

**Main Idea:** Gamma Decay

Gamma Decay is the emission of a high-energy photon – typically between 0.01[MeV] and 10[MeV] – due to the return to ground state of an excited nucleon (proton or neutron). It is, however, exceedingly rare for a particle to reach an atom's nucleus in order to put a nucleon into an excited state; therefore, gamma radiation almost always follows another form of radiation. Alpha decay – the loss of the highly-stable alpha particle, which is identical to a Helium nucleus, having two protons and two neutrons – causes the source's energy and element to change, which can result in nucleons now being in an excited state where they were not before. Beta decay – the conversion of a neutron to a proton ( $n \rightarrow p^+ + e^- + \bar{\nu}_e$ ) or vice versa ( $p^+ \rightarrow n + e^+ + \nu_e$ ) – can have a similar effect. Now we have a nucleon which can return to its ground state, and, by conservation of energy, that nucleon must therefore emit a photon.

While much of gamma decay occurs directly, where a photon is simply emitted by the nucleon itself, it is also possible for change in state to result in pair production if the difference in energy between states is at least the sum of the rest mass energies of an electron and a positron, which is about 1[MeV]. The pair will quickly annihilate, resulting in a photon of the same energy as the produced pair. Therefore, this indirect decay has the same overall effect as direct decay; it simply has an extra step in the middle.

Each isotope has a gamma “fingerprint” which we can use to identify it. This is because unique they contain unique combinations of protons and neutrons. Protons repel each other by electromagnetic forces, but these forces have no bearing on neutrons, and this repulsion becomes smaller at greater distances. At the same time, nucleons attract one another via the nuclear strong force, which increases with distance but cuts off abruptly; for larger isotopes, this means that some pairs of nucleons aren't interacting at all. While this makes calculating the exact

gamma energies of an isotope complex, there are accepted measured values that we can use to identify an isotope; this is what is meant by gamma spectroscopy.

**Equipment:** Multichannel Analyzer

A Multichannel Analyzer (MCA) is a device that records (and, in some cases, also analyzes) data about a signal which consists primarily of pulses. Typically – as in our experiment – these pulses are of voltage readings. Data is taken over a specified length of time, and each incoming pulse is placed in a bin (also known as a “channel”, functioning as a sort of index for arbitrarily-definable values), so the output provides data for bin number and the number of pulses that were sorted into that bin (typically referred to as “counts”). In our case, each channel corresponds to an incoming voltage and therefore to a given energy  $E = qV$  (where  $q$  is the charge). MCAs can be either analog or digital; the one used for this experiment used an analog to digital converter, converting continuous data into discrete values so that they can be read by the computer. While most MCAs are hooked up to computers for analysis, newer models may have their own microprocessors that can perform limited amounts of data analysis without an external connection.

MCAs generally have two modes. The first is Pulse Height Analyzer (PHA) mode; this sorts pulses into bins according to amplitude, with larger bin numbers corresponding to higher amplitudes. This is useful for looking at data like ours, where we are trying to determine what inputs are most likely or most common. The other mode is Multichannel Scaler (MCS) mode; this sorts pulses according to their time of arrival to the MCA, with larger bin numbers corresponding to a later time. This is particularly useful when looking for statistical data about how much or how frequently something sends out pulses but doesn't give much information about what the pulses might correspond to.

**Analysis:** Error Propagation

The first step in calculate our results, and therefore in propagating our error, was to find what bins corresponded to known values. In order to do this, we imported each known source's data to MATLAB, plotted it in the curve fitting app, limited the region over which MATLAB would analyze the data so as to isolate each gaussian, and had it create a gaussian fit. MATLAB automatically provided an uncertainty based on  $\chi^2$ ; I rounded each of these up to the nearest bin number, since that was our equipment's resolution. The next step was to create our calibration curve. This was done in python. We created three corresponding arrays — one for energy, to be used as the x-data, one for bin number, and one for the bin numbers' uncertainties. We then used a weighted fit to create a linear fit associating energy with bin number while accounting for previously-determined uncertainties. A covariance matrix allowed us to calculate uncertainties in the slope and intercept. Finally, we could calculate our energies by plugging a bin number into the acquired function, using

$$E = \frac{C-b}{m},$$

Where  $E$  is the energy,  $C$  is the channel number,  $b$  is the intercept, and  $m$  is the slope. Error propagation followed the form of

$$\sigma_f^2 = \Sigma \left( \sigma_i \frac{df}{di} \right)^2 + \Sigma_i \Sigma_{j \neq i} \left( \frac{df}{di} \frac{df}{dj} s_{ij} \right),$$

Where the cross terms are dropped because  $s_{i,j \neq i}$  is always zero in our case. This meant that our final term for uncertainty was

$$\sigma_E = \left( \sqrt{\sigma_C^2 + \sigma_b^2 + \frac{\sigma_m^2}{m^2}} \right) \frac{1}{m}.$$

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