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Determination of the Parameters

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Kansas State University, Manhattan, Kansas

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Table of Contents

I. Introductory Remarks	2
II. Decay of Os^{193} to Ir^{193}	4
III. The Harder Gamma Rays of Os^{191}	16
IV. Nuclear Energy States of Eu^{155}	21
V. Gamma Rays Emitted in Disintegration of Ir^{192} and Ir^{194}	31
VI. Additional Studies	32
VII. Personnel	34

I. Introductory Remarks

The program concerning nuclear structure as revealed by radioactive decay has continued during the past year at Kansas State University. Sponsorship of this work by the AEC commenced on 1 November 1966. During the preceding four years, similar measurements had been carried out under the auspices of the National Science Foundation. In consequence of this change of supporting federal agency, a period of overlap resulted in which certain previously unexpended funds of the National Science Foundation were used to support the work of this report concurrently with those monies which became available from the AEC on 1 November 1966.

Since the time of the previous annual report (Annual Report of the work of NSF GP-4945, issued in August, 1966), the following publications have appeared, resulting from this program.

1. "Some Nuclear States of Rh¹⁰³", V. R. Potnis, E. B. Nieschmidt, C. E. Mandeville, L. D. Ellsworth, and G. P. Agin, Phys. Rev. **146**, 883 (1966).
2. "Radioactive Decay of Os¹⁹³", G. P. Agin, G. E. Clark, C. E. Mandeville, and V. R. Potnis, Bull. Am. Phys. Soc. Series II, **12**, 37 (1967).
3. "Radioactive Decay of Ir¹⁹² and Ir¹⁹⁴", T. J. Palaska, V. R. Potnis, and C. E. Mandeville, Bull. Am. Phys. Soc. Series II, **12**, 37 (1967).

4. "Decay of Sm^{155} ", V. R. Potnis, G. P. Agin, and C. E. Mandeville,
Bull. Am. Phys. Soc. Series II, 12, 579 (1967).
5. "187-keV Transition in Ir^{191} ", G. P. Agin, G. E. Clark, C. E.
Mandeville, and V. R. Potnis, Bull. Am. Phys. Soc. Series II,
12, 579 (1967).
6. "Gamma Rays Emitted in Disintegration of Ir^{192} and Ir^{194} ",
T. J. Palaska, V. R. Potnis, and C. E. Mandeville, Nucl. Phys.
A95, 673 (1967).

II. Decay of Os¹⁹³ to Ir¹⁹³.

Abstract

The energies and relative intensities of the gamma rays of Os^{193} ($T_{1/2} = 32\text{h}$) have been measured with a Ge(Li) detector. Gamma-gamma coincidences and beta-gamma coincidences were studied to obtain energies of nuclear states in Ir^{193} . In all, twenty-four detected gamma transitions have been ordered between eleven nuclear energy states. The energies of these transitions are 73, 98, 107, 139, 180, 219, 252, 281, 289, 299, 322, 362, 379, 388, 420, 438, 461, 486, 512, 533, 559, 574, 713, and 874 keV, establishing excited energy states at 73, 139, 180, 362, 438, 461, 559, 680, 713, and 874 keV in the nucleus of Ir^{193} . Gamma rays corresponding to transition energies of 618, 780, and 830 keV were also observed, but these transitions could not be suitably incorporated into the disintegration scheme.

I. Introduction

The nuclear energy states of Ir^{193} , as indicated by beta decay of Os^{193} , have been the subject of a number of relatively recent investigations.¹⁻⁵ In the course of the earlier studies¹⁻⁴, such instruments as lens spectrometers, scintillation counters, and scintillation counters in coincidence were employed to determine the energies and relative intensities of the beta rays and gamma rays emitted in decay of the radionuclide. The most recent investigation⁵ involved the use of Ge(Li) detectors and such detectors coincident with scintillation counters.

The measurements of energies of gamma rays presently reported were carried out with utilization of a Ge(Li) detector (depletion layer thickness 4.2 mm) and of the Ge(Li) detector coincident with a scintillation counter of NaI(Tl). Beta ray spectra were measured with use of an anthracene counter which was in coincidence with the Ge(Li) detector. To produce Os^{193} ($T_{1/2} = 32\text{h}$), isotopically concentrated Os^{192} , enrichment 98.7 percent, was irradiated for an exposure time of 0.5 h on six successive occasions in the Kansas State University Triga Mark II Reactor.

II. Spectra of Single Counts

As observed in the Ge(Li) detector, the gamma rays of Os^{193} are shown in Fig. 1 to a maximum quantum energy of 139 keV. The similarly detected spectrum of the harder gamma rays is shown in Fig. 2. From the areas under the full energy peaks, after appropriate corrections for detection efficiencies as a function of energy, preabsorption, and full energy peak to total ratios, the relative intensities of the gamma rays of Os^{193} were determined. The energies and relative intensities of the gamma rays so obtained are compared with the results of some of the earlier investigations in Table I.

In estimating the intensity of the 73-keV gamma ray, the presence of the K_{β} x rays of iridium was taken into account. The intensity of the K_{β} line was calculated from the measured intensity of the K_{α} line and known relative intensities of K x ray components.⁶ The decay of the full energy peaks of all the quanta reported in Table I was followed over a time of three half periods to verify the isotopic assignment. It will be noted that several of the previously reported¹⁻³ gamma rays of Os^{193} were not detected. However, eleven gamma rays, until the present unreported, were found.

III. Gamma-gamma Coincidence Experiments

The coincidence circuitry of the gamma-gamma coincidence experiments is shown in Fig. 3. The detectors were respectively a crystal of NaI(Tl) (d. 2.54cm, h. 3.81cm) and the Ge(Li) detector of depletion layer thickness 4.2 mm. The schematic diagram of Fig. 3 shows how both true-plus-chance and chance coincidences alone are recorded. Pulses in the Ge(Li) detector which are coincident with any pulse in the scintillation counter are recorded in 1024 channels along the axis of abscissas of a multiparameter analyzer. Similarly, pulses in the scintillation counter which are coincident with any pulse in the Ge(Li) detector are recorded in 512 channels along the axis of ordinates of the same analyzer. In an additional 512 channels along the axis of ordinates of the same analyzer are recorded pulses in the scintillation counter which are only in accidental coincidence with pulses recorded in the Ge(Li) detector. This sorting procedure for separation of true-plus-chance coincidences from accidental coincidences alone, is implemented by a steering circuit. Pairs of channel numbers (address pairs) corresponding to both the accidental coincidences and the true-plus-chance coincidences are stored in the buffer memory and subsequently deposited upon magnetic tape. Thus, in one

extended period of data acquisition, every detectable true-plus-chance coincidence can be recorded simultaneously with observation of all detectable chance coincidences. The coincidence data on the magnetic tape can be displayed upon the multiparameter analyzer at any time following the direct observations. Channel widths for selecting "gate pulses" with which to obtain these successive passive displays are determined by the spectrum sorter. In the case of the actual measurements here being described, four sorting channels at a time were arbitrarily set at chosen intervals of energy along the scintillation counter spectrum so as to display each of the entire coincident spectra recorded in the Ge(Li) detector.

The coincident counters were placed at an angle of 140 degrees with each other, and absorbers of lead, cadmium, copper, and aluminum were introduced between them to reduce backscattering effects.

Gamma rays coincident with the K_{α} x rays of iridium are shown in Fig. 4. The particular features of this curve are that the presence of a 98-keV gamma ray is shown more clearly, and that the 461-keV gamma ray is shown to be preceded by partially converted quanta. Heretofore,¹⁻³ the level from which this gamma ray is emitted had been thought to be directly fed only by beta rays.

In Fig. 5 are shown gamma rays coincident with gate positions centered at 107, 139, and 180 keV. The spectrum of single counts in the gating crystal of NaI(Tl) is shown as an insert in the figure. Gamma ray full energy peaks which are coincident with full energy peaks in the gate positions are indicated as to energies in keV without parenthetical marks. Full energy peaks distinguished in energy by parenthetical marks are those which arise from coincidences with Compton recoils of harder quanta which fall in the gating region, or from inclusion of parts of neighboring full energy peaks in the gate.

Five gate positions, at 219, 251, 281, 289, and 299 keV, were employed to obtain the coincidence data of Fig. 6. Of these, only the 299-keV gamma ray is non-coincident with the 73-keV gamma ray which is emitted from the first excited state^{1,4} of Ir¹⁹³. The three most energetic gamma rays providing this group of gate pulses are seen to be non-coincident with one another. Parenthetical marks are to be interpreted as in Fig. 5.

Four additional gate positions at 322, 388, 420, and 461 keV were utilized to provide the coincidence data of Fig. 7. The curves indicate that only the 388 and 420-keV gamma rays are coincident with the 73-keV gamma ray. Only the 322 and 420-keV gamma rays are coincident with the 139-keV gamma ray which is emitted in de-excitation of the second excited state^{1,4} of Ir¹⁹³. These data also show the 461-keV gamma ray, emitted in a transition to the ground state¹⁻⁴, to be coincident with gamma rays at 98, 219, and 252 keV.

In Figs. 5-7, the intensity of the peak appearing at the K_β x-ray energy is seen to fluctuate in intensity relative to the K_α line, showing it to be a mixture of K_β radiation and 73-keV gamma rays.

IV. Beta-gamma Coincidence Experiments

Taking gating pulses from the Ge(Li) detector, beta-gamma coincidences were measured. The beta rays were detected in an anthracene scintillation counter. The axes of the cylindrically shaped counters were at an angle of 140 degrees with each other, and the Ge(Li) detector was shielded from beta rays by a plastic absorber. Fermi plots of beta spectra coincident with certain of the gamma rays are shown in Figs. 8 and 9. Because of poor resolution of the anthracene counter and poor statistical accuracy attainable, these data are interpreted to indicate an uncertainty of about 30 keV in

determination of the end points of the respective beta spectra. For example, in Fig. 8, gamma ray gate pulses at 107 and 180 keV are considered to be coincident with the same beta spectrum. That the 107 and 180-keV gamma rays are emitted from the same level is consistent with the fact that these quanta are non-coincident with each other.

V. The disintegration scheme of Os^{193}

Coulomb excitation experiments^{7,8} have established energy states in Ir^{193} at 73, 140, and 357 keV. The 140 and 357-keV states have been interpreted^{7,8} as having spin-parity assignments of $5/2^+$ and $7/2^+$, forming a rotational band with the ground state of Ir^{193} , which has a measured⁹ spin of $3/2$, and a positive parity if principles of the nuclear shell model are invoked. The measurement of the $L_1:L_2$ ratio¹⁰ suggests the 73-keV gamma ray to be emitted in an M1 + E2 transition. This result accords with shell model predictions that the spin-parity assignment of the 73-keV level should be $1/2^+$.

The presence of the three previously discussed energy states is confirmed by the measurements of this paper. Moreover, the beta-gamma and gamma-gamma coincidence experiments and precise energy measurements of the present provide evidence for the remaining energy states of the residual nucleus shown in Fig. 10 where Q_{β_-} is taken to be 1132 keV.¹¹ The spin-parity assignment of the 180 keV state has been taken $1/2^+$, $3/2^+$ in analogy with the proposed¹² spin-parity values of the corresponding level at 179 keV in Ir^{191} which is excited in the orbital electron capture decay of Pt^{191} . For comparison, the energy states of Ir^{193} as obtained by a number of investigators or groups of investigators are given in Fig. 11. Not shown in this figure are energy states at 660, 713, and 874 keV which have been specifically mentioned in the most recent report.⁵

Ideally, it would be desirable to calculate $\log ft$ for each of the beta spectra associated with the decay of Os^{193} . However, the internal conversion coefficients of at least thirteen of the gamma ray transitions of Fig. 10 are as yet unknown, making it impossible to compute the percent of beta rays in each spectrum from the relative intensities of the unconverted quanta given in Table I.

Some of the low lying energy states of Ir^{193} can be explained by the nuclear model in which core plus particle are weakly coupled.¹³⁻¹⁵ When a single proton of orbital $d_{3/2}$ is added to the nuclear core of Os^{192} in its first excited state ($2+$), the spins and parities of the first four excited states of Ir^{193} can be predicted, if the spin-parity assignment of the 180-keV level is indeed taken to be $3/2+$.

In Fig. 2 and Table I of this paper are listed gamma rays at 618, 780, and 830 keV. Though these quanta exhibited the proper decay time of Os^{193} , they do not appear to be coincident with any other gamma rays of Os^{193} . Moreover, these gamma rays do not correspond in energy to any available positions in the disintegration scheme of Fig. 10.

The transition denoted by the broken line in Fig. 10, originating at the level of excitation energy 362 keV, has been located according to energy considerations. The gamma ray itself has been recently detected¹⁶. If indeed the 182-keV gamma ray has been correctly placed in the disintegration scheme of Fig. 10, parenthetical marks should be removed from 180, Fig. 5, gate a, and from 107, Fig. 5, gate c.

Table I. Energies and relative intensities of the gamma rays of Os^{193} , emitted in de-excitation of Ir^{193} . Reference numbers are those of the text. Energies are in keV. Relative intensities are within parenthetical marks.

Ref. 1	Ref. 2	Ref. 3	Present results
73	73	73 (434)	73 (45 $\pm$ 2)
--	--	--	98 (0.7 $\pm$ 0.1)
106	106.8 (2.54)	106 (66.6)	107 (10.8 $\pm$ 0.5)
138	139.3 (78.6)	139 (333)	139 (82 $\pm$ 1)
--	180 (2.54)	180 (10)	180 (7.1 $\pm$ 0.1)
--	196 (1.78)	--	--
--	--	223 (16.7)	219 (5.8 $\pm$ 0.1)
234	--	235 (16.7)	--
--	243 (2.54)	--	--
--	248.5 (5.58)	--	--
252 (1)	251.4 (6.85)	251 (16.7)	252 (4.6 $\pm$ 0.1)
--	278 (13.5)	--	--
280 (15)	281 (33.0)	280 (66.6)	281 (35.6 $\pm$ 0.4)
--	288.5 (5.58)	--	289 (4.2 $\pm$ 0.2)
--	299.4 (7.36)	--	299 (2.4 $\pm$ 0.4)
--	--	308 (10)	--
--	314 (5.84)	--	--
320 (21)	321.8 (34.5)	321 (43.4)	322 (27.0 $\pm$ 0.7)
356 (6)	362 (11.4)	362 (10)	362 (6.9 $\pm$ 0.1)
--	--	--	379 (1.6 $\pm$ 0.2)
388 (32)	387.8 (35.6)	387 (33.3)	388 (23.9 $\pm$ 0.4)
--	419	--	420 (5.5 $\pm$ 0.4)
--	--	--	438 (2.1 $\pm$ 0.2)
458 (100)	460.4 (100)	460 (100)	461 (100)
--	485.7 (6.35)	--	486 (4.6 $\pm$ 0.1)

Table I - Continued

--	--	--	512	(0.31 ± 0.04)
--	--	--	533	(1.9 ± 0.1)
558 (45)	558.5 (53.3)	558 (40)	559	(48.2 ± 0.2)
--	--	--	574	(0.4 ± 0.1)
--	--	--	618	(1.2 ± 0.1)
--	--	--	713	(0.42 ± 0.03)
--	--	--	780	(1.9 ± 0.1)
--	--	--	830	(0.62 ± 0.06)
--	--	--	874	(0.57 ± 0.06)

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Captions

Fig. 1 - Spectrum of softer gamma rays of Os^{193} . Energies in keV.

These data and those of four similar accumulations were combined to obtain the relative intensities of gamma rays shown in Table I.

Fig. 2 - Spectrum of the harder gamma rays of Os^{193} . Energies in keV. These data and those of four similar accumulations were combined to obtain the relative intensities of gamma rays shown in Table I.

Fig. 3 - Block diagram of electronic circuitry for obtaining beta-gamma and gamma-gamma coincidences.

Fig. 4 - Spectrum in Ge(Li) of gamma rays of Os^{193} which are coincident with the $K\alpha$ x rays of Ir^{193} . Energies in keV. Pulses of the coincidence gate were taken from the low energy region of the $K\alpha$ peak in such manner as to exclude any contribution to the gate of pulses in the $K\beta + 73$ peak.

Fig. 5 - Spectra in Ge(Li) of gamma rays of Os^{193} which are coincident with quanta at 107, 139, and 180 keV. Insert at upper right shows gate positions in NaI(Tl) counter spectrum. Energies are in keV. Significance of parenthetical marks is discussed in text.

Fig. 6 - Spectra in Ge(Li) of gamma rays of Os^{193} coincident with quanta at 219, 251, 281, 289, and 299 keV. Insert at upper left shows gate positions in NaI(Tl) counter spectrum. Energies are in keV. Significance of parenthetical marks is discussed in text.

Fig. 7 - Spectra in Ge(Li) of gamma rays of Os^{193} coincident with quanta at 322, 388, 420, and 461 keV. Insert at top center shows gate positions in NaI(Tl) counter spectrum. Energies are in keV. Significance of parenthetical marks is discussed in text.

Fig. 8 - Fermi plots of beta-gamma coincidences in decay of Os^{193} . All energies in keV. Gate positions were at 107, 139, 180, and 362 keV in the Ge(Li) spectrum. Beta spectra were recorded in an anthracene scintillation counter.

Fig. 9 - Fermi plots of beta-gamma coincidences in decay of Os^{193} . All energies in keV. Gate positions were at 322, 388, 420, 461, 486 and 559 keV in the Ge(Li) spectrum. Beta spectra were recorded in an anthracene scintillation counter.

Fig. 10 - Disintegration scheme of Os^{193} . All energies in keV. Beta ray end point of the ground state transition is taken from Ref. 11. Data concerning the proposed 182-keV transition are contained in Ref. 16 of the text.

Fig. 11 - Energy states of Ir^{193} as proposed by some prior investigators and presently. Energies in keV.

^{193}Os

Fig. 1

^{193}Os

Fig. 2

Fig. 3

^{193}Os

Fig. 4

Os^{193}

Fig. 5

Os^{193}

Fig. 6

Os¹⁹³

Fig. 7

Fig. 8

Fig. 9

Fig. 10

III. The Harder Gamma Rays of Os¹⁹¹.

Abstract

^{191}Os was produced by slow neutron capture in ^{190}Os . A gamma ray at 187 keV was emitted from the irradiated target material, but its intensity was found to decay with a half life different from that of ^{191}Os .

A gamma ray of energy 185.8 keV has been reported to be emitted in the beta decay of the 15 day ^{191}Os , and correspondingly, a nuclear energy state has been proposed at 186 keV in ^{191}Ir , the residual nucleus [1]. A subsequent investigation [2] has revealed no evidence for the presence of this gamma ray. The accepted disintegration schemes [3] of the isomers of ^{191}Os are given in fig. 1, in which the proposed transition, energy state, and related beta transition are indicated by broken lines.

To produce ^{191}Os , five milligrams of isotopically concentrated ^{190}Os , enrichment 95.5 percent, were irradiated for a time of two hours in the KSU Triga Mark II reactor. The quantum radiations of the 15-day ^{191}Os were measured as to energies and relative intensities in a Ge(Li) detector of depletion layer thickness 4.2 mm. The resolution in energy was 4 keV.

The spectrum of the harder gamma rays of ^{191}Os is shown in fig. 1. Quanta at 129 and 187 keV were observed, but when the half periods of their full energy peaks were measured as also indicated in fig. 1, the 187 keV peak was found to have a half life of 9.9 ± 0.5 days. Thus, the 187 keV gamma ray cannot be associated with the decay of ^{191}Os , but rather with the induced activity of an impurity. For this reason, the broken lines of fig. 1 should not be considered real parts of the disintegration scheme. Relative to the intensity of the 129-keV gamma ray, that of the 187-keV gamma ray has been reported [1] to be 0.38. The 187-keV gamma ray of fig. 1 of this report has been calculated to have an intensity of 0.040 relative to the 129-keV quantum, when the data are corrected to time zero. The conclusions obtained from these data accord with the results reported in ref. 2.

References

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Caption

Fig. 1 - Currently accepted disintegration scheme of ^{191}Os (ref. 3 of the text). Spectrum of harder gamma rays of ^{191}Os at left. Decay of full energy peaks shown at right. All energies in keV. Results of measurements presently reported require removal of broken lines in the disintegration scheme.

^{191}Os

Fig. 1

IV. Nuclear Energy States of Eu¹⁵⁵.

Abstract

Isotopically concentrated ^{154}Sm has been irradiated in a research reactor to produce ^{155}Sm which decays by beta emission to ^{155}Eu . Twenty-nine gamma rays, observed in Ge(Li) detectors, have been ordered in a nuclear structure diagram which contains levels having the following excitation energies in keV, spins, and parities: $0(\frac{5}{2}^+)$, $79(\frac{7}{2}^+)$, $105(\frac{5}{2}^-)$, $168(\frac{7}{2}^-)$, $246(\frac{3}{2}^+)$, $307(\frac{5}{2}^+)$, $614(\frac{7}{2}^-)$, $768(\frac{1}{2}^+)$, $782(\frac{3}{2}^+)$, $876(\frac{5}{2}^+)$, $1102(\frac{3}{2}^-)$, $1264(\frac{1}{2}^-, \frac{1}{2}^+, \frac{3}{2}^+)$, and $1302(\frac{1}{2}^-, \frac{1}{2}^+, \frac{3}{2}^+)$. These nuclear states of ^{155}Eu have been assigned Nilsson numbers, or rotational properties.

1. Introduction

The radiations of the 22 minute ¹⁵⁵Sm have been studied in the course of several recent investigations²⁻⁷⁾. Kracik et al.²⁾, employing magnetic spectrograph and scintillation spectrometry, reported the presence of thirteen gamma transitions which were interpreted to correspond to de-excitation of seven excited states in ¹⁵⁵Eu, the residual nucleus. Also combining magnetic spectrograph and scintillation spectrometry, Funke et al.³⁾ reported seven beta spectra and twenty-five gamma transitions to be associated with the disintegration of ¹⁵⁵Sm. These radiations were considered to indicate the presence of nine excited states in the nucleus of ¹⁵⁵Eu. Agin et al.⁴⁾ observed twenty-two gamma rays from ¹⁵⁵Sm in a detector of Ge(Li), and commented specifically upon the presence of four excited states in ¹⁵⁵Eu. In continued study of ¹⁵⁵Sm, Funke et al.⁵⁾ detected thirty-four gamma transitions and located ten excited nuclear energy states in ¹⁵⁵Eu. Re-investigation by Potnis et al.⁶⁾, again using Ge(Li) yielded evidence of the presence of twenty-eight gamma transitions in ¹⁵⁵Eu. Sujkowski and Ungrin⁷⁾ have reported thirty-six gamma rays to be emitted in the decay of ¹⁵⁵Sm, employing Ge(Li) and Si(Li) spectrometry. The presently reported data may be regarded as resulting from an extension of the measurements of ref.⁶⁾.

2. The Measurements

To obtain sources of ¹⁵⁵Sm, quantities of ¹⁵⁴Sm₂O₃ (isotopic concentration 99.26 percent) were successively exposed in amounts of 5 mg each for periods of ten minutes in the KSU Triga Mark II reactor. Gamma ray spectra of single counts were observed in a Ge(Li) detector of depletion layer thickness 4.2 mm. The relative intensities of the gamma rays were obtained from the areas under the observed full energy peaks, after corrections were

introduced to take into account preabsorbing materials before the detector, efficiency of the detector, and full energy peak-to-total ratio, as functions of gamma ray energy.

The spectrum of the softer gamma rays of ^{155}Sm is shown in fig. 1. The spectrum of the harder gamma rays is presented in fig. 2. These data are ordered according to increasing quantum energy in table 1, along with calculated relative intensities. In table 1 are also given for comparison the energies and relative intensities of the gamma rays of ^{155}Sm as reported in ref. 5).

Two Ge(Li) detectors were placed in coincidence, and coincidences were measured between the 141 keV gamma ray and some of the softer gamma rays of the spectrum. These data are shown in fig. 3. From this figure it is apparent that the 141 keV gamma ray is coincident with quanta at 105, 79, and 63 keV, and with the K-shell X-rays of europium. To obtain these results, the gating pulse from a slow-fast coincidence circuit was provided by the 141 keV gamma, and the gamma ray spectrum coincident with it was displayed upon a multichannel analyzer. For the purpose of obtaining a necessary correction, a gating pulse was also taken from the region of energy just above 141 keV to observe any coincidences between the gamma rays of fig. 3 and the Compton distributions of gamma rays of high energy. These coincidences, as well as chance coincidences, were accumulated simultaneously with the total of coincidences of every variety, and subsequently subtracted from the total to give the genuine coincidences of fig. 3. The full energy peak at 79 keV is unduly intense because of the presence of backscattered radiation of the 105 keV quanta.

Attempts to observe coincidence spectra generated by gating pulses of gamma rays at energies greater than 141 keV failed because of the poor detection efficiency of the coincident Ge(Li) detectors (depletion layer

thicknesses 4.2 mm and 5 mm respectively), and because of the fact that the hard gamma rays of ^{155}Sm are few in number, ninety-three percent of the beta disintegrations feeding the 105 keV level ⁵⁾ of ^{155}Eu .

3. Discussion

The data of table 1 show five gamma rays to have been reported in ref. ⁵⁾ which were not detected by the techniques and methods of the present investigation. Evidence for the gamma rays at 135, 860, and 1050 keV had been earlier obtained with application of coincident scintillation spectrometers ³⁾, and the presence of the 280 keV gamma ray was observed ⁵⁾ in a single detector of Ge(Li). Since the results of table 1 also indicate that in the course of the present study, gamma rays of comparable or smaller intensity than the four above cited were indeed satisfactorily observed, no obvious explanation for the differing observations is apparent. Whether the presence of these four gamma rays ^{3,5)} might be related to contaminating ⁵⁾ ^{152}Eu is not certain. The presently unobserved fifth gamma ray is, of course, the one of energy 26 keV. Its intensity at the surface of the quantum sensitive Ge(Li) was too heavily reduced by preabsorbing materials such as lucite, aluminum and germanium. The lucite shield, thickness 0.64 cm, was introduced to stop hard beta rays from the source of ^{155}Sm , and the Ge(Li) detector was housed in an aluminum cup of wall thickness 0.0384 cm. The "dead layer" of germanium, before the sensitive volume of the detector, had a thickness of 0.03 cm.

The data of figs. 1-3 are summarized in fig. 4 where the nuclear level structure of ^{155}Eu is given. The measured ⁸⁾ spin values of the ground states of ^{151}Eu and ^{153}Eu are each $\frac{5}{2}$. By analogy, the spin of the ground state of ^{155}Eu can also be considered to be $\frac{5}{2}$. Gamma-gamma spatial correlation studies ⁹⁾ provide for the ground state and the excited states at 105 and 246 keV a spin sequence of $\frac{5}{2}, \frac{5}{2}, \frac{3}{2}$. Internal conversion studies ^{2,10)} suggest the 105, 141, and 246 keV transitions to $E1+M2$, $E1+M2$, and $M1+E2$ in character. Both the

correlation experiments and these measurements of the conversion coefficients are consistent with spin-parity assignments of $\frac{3}{2}^+$, $\frac{5}{2}^-$, and $\frac{5}{2}^+$ for the 246 keV and 105 keV excited states, and the ground state. On the Nilsson diagram¹¹⁾, the spacing in energy of the ground state and the 105 and 246 keV levels corresponds to a value of the deformation parameter of ^{155}Eu of about 0.2, which in turn indicates Nilsson quantum numbers of $\frac{5}{2}^+[413]$ for the ground state of ^{155}Eu , and $\frac{5}{2}^- [532]$ and $\frac{3}{2}^+[411]$ as Nilsson quantum numbers for the states at 105 and 246 keV respectively. Additional considerations of energy spacings of the nuclear states result in the choice of $\frac{7}{2}^- [523]$, $\frac{1}{2}^+[411]$, and $\frac{3}{2}^- [541]$ for Nilsson numbers of the states at 614, 768, and 1102 keV. Similarly, Nilsson numbers of $\frac{1}{2}^+[420]$, $\frac{3}{2}^+[422]$, or $\frac{1}{2}^- [550]$ could be assigned to either of the energy states at 1264 and 1302 keV. The state at 79 keV is interpreted as being the second member of a rotational band¹²⁾ based upon the ground state. The 168 keV state is interpreted as occupying an analogous position relative to the 105 keV Nilsson state. The 307 keV state is considered to be the second member of a rotational band founded upon the 246 keV single particle state, and the 782 and 876 keV states are assumed to be the second and third members of a rotational band commencing with the 768 keV state of spin-parity designation $\frac{1}{2}^+$. The energy spacings of the states of this particular rotational band yield a value of -0.50 for the decoupling parameter¹²⁾.

The arguments of the paragraphs immediately preceding provide the spin-parity assignments of the nuclear states presented in fig. 4.

4. Acknowledgments

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Table 1

Energies and relative intensities of the gamma rays of ^{155}Sm . Energies are in keV. Relative intensities are included between parenthetical marks.

ref. 5)	Present Results
26 (11 ± 5)	-----
62 (4.5 ± 1.5)	63 (6.6 ± 0.6)
79 (4.5 ± 1.5)	79 (≤ 0.5)
105 (2000 ± 200)	105 (2270 ± 40)
135 -----	-----
141 (45 ± 5)	141 (54 ± 2)
168 (1.8 ± 0.3)	168 (1.7 ± 0.3)
203 (4.0 ± 1.5)	203 (1.0 ± 0.2)
229 (1.2 ± 0.2)	229 (1.3 ± 0.1)
246 (100)	246 (100)
280 (0.4 ± 0.1)	-----
307 (0.4 ± 0.1)	307 (0.20 ± 0.05)
429 (0.4 ± 0.1)	429 (0.36 ± 0.04)
462 (1.8 ± 0.2)	462 (2.03 ± 0.05)
509 (0.5 ± 0.1)	509 (0.30 ± 0.04)
522 (4.4 ± 0.3)	522 (4.33 ± 0.06)
570 (0.6 ± 0.1)	570 (0.62 ± 0.04)
602 (0.4 ± 0.1)	602 (0.39 ± 0.04)
630 (0.6 ± 0.1)	630 (0.52 ± 0.04)

Table I (continued)

647 (0.20 ± 0.7)	650 (0.30 ± 0.04)
663 (1.9 ± 0.2)	663 (1.81 ± 0.05)
676 (0.18 ± 0.07)	677 (0.20 ± 0.05)
710 (0.23 ± 0.08)	711 (0.20 ± 0.05)
768 (0.22 ± 0.08)	768 (0.16 ± 0.05)
860 (_ 0.1)	-----
931 (0.18 ± 0.03)	931 (0.37 ± 0.06)
996 (0.4 ± 0.2)	997 (0.26 ± 0.05)
1004 (0.5 ± 0.2)	1000 (0.56 ± 0.06)
1050 (_ 0.2)	-----
1158 (0.33 ± 0.06)	1160 (0.30 ± 0.04)
1197 (0.16 ± 0.04)	1200 (0.12 ± 0.03)
1223 (0.7 ± 0.1)	1225 (0.62 ± 0.03)
1262 (0.14 ± 0.05)	1264 (0.08 ± 0.02)
1302 (2.6 ± 0.3)	1302 (2.11 ± 0.06)

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Captions

- Fig. 1 - Spectrum of the softer gamma rays of ^{155}Sm . Energies in keV.
- Fig. 2 - Spectrum of the harder gamma rays of ^{155}Sm . Energies in keV. Absorbers intervening between source and detector were of lead, thickness 1.9 mm, and of cadmium, thickness 1.2 mm.
- Fig. 3 - Spectrum of the gamma rays of ^{155}Sm coincident with quanta of energy 141 keV. Energies are in keV. These data were obtained when two Ge(Li) detectors were placed in coincidence.
- Fig. 4 - Nuclear structure diagram for ^{155}Eu . The nuclear states were ordered in energy according to the measurements of the present and certain coincidence experiments of ref. 3).

Fig. 1

Fig. 2

Fig. 3

155Eu³² 1.7 y

V. Gamma Rays Emitted in Disintegration of Ir¹⁹² and Ir¹⁹⁴.

see *Nuclear Physics* A95 (1967) 673-682

VI. Additional Studies

At the time of preparation of this report, many additional experiments are in progress. Under study are the radiations of the following elements.

Zr⁹⁷ - Nb⁹⁷

Ba¹³⁹

Ce¹⁴³

Er¹⁷¹

W¹⁸⁷

Pt¹⁹⁹

Among these disintegrating elements, many previously unreported gamma transitions have been discovered. Certain transitions earlier reported by others have not been observed.

VII. Personnel