Ozobot Evo Classroom Application: Radiation Half-Life Simulator

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Introduction

The study of radioactive decay and half-life is an essential part of any course in atomic and nuclear physics and is often encountered in lower level physical science courses as well as courses in earth science in the study of carbon-14 dating. Doing half-life experiments with actual radioactive isotopes, however, can be quite expensive. When considering the price of a Geiger counter and the source of the radioactive isotope, total costs can easily exceed $500. One of the most commonly used isotope generators is one that produces barium, which has a half-life of about 2.6 minutes. This isogenerator alone can have a cost approaching $250. Some instructors are also concerned about bringing radioactive materials into the classroom environment.

Enter Ozobot Evo—the radiation half-life simulator! No Geiger counter needed. No actual radioactive materials needed. And Ozobot Evo has the advantage that it can simulate more than one isotope just by changing the OzoBlockly program that it is running. Lab groups can be assigned any of three different simulated isotopes using the programs supplied with this classroom application.

The Ozomap for this Classroom Application

For reference while discussing this application, Figure 1 shows a small version of the Ozobot Evo map that students will be using. A full-page version that can be printed for use with Ozobot Evo appears on the last page of this document.

The map resembles a graph in which radiation counts are collected in simulated 10-second intervals, as could be done with an actual Geiger counter. Evo starts at time 0, moves up the chart and stops near the radiation count at that time. Evo then speaks the exact radiation count at that time. Students would then record this number on their data sheet. In a similar manner, Evo will move to 10, 20, 30, etc. simulated times in seconds, providing radiation counts for each of those simulated 10-second intervals.

The very light red line on the graph is not meant to represent any specific isotope, but rather it just reinforces the nature of radioactive decay half-life as being negative exponential in shape. Students can assume that the background radiation count is negligible during the short 10-second intervals—they need not correct radiation counts for background radiation.

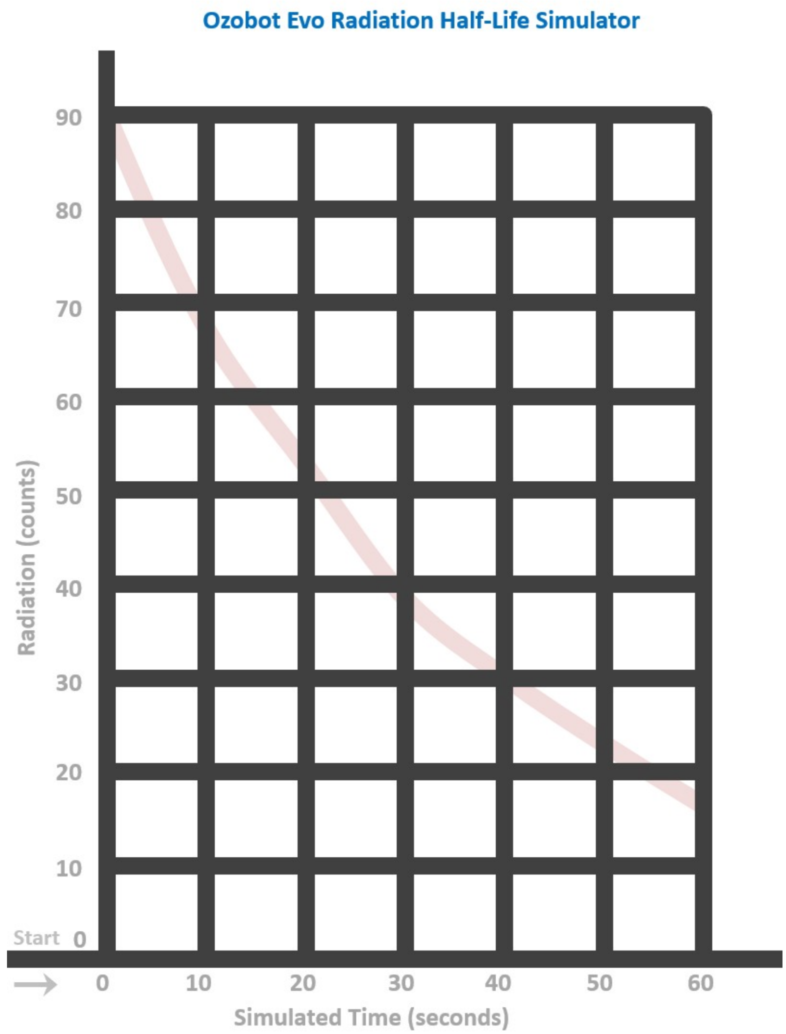


Figure 1

Running the OzoBlockly Programs

1. There are three different OzoBlockly programs included in this classroom application: *HalfLifeIsotope1.ozocode (share code* **z5pymo***), HalfLifeIsotope2.ozocode (share code* **spujg2***), and HalfLifeIsotope3.ozocode (share code* **h3wymb***)*. Thy differ only in the resultant half-life that will be simulated. The teacher can load the programs onto Ozobot Evos in advance or assign the student lab groups to load specific programs from the collection of the three ozocode programs.
2. Place Evo at the location labeled "Start", facing the direction shown by the gray arrow, and with Evo's leading edge on the curved gray line. Evo will display a RED LED while moving.
3. Start the program that has been loaded into Evo.
4. He will then travel up each of the simulated time vertical lines and pause to provide radiation count information, as explained in the previous section of this document. After displaying the radiation count for the simulated time of 60-seconds, he will stop and power down. Each time the student lab group runs the program, the results will be slightly different as the programs have some randomness built-in so that Ozobot appears to simulate real radioactive decay.

Student Exercises

Student Exercise #1 (Grades 7-12): *Have each of the lab groups run their OzoBlockly program while explaining to them how Evo speaks the radiation counts. There is no need for them to record this data, as the purpose of this exercise is to make sure they understand that Evo speaks the counts for each of the 10-second simulated times from 0 to 60 seconds.*

Student Exercise #2 (Grades 7-12): *Now that the student groups know how Evo speaks the radiation counts, ask them to collect radiation count data for three runs with their assigned OzoBlockly program and record their data in the data table at the top of page 5. To reduce the effects of randomness, have them compute the average radiation counts of the three runs for each of the seven simulated times from 0 through 60 seconds.*

Student Exercise #3 (Grades 7-10): *Ask the lab groups to plot the average radiation counts and corresponding simulated times on the graph at the bottom of page 5. The students will likely observe that the points do not seem to fall on a straight line. Ask them to use their best judgment in drawing a curved line that fits the data well even though it may not lie on every point. You can now define the concept of half-life, if you have not already done so. The* ***half-life*** *of a radioactive isotope is the time required for the radiation count to decrease to half of its value at time zero. Have the lab groups announce their half-life values (in seconds) while you record them on the board for all to see. When all groups have reported their values, ask them if they observe any patterns. Do the half-life values seem to fall into three different groups representing the three isotopes that the class investigated?*

Student Exercise #4 (Grades 11-12): *Radioactive decay is characterized by the negative exponential curve as given by the equation $R(t) = R_o e^{-\lambda t}$, where $R(t)$ is the decay rate at time t, R_o is the decay rate at time zero, and λ is the* ***decay constant*** *for the isotope.*

(a) *Using Excel or similar spreadsheet software, create a graph of average radiation count versus simulated time from your data of student exercise 2. Based on the graph and making use of the trendline feature of the spreadsheet, what are the initial radiation count and the decay constant?*
(b) *(For students with access to Vernier Software and Technology's* ***Logger Pro*** *software) If you have access to Logger Pro, this can be used* ***instead*** *of spreadsheet software such as Excel. Enter your average radiation count and simulated time data from student exercise 2 into a new LoggerPro file. Using the Analyze option in Logger Pro, define a model* ***A*exp (-C*x)*** *and fit your data to the model. Based on the graph, what are the initial radiation count and the decay constant?*

Student Exercise #5 (Grades 11-12): *In student exercise #4, we determined the decay constant, but we are interested in knowing the half-life of our radioactive isotope. There is a simple formula relating these two constants. Let's derive the formula. By the definition of half-life, at a time ($t_{1/2}$) equal to the half life, $R(t_{1/2}) = R_o/2$. Therefore, $R(t_{1/2}) = Ro/2 = R_o e^{-\lambda t1/2}$, and $\frac{1}{2} = e^{-\lambda t1/2}$. Taking the natural logarithm (ln) of both sides of this last equation, $-0.693 = -\lambda\, t_{1/2}$. Therefore,* ***$t_{1/2} = 0.693/\lambda$****. Use this equation and results from student exercise #4 to determine the half-life of the isotope that you investigated.*

Student Exercise #6 (Grades 11-12): *The average time that a radioactive particle will exist without decaying is called the* ***mean lifetime****. It can be shown that this amount of time, usually represented by the Greek lower case letter "Tau"* ***τ****, is the time required for the decay rate to decrease to 1/e (≈0.37 or 37%) of its original value*

R_o. (e is the base of the Naperian logarithms ≈ 2.7182818 .) Therefore, $R_o/e = R_oe^{-\lambda\tau}$. Cancelling R_o in the last equation, and taking the natural logarithm of both sides of the equation, we have

$\ln(1/e) = \ln e^{-\lambda\tau}$, or $-1 = -\lambda\tau$. Hence, $\boldsymbol{\tau = 1/\lambda}$. Calcualte the mean lifetime of the isotopte that you investigated.

Actually, any phenomenon that decays exponentially with time will decay to 37% of its initial value after one mean lifetime has elapsed. This occurs in many systems in science and engineering and is something that students of physics should understand well. See figure 2 for a graph illustrating the relationship between half-life and mean lifetime.

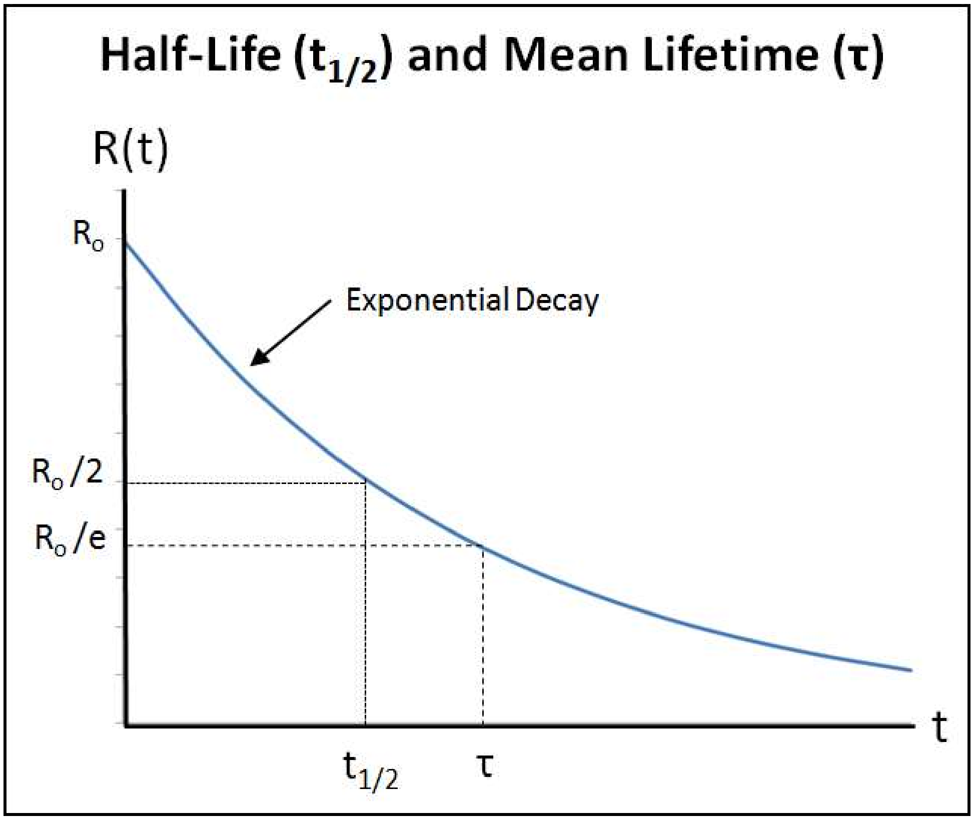


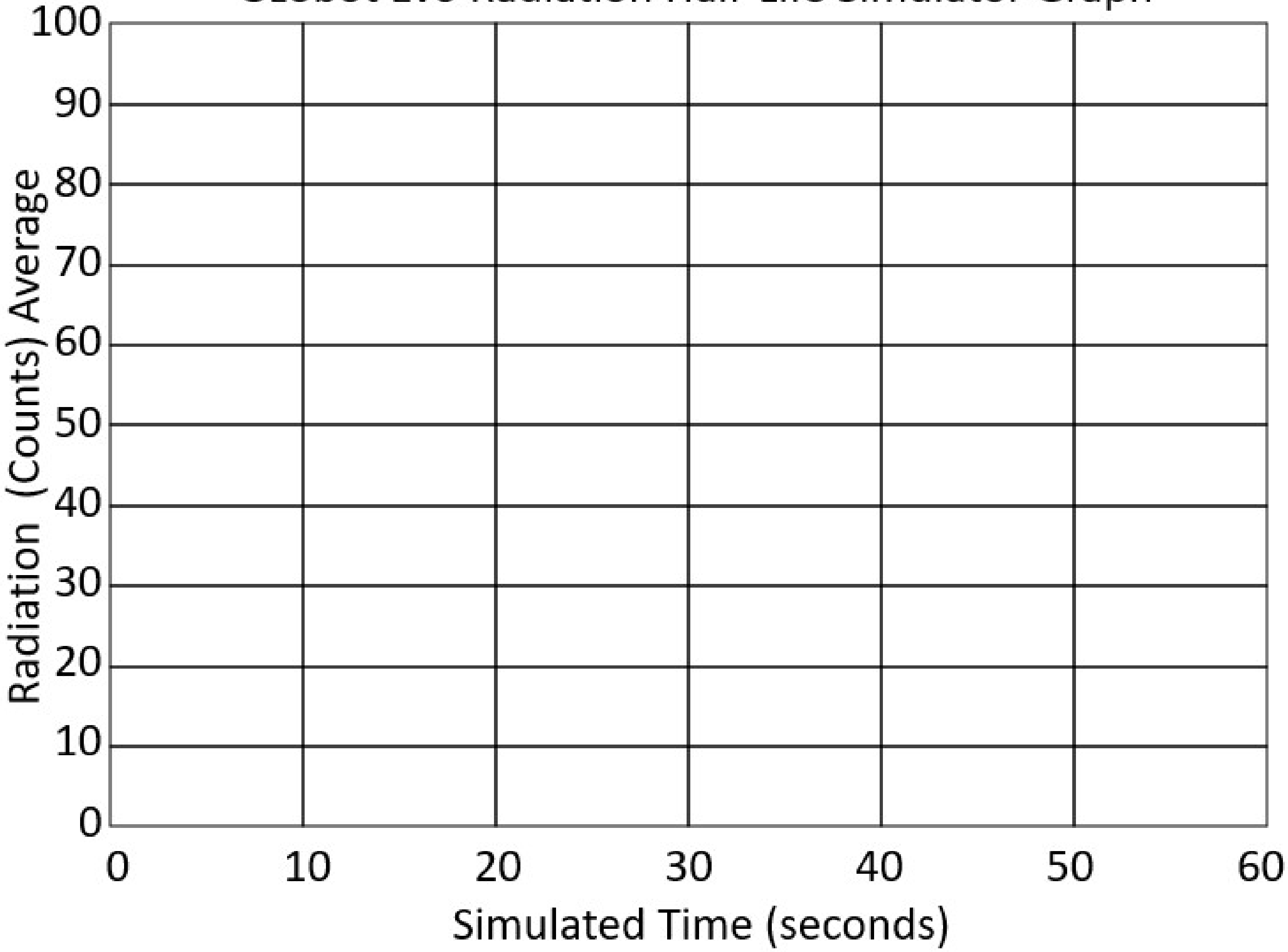
Figure 2

Student Exercise #7 (Grades 7-12): *A Cesium/Barium isogenerator along with a Geiger counter, are used to investigate radioactivity and half-life. The isogenerator produces Barium-137m, a metastable nuclear isomer of barium, that has a half-life of 2.6 minutes. If the initial radiation count, after being adjusted for background radiation, is 3000 counts, what is the expected count after 2.6 minutes? After 5.2 minutes? After 7.8 minutes? After 10.4 minutes?*

Ozobot Evo Radiation Half-Life Simulator Data Table

Simulated Time (seconds)	Radiation (counts)			
	Run 1	Run 2	Run 3	Average
0				
10				
20				
30				
40				
50				
60				

Ozobot Evo Radiation Half-Life Simulator Graph



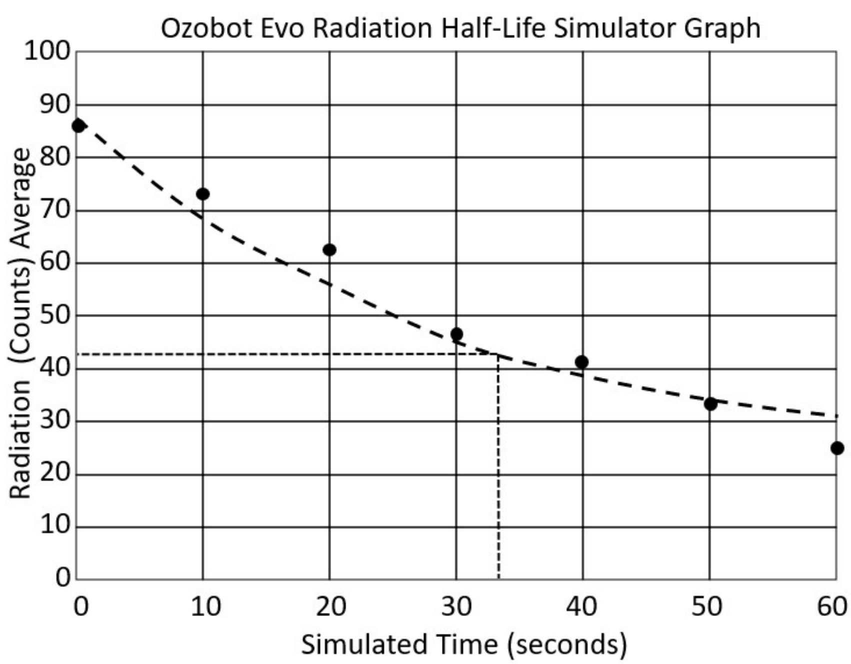
Answers to Exercises:

1. *See the section entitled "The Map for this Classroom Application".*
2. *Here is a typical data table for a lab group working with isotope #2:*

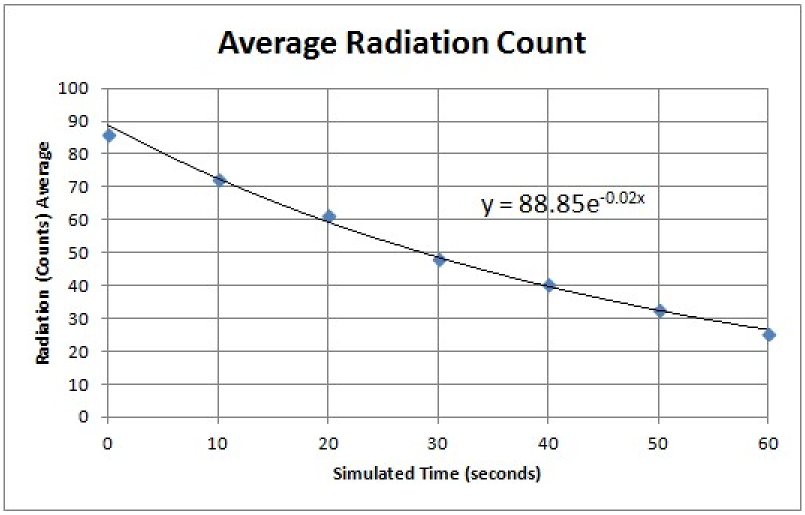
Ozobot Evo Radiation Half-Life Simulator Data Table

Simulated Time (seconds)	Radiation (counts)			
	Run 1	Run 2	Run 3	Average
0	92	89	86	86
10	73	70	75	72.7
20	56	64	65	61.7
30	48	49	48	48.3
40	39	40	43	40.7
50	32	35	31	32.7
60	26	27	24	25.7

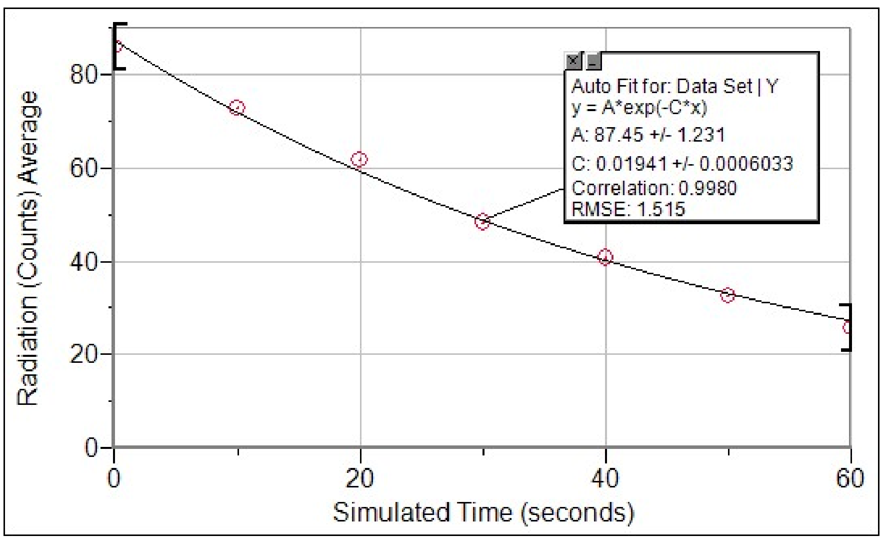
3. *Here is the graph corresponding to the data table above for isotope #2. The initial radiation count is 86. It gets down to half (43) of the initial value at about 33 seconds. Therefore, the half-life would be about 33 seconds. Expect some variation from lab group to lab group due to differences in their data and how they draw in their "curve of best eye fit". (Note that the half-life for isotope #1 is about 25 seconds, while the half-life for isotope #3 is about 16 seconds.)*



4. *The graph at the top of the next page was produced using Excel on the data from the table at the top of this page. The Excel feature of adding a trendline whose regression type is "exponential" was used and the option of displaying the equation on the chart was selected. We see that the initial radiation count was 88.85 and the decay constant is 0.02 sec^{-1}.*



The graph below was produced using Logger Pro. We see that the initial radiation count was 87.45 and the decay constant is about 0.019 sec^{-1}, in close agreement with the results from Excel.



5. *Using the value of the decay constant λ from either the Excel chart or the Logger Pro chart above, the half-life of radioactive isotope #2 would be* $\mathbf{t_{1/2} = 0.693/\lambda}$ *= 0.693/0.02 sec^{-1} ≈ 34.7 seconds.*
6. *Using the value of the decay constant λ from either the Excel chart or the Logger Pro chart above, the mean lifetime of radioactive isotope #2 would be* $\boldsymbol{\tau = 1/\lambda}$ *= 1/0.02 sec^{-1} ≈ 50 seconds.*
7. *Each of the times is 2.6 minutes, or one half-life, greater than the previous time. The radiation count would be expected to be halved each time:*

Time (minutes)	***Radiation Count***
0	*3000*
2.6	*1500*
5.2	*750*
7.8	*375*
10.4	*188*

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