rameters for the $L=4$ transitions.

In summary, the relation between the $\beta_L$ and $B(EL)$ is extremely sensitive to tha tail of the assumed transition density and comparisons between the $(p,p')$ and electromagnetic $B(EL)$'s should be made with caution. In order to obtain more meaningful comparisons, it might prove worthwhile to reanalyze both the proton inelastic scattering and the electron inelastic scattering while requiring both analyses to be self consistent.

The authors would like to thank in particular Professor S. Austin for the discussions in which several of the ideas contained in this paper were introduced. The authors would also like to thank Professor H. McManus, Professor J. Borysowicz, and Professor E. Kashy for several helpful discussions.

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*Work supported in part by the National Science Foundation.

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# $M1$ ADMIXTURES IN TRANSITIONS FROM THE $3_\gamma^+$ AND $4_\gamma^+$ LEVELS IN $^{154}$Gd

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(Received 6 October 1969)

Gamma-gamma directional correlations have been measured in $^{154}$Gd with a Ge(Li) detector in one channel. The $M1$ admixtures in the $3_\gamma^+-2^+$, $3_\gamma^+-4_\gamma^+$, and $4_\gamma^+-4^+$ transitions were measured to be <1, $(3.0\pm0.3)$, and $(4.8\pm0.8)$%, respectively. The $M3$ admixture in the $2_\beta^+-4^+$ and $2_\gamma^+-4^+$ transitions is $(0.1\pm0.1)$%.

Much experimental effort has been directed toward the measurement of properties of the $K=0$, beta vibrational bands in deformed rare-earth nuclei since the problem of the anomalous gamma-ray branching ratios from these bands was brought to light.[1-3] The most recent measurements of $M1$ admixtures in the $2_\beta^+-2^+$ transitions in $^{152}$Sm, $^{154}$Gd, and $^{178}$Hf are discussed by Hamilton, Ramayya, Little, and Johnson.[4] On the basis of these data,[4] it seems that the usual description of these $K=0$ states as collective quadrupole vibrations of the beta type is not adequate and that these states have strong admixtures of various other components which are quite different in $^{154}$Gd and $^{178}$Hf. It is significant that in $^{154}$Gd it is the $2_\beta^+-4^+$ transition[5,6] that is responsible for the anomalous behavior of the branching ratios from the $2_\beta^+$ state, while in $^{178}$Hf it is the $2_\beta^+-2^+$ transition.[4]

In general the theoretical description of the $K=2$, gamma vibrational bands has been considered to be good.[7] More recent evidence,[8,9] however, indicates that at least in the transitional nuclei like $^{152}$Sm and $^{154}$Gd, mixing of only the gamma and ground-state bands is not sufficient to explain the branching ratios from the gamma bands. It is well established that the $M1$ components in the $2_\gamma{}^+$-$2^+$ transitions are very small,[10] as predicted in the early theoretical formulation.[11] In Bodenstedt's recent survey[10] of $M1$ admixtures in $2_\gamma{}^+$-$2^+$ transitions, the most accurate results all yielded $E2$ admixtures $\geq 99\%$ for these transitions. It is possible to explain[8,9] the branching ratios from the gamma band by including mixing in of the beta band with the gamma- and ground-state–band mixing although this mixing of all three bands does not help the anomalous beta-band branching ratios. The strongest evidence[8] for $\beta$-$\gamma$ band mixing comes from the $4_\gamma{}^+$ state, and a sizable $M1$ component in the $4_\gamma{}^+$-$4^+$ transition could alter this interpretation. Further evidence for the breakdown of any simple picture of quadrupole vibrations for these beta and gamma bands is the report[9] of a transition in $^{152}$Sm from the $2_\gamma{}^+$ to the $2_\beta{}^+$ level. Such a transition is strictly forbidden in first-order theory, yet the reported $B(E2)$ for this transition is comparable with that of the ground-state band.[5]

These questions about the gamma vibrational bands in transitional nuclei like $^{152}$Sm and $^{154}$Gd call for additional information on the higher-spin states of the gamma band in these nuclei to give a broader picture from which to formulate an understanding of these bands. Also, additional information on decays of the $3_\gamma{}^+$ and $4_\gamma{}^+$ ground-state–band level may be helpful in developing an understanding of the anomalies in the $2_\beta{}^+$-$4^+$ transitions.[5,6] Thus, we have carried out $\gamma$-$\gamma$ directional correlation measurements to determine the $M1$ admixtures in transitions from the $3_\gamma{}^+$ and $4_\gamma{}^+$ levels in $^{154}$Gd. Because of the questions raised about the $2_\beta{}^+$-$4^+$ transitions in these nuclei, we have also searched for $M3$ components in the $2_\beta{}^+$-$4^+$ and $2_\gamma{}^+$-$4^+$ transition in $^{154}$Gd.

The NaI-Ge(Li) detector system was the same one used in our earlier work[12] with the exception of a new 35-cm$^3$ Ge(Li) detector. The $^{154}$Eu source was the same as used in that work.[12] The 248 keV, $4^+$-$2^+$ transition in the ground-state band was the transition selected as a gate from the NaI detector in order to study the 757-keV (13%), $3_\gamma{}^+$-$4^+$; 893-keV (1.3%), $4_\gamma{}^+$-$4^+$; 625-keV (0.9%), $2_\gamma{}^+$-$4^+$; and 444-keV (1.7%), $2_\beta{}^+$-$4^+$ transitions. All these transitions are weak in comparison with many other strong transitions around them so that one must use good resolution and a large Ge(Li) detector in order to study them. In addition we have analyzed the $3_\gamma{}^+$-$2^+$ transition from our earlier work[12] to complete the picture of these lowest three members of the gamma band. The system was set up with two gates to measure the correlations of all transitions that feed the 248-keV transition and of those in coincidence with the Compton background under the 248-keV peak (measured with a gate set on 320 keV). The solid-angle corrections for the Ge(Li) detector were calculated from the geometry. The $Q_2$ and $Q_4$ were applied to the 757-248–keV

Table I. Experimental results for 893-, 757-, 444-, and 1246- 248–keV correlations, and the 873-123– and 1005-123–keV correlations in $^{154}$Gd.

| γ-γ(keV) | Spin, Parity | $A_2$ | $A_4$ | δ | % E2 |
|---|---|---|---|---|---|
| 1246-248 | $3^-$, $4^+$, $2^+$ | -0.151±0.007 | 0.010±0.008 | -0.018±0.015 | 99.9±0.1[a] |
| 444-248 | $2_\beta^+$, $4^+$, $2^+$ | 0.196±0.009 | 0.095±0.011 | -0.001±0.001 | 99.9±0.1 |
| 757-248 | $3_\gamma^+$, $4^+$, $2^+$ | 0.161±0.004 | -0.174±0.006 | 5.7 ±0.2 | 97.0±0.3 |
| 893-248 | $4_\gamma^+$, $4^+$, $2^+$ | -0.037±0.010 | 0.160±0.013 | 4.4 ±0.5 | 95.2±0.8 |
| 625-248 | $2_\gamma^+$, $4^+$, $2^+$ | 0.187±0.014 | 0.108±0.019 | -0.023±0.023 | 99.9±0.1 |
| 1005-123 | $3_\gamma^+$, $2^+$, $0^+$ | -0.161±0.11 | -0.10 ±0.02 | <-16 | >99% |
| 873-123 | $2_\gamma^+$, $2^+$, $0^+$ | | | $10.1^{+1.4}_{-1.1}$ | $99.00^{+22}_{-25}$[b] |

[a]$E1$.

[b]From Ref. 10. The errors are in the numbers after the decimal.

cascade from which consistent $A_2$ and $A_4$ coefficients were obtained. The $Q_2$ correction is small as is the error associated with it. The $Q_4$ correction is larger, so the theoretical $A_4$ consistent with the experimental $A_2$ for $\delta = 5.7$ for this correlation was used to obtain a more accurate $Q_4$ correction for the other cascades. A $\delta_{757} \approx 0.4$ is excluded by the $K$-conversion coefficient.[13] Data were recorded for 23 h per angle at 90, 135, and 180° for a cycle. 30 cycles were recorded.

The results of the correlations are given in Table I. The 1246-248-keV, $3^-$-$4^+$-$2^+$ cascade was also measured. The $A_2$ coefficient for this correlation agrees with a pure $E1$ transition, as expected, giving an added check on the performance of the system. The $\delta$ values and $E2$ admixtures are given in Table I. These are the first accurate results for transitions from the $3_\gamma^+$ and $4_\gamma^+$ levels. Also given in Table I are the results of the $3_\gamma^+$-$2^+$, 1005-123-keV cascade. These data were obtained in earlier work[12] but were not analyzed at that time. The measured results[10] on the $2_\gamma^+$-$2^+$, 873-123-keV cascades are given for comparison.

The cascades from the $2_\gamma^+$ and $3_\gamma^+$ levels to the $2^+$ level in the ground-state band have very small ($\leq 1\%$) $M1$ admixtures. The transitions from the $3_\gamma^+$ and $4_\gamma^+$ levels to the $4^+$ ground-state level, however, have $M1$ admixtures larger by factors of 3 and 5 than those to the $2^+$ level. Thus, these data also suggest a difference in the $4^+$ level of the ground-state band over the $2^+$ member. These $M1$ admixtures are still too small to alter the branching ratios enough to change the conclusion[8] about the need for additional terms such as $\beta$-$\gamma$ band mixing in order to explain the gamma-band branching ratios in $^{154}$Gd. The $4_\gamma^+$-$2^+$ transition as well as the $4_\beta^+$-$2^+$ transition have essentially no $M3$ admixtures. These data provide additional information to help in the formulation of a new understanding of these $K=0$ and $K=2$ excited bands in these transitional nuclei.

*Work supported in part by a grant from the National Science Foundation.

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