SI Chemistry - Full Discipline Demo

Nuclear Chemistry

Final Report - Answer Guide

Institution	Science Interactive University
Session	SI Chemistry - Full Discipline Demo
Course	SI Chemistry - Full Discipline Demo
Instructor	Sales SI Demo

Test Your Knowledge

Match each term with the best description.

- Alpha decay
- Half-life
- Isotope
- Positron
- Radioactivity

Description	
Amount of time it takes for 50% of the radioactive parent isotope to decay to the daughter isotopes	1
A positively charged, antimatter counterpart to an electron	2
The decay of an unstable atom to a stable state	3
Emission of a helium nucleus from the radioactive parent	4
Atoms of the same element with different atomic masses	5

Correct answers:

1 Half-life 2 Positron 3 Radioactivity 4 Alpha decay 5 Isotope

Match each radioactive decay type with its respective emission particle.

Electron

Helium nucleus

Positron

α	1
β^-	2
β^+	3

Correct answers:

1 Helium nucleus 2 Electron 3 Positron

Exploration

Isotopes are atoms of the same atomic mass but different number of protons.

- True
- False ✔

During _____ decay, a proton is converted into a neutron through the emission of a positron.

- α
- β^-
- β^+ ✔
- γ

Alpha decay occurs with the emission of _____.

- 1 proton and 1 neutron
- 2 protons and 2 neutrons ✔
- 2 electrons and 2 protons
- 1 electron and 1 neutron

The decay product that results from radioactive decay is always a stable daughter isotope.

- True
- False ✔

Radiometric isotopes are used to _____.

- power homes
- treat human illness
- provide insight into Earth processes
- All of the above ✔

Exercise 1

How did the predicted values compare to the actual values in Data Table 1 and Graph 1? Explain sources of variability in the outcomes of this experiment.

Student answers may vary somewhat based on the outcomes of the coin tosses. However, the number of parent atoms remaining after each half-life should be reasonably similar between the simulated and predicted. The actual number of parent atoms remaining may deviate from the predicted as a result of the coin tosses being a probability-based scenario where a 50% decay with each half-life is not guaranteed.

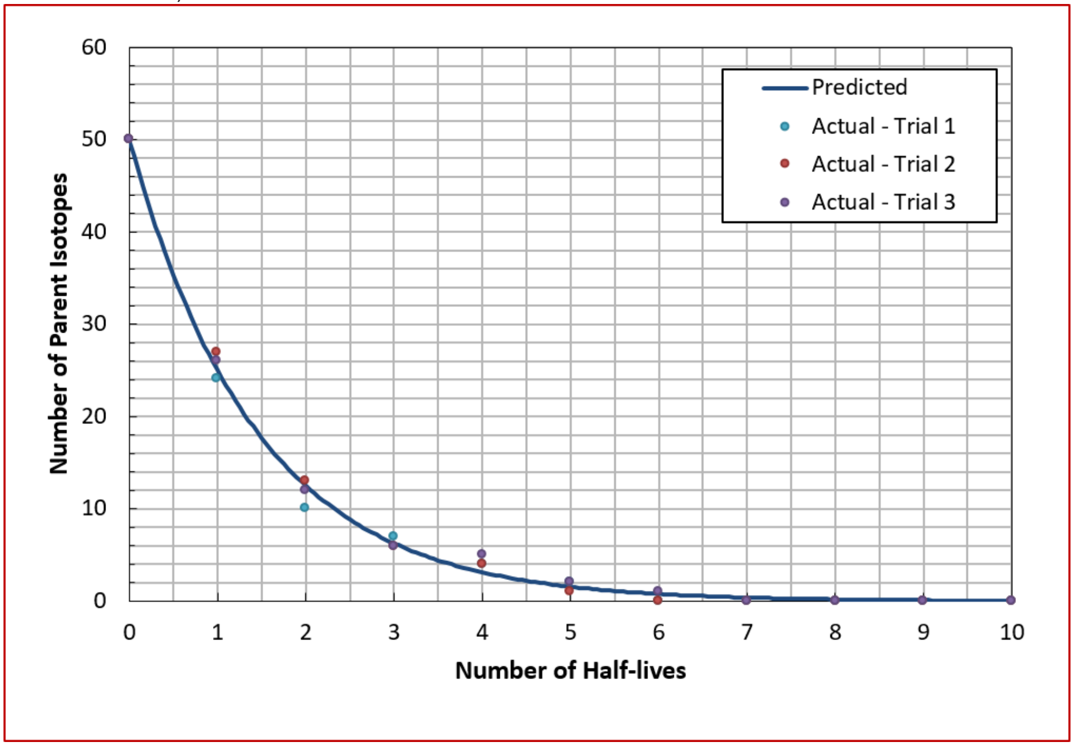
What would Graph 1 look like if only 5 pennies were used in this experiment? What if 10,000 pennies were used? Based on your responses, what might be inferred about the relationship of half-life and sample size?

A small sample size (starting with only 5 parent atoms) would likely result in major discrepancy, and could result in a graph that appears linear instead of a smooth curve. Using a larger sample size (such as starting with 10,000 parent atoms) would make any difference in the trends on the graph less common and indistinguishable when plotted, and result in a similar curve as shown in **Graph 1**. This means that the key concept for half-lives is that it works best with larger sample sizes and does not work well with small sample sizes.

Data Table 1: Predicted vs. Observed Simulated Parent Isotopes
(SAMPLE ANSWER BELOW)

Number of Half-lives	Predicted # of Parents	Actual # of Parents		
		Trial 1	Trial 2	Trial 3
0	50	50	50	50
1	25	24	27	26
2	12.5	10	13	12
3	6.25	7	6	6
4	3.13	4	4	5
5	1.56	2	1	2
6	0.78	0	0	1
7	0.39	0	0	0
8	0.20	0	0	0
9	0.10	0	0	0
10	0.05	0	0	0

Graph 1: Parent Isotopes for Each Half-life
(SAMPLE ANSWER BELOW)



Exercise 2

Explain the difference between alpha, beta, and gamma decay.

Alpha decay occurs with the emission of 2 protons and 2 neutrons, resulting in a slow moving alpha particle that can be stopped by clothes and human skin.
Beta decay occurs when there is an imbalance in the number of protons and neutrons in the nucleus of an atom. If too many neutrons are present, one neutron is converted into a proton and a high-energy electron is ejected. If too many protons are present, one proton is converted into a neutron through the emission of a positron.
Gamma decay occurs when unstable atomic nuclei emit electromagnetic radiation in the form of gamma rays. Gamma radiation is a high-energy ionizing radiation that does not alone change the mass or charge of an atom.

What percentage of daughter isotopes would be present after 5 half-lives have passed for ^{87}Rb?

After 5 half-lives have passed, 96.875% of daughter isotopes (3.125% of parent isotopes) would remain.

Use Graph 2 to determine the percentage of parent isotopes that would remain after 2 billion years have passed.

For the decay of ^{87}Rb to ^{87}Sr, 97.2% of the parent isotope would remain after 2 billion years. Answers may vary depending on whether the graph was hand-drawn or produced in Microsoft Excel; students should estimate between 95-99% of the parent isotopes remain.

List the uses for ^{87}Rb.

^{87}Rb has been used extensively in dating rocks, as a frequency standard in high-precision timing equipment such as GPS receivers, the production of Bose-Einstein condensates, and laser cooling.

Data Table 2: Radioactive Decay Research

(SAMPLE ANSWER BELOW)

Radiogenic Isotope	Rubidium-87
Daughter Isotope(s)	Strontium-87
Decay Type	Beta negative (B-) decay
Half-life	49.23 billion years
Is the daughter isotope stable?	yes
Source(s)	Research on radioactive isotopes was conducted at: http://www.colorado.edu/geolsci/Resources/WUSTectonics/CRFB/strontium.html and https://www.webelements.com/rubidium/isotopes.html

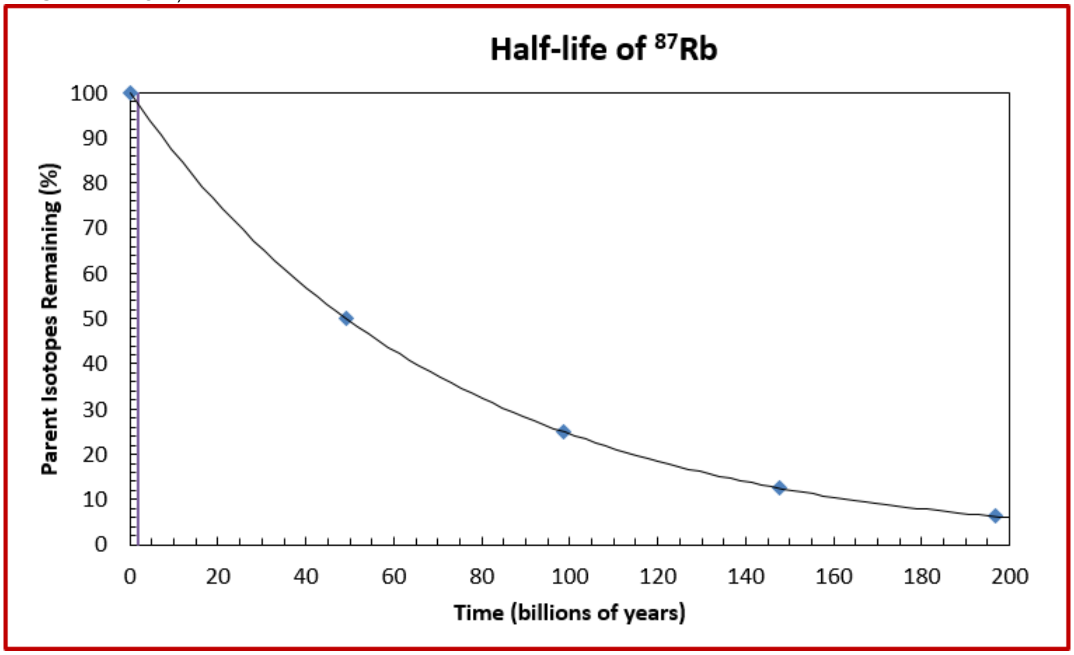
Data Table 3: Parent Isotopes over Predicted Time

(SAMPLE ANSWER BELOW)

Half-life	Time (billions of years)	Parent Isotopes Remaining (%)
0	0	100
1	49.23	50
2	98.46	25
3	147.69	12.5
4	196.92	6.25

Graph 2: Percentage of Parent Isotopes over Time

(SAMPLE ANSWER BELOW)



Competency Review

Isotopes are atoms of the same element with different numbers of protons.

- True
- False ✔

During _____ decay, a proton is converted to a neutron through the emission of a positron.

- alpha
- beta ✔
- gamma

The emission of a(n) _____ through the radioactive decay of a nucleus always leads to a change in the atomic number of the atom.

- alpha particle
- positron
- electron
- All of the above ✔

The notation β^- denotes the conversion of a(n) _____ to a proton through the emission of a high-energy _____.

- electron; gamma radiation
- neutron; electron ✔
- neutron; positron
- positron; electron

A half-life is the average time it takes for 50% of a radioactive parent isotope to decay into its respective daughter isotope.

- True ✔
- False

_____ is the stable daughter isotope produced from the decay chain for ^{212}Pb.

- ^{208}Tl
- ^{212}Bi
- ^{208}Pb ✔
- ^{212}Pb

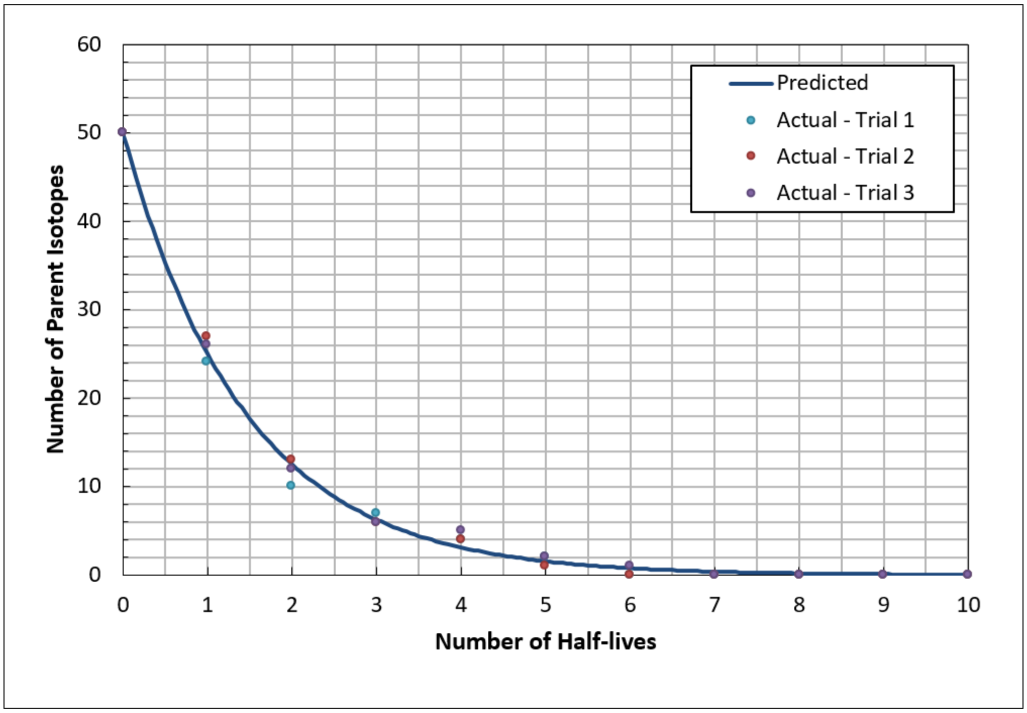
Because of the long half-life of ^{238}U, it is ideal for dating the formation of the Earth and ancient mountain belts.

- True ✔
- False

Doctors use _____ to image soft tissues, such as organs, in the body.

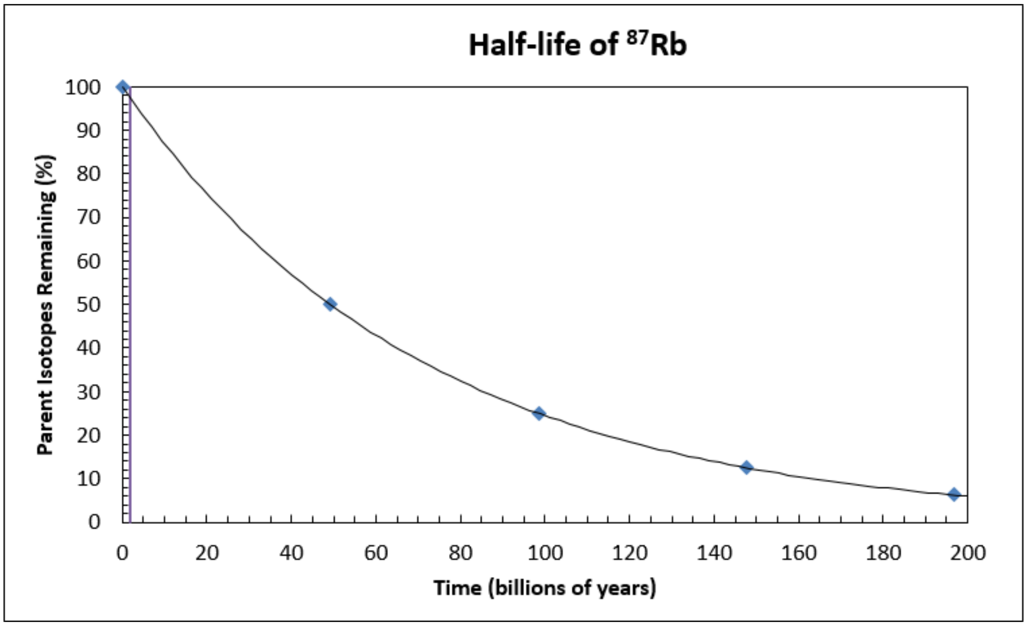
- X-rays
- alpha particles
- beta radiation
- gamma radiation ✔

Based on the graph, it is predicted that there will be _____ parent isotopes at the second half-life.



- 0
- 12 ✔
- 18
- 26

Based on the graph, approximately _____ of the parent isotopes remain after 40 billion years.



- 22%
- 40%
- 58% ✔
- 70%

Extension Questions

Which of the following scenarios would be optimal for obtaining a date from radioactive decay using these isotopes: ^{87}Rb, ^{147}Sm, ^{235}U, ^{238}U, ^{40}K, or ^{14}C? There may be more than one answer that is appropriate. Explain your reasoning for why the remaining scenario(s) would be inappropriate/impossible to use that particular isotope. Answers should include a discussion on usable ages for each system and whether the necessary isotopes would be found in the material to be dated.

a. A meteorite that formed early in the formation of the solar system.
b. A rock formed through a mountain building event around 420 million years ago.
c. Volcanic ash from an eruption 60 million years ago.
d. An earthquake scarp that formed along the San Andreas Fault 50 years ago.
e. An Incan archaeological dig site in the highlands of Peru.
f. A tree from a forest in England that is suspected to be the oldest in the British Isles.

(SAMPLE ANSWER BELOW)

Answers should include the practical range in age dates where daughter/parent isotopes are in detectable/measurable abundance. For example, the low half-life of ^{14}C (5,730 years) would not be useful for dating a billion year old rock for there would be essentially zero parent isotopes remaining. Likewise, isotopes with very long half-lives (e.g., ^{238}U with a half-life of 4.47 billion years) would not be useful for dating very young events (“recent” volcanic eruptions, earthquake scarp, etc.) because not enough time has passed to allow a detectable amount of daughter material to accumulate. Dating of the earthquake scarp does not have to be mentioned for any of the decay schemes listed for Exercise 2, however it may be possible if a felled tree was dated in the escarpment relative to undisturbed trees in the surrounding area. This was included to get the students to think about practical applications and scenarios where they may or may not work. Lastly, the student should say something about whether the isotopes would even be found in the scenario listed. For example, you wouldn't expect to have enough C in a meteorite or metamorphic rock to use ^{14}C; likewise, there wouldn't be U, Sm, Rb, or K in enough abundance to date trees. For the archaeological site, dating stone tools would not be useful for determining the age of the site, for it would give the geologic age of the tools. Rather coal from fires and discarded organics would be dated using ^{14}C.