Spectrum Analysis and the Identification of an Unknown Material Through Gamma Ray Detection

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Gamma rays and X-ray photons can interact with matter in three distinct ways. Dependent on the energy of the photon in question, Compton scattering, pair production, and the photoelectric effect can all occur. In this lab, through the use of energy dispersive spectrometers the operation of gamma ray detectors was analyzed. Through the use of a Sodium Iodide (NaI) detector, the spectra of a Cobalt-60 source were collected as data. These spectra changed for varying distances from the detector as well as the length of time used for source detection. Finally, bipolar pulses were used to compensate for undershoot and give a different perspective of the spectrum. Through the use of a Germanium Detector, the spectrum of Cobalt-60 was once again acquired with the addition of Cobalt-57. This was done as to calibrate the Multi-Channel Analyzer for energy versus channel number. A new spectrum from an unknown source was then acquired and using the previous calibration a hypothesis of Manganese-54 was determined to be the unknown source with a peak energy of 833.38 keV.

I. GAMMA RAY AND X-RAY INTERACTION WITH MATTER

Gamma ray detection is the measured results of gamma ray interactions with matter. There are three distinct mechanisms in which this can occur; Compton scattering, pair production, and the photoelectric effect,. Compton scattering occurs when the gamma ray collides with an electron causing an inelastic collision to occur as the electron absorbs some of the gamma energy. If both the electron and the scattered photon can be detected then the initial gamma energy can be inferred. Pair production occurs when the photon passes in close proximity to the nucleus causing the creation of an electron-positron pair. This electron-positron pair will eventually collide annihilating each other and creating a photon pair that can easily be detected to infer the gamma energy. The photoelectric effect is essentially the process that occurs when an atom absorbs a photon, in this case a gamma ray, and consequently emits an electron[1,2].

A. Compton Scattering

Compton Scattering is an example of the phenomenon of inelastic scattering. It occurs when a photon of a certain wavelength (in this case a gamma ray or X-ray) interacts with a free electron or a weakly bound electron, transferring part of its energy and being 'scattered" at a new angle with a new wavelength. The electron leaving the collision will often have energy very close to that of the lost energy of the gamma ray due to the minuscule value of binding energy of the electron in comparison to that of the gamma ray. The production of the scattered gamma ray and the released electron, when both detected, can result in the initial gamma ray energy being found through a simple calculation. Compton Scattering is considered the mid-energy level of light interaction with matter[3].

B. Pair Production

When a gamma ray has a certain energy, in the range of 1.022 MeV or greater, and is placed under an electromagnetic field of certain strength it can create an electron positron pair. This must occur near a nucleus to conserve momentum and energy. The gamma ray peaks are detected in the measured spectrum when the positron runs out of energy and collides with the electron in an annihilating interaction. This occurrence allows for the collection and measurement of gamma ray energy peaks in the spectrum. Pair Production is considered the high energy level of light interaction with matter[3].

C. Photoelectric Effect

The photoelectric effect is the lowest energy of light interaction with matter. Since this scenario occurs at such a low energy, the incident photon (gamma ray or x-ray) is of approximately equal or just greater value in energy to that of the electron binding energy. This causes an interaction in which the electron is freed at the cost of the whole gamma ray. The released photoelectron will have an energy equalling the value of the difference between the energy of gamma ray and the electron binding. A detector can acquire the total energy pulse of the gamma ray by receiving the freed photoelectron as well as various emitted x-rays that make up the electron binding energy[3].
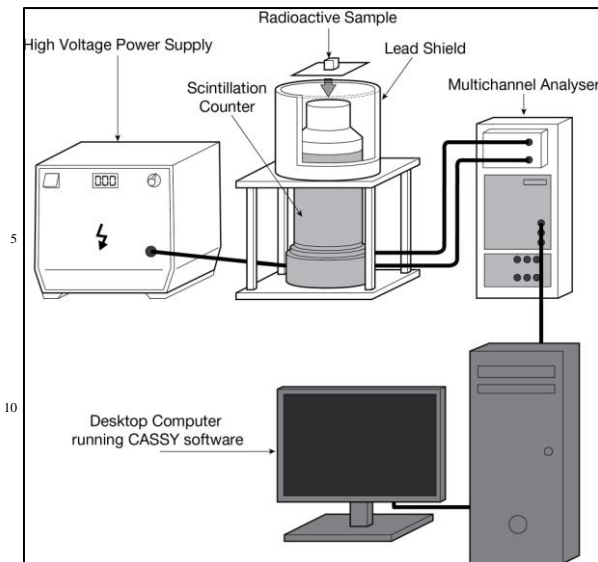
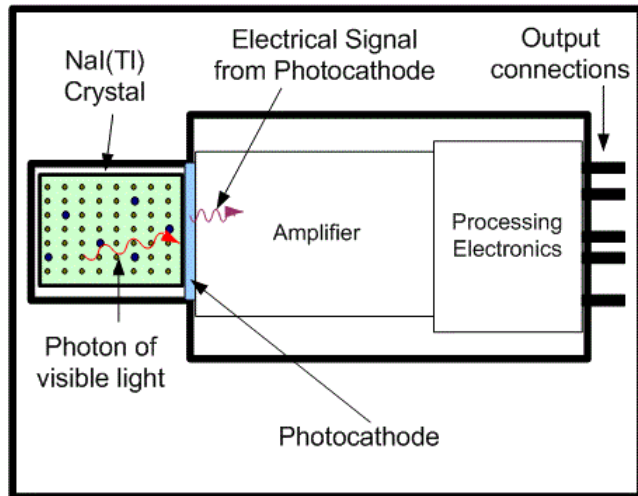FIG. 1: A Multi-Channel Analyzer Spectroscopy detection system. [5]

15 FIG. 2: A Sodium Iodide Detector contains a NaI crystal, which takes the incoming gamma ray and turns it into visible light. The photocathode turns this into an electrical signal, which is amplified and then sent to processing electronics like the Multi-Channel Analyzer. [4]

II. Multi-Channel Analyzer (MCA)

20 Multi-Channel Analyzers are tools used to produce data from various scientific measurements. Multi-Channel Analyzers take the input voltage pulses from the amplified electric signals and organize them into a readable graph or spectrum. This spectrum is the number of events versus 25 pulse-height. This spectrum can be used to gather data, including the Full Width Half Maximum, the integrated peak width at the Full Width Half Maximum, the gross integral, the centroid and the peak count. These various measurements can be used to interpret the understanding of 30 how distance, gain, and bipolar pulses affect the results of gamma spectroscopy. The Multi-Channel Analyzer and Detector experiment can be set up as pictured in FIG. 1 [5].
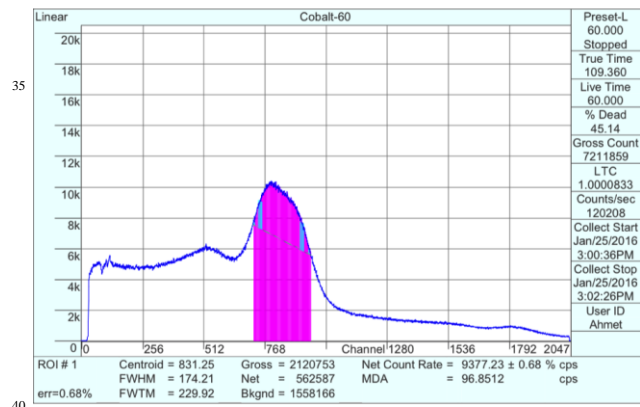

FIG. 3: The spectrum acquired from a Cobalt-60 source at a distance of 0 cm.

III. SPECTRUM ANALYSIS WITH A SODIUM IODIDE DETECTOR

45 The Sodium Iodide Detector, which is an example of a Scintillator detector system, is highly efficient in gamma detection. Due to the high Z of iodine and the consequent large number of electrons to interact with Sodium Iodide detectors make excellent scintillation 50 detectors. They are a cheaper option when it comes to detecting equipment but are generally only good for spectrometry. An example of the cross section of a Sodium Iodide Detector can be seen in FIG.2. [1,4,6,9].

A. Cobalt-60

55 For this experiment, a Cobalt 60 source was used to test the features of the Sodium Iodide Detector and to discover some pros and cons as well as come to any conclusions about this method of radiation detection. Several tests were undertaken at varying distances and at full and half gain. 60 As an example, shown in FIG. 3, a Cobalt-60 source was measured at 0cm away from the detector resulting in the spectrum shown through the Multi-Channel Analyzer.

Table I A collection of data from the Sodium Iodide Detector Results.

Test Description	Centroid	Full Width Half Maximum	Gross Integral	Time (s)
Cobalt 60 0cm	831.25	237 counts	2120753	60
Half Gain	418.59	118 counts	2104840	60
5s Full Gain	834.46	237 counts	176290	5
2cm Peak 1	859.48	77 counts	453874	60
2cm Peak 2	992.54	107 counts	462575	60
4cm Peak 1	884.67	83 counts	298791	60
4cm Peak 2	1020.33	86 counts	254499	60
Bipolar 4cm Peak 1	969.38	75 counts	285222	60
Bipolar 4cm Peak 2	1106.73	89 counts	270493	60
Bipolar 0cm Peak 1	951.92	73 counts	804021	60
Bipolar 0cm Peak 2	1090.77	86 counts	755185	60

B. Sodium Iodide Detector Results

Table I shows the large range of values gathered from the Multi-Channel Analyzer through the Sodium Iodide Detector. A low Full Width Half Maximum value relates to radiation peaks with a higher resolution. As can clearly be seen from Table I, the bipolar pulses produced the best resolved peaks. As the order of magnitude of the peak count was maintained the bipolar pulse method returned relatively lower full width half maximum values. A better resolution allows for the energy band of the peak to be more accurately calculated. Unipolar pulses could have possibly left charge on the capacitors resulting in errors for the pulses occurring one after the other.

Therefore as can be seen the Sodium Iodide detector yielded results of less than excellent calibre. For the Sodium Iodide detector to produce reliable results a large quantity of trials needs to be conducted over a larger amount of time. As can be seen the 5 seconds trial in Table I produced results of a very poor resolution.

Another point worth mentioning is the differences found in resolution between the different distances at which the Cobalt-60 source was placed. At 0 cm the resolution was not very good. At 2cm it was significantly better and at 4 cm the resolution had decreased again. It would make sense for the resolution to be better when the source was closer. For 0cm however, the source is saturating the detector at peak energy levels creating an element of significant error. [6][9]

IV. SPECTRUM ANALYSIS WITH A GERMANIUM DETECTOR

Semiconductor detectors like the Germanium Detector operate by knowing that the incident gamma ray will enable an electron-hole pair to be created in PN junction of the semiconductor. By applying a high biased voltage the electrons that have been freed will move to the P or the N side where they will be detected.

The Germanium Detector is much more efficient at returning a much better resolution. While being more expensive the Germanium Detector due to their liquid nitrogen cooling system they have a much lower formation energy per electron whole pair in comparison with the Scintillation detector.

Another key factor is that Germanium Detectors have little to no dead time. Dead time is the delay between the detection and the signal being fully processed.

The Germanium Detector was chosen for the calibration of a curve from gathering the spectrums of Cobalt-60 and Cobalt-57. The calibrated curve was then used to analyze the unknown sample and conclude on its nature[6,7].
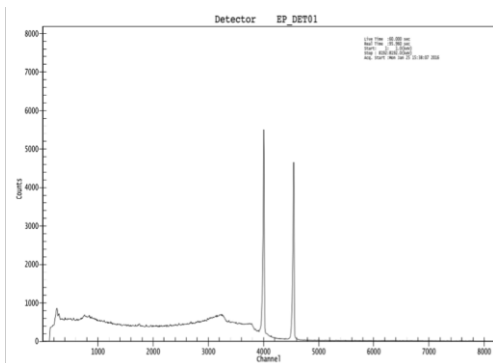
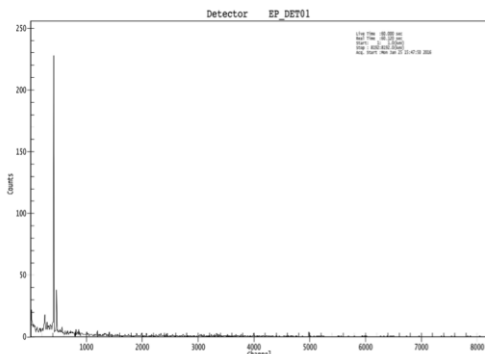**FIG. 4.** Measured spectrum of a Cobalt-60 source with the Germanium detector

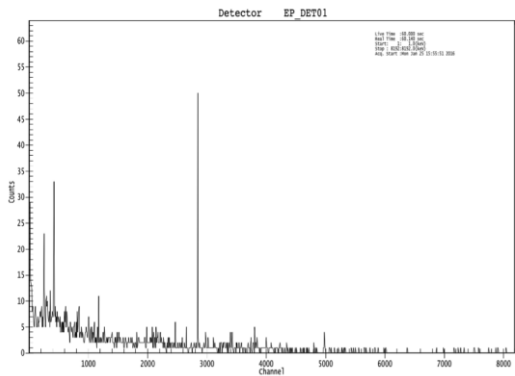**FIG. 5.** Measured spectrum of a Cobalt-57 source with the Germanium detector

5 **FIG. 6.** Measured spectrum of a unknown source with the Germanium detector

Table II Data collected from the Germanium Detector Spectra

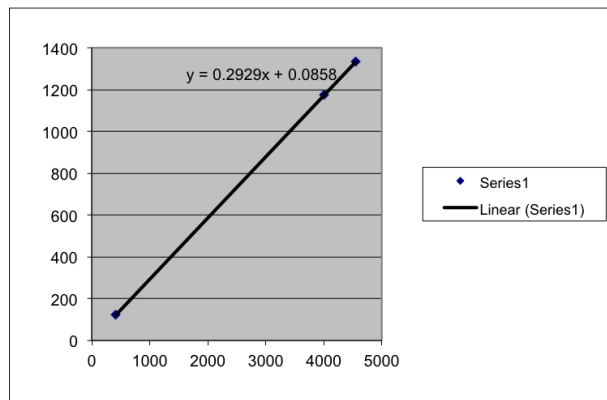| Source	Channel #	Peak Significance	Energy	
Cobalt-60	4006.23	84.67	1173.24	
Cobalt-60	4549.39	82.91	1332.5	
Cobalt-57	416.45	22.89	122.06	
Unknown Source	2844.98	14.21	N/A	

FIG. 6: A plot of channel number versus energy

A. Unknown Isotope Analysis

The data collected from the germanium detector was presented on the Multi-Channel Analyzer and the spectra 15 of the two known sources and the unknown sources were plotted and can be found above in FIG. 4, 5, and 6. Table II shows the important data from the spectra clearly. The energy column was found by taking the peak significance from the known sample isotopes, and finding their well- 20 known corresponding energies[8].

Using simple algebra and the calculation of the slope from the table of spectra values the following equation can be formed.

25 $$\text{Energy} = 0.2929(\text{Ch\#}) + 0.0858 \quad (1)$$

Using the channel number of the unknown isotope, the energy of the unknown isotope can be calculated and a educated guess based on the known Gamma Ray Energy 30 Peaks. The unknown isotope was found to be that of Manganese-54 which has one peak of 99.976% intensity and an energy of 883.38 keV.[8]

V. CONCLUSIONS

Both distance and time effect how gamma rays 35 travel and how well they are received. Over large amounts of time and many trials Sodium Iodide Detectors are excellent equipment for isotope analysis. Germanium Detectors are much more effective, accurate and resolute machines for analyzing the spectra of nuclear isotopes. If a 40 calibration curve of previous sources is undertaken, an unknown isotope can be measured and determined with surprising accuracy. Through the measurement of Cobalt-60 and Cobalt-57, an unknown source was determined to be Manganese-54 with a peak energy of 883.38 keV. The 45 source must be close enough as well as sufficiently far away to avoid saturation of the gamma ray. Lastly, bipolar pulses produce much higher resolution than that of unipolar pulses.

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Notes and references

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