Name: ___________________________ Section and Group:_____________ Date:_____________

Chemical Kinetics and the "Radium Girls"

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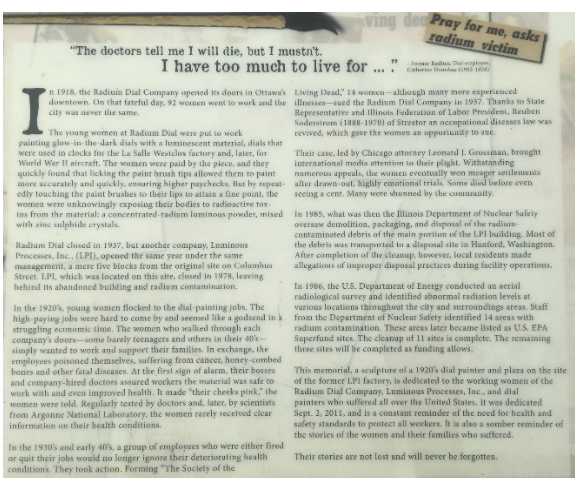
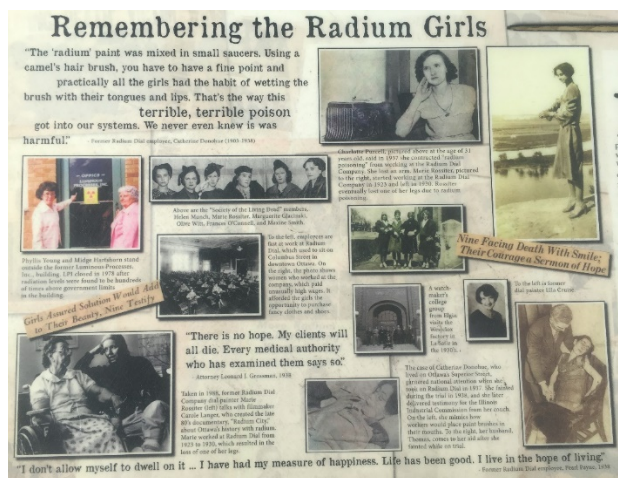
Learning Outcomes

- Describe the concept of half-life
- Calculate the amount of product produced in a nuclear decay reaction
- Interpret information in Safety Data Sheets to assess chemical hazards
- Describe historical events in the context of green chemistry and sustainability

Introduction

Located between Peoria and Chicago is the city of Ottawa, IL. This city is one of several locations around the world affected by contamination from radium-containing luminescent paint. In the 20th century, many workers at plants using this paint became ill or died from radium poisoning. In Ottawa, a statue has been erected to memorialize those afflicted by the poisoning. Visit the website describing this incident "The Radium Girls: An Illinois Tragedy" at https://www.nprillinois.org/post/radium-girls-illinois-tragedy.
See also the YouTube video shot at the memorial: https://youtu.be/n6LPXdtE7AE.





Photographs of the statue and plaques at the memorial site.

Now that you know a little bit of the history of this tragedy, delve a bit more into its chemistry. It can be useful to look at a Safety Data Sheet (SDS) when exploring the chemical properties and toxicity of a chemical. Look up the Radioactive Material Safety Data Sheet for radium-226 (see, for example: http://hep.man.ac.uk/safety/RadiationDataSheets/Radium_226.pdf). Safety data sheets for nonradioactive substances look somewhat different, but there are many similarities.

Name: ________________________ Section and Group:___________ Date:___________

Coin Flip Kinetics

What happened to the workers at Ottawa can be explored from the perspective of chemical kinetics, which explores the rates of chemical reactions. Other laboratory exercises will explore chemical kinetics further, but some simple kinetic principles can be illustrated with flipping coins. In this activity, you are studying the rate at which coins starting heads-up will flip to tails-up. You can write this with chemical reaction notation:

$$H \rightarrow T$$

Once the heads-up coin "reactant" goes to "tails-up" product, it is no longer flipped.

Starting with heads-up each time, flip a coin 64 times (or flip 64 coins all at once). Record the result of each flip in the Trial 1 table on the following pages as you go. Count and record the number of heads in Trial 1, which represents the first time interval in the reaction H → T. Divide the number of heads resulting from Trial 1 by the number of coins flipped in Trial 1 (64) to get the ratio of heads remaining and record that number.

For Trial 2, representing the second time interval, **only** flip the coin the number of times equal to the number of heads left from Trial 1. Record the result of each flip in the Trial 2 table on the following pages as you go. Count and record the number of heads in Trial 2, which represents the second time interval in the reaction H → T.
Divide the number of heads resulting from Trial 2 by the number of coins flipped in Trial 2 to get the ratio of heads remaining and record that number.

Repeat the procedure for Trial 2 for Trial 3, but you only flip the coin the number of times equal to the number of heads left from Trial 2. Proceed in the same fashion for Trials 4-6.

1) The probability of any flipped coin ending heads-up is 50% or 0.5. Which trials tended to give ratios closest to 0.5, those with many flips, or those with just a few flips? Explain why.

2) Hand-draw a graph below showing Trials 1, 2, 3, 4, 5, and 6 at equally spaced intervals on the x-axis and the number of heads at the **start** of each trial on the y-axis. Remember Trial 1 starts with 64 heads.

Name: ________________________ Section and Group:___________ Date:___________

Reminders: Start with heads for each flip
Write down the results of each trial as it occurs

Trial 1
Do 64 flips only for Trial 1

Flip	H or T	Flip	H or T
1		33	
2		34	
3		35	
4		36	
5		37	
6		38	
7		39	
8		40	
9		41	
10		42	
11		43	
12		44	
13		45	
14		46	
15		47	
16		48	
17		49	
18		50	
19		51	
20		52	
21		53	
22		54	
23		55	
24		56	
25		57	
26		58	
27		59	
28		60	
29		61	
30		62	
31		63	
32		64	

Trial 1 total heads =

ratio = heads after Trial 1 / heads before Trial 1 = ( ) / 64 =

Trial 2
flips = # heads from Trial 1

Flip	H or T	Flip	H or T
1		33	
2		34	
3		35	
4		36	
5		37	
6		38	
7		39	
8		40	
9		41	
10		42	
11		43	
12		44	
13		45	
14		46	
15		47	
16		48	
17		49	
18		50	
19		51	
20		52	
21		53	
22		54	
23		55	
24		56	
25		57	
26		58	
27		59	
28		60	
29		61	
30		62	
31		63	
32		64	

Trial 2 total heads =

heads after Trial 2 / heads before Trial 2 =

Trial 3
flips = # heads from Trial 2

Flip	H or T	Flip	H or T
1		33	
2		34	
3		35	
4		36	
5		37	
6		38	
7		39	
8		40	
9		41	
10		42	
11		43	
12		44	
13		45	
14		46	
15		47	
16		48	
17		49	
18		50	
19		51	
20		52	
21		53	
22		54	
23		55	
24		56	
25		57	
26		58	
27		59	
28		60	
29		61	
30		62	
31		63	
32		64	

Trial 3 total heads =

heads after Trial 3 / heads before Trial 3 =

Name: ________________________ Section and Group:___________ Date:___________

Reminders: Start with heads for each flip
Write down the results of each trial as it occurs

Trial 4
flips = # heads from Trial 3

Flip	H or T	Flip	H or T
1		33	
2		34	
3		35	
4		36	
5		37	
6		38	
7		39	
8		40	
9		41	
10		42	
11		43	
12		44	
13		45	
14		46	
15		47	
16		48	
17		49	
18		50	
19		51	
20		52	
21		53	
22		54	
23		55	
24		56	
25		57	
26		58	
27		59	
28		60	
29		61	
30		62	
31		63	
32		64	

Trial 4 total heads =

heads after Trial 4 / heads before Trial 4 =

Trial 5
flips = # heads from Trial 4

Flip	H or T	Flip	H or T
1		33	
2		34	
3		35	
4		36	
5		37	
6		38	
7		39	
8		40	
9		41	
10		42	
11		43	
12		44	
13		45	
14		46	
15		47	
16		48	
17		49	
18		50	
19		51	
20		52	
21		53	
22		54	
23		55	
24		56	
25		57	
26		58	
27		59	
28		60	
29		61	
30		62	
31		63	
32		64	

Trial 5 total heads =

heads after Trial 5 / heads before Trial 5 =

Trial 6
flips = # heads from Trial 5

Flip	H or T	Flip	H or T
1		33	
2		34	
3		35	
4		36	
5		37	
6		38	
7		39	
8		40	
9		41	
10		42	
11		43	
12		44	
13		45	
14		46	
15		47	
16		48	
17		49	
18		50	
19		51	
20		52	
21		53	
22		54	
23		55	
24		56	
25		57	
26		58	
27		59	
28		60	
29		61	
30		62	
31		63	
32		64	

Trial 6 total heads =

heads after Trial 6 / heads before Trial 6 =

Name: ___________________________ Section and Group:_____________ Date:_____________

Analysis

So, what does flipping coins have to do poisoning women painting watch dials? Read and answer the questions below to find out…

The trials in the coin flip activity represent intervals of time in the reaction H → T. Note that the number of coins that are heads-up roughly decreases by a factor of two from trial to trial. In chemistry, the time that it takes for the quantity of a reactant to decrease by a factor of two is called the half-life of the reaction. For some processes, the half-life changes as the reaction proceeds. For some processes, including those associated with radioactive decay, the half-life does not change over time. Therefore, the half-life of these processes (referred to as first-order processes) are a handy way of describing the rate of a chemical reaction. By making equal spacing between the trials in your graph, you have depicted a first order reaction.

1) You are likely familiar with glow-in-the-dark objects like stickers or toys. These often contain the compound zinc sulfide (with a little added copper). To activate the phosphorescence (glow) of the compound, it must be exposed to visible light or higher energy radiation. Turn off the light source, and the glow fades away. Make a rough estimate how long it takes the glow of a glow-in-the-dark object to fade completely away:

Assuming the fade of the glow of the zinc sulfide is first order (it is actually more complicated than that) give a rough estimate of the half-life of that fading process:

2) For devices that needed to glow a long time in the dark, like clock faces and instrument dials, a different approach was used. Radium salts were added to the zinc sulfide. Here, the radiation from the radium was used to constantly excite the zinc sulfide to make it glow all the time. The glow would only fade if the radium lost its radioactivity. Look up the half-life for the nuclear decay of radium-226 from the safety data sheet. How long does it take a sample of radium-226 to contain 1/8 the amount of radium that it originally contained? (show your work)

3) From the Safety Data Sheet and a Periodic Table, answer

- How many protons in a radium-226 **<u>ion</u>**?

- How many neutrons in a radium-226 **<u>ion</u>**?

- How many electrons in a radium-226 **<u>ion</u>**?

- In what group of the Periodic Table is radium found?

Name: ___________________________ Section and Group:_____________ Date:_____________

4) Much of the radiation produced by radium-226 is in the form of alpha particles, which each contain two protons and two neutrons. When a radium-226 nucleus loses an alpha particle, what radioactive isotope nucleus does it become?

Note the radiation burn in this radium sample holder.

5) From the Safety Data Sheet, what is the Critical Organ(s) in the body most impacted by ingestion of radium-226?

6) What element is commonly found in the Critical Organ(s) in the body that is in the same group in the Periodic Table as radium?

7) The element described in question #6 combines with phosphate and other ions in the human body. Radium can be taken up by the human body and can go to the same places as that common element. Apparently the human body is not very discriminating between those two ions. This similarity can be modeled by combining various cations with phosphate ions to look for the formation of phosphate salt precipitates. Combine small amounts of cation solutions and phosphate ion solutions in test tubes to complete the table below. A video featuring most of these potential reactions is located at https://youtu.be/G9gIu27i-AM. Predict whether or not radium ions will form a precipitate when combined with phosphate ions.

Cation combined with phosphate ions	Precipitate formation? (yes/no)
lead(II)	
ammonium	
magnesium	
barium	
strontium (including radioactive strontium-90)	
calcium	
potassium	
sodium	
lithium	
radium	prediction?

What types of ions form precipitates with phosphates (and can also accumulate in the body)?

Name: ________________________ Section and Group:___________ Date:___________

8) How was the radium in the paint of the factories ingested by the workers?

9) The half-life of radioactive decay processes cannot be altered by traditional chemical methods. Therefore, what is the half-life of radium-226 accumulated in the human body? In factory sites contaminated with radium?

10) The efforts to find a sort of eternal light in the use of radium-containing paint in the last century led to problems still being dealt with in this century. What happened in Ottawa and elsewhere can be connected to the growing field of Green Chemistry and to even larger issues of sustainability.

Please examine the following sites describing the 12 Principles of Green Chemistry:
https://www.compoundchem.com/2015/09/24/green-chemistry/
and the 17 United Nations Sustainable Development Goals
https://sdgs.un.org/#goal_section

Note: You will **not** need to memorize these principles and goals for this course.

Please select one Principle of Green Chemistry and one Sustainable Development Goal and describe in a paragraph how the use of radium-containing paint a century ago would be in conflict with the principle and the goal you selected.