

# Using a Microcontroller to Study the Time Distribution of Counts From a Radioactive Source

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## Abstract

In this lab we will study the time distribution of counts in a Geiger counter from a radioactive source. We first construct a simple microcontroller which is read by a computer and then use it to study the distribution of counts in a fixed time and the distribution of times between successive counts.

## Part I. What is a Microcontroller?

In the first part of the lab you will build a microcontroller called *Basic Stamp* following the instructions provided in the *Microcontroller Tutorial*

## Part 1: Microcontroller Tutorial

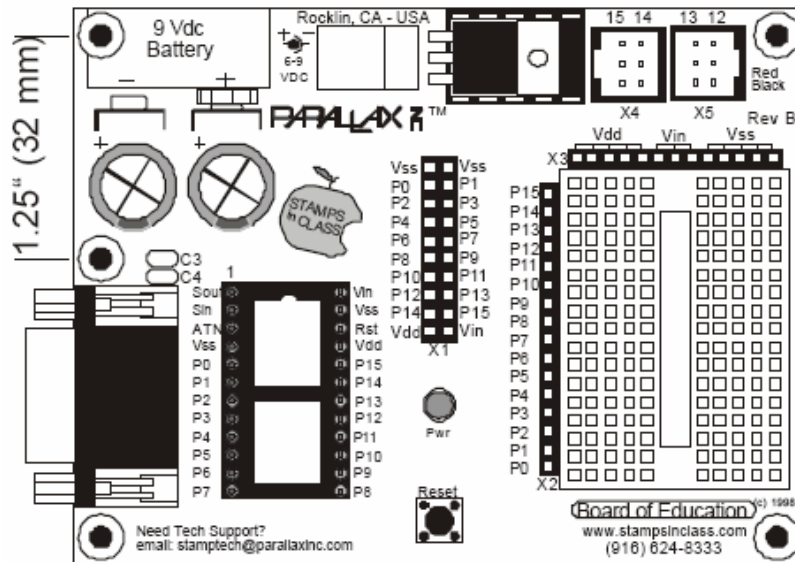
Microcontrollers are simply small (hence the name “Micro”) Central Processing Units (CPUs) much like the ones found inside of computers. The difference is that while you can interact with your CPU through a keyboard and a monitor, microcontrollers are made to interact with other electronic devices. Several everyday objects contain microcontrollers like your car, your watch and your hairdryer. In this lab we will be using a simple microcontroller called the Basic Stamp.

The Basic Stamp has a great advantage over other microcontrollers because it is easy to program. In this lab you will be programming it through the laptop using a computer language called PBasic, a special version of Basic. So let's get started.

You will need:

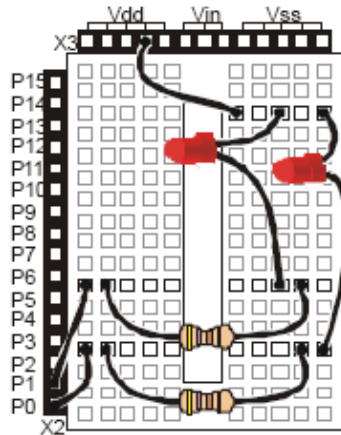
- Laptop with Basic Stamp II Module
- Board of Education with Basic Stamp (see Figure 1)
- Serial port cable
- (2) Light Emitting Diodes (LEDs)
- (2) 470  $\Omega$  resistors
- 9 volt battery or power supply
- Several wires

O.K., first we will be connecting the two Light Emitting Diodes (LEDs) to the Basic stamp. LEDs are devices that light up when there is a large enough voltage drop across them. There are a few things to be careful about when using LEDs. First, always connect the LED in series with a 470  $\Omega$  resistor so that too much current doesn't flow through it. Second, diodes are devices that are made to allow current to flow only one way, so it is crucial that you connect them correctly or they won't light up. If you look at the plastic shielding on an LED there is a flat side. Always connect it so that current flows out the wire next to the flat side. In other words, connect the rounded side to higher voltage.



**Figure 1: Board of Education**

Figure 1 shows the Board of Education. The bottom right side is where the breadboard is. Since the breadboard on our Board of Education is old and used, we will be creating our circuit in another breadboard that doesn't have problems. To understand how the breadboard works, turn over the newer breadboard. You can see the metal strips that are beneath the holes. Wires that are stuck in holes that share a metal strip become connected. Most of the metal strips are horizontal and 5 holes wide, but there are two long vertical strips along the sides. We will be using the breadboard to create a simple circuit with our LEDs. Construct the circuit shown below in Figure 2:



**Figure 2: LED circuit setup.**

Vdd is at 5 V so be sure to connect the rounded side of the LED to that wire. Pins P0 through P15 can be read or controlled by the basic stamp. We will be using just P0 and P1 here. Have the instructor check your work before you plug in the power supply.

Now we are ready to program the basic stamp. Connect the serial port cable to the back of the computer and also to the board of education. Double click on the Basic Stamp Editor Icon on the Desktop. We don't have enough time to teach you how to program in PBasic, but the following notes should be helpful:

1. The Basic Stamp executes commands from top to bottom, line by line.
2. Anything written after an apostrophe (') is ignored by the Basic Stamp.
3. After it is run, the Basic Stamp will execute the program once and then stop after it executes the last line of code.

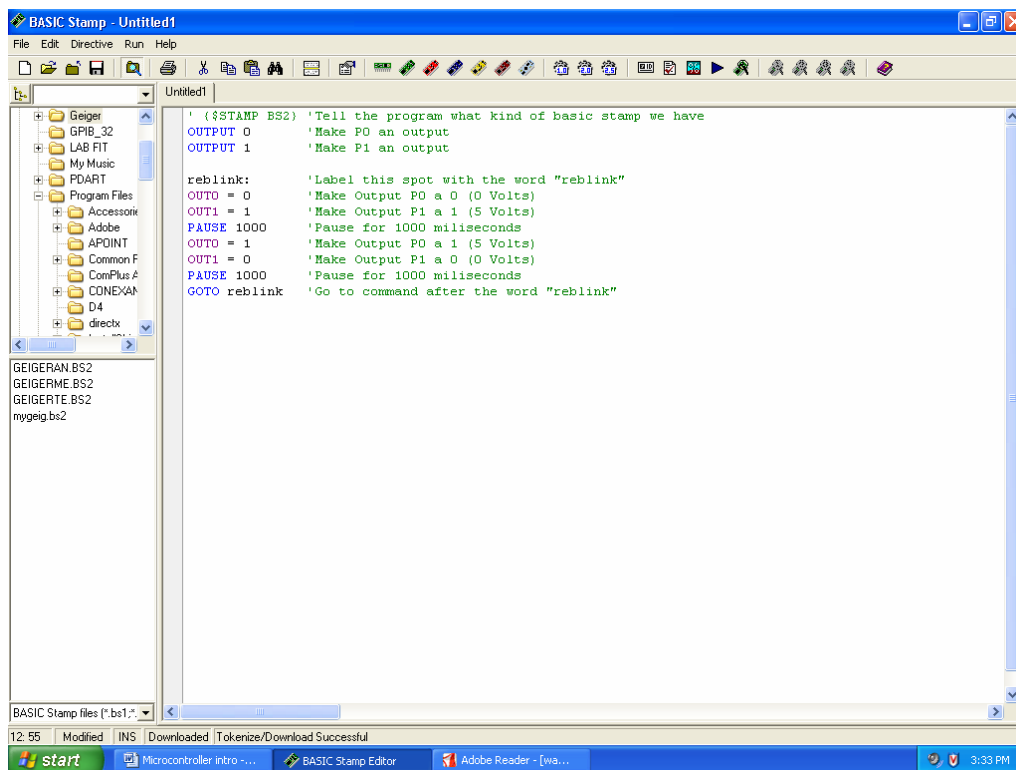
Now, copy the following code into the Basic Stamp Editor:

```
' {$STAMP BS2} 'Tell the program what kind of basic stamp we have
OUTPUT 0    'Make P0 an output
OUTPUT 1    'Make P1 an output
reblink:    'Label this spot with the word "reblink"
OUT0 = 0    'Make Output P0 a 0 (0 Volts)
OUT1 = 1    'Make Output P1 a 1 (5 Volts)
PAUSE 1000  'Pause for 1000 milliseconds
OUT0 = 1    'Make Output P0 a 1 (5 Volts)
```

```
OUT1 = 0    'Make Output P1 a 0 (0 Volts)
PAUSE 1000  'Pause for 1000 milliseconds
GOTO reblink 'Go to command after the word "reblink"
```

Notice the comments on the side are the English translation of PBasic. Read through them to see if you can understand what the Basic Stamp is going to do before you run the program. Try to guess what you should see the LEDs do. When you think you know what will happen press CTRL R to run the program.

Your screen should look something like this:



If everything is set up correctly, you should see the LEDs blinking on and off about once a second. When one is on, the other should be off. Once this is working, you can try varying the program and see that the result will change. For example, you can make both LEDs blink synchronously, or you can make them stay on for 2 seconds and stay off for 1 second. Go ahead and try something different!

## Part II. Using Your Basic Stamp to read out a Geiger Tube

In this part of the lab, we are going to use the Basic Stamp as a data acquisition system for a Geiger counter.

You need:

1. Board of Education with Basic Stamp 2
2. A power supply (or 9V Battery)
3. The interface cable to the computer (DB9 serial cable)
4. Computer running Basic Stamp software (with serial port)
5. A CD4040BE Ripple Carry Binary Counter (This is a Chip)
6. Model 528 Eberline Geiger counter and the special connector cable
7. The Geiger Tube program disk (may already be in your computer)
8. Some jumpers for making connections
9. An amplifier in a clear plastic box (just an OP AMP really)
10. A Breadboard and several wires
11. A radioactive source (ask your instructor)

### Procedure

- Set the stamp as you did in the first part of this Lab but leave the breadboard bare.
- Put the CD4040BE on the breadboard
- Connect the Board of Education and the CD4040BE chip according to Figure 1 and Table 1.

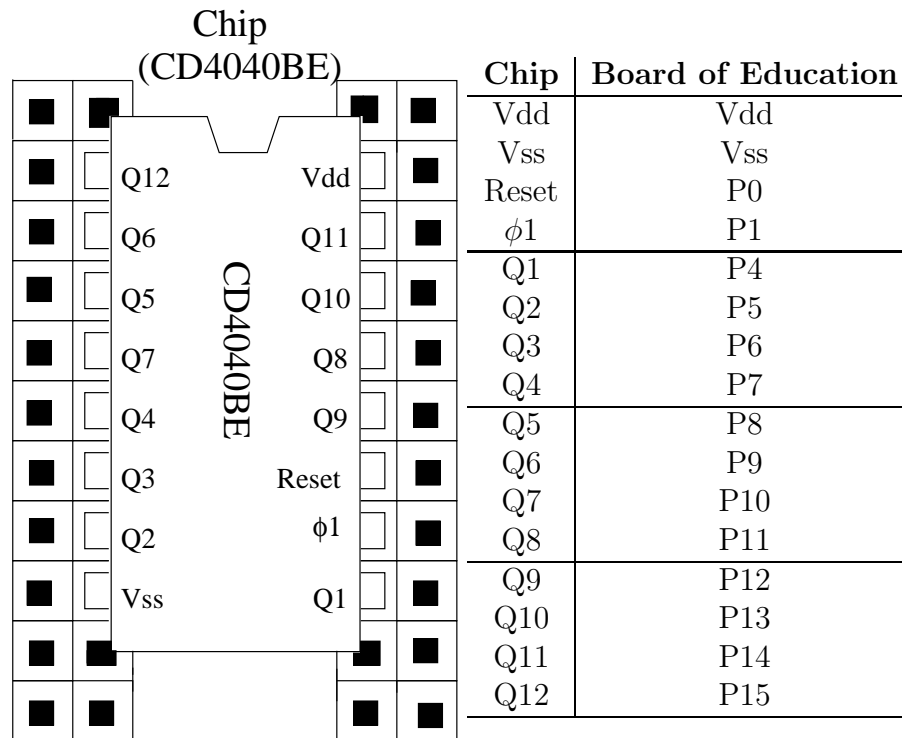


Figure 1: CD4040 Chip

Table 1: Connections between Board of Education and CD4040 chip

The idea is to pulse the  $\phi 1$  line up and down.

The CD4040 outputs a binary number that is supposed to be the number of times the  $\phi 1$  pin was pulsed. We are going to use this feature to count pulses from a Geiger tube, but first we need to check and make sure everything was hooked up correctly. We are going to do this by pulsing P0 enough times to check each binary output. Q1 corresponds to the 0 bit.

In case you've never been exposed to binary numbers, they work like this for the CD4040 (and lots of other things too). In the table below, 1 means the pin is "high" or about +5 V, 0 means the pin is "low" or about 0 V.

The number is the sum of the bit value (0 or 1) times 2, raised to the power of the bit position. You can actually watch this happening<sup>1</sup>.

<sup>1</sup>#counts = 2048\*Q12 + 1024\*Q11 + 512\*Q10 + 256\*Q9 + 128\*Q8 + 64\*Q7 + 32\*Q6 + 16\*Q5 + 8\*Q4 + 4\*Q3 + 2\*Q2 + Q1

Q12.....Q1	Num. of Counts	Q12.....Q1	Num. of Counts
000000000001	1	100000000000	2048
000000000010	2	110000000000	3072
000000000011	3	111000000000	3584
000000000100	4	101000000000	2560
000000000101	5	111111111111	4095
000000000110	6	000000000000	0

Table 2: Examples of binary numbers.

Once you have the chip hooked up,

- Double click the Basic Stamp icon on the Desktop
- Press

(ALT I)

to identify the hardware

- Load the file GEIGERTE.bs2 found in the Geiger file folder
- Run the program

(CTRL R)

This program is set up to pulse 128 times, read the binary output, and then form a word from the binary data. You can put different numbers into the program to test different pins, *i.e.* you could try 1, 2, 4, 8, 16, 32, 64, 128, 256, 512, 1024 and 2048. This would let you know if you mixed up any pins.

**Question:** How many counts do you read if you pulse 4096 times? Why?

You can set the number of pulses very high and watch the operation of the counter with a data probe. You may need to vary the amount of time you pause between the high and low pin settings so you can hear or see the individual points.

#### Hooking up the data probe:

First connect the data probe as shown in Figure 2 and touch the point to the data pin to test. Now move the probe from Q1-Q12.



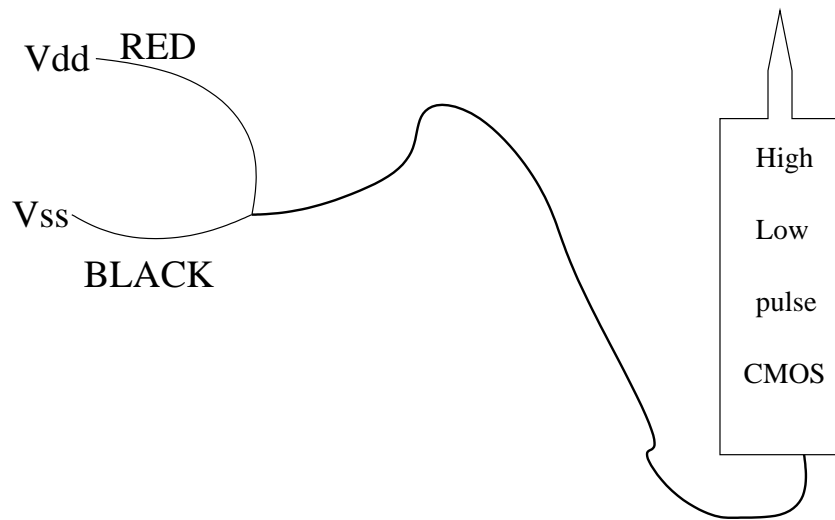


Figure 2: Data probe

**Question:** What did you noticed about the rate of pulsing? See how the different bits works?

If you are convinced that your counter is working, you can start to connect the Geiger Counter. Lets make sure the Geiger counter is working, at some level.

1. Check the battery by turning knob to BATT and looking to see if the needle is in the OK region
2. Turn knob so that X1 is selected
3. Have your instructor bring you a source. We will use a piece of Uranium ore, which contains mostly  $^{238}\text{U}$ . Follow the “radioactive source” link on the course web page ([www.hep.vanderbilt.edu/julia/VUteach/PHY225a/UraniumOre.htm](http://www.hep.vanderbilt.edu/julia/VUteach/PHY225a/UraniumOre.htm)) if you want to learn more about the  $^{238}\text{U}$  decay chain.
4. Bring counter close to source. Meter should raise a little. You don't need more than 2000/min. (Note: you may need to press RESET first)
5. Hook up the Geiger counter to the Data Probe using these connections:

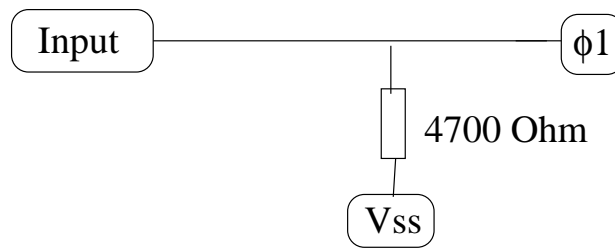
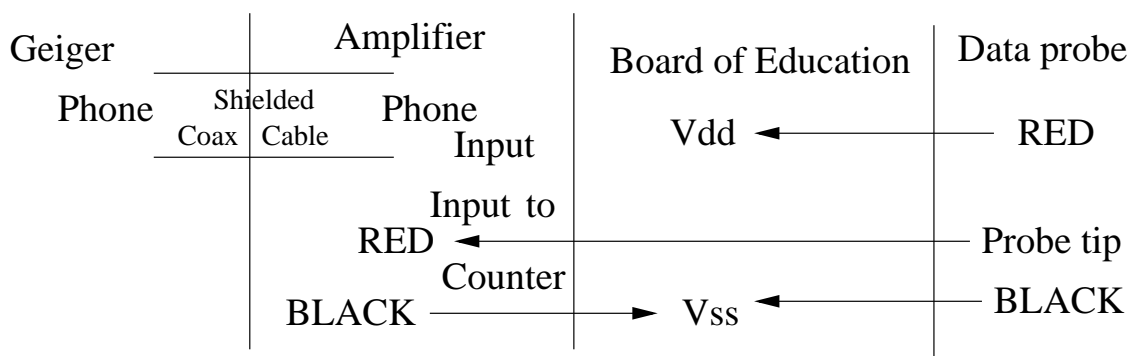


Figure 3: Auxiliary circuit.



Repeat step 4, Did you get pulses in the detector? Now, remove the connection from P1 to the CD4040 (we don't need to pulse artificially now) and hook up the Geiger counter "Input" to the  $\phi 1$  pin. Place the source close to the Geiger tube and look at Q1 with the data probe. Getting any action? You may want to check your connections, or you may need to hook up an auxiliary circuit to help the Geiger counter trigger the CD4040. A suggestion is shown in Figure 3 (you may want to have your instructor check your set up before you try this, and you may wait 20 sec. or so and look again.) "Conditioning" the input this way gives the CD4040 chip a better chance of recognizing a High level. The resistor sets a definite low level, and the Geiger counter will pulse the  $\phi 1$  pin High. (You may not need this though)

Now that the Geiger counter is working, leave the source in place and load the program GEIGERME.bs2. Run it. It is set up to take 12 readings of 10 sec. lengths each. If you add up these readings and divide by 2 you should roughly duplicate the meter reading on the Geiger counter.

You are ready to proceed with some physics measurements if your counter set up checked out OK. You may find it convenient to modify the GEIGERME.bs2

program to make your data taking easier. Before you modify this program though, copy it to a file you **won't destroy**, like mygeig.bs2.

### **Proceed to the following experiments**

Do experiment 2.6 first. If you have time, graph your results. If the results make sense then do experiment 2.7 next. Be sure you don't change the geometry between the source and the detector once you've started. You also may have to throw away your first data point.

**A note on program structure** Most of the programs in the lab have this kind of structure:

Top: Let the computer know what variables you need.

Middle: Operate on variables.

Bottom: Data output.

## Experiment 2.6 Counting Statistics

### Purpose

We will measure the decay rate of a radioactive source and investigate its statistical properties. Since the decay of radioactive atoms is a random event, we do not expect to measure the same number of decays per unit time every time we repeat the measurement. However, if we do a large number of measurements, we can determine the average decay rate. We can also determine the probability for getting a particular result.

The number of decays per unit of time of a radioactive source is distributed according to the Poisson Distribution. The probability  $P(k)$  that we will obtain  $k$  number of decays during a fixed time interval is given by:

$$P(k) = \frac{\mu^k}{k!} e^{-\mu} \quad (1)$$

The parameter  $\mu$  is the average number of counts (radioactive decays, in our case). This is a discrete distribution and it is valid not only for radioactive decays, but for any random uncorrelated events when counting in a fixed interval of time or area is involved. There are three features of the Poisson distribution that are interesting to note:

1. The standard deviation squared of the Poisson distribution is equal to its mean, i.e

$$\sigma^2 = \mu = \frac{\sum_{i=1}^N R_i}{N} \quad (2)$$

2. When the mean of the Poisson distribution is large ( $\mu > 20$ ), it becomes nearly identical to a Gaussian distribution with  $\sigma^2 = \mu$ . Note that this relation between  $\sigma$  and  $\mu$  does not hold for any Gaussian distribution.
3. For small  $\mu$ , the Poisson distribution has a characteristic tail toward large values of  $k$  (the measured number of counts in a fixed time interval). This is illustrated in the figure 4, where the probability to get  $k$  counts,  $P(k)$ , is plotted for several distributions with different mean values  $\mu = 2, 5, 15$ .

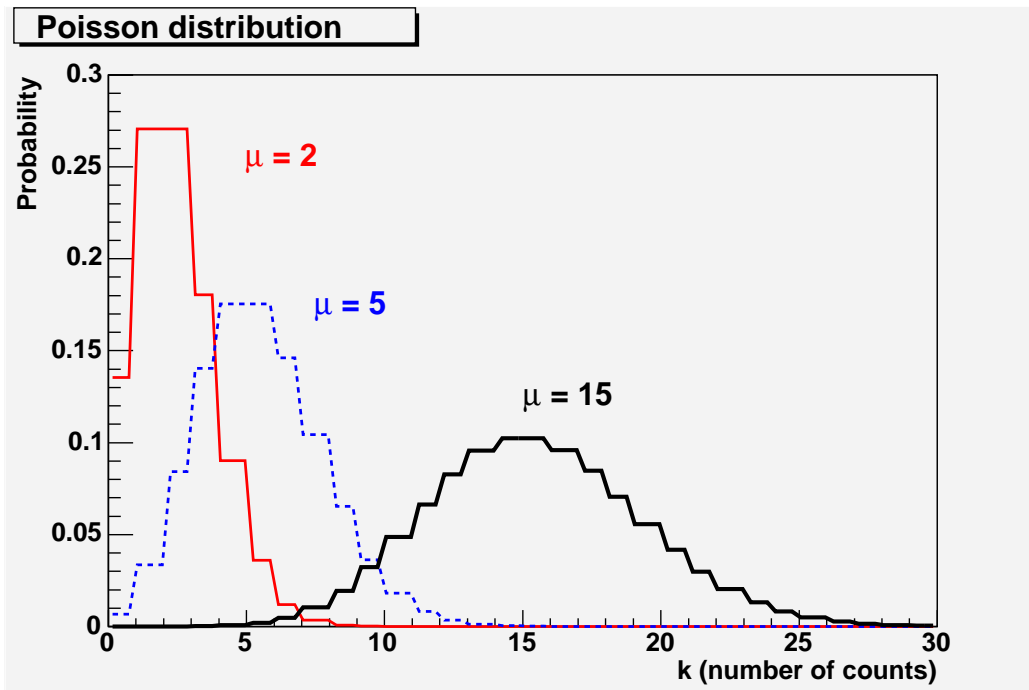


Figure 4: Poisson Distribution for different values of the mean  $\mu$ .

In our experiment we will make about 50 independent measurements of the number of radioactive decays within a fixed interval of time in order to determine the average decay rate and the probability distribution. We can control the average number of counts that we register by choosing the time duration of our measurements or by changing the distance from the source to the Geiger counter. Let's choose 0.5 min for our time interval and adjust the distance from the source such that we are getting about 100 - 1000 counts. With these values, we should observe that the probability of getting a particular number of counts looks like a Gaussian distribution centered about the mean value with  $\sigma^2 = \mu$ .

### Procedure and analysis

1. Set the operating voltage of the Geiger counter at its proper value.

2. Place the radioactive source far enough away from the window of the GM so that 100-1000 counts can be obtained in a period of 0.5 min.
3. Without moving the source, take 20-50 independent 0.5 min runs, and record the counter values,  $R$  in Table 3. (Note that you have to extend Table 3; we've shown only 10 entries.)
4. Using all your measured values of  $R$ , determine the average:  $\bar{R}$ . Fill in the values of  $R - \bar{R}$  and  $(R - \bar{R})^2$  in Table 3. Use the latter to determine the standard deviation:

$$\sigma = \sqrt{\frac{\sum_{i=1}^N (R - \bar{R})^2}{N}} \quad (3)$$

5. Fill the values of  $(R - \bar{R})/\sigma$  in the table using two decimal places and then round them off to the nearest 0.5 value.
6. Make a plot of the frequency of the round-off events  $(R - \bar{R})/\sigma$  vs the round-off values. Figure 5 shows this plot for an ideal case. Note that at zero there are eight events, etc. This means that in our complete round-off data in Table 3 there were eighth zeros. Likewise, there were seven values of +0.5, etc. Does your plot follow a normal distribution similar to that in Figure 5? How do  $\sigma$  and  $\bar{R}$  compare?

Run	R	$R - \bar{R}$	$(R - \bar{R})^2$	$(R - \bar{R})/\sigma$		$(R - \bar{R})/\sigma$ (Rnd'd Off)	
				Typical	Measured	Typical	Measured
1				-0.15		0	
2				+1.06		+1.0	
3				+0.07		0	
4				-1.61		-1.5	
5				-1.21		-1.0	
6				+1.70		+1.5	
7				-0.03		0	
8				-1.17		-1.0	
9				-1.67		-1.5	
10				+0.19		0	

Table 3: Typical values of  $(R - \bar{R})/\sigma$  and  $(R - \bar{R})/\sigma$  (Rnd'd Off) are listed for illustrative purposes only.

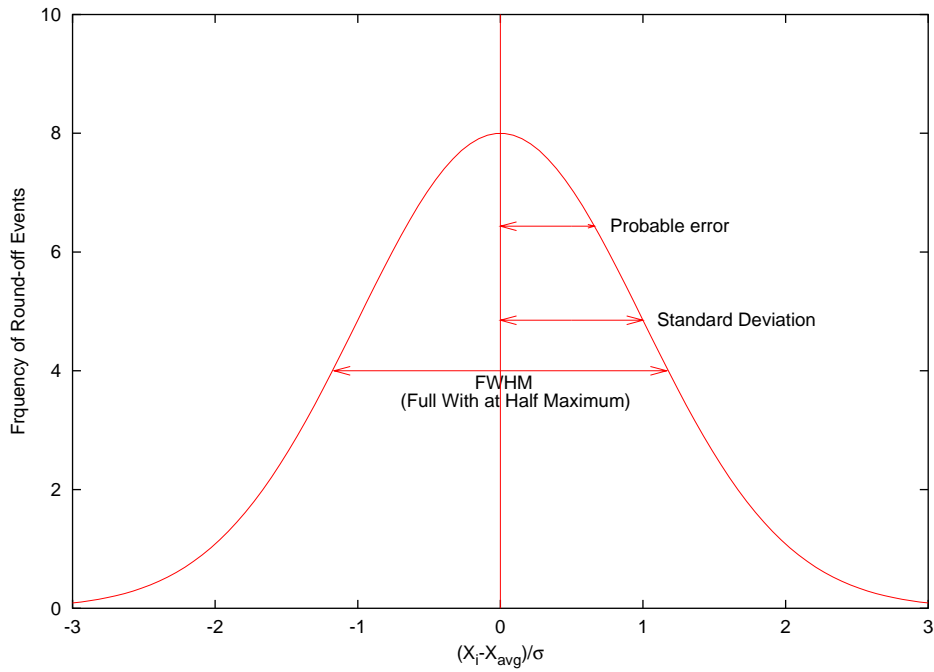


Figure 5: Typical Plot of Frequency of Round-Off Events vs the Round-Off Values

## Experiment 2.7

We will measure the time intervals between successive radioactive decays and study the statistics of this process. If we do a lot of measurements, we can determine the probability that an atom will decay in a certain time. This probability does not depend on any previous events and follows an exponential decay distribution. Here is why:

Consider a process such as a particle decay where:

1. In a small interval of time,  $\Delta t$ , there is at most a single decay.
2. The probability of finding a decay in this interval of time is proportional to  $\Delta t$ .
3. A decay in  $\Delta t$  is independent for the decays at other times.

The probability then of finding a decay in the time  $\Delta t$  is:

$$P_i(\Delta t) = M\Delta t$$

where  $M$  is a normalization constant. The probability of finding 0 decays in the time  $\Delta t$  is:

$$P_j(\Delta t) = 1 - P_i(\Delta t) = 1 - M\Delta t$$

If we keep in mind that the decays are independent, the probability to get no decays in a long time,  $t + \Delta t$ , can be expressed as:

$$P_j(t + \Delta t) = P_j(t)P_j(\Delta t)$$

Combining this with the above expression, one can form the quantity

$$\frac{P_j(t + \Delta t) - P_j(t)}{\Delta t} = -MP_j(t) \quad (4)$$

As  $\Delta t$  approaches 0, the left side of the equation becomes a derivative and the above equation becomes (after rearranging the terms):

$$\frac{dP}{P} = -Mdt \quad (5)$$



The solution to this differential equation is:

$$P_j(t) = P_j(0)e^{-Mt}$$

since  $P_j(0) = 1$  and  $P_j(t) = e^{-Mt}$

Let's combine some probabilities. The probability that you have no decay in time  $t$ , and one decay in  $\Delta t$  is:

$$P_j(t)P_i(\Delta t) = e^{-Mt}M\Delta t$$

and the probability/(unit length) becomes  $Me^{-Mt}$ . This is how the time between events should be distributed in a random process. You are going to verify this.

### **Procedure**

Once you have finished with the counting statistics portion of the lab, load the program `geigeran.bs2`. This program loops 65000 times (about 2.5 msec/loop) and checks to see if the counter has incremented. If so, you will get a number of loops since the last Geiger tube hit, (You may need to put a 4700 Ohm resistor on the input to stop multiple hits.) Write down each number. Probably you need 250 or so points to do a good job. Make sure that the rate in the counter is not too high (a few/sec is fine).

You can also do different rates as a check. If you completely remove the source, you can measure the background to see if its random.

### **Exercise**

Draw a histogram of your data. Choose your bin size in such a way, so that the scatter in the data looks reasonable. Does your data confirm the relationship  $Me^{-Mt}$ ? Use a fitting program to obtain  $M$  for your data. What is the average time between events for your data?