

Nuclear fission fusion and chain reactions

AQA GCSE Separate Physics 8463 only | Foundation and Higher | Paper 1

25 parts | 46 marks | Both tiers | Timing estimated/untrialled

Specification points covered

4.4.4.1: neutron-induced fission, products and controlled/uncontrolled chain reactions

4.4.4.2: fusion of light nuclei; qualitative conversion of mass into radiation energy

4.1.3: selected nuclear-energy resource evidence and environmental comparisons

An energy museum is commissioning exhibits about a fission reactor, an experimental fusion system and the Sun. Check the physics, test model predictions and correct the exhibit claims.

Original PhysicsUK practice, not an official AQA resource. All 25 parts / 46 marks are suitable for Foundation and Higher after teaching. Section 6 includes an original six-mark-style best-fit rubric. Model neutron counts and fusion-test figures are supplied teaching data, not predictions for a real plant.

1 Checking the exhibit labels

Card A describes a large unstable nucleus splitting. Card B describes two light nuclei joining to form a heavier nucleus. The Sun exhibit describes hydrogen nuclei combining.

1(a) Name the nuclear process described by Card A and the process described by Card B. **[2 marks]**

Answer / mark points: A: nuclear fission. [1] B: nuclear fusion. [1] These names identify different changes to nuclei.

1(b) A visitor says the Sun must use the same uranium chain reaction as a fission reactor because both release energy. Correct the visitor using the Sun exhibit. **[2 marks]**

Answer / mark points: The Sun releases energy through fusion of light/hydrogen nuclei. [1] These nuclei join to form a heavier nucleus, rather than a large uranium nucleus splitting. [1] Releasing energy alone does not identify which nuclear process occurs.

1(c) The fission exhibit says, "Fission can never happen unless a neutron arrives first." Is "never" justified? Explain. **[1 mark]**

Answer / mark points: No. Spontaneous fission is possible, although rare; neutron absorption usually initiates fission. [1] Do not replace usually with always.



2 Reading one fission event

Figure 1 shows a before-and-after model of one induced fission. Q groups two products; R groups three products. Symbols are not to scale and do not show individual protons or neutrons inside nuclei.

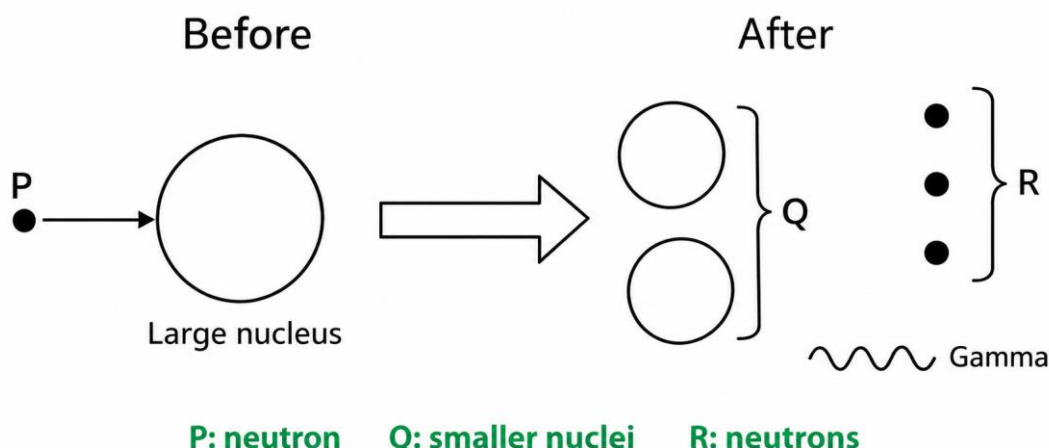


Figure 1

2(a) Identify the incoming particle P that can initiate this fission. **[1 mark]**

Answer / mark points: P is a neutron. [1] It must be absorbed by the nucleus to initiate this induced event.

2(b) Identify the two objects grouped by Q and the three objects grouped by R. **[2 marks]**

Answer / mark points: Q: two smaller nuclei, roughly equal in size. [1] R: three emitted neutrons in this model. [1] Q is not a pair of whole atoms with electron shells; R is not a group of electrons.

2(c) A visitor calls the gamma symbol an electron leaving the nucleus. State the correct type of emission. **[1 mark]**

Answer / mark points: Gamma is electromagnetic radiation/a gamma ray, not an electron. [1] No particular wavelength or frequency is inferred from the schematic wave.

2(d) Another visitor says P breaks into the three R particles. Explain why this is not what the fission diagram represents. **[2 marks]**

Answer / mark points: P is absorbed by the large unstable nucleus and initiates its fission. [1] The outgoing neutrons are emitted as that nucleus splits; the incoming neutron is not shown splitting into three. [1] The two smaller nuclei also come from the large nucleus.

2(e) A proposed label says all the released energy is carried by gamma radiation. Explain why this leaves out an important feature of the moving products. **[1 mark]**

Answer / mark points: The fission products, including the smaller nuclei and emitted neutrons, also have kinetic energy. [1] Therefore the emitted gamma radiation is not the only energy carrier.



3 Following the next neutrons

Figure 2 traces only the three neutrons released by fission A; gamma rays and other products are omitted. An absorber captures a neutron without causing another fission. A neutron absorbed by the next fuel nucleus can trigger its fission.

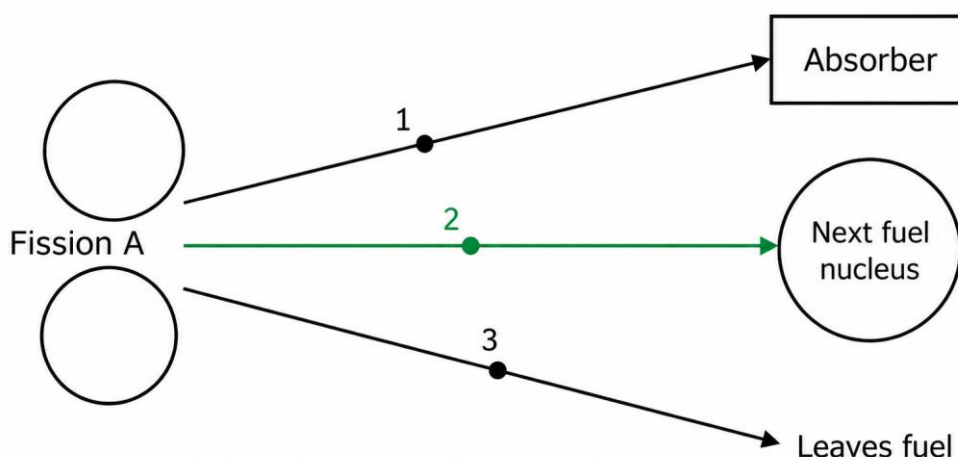


Figure 2

3(a) Which numbered path can continue the chain in Figure 2? Explain what must happen at the end of that path. **[2 marks]**

Answer / mark points: Path 2. [1] Its neutron is absorbed by the next fuel nucleus and can cause that nucleus to split. [1] Merely passing nearby does not represent absorption.

3(b) Only one of A's three neutrons causes another fission in this model. Explain how a chain can still continue rather than stopping after that next event. **[2 marks]**

Answer / mark points: The next fission releases further neutrons. [1] At least one of these can be absorbed by another fuel nucleus and cause a further fission, repeating the process. [1] One continuing neutron per fission can sustain the model; all three do not have to continue.

3(c) An additional absorber intercepts path 2 as well. With no other neutron source, what happens to the next generation of this model chain? **[1 mark]**

Answer / mark points: No further fission is triggered: the model chain dies out/stops. [1] The other two paths are already lost from the continuing chain.

3(d) In a different, idealised model, all three neutrons from each fission cause separate fresh nuclei to split. Starting with one fission A, calculate the number of fissions in the next generation and the generation after that. Do not include A in those totals. **[2 marks]**

Answer / mark points: Next generation: $1 \times 3 = 3$ fissions. [1] Following generation: $3 \times 3 = 9$ fissions. [1] These are per-generation counts, not cumulative totals of 4 and 13. This ideal model assumes sufficient fresh fuel and no losses.

3(e) The animator now labels every real fission "exactly three neutrons". Explain why the model does not justify this label. **[1 mark]**

Answer / mark points: The GCSE fission model allows two or three emitted neutrons; three in this chosen event is not a universal count. [1] No detailed isotope-dependent probabilities are required.



3 Following the next neutrons continued

3(f) Contrast a controlled reactor chain with an uncontrolled chain that produces an explosion. Refer to further fissions and the release of energy. **[2 marks]**

Answer / mark points: A controlled chain limits the neutrons causing further fissions so the energy release is controlled. [1] In an uncontrolled growing chain, many more fissions occur in successive generations and energy is released very rapidly. [1] A reactor is not an uncontrolled nuclear explosion running slowly.

4 Testing the control settings

In each separate model test, 100 nuclei undergo fission in one generation and emit 300 neutrons. Each neutron not absorbed elsewhere or lost causes exactly one new fission in fresh fuel. Generations have equal durations. Table 1 gives the losses.

Table 1

Setting	Neutrons emitted	Absorbed elsewhere or lost
X	300	200
Y	300	100
Z	300	300

4(a) Calculate the number of new fissions in the next generation for settings X, Y and Z. **[3 marks]**

Answer / mark points: X: $300 - 200 = 100$ new fissions. [1] Y: $300 - 100 = 200$ new fissions. [1] Z: $300 - 300 = 0$ new fissions. [1] Each successful neutron causes one event under the stated assumptions.

4(b) Which setting can maintain a steady chain at this stage? Explain using the starting 100 fissions and show why Y is not steady. **[2 marks]**

Answer / mark points: X gives 100 new fissions to replace the previous generation's 100. [1] Y gives 200, so the number increases rather than remaining steady. [1] Z stops this ideal chain; it does not maintain a non-zero steady output.

4(c) A safety note states that the fuel remains hot and its radioactive products can still emit radiation after shutdown. A visitor says setting Z makes the material immediately safe to handle. Evaluate the claim using both facts in the note. **[2 marks]**

Answer / mark points: Stopping new chain fissions does not instantly remove the existing thermal energy/heat, so hot material can still cause harm. [1] Radioactive products can continue emitting radiation after the chain stops. [1] The supplied note, not detailed reactor engineering, provides these two independent reasons.



5 Testing a fusion headline

Table 2 describes one experimental pulse. The 100 MJ supplied to the hot fuel is already included in the 160 MJ whole-facility input; do not add them. The 120 MJ is energy released by fusion, not a measurement of electricity delivered. No commercial-plant performance is implied.

Table 2

Energy boundary for one pulse	Energy / MJ
Supplied to hot fuel	100
Whole-facility input (includes the 100 MJ)	160
Energy released by fusion	120

5(a) A fusion label says, “The new nucleus is heavier than either light nucleus, so its mass must equal their combined starting mass.” Correct the conclusion and link your answer to the energy released. **[2 marks]**

Answer / mark points: Heavier than either individual light nucleus does not mean equal to their combined starting mass; the products can have a smaller total mass. [1] Some mass is converted into energy of radiation in fusion. [1] Compare the combined initial mass with the total products, not just one initial nucleus. No mass-defect calculation or $E = mc^2$ is required.

5(b) Using the whole-facility input and fusion output, calculate the energy shortfall for this pulse. **[1 mark]**

Answer / mark points: Shortfall = $160 - 120 = 40$ MJ. [1] Do not use only the 100 MJ hot-fuel input or add 100 MJ to 160 MJ.

5(c) The headline says, “120 MJ exceeds 100 MJ, so this experiment proves we can supply net electricity to the museum.” Give two reasons why Table 2 does not support this conclusion. **[2 marks]**

Answer / mark points: The complete facility takes in 160 MJ, more than the 120 MJ fusion output, so the smaller hot-fuel boundary does not establish a whole-facility energy surplus. [1] No electricity delivered is measured; fusion energy output is not automatically electrical output. [1] Neither claim requires an assumed conversion efficiency.

5(d) A supplied note says the light nuclei repel one another and must get very close to fuse. Heating makes them move faster. Use these facts to explain why a high temperature helps fusion occur. **[2 marks]**

Answer / mark points: At high temperature the nuclei have more kinetic energy/move faster. [1] They are more able to overcome their repulsion and approach close enough to fuse. [1] Accept equivalent qualitative wording; no Coulomb-force equation or required temperature value.

5(e) Before approving a much larger fusion exhibit, why should engineers use a small experimental model to test the energy claim? Give one reason linked to this situation. **[1 mark]**

Answer / mark points: For example: measure all energy inputs/outputs to test whether the predicted surplus is possible before committing to a costly full-scale system. [1] Also allow a specific model test of feasibility, safety or a design change. Merely saying models are useful is insufficient.



6 Writing the final museum explanation

Table 3 gives selected evidence for the museum display. Use the nuclear processes and the supplied evidence, not assumptions that every nuclear-energy claim describes the same system.

Table 3

Resource	Selected supplied evidence
Uranium fission	Finite fuel; no CO ₂ from the fission reaction; radioactive waste; mining disturbs land.
Natural gas	Finite fuel; combustion releases CO ₂ ; supply can be adjusted when fuel is available.

6(a) A label states, “Because no carbon dioxide is released in the fission reaction, fission electricity has no environmental effects.” Use Table 3 to give two reasons this is not a sound conclusion. **[2 marks]**

Answer / mark points: Radioactive waste still needs suitable management because it can harm the environment. [1] Uranium mining disturbs land, so the fuel supply has an environmental effect even without carbon dioxide from the fission reaction. [1] Do not claim zero operational carbon dioxide means zero lifecycle impact.

6(b) Give one further piece of evidence needed before recommending an electricity resource for the museum, beyond the selected facts and single test pulse supplied here. **[1 mark]**

Answer / mark points: For example: reliable electrical output over the museum’s operating hours, whole-system cost, or a comparable lifecycle environmental assessment. [1] A specific relevant missing measure is needed, not simply more research.

6(c) Write an explanation for the museum comparing neutron-induced fission with fusion. Explain how one fission can begin a chain, how neutron absorption can control it, and how fusion differs, including its mass–energy link. Use linked sentences, not only process names. **[6 marks]**

Answer / mark points: Original best-fit rubric, not an official AQA mark scheme. Level 3 (5–6): a clear, substantially accurate linked account of neutron absorption, fission and repeated neutron-triggered events; explains how limiting continuing neutrons controls the chain/energy release, and distinguishes fusion with its qualitative mass-to-radiation link. Level 2 (3–4): some linked explanation of fission and the chain/control, plus a correct fusion distinction, but an important link is omitted or unclear. Level 1 (1–2): isolated relevant statements with little causal connection. 0: no relevant content. Select a mark within a level using accuracy and completeness; do not award six independent ticks instead.

Example full answer: A large unstable nucleus absorbs a neutron and splits into two smaller nuclei. It releases energy, gamma rays and two or three neutrons; the moving products have kinetic energy. Released neutrons can be absorbed by other fuel nuclei and cause them to split, releasing more neutrons so the process repeats. Capturing some neutrons before they reach fuel reduces further fissions and controls the energy released; capturing all continuing neutrons stops this model chain. Fusion instead joins two light nuclei to form a heavier nucleus. Some of their mass is converted into energy of radiation. Fusion is not a uranium nucleus splitting, and energy release alone does not make it the same process as fission.

Review and improve

Insist on nucleus/nuclei, not atoms melting, burning or splitting chemically. A released neutron is not guaranteed to cause another fission. Control changes the number of further fissions and energy released per generation. Fusion output from hot fuel is not automatically net electricity from a whole facility.

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