Fusion and fission are nuclear reactions in which large amounts of energy are released.

(a) (i) In a fusion reaction, two hydrogen nuclei are forced together to form a helium nucleus.

Explain why a very high temperature is needed for this reaction to happen.

(3)

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(ii) In a fusion reaction, the combined mass of the two small nuclei is greater than the mass of the resulting nucleus.

This decrease in mass, m, appears as energy, E, according to the equation.

$$E = mc^2$$

c is the speed of light $= 3.0 \times 10^8$ m/s.

The energy released in one fusion reaction is 4.5×10^{-12} J.

Calculate the decrease in mass.

(3)

decrease in mass = ... kg

*(b) Nuclear fission is used in nuclear reactors in some power stations.

In the reactor, a fission chain reaction is maintained and controlled to produce a supply of energy to generate electricity.

Figure 14 is a diagram of a nuclear reactor.

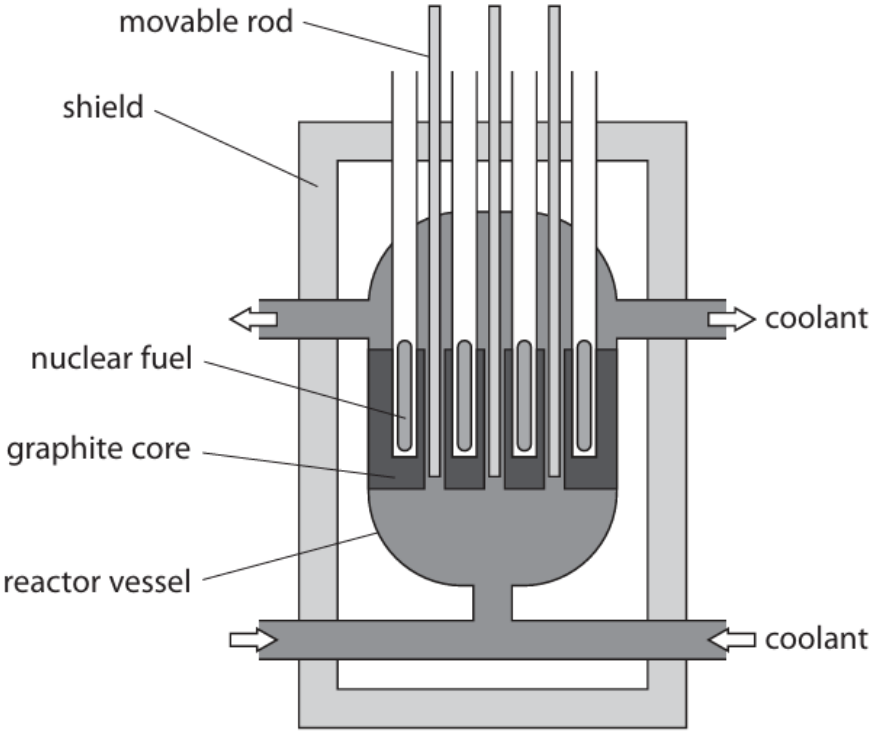

Figure 14

Explain how the graphite core and the movable rods are used to maintain and control the chain reaction.

(6)

(Total for Question 10 = 12 marks)

WWW	EBI…	DIRT Task
You can explain why a very high temperature is needed for this reaction to happen.	… you could explain why a very high temperature is needed for this reaction to happen.	What kind of particles are reacting? What charge do these particles have? What happens when two particles with the same charge get close to each other? What is needed to overcome this force? Why does a high temperature help?
You can calculate the decrease in mass.	… you could calculate the decrease in mass.	Have another attempt at the question a (ii).
You can explain how the graphite core and the movable rods are used to maintain and control the chain reaction.	… you could explain how the graphite core and the movable rods are used to maintain and control the chain reaction.	**What happens in a nuclear chain reaction?** → What kind of particles are released that keep the reaction going? **What does the graphite core do in a nuclear reactor?** → Does it stop, absorb, or slow something down? **Why is slowing down neutrons important?** → Are slow or fast neutrons more likely to cause fission? **What are the control rods made of and what is their function?** → Do they reflect, absorb, or release neutrons? **How can moving the control rods change the reaction rate?** → What happens when you insert them deeper or pull them out?
	Extension:	*Describe the differences between nuclear fusion and nuclear fission and explain how energy is released in each process.*

Question Number	Answer	Additional guidance	Mark
10(a)(i)	an explanation linking: (high temperature means) high energy (1) (needed) to overcome (force of) repulsion (1) between nuclei / because they both have the same charge (1)	 accept "them" / hydrogen for nuclei	**(3)** AO 2 1

Question Number	Answer	Additional guidance	Mark
10(a)(ii)	substitution (1) $4.5 \times 10^{-12} = m\ (3.0 \times 10^{8})^{2}$ rearrangement (1) $(m =) \frac{4.5 \times (10^{-12})}{9.0 \times (10^{16})}$ evaluation (1) 5.0×10^{-29} (kg)	 accept substitution and rearrangement in either order ignore POT errors until evaluation award full marks for the correct answer with no working	**(3)** AO 2 1

Question Number	Answer	Mark
10(b)*	Answers will be credited according to candidate's deployment of knowledge and understanding of the material in relation to the qualities and skills outlined in the generic mark scheme. The indicative content below is not prescriptive and candidates are not required to include all the material which is indicated as relevant. Additional content included in the response must be scientific and relevant. **AO1** • neutrons released in a chain reaction • slow(er) neutrons needed for fission • (some) neutrons are too fast • control rods can be moved in and out • control rods control speed of the reaction **AO2** • graphite core is the moderator • graphite core slows down the neutrons • moveable rods absorb neutrons • moveable rods make more or fewer neutrons available for fission	**(6)** AO 1 1 AO 2 1

Level	Mark	Descriptor
	0	No awardable content
Level 1	1-2	• An explanation that demonstrates elements of physics understanding, some of which is inaccurate. Understanding of scientific ideas lacks detail. (AO1) • The explanation attempts to link and apply knowledge and understanding of scientific ideas, flawed or simplistic connections made between elements in the context of the question. (AO2)
Level 2	3-4	• An explanation that demonstrates physics understanding, which is mostly relevant but may include some inaccuracies. Understanding of scientific ideas is not fully detailed and/or developed. (AO1) • The explanation is mostly supported through linkage and application of knowledge and understanding of scientific ideas, some logical connections made between elements in the context of the question. (AO2)
Level 3	5-6	• An explanation that demonstrates accurate and relevant physics understanding throughout. Understanding of the scientific ideas is detailed and fully developed. (AO1) • The explanation is supported throughout by linkage and application of knowledge and understanding of scientific ideas, logical connections made between elements in the context of the question. (AO2)

Total for Question 10 = 12 marks)

Answers for DIRT task questions:

1. **Explain why a very high temperature is needed for this reaction to happen.**

 The reaction involves the fusion of two positively charged nuclei (like hydrogen nuclei).
 These nuclei naturally repel each other due to the electrostatic (Coulomb) repulsion between like charges.
 To get close enough to fuse, the nuclei must overcome this repulsive force.
 This requires them to move extremely fast, which means they must have very high kinetic energy.
 A very high temperature gives the particles this energy because temperature is a measure of average kinetic energy.
 At high temperatures, more nuclei have enough energy to collide with enough force to fuse, making the reaction possible.

2.

3. **Explain how the graphite core and the movable rods are used to maintain and control the chain reaction.**
 In a nuclear reactor, a chain reaction occurs when neutrons released from fission cause more fission reactions.
 The graphite core acts as a moderator. It slows down the fast-moving neutrons produced during fission.
 Slower (thermal) neutrons are more likely to be absorbed by uranium nuclei, allowing the chain reaction to continue efficiently.
 The control rods (usually made of boron or cadmium) are used to absorb excess neutrons.
 These rods can be moved in or out of the reactor core to adjust how many neutrons remain available to cause further fission.
 Inserting the control rods deeper into the core absorbs more neutrons, slowing or stopping the reaction.
 Raising the rods reduces neutron absorption, allowing the reaction to speed up.
 Together, the graphite and control rods help maintain a steady, controlled chain reaction, preventing overheating or meltdown.

Extension
Describe the differences between nuclear fusion and nuclear fission, and explain how energy is released in each process.

- Nuclear fission is the splitting of a large, unstable nucleus (like uranium-235) into two smaller nuclei, releasing neutrons and energy.
- Nuclear fusion is the joining of two small nuclei (such as hydrogen isotopes) to form a larger nucleus, also releasing energy.
- The key difference is that fission splits heavy nuclei, while fusion combines light nuclei.
- In both processes, a small amount of mass is lost and converted into energy according to Einstein's equation $E = mc^2$.
- Fusion requires extremely high temperatures and pressures to overcome the repulsion between positively charged nuclei.
- Fission is used in nuclear power stations, while fusion occurs naturally in stars like the Sun.

Marks Breakdown:

Point	Detail	Marks
1. Definition of fission	Splitting of large nucleus into smaller ones	1 mark
2. Definition of fusion	Joining of small nuclei to form a larger one	1 mark
3. Key difference	Fission splits; fusion joins	1 mark
4. Energy release	Mass is converted to energy ($E = mc^2$)	1 mark
5. Fusion conditions	Requires high temperature and pressure	1 mark
6. Real-life examples	Fission in power stations, fusion in stars	1 mark