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OCR A LEVEL PHYSICS A (H556): QUESTIONS BY TOPIC

Forces in action (3.2)

A Level Physics A (H556) · Module 3: Forces and motion

94 questions · 609 marks · Mark schemes included

OCR A Level Physics A (H556), June 2017 – June 2025

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HOW TO USE THIS BOOKLET

Questions are grouped by specification sub-topic and run from the lowest mark tariff to the highest within each one.
Click any row below to jump straight to that sub-topic or question.
On every question page, click ANSWER in the top-right corner to jump to its mark scheme.
Diagrams, graphs, tables and data are printed exactly as they appeared in the original papers.

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QUESTIONS

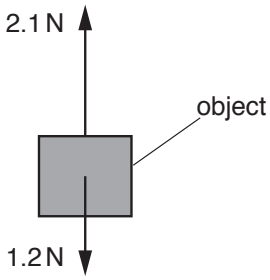
94 questions · 609 marks · 4 sub-topics

SUB-TOPIC 3.2.1

DYNAMICS AND TYPES OF FORCE

Sub-topic 3.2.1 · 48 questions · 299 marks · lowest tariff first

8 The diagram shows two opposite vertical forces of magnitude 1.2 N and 2.1 N acting on an object.



Which of the following statements could be correct?

1 The object is accelerating and moving up.
2 The object is decelerating and moving down.
3 The magnitude of the resultant force is 0.9 N.

A Only 3

B Only 1 and 3

C Only 2 and 3

D 1, 2 and 3

Your answer ☐ **[1]**

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Turn over

11 An electron moves in a circle of radius 2.0 cm in a uniform magnetic field of flux density 170 mT.

What is the momentum of this electron?

A $3.4 \times 10^{-3}\,\text{kg m s}^{-1}$

B $5.4 \times 10^{-17}\,\text{kg m s}^{-1}$

C $1.4 \times 10^{-18}\,\text{kg m s}^{-1}$

D $5.4 \times 10^{-22}\,\text{kg m s}^{-1}$

Your answer ☐ **[1]**

13 A beam of charged particles is not deflected when it passes through a region where both electric and magnetic fields are present.

Which statement is **not** correct?

A All the particles have the same speed.

B The resultant force on each particle is zero.

C The magnetic force is equal to the electric force on each particle.

D The magnetic field and the electric field are in the same direction.

Your answer ☐ **[1]**

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11 The table below shows some data on two wires **X** and **Y**.

Wire	Young modulus of material / GPa	Cross-sectional area of wire / mm^2
X	120	1.0
Y	200	2.0

The wires **X** and **Y** have the same original length. The tension in each wire is the same. Both wires obey Hooke's law.

What is the value of the ratio $\frac{\text{extension of } \mathbf{X}}{\text{extension of } \mathbf{Y}}$?

A 0.30

B 1.7

C 2.0

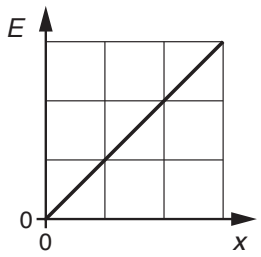
D 3.3

Your answer ☐ **[1]**

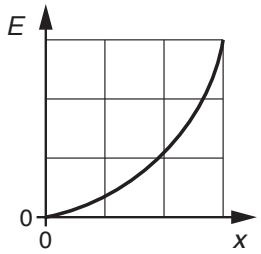
15 An object oscillates with simple harmonic motion.

Which graph **best** shows the variation of its potential energy E with distance x from the equilibrium position?

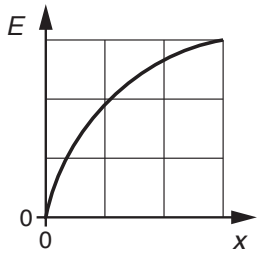
A



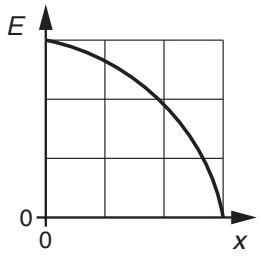
B



C



D



Your answer ☐ **[1]**

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SECTION B

Answer **all** the questions.

8 An object is falling.
The weight of the object is 4.5 N.
The wind provides a horizontal force of magnitude *F* on the object.
The **resultant** force on the object is 5.8 N.
Air resistance and upthrust on the object are negligible.

What is the value of *F*?

A 1.3 N

B 3.7 N

C 7.3 N

D 13 N

Your answer ☐ **[1]**

3 A tennis ball is hit with a racket. The force applied by the racket on the ball is *F*. The ball has a vertical path through the air.

Which statement is correct when the ball is at its **maximum** height?

A The ball has a downward acceleration.

B The force acting on the ball is *F*.

C The ball experiences greatest drag.

D The weight of the ball is equal to the drag.

Your answer ☐ **[1]**

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13 The Young modulus E of a metal can be determined using the expression $E = \frac{4F}{\varepsilon\pi d^2}$, where F is the tension in the wire, d is the diameter of the wire and ε is the strain of the wire.

Here is some data.

Quantity	Percentage uncertainty
F	5.3
ε	1.2
d	1.0

What is the percentage uncertainty in the calculated value of E?

A 2.1 %

B 6.4 %

C 7.5 %

D 8.5 %

Your answer ☐ **[1]**

2 Which sequence shows the materials arranged in the order of increasing number density of charge carriers?

increasing number density ⟶

A conductor, insulator, semiconductor

B conductor, semiconductor, insulator

C insulator, semiconductor, conductor

D semiconductor, insulator, conductor

Your answer ☐ **[1]**

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4 A student is doing an experiment on the magnetic force experienced by a current-carrying wire in a uniform magnetic field. The magnetic flux density *B* can be varied.

For a particular flux density, the current in the wire is 2.0A. The length of the wire in the field is 0.12m. The angle between the current and the magnetic field is 30°. The force experienced by the wire is 7.7×10^{-2}N.

The student calculates *B* and records the results in a table.

Which row shows the correct table heading for *B* and the correct value for *B*?

	Table heading for *B*	**Value for *B***
A	*B*/T	0.37
B	*B*/T	0.64
C	*B*/Wb	0.37
D	*B*/Wb	0.64

Your answer ☐ **[1]**

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1 Faraday's law of electromagnetic induction is written below with **two** terms missing.

The ..... induced in a circuit is directly proportional to the rate of change of magnetic flux ..... .

What are the **two** missing terms?

A current, density

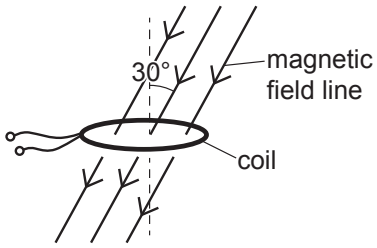
B current, linkage

C electromotive force, density

D electromotive force, linkage

Your answer ☐ **[1]**

12 A flat coil has 200 turns and a cross-sectional area of $1.20 \times 10^{-4}\,m^2$.



The coil is placed horizontally in a uniform magnetic field. The magnetic flux density is 0.050 T. The magnetic field is at an angle of 30.0° to the vertical.

What is the magnetic flux linkage for this coil?

A 3.00×10^{-6} Wb

B 5.20×10^{-6} Wb

C 6.00×10^{-4} Wb

D 1.04×10^{-3} Wb

Your answer ☐ **[1]**

3 A student has plotted a velocity against time graph for a trolley moving down a ramp.

Which of the following pair of quantities can be determined from the gradient of the graph and the area under the graph?

A acceleration, displacement

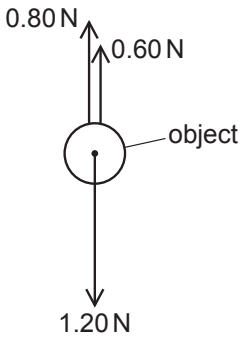
B acceleration, impulse

C displacement, kinetic energy

D force, work done

Your answer ☐ **[1]**

4 The diagram below shows the directions and magnitudes of the three forces acting on an object at a specific time as it moves through water.



The weight of the object is 1.20 N, the upthrust on the object is 0.80 N and the drag is 0.60 N.

Which statement is correct about this object at this specific time?

A It has reached its terminal velocity.

B It is accelerating.

C It is decelerating.

D It is moving upwards.

Your answer ☐ **[1]**

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Turn over

7 A particle is moving at right angles to a uniform magnetic field of flux density *B*. The particle has mass *m*, charge *q* and moves in a circular arc of radius *r* in the region of the magnetic field.

What quantities are required to determine the momentum of this particle?

A *B*, *q* and *r*

B *B*, *q* and *m*

C *B*, *q*, *r* and *m*

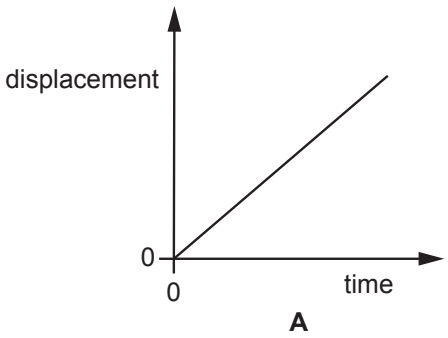
D *q*, *r* and *m*

Your answer ☐ **[1]**

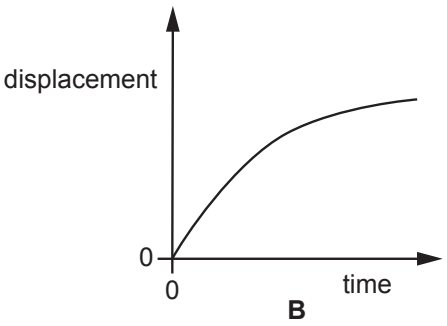
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3 The resultant force acting on a moving object is zero.

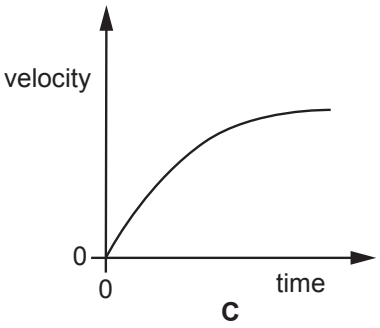
Which graph shows this?



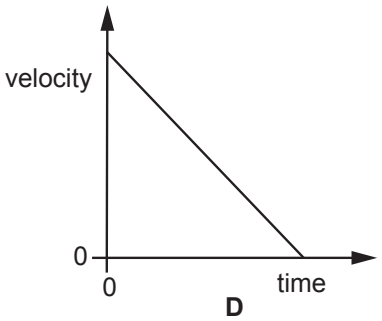
A



B



C



D

Your answer ☐ **[1]**

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3 A rubber bung is attached to a string. The bung is whirled around in a horizontal circle of radius r. The rotational period of the bung is T. The tension in the string is kept constant as the bung is whirled around at different speeds.

Which relationship is correct for this whirling bung?

A $T \propto r$

B $T^2 \propto r$

C $T \propto r^2$

D $T \propto \sqrt{r}$

Your answer ☐ **[1]**

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9 A mass suspended from a spring is pulled down 0.05 m from the equilibrium point and released.

It oscillates in simple harmonic motion. The frequency of the motion is 2 Hz.

At time $t = 0$ the mass passes through the equilibrium point.

What is the displacement in metres from the equilibrium point at time t?

A $0.05 \cos 2t$

B $0.05 \cos 4\pi t$

C $0.05 \sin 2t$

D $0.05 \sin 4\pi t$

Your answer ☐ **[1]**

11 A car drives over a bridge at speed v. The path of the car is part of a vertical circle of radius r. The mass of the driver is m.

At the top of the bridge the driver of the car experiences apparent weightlessness and no normal contact force from the car seat.

The acceleration of free fall is g.

Which statement is correct?

A $mg = 0$

B $v \geqslant gr$

C $v^2 \geqslant gr$

D $mv^2 \geqslant gr$

Your answer ☐ **[1]**

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11 At the Earth's equator the magnetic flux density B is approximately 25 μT.

What is the magnitude of the force on an electron with velocity $v = 100\,\text{km}\,\text{s}^{-1}$ as it is moving perpendicular to the Earth's magnetic field at the equator?

A $4.0 \times 10^{-25}\,\text{N}$

B $4.0 \times 10^{-22}\,\text{N}$

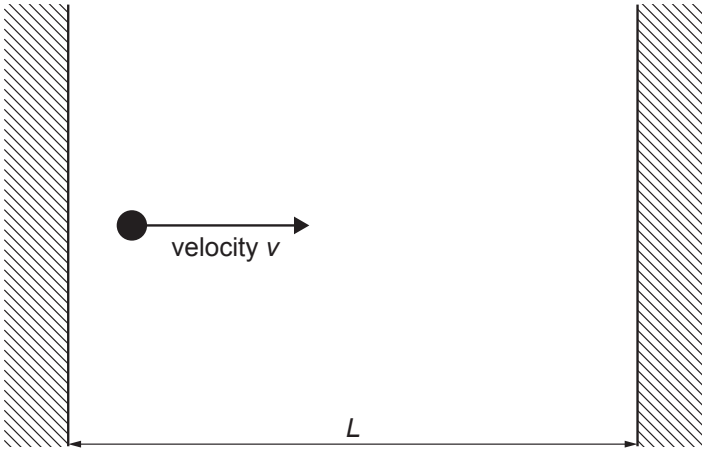
C $4.0 \times 10^{-19}\,\text{N}$

D $4.0 \times 10^{-16}\,\text{N}$

Your answer ☐ **[1]**

6 A small particle of mass m is travelling horizontally between two parallel walls with a velocity v. The weight of the particle is equal to the upthrust caused by the air. The distance between the walls is L. The effect of drag on the particle is negligible.

After colliding with a wall the particle rebounds with a velocity of equal magnitude and travels in the opposite direction, hitting the opposite wall. The motion continues.



Which row in the table is correct?

	Change in momentum during each collision	Time between collisions with the <u>same</u> wall	Average force exerted on the wall
A	mv	$\frac{2L}{v}$	$\frac{mv^2}{2L}$
B	$2mv$	$\frac{2L}{v}$	$\frac{mv^2}{L}$
C	$2mv$	$\frac{L}{v}$	$\frac{2mv^2}{L}$
D	$2mv$	$\frac{2L}{v}$	$\frac{2m}{L}$

Your answer ☐

[1]

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4 The current in a copper wire of radius 2.5×10^{-4} m is 1.4 A.

The number density of charge carriers (electrons) in copper is $8.5 \times 10^{28}\,m^{3}$.

What is the mean drift velocity of the electrons in the wire?

A $2.1 \times 10^{-4}\,mm\,s^{-1}$

B $0.13\,mm\,s^{-1}$

C $0.52\,mm\,s^{-1}$

D $1.9\,mm\,s^{-1}$

Your answer ☐

[1]

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Turn over

11 A proton with kinetic energy 1.6×10^{-17} J is travelling at right angles to a magnetic field. The magnetic flux density is 0.050 T.

What is the magnitude of the force on the proton?

A 8.0×10^{-19} N

B 1.1×10^{-15} N

C 2.8×10^{-6} N

D 6900 N

Your answer ☐

[1]

21 Fig. 21.1 shows a coil of a simple generator rotating in a uniform magnetic field.

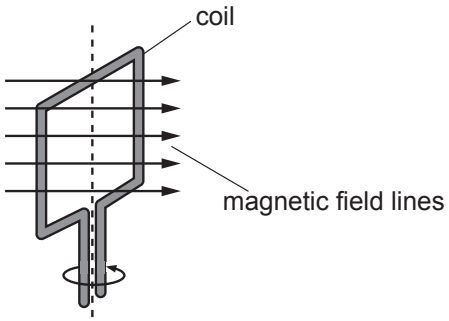


Fig. 21.1

The coil has 85 turns of insulated wire. The cross-sectional area of the coil is 14 cm^2.
Fig. 21.2 shows the variation of magnetic flux density B through the plane of the coil with time t as it rotates.

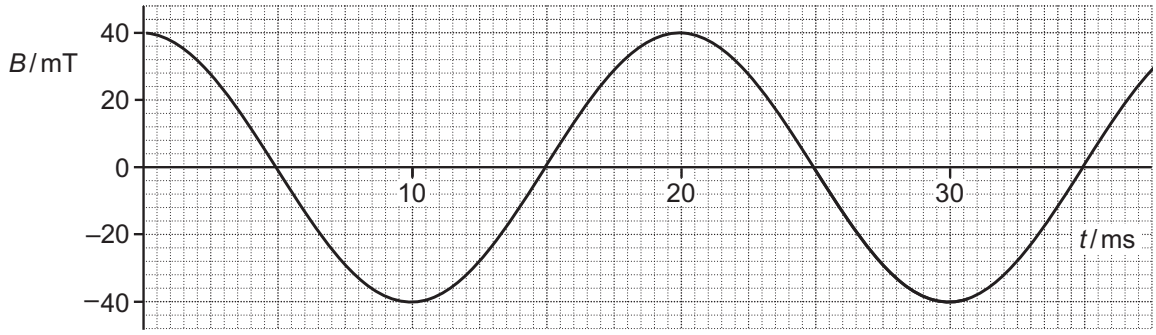


Fig. 21.2

(a) (i) Explain why the electromotive force (e.m.f.) induced across the ends of the coil is a **maximum** at the times when $B = 0$.

.....

.....

..... **[1]**

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(ii) Draw a tangent to the curve in Fig. 21.2 when $B = 0$, and hence determine the **maximum** e.m.f. induced across the ends of the coil.

maximum e.m.f. = ... V **[3]**

(b) Fig. 21.3 shows the variation of the e.m.f. induced across the ends of the coil with time t.

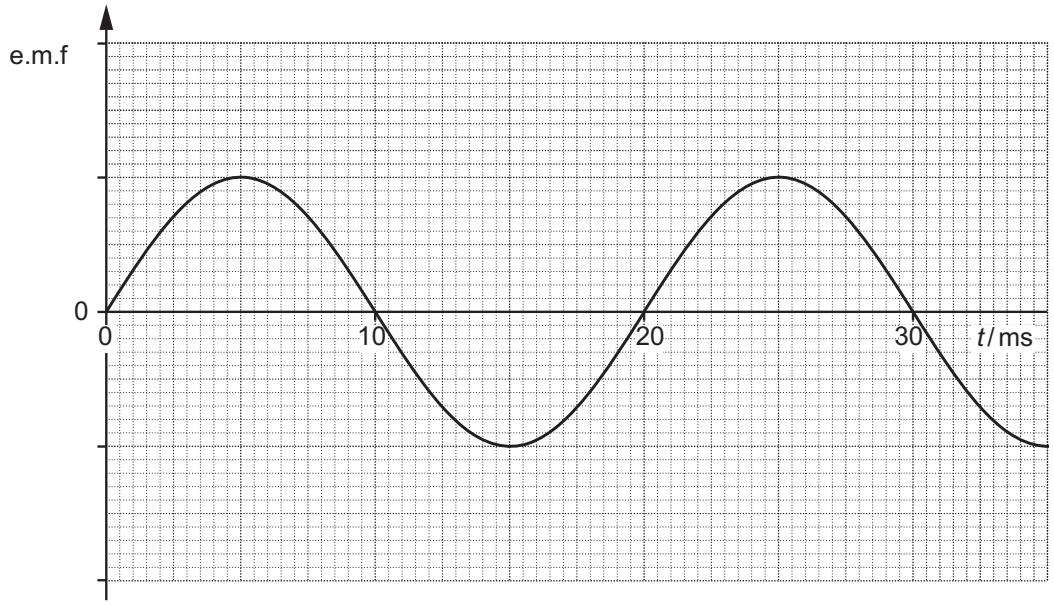


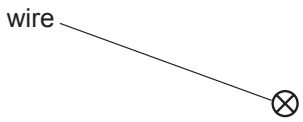
Fig. 21.3

The magnitude of the magnetic flux density of the uniform field is now halved and the coil is rotated at twice its previous frequency.

On Fig. 21.3 sketch the new variation of the e.m.f. induced with time t. **[2]**

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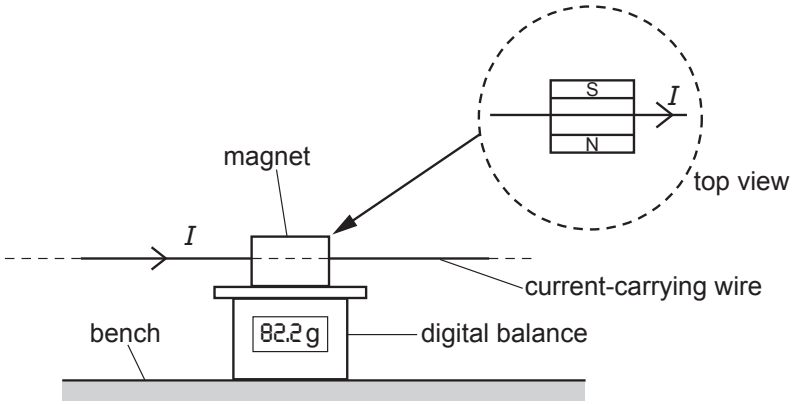
19 **(a)** The diagram below shows the top-view of a long current-carrying wire.



The direction of the current in the wire is into the plane of the paper.

Draw at least **three** field lines to indicate the magnetic field pattern around this wire. **[2]**

(b) The arrangement shown in the diagram below is used to determine the magnetic flux density between the poles of a permanent magnet.



The magnet is placed on the digital balance. The current-carrying wire is horizontal and at right angles to the magnetic field between the poles of the magnet. The wire is fixed.

The following results are collected.

- length of the wire in the uniform field of the magnet = 6.0 ± 0.2 cm
- balance reading with no current in wire = 80.0 g
- balance reading with current in wire = 82.2 g
- current in wire = 5.0 ± 0.1 A

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Calculate the magnetic flux density *B*, including the absolute uncertainty.
Ignore the absolute uncertainty in the balance readings.
Write your value for *B* to **2** significant figures and the absolute uncertainty to **1** significant figure.

B = ... ± ..... T **[4]**

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23 **(a)** Describe the nature of the *strong nuclear force*.

.....

.....

.....

..... **[2]**

(b) **(i)** Name a hadron found in the nucleus of an atom and state its quark combination.

name of hadron: ..... quark combination: ..... **[1]**

(ii) Write a decay equation in terms of a quark model for beta-minus decay.

[2]

(c) The radius of a nucleus is directly proportional to $A^{1/3}$, where A is the nucleon number.
The mass of a proton and a neutron are similar.
Explain why the mean density of all nuclei is about the same.

.....

.....

.....

..... **[2]**

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20 Fig. 20 illustrates a device used to determine the relative abundance of charged rubidium ions.

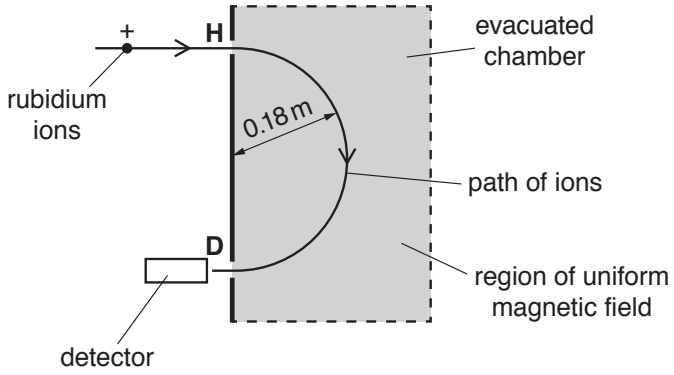


Fig. 20

A uniform magnetic field is applied to an evacuated chamber. The direction of the magnetic field is perpendicular to the plane of the paper.

A beam of positive rubidium ions enters the chamber through a hole at **H**. The ions travel in a semi-circular path in the magnetic field. The ions are detected at point **D**.

(a) Each rubidium ion has charge $+1.6 \times 10^{-19}$ C and speed 4.8×10^{4} m s^{-1}.
The radius of the semi-circular path of the ions is 0.18 m.
The mass of a rubidium ion is 1.4×10^{-25} kg.

Calculate the magnitude of the magnetic flux density B of the magnetic field.

B = ... T **[3]**

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(b) The chemical composition of ancient rocks found on the Earth can be used to estimate the age of the Earth.
Nuclei of rubidium-87 ($^{87}_{37}$Rb) decay spontaneously into nuclei of strontium-87 ($^{87}_{38}$Sr).
The half-life of rubidium-87 is 49 billion years.

(i) Name the two leptons emitted in the decay of a rubidium-87 nucleus.

1. .....

2. .....

[1]

(ii) The percentage of rubidium **left** in a sample of an ancient rock is 95%.

Estimate the age of the Earth in billion years.

age = ... billion years **[3]**

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20 **(a)** Fig. 20.1 shows a positively charged metal sphere and a negatively charged metal plate.

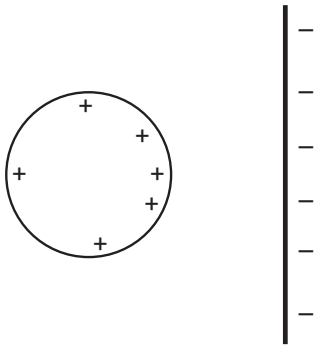


Fig. 20.1

On Fig. 20.1, draw a minimum of **five** electric field lines to show the field pattern between the sphere and the plate. **[2]**

(b) Define *electric potential* at a point in space.

.....

..... **[1]**

(c) A metal sphere is given a positive charge by connecting its surface briefly to the positive terminal of a power supply. The electric potential at the surface of the sphere is + 5.0 kV. The sphere has radius 1.5 cm.

(i) Show that the charge Q on the surface of the sphere is 8.3×10^{-9} C.

[2]

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(ii) Fig. 20.2 shows the charged sphere from **(i)** suspended from a nylon thread and placed between two oppositely charged vertical plates.

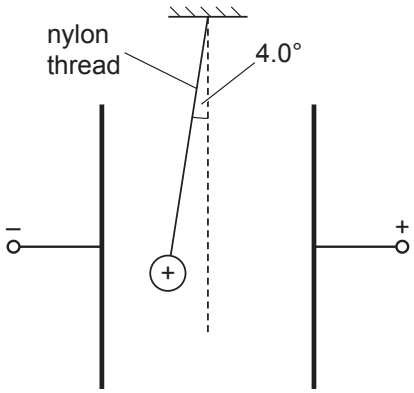


Fig. 20.2 (not to scale)

The weight of the sphere is 1.7×10^{-2} N. The string makes an angle of 4.0° with the vertical.

1. Show that the electric force on the charged sphere is 1.2×10^{-3} N.

[1]

2. Calculate the uniform electric field strength E between the parallel plates.

E = ... NC^{-1} **[2]**

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Turn over

21 Fig. 21 shows the drum of a washing machine.

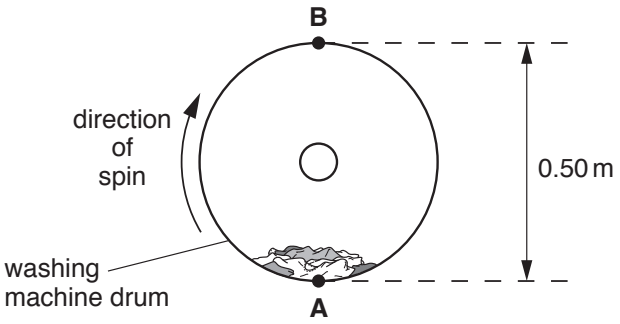


Fig. 21

The clothes inside the drum are spun in a **vertical** circular motion in a clockwise direction.

(a) When the drum is at rest, the weight of the clothes is equal to the normal contact force on the clothes at point **A**.

Explain why these two forces are not an example of Newton's Third Law of motion.

.....

.....

.....

.....

..... **[2]**

(b) The drum has diameter 0.50 m. The manufacturer of the washing machine claims that the drum spins at 1600 ± 100 revolutions per minute.

Calculate the speed of rotation of the drum and the absolute uncertainty in this value.

speed = ... ± ..... $m s^{-1}$ **[3]**

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(c) The washing machine is switched off and the speed of the drum slowly decreases. The clothes at the top of the drum at point **B** start to drop off at a certain speed v.

At this speed v, the normal contact force on the clothes is zero.

Calculate the speed v.

v = ... $m\,s^{-1}$ **[3]**

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24 (a) Proxima Centauri is the closest star to Earth.
Fig. 24.1 shows the apparent positions of this star against the background of very distant stars as seen from the Earth over a period of exactly 6 months.

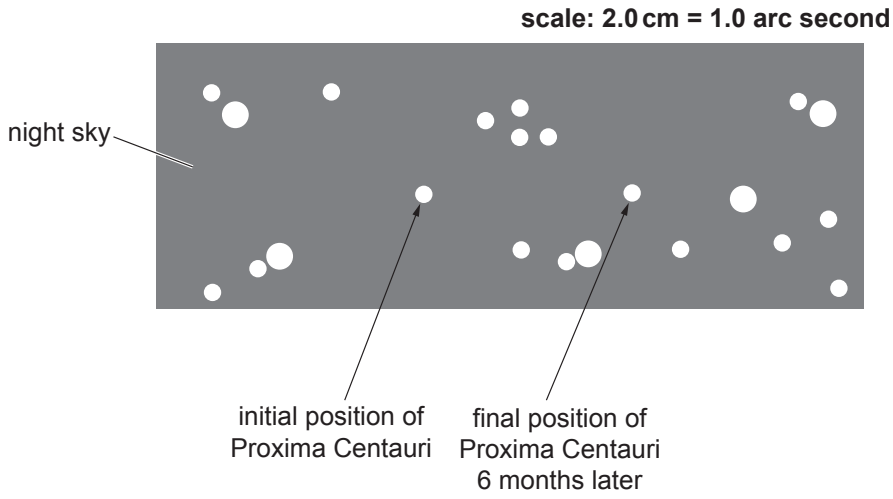


Fig. 24.1

The parallax angle for Proxima Centauri can be determined from Fig. 24.1 using the scale provided.

(i) Show that the parallax angle *p* for Proxima Centauri is about 0.8 arc second.

[2]

Question 24 continues on page 30

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(ii) Use your answer in **(i)** to calculate the distance *d* of Proxima Centauri from the Earth in light-years (ly).

1 pc = 3.26 ly

d = ... ly **[2]**

(b) The galaxies in the Universe may be assumed to be distributed uniformly through space.

In this model, the separation between two neighbouring galaxies is 1.4×10^{23} m and each galaxy occupies a cube of space of volume 2.7×10^{69} m^3 as shown in Fig. 24.2.

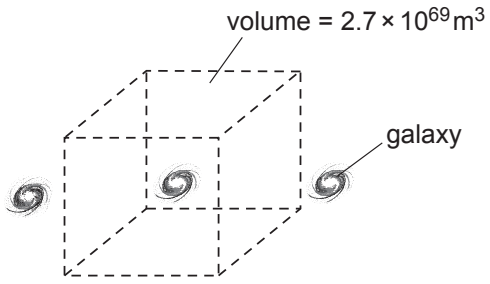


Fig. 24.2

There are on average 10^{11} stars in each galaxy and the mass of an average star is about 2.0×10^{30} kg.

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(i) Estimate the gravitational force between two neighbouring galaxies.

force = ... N **[2]**

(ii) Show that the mean density of the Universe is about $7 \times 10^{-29}\,\text{kg}\,\text{m}^{-3}$.

[1]

(iii) Suggest why the actual mean density of the Universe is different from the value calculated in **(ii)**.

.....

..... **[1]**

4 At an airport, the conveyor belt for suitcases moves at a constant speed of $1.5\,m\,s^{-1}$.
In Fig. 4.1, a suitcase of mass 8.0 kg has reached the line labelled **XX'**.

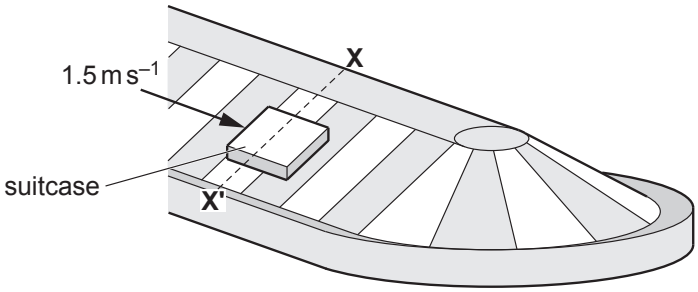


Fig. 4.1

Fig. 4.2 shows the situation in vertical cross-section.
The frictional force *F* prevents the suitcase of weight *W* from sliding to the bottom of the belt.
The normal contact force on the suitcase is *R*.
The belt is inclined at an angle of 30° to the horizontal.

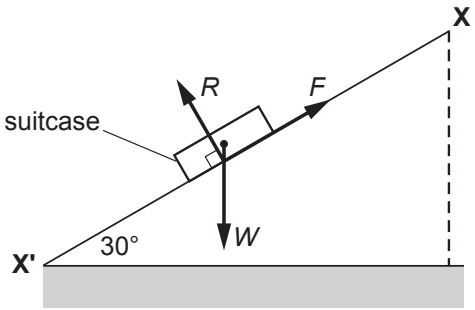


Fig. 4.2 (not to scale)

(a) By using a vector triangle, or by resolving forces, calculate the magnitude of forces *F* and *R*.

F = ... N

R = ... N
[3]

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(b) Fig. 4.3 shows the suitcase and the forces acting on it at the line labelled **YY'**.

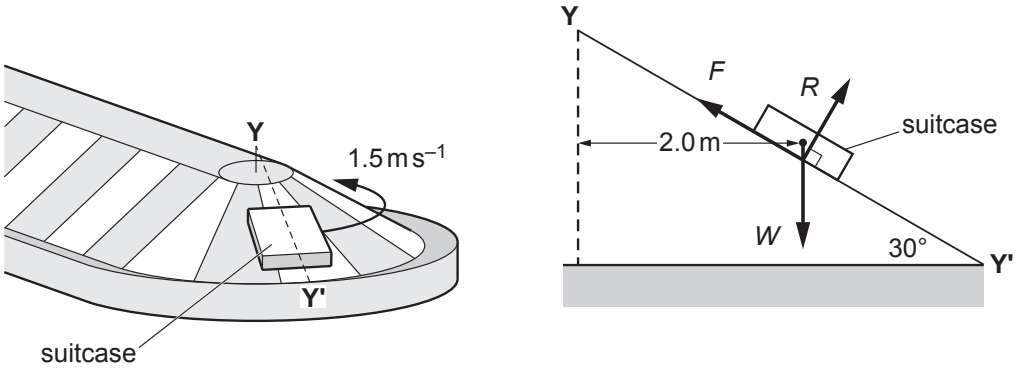


Fig. 4.3

The centre of mass of the suitcase is now moving at $1.5\,m\,s^{-1}$ along a semi-circular arc of radius 2.0 m.

(i) Calculate the magnitude of the centripetal force acting on the suitcase.

centripetal force = ... N **[2]**

(ii) When the suitcase is at line **YY'**, the magnitude of force *F* is larger and the magnitude of force *R* is smaller than at **XX'**.

Explain why this is so.

.....

.....

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..... **[4]**

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Turn over

3 A binary star is a pair of stars which move in circular orbits around their common centre of mass.

In this question consider the stars to be point masses situated at their centres.

(a) Fig. 3.1 shows a binary star where the mass of each star is m. The stars move in the same circular orbit.

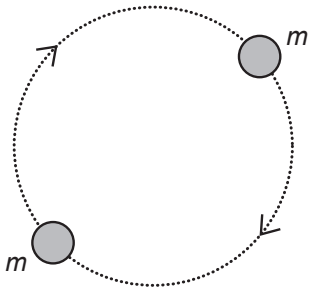


Fig. 3.1

(i) Explain why the stars of equal mass must always be diametrically opposite as they travel in the circular orbit.

.....

.....

.....

.....

..... **[2]**

(ii) The centres of the two stars are separated by a distance of $2R$ equal to 3.6×10^{10} m, where R is the radius of the orbit. The stars have an orbital period T of 20.5 days. The mass of each star is given by the equation

$$m = \frac{16\pi^2 R^3}{GT^2}$$

where G is the gravitational constant.

Calculate the mass m of each star in terms of the mass $M_\odot$ of the Sun.

1 day = 86400 s
$M_\odot = 2.0 \times 10^{30}$ kg

$m =$ ..... $M_\odot$ **[3]**

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(iii) The stars are viewed from Earth in the plane of rotation.
The stars are observed using light that has wavelength of 656 nm in the laboratory. The observed light from the stars is Doppler shifted.

Calculate the maximum change in the observed wavelength $\Delta\lambda$ of this light from the orbiting stars. Give your answer in nm.

$\Delta\lambda$ = ... nm **[2]**

(b) Fig. 3.2 shows a binary star where the masses of the stars are $4m$ and m.

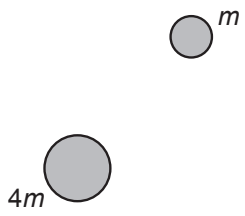


Fig. 3.2

(i) The centre of mass of the binary star lies at the surface of the star of mass $4m$. Draw on **Fig. 3.2** two circles to represent the orbits of **both** stars. **[1]**

(ii) Explain why the smaller mass star travels faster in its orbit than the larger mass star.

.....

.....

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.....

..... **[2]**

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Turn over

6 The London Eye, shown rotating anticlockwise in **Fig. 6.1**, is a giant wheel which rotates slowly at a constant speed.

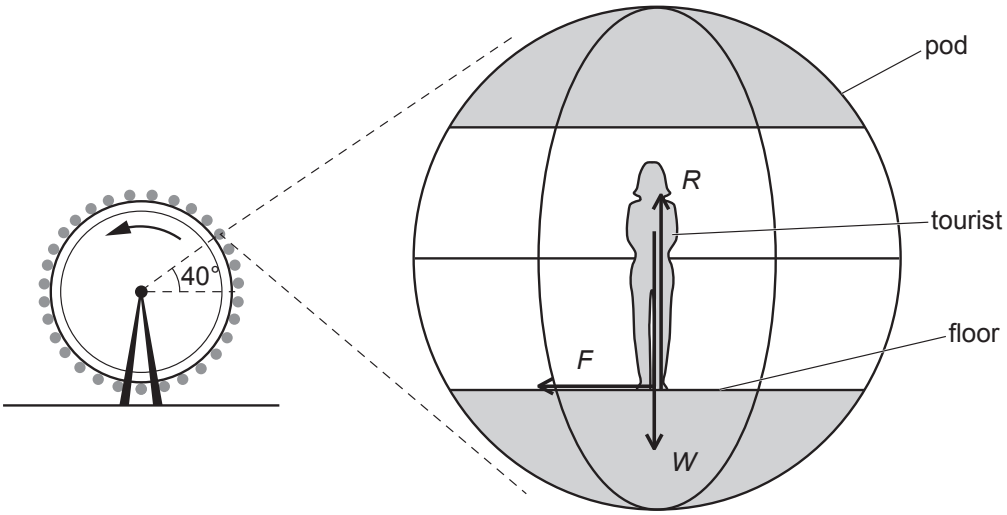


Fig. 6.1 **Fig. 6.2**

Tourists stand in pods around the circumference of the wheel.
The floor remains horizontal at all times.
At time $t = 0$, a tourist who has a weight W of 650 N enters a pod at the bottom of the wheel.
Fig. 6.2 shows the forces acting on the tourist at a later time, when the angle between the pod's position and the centre of the wheel is 40° above the horizontal. R is the normal contact force and F is friction.

(a) The resultant upward force ($R - W$) on the tourist changes during the 30 minutes of the rotation of the London Eye as shown in **Fig. 6.3**.

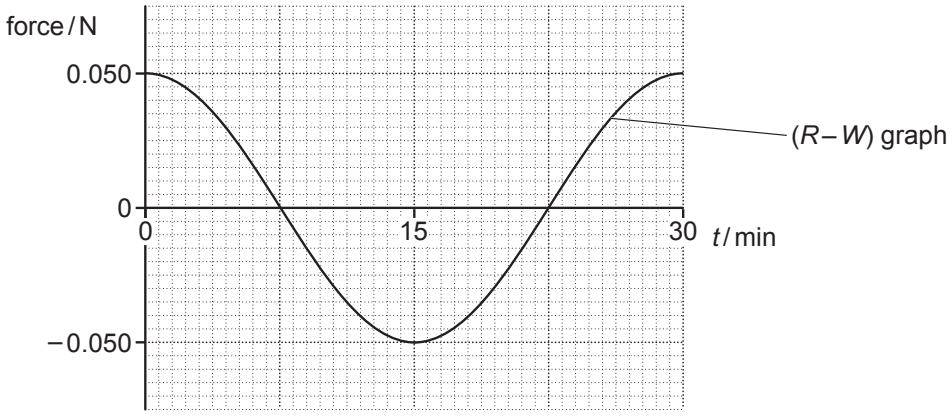


Fig. 6.3

Explain how the graph in **Fig. 6.3** shows that the magnitude of the centripetal force on the tourist during the rotation is 0.050 N.

.....

.....

..... **[1]**

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(b) (i) Explain why the horizontal force *F* between the floor and the tourist is necessary.

.....

.....

.....

.....

.....

..... **[2]**

(ii) Draw on **Fig. 6.3** the variation of the horizontal force *F* during the 30 minutes of the anticlockwise rotation of the London Eye. Take forces to the right to be positive. **[2]**

(iii) Calculate the magnitude of force *F* when the pod is at the position shown in **Fig. 6.2**, at 40° above the horizontal.

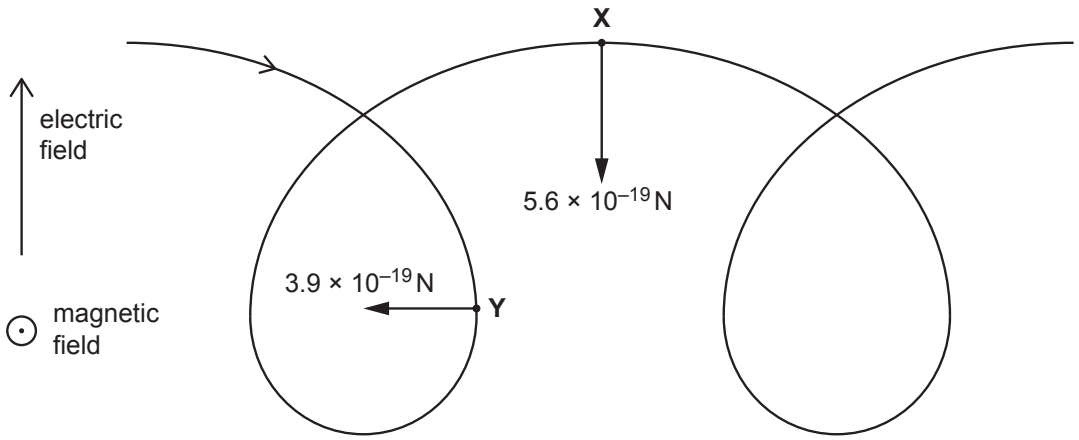
F = ... N **[2]**

(c) Calculate the distance *d* of the centre of mass of the tourist from the centre of rotation of the London Eye.

d = ... m **[3]**

6 The figure below shows the path of a proton moving in a region occupied by both an electric field and a magnetic field.

The direction of the electric field lines is perpendicular to the direction of the magnetic field lines.



The uniform electric field is directed upwards, with electric field strength $E = 0.90\,\text{N C}^{-1}$.

The uniform magnetic field is directed out of the plane of the paper, with magnetic flux density $B = 5.0 \times 10^{-5}\,\text{T}$.

At point **X** the proton is moving horizontally to the right. The magnitude of the **magnetic** force at **X** is $5.6 \times 10^{-19}\,\text{N}$.

At point **Y** the proton is moving vertically downwards. The magnitude of the **magnetic** force at **Y** is $3.9 \times 10^{-19}\,\text{N}$.

The **electric** forces acting on the proton at **X** and **Y** are **not** shown in the figure.

(a) Show that the magnitude of the constant **electric** force acting on the proton is about $10^{-19}\,\text{N}$.

[1]

(b)

(i) Suggest why the **magnetic** force acting on the proton has a different magnitude at **X** than at **Y**.

.....

.....

..... **[1]**

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(ii) At **X**, the motion of the proton is instantaneously equivalent to motion in a circle at a constant speed.

Calculate the radius of this circular motion.

radius = ... m **[4]**

(iii) **1** Calculate the magnitude of the resultant force on the proton at **Y**.

resultant force = ... N **[2]**

2 Explain why the motion of the proton at **Y** is **not** instantaneously equivalent to motion in a circle at a constant speed.

.....

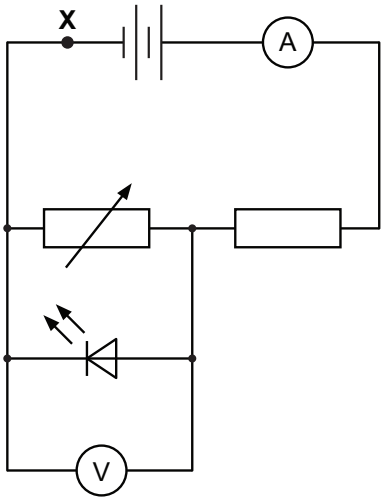
.....

.....

..... **[2]**

16 A student is investigating the behaviour of a light-emitting diode (LED).

They use the circuit below to determine the lowest potential difference (p.d.) at which the LED lights.



(a) State the name of the circuit arrangement of the battery, variable resistor and resistor in this circuit.

..... **[1]**

(b) Draw an arrow on the circuit to show the direction of conventional current. **[1]**

(c) State how the readings on the ammeter and the voltmeter change when the resistance of the variable resistor is increased.

Ammeter reading .....

Voltmeter reading .....

[2]

(d) The LED is made from two semiconducting materials.

Compare the number density of charge carriers in semiconductors, metals and insulators.

.....

.....

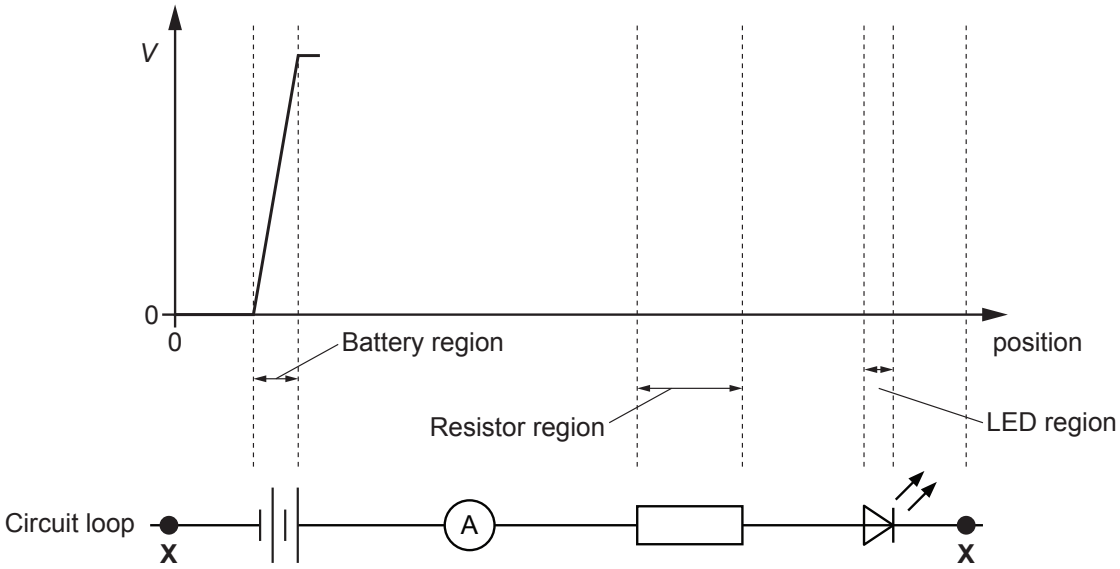
..... **[2]**

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(e) This question is about a clockwise circuit loop starting at **X**.

This loop is shown beneath the graph.

Assume the battery has negligible internal resistance. The resistance of the ammeter is also negligible.



On the axes above this loop, complete the graph to show the variation of the potential difference *V* relative to the point **X** with the position along this loop. **[4]**

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

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

.....

.....

.....

..... **[2]**

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

.....

.....

.....

..... **[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

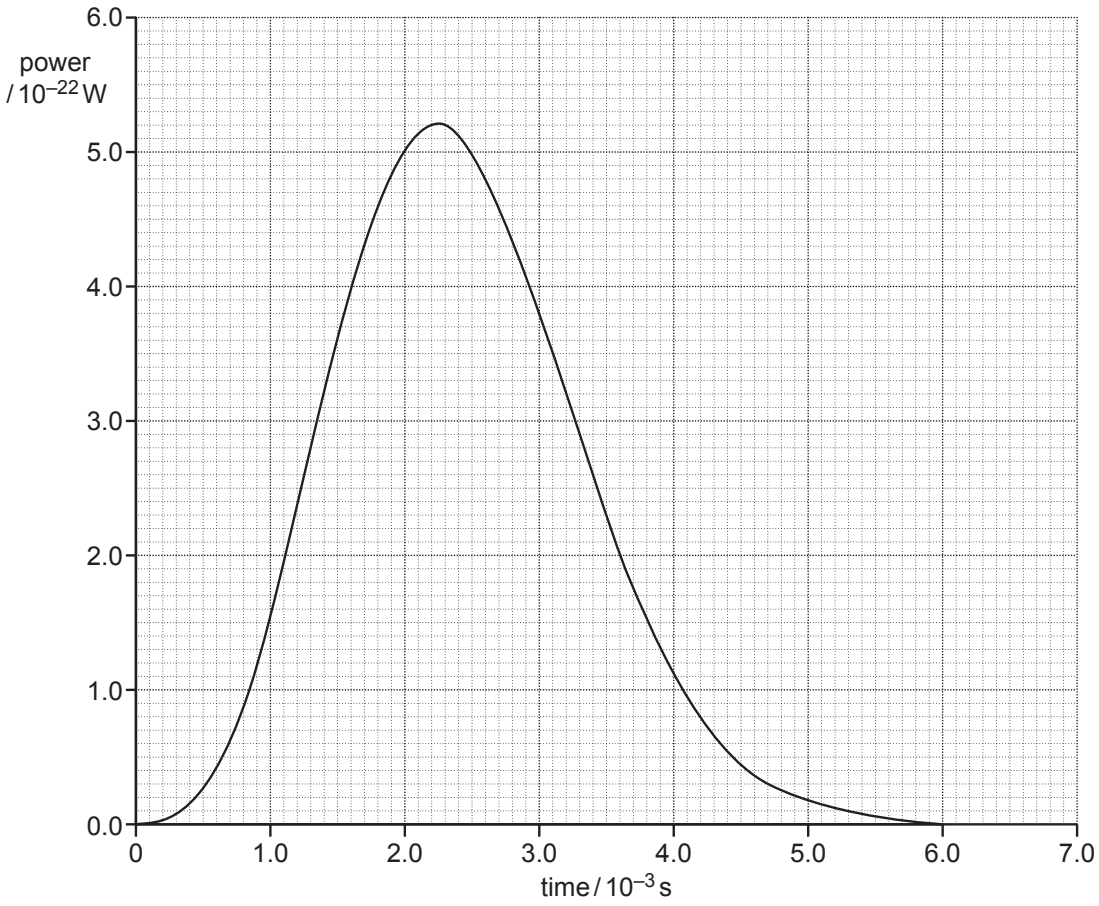
[3]

Question 3 continues on page 10

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(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.

total energy received = ... J **[2]**

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(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 emitted = ... J **[3]**

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Turn over

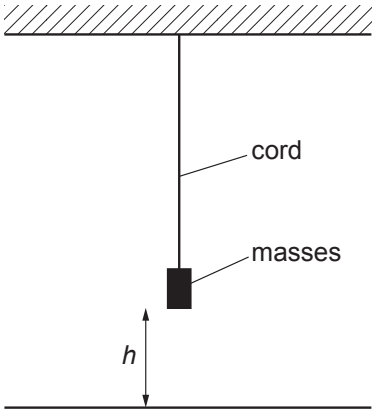
18 Mats made from rubber are often used in laboratories where heavy objects might be dropped.

A rubber cord is tested to determine the material's mechanical characteristics.

(a) The cord is suspended from a ceiling and masses can be attached to the free end.

The apparatus is set up as shown in **Fig. 18.1**.

Fig. 18.1



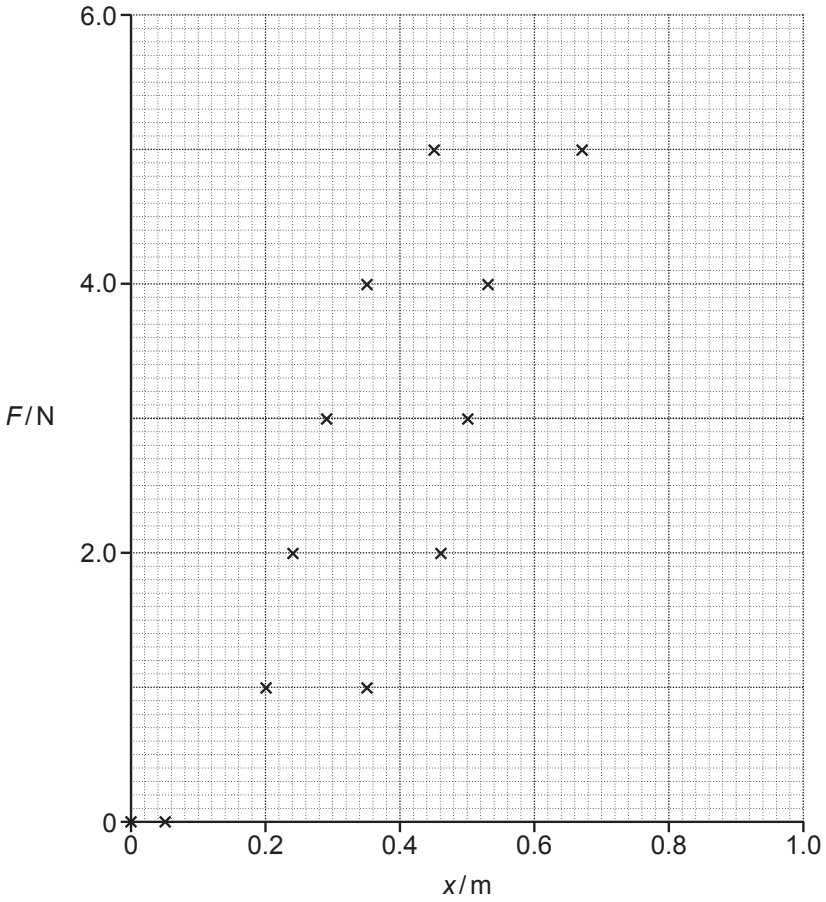
Masses are added and the height, *h*, of the base of the bottom mass from the floor is measured. The extension of the cord is *x* when the tension in the cord is *F*. After six masses have been added, they are removed one at a time and *h* measured each time.

The table shows the data collected.

***F*/N**	***h*/m**	***x*/m**
0.0	1.80	0.00
1.0	1.60	0.20
2.0	1.56	0.24
3.0	1.51	0.29
4.0	1.45	0.35
5.0	1.35	0.45
6.0	0.81	
5.0	1.13	0.67
4.0	1.37	0.53
3.0	1.30	0.50
2.0	1.34	0.46
1.0	1.45	0.35
0.0	1.75	0.05

(i) Complete the final column of the table. **[1]**

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(ii) Plot the data point for $F = 6.0\,N$ on the graph above. The other points have been plotted.

Draw and label **two** curves to show the loading and unloading of the cord. **[3]**

(iii) Discuss whether Hooke's law can be applied to the cord.

.....

..... **[2]**

(iv) There is an area between the two curves that you have drawn on the graph.

1. State the **name** of the derived SI unit of this area.

..... **[1]**

2. Explain the significance of this area to the planned use of the rubber.

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..... **[2]**

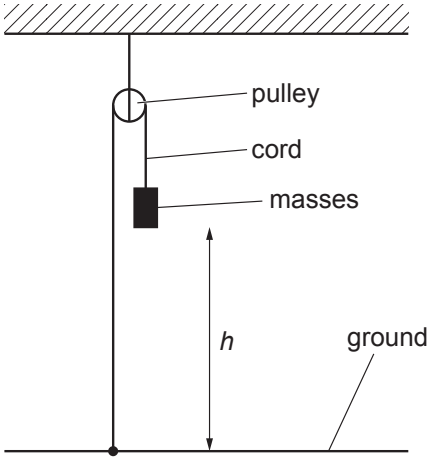
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Turn over

(b) An alternative arrangement for the experiment is to use a pulley as shown in **Fig. 18.2**.

The arrangement makes it possible to cover a larger range of extensions.

Fig. 18.2



The cord is fixed to the ground.

Describe **two** factors that would affect the accuracy of the results obtained using this alternative arrangement.

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[2]

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Turn over

2 A small thin rectangular slice of semiconducting material has width *a* and thickness *b* and carries a current *I*. The current is due to the movement of electrons. Each electron has charge $-e$ and mean drift velocity *v*. A uniform magnetic field of flux density *B* is perpendicular to the direction of the current and the top face of the slice as shown in Fig. 2.1.

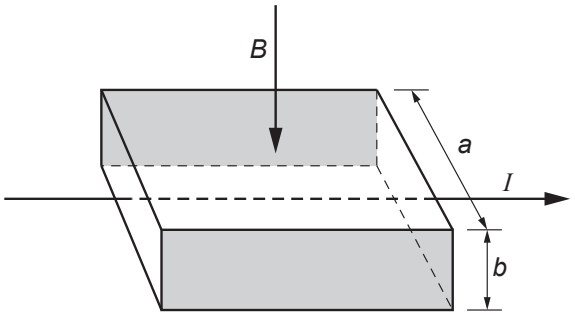


Fig. 2.1

(a) As soon as the current is switched on, the moving electrons in the current are forced towards the shaded rear face of the slice where they are stored. This causes the shaded faces to act like charged parallel plates. Each electron in the current now experiences both electric and magnetic forces. The resultant force on each electron is now zero.

Write the expressions for the electric and magnetic forces acting on each electron and use these to show that the magnitude of the potential difference *V* between the shaded faces is given by

$$V = Bva.$$

[3]

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(b) Here are some data for the slice in a particular experiment.

number of conducting electrons per cubic metre, $n = 1.2 \times 10^{23}\ m^{-3}$
$a = 5.0\,mm$
$b = 0.20\,mm$
$I = 60\,mA$
$B = 0.080\,T$

Use this data to calculate

(i) the mean drift velocity v of electrons within the semiconductor

$v =$ ..... $m\,s^{-1}$ **[3]**

(ii) the potential difference V between the shaded faces of the slice.

$V =$ ..... V **[1]**

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(c) The slice is mounted and used as a measuring instrument called a Hall probe. A cell is connected to provide the current in the slice. The potential difference across the slice is measured by a separate voltmeter.

A student wants to measure the magnetic flux density between the poles of two magnets mounted on a steel yoke as shown in Fig. 2.2. The magnitude of the flux density is between 0.02 T and 0.04 T.

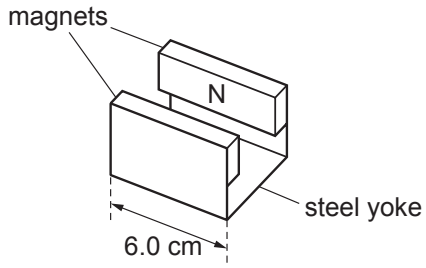


Fig. 2.2

(i) Suggest **one** reason why this Hall probe is **not** a suitable instrument to measure the magnetic flux density for the arrangement shown in Fig. 2.2.

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..... **[1]**

(ii) Another method of measuring the magnetic flux density for the arrangement shown in Fig. 2.2 is to insert a current-carrying wire between the poles of the magnet.
Explain how the magnetic flux density can be determined using this method and discuss which measurement in the experiment leads to the greatest uncertainty in the value for the magnetic flux density.

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..... **[4]**

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Turn over

4 This question is about an electric cooker, which consists of an oven and an electromagnetic induction hob.

***(a)** The oven is not sealed, so the air inside remains at atmospheric pressure of 1.0×10^5 Pa. The volume of the oven is $0.065\,m^3$. The air inside the oven behaves as an ideal gas.

The temperature of the oven increases from room temperature to 200 °C.

Show that the internal energy of the air in the oven is the same at **all** temperatures of the oven. Support your answer with an explanation of the motion of the air molecules in terms of kinetic theory. **[6]**

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Additional answer space if required

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Question 4 continues on page 12

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(b) The electromagnetic induction hob is shown in **Fig. 4.1**.

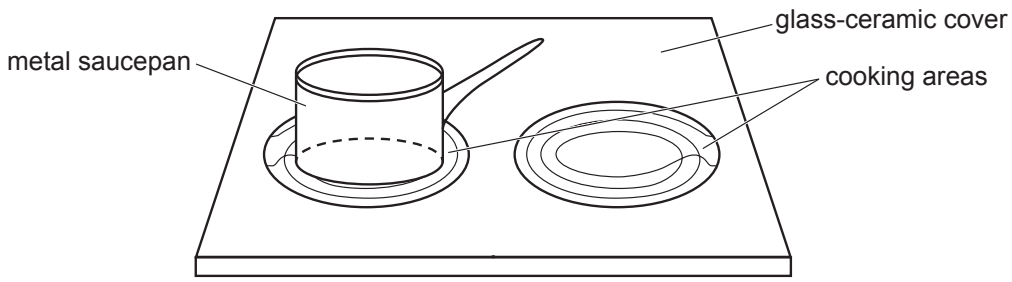


Fig. 4.1

Each cooking area has a coil below the glass-ceramic cover. When switched on, the coils carry a high-frequency **alternating** current.

A metal saucepan is placed above one of the coils. A large alternating current is induced in the saucepan base, and this causes the saucepan to heat up.

(i) **Fig. 4.2** shows one of the coils at a time when the current is in the direction indicated by the arrows.

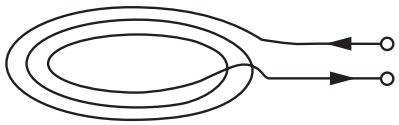


Fig. 4.2

On **Fig. 4.2**, sketch the magnetic field pattern for the current-carrying coil. **[2]**

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(ii) **Fig. 4.3** shows the path of the large alternating current induced in the metal base of the saucepan.

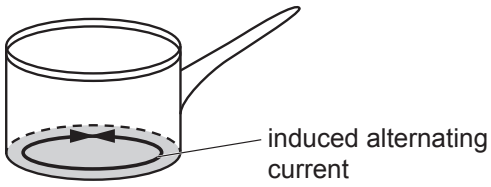


Fig. 4.3

Explain the origin of this large current.

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..... **[2]**

(iii) Explain why it would be safe for a person to place a hand on the cooking area before the saucepan is put onto it.

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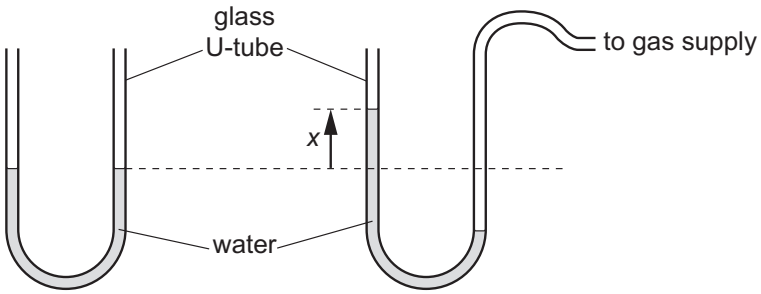
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20 **(a)** For a simple harmonic oscillator, the acceleration a is given by the equation $a = -\omega^2 x$, where ω is the angular frequency and x is the displacement.

Show that this equation is homogeneous by reducing both sides to S.I. base units.

[2]

(b) The diagram shows a glass U-tube partially filled with a mass of water.



One end of the U-tube is connected to a gas supply of **constant** pressure and the other end is open to the atmosphere. The displacement of the water from its equilibrium position is x. The density ρ of water is $1000\,\text{kg}\,\text{m}^{-3}$.

(i) The pressure from the gas supply raises the water in the U-tube.
The vertical distance between the two levels of water in the two vertical sections of the U-tube is 10.0 cm (x = 5.0 cm).

Δp is the difference between the gas pressure and atmospheric pressure.
Calculate Δp.

Δp = ... Pa **[2]**

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(ii) When the gas supply is disconnected, the water levels in the U-tube oscillates with simple harmonic motion. The acceleration a of the water level in the left-hand side of the U-tube is given by the equation

$$a = -\frac{2\rho g A}{m} x$$

where m is the mass of the water in the U-tube, A is the internal cross-sectional area of the U-tube, ρ is the density of water, g is the acceleration of free fall and x is the displacement of the water level in the left-hand side of the U-tube.

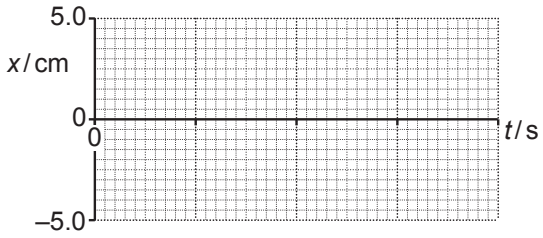
For this U-tube, $A = 1.0 \times 10^{-4}\,\text{m}^2$ and $m = 0.052\,\text{kg}$.

1 Show that the period T of the oscillations is about 1 second.

[3]

2 The oscillations of the water level are slightly **damped**.
At time $t = 0$, $x = 5.0\,\text{cm}$.

Sketch a suitable graph of displacement x against time t for the oscillating water level. Add suitable values to the time t axis.



[3]

3 The U-tube is now connected to another gas supply where the pressure oscillates at a frequency of about 1 Hz.

Explain the effect this will have on the water in the U-tube.

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..... **[2]**

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Turn over

22 (a)* A student conducts an experiment to confirm that the uniform magnetic flux density B between the poles of a magnet is 30 mT.

A current-carrying wire of length 5.0 cm is placed perpendicular to the magnetic field.

The current I in the wire is changed and the force F experienced by the wire is measured. Fig. 22.1 shows the graph plotted by the student.

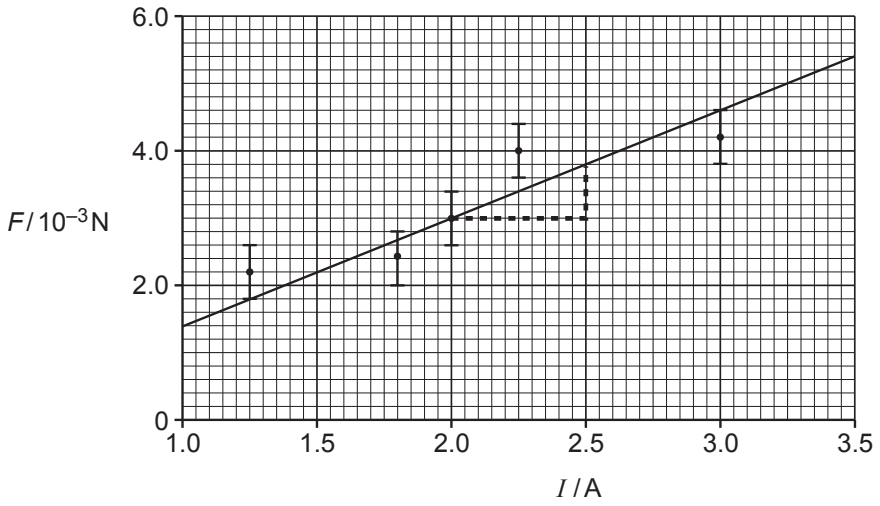


Fig. 22.1

The student's analysis is shown on the graph of Fig. 22.1 and in the space below.

$F = BIL$

$$\text{gradient} = BL = \frac{(3.8 - 3.0) \times 10^{-3}}{2.5 - 2.0} = 0.0016$$

$$B = \frac{0.0016}{0.05} = 0.032\,\text{T} = 32\,\text{mT}$$

This is just 2 mT out from the 30 mT value given by the manufacturer, so the experiment is very accurate.

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Evaluate the information from Fig. 22.1 and the analysis of the data from the experiment. No further calculations are necessary.

.... **[6]**

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(b) Fig. 22.2 shows a transformer circuit.

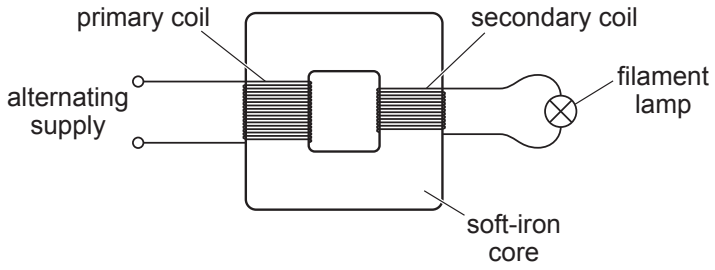


Fig. 22.2

The primary coil is connected to an alternating voltage supply. A filament lamp is connected to the output of the secondary coil.

(i) Use Faraday's law of electromagnetic induction to explain why the filament lamp is lit.

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..... **[3]**

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(ii) The primary coil has 400 turns and the secondary coil has 20 turns. The potential difference across the lamp is 12 V and it dissipates 24 W. The transformer is 100% efficient.

1. Calculate the current in the primary coil.

current = ... A **[2]**

2. The alternating voltage supply is replaced by a battery and an open switch in series. The switch is closed. The lamp is lit for a short period of time and then remains off. Explain this observation.

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..... **[2]**

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1 A toy rocket is made from a 1.5 litre plastic bottle with fins attached for stability.

The bottle initially contains 0.30 litres of water, leaving 1.2 litres of trapped air at a temperature of 17 °C.
A pump is used to increase the pressure of the air within the plastic bottle to 2.4×10^5 Pa at the start of lift-off.

Fig. 1.1 shows the rocket at the start of lift-off.

1 litre = 10^{-3} m^3

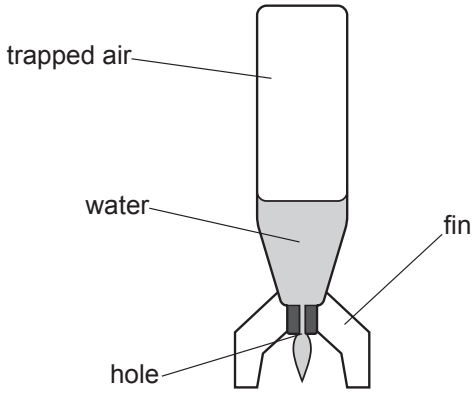


Fig. 1.1

(a) Calculate, in moles, the amount of trapped air in the bottle at the start of lift-off.

amount of air = ... mol **[2]**

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(b) The trapped air pushes the water downwards out of the hole, causing the rocket to rise. The temperature of this air remains constant.

Calculate the final pressure of the trapped air just before all the water has been released.

final pressure = ... Pa **[3]**

(c) Here is some data on the toy rocket.

mass of empty bottle and fins = 0.050 kg
area of cross-section of hole = 1.1×10^{-4} m^2
initial pressure of trapped air = 2.4×10^5 Pa
atmospheric pressure = 1.0×10^5 Pa
density of water = 1.0×10^3 kg m^{-3}

(i) Use the data above to show that the **upwards** force on the rocket at the start of lift-off is about 15 N.

[2]

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(ii) Hence calculate the initial vertical acceleration of the rocket.

initial acceleration = ... $m\,s^{-2}$ **[3]**

(d) Discuss whether adding more water initially would enable the rocket to reach a greater height.

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..... **[3]**

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18 A mass hanging from a vertical spring is pulled down.
It is then released from rest at time $t = 0$.
The mass oscillates vertically in a **vacuum** with simple harmonic motion about the equilibrium position. The spring is in tension at all times.

Fig. 18.1 shows the position of the mass at $t = 0$.

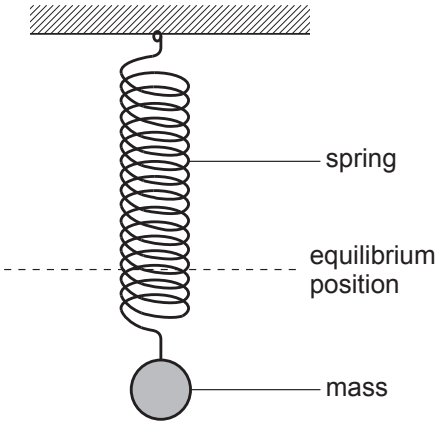


Fig. 18.1

At time $t = 6.5\,\text{s}$ the magnitude of the acceleration a of the mass is $3.6\,\text{m s}^{-2}$ and its displacement x is $4.6 \times 10^{-2}\,\text{m}$.

(a) (i) Use the defining equation for simple harmonic motion to show that the natural frequency f_0 of the mass-spring system is about 1.4 Hz.

[3]

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(ii) Calculate the amplitude *A* of the oscillations.

A = ... m **[2]**

(b) The mass-spring system shown in Fig. 18.1 is now made to oscillate in **air**.

Different types of energy are involved in the oscillations of this mass-spring system.

Describe the energy changes that will take place as the mass moves from the lowest point in its motion through the equilibrium position to the highest point in its motion.

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..... **[4]**

Question 18 continues on page 16

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(c) Fig. 18.2 shows the mass and spring now attached to a mechanical vibrator, which can oscillate with variable frequency.

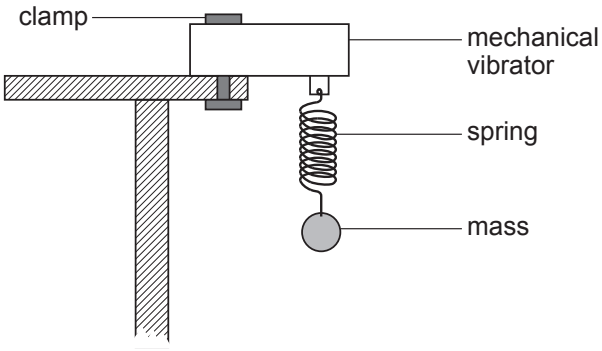


Fig. 18.2

The mass oscillates in air.

(i) The vibrator frequency is varied from 0 Hz to 2.5 Hz.
On Fig. 18.3, sketch a graph to show the variation with vibrator frequency of the amplitude of the mass. Label your graph **K**.

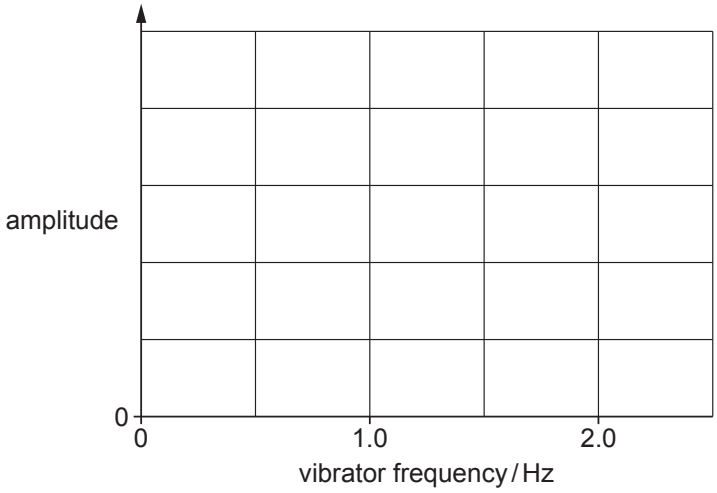


Fig. 18.3

[2]

(ii) A light disc is now attached to the mass to increase the damping.
The vibrator frequency is again varied from 0 Hz to 2.5 Hz.
Sketch a second graph on Fig. 18.3 to show the new variation of the amplitude.
Label this graph **D**. **[1]**

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(iii) Explain why the phenomenon demonstrated in this experiment can cause problems for engineers when designing suspended footbridges.

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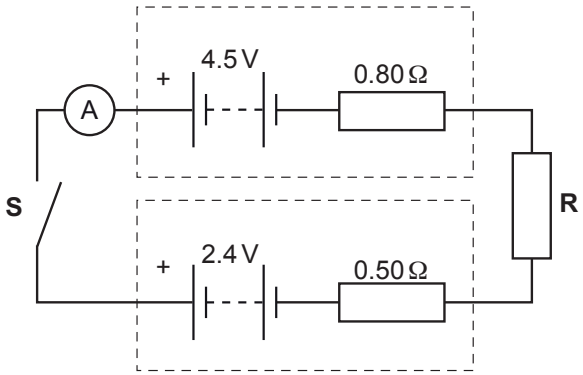
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..... **[2]**

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Turn over

18 **(a)** The circuit diagram of an electrical circuit is shown below.



The positive terminals of the batteries are connected together.
One battery has electromotive force (e.m.f.) 4.5 V and internal resistance 0.80 Ω.
The other battery has e.m.f. 2.4 V and internal resistance 0.50 Ω.
R is a coil of insulated wire of resistance 1.2 Ω at room temperature.

The switch **S** is closed.

(i) On the diagram, draw an arrow to show the direction of the conventional current. **[1]**

(ii) Calculate the current I shown by the ammeter.

I = ... A **[3]**

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Turn over

(iii) The insulated wire has diameter 4.6×10^{-4} m.
The number density of charge carriers in **R** is 4.2×10^{28} m^{-3}.

Calculate the mean drift velocity v of the charge carriers in **R**.

v = ... m s^{-1} **[2]**

(iv) The current measured by the ammeter is smaller than that calculated in **(ii)**. This is because the temperature of **R** increased due to heating by the current.

Without any changes to the circuit itself, state and explain what practically can be done to make the measured current the same as the calculated current..

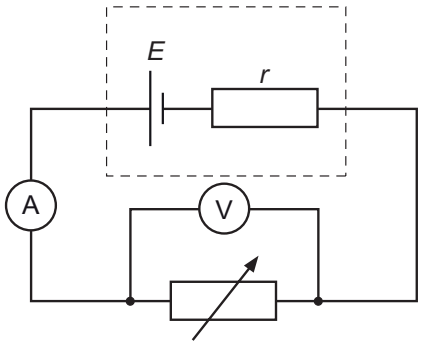
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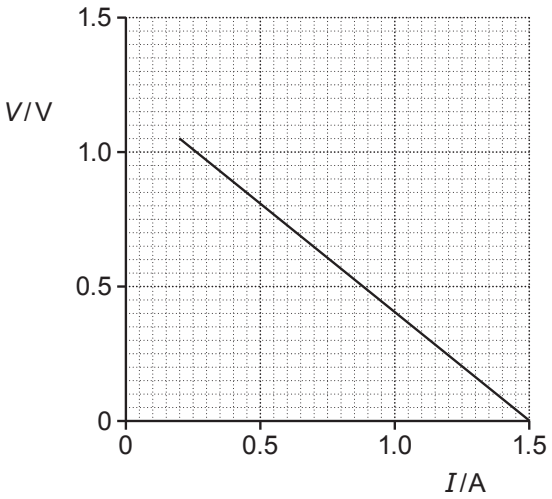
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(b)* A student is doing an experiment to determine the e.m.f. *E* of a cell and its internal resistance *r*. The circuit diagram of the arrangement is shown below.



The student changes the resistance of the variable resistor. The potential difference *V* across the variable resistor and the current *I* in the circuit are measured.

The *V* against *I* graph plotted by the student is shown below.



V/V	*I*/A	*R*/Ω	*P*/W
0.20	1.25		
0.40	1.00		
0.60	0.75		
0.80	0.50		
1.00	0.25		

There is an incomplete table next to the graph.
R is the resistance of the variable resistor and *P* is the power dissipated by the variable resistor.

- Use the graph to determine *E* and *r*. Explain your reasoning.
- Calculate *R* and *P* to complete the table. Describe how *P* depends on *R*.

[6]

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4 The length of an unloaded spring is approximately 4 cm.

The force constant k of the spring is 0.62 N cm^{-1}.

(a) Describe how you could determine k using an appropriate experiment.

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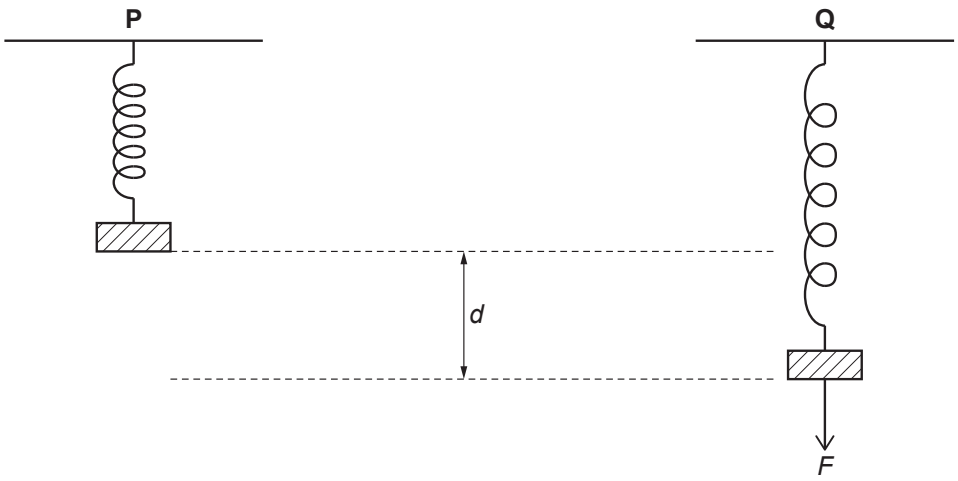
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..... **[3]**

(b) The figure below shows a block of mass 0.20 kg attached to one end of the spring. The other end of the spring is attached to a fixed support vertically above the block.

In position **P** the block rests in equilibrium. The extension of the spring is 3.2 cm.

In position **Q** a downwards force F has been applied to the block, so that it now rests a distance d below its position at **P**. The extension of the spring is now 8.5 cm.



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The force *F* is removed.

(i) Calculate the magnitude of the block's initial acceleration at the instant that the force *F* is removed.

Assume that the spring is not extended beyond its limit of proportionality.

acceleration = ... $m\,s^{-2}$ **[3]**

(ii) The block now moves with simple harmonic motion.

Calculate the frequency of this motion.

frequency = ... Hz **[3]**

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(c) The block is replaced by a strong magnet **L** of slightly greater mass.

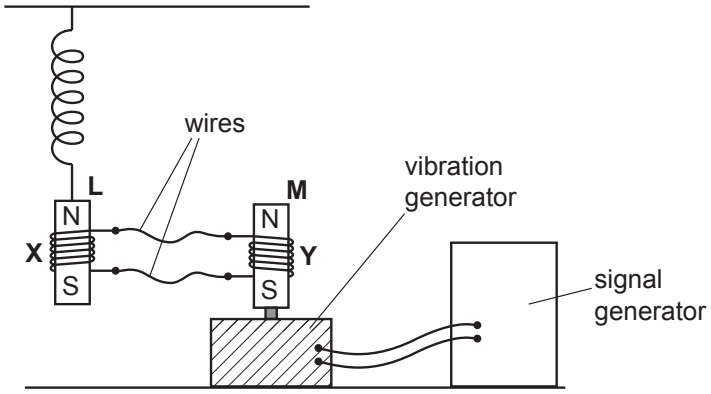
The oscillation frequency of this new arrangement is 2.5 Hz.

The magnet **L** is placed inside a coil **X** of insulated copper wire.

The coil **X** is connected with long wires to a second, identical coil **Y**.

A second strong magnet **M** is placed inside **Y** and attached to a vibration generator.

The vibration generator is then forced to oscillate with a frequency of approximately 2.5 Hz by adjusting the signal generator.



(i) As magnet **M** oscillates, it moves in and out of coil **Y**.

The magnet **L** also begins to oscillate.

Explain why **L** oscillates.

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..... **[3]**

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(ii) The frequency of the vibration generator is now varied between 0.5 Hz and 5.0 Hz.

Suggest how the amplitude and frequency of the oscillations of **L** will change as the frequency of the generator is varied.

You may draw a diagram to support your answer.

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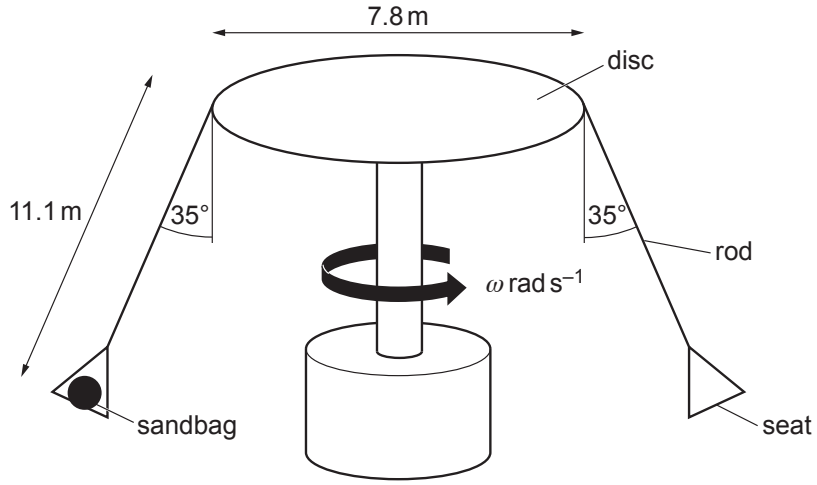
..... **[3]**

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17 The diagram below shows a fairground ride. Each rider is secured in a seat suspended by a rod.

The distance from the top of the rod to the base of the seat is 11.1 m.

The rod is attached to the edge of a disc of diameter 7.8 m.



(not to scale)

To test the equipment a sandbag is attached to the seat and the ride is started.

The combined mass of the seat and the sandbag is 12 kg.

The rod makes an angle of 35° with the vertical.

(a) (i) Draw an arrow labelled T on the diagram to represent the tension in the rod. **[1]**

(ii) Show that the radius of the circular path followed by the sandbag is about 10 m.

[2]

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(iii) Calculate the tension T in the rod.

T = ... N **[3]**

(iv) Show that the angular velocity of the ride is about 0.8 radians per second.

[2]

(b) When the seat is at its highest point the sandbag is 17 m above the ground. The sandbag is released from the seat to model an object being dropped by a ride.

(i) Calculate t, the time taken for the sandbag to reach the ground.

t = ... s **[2]**

(ii) Using your answer to **(a)(iv)**, determine the horizontal displacement s travelled by the sandbag before hitting the ground.

s = ... m **[3]**

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Turn over

(iii) Determine, with reasons, the effect on the horizontal displacement travelled if the object released from the ride was a shoe from a rider.

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..... **[3]**

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Turn over

5 A student experiments with microwaves emitted from a transmitter. The frequency f of the microwaves from the transmitter can be adjusted.

(a) The microwaves are produced by an alternating current in the transmitter.

In one experiment, f is 11 GHz. In a wire in the transmitter, the magnitude of the **maximum** alternating current is 20 mA. The wire has cross-sectional area $1.4 \times 10^{-8}\,m^2$ and is made of a metal with free electron number density $8.0 \times 10^{28}\,m^{-3}$.

(i) Show that the maximum drift velocity of each free electron in the wire is about $0.1\,mm\,s^{-1}$.

[3]

(ii) The student models the average motion of the free electrons in the wire as simple harmonic motion.

Use your answer to **(i)** to calculate the amplitude A of this motion.

A = ... m **[3]**

(iii) Without further calculation, explain how the maximum acceleration of a free electron varies as the frequency f is adjusted, provided that the maximum alternating current remains constant.

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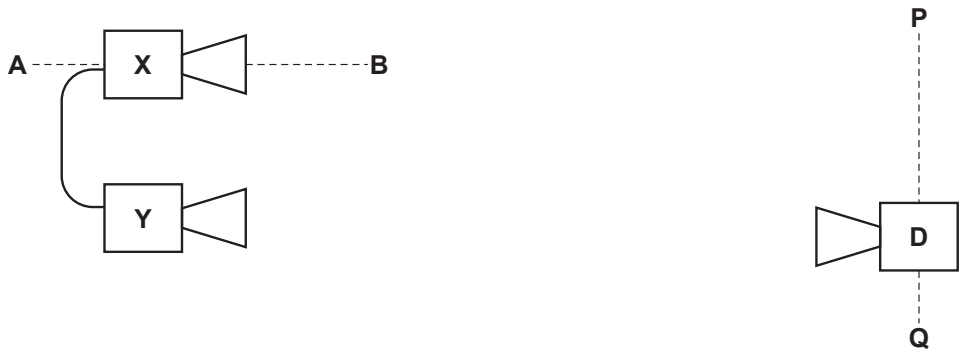
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(b) The student connects two microwave transmitters **X** and **Y**, and places them in front of a microwave detector **D**, as shown in the diagram below.



The transmitters **X** and **Y** produce **coherent** vertically polarised microwaves with the same frequency *f*.

The detector **D** is sensitive to vertically polarised microwaves only.

When the detector **D** is moved along the line **PQ**, a pattern of maximum and minimum intensity is observed. Adjacent maxima are separated by a distance *x*.

(i)* Explain:

- why this pattern of intensity occurs
- the expected relationship between the frequency *f* and the distance *x*
- how to verify this relationship experimentally. **[6]**

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Additional answer space if required

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(ii) Transmitter **X** is rotated about the line **AB** and the experiment is repeated at different orientations until it has been rotated by 180°.

Describe and explain the observed patterns of maximum and minimum intensity.

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21 (a) **Fig. 21.1** shows a stationary glider of mass m on an air track.

The glider has identical springs with force constant k attached to each end which are secured to fixed posts.

The air track blower is turned on and the glider is displaced a small distance x_0, as seen in **Fig. 21.2**. It is then released.

The glider moves horizontally in simple harmonic motion.

The springs remain in tension throughout the motion.

The time taken for 20 complete oscillations is measured, and the period T calculated.

Fig. 21.1

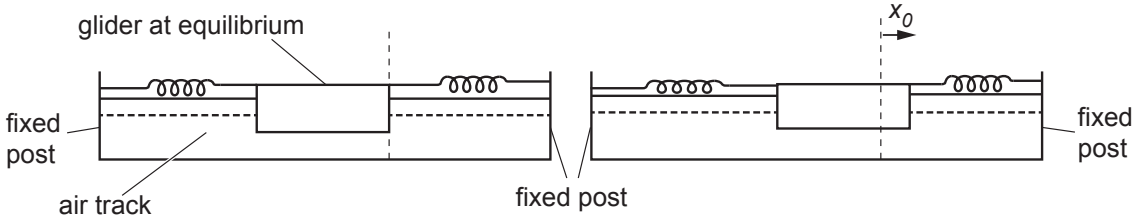


Fig. 21.2

The relationship between the period T, the mass of the glider m and the force constant k is described by the equation

$$T^2 = \frac{2\pi^2 m}{k}.$$

(i) Show that the equation above is homogeneous by reducing the equation to SI base units.

[2]

(ii) Explain why the magnitude of the resultant force F on the glider is given by $F = 2kx$ where x is the displacement at any time.

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(iii) State and explain the effect, if any, of increasing the initial displacement on the period of the subsequent motion.

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..... **[2]**

(b) Masses are added to the glider, and the measurement of $20T$ repeated.

The results table is below.

m/kg	$20T$/s	T	T^2
0.200	12.2	0.61	0.372
0.300	13.6	0.68	0.462
0.400	15.6	0.78	0.608
0.500	17.6	0.88	0.774
0.600	18.9	0.945	0.893
0.700	20.0	1	1

(i) Describe **two** different errors in the table.

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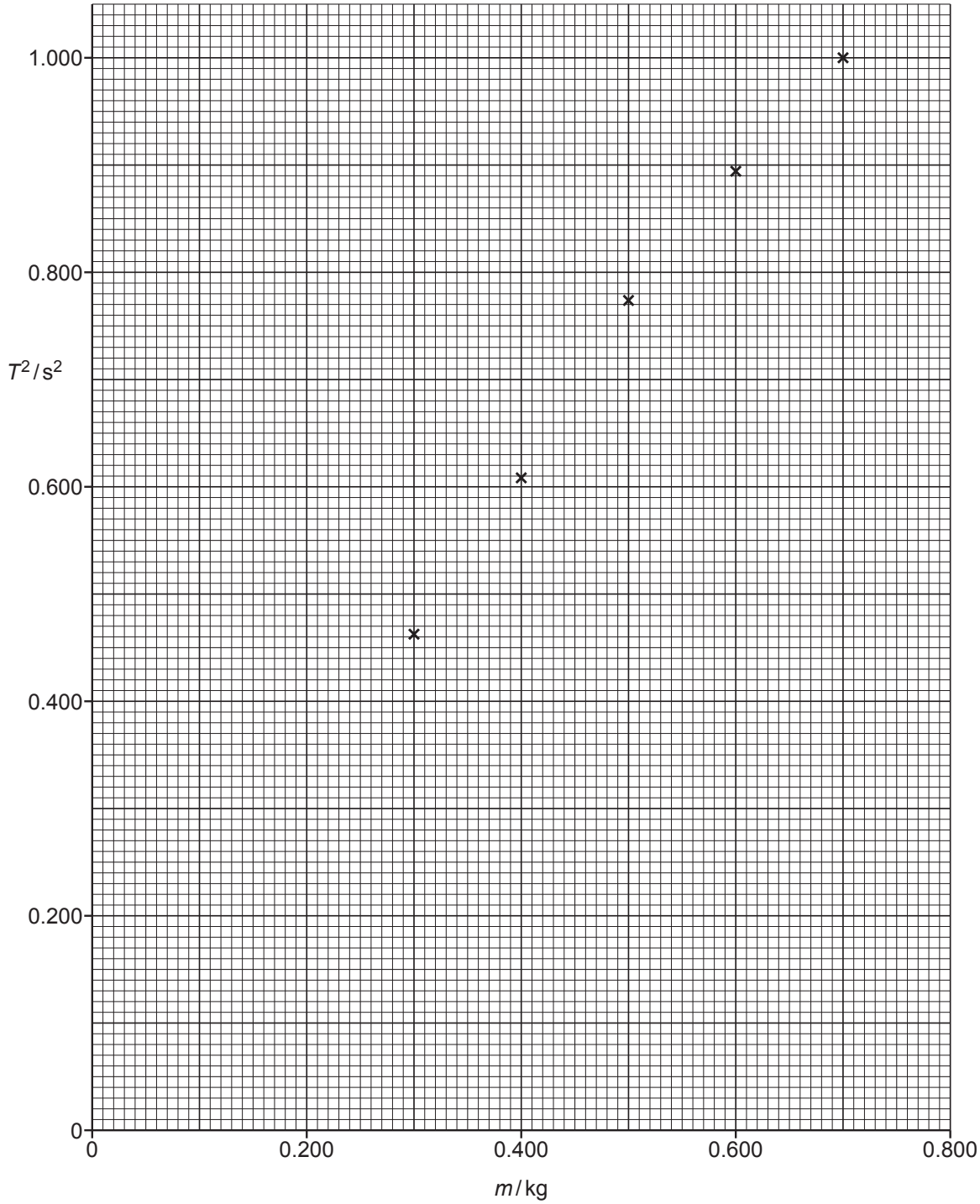
[2]

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(ii) Plot the **first** data point from the table on the graph below.

The other points have all been plotted. The table of results is repeated on the opposite page.

Include on your graph a line of best fit. **[2]**



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m/kg	$20T$/s	T	T^2
0.200	12.2	0.61	0.372
0.300	13.6	0.68	0.462
0.400	15.6	0.78	0.608
0.500	17.6	0.88	0.774
0.600	18.9	0.945	0.893
0.700	20.0	1	1

(iii) Use the graph to determine the value of k.

k = ... N m^{-1} **[3]**

(c) When the initial displacement is increased, one spring increases its extension while the extension of the other spring decreases.

Explain why the **maximum** kinetic energy of the motion increases.

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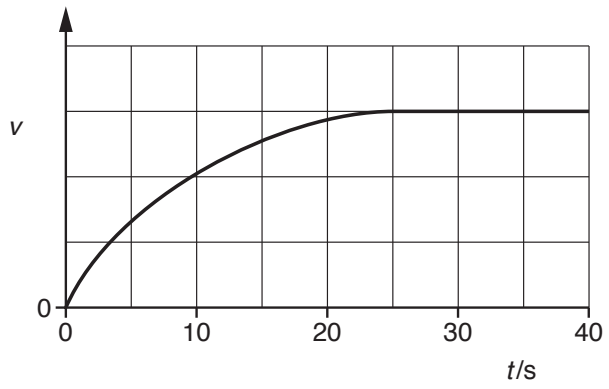
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SUB-TOPIC 3.2.2

MOTION WITH NON-UNIFORM ACCELERATION

Sub-topic 3.2.2 · 9 questions · 78 marks · lowest tariff first

12 An object is dropped from rest at time $t = 0$. It falls vertically through the air. The variation of the velocity v with time t is shown below.



Which statement is correct about this object?

A It has constant acceleration.

B It experiences zero drag at $t = 30\,s$.

C It has an acceleration of $9.81\,m\,s^{-2}$ at $t = 0\,s$.

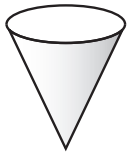
D It travels the same distance in every successive 10 s.

Your answer ☐ **[1]**

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Turn over

2 A paper cone is held above the ground and dropped. It falls vertically and reaches terminal velocity before it hits the ground.



Which statement correctly describes the **resultant** force on the falling cone before it reaches terminal velocity?

A decreasing and upwards

B decreasing and downwards

C increasing and downwards

D increasing and upwards

Your answer ☐ **[1]**

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18* A student is attempting to determine the value of g, the acceleration due to gravity, by two different methods.

Method 1. Vertical drop method

Measuring the time of fall of a small dense ball being dropped from rest from different heights.

Method 2. Rolling ball method

Measuring the time it takes for the same ball to roll 1.900 m down a ramp, set at different angles.

Single sets of results are shown below. The times were measured using a standard stopwatch operated by the student.

Compare and discuss the uncertainties of the two values of g that could be obtained using these single measurements.

Describe how the student would analyse both sets of data when a full range of results has been taken.

Vertical drop method

Drop height / m	Time taken / s
1.20	0.50

Rolling ball method

Length of ramp / m	Angle / °	Time taken / s
1.900	30	0.90

[6]

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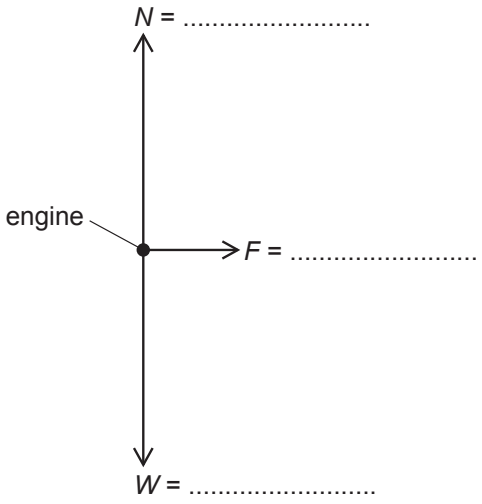
17 An electric engine of mass 17 000 kg has a constant power output of 280 kW and it can reach a maximum speed of 42 m s^{-1} on horizontal rails. The maximum kinetic energy of the engine is 15 MJ.

(a) The engine is initially at rest on long horizontal rails.
Show that the minimum time taken for the engine to reach its maximum speed is about 1 minute.

[1]

(b) The engine is moving along the horizontal rails at the constant maximum speed of 42 m s^{-1}.
The weight of the engine is *W*, the total normal contact force from the rails is *N* and the total friction between the wheels and the rails is *F*.
F is responsible for the motion of the engine to the **right**.

Complete the free body diagram for the engine by showing a missing force, and the magnitudes of all the forces. There is space for you to do any calculations below the diagram.



[3]

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(c) The speed of the engine is $42\,m\,s^{-1}$.

The driver sees an obstruction 167 m from the front of the engine. The engine is switched off and the brakes are applied.
The constant force opposing motion is 120 kN. The reaction time of the driver is 0.40 s.

Show with the help of calculations, that the engine will stop before reaching the obstruction.

[4]

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17 A student uses a motion-sensor connected to a laptop to investigate the motion of a hollow ball of mass 1.2×10^{-2} kg falling through air.

The ball is dropped from rest. It reaches terminal velocity before it reaches the ground.

The upthrust on the ball is negligible.

Fig. 17 shows the variation with time t of the velocity v of the ball as it falls towards the ground.

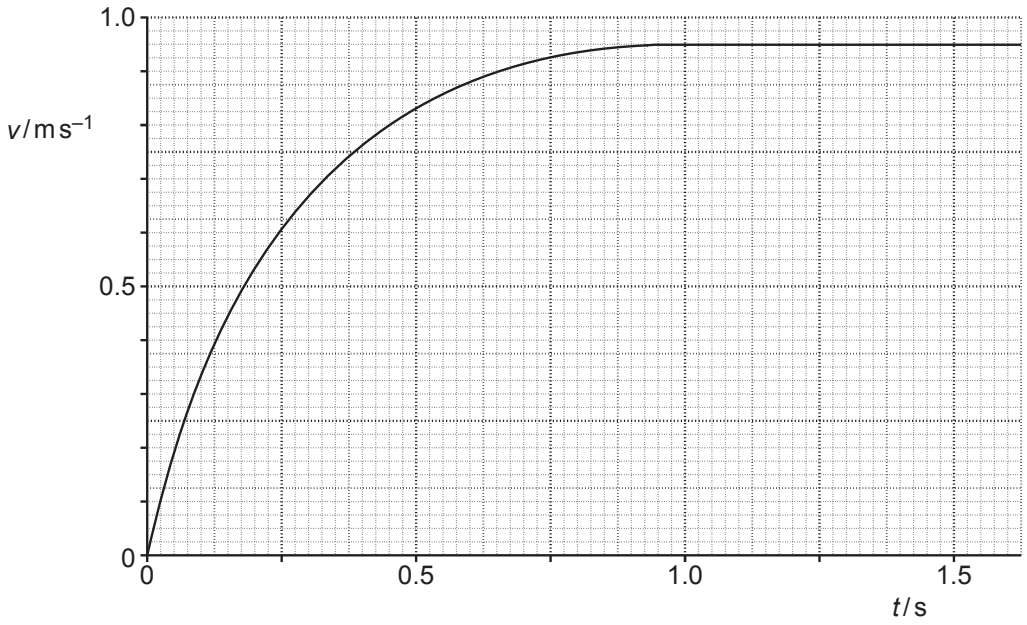


Fig. 17

(a) Draw a tangent to the curve at $t = 0.25$ s and determine the acceleration of the ball.

acceleration = ... $m\,s^{-2}$ **[3]**

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(b) Calculate the resultant force F acting on the ball at $t = 0.25\,s$.

$F =$ ..... N **[1]**

(c) Use your answer in **(b)** to calculate the drag on the ball at time $t = 0.25\,s$.

drag = ... N **[3]**

(d) The student now adds a small amount of sand inside the hollow ball.
As before, the ball is dropped from rest and it also reaches terminal velocity before it reaches the ground.

(i) Describe how the forces acting on the sand-filled ball at $v = 0.50\,m\,s^{-1}$ compare with the forces acting on the hollow ball at this speed.

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..... **[2]**

(ii) Explain why the terminal velocity of the sand-filled ball will be greater than the terminal velocity of the hollow ball.

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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.

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..... **[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.

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..... **[2]**

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***(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)	7 800		
Lead (solid sphere)	11 300		

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.

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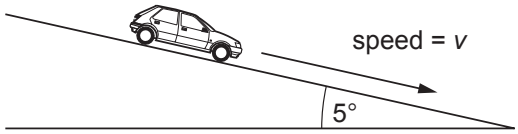
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16 A car of weight 9300 N is moving at speed v. The total resistive force, F, acting against the motion of the car is given by the formula

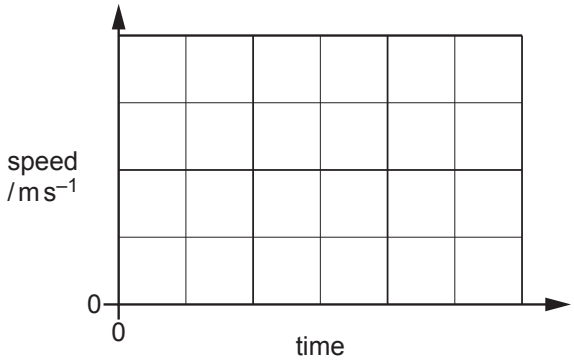
$F = kv^2$

where k is a constant.

(a) The car is allowed to roll from rest down a slope of 5° to the horizontal. The engine of the car is not switched on. The car reaches a maximum speed of 30 m s^{-1}.



(i) Sketch a graph on the axes below to show how the speed of the car changes over time. Add a suitable value to the vertical axis.



[2]

(ii) Explain why the car reaches a maximum speed.

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..... **[2]**

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(iii) Show that the value of k in the equation $F = kv^2$ is about 1.

[3]

(b) The car is now moving along a straight, level track. The engine of the car delivers a maximum power of 75 kW.

Calculate the maximum speed of the car.

maximum speed of car = ... $m\,s^{-1}$ **[3]**

(c) Changes are made to the engine of the car so that it can produce double the original maximum power.

Explain why the maximum speed of the modified car is **not** doubled.

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18 A swimming pool designer investigates the depth *d* below a water surface reached by a diver when diving from a height *h* above the water surface. The designer models the diver as a uniform wooden cylinder. The experimental arrangement is shown in Fig. 18.1.

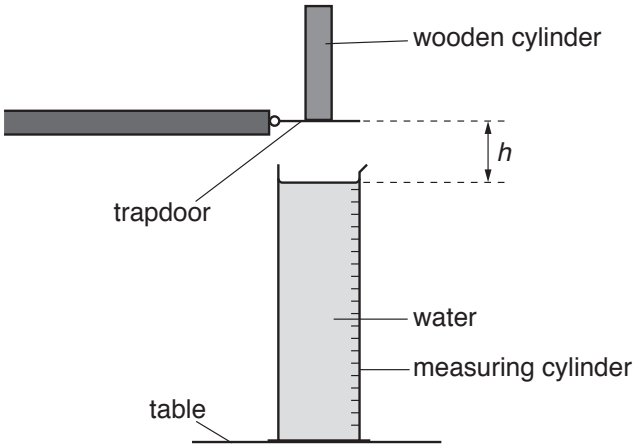


Fig. 18.1

(a) The wooden cylinder has mass 5.0×10^{-3} kg, diameter 1.0×10^{-2} m and length 7.0×10^{-2} m.

(i) Calculate the density of the wood.

density = ... kg m^{-3} **[2]**

(ii) Suggest why wood is an appropriate material to model the depth reached by a diver.

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Turn over

(b) The cylinder is released from **rest** from a trapdoor. The base of the cylinder is at a height $h = 0.30\,\text{m}$ above the water surface.
Calculate the speed of the cylinder just before the base hits the water. Ignore air resistance.

speed = ... m s^{-1} **[2]**

(c) Fig. 18.2 shows the cylinder fully submerged under the water surface before it has come to rest. The cylinder is moving vertically **down**.

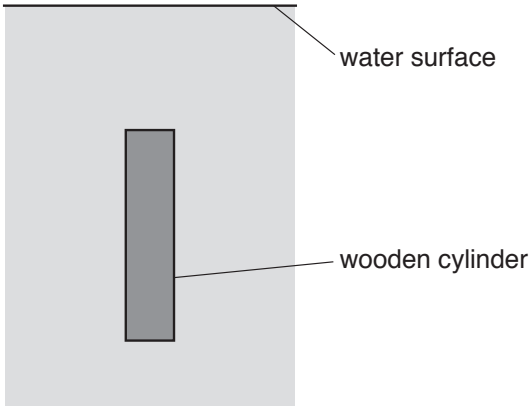


Fig. 18.2

(i) Add arrows to Fig. 18.2 to show the **three** forces acting on the wooden cylinder. Label the arrows. **[3]**

(ii) Describe and explain how the **resultant** force on the wooden cylinder varies from the moment the cylinder is fully submerged until it reaches its deepest point.

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..... **[3]**

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(d) The graph of Fig. 18.3 shows the depth *d* reached for different initial drop height *h*.

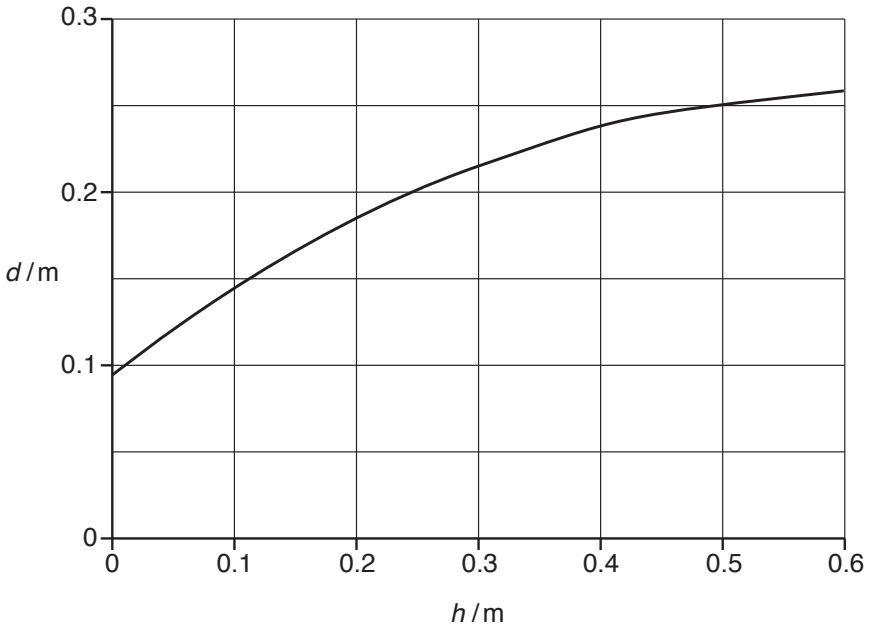


Fig. 18.3

The designer is required to double the height of a diving board for an existing swimming pool.
He suggests that the depth of the pool also needs to be doubled.
Use Fig. 18.3 to explain whether you agree with this suggestion.

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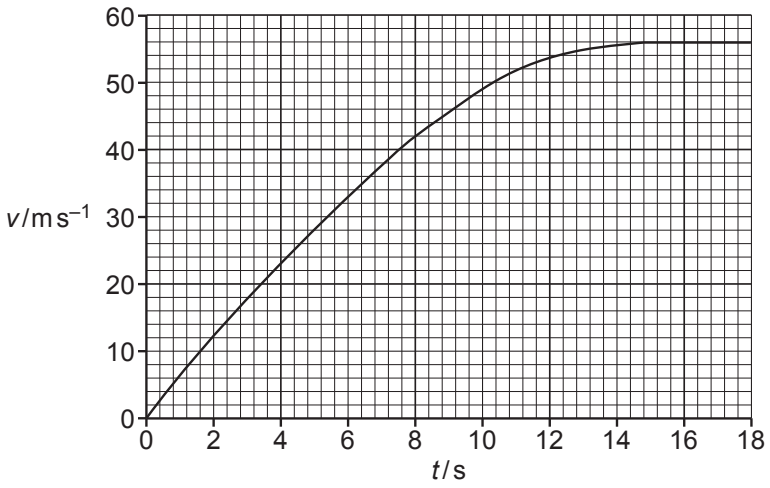
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16 An electric car of mass 1700 kg is tested to measure its maximum speed.

Fig. 16.1 shows a graph of velocity v against time t for the first 18 seconds of the test.

During this time the force produced by the motor is constant.

Fig. 16.1



(a)

(i) Describe using **Fig. 16.1**, the method you would use to estimate the distance travelled in 18 s.

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(ii) Use the graph in **Fig. 16.1** to show that the acceleration of the car at time t = 12 s is about 1.5 m s^{-2}.

[2]

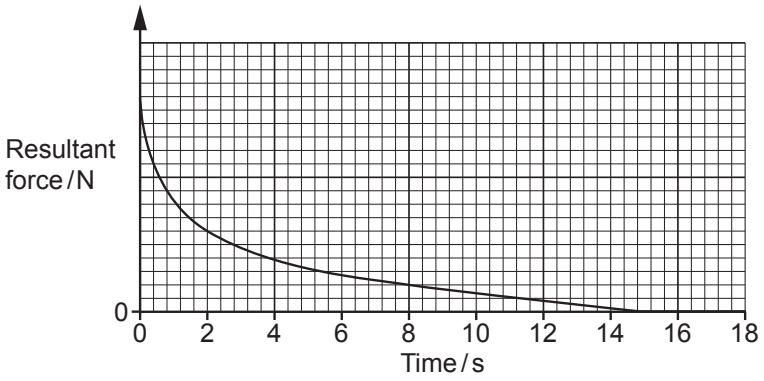
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(iii) Use **Fig. 16.1** to calculate the change of momentum of the car in 18 s.

= ..... kg m s^{-1} **[2]**

(b) **Fig. 16.2** shows a graph of **resultant** force against time during the test.

Fig. 16.2



(i) Explain, in terms of the forces acting on the car, the shape of the graph in **Fig. 16.2**.

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(ii) Explain why the value you have calculated in **(a)(iii)** is the area under the graph in **Fig. 16.2**.

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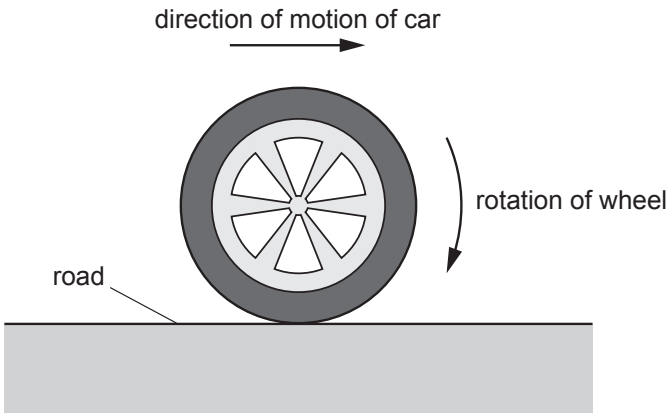
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Turn over

(c) The diagram below shows one of the wheels of the car that is driven by the electric motor.



(i) Use Newton's third law to explain how frictional forces cause the car to accelerate.

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..... **[2]**

(ii) Calculate the resultant force acting on the car at t = 12 s, using your answer to **(a)(ii)**.

resultant force = ... N **[1]**

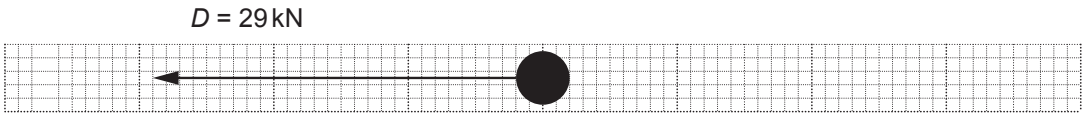
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(iii) The black dot in the diagram below represents the car at time t = 12 s. The total resistive forces acting on the car, D, are shown.

Calculate the constant **total** frictional force F from the powered wheels of the car which provides the thrust on the car.

Use your answer to draw an arrow on the diagram below to show the direction and magnitude of F.

F = ... kN



[2]

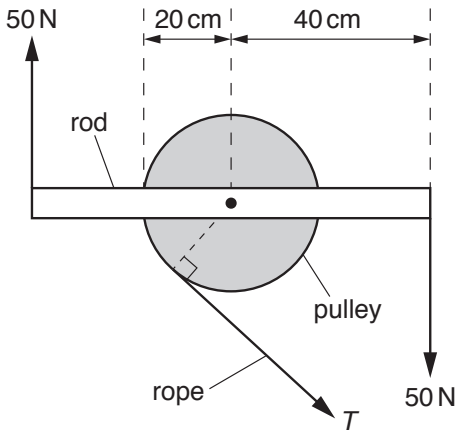
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SUB-TOPIC 3.2.3

EQUILIBRIUM, MOMENTS AND COUPLES

Sub-topic 3.2.3 · 16 questions · 88 marks · lowest tariff first

5 A rod is fixed to a pulley. Two 50 N forces are applied to the ends of the rod as shown. The tension in the rope attached to the pulley is *T*. The system is in equilibrium.



Not to scale

What is the moment of the tension *T* about the centre of the pulley?

A 10 N m

B 20 N m

C 30 N m

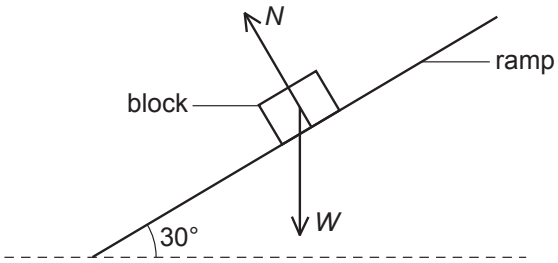
D 40 N m

Your answer ☐ **[1]**

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Turn over

8 A wooden block is **stationary** on a ramp.

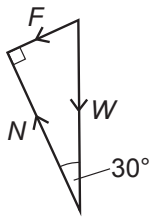


The diagram is **not** drawn to scale.

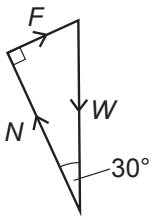
The block has weight *W*. The normal contact force on the block is *N*. The frictional force *F* on the block is not shown on the diagram.

Which triangle of forces diagram is correct?

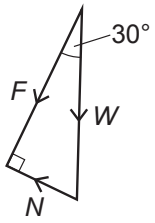
A



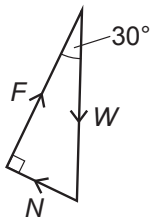
B



C



D



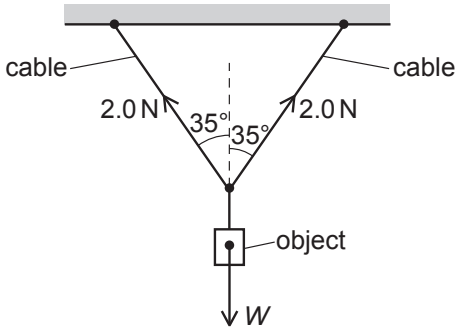
Your answer ☐ **[1]**

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Turn over

8 An object of weight *W* is suspended from two identical cables.

The tension in each cable is 2.0 N. Each cable makes an angle of 35° to the vertical.



What is the weight *W* of the object?

A 1.6 N

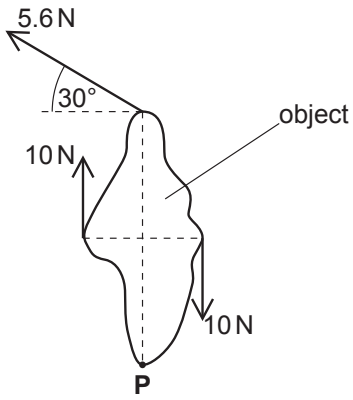
B 2.3 N

C 2.8 N

D 3.3 N

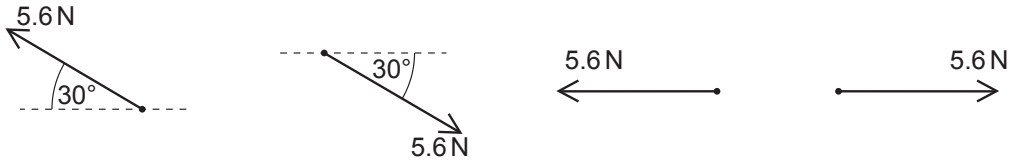
Your answer ☐ **[1]**

5 The object below is in equilibrium.



A force, not shown on the diagram, also acts on the object at point **P**.

Which of the following shows the correct direction and magnitude of the force acting at point **P**?



A **B** **C** **D**

Your answer ☐ **[1]**

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2 Forces are applied to a circular shaft of diameter d.

Which diagram shows a torque of a couple with magnitude Fd?



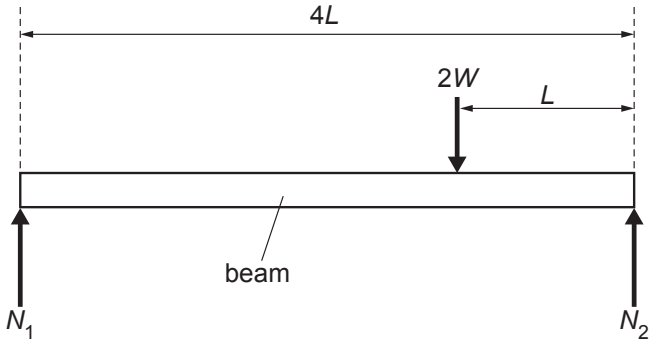
A **B** **C** **D**

Your answer ☐ **[1]**

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6 A horizontal uniform beam of length $4L$ and weight W is supported at both ends.

An object weighing $2W$ is placed on the beam at a distance L from one end.



What are the magnitudes of the normal reactions N_1 and N_2 on the supports at the ends of the beam?

A $N_1 = 0.5W$, $N_2 = 1.5W$

B $N_1 = W$, $N_2 = 2W$

C $N_1 = 1.5W$, $N_2 = 1.5W$

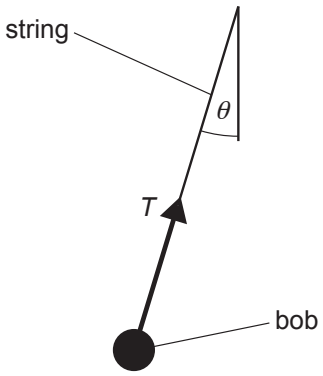
D $N_1 = 2W$, $N_2 = W$

Your answer ☐ **[1]**

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8 The bob of a pendulum is displaced slightly so that the string forms a small angle $\theta < 10°$ with the vertical.

The tension in the string is T. The small angle approximation applies.



Which of the following pairs of quantities would give approximately, within 2 significant figures, the same value for the horizontal component of T?

1 $T\cos\theta$ and $T\sin\theta$

2 $T\cos\theta$ and $T\tan\theta$

3 $T\sin\theta$ and $T\tan\theta$

A 1 only

B 1 and 3

C 3 only

D 2 and 3

Your answer ☐ **[1]**

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22 A screw is used to hang a wooden sign on a wall. It is screwed into the wall using a screwdriver.

(a) The width of the screwdriver blade is 5.0×10^{-3} m from end to end.
The ends of the blade exert equal and opposite forces on the screw.
The magnitude of each force is 350 N, as shown in Fig. 22.1.

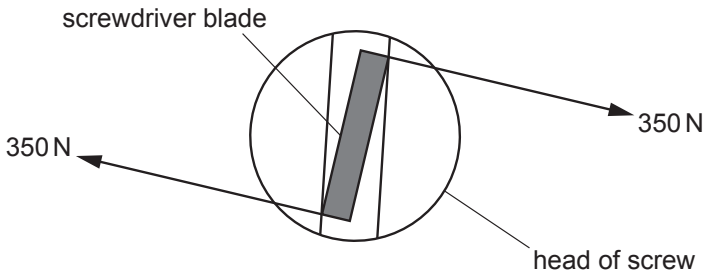


Fig. 22.1

Calculate the magnitude of the torque of the couple produced by the forces at each end of the screwdriver blade.

torque = ... N m **[1]**

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(b) The wooden sign is then hung on the screw at point **A**.
The forces acting on the screw are shown in Fig. 22.2.

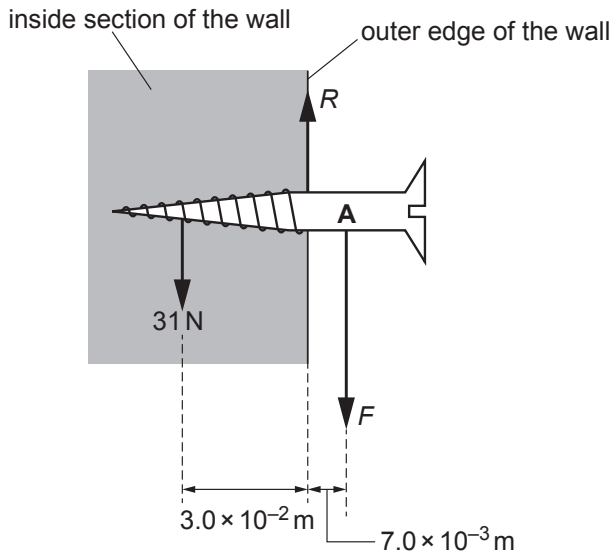


Fig. 22.2

The inside section of the wall exerts a maximum downwards force of 31 N at a distance of 3.0×10^{-2} m from the outer edge of the wall.
The hanging wooden sign exerts a force *F* at a distance 7.0×10^{-3} m from the outer edge of the wall.
There is a force *R* acting on the screw at the outer edge of the wall.
The mass of the screw is negligible.

Use the principle of moments to calculate the maximum mass of the wooden sign.

mass = ... kg **[3]**

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Turn over

19 **(a)** Describe how to find the centre of mass of a 2-dimensional shape, including any equipment required.

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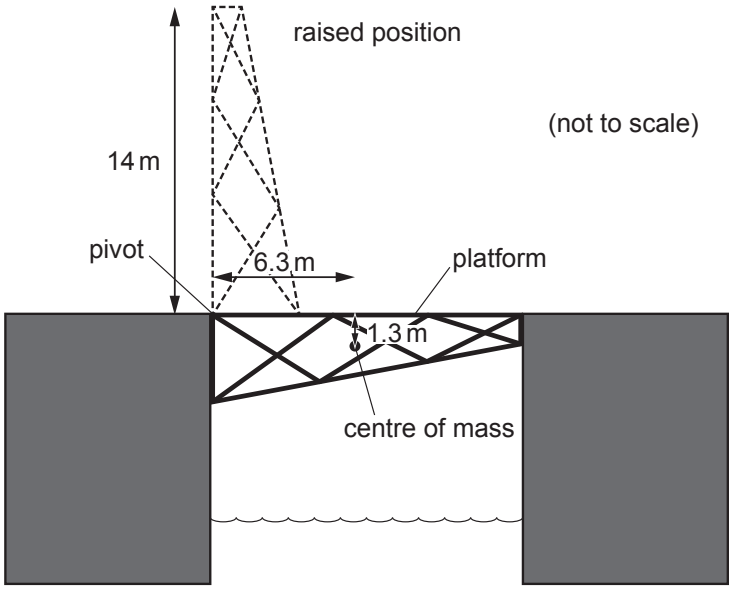
.....

..... **[3]**

(b) **Fig. 19** shows a bridge.

The bridge can be raised by an electric motor to allow tall ships to pass underneath.

Fig. 19



The moving section of the bridge is 14 m long and has a weight of 120 kN.

The centre of mass of the structure is 6.3 m from the pivot.

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(i) Calculate the average power required to raise the bridge to a vertical position in 90 s.

power ..... W **[2]**

(ii) Suggest why the actual electric motor used to lift the bridge has a maximum power output several times larger than the value calculated in **(b)(i)**.

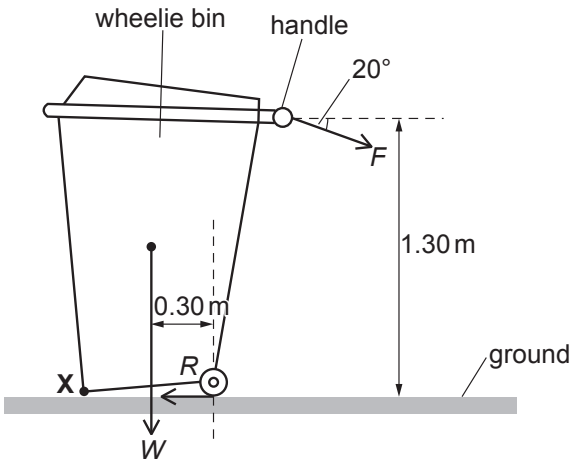
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..... **[1]**

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19 A wheelie bin is tipped onto its wheels by applying two forces *F* and *R*.



F is applied to the handle. *F* is to the right at an angle 20° below the horizontal.
The height of the handle above the ground is 1.30 m.
R is a horizontal force applied to the left to the wheels.
The total weight of the wheelie bin and its contents is *W*.
The perpendicular distance between the line of action of the weight and the bottom of the wheels is 0.30 m.

The wheelie bin and contents have a total mass of 40 kg.

(a) State the **principle of moments**.

.....

..... **[1]**

(b) **(i)** Show that the magnitude of the minimum force *F* which lifts the front end of the wheelie bin (point **X**) off the ground is 96 N.

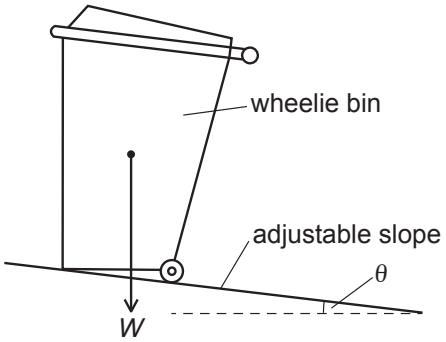
[3]

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(ii) Use your answer to **(b)(i)** to calculate the magnitude of the force R required to stop the wheelie bin from moving to the right.

R = ... N **[2]**

(c) The wheelie bin in now placed on an adjustable slope. The wheels are now fixed so they cannot move.



The angle θ made by the slope with the horizontal is steadily increased from zero.

Explain, without calculation, at what angle θ the wheelie bin starts to topple clockwise.

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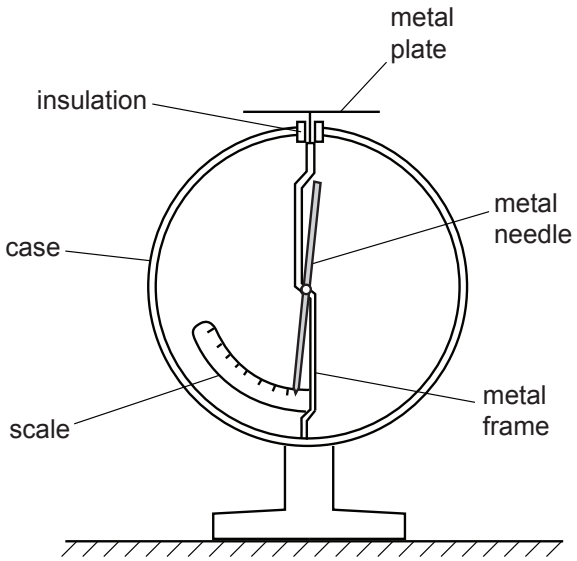
..... **[1]**

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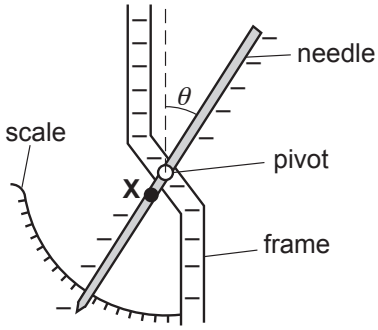
Turn over

4 An electroscope is an instrument used to measure electric charge.

The diagram shows one type of electroscope.



The diagram below shows the needle of the electroscope when it is negatively charged. The centre of mass, **X**, of the needle has been marked on the diagram.



(a) Suggest why the centre of mass of the needle is a **short** distance **below** the pivot.

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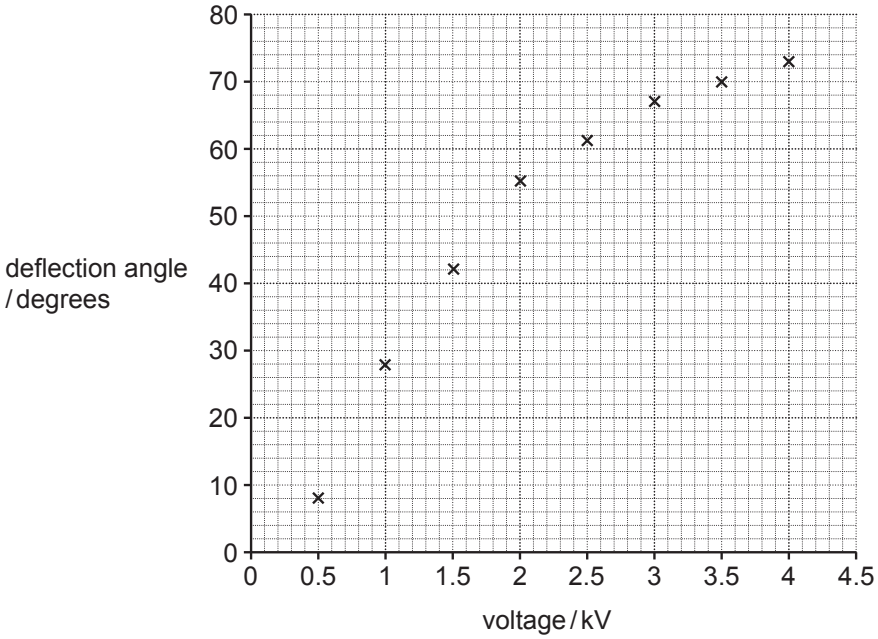
..... **[2]**

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(b) A student charges the electroscope by connecting the metal plate to the negative terminal of a high voltage power supply.

They record the deflection angle of the needle for a range of values of the voltage measured using a voltmeter.

Their results are shown in the graph below.



(i) The student concludes that the voltmeter has a zero error of 300 V.

Explain their reasoning.

.....

..... **[1]**

(ii) The capacitance of the electroscope is 20 pF.

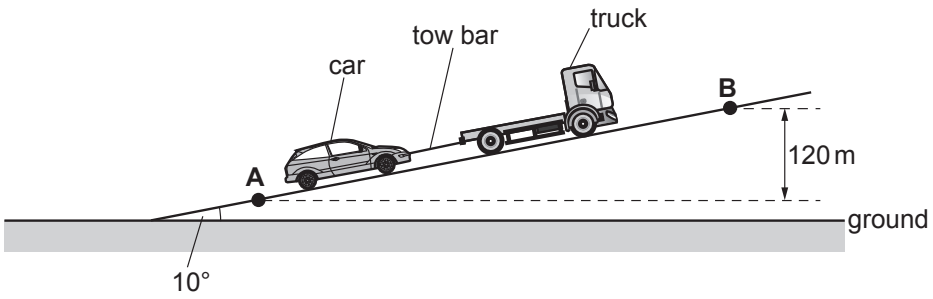
Estimate the number of electrons stored on the electroscope when the deflection angle is 45°.

number of electrons = ... **[4]**

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Turn over

16 A truck pulls a car up a slope at a **constant** speed.
The truck and the car are joined with a steel tow bar, as shown in the diagram.

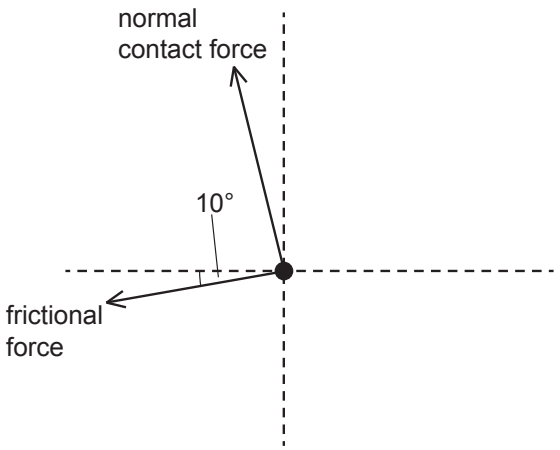


The diagram is **not** drawn to scale.

The slope is 10° to the horizontal ground.
The mass of the car is 1100 kg.
The car travels from **A** to **B**. The vertical distance between **A** and **B** is 120 m.

(a) There are four forces acting on the **car** travelling up the slope.

Complete the free-body diagram below for the car and label the missing forces.



[2]

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(b) Show that the component of the weight of the car W_s acting down the slope is about 1900 N.

[1]

(c) The total frictional force acting on the car as it travels up the slope is 300 N.

Calculate the force provided by the tow bar on the car.

force = ... N **[1]**

(d) Calculate the work done by the force provided by the tow bar as the car travels from **A** to **B**.

work done = ... J **[3]**

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(e) The steel tow bar used to pull the car has length 0.50 m and diameter 1.2×10^{-2} m.
The Young modulus of steel is 2.0×10^{11} Pa.

Calculate the extension x of the tow bar as the car travels up the slope.

x = ... m **[3]**

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18 A tent is secured by 3 ropes along each of its long sides, as shown in **Fig. 18.1**.

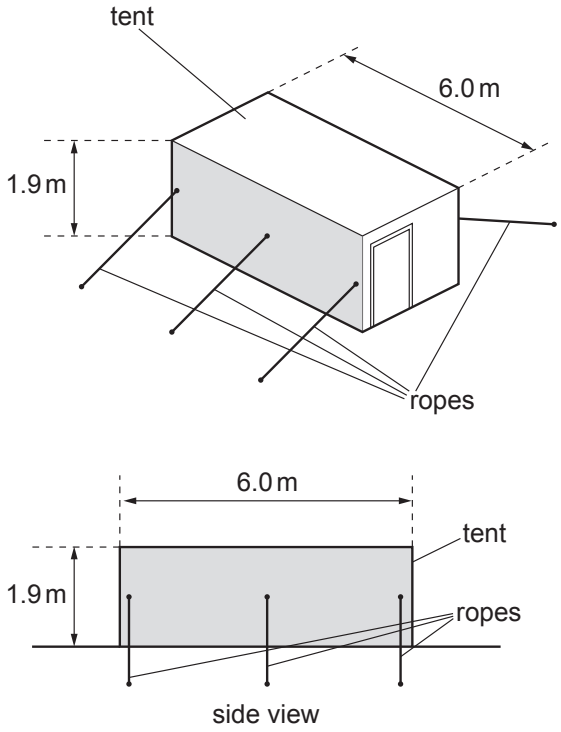


Fig. 18.1

(a) Wind of speed 12 m s^{-1} blows at right angles to the **shaded** side of the tent for 3.0 s. The density of air is 1.2 kg m^{-3}.

(i) Show that the mass of air which hits the tent in this time is about 490 kg.

[3]

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(ii) All of the air incident on the shaded side of the tent is deflected at 90° to the original direction as shown in **Fig. 18.2**.

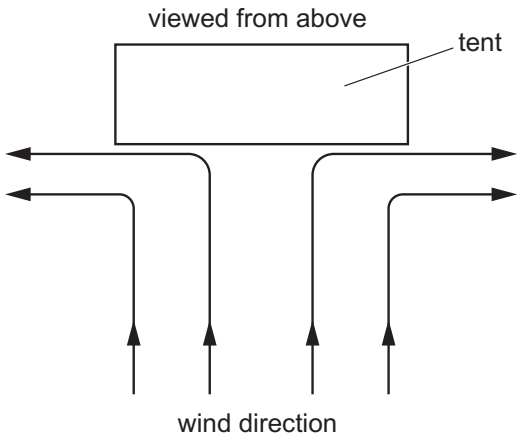


Fig. 18.2

Use the information given in **(a)(i)** to calculate the magnitude of the force *F* exerted by the wind on the shaded side of the tent.

F = ... N **[2]**

(b)* When the wind speed exceeds 20 m s^{-1} the ropes securing the tent break.

Describe, and explain in terms of forces, how the ropes and the shape of the tent could be modified to withstand wind speed exceeding 40 m s^{-1}. **[6]**

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Additional answer space if required

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6 This question is about the motion of a ball suspended by an elastic string above a bench. The mass of the string is negligible compared to that of the ball. Ignore air resistance.



Fig. 6.1

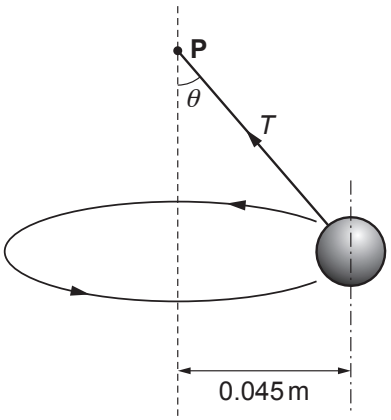


Fig. 6.2 (not to scale)

In Fig. 6.1 the ball of weight 1.2 N hangs vertically at rest from a point **P**. The extension of the string is 0.050 m. The string obeys Hooke's law.

In Fig. 6.2 the ball is moving in a horizontal circle of radius 0.045 m around a vertical axis through **P** with a period of 0.67 s. The string is at an angle θ to the vertical. The tension in the string is T.

(a) On Fig. 6.2 draw and label one other force acting on the ball. **[1]**

(b) **(i)** Resolve the tension T horizontally and vertically and show that the angle θ is 22°.

[2]

(ii) Calculate the extension x of the string shown in Fig. 6.2.

x = ... m **[3]**

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(c) Whilst rotating in the horizontal plane the ball suddenly becomes detached from the string. The bottom of the ball is 0.18 m above the bench at this instant. The ball falls as a projectile towards the bench beneath. Fig. 6.3 shows the view from above.

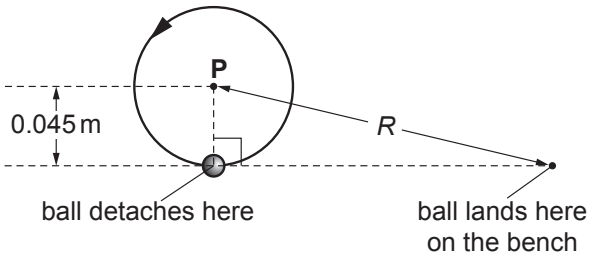


Fig. 6.3

Calculate the horizontal distance *R* from the point on the bench vertically below the point **P** to the point where the ball lands on the bench.

R = ... m **[4]**

(d) Returning to the situation shown in Fig. 6.2, state and explain what happens when the rate of rotation of the ball is increased.

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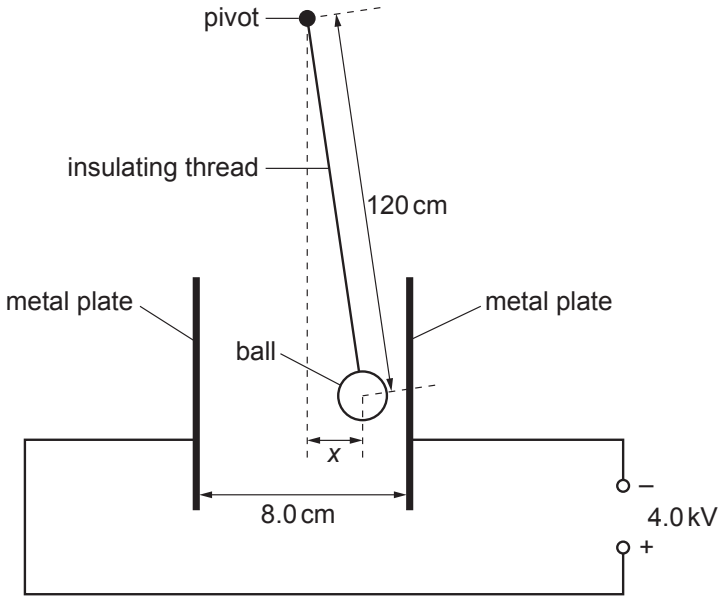
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..... **[2]**

1 A ball coated with conducting paint has weight 0.030 N and radius 1.0 cm. The ball is suspended from an insulating thread. The distance between the pivot and the centre of the ball is 120 cm.

The ball is placed between two vertical metal plates. The separation between the plates is 8.0 cm. The plates are connected to a 4.0 kV power supply.

(a) The ball receives a positive charge of 9.0 nC when it is made to touch the positive plate. It then repels from the positive plate and hangs in equilibrium at a displacement x from the vertical, as shown below. The diagram is **not** drawn to scale.



(i) Show that the electric force acting on the charged ball is 4.5×10^{-4} N.

[2]

(ii) Draw, on the diagram above, arrows which represent the **three** forces acting on the ball. Label each arrow with the name of the force it represents. **[2]**

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(iii) By taking moments about the pivot, or otherwise, show that $x = 1.8\,\text{cm}$.

[2]

(b) The ball is still positively charged.

The plates are now moved slowly towards each other whilst still connected to the 4.0 kV power supply. The plates are stopped when the separation is 5.0 cm.

Explain the effect that this has on the deflection of the ball and explain why the ball eventually starts to oscillate between the plates.

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..... **[4]**

Question 1 continues on page 4

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(c) When the ball oscillates between the plates, the current in the external circuit is 3.2×10^{-8} A.

A charge of 9.0 nC moves across the gap between the plates each time the ball makes one complete oscillation.

Calculate the frequency f of the oscillations of the ball.

f = ... Hz **[2]**

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2 A student investigates the oscillations of a uniform rod of length *L* which is pivoted at the top, as shown in **Fig. 2.1**.

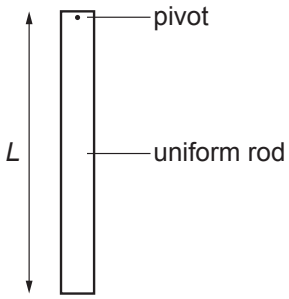


Fig. 2.1

(a) Describe how to determine accurately the period *T* of oscillations of this rod.

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.....

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..... **[2]**

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Turn over

(b) The relationship between the frequency f of the oscillations of the rod and its length L is

$$f = \frac{1}{2\pi}\sqrt{\frac{3g}{2L}},$$

where g is the acceleration of free fall.

The student varies the length L of the rod and determines the period T for each length.

The student plots a graph of T^2 against L, shown in **Fig. 2.2**. A line of best fit has already been drawn.

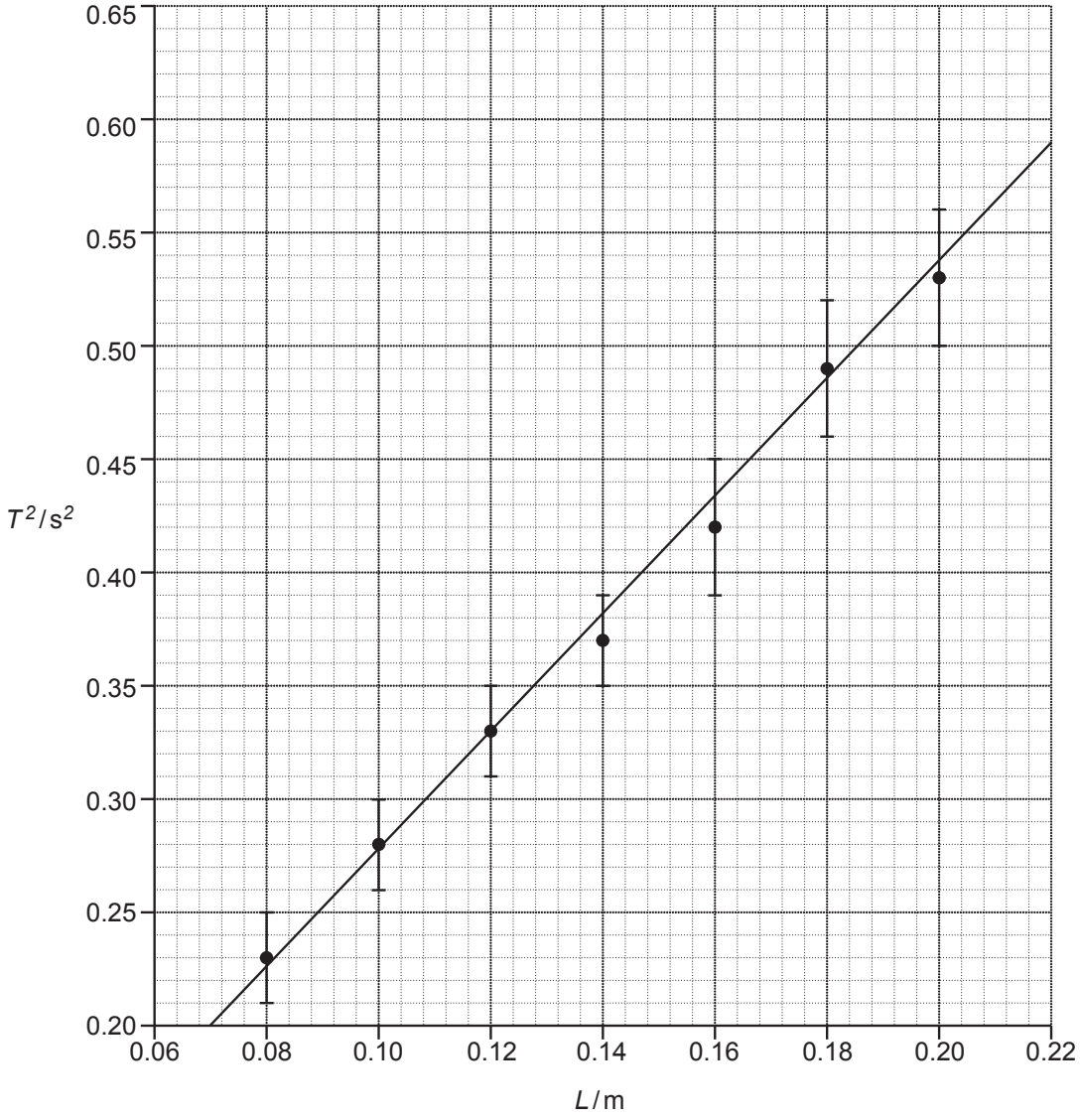


Fig. 2.2

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(i) Show that the gradient of the graph is given by the equation

$$\text{gradient} = \frac{8\pi^2}{3g}$$

[2]

(ii) The gradient of the line of best fit on **Fig. 2.2** is $2.64\,s^2\,m^{-1}$.

Use this value to determine g.

g = ... $m\,s^{-2}$ **[2]**

(iii) Draw a line of worst fit on **Fig. 2.2**. **[1]**

(iv) Use your line of worst fit to calculate the percentage uncertainty in g.

percentage uncertainty = ... % **[3]**

(v) Use the true value of g ($9.81\,m\,s^{-2}$) to evaluate the accuracy of the student's value of g from this experiment. Include a calculation in your answer.

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..... **[2]**

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Turn over

SUB-TOPIC 3.2.4

DENSITY AND PRESSURE

Sub-topic 3.2.4 · 21 questions · 144 marks · lowest tariff first

14 A container has an ideal gas. The mean square speed of the gas molecules in the container is $3.0 \times 10^5\,m^2\,s^{-2}$.

Over a period of time, a third of the gas molecules escape from the container. The pressure and volume of the gas in the container remain the same.

What is the mean square speed of the molecules left in the container?

A $1.0 \times 10^5\,m^2\,s^{-2}$

B $2.0 \times 10^5\,m^2\,s^{-2}$

C $4.5 \times 10^5\,m^2\,s^{-2}$

D $9.0 \times 10^5\,m^2\,s^{-2}$

Your answer ☐ **[1]**

14 The volume of one mole of an ideal gas is V. The gas exerts pressure p and has thermodynamic temperature T.

Which of the following has the units $\text{J mol}^{-1}\text{ K}^{-1}$?

A pV

B $\frac{p}{T}$

C $\frac{V}{T}$

D $\frac{pV}{T}$

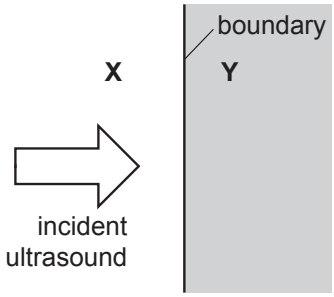
Your answer ☐ **[1]**

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12 The table shows some data on two tissues in a patient.

Tissue	Density	Acoustic impedance
X	ρ	$1.5Z$
Y	1.3ρ	Z

Ultrasound in tissue **X** is incident at the boundary between the tissues **X** and **Y**.



What is the percentage of the ultrasound intensity reflected at the boundary?

A 1.7 %

B 4.0 %

C 13 %

D 20 %

Your answer ☐ **[1]**

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10 Which of the following shows the correct base units for pressure?

A $kg\,m^{-2}$

B $kg\,m^{-2}\,s^{-2}$

C $kg\,m^{-1}\,s^{-2}$

D $kg\,m^{2}\,s^{-3}$

Your answer ☐ **[1]**

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Turn over

2 Which pair of quantities have the same S.I. base units?

A force, strain

B force, stress

C pressure, stress

D strain, upthrust

Your answer ☐ **[1]**

9 A piston has a fixed amount of trapped ideal gas.

The gas exerts pressure p and has volume V. The thermodynamic (absolute) temperature of the gas is T. The mass of each atom is m. There are N atoms of the gas. The Boltzmann constant is k.

What quantities are required to determine the root mean square speed $\sqrt{\overline{c^2}}$ of the atoms?

A k and T

B p and V

C p, V and T

D p, V, N and m

Your answer ☐ **[1]**

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14 A beam of ultrasound is incident normally at a boundary between two tissues **F** and **G**.

The table below shows some data on the two tissues.

	Tissue F	**Tissue G**
Density of tissue	ρ	1.2ρ
Speed of ultrasound in tissue	c	$1.5c$

What percentage of the intensity of the ultrasound is reflected at the boundary?

A 0.83%

B 8.2%

C 9.1%

D 29%

Your answer ☐ **[1]**

9 A container has 1.0 mole of gas at pressure 100 kPa.
The root mean square (r.m.s.) speed of the gas particles is 500 m s^{-1}. The mass of each gas particle is 4.7×10^{-26} kg.

What is the volume of the container?

A 3.9×10^{-26} m^3

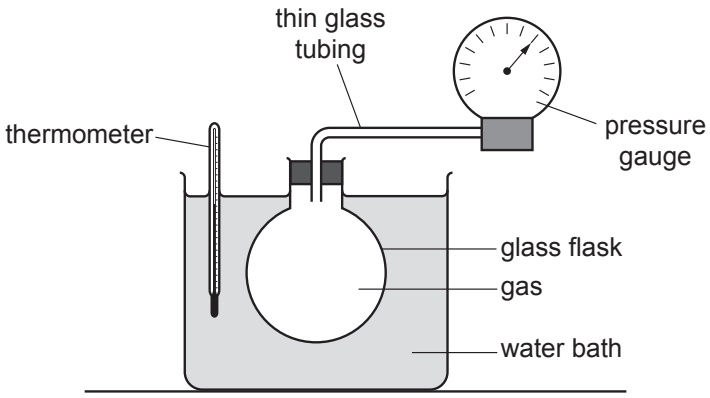
B 4.7×10^{-5} m^3

C 2.4×10^{-2} m^3

D 4.7×10^{-2} m^3

Your answer ☐ **[1]**

10 An experiment is carried out to estimate the value of absolute zero using the variation of gas pressure with temperature. The apparatus is shown below.



Which variable must be controlled during the experiment?

A Pressure of the gas

B Temperature of the gas

C Volume of the gas

D None of the above

Your answer ☐ **[1]**

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Turn over

5 A block of wood is floating in calm water.

The density of the wood is 700 kg m^{-3}. The density of water is 1000 kg m^{-3}.

What percentage of the volume of the block is **above** the waterline?

A 30

B 50

C 70

D 89

Your answer ☐ **[1]**

18 Wind turbines convert the kinetic energy of the wind into electrical energy.
Fig. 18 shows a wind turbine.

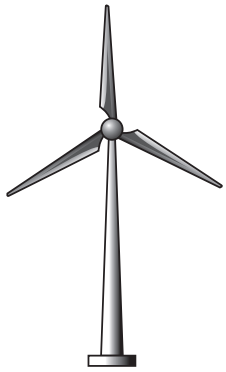


Fig. 18

(a) When the wind speed is $8.0\,m\,s^{-1}$, the kinetic energy of the air incident at the turbine per second is $1.2\,MJ\,s^{-1}$.
Calculate the mass of the air incident at the turbine per second.

mass per second = ... $kg\,s^{-1}$ **[2]**

(b) A group of engineers are investigating the design of wind turbines.
The maximum **input** power P from the wind is given by the equation

$$P = \frac{1}{2}\rho A v^3$$

where A is the area swept out by the rotating blades, ρ is the density of air and v is the speed of the wind.

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(i) Show that the equation is homogeneous with both sides of the equation having the same base units.

[3]

(ii) The input power to the wind turbine is 1.2 MW when the wind speed is 8.0 m s^{-1}. The density of air is 1.3 kg m^{-3}.

Calculate the length L of the turbine blades.

L = ... m **[2]**

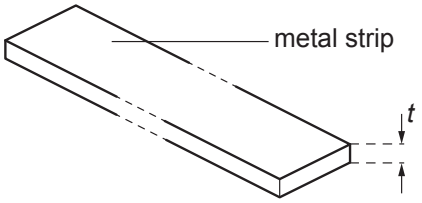
(iii) A wind farm is required to produce an output power of 50 MW when the average wind speed is 8.0 m s^{-1}. The efficiency of each wind turbine is 42%.

Calculate the minimum number N of wind turbines required to meet this demand.

N = ... **[2]**

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17 (a) A metal strip has thickness *t*, as shown below.



Five measurements of the thickness *t* at different positions along the length of the strip are shown below.

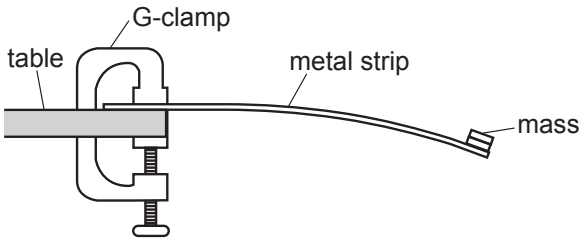
1.86 mm 1.88 mm 1.85 mm 1.89 mm 1.88 mm

Determine the percentage uncertainty in the thickness *t*.

percentage uncertainty = ... % **[3]**

(b)* A student wants to determine the Young modulus *E* of the metal of the strip in **(a)**.

The student clamps the metal strip to the edge of a table using a G-clamp. A mass is **permanently** fixed to the end of the strip as shown.



The mass oscillates freely when it is moved away from its equilibrium position and then released.

The Young modulus *E* of the metal can be determined using the equation $E = \frac{16\pi^2 mL^3}{wt^3T^2}$, where *m* is the mass fixed to the end of the strip, *L* is the length of the strip from the end of the table to the centre of the mass, *w* is the width of the strip, *t* is the thickness of the strip, and *T* is the period of oscillations.

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Describe how an experiment may be safely conducted, and how the data can be analysed to determine an accurate value for *E*. **[6]**

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Additional answer space if required.

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19 A lorry used to transport liquid oxygen has a tank with a maximum volume of $10\,m^3$.

The tank is filled until it contains $9.8\,m^3$ of liquid oxygen.

The pressure of the gas above the liquid is 100 kPa and the temperature of the gas and the liquid is –183 °C, the boiling point of oxygen.

The temperature of the oxygen remains constant.

The walls of the tank allow thermal energy to pass through at a constant rate of 1.3 kW.

The latent heat of vaporisation of oxygen is $214\,kJ\,kg^{-1}$.

The density of **liquid** oxygen is $1140\,kg\,m^{-3}$.

(a) State why thermal energy passes into the tank.

.....

.....

..... **[1]**

(b) Explain, in terms of particle energies, why the temperature of the oxygen remains constant despite the transfer of thermal energy into the tank.

.....

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..... **[2]**

(c) Show that in one hour the volume of liquid oxygen that evaporates is about $0.02\,m^3$.

[3]

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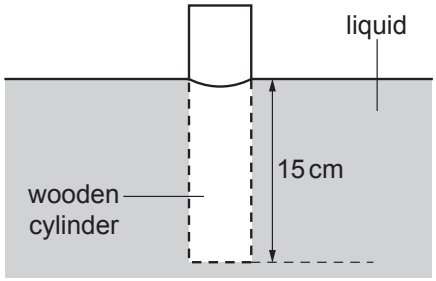
(d) After one hour the number of moles of gas above the remaining liquid oxygen is 710.

Calculate the pressure of the gas.

pressure = ... kPa **[3]**

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22 A long wooden cylinder is placed into a liquid and it floats as shown.



The length of the cylinder below the liquid level is 15 cm.

(a) (i) State **Archimedes' principle**.

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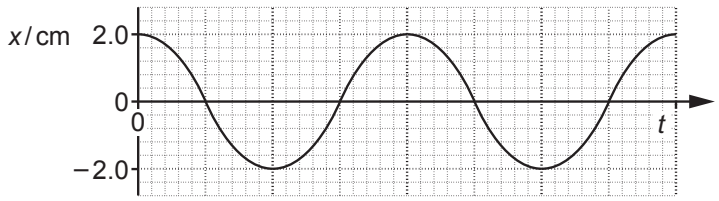
..... **[1]**

(ii) The pressure exerted by the liquid alone on the bottom of the cylinder is 1.9×10^3 Pa.

Calculate the density ρ of the liquid.

ρ = ... kg m^{-3} **[2]**

(b) The cylinder is pushed down into the liquid and then allowed to oscillate freely.
The graph of displacement x against time t is shown below.



The cylinder oscillates with simple harmonic motion with frequency of 1.4 Hz.

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(i) Calculate the displacement, in cm, at time $t = 0.60\,s$.

displacement = ... cm **[3]**

(ii) Calculate the maximum speed of the oscillating cylinder.

maximum speed = ... $m\,s^{-1}$ **[2]**

(iii) The cylinder is now pushed down further into the liquid before being released.
As before, the cylinder oscillates with simple harmonic motion.

State the effect this has on

1 the amplitude

.....

2 the period.

.....
[2]

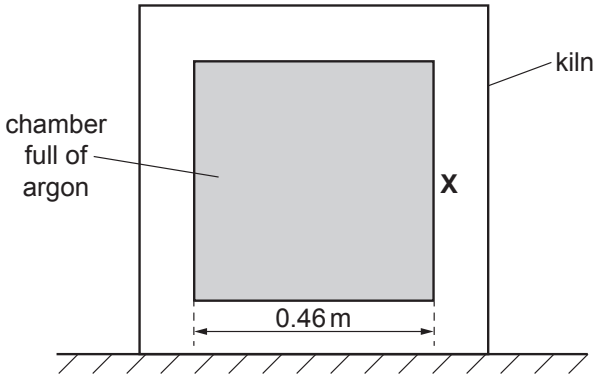
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21 A kiln used to harden ceramics is shown below.



The internal chamber is a cube. Each side of this cube has length 0.46 m.
The chamber is sealed and full of argon. Argon behaves as an ideal gas.

(a) The kiln is initially at 20 °C.
The argon in the kiln has an initial pressure of 100 kPa.

(i) Calculate the amount of argon *n* in the chamber in moles.

n = ... mol **[2]**

(ii) The temperature of the kiln is increased from 20 °C to 1300 °C.

Calculate the pressure in kPa at 1300 °C.

pressure = ... kPa **[2]**

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(b) The temperature of the kiln is 1300 °C.
A single atom of argon is travelling horizontally towards the vertical side **X** of the chamber.
The initial speed of this atom is 990 m s^{-1}. After collision, it rebounds at the same speed.

(i) Calculate the change in momentum Δp of this atom.
- mass of argon atom = 6.6×10^{-26} kg

Δp = ... kg m s^{-1} **[2]**

(ii) Assume that this atom does not collide with any other argon atoms inside the chamber. Instead, it travels horizontally, making repeated collisions with the opposite vertical walls of the chamber.

1 Show that the atom makes about 1000 collisions with side **X** in a time interval of 1.0 s.

[1]

2 Calculate the average force F on side **X** made by the atom.

F = ... N **[2]**

(iii) Without calculation, explain how your answer to **(ii)2** could be used to estimate the total pressure exerted by the atoms of the argon gas in the kiln.

.....

.....

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..... **[2]**

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19 **(a)** A fixed mass of nitrogen changes phase from liquid to gas at a constant temperature.

Explain the change in the total internal energy of nitrogen.

.....

.....

.....

..... **[2]**

(b) In a factory, nitrogen gas is added to packets of food to keep it fresh for longer.
In 1.0 hour, the factory uses 15 m^3 of nitrogen at pressure 100 kPa and temperature 23 °C.

(i) Show that the number of moles n, of nitrogen used per hour is about 600.

[3]

(ii) Calculate the mass of nitrogen gas used in one hour.

molar mass of nitrogen = 0.028 kg mol^{-1}

mass = ... kg **[1]**

(iii) The volume of nitrogen being used cannot be changed.

State how the rate of mass of nitrogen used can be reduced.

.....

..... **[1]**

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(iv) The nitrogen at the factory is stored as a liquid.
The liquid expands at constant temperature to form gas in a short section of pipe.

When the air temperature is 0 °C, a thick layer of ice forms on the outside of the pipe from water vapour in the air. In 1.0 hour, the mass of ice formed is 1.3 kg at a temperature of 0 °C.

Use the data below and your answer to **(b)(ii)**, to estimate the specific latent heat of vaporisation L of nitrogen.

- specific latent heat of fusion of ice = $3.34 \times 10^5\,\text{J kg}^{-1}$
- specific latent heat of vaporisation of water = $2.26 \times 10^6\,\text{J kg}^{-1}$

L = ... J kg^{-1} **[4]**

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1 The table shows some data on the planet Venus.

Mass / kg	4.87×10^{24}
Radius / km	6050
Density of atmosphere at surface / kg m^{-3}	65
Period of rotation about its axis / hours	5830

(a) Calculate the magnitude of the gravitational field strength g at the surface of Venus.

Give your answer to **3** significant figures.

g = ... N kg^{-1} **[3]**

(b) Two identical space probes, **A** and **B**, land on a flat surface on Venus.

Probe **A** lands at the north pole. Probe **B** lands on the equator.

Each probe has mass 760 kg and volume 1.7 m^3.

(i) Calculate the centripetal acceleration a of probe **B** at the equator due to the rotation of Venus about its axis.

a = ... m s^{-2} **[3]**

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(ii) The atmosphere exerts the same upthrust on each probe.

Using your answer to **(a)**, calculate the upthrust acting on each probe.

upthrust = ... N **[3]**

(iii) Explain which probe will experience the greater normal contact force from the surface of Venus.

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..... **[3]**

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20

(a)

(i) Define the internal energy of an ideal gas.

.....

.....

..... **[1]**

(ii) Use the formulae below to show that the average kinetic energy of a particle of an ideal gas is directly proportional to the absolute temperature of the gas.

$pV = \frac{1}{3}Nm\overline{c^2}$ $pV = NkT$

[2]

(b) The velocities of four gas particles at 290 K are given below in $m\,s^{-1}$.

310 370 440 550

(i) Show that the root-mean-square (r.m.s.) speed of the sample is about $430\,m\,s^{-1}$.

[2]

(ii) Calculate the molar mass of the gas assuming an absolute temperature of 290 K and r.m.s. speed of $430\,m\,s^{-1}$.

molar mass = ... $kg\,mol^{-1}$ **[3]**

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(c) Spherical filament lamps are manufactured by a process where they are filled with a gas at 290 K and low pressure.

When the filament lamp is switched on, the filament reaches a constant temperature of 2400 K. At this temperature, the pressure inside the filament lamp is 120 kPa.

(i) Explain, in terms of energy transfers, why the temperature of the filament does **not** increase beyond 2400 K. You are **not** expected to refer to the electrical characteristics of the filament lamp.

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..... **[3]**

(ii) Calculate the pressure of the gas within the filament lamp during manufacture.

pressure = ... kPa **[2]**

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20 **(a)** A sealed container contains n moles of an ideal gas. The gas has pressure p, absolute temperature T and occupies volume V.

The mass of one mole of the gas is M.

Use an ideal gas equation to show that the density ρ of the gas is given by the expression $\rho = \frac{pM}{RT}$.

[3]

(b) An airship has a cabin suspended underneath a gasbag inflated with helium.

The airship is floating above the ground and is stationary.

The volume of the gasbag is 12 000 m^3.
The temperature of the helium and the surrounding air is 20 °C.
Atmospheric pressure is 1.0×10^5 Pa.
The molar mass of air is 0.029 kg mol^{-1}.
The volume of the cabin is negligible compared to the volume of the gasbag.

(i) Show that the density of air under the conditions described is about 1.2 kg m^{-3}.

[1]

(ii) Calculate the weight of air displaced by the airship.

weight of air ..... N **[2]**

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(iii) Explain why the weight of air displaced by the airship has the same magnitude as the weight of the airship and its contents.

.....

.....

..... **[2]**

(iv) The pressure of the helium in the gasbag is maintained at a value only slightly greater than atmospheric pressure.
Suggest why a larger pressure is not used.

.....

.....

.....

..... **[2]**

(c) The airship engine drives a fan which moves 7.8 kg of air per second at a relative speed of 45 m s^{-1}, so the airship starts to move.

All other conditions given in **(b)** remain the same.

Calculate the thrust that the engine produces.

thrust ..... N **[2]**

(d) The airship has a higher maximum speed at high altitudes, but also produces less thrust from the engine.

Explain these observations.

.....

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..... **[2]**

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Turn over

17 A group of students are conducting an experiment in the laboratory to determine the value of absolute zero by heating a fixed mass of gas. The volume of the gas is kept constant.
Fig. 17.1 shows the arrangement used by the students.

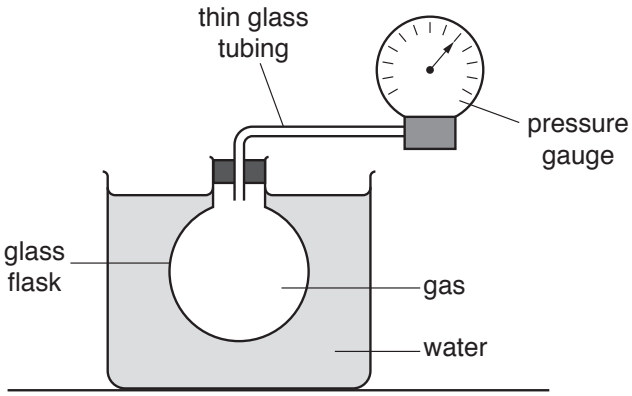


Fig. 17.1

The gas is heated using a water bath. The temperature θ of the water is increased from 5 °C to 70 °C. The temperature of the water bath is assumed to be the same as the temperature of the gas. The pressure p of the gas is measured using a pressure gauge.

The results from the students are shown in a table.

θ / °C	p / kPa
5 ± 1	224 ± 3
13 ± 1	231 ± 3
22 ± 1	238 ± 3
35 ± 1	248 ± 3
44 ± 1	
53 ± 1	262 ± 3
62 ± 1	269 ± 3
70 ± 1	276 ± 3

(a) Describe and explain how the students may have made accurate measurements of the temperature θ.

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.....

..... **[2]**

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(b) Fig. 17.2 shows the pressure gauge. Measurements of p can be made using the kPa scale or the psi (pounds per square inch) scale. The students used the psi scale to measure pressure and then converted the reading to pressure in kPa.



Fig. 17.2

(i) Suggest why it was sensible to use the psi scale to measure p.

.....

..... **[1]**

(ii) The students made a reading of p of 37.0 ± 0.5 psi when θ was 44 ± 1 °C.
Convert this value of p from psi to kPa. Complete the table for the missing value of p.
Include the absolute uncertainty in p.

1 pound of force = 4.448 N
1 inch = 0.0254 m

[2]

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(c) Fig. 17.3 shows the graph of p against θ.

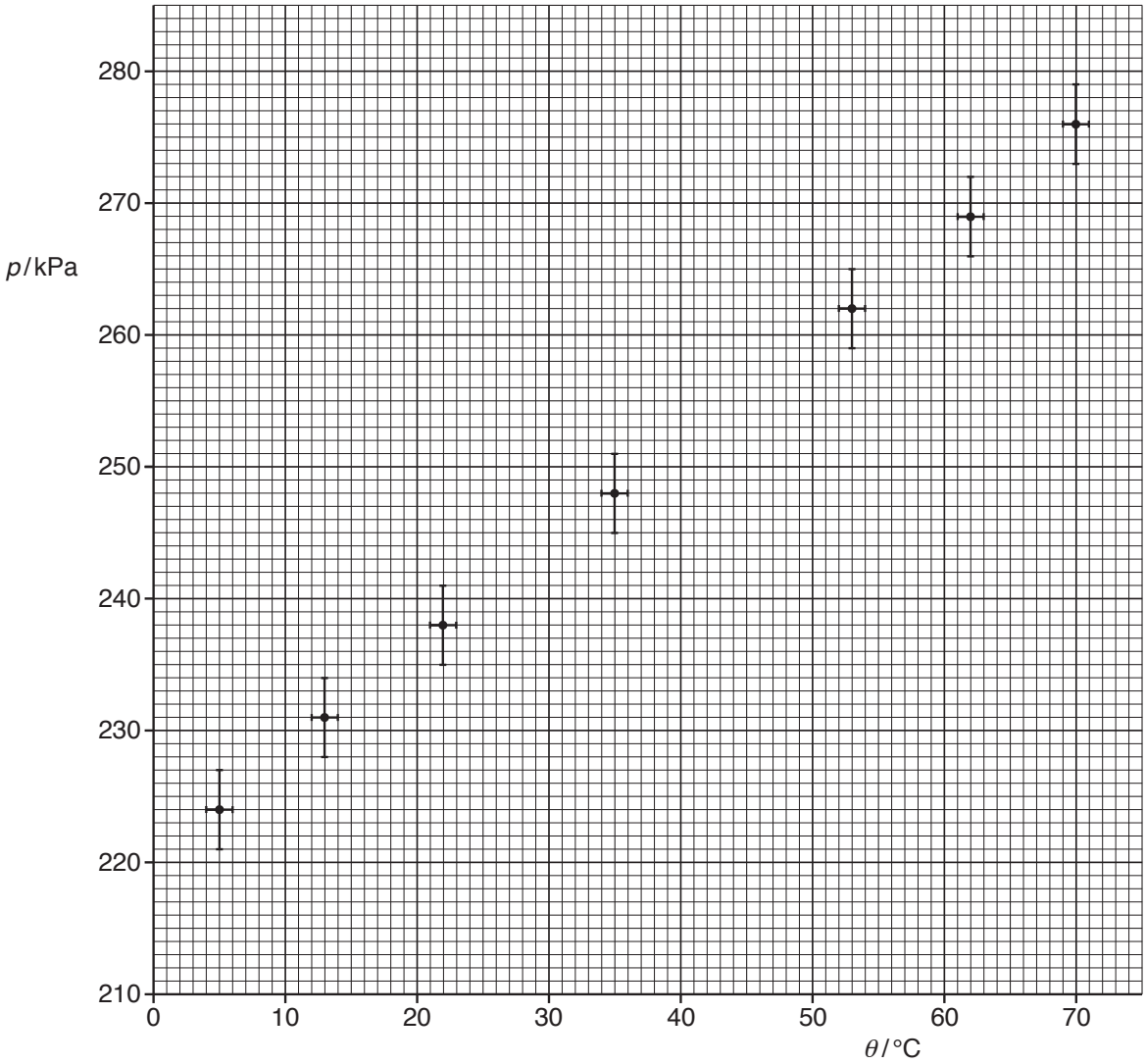


Fig. 17.3

(i) Plot the missing data point and the error bars on Fig. 17.3. **[1]**

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(ii)* Explain what is meant by *absolute zero*. Describe how Fig. 17.3 can be used to determine the value of absolute zero.
Determine the value of absolute zero. You may assume that the gas behaves as an ideal gas.

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.... **[6]**

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Turn over

(d) Describe, without doing any calculations, how you could use Fig. 17.3 to determine the actual uncertainty in the value of absolute zero in **(c)(ii)**.

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..... **[2]**

(e) The experiment is repeated as the water bath quickly cools from 70 °C to 5 °C. Absolute zero was found to be −390 °C.

Compare this value with your value from **(c)(ii)** and explain why the values may differ. Describe an experimental approach that could be taken to avoid systematic error in the determination of absolute zero.

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..... **[4]**

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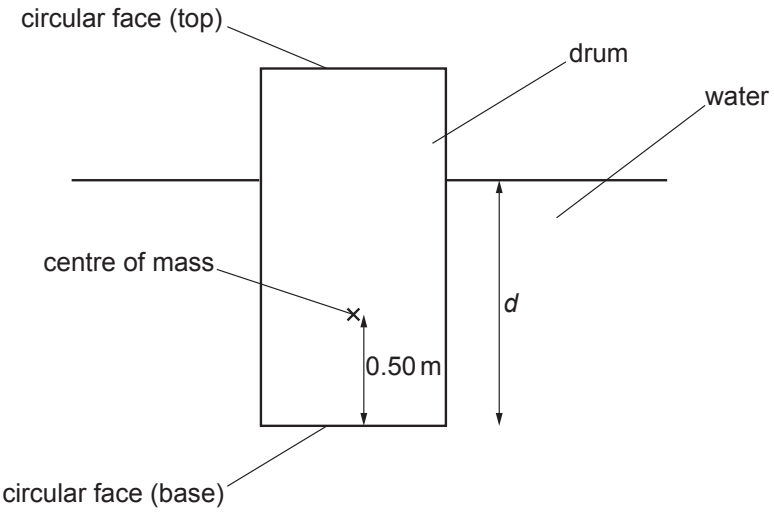
18 Part of a machine to generate electrical energy using waves is a cylindrical drum whose cross-section is shown below. The height of the drum is 2.0 m and its cross-sectional area is 0.79 m^2.

The mass of the drum is 1200 kg.

The centre of mass of the drum is 0.50 m from one of the circular faces, on a line joining the centres of the circular faces.

The density of water is 1000 kg m^{-3}.

The drum floats in flat water with its long axis vertical. The base of the drum is a distance *d* below the surface, where *d* is measured in m.



(a)

(i) Explain why the weight of water displaced must be equal to the weight of the drum.

.....

.....

..... **[1]**

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(ii) Calculate d.

d = ... m **[3]**

(iii) Upthrust forces act at the centre of mass of the fluid displaced.

Explain why the drum cannot float in **equilibrium** on its side with the long axis horizontal.

.....

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..... **[2]**

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Turn over

(b)

(i) When the vertical drum is displaced a distance x deeper into the water from the equilibrium position, the magnitude of the resultant force on the drum, F, is given by

$F = -kx$

where k is a constant and d is measured in m.

By considering the magnitude of the additional upthrust on the drum, show that k is about $8000\,\text{Nm}^{-1}$.

[2]

(ii) When the drum is released, it oscillates vertically. Explain why the oscillations are simple harmonic motion.

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..... **[2]**

(iii) Calculate the natural frequency f of the oscillations.

f = ... Hz **[2]**

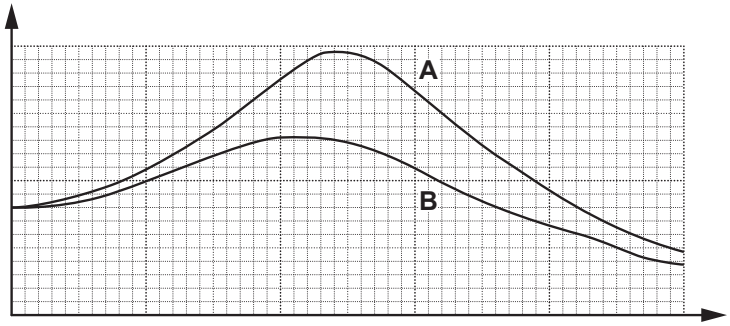
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(c)* Two designs, **A** and **B**, of the machine are tested in a large ripple tank.

The ripple tank can produce waves whose amplitude and frequency can be varied over wide ranges.

The natural frequencies of the two machines are identical. The graphs show the results of the tests but are incomplete.

- Describe how the amplitude of the machine could be measured at each frequency tested. You do not need to describe how to vary the amplitude or frequency of the waves.
- Complete the graphs with suitable labels and annotations.
- Discuss which of the designs is the most effective at generating electrical energy. **[6]**



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MARK SCHEMES

official mark schemes

8	**D**	**1**	

11	**D**	**1**	

13	**D**	**1**	

11	**D**	**1**	

15	**B**	**1**	
	Total	**15**	

SECTION B

Question	Answer	Marks	Guidance

8	B	1	

3	A	1	

13	D	1	

2	C	1	

4	B	1	

1	D	1	

12	D	1	

3	**A**	**1**	

4	**C**	**1**	

7	**A**	**1**	

3	A	1	

3	**B or D**	**1**	

9	**D**	**1**	

11	**C**	**1**	

11	**C**	**1**	

6	B	1	

4	C	1	

11	B	1	

21	(a)	(i)	The gradient is maximum / maximum rate of change of B / maximum rate of change of flux (linkage)	B1	**Allow** slope instead of gradient
		(ii)	Tangent drawn to curve at $B = 0$ gradient = 12.5 (maximum e.m.f. = $12.5 \times 14 \times 10^{-4} \times 85$) maximum e.m.f. = 1.5 (V)	C1 C1 A1	 **Allow** 11.70 to 13.30; no need to check calculation **Allow** fraction if calculated value is within the range **Allow** ECF from the gradient value if value is outside the range **Alternative:** $E = BAN\omega$ **C1** $E = 40 \times 10^{-3} \times 14 \times 10^{-4} \times 85 \times 2\pi \times 50$ **C1** maximum e.m.f. = 1.5 (V) **A1**
	(b)		Sinusoidal curve with the same peak e.m.f. Sinusoidal curve with half period	B1 B1	**Note** curve must show at least half a period **Allow** ± 1 small square for e.m.f. **Ignore** phase **Note** graph must show at least half a period **Allow** ± 1 small square for t
			Total	6	

Question	Answer	Marks	Guidance

19	**(a)**		Direction of field shown as clockwise <u>Three</u> field lines shown as concentric circles and distance between adjacent field lines increasing as distance from wire increases	**B1** **B1**	Expect at least one field line with an arrow **Allow** more than three lines, but distance between adjacent field lines increasing distance from wire must increase for all
	(b)		(force =) $2.2 \times 10^{-3} \times 9.81$ $2.2 \times 10^{-3} \times 9.81 = B \times 5.0 \times 0.060$ (= 0.072 T) (absolute uncertainty =) $\frac{0.2}{6.0} + \frac{0.1}{5.0}$ ($\times 0.072 =$ 0.0038 T) $B = 0.072 \pm 0.004$	**C1** **C1** **C1** **A1**	**Allow** calculation of percentage uncertainty = 5.3% **Allow** calculation of max B (=0.0759 T) and min B (=0.0683 T) **Note** *B* must be given to 2 SF and the uncertainty given to 1 SF. **Special case**: allow follow through from incorrect B calculation.
			Total	**6**	

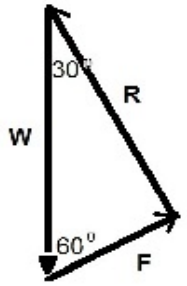
Question			Answer	Marks	Guidance
23	(a)		Any <u>two</u> from: It acts between quarks / nucleons / hadrons 'Short-range' force Repulsive below (about) 0.5 fm Attractive up to (about) 3 fm	B1×2	**Allow** any correctly named particle **Allow** any value between 0.5 fm and 5 fm
	(b)	(i)	proton = u u d or neutron = u d d	B1	
		(ii)	$d \rightarrow u + {}^{0}_{-1}e$ $+ \bar{\nu}_{(e)}$	M1 A1	**Allow** the equation expressed in words **Allow** $udd \rightarrow uud + {}^{0}_{-1}e$ **Allow** ${}^{0}_{-1}\beta$ **Not** e^- for electron **Allow** this mark if electron written as e^- or β^-
	(c)		mass (of nucleus) $\propto A$ volume (of nucleus) $\propto$ radius^3 $\propto A$ **and** clears steps using $\rho = m/V$ to show density is (about) the same	B1 B1	**Allow** mass = Am, mass = Au, etc. **Allow** r or R for radius **Allow** any sensible constant in front of the r^3
			Total	7	

20	**(a)**		$F = BQv$ **and** $F = mv^2/r$ **or** $B = mv/Qr$ (Any subject) $(B =) \frac{1.4\times10^{-25}\times4.8\times10^{4}}{1.6\times10^{-19}\times0.18}$ B = 0.23 (T)	**C1** **C1** **A1**	**Allow** *e*
	(b)	**(i)**	Electron **and** (electron) antineutrino	**B1**	**Allow** beta-minus (particle) / β^- ; $\bar{\upsilon}_{(e)}$ **Allow** anti electron neutrino
		(ii)	λ = ln2/49 **or** λ = 0.0141 (billion y^{-1}) 0.95 = e$^{-0.0141t}$ **or** 0.95 = e$^{-4.48\times10^{-19}t}$ (age = - ln(0.95)/0.0141) age = 3.6 (billion years)	**C1** **C1** **A1**	**Allow** $\frac{\ln2}{49\times10^{9}\times3.16\times10^{7}}$ **or** 4.48 × 10^{-19} (s^{-1}) **Allow** both C1 marks for ln(0.95) = ln(0.5) × *t*/49 **Allow** 0.05/0.0141 ≈ *t* (this gives 3.5.. for the final mark) **Note** age in seconds is 1.15 × 10^{17} (s); this will score 2 marks
			Total	**7**	

Question			Answer	Marks	Guidance
20	(a)		Correct pattern Correct direction of the field	B1 B1	**Note**: At least five field lines must be drawn and of these, two must be perpendicular (by eye) to the surface of the sphere and plate **Note**: This may be shown on just one line
	(b)		(Electric potential) is the work done per (unit) charge in bringing a positive charge from infinity (to the point).	B1	**Allow**: work done / energy required to bring a unit positive charge from infinity (to the point)
	(c)	(i)	$V = Q/4\pi\varepsilon_0 r$ (Allow any subject) $Q = 4\pi \times 8.85 \times 10^{-12} \times 0.015 \times 5000$ $Q = 8.3(4) \times 10^{-9}$ (C)	C1 C1 A0	**Note** using ***E = VId*** with $E = Q/4\pi\varepsilon_0 r^2$ is wrong physics and hence scores zero **Note** if the value of ε_0 is not given here, it could be implied in the correct 3sf answer **Allow** any subject here if the answer is given to more than 2sf **Allow** the use of $1/4\pi\varepsilon_0 = 9 \times 10^9$
		(ii)1	(electric force =) $1.7 \times 10^{-2} \times \tan 4.0$ (Allow any subject) (electric force = 1.19×10^{-3} N)	M1 (A0)	**Not** $1.7 \times 10^{-2} \sin 4$ or $1.7 \times 10^{-2} \cos 86$ **Allow** $1.7 \times 10^{-2} \times \sin 4/\cos 4$
		(ii)2	$E = 1.2 \times 10^{-3}/8.3(4) \times 10^{-9}$ $E = 1.4 \times 10^5$ (N C^{-1})	C1 A1	 **Allow** 2 marks for 1.45×10^5 (N C^{-1}), 8.3×10^{-9} used **Allow** 2 marks for 1.43×10^5 (N C^{-1}), 1.19×10^{-3} (N) used
			Total	8	

Question			Answer	Marks	Guidance
21	(a)		Both forces act on the same object (AW) The types of forces are different / one force is gravitational and the other force is electrostatic	B1 B1	 **Allow:** one force is gravitational (and the other is not)
	(b)		T = 60/1600 or $T = 3.75 \times 10^{-2}$ (s) ($v = \pi \times 0.50/3.75 \times 10^{-2}$) speed = 42 (m s^{-1}) uncertainty = 3 (m s^{-1})	C1 A1 A1	**Allow:** f = 26.7 or $\frac{1600}{60}$ (Hz) or ω = 168 (s^{-1}) **Note:** v must be to 2 or more SF **Note:** uncertainty must be to 1 SF **Allow:** ecf on candidate's value for speed i.e. uncertainty = candidate's value / 16 (to 1 SF) **Allow for 2 marks max: 84 ± 5 (m s^{-1})**
	(c)		$mv^2/r = mg$ or $v^2/r = g$ $v^2 = 9.81 \times 0.25$ v = 1.6 (m s^{-1})	C1 C1 A1	**Allow:** $v^2/r = a$ and $a = g$ or $mv^2/r = ma$ and $a=g$ **Allow:** any subject **Allow:** any subject **Note:** qualified 2.21 (ms^{-1}) scores 2 marks.
			Total	**8**	

24	**(a)**	**(i)**	distance between positions = 3.1 cm 2*p* = 3.1/2 (any subject) *p* = 0.78 arc seconds	**M1** **M1** **A0**	**Allow** distance in the range 2.9 to 3.2 cm
		(ii)	(*d* = 1 / *p*); *d* = 1 / 0.8) or 1.25 (pc) *d* =1.25 × 3.26 *d* = 4.1 (ly)	**C1** **A1**	**Allow**: their value for p Possible ECF from **(a)(i)** Answer is 4.2 using 0.78 arc seconds
	(b)	**(i)**	$F = GMm/r^2$ $F = G \times (2.0 \times 10^{41})^2 / (1.4 \times 10^{23})^2$ force = 1.4×10^{26} (N)	 **C1** **A1**	 **Note** the mark is for substitution, value of *G* is not required **Ignore:** minus sign **Allow** 1 mark for 1.4 x 10^4 N ;use of mass of star instead of mass of galaxy.
		(ii)	density = $10^{11} \times 2.0 \times 10^{30}/2.7 \times 10^{69}$ density = 7.4×10^{-29} (kg m^{-3})	**M1** **A0**	
		(iii)	Any reasonable answers questioning model such as observed average distance may be different, average mass may be wrong etc.	**B1**	**e.g.** black holes, dark energy/matter, expanding universe
			Total	**8**	

Question			Answer		Guidance
4	(a)		W (= mg) = 8.0 × 9.81 F = (W sin30 = 78.5 × 0.5 =) 39 (N) R = (W cos30 = 78.5 × 0.87) = 68 (N)	C1 A1 x 2	= 78(.5) (N) **not** 80 (N) **Allow** 8g **Allow** 1/2 for F and R the wrong way round  Credit full marks for use of a scale drawing which gives answers correct to ±2N **Special case:** Allow 2/3 for use of W = 80 (N) giving F = 40 (N) and R = 69 (N)
	(b)	(i)	F = (mv^2/r =) 8.0 × 1.5^2/2.0 F = 9.0 (N)	C1 A1	 **Allow** answer to 1s.f.

Question			Answer	Marks	Guidance
	(b)	(ii)		B1 x 4	Any answer that mentions **centrifugal** force scores 0/4 **Ignore** any statement that treats the centripetal force as an extra force
			• Suitcase accelerates / changes its velocity / (constantly) changes direction / has a resultant force acting on it / is no longer in equilibrium		**Allow** net or unbalanced or total for resultant throughout
			• The resultant force must act (horizontally) towards centre of circle / to the left		**or** $F\cos30^0 - R\sin30^0$ increases (from 0 to 9.0 (N)) / the (magnitude of the) horizontal component of *F* must exceed the (magnitude of the) horizontal component of *R* **not** a resultant force acts towards **Y**
			• The centripetal force can only be provided by (an increase in) *F*		e.g. Friction is the only force able to provide the centripetal force / only *F* has a component to the left **Allow** *F* provides the centripetal force **Not** the horizontal force must increase / increases
			• Increased vertical component of *F* means the vertical component of *R* must decrease (in order to balance *W*)		**or** $F\sin30^0 + R\cos30^0 = W$ / *W* is the vector sum of *F* and *R* / $W = (F^2 + R^2)^{½}$ (and *F* increases while *W* remains constant)
			So *R* must decrease	**A0**	
			Total	**9**	

Question	Answer	Marks	Guidance

Question			Answer	Marks	Guidance
3	(a)	(i)	(For circular orbit) centripetal force provided by gravitational force (of attraction) (Gravitational / centripetal) force is along line joining stars which must therefore be diameter of circle (AW)	M1 A1	
	(a)	(ii)	$T = 20.5 \times 86400$ (= 1.77×10^6 s) **and** $R = 1.8 \times 10^{10}$ (m) $m = 16 \times \pi^2 \times (1.8 \times 10^{10})^3/G \times (20.5 \times 86400)^2$ giving $m = 4.4 \times 10^{30}$ so $m = 2.2\ M_{\odot}$	C1 C1 A1	values of T **and** R scores first mark; **both** incorrect 0/3 correct substitution allowing π^2 and G $m = 16 \times 9.87 \times 1.8^3 \times 10^{30}/6.67 \times 10^{-11} \times 1.8^2 \times 10^{12}$ using 2R gives $35.2 \times 10^{30} = 17.6\ M_{\odot}$ or using T = 1 day gives $1850 \times 10^{30} = 930\ M_{\odot}$ **award** 2/3
	(a)	(iii)	$v = 2\pi R/T = 2 \times 3.14 \times 1.8 \times 10^{10} / 1.8 \times 10^6$ (giving $v = 6.3$ or 6.4×10^4) $\Delta\lambda = (v/c)\lambda = (6.3/3) \times 10^{-4} \times 656 = 0.14$ (nm)	C1 A1	**do not** penalise repeated error for R or T **ecf** for incorrect v, gives $\Delta\lambda = v \times 2.2 \times 10^{-6}$ $\Delta\lambda = 0.28$ for 2R; $\Delta\lambda = 2.9$ for 1 day and $\Delta\lambda = 5.7$ for both incorrect
	(b)	(i)	Two circles with centres at CoM with radii in ratio 4 :1 CoM at surface of larger star on line joining stars	B1	**allow** diameter of m orbit through CoM as 44 ± 10 % for example; full reasonable circles required; ignore arrows;
	(b)	(ii)	Same period/(angular) frequency of stars but longer path for smaller star/AW **or** $v = 2\pi R/T$ **or** $v \propto R$ **or** stars stay at opposite ends of line through CoM	B1 B1	any arguments using $F = mv^2/r$ score zero
			Total	**10**	

Question	Answer	Marks	Guidance

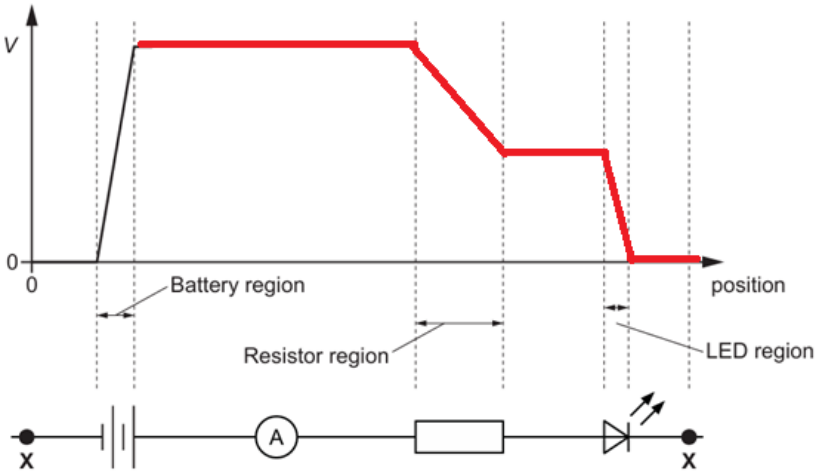
Question			Answer	Marks	Guidance
6	(a)		At $t = 0$ (and $t = 15, 30$) the (magnitude of the) centripetal force equals $R - W$ (as only vertical forces act on the tourist)	B1	**Allow** at $t = 0$ (**or** the bottom of the circle) the centripetal force is provided by the resultant/ upwards/vertical force
	(b)	(i)	(For circular motion) there must (always) be a resultant force towards the centre The resultant force is not always vertical/sometimes has a horizontal component This can only be provided by friction/cannot be provided by R and W / R and W are always vertical/only F is horizontal	B1 x 2	any 2 from 3 marking points **Allow** F provides the horizontal (component of the) centripetal force
		(ii)	Sine wave with period 30 min and amplitude 0.050 (N) Correct phase, i.e. negative sine wave	B1 B1	Must start at the origin
		(iii)	$F = 0.050 \cos 40^{o}$ $F = 0.038$ (N)	C1 A1	**Allow** alternative methods e.g. triangle of forces **Allow ECF** from graph if used
	(c)		$m = 650/g$ **or** $m = 650/9.81$ (= 66.3 kg) ($F = mr\omega^2$ gives) $d = 0.050 / m\omega^2 = 0.050 / 66.3 \times (3.5 \times 10^{-3})^2$ $d = 62$ (m)	C1 C1 A1	**Not** $m = 650$ kg or $m = 65$ kg **or** ($F = mv^2/r$ and $v = 2\pi r/T$ gives) $d = 0.050 \times (30 \times 60)^2 / (4\pi^2 \times 66.3)$
			Total	**10**	

6	**(a)**		F (= EQ) = 0.90 × 1.60 × 10^{-19} = 1.4(4) × 10^{-19} (N)	**B1**	Working and answer must both be shown Answer must be given to 2sf or more Unit need not be given but, if given, must be correct
	(b)	**(i)**	($F = BQv$ but B and Q are constant, so) (the magnitude of) the velocity is different /changes	**B1**	**Allow** speed **Ignore** the direction is different
6	**(b)**	**(ii)**	$v = (\frac{F_{mag}}{BQ} =) \frac{5.6 \times 10^{-19}}{5.0 \times 10^{-5} \times 1.60 \times 10^{-19}}$	**C1**	v = 7.0 × 10^{4} (m s^{-1}) implies first C1

Question			Answer	Mark	Guidance
			resultant force F_R= (5.6 – 1.4) × 10^{-19}	**C1**	**Allow** 10^{-19} for 1.4×10^{-19} (giving $\boldsymbol{F_R}$= 4.6 × 10^{-19}) F_R= 4.2 × 10^{-19} implies second C1 Do not credit if used as F_{mag} in F_{mag} = *BQv*
			$r = \left(\frac{mv^2}{F_R} =\right) \frac{1.673 \times 10^{-27} \times (7.0 \times 10^4)^2}{4.2 \times 10^{-19}}$	**C1**	Third C1 is for correct substitution into formula **Allow** m_p = 1.67 × 10^{-27} kg given to 3 s.f. **Not** m_p = 1.661 × 10^{-27} kg or m_p = 1.675 × 10^{-27} kg **Allow ECF** for incorrect *v* Use of $\boldsymbol{F_R}$ = 5.6 × 10^{-19} or = 1.4 × 10^{-19} is **XP**
			r = 20 (m)	**A1**	**Allow** *r* = 19 (m)
			Alternative all-in-one method:		
			$r = \frac{m{F_{mag}}^2}{F_R B^2 Q^2}$	**(C1)**	$\boldsymbol{F_R}$**= 4.2 × 10^{-19}** (4.16 ×10^{-19} to 3sf) implies second C1 An incorrect value of F_R is **XP** from this point
			resultant force F_R= (5.6 – 1.4) × 10^{-19}	**(C1)**	
			$r = \frac{1.673 \times 10^{-27} \times (5.6 \times 10^{-19})^2}{4.2 \times 10^{-19} \text{ x } (5.0 \times 10^{-5})^2 \times (1.60 \times 10^{-19})^2}$	**(C1)**	Third C1 is for correct substitution into formula
			r = 20 (m)	**(A1)**	**Allow** *r* = 19 (m)

6	(b)	(iii)1	$\lvert\text{resultant force}\rvert = (\sqrt{3.9^2 + 1.4^2}) \times 10^{-19}$	C1	**Ignore** attempt to calculate weight of proton **Allow** $F_E = 10^{-19}$
			$\lvert\text{resultant force}\rvert = 4.1 \times 10^{-19}$ (N)	A1	**Allow** $\lvert F\rvert = 4.0 \times 10^{-19}$ (N) using $F_E = 1.0 \times 10^{-19}$ **Allow** $\lvert F\rvert = 4.2 \times 10^{-19}$ (N) using $F_E = 1.44 \times 10^{-19}$
		(iii)2	<u>resultant / net</u> force is not perpendicular to velocity	B1	**Allow** direction of motion / path but **not** speed for velocity **Allow** acceleration / <u>resultant</u> force is not (always) towards centre (of circle) **Allow** electric force is not perpendicular to velocity / is in the same direction as velocity **Ignore** references to centripetal
			work is done on proton (therefore kinetic energy changes so speed is not constant)	B1	**Ignore** references to centripetal
			Total	10	

16	**(a)**	Potential divider / Series (circuit)	B1	**IGNORE** potentiometer
16	**(b)**	An arrow pointing in the correct direction (clockwise)	B1	**ALLOW** any arrow indicating correct direction All arrows drawn must be in the correct direction
16	**(c)**	(Ammeter reading) decreases (Voltmeter reading) increases	B1 B1	
16	**(d)**	Number density is high(est) in metals / low(est) in insulators Number density in semiconductors is higher than in insulators and lower than metals	B1 B1	**ALLOW** for use of *n* for number density in both marking points **ALLOW** answers in terms of charge carriers **ALLOW** any numbers as method of comparison in both marking points 2nd marking point is for idea that semiconductors lie in the correct position between metals and insulators and will score both B marks.

Question		Answer	Mark	Guidance
16	(e)	Continuous line, not rising at any point and at least one decrease	B1	
		Non-zero horizontal line across ammeter AND lower non-zero horizontal line from RHS of resistor and to LHS of LED ALLOW very small decrease of voltage across either/both	B1	
		Any decrease shown across the resistor and any decrease shown across LED	B1	
		Zero at (and beyond) RHS of LED	B1	

Question	Answer	Guidance

3	**(a)**	**(i)**	• remnant of a (red) super giant star • star can no longer generate (enough) energy by fusion / gravitational force exceeds radiation pressure • formed by (gravitational) collapse / implosion of core (of massive star) **or** gravitational force in core exceeds electron degeneracy pressure • star undergoes a (Type II) supernova (explosion) • core has mass above Chandrasekhar limit / 1.4 x solar mass (and below limit for black hole / 3 solar masses) • (in the core) protons combine with / capture electrons to produce neutrons	**B1 x 2**	Credit any correct statement, ignoring incorrect statements unless they contradict a previous credited bullet point **Allow** any star with mass greater than 10 solar masses **Allow** star cannot fuse iron without losing energy **Ignore** star runs out of fuel / fusion stops

13

Question			Answer	Mark	Guidance
3	(a)	(ii)			Credit any correct statement, ignoring incorrect statements unless they contradict a previous credited bullet point **Ignore** references to size / temperature / luminosity / spin / radio waves / composed (mainly/only) of neutrons
			either: extremely / very dense	**B1**	**Not** high density (must be extremely / very high density)
			or: has a very strong gravitational field		
			or: supported by neutron degeneracy pressure		
			or: fusion is no longer taking place		
			or: core has mass above Chandrasekhar limit / 1.4 x solar mass (and below limit for black hole / 3 solar masses)		Do not credit this point here if already credited in 3(a)(i)

Question			Answer	Mark	Guidance
3	(b)		$\rho = \frac{m}{V}$ **and** $V = \frac{4}{3}\pi r^3$ ($\approx 4\ r^3$)	**C1**	Formulae may be inferred from either calculation **Allow** m/r^3 = constant
			density of neutron star **≈ 5 × 10^{17}** kg m^{-3}	**A1**	**Ignore** number of s.f. in answer Volume of neutron star ≈ 4 × 10^{12} m^3
			density of nucleus **≈ 4 × 10^{17}** kg m^{-3}	**A1**	**Ignore** number of s.f. in answer Volume of nucleon ≈ 4 × 10^{-45} m^3 $m_{nucleon}$ ≈ u = 1.66 × 10^{-27} kg to 3 sf (**allow** 1.67 × 10^{-27} kg) If the calculation of separate densities is not shown explicitly then the two **A1** marks may be scored for either: • ratio of densities ≈ 0.8 **or** 1.2 • m/r^3 = 2.0 × 10^{18} (kg/m^3) for star **and** 1.7 × 10^{18} (kg/m^3) for nucleon • r^3/m = 5.0 × 10^{-19} (kg/m^3) for star **and** 6.0 × 10^{-19} (kg/m^3) for nucleon
	(c)	(i)	number of large squares = 11± 1	**C1**	May be inferred from calculation Any valid method allowed (counting squares, trapezium rule, splitting area into regular shapes) **Allow** number of medium squares = 44 ± 4 **Allow** number of small squares = 1100 ± 100
			no of squares × area of each = 11 x 1 x 10^{-25} = **1.1 × 10^{-24}** (J)	**A1**	**Allow** answers in the range 1.00 × 10^{-24} to 1.20 × 10^{-24} **Allow** answer to 1s.f.

Question			Answer	Mark	Guidance
3	(c)	(ii)	300 pc ≈ 300 × 3.1 × 10^{16} m (= 9.3 × 10^{18} m)	C1	Mark is for working leading to the correct distance. Distance does not need to be seen explicitly but 9.3 × 10^{18} m implies C1
			ratio of areas = $\frac{4\pi(300 \times 3.1 \times 10^{16})^2}{3000} = \frac{1.09 \times 10^{39}}{3000}$ (= 3.6 × 10^{35})	C1	Mark is for working leading to the correct ratio. Ratio does not need to be calculated but 3.6 × 10^{35} implies C1 **Allow** calculation of inverse ratio (= 2.8 × 10^{-36}) **Ignore** unit if one is given
			energy = ratio of areas × area under curve = **4.0 × 10^{11}** (J)	A1	Mark is for correct answer; **allow** answer to 1s.f. Answer = 3.6 × 10^{35} × candidate's answer to 3c(i) **Allow ECF** for incorrect calculation of area / energy in 3c(i) Expect an answer in the range 3.6 × 10^{11} to 4.4 × 10^{11} Note: candidates could also calculate the answer by using ratio of energies = ratio of powers or intensity of pulsar = intensity at telescope
			Total	**11**	

18	**a**	**i**	0.99	A1	Award mark for all candidates as some centres may not have seen the erratum for this question.
		ii	Data plotted at 6.0, 0.99 within half a small square	B1	ecf from (a)(i) treat use of 0.81 from table as ecf if candidate has left 18 (a)(i) blank
			Two trendlines drawn	B1	NOT straight lines connecting data points NOT straight line(s) of best fit
			Clear indication that upper curve's data is during loading and that lower curve's data is during unloading	B1	e.g Correct arrow direction or label 'loading' on upper curve and correct direction arrow or label 'unloading' on lower curve.
		iii	Any TWO from:		
			Not a straight line / AW	B1	
			(hence) not directly proportional	B1	allow 'k / spring constant not constant' allow Hooke's Law should be (directly) proportional
			Correct reference to plastic deformation when unloaded	B1	e.g. Mention of line not passing through origin when unloaded

Question			Answer	Mark	Guidance
		iv 1	joule	B1	Not J; since **name** is required. Allow joules NB if more than one answer given, mark first answer as per rubric on page 3
		iv 2	(the area is) increase in thermal or in internal energy of the rubber	B1	ignore unqualified 'energy' or 'work done' allow change in work done on rubber between loading and unloading
			reference to reduction in the energy of the object or in the force applied to the object or the force applied to the floor	B1	e.g. the energy absorbed by the rubber / not returned to the object e.g. energy dissipated as heat or energy not transferred back to KE e.g. The object will not bounce as high e.g. object less likely to be damaged because the force on object is smaller e.g. floor is less likely to be damaged because the force on the floor is smaller e.g. the larger the area between the curves the lower the damage caused

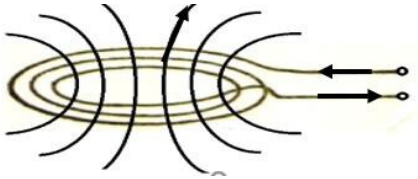
Question			Answer	Mark	Guidance
	b		Any TWO from pulley adds friction / the load values would no longer equal the weights Greater lengths being used will reduce (%) uncertainty Reference to pulley's suspension rope reduces h because it is not inextensible Larger range of h may make eye level more difficult Larger h makes effect of non-vertical ruler more prominent	B1 B1 B1 B1 B1	ignore plastic deformation
			TOTAL	10	

Question			Answer		Guidance
2	(		F = Bev **and** F = eE E = V/a **or** F=(eE) = eV/a Bev = eV/a giving V = Bva	**B1** **B1** **B1**	**allow** Q or q for e
	(b)	**(i)**	I = nAev; v = 60 x 10^{-3}/1.2 x 10^{23} x 1.6 x 10^{-19} x 5.0 x 0.2 x10^{-6} v = 3.1 (m s^{-1})	**C1** **C1** **A1**	**allow** any subject
		(ii)	V = 80 x 10^{-3} x 3.1 x 5.0 x 10^{-3} = 1.2 x 10^{-3} (V)	**A1**	**ecf (b)(i)**; **allow** 1.2 mV; 1.3 x 10^{-3} (V)
	(c)	**(i)**	Hall probe only compares B-fields/AW **or** V will be too small/less than 1 mV so not easy to measure	**B1**	allow any sensible comment, e.g. how do you convert the measured V into a B value
		(ii)	find B using F = B*Il*; F is measured by weighing magnets (e.g. placed on top pan balance assuming wire is fixed); graph of F against *I* to find B(*l*) from gradient/AW; greatest uncertainty: measurement of *l* in B-field sensible reason/justification for choosing *l* **or** small masses	**B1** **B1** **B1** **B1** **B1**	**max** 4 of the 5 marking points **alt** measure F by adding small masses to wire to return it to zero current position **or** use readings of F at several *I* to find average F/*I*, etc. **or** measurement of small masses in alt. method,etc quantitative suggestion about % error i.e. *l* small (1 mm in 60) leading to large % uncertainty **or** difficulty in determining edge/end of B-field
			Total	**12**	

H556/03 Mark Scheme June 2017

Question	Answer	Marks	Guidance

4	(a)	*	**Level 3 (5 - 6 marks)** Clear explanation using kinetic theory ideas **and either** a clear proof using formulae **or** a correct calculation *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.* **Level 2 (3 – 4 marks)** A partial explanation using kinetic theory ideas **and either** a partial proof using formulae **or** a partial calculation *There is a line of reasoning presented with some structure. The information presented is in the most part relevant and supported by some evidence.* **Level 1 (1 – 2 marks)** An attempt at either explanation **or** proof **or** calculation *There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.* **0 marks** *No response or no response worthy of credit.*	**B1 x 6**	**Indicative scientific points may include:** **Explanation using kinetic theory** • pressure = force/area • force is caused by air molecules colliding with oven walls • Newton's 2nd Law states force = rate of momentum change • increased temperature means each molecule has greater KE • hence greater velocity and hence greater momentum • and more collisions with walls per second • hence greater rate of momentum change on hitting walls. • This would lead to greater pressure if N remained constant • so number of molecules in oven must decrease (air escapes) • so fewer but 'harder' collisions at higher temperatures giving constant pressure. • Rms velocity c increases with temperature but number N decreases and so effects balance out to keep total KE ($\frac{1}{2}Nmc^2$) constant **Proof using formulae** • equate $pV = NkT$ and $E = \frac{3}{2}NkT$ to show $E = \frac{3}{2}pV$ • in an ideal gas, all internal energy E is kinetic energy • so E is independent of temperature **Calculation** • Internal energy = $\frac{3}{2}pV = 1.5 \times 0.065 \times 1.0 \times 10^5 = 9.8$ kJ • At $T = 293$K, $N = pV/kT = 1.6 \times 10^{24}$ and $n = 2.7$ moles • At $T = 473$K, $N = 1.0 \times 10^{24}$ and $n = 1.7$ moles • so we can show that NT (and/or nT) remain constant

Question			Answer	Marks	Guidance
4	(b)	(i)		B1 B1	One correct line (or dot and cross) drawn Line must go through centre of coil **Allow** an incomplete line or a complete circle round the coil **Ignore** direction of arrow More than one line drawn All lines drawn must go through centre of coil and follow correct shape and direction of field **Ignore** spacing of lines **Ignore** any lines to the right of the coil
		(ii)	• (the magnetic) flux (of the coil) links the base / saucepan • (the size/direction of) the flux linkage (constantly) changes/alternates (causing an alternating induced e.m.f.) • (induced) current is large because metal/base/ saucepan has low resistance	B1 x 2	2 out of 3 possible marking points **Allow** (the magnetic) field lines cut the (base of the) saucepan **Allow** the (magnetic) field constantly changes/alternates **Allow** a bald statement of Faraday's Law
		(iii)	The resistance of glass-ceramic/the (cook's) hand is (very) large So (induced) current (or heating effect of current) is zero/negligible	M1 A1	**Allow** glass-ceramic/hand is an insulator/not a (good) conductor **Do not allow** the induced e.m.f. is (very) small
			Total	12	

Question	Answer	Marks	Guidance

Question				Answer	Marks	Guidance
20	a			$\omega \rightarrow$ s^{-1} **or** $\omega^2 \rightarrow$ s^{-2}	M1	**Allow** $\omega \rightarrow$ (radians) s^{-1} **Allow** $\omega^2 = (2\pi f)^2$ **or** $(2\pi/T)^2$ with some evidence of units afterwards
				LHS = m s^{-2} **and** RHS = m s^{-2} clearly shown by unit algebra	A1	e.g. RHS = m . (s^{-1})^2
	b	i		Δp = 0.10 × 1000 × 9.81	C1	
				Δp = 980 (Pa)	A1	**Allow** 1 mark for 490 Pa; 5.0 cm used
		ii	1	$\omega^2 = \frac{2\rho g A}{m}$ **or** ω^2 = 37.7 (rad^2 s^{-1}) ω = 6.1	C1 C1	**NOT** ω = 37.7
				$T = \frac{2\pi}{6.1}$	C1	**Alternative route:** • Substitution of expression for omega • Re-arrangement to make T subject • Evidence of evaluation to T = 1.02 (s)
				T = 1.02 (s)	A0	
			2	Oscillation is isochronous starting from (0,5)	B1	Period same by eye.
				Correct value(s) on the horizontal axis	B1	**Note** scale must be linear and increasing
				At least 2 oscillations shown **and** amplitude is decreasing	B1	Amplitude of 2nd oscillation smaller by eye.
			3	The (driving) frequency is close to the natural frequency (of the system) / resonance will occur	B1	
				(Level of) water will oscillate with large amplitude	B1	**Allow** a description of consequence such as water leaving the tube or being unable to measure the height of liquid
				Total	12	

Question			Answer	Marks	Guidance
22	(a)*		**Level 3 (5–6 marks)** Clear evaluation of Fig. 22.1 **and** clear analysis *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.* **Level 2 (3–4 marks)** Some evaluation of Fig. 22.1 **and** some analysis *There is a line of reasoning presented with some structure. The information presented is in the most part relevant and supported by some evidence.* **Level 1 (1–2 marks)** Limited evaluation of Fig. 22.1 **or** limited analysis *There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.* **0 marks** *No response or no response worthy of credit.*	**B1×6**	Use level of response annotations in RM Assessor, e.g. L2 for 4 marks, L2^ for 3 marks, etc. **Ignore** incorrect references to the terms precision and accuracy **Indicative scientific points may include:** **Evaluation of Fig. 22.1** • Comment on the line • The straight line misses one error bar / anomalous point ringed or indicated • Too few data points plotted • The triangle used to calculate the gradient is (too) small • Some plots should have been repeated / checked • No error bars for current • 'Not regular intervals' (for current) • No origin shown (AW) **Evaluation of analysis** • The value of *B* is close to the accepted value • The difference of only 7% • No absolute or percentage uncertainty in *B* shown (AW) • Worst-fit line or maximum / minimum gradient line could have been used to determine the (absolute or percentage) uncertainty in *B* • *F* against I graph should be a straight line or • *BL* = gradient (any subject)

Question			Answer	Marks	Guidance
	(b)	(i)	There is a changing / fluctuating (magnetic) field / flux (linkage)	M1	**Note**: This changing flux can be anywhere **Allow** 'the direction of the field oscillates'
			(magnetic) field / flux (linkage) in core and secondary (coil)	A1	**Allow** 'the core helps to link the flux to the secondary coil'
			Statement of Faraday's law: e.m.f. (induced) ∝ rate of change of (magnetic) flux linkage	B1	**Allow** 'equal to / =' **Ignore** 'cutting of flux' **Not** just $E = (-)\Delta(N\phi)/\Delta t$
		(ii)1	(I_S =) 24/12 or 2.0 (A)	C1	
			(I_P =) $\frac{20}{400} \times 2.0$ (current in primary =) 0.10 (A)	A1	**Allow** 1 sf answer
			or		
			(V_P =) 12×20 or 240 (V)	C1	
			(I_P =) $\frac{24}{240}$ (current in primary =) 0.10 (A)	A1	**Allow** 1 sf answer
		(ii)2	Idea of changing / increasing (magnetic) field / flux / current (in primary) at the start	B1	**Note**: Any labels used must be clearly defined
			Eventually current and flux (linkage) are constant, therefore no e.m.f.	B1	
			Total	13	

Question			Answer		Guidance
1	(a)		n (= pV/RT) = 2.4 × 10^5 × 1.2 × 10^{-3}/8.31 × 290	C1	**Allow** any correct rearrangement of the equation **Allow** use of $pV = NkT$ and $n = Nk/R$ or $n = N/N_A$
			n = 0.12 (mol)	A1	(n = 0.1195)
	(b)		pV = constant (or $p_1V_1 = p_2V_2$)	C1	Alternative method: $p = nRT/V$ (p must be the subject) **Allow** use of $p = NkT/V$ (with N = 7.2 x 10^{22} and k = 1.38 x 10^{-23})
			p_{final} = 2.4 × 10^5 × 1.2/1.5	C1	Substitute p = 0.12 x 8.31 x 290 / 1.5 x 10^{-3} **ECF** from 1a for incorrect n and/or T
			= 1.9(2) × 10^5 (Pa)	A1	p = 1.9(3) x 10^5 (Pa)
	(c)	(i)	Δp = (2.4 – 1.0) × 10^5 = 1.4 × 10^5 (Pa)	C1	Alternative method: Downwards force (from trapped air) = pA = 2.4 x 10^5 x 1.1 × 10^{-4} = 26.4 (N) **and** upwards force (from atmosphere) = pA = 1.0 x 10^5 x 1.1 × 10^{-4} = 11.0 (N)
			upwards force (= ΔpA) = (2.4 – 1.0) × 10^5 × 1.1 × 10^{-4}	C1	So total upwards force = 26.4 – 11.0
			= 15 (N)	A0	= 15.4 (N) **Ignore** any attempt to calculate weight **Special case: Allow** 1/2 for the use of Δp = 2.4 × 10^5 (Pa) giving upwards force = 26.4 (N)

Question			Answer	Marks	Guidance
		(ii)	m = 0.3 + 0.05 (= 0.35) (kg)	C1	0.050 + (10^3 x 0.3 x 10^{-3})
			(Resultant force = upwards force – $W = ma$) 15.4 – (0.35 × 9.81) = 0.35a **or** a = 12/0.35	C1	Alternative approach: a = (15.4/m) - g **ECF** for incorrect value of m **No ECF ci** (since we are told that upwards force = 15(.4)(N))
			a = 34 (m s^{-2})	A1	Upwards force = 15 (N) gives a = 33 (m s^{-2})
	(d)		• (initial) upward force unchanged • (initial) downwards force/weight increases • (initial) resultant force decreases • (initial) acceleration decreases • (initial) rate of change in momentum of rocket decreases • time taken to expel water increases • valid conclusion that the maximum height depends on more than one factor	B1 x 3	**Maximum 3** marks from 7 marking points: **Ignore** comments which assume an increase in pressure **Ignore** heavier **Allow** net or unbalanced or total for resultant **Allow** fuel for water e.g. the height depends on the bottle's velocity and its height when all the water has been expelled / the height depends on both the acceleration and the time taken to expel the water
			Total	**13**	

H556/03 Mark Scheme June 2019

Question	Answer	Marks	Guidance

18	**(a)**	**(i)**	$a = -\omega^2 x$ seen Suitable linking $a = -\omega^2 x$ and either $\omega = 2\pi f$ or $\omega = 2\pi/T$ with substitution f = 1.41 (Hz)	**B1** **M1** **A1**	e.g. $4\pi^2 f^2 = 78.3$ or $f = \text{sqrt}(3.6/4\pi^2 \times 4.6 \times 10^{-2})$ or $f=8.85/2\pi$ or $T=0.71\ldots$ **Allow** f = 1.408… (Hz)
		(ii)	$A = \frac{x}{\cos \omega t}$ or $A = \frac{4.6\times10^{-2}}{\cos(2\times\pi\times1.4\times6.5)}$ (Any subject) A = 0.057 (m)	**M1** **A1**	**Not:** sine for cosine. **Note** A = 0.090(4)(m) if 1.41 used **Note** A = 0.0796 (m) if 1.408 used **Allow** 1 mark for cosine used with calculator in degrees

Question			Answer	Marks	Guidance
	(b)		EPE decreases (from bottom to top)	B1	**Not** EPE becomes 0 (or negative)
			GPE increases (from bottom to top)	B1	**Allow** for the first two marking points: description that refers to total potential energy starts at maximum, is minimum at equilibrium point and max again at top, provided total potential energy is stated to be the sum of EPE and GPE
			KE starts at zero, finishes at zero and max at equilibrium point.	B1	
			Air gains thermal energy / Total energy (of mass and spring) decreases over time	B1	**Allow** as alternative for first three marks: EPE to KE and GPE in bottom half EPE and KE to GPE in top half EPE at start to GPE at top
	(c)	(i)	(Smooth) curve showing amplitude increases and then decreases	B1	**Not:** more than 1 peak **Allow:** asymptote instead of peak
			maximum at 1.4 Hz by eye	B1	
		(ii)	Curve similar shape yet lower at all non-zero f points with peak shifted slightly to left (of 1.4 Hz)	B1	**Allow:** curve without shifted peak i.e. peak at 1.4 Hz ECF their K curve
		(iii)	Bridge close to resonance if frequency of driver is close to natural frequency of bridge	B1	**Allow:** footfall/people walking/wind for driver **Allow:** resonance (occurs) when frequency of driving force is at natural frequency of bridge
			(Close to resonance) giving larger amplitude which causes damage or other named consequence	B1	**Allow**: Maximum for larger
			Total	**14**	

18	**(a)**	**(i)**	Arrow in anticlockwise direction	**B1**	**Allow** this mark for correct direction shown on diagram either on or off connecting wires
		(ii)	(E =) 4.5 – 2.4 **or** (R_T =) 0.80 + 0.50 + 1.2 4.5 – 2.4 = $I \times$ (0.80 + 0.50 + 1.2) I = 0.84 (A)	**C1** **C1** **A1**	E = 2.1 (V); R_T = 2.5 (Ω) Treat missing 1.2 resistance as TE **Allow** 2 marks for 2.8 (A); E = 6.9 V used
		(iii)	($I = Anev$) $0.84 = \pi \times (2.3 \times 10^{-4})^2 \times 4.2 \times 10^{28} \times 1.60 \times 10^{-19} \times v$ $v = 7.5 \times 10^{-4}$ (m s^{-1})	 **C1** **A1**	 Possible ECF from **(ii)** **Note** answer is 2.5×10^{-3} (m s^{-1}) for I = 2.76 (A) **Allow** 1 mark for 1.9×10^{-4}; diameter used as radius
		(iv)	Sensible suggestion, e.g. use a water bath / fan / only switch on when taking readings Need to lower the temperature / reduce resistance of **R**	**M1** **A1**	**Allow** keep the surroundings cold **Allow** to keep the temperature / resistance constant **OR allow** increase in temperature increases resistance

<table>
<tr>
<td></td>
<td>(b)*</td>
<td></td>
<td>Level 3 (5–6 marks)
E and r calculated correctly and table completed correctly and clear description of P and R

There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.

Level 2 (3–4 marks)
Table completed correctly and some description of P and R / some attempt at E and r
OR
E and r calculated correctly
OR
Some attempt at calculating E and r and some description of P and R

There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.

Level 1 (1–2 marks)
Limited calculation of E and r
OR
Table completed correctly
OR
Limited description of relationship between P and R

There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.

0 marks
No response or no response worthy of credit</td>
<td>B1×6</td>
<td>Indicative scientific points may include:

Calculating E and r
• $E = Ir + V$
• gradient = (-) r
• y-intercept = E
• Line extrapolated to y-axis
• E = 1.2 (V)
• r = 0.8(0 Ω)

Table and description
• Table completed (ignore SF) – see below
• R increases as V increases (or I decreases)
• P increases and decreases
• Maximum power is when internal resistance is equal to R (0.8 Ω)

<table>
<tr><th>V / V</th><th>I / A</th><th>R / Ω</th><th>P / W</th></tr>
<tr><td>0.20</td><td>1.25</td><td>0.16</td><td>0.25</td></tr>
<tr><td>0.40</td><td>1.00</td><td>0.40</td><td>0.40</td></tr>
<tr><td>0.60</td><td>0.75</td><td>0.80</td><td>0.45</td></tr>
<tr><td>0.80</td><td>0.50</td><td>1.60</td><td>0.40</td></tr>
<tr><td>1.00</td><td>0.25</td><td>4.00</td><td>0.25</td></tr>
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<td>Total</td>
<td>14</td>
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4	(a)		3 out of the following 4: • Extension (or length) measured using a ruler • Extension = stretched length – original length • Force (weight of load) determined using a forcemeter **or** W = mg • (k is) gradient of graph of force against extension	**B1 x 3**	**Ignore** any incorrect statements unless contradictory **Allow** tape measure Could be shown on a labelled diagram **Allow** 4cm or 0.04m for original length **Allow** extension is change in length from original This mark may be scored by saying a graph of mass against extension would give gradient = k/g **Allow** k = gradient of graph of force against length **Allow** k/g = gradient of graph of mass against extension **Allow** *k* = load divided by extension, calculated for a single load

4	(b)	(i)	**Method 1** *d* = *8.5 – 3.2* (= 5.3(cm))	**C1**	**Mark whichever method leads to the most marks** *d* = 5.3cm does not need to be calculated explicitly but seeing 5.3 implies first C1 mark
			(*F* = *kd* so) *F* = 0.62 × 5.30 (= 3.3 (N))	**C1**	*F* = 3.3N does not need to be calculated explicitly but seeing 3.3 implies both C1 marks **Allow** *k* = 0.61 (N cm^{-1}) leading to *F* = 3.2 (N)
			$a = \frac{F}{m}$ so $a = \frac{3.3}{0.20}$		
			a = 17 (m s^{-2})	**A1**	and *a* = 16 (m s^{-2})
			Method 2 (*F* = *kd* so) *F* = 0.62 × 8.50 (= 5.27(N))	**(C1)**	*F* = 5.27(N) does not need to be calculated explicitly but seeing 5.27 or 5.3 implies first C1 mark **Allow** *k* = 0.61 (N cm^{-1}) leading to *F* = 5.19 (N)
			F_R = (0.62 × 8.50) – (0.20 × 9.81) (= 3.3 (N))	**(C1)**	*F* = 3.3(N) does not need to be calculated explicitly but seeing 3.3 implies both C1 marks **Allow** *k* = 0.61 (N cm^{-1}) leading to *F* = 3.2 (N)
			$a = \frac{F}{m}$ so $a = \frac{3.3}{0.20}$		
			a = 17 (m s^{-2})	**(A1)**	and *a* = 16 (m s^{-2})
			Method 3 (*F* = *kd* so) *F* = 0.62 × 8.5 (= 5.27(N))	**(C1)**	*F* = 5.27(N) does not need to be calculated explicitly but seeing 5.27 or 5.3 implies first C1 mark **Allow** *k* = 0.61 (N cm^{-1}) leading to *F* = 5.19 (N)
			$\left(a = \frac{F}{m} \text{ so}\right) a = \frac{5.27}{0.20}$ = 26 (m s^{-2})	**(C1)**	Note: a= 26 (ms^{-2}) is an intermediate calculation for $a_{initial}$ in this method only and is **not** the A1 mark
			$a_{initial}$ = 26.35 – 9.81 = 17 (m s^{-2})	**(A1)**	**Allow** *k* = 0.61 leading to *F* = 5.19 and *a* = 16

4	(b)	(ii)			The two C1 marks are independent and XP in one does not imply XP in the other
			Use of $a = (-)\omega^2 x$	C1	**Not** just formula alone Expect *a* = 17 but **allow ECF** of *a* from **(b)(i)** **Allow** any value for *x*
			Use of $f = \frac{\omega}{2\pi}$	C1	**Not** just formula alone Use *of a* = $(-)(2\pi f)^2 x$ scores both C1 marks
			f = 2.8 (Hz)	A1	**Allow** *f* = 2.9 (Hz)
			Alternative method: (*a* = *F* / *m* = *kx* / *m* and *a* = (-) $\omega^2 x$ gives)		
			$\omega^2 = \frac{k}{m}$	(C1)	**Allow** $T = 2\pi\sqrt{\frac{m}{k}}$ $f = \frac{1}{T}$
			$f = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$ $= \frac{1}{2\pi}\sqrt{\frac{0.62 \times 100}{0.2}}$	(C1)	
			f = 2.8 (Hz)	(A1)	**Allow** *f* = 2.9 (Hz)

4	(c)	(i)	(motion of magnet M causes) a change of flux (linkage) in coil Y (inducing an e.m.f.)	B1	**Allow** field (lines of M) cuts (turns of) coil Y **Allow** the coil or Y or solenoid for coil Y
			there is an (induced) current in (or through) coil X	B1	**Allow** the coils or the wire(s) or X for coil X **Ignore** (induced) e.m.f.
			alternating current / field / flux in coil X interacts with the field of magnet L (causing an alternating force)	B1	**Not** changing or varying or oscillating for alternating **Allow** current / field / flux in coil X interacts with field of magnet L **to c**ause an alternating force **Allow** changing direction for alternating **Allow** combines for interacts **Allow** cuts across for interacts with
	(c)	(ii)	frequency of magnet L (always) equals (forcing/driving) frequency of vibration generator / magnet M	B1	**Allow** frequency of magnet increases with frequency of vibration generator
			resonance occurs at / close to 2.5 Hz	B1	May be seen from a **labelled** graph of amplitude against frequency **Allow** resonance occurs when forcing / driving frequency = natural frequency
			amplitude is maximum at resonance	B1	May be seen from a labelled graph of amplitude against frequency
			Total	**15**	

17	**(a)**	**(i)**	Arrow **along** the line of the support rod labelled tension or T.	B1	Allow unlabelled single arrow along either rod Allow unlabelled arrows along both rods Allow arrow(s) up, down or both NOT any contradictory arrows
		(ii)	11.1 sin 35 or 11.1 cos 55 seen addition of 3.9 (half the diameter of the support disc) to candidate's horizontal component of rod length Total= 10.3m	M1 M1 A0	NOT use of tan 35 or tan 55 allow 7.8/2 for 3.9 10.27 to 2 dp NB use of 11.1 cos 35 or 11.1 sin 55 arriving at 12.99 scores 1 (wrong trig) NB reject use of radians (scores 0)
		(iii)	mg=T cos 35 T= mg ÷ cos 35 = 140 N	C1 C1 A1	Allow use of sin 55 NOT use of tan 35 or tan 55 Answer is 143.7 N to 4 sf

Question			Answer	Mark	Guidance
		(iv)	T sin 35 = mrω^2 $\omega=\sqrt{\frac{T\sin 35}{mr}}$ =0.8(17) radian s^{-1}	M1 A1 A0	Allow use of W tan 35 or W tan 55 Allow use of cos 55 and/or mv^2/r Allow use of Pythogoras to find centripetal force (82.4…) NOT use of T tan 35 or T tan 55 Allow ω^2 subject. Allow any combination of rearrangement and substitution ECF allowed for T and r. Use of 2 s.f. values for T and r gives 0.84 m

Question			Answer	Mark	Guidance
17	(b)	(i)	Use of $17=1/2\ g\ t^2$	C1	i.e. substitution of 17 and g or 9.81 or 9.8 e.g. $s=(ut)+ ½\ at^2$ $t=\sqrt{\frac{2s}{a}}$
			=1.9 (1.86) s	A1	$=\sqrt{\frac{2\ x\ 17}{9.81}}$ Allow any subject
		(ii)	Horizontal speed = rω or Horizontal distance = speed × time	C1	Use of data in the question stem (0.8 and 10) allowed, which gives 15.2 m.
			= 0.82 radians s^{-1} × 10.26 m × 1.86 s	C1	
			= 16 m (15.6 m)	A1	Ecf for use of candidate's value of r and ω, giving values rounding to between 14.9 and 16.0 m

Question			Answer	Mark	Guidance
		(iii)	Relevant variable identified	M1	e.g mass/weight, drag/air resistance, radius, height, starting condition (e.g. kicking shoe off) Assume “it” in response refers to the shoe. ignore velocity for first M1
			Effect on speed of shoe or time of flight of shoe correctly identified	M1	allow correct explanation of "no effect" on speed or time by change of mass
			Conclusion consistent with relevant physics e.g. ● Shoe is lower mass yet no change in angular velocity or radius since independent of mass so no change in horizontal displacement. ● Shoe is below seat so would be travelling with larger radius/speed so larger distance travelled horizontally ● Shoe might have be kicked off backwards so have lower speed so lower distance ● Shoe would come from below the seat/lower than the sandbag i.e. vertical distance to fall less, thus time of flight and horizontal distance less. ● Effect of air resistance hadn’t been included so shoe suffers drag, decelerating horizontally so distance would be smaller	A1	
			TOTAL	16	

15

Question			Answer	Marks	Guidance
5	(a)	(i)			**Allow** v for v_{max} throughout
			$I_{max} = nAv_{max}e$	**B1**	**Allow** I for I_{max} **Allow** q or Q for e / a for A / V for v but **not** N for n
			$v_{max} = \frac{20 \times 10^{-3}}{8 \times 10^{28} \times 1.6 \times 10^{-19} \times 1.4 \times 10^{-8}}$	**M1**	Substitution must be shown in full
			$v_{max} = 1.1 \times 10^{-4}$ (m s^{-1})	**A1**	Answer must be given initially to 2 or more sf (but may later be rounded to 1sf)
		(ii)	$\omega = 2\pi f$	**C1**	May be inferred from working $\omega = 2\pi \times 11 \times 10^{9} = 6.9 \times 10^{10}$ (rad s^{-1})
			$A\ (= v_{max}/\omega) = \frac{1.1 \times 10^{-4}}{2\pi \times 11 \times 10^{9}}$ **or** $A\ (= v_{max}/\omega) = \frac{1.1 \times 10^{-4}}{6.9 \times 10^{10}}$	**C1**	**Allow** use of $v_{max} = 1 \times 10^{-4}$ (m s^{-1}) **Allow** v_{max} from **(a)(i)** given to more than 2sf but **not ECF** from any value which does not round to 1×10^{-4} (m s^{-1})
			$A = 1.6 \times 10^{-15}$ (m)	**A1**	**Allow** use of $v_{max} = 1 \times 10^{-4}$ (m s^{-1})^1 giving $A = 1.4 \times 10^{-15}$ (m) to 2sf or 1.45×10^{-15} (m) to 3sf Special case: **Allow** $A = 1 \times 10^{-15}$(m) to 1 sf if $v_{max} = 1 \times 10^{-4}$ (m s^{-1}) is used
		(iii)	($a_{max} = \omega^2 A$ and $v_{max} = \omega A$)		
			$a_{max} = 2\pi f\, v_{max}$	**M1**	**Allow** $a_{max} = \omega\, v_{max}$ **Allow** a for a_{max} and v for v_{max}
			Since v_{max} is constant, $a_{max} \propto f$	**A1**	

Question			Answer	Marks	Guidance
5	(b)*	(i)	**Level 3 (5–6 marks)** Clear explanation **and** clear description *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.* **Level 2 (3–4 marks)** Clear explanation **or** clear description (but not both) **or** Some explanation **and** some description *There is a line of reasoning presented with some structure. The information presented is in the most part relevant and supported by some evidence.* **Level 1 (1–2 marks)** Limited explanation **or** Limited description *There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.* **0 marks** *No response or no response worthy of credit.*	**B1× 6**	Use level of response annotations in RM Assessor **Indicative scientific points may include:** **Explanation of pattern** • Interference / superposition occurs • Path difference a whole number of wavelengths • means waves are (exactly) in phase (or $\Delta\varphi = 0$) • giving (maximum) constructive interference • which leads to maximum intensity • Path difference an odd number of half wavelengths (or $\Delta\varphi = \pi$ radians) • means waves are in antiphase • giving (maximum) destructive interference • which leads to minimum intensity **Description of relationship between *f* and *x*** • $\lambda = ax/D$ **and** $c = f\lambda \rightarrow x = cD/af$ • so $x \propto 1/f$ (provided a and *D* remain constant) • Use ruler along QP to measure *x (or 10*x/10, say) • Connect oscilloscope to transmitter or detector to measure *f* • Vary *f (*keeping a and *D* constant) and measure corresponding *x* • Calculate *fx* which should remain constant • Or plot graph of 1/*x* against *f* (or x against 1/f) • Should give straight line <u>through the origin</u>

Question			Answer	Marks	Guidance
5	(b)	(ii)	At 90° rotation, (interference) pattern disappears	B1	**Allow** constant intensity along PQ **Not** zero intensity along PQ **Allow** from 0 to 90° the intensities of the maxima decrease (and the minimum intensities increase)
			At 180° rotation, intensities are the same as at 0° but the maximum/minimum positions are switched / reversed	B1	**Allow** from 90 ° to 180 ° the intensities of the maxima increase (and the minimum intensities decrease) but the maximum/minimum positions are switched / reversed from between 0 and 90°
			Waves with polarisations at 90° to each other do not interfere / only waves with same polarisation interfere / only waves with a component in the same plane interfere	B1	**Allow** waves must oscillate in same plane to interfere **Ignore** at 90° rotation, only waves from Y are detected at D because D can only detect vertical polarised waves
			Total	**17**	

21	**(a)**	**(i)**	newton in base units is kg m s^{-2} Substitution and cancelling of kg and m arriving at s^2 -> s^2	C1 A1	
		(ii)	One force is increased by kx and one is reduced by kx /AW Some working to include kx - (-kx)	B1 B1	reject 2 springs in series or 2 springs in parallel idea XP. accept one extension is reduced by x and one is increased by x / AW
		(iii)	period is independent of amplitude / AW No effect	M1 A1	Allow isochronous
	(b)	**(i)**	Units omitted from T **and** T^2 Valid statement about significant figures	B1 B1	 allow correct statement about individual data points or decimal place or "precision" e.g. sf of T does not match sf of 20T or sf of T not consistent throughout column or idea that 1 sf never enough
		(ii)	Correct plotting within half a small square Correct line of best fit	B1 B1	 ECF for incorrect plotting. NB Same number of points above and below the line AND fair distribution of distances from line

		(iii)	Gradient between 1.22 and 1.44 $k=2\pi^2 \div$ gradient k between 13.7 and 16.2	C1 C1 A1	reject use of data table ECF use of candidate's line ECF use of candidate's gradient as per rubric
	(c)		maximum four from: EPE gain (in stretched spring) > EPE lost (in relaxed spring) EPE is dependent on x^2 Total energy increases (and so KE increases since EPE -> KE) Max KE when the system has minimum EPE / at equilibrium position/when x=0 Minimum EPE is unchanged Omega is same, amplitude has increased v_{max} when x=0 so v_{max} has increased (omega^2 = sqrt(A^2-x^2)) v_{max} increased so KE_{max} increased	4 x B1	Allow EPE max is dependent on A^2 NOT EPE dependent on x alone Allow EPE dependent on x and F which is dependent on x (EPE = ½ Fx idea) KE = ½ kx^2 is XP
			TOTAL	17	

12	**C**	**1**	

2	B	1	

18			**Level 3 (5–6 marks)** Detailed quantitative discussion and comparison of uncertainties, and clear description of graphical analysis *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.* **Level 2 (3–4 marks)** Some quantitative discussion of uncertainty for one method and clear description of graphical analysis Or Discussion, with some quantitative ideas and comparison of uncertainty for both methods with some graphical analysis *There is a line of reasoning presented with some structure. The information presented is in the most part relevant and supported by some evidence.* **Level 1 (1–2 marks)** Incomplete discussion of uncertainty with no comparison Or Description of analysis *There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.*	B1 x 6	Use level of response annotations in RM Assessor **Indicative scientific points may include:** **Discussion of uncertainty** ● No repeat makes experiment inherently uncertain ● Height +/- 1cm ● Ramp length +/- 1mm ● Resolution/"precision" of stopclock is 0.01s, but reaction time is much greater ● Times +/- 0.1 s (or more) ● Calculation of g will use time squared so double the percentage uncertainty in t ● Angle likely to be +/- 1 or 2 degrees ● Ramp calculation uses sine of angle, so difficult to quantify the uncertainty as a percentage to combine with other variables **Comparison** ● Ramp method has greater time and length both greater so smaller percentage uncertainties ● Frictional effects ramp method more ● More difficult to measure times for drop ● Uncertainty for height and ramp different **Analysis** ● Ignore references to comparisons of the value of g found from both methods ● Find g from $s = \frac{1}{2} a t^2$ for multiple values of s **and average**

Question			Answer	Mark	Guidance
			0 marks *No response or no response worthy of credit.*		• Appropriate graphs plotted i.e. plotting t^2 on y-axis and s on x-axis, following some analysis/comparison with "y=mx+c" • Significance of gradient (e.g. t^2 against 2s gives gradient 1/g for drop method • Determine uncertainty graphically using best/worst line method
			TOTAL	6	

Question			Answer	Marks	Guidance
17	a		Working that leads to $t = \frac{15 \times 10^6}{280 \times 10^3}$ = 54 (s)	B1	**Allow** KE = t × P approach
	b		Horizontal arrow to the left same size as F At least one horizontal magnitude given as 6700 (N) At least one vertical magnitude given as 170 000 (N)	B1 B1 B1	by eye **Allow** $280 \times 10^3 \div 42$ or 6670 (N) **Allow** 17000×9.81 or 167000 (N)
	c		(thinking distance =) 0.40 × 42 or 17 m Acceleration = 7 (m s^{-2}) or ½ m v^2 = F d (braking distance =) 125 m Total stopping distance is 142 m (which is less than 167m)	B1 C1 A1 B1	**Allow** ECF in subsequent marks if thinking distance incorrect or omitted **Alternative approach using braking distance** (work done =) $120 \times 10^3 \times$ (167 – thinking distance) (work done =) 18×10^6 (J) Work done calculated **and** this is less than the initial KE **Allow** braking distance calculated and 125 m is less than the available braking distance of (167 – thinking distance)
			Total	**8**	

17	**(a)**		Tangent drawn correctly by eye Attempt made to determine the gradient of tangent acceleration = 1.3 (m s^{-2})	**B1** **C1** **A1**	 **Allow** answer in range 1.2 to 1.4 (m s^{-2})
	(b)		F (= ma = 1.2 x 10^{-2} x 1.3) = 0.016 (N)	**B1**	Possible ECF from **(a)** (1.2 x 10^{-2} x their answer) **Note** answer to 3 SF is 0.0156 (N)
	(c)		W = 1.2 × 10^{-2} × 9.81 or 0.118 (N) 0.0156 = 0.118 – drag (Any subject) drag = 0.10 (N)	**C1** **C1** **A1**	Possible ECF from **(b)** **Allow:** use of 'g' for 9.81 **Allow** 0.1 (N)
	(d)	**(i)**	Drag is the same (at a certain velocity) weight is greater or <u>resultant</u> force is larger	**B1** **B1**	**Allow** air resistance for drag
		(ii)	(TV requires) weight = drag **and** weight is greater Clear link to idea that greater speed gives greater drag (for same cross-sectional area)	**B1** **B1**	
			Total	**11**	

4	(a)		zero acceleration / constant velocity	B1	**Ignore** constant speed
			weight = drag (+ upthrust)	B1	**Allow** W or mg or gravitational force for weight **Allow** air resistance for drag **Allow** resistive forces for drag (+ upthrust)
			zero <u>resultant</u> force (vertically)	B1	**Allow** zero net / overall force (vertically) **Ignore** object is in equilibrium / forces are balanced **Not** there are no resultant <u>forces</u> (plural)

Question			Answer	Mark	Guidance
4	(b)	(i)	Any two points from this list of three:	B1 x 2	
			• $v \propto r^2$		**Allow** v increases with r (squared) OAW
			• (so) droplets with a small(er) radius have a small(er) v		ORA
			• (so) water droplets in mist must have a smaller radius (than water droplets of rain)		ORA
			Alternatively, **allow** any two points from the list below:		
			• $v \propto (\rho_s - \rho_f)$		
			• $\rho_f \approx \rho_s$ for water droplets in mist giving $v \approx 0$		**Allow** density of water is similar to density of mist so $v \approx 0$
			• $\rho_s > \rho_f$ (**or** $\rho_s \neq \rho_f$) for water droplets in air giving $v > 0$ (**or** $v \neq 0$)		**Allow** water/rain is more dense than air so $v > 0$
			• ρ_f is greater in mist than air (with ρ_s constant) so v is smaller for water droplets in mist than for water droplets in air ORA		**Allow** density of mist is greater than density of air so v is smaller for water droplets in mist than for water droplets in air ORA

4	(b)	*(ii)	**Level 3 (5–6 marks)** Clear description (must check for *terminal* velocity) **and** Clear analysis (**either** correct answer for lowest *v* (allowing POT error) **or** method which at least partially verifies the expression) *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.* **Level 2 (3–4 marks)** Some description (several points made, leading to a measurement of velocity) **and** limited analysis (as below) **or** Limited description **and** clear analysis (see above) *There is a line of reasoning presented with some structure. The information presented is in the most part relevant and supported by some evidence.* **Level 1 (1–2 marks)** Limited description (eg at least one valid point made) **or** Limited analysis eg • incorrect expression used with correct values • incorrect values used in correct expression • 'plot a graph' but with incorrect axes / no mention of how to use the graph to verify the expression *There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.* **0 marks** *No response or no response worthy of credit*	**B1** **× 6**	Use the annotations e.g. L2 for 4 marks, L2^ for 3 marks etc. Place the appropriate number of ticks below the annotation. **Indicative scientific points may include:** **Description of experiment to measure terminal velocity *v*** • Use a long, clear tube containing the liquid • Check the tube is vertical using a spirit level or plumb line • Measure a distance *d* using metre rule or tape measure • Measure a time *t* using a stopclock **or** light gates **or** give details of a video method • Describe a method to reduce parallax error • Describe a method to check that the spheres have reached *v* • Repeat using a different liquid and/or a different metal sphere • Possibly use several spheres with different values of *r*, measuring diameter *d* of spheres using callipers or micrometer **Analysis** • Calculate $v = d / t$ • Calculate $r = d / 2$ • Verify expression by plotting a suitable graph e.g. *v* against r^2 • and see if the results lie on a straight line through the origin • Verify expression by substituting into expression • e.g. calculating *g* from gradient and comparing result to 9.81 or comparing measured *v* to value of *v* predicted from expression • Steel spheres – lower ρ_s than lead so lower *v* • Sunflower oil – much higher η than water so lower *v* • Estimate lowest $v = 0.075$ m s^{-1} using steel and sunflower oil
			Total	**11**	

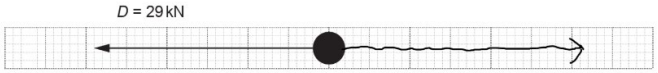
16	**a**	**i**	Curve starts at (0,0) with gradient decreasing to a maximum value 30 on vertical axis matching highest point of candidate's line	B1 B1	Accept horizontal asymptote NB ignore candidate's response after their line reaches 30 (m/s)
		ii	Resistive force increases (with speed) Zero net or zero resultant force	B1 B1	Allow drag / (air) resistance / friction for 'resistive force' Allow resistive force = component of weight down the slope NOT simply idea of resistive force = weight
		iii	Component of weight down slope = 9300 sin 5° Re-arrange to $(k=)F \div v^2$ (k=)810 ÷ 900 = 0.9...	M1 M1 A1	Allow 810 or 811 seen Allow substitutions for variables Mark is for substitution <u>and</u> candidate's value seen
	b		evidence of substitution of $F=kv^2$ into $P = Fv$ $v = (P \div k)^{1/3}$ v = 44 (m s^{-1})	C1 C1 A1	e.g. $P = kv^3$, $P = (kv^2)\ v$, etc Allow use of k = 1 which gives 42 Allow answer within range 36 to 53

Question			Answer	Mark	Guidance
	c		Power is proportional to the speed cubed / Max speed is proportional to the cube root of max power / power proportional to speed x kv^2	B1	
			Valid reference to the cube root of 2 increase in velocity for double power / Valid reference to factor of 8 increase in power for double the velocity	B1	NB cube root of 2 is 1.2599 e.g. 1.26 x 44 = 55 (m s^{-1})
			TOTAL	12	

Question			Answer	Marks	Guidance
18	(a)	(i)	volume = $7.0 \times 10^{-2} \times \pi \times (0.5 \times 10^{-2})^2$ or 5.5×10^{-6} (m^3)	C1	No ecf for incorrect volume.
			$\rho = 5.0 \times 10^{-3} / (7.0 \times 10^{-2} \times \pi \times (0.5 \times 10^{-2})^2)$		
			density = 910 (kg m^{-3})	A1	Answer to 3 s.f. is 909 **Allow** 1 mark for 230 ($r = 1.0 \times 10^{-2}$ m used)
		(ii)	The density (of wood is) similar to human (AW)	B1	
			Less than density of water / it needs to float / otherwise it will sink	B1	**Allow** 'greater upthrust than weight when fully submerged'
	(b)		($v^2 = 2as + u^2$); $v = (2 \times 9.81 \times 0.30)^{½}$ (Allow any subject)	C1	**Allow** ($s = ½ a t^2$) to give t = 0.247 and ($v = at$) gives 2.42
			speed = 2.4 (m s^{-1})	A1	
	(c)	(i)	weight / *W* / *mg* **and** downward arrow	B1	**Allow** labels used in **(c)(i)** throughout
			upthrust / *U* **and** upward arrow	B1	**Ignore** arrow sizes.
			drag / *D* / friction **and** upward arrow	B1	**Allow** '(water) resistance' for drag
		(ii)	Resultant force decreases (with time or as cylinder descends)	B1	
			Upthrust remains constant / drag decreases (as speed decreases) / resultant force is upwards / At lowest point, drag is zero	B1	**Allow** 'At lowest point, upthrust > weight' **Note**: Any incorrect answer from the list will not score this point
			At lowest point, resultant force is upwards	B1	**Not** 'resultant force = 0' **Note**: Resultant force is <u>always</u> upwards' scores B1x2
	(d)		Doubling the depth is too much / d is not (directly) proportional to h	B1	
			Qualifying statement using evidence from graph e.g. decreasing gradient, use of numbers to show not proportional, comment about non-zero intercept etc	B1	
			Total	14	

16	**(a)**	**(i)**	Reference to area (under the curve) Construct rectangle or square plus triangle/ trapezium	B1 B1	 Allow: reference to counting squares. Accept: annotation on the graph such as shapes Ignore: reference to integration Accept for 2 marks: Attempt to calculate number of squares (under the curve) and multiply by area of one square (even if the candidate has got the area of one square wrong)
		(ii)	Tangent drawn at (12, 54) Change in y / change in x =1.4	M1 A1	 Allow value that rounds to 2sf in the range 1.3 - 1.7 to 2sf
		(iii)	Change in velocity = 56 ms^{-1} Change of momentum = 56 × 1700 = 95000 ($kg\ ms^{-1}$)	C1 A1	 Answer is 95200 to 3sf
	(b)	**(i)**			Accept ‘air resistance’ or ‘friction’ for ‘drag’ throughout

Question			Answer	Mark	Guidance
			Any two from: Drag force is increasing (so resultant decreases) (Zero resultant when or towards end) drag = driving force/friction from wheels Idea that drag force is increasing at a decreasing rate (so resultant decreases at a decreasing rate)	 B1 B1 B1	 Accept reference to drag force function ($F = kv^2$)
		(ii)	(Area under graph =) impulse / related to the product of time and force / change in momentum	B1	
	(c)	**(i)**	 Tyre (or wheel) exerts a force on the road backwards / to the left / opposite to direction of motion Road exerts (equal and) opposite force (of the same type) on the tyre / AW	 M1 A1	Check diagram Allow “car” for “tyre” Accept alternatives such as “forward” or “to the right”
		(ii)	Candidate’s gradient from 1(a)(ii) × 1700 evaluated	B1	 Allow 1.5 (from stem) × 1700 = 2600 N NOTE: range in acceptable gradients for (a)(ii) gives force between 2210-2720
		(iii)	F = Resultant (2400) + D = 31000(N) = 31 (kN)	B1	Ignore PoT on answer line

Question			Answer	Mark	Guidance
			Arrow drawn from the circle to the right to scale i.e. 	B1	Allow ECF for resultant from part (ii) and/or D If using 1.5 from stem, F=32000 to 2sf Allow +/- half a small square by eye i.e. 31-32 squares Allow candidate's arrow consistent with number on answer line
			Total	14	

5	**D**	**1**	

8	B	1	

8	**D**	**1**	

5	**B**	**1**	

2	B	1	

6	**B**	**1**	

8	**C**	**1**	

Question					
22	(a)		(torque =) 350 × 0.0050 torque = 1.8 (N m)	C0 A1	 Answer is 1.75 to 3 sf. **Allow:** 1.7 (N m)
	(b)		(Clockwise moments = anticlockwise moments) 7 x 10^n × *F* = 30 x 10^n × 31 *F* = 130 (N) $(\text{mass} = \frac{F}{g})$ mass = 14 (kg)	C1 C1 A1	**Allow** any power of 10 for distance as long as unit consistent. **Allow** *R* = 164 (N) found by taking moments about flat head of screw/point A **Note** F to 3SF is 133 (N)
			Total	**4**	

Question	Answer	Marks	Guidance

19	**(a)**		Suspend object (freely) and mark vertical (down) Repeat(s) (from different point) and reference to intersection of verticals Plumb line/ plumb bob /AW	B1 B1 B1	Allow methods with unstable equilibrium e.g. balance shape on a pin/finger for 1 mark max Accept spirit level
	(b)	**(i)**	P = work ÷ time = 120 kN x (6.3+1.3) ÷ 90 = 10100 W	 C1 A1	 Omission of 1.3 m giving 8400 W scores 1 mark
		(ii)	Any reasonable suggestion e.g. ● Motor not 100% efficient / AW ● The value found is an average/the power required varies during the lift / AW ● decreased time such as needing to raise the bridge in a shorter time / AW ● External forces such as drag or extra weight change required work done / AW	B1	
			TOTAL	6	

19	**(a)**		For a body in (rotational) equilibrium the sum of the clockwise moments (about any point) is equal to the sum of the anticlockwise moments (about the same point)	**B1**	**Note** Accept Σ / total (AW) for sum
	(b)	**(i)**	(horizontal component of F =) $F \times \cos 20°$ $F \cos 20° \times 1.30 = 0.30 \times 40 \times 9.81$ F = 96.4 (N)	**M1** **M1** **A1**	 **Allow** ECF for incorrect trig i.e. use of sine (gives F =265) or cos(20 radians) which gives F = 222 for 2 marks. **Allow ECF** for incorrect units for angle and incorrect trig sin(20 radians) which gives F = 99(.2) for 1 mark
		(ii)	$R = F \cos 20°$ **or** $96(.4) \times \cos 20°$ (R =) 91 (N)	**C1** **A1**	**Allow** ECF from (b)(i) **Answer is 90.6 (N) to 3sf if 96.4 used.** **Answer is 90(.2) (N) to 3sf if 96 used**
	(c)		When (line of force of the) weight falls to the right of the (bottom of the) wheel/AW	**B1**	
			Total	**7**	

4	(a)		(below pivot to provide restoring force so that) needle rests vertically (with the pointer at the bottom) when there is no charge (short distance so that moment due to weight is as small as possible) to increase sensitivity	B1 B1	Must be clear that needle is vertical when at rest eg $\theta = 0°$ **Allow** to increase the resolution / to be able to clearly discriminate between charge values
4	(b)	(i)	Relevant comment **and** curved line of best fit drawn through 0.3 kV (by eye/ ±1 small square) at 0 deflection	B1	**Allow** statement that curved line of best fit would pass through 0.3 kV if line is missing/incomplete
4	(b)	(ii)	value read from their lobf at 45 degrees their value read at 45 degrees corrected for zero error $Q = CV = 20 \times 10^{-12} \times 1300$ (= 2.6×10^{-8} C) $2.6 \times 10^{-8} \div 1.6 \times 10^{-19}$ 1.6×10^{11} (electrons)	B1 B1 C1 A1	**Allow** 1.60 ± 0.05 kV if no line has been drawn Expect 1.30 ± 0.05 for range stated above **Allow** any value for V between 0 and 4.5 kV Expect (2.5 to 2.7) × 10^{-8} for ranges above (1.6 to 1.7) × 10^{11} Note answers in the range (1.9 - 2.1) x10^{11} gain both calculation marks (zero error not applied). **Accept** this answer given to one sig fig. An answer of 2 x10^{11} (one sig fig) gains 4 marks if (1.6 to 1.7) × 10^{11} seen in working Note an answer of (1.6 to 1.7) × 10^{11} gains 4 marks

Question			Answer	Mark	Guidance
			Total	7	

Question			Answer	Mark	Guidance

16	**(a)**		Arrow vertical down and an arrow opposite to the frictional force. Both arrows labelled correctly.	**M1** **A1**	 **Allow** weight / *mg* / W for the downward arrow and tension / *T* / 'force in rod' / 'force in tow bar' /'driving force' for the 'upward' arrow
	(b)		(W_s =) 1100 × 9.81 × sin 10° **or** 1100 × 9.81 × cos 80° (W_s = 1874 N or 1900 N)	**C1** **A0**	**Allow** *g* instead of value
	(c)		force = 1900 + 300 force = 2200 (N)	 **A1**	 **Allow** 1870 + 300 = 2170 (N)
	(d)		(distance =) 120 / sin 10° **or** 691 (m) (work done =) 2200 × 691 work done = 1.5×10^6 (J)	**C1** **C1** **A1**	 **Allow** ECF from **(c)** **Allow** ECF from an incorrect attempt at first mark.
	(e)		(A =) $\pi \times 0.006^2$ **or** 1.1×10^{-4} (m^2) (stress =) $\frac{2200}{\pi \times 0.006^2}$ and $2.0 \times 10^{11} = \frac{\text{stress}}{\text{strain}}$ $x = 4.8 \times 10^{-5}$ (m)	**C1** **C1** **A1**	 **Allow** ECF from **(c)** **Allow** x ($=FL/EA$) = $\frac{2174 \times 0.5}{2.0 \times 10^{11} \times 1.1 \times 10^{-4}}$ **Allow** 2 marks for 1.2×10^{-5}; 1.2×10^{-2} m used as radius **Allow** answer between 4.7 and 5.1×10^{-5} (m)
			Total	**10**	

Question			Answer	Marks	Guidance
18	(a)	i	(area of shaded region =) 1.9 × 6.0 or 11.4 (m^2) (volume of air in 3.0 s =) 11.4 × 3.0 × 12 (mass of air = 11.4 × 3.0 × 12 × 1.2) mass of air = 492(.48) (kg)	**C1** **C1** **A1**	 **Allow** volume found in one second leading to mass per second multiplied by 3 for 2nd and 3rd mark **Note:** volume of air is 410 (m^3)
		ii	Δp = 12 × 490 or 5900 (kg m s^{-1}) (force = Δp / Δt = 5900/3.0) F = 2000 (N)	**C1** **A1**	Expect to see mass of 490, 492, 492.5, 492.48 **Note** answer is 1970 to 3 SF using 492.48 **Note** answer is 1960 to 3 SF using 490

Question			Answer	Marks	Guidance
	(b)*		**Level 3 (5–6 marks)** Clear descriptions **and** explanations, supported by quantitative analysis *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.* **Level 2 (3–4 marks)** Some description and some explanation or quantitative analysis **or** Clear explanation **or** Clear description **or** Clear quantitative analysis *There is a line of reasoning presented with some structure. The information presented is in the most part relevant and supported by some evidence.* **Level 1 (1–2 marks)** Limited description **or** Limited explanation *There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.* **0 marks** *No response or no response worthy of credit.*	**B1× 6**	**Indicative scientific points may include:** **Description** • Increasing the area/diameter of the guy ropes • A different material with a larger breaking or yield stress • A more streamlined shape that allows the wind to pass over or around the tent **Explanation** • Correct reference/use of $F = \Delta p / \Delta t$ • Greater cross-sectional area of rope would reduce the stress • The rope would not exceed a higher breaking/yield stress • Changing shape produces a smaller momentum change and a smaller force • If the air passes over/around the tent, it still has some forward momentum and hence the change and force is less • Reduction of angle of ropes from ground reduces component of tension perpendicular to ground so tension decreases. **Quantitative analysis** • Mass (per unit time) and velocity **both** double (at 40 m/s) • Momentum change is x4 • Force would increase by a factor of 4 • Rope cross section must be × 4 (or diameter × 2) • Breaking or yield stress of material would need to be × 4 • Use of trigonometry to determine the angle of deflection that would reduce the momentum change by a factor of 4 (about 15° compared to the original 90°)
			Total	**11**	

Question			Answer		Guidance
6			arrow down through centre of ball labelled weight **or** W **or** mg **or** 1.2 N	 **B1**	zero if any other arrows or forces present
	(b)	**(i)**	(horizontally) mv^2/r (**or** $mr\omega^2$) = T sin θ **and** (vertically) W **or** mg = T cos θ (tan θ = v^2/rg **or** $r\omega^2/g$) tan θ = 0.045 x 4 x 9.87 x 2.2/9.81 **or** 0.48/1.2 (= 0.40) θ = 22°	 **M1** **A1** **A0**	**accept** figures in place of algebra, r = 0.045 m v = 0.42 m s^{-1} ω = 3π rad s^{-1}; $r\omega^2$ = 4.0 m s^{-2} ; W = 1.2 N and m = 0.12 kg and $mr\omega^2$ = 0.48 N **accept** labelled triangle of forces diagram **N.B.** this is a *show that Q* ; sufficient calculation must be present to indicate that the candidate has not worked back from the answer
		(ii)	k = (mg/x_0 = 1.2 / 0.050) = 24 (N m^{-1}) (T = mg / cos θ = kx giving) x = 1.2 / 24 cos 22 x = 0.054 (m)	**C1** **C1** **A1**	**or** solution by ratios
	(c)		(y = ½gt^2 =) 0.18 = 0.5 x 9.81 x t^2 giving t = 0.19 (s) (x = vt =) 0.42 x 0.19 = 0.08 (m) distance = √(r^2 + x^2) = √(0.0020 + 0.0064) = 0.092 (m)	**C1** **C1** **C1** **A1**	**alt**: projectile motion: x = vt, y = ½gt^2 y = ½g$(x/v)^2$ **ecf (b)i** for v; $x^2 = 2yv^2/g = 2 \times 0.18 \times 0.42^2/9.81$
	(d)		T increases **or** string stretches **or** angle θ increases to provide/create a larger centripetal force	**M1** **A1**	 **allow** mv^2/r **or** $mr\omega^2$ in place of *centripetal force* causality must be implied to gain the A mark
			Total	**12**	

Question			Answer		Guidance
1	(a)	(i)	$F = QE = QV/d$ **or** $E = 5(.0) \times 10^4$ (Vm^{-1}) $F = 9.0 \times 10^{-9} \times 4000 / 8.0 \times 10^{-2}$ ($= 4.5 \times 10^{-4}$ N)	**C1** **A1**	 $F = 5.0 \times 10^4 \times 9.0 \times 10^{-9}$
		(ii)	weight; arrow vertically downwards tension; arrow upwards in direction of string electric (force); arrow horizontally to the right (not along dotted line)	**B1 x 2**	All correct, 2 marks; 2 correct, 1 mark 1 mark maximum if more than 3 arrows are drawn **Ignore** position of arrows **Allow** W **or** 0.030(N) (**not** gravity or g) **Allow** T **Allow** F **or** E or 4.5×10^{-4}(N) or electrostatic **Ignore** repulsion or attraction **Not** electric field / electric field strength / electromagnetic
		(iii)	$W x = F l$ $0.03 x$ $= 4.5 \times 10^{-4} \times 120$ **or** $= 4.5 \times 10^{-4} \times 1.2$ $x = 1.8$ cm **or** $x = 0.018$ m	 **M1** **M1** **A0**	**Allow** any valid alternative approach e.g. M1 deflection angle $\theta = 1^o$ M1 $x = 120 \sin\theta$ 1 mark for each side of the equation

	(b)		Electric force/field (strength) increases Ball deflected further from vertical / moves to the right / touches negative plate Ball acquires the charge of the (negative) plate when it touches (Oscillates because) constantly repelled from (oppositely) charged plate	**B1** **B1** **B1** **B1**	Must be clear which force is increasing Must have the idea of a repeating cycle
	(c)		$I = Qf$ **or** $Q = It$ $f = 3.2 \times 10^{-8}/9.0 \times 10^{-9} = 3.6$ (Hz)	**C1** **A1**	
			Total	**12**	

Question	Answer	Marks	Guidance

2	(a)		use of stopclock (**or** stopwatch **or** timer) time *n* oscillations **and** divide by *n*	B1 B1	 If *n* is specified then *n* ≥ 5
	(b)	(i)	*f* = 1 /*T* working shown to give $T^2 = \left(\frac{8\pi^2}{3g}\right)L$	B1 B1	**Allow** $T = 2\pi\left(\frac{2L}{3g}\right)^{\frac{1}{2}}$ **or** $f^2 = 1/T^2$ Subject must be T^2 **Allow** $T^2/L = 8\pi^2/3g$
		(ii)	$g = \left(\frac{8\pi^2}{3 \times 2.64}\right)$ *g* = 9.97 (m s^{-2})	C1 A1	 Answer must be given to at least 3sf
		(iii)	line of worst fit drawn	B1	Steepest or shallowest possible line that passes through all the error bars (allow ±½ small square tolerance vertically) If two lines are drawn then they must both be correct
		(iv)	gradient of worst line calculated with large triangle working to find percentage uncertainty in *g* answer consistent with candidate's worst line	B1 M1 A1	ΔL≥ 0.06m Shallowest gradient ≈ 2.1(s^2 m^{-1}) and steepest ≈ 2.9 (s^2 m^{-1}) $\frac{\text{worst value of g} - 9.97}{9.97}$ (x 100%) **Allow** % uncertainty in gradient = $\frac{\text{gradient of wfl} - 2.64}{2.64}$ (x 100%) Expect answer ≈ 10% (steepest wfl) and ≈ 27% (shallowest wfl) **Allow** a negative answer
		(v)	percentage difference = $\frac{9.97 - 9.81}{9.81}$ x 100% = 1.6% **or** absolute difference = 9.97 - 9.81 = 0.16 **or** absolute uncertainty = (9.97 – value of *g* from wfl) conclusion consistent with candidate's answer to **(b)(iv)**	M1 A1	Possible **ECF** from **(b)(ii)** Value for *g* is accurate if % uncertainty >% difference **or** if absolute uncertainty > absolute difference **or** if 9.81 lies within the uncertainty range for *g*
			Total	**12**	

14	**C**	**1**	

14	**D**	**1**	

12	**B**	**1**	

10	**C**	**1**	

2	C	1	

9	D	1	

14	B	1	

9	**C**	**1**	

10	C	1	

5	**A**	**1**	

Question			Answer	Marks	Guidance
18	(a)		$1.2 \times 10^6 = ½ \times$ (mass per second) $\times 8.0^2$ mass per s = 3.8×10^4 (kg s^{-1})	C1 A1	 Answer is 3.75 x 10^4 (kg s^{-1}) to 3sf **Note:** 3.8 x 10^n (kg s^{-1}) scores 1 for PoT error.
	(b)	(i)	$A \rightarrow$ m^2 and $\rho \rightarrow$ kg m^{-3} $P \rightarrow$ kg m^2 s^{-3} Clear working to show units are equivalent on either side of equation	M1 M1 A1	**Note**: No mark for $v \rightarrow$ m s^{-1} since units are in **(a)** **Allow** $P \rightarrow$ kg m s^{-2} m s^{-1} (from $P = Fv$ or P=Work done/t) **Note:** clear working includes m^3s^{-3} seen.
		(ii)	$1.2 \times 10^6 = ½ \times 1.3 \times A \times 8.0^3$ or A = 3600 (m^2) seen L = 34 (m)	C1 A1	**Allow** volume s^{-1} = 28846 (m^3) using 3.75 x 10^4 (kg s^{-1}) or 29231 (m^3) using 3.8 x 10^4 (kg s^{-1}) **Allow** ECF from (a) **Note:** 3.4 x 10^n (m) scores 1 for PoT error.
		(iii)	(output power =) 0.42 $\times$ 1.2 / 0.504 (MW) (N = 50/0.504 = 99.2) N = 100	C1 A1	**Allow:** 50 x 10^6 / 0.42 = 119 MW and then 119 / 1.2 **Not** 99 **Note**: answer of 99.2 scores 1 mark max
			Total	9	

17	**(a)**		(mean) = 1.87(2) (mm) (range) = 0.04 mm (percentage uncertainty =) $\frac{0.02}{1.872} \times 100$ percentage uncertainty = 1 (%)	**C1** **C1** **A1**	 **Allow** use of resolution of micrometer (gives percentage uncertainty of 0.5%) **Allow** use of maximum or minimum deviation from the mean **Allow** 2 or 3 SF answer

	(b)*		**Level 3 (5–6 marks)** Clear description **and** clear analysis *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.* **Level 2 (3–4 marks)** Some description **and** some analysis **or** Clear description **or** Clear analysis *There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.* **Level 1 (1–2 marks)** Limited description **or** Limited analysis *There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.* **0 marks** No response or no response worthy of credit.	**B1× 6**	Use level of response annotation in RM Assessor. **Indicative scientific points may include:** **Description** • Determine *T* by measuring several oscillations • Independent and dependent variables identified (e.g. *L* and *T*) • Variables kept constant (e.g. for L and T experiment, *m* is kept constant) • Repeating to determine average *T* • Measure length *L* and width *w* with ruler • Measure thickness *t* with a vernier (calliper) / micrometer • Use video/phone camera / stopwatch / data-logger and motion sensor / light gates and timer • Use top-pan balance / scales to measure *m* **Analysis** • Plot an appropriate graph, e.g. T^2 against L^3 **or** tabulate $T^2 \div L^3$ • Gradient of **best line** determined **or** average of $T^2 \div L^3$ • Use a large triangle to determine gradient • Gradient (or equivalent) related to *E*, e.g. gradient = $16\pi^2 m/wEt^3$ for T^2 against L^3 graph
			Total	**9**	

19	**(a)**		Energy transfers from higher temperature to lower / AW	B1	Allow oxygen and surroundings are not in thermal equilibrium Allow idea that tank is cooler than the surroundings
	(b)		The potential energy (of the particles) is increasing The kinetic energy (of the particles) is constant	B1 B1	Accept to provide latent heat 'not increasing' is insufficient
	(c)		Energy transferred = 3600 × 1300 (= 4.68 MJ) / AW Mass vaporised = 4.68 MJ ÷ 214 000 (=21.9 kg) /AW V = 21.9 ÷ 1140 seen and evaluated to 0.019(2) (m^3)	M1 M1 A1	Alternate E = mL = ρVL and Pt = ρ VL (M1) V = Pt ÷ ρL = (1300 × 3600) ÷ (1140 × 214000) (M1) V = 0.0192 (A1) allow 0.019

Question			Answer	Mark	Guidance
	(d)		Volume occupied by gas= 0.2 + 0.019 = 0.22 m^3 p=((nRT)/V) = 710 x 8.31 x (-183+273) / 0.22 p=2410 (kPa)	C1 C1 A1	 Rearrangement and substitution NOTE: use of incorrect volume data in the question e,g, V = 9.8 + 0.2 = 10, V = 9.8 can still score this substitution and rearrangement mark but nothing else. No ECF. ECF incorrect addition or non-addition of volumes e.g use of either 0.2 or 0.02 or 0.019 for 2 marks. Treat incorrect conversion to kelvin as AE and allow ECF Non-conversion of temperature to kelvin is XP so cannot score second and third mark.
			TOTAL	9	

22	**(a)**	**(i)**	The upthrust (on an object in a fluid) is equal to the weight of fluid (it displaces)	**B1**	**Note** 'fluid' or 'liquid' must be mentioned at least once. **Allow** a named fluid, e.g. water
		(ii)	($p = h\rho g$) $1.9 \times 10^3 = 0.15 \times \rho \times 9.81$ $\rho = 1.3 \times 10^3$ (kg m^{-3})	 **C1** **A1**	
	(b)	**(i)**	$x = A\cos(\omega t)$ **or** $x = A\cos(2\pi ft)$ $x = 2.0\cos(2\pi \times 1.4 \times 0.60)$ displacement = 1.1 (cm)	**C1** **C1** **A1**	**Note**: Treat use of sine as **TE** **Note** answer is 1.07 (cm) to 3SF **Note** answer if calculator left in degrees of 1.99cm scores 2 marks.
		(ii)	(v_{max} =) $2\pi \times 1.4 \times 0.02$ maximum speed = 0.18 (m s^{-1})	**C1** **A1**	
		(iii)	**1** Larger (amplitude) **2** Same (period)	**B1** **B1**	
			Total	**10**	

Question	Answer	Marks	Guidance

21	**(a)**	**(i)**	($pV = nRT$) $100 \times 10^3 \times (0.46)^3 = n \times 8.31 \times (273 + 20)$ $n = 4.0$	 **C1** **A1**	 **Note** $T = 20$ is XP **Not** 1 SF answer of 4 **Note** answer is 4.00 to 3SF
		(ii)	$\frac{100}{293} = \frac{p}{1573}$ **or** $p \times (0.46)^3 = n \times 8.31 \times 1573$ pressure = 540 (kPa)	**C1** **A1**	**Note** $T = 1300$ is XP **Allow** use of correct, unrounded n
	(b)	**(i)**	(p =) $6.6 \times 10^{-26} \times 990$ **or** $6.5(3) \times 10^{-23}$ (kg m s^{-1}) (Δp =) $2 \times 6.6 \times 10^{-26} \times 990$ $\Delta p = 1.3 \times 10^{-22}$ (kg m s^{-1})	**C1** **A1**	 **Ignore** sign of answer
		(ii)1	$990/[2 \times 0.46]$ (= 1080)	**B1**	
		(ii)2	($F = \Delta p/\Delta t$) (F =) $1.3 \times 10^{-22} \times 1000$ $F = 1.3 \times 10^{-19}$ N	 **C1** **A1**	 Possible ECF from **(b)(i)** **Note** 1080 would give 1.4×10^{-19} (N)
		(iii)	Use of $p = F/A$ **or** pressure = (total) force/area Idea of multiplying by total number of atoms	**B1** **B1**	 **Allow** particles or molecules for atoms
			Total	**11**	

Question			Answer	Marks	Guidance
19	a		Kinetic energy of particles is constant **and** the potential energy increases. internal energy has increased (as the internal energy = KE + PE)	**B1** **B1**	 **Allow** internal energy of a gas is the kinetic energy of the particles **Allow** potential energy of particles in a liquid is negative/the potential energy has increased to zero
	b	**i**	$pV = nRT$ **and** T = 296 (K) $100 \times 10^3 \times 15 = n \times 8.31 \times 296$ n = 610 (mol)	**C1** **C1** **A1**	 **Note** answer is 609.81559 **Allow** 1 mark for 7850; 23 used instead of 300 K
		ii	(mass = 610 × 0.028) = 17 (kg)	**B1**	**Allow** ecf from (b)(i) Expect n=600,610,609(.8)
		iii	Reduce the pressure or increase the temperature (at which it is added)	**B1**	
		iv	The energy is transferred from the water vapour is equal to the energy gained by the liquid nitrogen $L_v = \frac{m_{H_2O} \times (L_{fusion\ H_2O} + L_{evaporation\ H_2O})}{m_{N_2}}$ $L_v = \frac{1.3 \times (334000 + 2260000)}{17}$ L_v = 2.0 × 10^5 (J kg^{-1})	**C1** **C1** **C1** **A1**	**Allow** use of only one of the specific latent heats of water at this stage e.g. $m_{N_2} \times L_{N_2} = m_{H_2O} \times L\ vaporisation_{H_2O}$ **NOTE:** this can be awarded across whole response Evidence of addition of **both** latent heats (of water) is required **Note** answer is 1.97 × 10^5 to 3 SF **Note: 1 mark only for :** answer using only fusion = 2.5 or 2.6 × 10^4 (J kg^{-1}) answer using only vaporisation = 1.7 × 10^5 (J kg^{-1})
			Total	**11**	

Question			Answer	Marks	Guidance
1	(a)		$g = GM/r^2$	C1	**Allow** m for M **Allow** d or D or x or X or R for r
			$g = \frac{6.67 \times 10^{-11} \times 4.87 \times 10^{24}}{(6\,050 \times 10^{3})^{2}}$	C1	Full substitution needed **Allow** r = 6 050 for this C1 mark
			g = 8.87 (N kg^{-1})	A1	**Allow** a negative answer Answer must be to exactly 3sf for the A1 mark. Do not use the **SF** penalty for the paper here
	(b)	(i)	$a = \omega^2 r$ **and** $\omega = 2\pi / T$ **or** $a = v^2/r$ **and** $v = 2\pi r / T$	C1	**Allow** use of $T^2 = 4\pi^2 r^3/(GM)$ **and** $v = 2\pi r / T$
			Either $\omega = \frac{2\pi}{5830 \times 3600}$	C1	ω = 2.99 × 10^{-7} (rad s^{-1})
			or $v = \frac{2\pi \times 6050 \times 10^{3}}{5830 \times 3600}$		v = 1.81 (m s^{-1})
			or $a = \frac{4\pi^2}{(5830 \times 3600)^2} \times 6050 \times 10^{3}$		$a = \omega^2 r$ = (2.99 × 10^{-7})^2 × 6050 × 10^3 $a = v^2/r$ = 1.81^2 / (6050 × 10^3) **Do not allow** incorrect or omitted conversion of T
			a = 5.42 × 10^{-7} (m s^{-2})	A1	**Allow** answer given to 2sf **Allow** any answer which rounds to 5.4 × 10^{-7} Do **not** penalise incorrect km conversion (giving a = 5.42 × 10^{-10}) if already penalised in **(a)**

Question			Answer	Marks	Guidance
1	b	(ii)	(Mass of fluid displaced = $\rho \times V =$) 65 x 1.7	C1	
			(Weight of fluid displaced = $\rho \times V \times g =$) 65 x 1.7 x 8.87	C1	Possible **ECF** from **(a)** but **do not allow** g = 9.81 N kg^{-1}
			U (= weight of fluid displaced) = 980 (N)	A1	
		(iii)	Any 2 from: • Forces are balanced at **A** /there is no centripetal force at **A /** forces are unbalanced at **B /** there is a resultant **or** centripetal force at **B** • correct balanced forces equation at **A** • correct expression of Newton's second law at **B** • calculation of centripetal force at **B** • calculation of normal contact force at **A** • calculation of normal contact force at **B**	B1 x 2	**Allow** the pole for **A** and the equator for **B** throughout **Allow** weight provides the centripetal force but **do not allow** normal contact force/upthrust provides the centripetal force **Allow** acceleration in place of force **Ignore** any statement that suggests that centripetal force is a separate or additional force e.g. $R_A = W - U$ e.g. ($mr\omega^2$ **or** ma **or**) $F = W - U - R_B$ Centripetal force (= ma = 760 x 5.4 x 10^{-7}) = 4.1 x 10^{-4} (N) Possible **ECF** from **(b)(i)** R_A (= $W - U = (680 \times 8.87) - 980$) = 5760 (N) Possible **ECF** from **(a)** and **(b)(ii)** R_B (= $W - U - ma$ = 5760 - 4.1 x 10^{-4}) Possible **ECF** from **(a), (b)(i)** and **(b)(ii)**
			<u>therefore</u> reaction force (must be) greater on **A**	B1	Conclusion must follow some valid and relevant reasoning in which upthrust is mentioned **Allow** reverse argument **Allow** CF is negligible therefore reaction force is same at A and B
			Total	**12**	

20	**a**	**i**	Internal energy (of an ideal gas) is the sum of the (randomly distributed) kinetic energies of the particles	B1	Allow use of KE or E_k and atoms/molecules for particles. Ignore reference to PE (of particles)
		ii	evidence of $NkT = \frac{1}{3}Nmc^2$ Manipulation to insert ½ to give *½ mc² = 3/2 kT*	M1 A1	
	b	**i**	(r.m.s. speed =) $\sqrt{\frac{310^2+370^2+440^2+550^2}{4}}$ r.m.s. speed evaluated as 427 (m s^{-1})	M1 A1	Not arithmetic mean 418. Treat as XP. Allow 729100 as evidence of summation of squares Allow mean squared speed = 182275 (m^2s^{-2}) Allow any candidate evaluation that rounds to or is 427 i.e. 426.93...
		ii	*½ mc² = 3/2 kT* ½ *m* × 430^2 = 3/2 × 1.38 × 10^{-23} × 290 (molar mass = 6.02 × 10^{23} × 6.49 × 10 $^{-26}$) molar mass = 0.039 (kg mol^{-1})	C1 C1 A1	allow ½ *Mc²* = 3/2 *RT* allow any valid rearrangement allow ½ *M* × 430^2 = 3/2 × 8.31 × 290 allow m = 6.5 x 10^{-26} (kg) or *m* = 6.7 x 10^{-26} (kg) Using 427 m s^{-1} gives 0.0396 i.e. 0.040
	c	**i**	Energy transferred from electrical (energy) to internal (energy) or thermal (energy) of filament	B1	Allow power supply doing electrical work on filament

Question			Answer	Mark	Guidance
			Energy transferred from filament to internal energy of gas	B1	Allow heating of gas by conduction Allow description of Newton's Law of Cooling Allow heating of gas by radiation
			(because) the (rate of) energy lost to the surroundings = the (rate of) energy transfer gained (by filament)	B1	Allow reference to thermal equilibrium of any part or whole of lamp structure
		ii	(P/T = constant) $\frac{120}{2400} = \frac{p}{290}$	C1	
			pressure = 14.5 (kPa)	A1	Allow 15 Allow 14
			TOTAL	13	

20	**(a)**		pV=nRT mass (or m) = nM Substitution into $\rho = \frac{m}{V}$ for m and V and cancelling n to give $\rho = \frac{pM}{RT}$	M1 M1 M1 A0	 Not n=1 Not n=1
	(b)	**(i)**	$\rho = \frac{100.000 \times 0.029}{8.31 \times 293}$ =1.19 kg m^{-3}	M1 A0	 Accept R for 8.31, T = 293.1(5) Reject 20 for T.
		(ii)	Mass of air = 1.19 × 12,000 = 14 300 kg Weight of air = mg = 140 000 N	C1 A1	 Accept all answers that round to 140 000 N, eg 140210, 141264
		(iii)	<u>Upthrust</u> = weight of fluid or air displaced Airship in equilibrium/resultant force is 0 (so upthrust = weight of the airship)	B1 B1	Do not accept unqualified “Archimedes’ principle” Not water for fluid

Question			Answer	Mark	Guidance
		(iv)	**Two** from ● (Greater pressure) would increase the density/mass/weight of the helium ● (increased pressure but) no change in volume therefore no more upthrust. ● If the volume goes up then the upthrust will increase / ORA ● Pressure only needs to be large enough to inflate the gasbag ● (increased pressure difference or volume) may cause structural failure ● (higher pressure means) more collisions of helium atoms with walls so more leakage of helium	B1 x 2	

Question			Answer	Mark	Guidance
20	(c)	(i)	F = ([delta mass ÷ delta time] x speed =) 7.8 x 45 = 350N	C1 A1	reject ‘F=ma = 7.8 x 45’ score zero annotate XP
	(d)		Density or mass per unit time is less so the (rate of) momentum change from the engines is reduced. There is less drag/resistive force on the airship.	B1 B1	
			TOTAL	14	

Question			Answer	Marks	Guidance
17	(a)		Use a thermometer (with ± 1 ^{o}C) Stir water bath / avoid parallax (for glass thermometer)	B1 B1	**Allow** 'temperature sensor/gauge' **Allow** 'avoid touching sides of water bath with thermometer' **Allow** 'take temperature in several places/times and average' **Allow** idea of 'leave thermometer for long time (to reach thermal equilibrium)' **Not** idea of 'use thermometer with finer resolution'
	(b)	(i)	Smaller (spacing between) divisions / increments (AW)	B1	**Ignore** any reference to accuracy or precision **Allow** 'less uncertainty' **Allow** better or smaller or greater or higher resolution
		(ii)	p = 37.0 × 4.448 / (1000 × 0.0254^{2}) 255 (kPa) uncertainty = 3 (kPa)	 B1 B1	**Allow** clearly identified correct answer in table or in working area. Must be 3sf Must be 1sf **Allow** 255.1 ± 3.4 scores mark 1
	(c)	(i)	Point plotted at (44, 255)	B1	ECF from **(b)(ii)** Plot to with ± half a small square **Ignore** checking error bars

		(ii)*	**Level 3 (5–6 marks)** Clear explanation, description **and** determination *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.* **Level 2 (3–4 marks)** Some explanation, description **and** determination Or Some explanation and clear determination *There is a line of reasoning presented with some structure. The information presented is in the most part relevant and supported by some evidence.* **Level 1 (1–2 marks)** Limited explanation or description or determination *The information is basic and communicated in an unstructured way. The information is supported by limited evidence and the relationship to the evidence may not be clear.* **0 marks** No response or no response worthy of credit.	**B1× 6**	**Indicative scientific points may include:** **Explanation and Description** • Absolute zero is the minimum possible temperature / at absolute zero KE is zero • At absolute zero *p* is zero • At absolute zero, the internal energy is minimum (allow 0) • Absolute zero should be (about) -273 °C • Reference to *p*V = *nRT* or *pV* = *NkT* or p ∝ T • A graph of *p* against θ is a straight line / straight line drawn on graph • Intercept of straight line with *x*- axis or θ-axis is absolute zero calculated by using y= mx + c **Determination** • Gradient in the range 0.7 to 0.9 (kPa K^{-1}) • *y* = *mx* + *c* used to determine the intercept *c* or absolute zero • Absolute zero in the range -320 °C to -240 °C Use only L1, L2 and L3 in RM Assessor.

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	(d)		Draw the worst fit line (through all the error bars) (AW). Determine the new value for absolute zero and find the <u>difference</u> between the value in **(c)(ii)** and this new intercept. (AW)	**B1** **B1**	
	(e)		Cooling gas value of absolute zero is lower than **(c)(ii)** (Whilst cooling, the) temperature of gas lags behind the temperature of water (AW, ORA) Graph is shifted to the left Stir water / <u>wait</u> for temperatures to be the same / attempt at measuring temperature of gas directly (AW)	**B1** **B1** **B1** **B1**	**Allow**: gradient is too shallow **Allow**: *p* measured is higher than expected for incorrect measurement of *T* (so affects the graph) (AW, ORA) **Not** insulation of water bath **Not** heat losses
			Total	**18**	

18	**(a)**	**(i)**	upthrust = weight (of drum or of water displaced)	B1	
		(ii)	Volume of water displaced = (m ÷ ρ) = 1200 ÷ 1000= 1.2 m^3 *d* = (volume ÷ area) = 1.2 m^3 ÷ 0.79 =1.5(2) (m)	C1 C1 A1	Accept approach: h × rho × g = weight / A (C1) h = weight / (A rho g) or substitution(C1) Accept approach: Density of drum = 1200/1.58 (C1) Ratio of densities gives fraction of drum underwater = 760/1000(C1) Depth of drum underwater = height of drum × ratio of densities = 1.5(2) (m) (A1)
		iii	Any two from: There is a distance between upthrust and the line of weight force or the centre of mass/ centre of weight/ centre of gravity Cause a net moment Equilibrium requires no resultant moment	 B1 B1 B1	 Allow diagram showing non-co-linear W down and U up / weight and upthrust are not at the same point Allow curved labelled arrow to show net moment Allow sum of moments must = zero Allow the force and weight form a couple for both marks

Question			Answer	Mark	Guidance
	(b)	(i)	(Additional upthrust = $xA\rho g$)=x × 0.79× 1000 × 9.81	M1	Accept candidate substituting in a number for x
			k = **additional upthrust** ÷ x =7800 or 7750	A1	Accept candidate's value for x and/or value for additional upthrust NOTE: Candidate's value for k is insufficient evidence for the A1 mark.
		(ii)	(Resultant) Force or acceleration is proportional to displacement	B1	
			The acceleration or force is in the opposite direction to the displacement	B1	Accept: the force is a restoring force Accept: directed to the centre of oscillation or to the equilibrium position
		(iii)	ω^2 = k/m = 7800 /1200	C1	ECF from (b)(i) for k
			($f = \frac{\omega}{2\pi}$ =) 0.41 Hz (0.406)	A1	Ignore use of ω = 8000 gives f >1 kHz Accept use of k = 8000 gives 0.411 Accept use of k = 7750 gives 0.404 Accept approach: acceleration divided by displacement gives omega squared C1

Question			Answer	Mark	Guidance
18	(c)		**Level 3 (5–6 marks)** A valid conclusion with sound and detailed reasoning. Clear description of data collection. Annotations with few or no omissions. *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.* **Level 2 (3–4 marks)** Some valid reasoning for the discussion with **one from:** • Clear description of data collection **or** annotations with few omissions • Some description **and** some annotations *There is a line of reasoning presented with some structure. The information presented is in the most part relevant and supported by some evidence.*	B1 x 6	**Indicative scientific points may include:** **Description of data collection** • Measure the frequency with appropriate equipment e.g. oscilloscope, stopwatch • Control amplitude of the waves • Discussion of suitable range of frequencies i.e. either side of the natural frequency • Measure the amplitude of the drum • Rule/marked depth gauge • Suitable method such as video analysis, position sensor and voltmeter for surface of water **Annotation of graphs** • f_0 / natural frequency labelled on x axis • Value of natural frequency labelled (check 18bii) • Amplitude on y axis • (Driving) frequency on x axis **Discussion** • Design B more heavily damped than design A • Energy being removed from the design B more effectively (as electrical output) • Damping is very heavy as peak has shifted “a lot” to the left • Design A has larger oscillations so more energy available

Question			Answer	Mark	Guidance
			Level 1 (1–2 marks) No conclusion or conclusion without valid reasoning with one of: • Some description **or** some annotation • Limited description **and** limited annotation *There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.* **0 marks** *No response or no response worthy of credit.*		• Conclusion consistent with candidate's discussion
			TOTAL	18	