

Physics 220 Lab 8, Spring 2009

Gamma ray spectroscopy

References: Introductory Nuclear Physics, Krane, sections 7.3, 7.6 (handout)

I. BACKGROUND

Nuclear energy states and gamma rays

Just as an electron in an atom is bound in a particular energy state, a proton or a neutron in a nucleus is bound in a specific energy level. The most obvious difference between these atomic and nuclear energy states is the amount of energy involved. Atomic states which are associated with optical transitions differ in energy by several electron volts (eV). Nuclear energy levels differ by several million electron volts (MeV). Bound neutrons or protons can undergo transitions to higher or lower energy states in a manner similar to bound electrons. Often, the result of such a transition is the absorption or emission of a photon. These photons with energies on the order of MeV are called gamma rays (γ rays).

Measuring the wavelength or energy of emitted photons is called spectroscopy. Just as spectroscopy of light emitted from atoms or molecules can be used to determine which elements or molecules are present in a sample, gamma-ray spectroscopy can be used to determine which radioactive elements (more specifically, isotopes) are present.

Detecting gamma rays

Gamma-ray detection relies on the fact that gamma rays are ionizing radiation—that is, the energy of a single gamma-ray photon is large enough to remove an electron from a typical atom. In a gamma-ray detector, the incoming gamma ray removes electrons from atoms of the material in the detector, and these removed electrons are eventually converted to an electrical signal.

In previous physics labs, you may have detected gamma rays using a gas-filled Geiger counter. Geiger counters are simple, compact, and reliable, but because they use gas rather than a solid, they have a low efficiency for detecting gamma rays. Geiger counters also do not measure the energy of the gamma rays they detect, just their presence.

In this lab, the device we will use to detect the gamma rays is a scintillation detector, specifically a large single crystal of NaI (with small amounts of Tl), which is coupled to a photomultiplier tube (PMT). Please read the marked sections from Krane's Nuclear Physics book and answer the following:

1. Briefly describe the function of each of the following parts of the detector system: the scintillator, the photocathode, the photomultiplier tube (PMT), the preamplifier, the amplifier, and the multichannel analyzer (MCA).

Interpreting gamma-ray spectra

Suppose we have a monoenergetic source of gammas (i.e., the gammas all have the same energy). You might naively expect that the resulting spectrum will be a single peak at the channel corresponding to the gamma-ray energy. In fact, the spectrum will look something like Fig. 7.25 in the handout from Krane. To understand the features, we need to understand the three ways in which a photon can interact with a material:

Compton scattering: photon scatters from an atomic electron, giving up some of its energy to the electron, and moving off at an angle

Photoelectric absorption: photon gives up all its energy to an atomic electron; photon ceases to exist

Pair production (only for photons of energy greater than 1.022 MeV): photon “vanishes,” creating a new pair of particles, an electron and a positron (the positron is the antiparticle of the electron, with the same mass but positive charge)

Please answer the following questions:

2. Use the concept of conservation of energy to explain why pair production can happen only for photons of greater than 1.022 MeV.
3. Sketch a version of Figure 7.25 in your lab book, and label the parts of the spectrum with the processes that create them (see Fig. 7.24).
4. One of the nuclear spectra you will look at is the spectrum of ^{137}Cs , which has a gamma-ray energy of 662 keV. Which of the features of Fig. 7.25 will be found in this spectrum, and why?

As Fig. 7.25 shows, the detector will have an energy resolution that will tend to broaden the peaks. In particular, the photopeak will have a gaussian shape with a finite width (specified as FWHM). In a system such as this, the width is primarily due to random fluctuations in the number of photoelectrons produced at the photocathode. The absolute detector resolution (FWHM of the photopeak) increases as the square root of the energy, so that the fractional resolution ($\Delta E/E$) decreases as $1/\sqrt{E}$.

II. PROCEDURE

You will use a scintillator to detect, measure, and understand the γ -ray spectra of several different sources. We will be looking at photopeak energies, Compton edges, other features of the spectrum, and the dependence of resolution on energy.

Turn the computer on if it's not already on, and open Icsw16 or UCS20.

The system should open with the Amp/HV settings dialogue box

The high voltage should be set on 1,000 volts; turn it ON

(Do not vary the high voltage; 1000 V is satisfactory for this detector.)

The Conversion Gain should be set to 1024 (this is the number of channels)

The Coarse and Fine Gain (amplification) settings can be adjusted as needed

Once adjusted, click on spectrum window, behind this dialogue box

You can return to the Amp/HV dialogue box by choosing it under the Settings menu, or by clicking on the button on the tool bar as shown here.



Familiarize yourself with the operation of the multichannel analyzer.

Find the Start; Stop; and Erase buttons. What are their functions?

Spectra can be extracted from the computer by choosing to display the spectrum, the data, or chosen regions of interest and then printing them out. (See Display menu.) The spectrum can also be exported in a form readable by Excel (tab-separated or comma-separated).

Start with a ^{22}Na source. Have your instructor show you how to look up the decay process and the principal decay radiations so you can record these in your lab book.

Vary the amplification (gain) and observe what happens to the spectrum.

Also do the following:

- Learn how to change scales (up and down arrows and the vertical slider)
- Expand certain sections of the spectra (expand/contract buttons and slider)
- Locate specific channel numbers and the number of counts in them. (Mouse or left and right arrows)
- Set a region of interest (ROI) and get statistics for that ROI, such as the total number of counts, or FWHM and centroid (central channel number) for a given peak

Now you should set the gain to a value that will be reasonable for all the different energy peaks you want to see. Here's how to do this. You will eventually want to detect gamma rays up to 1.3325 MeV. Since the maximum channel number is 1024, you'll want the 1.3325 MeV photopeak to be in a channel close to but less than channel 1024—say, in channel 900—so that all peaks of interest are at channel 1024 or less. Assuming that channel 900 corresponds to 1.3325 MeV and channel 0 corresponds to zero energy, calculate in which channel the 662 keV peak should go and adjust the gain to make this roughly correct.

It should be possible to calibrate the system (that is, determine the energy that corresponds to each channel) with the two gamma rays from the ^{22}Na source. This is accomplished by assuming

a linear relationship between energy and channel number. Knowing the two energies E_1 and E_2 and the channel numbers of their peaks C_1 and C_2 the unknown coefficients, m and b , in the linear equation:

$$E = mC + b$$

can be determined. The computer will determine the coefficients and thus the calibration given two peaks of known energy.

Go ahead and do a 2-point calibration using the ^{22}Na source's two main photopeaks. (Hint: the centroid value obtained from a ROI setting is a better estimate of the center of a peak than is your estimate by eye.)

NOTE: Do not vary the high voltage or gain setting after the calibration has been made. Otherwise the system will have to be recalibrated.

Before collecting data on specific decays, take a background run with no sources present so that you can be sure whether other background sources of radiation (cosmic rays, radioactive nuclei that are naturally present, etc.) contribute significantly to the spectra you'll be measuring.

^{137}Cs

Have your instructor help you look up the decay process and the principal decay radiations so you can record these in your lab book. Record the spectrum of a ^{137}Cs source and determine from the spectrum the energy of any peaks which appear in the spectrum. Estimate an uncertainty in each reading.

Calculate the energy of the Compton edge for the 662 keV gamma ray, and determine where it is in the spectrum. Does its measured location correspond to your calculation? Can you see the Compton edge for the other peak?

Would you expect to see escape peaks for this source? If so, at what energies? Do you see them (explain)?

The resolution of a system is often defined as the ratio of the full width half maximum (FWHM) of a peak to the center channel of the peak ($\Delta E/E$), converted to a percentage. Experimentally determine the resolution for the two main peaks of the ^{137}Cs source.

^{60}Co

Have your instructor help you look up the decay process and the principal decay radiations so you can record these in your lab book. Record the spectrum of a ^{60}Co source and determine the energy of the photopeaks. Compare to the accepted values. Also measure the resolution of the photopeaks.

Calculate the energies of the Compton edges, and determine where they are in the spectrum. Do their measured locations correspond to your calculations? (Be sure you understand why there are two Compton edges in this spectrum.)

Would you expect to see escape peaks for this source? If so, at what energies? Do you see them (explain)?

Mystery spectrum

Repeat the process for the mystery spectrum; describe the spectrum quantitatively in as much detail as possible. The spectrum will probably have been taken with a different gain than the gain you used, so you will need to calibrate it using the calibration spectrum, which was taken with both the ^{137}Cs and the ^{60}Co sources present. The claim is that this spectrum is from $^{99\text{m}}\text{Tc}$; is this consistent with your analysis of the spectrum?

Summary: For all the spectra you examined, summarize your results for the following, comparing measured values with accepted or calculated as appropriate:

- Agreement of photopeak energies with accepted values (a graph might be a useful way to show if there are any trends with energy)
- Existence and location of Compton edges and escape peaks
- Scaling of resolution with energy (a graph is probably the best way to show this); does this behave as you expect?

When you are done, please turn the HV off and return all sources to me.