NUCLEAR POPCORN

Teacher's Notes

OBJECTIVE:

Help students visualize the rate of radioactive decay.

Grade: 7 – 12

Intended Learning Outcome:

- Reason mathematically
- Make predictions
- Construct tables and graphs to describe and summarize data
- Collect and record data
- Understand science concepts and principles

Subjects: Physics, Math, Science, Statistics

Materials: Data Analysis sheet for each student (included)

128 un-popped popcorn kernels, M&M's, Skittles, coins or poker chips with stickers on one side may also be used. M&M's move the pace of the game quicker than popcorn kernels.

Teaching Time: One class period

Number of Players: Groups of 4 or 5

Teacher Information: This exercise is meant to show that by eliminating random kernels, the process of radioactive decay can be simulated.

AUTHOR BIO:

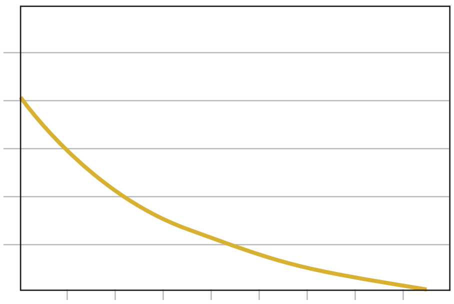
Marc Mayntz has taught general, AP and IB physics at Provo High School since 2005 after teaching similar courses in Florida for several years. He graduated with High Honors from Florida Institute of Technology with a Bachelor's of Science in physics education and was recognized as Intern Teacher of the Year in 1998. While working in Florida, he consulted on the design of an experiment that was conducted onboard a space shuttle and was nominated several times for Teacher of the Year. Marc has been an active participant and presenter in Physics with Technology, AP Physics and IB Physics workshops in addition to his work with the Energy*Solutions* Foundation. In 2008, he was awarded the Provo Council PTA Golden Apple Award.

TEACHER'S ANSWERS TO DATA ANALYSIS

Data Analysis:

1. Make a graph with spills on the x axis and kernels remaining on the y axis.

   A. Graphs will vary



2. On the same graph, plot expected kernels remaining on the y axis.

   A. Every graph should show exponential decay.

3. How accurate does your graph represent decay?

   A. The graphs should be similar

4. Each spill represents a "half-life." How many kernels were eliminated during the first half-life?

   A. About 64 kernels should decay (maybe more or less)

5. How many kernels were eliminated during the second half-life?

   A. About 32 kernels should decay (maybe more or less)

6. For each successive half-life, does the number of kernels increase, decrease or remain the same?

   A. The number of decayed kernels decreases

7. What percentage of kernels were eliminated during the first half-life (100 x #decayed kernels / 128)?

   A. About 50%

8. What percentage of kernels were eliminated during the second half-life (100 x #decayed kernels / amount remaining after 1st half-life)?

   A. About 50%

9. For each successive half-life, does the percentage of kernels eliminated increase, decrease or remain the same?

   A. The percentage is about 50% for each half-life

10. Suppose a popcorn company spilled one million kernels on the factory floor. Can you estimate how many kernels will be pointing east in some way?

    A. That can be estimated

11. If your answer to #10 was yes, about how many will point east? If your answer was no, why not?

    A. About 500 thousand will point east (or any other random direction)

12. Inside the batch of one million kernels, there is a magical blue popcorn kernel, which follows the same laws as regular kernels. Can you predict which way the magic blue kernel will be pointing after it spills?

    A. No way to predict the blue kernel's direction

13. If your answer to #12 was yes, which way will it point? If your answer was no, why not?

    A. An individual kernels direction is completely random.

14. Does half-life depend on the mass of the sample?

    A. Half-life is independent of mass.

15. Does half-life predict when individual elements or atoms decay, or only the probability that those elements will decay?

    A. Half-life only predicts probability and that probability is always 1:1 between staying and decaying.

Student Activity

This lab will simulate radioactive decay. By eliminating random kernels, the process of radioactive decay can be simulated.

Procedure:

1. Select a cup with kernels in it
2. Carefully “spill” the kernels onto the table. Do not drop them since the kernels have a tendency to bounce. Spread them out widly.
3. Each kernel has a “point” on it. If the kernel points towards the front of the room IN ANY WAY, it is still “good” and you place it back into the cup.
4. The kernels that point towards the back of the room IN ANY WAY is “decayed” and is pushed off to the side.
5. An option is to have any kernels that are pointing EXACTLY to the sides of the room will have their fate decided by paper-rock-scissors, best 2 out of 3.
6. Count how many kernels are still good and record that in your data table.
7. Repeat the procedure until all kernels have decayed.

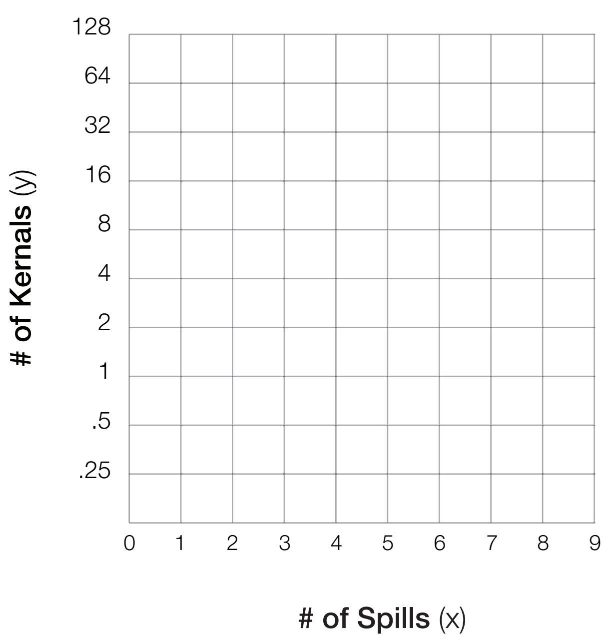
Data:

SPILLS		0	1	2	3	4	5	6	7
Expected Kernels Remaining based on previous sample size		128	64						
Kernels Remaining		128							
Summary	Total / %								

Data Analysis:

1. Make a graph with spills on the x axis and kernels remaining on the y axis.
2. On the same graph, plot expected kernels remaining on the y axis.
3. How accurate does your graph represent decay?
4. Each spill represents a “half-life.” How many kernels were eliminated during the first half-life?
5. How many kernels were eliminated during the second half-life?
6. For each successive half-life, does the number of kernels increase, decrease or remain the same?

7. What percentage of kernels were eliminated during the first half-life (100 x #decayed kernels / 128)?
8. What percentage of kernels were eliminated during the second half-life (100 x #decayed kernels / amount remaining after 1st half-life)?
9. For each successive half-life, does the percentage of kernels eliminated increase, decrease or remain the same?
10. Suppose a popcorn company spilled one million kernels on the factory floor. Can you estimate how many kernels will be pointing east in some way?
11. If your answer to #10 was yes, about how many will point east? If your answer was no, why not?
12. Inside the batch of one million kernels, there is a magical blue popcorn kernel, which follows the same laws as regular kernels. Can you predict which way the magic blue kernel will be pointing after it spills?
13. If your answer to #12 was yes, which way will it point? If your answer was no, why not?
14. Does half-life depend on the mass of the sample?
15. Does half-life predict when individual elements or atoms decay, or only the probability that those elements will decay?



Common student questions concerning radioactive decay:

If mass is conserved, how do radioactive atoms decay?

The term decay, which insinuates destruction, is a small misnomer. Radioactive elements transmute, or change, into more stable nuclei. Imagine 238 marbles in a box. If you take some marbles out of the box, the total number of marbles remains 238. The only difference is some of the marbles are in your hand. In the nucleus, the marbles being held represent the radiation that escapes, but the mass remains the same.

How can we know extremely long half-lives like uranium (4.6 billion years) when no people or civilization has existed long enough to measure that time?

All radioactive decay follows a precise mathematical formula called a decay relationship. The relationship states

$$\frac{\text{New Amount}}{\text{Old Amount}} = 2.718^{-kt}$$

The variable “k” in the equation is called the decay constant. The variable “t” is the time. A small constant means that it takes a long time for the nucleus to reach its half life. This equation works for any amount of elapsed time, not just half lives. After a set amount of time, the old and new amounts of a radioactive sample are compared, the decay constant is calculated, and the half-life can be predicted without the need to wait.

If the formula works for any time, why do we concentrate on “half-life?” Why not “tenth-life” or any other fraction?

Mathematically, our brains still function as they did 10,000 years ago. Our brain realistically only recognizes three numbers: one, two and “many.” As far as counting went, primitive humans needed to know these numbers to differentiate between scarcity and abundance, safety in numbers and isolation from the herd. Interestingly, zero is a recent discovery, since there is no point to counting something that is not there according to the primitive brain. Thus, the most important fraction, according to the brain, is a half. Our language has followed suit; one over three is a third and one over 93 is a ninety-third, but one over two is a half, not a second. Scientists in the early 20th century were not immune to this and adopted one-half as the significant fraction to measure radioactive decay.

What is the significance of the number 2.718? Where did that come from?

The number 2.718 is actually the first few digits of the transcendental number called “e”. Most people are familiar with another transcendental number, π. These numbers never repeat and cannot be solutions to algebraic equations. The value of e is 2.7182818284590……. To solve decay equations, a natural logarithm must be used to obtain the decay constant. Hence, e is sometimes called the natural number or natural base.

Why is e the value that it is? Where does it come from?

Actually, the world of finance first stumbled upon e. Imagine a person puts $100 into a savings account that earns 10% interest. If the interest is compounded once per year, then the person will end up with $110. But, what if the interest is compounded, meaning added throughout the year. This means that after 6 months, the account will be worth $105 (the bank pays only half the interest rate for only half of a year, so the account earns 5%, not 10%), but after the year is finished, the account will be worth $110.25, a full quarter more than the yearly interest. This is because during the last six months, the account earns interest on the interest for the first six months. This is called compound interest. The more times the interest is compounded, the better it is for the investor. Here is how the money would grow if the interest is compounded monthly, again assuming an initial investment of $100 and 10% per year:

These charts illustrate the affect of small changes over the course of time. The interest chart demonstrates the power of compounding interest where small incremental increases result in significant growth over time. Likewise, but in the opposite direction, radioactive decay results in significant loss of mass over time through small incremental changes.

MONTH	INTEREST EARNED	BALANCE
January	$0.83	$100.83
February	$0.84	$101.67
March	$0.85	$102.52
April	$0.85	$103.37
May	$0.86	$104.23
June	$0.87	$105.10
July	$0.88	$105.98
August	$0.88	$106.86
September	$0.89	$107.75
October	$0.90	$108.65
November	$0.91	$109.56
December	$0.91	$110.47
Total Interest Earned	$10.47	

Now, what happens if the bank were to be exceptionally generous and offer the best interest rate possible of 100%? Here is how much money will be available at different compounding schemes for $100:

INTEREST COMPOUNDED	BALANCE AT END OF ONE YEAR
Once (yearly)	$200.00
Twice (Semiannually)	$225.00
Four times (Quarterly)	$244.14
Twelve times (Monthly)	$261.30
52 times (Weekly)	$269.26
365 times (Daily)	$271.46
8760 times (Hourly)	$271.81
Infinite times (Constantly)	$100 x e

Once *e* was discovered, it was found in many formulas dealing with growth and decay found in nature, hence its nickname as the “natural” number.