CHAPTER IV

INSTRUMENTATION AND EXPERIMENTAL PROCEDURE

This chapter deals with the instrumentation which was fabricated and used to carry out the investigations of the internal hyperfine fields and g-factors using the integral perturbed angular correlation technique. A brief description of the arrangement for performing the experiments at liquid nitrogen temperature is also given.

4.1 The Crystal and photomultiplier Assemblies:

In the present investigations NaI (Tl) scintillators of size 1.72" (dia) x 2" (length) mounted on Dumont 6232 photomultiplier tubes were used. The NaI(Tl) crystals were mounted on photomultiplier tubes in a way to give best possible resolution. The energy resolution was ~10% for the 662 keV gamma ray of Cs\(^{137}\). Fig. 4.1 shows the circuit diagram of the voltage divider resistor chain used for supplying accelerating voltage to the dynodes of the photomultiplier tubes. The circuit diagram of the white cathode follower used is also shown alongwith. The voltage applied to the focusing electrode could be varied and it was adjusted to obtain the best possible energy resolution.

4.2 Fast Amplifiers:

A pair of fast amplifiers, utilizing the principle of shunt compensation\(^1\) were fabricated. The output of the fast amplifiers had an improved risetime and frequency response for
FIG. 4.1 CIRCUIT DIAGRAM OF THE PHOTOMULTIPLIER AND THE CATHODE FOLLOWER
the scintillation pulses. Fig. 4.2 shows the circuit diagram of the fast amplifier. Valve VI to V4 form a shunt compensated distributed amplifier and V5, V6 are limiter and cathode follower respectively. Plate circuit of each tube carries a small inductance, the value depending on the load resistance and anode capacitance of the tube. The fast amplifier output had an amplitude +10 volts and risetime 30 nsec.

4.3 Fast Coincidence Circuit:

A fast coincidence circuit\(^2\) incorporating a 6BN6 gated beam tube was assembled. Its circuit diagram is shown in fig. 4.3. Shaping of the fast amplifier pulses was done by E88 CC tubes having pulse transformers in their plate circuits. These pulse transformers were fabricated in the laboratory and the best results were obtained using 15 turns each of primary and secondary of SWG 44 wire on a ferrite core of diameter 5 mm. The outputs of the pulse shaper circuits had a FWHM of 30 nsec. The shape and FWHM of these pulses was responsible for the resolving time of the coincidence circuit. These output pulses had an amplitude +12 volts and were given to the grids of the 6BN6 tube. The grids of the coincidence tube were biased such that for single or no input pulse, there was no recordable output pulse. An output will only result whenever these pulses are simultaneous. The coincidence output of the 6BN6 tube was fed to EF91. EF91 serves as an amplifier and inverter for the coincidence output. The discrimination of singles pulses from the coincidence events was done with the help of a univibrator circuit consisting of two 6AK5 tubes. The bias of the 6AK5 input could be varied and it
FIG. 4.2 CIRCUIT DIAGRAM OF THE FAST AMPLIFIER UNIT.
FIG. 4.3  CIRCUIT DIAGRAM OF THE FAST COINCIDENCE UNIT
was set to such a position that only coincidence events were accepted. The output of univibrator circuit had an amplitude +16 volts and it was a square wave pulse with $4\mu$sec width. 12AU7 is the cathode follower having a pulse stretcher incorporated in it. Pulse stretching was necessary for matching the delay.

4.4 Univibrator Circuits:

The circuit diagram of univibrator is shown in fig. 4.4. The pulses from the slow channels were shaped to a width of $4\mu$sec for proper matching. The fast coincidence output was shaped to a width of $4\mu$sec and then this pulse was differentiated. The positive portion of this differentiated pulse was clipped using 0A85 diode to introduce the necessary delay in the fast channel for proper matching. This delay could be varied by varying the width of the univibrator output and it was set for maximum coincidence output of the triple coincidence unit.

4.5 Slow Triple Coincidence Unit:

The circuit diagram of the slow triple coincidence unit is given in fig. 4.5. It is a Rossi type slow coincidence circuit using 6AU6 tube. Tubes $V_1$, $V_2$, $V_3$ accept negative pulses. Therefore slow pulses from the univibrator were inverted using 6AU6 tube. The inverter circuit is also shown in fig. 4.4. An output of the triple coincidence will result whenever there is a simultaneous presence of all the three pulses at the grids of the respective tubes $V_1$, $V_2$ and $V_3$ and the pulses are present within the resolving time of the coincidence circuit.
FIG. 4.4  CIRCUIT DIAGRAM OF THE UNIVIBRATOR AND INVERTER UNIT.
FIG. 4.5 CIRCUIT DIAGRAM OF A SLOW TRIPLE COINCIDENCE UNIT.
4.6 Gamma Ray Spectrometer:

Fig. 4.6 shows the block diagram of the slow fast coincidence set up. High voltage to the photomultiplier is supplied by a regulated variable high voltage power supply (EHT) tube HV 200 obtained from Electronic Corporation of India Ltd. (ECIL). The output from the anode of the photomultiplier, after a cathode follower, was fed to a non overload amplifier (LA) type PAS20A (ECIL). The amplified output was fed to a single channel analyser (SCA) type SC600 (ECIL). The differential output of the single channel analyser had an amplitude of +12 volts and width 1 μsec. The output pulses of the single channel analysers were delayed by 4 μsec from the input pulse. The output of the single channel analysers were fed to a scaler type DS325 (ECIL).

4.7 Slow Fast Coincidence Set Up:

Fig. 4.6 shows the diagram of the slow fast coincidence set up having a resolving time $\tau = 60 \mu \text{sec}$. The two photomultiplier assemblies $PM_I$ and $PM_{II}$ feed pulses to the slow channels as well as the fast channels. The fast channel consists of a cathode follower (CF), a fast amplifier (FA) and a fast coincidence unit (FC). For a particular nuclear cascade of interest, with two gamma rays $\gamma_1$ and $\gamma_2$, energy selection was made by gating $\gamma_1$ in one slow channel and $\gamma_2$ in the other. Each slow channel consists of a cathode follower (CF), a linear amplifier (LA), a single channel analyser (SCA) and a univibrator circuit (UC). The fast channel improves the resolving time of the coincidence set up.
FIG. 4.6 BLOCK DIAGRAM OF A SLOW FAST COINCIDENCE SET UP.
The resolving time of the coincidence set up was checked by feeding the annihilation radiation from Na$^{22}$ in both the channels. The number of coincidences were recorded by varying the delay in one channel. FWHM from the plot of the coincidences vs delay gave the resolving time $2\tau$.

A second method of random coincidences was also used to find the resolving time of the coincidence circuit. Detectors were kept a large distance apart and two independent gamma sources were kept near them. If $N_1$ represents the counts registered per sec. in one channel and $N_2$ the counts registered in the second channel and $N_{ch}$ is the number of random coincidences, the resolving time is given by

$$2\tau = \frac{N_{ch}}{N_1 N_2}$$

(4.1)

from both these methods, resolving time was found to be $2\tau = 60$ nsec.

4.8 Electromagnet:

The electromagnet used in the measurements was obtained from the Polytronic Corporation of India. It was a C-type magnet and it had to be modified to make it suitable for our work. The upper portion of the Yoke was machined to remove sharp edges. Also the pole tips were surrounded by a soft iron cylinder with slots at the appropriate positions so that the magnet gets a closed cylindrical shape. All this was necessary to reduce the stray fields to the minimum. The diameter of the poletips was 1.2 cm. The maximum field obtained in 1.0 cm gap was 25 kOe at 4 amp. The gap between the pole tips could be varied. The field was measured using a hall probe to an
Perspex source holders were used for keeping the source in between the pole tips. The source holder was designed in such a way that it just fits in the pole gap and the base was 1.2 cm diameter so that there is no difficulty in centering the source exactly in between the pole tips. The source holders used in general, were 2mm in diameter and 4 mm height. For the fixed detector to view the source, a 6 cm diameter hole was made in the cylinder. On the other side a 15 cm slot was made so that the movable counter could be moved between \( \pi/2 \) and \( \pi \) with respect to the fixed counter.

Since the measurements reported in this thesis were carried out in the vicinity of high magnetic fields, the fringing field could effect the functioning of the photomultiplier tubes. One could use light guides to keep the photomultiplier tubes away from the magnetic field. But the use of light guide in between the crystal and photomultiplier tube makes the energy resolution of the detector poor. So use of light guides was avoided in the present investigations. However, the photomultiplier tubes were shielded by placing several layers of enatic and co-enatic shield, mu-metal shield and soft iron cylinders around it and the effect of the magnetic field on each photo-multiplier was checked by recording the counting rate on the falling part of the photopeak from a standard source with field up and down directions. The change in the counting rate was found to be less than 0.3\%.
4.9 **Low Temperature Arrangement:**

An arrangement for performing the experiments at liquid nitrogen temperature (77°K) was designed and fabricated. The previously reported arrangements for low temperature experiments usually consist of a double dewar and the lower part of the cryostat shaped as a tail. The tail passes through a hole drilled in the upper pole piece of the magnet and rests on the lower pole tip. The present arrangement was designed so as to avoid drilling a hole in the pole piece of the magnet. Fig. 4.7 shows the details of the arrangement. Near the bottom of the liquid nitrogen reservoir \( R \) made of thermocole is fitted a copper tube of inner diameter 4 mm and at the other end of this tube a small cup \( S \) of copper is soldered. This cup has inner diameter 2 mm, height 3 mm and thickness 1 mm. This cup was machined to be symmetrical. The source is held in this cup. From the point where the copper tube comes out of the reservoir, it is surrounded by a 2 mm thick brass tube of inner diameter 5 cm. The source \( S \) placed in the cup is enclosed in a symmetrical brass chamber. Fig. 4.8 shows the planar view of the chamber. The top and bottom discs of the chamber are having elevations of 1.2 cm in diameter so that these fit exactly in between the pole tips of the magnet, which have equivalent grooves. The top disc was detachable and an o-ring was used to make it vacuum tight. Near the source \( S \) is soldered an air bleeding tube of diameter 2 mm and it passes out of the vertical ring of the brass chamber through a rubber cork.
FIG. 4.7 DETAILS OF THE ARRANGEMENT FOR PERFORMING EXPERIMENTS AT LIQUID NITROGEN TEMPERATURE.
FIG. 4.8 PLANAR VIEW OF THE CHAMBER.
A Cr-Al thermocouple is also soldered at the copper tube and this also passes through the rubber cork fitted in the vertical section of the chamber. A vacuum pump is connected to an outlet at the centre of outer brass jacket. To another outlet is connected the thermocouple and penning gauge for measuring the vacuum. A vacuum of the order of $10^{-4}$ mm of mercury was created in the source chamber and outer brass jacket surrounding the copper tube. Fig. 4.9 shows the design of the ends A and B of the brass jacket for obtaining a perfect vacuum. An insulating perspex nut was placed in between the inner copper tube and the brass jacket to avoid mutual contact.

When the reservoir is filled with liquid nitrogen it flows through the copper tube, pushing the inner air out of the bleeder and after some time liquid nitrogen reaches the source, vapours of nitrogen start coming out of the bleeder and a constant temperature is reached. A calibrated Cr-Al thermocouple directly recorded the temperature.

This arrangement was used for measuring the internal hyperfine field of arsenic in gadolinium (reported in Ch. V of the thesis). Fig. 4.10 shows the photograph of the arrangement. The arrangement described above can be very easily modified for studying the variation of the hyperfine fields at intermediate temperatures between the liquid nitrogen and room temperature.
FIG. 4.9 DESIGN OF THE ENDS A AND B OF THE BRASS JACKET.
4.10 Experimental Procedure:

The internal hyperfine fields and magnetic dipole moments are determined from the following two steps of experiment.

(1) The directional correlation function \( W(\theta) \) is determined by noting the number of coincidence counts of a gamma-gamma cascade at different angles between the detectors. Since our rotation measurements were carried out in the magnet geometry, therefore directional correlation measurements have also to be performed in the free as well as the actual geometry.

(2) The quantity \('R'\) as defined in eq. (3.26) by noting the change in coincidence counts on field reversal.

The photomultipliers were mounted on a raised platform capable of rotation on a smooth aluminium table. The table is graduated in degrees. The platform holding the detectors could slide laterally and source to detector distance could be adjusted. On another concrete platform above the aluminium table the electromagnet was placed in such a position that the point of intersection of the axis of the detectors was at the centre of the pole tips of the electromagnet. Measurements of the directional correlation in the free geometry were carried out on a separate table. For measurements in the magnet geometry, liquid source and the source alloys were put in button type source holders and placed in between the pole tips of the electromagnet.
Directional correlation measurements were carried out in free and magnet geometry by keeping one detector fixed and recording the coincidence output of the second detector at different angles. For 'R' measurements, the detectors were kept at a fixed angle and the change in coincidence counts on field reversal was observed. The choice of the angle was made from the consideration of the angular correlation coefficients of the cascade. The gamma ray spectrometer was calibrated using the standard gamma ray sources like Hg$^{203}$, Cr$^{51}$, Na$^{22}$, Cs$^{137}$, Mn$^{54}$, Zn$^{65}$, Co$^{60}$ and the gates were set at appropriate positions by noting the position of the photopeaks of the actual source of interest. In the analysis of the experimental data the following points were taken into consideration.

a) The decentering of the source:

The corrections for the decentering of the source are discussed in detail by Breitenberger$^5$. For properly set sources, the corrections are small. The source holders used in the present measurements were made of perspex and were machined to be symmetrical. The source could always be centered to a variation less than 0.7% in the singles counting rate of the movable counter. Further the coincidence counts were normalized w.r.t. the singles counts of the two detectors to remove any decentering effects.

(b) The electronic stability:

The spectrometers used in the present measurements were quite stable. Also the gate settings were checked.
frequently throughout the course of the experiment and minor
instability was compensated. The normalization of coincidence
counts w.r.t. singles counting rate also took care of minor
electronic drifts.
(c) **Scattering in the geometry:**
Since geometry of our experiment was symmetrical therefore
scattering contribution is expected to be isotropic. But
the angular correlation coefficients are attenuated due to this
contribution. Also $R'$ measurements were carried out in the
same geometry, therefore in deducing rotation $\theta$ from the
measured value of $R$, the angular correlation coefficients
as measured in the magnet geometry were used and hence the
effect of scattering was automatically taken into account.
(d) **The attenuation of the angular correlation function due to
time dependent and quadrupole interactions.**
To determine the effect of quadrupole and time
dependent interactions, the angular correlation measurements
were carried out with the respective impurity-host alloys and
a comparison of the angular correlation coefficients with
that of dilute liquid sources could give us an estimate of
attenuation coefficient.
(e) **The effect of interfering cascades:**
The contribution from interfering cascades can
attenuate the true angular correlation. If the interfering
cascade is isotropic, then the correlation coefficients and
the value of $R'$ will be attenuated by the same amount.
and $\omega_C$ will remain unaffected. In such cases the error introduced by the isotropic contribution of the interfering cascade can be reduced by improving statistics. For anisotropic interfering cascades when the lifetime of the intermediate state is many orders of magnitude smaller than that of the true correlation cascade, the rotation $\omega_C$ because of the interfering cascade is expected to be negligible and can be kept within the statistical errors. But when the lifetime of the intermediate state of the interfering cascade is large, it is not possible to determine true $\omega_C$ and Ge(Li) detectors have to be used in such a case to separate the interfering gamma rays.

(e) The least squares fit of the angular correlation data:
The directional correlation measurements were carried out by recording the coincidence counts at seven angles between $90^\circ$ and $180^\circ$ at an interval of $15^\circ$ each. The coincidence counts were normalized w.r.t. $\theta=90^\circ$ and the random coincidences determined from the singles counting rate at $\theta=90^\circ$ were subtracted from each. The angular correlation coefficients and the corresponding errors were calculated from the true coincidence counts by the 'least squares fit' method developed by M.E. Rose. The fitting was carried out using IBM 1620 computer. The angular correlation coefficients thus obtained were corrected for the finite size of the detectors using the correction factors given by Yates. No correction was made for the finite size of the source.
4.11 Errors in the Measurements of the Hyperfine Fields and the g-Factors.

In general, in the measurements of the hyperfine fields and the g-factors, the following types of errors are involved:

1. Statistical error in the \( R \) measurement.
2. The error in the measured correlation coefficients.
3. The error in the measured value of the half life.
4. The error in the known g-factor or the hyperfine field value.

The statistical errors quoted in the measured values of \( R \) were obtained from the total counts collected for both field directions and then using the relation:

\[
\Delta R = \frac{2 \left[ (C_{up})_{\text{TRUE+HANCE}} + (C_{down})_{\text{TRUE+HANCE}} \right]}{(C_{up})_{\text{TRUE}} + (C_{down})_{\text{TRUE}}}^{\frac{1}{2}}
\]

The various values of the half lives and g-factors (or hyperfine fields) used in the calculation of the hyperfine fields (g-factors) were the weighted averages of the available results for the level of interest obtained by using the relation

\[
\bar{g}(\tau) = \frac{\sum_i \omega_i g_i(\tau_i)}{\sum_i \omega_i}
\]

where \( g_i(\tau_i) \) correspond to different values of the g-factors or lifetimes and \( \omega_i \) are their respective weights.
The errors quoted in our measured values of $H_{\text{int}}$ or the $g$-factors were all fractional and were obtained using the relation

$$\frac{\Delta x}{x} = \sqrt{(\frac{\Delta a}{a})^2 + (\frac{\Delta b}{b})^2 + (\frac{\Delta c}{c})^2}$$

where $\Delta x$ is the error in the quantity $X$ and $\Delta a$, $\Delta b$, $\Delta c$ correspond to errors in the quantities $a$, $b$ and $c$ respectively.
REFERENCES


5. E. Breitenborger; Phil. Mag. 45 (1954) 497.
