THE DECAY OF A NEW NUCLIDE: ^{71}Br

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Abstract

The decay of mass-separated samples of the previously unknown nuclide ^{71}Br have been investigated by means of the Chalk River on-line isotope separator. Eleven γ-transitions were assigned to the decay of this nuclide and its half-life was measured to be 21.4 ± 0.6 s. A simple decay scheme for ^{71}Br has been constructed incorporating six levels in its daughter, ^{71}Se. The half-life of the first excited state in ^{71}Se was measured to be 5.5 ± 1.0 μs and the transition from this state to the ground state was found to be highly converted. Systematic trends in the level schemes of ^{67}Zn, ^{69}Ge and ^{71}Se are investigated.

I. Introduction

Nuclides close to the centre of the $28 < (N,Z) < 50$ shell have been found to be strongly deformed. The effects of the subshell closures at Z=40 and N=38, seen in the region of stable nuclei, vanish entirely for nuclides near $^{78}_{40}Zr$ and instead strong collective effects are seen. Nuclides near the middle of the fp shell have therefore been the subject of many investigations[1-5]. Besides collective phenomena, the coexistence of different shapes in the same nucleus have also evoked interest in such investigations. It is of considerable interest to study systematic trends in this region and to delineate more precisely the onset of deformation.

The nuclide ^{71}Br is situated about half-way between the centre of the fp shell and its edge. The β-decay of this nuclide populates the N=37 nuclide ^{71}Se and thus offers an opportunity to study the effect of the N=38 subshell closure in that region. The decay of ^{71}Br has not yet been reported. The only previous indication of its existence was the observation[6] of a deviation from pure exponential decay of ^{71}Se, the β-decay daughter of ^{71}Br. This effect was attributed to build-up from the decay of ^{71}Br whose half-life was estimated to be 'somewhat less than 1 min'.

We wish to present here results for the decay of the $T_z=1/2$ nuclide ^{71}Br. Eleven γ-rays were assigned to the decay of this nuclide and a simple scheme incorporating six levels in ^{71}Se has been constructed. This level scheme is compared to those of the neighbouring N=37 isotones ^{67}Zn and ^{69}Ge and systematic trends are examined.

II. Experimental Procedure

Neutron deficient bromine isotopes were produced by bombarding a target of 2.5 mg/cm^2 natural calcium with a 132 MeV beam of ^{35}Cl, the evaporation residues recoiling through a thin tantalum window into the porous graphite catcher of the FEBIAD ion source of the Chalk River on-line isotope separator[7]. Bromine isotopes are readily released from the catcher and ionized in the plasma region of the source. After acceleration and separation according to mass, a selected beam was directed into a beam transport line connecting the isotope separator with an experimental counting chamber. The beam was implanted into the tape of a small cassette tape transport system[8] inside the experimental chamber.

Singles γ-rays from a saturated sample on the stationary tape were first detected in a 110 cm^3 Ge(Li) detector situated immediately behind the tape. Then, in a second arrangement the Ge(Li) detector was placed in a shielded counting position 76 mm away from the collection position. After a collection time of 40 s the separator beam was deflected and intercepted on a slit 5 m upstreams from the experimental chamber. The collected sample on the tape was subsequently moved in front of the Ge(Li) detector and eight consecutive spectra were recorded, each for a 10 s counting period.

The absolute intensities of the γ-rays from the decay of ^{71}Br were deduced from a third experiment in which the sample on the tape was stopped inside an aluminum block thick enough to stop and annihilate all positrons with less than 9 MeV energy. Eight consecutive γ spectra were recorded with a Ge(Li) detector immediately behind the aluminum block, and the intensity of the strongest γ-ray from ^{71}Br was determined relative to the component of the annihilation radiation peak that has the same half-life.

Coincidences between γ-rays and X-rays or low energy γ-rays were observed in a fourth experimental arrangement also situated along the path of the tape. Gamma rays were observed with the same Ge(Li) detector as used in the earlier experiment while a 200 mm^2 x 7 mm intrinsic Ge detector was used for the low energy events. The two detectors were arranged 90° apart. Singles spectra of low energy events were also recorded with the intrinsic Ge detector.

III. Results

The γ-ray spectrum obtained with the first experimental arrangement from a saturated source collected from the mass 71 beam is shown in fig. 1. A number of peaks originating from ^{71}Se and ^{71}As as well as peaks due to room background from activities belonging to the decay chains of ^{232}Th and ^{238}U can be seen in this spectrum. In

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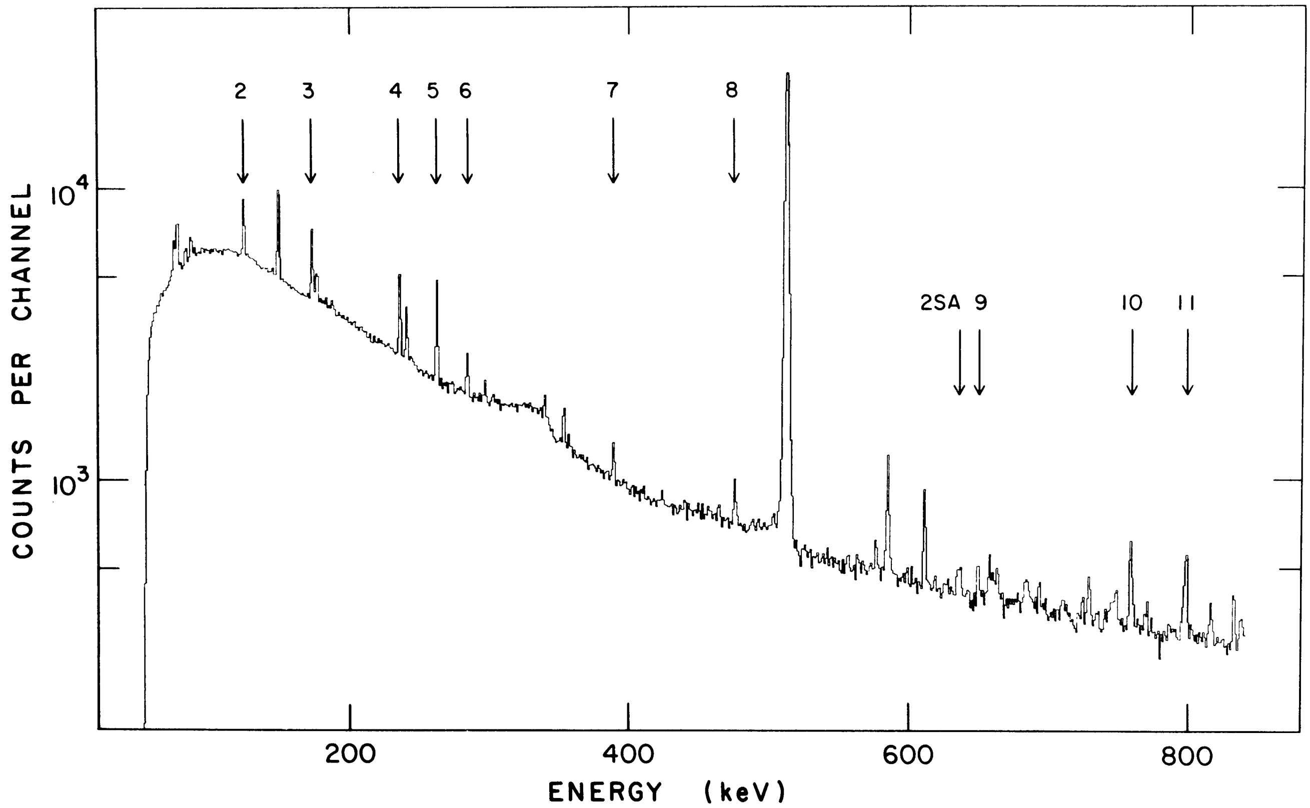

Fig. 1: The spectrum of γ-rays observed from a saturated source of activity from the mass 71 beam of the isotope separator. All peaks assigned to the decay of ^{71}Br are marked by arrows. The number above the arrow corresponds to the number given to each γ-transition in table 1. Peaks due to coincident summing with annihilation radiation are denoted by SA.

Table 1

Gamma Rays from ^{71}Br

Peak Number	Energy (keV)	Relative γ-intensity[a)]
1	48.78 ± 0.05	17 ± 3
2	122.72 ± 0.05	64 ± 5
3	171.6 ± 0.1	77 ± 6
4	233.7 ± 0.1	81 ± 6
5	260.5 ± 0.1	100 ± 5
6	282.4 ± 0.1	31 ± 6
7	387.4 ± 0.2	21 ± 3
8	474.6 ± 0.2	26 ± 4
9	647.6 ± 0.3	15 ± 3
10	756.9 ± 0.2	50 ± 5
11	796.4 ± 0.4	56 ± 6

a) For absolute intensity per 100 decays of ^{71}Br divide by 12.1.

addition to these well-known γ-transitions, 14 previously unknown peaks are seen in the spectrum. Ten of these were intense enough that their (common) half-life could be determined. Another low energy γ-ray as well as Se X-rays were observed to decay with that same half-life in the spectra obtained with the intrinsic Ge detector (fig. 2). This half-life was determined to be 21.4 ± 0.6 s from the measured decay curves of the four most intense γ-rays as well as

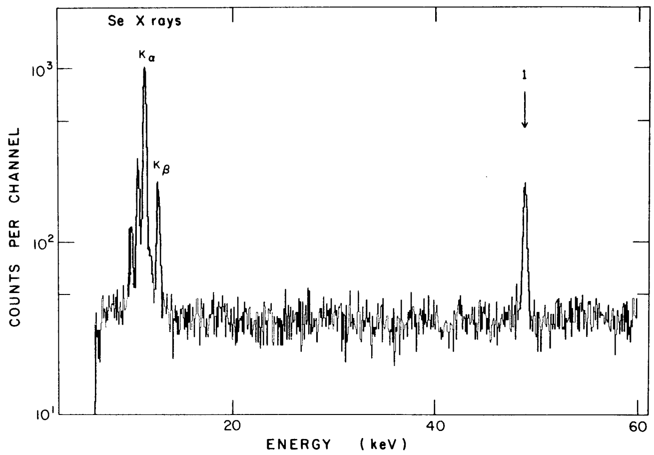

Fig. 2: The spectrum of low energy photons from radioactive samples on the tape collected from the mass 71 beam. The peak labelling system is explained in the caption to fig. 1.

the Se X-rays. The energies and relative intensities of the 11 γ-transitions exhibiting half lives consistent with this value are shown in Table 1.

The mass number 71, can be unambiguously assigned to the new activity owing to the use of mass separated samples. The element assignment is restricted to Kr, Br or Se from the target-projectile combination and the energy of the projectiles. The assignment of the γ-transitions listed in Table 1 to the decay of ^{71}Br is based on the following arguments.

(i) The half-life values of ^{71}Kr and ^{71}Se, known to be 97 ± 9 ms and 4.74 ± 0.05 min respectively[9,10), are not compatible with our measured value of 21.4 ± 0.6 s.

(ii) Se X-rays were observed with a 21.4 s half-life and, furthermore, the most intense γ-rays shown in Table 1 were also found to be coincident with Se X-rays.

(iii) A composite decay curve was established for the 147.5 keV γ-transition[10), which originates from the decay ^{71}Se (the β-daughter of ^{71}Br). This decay curve was found to be compatible with a genetic relationship between two activities with half-lives of 21.4 s and 4.74 min.

(iv) The parameters chosen for the operation of the isotope separator ion source favoured the extraction of bromine ions. Tests performed with heavier (i.e. well-known) isotopes of the same elements showed that with the same ion source parameters no Kr was produced and only minute amounts of Se appeared.

The γ-γ coincidence measurements initially yielded no conclusive results and in particular those events that included the 48.78 keV γ-ray, the lowest energy transition assigned to ^{71}Br, did not produce a prompt peak in the time spectrum even though the counting statistics should have been sufficient to have done so. It was concluded that the half-life of the state emitting this γ-ray was longer than our 1 μs sensitivity, and a separate two-parameter coincidence experiment was designed to measure it. In this case we used any event between 150 and 520 keV in the Ge(Li) detector as a start signal, and then recorded both the energy of any subsequent event in the intrinsic Ge detector and its time of occurrence after the start. In this experiment, delayed events were seen in time spectra for the 48.78 keV γ-transition and for Se X-rays. Statistically consistent half-lives were obtained from the decay curves of both types of delayed events. The weighted average for the half-life is 5.5 ± 1.0 μs.

The K-conversion coefficient for the 48.78 keV transition was deduced from the intensity ratio between delayed Se K_α X-rays and delayed 48.78 keV γ-rays observed in the two-parameter coincidence experiment. The result, a_k=9.6 ± 2.1, was determined with the values for the fluorescent yield and for the K_α/K ratio given in the Table of Isotopes[11).

The intensity of the 21.4 s component of the annihilation radiation relative to that of the 260.5 keV γ-transition from ^{71}Br was determined with the annihilation set-up. The resulting value for the ratio between the number of positrons emitted in the decay of ^{71}Br and the number of 260.5 keV γ-rays was deduced to be 12.1 ± 3.6.

IV. Discussion

A tentative decay scheme of ^{71}Br is shown in fig. 3. It should be noted that the only proven coincidence relation in this decay scheme is the one between the 122.72 and 48.78 keV γ-rays depopulating an excited state at 171.53 keV. All other states proposed in ^{71}Se are based on energy sums of γ-rays assigned to the decay of ^{71}Br with the further requirement that at least two γ-ray channels must agree for each level assignment. According to the latter criterions one γ-transition, at 796.4 keV, could not be definitely placed in the decay scheme.

If the decay scheme shown in fig. 3 is accepted then our measured value of 12.1 ± 3.5 for the intensity ratio of decay positrons to 260.5 keV γ-rays translates into a ground state β branch of (60 ± 15)%. The intensities of the β-transitions populating the proposed excited states in ^{71}Se can in principle be determined from a comparison of the total γ-ray intensity depopulating each level to that seen feeding it. However, the resulting side-feeding would be comparable in intensity to those unknown γ-rays whose half-life could not be determined due to poor counting statistics and, consequently, could not definitely be assigned to the decay of ^{71}Br. The uncertainties of the excited state β-branches

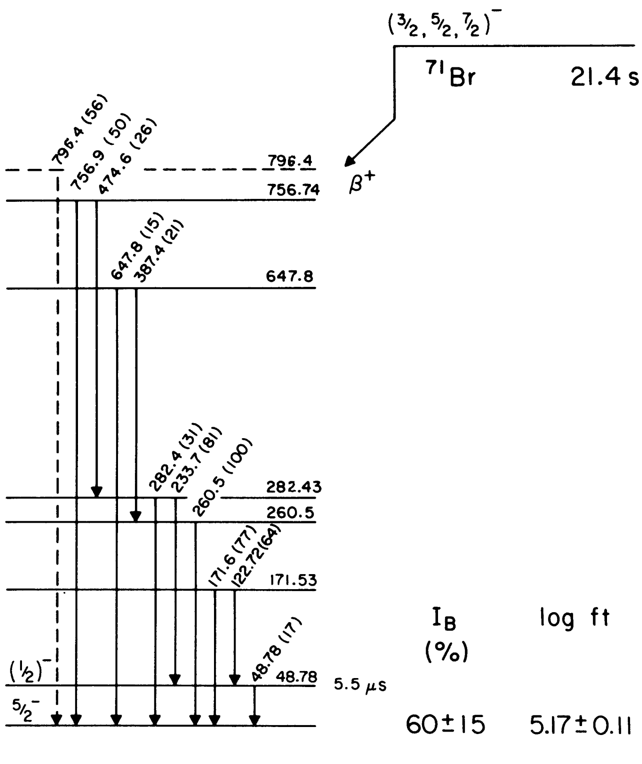

Fig. 3: The proposed decay scheme of ^{71}Br. The γ-ray energies and, in brackets, relative intensities are indicated for each transition. Owing to the fact that several fairly intense but previously unknown γ-rays could not definitely be assigned to ^{71}Br (and are not shown in this decay scheme) the beta decay branch and the log ft value are only given for the very intense, ground state transition.

would therefore be comparable to the branches themselves and no dependable conclusion could be based on the resulting log ft values. Consequently the only reliable log ft value that can be deduced from the present measurement is that for the strong ground state branch: viz, 5.17 ± 0.11.

The first excited state of ^{71}Se has a half-life of 5.5 ± 1.0 μs, as is demonstrated by our measured decay curve for the 48.78 keV transition. The K conversion coefficient for the transition from this state to the ground state of ^{71}Se, deduced to be 9.6 ± 2.1, agrees very well with a pure E2 assignment (theoretically[12] 9.2) and is not compatible with any other assignment.

The level scheme of ^{71}Se is presented together with those of ^{67}Zn and ^{69}Ge, its closest n=37 isotones, in fig. 4. The levels shown for ^{67}Zn and ^{69}Ge have previously been identified[2,4,15,16] either as single particle states arising from the odd neutron, or as configurations originating from coupling the same single particle states to vibrational states in the neighbouring even-even nuclides. The three level schemes shown in fig. 4 are all quite similar and offer an opportunity to look for systematic trends.

Some specific remarks on some of the levels of ^{71}Se are given below.

The ground state. The spin and parity of the ground state of ^{71}Se is known[10] to be $5/2^-$. The present log ft value of 5.17 for the β-transition to the ground state clearly indicates that this transition is allowed and hence the spin and parity of ^{71}Br is $(3/2,5/2,7/2)^-$.

The 48.78 keV state. Since the measured conversion coefficient for the 48.78 transition agrees very well with a pure E2 assignment the spin of the first excited state in ^{71}Se is presumably either 1/2 or 9/2 with negative parity. The first alternative is preferred from the systematic occurrence of a low-lying $p_{1/2}$ single particle state in the neighbouring isotones (fig. 4). The reduced transition probability of 1.7 ± 0.5 W.u., determined for the 48.78 keV transition, indicates the single particle nature of this state and lends further support for a $1/2^-$ assignment.

The 171.5 and 282.4 keV states. Both these states decay to the ground state and the first excited state by γ-transitions of comparable intensities. The same decay pattern has been found for the two lowest $3/2^-$ states in ^{67}Zn and ^{69}Ge (fig. 4). Based on systematics one might then speculate that the 171.5 keV level found in ^{71}Se has $J^\pi=3/2^-$ and originates from the coupling of the odd $f_{5/2}$ neutron to the 2^+ first excited state[3] in ^{70}Se while the 282.4 keV level is the $p_{3/2}$ neutron hole state[2,4,15,16].

The 260.5 and 647.8 keV states. Apart from γ-ray branches feeding the $5/2^-$ ground state of ^{71}Se neither of these two

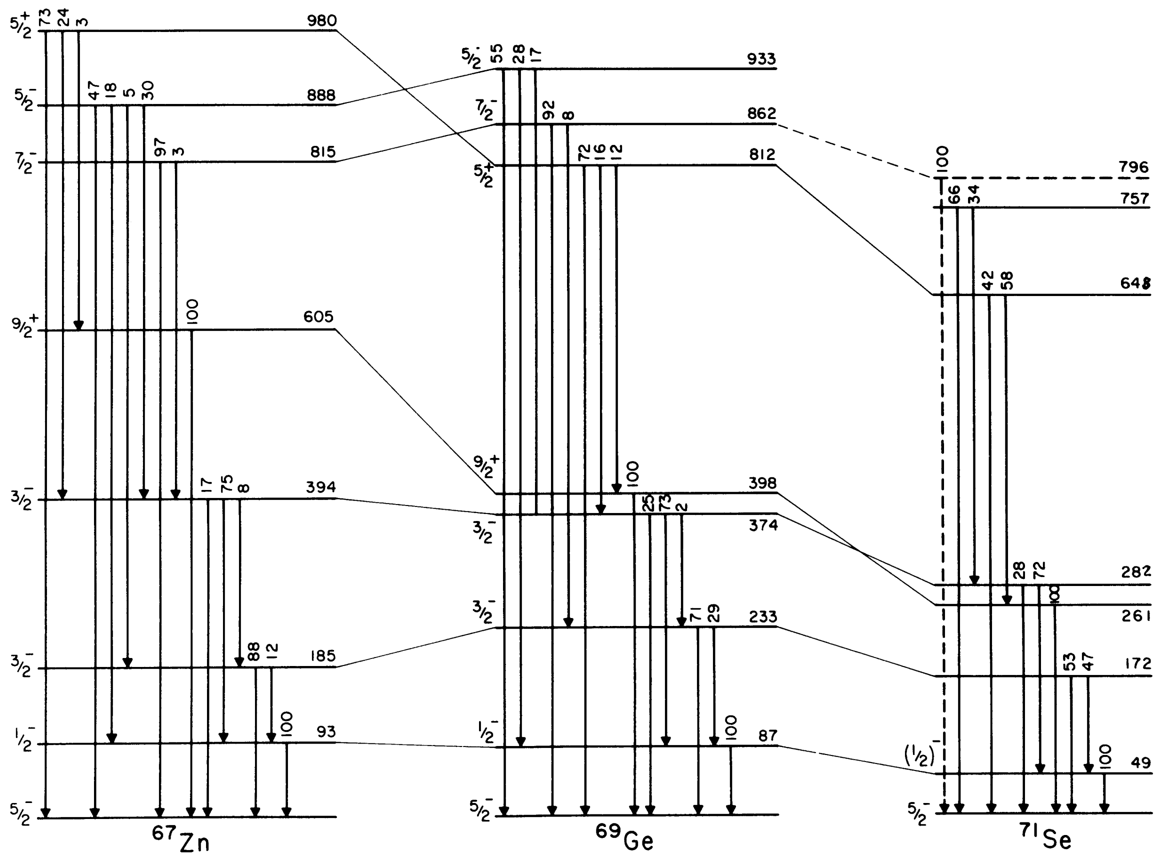

Fig. 4: The low energy level schemes of ^{67}Zn, ^{69}Ge and ^{71}Se. The branching ratios shown for ^{67}Zn were taken from Duffait et al[13] and from reference 11. The branching ratios for ^{69}Ge were taken from Alexandrov et al[14].

states exhibit any branches to low-lying states in ^{71}Se. However, there is a strong γ-branch connecting the two states. This fact together with systematics from ^{67}Zn and ^{69}Ge suggests that the two states have positive parity. The 260.5 keV level would then be the $g_{9/2}$ neutron single particle state and the 647.8 keV level would be the $5/2^+$ state arising from the coupling of the $g_{9/2}$ neutron to the 2^+ first excited state in ^{70}Se.

Without more detailed information on the decay of ^{71}Br, it is not possible to obtain a measure of the deformation of ^{71}Se. However, tentative conclusions can be made as to whether ^{71}Se is more or less deformed than its neighbours. A signature of increasing deformation for a $(f_{5/2})^{-1}$ configuration is a significant lowering of the $g_{9/2}$ state and, to some extent, of the $p_{1/2}$ state with respect to the $f_{5/2}$ ground state. If our speculations on the origins of the excited states in ^{71}Se are correct then such a trend of increasing deformation is indeed seen when going along the n=37 isotones from ^{67}Zn to ^{71}Se. Irrespective of our interpretation of the origin of the excited states in ^{71}Se, these states are generally found at a lower excitation energy than those of ^{67}Zn and ^{69}Ge indicating that ^{71}Br is continuing the trend to a region of deformation.

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