GAMMA- GAMMA (γ- γ)COINCIDENCE SPECTROSCOPY WITH THE 511 KeV POSITRON ANNIHILATED γRAYS

AYAN GHOSH

Abstract: In the present project work we have carried out an experimental set up based on gamma – gamma (γ-γ)spectroscopy. Here we use positron annihilated two oppositely (~ 180°) directed 511 keV γ rays. Positrons from radioactive nuclei (^{22}Na) have been used for the present work. Positron is an antiparticle of electron. Both positron and electron has a rest mass of m_0c^2 = 511 keV. Positrons normally annihilate with an electron in the medium (e.g., solid, liquid, gas etc.) emitting two oppositely directed 511 keV γ -γ rays. The typical lifetime of positron in a solid is ~ 100 – 1000 ps (1 ps = 10^{-12} sec). In the present project we have used two identical High Purity Germanium (HPGe) detector placed at 180° angle. Detailed electrons and circuit diagram will be discussed in the following sections. After setting up the γ -γ spectroscopy, we have recorded the typical Coincidence Doppler broadening of the positron annihilated γ -γ ray spectrum.

Keywords: Scintillator, HPGe detector, γ- γ coincidence, 511 keV γ ray.

Introduction: In lab, many spectra were measured. From know values of gamma-ray energies, a calibration curve was plotted. The best fit line on the calibration curve proved that the MCA channels all had the same width of energy. The best fit line matched the data with a least squares fit of R2 = 1. Using the HPGe detector in tandem with the *Multi ChannelAnalyser* (MCA), all of the spectra were measured. All of their features, including photo peaks, summation peaks andannihilation peaks were identified. Analyzing the background count showed a large amount of ambient radiation.

Gamma ray detectors:

PMT + BaF_2 scintillator: When a γ -photon incident on a scintillator crystal a short lived flash of light is emitted from it. This is called scintillation--- the result of a fluorescence process.This scintillation light travels to a light detecting device known as a *photomultiplier tube* (PMT). The PMT has a photosensitive surface in it which, upon incidence of light on it, emits photoelectrons. The bunch of electrons so emitted undergo multiplication in number within the tube and are finally collected by an anode producing a voltage pulse. The scintillation-PMT combination constitutes the basic unit of the detector assembly. The voltage pulse thus formed is amplified and finally counted in a scaler via a single channel analyzer or a multichannel analyzer. Obviously, each such pulse recorded as a count is a record of one radiation unit,a γ-photon in our example, having been detected. The photocathode is deposited as an ultrathin semitransparent layer of a photosensitive substance on the inner surface (concave in most end-on PMTs) of the window.Light from the scintillator incident on the photocathode releases photoelectrons from it inside the tube envelope. There arearray of electrodes called dynodes. These electrodes are made from CuBe, AgCs, etc. and possess the property of emitting more than one secondary electron from their surfaces upon incidence of each electron of adequate energy on them.

HPGe detector: Detectors made from this germanium are usually called *Hyper Pure Germanium* (HPGe) detectors. The cylindrical planar HPGe detectors having two plane faces on two sides on which electrodes are deposited are called planar detectors. These detectors may be fabricatedto have depletion layer thickness' of 1cm or a little more.

These detectors may be fabricated from high purity n-type germanium. One face of such a disc is heavily doped with a donor impurity to make a rectifying contact and this face serves as the positive electrode. The negative electrode is formed on the opposite face by heavily doping with an acceptor impurity, the contact being nonrectifying.

Larger HPGe detectors have coaxial geometry where one electrode is formed along the axis of a cylindrical hyper pure Ge crystal. On the

cylindrical outer surface is formed the other electrode. The major characteristics of the HPGe detector are high atomic number, low impurity concentration (large depletion depth), low ionizing energy required to produce an electron-hole pair, high conductivity, compact size, first time response, high resolution and relative simplicity of operation.

The high number of information carriers leads to a small percentage fluctuation and this is the reason for the high energy-resolution of Ge detectors. However, the detector cannot simply consist of the semiconductor material and two electrodes because there are inherent impurities in these materials. Both Si and Ge have a valence 4 and when an impurity of valence 3 (acceptor) or 5 (donor) exists in the crystal, it lowers the energy necessary to create electron-hole pairs and this tends to create too much noise. The Ge crystal with acceptor impurities is called p-type (Ge) material and the same with donor impurities is called n-type (Ge) material. The solution is to create a p–n junction at one electrode and to polarize it so that no current passes through when there is no ionizing radiation (this is called reverse biasing or using non-injecting or blocking electrodes). This creates a region called the depletion layer where few charge carriers remain, resembling a pure semiconductor. With a sufficient voltage, the electric field can create a large enough depleted volume to make a viable detector. The intrinsic region (depleted volume) is sensitive to ionizing radiation particularly –X rays and γ-rays. The performance of a detector depends on its depletion depth, which is inversely proportional to the net impurity concentration in the detector material.

Energy Resolution: The great advantage to using a germanium detector is the fact that they have excellentenergy resolution for gamma-ray spectroscopy. A high energy resolution means that thedetector can discriminate between gamma-rays with similar energies. The more resolution adetector has, the more defined a gamma spectrum becomes. Recall that the resolution of adetector is defined as

$$R = \frac{H_0}{FWHM}$$

Where, H_0 is the centroid peak number and FWHM is the full-width half-maximum of thePeak.

There are three factors that give germanium the excellent resolution that it has: the inherent statistical spread in the number of charge carriers, variations in the charge collection efficiency and contributions of electronic noise. Some of these factors will dominate over theother factors, but this is dependent on the energy of the radiation and the size and qualityof the detector in use.

Table: Conventional gamma ray sources

Source Name	Half life	Gamma ray energy
^{60}Co	5.26 year	1172 keV, 1332 keV
^{137}Cs	30 year	662 keV
^{133}Ba	10.5 year	270 keV, 300 keV, 355 keV, 380 keV
^{22}Na	2.6 year	511 keV, 1276 keV

Table – 1: Conventional gamma ray sources

The required instruments are as follows:

High Voltage (HV) Power supply, High purity Germanium γ-ray detector, Amplifier (FastComTech N986 / Ortec 572), Multichannel analyzer (MCA) or Multi Parameter System (PC based)

Multichannel pulse height analyzer (MCA): An MCA is an instrument which sorts all the incoming pulses according to their amplitudes and accumulates the countsin different memory channels(cf. scalers) as they arrive, each channel having been designated to a given pulse amplitude. Moreover, with an MCA the entire 10 volt spectrum can be divided into a large number of channels (4096 channels are quite common) making the window width (also called channel width) quite narrow. Each channel then corresponds to a particular value of V. For example, a 4096 channel MCA makes possible a 10 volts spectrum to be recorded with a window width of ΔV = 10/4096 = 2.44mV.

It is clear that the instrumental resolution in this case is very high. Moreover, when a spectrum from a radioactive source having a short lifetime is required to be recorded, an SCA will be found to be unsuitable because point by point recording of counts with it will take a time during which the source may decay

considerably. In this case an MCA becomes indispensable since only it can perform the task of recording the entire spectrum in a short time.

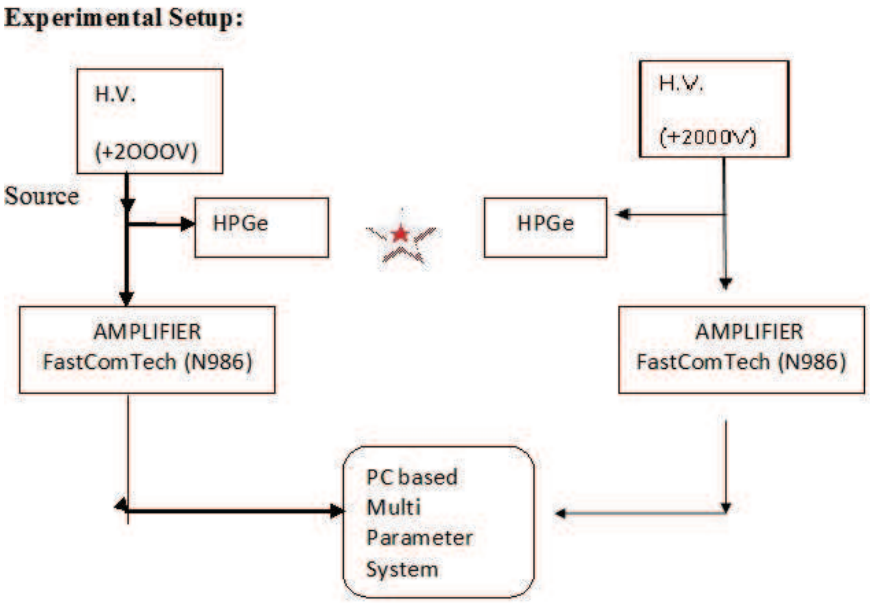

Figure 1: block diagram set up of γ-γ coincidence spectroscopy with the 511 keV positron annihilated γ rays by using two HPGe detectors

Experiments: At first we had taken two HPGe detectors. The detectors are placed in 180° angle (exactly in opposite direction). Using these two detectors with the associate electrons and multi-parameter data acquisition system a γ-γ coincidence assembly has been set-up. Using different standard radioactive sources (as listed in the Table 1) the detectors are calibrated. The calibrations of both the detectors are exactly similar. Figure 2 shows a typical gamma ray spectrum (for the radioactive ^{22}Na source). Apart from the 511 keV photopeak there is a broad Compton continuum. In this figure there are two small peaks (at energies ~ 170 and 341 keV) which are due to the 180° Compton (from the other detectors) scattered peaks.

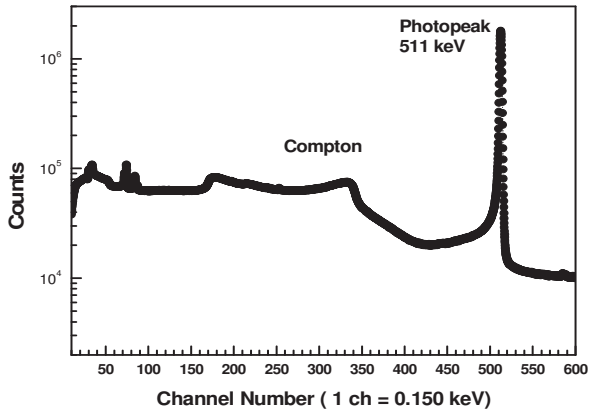

Figure 2. A typical gamma ray spectrum in aHPGe detector

Next using different γ-ray sources like 60_{Co} , 22_{Na} , 137_{Cs} both the detectors have been calibrated. Figure 3 shows the linearity of the detectors. Here we have also evaluated the energy of an un-known γ-ray source (133_{Ba}) from graph the energy of 133_{Ba} is 355.32 KeV and the actual value is 356 KeV. Thus the experimental result is very close to the actual value.

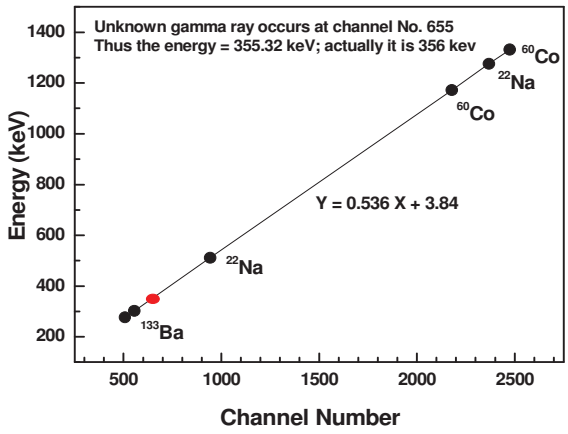

Figure 3. Energy calibration curveof the Multichannel Analyzer using known and unknown gamma ray source

After that using two detectors coincidence assembly we have recorded the γ-γ coincidence spectrum with two ADC (analog to digital converter) multi parameter systems. We have used two HPGe detectors which were placed 180^0 oppositely directed. Between these two detectors we used 22_{Na} as a γ-ray source. The two detectors were connected with high voltage system

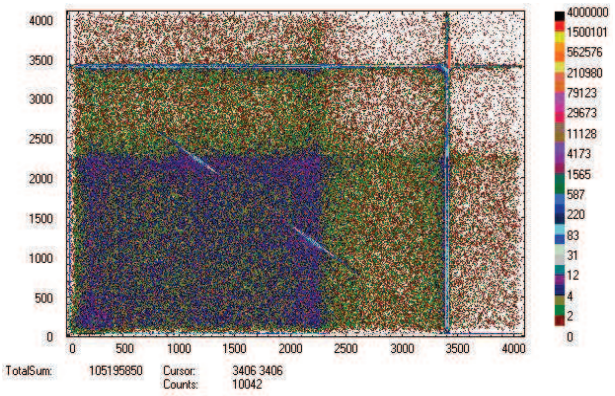

Figure 4. A typical gamma – gamma coincidence spectrum in a two dimensional multi-parameter

power supply ($\sim 2000\,V$). We got positron annihilated two oppositely ($\sim 180^0$) directed 511KeV γ-rays. Two special types of amplifiers were connected from the two detectors. The amplifier was special because it can maximize the signal to noise ratio. From these two amplifiers the signal came through "multi – parameter system "via two "analog to digital converter "in our computer and we got γ-γ coincidence spectrum. Here coincidence counts are in the third direction.

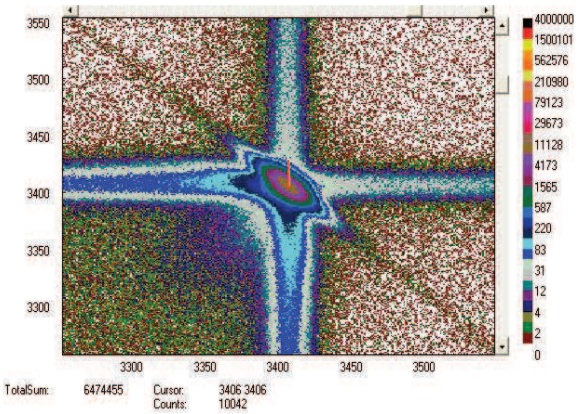

Figure 5

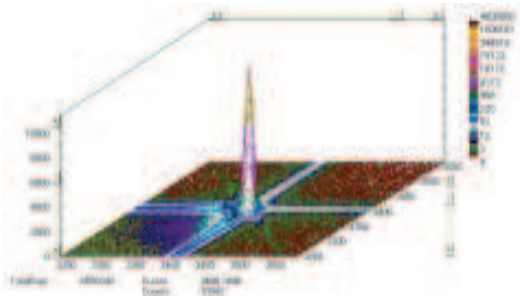

Figure 6

Figure 5 & 6. Selected portion of the coincidence (511 keV – 511 keV) spectra in 2 dimensions and in 3 dimension

Conclusion:

From this project work we identify the features of the different γ-ray spectra.We can identify the features of the γ-ray spectrum such as photopeak, Compton continuum etc. Here we have evaluated the energy of an unknown γ-ray source. In this experiment we have measured the Compton peaks for 180° scattered 511 keV γ-ray by two oppositely directed (180^0) HPGe detectors (using 511 keV of ^{22}Na source) with the help of γ-γ coincidence technique. The experimentally measured peaks positions are in agreement with the theoretical values.

Acknowledgment

For this work I would like to thank my guide Dr. Dirtha Sanyal, Varriable Energy Cyclotron Centre, Kolkata and Mr. Arnab Acharyya, Technique Polytechnic Institute.

References

1. Glenn F. Knoll, Radiation Detection and Measurement. John Wiley & Sons, Inc., USA,3rd Edition, 2000.
2. Bernard Shleien, Lester A. Slaback, Brian Kent Birky, Ed., Handbook of Health Physicsand Radiological Health. Williams & Wilkins, Baltimore MD, 3rd Edition, 1998
3. Ian Rittersdorf Nuclear Engineering & Radiological SciencesMarch 20, 2007

4. F. Adams and R. Dams, Applied Gamma-Ray Spectrometry (Pergamon Press,New York, 1975).
5. Gamma-Ray and Electron Spectroscopy in Nuclear Physics (Oxford Studies in Nuclear Physics) Hardcover, by H.EjiriJuly 13, 1989.
6. Serway, Moses and Moyer: Modern Physics, (scintillator/photomultiplier), 389-392 (beta and gamma decay).

* * *

Hooghly, West Bengal / Lecturer /
Technique Polytechnic Institute / ghosh.ayan90@gmail.com