# γ Ray Spectroscopy

**Introduction**

This study addresses the interaction of gammas with matter. Gamma rays interact with matter mostly through photoelectric effect, Compton scattering and pair production.

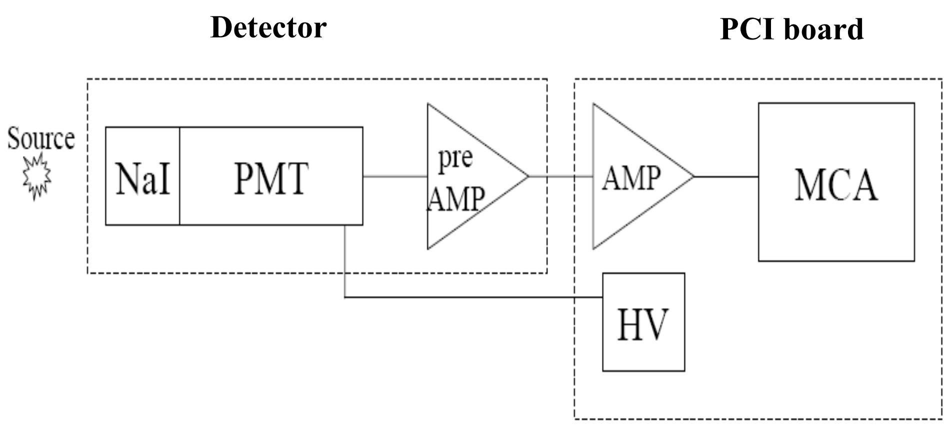
The experimental setup is a simple spectrometer (see Fig.1), constituted by a gamma ray source and a Sodium Iodine, Thallium activated scintillator - NaI(Tl) – coupled to a photomultiplier tube (PMT). The PMT is connected to a pre-amplifier and to a PCI board, which also incorporates a Multi-Channel Analyser (MCA). The board is in charge of providing the high voltage (HV) to the PMT and of the signal readout and amplification. The appropriate analysis software (GENIE 2000) is installed in the PC. An oscilloscope is used to monitor directly the detector signal. A set of absorbers will be used to study the absorption of gamma rays in matter. $^{137}$Cs and $^{60}$Co sources will be used in this study (the corresponding decay schemes are appended to this document). This type of decays typically include a β-decay into an excited state of the daughter nucleus, followed by the emission of one or more gammas in the de-excitation process before the fundamental state is attained.
β particles are in general absorbed in the aluminum housing of the PMT, before reaching the scintillator. Gammas, being penetrating particles, traverse easily the detector surface reaching the scintillator.

The work is divided in the following parts:

1. Configuration and parameter setting; Using the MCA; Energy calibration of the system.

2. Study of the spectrum of γ sources.

3. Study of the attenuation of γs in matter.



## 1. Configuration and parameter setting; Using the MCA; Energy calibration of the system

Configuration of the system and parameter setting in GENIE2000:

Menu **File** -> **Open data source** -> select **"Detector"**
Select the only detector in the list

Adjust the high voltage for the PMT: menu **MCA** -> **Adjust** -> **HV**
Rise the voltage to **900 V**, put it in **On** state and confirm with **OK**

Adjust the amplifier gain: **MCA** -> **Adjust** -> **Amp**
Use the value **x128**

**a)** Using the $^{137}$Cs source (decay scheme at the end of this guide) observe the detector output signal (see Fig. 1) with the oscilloscope and with the multi-channel analyser:

**a.1)** In the osciloscope, which variable do we have in the XX and YY axes?Draw the signal shape and register its amplitude and time width of the highest intensity curve (the brightest one in the screen).

**a.2)** In the multi-channel analyser (MCA), what is in the XX and YY axes? Noting that 20 V at the MCA input correspond to channel 1024, what is approximately the voltage corresponding to the highest intensity peak?
Relate the signal in the oscilloscope with the MCA spectrum.

**b)** We need to calibrate the MCA in energy: to establish a (linear) relation between its channels and the energy in the NaI scintilator. For this purpose, we will use the two total absorption peaks of the $^{137}$Cs source (32 keV X rays originated by internal conversion and the 662 keV gamma emission). Performing a 5 minute acquisition of the spectrum of this source, fill in the table:

| Peak | Energy (keV) | Centroid (channels) | Full width at half maximum FWHM (channels) | Area (# counts under the peak) |
|---|---|---|---|---|
| **X-ray** | 32 | | | |
| **γ-ray** | 662 | | | |

**b.1)** Using the nominal peak energy and the number of the channels where the centroid is located for each of the peaks, obtain a calibration line E(keV) = m . Channel + b

**b.2)** Obtain for each of the peaks the energy resolution $R=\Delta E/E=FWHM/E$ (note that since R is dimensionless you may choose to use all the quantities in units of channels or all in keV!)

**b.3)** Estimate the error in the position of the centroid (remember that $\sigma = FWHM/2.35$ and that the total number of counts under the peak must be taken into account !)

## 2. Study of the spectrum of the $^{137}$Cs and $^{60}$Co $\gamma$ sources

**a)** Using the $^{137}$Cs source and the previously obtained calibration, determine the energy of the backscattering peak and of the Compton "knee" (note: use the number of the relevant channel, not centroids – the backscattering and the "knee" are not true gaussian peaks). Compute the expected values (using the appropriate equations) and compare with the measured values. Briefly remind the physics interpretation of the different features of the spectrum.

| Cs | Channel | Measured energy (keV) | Expected energy (keV) |
|---|---|---|---|
| **Compton knee** | | | |
| **Backscattering peak** | | | |

**b)** Perform a 10 minutes long acquisition of the $^{60}$Co source spectrum.

**b.1)** Using the calibration obtained in **1.b.1**, compute the energy of the photopeaks of the $^{60}$Co and compare with the tabulated values (the energy of the emitted photons can be read from the decay schemes at the end of this guide).

**b.2)** For the $^{60}$Co source, determine the energy of the backscattering peaks and Compton "knees". Compare with the computed values and discuss.

| Co | Channel | Measured energy (keV) | Expected energy (keV) |
|---|---|---|---|
| **Photopeak 1** | | | |
| **Compton knee 1** | | | |
| **Backscattering peak 1** | | | |
| **Photopeak 2** | | | |
| **Compton knee 2** | | | |
| **Backscattering peak 2** | | | |

## 3. Study of the attenuation of $\gamma$s in matter

Using the $^{137}Cs$ or the $^{60}Co$ source, study the attenuation of gammas in lead absorbers with different thickness (use different combinations of the available absorbers).
The GENIE 2000 software allows the user to select interesting regions in the spectrum (ROI, *Region of Interest*) and obtain the total number of counts in the selected region.

**a)** Choosing a suitable ROI, register the counts integral for the higher energy peak, in the absence of any absorber. Keeping the same ROI, register the counts integral for each absorber or combination of absorbers, corresponding to different thicknesses.
Make sure the source and the detector are not moved in between measurements, placing the lead absorbers as much as possible close to the detector and to each other. Each acquisition should last long enough to keep the statistical error below 3%.

**b)** Verify the Lambert law for the absorption of gamma radiation and determine the Pb absorption length ($\lambda_{abs}$). Choose the suitable variables for the graphical representation of data so that a linear $\chi^2$ fit can be performed. Compare the value for $\lambda_{abs}$ obtained from the fit with the expected value (see graph below).
**($\rho$ (Pb) = 11.34 g/cm$^3$)**

| **Pb absorber** | **Thickness Pb (g/cm2)** | **Thickness Pb (cm)** | **Time interval (s)** | **Counts (area under peak) N±ΔN** | **Count rate R±ΔR ($s^{-1}$)** |
|---|---|---|---|---|---|
| **-** | **0** | **0** | | | |
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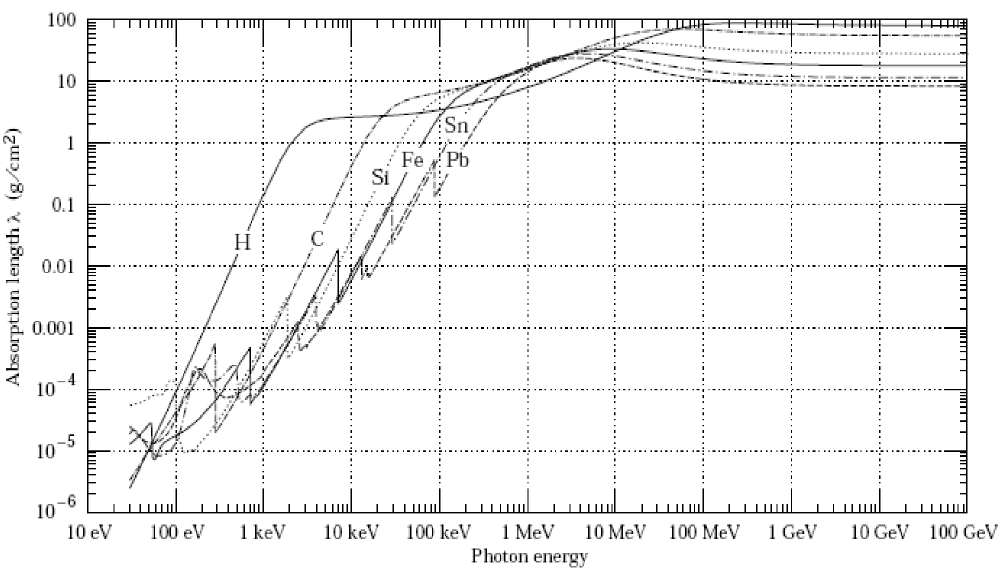
**Photon mass attenuation length $\lambda = 1/(\mu/\rho)$ for various absorbers as a function of photon energy:**



# Decay schemes