Low-spin isomer of ^{127}Ba†

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Neutron-deficient ^{127}Ba has been formed through the positron decay of its precursor ^{127}La produced by the ^{115}In(^{16}O, $4n$)^{127}La reaction. The γ-ray spectra have been studied using thin window intrinsic Ge and large volume Ge(Li) detectors. In contrast to the results reported earlier, γ rays of energies (relative intensities) 66.0 (22 ± 2), 72.7 (9 ± 1), 114.8 (85 ± 5), 180.8 (100), 567.5 (2.9 ± 0.3), 577.6 (4.0 ± 0.4), 626.0 (2.2 ± 0.2), 682.0 (2.5 ± 0.3), 692.5 (2.8 ± 0.3), 1087.0 (4.4 ± 0.4), and 1203.0 (20 ± 2) keV have been observed to be associated with the decay of ^{127}Ba. The half-life of ^{127}Ba has been established as 13.0 ± 0.5 min by following the decay of the photopeaks of intense γ rays. The γ-γ coincidence spectra were studied using two Ge(Li) detectors and a two parameter analyzer system. A revised decay scheme is proposed.

[RADIOACTIVITY ^{127}Ba [from ^{115}In(^{16}O, $4n$)^{127}La $\xrightarrow{\beta^+ \text{ EC}}$ ^{127}Ba]; measured $T_{1/2}$, E_γ, I_γ, $\gamma\gamma$ coinc; deduced ^{127}Cs levels, J^π; Ge(Li) and intrinsic Ge detectors.]

I. INTRODUCTION

In an earlier work by D'Auria, Bakhru, and Preiss,[1] the decay schemes of the two isomers of ^{127}Ba were reported. The high-spin activity was formed through ^{123}Sb(^{11}B, $7n$)^{127}Ba reactions, and the low-spin isomer produced from the β^+ decay of its precursor ^{127}La. The half-lives of the low- and high-spin isomers were reported to be 18 and 10 min, respectively. D'Auria *et al.*[1] employed a small planar Ge(Li) detector of about 10 keV resolution in the study of γ-ray spectra and assigned γ rays of energies 70, 90, 110, 180, and 200 keV to the decay of the high-spin isomer. The low-spin isomer was reported to decay primarily to the ground state of ^{127}Cs. No γ ray of energy greater than 30 keV was assigned to 10 min ^{127}Ba.

We have remeasured the γ-ray spectra of the "low-spin" isomer of ^{127}Ba using a high resolution large volume Ge(Li) and a thin-window intrinsic Ge detectors. These new results appear to agree with those of Arl't *et al.*[2] except with respect to the high energy γ rays reported therein. The ^{127}Ba formed from the decay of its precursor ^{127}La in the present study was observed to decay by emis-

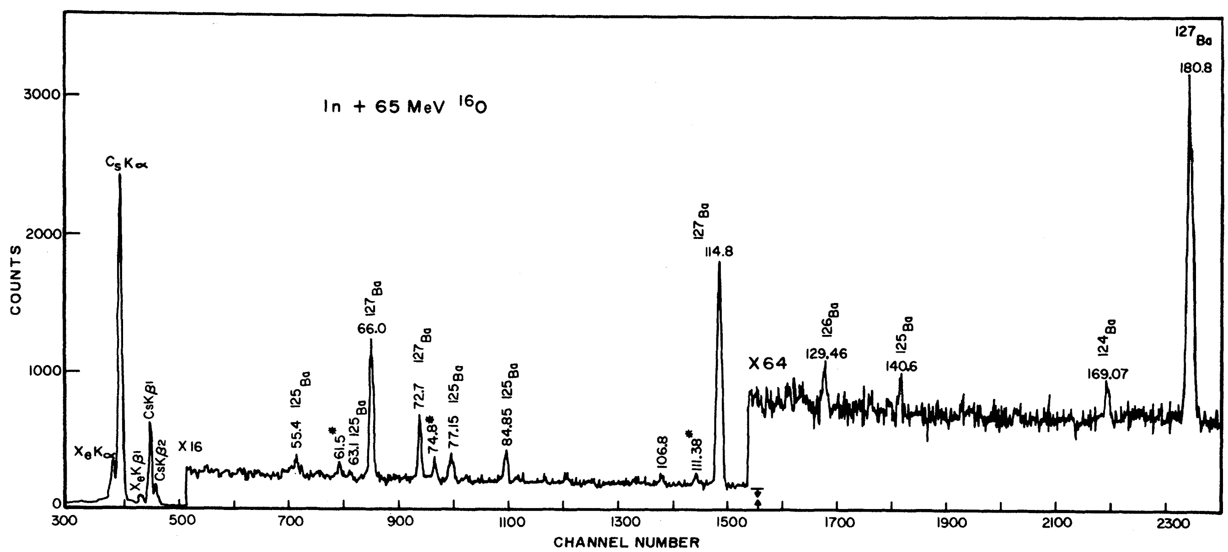

FIG. 1. A typical photon spectrum of ^{127}Ba using an intrinsic Ge detector. The photopeaks belonging to activities other than ^{127}Ba are labeled with the parent nuclei. The peaks that could not be identified are marked with an asterisk (*).

sion of intense γ rays of energies 66.0, 72.7, 114.8, and 180.8 keV. The analysis of the data on the decay of the photopeaks of these γ rays gave a half-life of 13.0 ±0.5 min. The γ-γ coincidence spectra were studied and a decay scheme is proposed.

II. EXPERIMENTAL

Radioactive sources of ^{127}Ba were obtained from the β decay of its precursor ^{127}La. The latter was produced through ^{115}In(^{16}O, 4η)^{127}La reactions. The target material was indium metal of high purity evaporated on a 0.0025 cm thick aluminum foil. The target thickness was 2 mg/cm^2. Irradiations were performed at the Heavy Ion Accelerator Laboratory, Yale University. Incident beam energy was reduced to the desired value by means of aluminum degrading foils. Recoiling nuclei were collected on a thin aluminum catcher foil placed behind the target. Beam energy and the duration of irradiation were adjusted to give maximum relative yield of ^{127}Ba compared to long-lived activities of ^{126}Ba (97 min), ^{128}Ba (2.4 day), and ^{129}Ba (2.1 h).

After irradiation times of 10 min, the samples were allowed to cool for 5 min to permit the ^{127}La ($T_{1/2}$ = 3.5 min) to decay to ^{127}Ba. This cooling time also allowed the short-lived activities of ^{125}Ba ($T_{1/2}$ = 3.5 min) and ^{123}Ba (2.7 min) to decay to a fairly low intensity. The Ba activity was radiochemically separated from the catcher foil by following the procedure given by Li *et al.*[3] and originally employed by Preiss and Strudler.[4]

Singles γ-ray spectra were studied using a 50 cm^3 Ge(Li) detector and a thin window intrinsic Ge detector. For γ-γ coincidence measurements a 40 cm^3 Ge(Li) and a 50 cm^3 Ge(Li) detectors were used. The electronic setup was a conventional two parameter coincidence system employing a PDP 8/E computer. The resolving time was adjusted to be < 50 nsec. The assignment of γ rays to ^{127}Ba was done by following the decay of the photopeak intensities of γ rays and the Cs K x rays.

III. RESULTS

A typical singles γ-ray spectrum of a chemically separated Ba sample is shown in Fig. 1. An intrinsic Ge detector was used for data collection. The photopeaks of the γ rays of energies 66.0, 72.7, 114.8, and 180.8 keV decayed with a half-life of 13 min, and hence were assigned to ^{127}Ba. For the determination of the half-life, photopeaks at 114.8 and 180.8 keV were selected using a single channel analyzer and the decay followed using a scaler. The results of half-life measurements are shown in Fig. 2. The analysis of the data on the decay of each photopeak (from both the intrinsic Ge and scaler experiments) gave a half-life of 13.0 ±0.5 min for ^{127}Ba.

Figure 3 shows a typical γ-ray spectrum of a Ba sample using a 50 cm^3 Ge(Li) detector. Weak γ rays of energies 567.5, 577.6, 626.0, 682.0, 692.5, 1087.0, and 1203.0 keV were observed to decay with an approximate half-life of 13 min and could not be attributed to known isotopes in this mass region. Therefore, they are assigned to ^{127}Ba. Energies and relative intensities of γ rays were obtained by utilizing the computer program SAMPO.[5] The results of singles measurements are summarized in Table I. The γ-ray spectrum in coincidence with 511 keV annihilation photons showed intense peaks at 114.8 and 180.8 keV. No γ ray was observed in coincidence with the 180.8 keV peak. The γ rays of 114.8 and 66.0 keV were found to be in coincidence. The 72.7 keV γ ray was observed in coincidence with the 66.0 keV peak.

IV. DECAY SCHEME

The results of singles and coincidence studies are summarized in the decay scheme shown in Fig. 4. The levels at 66.0 and 138.7 keV have been established by Conlon[6] from the study of the decay

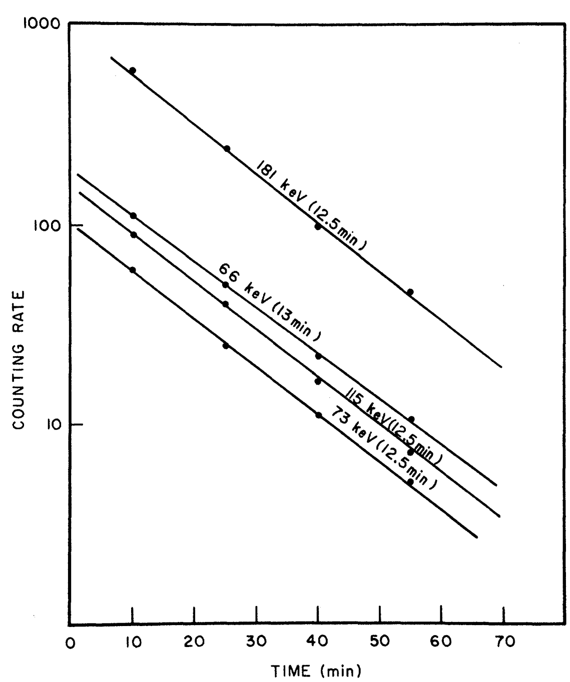

FIG. 2. Variation of the intensity of the photopeaks of the γ rays of ^{127}Ba with time. The data were obtained using intrinsic Ge detector.

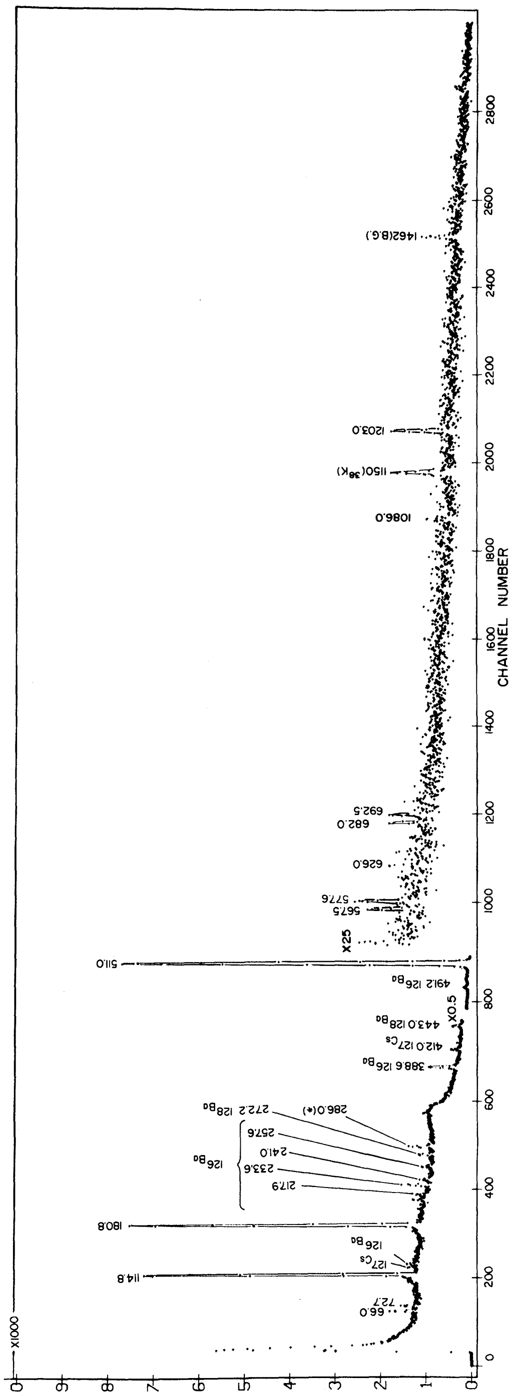

FIG. 3. A typical high energy γ-ray spectrum of ^{127}Ba. A 50 cm^3 coaxial Ge(Li) was used for data collection. The photopeaks due to activities other than ^{127}Ba are labeled with parent nuclei. The peaks that could not be assigned to any known activity are marked with an asterisk (*).

of 55 μsec isomer of ^{127}Cs. The coincidence between 66.0 and 114.8 keV γ rays indicates the existence of a level at 180.8 keV. Absence of coincidence between 114.8 and 180.8 keV γ rays is justified by showing the 180.8 keV transition between the 180.8 keV level and the ground state. This is further supported by the relative intensities of the 114.8 and the 180.8 keV γ rays in singles and coincidence spectra.

The weak γ rays of energies 567, 578, 626, 682, 692, 1087, and 1203 keV could not be observed in the coincidence spectra. However, these γ rays seem to form pairs whose energy differences are equal to the energies of well established transitions. This fact has been made use of in placing these γ rays in the decay scheme. The energy difference of 692 and 626 keV γ rays is 66 keV. This indicates that these γ rays result from the decay of a single level and feed the ground state and 66.0 keV levels, respectively. A level at 692 keV is suggested to include these γ rays in the decay scheme. The difference of 115 keV between the energies of 682 and 567 keV γ rays indicates that these transitions feed 66.0 and 180.8 keV levels respectively. A level at 748 keV is suggested to place these γ rays in the decay scheme. On the basis of similar arguments a level at 1269 keV is included. The 1203 and 577 keV γ rays are shown as transitions from this level to 66.0 and 692 keV levels, respectively. The 1087 keV transition is placed between 1269 and 180.8 keV levels.

The strong coincidence observed between annihilation photons and the 114.8 and 180.8 keV γ rays indicates that the ^{127}Ba isomer formed in this study decays mainly by positron emission. D'Auria *et al.*[1] reported a single positron group with an endpoint energy of 3.5 MeV. Assuming the β decay to be of allowed type, EC/β^+ ratio is predicted to be 0.2.

The intensity of the positron branch to the ground state of ^{127}Cs was estimated to be $(60 \pm 20)\%$ from the intensity of the 511 keV annihilation radiation observed in singles spectra. The gross intensity of the 511 keV peak was corrected for contribution from other positron emitters, such as ^{126}Cs, ^{127}Cs, and ^{128}Cs, by using their total decay rate based on the intensities of their characteristic γ rays and branching ratios.[7-9] The net decay following, this correction, representative of the over-all positron decay was then corrected for those transitions leading to γ-ray emission from energy levels associated with ^{127}Cs. The result obtained from this procedure is, of course, subject to a rather large systematic error. D'Auria *et al.*[1] employed a plastic scintillator in the study of β-ray spectra and, therefore, it is obvious that

TABLE I. Energies and relative intensities of γ rays observed in the decay of ^{127}Ba.

Present work		Arl't *et al.*	
$E\gamma$	$I\gamma$	$E\gamma$	$I\gamma$
66.0± 0.1	22 ± 2	66.3	27
72.7± 0.1	9 ± 1	72.8	8
114.8± 0.1	85 ± 5	114.8	96
180.8± 0.1	100	180.7	100
567.5± 0.5	2.9± 0.3	568	3
577.6± 0.5	4.0± 0.4	578	6
626.0± 0.5	2.2± 0.2		
682.0± 0.5	2.5± 0.3		
692.5± 0.5	2.8± 0.3		
1087.0± 0.5	4.4± 0.4	1085	3
1203.0± 0.5	20 ± 2	1201	12
		1501	3
		1568	4
		1620	2
		1757	2

they could not resolve positron groups with energy difference of 180 keV. Also, probably because of the presence of intense annihilation photons they could not observe even relatively intense γ rays of energies 114.8 and 180.8 using the small Ge(Li) of poor resolution.

The experimental data obtained in the present study is insufficient to establish precise intensities of β^+ and *EC* branches to various levels in ^{127}Cs. Further experimental information on the conversion coefficients and the multipolarities of transitions are needed for determining log*ft* values.

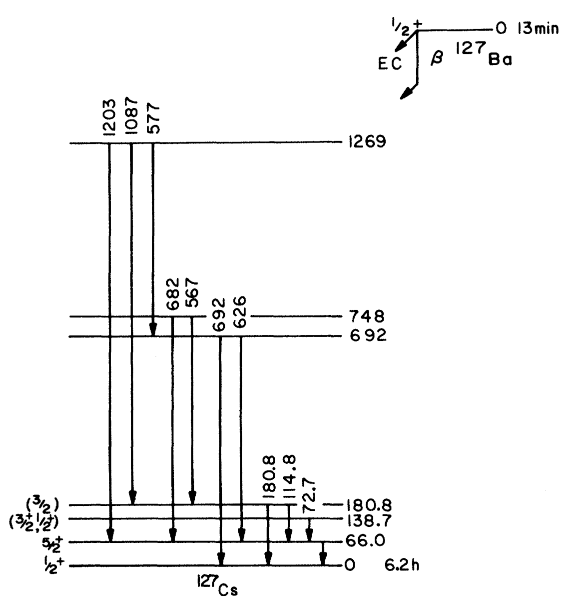

FIG. 4. Proposed decay scheme of ^{127}Ba.

TABLE II. Relative intensities of transitions populating and depopulating the 66.0 keV level.

$E\gamma$	$I\gamma$	Multipolarity	α_{total}	$I\gamma\ (1+\alpha_{total})$
66.0	22	*E*2	7.95	197
72.7	9	*M*1	2.3	30
		*E*2	5.9	62
114.8	85	*M*1	0.61	137
		*E*2	1.16	184
626	2.2	*M*1	7.1×10^{-3}	2.2
		*E*2	5.4×10^{-3}	2.3
682	2.5	*M*1	5.7×10^{-3}	2.5
		*E*2	4.4×10^{-3}	2.5
1203	20	*M*1	1.5×10^{-3}	20
		*E*2	1.1×10^{-3}	20

V. DISCUSSION

The energies and relative intensities of the γ rays observed in this study are in good agreement with those reported in Ref. 2. However, some of the high energy γ rays reported by Arl't *et al.*[2] could not be observed even by using large volume (50 cm^3) Ge(Li) detectors and accumulating data for several irradiations. The low energy γ rays of 65.9 and 72.9 keV reported by Conlon[6] appear to be the same as 66.0 and 72.7 keV photons observed in this work. The other intense γ rays reported by Conlon are not observed in this work. This indicates that only low-spin levels of ^{127}Cs are populated by the decay of ^{127}Ba. The ground state spin of ^{127}Cs is known to be $\frac{1}{2}^+$. The intense β^+ branch from ^{127}Ba to the ground state of ^{127}Cs supports the above assignment of low spin to the 13 min isomer of ^{127}Ba; the most likely spin and parity being $\frac{1}{2}^+$ or $\frac{3}{2}^+$. The assignment $\frac{1}{2}^+$ seems to be favored by the arguments given below.

Experimental data on the multipolarities and the conversion coefficients of γ transitions are not available. Conlon[6] assigned an *E*2 multipolarity to the 66 keV transition on the basis of the relative intensities of γ rays observed in the singles spectra of the 55 μsec isomer of ^{127}Cs. Assuming the validity of the decay scheme shown in Fig. 4 and the *E*2 multipolarity for the 66.0 keV transition, we make multipolarity assignments to other intense transitions on the basis of intensity balance at each level. The 66.0 keV level has been assigned spin $\frac{5}{2}^+$ by Conlon.[6] This level is populated by 114.8, 72.7, 626, 682, and 1203 keV transitions. The most probable multipolarities of these transitions are *M*1, *E*2, or an admixture of the two. The total transition intensities have been evaluated using conversion coefficients calculated by Hagar and Seltzer[10] and Dragoun, Plajner, and Schmutzlu[11] and are shown in Table II. A good intensity balance is obtained if the 114.8 and 72.7 keV transitions are taken to be *M*1. The high energy transitions have very small conversion coefficients for both *E*2 and *M*1 multipolarities and, hence, either multipolarity or admixture of both are equally probable.

The ground state of ^{127}Cs is known[7] to have $J\pi = \frac{1}{2}^+$, while the 66 keV level is suggested[6] to have $J\pi = \frac{5}{2}^+$. Arl't *et al.*[2] have suggested the most probable spin and parity of 13 min ^{127}Ba as $\frac{1}{2}^+$. This assignment is further supported by the systematics of the low-spin isomers of odd-mass neutron deficient Ba isotopes. From the intensity balance requirements at the 66.0 keV level, we expect the 72.7 and 114.8 keV transitions to be predominantly *M*1. Thus the probable spins of the 138.7 and 180.8 keV levels are $\frac{3}{2}^+$.

The 180.8 keV γ ray is not in coincidence with any intense photon and therefore, its conversion coefficient cannot be estimated. Assuming the validity of the spin assignment of $\frac{3}{2}^+$ to the 180.8 keV level, the probable multipolarities of the 180.8 keV transition are *E*2, *M*1, or an admixture of the two. The systematics of γ transitions between low-lying levels of odd-mass Cs isotopes show that wherever permitted by the spins of initial and final levels, *M*1 transitions are predominant (e.g. ^{133}Cs).

If we assume that the multipolarity of the 180.8 keV transition is *M*1, the Weisskoff estimate of the intensity ratios of 114.8 and 180.8 keV γ rays comes out to be 1 : 3.9. The observed intensity ratio is 1 : 1.2. The absence of 138.7 keV γ ray in the singles spectra indicates that the γ transition from the 138.7 keV level to the ground state is either absent or its intensity is less than 20% of that of 72.7 keV γ ray. Conlon[6] has suggested that the 66 keV transition from the first excited to the ground state is retarded due to the accompanying change in nuclear shape.

VI. CONCLUSION

The earlier work by D'Auria *et al.*[1] utilized a small volume Ge(Li) planar detector of about 10 keV resolution and hence, the energy assignments in this report are more precise, and in substantial agreement with those of Ref. 2.

Accepting the premise proposed by D'Auria *et al.*[1] that isomerism exists in ^{127}Ba, then the decay associated with the isotope of Ba produced in this study should mainly originate from the low-spin member of the pair. That is, the decay of the ^{127}La precursor should preferentially populate low-spin levels of the ^{127}Ba daughter. The half-life of 13.0 ± 0.5 min observed in this study is in substantial agreement with the value of 12 min reported by Strominger, Hollander, and Seaborg,[12] Kalkstein and Hollander,[13] and Lindner and Osborne.[14]

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