EXPERIMENT 18

First-Order Radioactive Decay

Introduction

Unstable atomic isotopes undergo first-order decay from parent to daughter isotopes. The equation for first order decay is given by;

$$\frac{[\Delta A]}{\Delta t} = -k[A] \qquad \textbf{(EQ 18.1)}$$

Solving this differential equation yields the integrated rate law;

$$[A] = [A]_0 e^{-kt} \qquad \textbf{(EQ 18.2)}$$

A graph of [A] versus time should exponentially decay to zero. A statistical fit of the curve to an exponential function will allow one to determine the rate constant, *k*.

Alternately, one can produce a straight line plot by taking the natural log of the equation above, producing a new equation;

$$\ln[A] = \ln[A]_0 - kt \qquad \textbf{(EQ 18.3)}$$

In this case, one can see that a plot of the natural log of concentration versus time will produce a straight line, with slope $-k$ and y-intercept $[A]_0$.

In general, when unstable isotopes decay radioactively, they will give off one of a number of common particles such as an alpha particle, a beta particle, a positron or a neutron. These particles carry off the excess nuclear binding energy produced when a less stable isotope produces a more stable isotope. Occasionally, some of the excess energy is carried off in the form of a high energy photon, called a gamma ray.

There are a number of devices used to measure the rate of radioisotope decay such as a scintillation counter or a Geiger counter. In this case, the kinetics of radioactive decay can be followed by plotting the number of decay events versus time. For obvious reasons, there are significant safety concerns for such experiments, especially in the undergraduate labs. These experiments require a significant amount of radiative shielding using such heavy metals as lead. For this reason, you will be modeling first order nuclear decay using a very simple physical model.

The Experiment

You will be given a container of approximately 100 of some sort of simple object such as paper clips or pins. Your job is to choose a reasonable value of *k* from Equation 18.2 above which will allow you to place your objects on a balance at a rate which will mimic first order decay. One possible approach would be to choose what you feel is an appropriate half-life and proceed from there. The data you collect will be mass readings on a balance versus time. You will need to choose a value for *k* which is sufficiently small so that you can keep up with adding the objects to the balance, but one which is not so small that it takes you hours to collect a single data run. Your job then, should you decide to accept it, is to create your own data table which will allow you to decide at what rate to put the items on a balance so as to produce as close to perfect first-order decay as possible.

After creating a table or whatever means you choose to tell you the timing for adding the objects to the balance, you can begin your experiment. At least one of your group should be assigned to simply record mass versus time at regular intervals. This person or persons needs to ignore whatever the others are doing to add the objects to the balance. You are required to take at least ten data points for a successful run. More than ten data points may be helpful. You may take mass readings every five seconds, every five minutes or anything in between. It is your choice.

After collecting mass versus time data in your lab book, make a graph of your data using the Vernier graphing software. You should enter your data into the program. After making a graph of your data, you will find the best exponential fit to the data. The group which produces the graph with the smallest “Mean Square Error” will get bonus credit for the lab. Feel free to repeat the experiment as many times as you like, perfecting your technique to see if you can beat the other teams.

May the best IMF special force group win!

Results

You will be submitting a group write-up. The group should submit just one copy of data from your lab note books. Please submit all data collected, including runs you did not choose as your best value. Also, I need to see the tables you used to help you choose when to add the objects to the balance. In addition, you must submit both a plot of your data alone and a plot of your data which has been fit to an exponential decay. The Vernier program should automatically calculate and display the “Mean Square Error.” Lastly, answer the questions. Be sure the names of everyone in your group is included on the write-up.

Questions

1. According to your graph, at what time would you have had 0.010 staples (or whatever object you used) left to put on the balance?
2. According to your graph and the equation produced, how many staples (or other

object) were in your sample one hour before you actually started putting them on the balance?