

A. Modeling First Order Kinetics
B. Determination of the Half Life of a Radionuclide

Background and Theory

Time is of course an important measurement. Usually the measurement of time is connected to a rate, that is, how long it takes to accomplish something or to have something happen. Therefore we say that a trip took 3 hours and we usually specify the points of origin and completion, for instance from Bloomsburg to Philadelphia. There are many rates in science: how fast a plant grows, how long it takes to get to the moon with a spaceship, how long a certain chemical reaction takes to go to completion. We will study the rates of two different processes. One of these is how long it takes to shake a certain number on **a set of dice** that have different number of sides. The other is to measure how long it takes for **a set of unstable nuclei** of a certain type of element to become stable. This involves studying what is referred to as a nuclear reaction. Although these two processes might seem to be completely unrelated, in fact they are exactly the same in terms of how they can be described mathematically.

Dice Shaking

Despite any notions of Lady Luck, enchantment or being “hot”, dice shaking is, pure and simply, explained by the laws of probability. Quick quiz. You are playing Monopoly and badly need a 12 to land on Free Parking. What is the probability you will shake a 12? Stop reading NOW. Use logic to figure out a best answer. Start reading again when you have an answer. Welcome back. Since you have two dice; you need two sixes; the chance of a 6 on one dice is $1/6$ and the chance of a six on the other dice is $1/6$. Therefore the chance of getting two sixes is $1/6$ times $1/6$ or one out of thirty six. Let’s play a different game. You have three different dice, one with four sides, one with 8 sides and one with 12 sides. The only numbers the four dice have in common are 1 through 4. OK now pick one of those numbers. Let’s say you pick 3. If you had to bet \$10 on your choice, which dice would you choose to throw that would most likely show your number after just one throw? The one with four sides of course – your chances are better. In this experiment your team will be shaking sets of dice having 4, 6, 8, 10, 12 and 20 sides and determining the “half lives” for each set of dice. You can now extend the logic you used in picking the four sided dice. For any selected number, the probability for obtaining that number on a shake for dice with more sides will be lower. Therefore it should take longer to shake that set of dice until each die has come up with the chosen number. [Die is the singular of dice]

The first reason we are doing this experiment is to model first order decay reactions. A second reason is to confirm the laws of probability, a very important idea that permeates science. A third reason is that we want to demonstrate how the quality of our results improves as we collect more and more data. Each individual in lab will do the shaking experiment with each set of 6 dice of different sides. How good of a value for the half life do you think we would get from just one set of

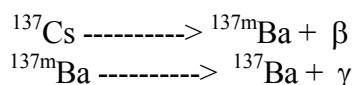
data? And how nice of a graphical display would we get? Now let's say we have 15 people shaking – we now have $6 \times 15 = 90$ dice shaken. Better half life value? Nicer graph? That's what we will see. This experiment is also intended to give you more confidence in using Excel and demonstrating just how powerful a well set up spreadsheet can be in organizing data and obtaining final answers.

Radioactive Decay

A nuclear reaction involves either the rearrangement of the nucleus of a given element to a more stable form (usually another element) or the reaction of two nuclei with each other through collision to form a new nucleus and other products. The second type of nuclear reaction occurs in nuclear reactors and in very hot places such as the sun. The reactions in reactors are the source of useful radioactive materials used in medicine. The reactions at the sun provide us with heat and light. It should be obvious that without these reactions this would be a cold dead planet. We will be studying nuclear chemistry and these types of reactions later in the course. The first type of reaction, and the type of reaction we will be studying here, is what is referred to as radioactive decay. This type of reaction is occurring all around us at all times; this causes what is referred to as background radiation. When material that is radioactive has been concentrated, for instance through the mining and processing of uranium, a tremendous amount of radiation can come from a small amount of matter that is radioactive. You immediately think this is dangerous. However concentrated radiation that is used day to day is more useful than it is dangerous: for instance x-rays! Problems arise however when the material that is radioactive is not handled or disposed of properly.

We will be studying a radioactive decay reaction. The rate of this type of reaction cannot be influenced by changing the conditions of the reaction. The rate can be increased by increasing the amount of radioactive material BUT the rate per unit of radioactive material cannot be changed.

The nuclear reaction we will study has two steps:



where the numbers indicate different isotopes of cesium and barium and where β is shorthand for a beta particle and γ is short hand for a gamma ray, both high energy radiations. The ${}^{137\text{m}}\text{Ba}$ is referred to as a metastable isotope. We will be studying the second reaction and measuring the rate of production of the gamma particles. We will be using a modified Geiger counter known as a Geiger-Mueller tube.

Experimental Details

Your two person team will organize your efforts such that you can complete both experiments. You can do the dice shaking while you are waiting for your radioactive half-life

determination to “setup” or “recycle”. Your instructor will describe the “logistics” of the experiment.

Dice Shaking

Obtain a set of 6 dice that have 4, 6, 8, 10, 12 or 20 faces. Take whichever set is available. **Each person has to shake each set of dice (a total of 36 dice).** The experiment does not have to be done in any particular order. [There are some sets that have dice missing – see below how to deal with this.] Choose **any** number, 1 to the highest number on the die, and start shaking the dice. On the data sheet provided indicate at the top the type of dice being shaken and the number you selected; record each shake with a check and if the number you selected comes up on one or more of the die on a given shake, indicate this with an x. Remove any dice that have come up with the number you selected immediately after that number has been obtained. Continue shaking the remaining dice until each die has come up with the number that you selected. [If you have do not have six dice in your cup, record the fact that the die’s number came up but keep it in play until you have shaken 6 dice]

Your data will be pooled with the data of other students. There will be a total 6x dice shaken for each type of dice, where x is the number of students in the class. Since the experiment is the same for each person, this would be the same as if one person had started by shaking 6x dice of one type until the selected number had come up on all the dice. You have to recognize that the shaking of one die does not influence the shaking of other dice. If you cannot believe this, then you should consult your local astrologer for help!

After collecting your data, go to the lab laptop and enter your data into the Excel program that has been set up. **YOU WILL BE SHOWN HOW TO DO THIS. DO NOT PUSH SAVE UNTIL YOU HAVE RECHECKED THE ENTRY. DO NOT ENTER ANY DATA UNTIL BOTH YOU AND YOUR PARTNER HAVE COMPLETED SHAKING ONE TYPE OF DICE. ENTER YOUR COMBINED RESULTS TOGETHER.** The program takes your individual results and adds them to other data that has been collected. The computer then plots the **percent of total number of dice remaining** ("undecayed dice") on the y-axis versus the **number of shakes** ("time elapsed") on the x-axis for each of the 6 different type of dice. In other words before any dice are shaken 100% of the dice remain. After the first shake, the numbers of dice that have “come up” are removed and the total number of dice still in play (as a percent) is calculated.

Determination of a half life

Receive instruction on how to use the Nucleus Minicounter. Place an empty “planchet” into the tray; set the timer for 10 minutes and count the background radiation [this may already have been done for you and the background is either announced or listed]. Record this value on your data sheet and in the spreadsheet for the experiment. **THE SPREADSHEET FOR THIS PART HAS BEEN POSTED AT THE WEBSITE. DOWNLOAD IT AND BRING IT ON YOUR DATA STICK**

LOAD IT ONTO THE LAPTOP YOU ARE USING. Change the time setting on the counter to 0.5 minutes. "Milk" the radioactive "cow" as demonstrated by your instructor (5 to 8 drops). Quickly place the "planchet" in the tray and start counting in the same way that was demonstrated. On the data sheet provided record the initial number of "counts" per half minute interval; record the number of counts for every succeeding half minute interval until the number of counts is less than 500. You have to do some pretty fast switching. You are after a rate, therefore absolute numbers do not mean anything; these numbers have to be considered with respect to a time that has elapsed. Correct your measured counts for the background radiation that is also present and record these values on your data sheet, in your lab notebook and on the spreadsheet for this experiment.

Complete the entries into the spreadsheet and make sure you save your results to your data stick or email your result to your email box. Each group will have a separate plot.

Treatment of Common Data and Graphing of Results

You may already be familiar with the potential of Excel for graphing. There will be a short tutorial period in your lab section to demonstrate how Excel can be used for graphing results obtained in chemistry experiments. It is expected that you will practice on your computer (or the laptop in the lab) and also seek guidance from your instructor in learning this important skill. It is also expected that you will be able to properly label a graph as well as apply a trendline to the graph.

The combined tabular results from the three lab sections of your lecture section for the dice experiment will be posted at the course lab website. The graph for the 4 sided dice will also be provided. Your goal is to make graphs for each of the five other kinds of dice. These graphs are to be formatted and presented in exactly the same way (title, axes, etc) as the example graph. You will then use these graphs to answer the questions that are asked at the end of this write-up.

Your graph for the radioactive decay is generated in class by substituting your values into the values in the downloaded spreadsheet. These values then automatically update the graph in that spreadsheet.

A measure of the rate of a nuclear reaction is its half life. This is the amount of time it takes for half of the radioactivity that you arbitrarily started with to be produced in the nuclear reaction. Since dice shaking obeys the same mathematical law, we can also determine the half lives of various sided dice. Determination of half lives can be done either by using the graphs or by doing a mathematical calculation that applies to first order kinetics (no explanation will be given at this time but will be covered in lecture). You will use both methods and compare the final results obtained.

Using your graphs determine the average half lives for each type of dice. This can be obtained by going from 100% to 50% or from 80% to 40% etc. on the graph and seeing what the

corresponding time for this change is on the x-axis (the half life!). Do three separate measurements and average the values for the times obtained in order to obtain a final **average half life** for each set of dice.

Also determine the half lives by using the following equations for three different sets of values for A_t , A_0 and t .

$$\ln A_0/A_t = k\Delta t \quad \text{and} \quad t_{1/2} = 0.693/k$$

A_0 = the total number of dice (or the percentage) at the beginning of the experiment (or at any other arbitrary earlier time); A_t = the total number of dice (or the percentage) at a later time in the experiment (or at any other arbitrary later time); t is the time interval between these two times (for dice shaking time is marked in shakes); k is the rate constant for the process (more on this in lecture); $t_{1/2}$ is the half life (more on why the relationship holds in lecture).

Determine the half life for the decay of the Ba isotope in this experiment in the same manner as described above for the dice experiment: three values from the graph; three values from the mathematical calculation using three different sets of A_0 and A_t .

Lab Report

Your lab report consists of properly presented tables and graphs and answers to questions. **Page 1** will consist of the following Table filled in with the values asked for. How to get the values is described in the previous section. Values used refer to the percentages you used in each of graphical or mathematical determinations of half lives and should be placed in parenthesis under the half life values.

Type of dice	graphical half life 1 & values used	graphical half life 2 & values used	graphical half life 3 & values used	AVERAGE – graphical half life	Half life from equation 1 & values used	Half life from equation 2 & values used	Half life from equation 3 & values used	AVERAGE – equation half life
4								
6								
8								

10								
12								
20								

Page 2 of your report consists of filling in table below of the values obtained in the determination of the half life of the radioisotope by graphical and computational means. Present the values in the same way as directed for the dice experiment above. Also on this page paste the graph obtained for this part of the experiment

graphical half life 1 & values used	graphical half life 2 & values used	graphical half life 3 & values used	AVERAGE – graphical half life	Half life from equation 1 & values used	Half life from equation 2 & values used	Half life from equation 3 & values used	AVERAGE – equation half life

Page 3 and Page 4 have three graphs each of the dice half life results: page 3 has 4, 6 and 8 sided and page 4 has 10, 12 and 20 sided

Page 5 of your report has answers to the following questions.

Answer the following questions in your report.

1. Did you verify that dice with more faces had longer half lives in the shaking experiment? If not, why not?
2. Were the differences in half lives related in any way that was proportional to the number of faces on the dice?
3. How well did the Trendlines fit the experimental data?
4. Which result do you have more confidence in: the one obtained from graphical analysis or the one obtained from the mathematical calculation? Why?
5. How does the value obtained for the half life of the ^{137}mBa compare to the known value? (you will have to find the known value!)
6. Given the switching time, would you expect the experimental value for the half life to be consistently higher or lower than the true value? Explain why.
7. Why are the results with very radioactive samples more accurate in determining half lives than with samples that have very low radioactivity?

KEEP A COPY OF YOUR RESULTS FOR LECTURE. YOUR LECTURE INSTRUCTOR WILL TAKE THE VALUES YOU OBTAINED FOR BOTH EXPERIMENTS AND DEMONSTRATE HOW ADDITIONAL INFORMATION CAN BE OBTAINED FROM YOUR DATA BY PREPARING WHAT IS REFERRED TO AS AN INTEGRATED PLOT.