Low-Intensity Conversion Lines from Sm^{151} and Sn^{113}†

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(Received November 13, 1958)

The electron spectrum of Sm^{151} has been measured with a lens spectrometer and its gamma-ray spectrum with a scintillation spectrometer. The L-conversion coefficient of the 21.7±0.3 kev de-excitation of the first excited state of Eu^{151} is 20±4, with $(\alpha_L/\alpha_{M+N})=2.2\pm0.4$ and $\alpha_M/\alpha_N=2.2\pm0.2$ indicating $M1$ multipolarity. The low intensity of the conversion electrons relative to the continuous beta spectrum of end point 75.9±0.6 kev implies the existence of a weak beta transition whose end point is 54.2±0.7 kev. The beta branching ratio, 54.2-kev beta transitions/75.9-kev beta transitions, is 1.7/100. $\text{Log}_{10}ft$ values for the two beta decays are 7.6±0.2 for the 75.9-kev decay and 8.8±0.2 for the 54.2-kev decay. A partial analysis of the decay in terms of the Nilsson-Gottfried scheme has been made, but no definitive assignment for the 21.7-kev state appears to be possible. Measurements of the electron spectrum of Sn^{113} with the lens spectrometer reveal the existence of a weak conversion line corresponding to a transition of 253 kev. The intensity of this conversion line is $(2.8\pm1.0)\times10^{-3}$ of the intensity of the conversion line from the 392-kev transition. This relative conversion electron intensity indicates that the 253-kev transition leads to the 392-kev state of In^{113}, implying the existence of an excited state at 645 kev. The existing uncertainty in the relative gamma-ray intensities for the two transitions makes it impossible to assign spin and parity to the 645-kev state; the decay scheme presented is therefore incomplete.

I. INTRODUCTION

THIS work grew out of certain discrepancies in the published literature on the decays $_{62}Sm^{151}-\beta^-\rightarrow {}_{63}Eu^{151}$ and $_{50}Sn^{113}-\text{EC}\rightarrow {}_{49}In^{113}$. At the time this work was begun, the generally accepted schemes were those published in the Hollander-Perlman-Seaborg Table.[1]

Sm^{151} was believed to decay by a 75-kev beta transition to an excited state of Eu^{151}. This excited state, evidence for which came exclusively from gamma-ray spectra,[2–4] was supposed to lie about 20 kev above the ground state. Conversion electrons from this transition never had been found; indeed one group[5] explicitly had stated the absence of any conversion electrons. This absence was somewhat surprising in view of the low energy of the transition. Rose's tables of L- and M-conversion coefficients[6] predict that the total conversion coefficient for a transition of ~25 kev in $Z=63$ can be no smaller than about 2.3, which implies that the intensity of the conversion electrons must be at least 72% of the intensity of the beta spectrum. A possible explanation for the absence of the conversion electrons was that, because of their low energy, they might have been completely absorbed before reaching the detectors used.

Sn^{113} was believed to decay by a single electron capture to an isomeric state of In^{113} lying 393 kev above the ground state. However, there had been some evidence[7,8] for another transition whose energy was about 255 kev. Contrary evidence had been presented by several workers.[9–11] The uncertainty of the existing data evidenced a need for further study.

The electron spectra were obtained with a magnetic lens spectrometer of moderate resolution (~3%) which has been described elsewhere.[9] To facilitate accurate measurements of relative intensities at quite low electron energies the earth's magnetic field was neutralized by a set of compensating coils.[12] The thin windows (~22 μg/cm^2) used in the study of Sm^{151} were made of U.S.P. collodion supported on Lectromesh with an open area of about 49%. Pressure in the side-window Geiger tube was maintained at a constant value by a Cartesian Manostat. The photon spectra were obtained with a conventional single-channel scintillation spectrometer using a 2-mm×1-in. diam NaI crystal and a DuMont-6292 photomultiplier tube.

II. THE DECAY OF Sm^{151}

A. Experimental Conditions

The sample of Sm^{151} (2.6 mg Sm_2O_3) was loaned to us through the kindness of G. W. Parker of the Oak Ridge National Laboratory. The samarium had been separated (in October, 1953) from europium by use of a hot ion-exchange citrate column.[13] The europium-samarium mixture had been separated previously from other fission products. Analysis of the sample (furnished by

† This research was supported in part by the U. S. Air Force through the Air Force Office of Scientific Research of the Air Research and Development Command, and in part under contracts with the U. S. Atomic Energy Commission.

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[1] Hollander, Perlman, and Seaborg, Revs. Modern Phys. **25**, 469 (1953). See this reference for the published literature prior to 1953.
[2] Scharff-Goldhaber, der Mateosian, McKeown, and Sunyar, Phys. Rev. **78**, 325 (1950).
[3] Wagner, Freedman, and Engelkemeir, Atomic Energy Commission Report AECD-3304, February, 1952 (unpublished).
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[5] Rutledge, Cork, and Burson, Phys. Rev. **86**, 775 (1952).
[6] M. E. Rose (privately circulated tables, 1955–1957).
[7] Cork, Stoddard, Branyan, Childs, Martin, a nd LeBlanc, Phys. Rev. **84**, 596 (1951).
[8] G. Gardner and J. I. Hopkins, Phys. Rev. **101**, 999 (1956).
[9] Broyles, Thomas, and Haynes, Phys. Rev. **89**, 715 (1953).
[10] Y. Deschamps and P. Avignon, Compt. rend. **236**, 478 (1953).
[11] P. Avignon, Ann. phys. **1**, 10 (1956).
[12] S. K. Haynes and J. W. Wedding, Rev. Sci. Instr. **22**, 97 (1951).
[13] G. W. Parker (private communication, 1957).

Parker[13]) indicated that Sm^{151} was present as 4.8% of total samarium. There was no Sm^{145} in the sample. Of the remaining four radioactive samarium isotopes three (Sm^{153}, Sm^{155}, and Sm^{156}) have half-lives of less than two days, while Sm^{147} decays by alpha emission with a half-life of $\sim 10^{11}$ years.[1] There was some Eu^{152} (one part in 10^9) present, but this was too feeble to be detectable. No other impurities were reported in the analysis. Thus the only measureable activity was that due to Sm^{151}.

The sample of Sm_2O_3 was dissolved in 1 cc of $\sim 4N$ HCl. The resulting $SmCl_3$ was dried drop by drop under vacuum onto a tantalum strip which served as a filament for vacuum evaporation in a cell such as that described by Broyles *et al.*[9] $SmCl_3$ is known to decompose upon heating,[14] and it is assumed that the sources made were in the form of elemental samarium. Two sources were used; their characteristics are recorded in Table I. The source thicknesses in Table I were calculated from the percentage Sm^{151} in the sample, the half-life of ~93 years,[15] lens spectrometer transmission factor, and lens spectrometer counting rates. The calculated values were doubled to give the values appearing in the table to allow for the presence of some non-radioactive calcium in the sample.[13]

The two sources used were extremely weak, the maximum total lens spectrometer counting rate (source plus background) being 121 counts/min for the weaker source (B) and 205 counts/min with the stronger source (A). The background counting rate (checked every four hours) averaged 64 counts/min. While the total source counts per point was quite low (~6500 in the region of the conversion peaks, less elsewhere), the spacing of points was rather close (~0.5% separation in momentum in the region of the conversion peaks, more widely space elsewhere). The range of energies studied was 6 kev to 85 kev. The work of Lane and Zaffarano[16] plus unpublished work of the Vanderbilt beta-ray spectrometry group both indicate that a 24-$\mu g/cm^2$ collodion window (the thickest used) transmits all electrons whose kinetic energy exceeds 10 kev; therefore no correction was made for the conversion electrons, all of which have energies somewhat greater than this.

The measured resolution obtained in this study was 3.0% for the weaker source (B) and 4.3% for the stronger source (A).

B. Experimental Results

Data from the two sources were used to obtain Kurie plots. These are shown in Fig. 1. The slopes and end points initially were approximated by a least-squares fit of those points whose energies were greater than the energy of the highest energy conversion peak. The slopes and end points then were adjusted slightly in order to obtain approximate agreement between the two sources for the ratio of the intensity of the conversion electron groups (L and $M+N$) to the intensity of the continuous beta spectrum. The weaker source end point was 75.8 kev; the stronger source gave an end point of 76.0 kev; the disintegration energy is taken to be 75.9±0.6 kev. Both Kurie plots are linear down to fairly low energies, the weaker source being linear down to about 17 kev and the stronger source being linear down to about 20 kev. The deviation upward of the Kurie plots below these energies leads to considerable uncertainty in the intensities of the conversion peaks.

TABLE I. Characteristics of Sm^{151} sources.

	Thickness	Backing	Diameter
Source A	0.03 $\mu g/cm^2$	10 $\mu g/cm^2$ Formvar 5 $\mu g/cm^2$ aluminum	10 mm
Source B	0.06 $\mu g/cm^2$	96 $\mu g/cm^2$ Formvar 20 $\mu g/cm^2$ aluminum	4 mm

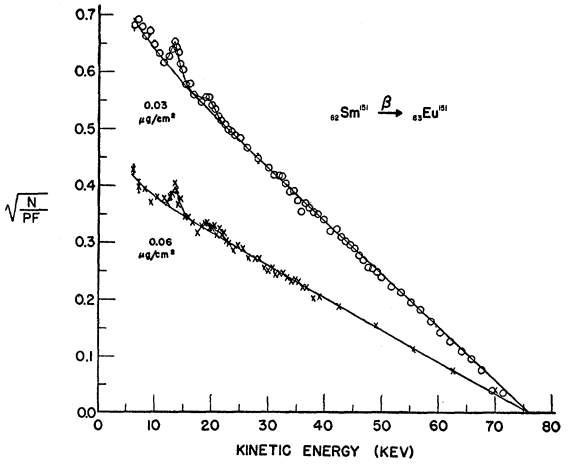

FIG. 1. Kurie plots for decay of Sm^{151}. Points were taken much closer together in the region of the conversion peaks than indicated in the figure.

The conversion spectra are shown in Fig. 2, where curve A is the conversion spectrum of the stronger source and curve B that of the weaker source. Curve A is clearly much more poorly resolved. Both curves give a peak at 13.5±0.1 kev: this peak is interpreted as the L-conversion peak from the de-excitation of the state at about 20 kev in Eu^{151}. The poorly resolved double peak is interpreted as the M- and N-conversion peaks of the same transition. For the weaker source (B) the energies are 19.7±0.3 kev and 21.7±0.3 kev, respectively, for the M- and N-conversion peaks. The corresponding figures for the stronger source are 19.8±0.5 kev and 21.4±0.5 kev.

The conversion intensity ratios are essentially the

[14] *Comprehensive Inorganic Chemistry*, edited by M. C. Sneed and R. C. Brasted (D. Van Nostrand Company, Inc., Princeton, New Jersey, 1955), Vol. 4, p. 173.

[15] Melaika, Parker, Petruska, and Tomlinson, Can. J. Chem. **33**, 830 (1955).

[16] R. O. Lane and D. J. Zaffarano, Phys. Rev. **94**, 960 (1954).

same for both sources. Combination of the data for both gives $L/(M+N)=2.2\pm0.4$, $M/N=2.2\pm0.2$, from which the ratio $L/M=3.2\pm0.6$ is calculated.

The ratio of the conversion electrons to the continuous beta spectrum is 1.6%. This is some 45 times smaller than the minimum required by Rose's tables[6] and the old decay scheme. The data thus imply the existence of a second beta transition of energy ~54 kev to populate the 22-kev excited state in Eu^{151}, the 76-kev transition being to the ground state. The branching ratio (54-kev transitions/76-kev transitions) can be no larger than 2.3%, again based on the minimum possible conversion coefficient from Rose's tables. The actual branching ratio is smaller than this, as will be seen later.

The L-conversion coefficient was determined through complementary measurements on the stronger source (A) with the single-channel scintillation spectrometer. The photon spectrum of that source is shown in Fig. 3. It is clear from this figure that there are no other gamma-rays between 22 and 100 kev. The intensity of

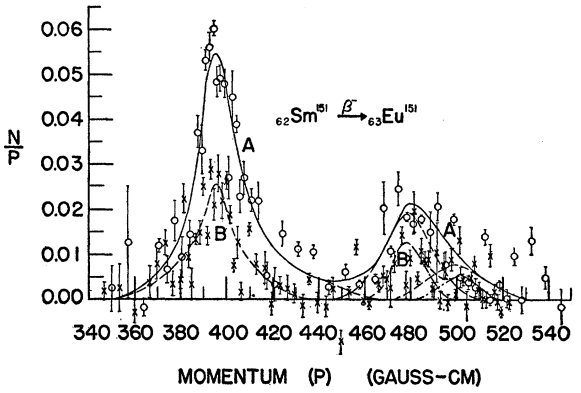

FIG. 2. Conversion spectra for decay of Sm^{151}. All points taken are shown in this figure.

the gamma-ray peak at 22 kev was obtained by assuming the peak shape to be Gaussian; this assumption was used to draw in the low-energy side of the peak. Comparison of the gamma-ray intensity and the L-conversion electron intensity (after appropriate corrections for geometry have been made)[17] gives a value of 20 ± 4 for the L-conversion coefficient.[18] This value

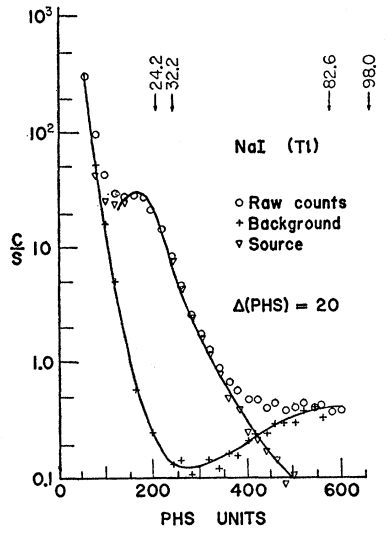

FIG. 3. Photon spectrum for decay of Sm^{151} obtained with source A.

indicates that the multipolarity of the 22-kev transition is $M1$. This is consistent with the measured energy separation and shapes of the conversion peaks (which are sensitive to the multipolarity because of the differences in the conversion ratios $L_I/L_{II}/L_{III}$ and $M_I/M_{II}/M_{III}/M_{IV}/M_V$ for different multipolarities[6]), and the L/M conversion ratio. None of these properties, however, leads to the unique multipolarity determination provided by the L-conversion coefficient.[19] The assignment of $M1$ multipolarity, first made in the preliminary account of this work[18] subsequently has been confirmed by the work of Shirley and Rasmussen[20] on the electron capture decay of $_{64}Gd^{151}$. With a resolution much superior to that of the present work they were able to show that, for the 22-kev transition, L-conversion occurs predominantly in the L_I shell, to a considerably lesser extent in the L_{II} shell, and with no detectable intensity in the L_{III} shell.

The energy of the excited state in Eu^{151} is 21.7 ± 0.3 kev. The intensity of the weak beta transition is too feeble to allow direct determination of its end point; subtraction of the energy of the excited state from the energy of the 75.9-kev beta transition between ground states shows the end point of the weak beta group to be 54.2 ± 0.7 kev. The branching ratio is determined from the total conversion coefficient ($L+M+N$) of 29 ± 4 to

[17] The conversion coefficient is calculated from the following equation: $\alpha_L=(C_L/\epsilon_L)/(C_\gamma/\epsilon_\gamma)$, where C_L and ϵ_L are the counting rate and efficiency (transmission) of the magnetic spectrometer, and C_γ and ϵ_γ are the counting rate and efficiency [(solid angle/4π) × (intrinsic efficiency)] of the NaI spectrometer. ϵ_γ was calculated from the known geometry while ϵ_L was determined experimentally by comparing the count of a uniform Cs^{137} source (identical in size to the Sm source) in the lens spectrometer with the count of the same source covered by a $\frac{1}{8}$-in. Al absorber with a $\frac{5}{64}$-in. hole over the source directly in front of a thin end-window Geiger counter. The chief errors are in C_L (determination of the baseline under the conversion peaks) and ϵ_L (estimation of scattering from the sides of the hole in the Al absorber). For further details see W. T. Achor, Ph.D. thesis, Vanderbilt University, 1958 (unpublished).

[18] Achor, Phillips, Hopkins, and Haynes, Bull. Am. Phys. Soc. Ser. II, 2, 259 (1957). The value $\alpha_L\sim12$ quoted in this reference was preliminary. Elimination of errors in the estimation and calculation of solid angles accounts for the difference between this value and the 20 ± 4 quoted in this paper.

[19] The only alternative interpretation might be $E1+M2$. This interpretation was rejected on both experimental and theoretical grounds. The ratio, $E1/M2\approx140/1$, necessary to give $\alpha_L=20$ when combined with the subshell conversion coefficients of Rose, does not fit the observed line shapes. From a theoretical point of view the conversion coefficient for $E1$ would need to be quite abnormally large in order for $E1-M2$ mixing to take place. While this phenomenon can occur for highly deformed nuclei, Eu^{151} is not highly deformed ($\delta\approx0.15$). Therefore we have rejected the $E1+M2$ assignment in spite of the fact that the $M1$ assignment leads to difficulties of interpretation of the level scheme of Eu^{151}.

[20] V. S. Shirley and J. O. Rasmussen, Phys. Rev. **109**, 2092 (1958).

be $1.7\pm0.3\%$. The $\log_{10}ft$ values, calculated with the help of the graphs of Feenberg and Trigg,[21] are 7.6 ± 0.2 for the 75.9-kev transition and 8.8 ± 0.2 for the 54.2-kev transition. Such large values seem to indicate that the beta transitions are either first- or second-forbidden. The linearity of the Kurie plot shows that the 75.9-kev transition cannot be first-forbidden, unique. For the 54.2-kev transition the value of $\log_{10}[(W_0^2-1)ft]$ is 8.2 and the value of $\log_{10}f_1t$ is 6.8,[22] both of which are much lower than expected for a first-forbidden, unique beta decay. This, together with the $M1$ multipolarity for the de-excitation of the 21.7-kev state in Eu^{151}, indicates that both transitions are either first-forbidden, allowed shape, or (although the $\log_{10}ft$ values are rather large for such transitions) allowed.

C. Interpretation

Evidence for the ground-state spin of Eu^{151} comes from hyperfine structure measurements. The magnetic moment[23] is 3.4, and the spin is $\frac{5}{2}$. The quadrupole moment[24] is 1.2 barns. The ground-state spin of Sm^{151} is not known; however, the ground-state spins of Sm^{147} and Sm^{149} both are $\frac{7}{2}$.[25] The quadrupole moment of Sm^{151} also has not been measured, but the quadrupole moments of Sm^{147} and Sm^{149} are known to be both less than 0.72 barn.[26] This indicates that in the decay under study both parent and daughter nuclei are weakly deformed. A calculation based on the procedure of Bohr and Mottelson[27] indicates that the deformation of the ground state of Eu^{151} is $\delta\approx0.10$. The quadrupole moments of Sm^{147} and Sm^{149} lead to a deformation no greater than $\delta\approx0.05$ for these two nuclei. On the other hand, the deformation of Sm^{152} determined from Coulomb excitation experiments[28] is $\delta\approx0.26$. The sharp break in nuclear properties which occurs between $N=88$ and $N=90$ is well known. There is some evidence[29] that the break occurs between $N=89$ and $N=90$. This discontinuity makes an estimate of the deformation of Sm^{151} somewhat uncertain, but a value of $\delta\sim0.10$ seems reasonable.

Because of the fairly small deformations involved, it seems reasonable to consider these nuclei in terms of both shell model and unified model.

The shell-model interpretation of the nature of the ground state of Eu^{151} is that it is $d_{5/2}$, which has positive parity. Since the calculations of Nilsson[30] and Gottfried[31] indicate that this state must have negative parity in order that the large difference in the magnetic moments of Eu^{151} and Eu^{153} be explained, the shell model seems inappropriate.

If the unified model as proposed by Nilsson and Gottfried be used, one has a wider variety of states from which to choose. In addition to the increased number of individual particle states which results from the removal of the degeneracy of the undeformed shell-model states, one also has both rotational and vibrational excited states.

In the Nilsson-Gottfried scheme the ground state of Eu^{151} must be $h_{11/2,\,5/2}$. Although this implies a deformation of $\delta=0.19$ to 0.20, considerably more than the calculated value $\delta\approx0.10$, this discrepancy among measured spin, measured quadrupole moment, the calculation of the deformation from the quadrupole moment, and the level predictions is probably not of a major character.

There are four possible choices for the Sm^{151} ground state: $f_{7/2,\,7/2}$, $f_{7/2,\,5/2}$, $h_{9/2,\,3/2}$, and $i_{13/2,\,3/2}$. The deformation of the last of these is too large ($\delta>0.22$) for serious consideration. The measured spins of Sm^{147} and Sm^{149} favor the choice of the $f_{7/2,\,7/2}$ state; in the absence of any evidence in favor of the other two possibilities this one has been selected.

There does not seem to be any individual particle state of negative parity which is suitable for the 22-kev state. The other substates of $h_{11/2}$ are too greatly separated in energy, and no other negative-parity states exist in the region. Likewise there is no pure rotational state which could occur at an energy so low as 22 kev. With a deformation $\delta\approx0.10$, the lowest rotational state should be at least several hundred kev above the ground state.

There remains either some form of configuration interaction or some combination of an individual particle state with some collective excitation. One such possibility suggested to us by Nilsson[32] is that Eu^{151} be considered as a Sm^{150} core plus a proton with spin $\frac{5}{2}$. The Sm^{150} core undergoes vibrations giving rise to a one-phonon state of spin 2 and energy ~300 kev. To the vibrational state with angular momentum 2 may be added the odd-proton spin of $\frac{5}{2}$ to obtain five different states scattered around the ~300 kev level; all these five have the same parity as the ground state. One of these states may be the 22-kev excited state in Eu^{151} while two of the others may be states of Eu^{151} which are Coulomb-excited.[33,34] It is interesting in this connection to note that Shirley and Rasmussen, in their work[18] on the decay of Gd^{151}, found evidence for five excited states in Eu^{151}. They feel, however, that at least one of their levels is of different character than the Coulomb-

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[23] H. Schuler and T. Schmidt, Z. Physik **94**, 457 (1935).
[24] H. Schuler and T. Schmidt, Z. Physik **98**, 430 (1935).
[25] R. J. Blin-Stoyle, Revs. Modern Phys. **28**, 75 (1956).
[26] R. J. Elliot and K. W. H. Stevens, Proc. Roy. Soc. (London) **219**, 387 (1953).
[27] A. Bohr and B. R. Mottelson, Kgl. Danske Videnskab. Selskab, Mat.-fys. Medd. **27**, No. 16 (1953).
[28] Alder, Bohr, Huus, Mottelson, and Winther, Revs. Modern Phys. **28**, 432 (1956).
[29] L. Grodzins, Bull. Am. Phys. Soc. Ser. II, **1**, 163 (1956).
[30] S. G. Nilsson, Kgl. Danske Videnskab. Selskab, Mat.-fys. Medd. **29**, No. 16 (1955), and private communication, 1957.
[31] K. Gottfried, Phys. Rev. **103**, 1017 (1956).
[32] S. G. Nilsson (private communication, 1958).
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[34] C. M. Class and U. Meyer Berkhout, Nuclear Phys. **3**, 656 (1957).

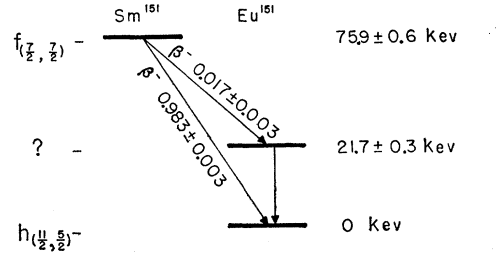

FIG. 4. Partial decay scheme for decay $Sm^{151} - \beta^- \rightarrow Eu^{151}$.

excited level at 304 kev. It is not clear yet whether the above scheme would explain the large $\log_{10} ft$ values for allowed beta transitions or the large difference in the $\log_{10} ft$ values for the two beta spectra. Present knowledge of the decay scheme is given in Fig. 4. Further investigation of the levels of Eu^{151} would appear to be necessary.

III. THE DECAY OF Sn^{113}

A. Experimental Conditions

The Sn^{113} used for making sources was obtained by irradiation for three weeks in the intense neutron flux of the LITR at the Oak Ridge National Laboratory of a 2-mg sample of SnO_2 enriched (72.49%) in Sn^{112}. A six weeks waiting period between termination of irradiation and data taking sufficed to insure that no other activity was present to more than one part in 10^3 of Sn^{113} activity. The sample was dissolved (only partial solution was effected) in $\sim 4N$ HCl. A fairly strong source was made by placing upon the source backing four drops of the dissolved Sn^{113} one at a time and allowing each drop to dry slowly. The backing, an aluminum foil 1.6 mg/cm² thick covered with a Mylar film 1.7 mg/cm² thick, had been treated previously with insulin to aid in uniform spreading. The source is estimated to be ~ 100 μg/cm² thick.

Because of the limited objective of this study, data were taken only in the vicinity of the conversion electrons from the 393-kev transition and from the possible 255-kev transition. In the latter region about 7000 counts per point were taken. Of these, at the maximum counting rate for the small conversion peak found there, about 1900 were source counts. In the region of the 393-kev conversion peak, total counts per point ranged from 2000 to 20 000. At the maximum counting rate, the contribution of background to the counting rate is almost negligible. Points in both regions studied were spaced about 1.1% apart in momentum.

B. Experimental Results

The conversion spectrum from the decay of Sn^{113} is shown in Fig. 5. It can be seen in this figure that the weak conversion peak does not have a zero counting rate baseline after the subtraction of background. This is due to a small amount of tailing from the strong

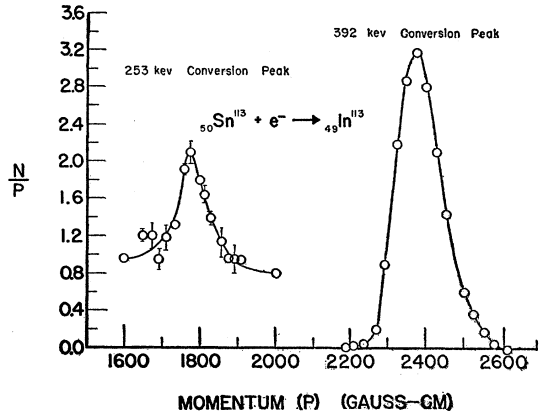

FIG. 5. Conversion spectrum for decay of Sn^{113}.

conversion peak. The uncertainty in the baseline position for the weaker peak makes the determination of its intensity relative to the stronger somewhat crude. The error in the area under the peak has been estimated to be 35% by adjustment of the possible positions of the baseline and by consideration of the probable errors of the individual points. This estimate is felt to be quite conservative.

Comparison of the areas under the two peaks shows that the intensity of the 253-kev conversion line is $(2.8 \pm 1.0) \times 10^{-3}$ of the intensity of the 393-kev conversion line. This is less than the upper limit of one percent set by Broyles *et al.*[9] and by Avignon.[11] The energy of the transition is 253 ± 4 kev, while the energy of the stronger transition is 392 ± 4 kev.

The data obtained above verify the existence of the 253-kev transition (found originally by Cork *et al.*[7]) from the conversion-electron point of view. It is useful also to know the conversion coefficient associated with the transition. Knowledge of the relative conversion-electron intensities and the relative gamma-ray intensities, together with the conversion coefficient for the 392-kev transition, enables one to calculate the conversion coefficient for the 253-kev transition. There have been several measurements of the conversion coefficient for the 392-kev transition[11,35–37]; of these, Avignon's[11] value of 0.52 ± 0.05 has been adopted for calculations.

The relative intensity of the two gamma rays is a matter of some uncertainty. Gardner and Hopkins (in their revised value[38]) found the 253-kev gamma-ray to be $3.3 \pm 1\%$ of the intensity of the 393-kev gamma-ray. Avignon[11] set an upper limit of 1% for the same ratio, while Bhatki *et al.*[39] found a ratio of 5%. These various values lead to different conversion coefficients for the

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[36] I. Antonova and U. Estulin, J. phys. radium **16**, 534 (1955).
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[38] G. Gardner and J. I. Hopkins (private communication, 1958).
[39] Bhatki, Gupta, Jha, and Madan, Nuovo cimento **6**, 1461 (1957).

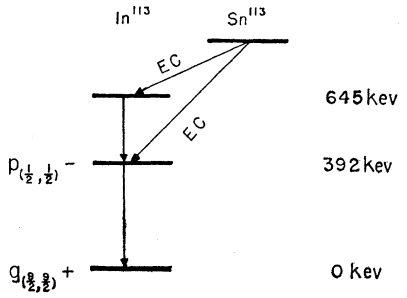

FIG. 6. Partial decay scheme for decay $Sn^{113} - {}^{EC} \rightarrow In^{113}$.

253-kev transition and consequently to different branching ratios for the two capture transitions (it will be shown later that capture must occur to levels at 645 kev and 392 kev in In^{113}) and also to different multipolarities for the 253-kev transition.[40] The effect of variation in the value of the 253-kev conversion coefficient is shown in Table II. Grench *et al.*[41] also have studied the decay of Sn^{113}. They obtained, for the 253-kev transition, a conversion ratio $K/(L+M)\sim 4$, and a K-conversion coefficient of 0.065. From their result it is possible to calculate both a branching ratio and a gamma-ray ratio. These also appear in Table II.

C. Interpretation

The ground-state spin of In^{113} has been measured[25] to be 9/2, while the spin of the isomeric state at 392 kev has been measured[42] as $\frac{1}{2}$. The ground-state spin for Sn^{113} has not been measured, but the measured[25] ground-state spins for Cd^{111} and Sn^{115} both are $\frac{1}{2}$. Calculation of the deformation of the In^{113} ground state using the method of Bohr and Mottelson[27] and the measured quadrupole moment[25] gives $\delta \approx 0.10$. There is no direct evidence which would allow determination of the deformation of Sn^{113}, but it might be expected to be fairly small.

The data obtained in this study indicate that the 392-kev transition follows the 253-kev transition. For the opposite ordering to occur, the conversion coefficient for the 253-kev transition could be no larger than $\sim 9\times 10^{-4}$, which is a factor of ten smaller than the smallest possible conversion coefficient.[6,40] It should be noted that the calculation upon which this upper limit is based is independent of the measured ratio of gamma-ray intensities. The absence of a strong K-conversion line for a transition of $\sim$140 kev[7,9,43] shows that the 253-kev transition cannot be part of a 139-kev, 253-kev cascade de-excitation of the 392-kev state. The data thus require capture to both the 645-kev and 392-kev states on In^{113}.

[40] Rose, Goertzel, and Perry, Oak Ridge National Laboratory Report ORNL 1023, June, 1951 (unpublished).
[41] Grench, Burson, and Schmid, Bull. Am. Phys. Soc. Ser. II, **3**, 207 (1958).
[42] W. J. Childs and L. S. Goodman, Bull. Am. Phys. Soc. Ser. II, **1**, 342 (1956).
[43] Thomas, Haynes, Broyles, and Thomas, Phys. Rev. **82**, 961 (1951).

TABLE II. Relationship among gamma-ray intensity ratio, branching ratio, and conversion coefficient for 253-kev transition.

$\left(\frac{253\text{-kev }\gamma\text{-rays}}{392\text{-kev }\gamma\text{-rays}}\right)$	α_{253}	Branching ratio[a]	Multipolarity
0.05	2.9×10^{-2}	3.5×10^{-2}	$M1$
0.033	4.4×10^{-2}	2.2×10^{-2}	$M1$ ($E2$)
0.018	8.1×10^{-2}	1.3×10^{-2}	$E2$
0.01	15×10^{-2}	0.8×10^{-2}	$M2$ ($E3$)

[a] Branching ratio = (captures to 645-kev state)/(captures to 392-kev state).

The 392-kev transition has been identified previously[35] as $M4$. The character of the 253-kev transition is somewhat uncertain as indicated by the first three values in Table II. Likewise the capture energies to the 392-kev and 645-kev states are not known with certainty, although Bhatki *et al.*[39] have assigned a value of 36 kev for the capture to the 645-kev state, based on their measured L/K capture ratio of 2.23. Jung and Pool[44] earlier obtained by measurement of inner bremsstrahlung a capture energy of $\sim$100 kev, presumably to the 392-kev state. This latter result is completely inconsistent with the existence of the 645-kev state.

Until the above uncertainties are eliminated, speculation concerning the spins and parities of the 645-kev state of In^{113} and the ground state of Sn^{113} necessary to fit this decay scheme seems unprofitable. This study, along with others[7,8,39,41,45] seems to establish the existence of the 645-kev level (Fig. 6). Since indium is only one proton removed from a complete proton shell, the question of whether this level is interpretable on the shell model or not is of considerable interest, and further investigation is indicated.

IV. ACKNOWLEDGMENTS

The authors wish to express their thanks to Mr. Roy A. Parker for his many hours of assistance in collection of data, electronic trouble shooting, chemical techniques, and decontamination of the spectrometer. We wish also to express our appreciation to Dr. G. W. Parker for furnishing us with the sample of Sm^{151} without which the first part of this investigation would not have been possible. Dr. S. G. Nilsson has contributed much to our interpretations of the decays in terms of the unified model; his interest and assistance have been invaluable. One of us (W. T. A.) wishes to acknowledge the help of the Ford Foundation for financial aid during a large part of this work, and the help of the Air Force Office of Scientific Research of the Air Research and Development Command during the analysis and reporting of the work presented herein.

[44] R. G. Jung and M. L. Pool, Bull. Am. Phys. Soc. Ser. II, **1**, 172 (1956).
[45] W. E. Phillips and J. I. Hopkins (private communication, 1958). They report the existence of gamma radiation of about 650 kev with an intensity about 5% of that of the 255-kev gamma radiation.