Decay of Y^{85} Isomers*

I. DOSTROVSKY,‡ S. KATCOFF, AND R. W. STOENNER
Chemistry Department, Brookhaven National Laboratory, Upton, New York
(Received 22 July 1963)

Two isomers of Y^{85} have been identified and their half-lives determined as 2.68±0.05 h and 5.0±0.2 h. Measurements were made by means of successive timed daughter separations and by direct observation of the decay of radiations from yttrium. Both isomers decay independently by positron emission. The 2.68-h isomer decays to the 70-min Sr^{85m} while the 5.0-h isomer decays to the 64-d Sr^{85}. No isomeric transition was observed. Positron spectra were measured with a β-ray spectrometer. The spectrum for the 2.68-h isomer has an end-point energy of 1.54±0.02 MeV, and the components of the 5-h isomer have end points of 2.24±0.01 MeV, 2.01±0.01 MeV, and 1.1±0.1 MeV. Conversion electron measurements disclosed a 503-keV transition, with a half-life of 2.68 h, K conversion coefficient of 1.9×10^{-3}, and K/L ratio of ~10. The γ spectrum for the Y^{85} isomeric mixture is complex. The observed transitions are: 503 and 925 keV from the 2.68-h isomer, and 231, 700, 772, (1030), (1130), 1230, 1390, 1590, 1870, 2160, 2340, and 2750 keV from the 5.0-h isomer. Sum-coincidence spectra showed summation of the following radiations: (231–511), (503–511), (231–1390), and (772–1390) keV. Beta-gamma coincidence measurements showed that the 2.01-MeV positron group is coincident with the 231-keV γ ray and that the 1.54-MeV positron from the 2.68-h isomer is in coincidence with the 503-keV γ ray. The 5.0-h isomer of Y^{85} is 3.26 MeV above the ground level of Sr^{85} while the 2.68-h isomer is at 3.30 MeV, thus being 40±30 keV higher. Spins of 9/2+ and 1/2− have been assigned to the 5.0-h and 2.68-h isomers, respectively. A partial decay scheme is presented.

I. INTRODUCTION

YTTRIUM-85 was first reported by Caretto and Wiig[1] as a spallation product from the bombardment of yttrium with 130- and 240-MeV protons. On the basis of strontium daughter separations from purified yttrium samples, a half-life of 5±1 h was assigned to Y^{85}. In the course of other work[2] in this laboratory involving bombardment of various targets with high-energy protons, it was noticed that the 70-min Sr^{85m} fraction isolated from gross yttrium activity indicated a half-life of its parent, Y^{85}, considerably shorter than 5 h. The behavior of 64-d Sr^{85} activity indicated that the half-life of its parent is about 5 h. The existence of two isomers of Y^{85} with independent decays was suspected. The decay of Y^{85} was therefore examined, and a partial decay scheme is reported in this paper. While the work was in progress a paper by Patro and Basu[3] on the decay of Y^{85} appeared in which the existence of the two isomers was not recognized, although their data show that both isomers were produced under their conditions. A report by Maxia, Kelly, and Horen[4,5] announcing the discovery of two isomers of Y^{85} also came to our knowledge at that time.

II. SOURCE PREPARATION

For most measurements, Y^{85} was made by bombarding[6] Sr^{84} with deuterons degraded by 280 mg/cm² of Al to ~8 MeV. This thickness of absorber minimizes the production of Y^{86} by the reaction $Sr^{86}(d,2n)Y^{86}$. It is estimated that no more than 1% of the total activity present in our samples at the end of irradiation was from Y^{86}. Y^{87} and Y^{88} were also produced in small proportions but their radiations appeared not to interfere with our measurements. In the daughter separation experiments only Y^{87} interfered to a minor degree. In the few cases where yttrium activity was prepared by the 30-GeV proton bombardment of silver, the samples contained substantial amounts of all the neutron deficient yttrium isotopes. These samples were used only for daughter extraction experiments.

In all cyclotron runs in which enriched Sr^{84} was used, the target was in the form of a few mg $Sr(NO_3)_2$ deposited by evaporation of a solution on aluminum foil. After irradiation, the target was dissolved in a few ml of acidified water and 20-ml of cold fuming nitric acid was added to precipitate most of the strontium. After cooling and centrifuging, the nitric acid phase was extracted with 20-ml tri-butyl phosphate (TBP). The TBP layer was washed three times with concentrated nitric acid and the yttrium was then back-extracted into water (2 washes, totaling 25 ml). The aqueous yttrium solution was washed with hexane and ether and then boiled down to a small volume. From this solution, sources for β- and γ-ray spectroscopy were prepared.

* Research performed under the auspices of the U. S. Atomic Energy Commission.
‡ On leave of absence from the Weizmann Institute of Science, Rehovoth, Israel.
[1] A. A. Caretto and E. O. Wiig, J. Am. Chem. Soc. **74**, 5235 (1952).
[2] I. Dostrovsky, S. Katcoff, and R. W. Stoenner, J. Inorg. Nucl. Chem. (to be published).
[3] A. P. Patro and B. Basu, Nucl. Phys. **37**, 272 (1962).
[4] V. Maxia, W. H. Kelly, and D. J. Horen, J. Inorg. Nucl. Chem. **24**, 1175 (1962).
[5] D. J. Horen and W. H. Kelly, Bull. Am. Phys. Soc. **7**, 341 (1962); **7**, 419 (1962).
[6] Obtained from Oak Ridge National Laboratory (54.5% Sr^{84}, 13.81% Sr^{86}, 4.21% Sr^{87}, and 27.5% Sr^{88}).

III. HALF-LIFE DETERMINATION

A. Timed Daughter Extractions

In these experiments the TBP layer containing the purified yttrium activity was washed at timed intervals with 20-ml portions of nitric acid containing a trace of strontium. To each extract, 2 ml of strontium-carrier solution was added, followed by 8 ml of cold fuming nitric acid. After cooling and centrifuging, the $Sr(NO_3)_2$ precipitate was separated. The strontium was further purified by a second nitrate precipitation followed by two scavenging precipitations with ferric hydroxide. The strontium was finally precipitated as carbonate and mounted on cards for counting. The activity was counted with a 3-in.×3-in. NaI crystal and a multichannel analyzer. The only gamma lines seen in the samples were the 150-keV and 230-keV lines or Sr^{85m}, the 514-keV line of Sr^{85}, and the 390-keV line of Sr^{87m}. The chemical yield of each strontium sample was determined by analysis. Each nitric acid extract was also analyzed for the small amounts of yttrium (about 1% of original yttrium carrier) lost from the TBP phase. These results were used to compute the actual amount of yttrium present at each growing interval. At the end of the experiment the yttrium remaining in the TBP was back-extracted into water and its quantity determined. Ninety-eight percent of the initial yttrium carrier was accounted for.

The γ-ray spectrum of each strontium sample was followed for several hours. The analysis of the data showed that the parent of the 70-min Sr^{85m} has a half-life of 2.67 h and that the parent of the 64-day Sr^{85} has a half-life of 5.0 h. The method of analysis was as follows.

The areas under the 150- and 231-keV peaks were measured and corrected for the Compton peak contribution of the 390-keV γ ray (Sr^{87m}). The net intensities thus obtained were analyzed by the method of least squares.[7] Since constant growth time intervals were used in each series (the intervals in various runs were 1, 5.3, and 6 h) the calculated activity of Sr^{85m} at times of separation could be used directly to compute the half-life of the Y^{85} parent. A typical result from measurements of the 231-keV peak is shown in Fig. 1(b). The value of the half-life thus obtained is 2.67±0.05 h.

The area under the 514-keV peak of the 64-d Sr^{85} was measured on spectra taken after all other activities had decayed. The 64-day activity is produced by two paths, the direct decay of Y^{85} and the decay of the 70-min Sr^{85m} isomer. In order to estimate the proportion of the direct decay to the 64-day level, it is necessary to subtract the contribution for the decay of Sr^{85m}. The amount of the 70-min isomer at time of separation from yttrium was determined from the intensity of the 231-keV isomeric transition. Corrections were applied for

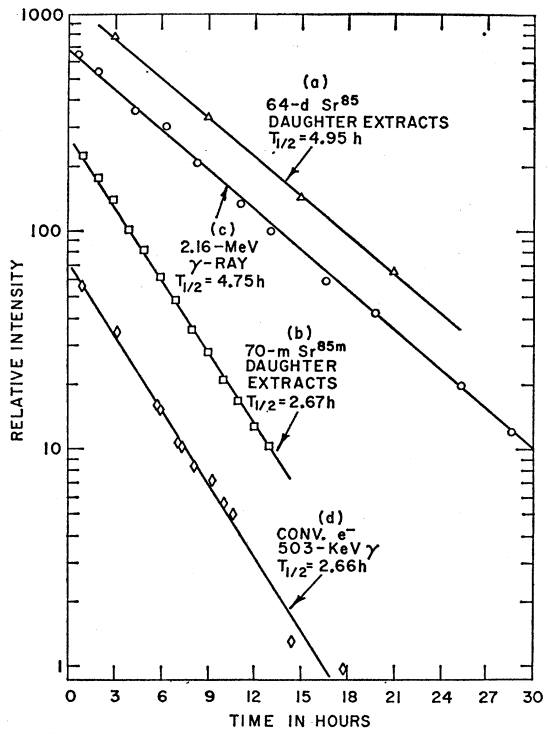

FIG. 1. Lines (a) and (b) show the activities of Sr^{85} and Sr^{85m}, respectively, as functions of time of separation from Y^{85}. Lines (c) and (d) show the decay of the 2.16-MeV γ ray and the 503-keV γ-conversion electrons, respectively, from Y^{85}.

internal conversion (3%) and for the relative photopeak efficiencies of the 231- and 514-keV γ rays. From this corrected intensity the 64-day Sr activity arising from the 70-min isomer was calculated. The contribution by this path can be quite large under certain conditions. The half-life of the parent of 64-day Sr^{85} was determined in three runs. In the first, where a growth interval of 1 h was used, the proportion of 64-day Sr arising from Sr^{85m} was 55% for the first separation and gradually diminished to 23% at the 13th separation. In the second run, where the growth period was 6 h, the initial amount was 10% and was negligible for the 4th separation. In the third run, where the growth interval was 5.3 h, and when strontium separations were started earlier than in the second run, the correction for the first separation was 30% and for the 6th separation was 1%.

The corrected activities of 64-day Sr^{85} calculated for the time of separation were used in computing the half-life of the parent by the least-squares analysis.[7] The following values were obtained from the three runs, respectively: (1) 5.34±0.14 h, (2) 4.95±0.19 h, (3) 5.31±0.24 h [Fig. 1(a)].

The least-squares analysis of the 64-day Sr^{85} activity produced directly and that produced through the 70-min isomer also yields the amounts of Y^{85} isomers present initially. When the Y^{85} was made by cyclotron

[7] J. B. Cumming, *Applications of Computers to Nuclear and Radiochemistry*, (National Academy of Sciences, National Research Council, Nuclear Science Series, 1962), NAS-NS-3107, p. 25.

bombardment, the ratio of the cross section for production of the 2.7-h isomer to that for the 5.0-h isomer is ~1.0. This ratio is ~0.60 when the Y^{85} is made by spallation of silver with 30-GeV protons.

B. Decay of Positrons

The half-lives of the two Y^{85} isomers were also measured by observing the decay of the positron emission for 76 h. The positrons were detected by means of their annihilation radiation produced in a copper absorber surrounding the source. The latter was placed midway between two 2-in.×2-in. NaI scintillators, and those 511-keV photons in coincidence were measured. Correction for coincidences between γ rays and annihilation radiation was determined by means of a third 2-in. ×2-in. NaI crystal placed at 90° to the other two. The results, after analysis by the least-squares procedure,[7] yield half-lives of 2.66±0.10 h and 5.04±0.10 h; and a ratio of intensities of the first to the second of 1.6 at the end of irradiation. The analysis is somewhat complicated by the presence of a small amount of longer lived β^+ activity, presumably 80-h Y^{87}.

C. Decay of γ Rays

The γ sprectrum of Y^{85} is complex and many of the lines are poorly resolved. Although every line could be assigned to one or both half-lives, only three photopeaks were well enough resolved to give fairly accurate half-life determinations. The 925-keV line decayed with a half-life of 2.7±0.1 h. The 2.16-MeV γ ray gave a value of 4.75±0.13 h [Fig. 1 (c)] and the 770-keV peak gave a value of 4.98±0.15 h.

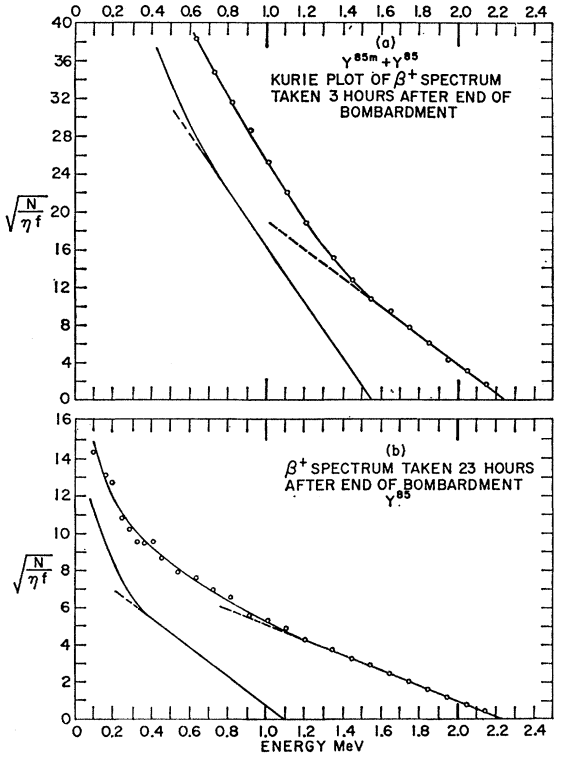

FIG. 2. Kurie plots of positrons from Y^{85}. (a) Spectrum taken 3 h after end of bombardment, (b) spectrum taken 23 h after end of bombardment.

D. Mean Half-Life Values

Taking all these determinations together with due consideration of the relative precision and systematic errors of the various experiments, we feel that the best values for the half-lives of the two isomers of Y^{85} are 2.68±0.05 h and 5.0±0.2 h.

IV. POSITRON SPECTRA OF Y^{85}

A series of β^+ spectra were taken on a 50 cm double focusing $\pi\sqrt{2}$ β-ray spectrometer. The source was made by evaporating a solution of carrier-free yttrium activity in the form of a strip 2 mm wide and 10 mm long. Figure 2 shows Kurie plots of the spectra obtained at two different times after the end of irradiation. Analysis of a number of such spectra taken at different times led to the following positron groups. The 5-h isomer showed end points of 2.24±0.01 MeV and 1.1±0.1 MeV, the intensity of the latter being 8% that of the former. The 2.68-h isomer showed an end point of 1.54±0.02 MeV and a possible weak group at ~1.0 MeV. In addition there may be very weak lower energy groups (~0.5 MeV) belonging to both isomers. Further information on these end points and on additional positron groups was obtained from coincidence experiments described below.

V. CONVERSION ELECTRONS

A search for conversion electrons in the energy range, 160–1200 keV, was carried out with a Gerholm lens spectrometer, and in the range 50–260 keV, with the

TABLE I. Summary of conversion-electron data.

Observed conversion electron energy keV	Assignment	Transition energy (keV) This work	Transition energy (keV) Lit. value	K/L ratio This work	K/L ratio Lit. value
134.9	$Rb^{85m}K$	150.1	150[a]	...	...
215.0	Sr^{85} K	231.1	225[a]	6.7	5[a]
228.9	Sr^{85} L	231.2			
220.5	$Sr^{85m}K$	236.6	233[a]	4.5	...
235.3	$Sr^{85m}L$	237.5			
362.3	Y^{87m} K	379.3	381[b]	5.8	5.4[b]
379.9	$Y^{87m}L$	379.3			
370.7	Sr^{87} K	386.8	388[b]	6.8	6.9[b]
385.4	Sr^{87} L	387.5			
486.9	Sr^{85} K	503.0	...	~10	6.6[c]
500.2	Sr^{85} L	502.4			...

[a] A. W. Sunyar, J. W. Michelich, G. Scharff-Goldhaber, M. Goldhaber, N. S. Wall, and M. Deutsch, Phys. Rev. 86, 1032 (1952).
[b] G. A. Graves, L. M. Langer, and R. D. Moffat, Phys. Rev. 88, 344 (1952).
[c] I. A. Antonova and I. V. Estulen, Izvest. Akad. Nauk U. S. S. R., Ser. Fiz. 18, 79 (1954).

double focusing spectrometer. The precise energies of the electrons were then measured with the high resolution double focusing spectrometer. The results are shown in Table I. The only new transition observed is that of 503 keV which showed a 2.7-h half-life [Fig. 1 (d)]. Its assignment to Sr^{85} is based on β-γ coincidences described below.

With the exception of the two transitions in Sr^{85} at 231 and 237 keV, the energies of the conversion electrons observed agree well with those reported in the literature.

The decay of the conversion electrons from the 231-keV transition indicates that it is fed mainly by the 2.68-h Y^{85} isomer (via the 70-min Sr^{85m}) with some contribution directly from the 5-h isomer. Least-squares analysis of the growth and decay of the intensity of these conversion electrons gives the ratio of the contributions from the two isomers to this transition. This, coupled with the known ratio of isomer activities, gives about 15% for the fraction of the 5.0-h isomer decaying through the 231-keV transition.

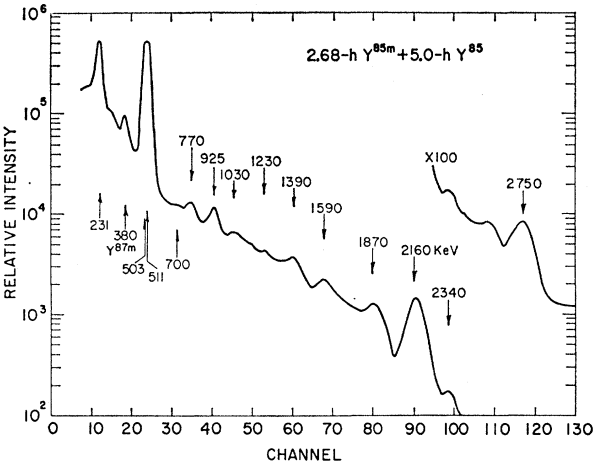

FIG. 3. Gamma-ray spectrum of Y^{85} taken 4 h after bombardment and 3 h after separation from daughter Sr^{85}. Source 19 cm away from 3-in.×3-in. NaI crystal.

VI. GAMMA-RAY SPECTRA OF Y^{85}

Gamma-ray spectra were observed with NaI scintillators and a multichannel analyzer. Measurements with a 3-in.×3-in. scintillator were made at two different solid angles. (1) High geometry with the sample very close to the crystal; and (2) low geometry with the sample 19 cm away. Measurements were also carried out with lead collimators and with the source 10 cm away from a 2-in.×2-in. NaI crystal. A typical spectrum taken with the 3-in.×3-in. crystal is shown in Fig. 3. One of the peaks, ~1030 keV, showed a pronounced enhancement in the high geometry measurement, thus indicating that it is largely a sum peak. Spectra were measured on many preparations and at various times after bombardment. From the decay of the various peaks, it was possible to assign most of these γ rays to one or the other of the two isomers. The results are summarized in Table II.

The intensities of the γ rays were calculated as fractions of disintegrations for each isomer separately. The total disintegration rate of the 2.7-h isomer was calculated both through the 231-keV γ-ray intensity and from that of the 511-keV annihilation radiation, while the disintegration rate of the 5-h isomer was obtained only from the 511-keV radiation intensity. Analysis of the growth and decay of the 231-keV γ ray by the least-squares procedure,[7] with correction for branching to Rb^{85} (14%), internal conversion, and for counter efficiency, gives the initial disintegration rate of the 2.7-h component. The area under the most intense peak at about 510 keV (which includes mainly 511-keV annihila-

TABLE II. Gamma rays observed from Y^{85} isomers.

Energy (keV)	Isomer Identification	Intensity, %	Remarks
231	5 h	13	This value is the average of conversion electron and γ-spectrum measurements and is in addition to the 231-keV transition from the decay of 70-min Sr^{85m}.
510	5 h and 2.7 h	...	Annihilation radiation and γ rays, the most intense peak in spectrum.
700	5 h (and 2.7 h ?)	...	Intensity comparable to that of 772-keV γ ray.
772	5 h (and 2.7 h ?)	8	Intensity applies to 5-h component.
925	2.7 h	9	
(1030)	5h	weak	A weak γ appearing at low geometry. The much stronger sum peak appearing near this energy in high geometry experiment is not included in intensity estimate.
(1130)	5 h	weak	
1230	5 h	~1	Estimated intensity by comparison with 2160-keV γ.
1390	5 h	~2	Estimated intensity by comparison with 2160-keV γ.
1590	5 h	~1	Estimated intensity by comparison with 2160-keV γ.
1870	5 h	~4	Estimated intensity by comparison with 2160-keV γ.
2160	5 h	~9	
2340	5 h	~1	Estimated intensity by comparison with 2160-keV γ.
2750	5 h	~0.8	Estimated intensity by comparison with 2160-keV γ.

tion radiation with minor addition of 503-keV γ ray) was measured soon after bombardment. With the assumption that most of the decay of the 2.7-h isomer proceeds through the 503-keV transition and with the knowledge of the abundance ratio of the two isomers (see Sec. IIIA), we calculate that about $\frac{1}{4}$ of the initial intensity of the 510-keV peak is due to the 5-h isomer. Estimating further that 30% of the decays of this isomer proceed by electron capture its disintegration rate was calculated. A similar procedure was used for the 2.7-h isomer after subtracting $\frac{1}{3}$ for the contribution of the 503-keV γ ray. The result agrees to within 15% with the value of the disintegration rate for the 2.7-h isomer obtained from the 231-keV γ ray.

The absolute intensity of each γ ray was then calculated from the observed area of the corresponding peak after correction for photopeak efficiency. Values for the absolute intensities (Table II) are accurate only to about 30% because of the assumptions and corrections involved in their derivation.

VII. SUM-COINCIDENCE SPECTRA

A sum coincidence spectrometer, following in general the arrangement first described by Hoogenboom,[8] was set up. Two 2-in.×2-in. NaI crystals mounted 90° to each other accepted radiation from the source through lead collimators. The crystals were well shielded from each other. Coincident pulses from both crystals were summed and those falling in a selected sum-channel were used to gate a multichannel analyzer, which recorded signals from one of the scintillators. The gating sum-channel position was varied from 600 keV to 2220 keV, and its width was adjusted to 5–10% of the energy setting. For those settings of the gating channel which correspond to the sum of the energies of two γ rays in cascade, the analyzer displays the photopeaks of the two γ's in equal intensity. In addition, γ rays in coincidence with positrons will also show sum peaks with annihilation radiation. We have observed both kinds of sum spectra. These are listed in Table III.

VIII. POSITRON γ-RAY COINCIDENCES

Our β-γ coincidence spectrometer consisted of a plastic scintillator mounted at 90° to a 2-in.×2-in. NaI crystal. Collimators were used with both scintillators which were well shielded from each other. The pulses from the scintillators were fed to a coincidence unit which included single-channel analyzers in each side. The output from the coincidence unit was used to gate a multichannel analyzer which could be made to record either the output from the plastic scintillator or from the NaI crystal. The arrangement was used in both modes. In one, coincidences were selected with specific γ rays, and the β^+ spectrum was analyzed. In the other, coincidences with portions of the β^+ spectrum were selected and the γ spectrum was analyzed. A 16 by 64-channel two-dimensional analyzer was also used to record these data during part of the experiments.

When positron coincidences with the 231-keV γ ray were used to gate the analyzer, a β^+ spectrum was obtained which, upon analysis by Kurie plot, showed an end point of 2.08±0.10 MeV. When coincidences with the 503-keV γ ray were used to gate the analyzer, the coincident β^+ spectrum showed an end point of 1.57±0.10 MeV. The coincidence rate for the 925-keV transition was too low to observe in our experiments.

In examining the γ-ray spectra in coincidence with portions of the β-ray spectra, two clearly defined photopeaks were observed, at 230 and at 500 keV. The relative intensities of these peaks varied with the energy of the coincident positrons. When positrons above 1.54 MeV were selected, only the 231-keV peak appeared in the coincident γ spectrum.

A series of coincidence spectra were taken over a period of 24 h. The 231-keV γ ray in coincidence with 2.08-MeV positrons was found to decay with a 5.0-h half-life. The 503-keV γ ray in coincidence with 1.54-MeV positrons decayed with a 2.7-h half-life. The half-lives of the 231- and 503-keV γ rays, and of the 1.54-MeV positrons deduced from these measurements are in agreement with our other results. The 2.08-MeV positron was not observed before in the positron spectra because of low intensity and the proximity of its energy to the 2.24-MeV group.

IX. PARTIAL DECAY SCHEME

A partial decay scheme based on the observations outlined above is shown in Fig. 4. Daughter activity separations clearly indicate the existence of two isomers of Y^{85}; a 5-h isomer decaying to the 64-day ground state of Sr^{85} and a 2.68-h isomer decaying to the 70-min Sr^{85m}. Both decays are predominantly brought about by positron emission. A direct transition between the two Y^{85} isomers has not been observed; neither γ rays nor conversion electrons, which could be assigned to the isomeric transition, were detected. On this basis an upper limit of about 1% was set for the direct isomeric transition, which corresponds to a partial half-life >12 days.

A. 2.58-h Y^{85}

This isomer decays by positron emission and electron capture. The proportion of decays by the former mode

TABLE III. Sum-coincidence spectra.

Sum channel (keV)	Photopeaks (keV)
742	231, annihilation radiation
1013	503, annihilation radiation
1620	231 1390
2162	772 1390

[8] A. M. Hoogenboom, Nucl. Instr. 3, 57 (1959).

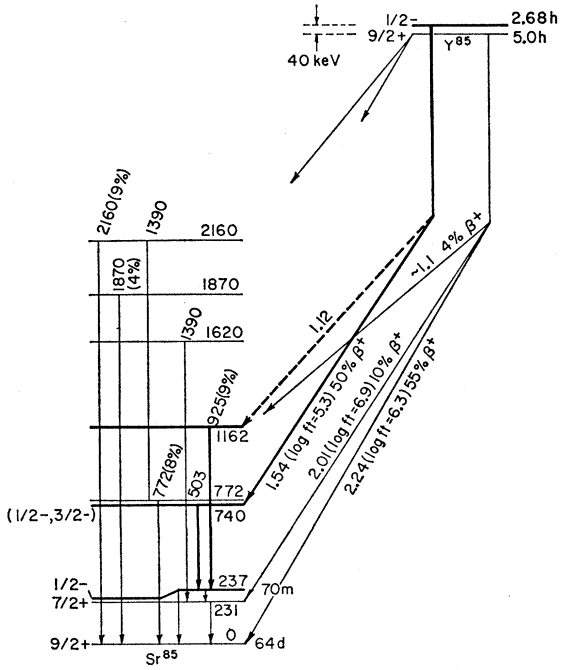

FIG. 4. Partial decay scheme of Y^{85} and Y^{85m}.

can be caluclated by making use of absolute positron intensities, the production ratio of the two isomers, and total disintegration rates (see Sec. VI). A value of 55% is obtained. The highest energy group observed has an end point of 1.54 MeV and an intensity of ~50%. There is some evidence for lower energy positrons, but their energy could not be determined accurately. The 1.54-MeV positron is in coincidence with the 503-keV γ ray, thus establishing a level in Sr^{85} at 740 keV. Although a positron transition of 2.04 MeV to the 237-keV level has not been observed for this isomer, the existence of a minor branch of this energy cannot be excluded.

No γ-γ coincidences involving the 925-keV transition have been observed. This transition can therefore feed either the ground state or the 70-min 237-keV level. The latter is more probable because a much smaller spin change is involved in the total decay. Accordingly, we place a level in Sr^{85} at 1162 keV. This level is probably fed by positrons of about 1 MeV and by electron capture. The failure to observe the spectrum of these positrons in coincidence experiments is probably due to the relatively low intensity of this transition and the small ratio of positrons to electron capture.

Insufficient information is available to place the weak and incompletely resolved γ rays of 700–800 keV energy.

B. 5.0-h Y^{85}

By a procedure analogous to that described for the 2.68-h isomer, it was calculated that 70% of the 5-h isomer decays by positron emission. No coincidences involving the intense 2.24-MeV positrons have been observed. This transition is therefore assumed to proceed directly to the ground state of Sr^{85}. The positron group in coincidence with the 231-keV γ ray proceeds to the 7/2+ 231-keV level of Sr^{85}. The end-point energy is, accordingly, 2.01±0.01 MeV, in good agreement with the value 2.08±0.10 MeV obtained in the β-γ coincidence experiments. The weak 1.1-MeV positron group, which may even consist of several positrons close in energy, evidently feeds a level, or levels, around 1100 keV in Sr^{85}. Although a number of weak γ rays have been observed in this energy range (1030-, 1130-, and 1230 keV) we cannot, at present, associate any of these with the 1.1-MeV positron group.

On the basis of sum-coincidence results, the 1620- and 2160-keV levels have been placed as shown in Fig. 4. These levels must be fed mainly by electron capture. The 772-keV γ ray has tentatively been assigned as a ground-state transition because of its high intensity as compared with the 1390-keV γ ray which is in coincidence with it. We have not identified the other transitions which must be feeding the 772-keV level. The 1870-keV γ ray is tentatively shown to feed the ground state because of the failure to detect any coincidences with other γ rays. The 700-keV γ ray has not been assigned.

C. Energy Separation and Spins for the Y^{85} Isomers

The energy levels of the two isomers may be readily obtained from the observed positron energies and our decay scheme. Thus the energy level of the 5.0-h Y^{85} is obtained from the ground state 2.24±0.01 MeV positron transition, and is 3.26±0.10 MeV above the ground state of Sr^{85}. This value is in good agreement with ~3 MeV estimated from β systematics.[9]

The highest energy positron group observed from the 2.7-h isomer has an end point of 1.54±0.02 MeV. This positron is in coincidence with the 503 γ-ray transition, and hence the energy level of the 2.7-h isomer is 3.30±0.02 MeV above the ground state of Sr^{85}. The two isomers are thus seen to be very close to each other in energy. The difference, 40±30 keV, is almost within the combined experimental errors. Although our measurements place the 2.7-h isomer above the 5.0-h isomer, thus making it Y^{85m}, we cannot be absolutely certain of this in view of the relative magnitude of the error.

The log *ft* value for the 2.24-MeV β^+ transition of the 5-h Y^{85} is caluclated as 6.3±0.1 (after making reasonable assumptions for other β^+ groups and electron capture). The log *ft* value of the 2.01-MeV positron from the same isomer is 6.9±0.3. Since these positrons proceed to the 9/2+ and 7/2+ levels of Sr^{85}, respectively, the assignment of 9/2+ spin and parity to the

[9] *Nuclear Data Sheets*, compiled by K. Way *et al.* (Printing and Publishing Office, National Academy of Sciences, National Research Council, Washington 25, D. C.), NRC 60-3-35.

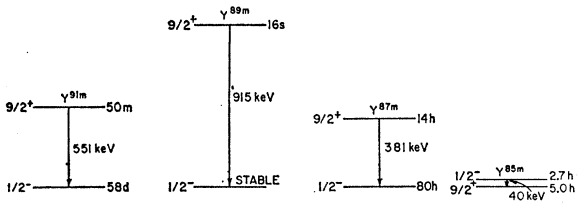

FIG. 5. Odd-A yttrium isomers.

5.0-h level of Y^{85} is reasonable and consistent with shell-model considerations. With the limit set for the half-life of the isomeric transition (>12 d) and the observed small energy difference, it is likely that the transition is $M4$. This assignment is in agreement with shell-model predictions and with other isomeric transitions of odd-A yttrium isotopes. For a 40-keV $M4$ transition in yttrium, a half-life of about 5 yr is predicted. We therefore assign a spin and parity of $\frac{1}{2}-$ to Y^{85m}.

The log ft value for the 1.54-MeV positron from the 2.68-h Y^{85} isomer is 5.3. This positron decays to the 740-keV level of Sr^{85}. The spin of the latter level may be deduced in the following way. The intensity of the 231-keV transition, after correcting for the small contribution from the 5-h isomer, is a measure of the total disintegrations of the 2.68-h isomer. If we assume, plausibly, that most of these disintegrations proceed through the 503-keV transition, we may calculate the intensity of the latter. From the observed intensity of the K conversion electrons from the 503-keV transition relative to that from the 231-keV transition, we may calculate the conversion coefficient, and hence, the multipolarity. The value so obtained for the K-conversion coefficient, 1.9×10^{-3}, agrees with that expected for an $M1$ (or $E2$) transition.[10] On this basis the possible spins are $\frac{1}{2}-$, $\frac{3}{2}-$, and $\frac{5}{2}-$. The allowed β^+ transition to this level from the $\frac{1}{2}-$ Y^{85} isomer is consistent only with the assignment of spin and parity $\frac{1}{2}-$ or $\frac{3}{2}-$ to the 740-keV level of Sr^{85}.

In Fig. 5 are collected the energy differences, spins, and parities of odd-A yttrium isotopes. In all of these the odd nucleon is a proton in a $1g$ or $2p$ level. Apart from an apparent shell effect at Y^{89}, (where the 50-neutron shell is filled), there is a steady lowering of the energy of the $9/2+$ state relative to that of the $\frac{1}{2}-$ state. It thus is not unreasonable that in Y^{85} the order of the levels may actually be reversed.

ACKNOWLEDGMENTS

The authors wish to thank the crews of the Brookhaven 60-in. cyclotron and the Brookhaven AGS for the irradiations. We would also like to thank G. Emery and M. McKeown for the use of the β-ray spectrometer, and M. L. Perlman for the use of the double focusing β-ray spectrometer. We are also grateful to Dr. Perlman for many helpful discussions and to D. J. Horen for sending us some of his results on Y^{85} prior to publication.

[10] M. E. Rose, *Internal Conversion Coefficients* (North-Holland Publishing Company, Amsterdam, 1958).