The Half-Life of an Isotope

Radioactive isotopes undergo *half-life* disintegrations. This means that half of the original sample will disintegrate in a certain amount of time (essentially independent of temperature and other usual rate-determining factors) called the *half-life*. During the elapse of another half-life period of the same duration, half of the sample left from the first disintegration will also disintegrate. The process continues until one atom remains. Decay of the last atom completes the transmutation of one element into another.

Half-lives vary widely. Certain Uranium isotopes have half-lives on the order of 10^9 years. Other isotopes, particularly those which are man-made, may have half-lives of micro-seconds.

Whatever the length of the half-life, decay follows a pattern which is logarithmic, best described by the equation:

$$\ln \frac{N_o}{N} = kt$$

Here, N_o is the starting sample (or, as in this experiment, the reference count taken after 60 seconds). N is the amount of sample remaining at time t (or the number of counts in succeeding minutes). The rate constant for the decay, k, is a measure of the tendency of the atoms to decay spontaneously. This is different for each isotope. Thus finding k (by graphical solution) will allow identification. Rearrangement of the equation above yields

$$\ln N = -kt + \ln N_o$$
$$y = mx + b$$

which is the equation of a straight line in slope/intercept form. A plot of the natural log of the counts per minute vs. time will thus give a line whose slope is -k. The intercept is a number we cannot measure since we have no way to obtain an instantaneous count at t=0.

The rate constant is further related to the half-life, $t_{1/2}$, by a simple expression:

$$t_{1/2} = \frac{0.693}{k}$$

The rate of decay is usually measured with a *Geiger counter*. The Geiger counter consists of a detecting tube and associated electronics. The tube is filled with a low pressure gas such as argon. A wire (insulated from the outside of the tube) runs down the middle. High voltage is applied across the wire and the outside of the tube. The tube has a "window" which is transparent to small particles and short wavelengths of electromagnetic radiation (i.e., alpha and beta particles, and gamma rays).

When a particle or photon enters the tube it causes ionization of the gas, which allows electric current to arc across from the central wire to the outside of the tube. This temporary "short circuit" is detected by the attached electronics and is sometimes evidenced by an audible click or recorded by a digital counter.

Such devices are expensive and it would be impractical to provide each student with one. There is also the hazard of working with radioactive materials to be considered. Therefore, you will perform this experiment with a calculator-simulated Geiger counter which you can download from the Science Department Network or from the class website [you will need your own GraphLink cable to download the program at home and transfer it to your calculator].

Determining the activity of a sample involves measuring the number of disintegrations ("counts") in a given amount of time. But because there is a low level of radiation in the environment around us all the time (*background radiation*) an initial measurement must be made before the sample is introduced to determine what part of the total count is from the sample and what part is from the environment. The average background count is subtracted from each count for the sample.

One other interesting avenue to pursue hearkens back to one of Rutherford's early experiments in which he characterized the three types of natural radioactivity. If the emitted particles are directed through a magnetic field or between charged metal plates, they will be deflected according to charge and mass. It is therefore possible to determine the *kind* of decay by doing such an experiment. The calculator simulation you will use includes this option.

Preparing to experiment

Allot about 15 minutes to do this experiment.

You will have to temporarily delete the CBL programs from your calculator in order to have enough memory to run the simulation (delete: CHEMENU, CHEMTIME, CHMCALIB, CHMMONIT, CHMTRIGP, MAT2LST, RESET). Once you have the GEIGER program in your calculator, run it from the Program menu (press   and highlight the GEIGER program. Press Í   twice).

To begin the simulation you need to enter the date of your birthday (e.g., 23). This provides the "seed" for the random number generator which will select your sample.

The opening menu provides the following choices:

Begin a background count. This gives a correction factor to subtract for natural radiation which will contribute to the overall count for your sample.

The counter screen looks like this:
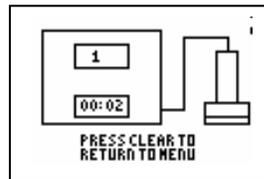
The upper display window gives the current accumulated count while the lower window gives the time elapsed in min:sec format. The object at the right is the Geiger tube and sample stand. The sample goes in the lower portion.

If you need to repeat the experiment for some reason, the background count should be the same IF you enter the same birth date.

The counter automatically stops after 5 minutes. Record the final count and press ' to return to the main menu. Counting your unknown sample is much the same but you MUST pay attention to the count because you need to keep track of the accumulated count at each minute so that you can later determine how many counts were recorded for *each* minute. **Be sure to record the number of counts at each minute interval**. **Be sure to record your sample number.** If you miss a count and need to re-start, you may do so at any time by pressing ' .

When the sample count is complete, press ' to return to the main menu. You are ready to begin the particle deflection tests.

The deflection menu looks like this:

Three known samples are included so that you can compare your own sample in order to determine how it is decaying. Check each known sample by pressing the appropriate menu number.

The deflection test screen looks like this:
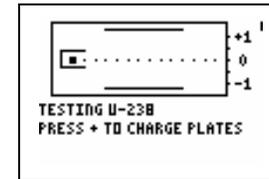
A high voltage power supply is attached to metal plates within the chamber. The sample container (block at left hand of chamber) is made of lead and has a hole drilled into it to hold the sample. Any particles given off as the sample decays are directed toward the right side of the chamber across a phosphorescent screen which glows when charged particles strike it (like the cathode-ray tube you may have seen in class). When the metal plates are charged by the power supply [press Ã to charge the plates], the stream of particles is deflected based on its charge and mass. The arbitrary scale at the right of the chamber is for your reference only.

After you have observed the deflection of the three known samples, check your unknown (*did you write down the sample number yet?????*).

The simulation writes a significant amount of data into the matrices and lists so be sure to exit through the menus so that this information will be cleared from the calculator memory. When you are satisfied that you have all the data you need you might as well delete the program and reload the CBL programs to have them ready for Unit 12.
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The following isotopes are possible in this experiment. Values for k, in units of s^{-1} are also given. These values have been calculated from half-lives found in the CRC handbook *Table of the Isotopes*.

Isotope	k, s^{-1}	Decay
Ca-49	0.0013	β^-
K-38	0.0015	β^+
Al-29	0.0018	β^-
Ti-51	0.0020	β^-
Rh-95	0.0023	β^+
S-37	0.0023	β^-
Fr-221	0.0024	α
Rb-77	0.0030	β^+
V-52	0.0031	β^-
Cf-242	0.0033	α
Po-218	0.0037	α
Lr-260	0.0039	α
Ra-213	0.0043	α
Ga-64	0.0044	β^+
P-30	0.0046	β^+
Re-180	0.0048	β^+
Al-28	0.0051	β^-
Bi-211	0.0054	α
Sr-79	0.0055	β^+
Po-198	0.0066	α
V-53	0.0072	β^-

Analysis

1. Calculate the average background count per minute.

2. Use your data to calculate the number of counts or disintegrations *in each minute* [note that the counter gives a *running* count].

3. Correct your counts/min from your sample for the background count.

4. Calculate the natural log (ln) of each count and plot a graph of these values vs. the time *in seconds*. Determine the slope of the best straight line among the points and use it to calculate k.

5. Identify your unknown from the table provided. Calculate the half-life in seconds.

6. Based on the type of decay you detected for your sample in the deflection test, write a balanced decay reaction for your isotope.