SCINTILLATION DETECTOR EXPERIMENT

INTRODUCTION

The Sodium Iodide (NaI) detector is a scintillation detector, and represents a quantum leap in the power to detect gamma ray radiation over the GM tube. It can not only detect gamma rays but also determine the energy of the ray. The detector system begins with a crystal of Sodium Iodide, which is similar to Sodium Chloride (common table salt). The Iodine has a relatively high Z so gamma rays will interact with a sufficiently high cross section. When they do, the crystal scintillates (gives off visible light).

The light released with each interaction is very faint relative to normal room light intensity. To detect and record this light we use a photo-multiplier tube. The photo-multiplier tube converts the light to an electrical impulses (using the photoelectric effect - see below), a pre-amp and amplifier to convert the pulses to voltage pulses. These pulses are then sorted by height, counted, and stored in a multi-channel analyzer which displays the resulting spectrum.

Gamma rays interact with matter in three ways, the photoelectric effect, Compton Scattering, and pair production. Each of these effects results in a signature artifact in the gamma ray spectrum.

PHOTOELECTRIC EFFECT

In the photoelectric effect, a photon is completely absorbed by an electron 8n the NaI crystal. The energy of the absorbed photon gives the electron a kinetic energy, which in the case of the NaI crystal results in the electron bouncing around the crystal and getting reabsorbed by creating flashes of light. The result is a flash of light that contains all the energy of the photon in one large pulse. The energy is related to the wavelength of the photon by

$$E = hc / l \, .$$

This would result in a cluster of closely spaced events that would form a photo-peak in the gamma ray spectrum.

COMPTON SCATTERING

Compton Scattering is where a photon is scattered off an electron in the NaI crystal, only part of the energy of the gamma ray is absorbed by the electron. As a result, the flash has less intensity that a photoelectron gives. But the scattered gamma ray now with less energy can interact with the crystal again or leave the crystal without interacting. The amount of energy lost to the electron depends on the impact parameter (a measure of how off center the collision was) which also determines angle with which the gamma ray scatters away from the original direction. The change in wavelength of the scattered photon, Δl, is related to the scattering angle by the Compton Equation

$$\Delta l = l' - l = \frac{h}{mc}(1 - \cos q),$$

where m = 9.11×10^{-31} kg, is the rest mass of the electron, and c=3.0×10^{8} m/s, is the speed of light in vacuum.

The scattered gamma ray suffers the greatest change of wavelength when the gamma ray backscatters at an angle of 180 degrees. This means that the electron will receive the greatest energy when the gamma ray is backscattered at 180 degrees.

From the Compton equation we can deterime the wavelength shift Δl

$$\Delta l = \frac{h}{mc}(1 - \cos 180°) = \frac{h}{mc}(1 - (-1)) = \frac{2h}{mc}.$$

The maximum amount of energy given to the electron is then

$$\Delta E = hc / l - hc / l'.$$

For example, Cs^{137} emits a 662 KeV gamma ray. From the above equations we can calculate that the maximum electron energy would be ΔE=476 KeV. Other electrons would have smaller energies when gamma rays were scattered at lesser angles. This continuum of electrons would also appear in the spectrum of gamma rays as a plateau from low energy up to the maximum energy. Then there would be a gap between this Compton edge and the photo peak for the 661 KeV gamma ray.

PAIR PRODUCTION

Pair production occurs when a gamma ray spontaneously creates an electron positron pair. A minimum of energy is needed to create this pair. Since the rest mass energy of an electron is 511 KeV, the photon must have an energy in excess of one MeV. Any energy above the minimum to create the masses of an electron and positron goes into the kinetic energy of the particles.

When an electron-positron pair is created, either or both may escape the crystal. When they do, they carry off their rest mass energy. When only one particle escapes the result is a single escape peak. When both depart the detector, the result is a double escape peak. A single escape peak may be observed at an energy 511 KeV below the photo-peak, and a double escape peak may be observed them in the spectrum at 1.22 MeV below the photo-peak of the gamma ray that created. In addition, the positron may annihilate with an electron from the crystal resulting in the creation of two 511 KeV gamma rays which also may be observed in the spectrum.

EXPERIMENT

Co^{60} emits two gamma rays, one at 1173 KeV and the other at 1332 KeV. Using the NaI crystal scintillation detector and computer based Multi Channel Analyzer (MCA) obtain a spectrum of Co^{60}. Identify the two photo-peaks by the channel number closest to the highest point in the photo-peak.

Place the Co^{60} source in the counting chamber above the NaI detector.

Start accumulating counts in the spectrum of the computer based MCA. Count for several minutes. Then stop the accumulation and observe the resulting spectrum. Follow the procedure to calibrate the x-axis in KeV using the known energies of the photo-peaks for Co^{60}.

Identify the Compton edges for each of these gamma rays and check the energy with that predicted for the Compton edges of the photo-peaks for Co^{60}.

Identify the 511 KeV annihilation radiation peak.

Identify the single and double escape peaks of each gamma ray where possible and verify the correct energies of these peaks.

Now take a long background count of an hour or more. Note the photo-peak energies in this spectrum. Using a table of know gamma ray energies, identify the source(s) of this background radiation.