EDEXCEL A LEVEL PHYSICS · TOPIC 11 · 6-MARK PROSE · PRACTICE QUESTIONS

Nuclear radiation: the long-answer questions

Each question type has its own chain: binding energy for fission and fusion, the fusion chain for the conditions, the decay chain for random and exponential decay, and the absorber chain for GM tube questions. Answers at the back.

6-MARK PROSE

Binding energy

THE BINDING ENERGY CHAIN up the curve → energy out

Say which way each process moves, then why that releases energy

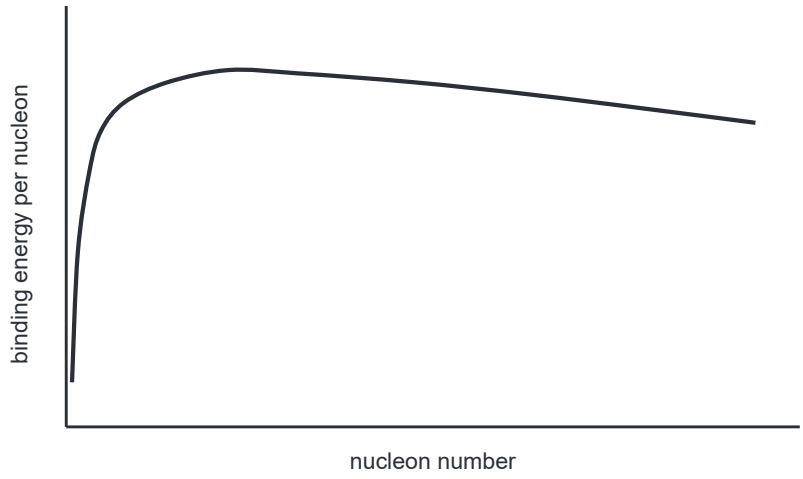
1. **Fusion: small nuclei join**
   Nucleon number increases, so the nuclei move up the left side of the curve.
2. **Fission: a large nucleus splits**
   Nucleon number decreases, so the products move up the right side of the curve.
3. **Both move towards iron-56**
   Iron-56 is at the peak: the highest binding energy per nucleon, the most stable nucleus.
4. **Binding energy per nucleon increases**
   The products are more tightly bound than what you started with.
5. **So the mass decreases**
   The total mass of the products is less than the mass before (the mass deficit increases).
6. **Energy released: $\Delta E = c^2 \Delta m$**
   The lost mass is released as energy, mostly kinetic energy of the products. Quote values off the graph when asked.

Question 1 · How fusion and fission both release energy

Edexcel A Level Physics past paper · 3 marks

Nuclear fusion involves small nuclei joining to make larger nuclei. Nuclear fission involves large nuclei splitting to become smaller nuclei. Both of these processes release energy.

(a) The graph shows how the binding energy per nucleon varies with nucleon number for a range of isotopes.



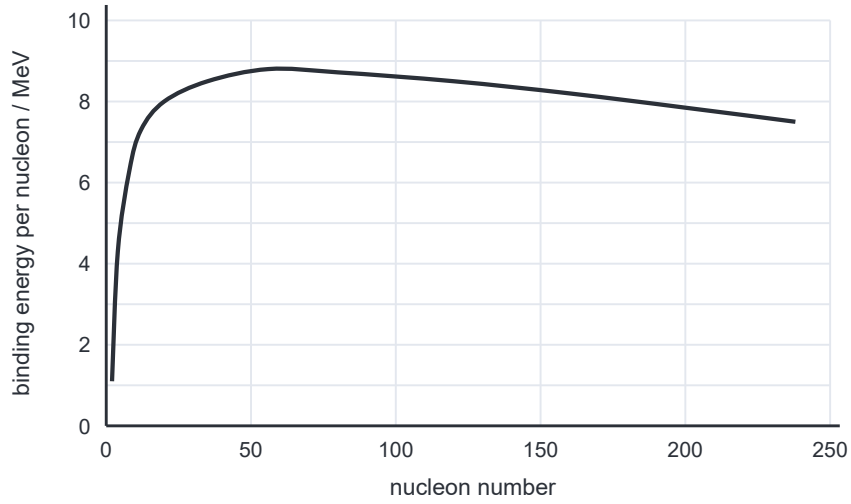
Use the binding energy per nucleon curve to explain how fusion and fission both release energy. **(3)**

Question 2 · Why fusion produces so much energy

Edexcel A Level Physics past paper · 3 marks

A fusion research centre was opened in Rotherham in 2021. The centre has a device which tests materials in the extreme conditions found inside a fusion reactor.

(b) The graph shows how the binding energy per nucleon varies with nucleon number for a range of nuclides.

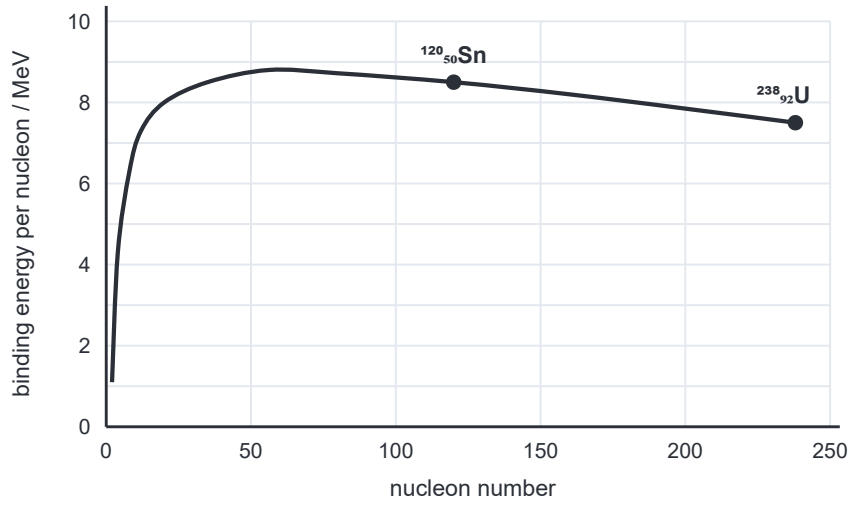


Explain why the fusion of nuclei can produce large amounts of energy. Your answer should refer to information from the graph. **(3)**

Question 3 · Fission of uranium-238

Edexcel International A Level past paper · 5 marks

The graph shows how the binding energy per nucleon varies with number of nucleons.



(a) Explain why energy is released when a nucleus undergoes fission. **(2)**

(b) A nucleus of ^{238}U undergoes fission. One of the fission products is Sn.

Estimate the energy, in MeV, released in the fission. You should use values from the graph. **(3)**

6-MARK PROSE

Conditions for fusion

THE FUSION CHAIN hot → close → often

Temperature brings it about; density keeps it going

1. **Very high temperature**
   About 10^7 K or more: the material is a plasma of nuclei and electrons.
2. **Nuclei are positive, so they repel**
   There is a large electrostatic repulsive force between the nuclei.
3. **High kinetic energy overcomes the repulsion**
   At a high temperature the nuclei move fast enough to overcome the repulsion.
4. **Close enough to fuse**
   They get within about 10^{-15} m, where the strong force acts and they fuse.
5. **Very high density**
   Lots of nuclei in a small volume (high pressure in a star).
6. **Collisions happen more frequently**
   The collision rate is high enough to sustain fusion, and the energy released keeps the temperature high.

Question 4 · The conditions for fusion in stars

Edexcel A Level Physics past paper · 6 marks



The energy radiated by stars is released by nuclear fusion.

* Explain the conditions required to bring about and maintain nuclear fusion in stars. **(6)**

Question 5 · The ITER plasma

Edexcel International A Level past paper · 4 marks

(b) It is hoped that the ITER will be the first fusion device on Earth to maintain nuclear fusion for long periods of time.

To achieve fusion in the ITER, a hot plasma is used. The plasma must

- be at an extremely high temperature
- have sufficient density for fusion.

Explain why each of these two conditions must be met. **(4)**

Question 6 · Inside a fusion reactor

Edexcel A Level Physics past paper · 3 marks

A fusion research centre was opened in Rotherham in 2021. The centre has a device which tests materials in the extreme conditions found inside a fusion reactor.

(a) Describe the extreme conditions inside a fusion reactor. **(3)**

6-MARK PROSE

Random decay

THE DECAY CHAIN chance → pattern → exponential

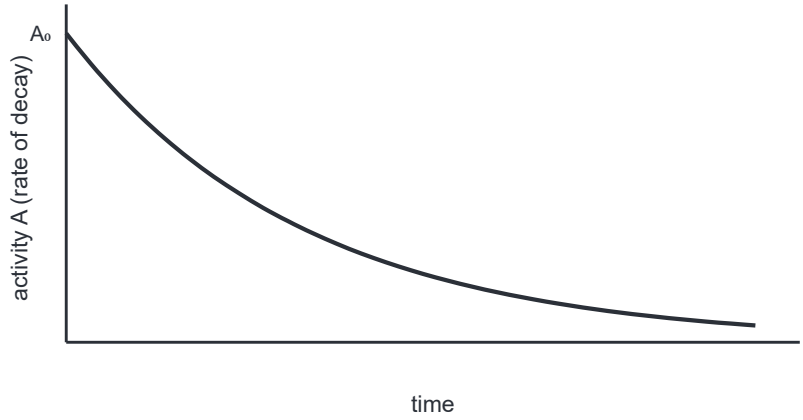
Start with one nucleus, end with the whole sample

1. **Fixed probability (λ)**
   Each nucleus has a fixed probability of decaying per second: the decay constant λ.
2. **Large number → predictable**
   Decay is random for one nucleus, but a large number of nuclei gives a predictable pattern.
3. **Fraction decaying per second = λ**
   So the same fraction of the remaining nuclei decays every second.
4. **Activity depends on N: A = λN**
   The number decaying per second depends on the number of unstable nuclei left.
5. **N decreases exponentially**
   As nuclei decay there are fewer left: $N = N_0 e^{-\lambda t}$.
6. **So the rate of decay decreases exponentially**
   $A = A_0 e^{-\lambda t}$: it halves every half-life.

Question 7 · Why the rate of decay falls exponentially

Edexcel A Level Physics past paper · 6 marks

Radioactive decay is often described in textbooks as a spontaneous, random process.



* (b) Explain why there is an exponential decrease in the rate of decay for a sample containing a large number of unstable nuclei. **(6)**

Question 8 · Finding the decay constant

Edexcel A Level Physics past paper · 2 marks

Nuclear decay is described as being spontaneous and random.

(a) (ii) Explain why the decay constant of an isotope can be determined even though nuclear decay is random. **(2)**

Question 9 · Warm radium

Edexcel A Level Physics past paper · 6 marks

* Radium is a radioactive element. The most common isotope of radium has a half-life of almost two thousand years. A sample of radium can remain at a higher temperature than its surroundings for a long period of time.

Explain how a sample of radium is able to release significant amounts of energy over a long period of time. **(6)**

6-MARK PROSE

Identifying radiation

THE ABSORBER CHAIN background → absorber → compare

Measure, put each absorber in, then reason from what gets through

1. **Measure the background count rate**
   With the source removed. Take it off every reading (corrected count rate).
2. **Measure the count rate with no absorber**
   Source and GM tube at a fixed distance, nothing in between.
3. **Paper stops alpha**
   If the count rate doesn't fall with paper in place, there is no alpha.
4. **A few mm of aluminium stops beta**
   If the count rate falls to background with aluminium, there is beta and no gamma.
5. **Gamma passes through both**
   If counts above background are left after aluminium, there is gamma.
6. **Compare the corrected count rates**
   Say what each change shows, or work out a fraction: (count with absorber − background) ÷ (count without − background).

Question 10 · Which radiation is it?

Edexcel International A Level past paper · 4 marks

The penetration of nuclear radiation through materials depends upon the ionising power of the radiation.

(a) A teacher tested an unknown radioactive source. He set up the source and a GM tube, as shown.



The initial count rate is determined without an absorber between the GM tube and the source.

When an aluminium sheet of thickness 0.5 cm was placed between the source and the GM tube, the count rate decreased to background level.

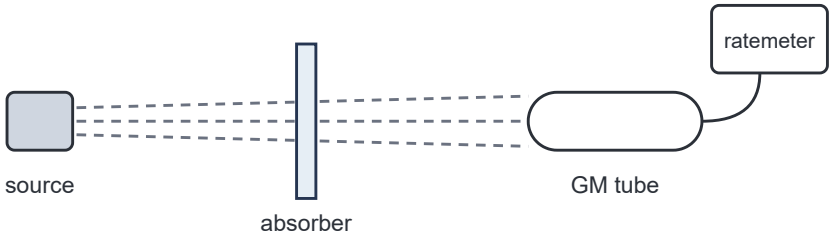
The teacher then removed the aluminium sheet and replaced it with a sheet of paper. There was no change in the initial count rate.

Explain which type of radiation is emitted from the source. You should refer to the penetration of each type of radiation through each sheet of absorber. **(4)**

Question 11 · How much of it is beta?

Edexcel A Level Physics past paper · 4 marks

(b) A radioactive source used in a school laboratory emits alpha and beta radiation.



Describe how the percentage of the activity due to beta radiation may be determined using a Geiger–Müller tube and ratemeter. **(4)**

Answers

Question 1 · How fusion and fission both release energy

STEP 1 Run the chain in note form

1. fusion: small join → nucleon no. up → BE/nucleon up
2. fission: large splits → nucleon no. down → BE/nucleon up
3. both towards iron-56
4–6. BE/nucleon up → mass down → energy released, $\Delta E = c^2\Delta m$

STEP 2 Write it in full sentences

1. In **fusion**, small nuclei join, so the nucleon number **increases**. On the left of the curve this means the **binding energy per nucleon increases**. ✓ 1 mark
2. In **fission**, a large nucleus splits, so the nucleon number **decreases**. On the right of the curve this also means the **binding energy per nucleon increases**. ✓ 1 mark
3. Both processes move towards **iron-56**, at the peak of the curve. shows you understand
4. When the binding energy per nucleon **increases**, the products have **less mass** than the starting nuclei, so **energy is released** ($\Delta E = c^2\Delta m$). ✓ 1 mark

Three marks: one for each direction on the curve, one for why that releases energy.

▼ Check it against the mark scheme

Mark scheme says	Link	
Fusion involves an increase in binding energy (per nucleon) as the number of nucleons increases	1	(1)
Fission involves an increase in binding energy (per nucleon) as the number of nucleons decreases	2	(1)
If binding energy per nucleon increases, energy is released in the process	4–6	(1)
3 marks. “Larger nuclei” and “smaller nuclei” are accepted for the nucleon number increasing and decreasing.		

Question 2 · Why fusion produces so much energy

STEP 1 Run the chain in note form

1 small nuclei fuse → larger nucleus

4–6 BE/nucleon increases → mass decreases → energy released

6 graph: ~1 MeV (^{2}H) → ~7 MeV (^{4}He): a big jump

STEP 2 Write it in full sentences

1 **Small (light) nuclei fuse** to form a **larger nucleus**. ✓ 1 mark

2 The **binding energy per nucleon increases**, so the mass decreases and **energy is released** ($\Delta E = c^2\Delta m$). ✓ 1 mark

3 From the graph, the binding energy per nucleon rises from about **1 MeV** for hydrogen-2 to about **7 MeV** for helium-4: an increase of about 6 MeV for **every** nucleon. The curve is steepest here, so fusing light nuclei releases a lot of energy per nucleon. ✓ 1 mark

"Refer to the graph" means numbers. Any two sensible values read off the curve, compared, earn the mark.

▼ **Check it against the mark scheme**

Mark scheme says	Link	
Small(er) nuclei fuse to form larger nuclei	**1**	**(1)**
The binding energy (per nucleon) increases, releasing energy, or the mass deficit increases and $E = c^2\Delta m$	**4–6**	**(1)**
Comparison of values from the graph, e.g. H to He is about 7 MeV	**6**	**(1)**

3 marks. The mark scheme's own example compares hydrogen and helium. Any correct pair of values from the curve works.

Question 3 · Fission of uranium-238

STEP 1 Run the chain in note form

2 (a) large nucleus splits

4 (a) BE/nucleon increases → energy released

6 (b) 7.5 → 8.5 MeV: up 1.0 MeV per nucleon

6 (b) × 238 nucleons ≈ 240 MeV

STEP 2 Write it in full sentences

(A) WHY ENERGY IS RELEASED

2 In fission, a **large nucleus splits** into two smaller nuclei (and some neutrons). ✓ 1 mark

4 The **binding energy per nucleon increases**, so the total binding energy increases and the mass decreases: **energy is released**. ✓ 1 mark

(B) THE ESTIMATE

6 From the graph: binding energy per nucleon of ^{238}**U ≈ 7.5 MeV** and of **Sn ≈ 8.5 MeV**. ✓ 1 mark

6 Increase in binding energy per nucleon = 8.5 − 7.5 = 1.0 MeV, for each of the **238 nucleons**: increase in binding energy ≈ 238 × 1.0 MeV. ✓ 1 mark

6 **Energy released ≈ 240 MeV** ✓ 1 mark

Assume every nucleon ends up about as tightly bound as tin. That's why it's an estimate.

▼ **Check it against the mark scheme**

Mark scheme says	Link	
(a) A large nucleus splits (into two nuclei plus neutrons)	2	(1)
(a) The binding energy (per nucleon) increases, so energy is released, or there is a decrease in (total) mass	4	(1)
(b) Binding energy per nucleon read from the graph for before and after fission	6	(1)
(b) Binding energy before and after fission calculated, or the binding energy increase calculated	6	(1)
(b) Energy released ≈ 240 MeV	6	(1)

2 + 3 marks. Mark scheme example: (8.5 − 7.5) MeV = 1.0 MeV; 238 × 1.0 MeV ≈ 240 MeV.

Question 4 · The conditions for fusion in stars

STEP 1 Run the chain in note form

1. very high temperature
2. nuclei positive → electrostatic repulsion
3. high KE → overcome repulsion
4. close enough → strong force → fuse
5. very high density
6. collisions more frequent → sustained

STEP 2 Write it in full sentences

BRINGING FUSION ABOUT

1. Fusion requires a **very high temperature** (about 10^7 K). ✓ 1 mark
2. All nuclei are **positively charged**, so there is a large **electrostatic repulsive force** between them. ✓ 1 mark
3. At a very high temperature the nuclei have a **high kinetic energy**, enough to **overcome the repulsion**. ✓ 1 mark
4. So the nuclei get **close enough** (about 10^{-15} m) for the **strong force** to act, and they **fuse**. ✓ 1 mark

MAINTAINING FUSION

5. Fusion also requires a **very high density**. ✓ 1 mark
6. With so many nuclei close together, **collisions happen more frequently**, so the collision rate is high enough to **sustain** fusion. ✓ 1 mark

Six points in a logical order: 4 marks for the points and 2 for the reasoning. Leaving out any one point costs you a mark.

▼ **Check it against the mark scheme**

Mark scheme says	Link	
Requires a (very) high temperature	1	(1)
Nuclei all have positive charge, leading to a large repulsive force between nuclei	2	(1)

At high temperature nuclei have high kinetic energy, sufficient to overcome repulsion	3	(1)
Nuclei must get close enough to fuse (accept close enough for the strong force)	4	(1)
Requires (very) high density	5	(1)
Collision rate must be high enough to sustain fusion	6	(1)

6 marks, indicative content (the * on the question). Six points seen earn 4 marks; the last 2 are for a logical, linked answer. The chain gives you both: every link is a point, and you write them in order.

Question 5 · The ITER plasma

STEP 1 Run the chain in note form

3 high temp → nuclei have enough KE

2 …to overcome electrostatic repulsion

4 …so they get close enough to fuse

6 density → collision rate high enough

6 …which maintains the temperature

STEP 2 Write it in full sentences

EXTREMELY HIGH TEMPERATURE

3 The temperature must be extremely high so that the nuclei have **enough kinetic energy**… ✓ 1 mark

2 …to **overcome the electrostatic repulsion** between the positively charged nuclei… ✓ 1 mark

4 …so that the nuclei come **close enough to fuse**. ✓ 1 mark

SUFFICIENT DENSITY

6 The density must be high enough that **collisions happen frequently**: the collision rate is high enough for fusion to continue, and the energy released **keeps the temperature very high**. ✓ 1 mark

Five marking points for four marks, so you have one spare. Don't just repeat the two bullet points: the marks are all in the reasons.

▼ **Check it against the mark scheme**

Mark scheme says	Link

Very high temperature so that the nuclei have sufficient kinetic energy	3	(1)
Nuclei must overcome electrostatic repulsion (allow repulsion due to positively charged nuclei)	2	(1)
So that the nuclei come close enough to fuse	4	(1)
Sufficient density so that the collision rate (between nuclei) is high (enough)	6	(1)
Sufficient collision rate to maintain the (very high) temperature	6	(1)
Max 4 marks from these 5 points.		

Question 6 · Inside a fusion reactor

STEP 1 Run the chain in note form

1 very high temperature, ~10^7–10^8 K | plasma: fully ionised | very strong magnetic field | bombarded by fast neutrons

STEP 2 Write it in full sentences

1 A **very high temperature**, about 10^7–10^8 K. ✓ 1 mark

\+ The material is a **plasma**: it is **fully ionised**. ✓ 1 mark

\+ There is a **very high magnetic flux density** (strong magnetic field), which holds the plasma away from the walls. ✓ 1 mark

\+ Materials are **bombarded by neutrons** released in the fusion reactions. a fourth point, spare

"Describe" is a list of what's there. Very high density or pressure also scores, but the reactor-only points are safer.

▼ **Check it against the mark scheme**

Mark scheme says	Link	
Very high temperatures (accept T ≈ 10^7–10^8 K)	1	(1)
High magnetic flux density	+	(1)
Bombardment by neutrons	+	(1)

Material is a plasma, or material is fully ionised	+	(1)

Max 3 marks. Conditions for stars are accepted too: high density, high pressure.

Question 7 · Why the rate of decay falls exponentially

STEP 1 Run the chain in note form

1 fixed probability per second (λ)
2 large number → predictable pattern
3 fraction decaying per second = λ
4 $A = \lambda N$
5 $N = N_0 e^{-\lambda t}$
6 $A = A_0 e^{-\lambda t}$

STEP 2 Write it in full sentences

1. Each nucleus has a **fixed probability** of decaying in the next second: the **decay constant λ**. ✓ 1 mark
2. Decay is random for an individual nucleus, but for a sample with a **large number of unstable nuclei** there is a **predictable pattern**. ✓ 1 mark
3. The **fraction** of the nuclei decaying in the next second is equal to the decay constant λ. ✓ 1 mark
4. So the number of nuclei decaying per second **depends on the number of unstable nuclei** left: **$A = \lambda N$**. ✓ 1 mark
5. As nuclei decay, the number of unstable nuclei **decreases exponentially** with time: $N = N_0 e^{-\lambda t}$. ✓ 1 mark
6. So the **rate of decay decreases exponentially** with time: $A = A_0 e^{-\lambda t}$. ✓ 1 mark

Each link leads into the next. That chain of reasoning is what earns the 2 marks for structure.

▼ Check it against the mark scheme

Mark scheme says	Link	
There is a fixed probability (λ) of an individual nucleus undergoing decay (in the next second)	1	(1)
For a sample with a large number of unstable nuclei there is a predictable pattern	2	(1)
The fraction of nuclei decaying in the next second is equal to the decay constant (λ)	3	(1)

Hence the number of nuclei decaying (in the next second) depends on the number of (unstable) nuclei, or activity = λN	4	(1)
The number of unstable nuclei decreases exponentially (with time), or $N = N_0e^{-\lambda t}$	5	(1)
So the rate of decay decreases exponentially (with time), or $A = A_0e^{-\lambda t}$	6	(1)

6 marks, indicative content (the * on the question). Six points seen earn 4 marks; the last 2 are for a logical, linked answer. The chain gives you both: every link is a point, and you write them in order.

Question 8 · Finding the decay constant

STEP 1 Run the chain in note form

1 λ = probability of decay per second: can be found

2 very large numbers of nuclei

2 marks: stop here

STEP 2 Write it in full sentences

1 The decay constant is the **probability** that a nucleus decays per unit time, and this probability **can be determined**… ✓ 1 mark

2 …because a sample contains a **very large number** of nuclei, so the fraction decaying per second is predictable even though each decay is random. ✓ 1 mark

Two marks, two links. The idea is in the first two links of every decay answer.

▼ Check it against the mark scheme

Mark scheme says	Link	
The probability of decay (in a specified time) may be determined	1	(1)
(The probability may be applied accurately because) very large numbers are involved	2	(1)

2 marks.

Question 9 · Warm radium

STEP 1 Run the chain in note form

4 A = λN: rate depends on N

long half-life → nuclei there for a long time

each decay: small decrease in mass

ΔE = c²Δm

Δm small, c² huge → lots of energy

energy → KE of atoms → sample stays warm

STEP 2 Write it in full sentences

WHY IT LASTS A LONG TIME

4 The rate of decay depends on the number of unstable nuclei in the sample: **A = λN**. ✓ 1 mark

\+ Radium has a **long half-life** (small λ), so **unstable nuclei are present for a long time** and decays keep happening. ✓ 1 mark

WHERE THE ENERGY COMES FROM

\+ When a nucleus decays, there is a small **decrease in mass**. ✓ 1 mark

\+ Energy is released according to **ΔE = c²Δm**. ✓ 1 mark

\+ Δm is small but **c² is very large**, so a **significant amount of energy** is released. ✓ 1 mark

\+ The energy released becomes **kinetic energy of the atoms** in the sample, so the sample stays **above the temperature of its surroundings**. ✓ 1 mark

Only one link comes straight from the chain. The other five are about energy: mass deficit and ΔE = c²Δm.

▼ **Check it against the mark scheme**

Mark scheme says	Link	
The rate of decay depends upon the number of unstable nuclei in the sample (A = λN)	4	(1)
Radium has a large half-life, so unstable nuclei are present in the sample for a long time	+	(1)
When a nucleus decays there is a (small) decrease in mass	+	(1)
Energy is released according to ΔE = c²Δm	+	(1)

Δm is small but c is large, so a significant amount of energy is released	+	(1)
Energy released by the decay becomes kinetic energy of the atoms in the sample (hence the sample is above the temperature of the surroundings)	+	(1)

6 marks, indicative content (the * on the question). Six points seen earn 4 marks; the last 2 are for a logical, linked answer. The chain gives you both: every link is a point, and you write them in order. A reference to binding energy increasing is accepted for the decrease in mass.

Question 10 · Which radiation is it?

STEP 1 Run the chain in note form

3 α stopped by paper

3 no change with paper → no α

5 γ would pass through Al → count fell to background → no γ

4 β stopped by Al → it's β

STEP 2 Write it in full sentences

3 Alpha radiation **would not pass through the sheet of paper**. ✓ 1 mark

3 There was **no change in the count rate** when the paper was placed between the source and the GM tube, so there **can't be any alpha** radiation. ✓ 1 mark

5 Gamma radiation **would pass through the aluminium sheet**, but the count rate fell to background, so there **can't be any gamma** radiation. ✓ 1 mark

4 So it **must be beta** radiation: beta passes through paper but **not through 0.5 cm of aluminium**. ✓ 1 mark

One sentence per absorber, then the conclusion: the question asked you to refer to each sheet.

▼ **Check it against the mark scheme**

Mark scheme says	Link	
Alpha radiation would not pass through the sheet of paper	3	(1)
No change in count rate when paper placed (between source and GM tube), so there can't be any alpha radiation	3	(1)
There can't be any gamma radiation, as gamma radiation would pass through the aluminium sheet, or as the count rate decreases to background with the aluminium sheet	5	(1)

It must be beta radiation, as beta radiation would not pass through the aluminium sheet	**4**	**(1)**

4 marks.

Question 11 · How much of it is beta?

STEP 1 Run the chain in note form

1 background count rate
2 count rate from the source, no absorber
3 paper in: absorbs α
6 % = (with paper − bg) ÷ (without − bg) × 100

STEP 2 Write it in full sentences

1. Measure the **background count rate** with the source removed. ✓ 1 mark
2. Measure the **count rate from the source**, with nothing between it and the GM tube. ✓ 1 mark
3. Place a **sheet of paper** between the source and the GM tube to **absorb the alpha radiation**, and measure the count rate again. ✓ 1 mark
6. Percentage due to beta = **(count rate with paper − background) ÷ (count rate without paper − background) × 100**. ✓ 1 mark

Keep the distance between the source and the GM tube the same for every reading, so only the absorber changes.

▼ **Check it against the mark scheme**

Mark scheme says	Link	
Measure the background count (rate)	**1**	**(1)**
Measure count (rate) from source	**2**	**(1)**
Use paper to absorb alpha radiation	**3**	**(1)**
Percentage = (count with paper − background rate) ÷ (count from source − background rate) × 100	**6**	**(1)**

4 marks.