Health Physics Society
Specialists in Radiation Safety

Half-Life

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A radioactive nucleus is unstable and will change, or decay. Once the nucleus changes, it is no longer the same as it was before. For most radioactive decays, the number of protons and neutrons in the nucleus changes, producing a different nucleus. Because the number of protons in the nucleus determines the element, the element also changes. The changed nucleus can either be stable or radioactive; however, the feature of radioactive decay that is important to understand for doing this activity is that once the nucleus has decayed, it is no longer the same.

The rate at which the radioactive nuclei change depends on the individual nucleus. Some decay rapidly, in a matter of seconds or minutes, while others decay over years. The rate of decay depends on the probability of decay per time. If a sample of 100 radioactive nuclei has a 50 percent probability of decay per minute, then after one minute, 50 percent (or 50) will have decayed.

This activity will investigate the process of radioactive decay. To simulate this process, we will use coins. A coin has two sides, so flipping a coin has a 50 percent probability of landing with heads up and a 50 percent probability of landing tails up. We will say that when a coin lands heads up the nucleus has decayed, while a tails up means the nucleus has not yet decayed.

1. A class has 200 coins to flip. If the class flips all 200 coins, how many would you expect to land heads? How many will be tails?

2. If we remove the “decayed” coins (i.e., the heads) and flip the remaining coins, how many would you expect to land heads? How many will be tails?

3. You can repeat this process of removing the heads and flipping the remaining coins that were tails. Estimate how many flips you will need to have all the coins decay. Explain how you got your answer.

Now the class will break into groups and each group will have a number of coins determined by the teacher. Each group will have a plastic bag to hold and shake the coins. Shake the bag and CAREFULLY dump the coins on the table or desk and spread them out. Count the number of heads and the number of tails. Record that number in the table below. Put the coins that came up heads aside and put the coins that came up tails into the bag. Shake the bag again and dump the coins on the table or desk. Count the heads and tails and record the number below. Repeat this process five times.

Coin Data
Group

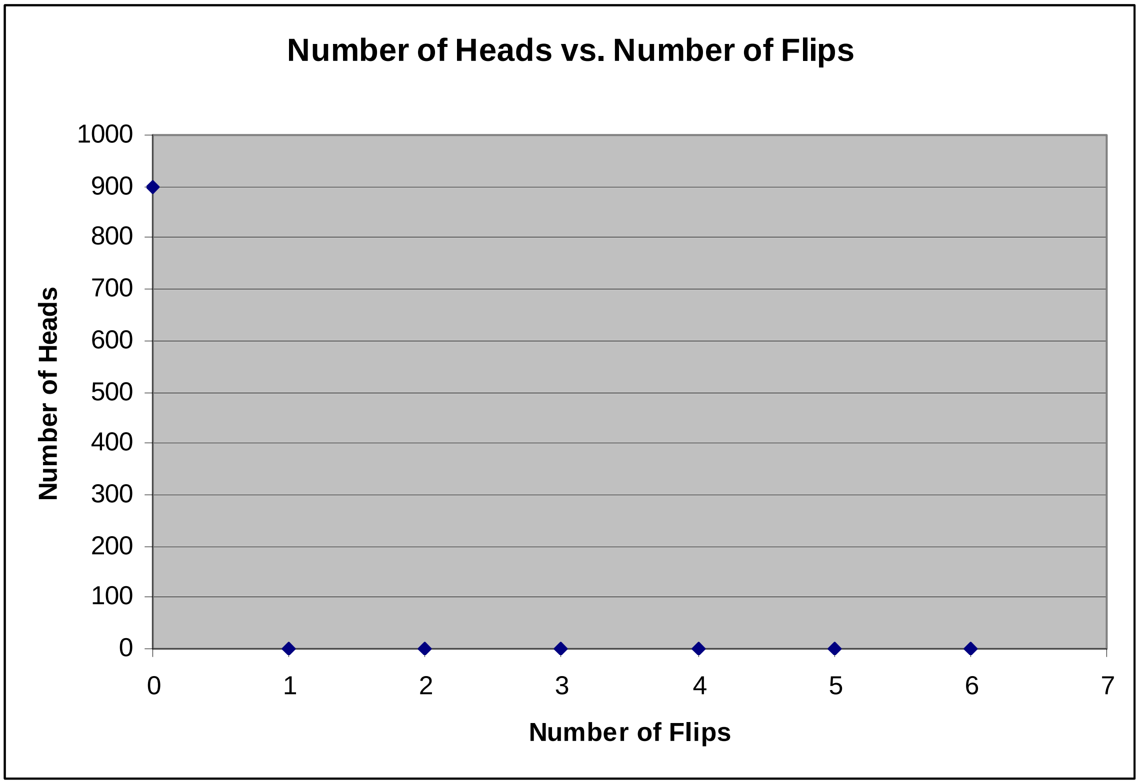
Flip number	Heads	Tails
1	_____	_____
2	_____	_____
3	_____	_____
4	_____	_____
5	_____	_____
6	_____	_____

Your teacher will gather all the groups' data and put it on the board. Record these data below.

Coin Data
Class

Flip number	Heads	Tails
1	_____	_____
2	_____	_____
3	_____	_____
4	_____	_____
5	_____	_____
6	_____	_____

Plot the number of heads on the graph below, or if you have a computer graphing system, put it on the computer. The number at zero flips is the initial number of coins. Draw a smooth curve through the points.



4. The half-life of a radioactive nucleus is defined as the time it takes for half the radioactive nuclei to decay. From the class data and graph, what is the half-life of these coins (i.e., how many flips does it take for the number of heads to be half the original number)?

5. How many radioactive nuclei (i.e., heads) are left after three half-lives?

6. Is this the number you would expect? Explain.

7. Suppose you had a collection of dice. A die is in the shape of a cube. How many sides does a cube have?

8. When you roll a die, what is the probability of getting a "2"? If you roll 120 dice, how many 2s would you expect to get?

9. If we say that a 2 represents a decay, how many of the 120 dice would NOT have decayed? Express this as a number. Also express this as a fraction and as a percent of the original number.

10. If we remove the 2s and roll the remaining dice, how many 2s would you expect to get?

11. If we repeat this process (removing the 2s as decayed nuclei), estimate or calculate how many rolls are needed to have half the 120 dice remaining.

12. How does your answer for the dice compare with your answer in Question 4 for the coins? Explain why they are different.

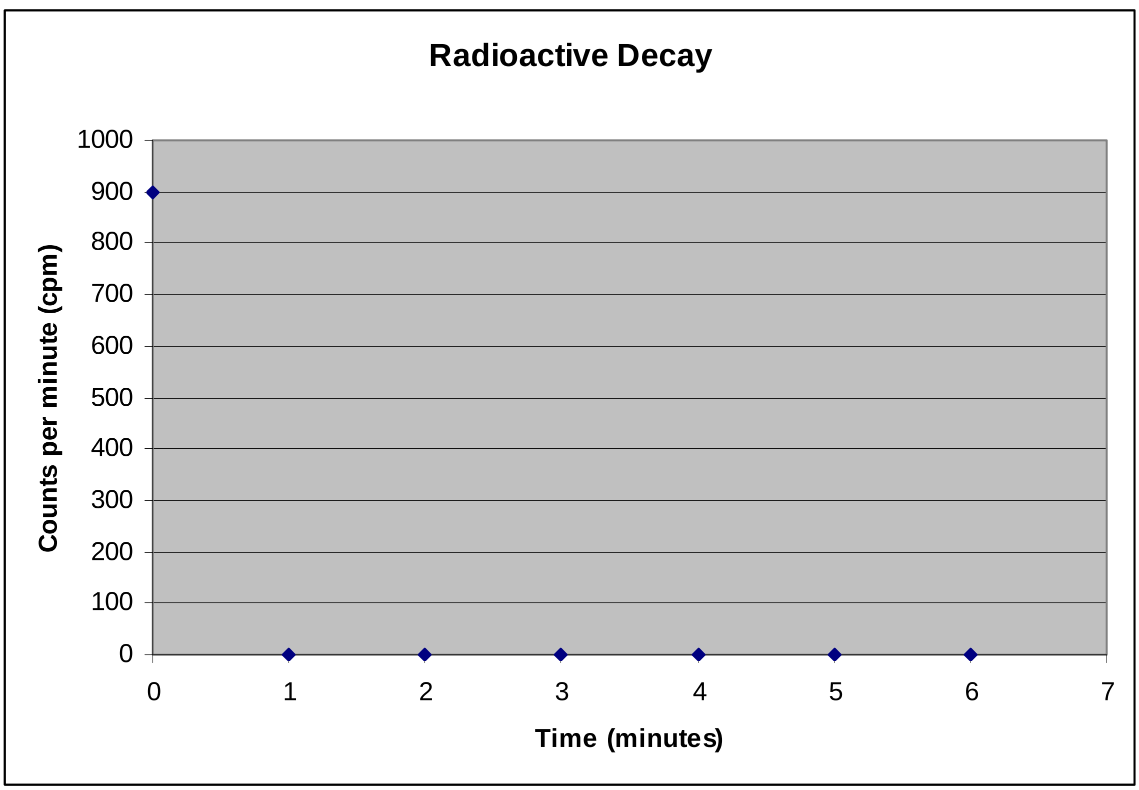
13. Now we will use real radioactive material. Your teacher has an apparatus called an isogenerator. It produces a short half-life radioactive material. You will use your radiation detector to measure the radioactivity as a function of time. However, to prepare to take data, you will need to arrange your equipment properly and then take data quickly.

Place your detector on the table; note the location of the end of the Geiger tube. You will have a small planchet (metal "dish") with your detector. When ready, your teacher will put a drop or two of the radioactive material into your planchet. When that happens, place the planchet right in front of the end of the Geiger tube and turn on the detector, set for one-minute counts (cpm). Practice this procedure with your teacher present so you are sure you know you can do this quickly without spilling any radioactive material. When everybody is ready, your teacher will give each group the drop or two of radioactive material and you will start counting.
At the end of each minute, record the count on the table below. <u>Do not turn off the detector between counts; it will cycle through the counts by itself.</u> The first count will be at time zero, the second will be at time 1, etc. Count for a total of 7 minutes. Subtract the background count rate from each data point.

Radioactive Counts

Time	Count		Background		Net Count
0 min.	______ cpm	-	_____cpm	=	______cpm
1 min.	______ cpm	-	_____cpm	=	______cpm
2 min.	______ cpm	-	_____cpm	=	______cpm
3 min.	______ cpm	-	_____cpm	=	______cpm
4 min.	______ cpm	-	_____cpm	=	______cpm
5 min.	______ cpm	-	_____cpm	=	______cpm
6 min.	______ cpm	-	_____cpm	=	______cpm
7 min.	______ cpm	-	_____cpm	=	______cpm

14. Plot your counts as a function of time on the graph below. Adjust the count scale if needed.



15. From your graph and/or data, estimate the half-life of this radioactive nucleus.

Teacher Notes

Materials:

Use about 600 coins to get decent statistics. Pennies work just as well as any other coin!

NOTE: another popular option is M&M's; shake a bag and say that the ones with the M's up have decayed, so "dispose" of these!

Optional: If you have time, you can use dice. The procedure will be the same as for the coins. However, the process will take longer because it is harder to separate out the "decayed" dice and it takes about 8 rolls to get down to less than one-fourth the original number. To do the exercise with dice, you will need about 600 dice; try casino "throw-aways."

Plastic sandwich bags or quart storage bags, one for each group.

Cesium-137 iso-generator. This consists of a long half-life material, cesium-137 (^{137}Cs) (30-year half-life) that decays into barium-137 (^{137}Ba). In this decay, a beta particle is emitted to change the ^{137}Cs nucleus to ^{137}Ba. In the process of decay, a gamma ray is also emitted. Actually ^{137}Ba is stable, but this is one of those interesting quirks of nature where the emission of the gamma ray is delayed. After the decay of ^{137}Cs, the ^{137}Ba is left in an excited state, called a meta-stable state, and decays just as any other radioactive nucleus decays, but in this case it only emits a gamma ray. If you look on a chart of nuclei, the ^{137}Ba is listed as $^{137}Ba^m$, where "m" signifies metastable.

Teacher's instructions:

The first three questions are based on the fact that the probability that the chance of getting a head (or tail) is 50 percent. Question 2 attempts to overcome the misconception that half the nuclei decay in one half-life and the rest in a second half-life, so emphasize this point. Half of one-half is ¼, then half of ¼ is 1/8, etc. For Question 3, the students will probably say something like 5 to 10 tosses, or a few may say they never go to zero. Because the activity falls off exponentially, for a large sample of radioactive nuclei with a long half-life, the activity would never go to zero. However, in the coin toss with 200 coins, mathematically the number left after 8 tosses would be 1, so the 9^{th} toss or later will make the last one decay.

Questions 4 through 6 require some graphical interpretation. Emphasize that drawing a smooth curve through the data points does not mean going from point-to-point. On the vertical scale on the graph, the students should mark half of the initial number of coins and find the time that the curve intersects this mark. With a bit of luck, it will be close to one flip. Question 5 emphasizes the concept of half of half of half… So, after three half-lives, the numbers should be ½ X ½ X ½ = 1/8 of the initial number.

This section is also an opportunity to discuss randomness. Most likely the numbers will not be exactly half, a fourth, etc., after each successive half-life. However, if the sample were large enough (millions of coins) the actual numbers and the calculated numbers would be very close.

Questions 7 through 12 use the same concepts as outlined in the coin-toss activity, but now the probability is 1/6 for getting a "decay." Therefore, the probability of not decaying is 5/6, which means that the number remaining after each roll is 5/6 X 5/6 X 5/6, etc.

Activity 13 needs to be done somewhat quickly, but do not rush it. Make sure the students know what they are supposed to do and practice putting the planchet in front of the detector (screened area) and then turn on the detector. To elute the radioactive material, follow the direction for the iso-generator. Be sure you inject the eluent in the proper direction. When the students are ready, put a drop on each planchet. One elution will give 5 or 6 drops. Generally, the first drop is the most active and the following are less. Therefore, depending on the number of groups, you may want to put one drop on the first, two on the second, and the rest on the third. If there are more than three groups, the generator takes about 8 minutes to regenerate to 90 percent of its maximum activity, so if one or two groups are lagging behind with their earlier activities, you can do this activity in two sessions, 8 minutes apart.

Generally the count rate starts at several hundred counts per minute; if less, the students can adjust the scale for the count rate on the graph.

Activity 14: The half-life of Ba-137m is 2.55 minutes.

Optional data handling: adding all the student numbers together gives better statistics, but it removes the individuality.

Optional activity: one group could measure the increase in the activity of the generator after it has been eluted. When all the eluent is through the generator, put the generator in front of a detector and have the students take repeated one-minute counts. They will see that the count rate increases, reaching a maximum value in about 15 minutes.

Optional analysis: If the students can use a computer graphing program that has a linear fit, they can plot the ln (natural log) of the count rate as a function of time. A linear fit will give the negative of the probability of decay (-l) (in inverse minutes). The half-life is related to the probability of decay by: half-life = (0.693)/ l. Generally this analysis gives the correct half-life to within 5 percent of the actual value.