CHAPTER 3

Experimental Equipment
3.1: Introduction:

Scintillation by gamma rays method of detecting nuclear radiations was by the luminescence, they produced in certain substances. Crookes in England and Elster and Geitel (1903) in Germany independently reported that alpha particles impinging on zinc sulphate screens produces individual flashes which could be observed through a microscope. The first attempt to count alpha particles, by observing flashes of light (scintillations) generated in diamond by them, was made by Regener (1908) in Germany. In the same year Rutherford and Geiger compared the number of scintillations seen with the number of pulses recorded by an ionization chamber. The number were the same in both the cases. Hence if each particles caused a single pulse in the counter then it also gave rise to one scintillation. In this way this method was available for counting alpha particle. The observations of scintillation through low power microscope were very tedious and limited to relatively low counting rates. For this reason early forms of scintillation method soon became obsolete and more attention was paid to the development of gas counter.

Since 1945, this old technique is now playing a most important role. This has been due to the development of the photomultiplier tube and the intensive study of the luminescent properties of many inorganic solid as well as organic compounds either in the solid state or in solution.
Gamma rays are emitted by excited nuclei in general and are also associated with beta and alpha decays. Sometimes a cascade of gamma decays takes place with several discrete energy transitions of the nuclei. Gamma rays associated with beta decays have a characteristic angular distribution. The knowledge of the energy and a angle of emission w.r.t. beta particles is necessary to determine the decay scheme of the nuclei and for the assignments of their spin and parity. Hence gamma ray spectrometers have been extensively used in following types of applications:

1) Delayed coincidence measurements for finding the lifetimes of isomeric states of nuclei in the range $10^{-5}$ to $10^{-9}$ sec.

11) Angular correlation experiments for the assignments of spin and parity and to fix up the gamma energy of nuclei.

111) Study of Bremsstrahlung and k-capture in radioactive material.

Gamma ray spectrometers should have the following essential characteristics:

1) A high efficiency of detection of gamma rays.

11) Good resolving power.

111) A linear response to electrons and

11v) Good mechanical and electrical stability.

Taking all these points in view Na(Tl) phosphor is the best for gamma ray work which has a very good stopping power
for gamma rays and a reasonably small resolving time = 250 × 10^{-9} \text{ sec}.

Radiation from the source falling on the scintillator can dissipate a part of its energy in the ionisation and excitation of the molecules. Gamma ray (or X ray) incident on the scintillator may interact with matter in three processes:

1. photoelectric effect
2. Compton effect
3. pair production.

In each process electrons are produced and by successive interaction, the gamma ray can transfer all or part of its energy into the kinetic energy of such electrons. These secondary electrons will give up their kinetic energy in ionisation or excitation in the scintillator material. In these processes scintillator absorbs energy. This absorbed energy appears either as heat energy or luminescence photons. In the latter process the atoms in the excited states of the scintillator de-excite to lower states by light emission in less than 10^{-8} \text{ sec}. The emitted light is named as scintillation. Some of these emitted scintillations are made to fall on the photocathode of the photomultiplier. The electrons ejecting from the cathode are multiplied at each dynode of the same photomultiplier. After multiplication at each stage, an avalanche of electrons arrives at the anode where it produces a voltage pulse across a resistance. This voltage pulse is then analysed. The schematic diagram of the scintillation is shown in Fig. (3.1).
To understand the system the operation can be divided into following events.

1) The absorption of radiation in the scintillator resulting in excitation and ionization within it.

11) The conversion of energy dissipated in the scintillator to light energy.

111) The transmission of light photons to the photocathode of the photomultiplier.

1v) The absorption of light photon at the photocathode and emission of photoelectrons.

v) The electron multiplication process within the photomultiplier tube.

v1) Analysis of voltage pulse furnished by the photomultiplier tube.

The height of this pulse is proportional to the energy loss in the scintillator.

3.2: Sources:

We use various sources of gamma rays for energy dependence of the substances. The sources are listed in the Table (3.1). They are obtained from Electronic Corporation of India, Ltd. Hyderabad.
Table 3.1: Table of radioactive sources:

<table>
<thead>
<tr>
<th>Source</th>
<th>Energy (MeV)</th>
<th>Normal activity (nCi)</th>
<th>Half life</th>
</tr>
</thead>
<tbody>
<tr>
<td>Co-57</td>
<td>0.123</td>
<td>3.0</td>
<td>273 days</td>
</tr>
<tr>
<td>Ba-133</td>
<td>0.36 (main)</td>
<td>2.0</td>
<td>7.5 Years</td>
</tr>
<tr>
<td>Na-22</td>
<td>0.511 ; 1.280</td>
<td>2.0</td>
<td>2.6 Years</td>
</tr>
<tr>
<td>Cs-137</td>
<td>0.662</td>
<td>1.0</td>
<td>30 Years</td>
</tr>
<tr>
<td>Mn-54</td>
<td>0.84</td>
<td>3.0</td>
<td>291 days</td>
</tr>
<tr>
<td>Co-60</td>
<td>1.17 ; 1.33</td>
<td>1.0</td>
<td>5.3 Years</td>
</tr>
</tbody>
</table>

3.3: Detector:

Detectors are used to detect and record the number of particles emitted in various experiments involved in the study of nuclear radiation, disintegration and transmutation. In the study of petroleum, geology, cosmic rays, reaction rate, molecular structure, surface properties, equilibrium measurements and catalysis the nuclear detectors have found a use.

For gamma ray spectroscopy a cylindrical NaI(Tl) detector of \( \frac{3}{4} \) " x 2" crystal is as used the detector throughout the work. The chief advantage of NaI(Tl) are given below:

1. It is very fast.
2. It gives a pulse size proportional to the energy.
111) It has high efficiency to detect gamma rays.

1v) It is a water clear, hygroscopic, cubic crystal.

The general properties of NaI(Tl) crystal at room temperature given in the Table (3.2).

Table 3.2: General properties of NaI(Tl) detector.

<table>
<thead>
<tr>
<th>Properties</th>
<th>NaI(Tl)</th>
<th>Pure NaI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>3.69 g/cm³</td>
<td>3.67 g/cm³</td>
</tr>
<tr>
<td>Melting Point</td>
<td>651°C</td>
<td>651°C</td>
</tr>
<tr>
<td>Emission band maximum</td>
<td>4200 Å</td>
<td>3030 Å</td>
</tr>
<tr>
<td>Tl concentration</td>
<td>1 x 10⁻³</td>
<td>&lt; 10⁻⁷</td>
</tr>
<tr>
<td>Emission decay constant</td>
<td>0.25 x 10⁻⁶ sec</td>
<td>0.30 x 10⁻⁹ sec</td>
</tr>
<tr>
<td>Emission conversion efficiency</td>
<td>0.12 (21°C)</td>
<td>0.25 (−196°C)</td>
</tr>
</tbody>
</table>

In NaI(Tl) crystal the light emitted in ionisation and excitation processes lies in the ultraviolet region and is not detected easily. The crystal is therefore activated with a fraction of percentage of thallium iodide which shifts the wavelength into visible region, suitable for detection.

3.4.3. Single crystal Na(Tl):

Gamma rays are detected through secondary electrons produced in

(1) photoelectric absorption

(11) pair production
(111) Compton scattering. Below 1 MeV energy, photoelectric absorption plays the major part and pair production is totally absent. The incident energy $E_r$ is mostly taken by photoelectron and a very small fraction appears in K, L, M etc. X-ray emission. If all the energy of the photoelectrons and the secondary X-rays is totally absorbed by the crystal, the size of the pulse is proportional to $E_r$. In actual practice about 80% of the secondary X-rays are from K shell and a part of the escape out of the crystal (if it is small, escape factor is large) and an energy $(E_r - E_k)$ is also recorded. Two peaks appear in this arrangement, one corresponding to $E_r$ and other due to $(E_r - E_k)$. The pulse corresponding to $(E_r - E_k)$ starts overlapping the $E_r$ pulse toward lower energy in such spectrometers and limits the low energy resolution at $E_r = 30$ keV as $E_k = 29$ keV for Iodides. This limitation is overcome by taking a large size crystal so that K X-ray is not allowed to escape. Thus from 5 to 500 keV photoelectrons give a good energy resolution for gamma rays in large size crystal spectrometers.

Very large size NaI(Tl) crystals have been grown and total absorption spectrometry has been made possible which gives very good energy resolution and single peaks corresponding to the total monochromatic energy of gamma rays.

3.4 : Electronics :

In the nuclear technology electronic equipments like power supply, voltage stabilizer, linear amplifier,
photomultiplier tube, Single Channel Analyser (SCA), Multichannel Analyser (MCA), Scaler, Timmer etc. are very useful for the detection of radiation measurements.

A brief description of the electronic units is given below:

3.4.1: Photomultiplier Tube:

In modern scintillation counter human eye is replaced by an electronic device called photomultiplier tube. It is highly sensitive photocell, converting light energy into electrical energy. In one of the commonest types of photomultipliers a semitransparent Cs – Pb cathode is deposited on the inside of the end of high vacuum envelope. Cathodes of this type have a maximum response to light at the blue end of the spectrum. The electrons ejected from this cathode are accelerated towards the electrode D₁ and are collected by the electrode where they liberate more secondary electrons. These are focused on an electrode D₂. The process is repeated in several stages by focusing the electrons from one surface to the next. These collecting electrode D₁, D₂ etc. are called dynodes. A photomultiplier tube may have as thirteen or sixteen dynodes, each one being maintained at a previous one. The total voltage drop across the whole system is supplied from the rectifier power pack. The dynode has a venetian blind structure, and is cover with a layer of material with a high secondary emission.
coefficient, such as Cs - Pb or Ag - Mg. The number of electrons reaching the anode A is thus a million or more times the number of electrons reaching the first dynode. The anode A is connected to the positive voltage supply through a series resistance R. Because of the voltage drop across the load resistor, a negative output pulse is produced by a flash of light falling on the photocathode. This pulse can be recorded by scalars. At room temperature there will be an appreciable emission of thermionic electrons from the cathode to produce undesirable current known as dark current. This noise can be discriminated if the initial light pulse is sufficiently large. When very weak light pulses are to be detected, the dark current is reduced by operating the phototube at a very low temperature. The schematic diagram of photomultiplier tube as shown in Fig.(3.2) and Scintillation counter in Fig.(3.1).

In these days, many types of scintillation counters have been devised in the study of cosmic rays, for the detection of mesons and other unstable particles of very high energy.

3.4.2 : Linear amplifier :

PA 521 linear amplifier has been used for this research. The primary function of the linear amplifier is to increase the amplitude of detector signal, while introducing as little noise and non linearity as possible. Secondary function includes pulse shape and impedance transformation.
3.4.3: Single Channel Analyser:

The amplified pulses are next sorted out according to their pulse height by the pulse height analyser which could be a single channel or multichannel analyser. In the present studies SC 604 B single channel analyser (SCA) was used. It can be used in integral and differential modes. In integral mode a pulse height analyser is just a discriminator and it allows only those pulses to pass which have an amplitude higher than a certain discriminator level. In the differential mode, the analyser is said to be work as single channel analyser (SCA). The input pulses is divided and fed into two discriminator circuits and then into an anti-coincidence circuit. Single Channel Analyser (SCA) produces output pulse only if the input pulse has an amplitude lying between upper and lower level. The window width is variable.
Fig. 3.1 : Schematic diagram of scintillation counter
Fig. 3.2: Photomultiplier tube.
3.5: Gamma spectra from various sources:

For scintillation counters, the counter voltage is the one applied to the photomultiplier tube. It is possible to obtain a counting plateau for a scintillation system which will be a function of crystal size, the source and background scattering as well as the performance of the phototube.

Rather than manual operation, a scintillation spectrometer may be operated by a constant speed scan through the spectrum using a motor driven potentiometer. In this case the discriminator output is fed to a count rate meter is traced on the recorder. No matter how the spectrometer is operated, it is necessary to calibrate the spectrum with photopeaks of known energy. For gamma standards, Na$^{22}$ and Cs$^{137}$, Ba$^{133}$, Co$^{60}$, Co$^{57}$, Mn$^{54}$ provide well defined photopeaks. Fig.(3.5.1) demonstrates the calibration curve obtained using these nuclides.

By using Na$^{22}$, Cs$^{137}$, Co$^{60}$, Co$^{57}$, Ba$^{133}$ determined the spectra as shown in Figs.(3.5.2 to 3.5.7). If at constant window width the gain is increased by a factor of two, the spectrum will be stretched over twice the voltage range. Unless this is necessary to better resolve two intense peaks of similar energy, the stretching out of the spectrum may reduce the low intensity peaks to the point where it is difficult to resolve them from the background.
Fig. 3.5.1: The calibration curve is drawn through the points determined by channel setting and the energy of the photopeaks of the standards.
Fig. 3.5.2: Gamma ray spectra for $^{57}$Co.
Fig. 3.5.3 : Gamma ray spectra for Ba\textsubscript{133}. 
Fig. 3.5.4 : Gamma ray spectra for Cs$_{\text{137}}$. 
Fig. 3.5.5: Gamma ray spectra for Na$_{22}$. 
Fig. 3.5.6: Gamma ray spectra for Mn\textsuperscript{54}.

Counts (Thousands)
Fig. 3.5.7: Gamma ray spectra for Co$_{60}$. 

Count (Thousands)

Channel Number

□ For Co$_{60}$