225/143, and 5, respectively, operating to reduce the predicted single-particle half-life. These factors have been taken into account in Fig. 4(b), where the ordinate is T_{IT}/T_{MS}, with T_{MS} the statistically corrected Moskowski half-life. The points show no perceptible correlation with spin. The average of all 51 statistically corrected values is 7.72.

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Decay of 18.6-min ^{81g}Se and 57.3-min ^{81m}Se

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The γ rays following the decay of the ^{81}Se isomers have been studied using Ge(Li) detectors and coincidence techniques. γ rays of 260.2, 492.4, and 767.3 keV were found to follow the β decay of ^{81m}Se and γ rays of 178.3, 275.9, 290.1, 538.2, 552.4, 566.0, 649.8, and 827.3 keV to follow the β decay of ^{81g}Se. Levels were established at 275.9, 536.1, 538.2, 566.0, 649.8, 767.3, and 828.3 keV. No evidence was observed for levels at 815 or 1146 keV nor was definite β feeding observed to known levels at 836.4, 1122, and 1203 keV. The log*ft* values are discussed and comparisons of the levels made with those of ^{79}Br and ^{83}Br.

I. INTRODUCTION

THE levels of ^{81}Br have been studied by several different techniques, including Coulomb excitation,[1,2] nuclear reactions,[3] and radioactive decay studies of ^{81}Se isomers.[4–6] The decay schemes proposed from the results of the decay-scheme studies are not in agreement with each other concerning the β branching from the 57-min ^{81m}Se, the existence of levels at 815 and 1146 keV, and the placement of several γ-ray cascades. We have reinvestigated the decay of ^{81}Se isomers in order to establish the decay schemes of these isomers, as well as search for β decay to levels observed in reaction studies. With these new data, useful systematic comparisons of the levels of ^{79}Br, ^{81}Br, and ^{83}Br are permitted.

II. EXPERIMENTAL

A. Source Preparation

Sources of 18.6-min ^{81}Se and 57.3-min ^{81m}Se were prepared by irradiating enriched ^{80}Se metal (99.87%) in the MIT Reactor for varying periods of time ranging from 10 min to 1 h. Each sample was dissolved in a few drops of boiling HNO_3, and evaporated to near dryness. The cooled residue was taken up in 10 ml of cold concentrated HCl, and SO_2 bubbled into the solution to precipitate Se metal. The Se was then filtered and mounted for counting. The chemical separation required about 5 min and resulted in a sample in which no impurities were observable except other Se isotopes produced by neutron capture.

B. Counting Equipment

γ-ray spectra were taken using an 18-cm^3 Ge(Li) detector which gave a photopeak with a full width at half-maximum (FWHM) of 2.5 keV for the 1332-keV line of ^{60}Co. Coincidence experiments were performed using a 30-cm^3 Ge(Li) detector which gave a FWHM of 7.0 keV for the same peak and a 7.6×7.6-cm NaI(Tl) detector. The 4096-channel multiparameter analyzer system employed has previously been described.[7]

III. RESULTS

As neither the half-lives of the ^{81}Se isomers (18.6±0.2 and 57.3±0.4 min) nor the thermal-neutron production cross sections (0.5 and 0.1 b) differ sufficiently, it is not possible to obtain a separate γ-ray spectrum from either isomer. We show in Fig. 1 two γ-ray spectra, one rich in 19-min ^{81g}Se taken for 20 min immediately following

* Work supported in part by the U.S. Atomic Energy Commission under Contract No. AT(30-1)-905.

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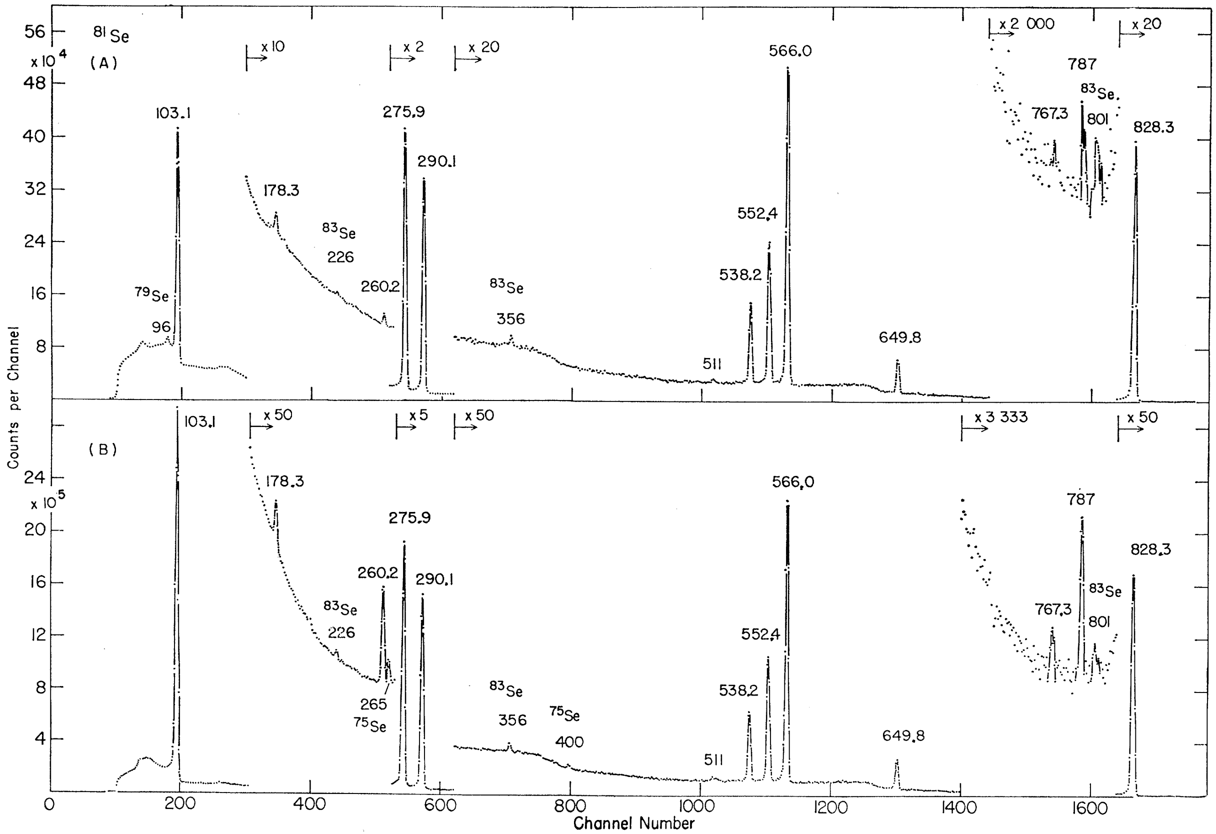

FIG. 1. γ-ray spectra of an ^{81}Se sample taken on an 18-cm^3 Ge(Li) detector. (A) Early count, predominately ^{81g}Se, (B) $^{81m+g}$Se source in transient equilibrium.

irradiation and separation. The other was taken for 1 h, starting 2 h after the end of irradiation and represents a source in transient equilibrium. It may be noted that the major peak[8] of 25-min ^{83}Se at 356 keV is seen in the early spectrum and the 265-keV peak of 75-day ^{75}Se is observed in the later spectrum. The higher relative intensities of the 103.1-, 260.2-, and 787-keV γ rays may be observed in the later spectrum. The weak γ ray at 787 keV has not been observed in coincidence spectra and was not placed in the decay scheme. We have listed

TABLE I. Energies and relative intensities of γ rays.

Energy (keV)	^{81g}Se I_γ	$^{81g+m}$Se [a] I_γ	$^{81g+m}$Se [a] (renormalized) I_γ
103.1±0.1	···	100	···
178.3±0.1	0.99±0.10	0.08±0.01	0.98±0.10
260.2±0.2	···	0.59±0.06	7.2±0.7
275.94±0.05	100	8.8±0.9	107.2
(A)290.08±0.05	86±9	6.7±0.7	82±8
(B)290.1±0.1	2.0±0.5	0.16±0.04	1.9±0.5
492.4±1.0[b]	···	0.0010±0.0002	0.012±0.006
538.2±0.1	6.8±0.7	0.57±0.06	6.9±0.7
552.4±0.1	12.6±1.2	1.02±0.10	12.5±1.2
566.04±0.05	29.6±3.0	2.7±0.3	33.0±3.3
649.8±0.1	3.7±0.4	0.29±0.03	3.5±0.4
767.3±1.0	···	0.0048±0.0005	0.059±0.06
787±2[c]	···	0.033±0.010	0.4±0.1
828.27±0.05	37.3±3.7	3.3±0.3	40.2±4.0

[a] Source in transient equilibrium.
[b] Taken from NDS (Ref. 2); obtained by Coulomb excitation and coincidence experiments.
[c] Isomeric assignment not determined.

[8] K. W. Marlow and M. A. Woggoner, Phys. Rev. **163**, 1098 (1968).

TABLE II. Coincidences ratios observed in Ge(Li)-NaI(Tl) experiments.

Gate (keV)	γ-ray energy (keV) coincidence ratio 178	260	276	290	538	552	566	650	828
1. 120–208		0.06	0.15	0.15	0.20	0.28	0.015	0.75	0.02
2. 255–283		0.57	0.18	0.48	0.10	0.97	...	...	0.01
3. 285–314		0.29	0.40	0.18	0.75	0.43	0.008	...	0.01
4. 523–541		...	0.02	0.005	...	...	...	...	...
5. 548–570		...	0.03	0.004	...	...	...	...	...
6. 619–692	0.83	...	0.001	...	...	...	...	...	...

the energies and relative intensities of the γ rays observed in Table I. The relative intensities of the two activities were determined by resolving the decay curve for each γ ray into its two components. No short-lived components were observed for the 103.1-, 260.2-, and 787-keV γ rays. Within the limits of uncertainty placed upon the intensity of the 650-keV transition, no extra feeding from ^{81m}Se could be observed. To indicate the absence of γ feeding from ^{81m}Se to any other levels, we have shown a third column of intensities in which the data from ^{81m}Se are renormalized by setting the portion of the 276-keV γ-ray intensity resulting from ^{81g}Se decay to 100. As no significant differences are observed between columns 1 and 3, no additional β branching from ^{81m}Se is proposed.

The results of the coincidence experiments are shown in Table II and represented by closed circles on the decay scheme of Fig. 2. The numbers listed in the Table are computed by dividing the peak area counts in a coincidence gate by the peak area from a singles spectrum taken at the same time.[9] Our coincidence results confirm many of the assignments proposed by others.[1–6] We observe coincidences between the 178- and 650-keV γ rays. No coincidences are observed for the 566- and 828-keV γ rays. The 260-, 290-, and 552-keV γ rays are in coincidence with the 275-keV transition showing the presence of levels at 536, 566, and 828 keV, respectively.

Prawirosoehardjo[4] placed the 538-keV γ ray as a transition from a level at 815 keV to the 275-keV level, an assignment that disagrees with our results. The 538-keV γ ray is seen in strong coincidence with the 290-keV γ-ray area. As a 290-keV γ ray feeds into the 276-keV level from the 566-keV level, the 538-keV γ ray either must feed into the 566-keV level or two γ rays with energies near 290 keV must be present. The former possibility is ruled out, as the 538-keV γ ray is not in coincidence with the 276-keV area. We have determined an intensity value of 2.0 for the weaker 290-keV γ ray from coincidence data. As it is less than the value of 6.8 for the 538-keV γ ray, it must feed into a level at 538 keV from the 828-keV level as has been suggested

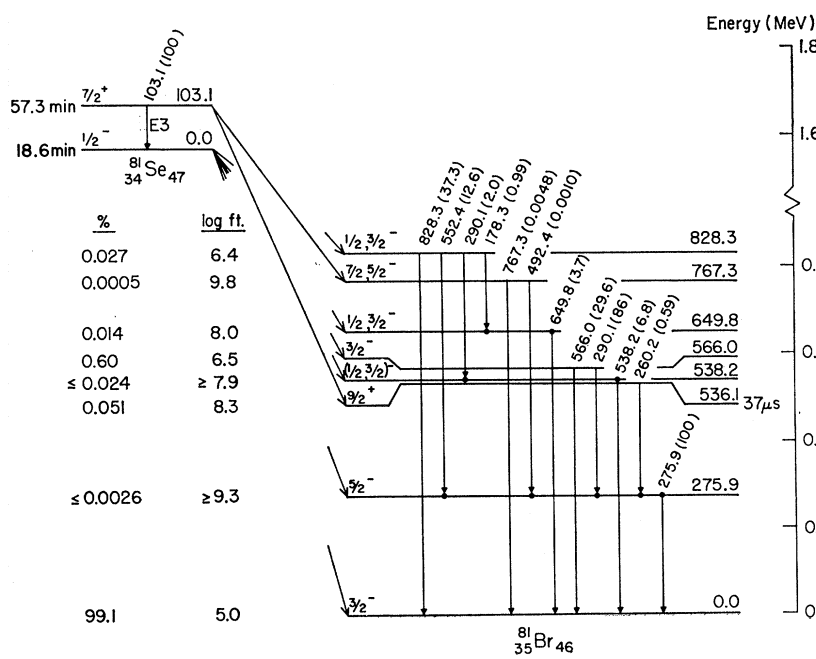

FIG. 2. Decay schemes of 18.6-min ^{81m}Se and 57.3-min ^{81g}Se.

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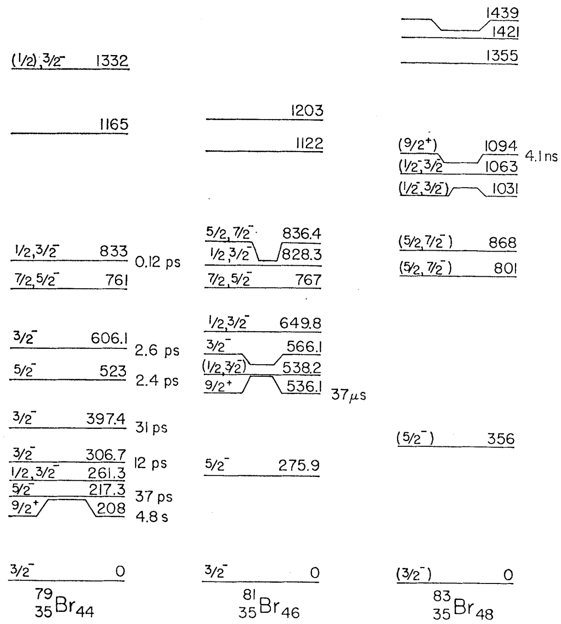

FIG. 3. Comparison of the low-lying levels of ^{79}Br, ^{81}Br, and ^{83}Br.

earlier.[5,6] Within limits of the uncertainties on the energies involved, this assignment is not unreasonable. Ythier *et al.*[5] have suggested two other positions for the 260-keV transition, between the 828- and 566-, or the 538- and 276-keV levels as well as where we have placed the transition. The energy of this transition is 260.2 ± 0.2 keV, not 262 keV as would be required by the other suggested cascades and consequently it could not occur at the other proposed placements. We have found no evidence for a 1146-keV γ ray as claimed by Prawirosoehardjo.[4] In samples in which Cl is not removed, however, a 1145-keV double escape peak from the 2167-keV γ ray of 37-min ^{38}Cl is observed. If the Na is removed from sources it can be noted that the Compton edge at 1146 keV observed in Ref. 4, resulting from the decay of ^{24}Na, also disappears. Coulomb excitation[1,2] results show the presence of a level at 767 keV. We observe a weak γ ray at 767 keV in our experiments, which decays with a half-life similar to that of the 260-keV γ ray. In our coincidence spectra we have observed a weak line at 492 keV, which results from the transition between the 767- and 276-keV levels. The intensity given for this γ ray in Table I comes from both the coincidence results, and the ratio of the 767- and 492-keV lines as observed in Coulomb excitation.[1,2]

Coulomb excitation experiments have shown the presence of a level at 836.4 ± 0.5 keV that was initially regarded as the same as the level observed in ^{81}Se decay at $\approx$830 keV. This is not the case, however, as our value for the energy of the intense γ ray in this energy range is 828.27 ± 0.05 keV. We do, however, observe a possible very weak peak at 835 ± 2 keV that may represent decay of the 836.4-keV level. The peak is too small to permit a half-life determination but the logft value is greater than 10 in either case. Because of the presence of an 834-keV γ ray in the decay[8] of 25-min ^{83}Se and the presence of some ^{83}Se in our sources, we can only set an upper limit of $\leq 0.0003\%$ on the intensity of any 836-keV γ rays in ^{81}Se decay and a lower limit for the logft value for β feeding from 57-min ^{81m}Se.

The determination of the logft values was made by measuring the relative intensities of the 103-keV internal transition and the γ rays from ^{81g}Se from a source in transient equilibrium. Values of 8.4 for α_K and 4.0 for K/LM for the 103-keV transition were taken from the work of Rao and Fink,[10] and Drabkin *et al*,[11] respectively. As noted by Rao and Fink,[10] this value is much higher than the computed value of 5.3 given by Hager and Seltzer[12] and indicates an $E3$-$M4$ mixed transition. Using this higher value has resulted in lower absolute γ-ray intensities and higher logft values than were determined in earlier work. The absolute γ-ray intensities are also lower than those suggested by the β-ray branching values of Kuroyanagi.[13]

IV. ASSIGNMENTS OF SPIN AND PARITY

The ground state of ^{81}Br is known to have a spin of $\frac{3}{2}$ and negative parity.[2] The levels at 256, 536, and 566 keV are also known to have spins and parities of $\frac{5}{2}^-$, $\frac{9}{2}^+$, and $\frac{3}{2}^-$, respectively.[2] As we observe β^- feeding from the $\frac{1}{2}^-$ ground state of ^{81}Se to the levels at 650 and 828 keV with logft values which correspond to allowed transitions, the spins and parity of these levels must be $\frac{1}{2}^-$ or $\frac{3}{2}^-$. Ythier *et al.*[5] proposed assignments of $\frac{7}{2}^+$, $\frac{5}{2}^-$, or $\frac{7}{2}^-$ to the 650-keV level on the basis of its feeding from the $\frac{7}{2}^+$ isomer. Because the intensity of the 650-keV γ ray cannot be accounted for by the intensity of the 178-keV γ ray regardless of which of the spin and parity assignments is taken to correct for internal conversion, and since we find no evidence for feeding from the $\frac{7}{2}^+$ isomer, the 650-keV level must be independently fed by the $\frac{1}{2}^-$ ^{81}Se decay. We have assigned $\frac{7}{2}^-$ or $\frac{5}{2}^-$ to the 767.3-keV level since it is fed by the $\frac{7}{2}^+$ isomer of ^{81}Se with a logft of 9.9, consistent with the values of first-forbidden β transitions.

The 836-keV level must also be a $\frac{5}{2}^-$ or $\frac{7}{2}^-$ level as it was strongly excited in Coulomb excitation and very weakly, if at all, in the β decay of the ^{81}Se isomers. The most likely feeding would be from the $\frac{7}{2}^+$ ^{81m}Se by a first-forbidden transition.

The measurement of β feeding to the 538-keV level from ^{81g}Se is difficult. In the decay scheme we show a weak β branch, although this is based on the small difference of two rather large γ-ray intensities, one of

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which is not known very well. For these reasons, we only set an upper limit for feeding to the 538-keV level. In the decay scheme we give the level a negative parity and tentative spins of either $\frac{1}{2}$ or $\frac{3}{2}$.

V. DISCUSSION

We show the low-lying levels[2,8,14] of ^{79}Br, ^{81}Br, and ^{83}Br in Fig. 3. A comparison of $B(E2)$ values, logft values, and γ-ray deexcitation patterns reveals that a number of ^{81}Br levels have properties similar to those observed in ^{79}Br. We have examined our spectra carefully for any evidence for decay from levels at 1122 and 1203 keV and can set relative intensity limits of 0.001 for these γ rays. These levels were observed with sizeable cross sections in (^{3}He, d) reactions suggesting $l=1$, 2, or 3 states. A detailed discussion of the structure of Br nuclei must await published high-resolution Coulomb excitation results on ^{81}Br similar to those on ^{79}Br and detailed (^{3}He, d) reaction studies on the stable even-even Se nuclei. Unfortunately, the companion (d, ^{3}He) studies on the even-even Kr nuclei will be difficult because of the gaseous nature of the target.

The trends observed in the Br nuclei with the addition of neutron pairs are clear, however, since the level spacing increases as the closed neutron shell at $N=50$ is approached. As most of the excited states have considerable collective character, such a trend is expected as the energy of the collective excitations in neighboring even-even nuclei increase as $N=50$ is approached. Also striking is the rapid relative rise in the position of the $g_{9/2}$ state (it is at 109 keV in ^{77}Br). A similar rapid rise of the $h_{11/2}$ single-proton state has been observed in odd-mass Sb nuclei.[15] Such a shift is not observed in As nuclei although data are available only for ^{73}As, ^{75}As, and ^{77}As. The data are also incomplete for Rb nuclei, but such a trend is indicated by the available data.

The logft value of 8.3 for the decay from the $\frac{7}{2}^+$ ^{81m}Se to the $\frac{9}{2}^+$ 37-μsec isomer of ^{81}Br is quite high for an allowed transition as are the logft values of 9.9 and ≥ 10.5 for the first-forbidden transitions to the $\frac{5}{2}^-$ or $\frac{7}{2}^-$ levels at 767 and 836 keV. These high values may result from the configuration of the $\frac{7}{2}^+$ ^{81m}Se which is probably a $(g_{9/2})_{7/2}{}^3$ three-quasiparticle level. The configuration of the final $\frac{9}{2}^+$ state may be a factor in view of the above mentioned sensitivity to nuclear size or neutron number. Considerable variation is also observed in the logft values (5.0–8.0) for the allowed decay of the $\frac{1}{2}^-$ ^{81}Se isomer but no definite correlations with level configuration can be made at this time.

ACKNOWLEDGMENTS

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