Experiments with Gamma photons

In the following experiments, you will be using data from our gamma detectors. First you will learn how to operate our NaI detectors and use them to determine the identity of an unknown isotope. Then you will use the gamma detectors to measure a Compton scattered photon in order to test the kinematics of a photon scattering off an electron (Compton scattering). Finally, you will examine X-ray data from our high resolution gamma detector is investigate how the characteristic X-ray depends on the number of protons in the nucleus.

Part I: Energy Calibration of the MCA

Your goal in this part is to calibrate the MCA, determine the energies of the unknown, and identify it. You can assume that **the energy of the gamma is proportional to the channel number**. **Do not change the amplifier setting during this part**. If you do, your calibration will change. Be sure that both peaks of Na^{22} are present in your spectra before you start. As calibration standards, you will be given ^{22}Na, ^{137}Cs, ^{54}Mn, and ^{60}Co. The links on my homepage list the energies of the primary gamma rays of these sources to be:

> ^{137}Cs: 661.64 KeV
> ^{22}Na: 511.0034 and 1274.5 KeV
> ^{54}Mn: 834.827 KeV
> ^{60}Co: 1173.237 and 1332.501 KeV

For your analysis, First determine the channel numbers of the photopeaks corresponding to the energies of the calibration standards above. You can assume that the energy increases linearly with the channel number.

a) Make a graph of energy vs. channel number for the 6 energies of the standards. You can use Excel, and try and fit the data with a line. Display the equation (calibration equation) on the graph. From the channel numbers of your unknown and the calibration equation, determine the energies of the gamma rays of the unknown.

b) Use the link on my home page to deterine the unknown isotope.

Part II: Compton Scattering

In this experiment we will scatter gamma particles of energy 661.64 KeV (from Cs^{137}) off of electrons in an aluminum rod. We will measure the energy of the scattered gamma as a function of scattering angle and test Compton's formula.

Set up the Cs^{137} source, aluminum rod and NaI gamma detector to collect the gamma spectrum as a function of scattering angle. Record your data:

Angle	Channel Number of Peak Center
0°	—
20°	—
40°	—
60°	—
80°	—
100°	—
120°	—

Using only relativistic energy and momentum conservation for a massless particle, Compton derived a relationship between the energy of a scattered photon as a function of angle:

$$\frac{1}{E} = \frac{1}{E_0} + \frac{1 - cos(\theta)}{m_e c^2} \tag{1}$$

where E is the energy of the scattered photon, E_0 is the energy of the incoming photon, m_e is the mass of the electron, and θ is the scattering angle.

a) Graph the data in an appropriate way so that a straight line plot verifies the validity of Compton's formula. Is your data consistent with Compton's formula?

b) What is the slope of your graph in part a)?

c) From the value of your slope, what is the mass-energy of the electron in units of KeV?

Part III: X-rays

In this part of the experiment, we will examine the X-ray spectrum from four elements: Pb, Ho, I, and Ba. The spectra will be taken with our high resolution gamma detector.

a) For each spectrum, identify as many X-ray lines as you can.

b) Determine the channel number of the K_α line for each element. Use as an energy standard the four X-rays from Pb. The energies are 72.8 KeV, 75.0 KeV, 84.7 KeV, and 87.1 KeV. Obtain a calibration equation using these four X-rays as standards.

c) Make a graph of the square root of the energy of the X-ray transitions versus Z for the four elements. Z is the number of protons in the nucleus. Does your graph agree with Mosley's formula:

$$\sqrt{E} \approx C(Z - a) \tag{2}$$

d) If your data follow the above formula, what do you obtain for the constants C and a? Are your values for C in close agreement for the $n = 2 \rightarrow n = 1$ and the $n = 3 \rightarrow n = 1$ transitions?

e) You will next look at the spectra from a rock containing uranium. Notice all the x-ray emission lines. Measure their energies and determine what heavy nuclei are present in the sample.

Laboratory Writeup for Experiment 4

Your lab writeup will consist of the following:

1) Display the data table of channel number and energy for the standards as well as the channel numbers of the unknown photopeaks.

2) Turn in your calibration graph and the calibration equation.

3) Describe how you determined the unknown gamma energies and identify the unknown isotope.

3) Display the data table for the Compton scattering experiment.

4) Make an appropriate graph for checking the Compton formula. Does the data follow Compton's prediction?

5) Your calculation for the slope of your graph and for the mass-energy of the electron.

6) Display the data table for the X-ray energies of the 4 isotopes. Show your calibration graph and fitted equation.

7) Discuss the X-ray energy results as a function of atomic number Z and your check of Mosley's formula.

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8 Discuss your X-ray measurements of the uranium rock and your analysis regarding the presence of heavy elements in the rock.

Operation of the NaI gamma detector

The sodium iodine (NaI) gamma detector consists of a NaI crystal, photomultiplier tube, amplifier and high voltage. The two quantities that you have to set on the equipment are the **high voltage** and the **amplifier gain**.

The **high voltage** setting is usually written on the detector, and ranges from 530 volts to 900 volts. Check with the instuctor before turning on the equipment to insure that the voltage setting is correct.

The **amplifier gain** should be set so that all the photo-peaks of the standards lie within the channel number range of the detector.

There are three different computer interfaces in the lab: 5 DOS based cards from "The Nucleus", a card from "Ortec", and two USB interfaces from "Ortec". The instructor will show you how each one works at the start of the session. The output for all the interfaces is the same: a spectrum with the horizontal axis being **channel number** and the vertical axis **counts**. To a good approximation, the **energy of the detected radiation is proportional to the channel number**. The proportionality constant is determined by the amplifier gain setting and the high voltage setting.

Below is a brief explaination of how to use the different interfaces:

DOS based cards:
1. Place the DOS bootdisk in the floppy drive and turn the computer on. The computer will boot up in DOS, and you will be in "a" drive. The screen will show: $A >$.
2. Type "c:" and enter to shift directory to the hard disk.
3. Type "cd phy235L" and enter to shift to the phy235L directory.
4. To run the detector type "pcae" from the phy235L directory.

USB interface:
1. Boot up in windows 2000
2. Run the Maestro program

3. The instructor will show you how to set the High Voltage and collect data.

Ortec 2000 channel card

1. Boot up in windows 98
2. Run the Maestro program