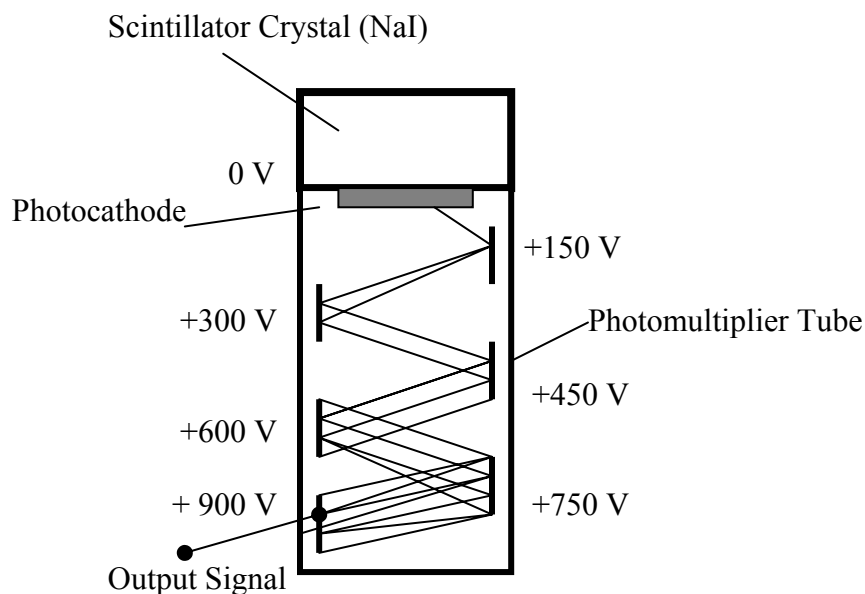# GAMMA-RAY SPECTROSCOPY

INTRODUCTION/THEORY

This experiment will demonstrate that excited atomic nuclei occupy discrete and unique nuclear energy levels in much the same way that excited atoms exhibit discrete and unique atomic energy levels. When an atom undergoes a de-excitation transition, a photon is often emitted which carries off energy equal to the difference in energies of the two electronic levels involved. An analogous phenomenon occurs in nuclear transitions between nuclear energy levels. The photons emitted in nuclear transitions are called gamma-rays and generally have energies several orders of magnitude greater than atomic photons.

In both the atomic and nuclear processes, the resulting photon spectrum is unique and provides a means of identifying either the chemical element or radioisotope present. The fact that the radiation pattern (spectrum) of each radioisotope is unique and the very high detection efficiencies of nuclear counting systems, facilitates many useful scientific applications of radioactive materials - medical diagnosis, biological and chemical tracers, neutron activation, etc.

The gamma-ray spectrum will be obtained by using a Sodium Iodide (NaI) Scintillator Detector. The atoms of these type of detectors are easily excited by radiation and produce a spectrum that is characteristic of the chemical element present. A typical diagram of a NaI detector is shown below.

Scintillator Crystal (NaI)

0 V

Photocathode

+150 V

+300 V

Photomultiplier Tube

+450 V

+600 V

+ 900 V

+750 V

Output Signal

When a gamma-ray strikes the NaI crystal some of the atoms in the crystal will become excited and then emit photons as the atoms fall to their lower energy state. These photons will then collide with a plate called a photocathode and as a result electrons will be ejected due to the photoelectric effect. At the end of the photocathode a device called a photomultiplier (PM) is attached. The PM tube consists of several electrodes, called dynodes, whose electric potentials increase in succession along the tube. When an electron is ejected from the photocathode it will

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accelerate towards the first electrode having sufficient energy to eject several electrons. These electrons will then be accelerated towards the second electrode and eject several more electrons. This multiplication process continues until the electrons (several millions) reach the last electrode. The result is an electrical pulse at the output signal of the PM tube that is converted into a voltage pulse whose size is proportional to the gamma ray's energy.

The voltage pulse is amplified and measured by an analog-to-digital conversion (ADC) process. The result of this measurement is an integer between 0 and 1023 for a 10-bit ADC. Zero is the measure for a voltage pulse less than a hundredth of a volt, and 1023 is the measure for a pulse larger than about 8 volts (or the largest voltage pulse accepted by the ADC). Pulses between 0V and 8V are proportionately given an integer measure between 0 and 1023. This measure is called the channel number. The analog to digital conversion is performed by the interface card that is installed in the computer. The computer software that comes with the hardware records and displays the number of gamma rays observed for each channel number. The screen displays the number of gamma rays as a function of the channel number.

Calibration with sources of known energies allows you to correlate the channel number with the gamma energy. The result is a graph of the frequency (counts) as a function of gamma-ray energy (channel number). Figure 1 below is a calibrated spectrum. The photopeaks have been labeled; other structures in the data will be discussed in future experiments.
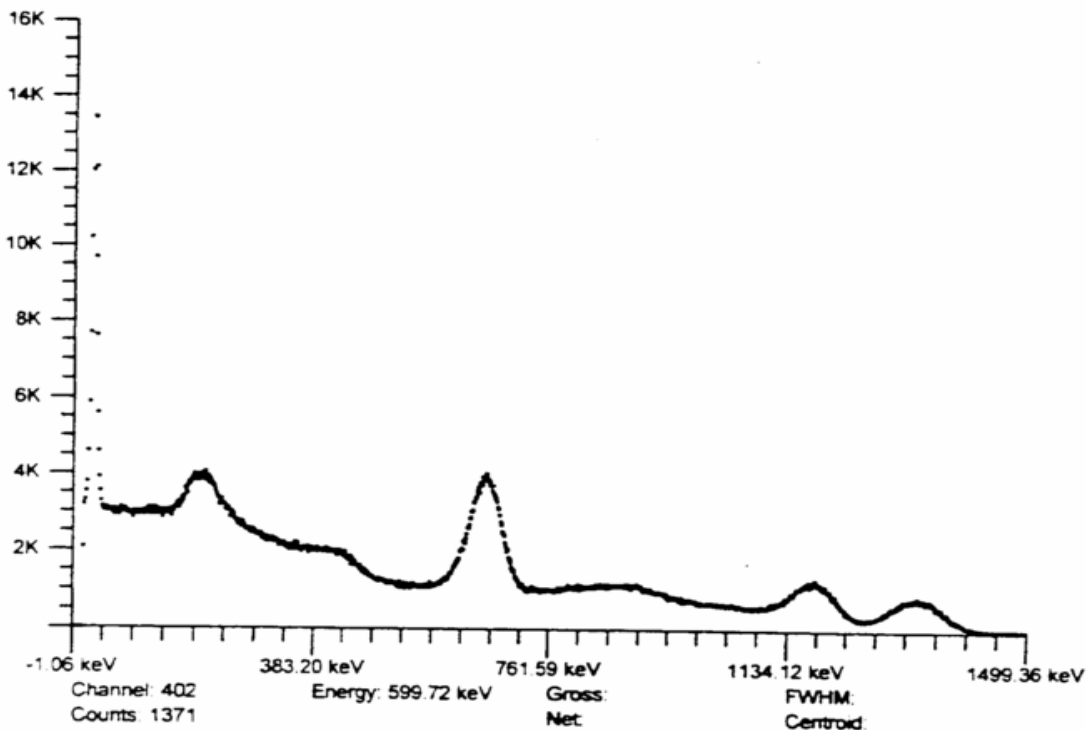

Figure 1 (Calibrated Spectrum)

OBJECTIVE

A. Learn how to calibrate a gamma-ray spectroscopy system.
B. Identify two unknown radioactive sources by analyzing their gamma spectra.
C. Calculate the resolution of the system.

EQUIPMENT

1. NaI detector
2. Computer-Based MCA (multi-channel analyzer-already installed inside computer)
3. ^{22}Na source, ^{137}Cs source, 2 unknown radioactive sources.

CALIBRATION PROCEDURE

1. Start the ICS10 multi-channel analyzer program:
   Select **Start--->Programs--->SpecTech--->Icsw32**
2. Click on **Setting** on the menu, then click on **AMP/HV**.
3. Set the **High Voltage** to 550 V, click **ON**.
4. Set the amplifier **COARSE GAIN** to 4 and set the **FINE GAIN** to 1.498 .
5. Set the **Lower Level Discriminator (LLD)** to 2.1 and the **Upper Level Discriminator (ULD)** to 106.2. These settings are used to eliminate unwanted noise and high energy signals.
6. Set the **Conversion Gain** to 1024.
7. Place the ^{22}Na source near the crystal end of the detector. Begin collecting data by clicking on the green start button at the upper-left side of the screen.
8. Acquire data for approximately 5 minutes or until you see a "well-defined curve". Stop collecting data by clicking on the red stop button at the upper-left side of the screen. Your spectrum should look like figure 2 below.
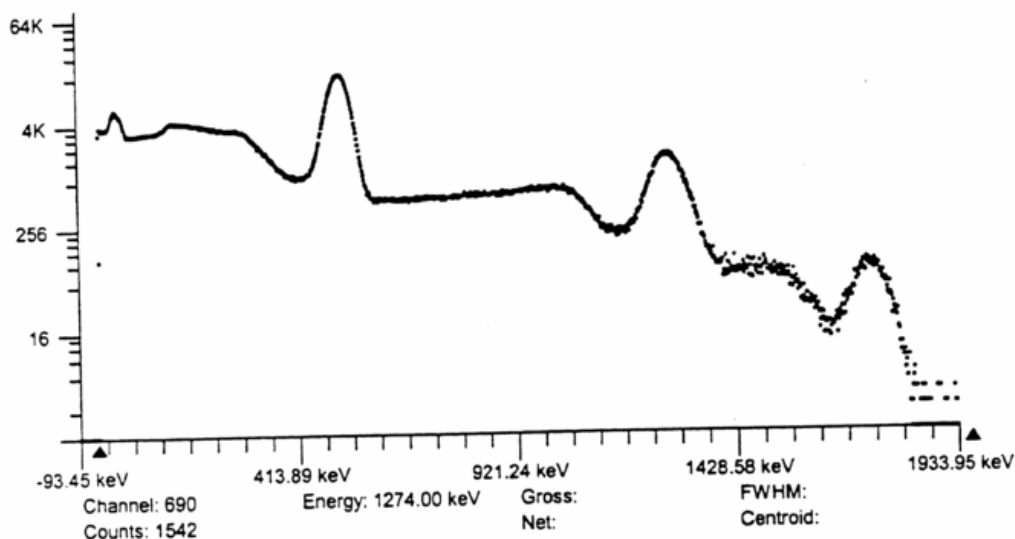

Figure 2 (^{22}Na Source)

9. You will now perform a 2-point calibration:

   A. Select **Setting--->Energy Calibrate--->2 point calibration**
   B. Position the marker at the highest channel of the first peak and enter 511 KeV. Move the marker to the high point on the second peak and enter 1274 KeV.
   C. The system is now energy calibrated and the marker position will read directly in energy.
   D. Print the ^{22}Na spectrum.

10. Check the calibration of the system by using the ^{137}Cs source. The observed peak should be centered near 661.6 keV. If it is not within 10 keV of the accepted value, you will need to re-calibrate the system. Print the ^{137}Cs spectrum.

EXPERIMENTAL PROCEDURE

1. Place one of the unknown sources near the crystal end of the detector and acquire data for approximately 15 minutes or until you see a "well-defined" curve.
2. Select an ROI (region of interest) for each displayed peak on the spectrum.
   A. Click the right mouse button
   B. Click on ROI
   C. Move the marker to either side of the peak.
   D. Hold down the left mouse button and drag the marker to the other side of the peak and release mouse button.
3. When clicking on a ROI the screen will show several important information about that peak. One will be the centroid energy. Check that the centroid energy agrees with the peak energy by locating the marker at the highest point of the peak.
4. Print the spectrum.
5. Select **Display--->Data Report** and print out Data Report for spectrum.
6. Repeat steps 1-5 for the second unknown.

ANALYSIS

A. Using the spectrum for unknown #1 source identify the radioactive element. Refer to the table 'List of Commonly Observed Gamma Energies' to identify unknown sources.

B. Using the spectrum for unknown #2 identify the radioactive element.

C. Determine the fractional energy resolution of one of the gamma energy peaks for each of the unknowns.

$$\text{Fractional energy resolution} = \frac{\text{energy spread of peak at half height}}{\text{peak energy}} = \frac{\text{FWMH}}{\text{peak energy}}$$

D. Calculate the % error for the calculated gamma-ray energies and the expected values
E. Comment on sources of errors involved.