ENGPHYS 3D04

Lab 1: Gamma Detection

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Lab date: September 27 (Group 6)

Submission Date: October 18

Executive Summary:

In this laboratory experiment, we employed three distinct radiation detectors: a Geiger-Müller (GM) counter, a Sodium Iodide (NaI) scintillation detector, and a High-Purity Germanium (HPGe) semiconductor detector. The primary aim was to study the response of these detectors to various low-activity radioactive sources and discern the identity of an unknown radioactive source.

The GM counter demonstrated the inverse square law relationship between count rate and source-detector distance, underscoring the geometrical spreading of radiation. The NaI and HPGe detectors, known for their gamma spectroscopy capabilities, exhibited distinct energy spectra when exposed to Cobalt-60 and Cesium-137 sources. The superior energy resolution of the HPGe detector was evident, with narrower and more defined peaks, while the NaI detector showed higher efficiency, registering more counts for the same sources.

Utilizing the known gamma-ray energies of Cobalt-60 and Cesium-137, we calibrated the HPGe detector. This calibration enabled the identification of an unknown radioactive source, which was conclusively determined to be Sodium-22 (22Na), based on the observed gamma-ray energies and their relative intensities.

In conclusion, this experiment provided valuable insights into the operational characteristics and capabilities of different radiation detectors. The HPGe detector, with its high resolution, proved invaluable for precise isotope identification, while the NaI and GM detectors showcased their unique strengths in efficiency and illustrating fundamental radiation principles, respectively.

Data Analysis and Discussion:

Uncertainty Analysis:

GM Counter: Count rates have inherent uncertainty due to the Poisson nature of the data, represented as the square root of the count rate ($\sigma R=R$). Additional uncertainties arose from background radiation and measurement errors.

NaI and HPGe Detectors: Uncertainties stemmed from statistical fluctuations in counts, energy calibration errors, peak integration methods, detector resolution, and background radiation.

General: Tools used for measurements introduce their own precision errors, and environmental factors like temperature and electronic noise can affect results.

Tables and Data:

- Table 1: GM Counter Data:

GM Counter data with Europium - 152		Count Rate (Count/s)
Background count	6	0.1
1 cm	1687	((1687 +1712+1604)/3)/60) = 27-79 -0.1 = 27.68 counts/s
1 cm	1712	
1 cm	1604	
2 cm	598	9.87
3 cm	303	4.95
4 cm	192	3.1
5 cm	143	2.28
6 cm	94	1.47
7 cm	79	1.22
8 cm	66	1

Table 1

- Sodium Iodide Scintillation Detector Data: (From provided screenshots)

  Background Spectrum:
  Acquisition time: 60 seconds

  Spectrum of Cobalt-60 at 12 cm:
  Acquisition time: 60 seconds
  Peak channel numbers: 497 (first peak), 557 (second peak)
  Peak width (FWHM): 45 (first peak), 39 (second peak)
  Gross integral: 161372 (first peak), 90210 (second peak)

  Spectrum of Cobalt-60 at 12 cm with reduced acquisition time:
  Acquisition time: 10 seconds
  Peak channel numbers: 498 (first peak), 548 (second peak)
  Peak width (FWHM): 45 (first peak), 39 (second peak)
  Gross integral: 27097 (first peak), 14282 (second peak)

  Spectrum of Cobalt-60 at doubled distance (24 cm):
  Acquisition time: 60 seconds
  Peak channel numbers: 477 (first peak), 543 (second peak)
  Peak width (FWHM): 29 (first peak), 32 (second peak)
  Gross integral: 56529 (first peak), 47141 (second peak)

- High-Purity Germanium (HPGe) Semiconductor Detector Data: (From provided screenshots)

  Background Spectrum:
  Acquisition time: 60 seconds

Spectrum of Cobalt-60 at 12 cm:
Acquisition time: 60 seconds
Peak channel numbers: 4885 (first peak), 5542 (second peak)
Peak width (FWHM): 43 (first peak), 44 (second peak)
Gross integral: 54682 (first peak), 47527 (second peak)

Spectrum of Cesium-137 at 12 cm:
Acquisition time: 60 seconds
Peak channel number: 2748
Peak width (FWHM): 8
Gross integral: 2535

Spectrum of Unknown Source at 12 cm:
Acquisition time: 60 seconds
Peak channel numbers: 2123 (first peak), 5290 (second peak)
Peak width (FWHM): 12 (first peak), 11 (second peak)
Gross integral: 1133 (first peak), 315 (second peak)

Analyzed Data and Figures:

Figure 1: Plot of inverse count rate (1/count rate) measured with the GM counter against the source-detector spacing

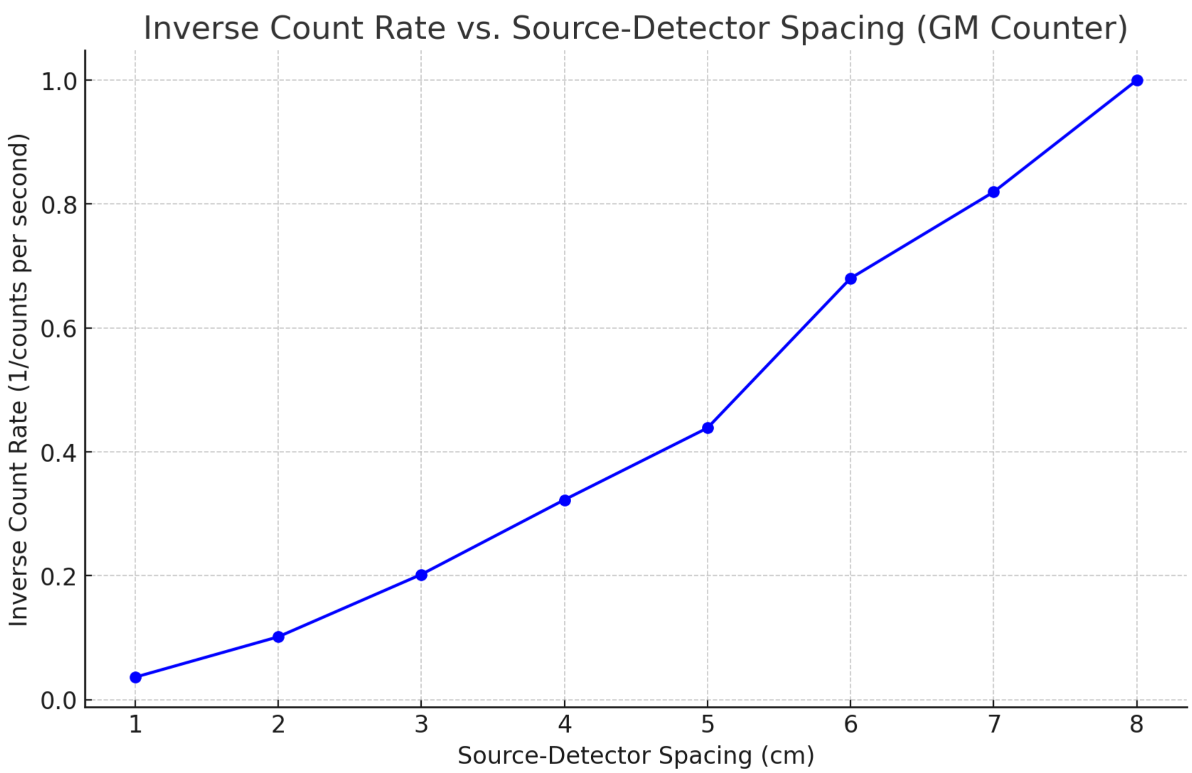

Figure 1

Figure 2: Energy vs. Channel Number calibration curve for the High-Purity Germanium (HPGe) detector:

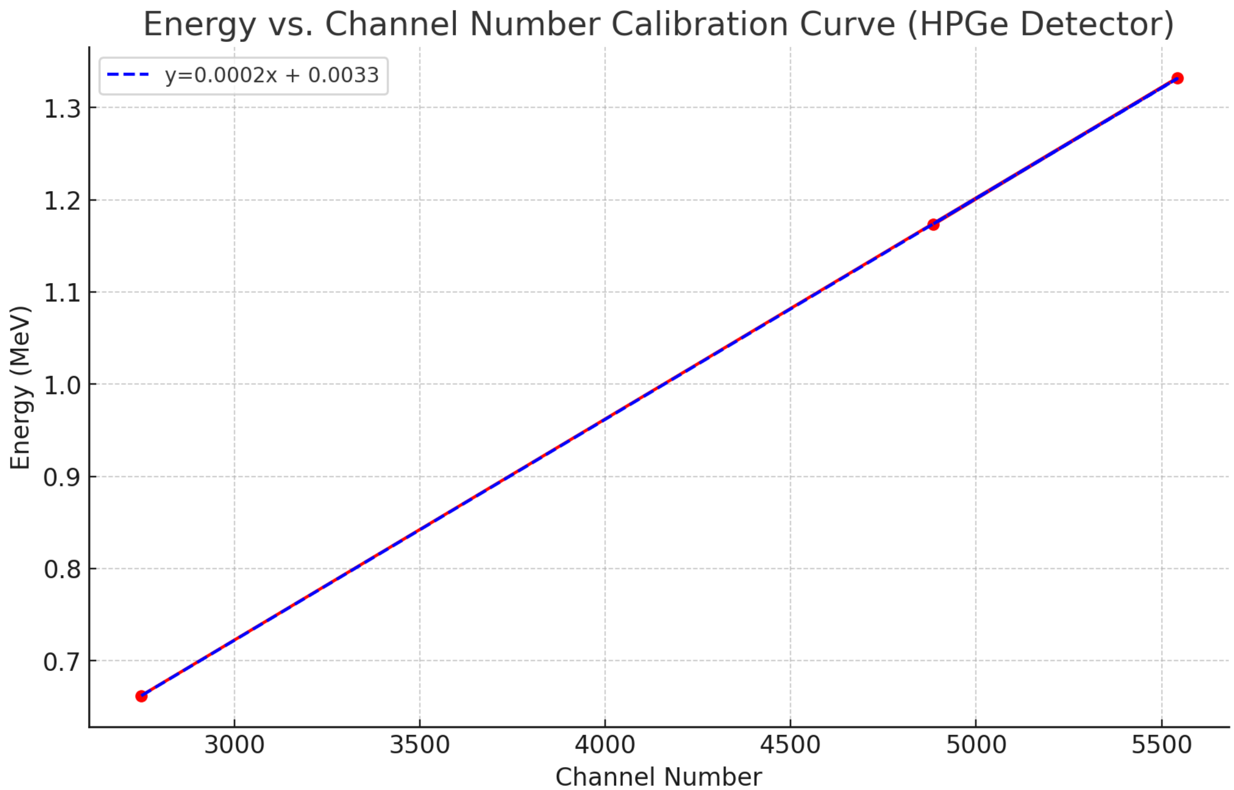

Figure 2

Discussion and Lab Questions:

1. From the plot, (Figure 1) we can observe that the inverse count rate increases as the source-detector spacing increases. The relationship observed in the plot can be described by the inverse square law, which is a fundamental principle for point sources of radiation.

2. The spectra obtained from the Sodium Iodide (NaI) and High-Purity Germanium (HPGe) detectors showcased distinct characteristics. The NaI detector exhibited higher efficiency, registering more counts for the same sources. In contrast, the HPGe detector demonstrated superior energy resolution with narrower, more defined peaks. The differences can be attributed to the inherent properties and operational mechanisms of each detector. The NaI's scintillation process is efficient in detecting gamma rays, but with lesser precision, while the HPGe's semiconductor properties allow for precise energy measurements but at the cost of efficiency.

3. Pros and Cons of the Detectors:

Geiger-Müller (GM) Counter:

- Pros:
  - Cost-effective.
  - Simple to use and robust.
  - Effective for detecting the presence of radiation.
- Cons:
  - Lacks energy resolution; cannot differentiate between different types of radiation.
  - Can saturate with high radiation levels.

Sodium Iodide (NaI) Scintillation Detector:

- Pros:
  - High efficiency; registers more counts for the same sources.
  - Relatively faster response time.
- Cons:
  - Moderate energy resolution; peaks can be broader.
  - Susceptible to temperature and humidity changes.

High-Purity Germanium (HPGe) Detector:

- Pros:
  - Superior energy resolution; ideal for precise isotope identification.
  - Can measure low radiation levels with high precision.
- Cons:
  - Expensive.
  - Requires cooling, often with liquid nitrogen.
  - Lower efficiency compared to NaI detectors.

4. To generate an energy versus channel number calibration curve, we needed to know the gamma-ray energies of the isotopes used (in this case, Cobalt-60 and Cesium-137) and then correlate those energies with the channel numbers where the peaks were observed.

   From the nuclear database: (NuDat)

   Cobalt-60: Emits two gamma rays with energies of 1.173 MeV and 1.332 MeV
   Corresponding channel numbers: 4885 and 5542

   Cesium-137: Emits a primary gamma ray with an energy of 0.662 MeV
   Corresponding channel number: 2748

Using this data, we plotted the gamma-ray energies against the channel numbers to get our calibration curve. The slope of this curve provided us with an estimate of the energy resolution of the HPGe detector.

From the linear regression, the updated calibration equation is approximately:

$$\text{Energy (MeV)} = 0.0002396 \times \text{Channel Number} + 0.0033$$

Given that the peaks of the Unknown source were at channels 2123 and 5290,

Using the calibration, the gamma-ray energies of the peaks for the unknown source are approximately:

- 0.512 MeV (for the channel 2123)
- 1.271 MeV (for the channel 5290)

For determining the unknown source, I used NuDat's Nuclear Levels and Gamma Search function to enter a range of energies between 500 keV and 1300 keV. I further refined my search by ruling out all isotopes with short half lives. After observing the Decay Radiation results for all the candidate isotopes, I concluded the unknown source to be Na-22. This was because Na-22 was found to have Gamma radiation peaks of 511 keV (Intensity of 179.91%) and 1274.5 keV (Intensity of 99.94%). These values aligned with the gamma-ray energies of the peaks of the unknown source.

Gamma and X-ray radiation:

	Energy (keV)	Intensity (%)	Dose (MeV/Bq-s)
XR kα2	0.848	0.056 % *6*	4.7E-7 *5*
XR kα1	0.849	0.111 % *11*	9.4E-7 *9*
Annihil.	511.0	179.91 % *18*	
	1274.537 7	99.940 % *14*	1.27377 *18*

Figure 3: Gamma-ray energies Na-22

5. When a 2 MeV gamma-ray enters detectors of varying sizes:

   Small Ge Detector: The spectrum primarily shows a Compton continuum with a possible backscatter peak. A full-energy peak might be minimal or absent since the gamma ray might not deposit its entire energy in the detector.
   Medium-sized Ge Detector: A pronounced full-energy peak is present due to the gamma ray depositing its entire energy. Compton continuum and backscatter peak are less dominant. There might also be peaks corresponding to pair

production and associated escape peaks, given the energy threshold for pair production.
Infinite-sized Ge Detector: The spectrum is dominated by a clear full-energy peak, with minimal to no Compton continuum or backscatter peak. Pair production and its associated escape peaks are evident.

Main Conclusion:

In this comprehensive laboratory experiment, we explored the intricacies of radiation detection using three distinct detectors: the Geiger-Müller (GM) counter, the Sodium Iodide (NaI) scintillation detector, and the High-Purity Germanium (HPGe) semiconductor detector. Each detector showcased its unique strengths and limitations in the realm of radiation detection and analysis.
The GM counter illuminated the foundational principles of radiation spreading, demonstrating the inverse square law relationship between count rates and source-detector distances. On the other hand, the NaI and HPGe detectors, employed for gamma spectroscopy, presented discerning energy spectra when exposed to radioactive sources. Notably, the HPGe detector, with its exceptional energy resolution, proved pivotal in the precise identification of an unknown radioactive source, underscoring its value in isotope analysis. Meanwhile, the NaI detector, with its heightened efficiency, highlighted the trade-off between precision and efficiency in gamma-ray detection.