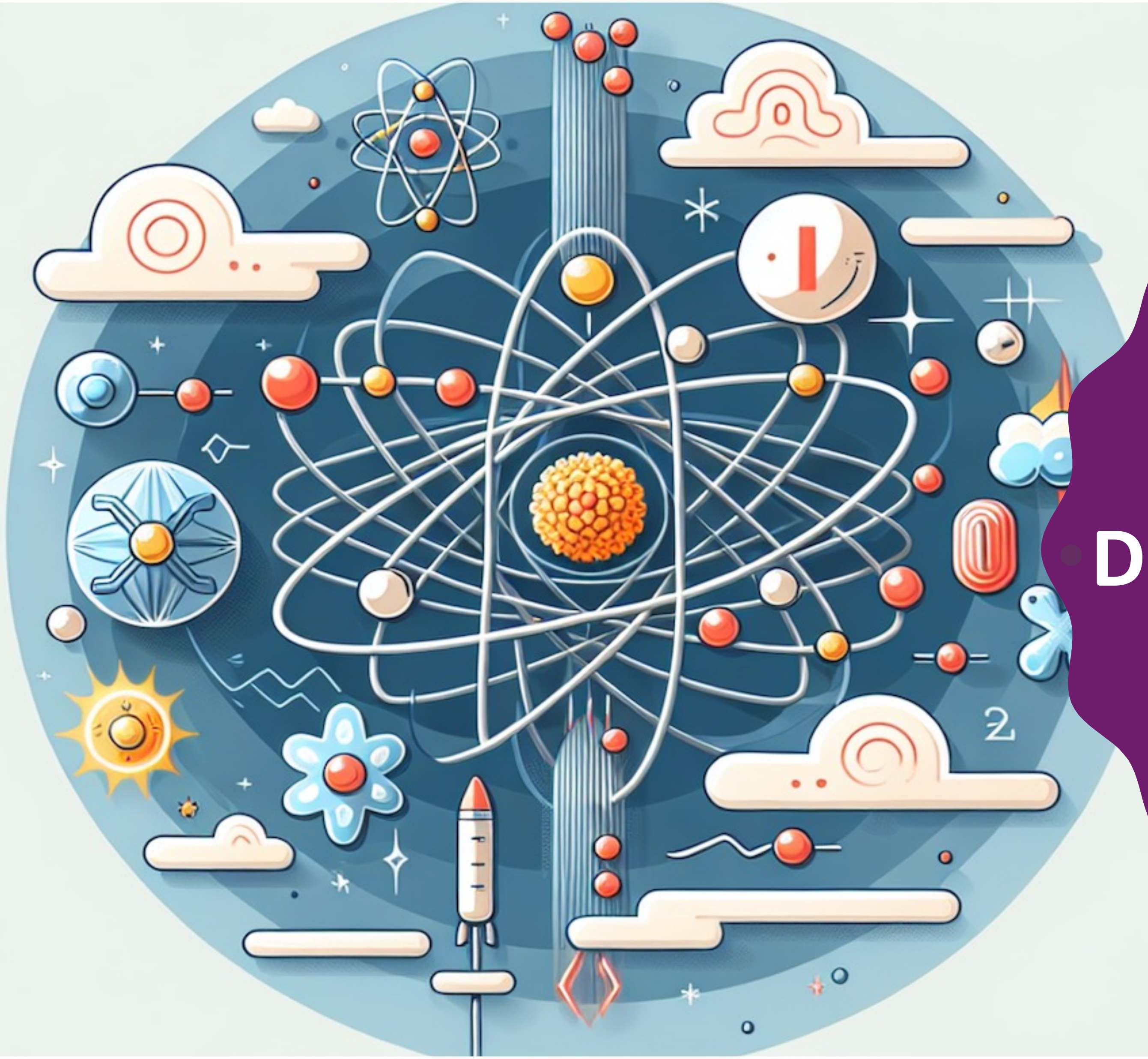
SPACED RETRIEVAL / INTERLEAVING

RETRIEVAL

Explain how an overabundance of protons in the nucleus can lead to radioactive decay. (4 marks)



LESSON 4

Decay Equations and Decay Series

LEARNING OBJECTIVES

By the end of the next two lessons, you should be able to:

- ❑ **Describe** spontaneous alpha, beta positive and beta negative decay using decay equations.
- ❑ **Solve** problems involving balancing nuclear equations.
- ❑ **Explain** how a radionuclide will, through a series of spontaneous decays, become a stable nuclide.

TASK / ACTIVITY

DECAY TYPES

The isotope gold-197 $\left({}^{197}_{79}\mathrm{Au}\right)$ is stable but the isotope gold-199 ${}^{199}_{79}\mathrm{Au}$ is not.

A nucleus of ${}^{199}_{79}\mathrm{Au}$ decays to a nucleus of ${}^{199}_{80}\mathrm{Hg}$. State the **two** particles, other than γ-photon, emitted in this decay.

LESSON CONTENT

DECAY EQUATIONS – GENERAL FORM

	Alpha Decay	Beta +	Beta -
Process	Large quantity of mass is ejected from the nucleus.	A proton turns into a neutron.	A neutron turns into a proton.
Product	Alpha Particle and energy ($^{4}_{2}\mathrm{He} + \gamma$)	Positron, neutrino and energy ($^{0}_{1}\mathrm{e} + \nu_e + \gamma$)	Electron, anti-neutrino and energy ($_{-1}^{\ 0}\mathrm{e} + \check{\nu}_e + \gamma$)
Result	Decrease in atomic number by 2, and atomic mass by 4.	Decrease in atomic number by 1. No change to atomic mass.	Increase in atomic number by 1. No change in atomic mass.
Equation	$^{A}_{Z}\mathrm{X} \rightarrow {}^{A-4}_{Z-2}\mathrm{Y} + {}^{4}_{2}\mathrm{He} + \gamma$	$^{A}_{Z}X \rightarrow {}_{Z-1}^{\ \ \ A}Y + {}_{+1}^{\ \ 0}e + \nu_e + \gamma$	$^{A}_{Z}X \rightarrow {}_{Z+1}^{\ \ \ A}Y + {}_{-1}^{\ \ 0}e + \bar{\nu}_e + \gamma$

LESSON CONTENT

BALANCING NUCLEAR EQUATIONS

This is different to balancing chemical equations in Chemistry.

When balancing nuclear decay equations, we are concerned with making sure that:

$$\sum A_{reactants} = \sum A_{products}$$

and

$$\sum Z_{reactants} = \sum Z_{products}$$

(remember: A = atomic mass number & Z = atomic number)

Take the example of Uranium-238 decaying into Thorium:

$$^{238}_{92}\mathrm{U} \rightarrow {}^{234}_{90}\mathrm{Th} + {}^{4}_{2}\mathrm{He} + \gamma$$

This equation is balanced because the mass number of the left equals the mass number on the right:

$$238 = 234 + 4$$

AND the atomic number on the left equals the atomic number on the right:

$$92 = 90 + 2$$

Questions regarding the balancing of nuclear equations will often give you an incomplete nuclear equation and ask you to identify the unknown isotope

COMPLETE DECAY EQUATIONS

Complete decay equations represent **all** particles that are produced during the decay - each of these particles serve a purpose.

When asked to construct decay equations you must represent the energy released (γ), and the neutrinos produced (ν_e and $\check{\nu}_e$), if applicable.

Representing the Energy

$$\gamma$$

You can represent energy with + γ
or simply write + energy

Representing all Particles

${}^{4}_{2}\mathrm{He}$ for alpha particle
${}^{0}_{-1}e$ for electron
${}^{0}_{1}e$ for positron
ν_e for neutrino
$\bar{\nu}_e$ for anti-neutrino

Remember: when asked to construct a decay equation, you must include these particles where relevant.

INFORMATION

Not examinable

WHAT DO YOU MEAN γ AND ν_e?

Complete decay equations represent **all** particles that are produced during the decay - each of these particles serve a purpose. When asked to construct decay equations you must represent the energy released (γ), and the neutrinos produced (ν_e and $\check{\nu}_e$), if applicable.

Representing the Energy

All radioactive processes release energy – they would not occur at all if they didn't. This energy is released via packets of electromagnetic radiation (gamma radiation) which we represent using the gamma symbol - γ

Remember: when asked to construct a decay equation, you must include these particles where relevant.

Representing Particle Conservation

All beta decay results in a new matter (electron) or antimatter (positron) particle being created. This ensures conservation of charge during the process. In addition to charge, conservation of matter particles is also an important law of the universe. This is the role the (electron) neutrinos play in beta decay, represented using the nu symbol - ν_e.

$$\underbrace{{}^{1}_{0}\mathrm{n} \rightarrow {}^{1}_{1}\mathrm{p}}_{\text{1 matter nucleon on both sides – balanced ✓}} + \underbrace{{}^{0}_{-1}e + \check{\nu}_e}_{\text{NEW matter particle produced – corresponding anti-neutrino also produced. This “balances” the amount of matter \& antimatter – balanced ✓}} + \gamma$$

$$\underbrace{{}^{1}_{1}\mathrm{p} \rightarrow {}^{1}_{0}\mathrm{n}}_{\text{1 matter nucleon on both sides – balanced ✓}} + \underbrace{{}^{0}_{+1}e + \nu_e}_{\text{NEW antimatter particle produced – corresponding matter neutrino also produced. This “balances” the amount of matter \& antimatter – balanced ✓}} + \gamma$$

We will expand on the "why" behind these neutrinos in Unit 4 – for now know they are chargeless particles with an atomic mass of 0, so they are able to conserve the number of matter/antimatter particles without affecting the conservation of charge.

DEMO / WORKED SOLUTIONS

BALANCING EXAMPLES - ALPHA

Alpha Decay:

Determine the unknown isotope in the nuclear equation

$$^{247}_{96}\mathrm{Cm} \rightarrow \ ? \ + ^{4}_{2}\mathrm{He} + \gamma$$

BALANCING – BETA EXAMPLES

$${}^{230}_{91}\mathrm{Pa} \rightarrow ? \ + {}^{0}_{+1}e$$

$$? \rightarrow \ {}^{10}_{5}\mathrm{B} + {}^{0}_{+1}e$$

$${}^{14}_{6}\mathrm{C} \rightarrow ? + {}^{0}_{-1}e$$

$$? \rightarrow {}^{228}_{90}\mathrm{Th} + {}^{0}_{-1}e$$

TASK / ACTIVITY

YOU TRY – BALANCING EQUATIONS

5 minutes

1. Radium-223 emits an alpha particle during decay

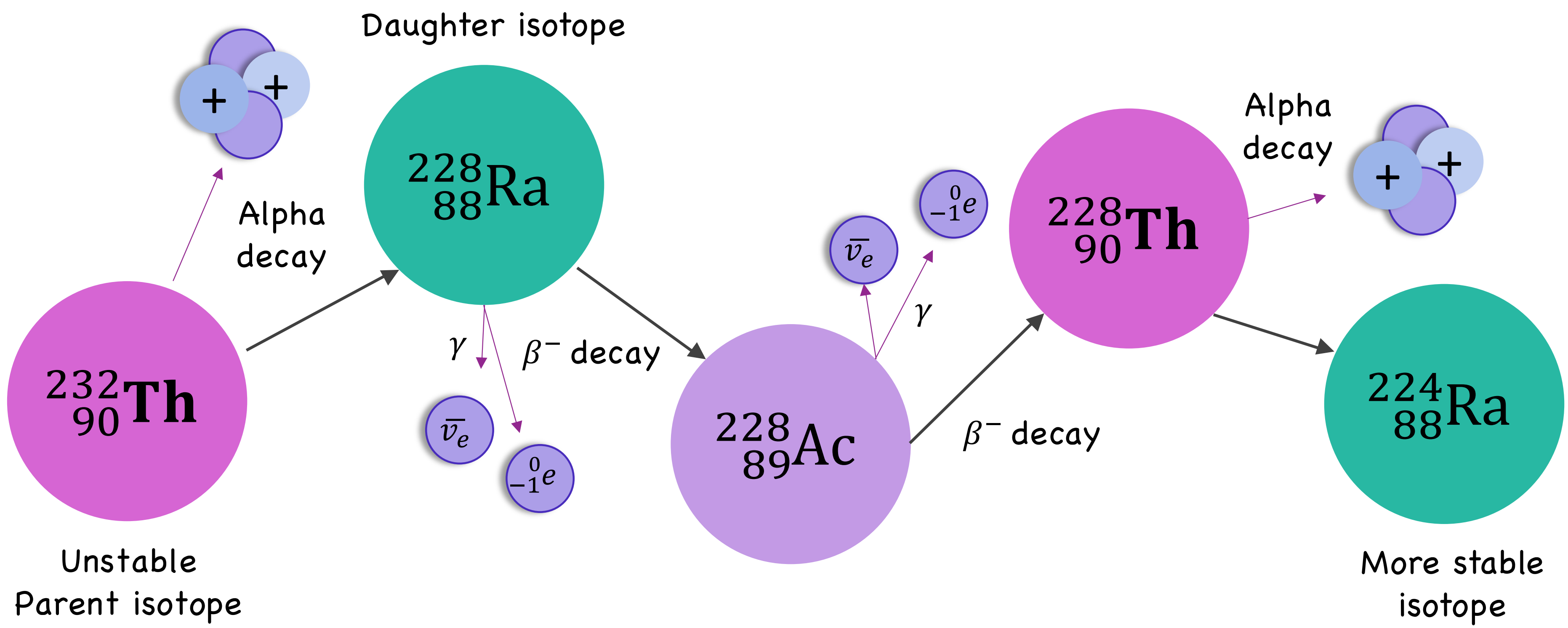
2. Carbon-14 undergoes a beta negative decay

3. Bromine-78 undergoes a beta positive decay

LESSON CONTENT

DECAY SERIES

A **decay series** is a **sequence** of nuclides formed by **successive radioactive decays** until a stable decay product, the end product, is formed.



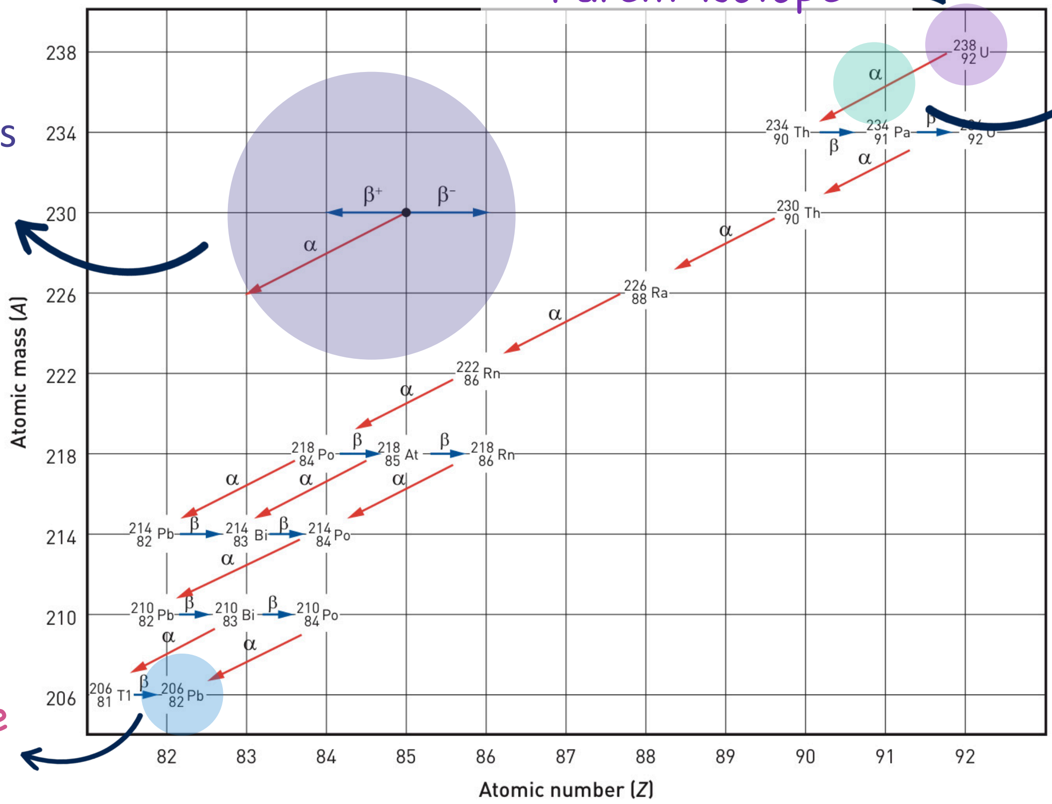
DECAY SERIES GRAPH

To keep track of the decay series, scientists use a **graph** with the atomic symbols.

Unstable
Parent isotope

Decay type

The **length** and **direction** of the arrows indicate changes in atomic mass (A) and atomic number (Z).



Note: Gamma radiation does not involve transmutation therefore it can't be represented on the graph.

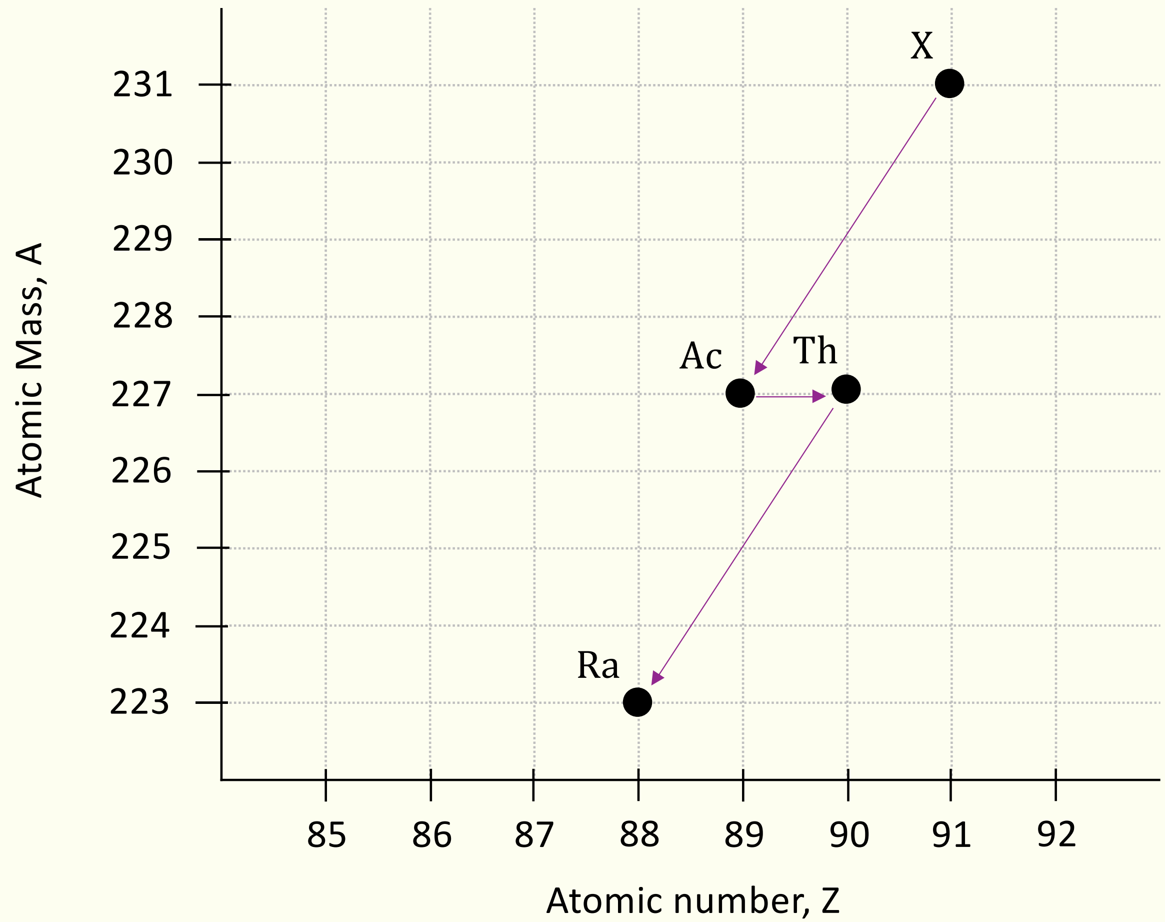
Stable, end isotope

DEMO / WORKED SOLUTIONS

WORKED EXAMPLE

Analyse the graph and answer the following questions:

1. Identify isotope X, giving your answer in the form ${}^{A}_{Z}X$
2. Identify the type of decay that occurs between Ac → Th. Justify your response.
3. Determine the decay equation for the third reaction in the series.



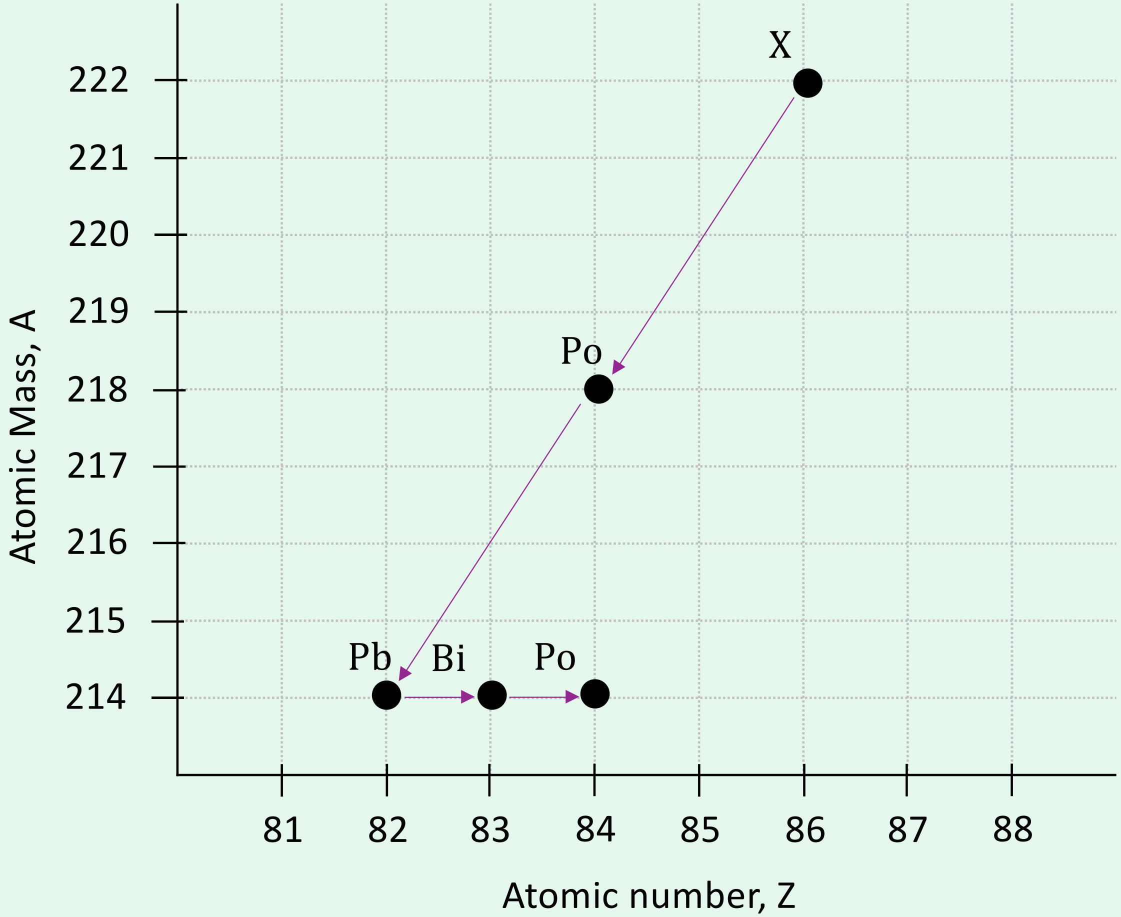
TASK / ACTIVITY

YOU TRY

Analyse the graph showing the part of the series decay of uranium-238 to lead-206.

1. Identify isotope X, giving your answer in the form ${}^{A}_{Z}X$

2. Determine the decay equation for Bi→Po.



TASK / ACTIVITY

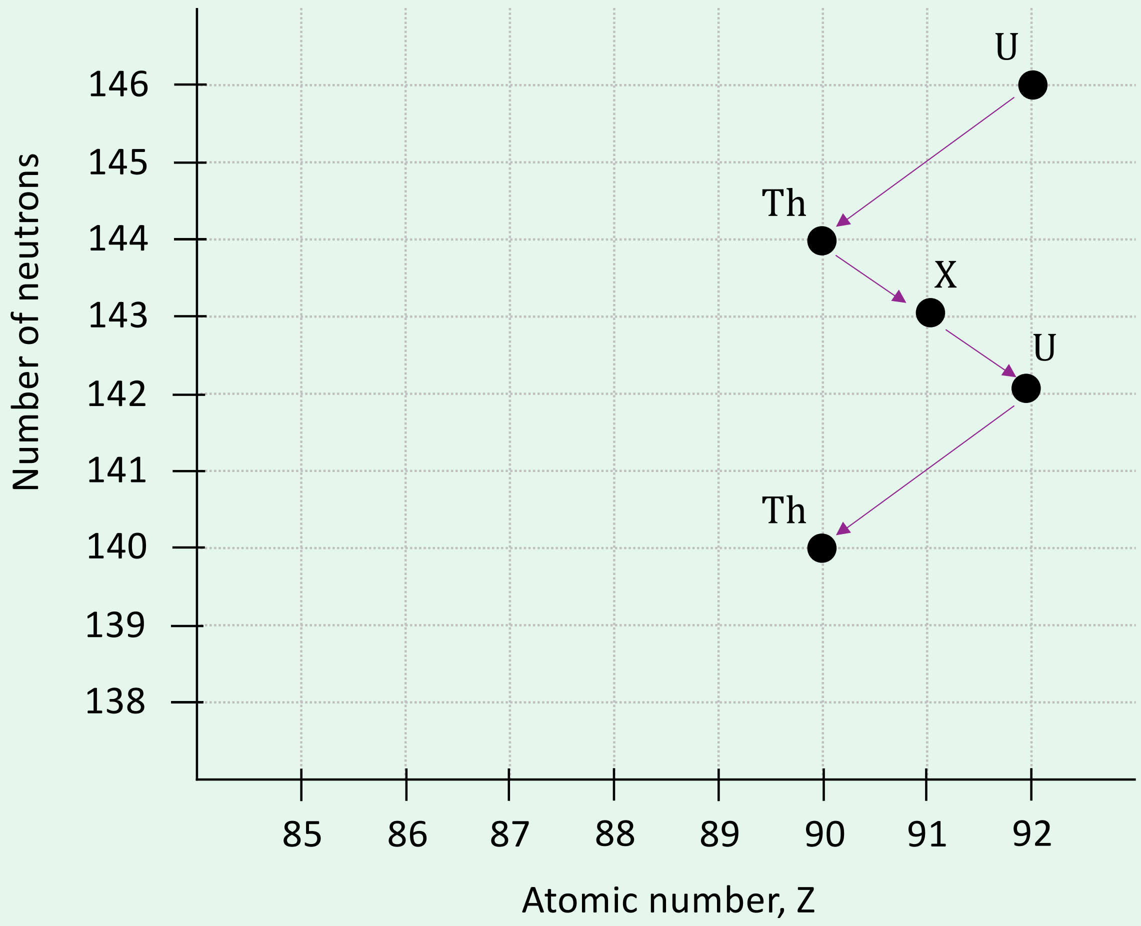
YOU TRY

Analyse the graph showing the partial decay series of uranium-238 to lead-206.

1. Identify isotope X, giving your answer in the form ${}^{A}_{Z}X$

2. Identify the type of decay that occurs in the first decay chain.

3. Determine the decay equation for U-234 →Th-230.



RECOMMENDED / WATCH

RECOMMENDED WATCH

MUST WATCH. This video summarises the content we've learned about different types of nuclear decay, including chain of decay equations and explain how to read a graph of a decay series.

Atomi video – Physics: Decay Series (7:20)
https://www.youtube.com/watch?v=jpAANAetuMQ

Unit 1 Topic 2 – Nuclear Physics

LEARNING OBJECTIVES

Can you:

✓**Describe** alpha, beta positive, beta negative and gamma radiation, including the properties of penetrating ability, charge, mass and ionisation ability.

✓**Explain** how an excess of mass, protons or neutrons in a nucleus can result in alpha, beta positive, beta negative.

✓**Describe** spontaneous alpha, beta positive and beta negative decay using decay equations.

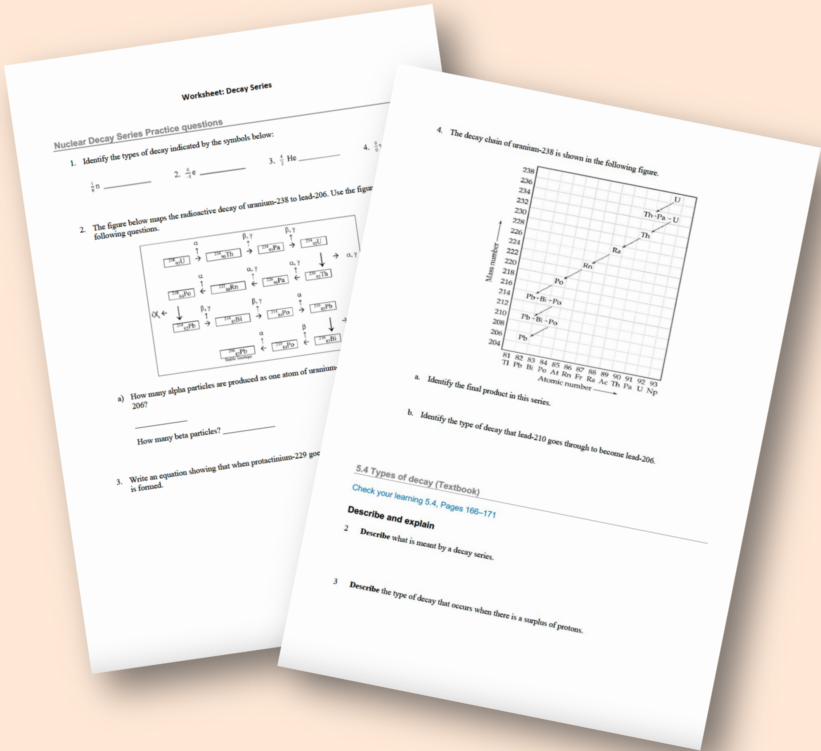
✓**Solve** problems involving balancing nuclear equations.

✓**Explain** how a radionuclide will, through a series of spontaneous decays, become a stable nuclide.

AFTER CLASS

HOMEWORK

1. Complete Worksheet – WS 1.2.3 Decay Series



RECOMMENDED / WATCH

STILL WOBBLY?

1. Polonium-218 decays by emitting an alpha particle followed by a gamma ray. The nuclear equation of the alpha decay is:

$$^{218}_{84}Po \rightarrow X + {}^{4}_{2}\alpha + energy$$

Determine the atomic number and mass number of X, and then use the periodic table to identify the element.

2. Determine the unknown particle or nuclei in the following incomplete reaction and identify the type of decay that is occurring.

$$^{35}_{16}S \rightarrow {}^{35}_{17}Cl + X_1 + X_2 + energy$$

3. Oxford textbook 5.2, 5.5 & 5.6

4. [Khan Academy Tutorial Video]