

γ Ray Spectroscopy

Ben LaRoque

July 31, 2012

*You should read this in full before beginning and use it as you plan your work. I expect you to complete this in the format of an original science experiment and **not** as a “cookie cutter” lab. In particular, that means your lab notebook must make sense to someone reading without access to this document or the lab manual.*

1 Purpose

Spectroscopy using gamma rays is a common technique used in high energy physics. There are many applications which you are encouraged to look into, but the one you will be interested in here is identification of radioactive isotope(s) in a sample and quantifying the radioactive content. Try not to miss the forest for the trees, this is the interesting physics technique for this lab, everything else (which may be much of your time) should be supporting this but is not of interest on its own.

2 Goals

At the end of this lab you should have a response to the following:

1. What isotope(s) is/are present in the sealed source labeled “unknown”?
2. For each isotope identified in the “unknown” approximately how much is present (in units of μCi will be sufficient)?
3. For some other sample, what isotope(s) are present and at what level? Some options for this are:
 - The sample of uranium ore
 - A soil sample from somewhere on campus or near your home
 - Some other sample brought from home or provided by your TA

NOTE: your sample **must** be fully contained (in a plastic bag or other container) regardless of what it is. Also if you bring in a food type item you may **not** take it with you when you leave, it must be disposed of in the lab.

4. Why should your results be considered reliable? (I’ll expand on this in a later section).

3 Theory/Background

I'm not going to write this for you. You should read whatever is in the manual. Most of the concepts will have come up at some point or another in other course work. It is important that you understand:

1. where do gamma rays come from?
2. what are the three important interactions a gamma ray can have in the detector?
3. for each type of interaction, is there a maximum energy deposit? is there a minimum? at low, medium, and high energies, which interaction dominates?
4. once a gamma ray deposits energy in the NaI crystal, how does the PMT become involved? What happens in the PMT between its initial interaction and the final electrical signal? Can you predict/explain the PMT's signal shape (polarity, amplitude, etc.)?
5. what do you expect a background spectrum would look like (and why)?

This list is not exhaustive, you may (and should) include other things which you deem to be important.

4 Why Should I Believe You?

You need to respond to two different issues here. First, this is a class, so you need to convince your TA that you have an understanding of how things work. In general, these are the sort of things people will assume you know and do correctly if it were professional research. Second, even if you were an established member of the field, detectors can be very complicated and often something subtle can cause a very big mistake (see recent arXiv.org posts regarding faster than light neutrinos). To that end you must:

1. Include a spectrum of every source you measure. It must have **all** features labeled. This should be in your lab notebook, printing the spectrum the writing in the labels is fine.
2. When you identify an isotope in an unknown, describe what “candidate” isotopes you considered, how you eliminated the others, and any other details of your thought process to make it clear how you came to your answer.
3. Include full details regarding every step of your analysis.
4. Ensure that the PMT is producing reasonable pulses. Do this by looking at the signal output directly on an oscilloscope (remember to use a 50Ω terminating resistor). Save or sketch the scope trace and comment.
5. Normally you would need to determine the optimal PMT bias. Here we tell you to take 550V as the correct operating bias. You should take a spectrum at 600V and 500V and discuss any differences you see.
6. Understand and optimize the gain and other settings in the controller software. Take a few quick runs at different settings and see what changes. You should think about what you want to do with the data and set things in a consistent way for all of your runs.

7. Convert the setup specific results to meaningful physics results (ie. nobody cares what bin number your peak is in, we care what energy it is). We generally assume that the energy response of a detector is well described by a polynomial. You must quantitatively justify the order of polynomial you choose to use. (Think measures of goodness of fit and/or what it means for a fit parameter to be less than its variance).
8. Understand how your energy resolution behaves as a function of energy. You must be quantitative in this.
9. Understand how your efficiency changes as a function of energy. This too must be quantitative. Your efficiency is a function not only of the detector, but of your sample geometry. Rather than try to understand this, you should use a “relative” efficiency which leaves the geometry (held constant) as part of the efficiency.
10. Understand your background spectrum (what is its shape and does it have any features? if so explain them.). You should be background subtracting any spectrum you analyze.

5 Resources/Comments

- NNDC (I’ve bookmarked this for you in firefox). It includes the decay data for all isotopes including branching ratios, half lives, energies, etc. The back of the manual also has some of this data.
- The “experiments” described in the lab manual. I don’t expect you to do these explicitly but you will find the above activities basically cover most of the same things. The descriptions of what to do there can help you figure out what you are supposed to do.
- If you want more advanced references, the book by Glen Knoll is my go to source for any sort of radiation detection and the particle data group contains statistical analysis that can supplement what you find in the standard texts (Bevington or Taylor should be the suggested book for this class).

6 Other Tips

- the spectrum software can dump data to a CSV, which you can then use for your analysis
- the spectrum software will do some crude peak “fitting” and calibration. It is fine to use these when you are first looking at your data but you **must** do proper fits to the data yourself for your quantitative analysis. This is important because you presumably don’t know how the software is doing those fits, nor does it provide uncertainties in the values it returns, which are required.