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IN-BEAM STUDY OF ^{78}Br

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Abstract: High-spin states in ^{78}Br decaying into the 4^+ isomer at 180.8 keV were excited via the ^{77}Se(α, 2np) and ^{76}Ge (^{7}Li, 5n) reactions. A sequence of closely lying levels with $I \leq 8$ is found between 227.6 and 467.6 keV. The highest state in this group is populated by a relatively strong 904.1 keV $\Delta I = 2$ transition. These features provide a basis for a comparison with the positive-parity ground-state Coriolis-distorted band of ^{79}Kr, in the light of a rotor plus one- and two-quasiparticle descriptions.

Other previously reported low-spin states are also seen weakly with this reaction. Two new isomeric states of 9 ± 1 ns at 337.8 keV and 84 ± 8 ns at 227.6 keV are found. The latter decays into the 4^+ isomer through a 46.8 keV transition, which lies unresolved from the 46.3 keV line. The existence of this doublet explains an earlier discrepancy.

NUCLEAR REACTIONS ^{77}Se(α, 2npγ), $E = 30$–55 MeV; ^{76}Ge(^{7}Li, 5n), $E = 40$–50 MeV, measured $\sigma(E, E_\gamma)$ E_γ, I_γ, $I_\gamma(\theta, t)$ $\gamma\gamma$-coin. ^{78}Br deduced levels, J, $T_{1/2}$. Enriched targets.

1. Introduction

In a recent letter [1]) we reported on a decay scheme for levels in ^{78}Br depopulating into the 4^+ isomer, which extends above it by approximately 300 keV. A motivation for this study and others [2]) was provided by the earlier observation [3]) of an unexpected parallelism between the 4^+ band [4]) in ^{76}Br and the $\frac{5}{2}^+$ ground-state band [5]) in ^{77}Kr.

The theoretical investigation [6]) of this phenomenon indicates that there is a common parentage in both bands. At least, in the particular case of the $N = 41$

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isotones ^{76}Br and ^{77}Kr, the lowest states of ^{76}Br appear to be essentially unaffected by the unpaired proton. In the case of ^{78}Br one wishes to explore the occurrence of this physical situation by comparing its high-spin positive-parity states with those of ^{79}Kr. In fact, different spectra are expected because of the decrease in deformation taking place from $N = 41$ to 43, and this circumstance should alter the situation as compared to the case of ^{76}Br and ^{77}Kr. Such changes may be valuable for a better understanding of the underlying phenomena.

The data on the positive-parity band of ^{79}Kr are unfortunately incomplete [7-10]. However, the effect of the smaller deformation is evident; the Coriolis distortions are considerably enhanced as compared to ^{77}Kr, so that while the splitting of states associated with the same collective angular momentum R is small, the separation energies between those associated to different collective excitations are as large as 800 keV and more [8,9]. It is important to reach such excitation energies above the 4^+ isomer in ^{78}Br in order to allow a comparison of significance within the present context.

With this purpose, the previous work [1]) was carried on further to achieve observation of higher states. The results of this work are given below and the possibility that the common parentage hypothesis applies to ^{78}Br and ^{79}Kr is discussed in the light of the new data.

2. Experimental procedures and measurements

In the experiments to be described, a 55 MeV α-particle beam from the Buenos Aires synchrocyclotron, which can be degraded to achieve energies between 30 and 55 MeV, was used to produce the ^{77}Se(α, 2np) reaction.

The target was made of 91.8% enriched ^{77}Se. The selenium, in powder form, was uniformly distributed on a 4 μm mylar foil and bound to it with spray lacquer. The target area was about 4 mm^2 and the thickness was 5 mg/cm^2.

The γ-radiation was detected with two coaxial detectors, one of 10% efficiency and 2.3 keV resolution, and the other of 6% efficiency and 3 keV resolution. In addition, the low-energy spectrum was investigated with a small X-ray Ge(Li) detector with a resolution of about 800 eV at 100 keV.

The analyses of the spectra were performed with the aid of the computer programme SAMPO [11]) and sources of ^{152}Eu, ^{133}Ba and ^{241}Am were used for energy and efficiency calibration.

In addition, γ-γ coincidence and singles measurements were carried out at the Grenoble isochronous cyclotron using the ^{76}Ge (^{7}Li, 5n) reaction.

Fig. 1 shows the singles γ-ray spectrum taken with the 10% efficiency detector at $E_\alpha = 45$ MeV, while the low-energy spectrum taken with the X-ray detector at the same bombarding energy is shown in fig. 2. Besides the most intense γ-lines of ^{78}Br at 99.8, 110.2 and 148.5 keV, the ground-state band transitions of ^{78}Kr are prominent in the spectrum of fig. 1. In the better resolution spectrum of fig. 2

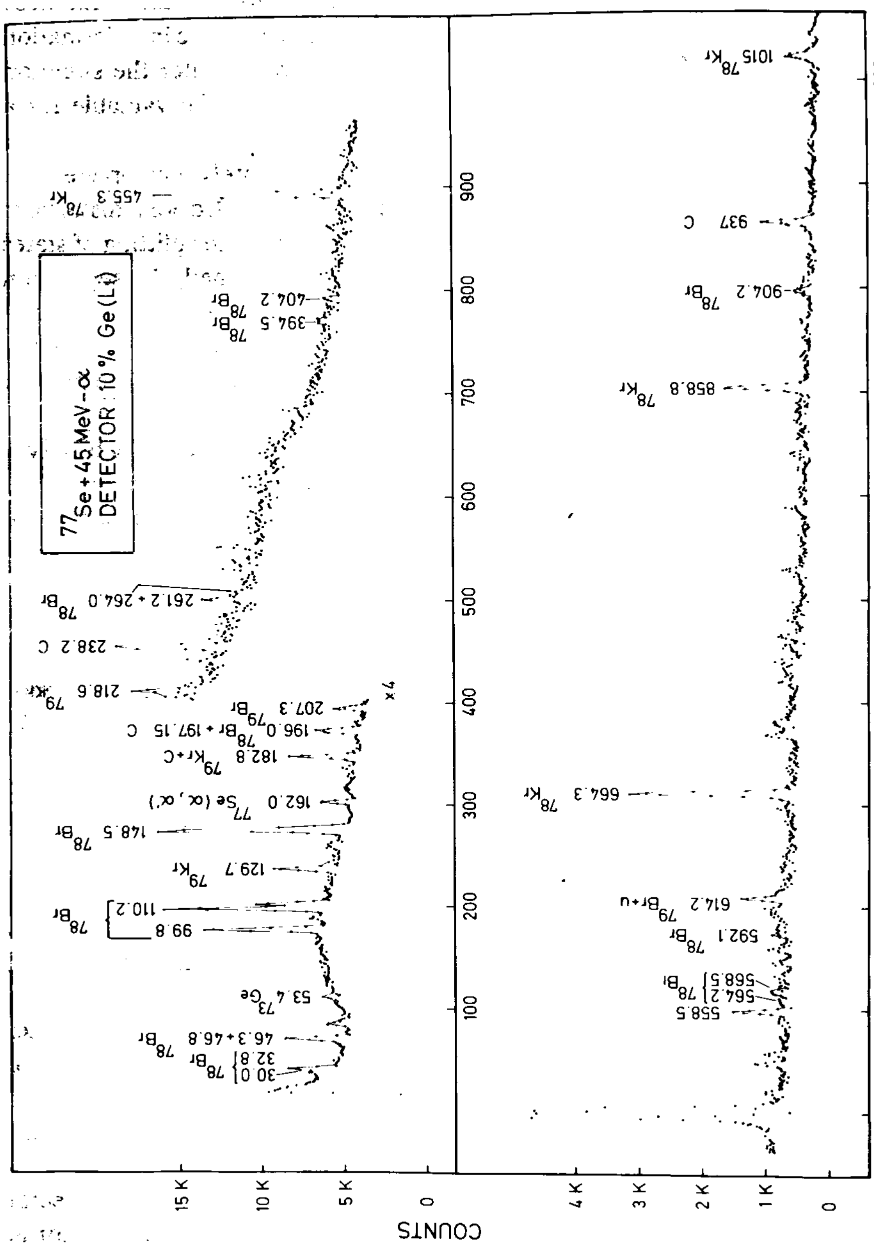

Fig. 1. Singles γ-spectrum taken with a 10% efficiency Ge(Li) detector at 45 MeV. C indicates lines originating in the mylar and u corresponds to unidentified lines.

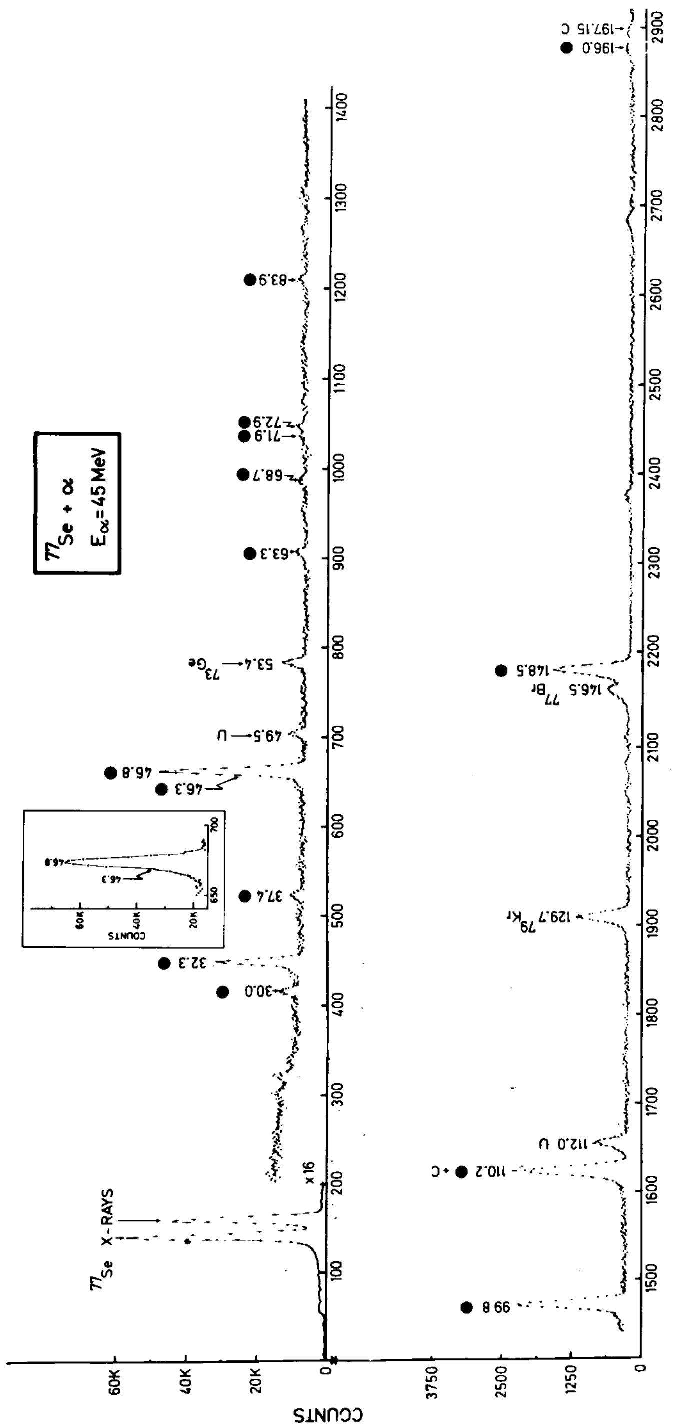

Fig. 2. Singles γ-ray spectrum obtained with the X-ray detector. Full circles indicate ^{78}Br transitions. U stands for unidentified lines and C for known γ-rays originating in the mylar. The 46.3 + 46.8 keV line is shown in the insert under the best resolution conditions.

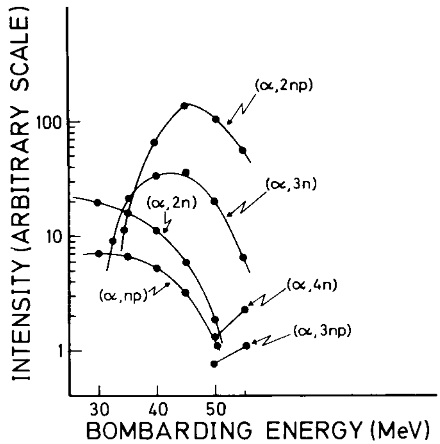

Fig. 3. Excitation functions of representative γ-rays from the most intense reaction products after bombardment of ^{77}Se with α-particles.

the doublet at 46 keV is just discernible, as shown in the insert. The existence of this doublet is confirmed by the timing and coincidence data (see below).

The isotopic assignment of the γ-rays was done on the basis of their relative excitation functions. The α-beam energy was varied between 30 and 55 MeV in steps of 5 MeV. The excitation functions for representative γ-rays from the most intense reaction products after bombardment of ^{77}Se with α-particles are shown in fig. 3. One sees that reactions involving two, three and four particles are easily distinguished from each other. Since the level scheme of ^{78}Kr is well known from the decay of ^{78}Rb and also from (HI, xn) reaction work, the γ-transitions which belong to ^{78}Kr can be readily identified. Similarly, other reactions in which three particles are emitted leading to nuclei such as ^{75}Se, ^{78}Se and ^{75}As can be taken adequately into account since enough information exists on these nuclei. The remaining γ-rays which exhibit an excitation function similar to that of the 99.8, 110.2 and 148.5 keV lines were assigned to ^{78}Br. All these assignments are consistent with those of Kluger-Bell *et al.* [2]).

Energies and intensities of the lines observed in the present work and assigned to ^{78}Br are given in table 1. Estimated total intensities are also shown. In cases where multipolarity is not known the different possibilities are indicated. The results corresponding to the (α, nγ) work of ref. [2]) are also presented in the last two columns of the table.

Measurements of γ–γ coincidences were carried out using two large Ge(Li) detectors and a combination of one large detector and a high-resolution planar counter. Conventional coincidence circuits with time resolutions ranging from $2\tau = 10$ to 60 ns were used in these measurements and the coincidences were stored in the event-by-event mode.

TABLE 1

Energies, intensities, angular coefficients and half-lives determined from the present experiment, together with information extracted from ref. [2])

Present results					Ref. [2])	
E_γ [a]) (keV)	I_γ [f]) γ-intensity	I_T [e]) total intensity	A_2	$T_{1/2}$	I_γ	$T_{1/2}$ (ns)
30.0	15±5	60±20 (E1) 75±25 (M1)	0.03±0.06		10	
32.3	62±8	210±30 (E1)	0 ±0.02		100	8.3±0.3
37.4	7±2	17± 5 (E1) 20± 8 (M1)	0.16±0.10		9	
46.3	7±2	13± 2 (E1)	0.09±0.02 [d])	17±2 ns	68	13.8±1.1
46.8	60±5	108±10 (E1) 120±10 (M1)		84±8 ns		
63.3 [b])	5±1				3.33	
68.8 [b])	3±1.5				2	
71.9 [b])	3±0.6				3	
72.9	4±0.6	5.0±0.8 (E1)	−0.4 ±0.2		3	6.4±0.2
83.9	4±0.5	4.5±0.6 (E1)	−0.5 ±0.3		4	5.1±0.1
99.8	100±5	112±6 (M1)	−0.18±0.02	<3 ns	40	
110.2	110±10	120±11 (MI)	−0.05±0.014	9.0±1 ns	80	6.5±0.1
148.5	180±10	230±15 (M2)	−0.01±0.02	120±1 μs	180	
196.0	25±2		−0.13±0.12	<25 ns	27	
242.9	3±1				2	
261.2	9±2				5	
394.5	16±3				2	
404.2	9±2				3	
419.6	5±1 [c])				2.2	
457.2	4±1				2	
509.2	35±5 [g])				2	
564.2 [b])	6±3					
568.5	18±4		−0.30±0.18		3	
592.1 [b])	6±3					
904.1	38±4		0.30±0.10		2	

[a]) The energy errors for the strongest lines are ±0.2 keV and for the weakest ±0.5 keV.
[b]) Unplaced in the level scheme.
[c]) Intensity estimated from the branching ratio quoted by Kluger-Bell *et al.* [2]).
[d]) This result corresponds to the unresolved 46.3±46.8 keV lines.
[e]) Assuming indicated multipolarities.
[f]) Intensities from both reactions are equal within errors.
[g]) Intensity deduced from coincidence measurements.

The results of these experiments are summarized in tables 2 and 3. The numbers represent the peak areas corrected for the efficiency of both detectors. Some coincidence spectra are shown in figs. 4 and 5.

The γ-ray angular distributions were measured by recording spectra at four different angles (90, 110, 130 and 145°) with respect to the beam direction. The movable detector was placed at 15 cm from the target. The spectra taken at different

TABLE 2

X-gamma coincidence intensities in ^{78}Br [a])

Gate \ Energy	30.0	37.4	46.3	46.8	72.9	83.9	99.8	110.2	196.0
30.0				1.7±0.6			16±2	15±2	
37.4				1.4±0.7	3±1		w		
46.3±46.8	1.7±1	1±0.8			w		13±2	16±2	5±1
72.9		3±1		w		2±1	3±1		
83.9					2±1		1±0.5		
99.8	12±2	w		10±2	3±1	1±0.5		133±15	
110.2	14±1			14±2			167±20		
196.0			4.5±1						
394.5	<1.2			2±1			9±2	9±2	
568.5				<3			14±2	16±3	
904.1	2±1			3±1			14±2	17±2	

Energies are given in keV.

The measurements were carried out with both detectors at 90° with respect to the beam. Corrections for angular distributions were not included explicitly as they are small compared with the intensity errors shown in the table.

[a]) The letter "w" denotes weak intensities.

angles were normalized to the 148.5 keV line, which, due to its long half-life of 120 μs, has an isotropic angular distribution.

The normalized peak areas were fitted to the angular distribution function $W(\theta)=A[1+A_2P_2(\cos\theta)]$. (In a two-parameter fit A_4 was always consistent with zero so that a second fit was carried out with only A_2 as a free paremeter.) The angular distribution coefficients are given in table 1.

A search for isomeric states with lifetimes larger than a few ns was performed in two different kinds of experiments. In the first one, the natural pulsing of the synchrocyclotron beam (one burst every 100 ns) was used to stop a TAC which was triggered by the γ-ray signals from the X-ray detector. In this way a half-life of 9 ± 1 ns was determined for the 110.2 keV line (fig. 6). The 46 keV γ-ray exhibits a time distribution with a long-lived component. When this component is subtracted, a slope corresponding to $T_{1/2}=17\pm2$ ns is obtained (fig. 6). Suspecting that the 46 keV line was a doublet belonging to ^{78}Br, a second lifetime experiment was carried out in which the time delay between the 110.2 and the 46 keV γ-rays was measured, obtaining $T_{1/2}=84\pm8$ ns for the effective half-life of the latter's long-lived component. These results, combined with the γ–γ coincidence measurements, clearly confirm that there are two unresolved γ-rays under the peak at 46 keV. Although the 46 keV doublet is not resolved, a distinct shift is observed when comparing the spectra gated with the 196.0 keV line and those gated with the 110.2 and 99.8 keV lines. This shift indicates that the 46.3, and not the 46.8 keV line is in coincidence with the 196.0 keV γ-ray and corresponds to that placed by Kluger-

TABLE 3

Gamma–gamma coincidence intensities in ^{78}Br with two large Ge(Li) detectors

Gate \ Energy	30.0	46.3+46.8	99.8	110.2	196.0	242.9	261.2	394.5	404.2	509.2	564.2	568.5	904.1
46.3+46.8			30±5	30±5	11±5				4±1				
			2±1	2±1	1±0.5								
99.8		20±5		100				9±4			4±2	11±3	25±3
	16±4	5±2		100				8±2		28±8	5±3	12±3	28±3
110.2		20±5	104±10					9±4			6±3	13±4	29±3
	17±4	6±2	95±10					7±3		24±8	5±3	11±4	20±3
196.0		10±5					8±1		5±2				
		2±1					8±1		6±2				
261.2					7±2								
					8±1								
394.5			7±2	6±2									
	1±0.5		9±2	8±2						9±2	w	4±1	
404.2		3±2			7±3								
		w			9±3	w							
509.2	5±2		39±6	29±5				8±2				4±2	
568.5			9±2	11±2									
	3±2		17±3	15±3				4±2		3±1			9±3
904.1			21±3	21±3									
	3±2		22±3	15±3								9±3	

For each gate energy the upper and lower rows indicate the intensities from the ^{77}Se(α, 2np) and ^{76}Ge(^{7}Li, 5n) reactions respectively. Intensity values are corrected for the efficiency of both detectors and are normalized to the intensity of the 99.8–110.2 keV coincidence. Uncertainties corresponding to the efficiency defect of the coincidence set up for low energies are not included. The letter "w" denotes weak intensity ($I \leq 1$). Coincidence resolution times for the measurements with the ^{76}Ge(^{7}Li, 5n) and ^{77}Se(α, 2np) reactions were approximately $2\tau = 10$ and 60 ns respectively. This difference is reflected in the 46–99.8 and 46–110.2 keV coincidence intensities due to the 84 ns half-life of the 227.6 keV state.

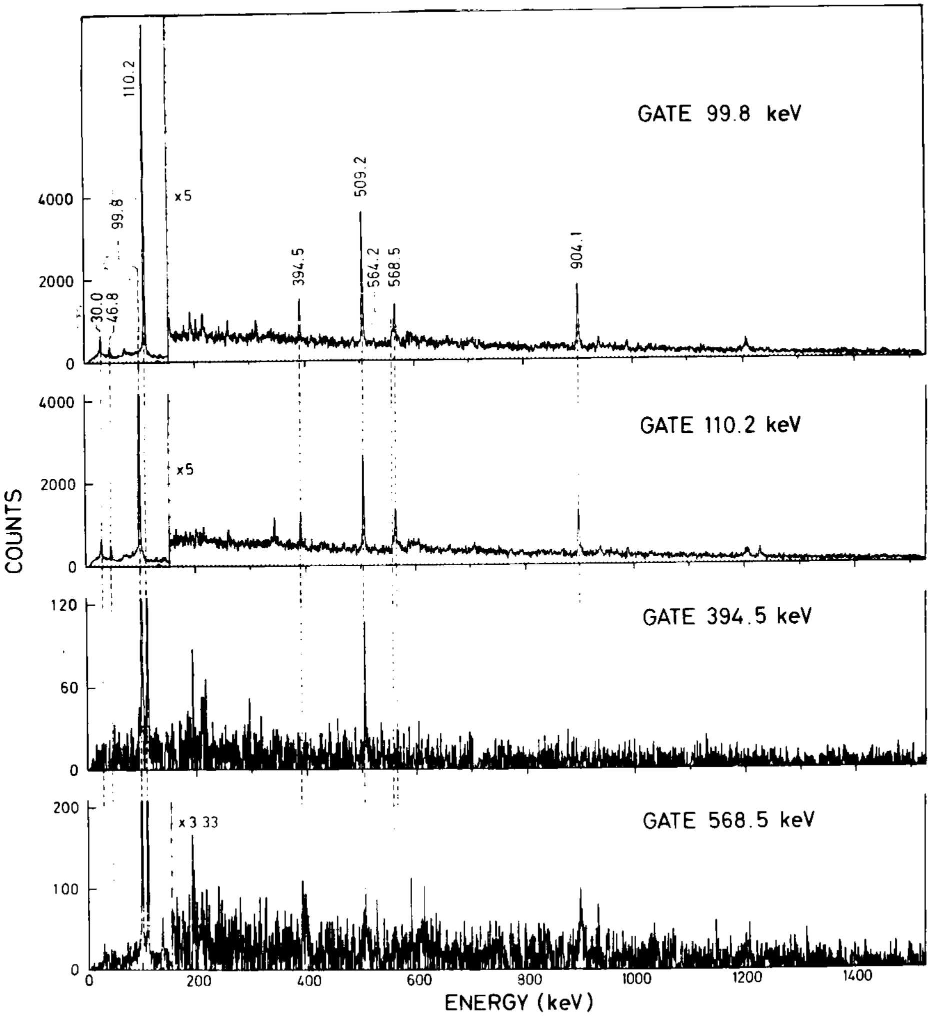

Fig. 4. Coincidence spectrum obtained with the $^{76}Ge(^{7}Li, 5n)$ reaction at $E = 48$ MeV.

Bell *et al.* [2]) as deexciting their 242.3 keV level. This is further corroborated by the fact that the 110.2 and 196.0 keV transitions are not in coincidence, and that by using the same delayed coincidence technique between the 46.3 keV and the 196.0 keV lines a time limit of 25 ns was determined between the two. The half-life of 84 ns corresponds to the stronger 46.8 keV transition. The results of the present measurements are shown in column 5 of table 1 and are compared to those of ref. [2]) in column 8. Our values are about 50% larger than those of Kluger-Bell *et al.* [2]). This shift is approximately the same as observed when comparing the half-life reported in ref. [2]) for the 32.3 keV line and that previously measured [8]).

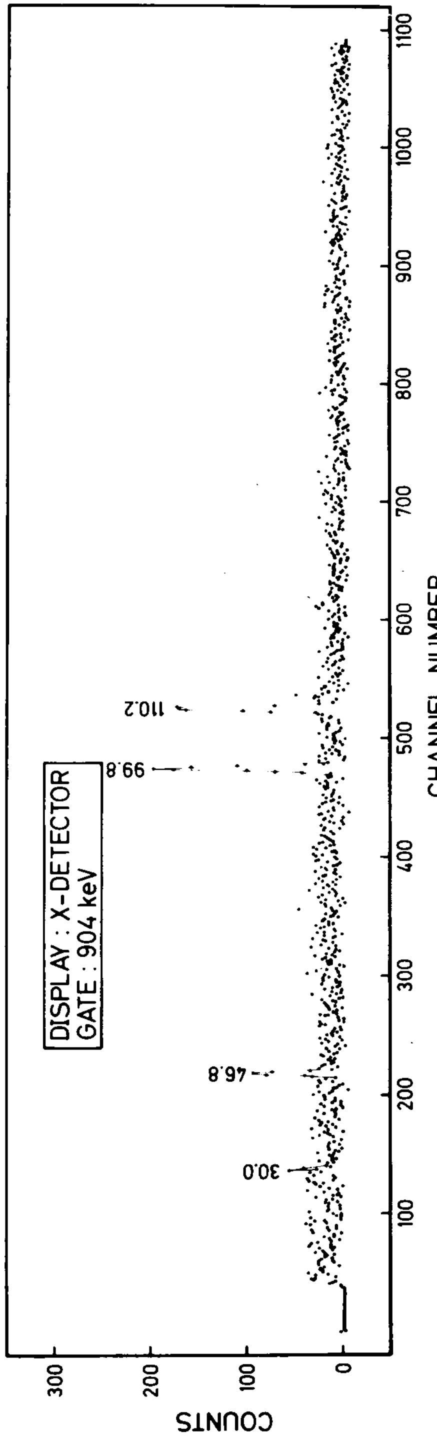

Fig. 5. Coincidence spectrum obtained with the Ge(Li) X-ray spectrometer after background subtraction from ^{77}Se(α, np) at 45 MeV.

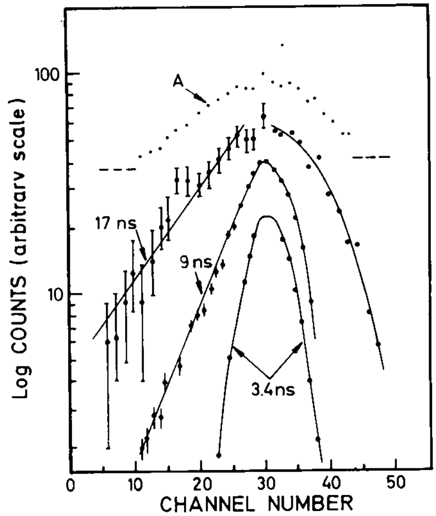

Fig. 6. Time distribution data. A indicates raw data for the 46.3+46.8 keV doublet. After background subtraction $T_{1/2} = 17 \pm 2$ ns is obtained for the 46.3 keV line. The time distribution corresponding to the 110.2 keV line ($T_{1/2} = 9 \pm 1$ ns) and the prompt distribution corresponding to the 99.8 keV γ-ray are also shown.

3. Energy levels and decay scheme

The energy levels of ^{78}Br observed in this work and their decay scheme are shown in fig. 7.

The ground state has spin and parity $I^{\pi} = 1^{+}$ [(ref. [8])] while the corresponding assignments for the 32.3 and 180.8 keV levels have been established by Pleiter *et al.* [12]) to be 2^{-} and 4^{+}, respectively. This result was later corroborated by Kluger-Bell *et al.* [2]) by determining an $l = 1$ transfer in the (p, d) reaction leading to the 32.3 keV state. Since the 148.5 keV isomeric transition is known to be M2, this implies a 4^{+} assignment for the 180.8 keV isomer.

3.1. LOW-SPIN STATES ($I < 4$)

With the exception of the 457.2 keV level these states have been identified in previous charged-particle reaction works [2,8]), or via the (α, nγ) reaction [2]). We believe, as discussed below, that the 457.2 keV state has also been excited, though not identified, in the latter study.

Earlier work of Finckh *et al.* [13]) indicated the existence of a doublet at about 195 keV. Later, two states at 193.5 and 197.0 keV were determined [8]). Kluger-Bell *et al.* [2]) have proposed $I^{\pi} = (0, 1)^{+}$ for the former, an assignment which may be compatible with the fact that we do not observe this state. On the other hand, these authors do not place in their level scheme the ground-state transition from

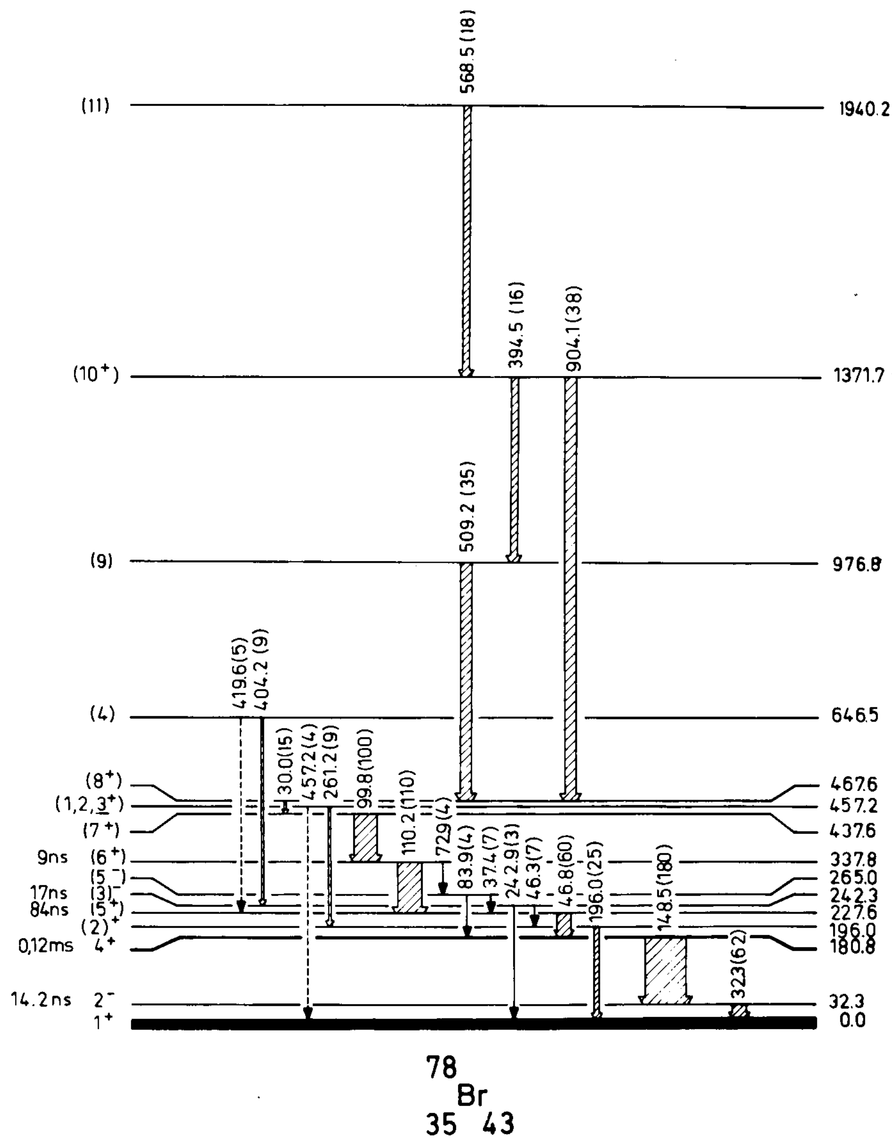

Fig. 7. Level scheme of ^{78}Br. Numbers in parenthesis following the energy values represent γ-intensities, while total intensities are indicated by the relative widths of the transitions.

the 197.0 keV state as hitherto proposed [8]), while they report on a new strong 46.8 keV transition feeding it which implies a large deficit ($I_{in}/I_{out} > 15$) for the outgoing intensity from this state, and this intensity unbalance is not resolved even if the 195.76 keV transition is regarded as the ground-state transition.

The observation of a doublet at 46 keV with two different half-lives for each component, as discussed above, allows us to understand this discrepancy. The transition feeding the state, now proposed at 196.0 keV, is the weak low-energy component of 46.3 keV showing a half-life of 17 ns, which we assign to the 242.3 keV level. The 196.0 keV transition is identified with the ground-state transition, in accordance with previous results [8]), and it probably corresponds to the 195.76 keV γ-ray observed by Kluger-Bell *et al.* [2]) on account of its relative intensity. The cross-over transition from the 242.3 keV level is weakly observed in coincidence with the 404.2 keV line and its placement in the level scheme of fig. 7 agrees with the results of Kluger-Bell *et al.* [2]).

The (^3He, d) data [2]) indicate that the 196.0 keV level has positive parity and $I = 2$ or 3. The present information is consistent with this assignment. Because the anisotropy of the 196.0 keV γ-ray is slightly negative, and its half-life is less than 25 ns, $I = (2)$ is favoured.

The 242.3 keV level has a negative parity and $I = 3$ or 4, as deduced from the $l =$ transfer analysis of the (p, d) reaction [2]). The measured half-life of 17 ns indicates $I = (3)$ for this state.

The 457.2 keV state is established on the basis of the coincidence between the 261.2 and 196.0 keV lines and the non-coincidence between the 261.2 and 46.3 keV lines. Gamma rays of 261.3 and 457.2 keV were observed but not placed in the level scheme by Kluger-Bell *et al.* [2]).

Because of the energy fit we have placed the latter in our level scheme as the ground-state transition from this level. Spin-parity values $I^\pi = 1^\pm$, $2^\pm$ or $3^\pm$ are possible for this state on the basis of the available data. However, the $I_\gamma(261.2)/I_\gamma(457.2)$ branching ratio suggests that $I^\pi = 3^+$ is the most likely assignment.

3.2. STATES DECAYING INTO THE 4^+ ISOMER

The 227.6, 265.0, 337.8, 437.6 and 467.6 keV levels were reported in ref. [1]). With the exception of the 265.0 keV level they provide the main path for the γ-decay of the residual nucleus in the $^{77}Se(\alpha, 2np)$ reaction at bombarding energies of 30 MeV and above. In fact the predominant 99.8, 110.2 and the 46.8 keV transitions were also seen, but not placed in the level scheme, in the $^{75}As(\alpha, n)$ reaction work [2]). These γ-rays are in coincidence and thus constitute a cascade. The latter is the stronger component of the 46 keV doublet, and the time coincidence measurements show that it follows the 110.2 keV γ-ray with a half-life of 84 ns. From this measurement one concludes that the 46.8 keV transition lies lowest in the cascade. In this case a minimum value for this transition's total conversion coefficient can be deduced from the total intensity feeding the 227.6 keV level. We compute the minimum intensity by neglecting the tentative 419.6 keV transition and assuming E1 multipolarities for the 37.4 and 110.2 keV lines (although the latter is believed to be M1 as discussed below), since M1 transitions would yield a larger contribution as indicated in table 1. From this value we deduce $\alpha_T(46.3) > 1.05$. The corresponding E1 and M1 conversion coefficients are 0.80 and 1.00, respectively. Therefore the data indicate a minimum amount of quadrupole mixing, of 1.2% (M2) and 0.35% (E2) in each case. Taking into account that the partial half-life of an M2 transition of this energy is larger than (since M2 transitions are usually hindered) the single-particle (Weisskopf) value of 2.4 ms, even a small, 1.2, percentage implies that the half-life of the 227.6 keV level should at least be 300 times longer. Hence it is most likely that the 46.8 keV transition does not entail parity change.

Because of its intensity, and the fact that the cascade is not observed in the low angular momentum charged particle reactions, it can only feed the 4^+ isomer at 180.8 keV. Hence positive-parity is favoured for the 227.6 keV state.

The observation of a strong cascade without cross-over transitions suggests an increasing sequence of spin values with energy. Indeed the 99.8 keV γ-ray clearly corresponds to a $\Delta I = 1$ transition because of its negative anisotropy. This characteristic is also exhibited by the 110.2 keV γ-ray and the weak 72.9 and 83.9 keV lines, although the angular distribution is attenuated in the first case, and is less accurate in the latter cases.

This combined information suggests that the spins of the 227.6, 265.0, 337.8 and 437.6 keV states are $I = (5)$, (5), (6) and (7), respectively. The $I = (5)$ assignment for the 227.6 and 265.0 keV states is further supported by the positive anisotropy shown by the 37.4 keV γ-ray which is consistent with a $\Delta I = 0$ transition.

The spin of the 467.6 keV level is tentatively proposed as $I = (8)$ because the prompt character of the 30.0 keV transition excludes the possibility of quadrupole multipolarity, and because of the non-observation of a cross-over transition to lower states, which makes it less likely to be $I = 6$ or 7.

The 646.5 keV state is established by the observed coincidences between the 404.2 and both the 46.3 and 196.0 keV lines. Two transitions of 404.2 and 419.6 keV are shown in fig. 7 depopulating this state. We have not observed the second one, which is placed in the level scheme on the basis of the singles data given by Kluger-Bell *et al.* [2]). There is no angular distribution data to help determine the spin of this level. However, its decay into $I = 3$ and 5 states with comparable intensity suggests $I = (4)$ for this level.

The state at 1371.7 keV is particularly well populated in this reaction as indicated by the intensity of the 394.5 and 904.1 keV transitions and therefore bears special interest as will be discussed in the next section. The 904.1 keV line is observed in coincidence with the 30.0–99.8–110.2–46.8 keV cascade and its angular distribution exhibits positive anisotropy, so that $\Delta I = 0$ or 2. The latter is more likely on account of the absence of competing branches into lower states and hence I (976.2 keV) = (9).

The 568.5 keV γ-ray is a relatively strong line in the spectrum. It is in coincidence with the 30.0, 99.8, 110.2, 394.5, 509.2 and 904.1 keV lines. Thus, the 1940.2 keV state is obtained. Because of its negative anisotropy, and lack of higher energy lines from this state into lower ones, the spin of this state is proposed to be $I = (11)$.

The present data are not sufficient to allow an unambiguous determination of the parity of these states. There are, however, a few arguments to be made in this respect. The branching ratio of the 110.2 and 72.9 keV γ-rays, showing the latter regarded, suggests that the 72.9 keV line is E1 (as these transitions are usually hindered several orders of magnitude), while the 110.2 keV γ-ray is M1. This argument would imply negative and positive parities for the 265.0 and 337.8 keV states, respectively. However, the argument is too weak and warrants only a tentative assignment. Likewise the prompt character of the 99.8 and 30.0 keV transitions favours positive parity for the 437.6 and 467.6 keV states. Finally, it is more likely that the 904.1 keV quadrupole transition, be E2 rather than M2, since it is difficult to envisage a case in which transitions of lower multipolarity will not provide a decay mode for states at energies of 1371.7 keV or more.

4. Discussion of the results

The identification [1]) of high-spin states decaying into the 4^+ isomer in ^{78}Br adds interest to the investigation of the $\tilde{\pi}g_{9/2} \otimes \tilde{\nu}g_{9/2}$ system in this nucleus and its relationship with the $\tilde{\nu}g_{9/2}$ band [10]) in ^{79}Kr. Following the observation of such a system [4]) in ^{76}Br, and its interpretation [6]) in terms of two non-interacting quasiparticles coupled to a rotor using neutron and core parameters which fit the $\frac{5}{2}^+$ ground-state band [5]) of ^{77}Kr, it becomes of interest to explore how and to what degree the high-spin states in ^{78}Br, discussed above, can be described in these terms.

From the calculations [6]) of ^{76}Br and ^{77}Kr two results are particularly significant; the first excited states in both nuclei correspond to almost identical average values of the core angular momentum R, and the $\tilde{\pi}g_{9/2}$ proton in ^{76}Br is essentially inert (i.e. its quasiparticle energy remains nearly constant) in these first states. These observations follow the early suggestion [3]) that such states share a common parentage so that the doubly odd system might be described in terms of an odd-A "core".

In ^{78}Br we must expect a different spectrum from that in ^{76}Br owing to the smaller deformation. This is well reflected in the rather distinct increase in 2^+ energies for $A > 78$ in the even–even Kr nuclei, and in the larger spacing between states corresponding to different collective excitations in ^{79}Kr as compared to ^{77}Kr.

In this connection, the observation in the present work of a high-energy quadrupole transition of 904.1 keV feeding the multiplet of states above the 4^+ isomer is particularly interesting, as this energy is comparable to the $\frac{13}{2}^+ \rightarrow \frac{9}{2}^+$ transition [10]) in ^{79}Kr. Although this result is indeed encouraging, a very detailed calculation is not warranted in the present case because of the remaining uncertainties concerning the character of the high-spin states shown in fig. 7, especially regarding their parity. Nevertheless it is of value to investigate, in the framework of the same model as used for ^{76}Br and ^{77}Kr, both the way in which the main predicted features vary owing to the change of deformation, and the degree to which these reproduce the observed spectrum.

The model [6]) consists of a non-interacting quasineutron and a quasiproton both moving in the $g_{9/2}$ Nilsson multiplet coupled to a rigid rotor, whose inertial parameter is taken from the even–even Kr core.

The parameters were chosen as follows: the deformation $\beta = 0.27$ corresponds to the $B(E2, 2^+ \to 0^+)$ value of ^{80}Kr; the pairing strengths for the neutron and proton, $G_n = 22/A$ MeV and $G_p = 24/A$ MeV, are the same as those used in ref. [6]); the inertia constant $\hbar^2/2\theta = 89$ keV corresponds to the mean value of that deduced from the 2^+ energies of ^{78}Kr and ^{80}Kr. Thus the only adjustable parameters were the neutron and proton Fermi levels which were set equal to $\lambda_n = 0.069$ MeV and $\lambda_p = 0.529$ MeV relative to the $\Omega_n = \frac{5}{2}$ and $\Omega_p = \frac{1}{2}$ state energies, respectively. The results (see table 4) show:

(a) The small $\frac{9}{2}^+$–$\frac{7}{2}^+$ splitting in ^{79}Kr is obtained and the center of gravity of the $\frac{13}{2}^+$–$\frac{11}{2}^+$ doublet lies close to the position of the $\frac{13}{2}^+$ state [10]). A slight change in deformation (from $\beta = 0.27$ to 0.25) improves markedly the agreement (see energies in parenthesis in table 4) showing that the model is basically adequate to describe the positive-parity band in ^{79}Kr. We note also that the lowering of the $\frac{7}{2}^+$ state to become the ground state, instead of the $\frac{5}{2}^+$ state as in ^{77}Kr, is correctly given by the calculations.

(b) In ^{78}Br, the $4^+, 5^+ \cdots 8^+$ members of the lowest multiplet corresponding to almost vanishing core rotation, lie within 300 keV (in contrast to 600 keV as in ^{76}Br). This agrees with the experimental data, if the tentatively proposed positive parities for the levels above the 4^+ isomer up to 467.6 keV are correct. Under this assumption it is seen that the calculation yields a very good agreement with the position of the 4^+ state (correctly predicted to be the band head) and the 5^+ and 8^+ states, while the 6^+ and 7^+ states come about 150 keV below the experimental values.

(c) The agreement with the tentative (10^+) state at 1371.7 keV is excellent. At the same time it may be noted that the energy predicted for the 11^+ member of the ^{78}Br band lies close to the 1940.2 keV level. It should be therefore interesting to confirm the character of this level.

(d) The 9^+ member of the ^{78}Br band may be the state observed at 976.8 keV. The calculation predicts this state to be separated from the rest of the $\tilde{\pi} g_{9/2} \otimes \tilde{\nu} g_{9/2}$ multiplet by more than 300 keV, a result which is in qualitative agreement with the present data. This "push-up" effect is also seen in the neighboring doubly odd Br isotopes gradually increasing with neutron number.

The calculation also shows that the R-values remain nearly constant around $1.5\hbar$ for the $4^+ \leq I^\pi \leq 8^+$ states in ^{78}Br. This result differs slightly from those of ^{76}Br [ref. [6])], in that for this nucleus the 8^+ state is seen to involve a larger amount of

TABLE 4

Excitation energies (relative to band head states), R-values and quasiparticle energies of the positive parity bands in ^{78}Br and ^{79}Kr

^{78}Br						^{79}Kr				
I^π	E_{th}	E_{exp} [a]) (keV)	R ($\hbar$)	ε_p (MeV)	ε_n (MeV)	I^π	E_{th} [b]) (keV)	E_{exp} (keV)	R ($\hbar$)	ε_n (MeV)
4^+	0	0	1.46	1.54	1.45					
5^+	56	46.8	1.85	1.54	1.35					
6^+	4	157.0	1.30	1.54	1.51					
7^+	101	256.8	1.42	1.56	1.54	$\frac{5}{2}^+$	20 (29)	160.8	1.82	1.28
8^+	273	286.8	1.53	1.59	1.65	$\frac{7}{2}^+$	0	0	1.26	1.46
9^+	596	796.0	2.04	1.63	1.71	$\frac{9}{2}^+$	97 (23)	19.1	0.81	1.68
10^+	1190	1190.9	3.09	1.64	1.73	$\frac{11}{2}^+$	632 (583)	766.9 [c])	2.35	1.65
11^+	1740	1759.4	3.65	1.70	1.83	$\frac{13}{2}^+$	962 (825)	846.9	2.55	1.87
12^+	2815		4.98	1.69	1.78	$\frac{15}{2}^+$	2036 (1952)		4.30	1.72

Calculated values correspond to the following parameters [b]): $\hbar^2/2\theta = 89$ keV; $\beta = 0.27$; $G_n = 22/A$ MeV; $G_p = 24/A$ MeV; $\lambda_n = 69$ keV; $\lambda_p = 529$ keV (see text).

[a]) E_{exp} corresponds to experimental energies above the 4^+ isomer.

[b]) Values in parenthesis correspond to $\beta = 0.25$ instead of $\beta = 0.27$.

[c]) This state is given in ref. [8]) as $(\frac{9}{2}^+)$ at 877.3 keV. The assignment was made [7]) at a time when the low-lying $\frac{9}{2}^+$ state at 148.8 keV [ref. [9])] was not known and therefore was taken to decay through the 747.8 keV γ-ray into the $\frac{7}{2}^+$ state at 129.7 keV [ref. [8])]. Here, we would like to tentatively reinterpret this state, mainly on the basis of theoretical considerations and also preliminary experimental results, as the unfavored $\frac{11}{2}^+$ member of the $R = 2$ doublet in ^{79}Kr. Hence, the 747.8 keV γ-ray would feed the $\frac{9}{2}^+$ state defining the level given in the table at 766.9 keV relative to the $\frac{7}{2}^+$ band head.

core rotation. In both cases a typical Coriolis distorted sequence of R-values (sawtooth shape) as I increases is observed to develop for $I^\pi \geq 9$, which accompanies that obtained in the odd-A case for ^{79}Kr, as well as ^{77}Kr, for $I^\pi \geq \frac{9}{2}^+$. This is not difficult to understand, since, as was previously indicated [6]), the spin values 9 and $\frac{9}{2}$ correspond to the maximum obtainable intrinsic angular momentum in the doubly odd and odd-A systems, respectively. The ^{79}Kr and ^{77}Kr R-values are nearly the same for every I-value. For $I^\pi \leq \frac{9}{2}^+$ these fall between 0.8 to 1.8$\hbar$ and are similar to those in the doubly odd-nuclei. However this similarity, which clearly indicated [6]) a common parentage phenomenon between ^{76}Br and ^{77}Kr, is less marked in the case of ^{78}Br and ^{79}Kr.

On the other hand the condition of "inertness" of the valence proton is seen to be even better fulfilled in ^{78}Br than in ^{76}Br, as exhibited by the constancy of its quasiparticle energy for the $I^\pi = 4^+, 5^+ \cdots 8^+$ states.

In summary, the states of ^{78}Br decaying into the 4^+ isomer, observed in this work, seem to correspond to those expected from two non-interacting particles of $g_{9/2}$ parentage coupled to an even–even core.

The calculation shows that the phenomenon of a $\tilde{\pi}g_{9/2} \otimes \tilde{\nu}g_{9/2}$ particle configuration plus core system exhibiting a direct parentage with the structure due to the motion of a single $g_{9/2}$ neutron coupled to the same core is fully realized in ^{78}Br, as it is in ^{76}Br, as shown principally by the initial "inertness" of the unpaired proton, and by their similar behaviour at higher angular momenta.

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