OXFORD AQA
INTERNATIONAL QUALIFICATIONS

Please write clearly in block capitals.

Centre number | | | | | | Candidate number | | | | |

Surname StemUp Model Solution

Forename(s)

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I declare this is my own work.

INTERNATIONAL A-LEVEL
PHYSICS

Unit 4 Energy and Energy resources

Tuesday 16 January 2024 07:00 GMT Time allowed: 2 hours

Materials
For this paper you must have:
- a Data and Formulae Booklet as a loose insert
- a ruler with millimetre measurements
- a scientific calculator, which you are expected to use where appropriate
- a protractor.

Instructions
- Use black ink or black ball-point pen.
- Fill in the boxes at the top of this page.
- Answer **all** questions.
- You must answer the questions in the spaces provided. Do not write outside the box around each page or on blank pages.
- All working must be shown.
- If you need extra space for your answer(s), use the lined pages at the end of this book. Write the question number against your answer(s).
- Do all rough work in this book. Cross through any work you do not want to be marked.

Information
- The marks for questions are shown in brackets.
- The maximum mark for this paper is 80.

For Examiner's Use	
Question	Mark
1	
2	
3	
4	
5	
6	
7	
8–22	
TOTAL	

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Section A

Answer **all** questions in this section.

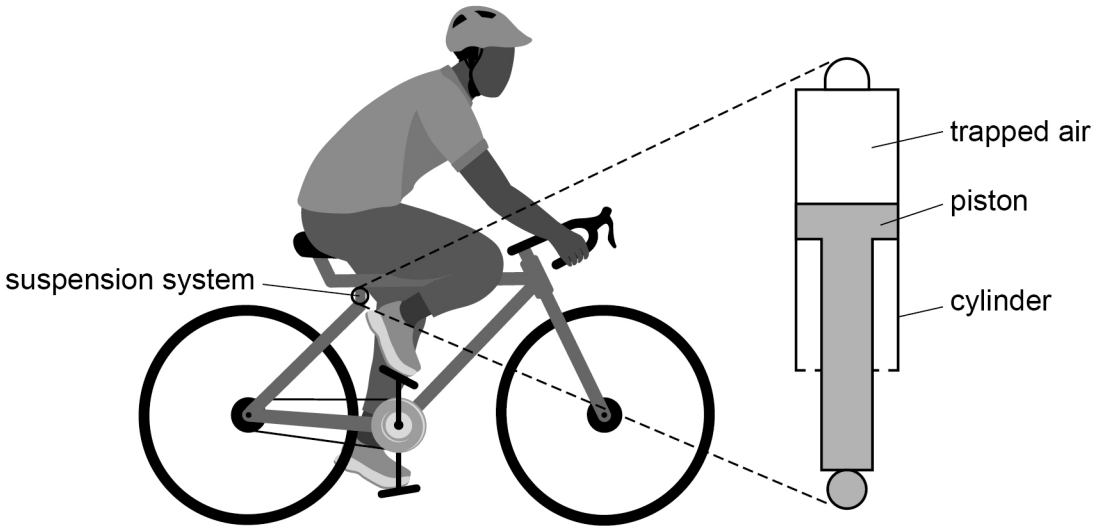
0 1 . 1 State what is meant by the internal energy of a system.

[2 marks]

The internal energy is the sum of the randomly distributed kinetic energies and potential energies of all the particles (molecules) in the system.

0 1 . 2 **Figure 1** shows an enlarged view of a cylinder used in a bicycle suspension system. Air trapped in the cylinder is compressed when a person is on the bicycle.

Figure 1



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The trapped air and the cylinder and piston are at the same temperature. As the person gets off the bicycle the trapped air expands.

The trapped air does $350\ \mathrm{J}$ of work and $20\ \mathrm{J}$ of energy is transferred by heating.

Calculate the change in internal energy ΔU of the trapped air as the person gets off the bicycle.

[2 marks]

$\Delta U = Q + W$

$Q = +20\ \mathrm{J}$ (energy in by heating), $W = -350\ \mathrm{J}$ (work done by the air)

$\Delta U = 20 + (-350)$

$\Delta U = -330\ \mathrm{J}$

$\Delta U =$ −330 J

4

Turn over for the next question

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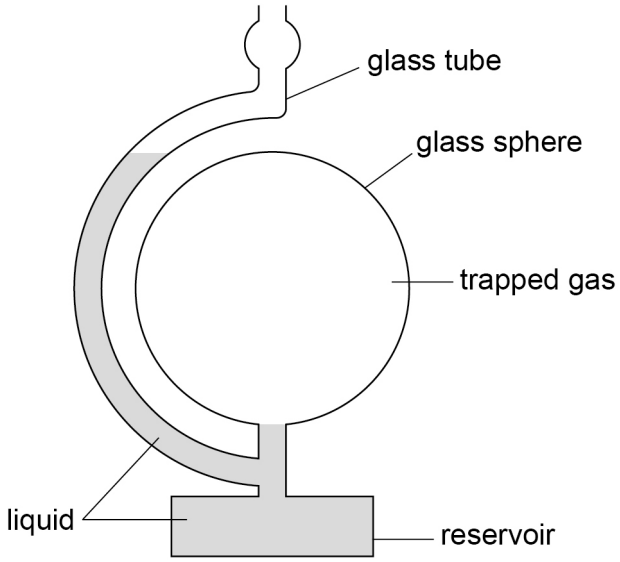
0 2 **Figure 2** shows a glass sphere containing a fixed mass of an ideal gas. The gas is trapped by a liquid in the glass tube and reservoir.

Figure 2



Under the following conditions, the trapped gas fills the sphere exactly:

pressure of gas = 102 kPa
mass of gas = 6.3×10^{-4} kg
mean square speed of gas molecules = 2.53×10^{5} m^2 s^{-2}

There are 1.3×10^{22} molecules in the trapped gas.

0 2 . 1 Calculate the radius of the sphere.

[3 marks]

$pV = 1/3\ Nm(c_{rms})^2$ where Nm = total mass = 6.3×10^{-4} kg

$V = Nm(c_{rms})^2 / 3p = 6.3 \times 10^{-4} \times 2.53 \times 10^{5} / (3 \times 1.02 \times 10^{5})$

$V = 5.21 \times 10^{-4}\ m^3$

$V = 4/3\ \pi r^3$ so $r = (3V / 4\pi)^{1/3} = (3 \times 5.21 \times 10^{-4} / 4\pi)^{1/3}$

$r = 4.99 \times 10^{-2}$ m $= 5.0 \times 10^{-2}$ m

radius = 5.0×10^{-2} m

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0 2 . 2 Calculate the average kinetic energy of a molecule of the gas.

[3 marks]

mass of one molecule $m = 6.3 \times 10^{-4} / 1.3 \times 10^{22} = 4.85 \times 10^{-26}$ kg

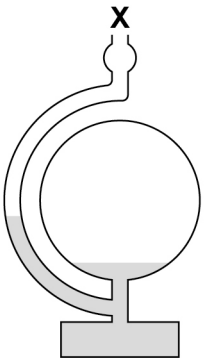
average $E_k = 1/2\ m(c_{rms})^2 = 1/2 \times 4.85 \times 10^{-26} \times 2.53 \times 10^5$

average $E_k = 6.1 \times 10^{-21}$ J

average kinetic energy = 6.1×10^{-21} J

0 2 . 3 The tube is open to the atmosphere at **X**. A change in atmospheric pressure causes some of the liquid to move into the sphere, as shown in **Figure 3**. The temperature of the trapped gas does not change.

Figure 3



Explain, with reference to the kinetic theory model, why the volume of the trapped gas decreases.

[3 marks]

The pressure of the gas in the sphere increases (atmospheric pressure has increased), so the rate of change of momentum of the molecules hitting the liquid surface and walls must increase.

The temperature is constant, so the mean speed of the molecules does not change and the average force per molecular collision is unchanged.

So the collision rate must increase: a smaller volume means the molecules hit the walls more often, so the volume decreases.

9

Turn over ►

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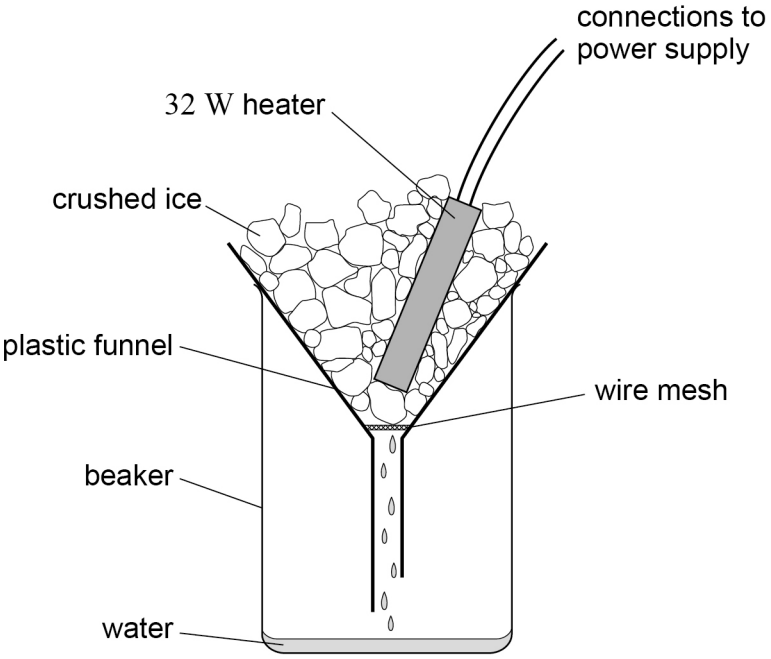
0 3 **Figure 4** shows apparatus used by a student in an experiment to estimate the specific latent heat of ice.

Figure 4



Crushed ice at a temperature of 0 °C is packed around an electrical heater which is initially switched off.
Water from melted ice passes through a wire mesh and is collected in a beaker.
More crushed ice is added to the plastic funnel to replace this melted ice.

Measurements are made to determine how much ice is melted by heating from the surroundings.
16.0 g of water is collected in 10.0 minutes with the heater switched off.

The heater is switched on and new measurements are made. The heater transfers energy at a rate of 32 W.
41.6 g of water is collected in 5.0 minutes with the heater switched on.

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0 3 . 1 Determine the specific latent heat of ice for this experiment.
State an appropriate unit for your answer.

[4 marks]

ice melted by surroundings in 5.0 min = 16.0 / 2 = 8.0 g

ice melted by heater in 5.0 min = 41.6 − 8.0 = 33.6 g = 0.0336 kg

energy from heater = Pt = 32 × 5.0 × 60 = 9600 J

Q = mL so L = 9600 / 0.0336 = 2.86×10^5 J kg^{-1}

specific latent heat of ice = 2.86×10^5 unit = J kg^{-1}

The student obtains the following data for the funnel:

thickness of plastic = 1.7 mm
temperature of outer surface = 5.5 °C
area in contact with melting ice = 1.75×10^{-2} m^2
thermal conductivity of plastic = 0.12 W m^{-1} K^{-1}

0 3 . 2 Determine the ratio

$$\frac{\text{rate of heat transfer from heater}}{\text{rate of heat transfer by conduction through funnel}}$$

[2 marks]

rate of heat transfer by conduction = kAΔθ / L

= $0.12 \times 1.75 \times 10^{-2} \times 5.5 / 1.7 \times 10^{-3}$ = 6.8 W

ratio = 32 / 6.8 = 4.7

ratio = 4.7

Question 3 continues on the next page

Turn over ►

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0 3 . 3 The student suggests that the mass of ice melted before the heater is switched on is only due to heat transfer by conduction through the plastic funnel.

Show, using your answer to Question **03.2** and data from page 6, that the student's suggestion is incorrect.

[2 marks]

mass melted by heater in 5 min / mass melted with heater off in 5 min

= (41.6 − 16.0/2) / (16.0/2) = 33.6 / 8.0 = 4.2

4.2 is not equal to the ratio 4.7 from 03.2, so conduction through the funnel alone does not explain the melting; the suggestion is incorrect.

0 3 . 4 The value for the specific latent heat of ice obtained from this experiment is less than the accepted value.

Explain **two** changes to the experimental procedure that will increase the accuracy of the result.

[2 marks]

1 Cover the top of the ice (insulate the funnel) or do the experiment in cooler surroundings, so that less energy reaches the ice from the room and less ice melts that is not due to the heater.

2 Dry the crushed ice before use to remove water that has already melted, so the measured mass of melted ice is not too big; also increase the heater power so heating from the surroundings is less significant.

10

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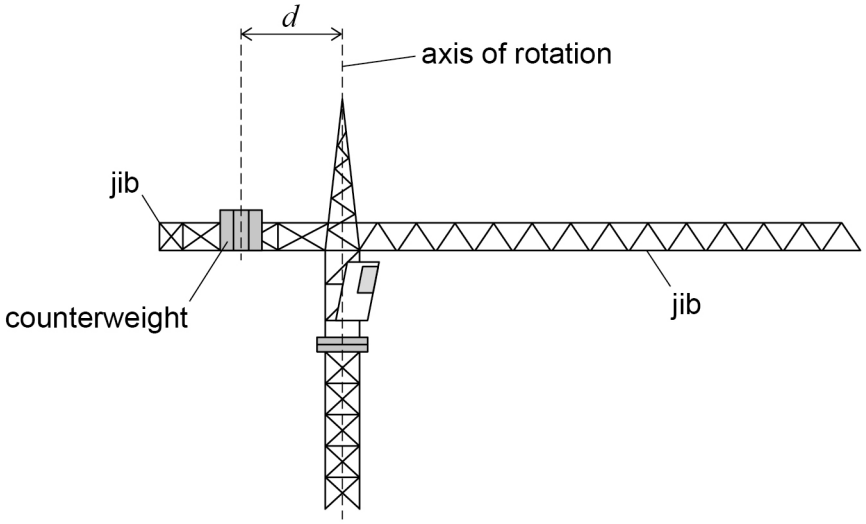
0 4 **Figure 5** is the side view of a crane. The jib is the horizontal arm of the crane and has a counterweight attached to it.
The jib and counterweight can rotate in a horizontal circle.
The distance d of the counterweight from the axis of rotation can be adjusted.

Figure 5



0 4 . 1 Initially d is $7.2\ \mathrm{m}$ and the total moment of inertia of the jib and counterweight about the axis of rotation is $3.75 \times 10^7\ \mathrm{kg\ m^2}$.

The counterweight is now moved so that d is $5.6\ \mathrm{m}$.
The total moment of inertia of the jib and counterweight is now $3.62 \times 10^7\ \mathrm{kg\ m^2}$.

Calculate the mass of the counterweight.

[3 marks]

$I = I_{jib} + Md^2$

$3.75 \times 10^7 = I_{jib} + M \times 7.2^2$ and $3.62 \times 10^7 = I_{jib} + M \times 5.6^2$

difference: $3.75 \times 10^7 - 3.62 \times 10^7 = M(7.2^2 - 5.6^2)$

$1.3 \times 10^6 = 20.48\ M$

$M = 6.35 \times 10^4\ \mathrm{kg} = 6.3 \times 10^4\ \mathrm{kg}$

mass of counterweight = 6.3×10^4 kg

Question 4 continues on the next page

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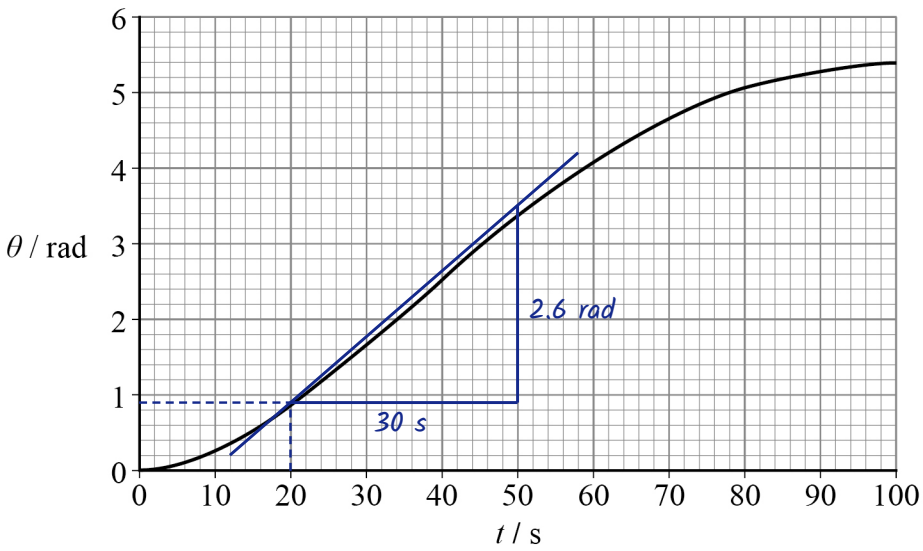
At time $t = 0$ the jib is at rest.
A torque is then applied to make the jib and counterweight rotate.

Figure 6 shows the variation of angular displacement θ with t.

A constant resistive torque of 3.5×10^4 N m acts on the jib when it is moving.
The total moment of inertia of the jib and counterweight is 3.62×10^7 kg m^2.

Figure 6



0 4 . 2 From $t = 0$ to $t = 20$ s, the angular acceleration is constant.

Calculate the applied torque that produces this acceleration.

[4 marks]

from graph: θ = 0.90 rad at t = 20 s, starting from rest

$\theta = \omega_0 t + 1/2\ \alpha t^2$ so $\alpha = 2\theta / t^2 = 2 \times 0.90 / 20^2 = 4.5 \times 10^{-3}$ rad s^{-2}

resultant torque $T = I\alpha = 3.62 \times 10^7 \times 4.5 \times 10^{-3} = 1.63 \times 10^5$ N m

applied torque $= 1.63 \times 10^5 + 3.5 \times 10^4$

applied torque $= 1.98 \times 10^5$ N m

applied torque = 1.98×10^5 N m

Do not write outside the box

0 4 . 3 For safety, the angular speed of the jib must not exceed $0.10\ \text{rad s}^{-1}$.

Determine whether the jib exceeds this speed as it rotates.

[3 marks]

maximum angular speed = gradient of the steepest part of the graph

(tangent drawn on Figure 6, between t = 20 s and t = 50 s)

$\omega_{max} = \Delta\theta / \Delta t = (3.5 - 0.9) / (50 - 20) = 2.6 / 30$

$\omega_{max} = 0.087\ \text{rad s}^{-1}$

0.087 rad s^{-1} is less than 0.10 rad s^{-1}, so the jib does not exceed the safe speed.

0 4 . 4 On another occasion the jib is moving at a constant angular speed ω. The applied torque is removed and the jib moves through an angle θ_1 before coming to rest.

The distance d is increased and the jib is again made to move at a constant angular speed ω. The applied torque is removed and the jib now moves through an angle θ_2 before coming to rest.

The resistive torque does not change.

Compare θ_2 with θ_1.
Explain your answer.

[3 marks]

θ_2 is greater than θ_1. Increasing d increases the moment of inertia I of the jib and counterweight.

At the same ω the initial kinetic energy $1/2\ I\omega^2$ is greater, so the resistive torque must do more work to stop it.

Work done = Tθ with T unchanged, so $\theta_2 > \theta_1$ (also $\alpha = T/I$ is smaller, and $\theta = \omega^2/2\alpha$ is larger).

13

Turn over ►

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0 5 A solar array is made from identical solar cells.

Table 1 contains data about one solar cell in the array when light of intensity L_1 is incident on the solar cell.

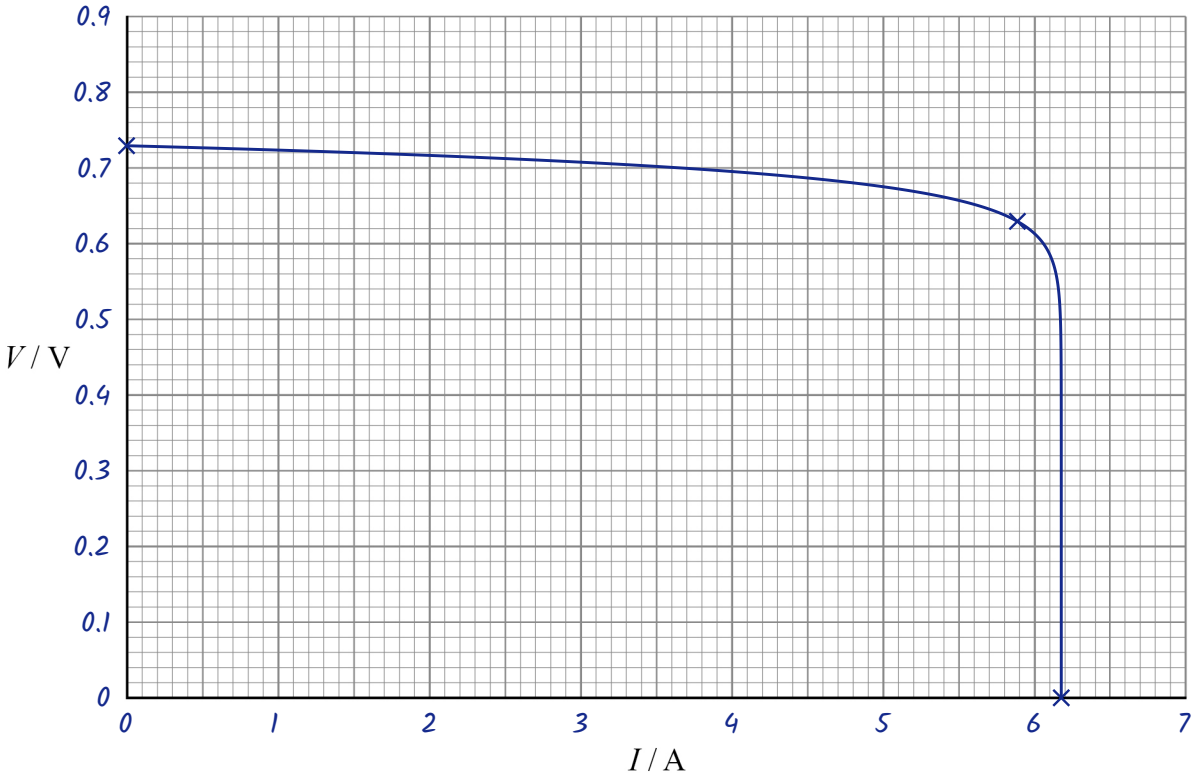
Table 1

Quantity	Value
short-circuit current	6.18 A
open-circuit voltage	0.73 V
current at maximum power	5.89 A
voltage at maximum power	0.63 V

0 5 . 1 Sketch, on **Figure 7**, a V–I characteristic for the solar cell at intensity L_1. Label the axes with suitable scales.

[4 marks]

Figure 7



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During a test, light of intensity L_2 is incident normally on the solar cell. The efficiency of the solar cell is 24%.
The maximum power output of the solar cell is now 3.5 W and the voltage at maximum power is 0.61 V.

0 5 . 2 The area of the solar cell is 150 cm^2.

Calculate L_2.

[3 marks]

input power = output power / efficiency = 3.5 / 0.24 = 14.6 W

area = 150 cm^2 = 150 × 10^{-4} m^2 = 1.50 × 10^{-2} m^2

L_2 = power / area = 14.6 / 1.50 × 10^{-2} = 970 W m^{-2}

L_2 = 970 W m^{-2}

0 5 . 3 When the intensity is L_2 the solar array has a maximum power output of 364 W.
The voltage across the array at maximum power is 4.88 V.

Deduce the arrangement of cells in the array.

[3 marks]

number of cells = 364 / 3.5 = 104

cells in series in each row = 4.88 / 0.61 = 8

current per cell = 3.5 / 0.61 = 5.74 A; total current = 364 / 4.88 = 74.6 A

number of rows in parallel = 74.6 / 5.74 = 13 (check: 8 × 13 = 104)

An 8 × 13 array: 13 parallel rows, each with 8 cells in series.

10

Turn over ►

Do not write outside the box

0 6 Fast-moving neutrons are released during fission in a thermal nuclear reactor. The function of part **X** of this reactor is to reduce the speed of these fast-moving neutrons to thermal speeds.

0 6 . 1 Name part **X**.

[1 mark]

Moderator

0 6 . 2 Name **one** suitable material for **X**.

[1 mark]

Graphite

0 6 . 3 Explain why the fast-moving neutrons need to be reduced to thermal speeds to maintain a chain reaction in this reactor.

[2 marks]

Thermal (slow) neutrons have a much higher probability of being absorbed by U-235 nuclei and causing fission than fast neutrons. For a chain reaction, on average each fission must lead to at least one further fission.

0 6 . 4 A fast-moving neutron has a kinetic energy of 2.4 MeV. After one collision, the kinetic energy is reduced to 1.8 MeV.

Estimate the kinetic energy of the neutron after three more collisions.

Assume that the neutron's kinetic energy decreases by the same percentage in each collision.

[2 marks]

fraction of kinetic energy left after each collision = 1.8 / 2.4 = 0.75

after three more collisions: $E_k = 1.8 \times 0.75^3$

$E_k = 0.76$ MeV

kinetic energy = 0.76 MeV

Do not write outside the box

0 6 . 5 Another thermal nuclear reactor uses a different material for **X**. In this reactor, a fast-moving neutron needs fewer collisions to reduce it to thermal speeds.

Suggest why fewer collisions are needed when using **X**.

[2 marks]

The mass of a nucleus of X is closer to the mass of a neutron (e.g. a lighter nucleus).

So in each collision a greater percentage of the neutron's kinetic energy is transferred to the nucleus, and fewer collisions are needed.

0 6 . 6 One fission reaction is

$$^{235}_{92}\text{U} + ^{1}_{0}\text{n} \rightarrow ^{137}_{52}\text{Te} + ^{97}_{40}\text{Zr} + 2\,^{1}_{0}\text{n}$$

Calculate, in MeV, the energy released in this reaction.

mass of $^{235}_{92}\text{U}$ = 235.0439 u

mass of $^{137}_{52}\text{Te}$ = 136.9256 u

mass of $^{97}_{40}\text{Zr}$ = 96.9110 u

mass of $^{1}_{0}\text{n}$ = 1.00867 u

[4 marks]

$\Delta m = (235.0439 + 1.00867) - (136.9256 + 96.9110 + 2 \times 1.00867)$

$= 235.0439 - 136.9256 - 96.9110 - 1.00867$

$= 0.1986$ u

1 u = 931.5 MeV

energy released = $0.1986 \times 931.5 = 185$ MeV

energy released = 185 MeV

Question 6 continues on the next page

Do not write outside the box

0 6 . 7 State **one** risk and **one** benefit in the use of thermal nuclear reactors for power generation.

[2 marks]

risk Leaks of radioactive material or radioactive waste can cause environmental damage.

benefit No greenhouse gases are emitted, so it reduces dependence on fossil fuels.

14

Do not write outside the box

0 7 The average radius R of a nucleus is related to the nucleon number A by

$$R = R_0 A^{\frac{1}{3}}$$

0 7 . 1 Show that this relationship is consistent with the assumption that all nuclei have the same density.

[2 marks]

mass of nucleus ∝ A (mass ≈ A × u)

$R = R_0 A^{1/3}$ so $R^3 = R_0^3 A$, and volume = $4/3\ \pi R^3 \propto R^3 \propto A$

density = mass / volume = $Au / (4/3\ \pi R_0^3 A) = 3u / 4\pi R_0^3$

u, R_0 and π are constants, so A / R^3 is constant and

the density is the same for all nuclei

0 7 . 2 A helium $\left({}^{4}_{2}\mathrm{He}\right)$ nucleus has a radius of 1.68×10^{-15} m.

Calculate, in fm, the radius of a gold $\left({}^{197}_{79}\mathrm{Au}\right)$ nucleus.

[3 marks]

$R_0 = R / A^{1/3} = 1.68 \times 10^{-15} / 4^{1/3} = 1.06 \times 10^{-15}$ m = 1.06 fm

$R_{Au} = R_0 \times 197^{1/3} = 1.06 \times 5.82$

R_{Au} = 6.16 fm

radius = 6.16 fm

5

END OF SECTION A

Do not write outside the box

Section B

Each of the questions in this section is followed by four responses, **A**, **B**, **C** and **D**.

For each question select the best response.

Only **one** answer per question is allowed.
For each question, completely fill in the circle alongside the appropriate answer.

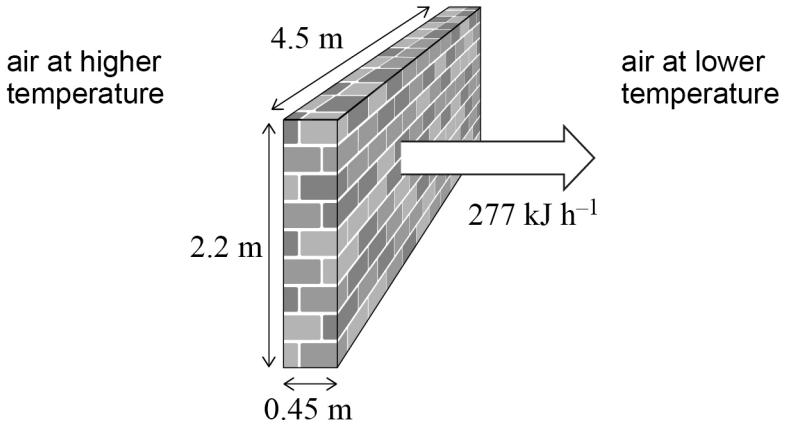
CORRECT METHOD ● WRONG METHODS

If you want to change your answer you must cross out your original answer as shown.

If you wish to return to an answer previously crossed out, ring the answer you now wish to select as shown.

You may do your working in the blank space around each question but this will not be marked.
Do **not** use additional pages for this working.

0 8 The wall of a building separates air at different temperatures.
It has a U-value of $0.65\ \mathrm{W\ m^{-2}\ K^{-1}}$.
The wall is $4.5\ \mathrm{m}$ wide, $2.2\ \mathrm{m}$ high and $0.45\ \mathrm{m}$ thick.



The rate of energy transfer through the wall is $277\ \mathrm{kJ\ h^{-1}}$.

What is the temperature difference across the wall?

[1 mark]

A 5.4 K

B 12 K

C 17 K

D 285 K

Do not write outside the box

0 9 A fixed mass of an ideal gas has a pressure P and a volume V.
The temperature of the gas increases from $273\ \mathrm{K}$ to $410\ \mathrm{K}$.

Which row shows possible values for the new pressure and new volume of the gas?

[1 mark]

	Pressure	Volume	
A	P	$\frac{V}{2}$	○
B	$2P$	V	○
C	$2P$	$\frac{V}{3}$	○
D	$3P$	$\frac{V}{2}$	●

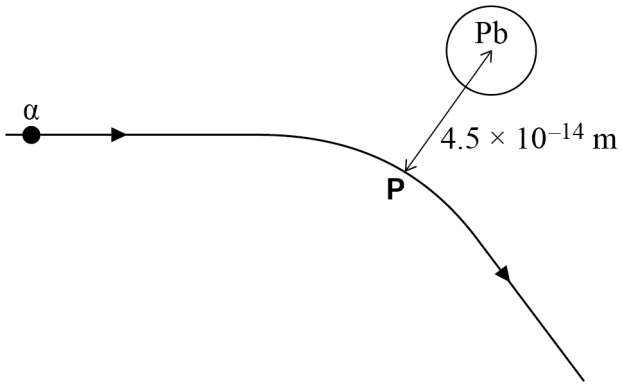
Turn over for the next question

Do not write outside the box

1 0 An alpha particle (α) has an initial kinetic energy of 2.1×10^{-12} J.

It travels towards a lead $\left({}^{179}_{82}\text{Pb}\right)$ nucleus.

Assume that the lead nucleus remains stationary.



The alpha particle is closest to the lead nucleus at point **P**.

The separation between the centre of the lead nucleus and the alpha particle at **P** is 4.5×10^{-14} m.

What is the kinetic energy of the alpha particle at **P**?

[1 mark]

A 2.7×10^{-13} J ⬭

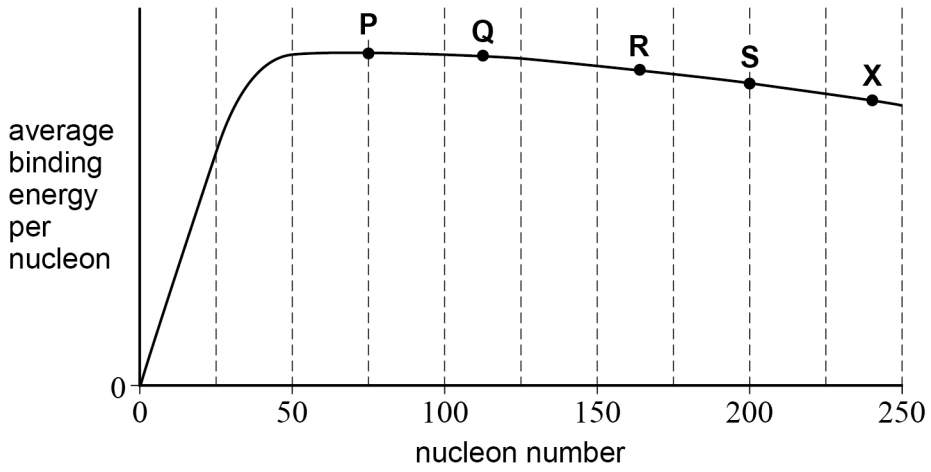
B 8.4×10^{-13} J ⬭

C 1.3×10^{-12} J ⬬

D 1.7×10^{-12} J ⬭

Do not write outside the box

1 1 Nuclei **P**, **Q**, **R**, **S** and **X** are shown on a plot of average binding energy per nucleon against nucleon number.



X undergoes nuclear fission to produce a pair of nuclei.

Which pair of nuclei are possible products of this fission?

[1 mark]

A **P** and **Q** ○

B **P** and **R** ●

C **P** and **S** ○

D **Q** and **R** ○

1 2 The solar fusion (hydrogen) cycle is a series of fusion reactions that occur in the Sun.

Which is a reaction in the solar fusion cycle?

[1 mark]

A $^{2}_{1}\text{H} + ^{2}_{1}\text{H} \rightarrow ^{4}_{2}\text{He}$ ○

B $^{3}_{1}\text{H} + ^{1}_{1}\text{H} \rightarrow ^{4}_{2}\text{He}$ ○

C $^{3}_{2}\text{He} + ^{2}_{1}\text{H} \rightarrow ^{4}_{2}\text{He} + ^{1}_{1}\text{H}$ ○

D $^{3}_{2}\text{He} + ^{3}_{2}\text{He} \rightarrow ^{4}_{2}\text{He} + 2^{1}_{1}\text{H}$ ●

Turn over ►

Do not write outside the box

1 3 A mixture of two unreactive gases **P** and **Q** is at a constant temperature.

The particles of **P** each have a mass m. The particles of **Q** each have a mass $2m$.

The root mean square speed of the particles of **P** is v.

What is the root mean square speed of the particles of **Q**?

[1 mark]

A $\frac{v}{2}$

B $\frac{v}{\sqrt{2}}$

C v

D $\sqrt{2}\,v$

1 4 A wind turbine generator (WTG) has blades that sweep out a circle of diameter $4.20\ \mathrm{m}$.

The power output of the WTG is 40% of the maximum power available from the wind.

At one instant, the speed of the wind on the blades is $6.9\ \mathrm{m\ s^{-1}}$.

What is the maximum electrical power available from the WTG at this instant?

density of air $= 1.2\ \mathrm{kg\ m^{-3}}$

[1 mark]

A $1.1\ \mathrm{kW}$

B $2.7\ \mathrm{kW}$

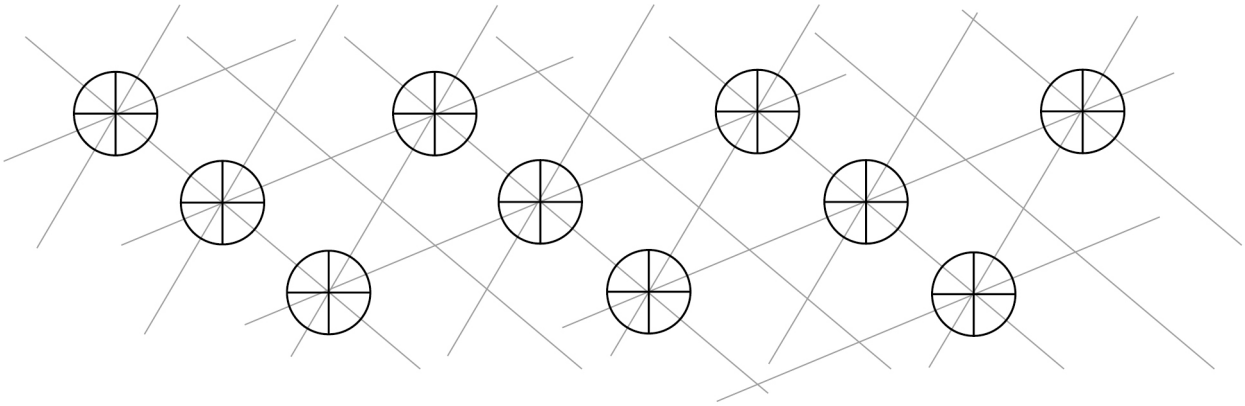
C $4.4\ \mathrm{kW}$

D $6.8\ \mathrm{kW}$

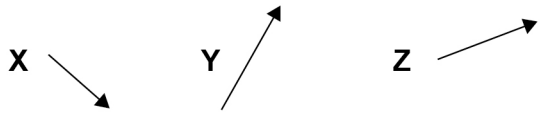
Do not write outside the box

1 5 The diagram shows the plan view of a wind farm that consists of ten identical wind turbines.
The location of each wind turbine is represented by ⊕

The wind farm is on horizontal land.



plan view



At different times, the wind blows in the horizontal directions given by the arrows **X**, **Y** and **Z**.

In which wind direction is the effect of wind shadow the largest and in which direction is it the smallest?

[1 mark]

	Largest	Smallest
A	**X**	**Y**
B	**X**	**Z**
C	**Y**	**X**
D	**Z**	**Y**

Turn over ►

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1 6 The components of a pumped storage system (PSS) include a turbine and a generator.

Which statement is correct?

[1 mark]

A Gravitational potential energy of the water is transferred to kinetic energy in the turbine. ○

B The generator transfers electrical energy to kinetic energy of the water. ○

C The turbine acts as a motor when energy is being stored in the PSS. ○

D Over a cycle, the electrical energy input to the PSS is greater than the electrical energy output. ●

1 7 Which is a defining property of a back-up power station?

[1 mark]

A It uses wind, solar or hydroelectric energy sources. ○

B It can be switched on quickly in periods of high demand. ●

C It can store excess energy from base-power stations. ○

D It is more efficient than a base-power station. ○

1 8 Which is the fundamental (base) unit for specific heat capacity?

[1 mark]

A $kg\ m^2\ s^{-2}\ K^{-1}$ ○

B $kg^{-1}\ m^2\ s^{-2}\ K^{-1}$ ○

C $m^2\ s^{-2}\ K^{-1}$ ●

D $kg\ m^2\ s^{-4}\ K^{-1}$ ○

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1 9 A satellite orbits the Sun at an orbital radius of 2.2×10^{11} m.

The satellite has an array of five solar panels. Each panel has an area of $20\ \text{m}^2$.

What is the maximum rate at which solar energy is incident on the array?

power output of Sun = 3.8×10^{26} W

[1 mark]

A 6.25×10^{2} W ○

B 1.25×10^{4} W ○

C 6.25×10^{4} W ●

D 2.50×10^{5} W ○

Turn over for the next question

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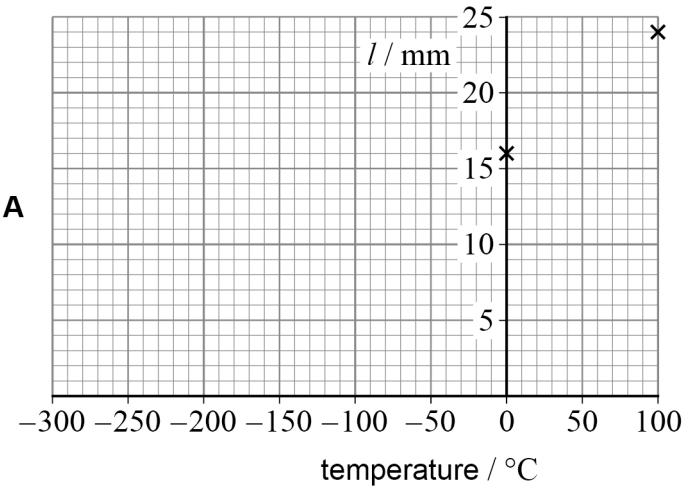
2 0 In four experiments **A**, **B**, **C** and **D** the length l of a column of trapped air in a thin tube is measured over a range of temperatures.

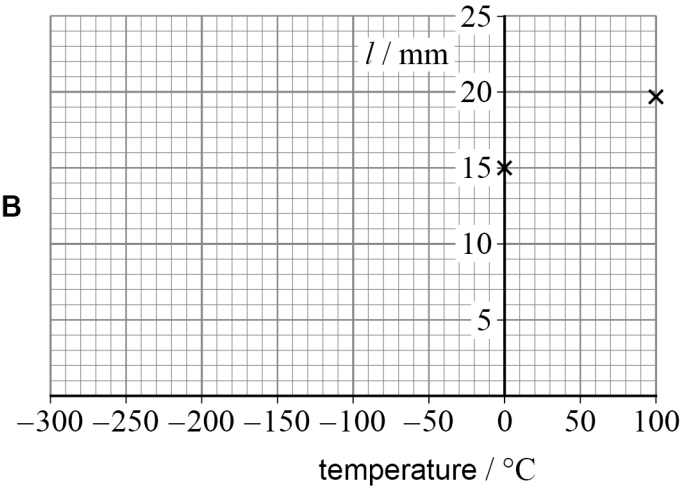
The amount of trapped air in the tube is different in each experiment. The pressure of the trapped air in the tube is the same in each experiment and remains constant.

The graph of length l against temperature is given for each experiment.

Experiment **A**



Experiment **B**



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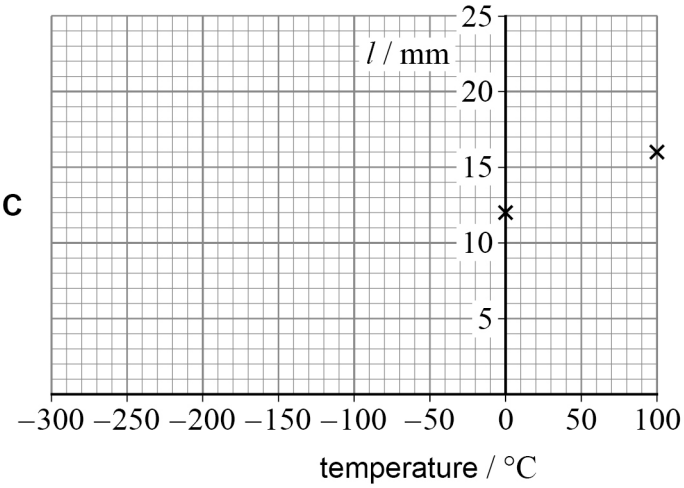
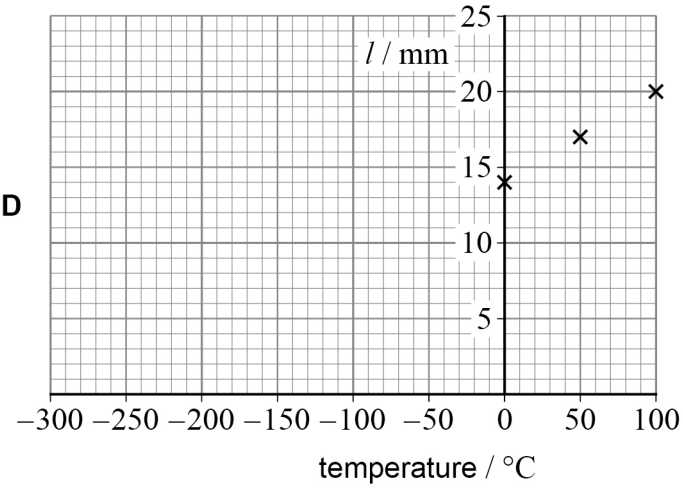
Experiment **C**



Experiment **D**



Which experiment gives the most accurate value of absolute zero?

[1 mark]

A ○

B ○

C ●

D ○

Turn over ►

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2 1 The table shows the readings taken to determine the amount of gas n, in mol, in a sample.

Quantity	Reading	Absolute uncertainty
pressure	1.00×10^5 Pa	1×10^3 Pa
temperature	27.0 °C	0.5 °C
volume	1.00 m^3	0.01 m^3

The uncertainty in the molar gas constant is negligible.

What is the percentage uncertainty in n?

[1 mark]

A 1.8% ○

B 2.2% ●

C 3.9% ○

D 6.0% ○

2 2 A nuclear fusion reactor uses plasma containment.

Which is **not** a difficulty for this type of reactor?

[1 mark]

A confining the plasma ○

B maintaining the high temperature of the plasma ○

C processing radioactive products of the reactions ●

D sustaining fusion over a period of time ○

15

END OF QUESTIONS

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