

Life cycle of stars and element formation

AQA GCSE Separate Physics 8463 only | Foundation and Higher | Mainly Paper 2; fusion link to Paper 1

24 parts | 48 marks | Both tiers | Six-mark-style synthesis in 6(a)

Specification points covered

4.8.1.1: star formation from a nebula and main-sequence equilibrium

4.8.1.2: Sun-like and massive-star pathways; element formation and dispersal

4.4.4.2: fusion of light nuclei; mass converted to energy of radiation

An observatory team prepares a display about star-forming clouds, two model stars R and T, and material used in new planets.

Original PhysicsUK practice, not an official AQA resource. Both tiers; Separate Physics only. Most marks reward applying the stellar model to evidence. Six-mark response uses best-fit levels. Timings are estimated and untrials.

1 Interpreting a star forming cloud

Cloud P contains gas and dust. A dense region contracts under gravity and becomes hotter, but its centre has not yet reached the temperature for sustained hydrogen fusion.

1(a) What is the astronomical name for a cloud of gas and dust such as P? **[1 mark]**

Answer / mark points: A nebula. [1] Accept stellar nebula.

1(b) Explain how contraction of cloud P can eventually lead to a main-sequence star. **[3 marks]**

Answer / mark points: Gravity draws the gas and dust closer together. [1] During contraction, the central region heats up. [1] At a sufficiently high temperature, sustained fusion of hydrogen nuclei starts, leading to the main-sequence stage. [1] A protostar is an intermediate stage; naming it alone is not a substitute for the causal steps.

1(c) The team labels the hot, contracting object in P a main-sequence star. Use the supplied observation to explain why this label is premature. **[1 mark]**

Answer / mark points: Its centre has not yet reached the temperature for sustained hydrogen fusion, so it has not entered the main sequence. [1] It is a forming protostar, not an established hydrogen-fusing star.

1(d) A visitor says P will become a star only if oxygen arrives so that its gas can burn. Explain the error and identify the energy-releasing process in a main-sequence star. **[2 marks]**

Answer / mark points: A star does not need chemical combustion with oxygen. [1] Its main energy source is nuclear fusion: light nuclei join to form heavier nuclei and release energy. [1] Do not award the second mark for saying that atoms split.



2 Comparing two stable stars

Table 1 is a simplified model for two single main-sequence stars. Both currently fuse hydrogen in their cores. Initial mass means mass when the star began its life; lifetimes are approximate model values.

Table 1

Star	Initial mass / Sun mass	Main-sequence lifetime / million years
R	1.0	10 000
T	20	8

2(a) Which star in Table 1 is the better model for the Sun's broad lifecycle route? Use the mass information. **[1 mark]**

Answer / mark points: R, because its initial mass is the same as the Sun's. [1] The eventual red-giant route is not selected just by present colour or apparent brightness.

2(b) How many times greater is T's initial mass than R's? **[1 mark]**

Answer / mark points: Mass ratio = $20 / 1.0 = 20$. T starts with 20 times R's mass. [1] A ratio has no unit.

2(c) R's radius stays approximately constant during its main-sequence lifetime. Explain this stability in terms of forces and the source of energy. **[2 marks]**

Answer / mark points: Inward gravitational forces oppose outward pressure forces supported by energy from fusion. [1 for both opposed effects and fusion link] These forces are balanced/in equilibrium, so there is no continuing overall collapse or expansion. [1] Accept radiation pressure. Do not invent an outward force of gravity.

2(d) A trainee says a stable R must have stopped all fusion. Explain why this does not follow. **[1 mark]**

Answer / mark points: Stable radius does not mean the reactions stop: ongoing fusion supplies energy that supports the outward pressure while gravity still acts. [1] Credit the link between continuing fusion and equilibrium, not merely the word stable.

2(e) A visitor predicts that T must stay on the main sequence longer because it starts with more fuel. Use Table 1 and the supplied fact that T uses its fuel much faster to evaluate the prediction. **[2 marks]**

Answer / mark points: The model contradicts it: T lasts about 8 million years, compared with R's 10 000 million years. [1] More initial fuel does not guarantee a longer lifetime because T uses its fuel at a much greater rate. [1] No power law for lifetime is required.



3 Following different stellar pathways

Use Figure 1 as a reference model, not a scale drawing or timeline. R begins with a Sun-like mass; T is much more massive. Apply the paths to the evidence in each question.

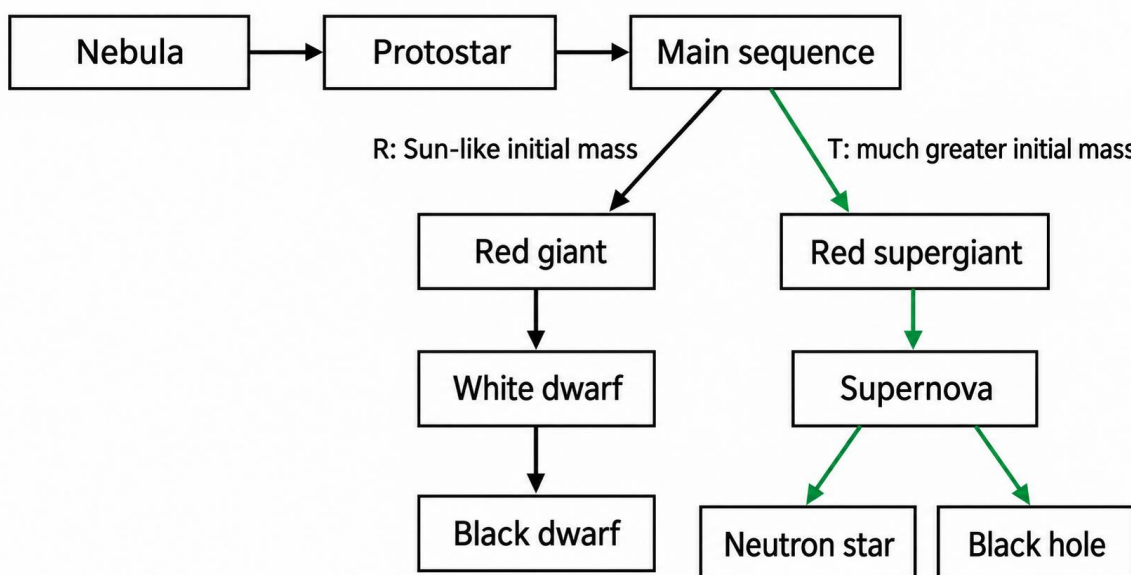


Figure 1

3(a) R begins to run out of hydrogen in its core. State its next major lifecycle stage and the change in its overall size. **[1 mark]**

Answer / mark points: R expands to become a red giant. [1 for linked expansion and named stage]
It does not next become a red supergiant.

3(b) A later image shows R and T as large red objects. Explain why their red appearance alone cannot determine which final remnant each will leave. **[2 marks]**

Answer / mark points: The broad evolutionary route depends on initial mass, not colour alone or present radius. [1] R follows the red-giant/white-dwarf path whereas the much more massive T follows the red-supergiant/supernova path. [1] The two red stages are not interchangeable.

3(c) After R loses its outer layers, the team finds a small hot remnant with no sustained fusion. Identify the remnant and describe its long-term change. **[2 marks]**

Answer / mark points: It is a white dwarf. [1] It radiates energy and cools, eventually approaching the black-dwarf stage in the model. [1] Do not describe this as a white dwarf exploding to become a black dwarf.

3(d) T produces a brilliant outburst and an expanding cloud of debris. Name the event and describe what it does to the material in the outer part of the star. **[2 marks]**

Answer / mark points: A supernova. [1] The explosion ejects/disperses stellar material into the surrounding space. [1] The compact remnant and the expelled material are not the same thing.

3(e) Two stars that began much more massive than the Sun leave different remnants: a neutron star and a black hole. Explain why this does not contradict Figure 1. **[2 marks]**

Answer / mark points: The massive-star branch has alternative endpoints, not a neutron-star-to-black-hole sequence for every star. [1] Different remaining core masses can leave a neutron star or a black hole; not every massive star must leave the same remnant. [1] No numerical threshold is required.



4 Explaining the elements in new worlds

The observatory detects helium in main-sequence T. Later stages can produce carbon and iron before an explosion; gold is detected in material from a supernova. Use the GCSE model. Carbon is lighter than iron; gold is heavier.

4(a) In main-sequence T, hydrogen becomes less abundant while helium becomes more abundant. Explain this pattern and how the process supplies energy. **[2 marks]**

Answer / mark points: Hydrogen nuclei join through fusion to form helium nuclei. [1] A small amount of mass is converted to energy carried by radiation. [1] This is not hydrogen atoms combining with oxygen, and it is not splitting a heavy nucleus. No mass–energy equation is required.

4(b) Could carbon and iron be produced inside a massive star before the supernova? Explain using successive nuclear reactions. **[2 marks]**

Answer / mark points: Yes: successive fusion reactions build heavier nuclei from lighter nuclei. [1] In the GCSE model this process can produce nuclei up to iron, so both carbon and iron can be made before the explosion. [1] Do not claim that ordinary hydrogen fusion alone directly produces iron.

4(c) A display claims that the gold was made by ordinary hydrogen fusion in a Sun-like main-sequence star. Explain why this is not the GCSE account. **[2 marks]**

Answer / mark points: Hydrogen fusion in a main-sequence star produces helium, not gold. [1] Gold is heavier than iron; the GCSE account associates production of these heavier elements with nuclear reactions during a supernova. [1] This is a syllabus-level model, not a detailed account of every astrophysical production site.

4(d) Trace how carbon and iron made in T could later become part of a rocky planet forming in a different cloud. Distinguish making the elements from moving them. **[3 marks]**

Answer / mark points: Fusion inside the star builds the carbon and iron nuclei. [1] The supernova expels and distributes material containing those elements into space. [1] This material can mix with gas and dust in a later star/planet-forming cloud and become part of a new planet. [1] The planet does not need to manufacture those nuclei by fusion.

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5 Accounting for material that leaves a star

Table 2 gives illustrative mass budgets after the two stars have evolved. R leaves a white dwarf; T leaves a neutron star in this model. Assume the difference is expelled material; ignore mass converted to radiation for these calculations.

Table 2

Model star	Initial mass / kg	Remaining core mass / kg
R	2.0×10^{30}	1.2×10^{30}
T	4.0×10^{31}	3.0×10^{30}

5(a) Use Table 2 to calculate the mass of material expelled by R. Give your answer in standard form. **[2 marks]**

Answer / mark points: Expelled mass = $2.0 \times 10^{30} - 1.2 \times 10^{30} = 0.8 \times 10^{30}$ kg. [1 for subtraction]
This is 8.0×10^{29} kg in standard form. [1] Keep the powers of ten aligned before subtracting.

5(b) Calculate the percentage of R's initial mass represented by this expelled material. **[2 marks]**

Answer / mark points: Fraction expelled = $(8.0 \times 10^{29}) / (2.0 \times 10^{30}) = 0.40$. [1] Percentage expelled = $0.40 \times 100 = 40\%$. [1] Use initial mass as the denominator; allow consistent follow-through from (a).

5(c) T's final core is only 1.5 times the Sun's mass. A trainee therefore concludes T never had a much greater mass than the Sun. Use Table 2 to explain why this is wrong. **[2 marks]**

Answer / mark points: The final core is not the whole original star: material has been expelled. [1]
Table 2 gives T an initial mass of 4.0×10^{31} kg, 20 times the Sun/R reference mass, despite its much smaller remaining core. [1] Use initial mass when choosing the broad lifecycle route.

5(d) The white dwarf left by R still emits light. Does this prove that it is still a main-sequence star? Explain the energy source. **[2 marks]**

Answer / mark points: No: emitting light alone does not establish the main-sequence stage or ongoing hydrogen fusion. [1] A hot white dwarf can radiate stored energy while cooling, without sustained fusion. [1] Do not call the white dwarf cold as soon as it forms.



6 Writing the observatory explanation

Use R and T throughout your account. Plan a clear order and connect the observations to the physics. The diagram is a reference; stage names alone are not a full explanation.

6(a) The team's display follows material from a nebula into R and T and later into new planets. Write a linked account comparing the stars. Include formation and main-sequence stability, their different later stages, and how T can supply newly formed elements for future planets. **[6 marks]**

Answer / mark points: Use best-fit levels, not one mark per sentence. Level 3 (5–6): a coherent account links formation and equilibrium, correctly contrasts both mass-dependent later routes, and connects element production with dispersal into future planetary material. Level 2 (3–4): relevant processes are described with some correct links, but one major strand is missing or the comparison is incomplete. Level 1 (1–2): a few correct statements or ordered stage names with little explanation. 0: no relevant physics. Within a level, reward scientific accuracy, relevant evidence and linkage. An example of a full account: Gravity concentrates the gas and dust, raising the central temperature until hydrogen fusion is sustained. The energy supplied by fusion supports outward pressure that balances inward gravity during the main sequence. R later expands as a red giant, sheds outer material and leaves a hot white dwarf that cools towards a black dwarf. The much more massive T becomes a red supergiant, then explodes as a supernova, leaving a neutron star or black hole. Fusion in massive stars builds nuclei up to iron; supernova conditions can produce heavier elements. Ejected material enriches later clouds, from which new stars and planets can form. Accept equivalent correct accounts and do not require reaction chains, threshold masses or A-level terminology. A collection of stage names without causal links is not a top-level account.

6(b) A trainee says one night of observing R and T directly shows a whole star completing every lifecycle stage. Use the supplied timescales to explain the limitation and how observations of different stars still help. **[2 marks]**

Answer / mark points: The model lifetimes are millions to thousands of millions of years, far longer than one night, so these observations do not directly follow one star through its entire life. [1] Scientists compare stars/remnants with different properties and stages to test and develop the lifecycle model. [1] This does not mean that stellar changes are never observed.

Review and improve

Accept equivalent causal physics. Fusion is a nuclear process, not chemical burning. Initial mass determines the broad lifecycle route. A white dwarf can radiate while cooling without sustained fusion. The black-dwarf endpoint is a future cooled state, not an observation claimed by this worksheet.

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