List of author's publications and reports


5. Gamma-gamma angular correlation in $^{131}$Cs, P.C. Mangal, S.P. Sud, Parveen Bawa and P.N. Trehan (to be published in Australian J. Phys.).


Sum Coincidence Spectrometer & the Study of Weak Cascading Gamma Rays*

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A sum coincidence spectrometer of the type developed by A. M. Hoogenboom [Nucl. Instrum. Meth., 3 (1958), 57] has been set up for the determination of relative intensities of weak gamma rays involved in the de-excitation of complex nuclei. A fast coincidence circuit is incorporated to reduce the random coincidences. The performance of the set-up has been checked with 60Co and 22Na sources. The relative intensities of 54, 162 and 276 keV γ-rays of 133Cs have been found out to be 2.9 ± 0.3, 2.7 ± 0.3 and 10.7 ± 1.1 per cent respectively as compared to 356 keV γ-ray.

SCINTILLATION spectrometer is a versatile tool for the investigations of the decay of radioisotopes. In the study of complex radioactive sources, with a single crystal spectrometer, the photopeaks of the low energy weak gamma rays are masked in the Compton background of intense high energy gamma rays and, therefore, the complete analysis of the spectrum becomes difficult. To overcome this difficulty, several multiple crystal spectrometers have been developed. However, Hoogenboom's sum coincidence spectrometer is considered to be the most suitable, in its usefulness, for the study of nuclei with complex spectra.

In the present investigations, a fast coincidence circuit has been incorporated in the Hoogenboom's sum coincidence spectrometer. The behaviour of this modified set-up has been checked up and compared with that developed by Viswesvara Rao et al. This set-up has been utilized for the determination of intensities of some very weak gamma rays of 133Cs. The results of all these investigations are presented in this paper.

Experimental Set-up

A block diagram of the experimental set-up is shown in Fig. 1(a). PM I and PM II are a matched pair of Harshaw integral line assemblies hermetically sealed with 3 x 3 in. NaI(Tl) crystals mounted on Dumont 6363 photomultiplier tubes. The fast coincidence circuit used has a resolution better than 100 nanosec. The output from the single channel analyser (SCA) and the fast coincidence circuit (FCC) are fed to a slow coincidence circuit (SCC) of resolving time of 3 μsec. The output of this circuit is used to gate a 256-channel analyser (MCA).

A slow-fast coincidence set-up used by Viswesvara Rao et al. is shown in Fig. 1(b). Here the fast coincidence circuit is put in between the sum channel and the channel driving the multichannel analyser. A relative study of the two set-ups of Fig. 1 has been made for their effectiveness in reducing the random coincidence contributions.

It is found that the set-up of Fig. 1(b) is about 25 per cent less effective in reducing the random coincidences than the set-up of Fig. 1(a). This was checked up after making all the necessary adjustments for any additional delays coming up in the circuit. The occurrence of relatively more random coincidences in the final sum coincidence output of Fig. 1(b) may be attributed to the fact that the pulses from the adder network are comparatively slower and, therefore, the effective resolution of the fast coincidence circuit becomes...
poorer. In the arrangement of Fig. 1(a) both the pulses have equally fast rise time; consequently, this results in better resolution.

Discussion

In the set-up of Fig. 1(a) the sum-peak is eliminated. This elimination of the sum-peak in the set-up of Fig. 1(a) does not in any way hamper the studies of the relative intensities, angular correlation and cascading relations. The sum-peak in the sum coincidence spectrum is useful only in the determination of cascade-to-crossover ratio in case of nuclei having only one cascade transition. In the case of complex nuclei, one generally has more than one cascade contributing to the sum-peak and in such cases sum-peak observation is of not much utility. In fact, in some cases where the total sum-peak energy is closer to the higher energy component of the cascade under study, it is preferable to remove the sum-peak from the sum coincidence spectrum for proper analysis of the sum coincidence spectrum.

At this point it is worth while to mention the different processes which are responsible for the formation of a sum coincidence spectrum.

1. The detection of $\gamma_1$ in crystal I in coincidence with $\gamma_2$ which is detected in crystal II gives rise to a peak corresponding to energy $\gamma_1$ ($\gamma_1$ and $\gamma_2$ are assumed as the constituents of a particular cascade under study and crystal I is assumed as the scanning crystal put on the multichannel analyser side).

2. The detection of $\gamma_2$ in crystal I in coincidence with $\gamma_1$ which is detected in crystal II gives rise to a peak corresponding to energy $\gamma_2$ in the sum coincidence spectrum.

3. The summing of $\gamma_1$ and $\gamma_2$ in crystal I gives rise to a peak corresponding to energy ($\gamma_1+\gamma_2$) in the sum coincidence spectrum.

4. The summing of $\gamma_1$ and $\gamma_2$ in crystal II is of no interest because it is not registered in the sum coincidence spectrum.

Now, in case of the set-up of Fig. 1(b), first three types of events are registered and consequently give rise to three peaks at $\gamma_1$, $\gamma_2$ and ($\gamma_1+\gamma_2$). The true-to-chance ratio for $\gamma_1$ and $\gamma_2$ peaks of this spectrum is determined by the resolving time of the fast coincidence circuit, whereas in case of ($\gamma_1+\gamma_2$) peak it is the function of the resolution of crystal I in which $\gamma_1$ and $\gamma_2$ are summed up. The fast coincidence circuit does not help at all to reduce the random coincidence contribution from this peak.

In case of the set-up of Fig. 1(a), only the first two types of events are registered and, therefore, one gets only two peaks corresponding to $\gamma_1$ and $\gamma_2$. The peak corresponding to ($\gamma_1+\gamma_2$) is eliminated. The true-to-chance ratio for these two peaks is again a function of the fast coincidence circuit and because of the fact that the two pulses in this case are well matched, as discussed earlier, it is better than that of the set-up of Fig. 1(b). The photopeak coincidence detection efficiency in both the set-ups remains the same as in a set-up without fast coincidence circuit. Therefore, it may be concluded that in view of the the above advantage the set-up of Fig. 1(a) is superior to that of Fig. 1(b) for determination of relative intensities, angular correlation measurements and studying cascading relations. Further it may be mentioned that even for measurement of cascade-to-crossover ratio, it is better to get the area under the sum-peak by using no fast
The K-Shell Internal Conversion Coefficient of the 53 keV Gamma Ray of $^{103}$Rh*

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Manuscript received 16 December 1968; revised manuscript received 26 February 1969

The K-shell internal conversion coefficient ($\alpha_K$) of the 53 keV gamma ray of $^{103}$Rh has been measured by K X-ray peak to gamma peak method to be $\alpha_K = 1.90 \pm 0.06$. This indicates a predominant M1 character with less than 1% E2 admixture for this gamma transition.

The most recent determination1 of K-shell internal conversion coefficient ($\alpha_K$) for the 53 keV gamma transition observed in the decay of $^{103}$Ru to $^{103}$Rh has yielded a value of $\alpha_K = 1.77 \pm 0.03$. This value is significantly different from the values 2.74 + 0.13 and 1.2 + 0.3 reported by Mukerjee et al2 and Saraf3 respectively. Since the knowledge of this conversion coefficient is essential for a correct interpretation of the directional correlation results of the 445-53 and 557-53 keV gamma ray cascades in $^{103}$Rh, it was, therefore, thought worth while to carefully measure the conversion coefficient of the 53 keV gamma transition.

The radioisotope $^{103}$Ru, prepared by distillation of fission products of natural uranium which was irradiated for a short time, was supplied by the Bhabha Atomic Research Centre, Bombay. The isotope was in the form of RuCl$_3$ in HCl solution. A few drops of this active solution were put in a thin cylindrical perspex holder of wall thickness 1 mm.

Fig. 1 shows the level scheme of $^{103}$Rh populated in the decay of $^{103}$Ru (ref 1). The 445 and 557 keV gamma rays are in coincidence only with the 53 keV gamma ray. The K-conversion coefficient was measured by observing the 53 keV gamma ray and K X-rays due to conversion of the 53 keV gamma ray, in coincidence with the 557 keV gamma transition. A Harshaw integral line assembly (type 8S8) incorporating a 2 in. diam x 2 in. thick NaI(Tl) crystal was used to select a gate on the 557 keV gamma ray. The gamma ray spectrum in coincidence with the gate energy was recorded with the help of a 1 in. diam x 1 in. thick NaI(Tl) crystal using a 256-channel pulse height analyser. The effective resolving time of slow-fast coincidence set-up was 100 nsec. The coincidence detection efficiency of the set-up was checked with the help of $^{22}$Na to be 100% from 15 keV upwards.

Fig. 2 shows a typical coincidence spectrum corrected for random coincidences with the gate set at 557 keV. The spectrum shows two peaks at 20 and 53 keV respectively. The first peak is

![Fig. 1 — Level scheme of $^{103}$Rh populated in the decay of $^{103}$Ru](image)

![Fig. 2 — Gamma-gamma coincidence spectrum of $^{103}$Ru with gate set at 557 keV gamma ray peak](image)

**Table 1 — Parameters of Measurements of $\alpha_K$**

<table>
<thead>
<tr>
<th>Source-to-detector distance cm</th>
<th>Counts in</th>
<th>Escape and absorption corrected $\alpha_K$</th>
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<tr>
<td></td>
<td>Gross spectrum</td>
<td>Chance spectrum</td>
</tr>
<tr>
<td></td>
<td>K X-ray peak</td>
<td>$\gamma$-ray peak</td>
</tr>
<tr>
<td>7</td>
<td>3769 ± 61</td>
<td>3571 ± 60</td>
</tr>
<tr>
<td>7</td>
<td>2475 ± 49</td>
<td>2376 ± 49</td>
</tr>
<tr>
<td>5</td>
<td>2450 ± 50</td>
<td>2313 ± 48</td>
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</tbody>
</table>

$\alpha_K = 1.90 \pm 0.06$
due to the K X-rays of rhodium emitted because of the conversion of the 53 keV gamma rays in the K-shell. The second peak is the unconverted part of the same gamma ray. The decay of this source was followed over a period of two half-lives to check the purity of the source. The ratio of the areas under the K X-ray and the gamma ray peaks was found to be constant within 2% (Table 1) during this period, indicating an absence of impurities in any significant proportion in the radioisotope.

The K-shell conversion coefficient was calculated from the ratio of the number of counts under the X-ray and gamma ray peaks. Corrections were introduced to take into account (i) attenuation due to the thickness of the window of the 'display' crystal (equivalent to 0.08±0.01 mm of aluminium) and walls of the source holder, (ii) escape of iodine X-rays for the 53 keV gamma ray, (iii) K-shell fluorescence yield for rhodium and (iv) variation of detection efficiency with gamma ray energy. Since the escape peak of the 53 keV gamma ray lies under the 20 keV X-ray photopeak, the area of the X-ray peak was decreased by the same amount by which the area of the gamma ray peak was increased. An average of three measurements yielded a value of \( a_K = 1.90 \pm 0.06 \) (Table 1). This value is in fair agreement with the value reported by Potnis et al but does not agree with the values reported by Mukerjee et al and Saraf.

The value of \( a_K = 1.90 \pm 0.06 \) indicates a predominant M1 character with less than 1% E2 admixture, for the 53 keV gamma ray, if comparison is made with the values of \( a_K \) taken from the tables of Sliv and Band. This conclusion is in agreement with the recent measurement of L-subshell ratios for the 53 keV transition which indicate a pure M1 character for this transition.

The authors wish to thank Shri P. C. Mangal for discussions. The study was supported by the National Bureau of Standards, Washington, and the Department of Atomic Energy, Government of India.

References
coincidence circuit and get the areas under $\gamma_1$ and $\gamma_2$ peaks with the help of the set-up of Fig. 1(a).

The operational behaviour of the set-up of Fig. 1(a) was checked up for proper resolution and 100 per cent coincidence detection efficiency. This set-up has then been utilized for the determination of relative intensities of some weak gamma rays in $^{133}$Cs. The level scheme of $^{133}$Cs, as observed from the electron capture decay of $^{133}$Ba, is shown in Fig. 2. The excited levels at 82, 162 and 438 keV. are well established. The relative intensities of 80-82, 302, 356 and 384 keV. gamma rays, reported by various workers, are found to disagree slightly, but there exists a considerable discrepancy in the intensity measurements by various authors for 54, 162, 222 and 276 keV. gamma rays. Particularly the disagreement becomes more marked in the case of 54 keV. gamma ray on account of the complexities due to the presence of intense Compton background of higher energy gamma rays and escape-peak of 80 and 82 keV. gamma rays in the region of 54 keV. gamma ray. The sum coincidence technique is a powerful method in such studies as it eliminates most of these difficulties.

The sum coincidence spectrum of $^{133}$Ba with gate set at 438 keV. is shown in Fig. 3. The three competing gamma ray cascades of energies (356, 82 keV.), (276, 162 keV.) and (54, 384 keV.), which individually sum up to 438 keV., are present in this spectrum. The 54 and 384 keV. gamma rays, which are not separated out in a single or simple coincidence spectrum, are showing up here. The experiment was run twice, 5 hr each time, to get good statistics. The gate was regularly checked after every half an hour. From these measurements the relative intensities of 54, 162 and 276 keV. gamma rays have been calculated and are given in Table 1 along with the values reported by other workers. To get the true intensity of 356 keV. gamma ray, correction has been made for the internal conversion of 82 keV. gamma ray. From our measurements the uncorrected relative intensity of 162 keV. gamma ray was found out to be 2.5 per cent. If we assume the branching ratio of the electron capture transition of 162 keV. level to be 1 per cent and cascade-to-crossover ratio of N80/N162 to be 3-8, the corrected value for the intensity of 162 keV. gamma ray comes to 2.7 per cent. The relative intensity of 276 keV. gamma ray has also been corrected for cascade-to-crossover ratio (N80/N162) taking it to be 3-3 as calculated from our result of intensity of 162 keV. gamma ray given by Stewart and Lu. The relative intensity of 54 keV. gamma ray has been corrected for cascade-to-crossover ratio (N302/N384) taking its value from single crystal spectrometer measurements. The correction due to the participation of 222 keV. gamma ray in de-exciting the 384 keV. level is very insignificant and has, therefore, been left out.

The authors wish to thank Shri K. K. Suri for helpful discussions.

References


Table 1 — Relative Gamma Ray Intensities

<table>
<thead>
<tr>
<th>Gamma ray energy (keV)</th>
<th>Gupta et al.8</th>
<th>Stewart and Lu9</th>
<th>Ramaswamy et al.10</th>
<th>Mann and Chaturvedi17</th>
<th>Present results</th>
</tr>
</thead>
<tbody>
<tr>
<td>356</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>54</td>
<td>7.32</td>
<td>3</td>
<td>2.4</td>
<td>2.5 ± 1</td>
<td>2.9 ± 0.3</td>
</tr>
<tr>
<td>162</td>
<td>0.4</td>
<td>0.1</td>
<td>2.0</td>
<td>10.1 ± 1</td>
<td>10.7 ± 1.1</td>
</tr>
<tr>
<td>276</td>
<td>3.3 ± 0.2</td>
<td>8</td>
<td>2</td>
<td>10.1 ± 1</td>
<td>10.7 ± 1.1</td>
</tr>
</tbody>
</table>

The operational behaviour of the set-up of Fig. 1(a) was checked up for proper resolution and 100 per cent coincidence detection efficiency. This set-up has then been utilized for the determination of relative intensities of some weak gamma rays in $^{133}$Cs. The level scheme of $^{133}$Cs, as observed from the electron capture decay of $^{133}$Ba, is shown in Fig. 2. The excited levels at 82, 162 and 438 keV. are well established. The relative intensities of 80-82, 302, 356 and 384 keV. gamma rays, reported by various workers, are found to disagree slightly, but there exists a considerable discrepancy in the intensity measurements by various authors for 54, 162, 222 and 276 keV. gamma rays. Particularly the disagreement becomes more marked in the case of 54 keV. gamma ray on account of the complexities due to the presence of intense Compton background of higher energy gamma rays and escape-peak of 80 and 82 keV. gamma rays in the region of 54 keV. gamma ray. The sum coincidence technique is a powerful method in such studies as it eliminates most of these difficulties.

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References

SUM-PEAK-COINCIDENCE SPECTROMETER AND GAMMA-GAMMA ANGULAR CORRELATION STUDIES IN Ca^{129+}

By
S. P. SUD, P. C. MANGAL, K. K. SURI AND P. N. TREHAN

INDIAN ASSOCIATION FOR THE CULTIVATION OF SCIENCE CALCUTTA-32
SUM-PEAK-COINCIDENCE SPECTROMETER AND GAMMA-GAMMA ANGULAR CORRELATION STUDIES IN Cs\textsuperscript{133}

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ABSTRACT. A sum-peak-coincidence spectrometer has been set up to study the directional correlation of 356.82 KeV and 276.162 KeV cascades in Cs\textsuperscript{133} following the decay of Ba\textsuperscript{133}. The correlation functions for these cascades have been found out to be:

\[ W(\theta) = 1 + (0.0350 \pm 0.0015)P_2(\cos \theta) - (0.0048 \pm 0.0034)P_4(\cos \theta) \]

and

\[ W(\theta) = 1 - (0.412 \pm 0.018)P_2(\cos \theta) - (0.025 \pm 0.015)P_4(\cos \theta) \]

respectively. These results support spin assignments \( \frac{1}{2}^+ \) for 438 KeV level and \( \frac{5}{2}^+ \) for 162 KeV level in Cs\textsuperscript{133}. The mixing ratios for 82 KeV and 162 KeV transitions come out to be \((97.2 \pm 0.3)\% M_1 + (2.8 \pm 0.3)\% E_2\) and \((75.8 \pm 3.2)\% + (24.2 \pm 3.2)\% E_2\) respectively.

INTRODUCTION

An ordinary slow-fast coincidence spectrometer is suitable for the study of angular correlation for those cascades which are well resolved and have moderately high intensities. In case the competing cascades deexciting the same level are close in energy, the slow-fast coincidence spectrometer fails to yield very accurate results and especially in those cases where the asymmetry is relatively small it rather becomes impossible to draw any unambiguous conclusions regarding the spin assignments to the levels involved. Further even when the measurements on such cascades is attempted by gating at the lower or the higher energy ends of the constituents peaks, it puts a stringent requirement of high degree of electronic stability on the spectrometer which is generally hard to achieve. In case of relatively weak cascades slow-fast-coincidence spectrometer requires a lot of time to make any worthwhile angular correlation measurements.

Sum-peak coincidence spectrometer of Kantele et al, (1962) possesses some special advantages over the ordinary slow-fast coincidence spectrometer which makes it more suitable for carrying out gamma-gamma angular correlation measurements in the above mentioned cases. These advantages are (a) double coincidence detection efficiency (b) a lack of narrow gating channels (c) insensitivity to minor electronic drifts. Further in some cases where the sum peaks are well
separated the angular correlation for various cascades can be studied simultaneously 
with the help of a sum-peak coincidence spectrometer incorporating multichannel 
analyser.

With these advantages in view a sum-peak coincidence spectrometer has been 
set up for angular correlation measurements. Its behaviour has been checked 
with a standard cascade of Ni$^{60}$ and gamma-gamma angular correlation measure­
ments have been carried out for $358-82$ KeV and $276-162$ KeV cascades in Cs$^{133}$.

EXPERIMENTAL ARRANGEMENTS

A schematic diagram of the sum-peak coincidence spectrometer is shown in 
figure 1. The two detectors (SH) are a matched pair of $2''$ dia $\times 2''$thick NaI(TI) 
crystals mounted on RCA 6292 photomultipliers. The effective resolving time 
of the set up was checked to be 65 n-secs. Two single channel analysers (SCA), 
operated in integral-bias mode, delivered output pulses of constant amplitude 
which along with the output pulses of the fast coincidence circuit (FCC) operated 
a slow coincidence circuit (SCC). The output of the slow coincidence circuit 
gated a RCL 256 channel analyser. The linear adding circuit (LAC) received 
pulses from the two scintillation heads, the gains for which were set almost equal. 
Final equalization of the gain was achieved by adjusting a potentiometer in the 
linear adding circuit itself. The output of the adder was fed to the multichannel 
analyser. Compton graded lead cylinders and lead cones were used to mini­
mize the crystal to crystal scattering.

MEASUREMENTS AND RESULTS

All the measurements were carried out at a source to crystal distance of 10 
cm. The radioactive source Ba$^{133}$ in the form of BaCl$_{2}$ dissolved in HCl was 
obtained from Bhabha Atomic Research Centre, Bombay, India. A small source 
was prepared in a perspex holder of cylindrical shape with a small hole at the top.
The diameter of the hole was 2 mm. and the depth was about 6 mm.; the wall thickness was 2 mm. The source could be centered within 0.5% accuracy. The coincidences were recorded at seven angles, at an interval of 15° each, between 90° and 180°. Integral counts of the movable arm were recorded at all the angles to correct for any decentering of the source. After making a least square fit of the correlation data (Rose, 1953) the correlation coefficients were corrected for finite angular resolution of the detectors (Yates, 1964).

The whole set up was checked for angular correlation measurements with the standard cascade (1.33—1.17 MeV) of Ni60. To check the insensitivity of the whole set up to minor electronic drifts the integral biases were varied a little on both sides from the original setting. It was observed that the area under the sum peak is not affected at all. An inequalization at the adder made the sum-peak broader but its area as a whole did not change. The coincidence rate with this spectrometer was found to be almost double of that with a simple slow-fast coincidence set up.

356-82 KeV CASCADE IN Cs133

The decay scheme of Ba133 as given by Yin et al., (1964) is shown in figure 2. Gamma-gamma angular correlation measurements for 356-82 KeV cascade in Cs133 have been carried out by sum-peak coincidence method. The integral biases in the two channels were set at 70 KeV so as to bias out Cs133 K X ray and 54 KeV gamma ray.

Figure 3. (solid curve) shows the observed sum-peak coincidence spectrum with 70 KeV bias. Sum-peaks at 162 KeV, 384 KeV and 438 KeV are observed corresponding to the summing of 80-82 KeV, 302-82 KeV, 356-82 KeV and 276-162 KeV cascades. The 438 KeV sum-peak contains contributions due to two cascades namely 356-82 KeV and 276-162 KeV. The contribution due to the latter cascade was measured and subtracted at each angle separately (measurements discussed in next section). To avoid any contribution from the sum of 302-82
KeV gamma rays, falling in the lower portion of the sum-peak at 438 KeV, only the upper half of the area of 438 KeV peak was taken. This way about $1.6 \times 10^5$

![Graph](image_url)

Fig. 3. Sum-peak-coincidence spectra of Ba$^{133}$ with a pair of 2"x2" NaI(Tl) detectors and source-to-crystal distance of 10 cm. Solid line and dotted line show the 70 KeV bias and 120 KeV bias spectra respectively.

coincidence counts were collected at each angle. After applying finite solid angle correction the coefficients $A_2$ and $A_4$ for 356-82 KeV cascade are given in table 1 along with the results of other authors. Figure 4 (solid curve) shows the observed angular correlation function $W(\theta)$ for the 356-82 KeV cascade.

![Graph](image_url)

Fig. 4. Plots of $W(\theta)$ vs $\theta$ for the cascades 356-82 KeV and 276-162 KeV respectively.

The spin of the ground state of Cs$^{133}$ and Ba$^{133}$ have been measured (Mack et al, 1950 and Goldhaber et al, 1952) to be $7/2^+$ and $1/2^+$ respectively. The electron capture transition from the ground state of Ba$^{133}$ to the 438 KeV level of Cs$^{133}$ being of allowed type the spins $1/2^+$ and $3/2^+$ are possible for the 438 KeV level,
A spin of $3/2^+$ has been proposed (Subba Rao, 1961) on the basis of $81\text{K}^\gamma-356\gamma$ electron gamma directional correlation measurements. Other authors (Bodenstedt et al., 1959; Münich et al., 1963; Arya, 1961 and Yin et al., 1964) assign a spin $1/2^+$ on the basis of $356-82\text{K}\gamma$ gamma-gamma angular correlation measurements. The assignment $3/2^+$ to the $438\text{ KeV}$ level is rejected as this level is not reached in the coulomb excitation of Cs$^{133}$ (Fagga, 1958). Our results confirm $1/2^+$ assignment to the $438\text{ KeV}$ level. Assignment of $3/2^+$ requires $A_4$ to be positive while experimentally it is found to be negative. Recent measurements (Thun et al., 1966 and Othaz, 1965) on the directional correlation of $81\text{K}^\gamma-356\gamma$ electron gamma correlation also support $1/2^+$ spin assignment to $438\text{ KeV}$ level. Thus the spin sequence for the $356-82\text{ KeV}$ cascade is:

$\frac{1}{2} (Q) \neq (D, Q) \frac{1}{2}$

Figure 5 shows a graphical analysis of the results for $356-82\text{ KeV}$ cascade in terms of above spin sequence for determining the quadrupole admixture in the $82\text{ KeV}$ transition using the single transition mixture curve (Arns and Wiedenbeck, 1958). A quadrupole content of $Q_1 = 0.028 \pm 0.003$ is given for the $82\text{ KeV}$ gamma ray. The value $Q_2$ is incompatible with the positive value of $A_4^{(\text{expt})}$. Thus
it is concluded that the mixing ratio of 82 KeV gamma ray is $2.8 \pm 0.3\% E_2$ and $97.2 \pm 0.3\% M_1$. This result is in agreement with the recent value obtained by Thun et al (1966) (Viz $\delta = -0.155 \pm 0.005$ giving $E_2 = 2.34 \pm 0.08 \%$) on the basis of 81K-356y KeV angular correlation.

![Graphical representation of quadrupole admixture for the 162 KeV transition (5/2+→7/2+)](image)

**Fig. 6.** Quadrupole admixture for the 162 KeV transition (5/2+→7/2+)

For this cascade, the single channels were biased to cut all gamma rays up to 120 KeV. The spectrum, (figure 3 dotted line), shows a sum-peak at 438 KeV which is now only due to 276-162 KeV cascade. A total of $4.0 \times 10^4$ true coincidences were accumulated at each angle. The angular correlation coefficients after finite solid angle correction along with the results of other workers are given in table Figure 4 (dotted curve) shows the angular correlation function $W(\theta)$ for the 276-162 KeV cascade.

Since the spin of 438 KeV level has been confirmed to be $1/2^+$ and the ground state spin being $7/2^+$, the results for the 276-162 KeV cascade require a spin $5/2^+$ for the intermediate 162 KeV level. The other possible assignment of $3/2^+$ is eliminated as it requires $A_2$ to be zero and experimentally it is found to be non-zero. Therefore the spin sequence for 276-162 KeV cascade is:

$$1/2(0) 5/2^+ 7/2^+$$

Figure 6 shows a graphical analysis of the results for the 276-162 KeV cascade in terms of the above spin sequence for the second transition to be mixed. The two possible solutions on the basis of $A_2^{(1)}$ (expt.) are:

- $Q_1 = 0.240 \pm 0.32$
- $Q_2 = 0.867 \pm 0.027$
Gamma-Gamma Angular Correlation in Cs$^{133}$

The experimental value of $A_4^{(2)}$ restricts $Q$ within the limits $0.09 < Q < 0.35$; so the value $Q_2$ is rejected. Therefore the mixing ratio of the 162 KeV gamma ray is $24.2 \pm 3.2\% E_2$ and $75.8 \pm 3.2\% M_1$. These results are in agreement with the results of Aggarwal et al, (1965) Münich et al, (1963) and Thun et al, (1966) but not in agreement with the results for Yin and Wiedenbeck, (1964).

### Table 1
Gamma-gamma directional correlation measurement results on 356-82 KeV cascades in Cs$^{133}$

#### 356-82 KeV cascade

<table>
<thead>
<tr>
<th>Authors</th>
<th>$A_2$</th>
<th>$A_4$</th>
<th>Assignments</th>
</tr>
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<tbody>
<tr>
<td>Subba Rao (1961)</td>
<td>$0.046 \pm 0.011$</td>
<td>$-0.008 \pm 0.014$</td>
<td>$3/2^+(M_1+E_2)5/2^+(M_1+E_2)7/2^+$ $Q_{82}=0.004$</td>
</tr>
<tr>
<td>Bodenstedt, et al, (1959)</td>
<td>$0.042 \pm 0.005$</td>
<td>$-0.004 \pm 0.007$</td>
<td>$1/2^+(E_2)5/2^+(M_1+E_2)7/2^+$ $Q_{82}=0.023$</td>
</tr>
<tr>
<td>Münich et al, (1963)</td>
<td>$0.037 \pm 0.0020$</td>
<td>$-0.0031 \pm 0.0015$</td>
<td>$1/2^+(E_2)5/2^+(M_1+E_2)7/2^+$ $Q_{82}=0.0236 \pm 0.0010$</td>
</tr>
<tr>
<td>Arya, (1961)</td>
<td>$0.042 \pm 0.0050$</td>
<td>$-0.0041 \pm 0.0038$</td>
<td>$1/2^+(E_2)5/2^+(M_1+E_2)7/2^+$ $Q_{82}=0.035 \pm 0.005$</td>
</tr>
<tr>
<td>Yin et al, (1964)</td>
<td>$0.0331 \pm 0.0017$</td>
<td>$0.0045 \pm 0.0033$</td>
<td>$1/2^+(E_2)5/2^+(M_1+E_2)7/2^+$ $Q_{82}=0.024 \pm 0.001$</td>
</tr>
<tr>
<td>Thun et al, (1965)</td>
<td>$0.037 \pm 0.005$</td>
<td>$-0.002 \pm 0.006$</td>
<td>$1/2^+(E_2)5/2^+(M_1+E_2)7/2^+$ $Q_{82}=0.023 \pm 0.006$</td>
</tr>
<tr>
<td>Present work</td>
<td>$0.0359 \pm 0.0015$</td>
<td>$-0.0048 \pm 0.0034$</td>
<td>$1/2^+(E_2)5/2^+(M_1+E_2)7/2^+$ $Q_{82}=0.028 \pm 0.003$</td>
</tr>
</tbody>
</table>

#### 276-162 KeV Cascade

<table>
<thead>
<tr>
<th>Authors</th>
<th>$A_2$</th>
<th>$A_4$</th>
<th>Assignments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bodenstedt, et al, (1959)</td>
<td>$-0.442 \pm 0.009$</td>
<td>$-0.040 \pm 0.012$</td>
<td>$1/2^+(E_2)5/2^+(M_1+E_2)7/2^+$ $Q_{42}=0.31$ or 0.83</td>
</tr>
<tr>
<td>Münich et al, (1963)</td>
<td>$-0.421 \pm 0.015$</td>
<td>$-0.016 \pm 0.013$</td>
<td>$1/2^+(E_2)5/2^+(M_1+E_2)7/2^+$ $Q_{42}=0.30 \pm 0.02$</td>
</tr>
<tr>
<td>Yin et al, (1964)</td>
<td>$-0.328 \pm 0.009$</td>
<td>$-0.067 \pm 0.01$</td>
<td>$1/2^+(E_2)5/2^+(M_1+E_2)7/2^+$ $Q_{42}=0.90 \pm 0.006$</td>
</tr>
<tr>
<td>Aggarwal et al, (1965)</td>
<td>$-0.442 \pm 0.011$</td>
<td>$-0.026 \pm 0.014$</td>
<td>$1/2^+(E_2)5/2^+(M_1+E_2)7/2^+$ $Q_{42}=0.32 \pm 0.03$</td>
</tr>
<tr>
<td>Present work</td>
<td>$-0.412 \pm 0.018$</td>
<td>$-0.025 \pm 0.015$</td>
<td>$1/2^+(E_2)5/2^+(M_1+E_2)7/2^+$ $Q_{42}=0.24 \pm 0.03$</td>
</tr>
</tbody>
</table>
S. P. Sud, P. C. Mangal, K. K. Suri and P. N. Trehan

REFERENCES

Aggarwal, Y. N., Baba, C. V. K. and Bhattacharjee, S. K., 1965, Nuclear Physics, 63, 685.
Bodenstedt, E., Korner, H. J. and Mathias, E., 1959, Nuclear Physics, 11, 584.
In the present study the level scheme of W182 has been investigated using a sum-peak coincidence spectrometer in almost 4π geometry. Since this spectrometer, when used in 4π geometry, has the highest coincidence detection efficiency and is almost insensitive to minor electronic drifts, it is considered to be a good tool for studying the weak and multiple cascading γ-rays as are encountered in the decay of Tantalum-182.

The block diagram of the spectrometer is shown in Fig. 2. Since this spectrometer, when used in 4π geometry, has the highest coincidence detection efficiency and is almost insensitive to minor electronic drifts, it is considered to be a good tool for studying the weak and multiple cascading γ-rays as are encountered in the decay of Tantalum-182.

The sum-peak at 590 keV shows up due to the summing of 351 and 229 keV γ-rays of W182. The sum-peak at 1810 keV is explainable if we assume the summing of 1410, 229 and 100 keV γ-rays. Since a triple sum-peak in this energy range is expected to be about 70 keV higher than the actual sum of the constituent γ-rays, a new level is proposed at 1740 keV which deexcites by 1410-229-100 keV triple cascade. In order to check the existence of this cascade a sum-peak coincidence spectrum, with integral bias settings raised to about 390 keV, has been run and is shown in Fig. 3 b. In this setting 100, 229 keV γ-rays and the single crystal sum of 100 and 229 keV γ-rays are blasted out. There is no indication of 1810 keV sum-peak in this spectrum. In the region of 1810 keV a flat background comes up which is mainly because of the chance summing of high energy γ-rays of W182. The spectrum of curve (b) was subtracted from that of curve (a) in order to take care of the chance contribution from the
former spectrum. The high energy portion of the subtracted spectrum is shown in the inset of this diagram. Here 1810 keV peak is showing up more clearly which clearly indicates a new level at 1740 keV.