deviations of each measurement from the mean, n is the number of measurements, and the ΔE_i are the uncertainties assumed to exist in any one given measurement. For the present measurements all the data were given equal weighting factors. In calculating the internal error the ΔE_i's were taken to be 0.1% of the separation energy between the states of interest and the 0.656-MeV state. To obtain the final error in the excitation energy, the statistical uncertainty, which is taken as the larger of the standard deviation of the mean, and the internal error are combined with the spectrograph-calibration uncertainty. An uncertainty of 0.03% of the separation energy has been adopted for the error in the shape of the calibration curve. The final error also includes the ±1.1-keV uncertainty in the 0.656-MeV state. Combining these uncertainties quadratically gives an error of ±3.1 keV for each of the two levels. If one attempts to estimate systematic error due to uncertainty in beam-spot position and angle, the above errors are increased to ±5 keV. The final results of 5.932 ± 0.005 and 6.013 ± 0.005 MeV are in good agreement with the γ-ray numbers and the lower-energy (d,p) measurements.

The angular distributions for these two levels observed in the present experiment are compared with the two levels given by El-Bedewi as occurring at 5.87 and 5.95 MeV, as shown in Fig. 2. The 0.656-MeV state is also shown for comparison purposes. Error bars represent the statistical uncertainty in the data. The curves are taken from Ref. 1. Clearly, the levels which El-Bedewi calls 5.87 and 5.95 MeV have angular distributions which are identical to the two levels observed in this experiment.

The excitation-energy measurements and angular distributions obtained in the present experiment demonstrate that the two levels near 6 MeV which exhibit $l_n = 1$ stripping patterns and which were reported previously as being at 5.87 and 5.95 MeV are, in fact, the same two levels observed in the (n, γ) experiments and reported as 5.9360 and 6.0173 MeV.

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Nanosecond Isomeric Transitions in Gd^{155}†

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The half-lives of the excited states at 86.5 and 105.3 keV in Gd^{155} have been determined as $T_{1/2}(86.5\text{ keV}) = 6.3 \pm 0.1$ nsec and $T_{1/2}(105.3\text{ keV}) = 1.18 \pm 0.02$ nsec. The results are compared with the theoretical calculations of $E1$ transition rates taking into account the retarding effect of pairing correlations. The importance of taking into account wave-function components admixed by the Coriolis coupling is discussed.

The half-lives of the 86.5- and 105.3-keV levels in Gd^{155} have been measured by several investigators[1-8] as shown in Table I. There is considerable disagreement among the reported values of the half-lives for both levels. The two states are of interest in interpreting the nuclear structure of deformed Gd^{155}.[9] The $E1$ nature of the transitions from these states to the $\frac{3}{2}$ ground state of Gd^{155},[10] together with the logft values for the β decay of Tb^{155},[11] establish both states as having positive parity. Recent angular-correlation measurements with Ge(Li) detectors[12] give a definite spin assignment of $\frac{5}{2}+$ to 86.5-keV level. In this note we report lifetime measurements for the 86.5- and 105.3-keV states in Gd^{155}. The results are compared with the theoretical calculations of $E1$ transition rates taking into account the retarding effect of pairing correlations. These estimates for the γ-ray transition probabilities suggest that there is a mixing of the positive-parity levels. The conclusion which is drawn with respect to the 86.5- and 105.3-keV levels in Gd^{155} is that the

TABLE I. Reported values of half-lives for the 86.5- and 105.3-keV levels in Gd^{155}.

Level (keV)	Source	$T_{1/2}$ (nsec)	Reference
86.5	Eu^{155}	5 ± 1	1
	Eu^{155}	5.04 ± 0.2	2
	Eu^{155}	≃ 5.0	3
	Eu^{155}	6.65 ± 0.2	4
	Eu^{155}	6.27 ± 0.35	5
	Tb^{155}	6.7 ± 0.3	6
	Tb^{155}	6.68 ± 0.12	7
	Tb^{155}	6.3 ± 0.1	Present value
105.3	Eu^{155}	<1.2	1
	Eu^{155}	0.42 ± 0.42 0.14	8
	Eu^{155}	1.05 ± 0.05	2
	Eu^{155}	1.11 ± 0.06	4
	Eu^{155}	1.2 ± 0.04	5
	Tb^{155}	1.18 ± 0.02	Present value

pairing-correlation correction factors improve the agreement with experiment for the 105.3-keV $\Delta K = \pm 1$ transition.

The 5.6-day Tb^{155} was produced in the $(\alpha, 2n)$ reaction on 98.5% enriched Eu^{153} with 27-MeV α particles from the heavy-ion accelerator at Yale University. In order to minimize extranuclear effects, liquid sources were used in all the experiments. The source holders used were made of Plexiglas 1.27 cm long, in which a 3.15-mm hole was drilled. The γ-γ directional-correlation measurements using a Ge(Li) and a NaI(Tl) detector have been previously reported by us.[12] Figure 1 shows the low-energy γ-ray spectrum taken with a cooled Si(Li) detector. The detector had a system resolution of 250 eV at 100 keV. For the measurement of lifetimes, two Amperex XP-1020 Photomultipliers were used. For detection of low-energy γ rays, 1-in.-thick × 2-in.-diam NaI(Tl) crystals were employed. For detection of low-energy electrons and to improve the prompt resolution, Naton plastic scintillators 1 in. × 1 in. or $\frac{1}{8}$-in.-thick × 1-in.-diam were used. Fast signals were derived from two ORTEC fast discriminators and fed into an ORTEC time-to-pulse-height converter. Figure 2 shows some of the typical spectra obtained with γ-γ or γ–conversion-electron coincidences. The upper curve (I) was obtained using NaI(Tl) detectors. The curves (II, III, IV) were obtained by using one NaI(Tl) detector and a 1-in.-thick × 1-in.-diam plastic detector. A least-squares fit to the data shows that the 86.5-keV level has a half-life of $(6.3 \pm 0.1) \times 10^{-9}$ sec and that a $(1.18 \pm 0.02) \times 10^{-9}$-sec half-life must be ascribed to the 105.3-keV level in Gd^{155}. With the selected energy of the exciting transition being greater than 180 keV, the slopes of the coincidence curve (IV) indicate a prompt decay. The γ-conversion–electron data also shown in Fig. 2 support this argument (See curves V, VI, VII, and VIII). Eight separate determinations were made of the half-life of the 105.3-keV level. The weighted average of the eight measurements results in a value of 1.18 ± 0.02 nsec. The errors arise from a 1% error in the spread of the data, a 1% error due to stability, and in calibration. The present value

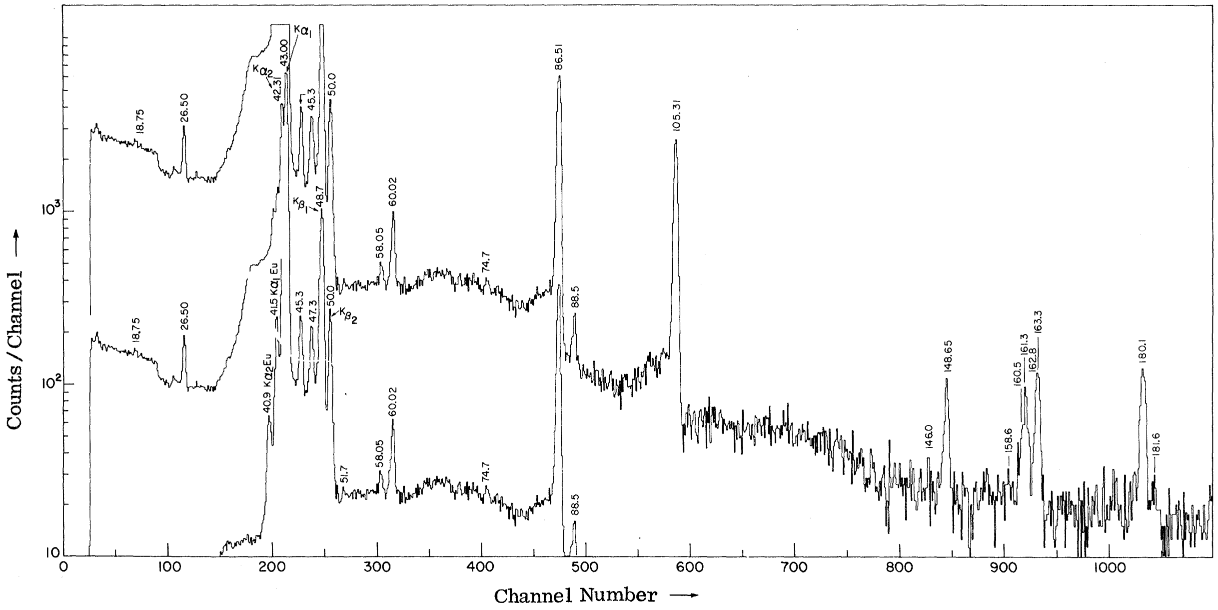

FIG. 1. γ-ray spectrum taken with a cooled Si(Li) detector.

of 1.18 ± 0.02 nsec is in definite disagreement with the value reported by Deutch, Metzger, and Wilhelm,[8] but agrees, within errors, with the value reported by McAdams and Hatch.[5]

Table II shows the measured experimental half-lives, transition energies, and partial γ-ray and conversion line intensities derived from experimental data. The partial γ-ray half-life is calculated from

$$T_{1/2\ \gamma}(\mathrm{exp}) = T_{1/2\ \mathrm{level}} \sum N/N_\gamma\,,$$

where $\sum N$ is the sum of all the relative intensities of the transitions depopulating the level.

The γ ray lifetimes obtained from the above measurements are compared with the theoretical $E1$ lifetimes in which the effect of the pairing correlation has also been taken into account. Nilsson[13] showed that the $E1$ transition probability between two single-particle levels in a deformed nucleus could be written as

$$P(E1) = 2.93\times10^{21}\left(1-\frac{Z}{A}\right)^2\left(\frac{E_\gamma}{197}\right)^3 A^{1/3} \times |\langle I, 1, k, k^1-k|I, 1, I^1, k^1\rangle|^2 (G_{E1})^2\ \mathrm{sec}^{-1}\,,$$

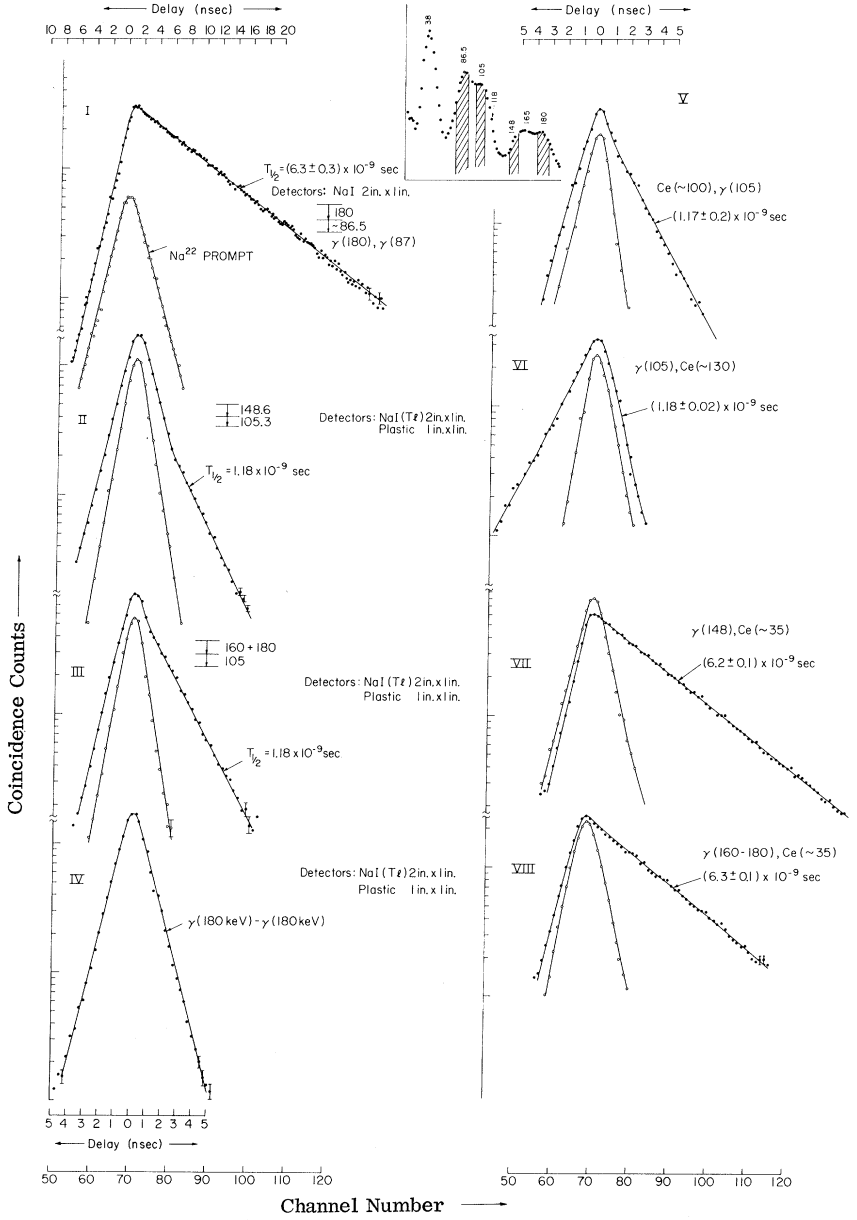

FIG. 2. γ-γ and γ-Ce delayed coincidences in Tb^{155} decay. The solid points represent the time-delayed curve; the open points are those of the prompt curve taken with Na^{22} source at the same channel settings.

TABLE II. Comparison of the experimental and theoretical $E1$ transition probabilities.

Nucleus	E_γ (keV)	Transition	$T_{1/2}$ (10^{-9} sec)	Multipolarity	Relative N_γ	Relative N_e	$T_{1/2\gamma}$ (exp) sec	F_W	F_N [a]	δ	$F_N \times R$
Gd^{155}	86.5	$\frac{3}{2}+(651) \rightarrow \frac{3}{2}-(521)$	6.3 ± 0.1	$E1$	4110	1912	10^{-8}	2.8×10^4	2.85	0.3	0.3
	105.3	$\frac{5}{2}+(642) \rightarrow \frac{3}{2}-(521)$	1.18 ± 0.2	$E1$	4545	1239	1.7×10^{-9}	8.7×10^3	7.7	0.3	1.5

[a] $F_N = \left[\frac{(G_{E1})_{\text{Theo}}}{(G_{E1})_{\text{exp}}}\right]^2$.

where symbols have been taken from Ref. 13.

Table II summarizes the various reduction factors and the experimental $E1$ transition probabilities for the 86.5- and 105.3-keV transitions in Gd^{155}. The theoretical transition probability has been computed by using the spherical-shell model (transition probability P_W, reduction factor F_W), and the Nilsson model (transition probability P_N). It is assumed that the theoretical probability for an electric transition between one-quasiparticle states may be written as the product of the ordinary particle transition probability P_N and by a reduction factor R. The values of R have been calculated by Vergnes and Rasmussen[14] and Lobner and Malmskog.[15] It is clear from Table II that the mere inclusion of the pairing correlation does not solve the problem of the $E1$ transition rates. For the 86.5-keV transition with $\Delta K = 0$, the reduction factor F_N is already close to 1, which means there is relatively good agreement between the experimental and the Nilsson-theoretical transition probability. This agreement tends to be destroyed as a result of the inclusion of the pairing force. On the other hand, for the 105.3-keV transition with $\Delta K = 1$, the reduction factor F_N is large, and the agreement is improved by the introduction of the pairing reduction factor. However, the agreement is still far from good, and there exists a possibility that effective band mixing in the $\frac{5}{2}[642]$ orbital is the main cause for this disagreement. Calculations of the theoretical $E1$ transition probabilities using the Nilsson model show that the $E1$ probabilities are very sensitive to small admixtures of the Nilsson states. Recently, Monsonego and Piepenbring[16] have tried taking into account octupole vibrations and octupole quasiparticle interactions, and calculated the $E1$ transition rates and the lifetimes for the 86.5- and 105.3-keV levels. Their results are closer to the measured lifetimes for the 86.5($\frac{5}{2}$+) and 105.3($\frac{3}{2}$+) states.

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