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Decay of Sm^{155}†

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Sm^{155} was found to decay to Eu^{155} with a half-life of 21.9±0.2 minutes. Internal conversion electrons corresponding to the gamma rays in Eu^{155} were observed in a magnetic spectrometer. The gamma ray spectrum was studied with a well crystal. The spectra of gamma rays coincident with the x ray, 104-kev, 142-kev, and 246-kev gamma rays were observed. A number of new, weak transitions are proposed. Directional correlation measurements were made on the 142-kev—104-kev cascade. Possible spin assignments are discussed.

I. INTRODUCTION

A TWENTY-ONE minute activity from samarium was first observed by Pool and Quill.[1] Inghram et al.[2] and Winsberg[3] assigned this activity to Sm^{155}. Rutledge et al.[4] observed gamma rays of 104.6 kev and 245.8 kev on internal conversion and photoelectron spectrograms. Schmid and Burson[5] obtained coincidences between the 105-kev gamma ray and a gamma ray of 141 kev, and proposed the decay scheme shown in Fig. 1.

Because of the position of Sm^{155} in the region of $150<A<185$, it is expected that the excited levels in Eu^{155} will exhibit the characteristics of deformed nuclei. The present investigation was undertaken in order to study more completely the excited levels occurring in Eu^{155}.

II. EXPERIMENTAL METHOD

Samples of samarium oxide enriched to 99.1% in Sm^{154} were irradiated in a flux of 2×10^{12} neutrons/cm²/sec in the Ford Nuclear Reactor. Except for half-life measurements, all data were taken during the first 30 minutes after irradiation.

The magnetic spectrograph sources consisted of about 1 mg/cm² of samarium oxide powder mounted on Scotch tape. Two identical sources were used. The elapsed time between removing the sources from the reactor and starting the exposure on the photographic plate was about 3 minutes. While one source was in the camera, the other sample was irradiated. The irradiation time averaged about 20 minutes and the exposure time was about 25 minutes. Three spectrograms of 23, 25, and 59 exposures were taken. When the Sm^{155} had decayed sufficiently after each spectrogram, a photographic plate was exposed for a long time with one of the samples to determine which lines were due to the 47-hour Sm^{153}. Sources of Eu^{152m} and Dy^{165} were used to calibrate the plates.

The sources used in the half-life determination, gamma-ray spectra, coincidence measurements, and the directional correlation measurements were made by dissolving the Sm_2O_3 powder in dilute nitric acid and irradiating the samples from 10 seconds to 3 minutes.

A conventional fast-slow coincidence circuit with a resolving time of 50 millimicroseconds was used in the coincidence and angular correlation measurements. The detectors were 2-in. by 2-in. NaI(Tl) crystals mounted on RCA 6342A phototubes.

The coincidence measurements employed a linear gate circuit, which allowed pulses in coincidence with gamma rays in a selected energy range to be recorded on a 256-channel analyzer. A Compton shield of 6.4 mm thick lead, surrounded by 0.8 mm of Cd and 0.4 mm of Cu, was placed between the two detectors.

Differential analyzers and lateral lead shielding around the crystals provided energy selection in the directional correlation measurements. Data were taken at five angles in a double quadrant sequence. After making a least squares fit,[6] the expansion coefficients were normalized.

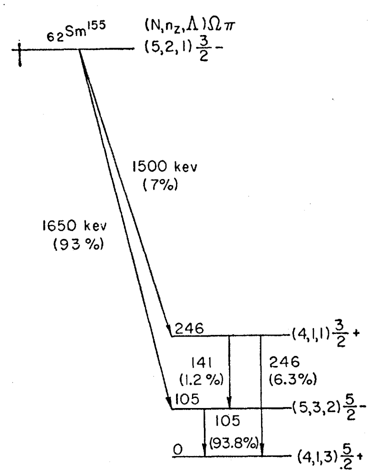

FIG. 1. Decay scheme of Sm^{155}, due to Schmid and Burson.

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1 M. L. Pool and L. L. Quill, Phys. Rev. **53**, 437 (1938).
2 M. G. Inghram, R. J. Hayden, and D. C. Hess, Jr., Phys. Rev. **71**, 643 (1947).
3 L. Winsberg, *Radiochemical Studies: The Fission Products* (McGraw-Hill Book Company, Inc., New York, 1951), Paper No. 196, National Nuclear Energy Series, Plutonium Project Record, Vol. 9, Div. IV.
4 W. C. Rutledge, J. M. Cork, and S. B. Burson, Phys. Rev. **86**, 775 (1952).
5 L. C. Schmid and S. B. Burson, Phys. Rev. **115**, 447 (1959).
6 M. E. Rose, Phys. Rev. **91**, 610 (1953).

III. RESULTS AND DISCUSSION

Half-Life Measurement

The half-life was followed for 31 hours, and the 47-hour Sm^{153} activity did not become significant until after approximately eight half-lives had elapsed. The counting rates were corrected for background, the Sm^{153} activity, and Geiger tube dead time. A least squares fit was made on two sets of data, and a value of 21.9 ± 0.2 minutes was determined for the half-life. The error includes the probable error and also an estimate of the systematic error.

Magnetic Spectrograph Measurements

Twelve conversion electron lines corresponding to nine gamma-ray transitions were observed in the spectrograph measurements. The conversion electron energies for Sm^{155} and their assignments are given in Table I. The line with electron energy of 57.2 kev was on the order of a hundred times weaker than the K line of the 104-kev transition and could possibly be explained by external conversion of the 104-kev transition in Sm. This weak line together with internal conversion lines from the 104-kev and 246-kev transitions has been observed previously.[4] A spectrogram of blank Scotch tape sources taken under conditions similar to the samarium sources showed no lines.

TABLE I. Magnetic spectrograph measurements for Sm^{155}.

Electron energy (kev)	Assignment	(kev)	Strength[a]
29.7	K	78.2	w
	or L	37	
33.3	K	81.8	w
	or L	41	
55.8	K	104.3	vvs
57.2	K(Eu)	105.7	w
	or K(Sm)[b]	104.3	
	or L(Eu)	65.0	
65.2	K	113.7	w
71.1	K	119.6	m
77.0	K	125.5	w
93.4	K	141.9	m
96.8	L	104.3	vs
103.0	M	104.3	s
104.9	K	153.4	w
197	K	246	m

[a] v = very, s = strong, m = medium, w = weak.
[b] Possibly photoelectrons from Sm.

Well Crystal

Figure 2 shows the gamma-ray spectrum as recorded on a 256-channel analyzer. Figure 3 is a spectrum taken with a weak source in a 2-in. NaI(Tl) well crystal. The well crystal spectrum shows an enhancement of the 246-kev gamma ray, corresponding to a sum of the 104-kev and 142-kev transitions. There is also a peak at 288 kev from the 246-kev gamma ray summing with the x ray.

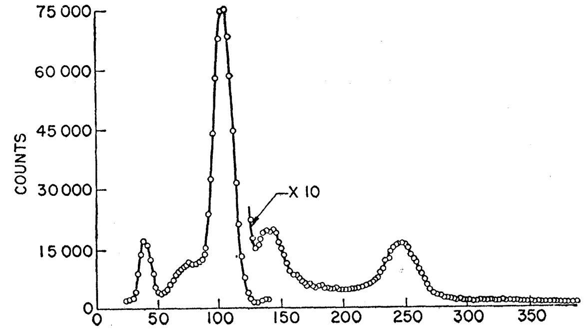

FIG. 2. Scintillation spectrum of gamma rays in Eu^{155}.

The peak at about 75 kev in the spectra could be caused by the iodine x-ray from the 104-kev gamma ray escaping from the crystal. The ratio of the 75-kev peak to the 104-kev peak was 6% in the "singles" spectrum and 3% in the well crystal spectrum. The theoretical value for the relative intensity of the iodine x-ray escape peak to the total peak for gamma rays entering perpendicular to an infinite NaI surface is about 4% for a 104-kev gamma ray.[7] The experimental ratios for a source distance of 0.4 cm are somewhat larger than the calculated values.[7]

Coincidence Measurements

Figure 4 illustrates the spectrum of lines in coincidence with the x ray. In addition to coincidences with the x ray, 104-kev gamma ray, and 142-kev gamma ray, coincidences are shown with a gamma ray of about 68 kev and with the 246-kev transition.

The spectrum of coincidences with the 142-kev gamma ray, Fig. 5, indicates that the x-ray and 104-kev transitions are in coincidence with the 142-kev transition. Similarly, Fig. 6 indicates that the x ray and 142-kev transitions are the prominent coincidences with the 104-kev gamma ray. A weak coincidence with

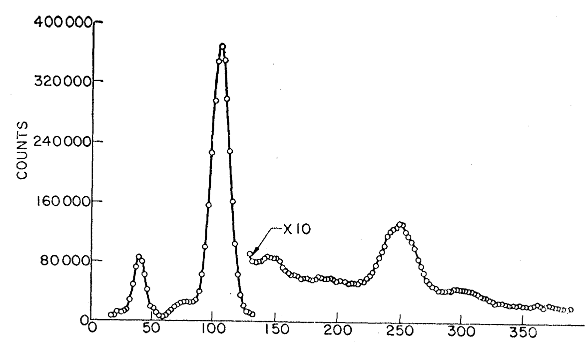

FIG. 3. Spectrum of gamma rays in Eu^{155} taken with source in a 2-in. well crystal.

[7] P. R. Bell in *Beta- and Gamma-Ray Spectroscopy* (North-Holland Publishing Company, Amsterdam, 1955), p. 155.

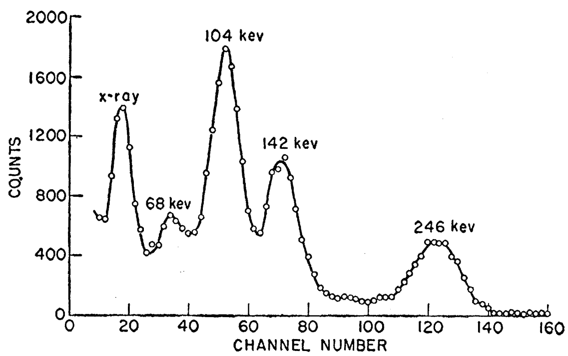

FIG. 4. Gamma rays in coincidence with the x ray.

the 68-kev gamma ray is possible in both the 104-kev and 142-kev coincidence spectra.

Figure 7(A) is the spectrum of gamma rays coincident with the 246-kev photopeak. Coincidences are indicated with the x ray and with weak gamma rays of about 68 kev and 103 kev. Because of the strong peak at the x-ray energy, selective absorption was used to determine whether part of this peak is due to a gamma ray with an energy close to that of the x ray. The coincidence measurements with the 246-kev gamma ray were repeated, using on successive runs (0.076±0.008) g/cm^2 of Ce, (0.060±0.005) g/cm^2 of Pr, and no absorber (except a β shield) in front of the crystal feeding the multichannel analyzer. The coincidence spectrum with the Ce absorber is shown in Fig. 7(B) and indicates considerable attenuation of the x ray, whereas the coincidence spectrum with the Pr absorber shows much less attenuation, as shown in Fig. 7(C). These results can be adequately explained by assuming that the entire photopeak is due to the x ray.

In all cases the accidental spectra were small and were subtracted to get the curves shown. All of the gamma rays decayed with the proper half-life.

The proposed decay scheme is shown in Fig. 8. It agrees with the decay scheme reported by Schmid and Burson[5] except for the weakly fed levels at 314 kev and 349 kev, and the corresponding gamma transitions. The additional levels are supported by the coincidence measurements and by the sum peak observed between the x ray and the 246-kev transition. Schmid and Burson[5] explained the lack of a beta transition to the ground state of Sm^{155} in terms of the selection rules for deformed nuclei proposed by Alaga.

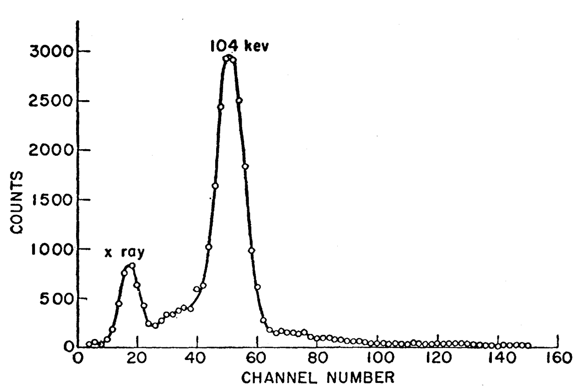

FIG. 5. Gamma rays in coincidence with the 142-kev gamma ray.

The intensities have been calculated from the gamma spectrum, correcting for absorbers, crystal efficiency, and the internal conversion coefficients[5] of 0.27 for the 104-kev transition and 0.16 for the 142-kev transition. In the calculation, the internal conversion coefficient for the 246-kev transition was assumed to have the theoretical value[8] for a $M1$ transition on the basis of a K/L ratio equal to eight.[4]

On the basis of relative source strengths and counting rates in the coincidence measurements, the intensity of the 103-kev transition is on the order of magnitude of 2% of the intensity of the 142-kev gamma ray, with the 68-kev transition being somewhat weaker. The

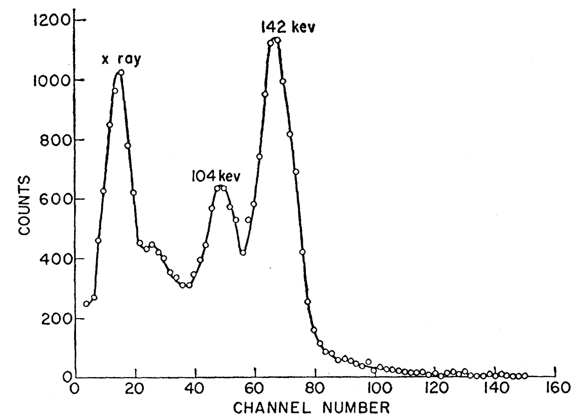

FIG. 6. Gamma rays in coincidence with the 104-kev gamma ray.

very weak intensity of the 103-kev—246-kev cascade in comparison with the 104-kev—142-kev cascade explains the low number of counts at 246 kev in the 104-kev coincidence spectrum.

A number of weak lines observed in the internal conversion measurements are not shown in the decay scheme. These gamma rays are too weak to be observed in the gamma-ray spectra or in the coincidence measurements. On the basis of the coincidence measurements the intensity of any of these transitions is less than about 0.1% of the total number of disintegrations. However, the uncertainty in the position of these transitions in the decay scheme may allow somewhat higher intensities.

[8] L. A. Sliv and I. M. Band, Leningrad Physico-Technical Institute Report, 1956 [translation: Report 57 ICC K1, issued by Physics Department, University of Illinois, Urbana, Illinois (unpublished)].

Directional Correlation Measurements on 142-Kev—104-Kev Cascade

The directional correlation was measured by accepting a range of energies from 95 kev to 150 kev in both pulse-height analyzers. The interference between the gamma rays in this energy range and the Comptons of higher energy gamma rays was found to be $10.5\pm1.1\%$. After subtracting this interference and correcting for finite resolution,[9] the expansion coefficients were found to be $A_2=-0.086\pm0.028$ and $A_4=-0.057\pm0.050$.

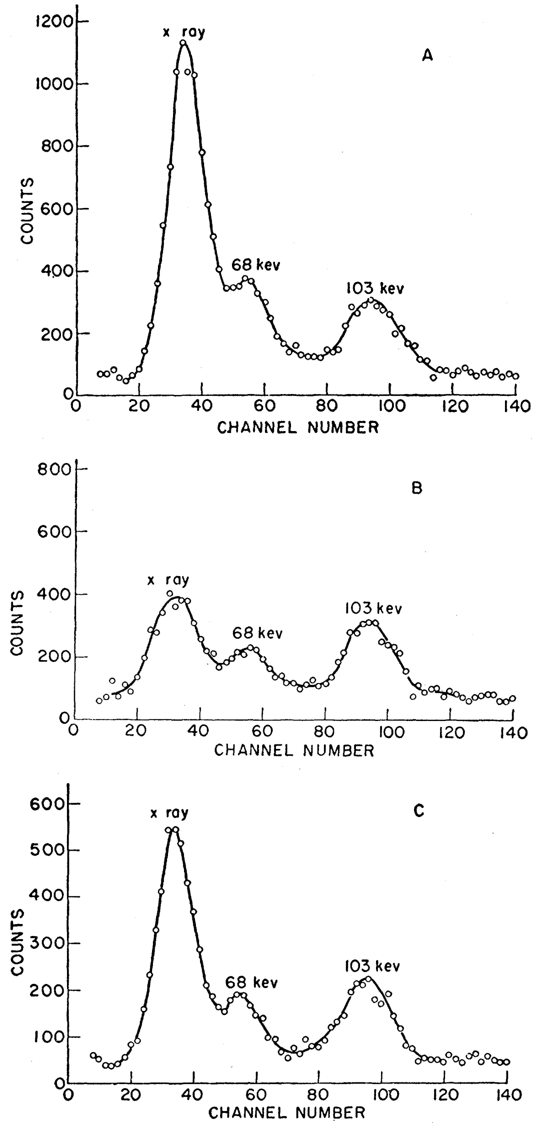

FIG. 7. Spectrum of gamma rays in coincidence with the 246-kev gamma ray, using various absorbers in front of the crystal feeding the multichannel analyzer. Curve A was taken with a β absorber. Curve B was taken with an additional (0.076±0.008) g/cm² Ce absorber. Curve C was taken with an additional (0.060±0.005) g/cm² Pr absorber.

[9] R. G. Arns, R. E. Sund, and M. L. Wiedenbeck, University of Michigan Research Institute Report 2375-4-T, February, 1959 (unpublished).

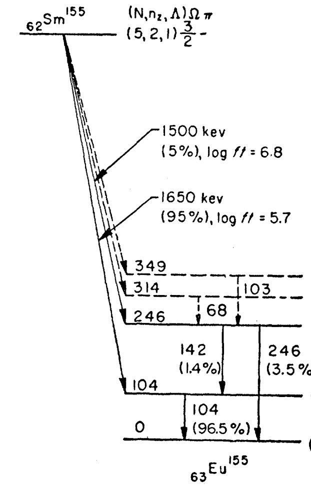

FIG. 8. Decay scheme of Sm^{155}.

Interference from the 103-kev—142-kev cascade and the 103-kev—104-kev cascade is not significant due to the low intensity of the 103-kev transition.

For a nuclear deformation of 0.33 for $_{63}Eu^{155}$, the Nilsson model[10] predicts a ground-state spin of $\frac{5}{2}+$. The measured spin[11,12] of $\frac{5}{2}+$ for Eu^{153} supports this. The spin[11,12] of $\frac{5}{2}-$ for Eu^{151} is due to the small deformation and the corresponding change in the position of the energy levels. For $_{62}Sm^{155}$, the Nilsson calculations[10] predict a spin of $\frac{3}{2}-$ or $\frac{5}{2}+$ for the ground state. A spin[13,14] of $\frac{3}{2}-$ for the ground state of $_{64}Gd^{157}$ and the lack of a beta transition between the ground state of Sm^{155} and Eu^{155} support a spin of $\frac{3}{2}-$ for the ground state of Sm^{155}.

The calculated log *ft* values are 5.7 for the 1.65-Mev beta ray and 6.8 for the 1.50-Mev beta transition. The internal conversion coefficients[5] of 0.27 ± 0.06 for the 104-kev transition and 0.16 ± 0.06 for the 142-kev gamma ray indicate that both transitions are predominantly $E1$. These data indicate that the spin of the 246-kev level is $\frac{1}{2}+$, $\frac{3}{2}+$, or $\frac{5}{2}+$, and that the spin of the 104-kev level is $\frac{5}{2}-$ or $\frac{3}{2}-$. The possible spin assignments for the 246-kev level and the K/L ratio[4] of about 8 for the 246-kev gamma ray agree in indicating that the 246-kev transition is $M1$. If the experimental internal conversion coefficients are interpreted with the K-conversion coefficients calculated by Sliv,[8] the 104-kev transition is found to be an $E1+M2$ mixture with $Q\leqq0.011$, and the 142-kev transition is $E1+M2$ with $0.001\leqq Q\leqq0.032$. The graphical analysis[15] the directional correlation data in terms of a $\frac{3}{2}(D,Q)\frac{5}{2}(D,Q)\frac{5}{2}$ sequence is shown in Fig. 9. The limits of quadrupole

[10] B. R. Mottelson and S. G. Nilsson, Phys. Rev. **99**, 1615 (1955).
[11] J. E. Mack, Revs. Modern Phys. **22**, 64 (1950).
[12] B. Bleaney and W. Low, Proc. Phys. Soc. (London) **A68**, 55 (1955).
[13] W. Low, Phys. Rev. **103**, 1309 (1956).
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[15] R. G. Arns and M. L. Wiedenbeck, Phys. Rev. **111**, 1631 (1958).

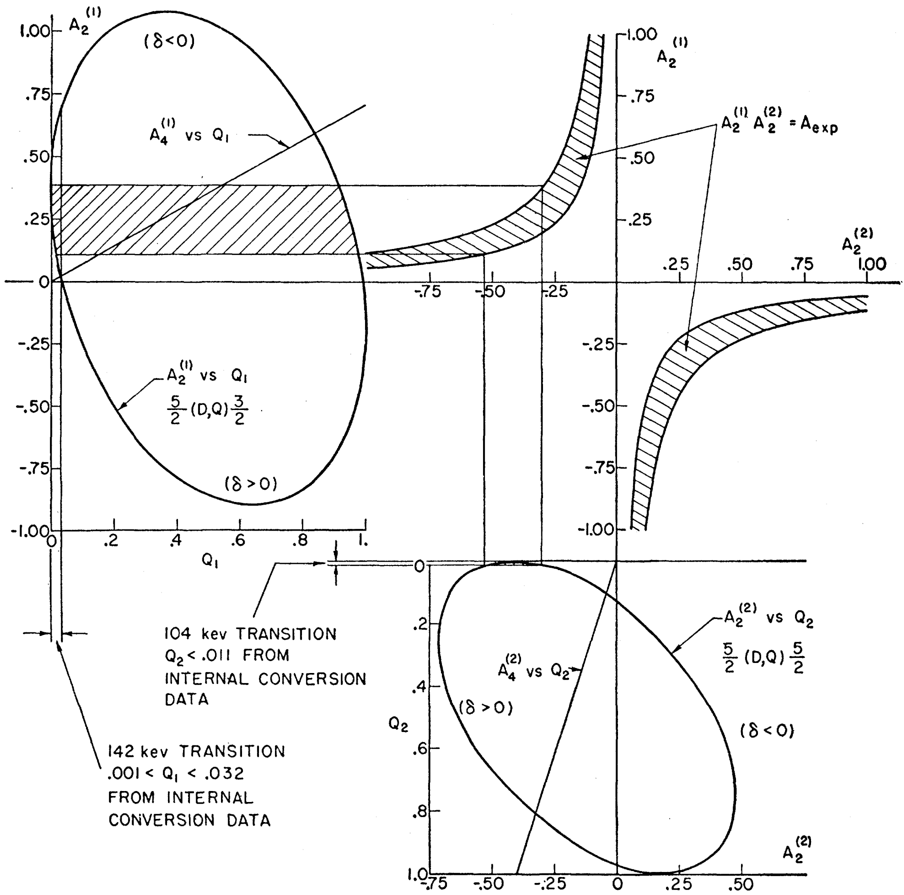

FIG. 9. Analysis of the 142-kev—104-kev directional correlation in terms of a $\frac{3}{2}(D,Q)\frac{5}{2}(D,Q)\frac{5}{2}$ sequence.

content consistent with the internal conversion data are indicated. A $\frac{5}{2}(D,Q)\frac{3}{2}(D,Q)\frac{5}{2}$ sequence is also allowed by the angular correlation and conversion data. For a deformation of 0.33 and a ground-state spin of $\frac{5}{2}+$ for Eu^{155}, the Nilsson model[10] predicts low-lying excited states of $\frac{3}{2}+$ and $\frac{5}{2}-$. Therefore the $\frac{3}{2}(D,Q)\frac{5}{2}(D,Q)\frac{5}{2}$ cascade is favored. Other spins for the ground states of Sm^{155} and Eu^{155} would permit different interpretations of the directional correlation data.

ACKNOWLEDGMENTS

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