Radioactive Dating

February 10, 2011

Introduction

The radioactive decay of one substance into another can be used as a sort of natural clock. Examples of this include carbon dating to find the age of organic material, potassium dating to find the age of rocks (like the K-T boundary), and muon life times for measuring the time and space effects of relativity. When a substance radioactively decays there are a number of things that are produced. Typically there is a relatively heavy (comparable in mass to the original substance) decay product and light radiation particles that fly away. There are three important types of radiation (radiation that can effect people); α, β, and γ. These are helium nuclei (clump of 2 protons and 2 neutrons), electrons/positrons, and highly energetic light.

The Clockworks

For this time telling to work there must be some event that sets the clock, a mechanism that ticks off the time, and a means of reading the clock. In this context the clock is set by a process that changes the concentration of the radioactive material. In the case of carbon dating it is the death of the plant or animal which stops the absorption/ingestion of carbon 14, (or ^{14}C which is a radioactive form of carbon), from the environment. In the case of potassium to argon dating it is the solidification of a rock which traps the argon gas that is released when potassium decays. In the case of muons, it is their creation by the bombardment of the earth's atmosphere by cosmic rays.

The ticking of the clock is done by the process of radioactive decay, which we will investigate in this laboratory. For some radioactive material there is only one way for the decay to happen. This is the case for ^{14}C, the details of which are given by

$$^{14}C \rightarrow ^{14}N +^{-} e + \bar{\nu}_e \tag{1}$$

where ^{14}N is the variety (isotope) of nitrogen that is common in air, ^{-}e is an electron, and $\bar{\nu}_e$ is an electron antinutrino (a nearly massless particle). It is also true for muons

$$^{-}\mu \rightarrow^{-} e + \bar{\nu}_e + \nu_\mu \tag{2}$$

where $^{-}\mu$ is a muon and ν_μ is a muon nutrino. For other substances the decay can happen in multiple ways as for potassium

$$^{40}K \rightarrow \begin{cases} ^{40}Ca +^{-} e + \bar{\nu}_e & (90\%) \\ ^{40}Ar +^{+} e + \nu_e & (10\%) \end{cases} \tag{3}$$

where ^{40}K is the radioactive variety (isotope) of potassium, ^{40}Ca is a common isotope of calcium, ^{40}Ar is an isotope of argon, and ^{+}e is a positively charged electron (positron).

The decay of any one radioactive particle (e.g. a ^{14}C atom, ^{40}K atom, or μ particle) is a random process and is unpredictable. However each variety of radioactive substance decays, on average, at a characteristic rate. After a time that is unique to each radioactive substance one half of the material will have undergone decay. The amount of time this takes is called the half life of the substance, $t_{1/2}$. For ^{14}C $t_{1/2} = 5730y$, for ^{40}K $t_{1/2} = 1.25x10^9y$, and for μ $t_{1/2} = 1.5x10^{-6}s$. After each $t_{1/2}$ of time has passed half of the material that was present will have decayed. For example if substance X has a half life of 10 years and there was initially 160 atoms of substance X present, then 10 years later there would be 80 atoms present. After another 10 years there would be 40 atoms present and after another 10 years there would be 20 atoms present.

Finally there must be a way to read the clock. This is done by comparing the amount of radioactive material that was originally present to the amount that is left. The tricky part is figuring out how much was originally there. For the decay of ^{14}C this is done by assuming the amount of ^{14}C present in the dead plant or animal is the same as it was in the carbon dioxide in the air. The proportion of original radioactive material present to what is left can also be deduced by measuring the amount of the decay end product currently in the object (as is done for rocks with the decay $^{40}K \rightarrow ^{40}Ar$). This method is only possible if the decay end product is uncommon in the environment.

In today's lab we will be working with a metastable state of Barium 137, ^{137m}Ba. Metastable essentially means sort of stable. ^{137m}Ba is an isotope that is packed with extra energy that it can hold onto for a while. It is because of this property that I have selected it, ^{137m}Ba has half-life that is neither too short nor too long to easily measure in the lab. The details of the decay we will be measuring are

$$^{137m}Ba \rightarrow ^{137}Ba + \gamma \tag{4}$$

where γ is a gamma ray, which is where the energy from the metastable state goes leaving non-radioactive barium. The ^{137m}Ba has recently been separated from a plug of Cesium 137 (a man made isotope whose half life is 30 years) that continually decays to produce our barium.

Procedure

Every second a certain fraction of the radioactive barium decays present in your sample will decay and your job today is to measure how quickly the radioactive barium is decaying, i.e., the half-life of ^{137m}Ba.

To do this you will have the following equipment:

- A sample of ^{137m}Ba in an acid solution.
- A Geiger-counter.
- A stop-watch.
- Some regular graph paper.[1]
- Some semi-log graph paper.[1]
- A ruler.[1]

. The Geiger counter will detect γ-rays that pass through it and count the number of detections in a specific period of time. Radiation is everywhere and the Geiger counter will detect all the radiation that passes through it, not just the radiation from your sample. It is important to know how much radiation is coming from your environment, to determine this background radiation have the Geiger counter measure the radiation level (number of counts) without any sample present. Take and record 3 measurements of the the background radiation and use your average result in your calculations.

Background radiation counts for 30s interval.

Once you have measured the background radiation you are read for your sample. **Be sure to wear gloves and goggles while your sample is present**. You will now use the Geiger counter to measure the amount of ^{137m}Ba present in your sample. You will not do this directly, but rather will measure the number of ^{137m}Ba that decay in a period of time, this is proportional to the total number of ^{137m}Ba present. The data you need to collect is the number of counts in successive $30s$ intervals over the course of 10min to 15min. The pattern of data collection you will use is: collect for 30s, wait 30s, collect 30s, wait 30s.

[1] You are welcome to use a computer to make your graphs if you prefer

Analysis

- We are interested in finding the decay rate of ^{137m}Ba. To find this you will first need to remove the background radiation from your counts. To do this you must subtract the background rate from each of your measurements.

- At this point you just have a long list of numbers. To make sense of the count rate graph the decay rate of ^{137m}Ba vs time.

- You should find that this is a graph that starts out big and goes small, and that it does so in a special way. Measure the amount of time it takes for the decay rate to drop to half of its original value. Record this estimate of the half-life.

- Repeat your measurement of the half-life starting at two other values of the count rate (e.g., 5min, and 10min). For both measurements find how much time must pass for the count rate to become half of the value of your selected point.

- Another way to show the results of your experiment is to graph them on semi-log paper. Do so and describe on the shape your data makes on this paper.

- Fit a line to the data on this graph. Select a point on the line (not necessarily a data point) near the top of the line and another near the bottom of the line and record their count rates and times.

- Calculate the lifetime of ^{137m}Ba, τ as follows:

$$\tau = \frac{t_t - t_b}{ln(r_t/r_b)} \tag{5}$$

  where t_t and t_b are the times of the top and bottom points, r_t and r_b are the decay rates of the top and bottom points.

- The life-time and the half life are related to each other: $t_{1/2} = \tau ln(2)$. Calculate the half life from your decay rate and compare it to the results you found on from the regular graph.