Transitions to the isomeric levels in $^{79,81}Br$ produced indirectly by Coulomb excitation

1974 J. Phys. A: Math. Nucl. Gen. 7 100

(http://iopscience.iop.org/0301-0015/7/1/017)

J. Phys. A: Math., Nucl. Gen., Vol. 7, No. 1, 1974. Printed in Great Britain. © 1974

Transitions to the isomeric levels in ^{79,81}Br produced indirectly by Coulomb excitation

C W Cottrell

Nuclear Physics Laboratory, University of Oxford, Keble Road, Oxford, UK

Received 15 June 1973, in final form 17 September 1973

Abstract. Observations have been made of the transition from the 762 keV, $7/2^-$ level to the 207 keV, $9/2^+$ isomeric level in ^{79}Br. The $7/2^-$ level was populated by Coulomb excitation using alpha particles as the projectiles. Measurements were made on both the singles gamma ray spectra and the delayed $9/2^+ \rightarrow 3/2^-$ (GS) isomeric transition. The strength of the transition was such as to give a branching ratio of $(3\cdot6 \pm 0\cdot4)$% from the $7/2^-$ level. An upper limit of 0·3 % was obtained for the equivalent branch in ^{81}Br.

1. Introduction

The low-lying negative-parity states of ^{79}Br and ^{81}Br have recently been investigated in some detail (Robinson *et al* 1967, 1968, 1972, Langhoff *et al* 1966, Salomen and Hojvat 1969, Rao and Fink 1967, Wolicki *et al* 1957, Bonacalza 1964, Winter 1965, Weiss *et al* 1970), particularly by Coulomb excitation, radioactive decay and by (p, γ) experiments on Se isotopes. The theoretical attempts to explain the results have generally made use of the weak and intermediate coupling models (Robinson *et al* 1967, 1968, de Shalit 1961, Lawson and Uretsky 1957, Stewart and Castel 1970, Kisslinger and Sorensen 1963). The ground states of both ^{79}Br and ^{81}Br have spin–parity of $3/2^-$. This J^π can be explained by considering one nucleon (or hole) in a $p_{3/2}$ shell model level and the rest of the nucleus as a core in its ground state (0^+). This core should be similar to neighbouring even–even nuclei and have similar excitation properties.

There are 35 protons in the Br nuclei. The levels in the shell model scheme are consequently filled up to the $2p_{3/2}$ level, which is partially filled. The $1f_{7/2}$, $1f_{5/2}$ and $1g_{9/2}$ levels are close in energy to the $2p_{3/2}$ level and so single particle excitations involving these levels are expected.

A $9/2^+$ level can be formed by contributions from a nucleon in the $1g_{9/2}$ level or by the coupling of the $3/2^-$ ground state to a 3^- core state. Such a $9/2^+$ level may have a long half-life, depending upon its position in the energy level scheme. There are two possible extremes, one of which is a low energy E3 transition ($9/2^+ \rightarrow 3/2^-$) with a half-life of the order of seconds, and the other is a high energy E1 transition ($9/2^+ \rightarrow 7/2^-$) with a very short lifetime.

The isomers in the Br isotopes have lifetimes which approach these extremes. The ^{79}Br isotope has a $9/2^+$ isomeric level which decays by E3 to the $3/2^-$ ground state with a half-life of 4·8 s (Scharff-Goldhaber 1954, Goodman and Schardt 1959, Yule 1967) and ^{81}Br has a similar isomeric level which decays by M2 to a low-lying $5/2^-$ level with a half-life of 37 µs (Duffield and Vegors 1958, Goodman 1961, McCarthy *et al* 1965).

The Coulomb excitation of ^{79}Br and ^{81}Br using alpha particles will mainly populate the negative-parity levels by E2 excitation. The $9/2^+$ level may be populated by decay from these levels or by direct E3 excitation. The excitation function of the isomeric yield will be characteristic of the level from which the indirect population arises, providing that this yield is much greater than that from the direct excitation.

2. Experimental arrangement

The detailed experimental procedure has been described in a previous paper (Cottrell 1973). An alpha particle beam was used to bombard a lead bromide target. The targets consisted of lead bromide evaporated on to a lead foil 0·12 mm thick. The alpha particle energy was varied from 5·6 to 7·0 MeV to assist determination of the origin of gamma rays by the excitation function.

The alpha particle beam was chopped 'on' and 'off' the target both mechanically and electrically (Cottrell 1971). The decay from the isomeric levels in the bromine isotopes were observed during the relatively quiet conditions while the beam was 'off' the target.

The Ge(Li) detectors were placed at 90° to observe the delayed gamma rays and 55° for the singles spectra ($P_2 = 0$). The relative efficiencies of the Ge(Li) detectors were measured using sources with energies from 60 to 1332 keV. The branching ratios from the energy levels in the bromine isotopes can then be determined.

3. Experimental results

The gamma rays observed in the prompt spectra were mainly identified as being associated with the ^{79}Br and ^{81}Br nuclei. Some contaminant gamma rays were also observed. A typical prompt spectrum, taken at an alpha particle energy of 6·8 MeV, is shown in figure 1. The contaminant gamma rays are labelled C in this figure. Two of these contaminant gamma rays with the energies of 416 and 440 keV were particularly strong. The former has been attributed to the first excited state of ^{26}Al and the latter to the first excited state of ^{23}Na (Robinson *et al* 1967).

A typical delayed gamma ray spectrum is shown in figure 2. This spectrum was obtained using an alpha particle energy of 6·8 MeV. An electrostatic beam deflector, with a cycle time of 60 μs, was used to obtain this spectrum. The spectrum obtained under these conditions would show both delayed gamma rays of bromine, providing the isomers were populated. A spectrum taken with a cycle time of the order of seconds would only show the long-lived ^{79}Br isomeric transition.

The isomeric level in ^{79}Br at 207·2 keV was observed in this experiment to have a half-life of $4{\cdot}5 \pm 0{\cdot}4$ s. This value for the half-life is in agreement with previous measurements, $t_{1/2} = 4{\cdot}8$ s. The lifetime and energy of this delayed gamma ray effectively identifies it as that of the isomeric decay in ^{79}Br.

The $7/2^-$ level at 762 keV (Robinson *et al* 1967) is expected to be the source of the population of the $9/2^+$ isomeric level. An E1 transition is possible between these levels, whereas an M2 or E3 transition would be required of all the other Coulomb excited levels. A check on the source of the $9/2^+$ level population is provided by normalizing the isomeric yield to the 762 keV yield. Such a normalization gives a branching ratio and consequently should be independent of the alpha particle bombarding energy, providing

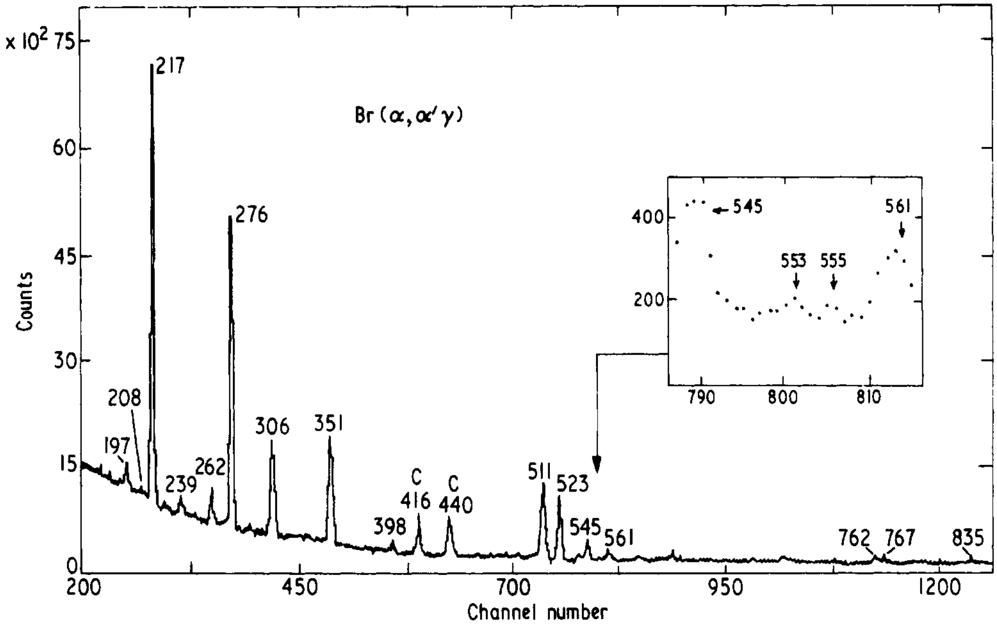

Figure 1. The prompt gamma ray spectrum for ^{79,81}Br obtained at an alpha particle energy of 6·8 MeV.

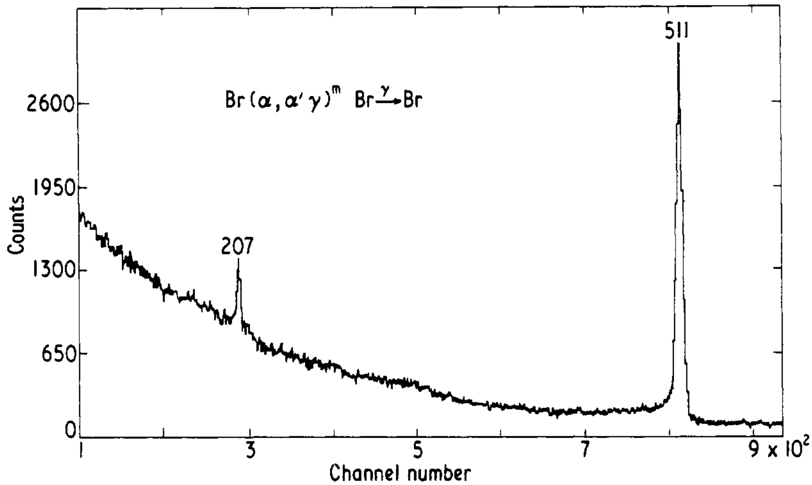

Figure 2. The delayed gamma ray spectrum for ^{79,81}Br obtained at an alpha particle energy of 6·8 MeV.

the 762 keV level is the dominant source. The excitation function for the isomer, normalized to the 762 keV level yield is shown in figure 3.

In the prompt spectra a weak gamma ray of the appropriate energy for the $7/2^- \rightarrow 9/2^+$ transition, 555 keV, was observed. The intensity of the gamma ray was consistent with this assignment over several spectra, but the statistical uncertainty was quite considerable. The branching ratio to the isomeric level obtained from the singles spectra was $(3{\cdot}0 \pm 1{\cdot}5)$ %, whereas that obtained from the delayed gamma ray spectra was $(3{\cdot}6 \pm 0{\cdot}4)$ %.

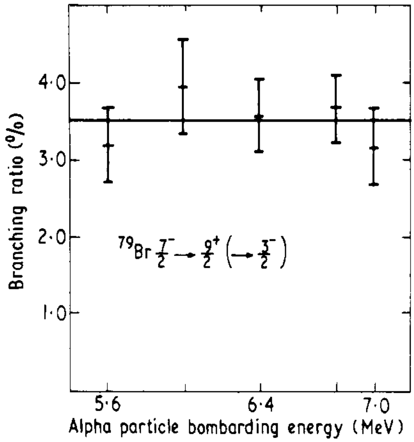

Figure 3. The isomeric excitation function in ^{79}Br expressed as a branching ratio from the $7/2^-$ level.

An internal conversion factor of 1·45, $(1+\alpha_T)$ (Siegbahn 1965), has been included in the strength of the transition from the isomer.

The direct E3 excitation of the isomer in ^{79}Br is calculated from the decay probability since it decays to the ground state. This contribution to the isomeric yield amounts to less than 1 % of the observed yield at all the alpha particle energies used. The direct yield does not appreciably affect the excitation function.

The 207 keV gamma ray was also observed in the singles spectra. The intensity of this gamma ray, however, was approximately 60 % more intense than was expected from the delayed observation. Robinson *et al* (1967) report a 208 keV gamma ray in the de-excitation of the negative-parity levels of ^{79}Br. They attribute the gamma ray to the $3/2^-$ (606 keV level) → $3/2^-$ (398 keV level) transition. However, the branching ratios they obtained from Coulomb excitation (12 %) and from the decay of ^{79}Kr (6 %) are significantly different. The isomer is not populated by the ^{79}Kr beta decay, whereas it is, indirectly, by Coulomb excitation. If the isomeric contribution is taken into account then these two branching ratios are in agreement.

The isomer could also be populated by transitions from the 762 keV level which are not direct, although there is no evidence for an appropriate intermediate level. A search for possible cascade gamma rays was unsuccessful. This is expected as the direct transition would appear to account for most, if not all, of the isomeric feed.

The energy level scheme and the transitions between these levels for ^{79}Br are illustrated in figure 4. The transitions observed in this experiment, particularly those from the 762 keV level, are shown.

No evidence was observed for the production of the 37 μs isomer in ^{81}Br and an upper limit of less than 0·3 % was obtained for the branching ratio from the 836 keV level. The energy level scheme for ^{81}Br is shown in figure 5.

4. Discussion

The transitions between the negative-parity levels have been discussed previously (Robinson *et al* 1967, 1968, 1972, Langhoff *et al* 1966, etc). This is not the case for the transition to the $9/2^+$ level in ^{79}Br from the $7/2^-$ level.

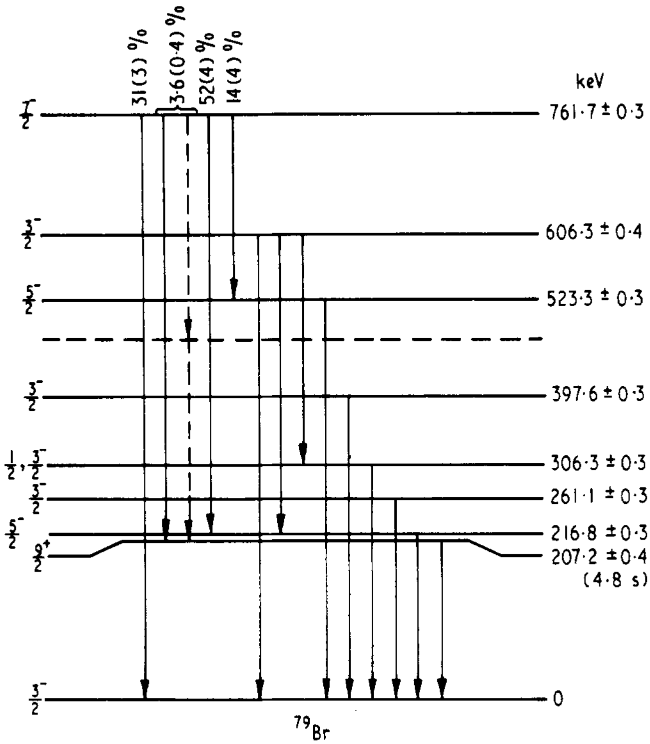

Figure 4. The level scheme of the low-lying energy levels of ^{79}Br with the transition observed in this experiment.

There are 35 protons in the Br isotopes, seven of which are outside the closed shell at $n = 28$. These 7 protons partially fill up the $2p_{3/2}$, $1f_{5/2}$, $1f_{7/2}$ and $1g_{9/2}$ levels. The probable proton configurations contributing to the $3/2^-$ (GS), $7/2^-$ and $9/2^+$ levels are

$$|3/2^-\rangle_{GS} = (f_{5/2})^6(p_{3/2})^1 + (f_{5/2})^4(p_{3/2})^3 + (2^+ \text{ core})(p_{3/2})^1 + (2^+ \text{ core})(p_{3/2})^{-1}$$

$$|7/2^-\rangle = (2^+ \text{ core})(p_{3/2})^1 + (2^+ \text{ core})(p_{3/2})^{-1} + (p_{3/2})^4(f_{5/2})^4(f_{7/2})^{-1} + (p_{3/2})^2(f_{5/2})^6(f_{7/2})^{-1}$$

$$|9/2^+\rangle = (3^- \text{ core})(p_{3/2})^1 + (3^- \text{ core})(p_{3/2})^{-1} + (f_{5/2})^6(g_{9/2})^1 + (p_{3/2})^2(f_{5/2})^4(g_{9/2})^1 + (p_{3/2})^4(f_{5/2})^2(g_{9/2})^1$$

where the (core) states represent the collective excitation of the remaining protons.

The E3 transition from the $9/2^+$ level to the $3/2^-$ GS is retarded a hundredfold on single particle strength. This could be caused by a chance cancellation of single particle and collective contributions to the transition, or because the dominant single particle contributions to the wavefunctions do not permit an E3 transition.

The E1 transition between the $7/2^-$ and $9/2^+$ levels is not possible with the single particle contributions indicated above. Other configurations, however, may also make significant contributions to the wavefunctions. A configuration in the $7/2^-$ state involving a pair of protons in the $1g_{9/2}$ shell could give rise to an E1 transition:

$$(p_{3/2})^4(f_{5/2})^2(g_{9/2})^2(f_{7/2})^{-1} \xrightarrow{E1} (p_{3/2})^4(f_{5/2})^2(g_{9/2}).$$

The E1 transition probability between these configurations in ^{79}Br is $3{\cdot}94 \times 10^{13}$ s^{-1},

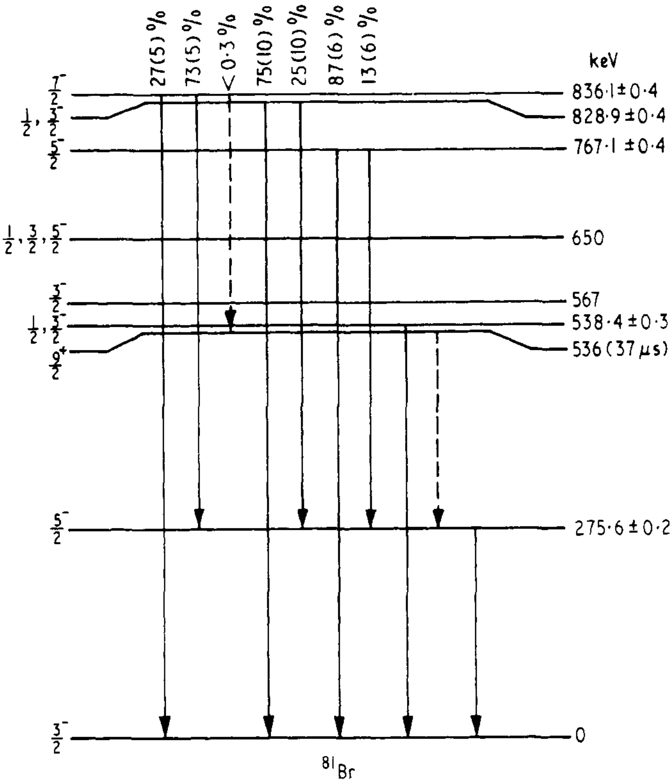

Figure 5. The level scheme of the low-lying energy levels of ^{81}Br with the transitions observed in this experiment.

whereas the experimental value is $2{\cdot}35 \times 10^{10}$ s^{-1}. The transition would be retarded by a factor $1{\cdot}7 \times 10^3$. The equivalent M2 transition would need to have a strength 1000 times the single particle strength to account for the experimental result and so can be rejected. The E1 transition is also possible between the collective contributions to the two levels. The $7/2^-$ level has a major collective component as indicated by the enhanced *B*(E2) value for the $7/2^- \rightarrow 3/2^-$ GS transition (Robinson *et al* 1967). The collective contribution to the $9/2^+$ level is uncertain, as mentioned above.

Similarly for ^{81}Br the upper limit for the branching ratio of 0·3% gives a minimum retardation of 2×10^3 for an E1 transition. This value is similar to that for the transition in ^{79}Br. The transition in ^{81}Br, however, may be significantly less than this upper limit.

Acknowledgment

I wish to thank Dr G A Jones for his interest in this work.

References

Bonacalza E C O 1964 *Ark. Fys.* **26** 141
Cottrell C W 1971 *DPhil Thesis* University of Oxford
—— 1973 *Nucl. Phys.* A **204** 161

Duffield R B and Vegors S H 1958 *Phys. Rev.* **112** 1958
Goodman A 1961 *PhD Thesis* University of New Mexico
Goodman A and Schardt A W 1959 *Bull. Am. Phys. Soc. Ser.* 2 **4** 56
Kisslinger L S and Sorensen R A 1963 *Rev. mod. Phys.* **35** 853
Langhoff H, Frevert L, Schott W K and Flammersfeld A 1966 *Nucl. Phys.* **79** 145
Lawson R D and Uretsky J L 1957 *Phys. Rev.* **108** 1300
McCarthy A L, Cohen B L and Goldman L H 1965 *Phys. Rev.* **137** 250
Rao P V and Fink R W 1967 *Phys. Rev.* **154** 1023
Robinson R L, McGowan F K, Stelson P M and Milner W T 1967 *Nucl. Phys.* A **96** 6
—— 1968 *Oak Ridge National Laboratory Annual Progress Report* ORNL 4395 12
Robinson R L, McGowan F K, Milner W T and Stelson P M 1972 *Nucl. Phys.* A **193** 14
Salomen M and Hojvat C 1969 *Can. J. Phys.* **47** 2255
Scharff-Goldhaber G and McKeown M 1954 *Phys. Rev.* **95** 613
de Shalit A 1961 *Phys. Rev.* **122** 1530
Siegbahn K ed 1965 *Alpha-, Beta- and Gamma-ray Spectroscopy* (Amsterdam: North Holland)
Stewart K W C and Castel B 1970 *J. Phys.* A: *Gen. Phys.* **3** 390
Weiss J, Langhoff H and Schumacher M 1970 *Z. Phys.* **230** 371
Winter G 1965 *Zentralinstitut fur Kernforchung Rosendorf bei Dresden Report* Zfk-Ph A17
Wolicki E A, Fagg L W and Geer E H 1957 *Phys. Rev.* **105** 238
Yule H P 1967 *Nucl. Phys.* A **94** 442