OCR
Oxford Cambridge and RSA

Thursday 15 June 2023 – Morning

A Level Physics A

H556/03 Unified physics

Time allowed: 1 hour 30 minutes

A Level Physics Online.com
/ocr-a-unified-physics

You must have:
- the Data, Formulae and Relationships Booklet

You can use:
- a scientific or graphical calculator
- a ruler (cm/mm)

Please write clearly in black ink. **Do not write in the barcodes.**

Centre number	5	3	6	0	2	Candidate number	8	7	4	7

First name(s) Lewis

Last name Matheson

INSTRUCTIONS
- Use black ink. You can use an HB pencil, but only for graphs and diagrams.
- Write your answer to each question in the space provided. If you need extra space use the lined pages at the end of this booklet. The question numbers must be clearly shown.
- Answer **all** the questions.
- Where appropriate, your answers should be supported with working. Marks might be given for a correct method, even if your answer is wrong.

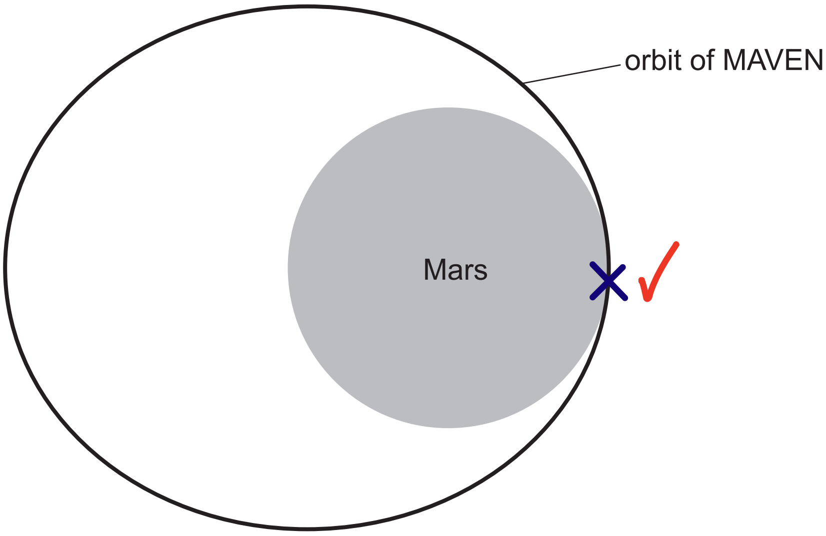
INFORMATION
- The total mark for this paper is **70**.
- The marks for each question are shown in brackets **[ ]**.
- Quality of extended response will be assessed in questions marked with an asterisk (*).
- This document has **24** pages.

ADVICE
- Read each question carefully before you start your answer.

© OCR 2023 [601/4743/X]
DC (ST/SG) 321125/5
OCR is an exempt Charity

1 The MAVEN spacecraft orbits Mars and studies its upper atmosphere.

(a) The diagram below shows the orbit of MAVEN around Mars.



(i) Mark an **X** on the diagram to show the point in the orbit where MAVEN has maximum acceleration. **[1]**

(ii) Explain how Kepler's 1st law applies to MAVEN's orbit around Mars.

The orbit is elliptical ✓ with the centre of gravity of Mars as one focus. ✓

.... **[2]**

© OCR 2023

(b) The table shows data for four orbits around Mars.

Phobos and Deimos are moons of Mars.

An areostationary orbit for Mars is the equivalent of a geostationary orbit for Earth.

Orbit	Time period / hours	Average distance from centre of Mars / km	T^2/R^3
MAVEN	4.5	6500	7.4×10^{-11}
Phobos	7.7	9400	7.1×10^{-11} ✓
Deimos	30	23000	7.4×10^{-11}
Areostationary	25	20000	7.8×10^{-11}

(i) Show that Kepler's 3rd law applies to this data.

$T^2 \propto r^3$

$T^2 = k r^3$

$\frac{T^2}{r^3} = k =$ a constant ✓

[2]

(ii) Suggest **two** reasons why MAVEN was **not** placed in an areostationary orbit.

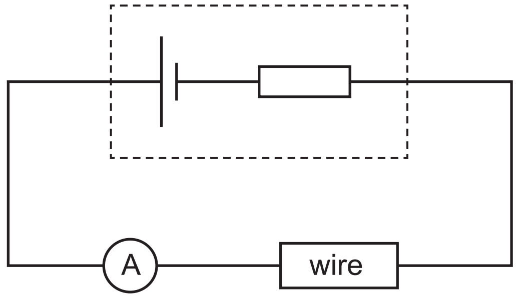
1 MAVEN needs to survey the whole planet. ✓

2 MAVEN needs to be near to the upper atmosphere. ✓

[2]

© OCR 2023

2 A student uses the circuit below to investigate the resistivity of a wire.



The cell has e.m.f. ε and internal resistance r. The wire has resistivity ρ and diameter d.

(a) The student takes five measurements of the diameter of the wire, which are shown in the table below.

Diameter / mm	0.460	0.450	0.455	~~0.495~~	0.455

(i) Suggest how the student made these measurements.

Using vernier callipes ✓ at different positions and orientations along the wire. ✓

[2]

(ii) The student calculates the value of the diameter as d = 0.455 ± 0.005 mm.

Explain how the student calculated the value of the diameter, and its uncertainty, from the data in the table above.

0.495 is an anomaly so is discarded ✓

$d_{mean} = \frac{0.460 + 0.450 + 0.455 + 0.455}{4} = 0.455$ mm ✓

Range = 0.460 − 0.450 = 0.010 mm

Uncertainty = ½ Range = 0.005 mm ✓

∴ d = 0.455 ± 0.005 mm

[3]

© OCR 2023

(b) The student varies the length L of the wire in the circuit and records the current I using the ammeter.

(i) Show that

$$\frac{1}{I} = \left(\frac{4\rho}{\pi\varepsilon d^2}\right)L + \frac{r}{\varepsilon}$$

$$R = \frac{\rho L}{A} \qquad A = \frac{\pi d^2}{4}$$

✓

$$R = \frac{4\rho L}{\pi d^2}$$

$$\varepsilon = V + Ir = IR + Ir \checkmark = I\frac{4\rho L}{\pi d^2} + Ir$$

$$\div I \qquad \frac{\varepsilon}{I} = \frac{4\rho L}{\pi d^2} + r$$

$$\div \varepsilon \qquad \frac{1}{I} = \frac{4\rho L}{\pi d^2 \varepsilon} + \frac{r}{\varepsilon}$$

[3]

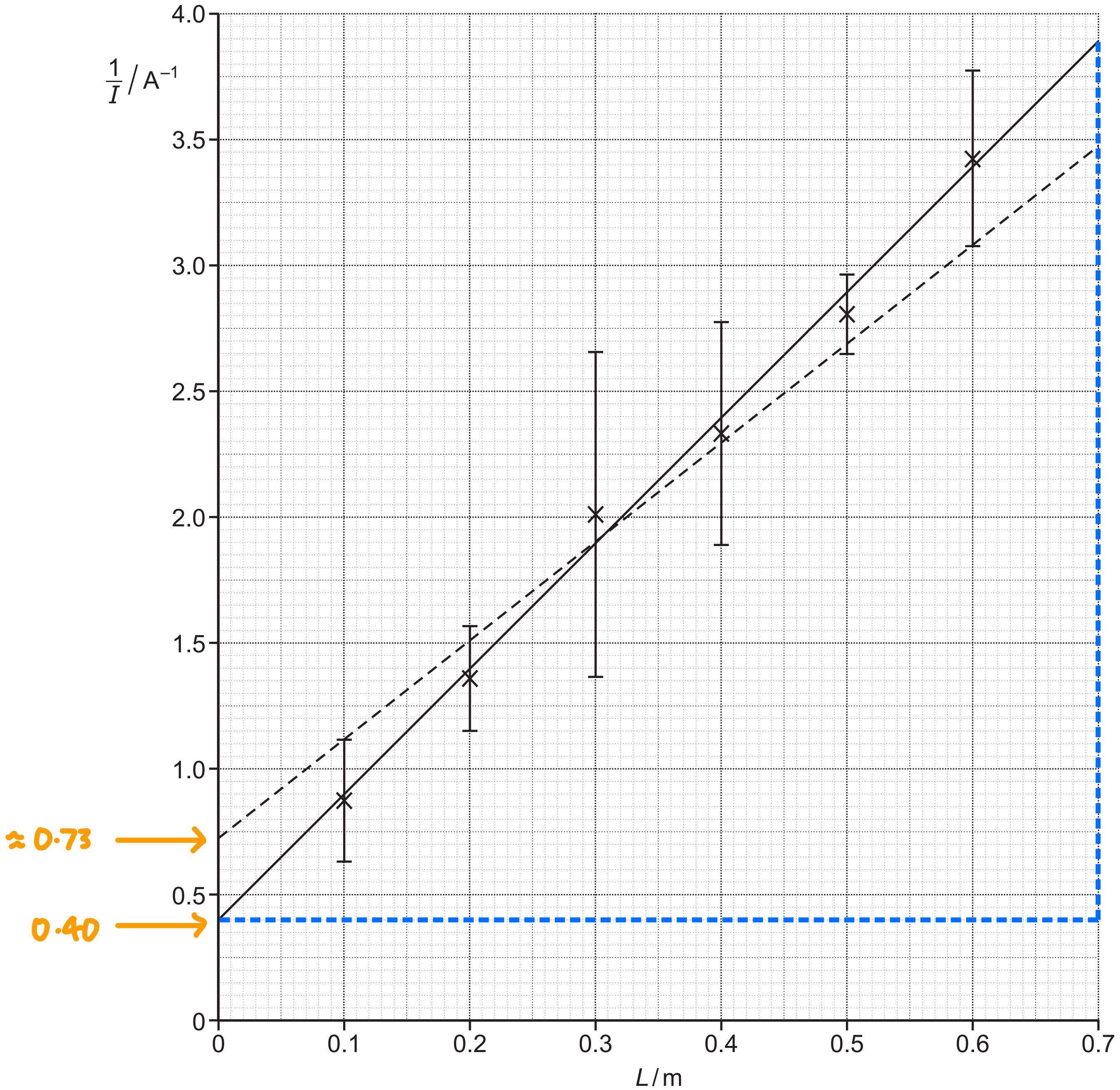
$$\frac{1}{I} = \frac{4\rho}{\pi\varepsilon d^2}L + \frac{r}{\varepsilon} \checkmark$$

$$y = m x + c$$

Question 2 continues on page 6

© OCR 2023

(ii) The student plots a graph of $\frac{1}{I}$ against L. The data points, error bars, line of best fit and a line of worst fit are shown in the graph below.



The cell has e.m.f. $\varepsilon = 1.45 \pm 0.05\,V$

The wire has diameter $d = 0.455 \pm 0.005\,mm$

1 Calculate the gradient of the best fit line and use this to determine a value for the resistivity ρ of the wire.

You are **not** required to determine an uncertainty.

gradient $= \frac{\Delta y}{\Delta x} = \frac{3.85 - 0.40}{0.70 - 0} = 4.93\ A^{-1}m^{-1}$ ✓

gradient $= \frac{4\rho}{\pi \varepsilon d^2}$ $\rho = \text{gradient} \times \frac{\pi \varepsilon d^2}{4}$

$\rho = 4.93 \times \frac{\pi \times 1.45 \times (0.455\times10^{-3})^2}{4}$

$= 1.16 \times 10^{-6}$

ρ = 1.2×10^{-6} ✓ Ω m **[2]**

2 Determine a value for the internal resistance *r* of the cell **and** its absolute uncertainty.

y-intercept $= \frac{r}{\varepsilon}$ $r = \text{y-intercept} \times \varepsilon$

$r = 0.40 \times 1.45 = 0.58\,\Omega$

worst y-intercept ≈ 0.73 ✓

% uncertainty $= \frac{0.73 - 0.40}{0.40} \times 100 = 82.5\%$

% uncertainty in $\varepsilon = 0.05/1.45 \times 100 = 3.44\%$

r = 0.58 ✓ ± 0.50 ✓ Ω **[4]**

Combined uncertainty $= 82.5 + 3.44 = 85.94\%$ ✓

Absolute uncertainty $= 0.58 \times 0.8594 = 0.498\,\Omega$

© OCR 2023

(I used a different approach to the mark scheme)

BLANK PAGE

PLEASE DO NOT WRITE ON THIS PAGE

© OCR 2023

3 A pulsar is a rapidly rotating neutron star that emits radio waves.

(a) (i) Describe the formation of a neutron star.

Red super giant has stopped fusion ∴ collapses because gravitational force is greater than radiation pressure ✓ Collapse results in a supernova ✓, leaving behind neutron star. **[2]**

(ii) State **one** characteristic of a neutron star.

Extremely dense. ✓

[1]

(b) A typical neutron star can be modelled as a sphere with mass ≈ 2×10^{30} kg and radius ≈ 10 km.

Show that the average density of a neutron star is similar to the average density of an atomic nucleus.

- radius of a nucleon ≈ 1 fm

Star: $\rho = \frac{m}{V} = \frac{2 \times 10^{30}}{\frac{4}{3}\pi \times (10 \times 10^3)^3} = 4.77 \times 10^{17}$ kg m^{-3} ✓ ✓

Nucleus: $\rho = \frac{m}{V} = \frac{1.66 \times 10^{-27}}{\frac{4}{3}\pi \times (1.2 \times 10^{-15})^3} = 2.3 \times 10^{17}$ kg m^{-3} ✓

u

r_0

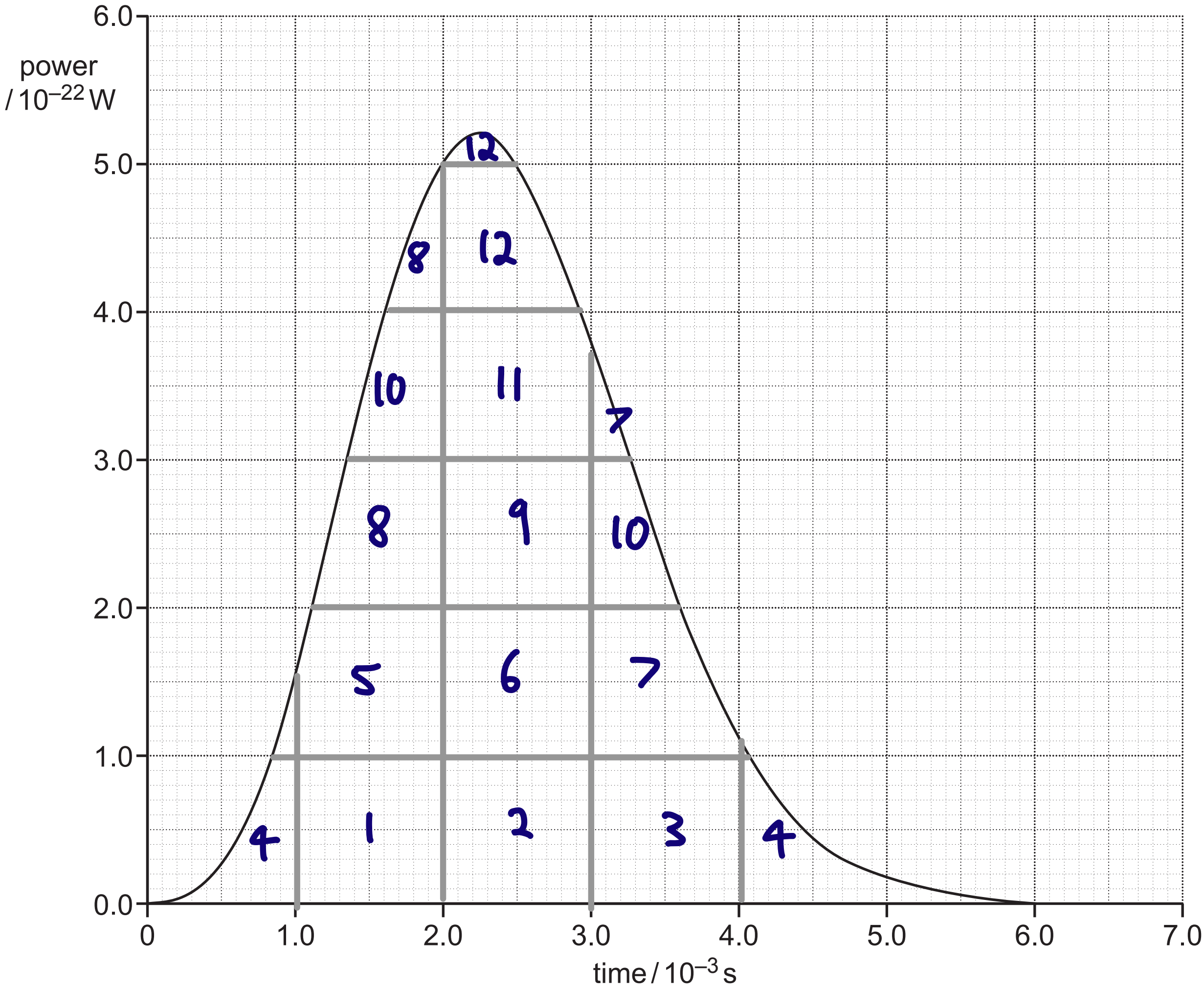
[3]

Question 3 continues on page 10

© OCR 2023

(c) An astronomer uses a radio telescope to observe a pulsar.

The graph below shows the power that the telescope receives due to the radio waves from one full rotation of a pulsar.



(i) By calculating the area between the curve and the horizontal axis, estimate the total energy received by the telescope in one full rotation of the pulsar.

≈ 12 large squares ✓ (slightly under)

Area = $12 \times 1.0 \times 10^{-22} \times 1.0 \times 10^{-3}$

total energy received = 1.2×10^{-24} ✓ J **[2]**

© OCR 2023

(ii) The surface area of the telescope is about 3000 m^2.

The distance to the pulsar is about 300 pc.

By assuming that the radiation from the pulsar is emitted equally in all directions, estimate the total energy emitted in one full rotation.

Energy $\propto$ Area

$$\frac{E_T}{E_P} = \frac{A_T}{A_P} \qquad E_P = E_T \frac{A_P}{A_T}$$ ✓

$$A_P = 4\pi r^2 = 4\pi \times (300 \times 3.1 \times 10^{16})^2 = 1.09 \times 10^{39}\ m^2$$ ✓

$$E_P = 1.2 \times 10^{-24} \times \frac{1.09 \times 10^{39}}{3000} = 3.985 \times 10^{11}\ J$$

From part i)

energy emitted = 4.0×10^{11} ✓ J **[3]**

© OCR 2023

4 A cloud is made up of droplets of water falling at terminal velocity.

(a) Describe and explain the motion of an object falling at terminal velocity.

Zero acceleration so a constant velocity, ✓ because the resultant force is zero ✓ as the weight = drag + upthrust. ✓

[3]

(b) (i) The terminal velocity v of a small sphere of density ρ_s and radius r falling through a fluid of density ρ_f is given by the formula:

$$v = \frac{2gr^2(\rho_s - \rho_f)}{9\eta}$$

where η is a constant for the fluid and g is the acceleration of free fall.

Water droplets of rain fall to the ground whereas water droplets in mist appear to float.

Use the formula above to suggest why.

From the formula $v \propto r^2$ ✓. Mist droplets have a much smaller radius than rain, ✓ ∴ a much lower terminal velocity.

[2]

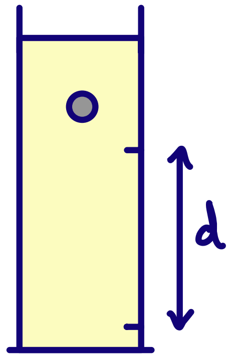
© OCR 2023

***(ii)** A student models water droplets falling through air using small solid spheres in a liquid.

The table shows properties of the materials available to the student.

Material	**Solid density, ρ_s / kg m^{-3}**	**Liquid density, ρ_f / kg m^{-3}**	**Approximate value of η / 10^{-3} kg m^{-1} s^{-1}**
Water (liquid)		1000	1
Sunflower oil (liquid)		920	50
Steel (solid sphere)	7800		
Lead (solid sphere)	11300		

Describe an experiment to verify the expression given in **(i)** as accurately as possible. As part of your answer, estimate the **lowest** terminal velocity if the student uses a solid sphere of diameter = 1 mm.



Use a long wide clear tube containing sunflower oil. Ensure it is vertical using a set square. Mark a measured distance about half-way down the tube so the ball will have reached terminal velocity. Time how long it takes ball to fall through this distance, keeping eye level with start and end position to reduce parallax error. ✓✓

Repeat experiment, and use different diameters of steel ball bearing, the diameter measured with callipers. ✓

[6]

© OCR 2023

Additional answer space if required

v = distance ÷ time   r = diameter/2

$$v = \frac{2g(\rho_s - \rho_f)}{9\eta} \cdot r^2$$

$$y = m x + c$$

A graph of v against r^2 should be a straight line that passes through the origin. Verify that the gradient is equal to the value of $2g(\rho_s - \rho_f)/9\eta \approx 3.0 \times 10^5\ m^{-1}s^{-1}$ ✓

Oil has greater viscosity and steel has lowest density ∴ lowest v ✓

$$v = \frac{2g(\rho_s - \rho_f)}{9\eta} \cdot r^2$$

$$v = \frac{2 \times 9.81 \times (7800 - 920)}{9 \times 50 \times 10^{-3}} \times \left(\frac{1 \times 10^{-3}}{2}\right)^2$$

$v = \underline{0.075}\ m\,s^{-1}$ ✓

© OCR 2023

BLANK PAGE

PLEASE DO NOT WRITE ON THIS PAGE

5 Large power stations generate an electrical power of about 1 GW.

Current methods of energy production that use nuclear fusion are unable to produce enough energy for large-scale energy production. A proposed method of controlling nuclear fusion is inertial confinement fusion (ICF). ICF uses a large number of powerful lasers to create the high temperatures required for nuclear fusion to occur.

One ICF experiment uses a network of capacitors to store the energy needed to power the lasers. When the network is fully charged:

- potential difference across the network = 24 kV
- total energy stored in the network = 400 MJ

(a) **(i)** Calculate the total capacitance, C, of the network.

$W = \frac{1}{2}CV^2 \qquad C = \frac{2W}{V^2} = \frac{2 \times 400 \times 10^6}{(24 \times 10^3)^2} = 1.389\,F$ ✓

C = 1.4 ✓ F **[2]**

(ii) Explain why the individual capacitors in the network should be connected in parallel in order to produce this total capacitance.

This increases total capacitance. ✓

[1]

(b) The total stored energy must be released in a time of less than 1 millisecond.

Explain, using a calculation, why the lasers are powered by the network of capacitors instead of being connected directly to the mains electricity supply.

$P = E/t = 400 \times 10^6 / 1 \times 10^{-3} = 4 \times 10^{11}$ W ✓

One power station = 1 GW = 1×10^9 W

$\therefore$ P required for fusion = 400 power stations! ✓ **[2]**

© OCR 2023

(c) The fusion reaction in the ICF experiment is

deuterium + tritium ⟶ alpha particle + neutron

Calculate the number of fusion reactions that must occur for the energy released by fusion to be equal to the electrical energy stored in the network of capacitors.

- mass of deuterium = 2.014102 u
- mass of tritium = 3.016049 u
- mass of alpha particle = 4.002603 u
- mass of neutron = 1.008665 u

Mass defect:

$\Delta m = 3.016049 + 2.014102 - 4.002603 - 1.008665$

$= 0.018883\ u$ ✓

$E = mc^2 = 0.018883 \times 1.661 \times 10^{-27}$ ✓ $\times\ 9.00 \times 10^{16}$

$= 2.8228 \times 10^{-12}$ J per reaction ✓

$N = \frac{E_T}{E_{per\ reaction}} = \frac{400 \times 10^6}{2.8228 \times 10^{-12}} = 1.417 \times 10^{20}$

number of fusion reactions = 1.4×10^{20} ✓ **[4]**

6 A 3D printer can manufacture small objects.

Some 3D printers use polylactic acid (PLA). PLA is supplied in the form of long filaments. The 3D printer melts the PLA and builds up the shape of the desired object in layers.

The electrical supply to the heater in the printer has an e.m.f., ε, of 12 V. The power of the heater is 40 W.

(a) Calculate the resistance, R, of the heater.

$P = \frac{V^2}{R}$ $\quad R = \frac{V^2}{P} = \frac{12^2}{40} = 3.6\,\Omega$ ✓

R = 3.6 ✓ Ω **[2]**

(b) The specific latent heat of fusion of PLA is $9.4 \times 10^4\,\mathrm{J\,kg^{-1}}$ and its melting point is 160 °C.

(i) Define **specific latent heat of fusion**.

Energy required to change 1 kg of a solid to liquid at constant temperature. ✓

[1]

(ii) Calculate the **maximum** mass m of PLA that the heater could melt in one minute.

$E = mL = Pt$

$m = \frac{Pt}{L} = \frac{40 \times 60}{9.4 \times 10^4} = 0.0255\,\mathrm{kg}$ ✓

m = 0.026 ✓ kg **[2]**

(iii) Explain why the printing process is slower in practice than your answer to **(ii)** suggests.

Not all the energy supplied is used to melt the PLA. ✓ Some energy is used to raise its temperature ✓ up to, or above, its melting point.

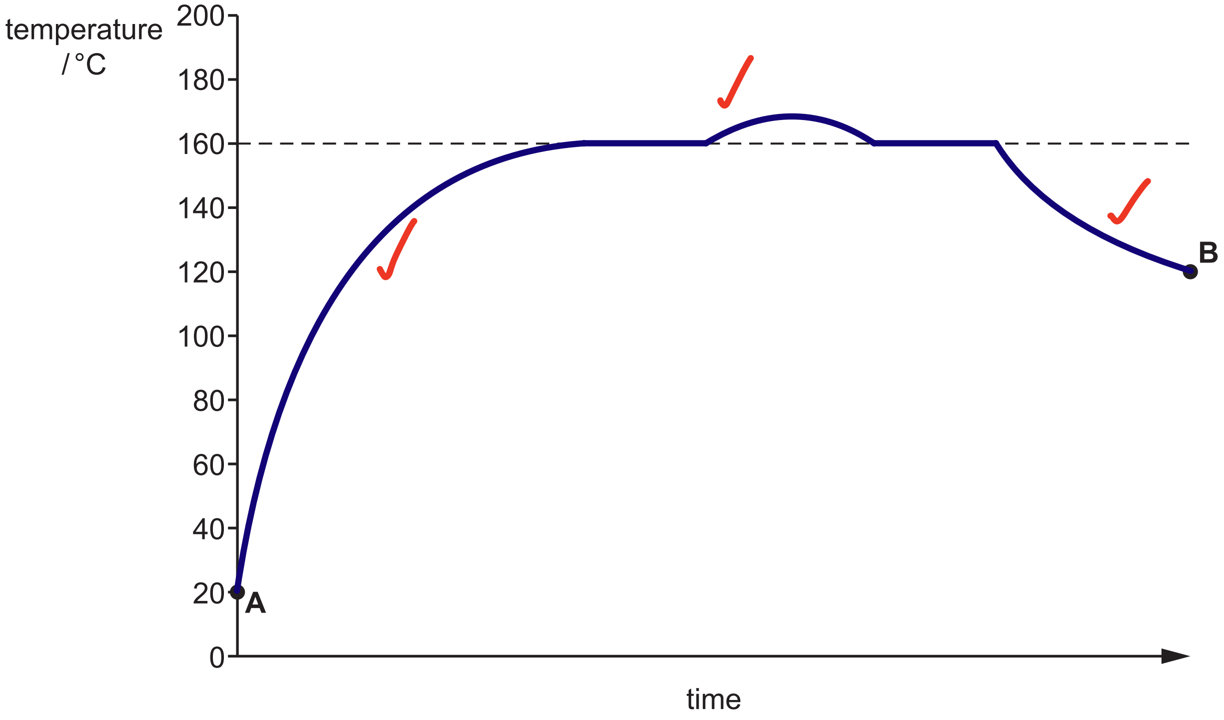
[2]

© OCR 2023

(iv) **Fig. 6.1** shows the initial and final temperature of the PLA during the printing process.

Initially (point **A**), the solid PLA is at 20 °C and is just entering the heater. Later (point **B**), the PLA has been added to the object and is solid again.

Fig. 6.1



Complete **Fig. 6.1** to show how the temperature of the PLA changes between **A** and **B**. You are **not** required to label the time axis. **[3]**

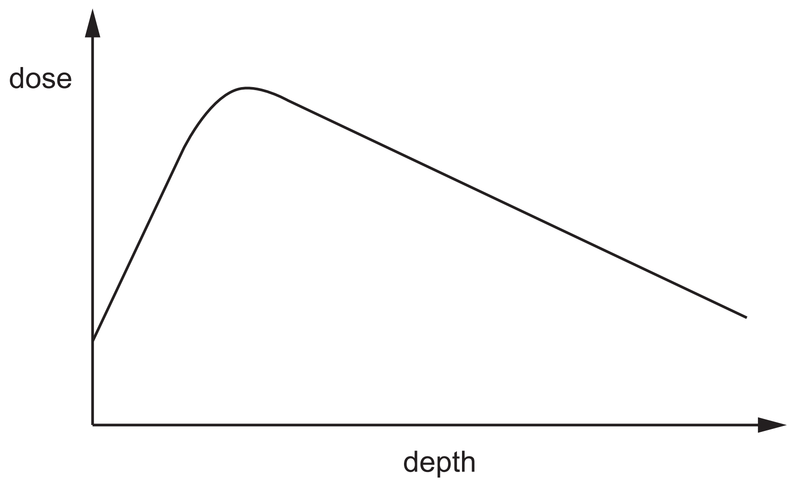
© OCR 2023

(c) High-energy X-ray photons can destroy living cells. In radiotherapy, these photons are targeted at cancer cells.

The radiation **dose** is the amount of energy that a patient's body absorbs from the high-energy X-ray photons.

Fig. 6.2 shows how this dose changes with depth below the surface of the skin.

Fig. 6.2



The dose initially rises with depth because the high-energy X-ray photons produce electrons and positrons as they pass through the body. These electrons and positrons are quickly absorbed, increasing the dose.

(i) Explain why high-energy X-ray photons produce electrons **and** positrons as they pass through the body.

Photon interacts with nucleus ✓. The energy of the photon produces matter and anti-matter (pair production) ✓ i.e. the electron and positron.

.... **[2]**

© OCR 2023

***(ii)** A 3D object called a **bolus** is used in radiotherapy for patients with skin cancer. A bolus targets the maximum radiation dose near the surface of the skin. So using a bolus makes the radiotherapy more effective.

A bolus can be made from PLA using a 3D printer. The bolus must fit the shape of the patient's body exactly. This shape is found beforehand by giving the patient either a CAT scan or a PET scan.

- Explain how CAT scans and PET scans work.
- Discuss the advantages and disadvantages of having a scan to produce a bolus for radiotherapy.

CAT: A thin fan shaped beam of X-rays and a ring of detectors rotates about a patient. This moves along the patient taking images. These are combined with software to create a 3D image. ✓✓

PET: A positron emitting tracer is injected into the patient. As it decays, the positron annihilates a nearby electron producing two gamma photons that travel in opposite directions. These are detected by a ring of gamma cameras. The delay between photons arriving locates where the annihilation, and therefore the tracer, is in the body. ✓✓

[6]

Additional answer space if required

Both scans subject healthy tissue to ionising radiation and are expensive. A bolus means that a lower dose is required during therapeutic radiotherapy, so even though

The patient is exposed to harmful radiation to make the bolus, their overall exposure during treatment may be reduced which results in less harm to the patient. ✓✓

END OF QUESTION PAPER

ADDITIONAL ANSWER SPACE

If additional space is required, you should use the following lined page(s). The question number(s) must be clearly shown in the margin(s).

© OCR 2023

OCR
Oxford Cambridge and RSA

Copyright Information

OCR is committed to seeking permission to reproduce all third-party content that it uses in its assessment materials. OCR has attempted to identify and contact all copyright holders whose work is used in this paper. To avoid the issue of disclosure of answer-related information to candidates, all copyright acknowledgements are reproduced in the OCR Copyright Acknowledgements Booklet. This is produced for each series of examinations and is freely available to download from our public website (www.ocr.org.uk) after the live examination series.

If OCR has unwittingly failed to correctly acknowledge or clear any third-party content in this assessment material, OCR will be happy to correct its mistake at the earliest possible opportunity.

For queries or further information please contact The OCR Copyright Team, The Triangle Building, Shaftesbury Road, Cambridge CB2 8EA.

OCR is part of Cambridge University Press & Assessment, which is itself a department of the University of Cambridge.

© OCR 2023