

Nuclear Equations

Mark Scheme



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1. Just like chemical equations show us how atoms rearrange in a chemical reaction, nuclear equations show us how the nucleus of an atom changes during radioactive decay.

For each of the following questions **circle** the letter of the correct answer.

- a) Uranium-238 ($^{238}_{92}\text{U}$) undergoes alpha decay to become an isotope of Thorium (Th).

What are the mass number and atomic number of the Thorium nucleus produced?

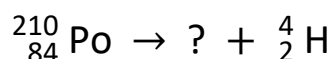
C – is the only correct answer.	1 mark
	Total: 1 mark

- b) Carbon-14 ($^{14}_6\text{C}$) decays into Nitrogen-14 ($^{14}_7\text{N}$) by emitting a beta particle.

Which symbol correctly represents a beta particle in a nuclear equation?

B – is the only correct answer.	1 mark
	Total: 1 mark

- c) Look at the incomplete nuclear equation below for the decay of Polonium-210:



Which isotope correctly fills in the missing gap to balance the equation?

A – is the only correct answer.	1 mark
	Total: 1 mark

- d) A highly excited nucleus of Cobalt-60 ($^{60}_{27}\text{Co}$) emits a gamma ray.

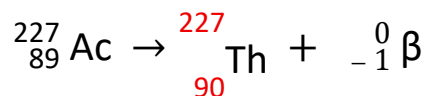
What happens to the mass number and the atomic number of the nucleus after this emission?

D – is the only correct answer.	1 mark
	Total: 1 mark

(Total for Question 1 is 4 marks)

2. Actinium-227 ($^{227}_{89}\text{Ac}$) is an unstable, radioactive isotope.
Actinium-227 decays to form an isotope of Thorium (Th).

a) Complete the incomplete nuclear equation below for this decay.



Mass number (top box): 227	1 mark
Atomic number (bottom box): 90	1 mark
	Total: 2 marks

b) Identify the type of decay that Actinium-227 undergoes.

Beta / β decay	1 mark
	Total: 1 mark

The Thorium nucleus produced in part (a) is also unstable.

It decays by emitting an **alpha** particle to form an isotope of Radium (Ra).

c) Write the fully balanced **nuclear equation** for this decay.



Award 1 mark for each correct reactant.	1 mark
Award 1 mark for each correct product (Ra)	1 mark
Award 1 mark for each correct product (He)	1 mark
	Total: 3 marks

d) Following radioactive decay, a nucleus will often emit gamma radiation to release excess energy.

Explain why the emission of a gamma ray does not change the mass number or the atomic number of the nucleus.

An explanation to include:	
Gamma is an electromagnetic wave / radiation / not a particle.	1 mark
It has no mass AND no charge.	1 mark
Accept: it contains no protons or neutrons" for the second mark.	
	Total: 2 marks

(Total for Question 2 is 8 marks)

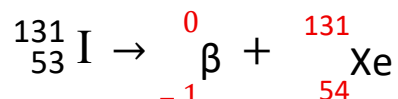
3. Iodine-131 ($^{131}_{53}\text{I}$) is radioactive. It has a half-life of 8 days.

a) State the composition of the nucleus of iodine-131.

53 protons	1 mark
78 neutrons	1 mark
	Total: 2 marks

Iodine-131 decays by β -decay to an isotope of xenon, Xe.

b) Complete the equation for the decay of iodine-131. —



Award 1 mark for the correct beta numbers.	1 mark
Award 1 mark for the correct Xe mass number.	1 mark
Award 1 mark for the correct Xe atomic number.	1 mark
	Total: 3 marks

The count rate from a sample of iodine-131 is 480 counts/s.

c) Predict the count rate from the sample after 24 days.

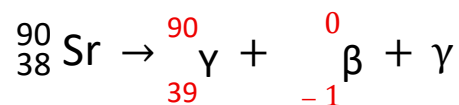
Number of half-lives = 3 (or showing $24 / 8 = 3$)	1 mark
Final count rate = 60	1 mark
	Total: 2 marks

d) State **two** of the social, economic or environmental issues involved in the storage of radioactive materials with very long half-lives.

Any two from:	
- Risk of leaks/contamination into groundwater or soil. - Harm/mutation to local wildlife or ecosystems. - High cost of building secure storage facilities (e.g., deep geological repositories). High cost to maintain security/monitor the site over thousands of years. - Public fear/opposition to having nuclear waste stored near their homes. - Danger to workers transporting or managing the waste.	
	Total: 2 marks

(Total for Question 3 is 9 marks)

4. The isotope strontium-90 ($^{90}_{38}\text{Sr}$) is radioactive.
- a) Strontium-90 decays to an isotope of yttrium (Y).
- i. Complete the equation for this decay.



Award 1 mark for correct Y mass number.	1 mark
Award 1 mark for correct Y atomic number.	1 mark
Award 1 mark for correct Beta numbers.	1 mark
	Total: 3 marks

- ii. Identify the types of radioactive decay that are shown by the equation above.

Beta / β	1 mark
Gamma / γ	1 mark
	Total: 2 marks

- iii. Explain why this γ -emission does not affect the numbers in the equation in (a)(i).

An explanation to include:	
Gamma radiation is an electromagnetic wave / has no mass.	1 mark
Accept: 1 mark for mentioning lack of mass/it being a wave.	
It has no charge / consists of no protons or neutrons.	1 mark
Accept: 1 mark for mentioning lack of charge/particles.	
	Total: 2 marks

- iv. Suggest **one** reason why a nucleus of strontium-90 is unstable.

It has an imbalance of protons and neutrons.	1 mark
Accept: wrong ratio of protons to neutrons, too many neutrons, or it has excess energy.	
	Total: 2 marks

- b) Strontium-90 is often produced in nuclear reactors alongside heavier radioactive isotopes, such as Plutonium-239 ($^{239}_{94}\text{Pu}$).

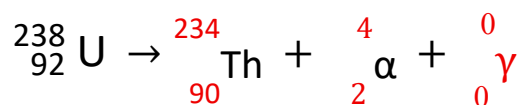


Award 1 mark for the correct reactant.	1 mark
Award 1 mark for the correct uranium product.	1 mark
Award 1 mark for the correct helium product.	1 mark
	Total: 3 marks

(Total for Question 4 is 11 marks)

5. Uranium-238 ($^{238}_{92}\text{U}$) is a naturally occurring radioactive isotope that undergoes a long series of decays to eventually become a stable atom.

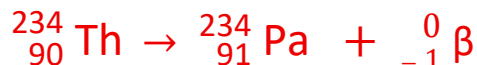
a) Complete the nuclear equation for this decay.



Award 1 mark for both correct numbers for Thorium. Top box: 234 AND bottom box: 90	1 mark
Alpha (α): top box: 4 AND bottom box: 2	1 mark
Award 1 mark for the correct third particle numbers: Top box 0 AND bottom box 0	1 mark
Award 1 mark for the third particle symbol: γ or written gamma.	1 mark
	Total: 4 marks

- b) The Thorium nucleus produced in part (a) is also unstable. It decays into Protactinium (Pa) by emitting a beta (β) particle.

Write the fully balanced nuclear equation for this decay.



Award 1 mark for the correct reactant mass number and atomic number.	1 mark
Award 1 mark for the correct product mass number and atomic number.	1 mark
Award 1 mark for the correct numbers on the beta particle.	1 mark
	Total: 3 marks

- c) Later in the decay chain, a nucleus emits one alpha particle, followed immediately by two beta particles.

A student states: "After these three decays, the nucleus will be an isotope of the original element."

Explain why the student is correct. You may use numbers to support your answer.

An explanation to include the following:	
Emitting an alpha particle decreases the atomic/proton number by 2.	1 mark
Emitting two beta particles increases the atomic/proton number by 2 (1 for each).	1 mark
The overall change to the atomic number is zero, meaning it must be the same element.	1 mark
	Total: 3 marks

(Total for Question 5 is 10 marks)

6. Radioactive isotopes often undergo multiple decays or nuclear reactions.

- a) An unknown radioactive nucleus, X, has a mass number of A and an atomic number of Z. It undergoes one α -decay followed immediately by one β -decay to form a new nucleus, Y.

Write the mass number and atomic number of nucleus Y in terms of A and Z.

Mass number of Y = $A - 4$	1 mark
Atomic number of Y = $Z - 1$	1 mark
	Total: 2 marks

- b) Radon-222 ($^{222}_{86}\text{Rn}$) decays through a series of steps to become the stable isotope Lead-210 ($^{210}_{82}\text{Pb}$).

During this sequence, the nucleus emits a mixture of alpha (α) and beta (β) particles.

Calculate the exact number of alpha particles and beta particles emitted in this decay chain.

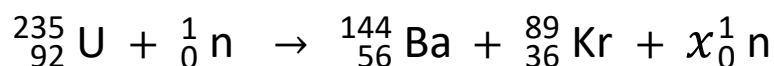
You must show your working.

Calculation of mass difference: $222 - 210 = 12$	1 mark
Number of α particles = 3	
Calculation of atomic number expected if only alpha decay occurred: $86 - (3 \times 2) = 80$	1 mark
Number of β particles = 2	1 mark
	Total: 4 marks

- c) Nuclear equations are also used to show artificial reactions, such as nuclear fission.

When a nucleus of Uranium-235 absorbs a neutron (^1_0n), it splits into Barium-144, Krypton-89, and a number of spare neutrons.

Complete the balanced equation for this fission reaction and determine the number of spare neutrons produced (represented by the letter x).



Total mass on left side = 236	1 mark
Mass of Ba and Kr on right side = 233	1 mark
Value of x = 3	1 mark
	Total: 3 marks

(Total for Question 6 is 9 marks)