Table I. Suggested $(f_{7/2})^2$ level scheme in Sc^{42}.

J	E_x (keV)
0	0
1	615
2	1593
3	1498
4	~2800[a]
5	1518
6	~3200[a]
7	625

[a]Energies not experimentally established but approximated values inferred from known analog states in Ca^{42}.

ably the 2^+ state. This is supported by a comparison of the angular distributions shown in Fig. 2, which indicates that the 1593- and 615-keV levels are reached with the same orbital angular-momentum transfer. This may be $l=0$ and/or 2, since the 615-keV peak is predominantly due to the state with spin 1. However, the angular distributions of transitions to these two levels bear no resemblance to that of the $l=0$ transitions to the ground state and, therefore, are presumably $l=2$ transitions. (It is of interest to note that, where two l values can contribute to the angular distributions, the higher l value appears to make the larger contribution in the experimental data.) The final $(f_{7/2})^2$ level scheme suggested for Sc^{42} is shown in Table I.

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TEST OF $M1$-$E2$ MIXING IN THE DECAY OF $2^{+\prime}$ BETA VIBRATIONAL STATES

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The simple intensity predictions of Alaga et al.[1] for the ratios of reduced transition probabilities from a vibrational excited state to different members of the ground-state band are modified when there is mixing of the bands. Nielsen[2] first analyzed data from the decay of gamma vibrational states and found that the experimental data could be fitted with a single mixing parameter Z_2, which is a measure of the rotation-vibration interaction. Initial studies[3] of the beta band in ^{154}Gd indicated that a single value of Z_0 could explain the results there too, but the limits of error were large.

Very recently, however, Riedinger, Johnson, and Hamilton[4] and Liu, Nielsen, Salling, and Skilbried[5] have obtained more accurate gamma-ray intensities in ^{152}Sm and ^{154}Gd with Ge(Li) detectors. The gamma-band results[4,5] are still consistently explained by a single Z_2 for a given nucleus but the beta-band data[4,5] cannot be fitted by a single Z_0 unless the gamma intensity of the $2^{+\prime} \rightarrow 2^+$ transition is reduced by approximately 50%. As suggested by Liu et al.,[5] one is tempted to attribute this to $M1$ radiation, which is allowed by spin and parity selection rules. Such an admixture is forbidden, however, in the characterization of these states as symmetric quadrupole vibrations[6] although such could be allowed if one admixed some $K=1^+$ state in the two bands. There has not been a direct test of the long-standing theoretical prediction[6] that the transitions depopulating the beta vibrational states should be essentially $E2$ as has been verified for the gamma band from γ-γ directional correlation studies (for example, see Debrunner and Kundig[7]). In the gamma bands the $M1$ admixtures in the $2^{+\prime\prime} \rightarrow 2^+$ transitions are of the order of a few percent at most, so a 50% admixture in the beta bands would be surprisingly large.

The $K=0$ bands, identified as beta vibrational states, have been observed in only a few nuclei and then they are weakly populated. However, large-volume, high-resolution Ge(Li) detectors make γ-γ directional correlation studies feasible in some cases such as the one in ^{154}Gd populated by the decay of 16-yr ^{154}Eu. We have measured the 693-123-keV, $2^{+\prime}\rightarrow 2^{+}\rightarrow 0^{+}$, γ-γ directional correlation in ^{154}Gd in search of a $M1$ admixture. It should be noted that the internal conversion process has been shown to be about 80% $E0$ radiation[8] and so it is very difficult to extract information on $M1$ admixtures from α_K or L-subshell ratio data.

The source of ^{154}Eu, in liquid form, was placed in a plastic cylinder and the rotating detector centered about it. The γ-γ directional correlation was measured with a fixed 15-cc Ge(Li) detector and a NaI detector, which was set on the 123-keV peak and was rotated through a cycle of 90°, 135°, and 180°. A coincidence gate signal from the two detectors opened 2048 channels of the memory of a Nuclear Data analyzer for storage of the data from the Ge(Li) detector. In each of the cycles, data were recorded at each angle for a 23-h period to achieve statistical accuracy on the weak 693-keV peak. Drifts in the electronics over this period and from run to run were of the order of one channel or less as determined from the peak position and resolution which were compared with singles spectra taken for a 10-min period before and after each run. The data were plotted and analyzed in two groups of ten cycles each and in one group. These two methods of analysis give very consistent results. Figure 1 shows the spectra at the three angles for the 693-123-keV γ-γ directional correlation.

It is well known[9] that directional correlations involving the 123-keV state are attenuated even in liquid sources. Stiening and Deutsch[9] have carefully measured the 1274-123-keV γ-γ directional correlation and Debrunner and Kundig[7] the 874-123-keV correlation. These correlations have large A_2 and A_4 terms, respectively, which were used to obtain the attenuation and Ge(Li) solid-angle correction factors for the 693-123-keV correlation. The 1274-123-keV correlation was compared with the results of Stiening and Deutsch[9] to obtain $\Omega_2 G_2$. For the source-to-Ge(Li) detector distance of 7 cm and detector size, the variation in Ω_2

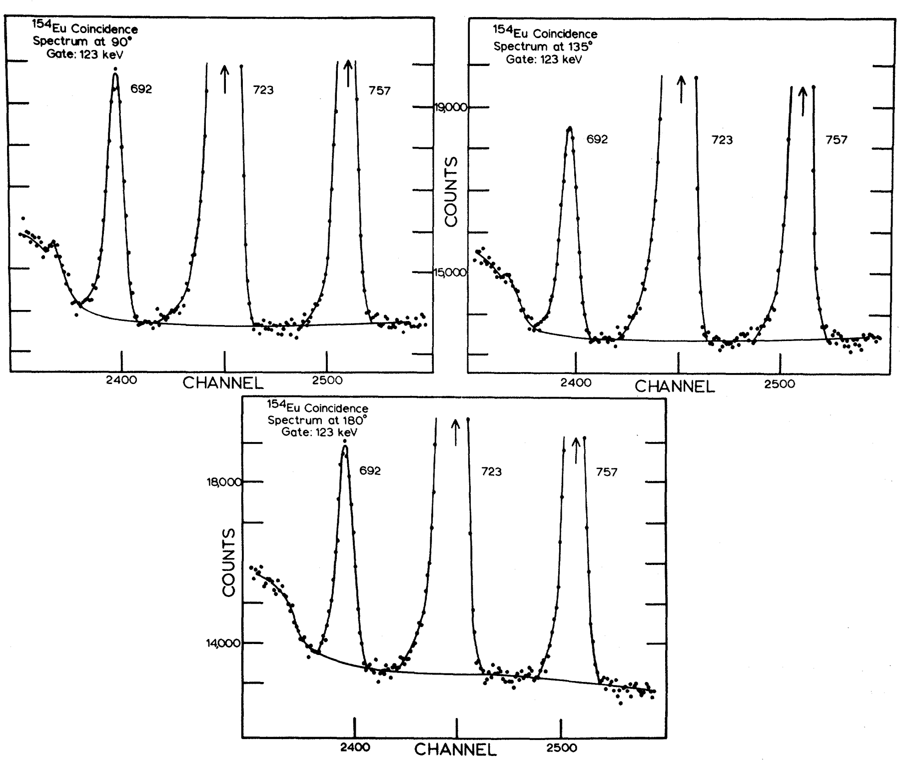

FIG. 1. 693-123-keV coincidence spectra at three angles.

Table I. Directional correlations of γ rays in ^{154}Gd.

$\gamma\gamma(\theta)$ (keV)	Spins and parities	$\Omega_2G_2A_2$	$\Omega_4G_4A_4$	A_2	A_4
1274-123	$2^-, 2^+, 0^+$	0.202 ± 0.004[a]	0.003 ± 0.004	0.227 ± 0.006[b]	...
1596-123	$2^-, 2^+, 0^+$	0.170 ± 0.011	-0.010 ± 0.012	0.191 ± 0.013[c]	-0.016 ± 0.019[f]
Theory	2(1)2(2)0	...	...	0.250	0
874-123	$2^{+''}, 2^+, 0^+$	-0.011 ± 0.013	0.204 ± 0.014[d]	-0.012 ± 0.014[c]	0.324 ± 0.001[e]
693-123	$2^{+'}, 2^+, 0^+$	-0.119 ± 0.023	0.148 ± 0.024	-0.134 ± 0.026[c]	0.235 ± 0.041[f]
1005-123	$3^{+'}, 2^+, 0^+$	-0.144 ± 0.010	-0.06 ± 0.01	-0.161 ± 0.011[c]	-0.09 ± 0.02[f]
1494-123	$3^-, 2^+, 0^+$	-0.065 ± 0.026	-0.013 ± 0.026	-0.073 ± 0.029[c]	-0.021 ± 0.041[f]

[a] $\Omega_2G_2 = 0.89\pm0.03$ obtained as ratio of this entry to that in Column 5.
[b] Stiening and Deutsch, Ref. 5.
[c] Corrected with $\Omega_2G_2 = 0.89$.
[d] Corrected with $\Omega_4G_4 = 0.63\pm0.04$ obtained as ratio of this entry to that in Column 6.
[e] $A_{4\text{th}}$ compatible with $A_{2\text{exp}}$.
[f] Corrected with $\Omega_4G_4 = 0.63$.

from 1274 to 693 keV was estimated to be no more than one percent. This Ω_2G_2 was applied to the 874-123-keV correlation and Ω_4G_4 was obtained by comparing the experimental results with the theoretical A_4 value, predicted by the corrected A_2 value. Our results on this correlation agree with those of Debrunner and Kundig.[7] The theoretical A_4 is essentially constant for A_2 values in the range observed. These corrections were then applied to the correlation of interest and to three other correlations as added tests.

Our results on the six γ-γ directional correlations are given in Table I. The Ω_2G_2 and Ω_4G_4 corrections as obtained from the 1274-123-keV and 874-123-keV A_2 and A_4 terms, respectively, were applied to the 1004-123-keV, 1492-123-keV, 1596-123-keV, and 693-123-keV correlations. The 1274-123-keV data imply about a 0.1% $M2$ admixture in the 1274-keV transition.[9] The 1596-123-keV data indicate about 0.5% admixture in the 1596-keV gamma ray. The presence of a weak (2.5%) 1248-keV transition with a negative A_2 term,[10] however, was undetected in the Stiening and Deutsch[9] work. This should raise their A_2 term by about 4% and consequently slightly lowers our correction factor. This increase in the A_2 value of the 123-1274-keV correlation further reduces the $M2$ admixture in the 1274-keV transition. This effect does not, however, change any conclusion about the 693-123-keV correlation. The 1004-123-keV correlation also showed an essentially pure $E2$ character for the 1004-keV transition as expected. This gives added verification to our correction factors. One notes for the 693-123-keV correlation that the values of A_2 and A_4 do not overlap in δ as seen in Fig. 2. However, of the two values of δ predicted from A_2, 77% $M1$ or 100% $E2$, the A_4 result is only two standard deviations from the latter and four from the former. The 50% $M1$ admixture possibly implied from other data[4,5] is clearly ruled out. In all our runs the pattern of the correlation is very similar to that of the 874-123-keV $2'' \to 2^+ \to 0^+$ cascade where the first transition is nearly pure $E2$.[7] The 80% $M1$ admixture has A_4 much less than A_2 and the reverse was obtained in all cases in our work on the 693-123-keV correlation as it would be for a pure $E2$ 693-keV gamma ray. Thus we conclude that the 692-keV tran-

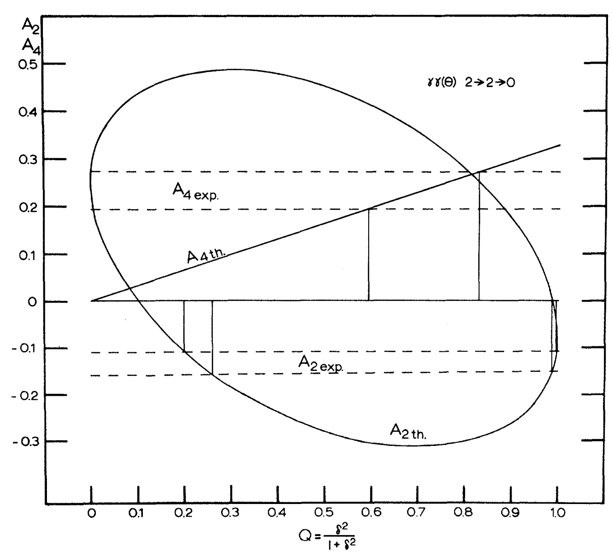

FIG. 2. Theoretical correlation coefficients A_2 and A_4 for $2 \to 2 \to 0$ cascade. The dashed lines are the experimental values.

sition is essentially pure $E2$.

McGowan, Sayer, and Stelson[11] have performed directional correlation measurements on ^{152}Sm in the Coulomb excitation of the $2^{+\prime}$ level. Their preliminary results indicate the $2^{+\prime}\to 2^+$ transition in ^{152}Sm is either about 80% $M1$ or 100% $E2$. Unforunately, they do not get the A_4 term. Since ^{152}Sm and ^{154}Gd are very similar in nuclear structure (both have 90 neutrons and are at the beginning of the deformed nuclear region), one is inclined to assume that the $2^{+\prime}\to 2^+$ transition in ^{152}Sm and the one in ^{154}Gd are both essentially pure $E2$. From the standpoint of obtaining a consistent Z_0 value, it should be emphasized that the 80% $M1$ result is just as bad as, if not worse than, the 100% $E2$ result.

This leaves unanswered the problem of the inconsistency[4,5] of the Z_0 mixing parameters. Our results are consistent with the first prediction of Bohr and Mottelson[6] that the radiations are essentially $E2$. If one combines the mixing-parameter[4,5] work with our work, however, it appears then that the characterization of these rotational states built on the low-lying 0^+ states in ^{152}Sm and ^{154}Gd as symmetric vibrations in the quadripole field of the nucleus is not correct and a new description of these vibrational states is needed.

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EVIDENCE FOR A NEW PRODUCTION PROCESS FOR 10^{12}-eV MUONS*

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In the course of a preliminary study of muon backgrounds with the University of Utah neutrino detector, the intensity of cosmic-ray muons has been measured as a function of depth and zenith angle. Slant depths from 2000 to 8000 hg/cm^2 (1 hg $=10^2$ g) have been studied corresponding to muon energies from 10^{12} to 10^{13} eV. Because of the rugged mountainous overburden, contours of equal slant depth span a considerable range of zenith angles as the azimuth is varied. At a given zenith angle θ, we find excellent agreement with the currently accepted dependence of intensity on depth. However, we find almost no variation in intensity with zenith angle, in strong contradiction to the $\sec\theta$ enhancement expected if these muons are the progeny of pions and kaons. At these energies most pions or kaons undergo nuclear interaction. Consequently, they have a better chance to decay in the rarer atmosphere encountered at the larger zenith angles.

The detector has been described by the Utah group.[1-3] Briefly, the trajectories of muons are determined by an array of cylindrical spark counters, each counter being in the form of a 15-cm-diam steel pipe with a wire down the