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The decay of ^{74}Kr and its daughter

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Abstract. A level scheme has been established for ^{74}Br by observing the γ rays following the decay of ^{74}Kr. The decay of its daughter nucleus ^{74}Br has also been studied, and comparison of this and previous work leads to the identification of an isomeric state in ^{74}Br, and it is shown that the new state in ^{74}Br which decays by β^+ emission possesses $J^\pi = 0^-$ or 1^- in contrast to $J^\pi = 4^-$ for the previously observed state of ^{74}Br.

1. Introduction

In our recent study of the decay of ^{74}Br (Coban *et al* 1972) it was concluded that the parent state ^{74}Br, with a half-life of 41·5 min, possesses $J^\pi = 4^-$ whereas previous work on the decay of ^{74}Kr to ^{74}Br (Gray *et al* 1960) suggested that the ground state of ^{74}Br possessed $J^\pi = 0^+$ or 1^+. In order to resolve this ambiguity it was decided to investigate the decay scheme of ^{74}Kr.

Indeed, very little is known about the decay of ^{74}Kr. It was identified by Butement and Boswell (1960). They measured its half-life to be 12 min from the build-up of a 25·7 min bromine activity which they assigned to ^{74}Br. Gray *et al* also identified ^{74}Kr in 1960 but with a half-life of 20 min. They did not observe any γ ray except 511·0 keV annihilation radiation. Recently during the course of the present work Davids *et al* (1973) reported nine γ rays from the decay of ^{74}Kr but no information was given on its daughter nucleus ^{74}Br.

2. Experimental procedure

2.1. *Gamma ray singles measurements*

The ^{74}Kr sources were produced by the ^{63}Cu(^{14}N, 3n)^{74}Kr and ^{60}Ni(^{16}O, 2n)^{74}Kr reactions using the Manchester HILAC. The production of ^{74}Kr was identified by means of its 12 min half-life in the excitation function measurements of the ^{63}Cu + ^{14}N reactions using 1 mg cm^{-2} enriched targets of ^{63}Cu. The excitation function for the ^{63}Cu(^{14}N, 3n)^{74}Kr reaction peaked at about 52 MeV bombarding energy. The results of these measurements however indicated that cross sections for the np, 2np and α2n reactions were much larger than that of the 3n reaction. Similar results were reported by Robinson *et al* (1971) for the ^{60}Ni + ^{16}O and ^{58}Ni + ^{16}O excitation function measurements. Consequently it proved necessary to perform a chemical separation of krypton from other unwanted reaction products.

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The target was dissolved in nitric acid thus releasing krypton and other gaseous reaction products, principally bromine. This gas was passed through a copper spiral cooled to dry ice temperature, where the bromine was removed, and the krypton was absorbed in an activated charcoal trap maintained at the temperature of liquid nitrogen. The charcoal was then used as the source. The whole process was completed in less than five minutes after the bombardment stopped, and was found to be very efficient in removing bromine.

Figures 1 and 2 show two typical singles spectra obtained after such a separation. The spectrum shown in figure 1 was taken with a Ge(Li) x ray detector with a resolution of 550 eV FWHM at 14·4 keV while the spectrum in figure 2 was obtained with a large (70 cm^3) Ge(Li) counter with a resolution better than 2·5 keV FWHM at 1332·5 keV.

Half-lives were determined by recording the spectra for times between 100 and 300 s over a period of two hours. The weighted average of the measurements yielded a value of $11{\cdot}6 \pm 0{\cdot}6$ min for the half-life of ^{74}Kr. Standard radioactive sources were used for energy and detector efficiency calibrations.

The γ rays assigned to the decay of ^{74}Kr are listed in table 1 with their relative intensities.

In following the decay of ^{74}Kr with the separated sources the build up and decay of the 219·0, 634·7, 985·0, 1022·8, 1204·0 and 1269·1 keV γ rays, associated with the daughter ^{74}Br activity, were observed. Several other γ rays which were also previously assigned to the decay of ^{74}Br (Coban *et al* 1972) showed similar trends but other prominent lines seen previously in the decay of the 41·5 min decay of ^{74}Br, including the 615·5, 728·3, 838·9, 1200·5 and 1249·5 keV transitions, were not observed. The weighted average of the half-lives of the γ rays following the decay of ^{74}Br is $28{\cdot}0 \pm 2{\cdot}0$ min. All the γ rays observed in the 28 min decay of ^{74}Br from several different runs are collected together and listed in table 2 with their relative intensities.

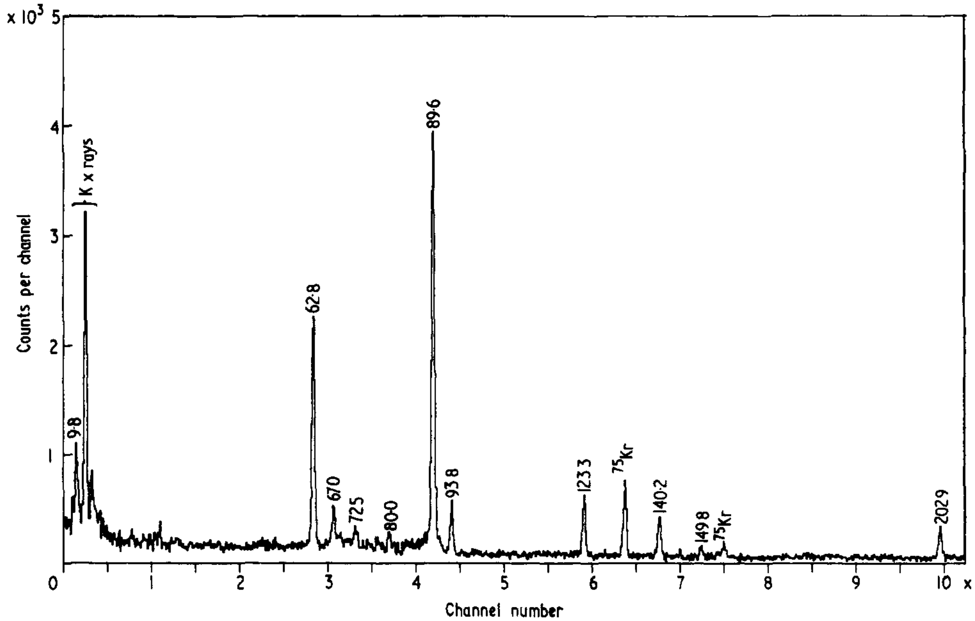

Figure 1. Gamma ray singles spectrum following the decay of ^{74}Kr (Ge(Li) x ray detector).

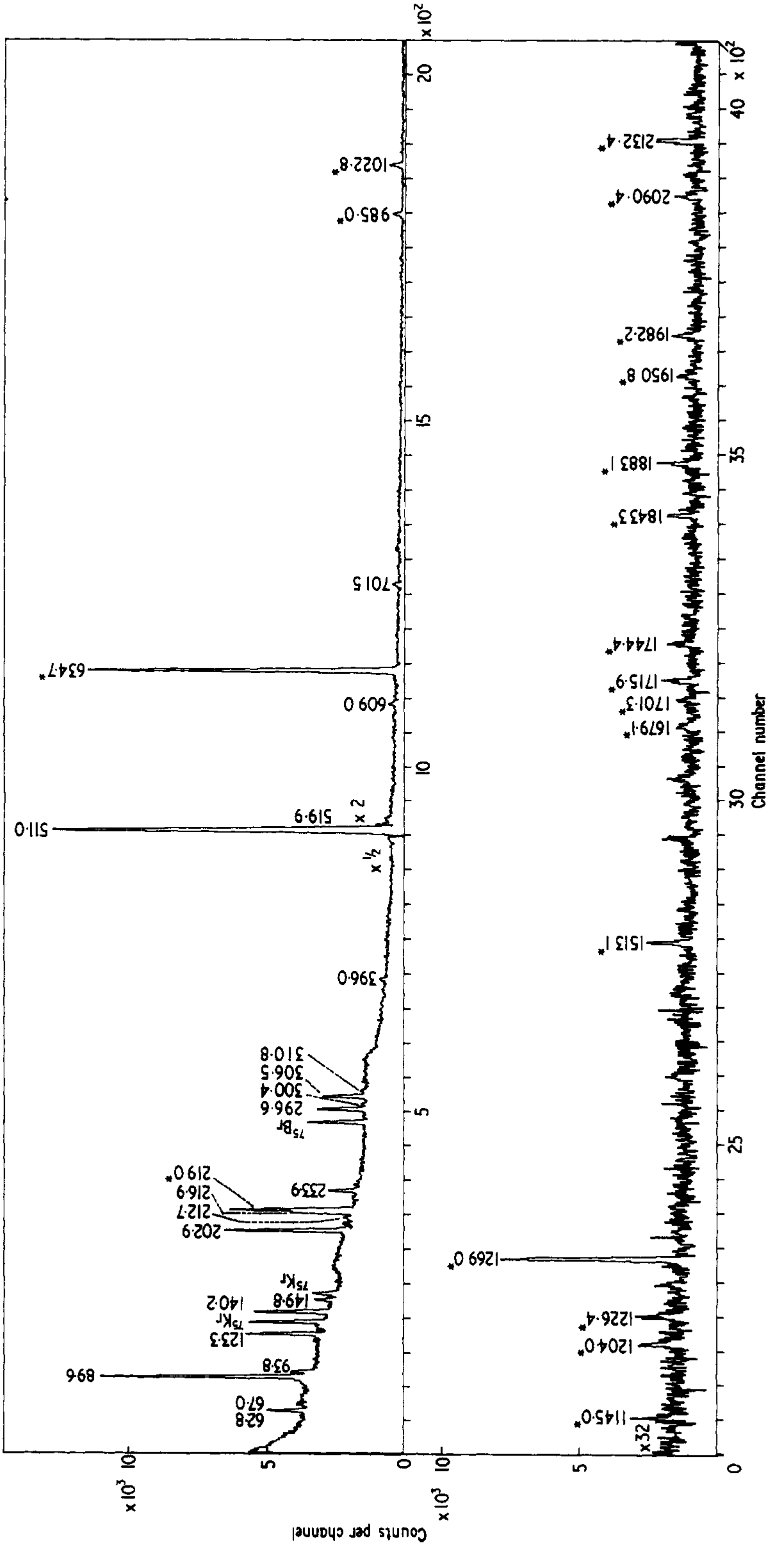

Figure 2. A gamma ray singles spectrum following the decay of ^{74}Kr and its daughter ^{74m}Br (70 cm^3 Ge(Li) detector). * denotes ^{74m}Br.

Table 1. Energies and relative intensities of the γ rays following the decay of ^{74}Kr.

E_γ(keV)		Relative intensity I_γ
9·8 ±0·2		30±8
62·85±0·15		95±10
67·0 ±0·2		12±2
72·5 ±0·2		5·2±1·2
80·0 ±0·2		3·2±0·9
89·64±0·15		220±20
93·76±0·15		20±2
123·31±0·15		44±3
140·22±0·20		41±3
149·80±0·20		14±1
167·0 ±0·5		5±1
202·93±0·15		100
212·71±0·20		7·3±0·6
216·90±0·20		42±3
230·0 ±0·5		4·8±1·0
233·86±0·15		27±2
239·6 ±0·6		5±1
296·63±0·15		52±4
300·4 ±0·5		5·2±0·6
306·52±0·15		50±4
310·8 ±0·5		5·1±0·6
396·0 ±0·3		6·8±0·8
511·00	annihilation radiation	1100±150†
519·9 ±0·5		5·3±0·6
536·0 ±1·0		3±1
609·0 ±1·0		6±1
701·5 ±0·5		12·0±1

† In measuring the intensity of the 511·0 keV annihilation radiation, the source was sandwiched between 15 mm thick plastic absorbers to stop all positrons within a confined volume.

These observations indicate that there is an isomeric state in ^{74}Br, which decays by β^+ emission directly to levels in ^{74}Se.

2.2. Gamma–gamma coincidence measurements

To establish accurate decay schemes for both ^{74}Kr and ^{74}Br γ–γ coincidence measurements were made for the γ rays in the energy range 30 keV to 1 MeV using two large Ge(Li) counters. The data were collected on an event-by-event basis, each event consisting of three digital numbers two corresponding to the two pulse heights and the third to the time interval between them. The events were stored on industry compatible magnetic tapes using a PDP9 computer. About 0·02 mm thick natural copper targets were used and a chemical separation was carried out after each bombardment to remove bromine produced by (^{14}N, $x$np) reactions. A new source was produced every 30 min but each source was counted for about two hours to allow the daughter activity to build up and decay, so that coincidences between the γ rays associated with the 28 min activity of ^{74}Br could also be observed. Over a 36 h period about 10^7 events were collected.

Table 2. Gamma rays associated with the decay of ^{74m}Br.

E_γ (keV)	I_γ	Coincidences observed (keV)
219·0 ± 0·1	29·5 ± 30	634·8, 985·0
511·0 annihilation radiation	300 ± 50	219·0, 634·7, 985·0
634·3 ± 0·2†	20·3 ± 3·0	634·8
634·8 ± 0·1†	100	219·0, 634·3, 985·0
879·0 ± 1·0	0·5 ± 0·2	
985·0 ± 0·2	5·2 ± 0·5	
1022·8 ± 0·2	7·8 ± 0·5	
1044·7 ± 1·0	0·9 ± 0·3	
1080·2 ± 1·0	0·5 ± 0·2	
1145·0 ± 1·0	0·5 ± 0·2	
1204·0 ± 0·3	2·5 ± 0·3	
1226·4 ± 0·3	2·2 ± 0·3	
1269·1 ± 0·2	9·6 ± 0·5	
1339·2 ± 1·0	1·0 ± 0·5	
1410·0 ± 1·0	1·0 ± 0·3	
1460·0 ± 0·5	1·2 ± 0·3	
1513·1 ± 0·5	1·9 ± 0·3	
1679·1 ± 0·5	1·9 ± 0·3	
1701·3 ± 0·6	0·9 ± 0·3	
1715·9 ± 0·5	2·9 ± 0·5	
1744·4 ± 1·0	1·1 ± 0·3	
1843·3 ± 0·5	2·6 ± 0·5	
1883·1 ± 1·0	3·1 ± 0·5	
1950·8 ± 1·0	2·0 ± 0·5	
1982·2 ± 1·0	2·3 ± 0·5	
2090·4 ± 1·0	2·3 ± 0·5	
2132·4 ± 1·0	4·6 ± 1·0	
2270·0 ± 3·0	1·5 ± 0·5	
2397·0 ± 3·0	1·5 ± 0·5	
2662·2 ± 2·2	6·0 ± 1·5	
2980·0 ± 3·0	1·5 ± 0·5	
3122 ± 5	1·0 ± 0·5	
3248·5 ± 3·5	4·0 ± 1·2	
3306·0 ± 4·0	2·0 ± 0·6	
3370·0 ± 4·0	2·0 ± 0·7	
3640·5 ± 3·0	7·0 ± 2·0	
3812·0 ± 3·0	6·0 ± 2·0	
3882·0 ± 4·0	1·0 ± 0·5	
3895·0 ± 4·0	1·5 ± 0·5	

† Observed and resolved in the coincidence measurements.

The data obtained in this experiment were subsequently analysed for γ–γ coincidences by setting digital windows over the time and γ ray peaks. The contributions from Compton tails of higher energy γ rays were accounted for by setting a window just above the peak. Examples of the coincidence spectra obtained in this way are shown in figures 3 and 4 for the decays of ^{74}Kr and its daughter respectively. The coincidences thus observed between the higher energy γ rays of the ^{74}Kr decay are summarized in table 3.

In the decay of ^{74}Br useful data were obtained only for three lines all with energies below 1 MeV. The results are listed in the third column of table 2.

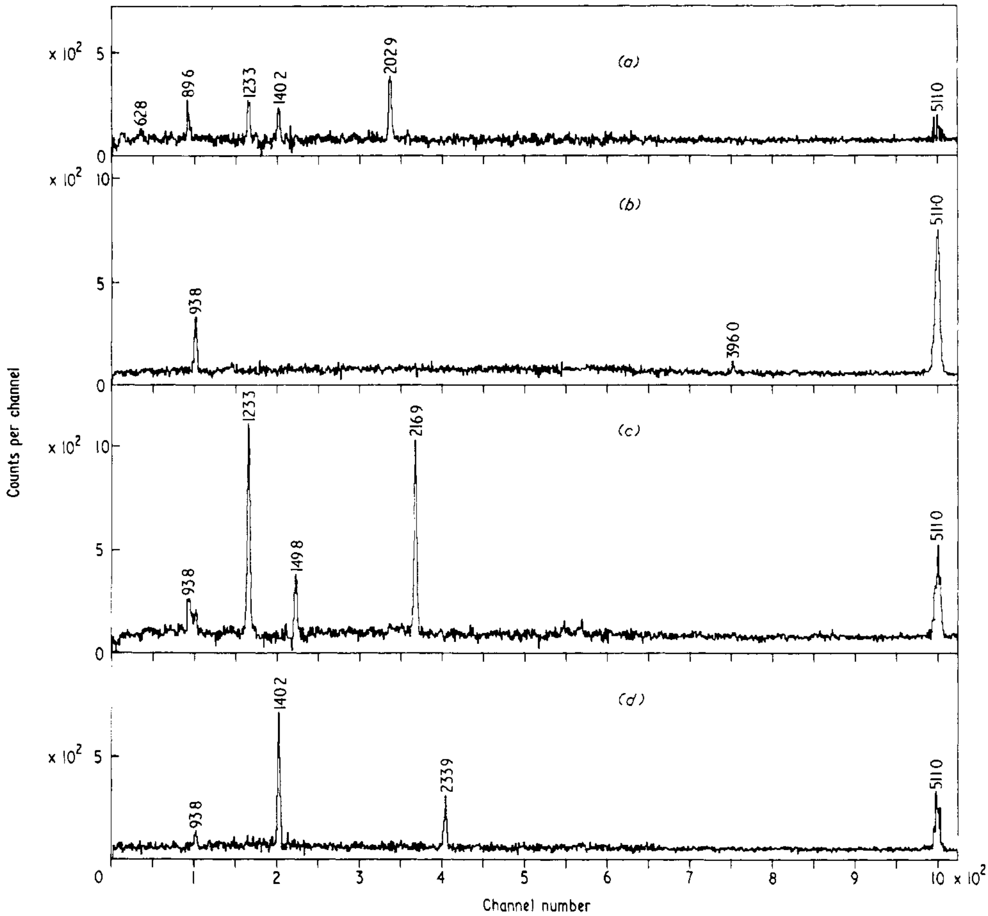

Figure 3. The ^{74}Kr gamma ray spectra observed in coincidence with: (*a*) the 93·8 keV γ ray; (*b*) the 202·9 keV γ ray; (*c*) the 89·6 keV γ ray; and (*d*) the 62·8 keV γ ray.

3. Results

3.1. The ^{74}Kr decay scheme

It is not possible to determine the relative positions of the two states of ^{74}Br with half-lives of 28·0 min and 41·5 min. We, therefore, arbitrarily refer to the state with 28·0 min activity as ^{74m}Br, the isomeric state, and that with the 41·5 min activity as ^{74}Br, the ground state. In establishing the decay scheme, however, the decay of ^{74}Kr is assumed to proceed mainly to a level system in ^{74}Br based on the ^{74m}Br state.

We are able to show for two reasons rather conclusively that no electromagnetic transition occurs between ^{74m}Br and ^{74}Br or vice versa. Firstly, as mentioned in § 2.1, we did not observe in the present work some of the most prominent lines such as those with 615·5, 728·3, 838·9, 1200·5 and 1249·5 keV associated with the decay of ^{74}Br (Coban *et al* 1972); secondly, in our previous work (Coban *et al* 1972) no build up was observed in any of the γ rays following the decay of ^{74}Br, which would, otherwise, be expected if an isomeric transition existed between ^{74}Br and ^{74m}Br.

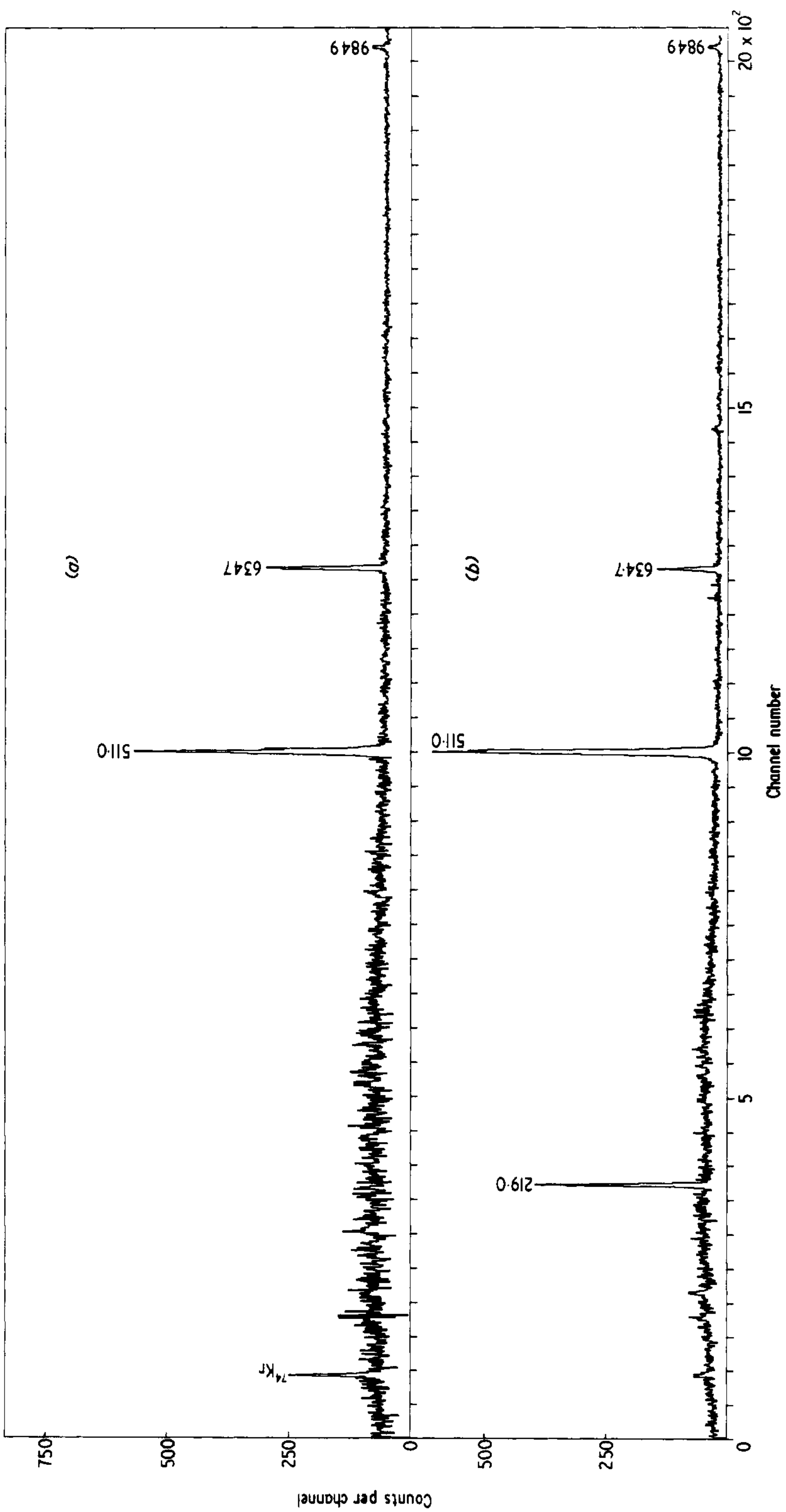

Figure 4. The ^{74m}Br gamma ray spectra observed in coincidence with: (*a*) the 219·0 keV γ ray; and (*b*) the 634·7 keV γ ray.

Table 3. Gamma–gamma coincidences observed in the β^+ decay of ^{74}Br†.

Gates (keV) \ Coincidences (keV)	62·8	89·6	93·8	123·3	140·2	149·5	203·0	212·7	216·9	233·8	296·6	306·5	396·0	511·0
62·8			×		×					×				×
89·6			×	×		×			×				×	×
93·8	×	×		×	×		×	×						×
123·3		×	×										×	×
140·2	×		×										×	×
149·5		×												×
203·0			×										×	×
216·9		×												×
233·8	×													×
296·6														×
306·5														×
511·0	×	×	×	×	×	×	×	×	×	×	×	×	×	×

† Observed coincidences are indicated by ×.

Coincidences with the 9·8 keV γ ray could not be observed due to the timing difficulties associated with such a low energy γ ray. However, there are several pieces of evidence for the presence of a level at such an energy in the proposed decay scheme for ^{74}Kr shown in figure 5. Firstly, five pairs of γ rays, namely 62·8–72·5, 80·0–89·6, 202·9–212·7, 230·0–239·5 and 296·6–306·5 keV, all differ by about 9·8 keV. Secondly, when a minimum possible amount of internal conversion is considered, corresponding to an electric or magnetic dipole transition ($\alpha \simeq 8$), the 9·8 keV line becomes the strongest transition in the γ decay of ^{74}Kr. The γ–γ coincidence measurements that have been performed are completely consistent with this interpretation.

The proposed decay scheme as presented accounts for all γ rays except the 300·4, 310·8 and 701·5 keV lines which were not observed in the coincidence spectra. It is possible, however, that the 300·4 keV and 310·8 keV γ rays might be associated with a 310·8 keV level. Unfortunately, if this is the case other possible transitions from this state would have been impossible to resolve from the stronger γ rays de-exciting the 306·4 keV level.

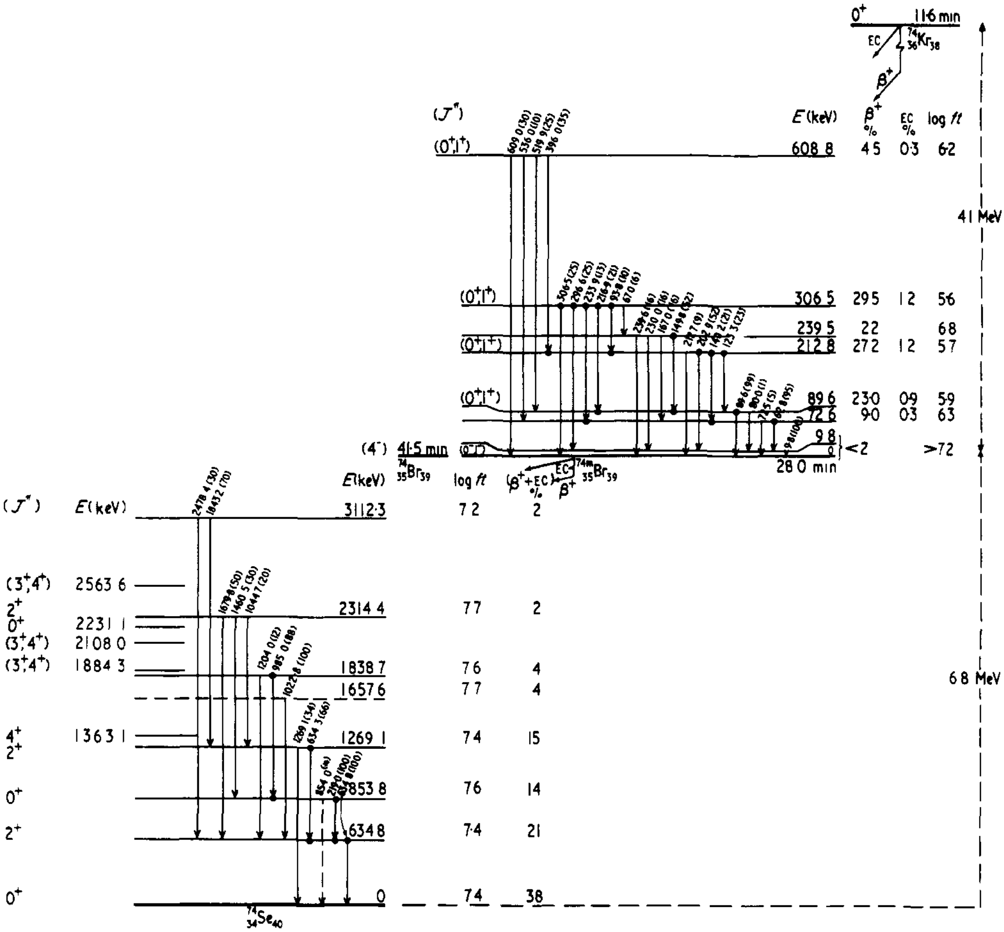

Figure 5. Decay schemes of ^{74}Kr and its daughter ^{74m}Br. The level scheme of ^{74}Se deduced from the 41·5 min ^{74}Br decay is compared on the left. The 854·0 keV E0 transition has been reported by Goring and Hartrott (1970).

3.2. The ^{74m}Br decay scheme

The proposed decay scheme of ^{74m}Br is also shown in figure 5. The level scheme of ^{74}Se as presented is compared, on the left-hand side of figure 5, with the low-lying part of the scheme deduced from the decay of ^{74}Br (Coban *et al* 1972). Coincidences were only measured between the 219·0, 634·7 and 985·0 keV γ rays. The results confirm the levels at 634·8, 853·8, 1269·1 and 1838·7 keV. Cascade cross-over sums together with the previous γ–γ coincidence measurements between the rest of the γ rays also confirm the levels at 3112·3 and 2314·4 keV levels. Previously the 1022·8 keV γ ray was observed very weakly and found to be in coincidence with the 634·7 keV line (Coban *et al* 1972). In the present work it is one of the most prominent lines in the decay of ^{74m}Br. Thus, a level at 1657·6 keV is tentatively proposed.

Owing to the complex nature of the spectrum more comprehensive coincidence measurements are needed. However, these are not expected to change significantly the main features of the decay scheme.

4. Discussion of the results

4.1. The ^{74m}Br decay

The relative intensities of the β^+ decay branches to various levels in ^{74}Se and the extracted log *ft* values are shown on the right-hand side of the decay scheme (figure 5). In extracting the log *ft* values we have assumed the decay energy of 6·8 MeV which was deduced by Coban *et al* (1972) from the results of Ladenbauer-Bellis and Bakhru (1969). The log *ft* values for the transitions to all the observed states and the ground state of ^{74}Se vary between 7·0 and 8·0 which are compatible with first forbidden transitions. With the known spin and parity values of the 634·8, 853·8, 1269·1 and 1838·7 keV levels in ^{74}Se, which are 2^+, 0^+, 2^+ and 2^+ respectively (Coban *et al* 1972), the first forbidden β^+ transitions to these levels indicate that ^{74m}Br must possess $J^\pi = 0^-$, 1^- or 2^- in contrast to $J^\pi = 4^-$ for ^{74}Br (Coban *et al* 1972). However, since no electromagnetic transition has been observed between ^{74m}Br and ^{74}Br the possibility of $J^\pi = 2^-$ for ^{74m}Br, can be ruled out thus limiting its spin and parity assignments to $J^\pi = 0^-$ or 1^-. These assignments are obviously consistent with the fact that the levels seen in the decay of ^{74}Br at 1363·1, 1884·3, 2108·0, 2231·1 and 2563·6 keV, for which J^π assignments were 4^+, $(3^+, 4^+)$, $(3^+, 4^+)$, 6^+ and $(3^+, 4^+)$ respectively, were not observed in the decay of ^{74m}Br.

4.2. The ^{74}Kr decay

From the decay scheme, the known half-life of ^{74}Kr and the β^+ decay energy (Gray *et al* 1960) we have extracted the log *ft* values for the various decay branches. In calculating the β^+ decay branches to various levels allowances were made for the expected internal conversion processes particularly in the lower energy transitions such as 9·8, 62·9, 89·6 keV γ rays.

It is apparent from the β^+ branches to various levels (figure 5) that the transitions feeding the ground state and 9·8 keV state are weak (less than 2%). Thus, the log *ft* values for these states are probably greater than 7·2 which indicate at least first forbidden β^+ transitions, and because the ground state spin and parity of the even–even nuclide ^{74}Kr is almost certainly 0^+, this is consistent with the $J^\pi = 0^-$, 1^- assignment for ^{74m}Br.

The log *ft* values for β^+ branches to the states above 72·6 keV, except that at 239·5 keV, vary between 5·6 and 6·2, and are compatible with the allowed transitions implying that the possible J^π values for these states are 0^+, 1^+. However, the large number of interconnecting γ rays between these states limits the number that could possibly possess $J^\pi = 0^+$ to one. It is difficult to make any firm deductions about the 72·6 keV state. While the apparent log *ft* value to the 72·6 keV state is 6·3 there exists the possibility of a highly converted 16·0 keV transition from the 89·6 keV level, which could lead to a marked decrease in the intensity of the β^+ branch to this state. Similarly, little can be said about the 239·5 keV state. The log *ft* value for the estimated β^+ branch to this level is $6{\cdot}8 \pm 0{\cdot}3$.

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References

Butement F D S and Boswell G G J 1960 *J. Inorg. Nucl. Chem.* **16** 10
Coban A, Lisle J C, Murray G and Willmott J C 1972 *Particles and Nuclei* **4** 108
Davids N, Parks L A and Whitmire D P 1973 *Bull. Am. Phys. Soc.* **18** 1408
Goring S and Hartrott M V 1970 *Nucl. Phys.* A **151** 241
Gray J H III, Hamester H L and Caretto A A Jr 1960 *Phys. Rev.* **120** 977
Ladenbauer-Bellis I and Bakhru H 1969 *Phys. Rev.* **180** 1015
Robinson R L, Kim H J and Ford J L C Jr 1971 *J. Phys., Paris* **32** 265