

## A Lesson in Radioactivity and Half-Life: Voyager/Scratch Geiger Counter Simulation

### Introduction

This lesson makes it possible for your students to study radioactive decay and half-life concepts without the need to purchase expensive radiation monitors and actual radioactive isotopes. Scratch and Voyager work together to accomplish this via a simulation that matches that of true radioactive decay. ScratchX is not required, but may be used. The Scratch program provides the decay process. With each decay of a simulated atom, the Scratch screen quickly flashes white and emits a beep sound similar to that of a typical Geiger counter. Voyager's light sensor records each of the decays as a "blip" in the light intensity versus time graph, as shown in Figure 1. A detailed analysis of this graph allows students to determine the half-life of one of four different isotopes that can be simulated by the Scratch program. Half-lives of the four isotopes range from approximately 75 to 240 seconds. The teacher can assign a specific isotope from the four to each student group. A video accompanies this lesson.

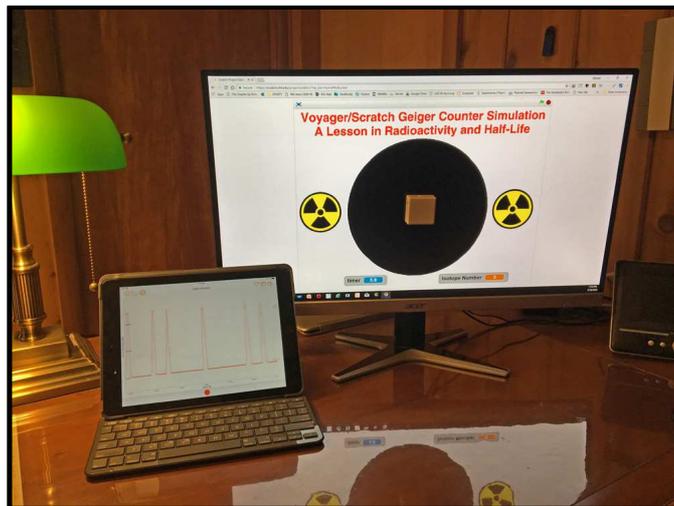


Figure 1

The data collection rate should be set to 50 points/second in the PocketLab app, and the device running the Scratch program should be set to maximum brightness. The blue timer on the bottom left of the scratch screen shows the elapsed time since data collection began. This should closely match the elapsed time on the PocketLab app screen provided that data recording is started **simultaneously** with entering (*i.e.*, clicking the blue arrow) the isotope number requested by the Scratch program:

Which isotope (1, 2, 3, 4) do you want to investigate?

Students can assume that the background radiation is negligible as the Scratch program **RadioactiveDecay.sb2** included with this lesson does not produce any background counts. There is also a Scratch program **RadioactiveDecayWithBackground.sb2** with which students can study the effect of background radiation on the measured half-life.

## Data Analysis

The top graph of Figure 2 shows light intensity versus time for the 3½ minutes (210 s) of data collection.

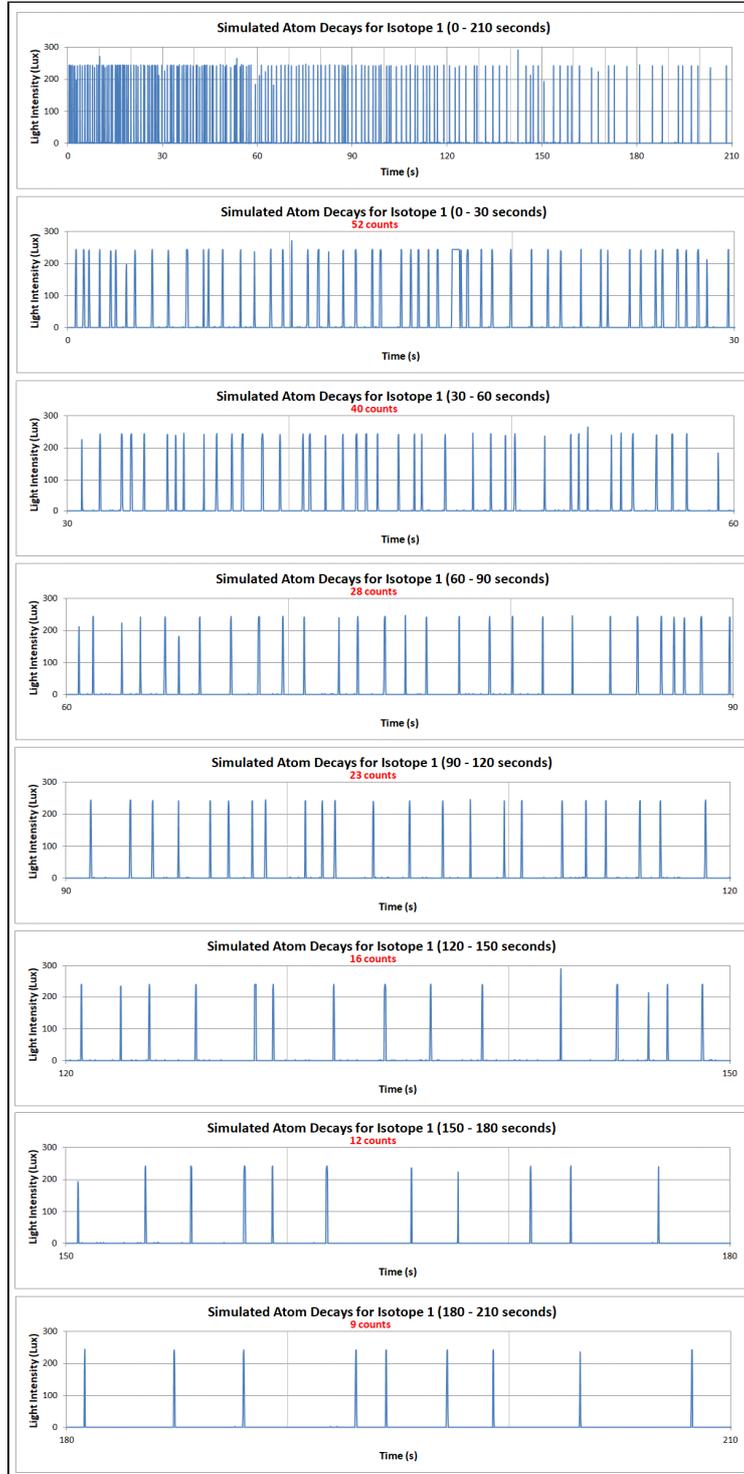


Figure 2

The first thing we notice is that the decays occur in a random fashion. In addition, through the decreasing density of blips over time, the top graph clearly shows that the time between decays appears to increase with the passage of time. In other words, the rate of decay decreases over time. But is there a way to describe this decay rate mathematically?

To aid in answering this question, each of the remaining graphs in Figure 1, zoom in on 30 second intervals of data collection from start to finish. The blips in each of these intervals are counted, and have been recorded in red below the title of each graph.

A chart of decay count versus time is then constructed and is shown in Figure 3. The data points have been plotted in the center of their respective 30-second intervals. The blue data points suggest that the shape of the graph is negative exponential. Therefore, an exponential trend line is added and the fit equation is seen to be  $y = 60.890e^{-0.010x}$ . With an  $R^2$  value of 0.998, the fit is very good.

At time zero, when  $x=0$ , the decay rate ( $y$ ) is 60.890 (counts/30 sec), where the curve intercepts the  $y$ -axis. The green dotted lines indicate that the decay rate is halved to 30 after about 70 seconds have elapsed—indicating that isotope #1 has a **half-life** of about 70 seconds. The dashed purple lines show that the decay rate is halved again to 15 counts after another 70 seconds. This is a good way for junior high students to determine the half-life as it is graphical and does not require a lot of math.

For high school students, who are more mathematically advanced, the half-life ( $t_{1/2}$ ) can also be determined from the coefficient of  $x$ , -0.010, in the exponential equation of best fit. The coefficient of  $x$  is called the **decay constant**, and has units of reciprocal of time. From Figure 4, we see that the half-life of our isotope sample is  $t_{1/2} = 0.693/0.010 (30s)^{-1} \approx 69 (30s)^{-1}$ , in close agreement with the value 70 s that we found by studying the graph.

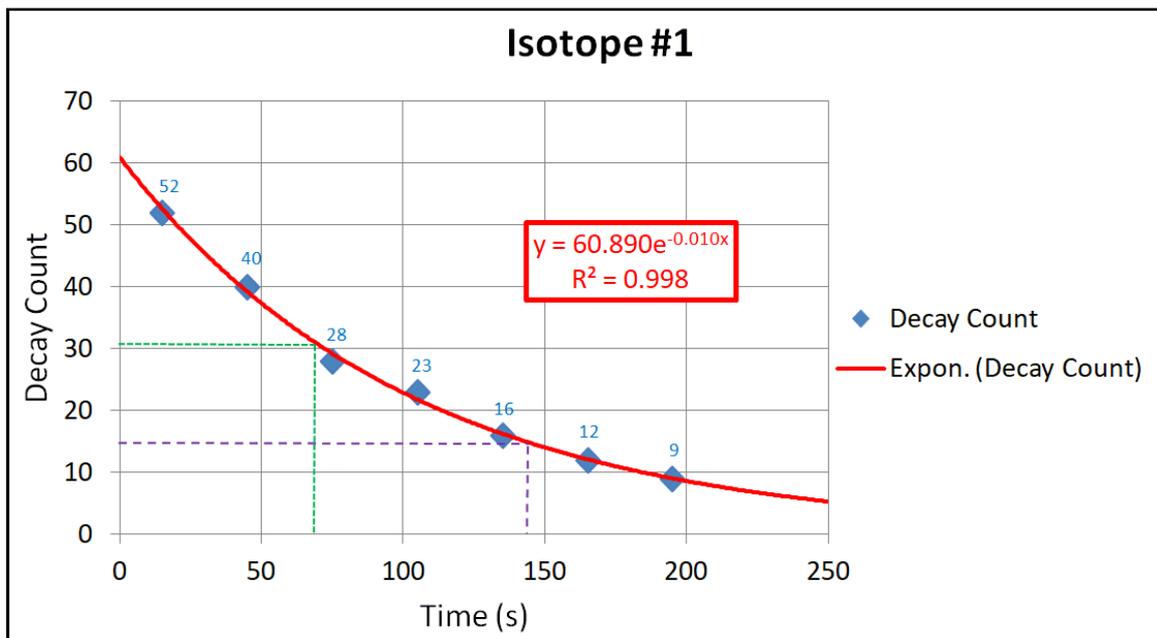


Figure 3

The decay rate  $r_t$  at time  $t$  is given by  $r_t = r_0 e^{-\lambda t}$  where  $r_0$  is the rate at time 0 and  $\lambda$  is the decay constant.

At time  $t = t_{1/2}$ ,  $R_t = \frac{1}{2}r_0$ , by the definition of half-life.

Therefore,  $\frac{1}{2}r_0 = r_0 e^{-\lambda t}$  and  $\frac{1}{2} = e^{-\lambda t}$ .

By taking the natural log of both sides, we have  $-\ln 2 = -\lambda t$ .

Finally,

$$t_{1/2} = (\ln 2) / \lambda = 0.693 / \lambda.$$

Figure 4

### The Scratch Geiger Counter Simulation Program

Figure 5 provides an overview of the sprites that constitute the Scratch Geiger counter simulation program. Sprite2, "Main", contains the code for what happens when the light green flag is clicked to start the program. Sprite1 contains the code that causes the large black circle to flash white and display one of four red arrows randomly for each atom that decays. It also produces the audible beep each time an atom decays.

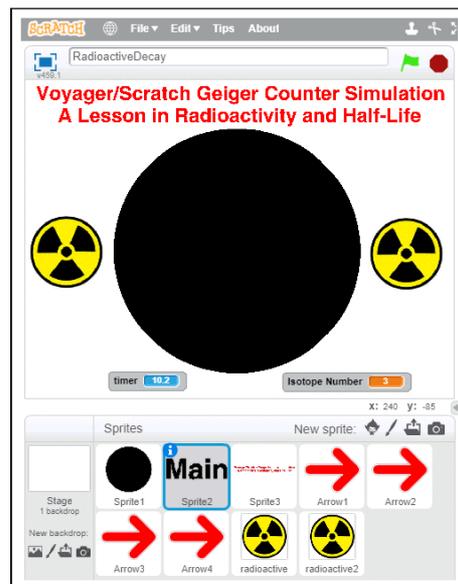


Figure 5

The code for all sprites can be viewed by opening the Scratch program **RadioactiveDecay.sb2** that is included with this lesson. Strategic comments have been included with a number of Scratch blocks to explain what the block accomplishes for those blocks that are not self-explanatory. For students of computer science, a challenging project is to modify the program so that it includes random background radiation with an average rate of 12 counts per minute. When the program starts, users should initially be able to select whether they want to measure only background radiation, or measure combined background and isotope radiation. In the latter case the experiment analysis requires subtracting the average background count from the collected isotope data.

### Studying the Effect of Background Radiation on Half-Life Measurement

Background radiation can have a significant effect on the resultant measurement of half-life of an isotope, especially if the isotope radiation is relatively weak. The four isotopes simulated by our scratch program all have radiation levels that are not a whole lot larger than the background radiation. Therefore, they provide for a great chance for students to investigate the effect that background radiation has on the measurement of an isotope's half-life.

For this investigation, students need to open the Scratch file *RadioactiveDecayWithBackground.sb2*. When the program is started by clicking the light green flag in Scratch, students are asked the following question:

Measuring background (B) or combined (C) background and isotope?

B  C

They should begin by selecting **B** to measure background. They can collect data for several minutes. When a light intensity graph is constructed, it will appear similar to that shown in Figure 6.

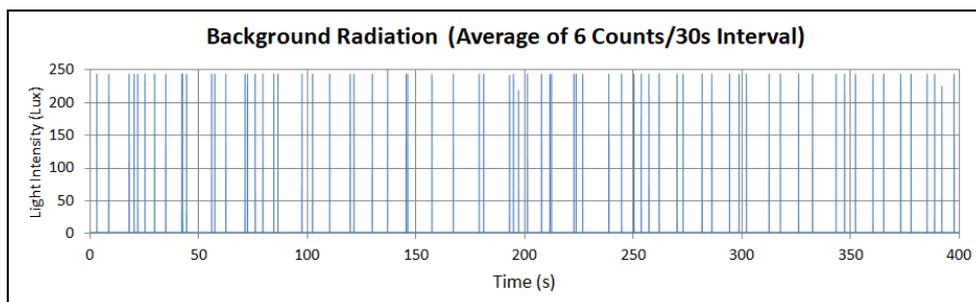


Figure 6

Background is clearly random, but uniformly distributed. They will find that the average background rate is approximately 6 counts per 30 second interval. The Scratch program can then be started a second time, but this time selecting **C** to measure combined background and isotope. Since a Geiger counter cannot distinguish between background and isotope counts, students will need to subtract the average background count that they got from their graphs similar to Figure 6 from the counts when selecting **C**. They can then construct a graph similar to that of Figure 7.

This graph reveals a great deal about the effect of background on half-life. Everything in blue refers to isotope counts per 30 second interval (Isotope #1), while everything in red refers to isotope counts minus the average background radiation (6 counts per 30 second interval). The half-life can be determined graphically as shown in the graph, or can be determined from the decay constant in the exponential fit equation. The half-life of 99s, uncorrected for background, is significantly higher than the half-life of 76s, when corrected for background radiation. The reason for this relates to the fact that the right tail of the uncorrected counts is higher and trends toward the background count of 6 per 30s interval as time progresses. In contrast, the tail of the corrected count trends toward zero as time progresses.

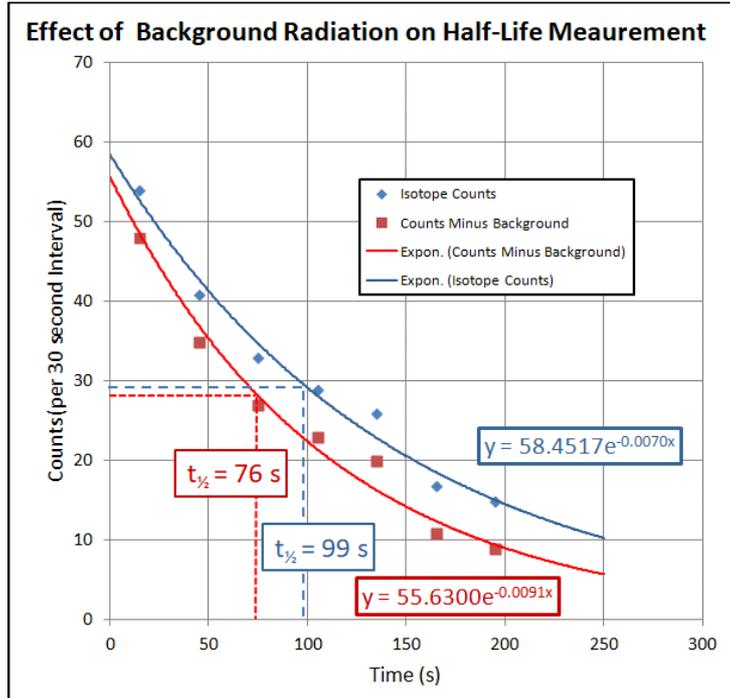


Figure 7