TABLE VII. Angular distribution of the gamma rays observed at the 414-kev resonance.

Gamma-ray energy (Mev)	Angular distribution expression
6.04	$1+(0.17\pm0.02)\cos^2\theta$
5.36	$1-(0.19\pm0.03)\cos^2\theta$
0.69	$1-(0.095\pm0.02)\cos^2\theta$

the matrix element for $M1$ radiation is reduced[5,6] or that for E_2 radiation is enhanced. The latter implies a deformed nuclear potential for P^{30}. In this connection, it is interesting to note that the ground state of P^{30} can be described[7] as $K=I=\Omega_p+\Omega_n=1$ where Ω_p and Ω_n are each $\frac{1}{2}$. It is thus possible to describe the 700-kev doublet as the $K=0$ bands of the ground-state configuration. Further work, using Nilsson's[8] diagrams to determine whether the other excited states are rotational in character, is in progress.

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Decay of $_{62}Sm^{155}$(23.5 min)*

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The decay of Sm^{155}(23.5 min) is characterized by beta emission to excited states in Eu^{155}. This activity was studied by means of the Argonne 256-channel scintillation coincidence spectrometer. Sources were prepared by neutron irradiation of samarium oxide, enriched in Sm^{154}, in the Argonne reactor CP-5. Three gamma-ray transitions and two beta-ray branches are reported. These radiations are fitted into a decay scheme which indicates the presence of excited states in Eu^{155} at 105 and 246 kev. The total decay energy is found to be 1.8 ± 0.1 Mev. Possible spin and parity assignments for each of the levels are discussed.

POOL and Quill[1] were the first to observe a 21-minute activity in samarium. This activity was observed to decay[2] by the emission of beta particles with maximum energy of 1.8 Mev. By determining the fission yield, Winsberg[3] was able to assign the activity to Sm^{155}. Later, in addition to the beta decay, two gamma rays were observed[4] with energies of 104.6 kev and 245.8 kev.

Sources of Sm^{155} were prepared by neutron irradiation of samarium oxide (99.1% Sm^{154}) in the Argonne reactor CP-5. The radiations were studied by means of gamma-gamma and beta-gamma coincidence experiments with the Argonne 256-channel scintillation spectrometer.

The gamma-ray spectrum shown in Fig. 1 was obtained with a lead collimator placed between the crystal and source. In addition to the previously reported gamma rays,[4] a 141-kev gamma ray was observed. Gamma-gamma coincidence experiments (see Fig. 2, curves *A* and *B*) show that the 105- and 141-kev gamma rays are in coincidence with each other and that neither one is in coincidence with the 246-kev gamma ray.

Beta-gamma coincidence experiments, employing techniques in which the beta particles are absorbed by aluminum, indicate that the beta spectrum is complex (see Fig. 1). There is little if any beta branching to the ground state. This is concluded from the fact that the ratio of the total number of beta-gamma coincidences to the number of beta counts remains constant for each thickness of aluminum. From these data, the intensity of a possible beta branch to the ground state is concluded to be less than 2%.

The experimental information obtained for the radiations of Sm^{155} is summarized in Tables I and II. The *K*-shell internal-conversion coefficients for the 105- and 141-kev transitions were calculated from measurements of the x-ray and gamma-ray intensities for each

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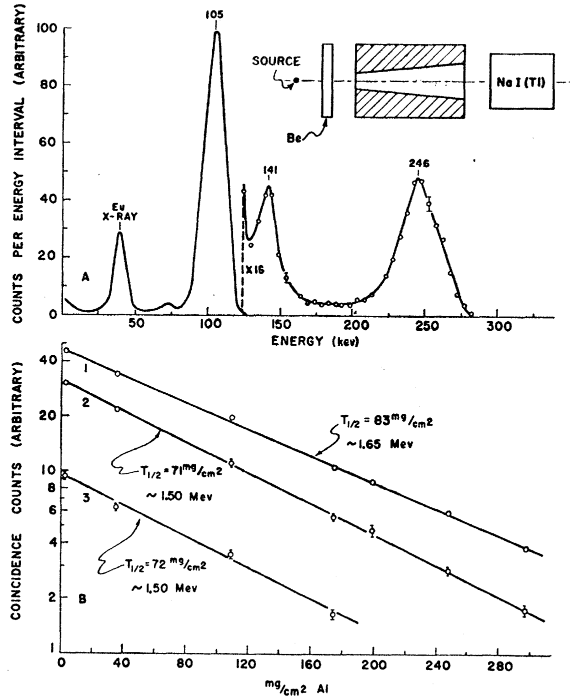

FIG. 1. The gamma and beta rays of Sm^{155}. (A) shows the scintillation spectrum of the collimated gamma rays. Where experimental points are not shown the uncertainties are less than or approximately equal to the line width and points are about 2.5 kev apart. Curves 1, 2, and 3 of (B) show the absorption in aluminum of the beta rays in coincidence with the 105-, 141-, and 246-kev gamma rays, respectively.

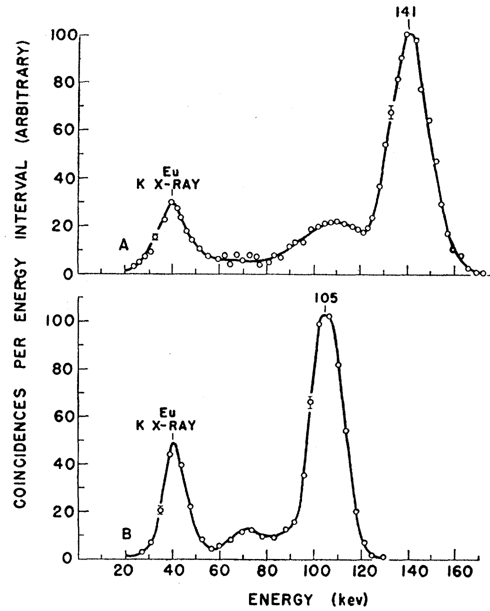

FIG. 2. Gamma-gamma coincidence spectra of Sm^{155}. Coincidence circuit gated by (A) the 105-kev gamma ray and (B) the 141-kev gamma ray.

transition. For these calculations, it is necessary to obtain the intensity of the x-rays from one transition independent of the intensity of those from the other transition. The required intensities could not be obtained from the "singles" spectrum (Fig. 1) since the x-ray peak in this spectrum contains counts from both transitions. Instead, the intensities were obtained from spectra taken in coincidence experiments. In these experiments, the x-ray and gamma-ray counts from each transition are observed independently (see Fig. 2). After making corrections for counter efficiencies and, in the case of the x-rays, for the fluorescence yield, α_K values of 0.27 ± 0.06 and 0.16 ± 0.06 were calculated for the 105- and 141-kev transitions, respectively. Comparison of these experimental coefficients with the theoretical values[5] indicates that both transitions are $E1$ (see Table I). The K/L ratios reported by Rutledge *et al.*[4] for the 105-kev transition is not inconsistent with this interpretation.

TABLE I. Gamma-ray measurements of the decay of Sm^{155}.

Energy Mev	Gamma-ray intensity	Internal-conversion coefficients for the K shell: Experimental	Theoretical (Rose[a]) $E1$	$E2$	$M1$	$M2$
0.105	93.8%	0.27	0.22	1.05	1.54	12.1
0.141	1.2%	0.16	0.15	0.68	1.08	8.3
0.246	6.3%					

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

The conversion coefficients were used to correct the relative gamma-ray intensities (Table I) for the internal-conversion electrons which accompany the gamma rays. In this way, total relative intensities of the gamma transitions were obtained. The relative intensities listed in Table II for the beta transitions were deduced, in turn, from these total intensities.

The foregoing data can be summarized unambiguously by the decay scheme shown as Fig. 3.† The spins and parities of the ground states are assigned from the Nilsson energy level diagrams[6] assuming a deformation parameter $\delta=0.33$. The spin of $\frac{3}{2}$ for the ground state

TABLE II. Beta-particle measurements of the decay of Sm^{155}.

Energy Mev	Intensity	$\log ft$	Spin change	Parity change
1.50	7%	6.7	0, 1	yes
1.65	93%	5.7	0, 1	no
1.8	not observed (<2%)			

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

† *Note added in proof.*—From private communication it is understood that experiments conducted by Heath, Cline, and Rich (Phillips Petroleum Co., Atomic Energy Division) are in substantial agreement with these results. Their findings are to be published.

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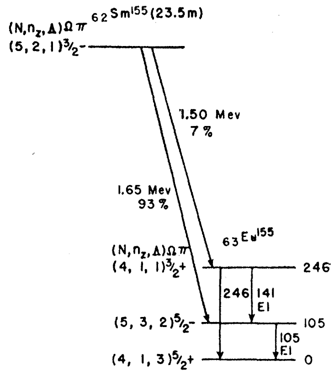

FIG. 3. Decay scheme of Sm^{155}. Energies are in kev unless marked otherwise.

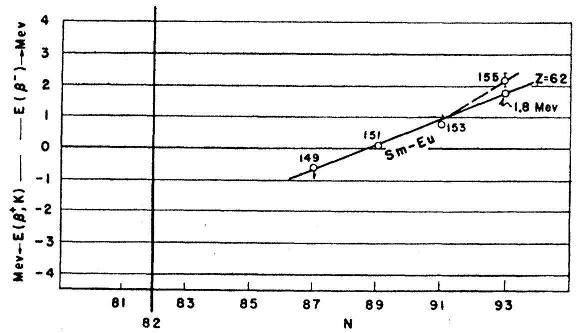

FIG. 4. Observed total disintegration energies E for the Sm-Eu decays as a function of neutron number N. The arrow at the point for $N=87$, $A=149$ indicates the energy is not less than the value at the point.

of $_{62}Sm^{155}$ (Nilsson level 52) is supported by the measured spin[7] of $_{64}Gd^{157}$ which has the same number of neutrons. Also the predicted spin of $\frac{5}{2}$ for the ground state of Eu^{155} (Nilsson orbit No. 27) with 63 protons agrees with the measured spins[8] of the europium isotopes of mass 151 and 153. However, Eu^{151} has a much smaller deformation than either Eu^{153} or Eu^{155} and, because of this, its ground state is actually a different level (No. 36) which has negative parity and spin of $\frac{5}{2}$.

The combination of the $E1$ cascade of the 141- and 105-kev transitions with the selection rules imposed by the beta transitions signifies that the 105-kev level has spin $\frac{3}{2}$ or $\frac{5}{2}$ and negative parity. Similarly, the 246-kev level must have spin $\frac{1}{2}$, $\frac{3}{2}$, or $\frac{5}{2}$ and positive parity. Rutledge *et al.*[4] have reported a K/L ratio of 8 for the 246-kev transition. This information combined with the parities assigned for the ground state and for the 246-kev level indicate that the 246-kev transition is probably predominantly $M1$ with possibly some $E2$ admixture. If this is the case, the 246-kev level can only have spin $\frac{3}{2}$ or $\frac{5}{2}$ and not $\frac{1}{2}$.

According to the Nilsson diagrams, there is a $\frac{5}{2}-$ and a $\frac{3}{2}+$ state lying close to the ground state of Eu^{155}. These are the Nilsson orbits 36 and 33 which have the quantum numbers $(5,3,2)\frac{5}{2}-$ and $(4,1,1)\frac{3}{2}+$, respectively. In this notation, the total oscillator quantum number N, its component n_z along the symmetry axis of the nucleus, and the component Λ of the particle orbital angular momentum along the symmetry axis are listed, in that order, in the parenthesis; and outside the parenthesis are the nuclear spin Ω and parity π. It is interesting to note that these $\frac{5}{2}-$ and $\frac{3}{2}+$ states occur as excited states[9–11] of Eu^{153} and that the $\frac{3}{2}+$ state also appears as the ground state [9,10,12] of Tb^{159}. These analogous states in Eu^{153} are considered in some detail in the recent treatise by Mottelson and Nilsson.[13] When the asymptotic quantum numbers are considered, it is found that transitions from the $\frac{3}{2}+$ level to both the $\frac{5}{2}-$ and the $\frac{5}{2}+$ ground-state are highly hindered. Consequently theoretical transition probabilities are not expected to be reliable and therefore have not been calculated.

According to the selection rules proposed by Alaga[9] for beta transitions of deformed nuclei, a beta transition to the ground state would be a first forbidden transition which is hindered ($\Delta\Lambda=2$ instead of $\Delta\Lambda=0$ for an unhindered transition) while the 1.50-Mev beta ray should be first forbidden also but unhindered. This may be the reason that a groundstate beta transition, which otherwise should be able to compete with the transition to the 246-kev level, was not observed.

Figure 4, obtained from the charts of Way and Wood,[14] shows the observed total decay energies as a function of neutron numbers for the Sm-Eu decays. A value[15] for the Sm^{149}-Eu^{149} decay energy, which was not available when they compiled the data, is also shown. In addition, the figure shows the value of 1.8 ± 0.1 Mev, as observed in this study, for the Sm^{155}-Eu^{155} decay. The latter point falls on a straight line with the points representing the decay of other nuclei which have the same atomic number. As can be seen in Fig. 4, the previously reported value of 3.2 Mev for the total decay energy did not evidence this linear relationship.

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