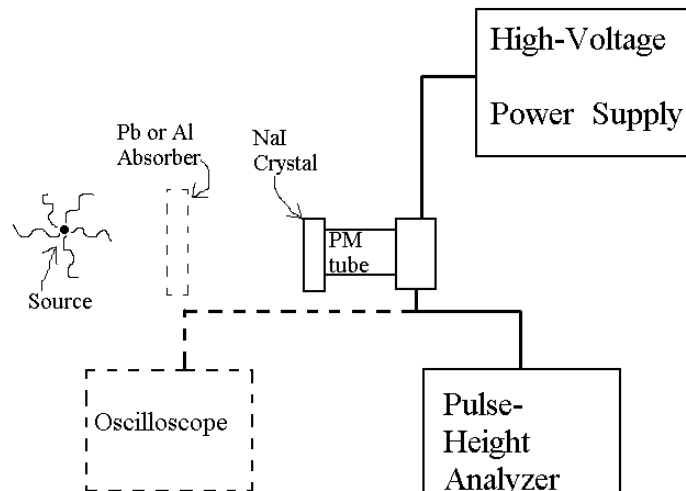


Gamma-Ray Scattering and Absorption

Introduction: In the first portion of this experiment, you will familiarize yourself with the NaI crystal detector and the pulse height analyzer (PHA). You will look at spectra of several radioactive elements and calibrate the PHA. Next, you will analyze what happens when a slab of aluminum or lead is placed between the source and the detector. You will find the absorption coefficients of aluminum and lead, λ_{Al} and λ_{Pb} .



Above is a diagram of the experimental setup. Our sources are small radiation disks, kept in the plastic sources box in the radiation cabinet. Please EXERCISE CAUTION. Radioactive sources can be harmful. These sources are weak (about $1 \mu\text{Cu}$), and if handled for short periods of time are harmless. However, if you were to put one into your pocket and leave it there, it could do harm. Treat radioactive sources with respect, always locking them into the cabinet at the end of class.

References:

A.C. Melissinos, *Experiments in Modern Physics*, pp. 137-149, Chapter 5 especially pp.165-169, pp. 194-208.

Walter E. Meyerhof, *Elements of Nuclear Physics*, pp. 91-108.

C.M. Davisson and R.D. Evans, *Reviews of Modern Physics*, 24, 19 (52), especially pp. 101-104.

E. Bleuler and G.J. Goldsmith, *Experimental Nucleonics*.

Handbuch der Physik, Volume XLV, Nuclear Instrumentation II, p. 86 (for NaI photomultiplier detector system).

Theory:

Our detector consists of a thallium-doped sodium iodide, NaI(Tl), scintillation crystal coupled to a photomultiplier tube (PMT). A gamma-ray traversing the crystal may lose energy to it, and if that happens a large number of optical photons are produced, the

number being proportional to the amount of energy transferred to the crystal. The NaI crystal is transparent to light, so many of the photons produced in it by the γ -ray strike the cathode of the PMT. The cathode releases an average of about one electron for every ten incoming photons. Each electron leaving the cathode is multiplied by the PMT, causing a pulse of current at the PMT output proportional to the number of incoming photons, and hence proportional to the amount of energy given to the crystal by the γ -ray.

The pulses caused by many incoming γ -rays are fed into a pulse-height analyzer (PHA), which amplifies them, measures them, and counts them according to pulse size. The PHA then displays a graph which is a histogram of the number of pulses vs. pulse-size -- i.e., the number of γ -rays detected vs. the energy each transferred to the crystal.

Melissinos explains the three types of interaction, which have probabilities of occurrence that are different functions of the energy of the incoming γ -ray. For an NaI crystal, photoelectric collision is the most likely interaction for a γ below 0.4 MeV, Compton collision is the most likely for one between 0.4 and 5 MeV, and pair-production is likely for a γ -ray above 5 MeV. Below 1.6 MeV pair-production is rare, as is photoelectric collision above 2.1 MeV.

The spectra observed on the PHA contain peaks representing some or all of these interactions. Melissinos has an excellent discussion of this.

If an absorber is placed between the source and the detector, the intensity of the γ -rays is decreased as any of the above processes occur. The intensity diminishes exponentially with the thickness of the absorber, x :

$$I = I_0 e^{-x/\lambda},$$

where I_0 is the intensity with no absorber and λ is the linear absorption coefficient.

Questions to consider before starting:

1. Read up on the NaI - photomultiplier detector system, the Compton effect, the photoelectric effect, and pair production.
2. What do the various peaks and other areas in the spectra represent?
3. How can you make a calibration curve of energy vs. channel number?
4. What are the important γ -ray energies of the various sources?
5. How would the distance between the absorber and the source affect the intensity? How about the absorber and the detector?

Instructions:

Set up the equipment as shown, without the absorber. You only need to use the oscilloscope once, to let you see the pulses that the PHA is analyzing. Use various sources to calibrate the PHA. Draw the spectra for various sources, labeling the channels of important peaks, valleys, etc. Choose one source (Cs-137 is good) and see what happens when you change the distance between the source and the detector.

Now, place an aluminum absorber between the source and detector. Investigate how different thicknesses of aluminum affect the number of counts in the main peak on the PHA. Find λ_{Al} . Do the same for lead, and find λ_{Pb} . Also investigate question 5, above.