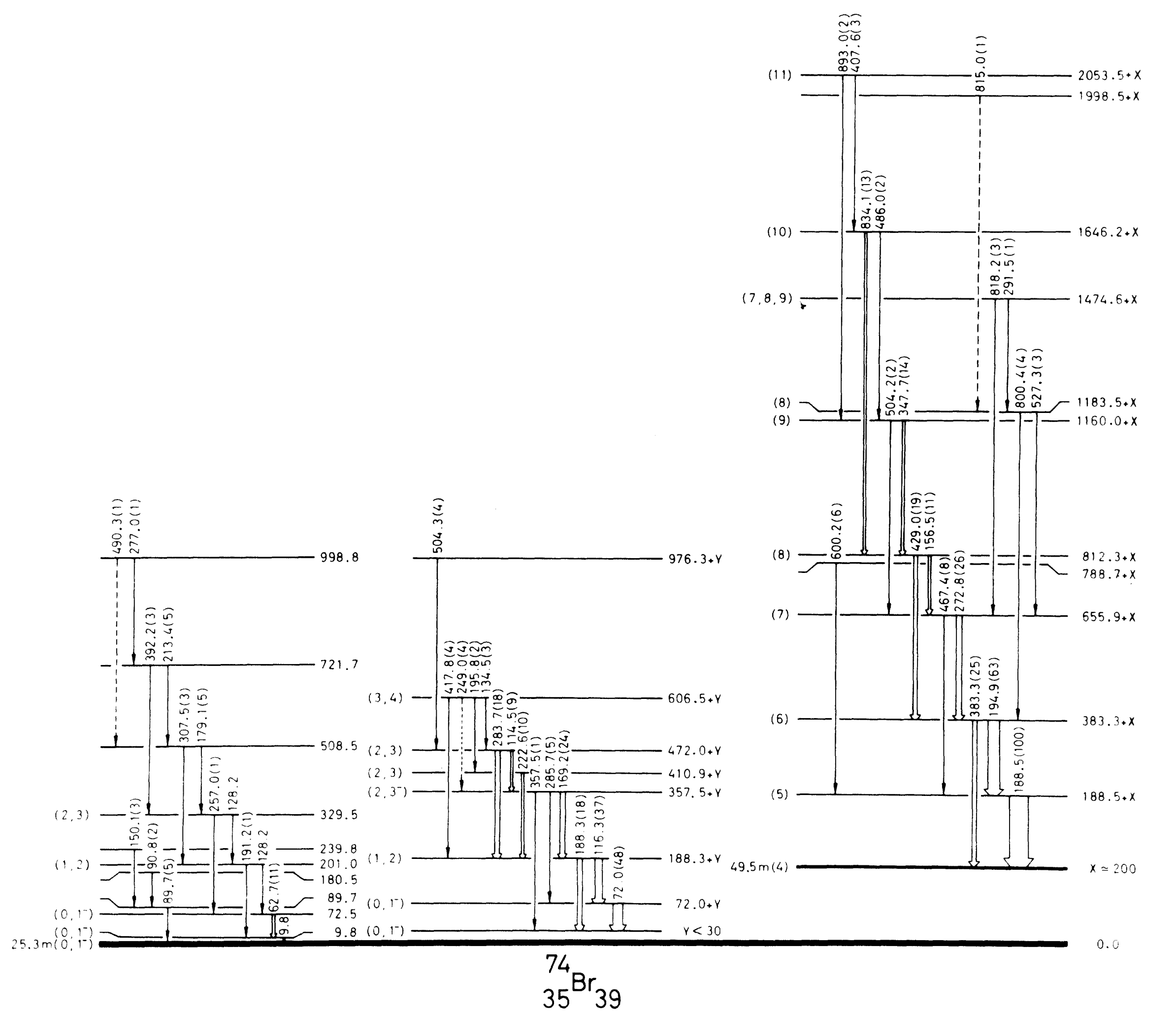

FIG. 2. Level scheme for ^{74}Br. Three independent groups of γ rays, identified by the energies of the strongest transitions feeding the lowest state, namely 188.5, 72.0, and 62.7 keV are shown. The energies of the lowest states for the 188.5 and 72.0 keV group is uncertain and are indicated by $X(\simeq 200$ keV) and $Y(< 30$ keV), respectively. The assignment of the 62.7 keV group to ^{74}Br is not entirely conclusive. For the intensity of the 128.2 keV doublet see Tables III and IV.

TABLE I. Relative coincidence intensities for the 188.5 keV group. The experimental values (upper row) are compared to the expected values (lower row, in parentheses) obtained by assuming the level scheme of Fig. 2. The numbers are normalized to the intensity of the 188.5 keV line in coincidence with the 194.9 keV gate. The letter W denotes weak intensities (less than 0.5 units).

Gate \ E_γ	156.5	188.5	194.9	272.8	291.5	347.7	383.3	407.6	429.0	467.4	486.0	504.2	527.3	600.2	800.4	818.2	834.1	893.0
156.5		7 (9)	5 (6)	10 (8)		3 (5)	3 (2)	0.7 (1)		2 (3)	W (0.6)						1.4 (4)	1 (0.6)
188.5	8 (9)		64 (63)	15 (19)	W (0.7)	10 (9)		3 (2)	14 (14)	9 (8)	1 (1.5)	2 (1.5)	3 (2)	5 (6)	3 (3)	2 (2)	6 (9)	2 (1.5)
194.9	4 (6)	63 (63)		15 (19)	1 (0.6)	10 (9)		3.5 (2)	14 (14)		0.7 (1.3)	W (1)	1 (1.6)		2 (3)	1 (1.6)	5 (8)	0.7 (1.3)
272.8	7.4 (8)	15 (19)	15 (19)		0.5 (0.3)	2 (4)	8 (7)	W (0.8)			W (0.7)	1 (1.5)	3 (2)			2 (2)	2 (3)	W (0.7)
347.7	4 (5)	9 (9)	9 (9)	2 (4)			5 (4)	W (0.3)	7 (9)	W (1)	1 (1.7)							1.2 (1.7)
383.3	2 (2)			6.4 (7)	0.5 (0.3)	3.3 (4)		1 (1)	9 (5)		W (0.5)	W (0.5)	1 (0.6)		2 (1)	0.5 (0.6)	3 (3)	1 (0.5)
429.0		14 (14)	14 (14)			8 (9)	10 (5)	2 (2)			W (1)						7 (8)	1.5 (1)

B. Decay measurement

The isotopic identification was primarily performed studying the γ-ray intensity balance for each reaction channel from in-beam and off-beam measurements. For this purpose a singles spectrum was collected for 3 h while a ^{60}Ni target was irradiated with a 40 MeV ^{16}O beam. In the same experimental conditions and immediately after the irradiation stopped, singles were accumulated for intervals of 9 min during a period of 200 min to study the half-life of the γ rays. During the first 15 min, the intervals were smaller in order to study shorter half-lives.

1. The ^{74}Br decay

The ^{74}Br decay to levels of ^{74}Se has been studied by Coban *et al.*[9] Their source was produced by the ^{63}Cu(^{14}N, $2pn$) and ^{65}Cu(^{12}C, $3n$) reactions and a half-life of (41.5 ± 1.5) min for the $I = (4^-)$ state of ^{74}Br was measured. From the decay study of ^{74}Kr (Ref. 10) to levels of ^{74}Br a state of (25.3 ± 0.3) min and $I = (0, 1^-)$ was established. Both decays populate the ^{74}Se level deexcited by the $2^+ \rightarrow 0^+$ 634.6 keV transition but the 41.5 min decay also populates the level deexcited by the $4^+ \rightarrow 2^+$ 728.6 keV transition. Lueders *et al.*[11] analyzed the excitation functions of the ^{74}Se$(p,n)^{74}$Br reaction and determined that the 25.3 min activity is from the ground state and the 41.5 min activity is from an isomeric state lying between 135 and 255 keV energy.

The decay curves, obtained in this work for the 634.6 and 728.6 keV transitions are shown in Fig. 4. Fitting the data points for the 728.6 keV γ ray with a single exponential function, a half-life of (49.5 ± 1) min was found, differing from the value of 41.5 m reported by Coban *et al.*[9] On the other hand, when the data for the 634.6 keV transition are fitted with a single exponential function, a half-life of (43 ± 2) min is obtained. However, assuming a composite decay curve having a 49.5 min component we find the other component to be (26 ± 3) min which is compatible with the half-life of the ^{74}Br ground state. The latter contributes 22% of the total decay intensity.

From this it can be concluded that both the ground and isomeric states of ^{74}Br were populated in this reaction. The resulting discrepancy with regard to the half-life obtained by Coban *et al.*[9] may be explained by taking into account that while similar reactions were used in both their and our work, they did not know of the existence of the ground state 25.3 min decay and thus its contribution to the intensity of the 634.6 keV line was not taken into account.

Therefore the logft study[9] that assigned $I = (4^-)$ to the isomeric state of ^{74}Br needs to be corrected

TABLE II. Relative coincidence intensities for the 72.0 keV group. For explanation see Table I.

Gate \ E_γ	72.0	114.5	116.3	134.5	169.2	188.3	195.8	222.6	249.0	283.7	285.7	357.5	417.8	504.3
72.0			33 (43)	1 (2)	9 (16)		1 (1)	3 (7)	W (3)	5 (12)	6 (5)		1 (3)	1 (2)
114.5	10 (6)		4 (5)	1 (1)	11 (7)	3 (2)					3 (1)	W (0.3)		2 (1)
116.3	37 (37)	4 (5)		2 (2)	23 (16)		1 (1)	9 (7)	2 (2)	11 (12)			4 (3)	2 (2)
169.2	15 (16)		38 (23)	1 (1)		13 (8)			5 (3)					W (1)
188.3		3 (2)		2 (1)	13 (8)		a (1)	5 (3)	1 (1)	8 (6)			3 (1)	1 (1)
283.7	10 (12)		13 (12)	3 (2)	8 (6)									2 (3)

[a] Transition intensity obscured by the 194.9 keV line in coincidence with the 188.5 keV line.

to take into account the 25.3 min component in the decay. Nevertheless, the strong feeding of the $4^+ \rightarrow 2^+$ 728.5 keV transition of ^{74}Se observed in the decay of the 49.5 min isomeric state still supports the assignment of $I = (4)$ for this state.

2. *Isotopic identification*

Relative cross sections for the different reaction channels (σ_p) were deduced from a 3 h prompt γ-ray singles spectrum at 40 MeV beam energy. Similar quantities (σ_d) were inferred through the decay measurement taken in the same experimental condition immediately after the in-beam measurement. Both quantities should be comparable except for unobserved side feeding into the ground or isomeric state of the parent nucleus which would yield σ_d larger than σ_p. Since at this energy only the reaction channels involving two and three outgoing particles are important[14] the analysis was limited to these reactions. The relative cross sections σ_p and σ_d were normalized to the sum of the intensities of the 188.5 and 383.3 keV transitions that was set equal to 100. In the following, a brief discussion is given on how the values of σ_p and σ_d were obtained for each reaction channel.

$(^{16}O, 2p)^{74}Se$. The high spin states of ^{74}Se are well known[15] and the transitions of the ground state band are clearly seen in the prompt spectra. The three lower states of this cascade, the 634.6, 1363.2, and 2231.4 keV levels, were also populated in the decay of the 25.3 and 49.5 min states of ^{74}Br during the 3 h measurement. An estimate of the direct population can be obtained from the intensity of the upper (967.3 keV) transition in the cascade, that is not influenced by the ^{74}Br decay, assuming that the relative γ-ray intensities reported in the ^{64}Ni(^{12}C, $2n$)^{74}Se reaction work[15] are

TABLE III. Relative coincidence intensities for the 62.7 keV group. The intensity for each member of the 128.2 keV doublet was estimated from intensity balance arguments to be 8 for the transition depopulating the 329.5 keV level and in turn the other one is 10. The error of this estimation is 30%. For further explanation see Table I.

Gate \ E_γ	62.7	128.2	179.1	191.2	213.4	257.0	277.0	307.5	392.2	490.3
62.7		17 (17)	5 (4.5)		3 (4.5)	1 (1)	W (0.9)	2 (3)	2 (3)	W (1)
128.2	17 (17)	16 (16)	7 (8)	2 (1)	6 (7)		1 (1.6)	W (2.7)	3 (5)	3 (2)
179.1	5 (5)	8 (8)		0.7 (0.5)	3 (3)		W (0.4)			W (0.6)
213.4	3 (4)	6 (7)	2 (3)	W (0.5)		0.8 (0.3)	1.7 (0.6)	1 (2)		

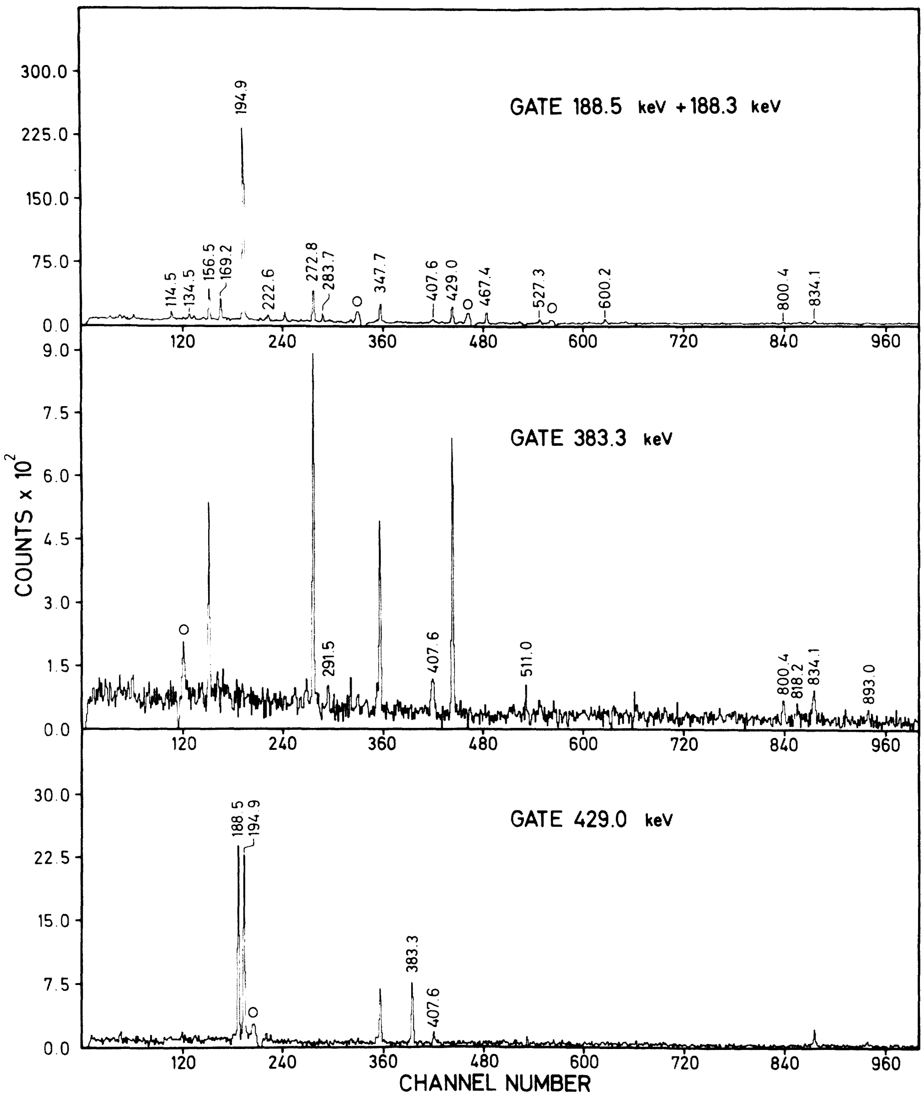

FIG. 3. Coincidence spectra with gates set on the 188.5 + 188.3 keV doublet, 383.3 and 429.0 keV transitions. Lines indicated by circles are due to improper subtraction of backscattering intensity in the gates.

comparable to the ^{60}Ni(^{16}O, 2p)^{74}Se reaction. Another independent estimate can be obtained by calculating how much of the total intensity of the 634.6 keV transition observed in the prompt spectrum belongs to the decay of ^{74}Br. Such an estimate can be deduced from the off-beam spectrum of Fig. 4. Both results agree within experimental errors and a value of $\sigma_p(2p) = 40 \pm 4$ is obtained.

(^{16}O, np)^{74}Br. Different cascades of γ rays may be assigned to ^{74}Br (see discussion below). These are labeled by the strongest γ-ray transitions to the lowest states: 188.5, 72.0, and 62.7 keV. From the total intensity populating the lowest states, values of $\sigma_p(np, 188.5) = 100 \pm 5$, $\sigma_p(np, 72.0) = 80 \pm 4$, and $\sigma_p(np, 62.7) = 14 \pm 1$ were obtained. The total population of the ground and isomeric states of ^{74}Br could be calculated from the decay study of the 634.6 keV transition and using the available information on the ^{74}Br decay scheme. The decay of the 25.3 min ground state of the ^{74}Br is well known[20] and a value of $\sigma_d(np, 25.3\text{ min}) = 120 \pm 15$ has been obtained. The decay scheme of the 49.5 min isomeric state of ^{74}Br is not well known. However, by use of the information available from the 41.5 and 25.3 min decay studies[9,20] the absolute γ-ray intensity for the 634.6 keV transition and therefore $\sigma_d(np, 49.5\text{ min}) = 240 \pm 90$ were determined.

(^{16}O, 2n)^{74}Kr. Nolte *et al.*[19] established the high spin scheme for ^{74}Kr and from the intensity of the

TABLE IV. Energies, intensities, and angular distribution coefficients of γ rays assigned to the ^{60}Ni(^{16}O, np)^{74}Br reaction at 50 MeV energy. The errors in the last numerals are given in parentheses.

$E_\gamma(\pm 0.3)$ (keV)	I_γ[a]	A_2	A_4
62.7	11	−0.13(6)	−0.08(9)
72.0	48	0.02(4)	−0.08(8)
89.7	5[c]		
90.8	2[c]		
114.5	9[b]		
116.3	37	−0.56(5)	−0.02(8)
128.2	18[d]	−0.22(4)	−0.03(6)
134.5	3		
150.1	3[c]		
156.5	11	−0.46(6)	0.02(9)
169.2	24	−0.43(3)	0.09(4)
179.1	5		
188.3	18[b]	−0.43(2)	0.02(3)
188.5	100		
191.2	1		
194.9	63	−0.52(2)	−0.01(3)
195.8	2[b]		
213.4	5		
222.6	10[b]		
249.0	4[b]		
257.0	1		
272.8	26	−0.63(8)	0.08(10)
277.0	1[b]		
283.7	18	−0.24(8)	−0.06(10)
285.7	5	0.31(10)	−0.26(15)
291.5	1	−0.2(2)	0.2(4)
307.5	3		
347.7	14	−0.47(3)	−0.01(4)
357.5	1[b]		
383.3	25	0.27(4)	−0.07(6)
392.2	3		
407.6	3	−0.8(3)	0.4(4)
417.8	4[b]		
429.0	19[b]		
467.4	8	0.21(8)	−0.1(1)
486.0	2		
490.3	1[b]		
504.2	2[b]		
504.3	4[b]		
527.3	3	−0.8(4)	−0.1(6)
600.2	6		
800.4	4	0.35(10)	−0.1(1)
815.0	1[b]		
818.2	3		
834.1	13	0.35(6)	−0.20(12)
893.0	2		

[a] The intensities are normalized to the 188.5 keV transition. The errors are 5% for the strongest peak and 40% for the weaker ones.

[b] The intensities are estimated from the coincidence results. The errors are 30%.

[c] Intensity obtained from the coincidence experiment after subtracting the contribution of the ^{74}Kr decay.

[d] Doublet.

455.6 keV transition a value of $\sigma_p(2n) = 4.0 \pm 0.5$ was obtained. The 11.5 min decay of ^{74}Kr to levels of ^{74}Br is well known from the work of Schmeing *et al.*[10] From the measurement of the decay of 89.7 keV transition a $\sigma_d(2n) = 30 \pm 10$ was established.

(^{16}O, αp)^{71}As. The ^{69}Ga(α, $2n$) reaction was used by Heits *et al.*[16] to study the decay scheme of ^{71}As. From the intensity of the 1000.8 keV transition a relative cross section of $\sigma_p(\alpha p) = 30 \pm 2$ was found. Due to the long half-life of ^{71}As (61 h) it is difficult to obtain a value for $\sigma_d(\alpha p)$.

(^{16}O, αn)^{71}Se. $\sigma_p(\alpha n)$ is not evaluated because there is no high spin data available. A $\sigma_d(\alpha n) = 6 \pm 1$ results from the analysis of the 147.2 keV transition characteristic of the 4.9 min decay of ^{71}Se (Ref. 21) to levels of ^{71}As.

(^{16}O, $3n$)^{73}Kr and (^{16}O, $2np$)^{73}Br. Only the ground state decay of ^{73}Kr and ^{73}Br nuclei are known.[21] In the decay measurements the 178.1 and 125.5 keV transitions which deexcite levels of ^{73}Br and ^{73}Se, respectively, were not observed. Therefore an upper limit for the relative cross section of $\sigma_d(3n) < 1$ and $\sigma_d(2np) < 10$, respectively, were obtained.

(^{16}O, $2pn$)^{73}Se and (^{16}O, $3p$)^{73}As. The high spin states of ^{73}Se (Refs. 17 and 18) and ^{73}As (Ref. 16) are well established. The characteristic γ rays of 125.6 keV (^{73}Se) and 361.0 keV (^{73}As) could not be seen in the prompt spectra and an upper limit of $\sigma_p(2pn) < 6$ and $\sigma_p(3p) < 4$ was obtained for the relative cross sections.

(^{16}O, $\alpha 2n$)^{70}Se and (^{16}O, αnp)^{70}As. The nonobservation in the prompt spectrum of the 945.8 keV transition assigned to ^{70}Se from previous work[22]

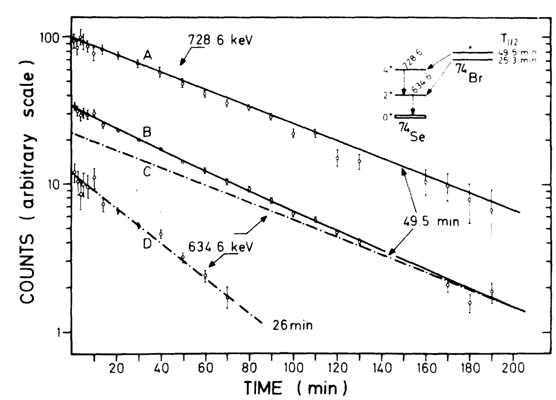

FIG. 4. Decay curves for the 728.6 and 634.6 keV transition, originating from the decay of ^{74}Br to levels in ^{74}Se. The inset shows a partial decay of ^{74}Br to clarify the following description. Fitting the 728.6 keV data with a single exponential gives a half-life of 49.5 min. The curve labeled *B* shows the results of fitting the 634.6 keV data with a sum of two exponentials in which one half-life was set equal to 49.5 min. Curves *C* and *D* represent each term of this sum.

allowed us to set an upper limit for the cross section of $\sigma_p(\alpha 2n) < 4$. The 426.2 keV transition that deexcites a level of ^{70}As populated by the 4.1 min decay of ^{70}Se was not seen in the decay measurement and, therefore, an upper limit of $\sigma_d(\alpha 2n) < 8$ was established. The high spin states of ^{70}As have been studied using the ^{60}Ni(^{12}C,np)^{70}As reaction,[23] and the 81.3 keV γ ray has been assigned as one of the strong transitions in the decay scheme. Since this transition was not observed in the in-beam experiments, a value of $\sigma_p(\alpha np) < 8$ was set. The 1039.6 keV γ ray is a characteristic transition that deexcites the first excited state of ^{70}Ge populated by the 53 min decay of ^{70}As. From the intensity of this γ ray in the off-beam spectrum, $\sigma_d(\alpha np) = 6 \pm 1$ was established.

(^{16}O, α2p)^{70}Ge. Morand *et al.*[24] investigated the high spin structure of ^{70}Ge via the ^{68}Zn(α, $2n$)^{70}Ge reaction and because we do not observe the 1039.6 keV ground state transition an upper limit of $\sigma_p(\alpha 2p) < 4$ could be established.

A summary of the relative partial cross section discussed above is shown in Table V. From the intensity balance between σ_p and σ_d and the information about high-spin states of some of the product nuclei relevant to this experiment, we can conclude that at least the strongest cascades, namely the 188.5 and 72.0 keV cascades, correspond to excited states of ^{74}Br. Each of these cascades could, in principle, populate either the isomeric state or the ground state of ^{74}Br. The data of Table V show that the relative cross section for the 72.0 and 188.5 keV cascades are $\sigma_p(np, 72.0) = 80 \pm 4$ and $\sigma_p(np, 188.5) = 100 \pm 5$, respectively. The isomeric state of ^{74}Br has a cross section of $\sigma_d(np, 49.5\ \text{min}) = 240 \pm 90$ and therefore, it can be populated by both cascades simultaneously. This is not the case for the ground state of ^{74}Br, where the value of $\sigma_d(np, 25.3\ \text{min}) = 120 \pm 15$ allows only one of the previous cascades to populate this level. This uncertainty can be removed when one considers the results of the excitation function reported in the next section.

TABLE V. Summary of relative partial cross sections from the ^{60}Ni + 40 MeV ^{16}O reaction. Results from the prompt and decay experiment are labeled by σ_p and σ_d, respectively. For details see text.

Outgoing particles	Residual nucleus	Relative partial cross section σ_p	σ_d
$2n$	^{74}Kr	4 ± 0.5	30 ± 10
np	^{74}Br^m	100 ± 5[a]	240 ± 90
	^{74}Br	80 ± 4[b] 14 ± 1[c]	120 ± 15
$2p$	^{74}Se	40 ± 4	
αn	^{71}Se		6 ± 1
αp	^{71}As	30 ± 2	
$3n$	^{73}Kr		<1
$2np$	^{73}Br		<10
$2pn$	^{73}Se	<6	
$3p$	^{73}As	<4	
$\alpha 2n$	^{70}Se	<4	<8
αnp	^{70}As	<8	6 ± 1
$\alpha 2p$	^{70}Ge	<4	

[a] The 188.5 keV group normalized to 100.
[b] The 72.0 keV group.
[c] The 62.7 keV group.

C. Excitation functions

In the last section it was determined that the 188.5 and 72.0 keV cascades comprised excited states of ^{74}Br. From excitation function measurements, information can be obtained to elucidate whether these cascades feed either the isomeric or the ground state of ^{74}Br. Singles spectra for periods of 15 min at 40, 45, 50, and 55 MeV beam energy were collected. After normalizing the peak areas with respect to the intensity of the 194.9 keV transition, the relative excitation functions shown in Fig. 5 were obtained. The choice of the normalizing transitions is arbitrary as the object is to compare the relative yields of the excitation functions. The 194.9, 272.8, and 156.5 keV transitions deexcite levels of increasing energy in the 188.5 keV cascade (see Fig. 2). It is to be expected that the population of states with higher energies and spins is favored at higher beam energies (see Fig. 5). The 89.7 keV transition is a well known γ ray feeding the ground state of ^{74}Br from the decay of ^{74}Kr (Ref. 10) and it is also produced by the ^{60}Ni(^{16}O,np)^{74}Br reaction. Studying the excitation function of this γ ray with short bombardments and correcting for the ^{74}Kr decay we obtain the yield of direct production of ^{74}Br in its ground state shown in Fig. 5. The intensity of the 72.0 keV cascade decreases compared to the intensity of the 188.5 keV at increasing beam energy and shows a similar behavior as the known 89.7 keV transition that populates the ground state of ^{74}Br. This observation together with the above mentioned cross-section arguments indicate that the 72.0 keV cascade populates the ground or a low lying state and therefore that the 188.5 keV cascade populates the isomeric state of ^{74}Br. The weaker 62.7 keV cascade shows a similar excitation function as the 89.7 keV transition. This fact together with the existence of a transition of the same energy in the decay of ^{74}Kr depopulating a 72.6 keV ^{74}Br level strongly indicates that the 62.7 keV cascade populates the 9.85 keV level in ^{74}Br.

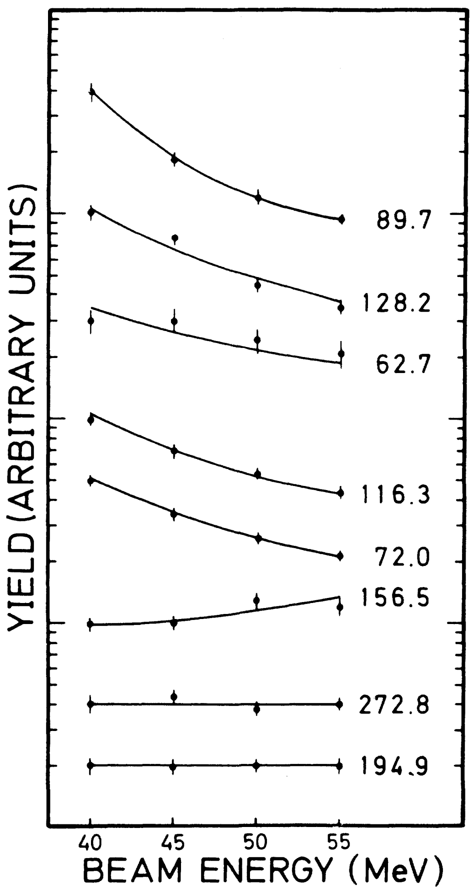

FIG. 5. Excitation function of ^{74}Br transitions between 40 and 55 MeV energy.

III. THE LEVEL SCHEME

As mentioned above, three γ-ray groups have been identified as corresponding to the decay of excited states in ^{74}Br. These are shown in Fig. 2. A discussion of the properties of each one follows.

A. The 188.5 keV group

This is the strongest group and its band head is identified with the 49.5 min $I=(4)$ isomer on the basis of the excitation functions of the γ rays belonging to this group. This assignment agrees with that proposed by Piercey *et al.*[12]

The parity of the band head had been tentatively given as negative.[9] However, because of the lifetime measurements discussed above, this assignment appears not to be justified. Thus, no parity is proposed for this state or for the upper ones.

The angular distribution data of both direct and crossover transitions make it possible to establish the indicated spins of most of the excited states rather unambiguously. The results of the present work do not allow a better determination of the band head excitation energy than that achieved before.[11]

Only a few differences exist with the scheme proposed by Piercey *et al.*[12] regarding this group of γ rays. We do not observe a 1106.9 keV transition which feeds, in the scheme of Piercey *et al.*, the $I=(10)$ state at $1646.2+X$ keV. On the other hand, we observe the 600.2 keV transition from a level proposed at $788.7+X$ keV, and the 527.3 and 291.5 keV from the $1183.5+X$ and $1474.6+X$ keV states, respectively. Furthermore, in the present work the 188.5, 429.0, and 504.2 keV γ lines are identified as doublets so that the intensities of the corresponding γ rays belonging to this group, as determined from the coincidence data, are smaller than hitherto thought.[12]

B. The 72.0 keV group

Although the total intensity feeding the band head is such that this group could also be placed on top of the $I=(4)$ isomer together with the 188.5 keV cascade, the corresponding excitation functions suggest that it populates low lying low spin states. There is a 72.6 keV state known[10] in ^{74}Br. However, the first excited level of this group cannot be identified with that state because the observed intensity of the 72.0 keV line is incompatible with the reported[10] branching ratio with the 62.7 keV transition. On the other hand, an inspection of the spectrum in coincidence with the 72.0 keV γ ray shows that this group's lowest state must lie less than 30 keV above the ground state.

It is interesting to note that the weak 72.2 keV line previously reported to decay from the 72.6 state, which is mainly deexcited by the 62.8 keV transition, was placed only on the basis of its energy. Thus, it is also possible that this line, which was weakly seen in the decay of ^{74}Kr, actually corresponds to that seen in this work.

Therefore we conclude that in addition to the hitherto known state at 72.6 keV there is another state lying no more than 30 keV above this energy. A tentative assignment of 0 or 1^- is proposed for the lowest state of this group since if it were larger the high spin isomer would have a faster decay path and if it were 1^+ a strong feeding from the ^{74}Kr decay should be expected. The 72.0 keV γ line is nearly isotropic. The same arguments given above apply in this case so that $I^\pi(72.0+Y)=(0,1^-)$.

The 116.3 keV γ ray is clearly a $\Delta I=1$ transition because of its large negative anisotropy and small A_4 (see Table IV). Hence $I^\pi(188.3+Y)=(1,2)$. Likewise, the angular distributions of the remaining γ rays of this group allow us to propose the assignments indicated in Fig. 2. The negative parity suggested for the spin 3 in the case of the level at $357.5+Y$ keV stems from the quadrupole character of the 285.7 keV transition and the fact that the coincidence measurements limit the lifetime of that level to a few nsec.

C. The 62.7 keV group

The assignment of this group of γ rays to ^{74}Br is supported by the excitation functions, the lack of alternatives owing to its relative cross section (see Table V) and the available spectroscopic data on other product nuclei, and the identification of the strongest transition, the 62.7 keV line, with a previously known γ ray in the decay of ^{74}Kr. However, we regard this assignment as not entirely conclusive.

The indicated spins and parities are based on the same arguments used in the previous paragraph.

IV. DISCUSSION AND CONCLUSIONS

As mentioned in the Introduction one feature of ^{74}Br which was to be expected from the observations made in the heavier isotopes ^{76}Br and ^{78}Br is the presence of states associated with the high spin intrinsic $\tilde{\pi}g_{9/2}\otimes\tilde{\nu}g_{9/2}$ configuration. Identification of such states has not been achieved in this work but evidence supporting the hypothesis that the 188.5 keV group of γ rays (Fig. 2) corresponds to a band based on that structure is obtained. Figure 6 shows the available data concerning these states in the three isotopes. The behavior of the energy spacings is gradual and it follows the change in deformation. As has already been discussed[4,7] the effect of the smaller deformation is to shrink the lowest $\tilde{\pi}g_{9/2}\otimes\tilde{\nu}g_{9/2}$ multiplet and expand the collective excitations above the 9^+. For larger deformation such as in ^{74}Br, the spectrum gradually approaches the $I(I+1)$ limit in which the level staggering disappears. Furthermore, the energies of the known 4^+ states in ^{76}Br and ^{78}Br lead one to expect that the analogous state in ^{74}Br should lie within a few hundred keV above the ground state. These facts support therefore the possibility that the $I=(4)$ isomer and the band built on it corresponds to the structure under consideration.

One additional property of the $\tilde{\pi}g_{9/2}\otimes\tilde{\nu}g_{9/2}$ plus core system, which was pointed out in the Introduction, is the prediction[4,6] that a change of phase in the level staggering should take place above the 9^+ state. As already stated, this prediction has not been checked until now for the Br isotopes since in ^{76}Br no states above the 9^+ have been identified while in ^{78}Br the 9^+ state remains to be observed. It is interesting to note that the assumption of positive parity for the $I=(4)$ band yield a remarkable confirmation of this prediction (see Fig. 6).

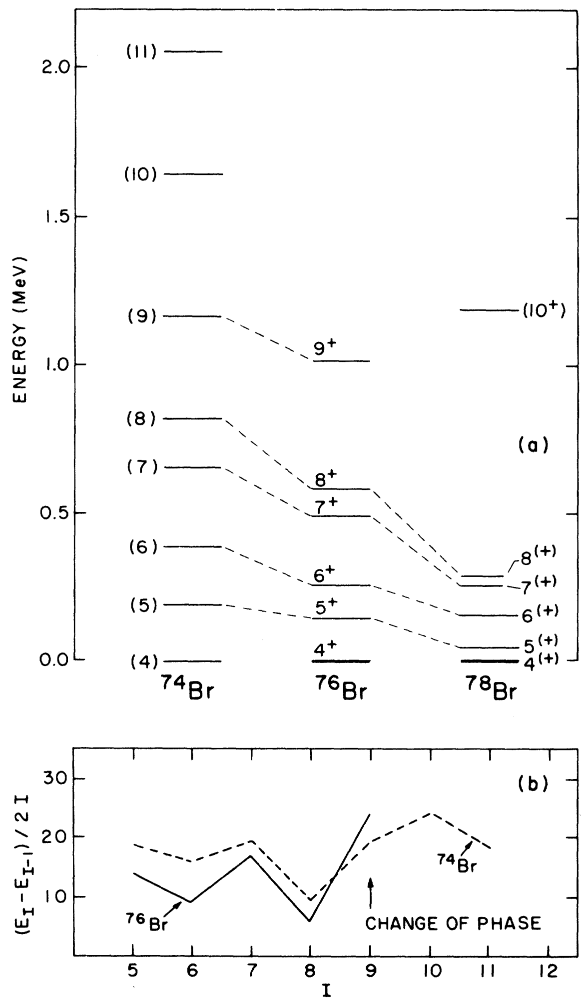

FIG. 6. (a) Comparison of the partial decay scheme of ^{74}Br with the $\tilde{\pi}g_{9/2}\otimes\tilde{\nu}g_{9/2}$ structure found in ^{76,78}Br (Refs. 5 and 7). The energies of the $I=4$ states are set equal to zero. (b) A plot of the quantity $(E_I - E_{I-1})/2I$ for ^{76}Br (solid line) and ^{74}Br (dashed line) assuming $I=4$ for the band head of the 188.5 keV group. For a rigid rotor this quantity assumes a constant value of $\hbar^2/2\theta$. The figure shows a remarkable parallelism between ^{76}Br and ^{74}Br as regards the deviations from the $I(I+1)$ law and also indicates that a change of phase in the level staggering occurs at $I=9$.

In summary, the main results of the present work are presented below.

(a) Observation of ^{74}Br states not seen (with only three exceptions) in the radioactive decay[10] of ^{74}Kr with probable spin values ranging up to $I=(11)$, constituting three essentially independent groups of γ rays.

(b) Confirmation of previous tentative assignments[12] concerning the group of γ rays feeding the high spin isomer.

(c) Determination of a half-life of 49.5 min for the high spin isomer which is at variance with an earlier reported value[9] of 41.5 min. The interpretation of this discrepancy leads to the conclusion that the previous tentatively proposed negative parity assignment for this isomer is not justified.

(d) A search for intergroup transitions, mainly undertaken with the purpose of establishing the energy of the isomer, proved unsuccessful.

(e) The observation of similarities with recently reported bands built on a 4^+ isomer in both ^{76}Br and ^{78}Br suggest that part of the group of γ rays feeding the $I = (4)$ isomer in ^{74}Br constitutes the analogous band in this nucleus. In this case, this band would correspond to the positive parity $\tilde{\pi}g_{9/2} \otimes \tilde{\nu}g_{9/2}$ structure according to a description successfully applied in the case of ^{76}Br.

(f) A change of phase in the level staggering above the $I = (9)$ state is observed. If the identification of this state with the 9^+ member of the $\tilde{\pi}g_{9/2} \otimes \tilde{\nu}g_{9/2}$ band is correct, this change of phase provides the first direct confirmation of the occurrence of this phenomena in the Br isotopes as earlier predicted.

Note added: We have learned of results of L. Funke *et al.* [*Future Directions in Studies of Nuclei far from Stability* edited by J. H. Hamilton *et al.* (North-Holland, New York, 1980), p. 231] who have established the 188.5 keV and 72.0 keV groups in ^{74}Br by cross bombardment. Their results are in agreement with those presented here.

This work has been carried out under the auspices of the Consejo Nacional de Investigaciones Cientificas y Tecnicas, Argentina, the National Science Foundation, and the U. S. Department of Energy under Contract No. DE-AC02-76CH00016.

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