

**PHYSICS 223****EXPERIMENT 6 : Radioactivity****INTRODUCTION :**

Henri Becquerel was credited to have “accidentally” discovered radioactivity in uranium salts in 1896. Later investigations by Pierre and Marie Curie (who coined the term “radioactive”) led to the discovery of other radioactive elements. In this experiment, we will study the phenomenon of radioactivity, a consequence of nuclear instability. This is a worthwhile exercise because radioactive substances are commonly used today in a variety of applications and because their safe use and disposal is an important social and political issue. This experiment consists of two parts. The first part introduces a method for determining the half-life and decay rate of a radioactive substance. The second part involves the study of the absorption of beta using absorbers of various thickness.

## PART A : DECAY CONSTANT AND HALF-LIFE

Radioactive decay, by nature, is a random process. While we cannot predict exactly when a nucleus will decay, we can measure and sometimes predict the probability that a certain decay process will take place within a time period. If there are  $N(t)$  unstable nuclei at time  $t$ , then the rate with which these  $N(t)$  nuclei decay within the time period  $dt$  is

$$\frac{dN(t)}{dt} = -\lambda N(t) \quad (1)$$

where  $\lambda$  is known as the decay constant. The negative sign specifies that the number of radioactive nuclei is decreasing. Equation 1 shows that the rate of decay  $dN/dt$  is proportional to the amount of radioactive nuclei that exists at time  $t$ . As  $N(t)$  decreases with time, the rate of decay consequently decreases. Notice that the decay constant  $\lambda$  is independent of when the nucleus was formed, i.e. the nucleus does not know about its past.

If we have an initial amount  $N_0$  of a radioactive substance or nuclei at time  $t = 0$ , how can we find  $N(t)$  at any given time? We solve Equation 1 as follows:

$$\frac{dN(t)}{N} = -\lambda dt.$$

Taking the integral of both sides, we get

$$\int_{N_0}^{N(t)} \frac{dN(t)}{N} = -\lambda \int_0^t dt$$

$$\ln[N(t)] - \ln N_0 = -\lambda t \quad (2)$$

$$\ln\left[\frac{N(t)}{N_0}\right] = -\lambda t$$

$$\frac{N(t)}{N_0} = e^{-\lambda t}.$$

This implies that

$$N(t) = N_0 e^{-\lambda t}. \quad (3)$$

This is the familiar exponential decay expression (see the experiment for the discharge of a capacitor). Here we see that the number of undecayed nuclei will decrease exponentially with time.

We often describe how fast a given sample of radioactive material decays in terms of a characteristic half-life  $t_{1/2}$ . This is defined as the time it takes for the number of radioactive nuclei to decrease to half of its original value. Using Equation 3, this means that

$$\frac{N(t_{1/2})}{N_0} = \frac{1}{2} = e^{-\lambda t_{1/2}}.$$

It is then straightforward to show that

$$t_{1/2} = \frac{\ln 2}{\lambda}. \quad (4)$$

As Equation 4 shows, the half-life is a constant for a particular radioactive sample and is another way of expressing the decay constant. Note that the half-life does not depend on our choice of when we start the radioactive count. For example, let us say that we have a sample of  $N_0$  initially and find that it takes one year for it to decay to  $N_0/2$ . If we come back 10 years later and look at the same sample, it may have a much smaller

number of radioactive nuclei  $N_0'$  from the original  $N_0$ , but it will still take one year for it to reach  $N_0'/2$ .

The analysis of the decay curve in this experiment may be done in one of two ways. Since you will be measuring  $N(t)$  at various times, a plot of this data will result in an exponential decay curve as shown in Figure 1. Now it is possible, if you have a good data analysis program, to fit this data to an exponential decay curve and obtain the decay constant. More often than not, it is less cumbersome if we can still somehow make use of the linear line fit to analyze our data.

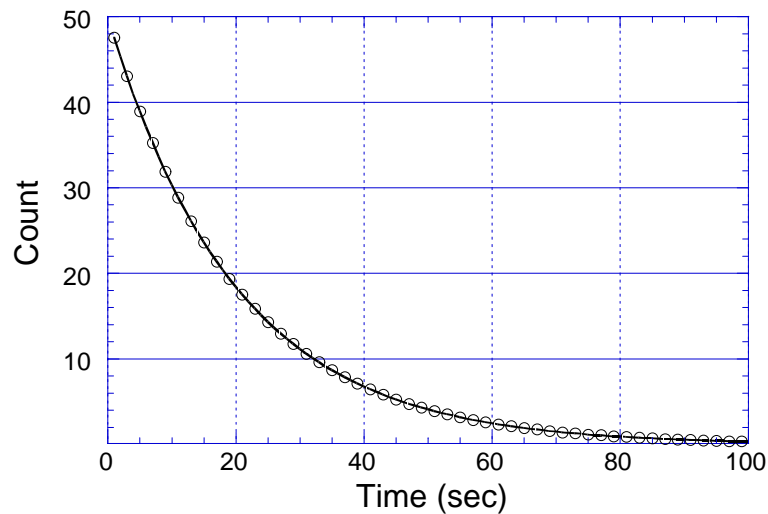


Figure 1: Exponential Decay Curve.

The first technique is by noticing from Equation 2, that if we plot  $\ln[N(t)]$  versus  $t$ , we will obtain a straight line if this relationship holds in our data (see Figure 2b). The slope of this straight line corresponds to  $-\lambda$ , while the  $y$ -intercept corresponds to  $\ln N_0$ . [You must show this derivation in the theory section of your laboratory report].

The second technique, which is technically similar to the first one, is to plot  $N(t)$  versus  $t$ , but this time using a logarithmic scale for the vertical axis. Unlike a regular linear scale, where the intervals between equal units are constant, logarithmic scale does not have a constant interval. In essence, this is the same as plotting  $\ln[N(t)]$ , but here the

function of finding the natural logarithm value is being “done” by the logarithmic scale. The result of this plot is identical to the first technique, i.e. we will obtain a straight line if our data follows Equation 2 (see Figure 2a). The only trap here is that when finding the slope of this line, you must not forget to take the natural logarithm of the vertical axis values. Since the horizontal axis for  $t$  is still linear, we call this a semi-logarithmic plot. There is of course, a full logarithmic plot when both axes have logarithmic scales.

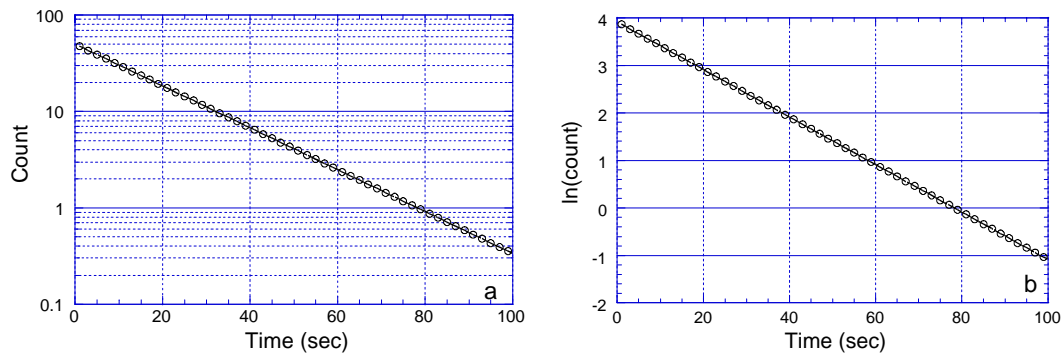


Figure 2: (a) Decay Curve Plotted on Semi-Log Scale; (b) Plot of  $\ln[N(t)]$  versus  $t$  on a linear scale.

In this experiment, you will determine the decay constant and half-life of  $^{137}\text{Ba}$ . This isotope of barium has a half-life of approximately 2.6 minutes. It is extracted chemically from a mixture of  $^{137}\text{Cs}$  (half-life of around 30 years) and  $^{137}\text{Ba}$ . Unfortunately, the extraction process may not be 100% efficient and your Ba sample will most likely contain some additional Cs nuclei. You will have to subtract the  $^{137}\text{Cs}$  decay from your measurement.

**CAUTION :** The radioactive sources used in this experiment are considered safe for handling. If they are used in accordance with instructions and with the use of common sense, they are not dangerous. However, careless and irresponsible behavior may result in serious consequences. In using radioactive materials, you must comply to the following guidelines:

- **No eating, drinking, and smoking in the laboratory. This rule applies to all laboratory sessions and will be strictly adhered to for this experiment. Radioactive sources can cause maximum damage when absorbed or ingested within the body.**
- **Never remove a source from the laboratory.**
- **Never bring a source close to your face.**
- **Never touch the source directly. Most sources used in this experiment are encased in plastic discs and are safe to be handled. However, the  $^{137}\text{Ba}$  source is in a liquid form and must be handled with extreme care. Do not touch the liquid or the absorbing paper. You must wear rubber gloves at all times when handling these sources.**

**Failure to abide by these rules will result in deductions of safety points.**

## PROCEDURE :

1. Check if the Geiger counter is ready to be used. The counter should already be set to measure for 30 seconds. Obtain a test source from your laboratory instructor and place it on the third shelf from the top. Hit the count button on the counter. The digital display should now start changing until the 30 seconds is up. Verify with a stopwatch that it is counting for 30 seconds.
2. After you are satisfied that your apparatus is working fine, return the test source. With no source, find the background count by measuring **four** 30-second intervals. The average value will be your background count with no source for one 30-second interval.
3. Inform your laboratory instructor that you are ready to do Part A of the experiment. The instructor will then extract the  $^{137}\text{Ba}$  source. You must be prepared to take data as soon as the sample is ready (make sure you have your rubber gloves on).

4. Place the source on the second shelf from the top. Start the count immediately for 30 seconds. This count will be  $N(t)$  for  $t = 0$  (i.e.  $N_0$ )
5. As soon as the count stops at the end of 30 seconds, quickly note the count number and immediately begin the next count. The second count will be  $N(t)$  for  $t = 30$  seconds, and so on.
6. You should continue making consecutive readings of the number of counts emitted from the sample every 30 seconds for at least seven minutes, or until the number becomes essentially constant for four consecutive time intervals. These last four counts may be different than the background you obtained earlier with no sample due to the possible presence of  $^{137}\text{Cs}$  nuclei. This is your actual background count.
7. Record your raw data in a table for  $N(t)$  and  $t = 0, 30, 60, 90, \dots$  seconds.

## ANALYSIS :

1. Average the last four counts in your data to obtain the actual background count.
2. Subtract the background count from the various  $N(t)$  values. Record this in an additional column in your table. [Omit the last four counts from your analysis from this point on.]
3. Plot your data and using the best fit line, find the decay constant  $\lambda$ . [You may use either technique mentioned earlier.]
4. Using your graph, find the experimental half-life  $t_{1/2}$  by locating the time for  $N_0/2$ .
5. Verify and compare the experimental half-life value by using Equation 4 and the decay constant found earlier.
6. Question 1: In Procedure 2, we subtracted a constant background count due to  $^{137}\text{Cs}$  decay. Why is it justified for us to assume that the decay count due to  $^{137}\text{Cs}$  is constant throughout this experiment?

## PART B : INTERACTION OF BETA RADIATION WITH MATTER

The shielding of radiation is an important issue, especially with regards to human safety. How much and what type of material should be used to adequately stop various forms of radiation must be known. The purpose of Part B is to measure the attenuation of beta rays in matter. We will accomplish this by measuring the amount of beta radiation passing through absorbers of various thickness per unit time. It will be shown that the attenuation decreases exponentially as a function of the thickness of the material, and that the rate of attenuation is characterized by an absorption coefficient.

Beta rays are nothing more than energetic electrons (or in some cases, positrons). Here, we will study the rate of absorption of beta rays using various thickness of aluminum. The source of beta rays that will be used has a very long half-life (in years), so we can safely assume that the amount of beta rays emanating from the source is constant.

Consider  $N_0$  beta particles sent to a material of thickness  $x$ . The decrease in the number of beta particles after passing through a thickness  $dx$  of the material is proportional to the number of atoms it encounter (which in turn is directly proportional to the thickness  $dx$ ) and the number of beta particles entering the thickness  $dx$  (see Figure 3). We express this mathematically as

$$\frac{dN(x)}{dx} = -\mu N(x). \quad (5)$$

where  $\mu$  is the attenuation constant. Here the negative sign indicates that the number of beta particles is decreasing as the thickness increases.

This expression is identical in form to the radioactive decay expression of Equation 1. Therefore, using similar algebraic manipulation, we obtain the expression for the number of beta particles  $N(x)$  after passing through a thickness  $x$  of the material as

$$N(x) = N_0 e^{-\mu x}. \quad (6)$$

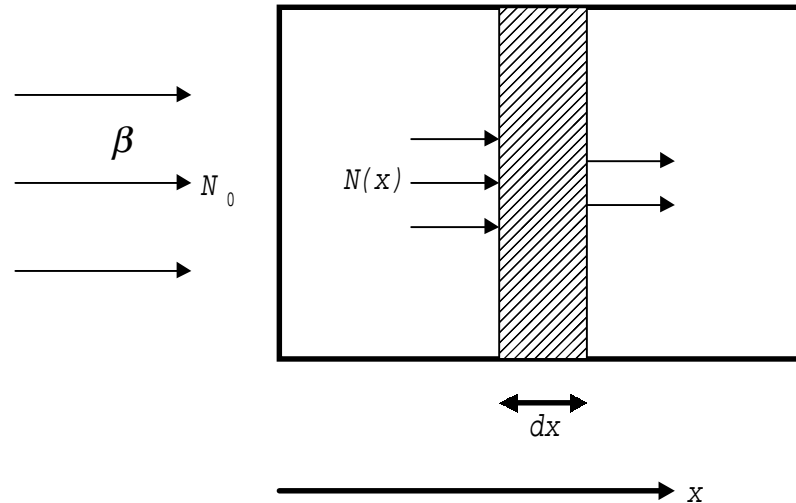


Figure 3: Attenuation of Beta Rays in a Material of Thickness  $x$ .

## PROCEDURE :

**CAUTION :** The aluminum absorbers used in this experiment can be very thin and delicate. They can be easily torn or punctured with careless handling.

1. Without any sources, obtain the background count for one minute. Do this one more time to obtain an average of the background.
2. Obtain a beta source from your laboratory instructor and place it on the third shelf from the top.
3. With no absorbers in place ( $x = 0$ ), find the count for one minute. Do this a total of two times to obtain two count values.
4. Insert the thinnest aluminum absorbers into the second shelf from the top. Repeat Procedure 3.
5. Repeat the experiment with other aluminum absorbers of various thickness until the count rate is approximately the background value.
6. Record your data in tabular form, that should contain the thickness  $x$ , the two count rates, and the average count rate  $N(x)$ .

## ANALYSIS :

1. Subtract the average background from the average count  $N(x)$  in your data table. Record this as part of your data table.
2. Plot your data. You may use either technique mentioned in Part A, i.e. either plot  $\ln[N(x)]$  versus  $x$ , or plot  $N(x)$  versus  $x$  on a semi-log scale.
3. From the best-fit line on your plot, find the attenuation constant  $\mu$ . [As before, this derivation must be shown in the theory section of your report.]