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EDEXCEL A LEVEL PHYSICS: QUESTIONS BY TOPIC

Electric and Magnetic Fields (7)

A Level Physics Topic 7

57 questions · 368 marks · Mark schemes included

A Level only content · Pearson Edexcel 8PH0 / 9PH0 papers, 2016–2025

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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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7.1 ELECTRIC FIELDS, POTENTIAL AND COULOMB'S LAW		16 Qs · 75 marks	4
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2. Q7	A Level Paper 1 June 2019	1	6
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4. Q6	A Level Paper 1 October 2020	1	8
5. Q8	A Level Paper 1 November 2021	1	9
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QUESTIONS

57 questions · 368 marks · 4 sub-topics



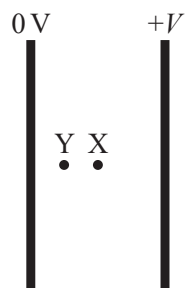
SUB-TOPIC 7.1

ELECTRIC FIELDS, POTENTIAL AND COULOMB'S LAW

Sub-topic 7.1 · 16 questions · 75 marks · lowest tariff first



- 7 A potential difference V is applied across two parallel plates. An electron midway between the two plates at point X experiences an electric force F .



The electron moves to point Y which is halfway between point X and the left-hand plate.

Which of the following is the electric force experienced by the electron at Y?

- ☐ A $2F$
- ☐ B F
- ☐ C $\frac{F}{2}$
- ☐ D $\frac{F}{4}$

(Total for Question 7 = 1 mark)



7 The force between two identical point charges, X and Y, is F .

Charge X is doubled; charge Y remains the same.

Which row of the table gives the force on each charge?

	X	Y
☐ A	F	F
☐ B	F	$2F$
☐ C	$2F$	F
☐ D	$2F$	$2F$

(Total for Question 7 = 1 mark)



3 The distance between a proton and an electron is r . The electrostatic force is F .

The distance between the proton and electron is doubled.

Which of the following is equal to the electrostatic force at this separation?

☐ A $2F$

☐ B $\frac{F}{2}$

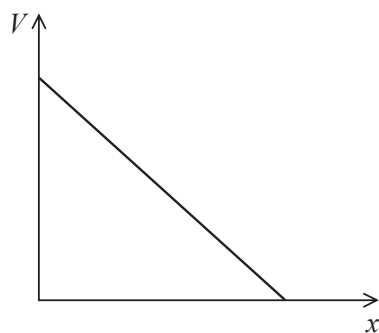
☐ C $\frac{F}{3}$

☐ D $\frac{F}{4}$

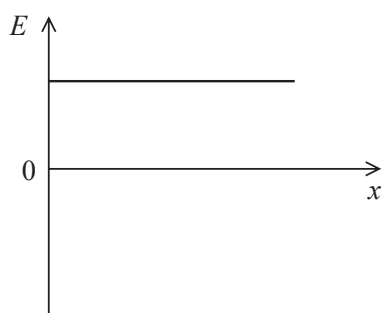
(Total for Question 3 = 1 mark)



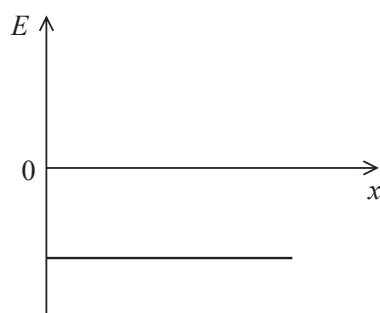
- 6 The graph shows how an electric potential V varies with distance x .



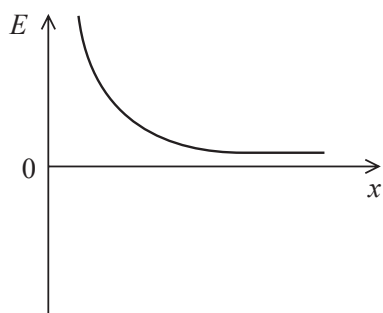
Which of the following shows the corresponding variation of electric field strength E with x ?



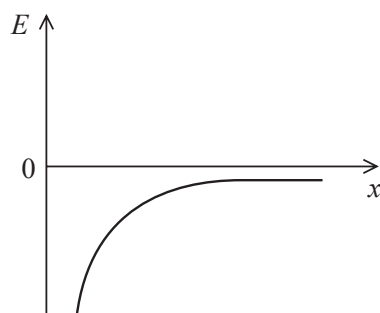
☐ A



☐ B



☐ C



☐ D

(Total for Question 6 = 1 mark)

- 8 A potential difference is applied across two parallel plates. A particle carrying a charge of $+0.1\text{ C}$ is placed between the plates and experiences a force F .

The distance between the plates is halved. The potential difference remains constant.

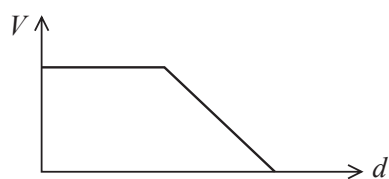
Which of the following is now equal to the electric field strength between the plates?

- ☐ A $5F$
- ☐ B $10F$
- ☐ C $20F$
- ☐ D $40F$

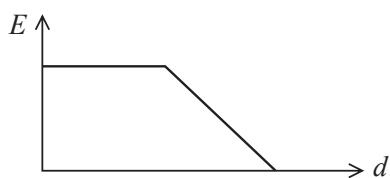
(Total for Question 8 = 1 mark)



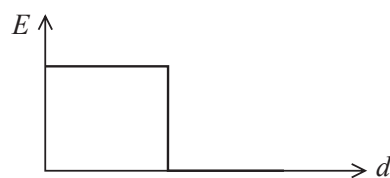
- 6 The graph shows how the potential V varies with distance d in an electric field.



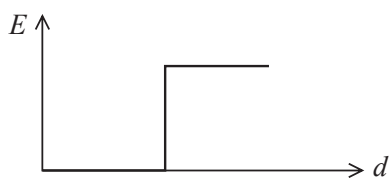
Which of the following shows the corresponding variation in electric field strength E ?



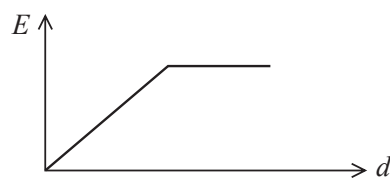
☐ A



☐ B



☐ C

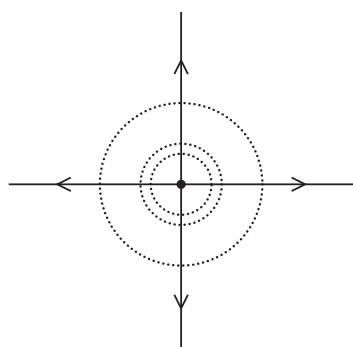


☐ D

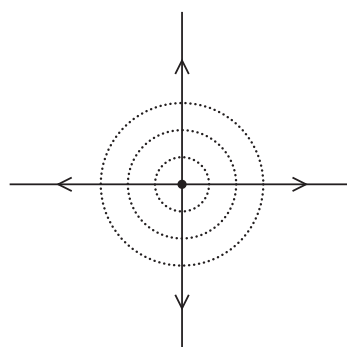
(Total for Question 6 = 1 mark)

8 A point object has a charge $+Q$.

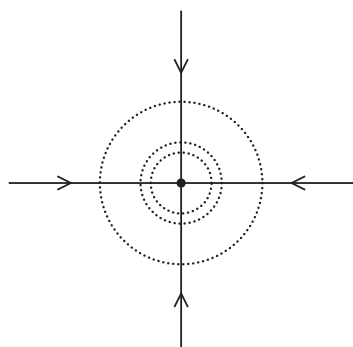
Which of the following diagrams shows equipotential lines differing by a constant potential difference, and electric field lines around the object?



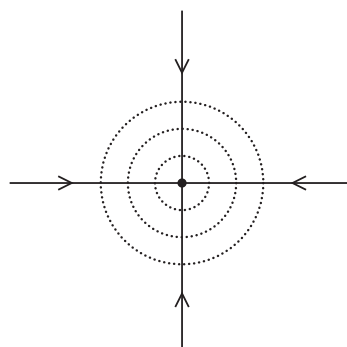
☐ A



☐ B



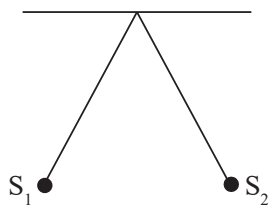
☐ C



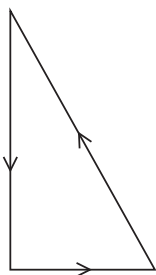
☐ D

(Total for Question 8 = 1 mark)

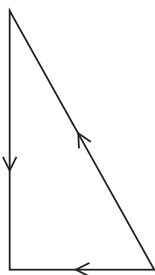
Questions 4 and 5 refer to two small positively charged spheres S_1 and S_2 suspended by threads, as shown.



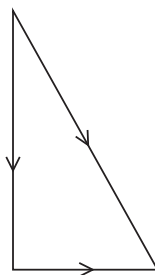
4 Which of the following vector diagrams shows the forces acting on S_2 ?



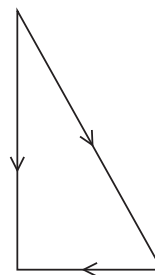
A



B



C

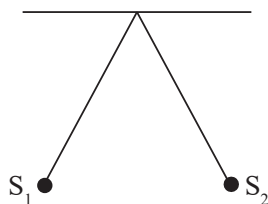


D

- ☐ A
- ☐ B
- ☐ C
- ☐ D

(Total for Question 4 = 1 mark)

Questions 4 and 5 refer to two small positively charged spheres S_1 and S_2 suspended by threads, as shown.



- 5 The electrostatic force between the two charges is initially F .

The charge on S_1 is doubled whilst the charge on S_2 is unchanged. The distance between S_1 and S_2 doubles.

Which of the following is the new force on S_2 ?

☐ A $\frac{F}{4}$

☐ B $\frac{F}{2}$

☐ C F

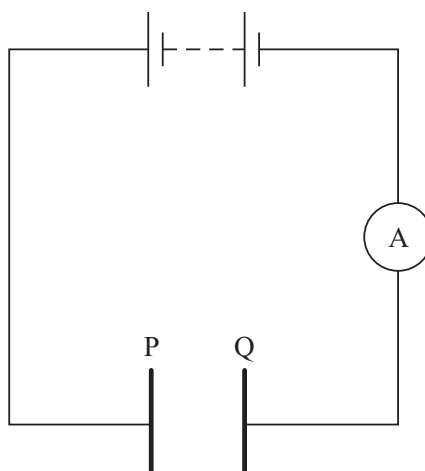
☐ D $2F$

(Total for Question 5 = 1 mark)



Questions 6 and 7 refer to the information below.

A high-voltage d.c. power supply was connected to two parallel metal plates and an ammeter, as shown.



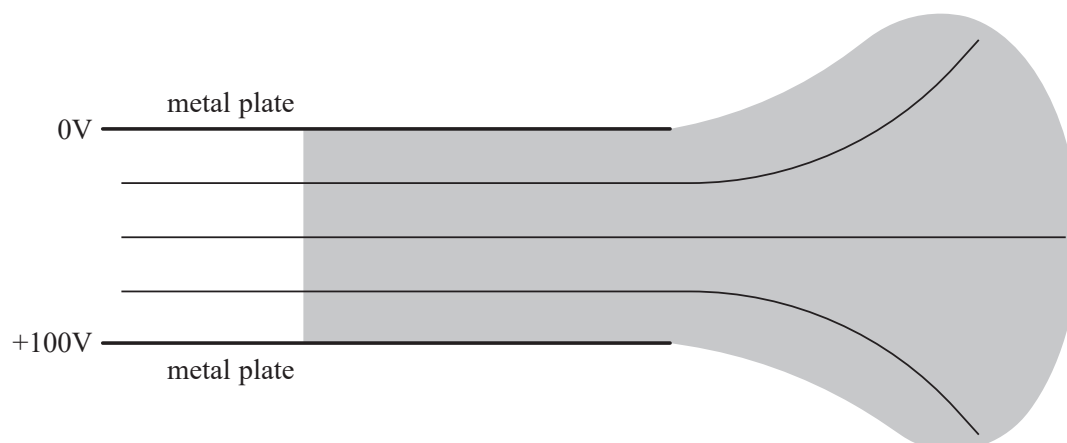
- 6 The distance between the two plates was decreased.

Which row of the table is correct?

	Direction of electric field	Change in electric field strength
☐ A	P to Q	decreased
☐ B	Q to P	decreased
☐ C	P to Q	increased
☐ D	Q to P	increased

(Total for Question 6 = 1 mark)

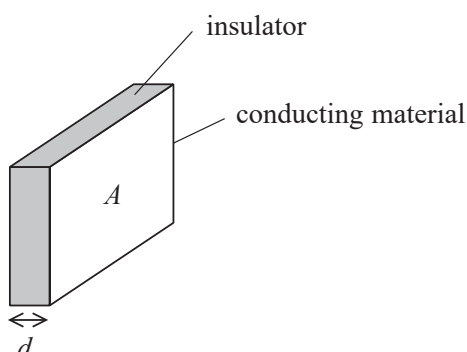
- 13** The diagram shows two parallel metal plates with a potential difference (p.d.) of 100 V across them. Three equipotential lines are shown.



- (a) Draw lines to represent the electric field in the shaded area.

(4)

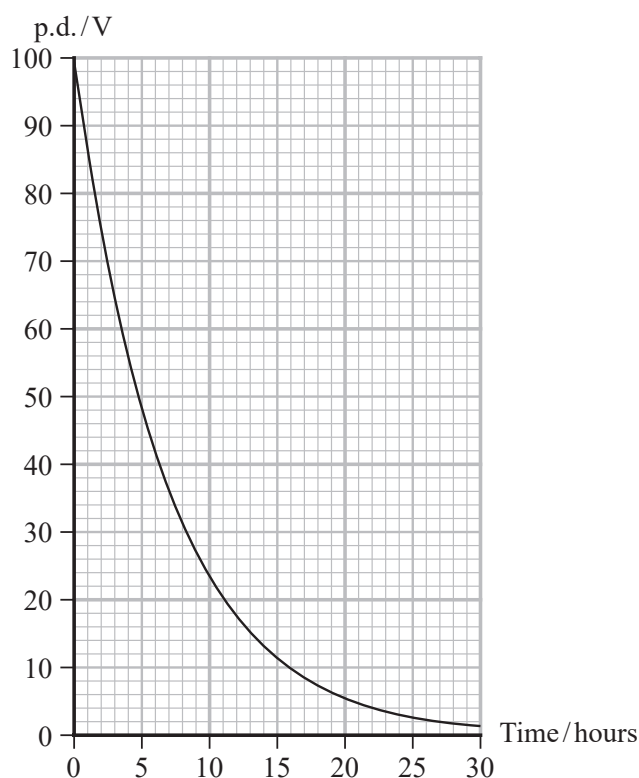
- (b) A parallel plate capacitor consists of a thin layer of insulator of thickness d between two plates of conducting material of area A .



The capacitor has a capacitance $0.1 \mu\text{F}$ and is charged to a p.d. of 100 V by connecting it to an electrical supply.

The capacitor is then disconnected from the supply and the p.d. between the two plates slowly decreases. This is because the insulator is not perfect and a small charge can flow through it.

The graph shows how the p.d. varies with time.



The insulator is a type of plastic and should have a resistivity greater than $10^{14} \Omega\text{m}$.

Deduce whether the plastic used in this capacitor has a resistivity greater than this value.

$$A = 5.6 \times 10^{-3} \text{ m}^2$$

$$d = 0.6 \times 10^{-6} \text{ m}$$

(5)

(Total for Question 13 = 9 marks)

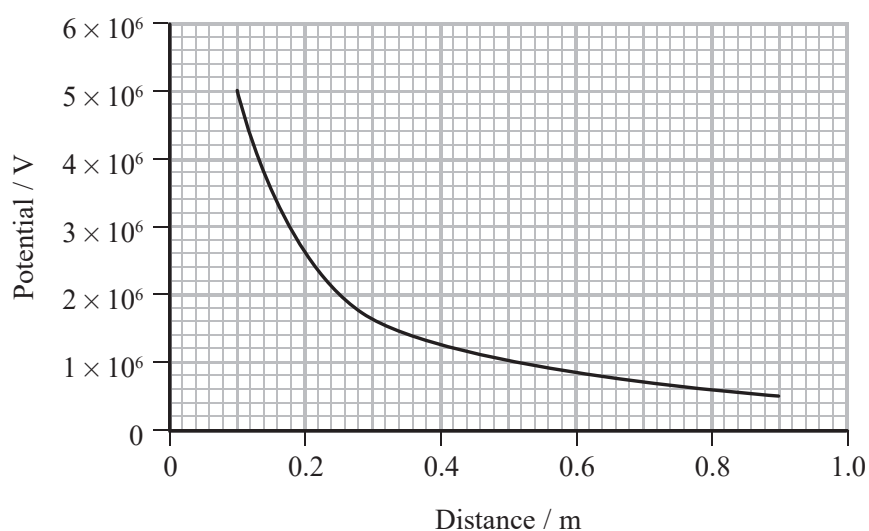


16 (a) Sketch the electric field around a positive point charge.

(3)



(b) The graph shows how potential varies with distance from the centre of a charged sphere.



Air molecules will be ionised if the electric field strength exceeds $3 \times 10^6 \text{ V m}^{-1}$.

Deduce whether air molecules will be ionised at a distance of 30 cm from the centre of this sphere.

(4)

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- (c) A magician did a trick which he claimed was the most dangerous ever. He positioned himself midway between two charged spheres which were separated by a distance of about two metres. Each sphere was charged to a potential that would cause ionisation at a distance of one metre. He wore a protective suit of chain mail and a helmet consisting of a metal cage. The protective suit and helmet were earthed to a potential of 0 V.



A scientist said “there is no danger in this and I would happily do it tomorrow”.

Explain whether this statement is justified.

(3)

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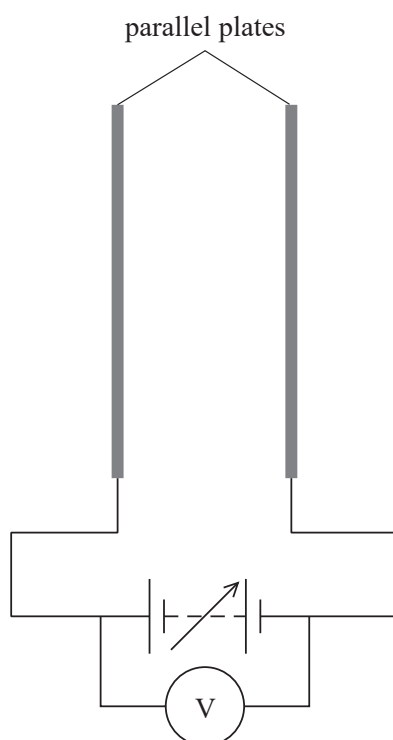
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(Total for Question 16 = 10 marks)

- 15** A teacher demonstrates the electric field produced between two parallel metal plates. The plates are connected to a variable power supply, as shown. The power supply has a very large internal resistance and includes a voltmeter that indicates its output.



- (a) (i) Add to the diagram to show the electric field between the two plates.

(3)

- (ii) Explain why the reading on the voltmeter indicates the e.m.f. of the power supply.

(2)

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(b) The power supply output is increased until sparks are heard and are seen in the gap between the plates. Sparks form in air when the electric field strength exceeds $3.0 \times 10^6 \text{ V m}^{-1}$ and the air becomes conducting for a short time.

- (i) Calculate the minimum potential difference across the plates for sparks to be created.

distance between parallel plates = 2.0 mm

(2)

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Minimum potential difference = ...

- (ii) Explain why the voltmeter reading decreases significantly whenever sparks are produced.

(3)

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(Total for Question 15 = 10 marks)



14 Flowers can attract bees by being colourful or by producing a scent. Some flowers also attract bees by producing an electric field.

(a) Draw the electric field around a negative point charge.

(2)



(b) When a bee gets close to a flower it can detect the electric field. The charge on the flower acts as a point charge at the centre of the flower.

(i) At a distance of 0.06 m from the centre of a particular flower the potential is -16 V .

Show that the charge on this flower is about -0.1 nC .

(3)

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- (ii) The minimum field strength that a bee can detect is 120 V m^{-1} .

A teacher suggests that bees can detect the field when they are closer than 10 cm from the flower in (b)(i).

Deduce whether this suggestion is correct.

(3)

- (c) It is suggested that the hairs on a bee deflect slightly when close to the flower.

Explain what would cause a hair to deflect in an electric field.

(2)

(Total for Question 14 = 10 marks)

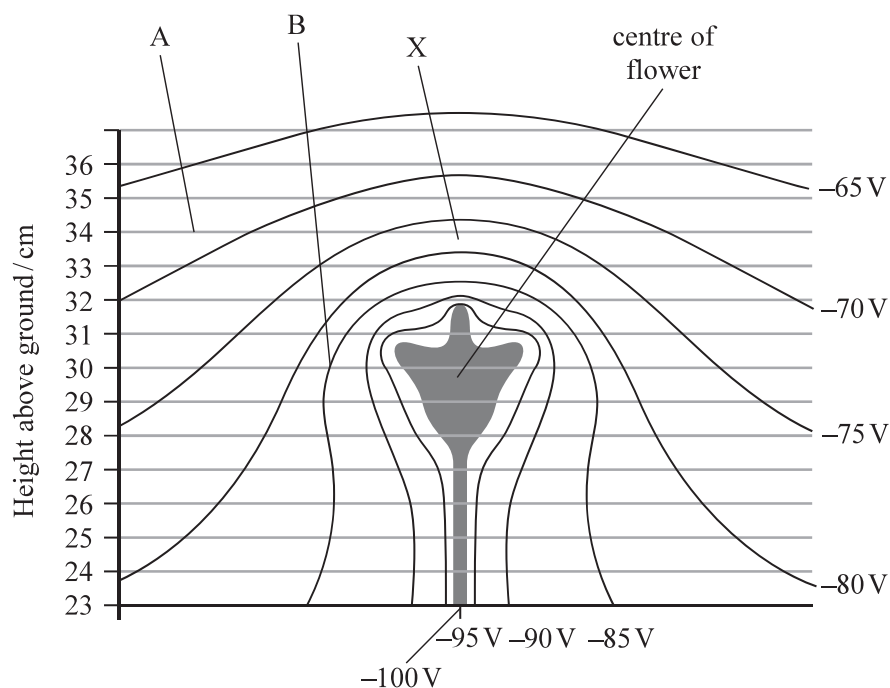


13 Some flowers are negatively charged and surrounded by an electric field. This helps to attract bees.

(a) State what is meant by an electric field.

(1)

(b) The diagram shows lines of equipotential surrounding a flower.



(i) Determine the electric field strength at X.

(3)

Electric field strength at X = ...

(ii) Draw the electric field line between point A and point B on the diagram.

(2)

(iii) An equation for electric potential V is

$$V = \frac{Q}{4\pi\epsilon_0 r}$$

This applies to a radial field.

Deduce whether the electric field in the region directly above the flower is radial. You should take values from the diagram. A graphical method is not required.

(3)

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(c) A bee has short hairs which are thought to carry charge.

State how the bee might use this to detect the electric field of a flower.

(1)

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(d) When the bee is collecting nectar from the plant, the electric field strength decreases. It is thought that this warns other bees that the nectar supply is low.

State the effect of a decreased electric field strength on the equipotential lines.

(1)

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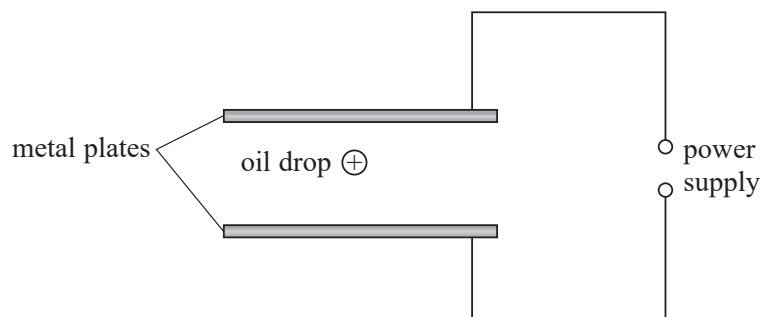
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(Total for Question 13 = 11 marks)



- 9 A student investigated the behaviour of small, positively charged oil drops in an electric field.

He introduced an oil drop between two horizontal metal plates. A potential difference V was applied to bring the oil drop to rest as shown.



- (a) (i) Add to the diagram to show the polarity of the power supply when the oil drop is at rest.

(1)

- (ii) The oil drop was at rest when $V = 4870 \text{ V}$.

The student expected the charge on the oil drop to be a whole number multiple of the charge on an electron.

Deduce whether this is confirmed by the experimental data.

distance between top plate and bottom plate = 1.55 cm

density of oil = 920 kg m^{-3}

radius of the oil drop = $1.78 \times 10^{-6} \text{ m}$

(6)

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- (b) The student determined the terminal velocity of the oil drop in order to obtain a value for the weight of the oil drop.

He disconnected the power supply and the oil drop fell downwards. He viewed the oil drop through a microscope.

- (i) Explain why the student should wait a short while before starting to take measurements.

(2)

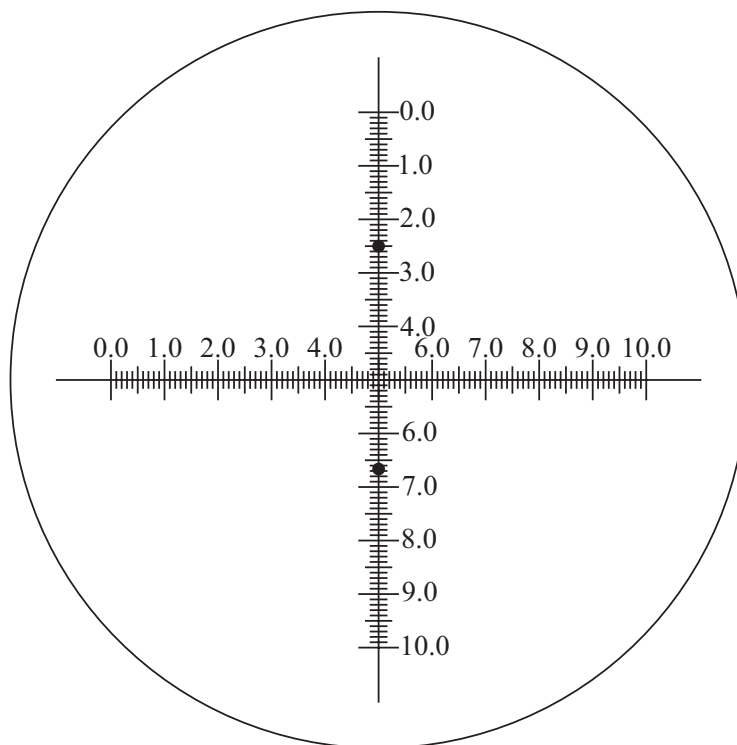
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(ii) The view through the microscope is shown below. The scale is in millimetres.



The position of the oil drop at the start and end of a 120 s time interval is indicated by the black dots.

Determine the terminal velocity of the oil drop.

(3)

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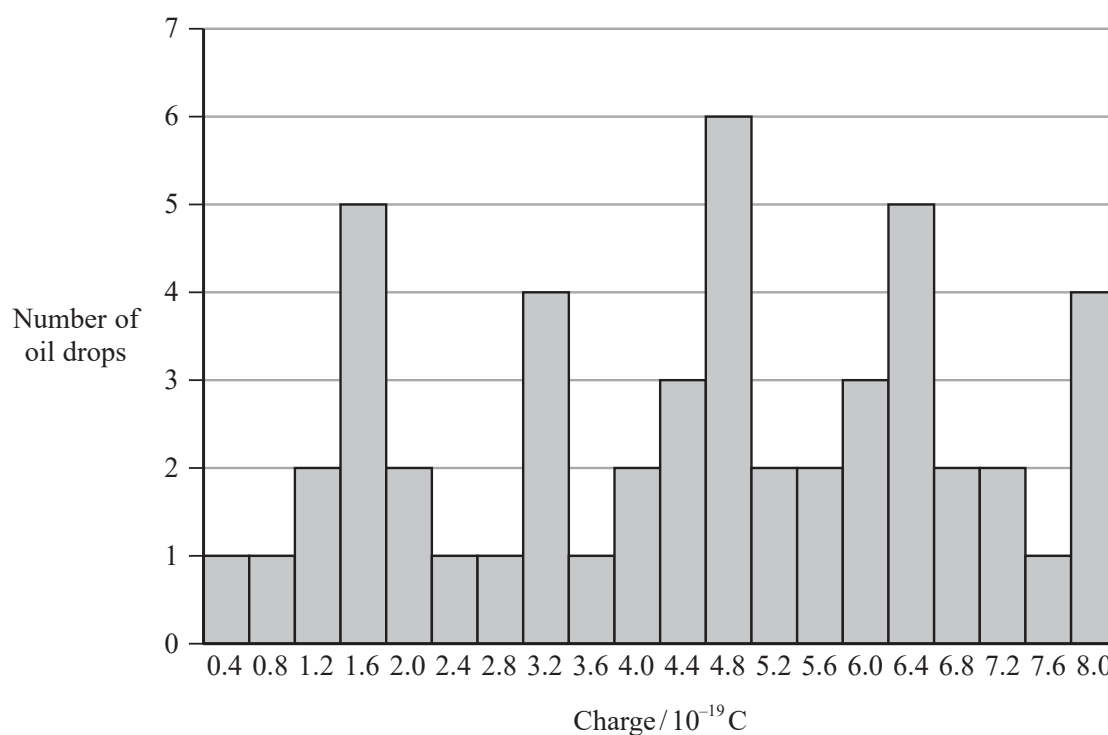
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Terminal velocity = ...

- (c) The student repeated the measurements on fifty oil drops. For each drop the student calculated the charge on the oil drop.

His results are shown in the bar chart.



The student predicted that the charge on each oil drop would be a whole number multiple of the charge on an electron.

Comment on the extent to which the bar chart supports the student's prediction.

(3)

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(Total for Question 9 = 15 marks)

SUB-TOPIC 7.2

CAPACITORS: ENERGY, CHARGING AND DISCHARGING

Sub-topic 7.2 · 9 questions · 34 marks · lowest tariff first



- 5 A capacitor of capacitance C is charged to a potential difference V by a power supply. The energy stored on the charged capacitor is W .

What would be the energy stored if the potential difference were $2V$?

- ☐ A $\frac{W}{4}$
- ☐ B $\frac{W}{2}$
- ☐ C $2W$
- ☐ D $4W$

(Total for Question 5 = 1 mark)



- 8 A capacitor of capacitance C is discharged through a resistor of resistance R . The initial discharge current is I_0 .

Which of the following expressions gives the current after a time equal to RC ?

☐ A $\frac{I_0}{e}$

☐ B $\frac{I_0}{2}$

☐ C $I_0 e^{-RC}$

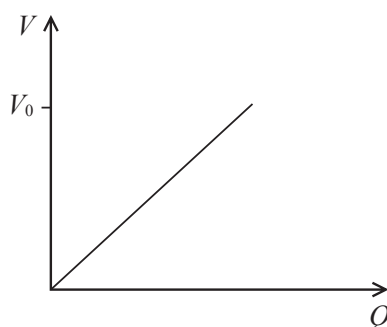
☐ D $I_0 \ln \frac{1}{e}$

(Total for Question 8 = 1 mark)



- 9 A capacitor is connected to a power supply and charged to a potential difference V_0 .

The graph shows how the potential difference V across the capacitor varies with the charge Q on the capacitor.



At a potential difference V_0 a small charge ΔQ is added to the capacitor. This results in a small increase in potential difference ΔV across the capacitor.

Which of the following gives the approximate increase in energy stored on the capacitor due to this extra charge?

- ☐ A $\Delta V \times \Delta Q$
- ☐ B $\frac{\Delta V \times \Delta Q}{2}$
- ☐ C $V_0 \times \Delta Q$
- ☐ D $\frac{V_0 \times \Delta Q}{2}$

(Total for Question 9 = 1 mark)

- 3 A charged capacitor is discharged through a resistor. The potential difference across the capacitor halved in a time t . The time constant is T .

Which of the following is the equation for t ?

☐ A $t = \frac{\ln 2}{T}$

☐ B $t = \ln \frac{1}{2T}$

☐ C $t = T \ln \frac{1}{2}$

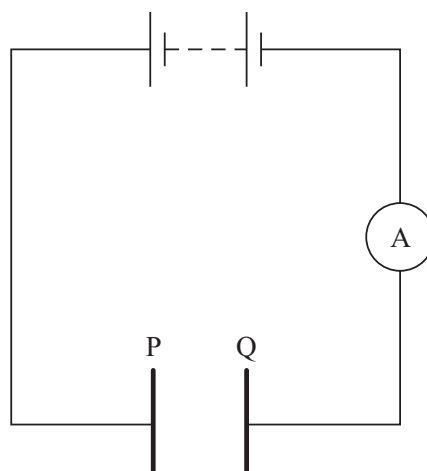
☐ D $t = T \ln 2$

(Total for Question 3 = 1 mark)



Questions 6 and 7 refer to the information below.

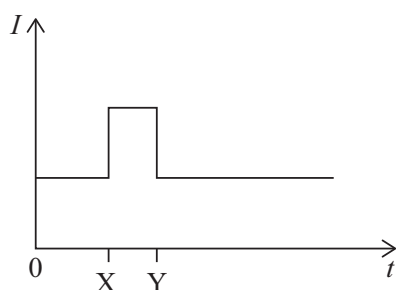
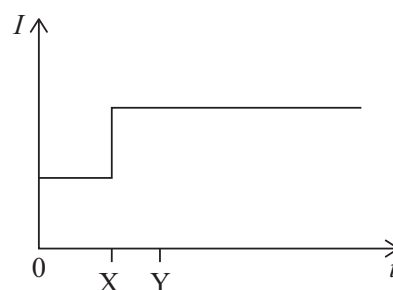
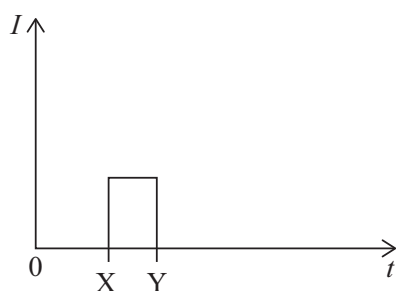
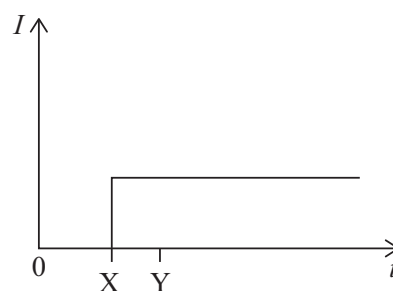
A high-voltage d.c. power supply was connected to two parallel metal plates and an ammeter, as shown.



- 7 Decreasing the distance between the two plates increases the capacitance of the two parallel plates.

The separation was decreased at time X. At time Y the separation became constant.

Which of the following graphs shows how the reading I on the ammeter changed with time t ?

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

- ☐ A
- ☐ B
- ☐ C
- ☐ D

(Total for Question 7 = 1 mark)

- 8 The initial potential difference (p.d.) across a capacitor is V_0 . The capacitor is discharged through a resistor. The p.d. across the capacitor decreases to $\frac{V_0}{3}$ in 2 milliseconds.

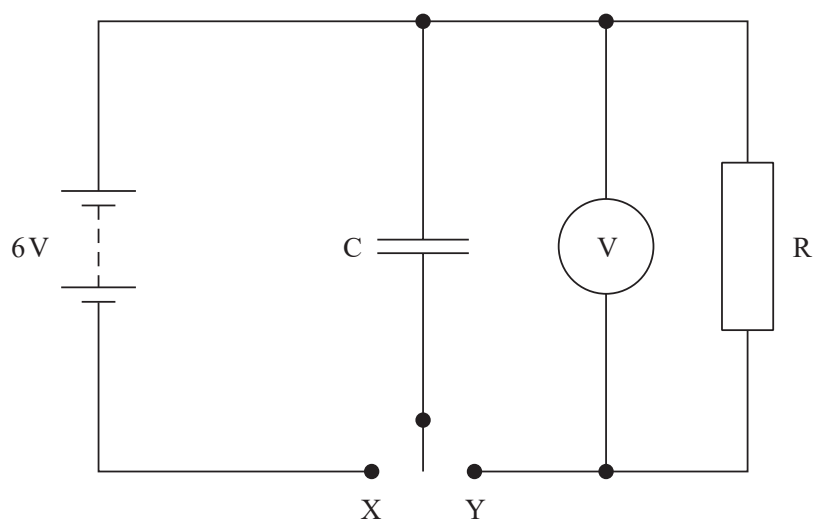
Which of the following is equal to the time constant, in milliseconds, for this capacitor-resistor circuit?

- ☐ A $\frac{\ln 3}{2}$
- ☐ B $\frac{2}{\ln 3}$
- ☐ C 3
- ☐ D $\frac{2}{3}$

(Total for Question 8 = 1 mark)



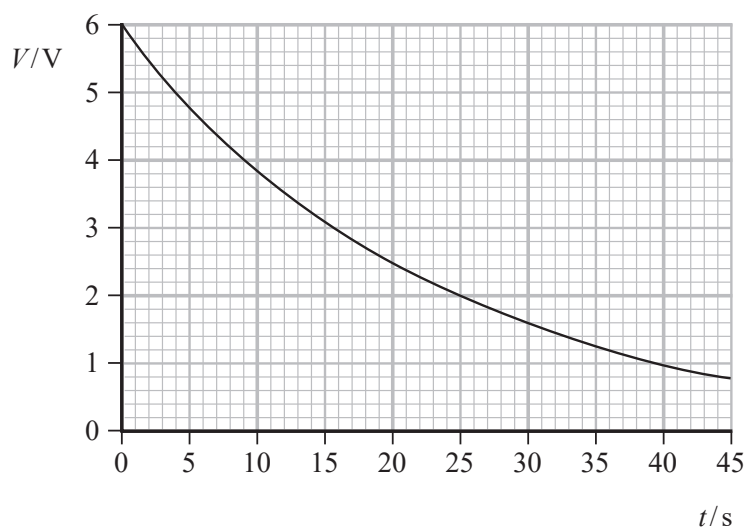
- 8 A student investigated the discharge of a capacitor C through a resistor R using the circuit shown.



The student used the switch to connect C to X to charge the capacitor. She then connected C to Y to discharge the capacitor through R .

As the capacitor discharged, she recorded values of the potential difference V across C and corresponding values of time t . She used a stopwatch to measure t .

The student used her results to plot the following graph.



- (a) The capacitor was marked $220\text{ }\mu\text{F} \pm 20\%$.

Deduce whether the student's data give a value of capacitance within the stated range.

$$R = 82\text{ k}\Omega$$

(5)

- (b) The student suggested that her results would have been more accurate if she had used a data logger to record the data.

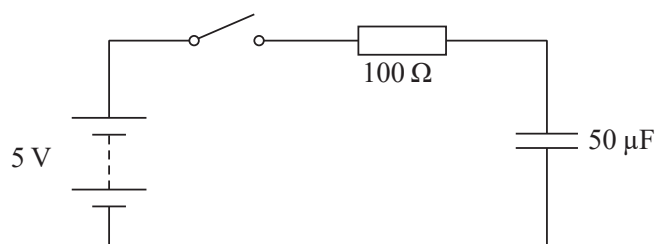
Assess the student's suggestion.

(3)

(Total for Question 8 = 8 marks)



- 15** A circuit consists of a battery of e.m.f. 5 V and negligible internal resistance, a switch, a $100\ \Omega$ resistor and an uncharged $50\ \mu\text{F}$ capacitor.



- (a) Describe what happens to the potential difference across the resistor and the potential difference across the capacitor after the switch is closed.

(4)

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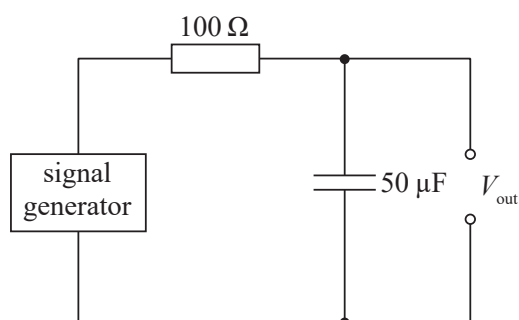
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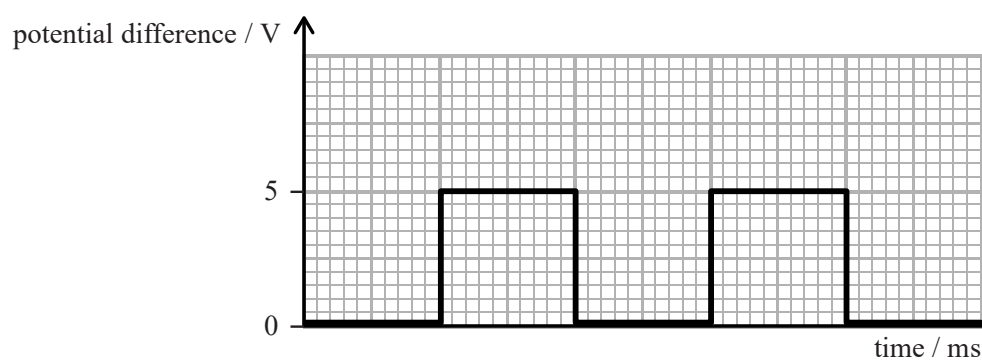
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- (b) The battery and switch are replaced by a signal generator providing a square wave output of peak potential difference 5 V. The signal generator has negligible internal resistance.



The graph shows the square wave output of the signal generator. The frequency of the square wave is 20 Hz.



On the graph add values to the time axis and sketch a graph of the potential difference, V_{out} , across the capacitor for two cycles of the square wave. Assume the capacitor is initially uncharged.

(5)

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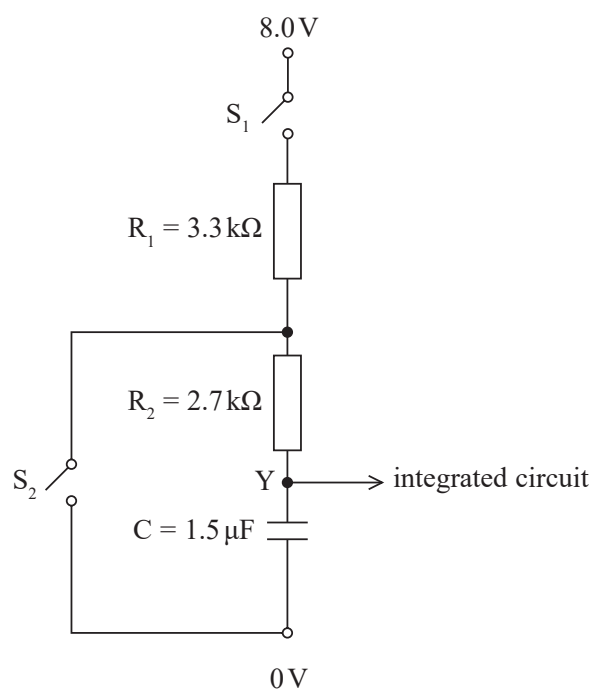
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(Total for Question 15 = 9 marks)

15 The properties of capacitors make them useful in timing circuits.

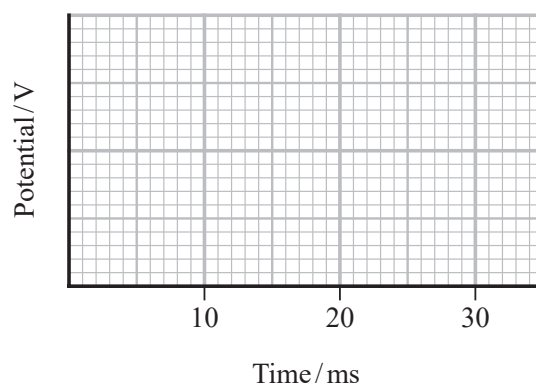
The following circuit is used to provide an input Y to an integrated circuit.



(a) Initially the capacitor is uncharged. The switch S_1 is closed.

Sketch a graph to show how the potential at point Y varies with time.

(3)



(b) When the potential at Y is 8.0 V, the switch S_2 is closed.

(i) Calculate the time taken for the potential at Y to decrease to 2.0 V.

(3)

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Time taken = ...

(ii) Calculate the energy stored on the capacitor when the potential at Y is 2.0 V.

(2)

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Energy stored = ...

(c) When the potential at Y is 2.0 V, the switch S_2 is opened.

Calculate the power dissipated by the resistance R_1 when the potential at Y is 2.0 V.

(3)

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Power dissipated = ...

(Total for Question 15 = 11 marks)



SUB-TOPIC 7.3

MAGNETIC FIELDS AND FORCES ON CURRENTS AND CHARGES

Sub-topic 7.3 · 16 questions · 139 marks · lowest tariff first



9 Electric and magnetic fields can be used in particle accelerators.

Which row in the table correctly describes the use of electric and magnetic fields in the particle accelerator indicated?

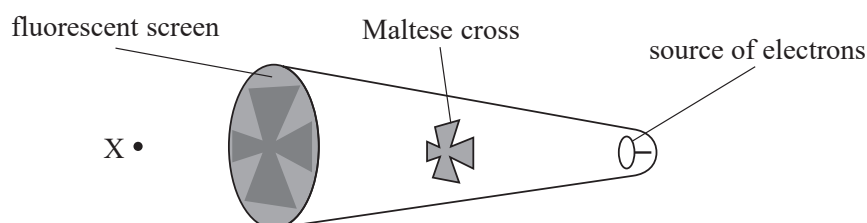
	Particle accelerator	Magnetic field	Electric field
☒ A	cyclotron	not used	used to accelerate particles
☒ B	cyclotron	used to accelerate particles	used to accelerate particles
☒ C	linac	used to accelerate particles	not used
☒ D	linac	used to accelerate particles	used to accelerate particles

(Total for Question 9 = 1 mark)

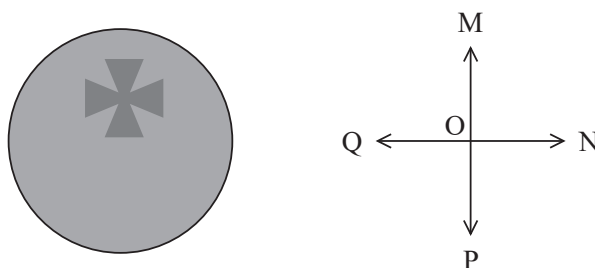
Questions 4 and 5 refer to the information below.

A demonstration is carried out using a beam of electrons in an evacuated tube.

When electrons hit a fluorescent screen, light is emitted. A piece of metal, in the shape of a Maltese cross, stops electrons and produces a shadow on the screen as shown.



- 5** The screen is viewed by an observer at point X in the diagram above. A magnetic field is directed at the beam of electrons. This causes the shadow to move upwards on the screen in the direction OM.

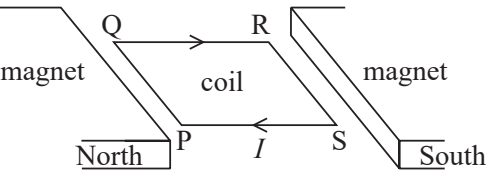


In which of the following directions is the magnetic field acting as seen by this observer?

- ☒ **A** OM
- ☒ **B** ON
- ☒ **C** OP
- ☒ **D** OQ

(Total for Question 5 = 1 mark)

6 A square coil has sides of length l and carries a current I , as shown. The plane of the coil is parallel to a magnetic field of flux density B .

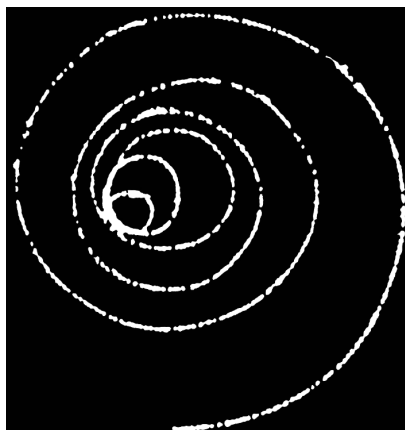


Which row of the table gives the magnetic force on the named side of the coil?

	Named side	Magnetic force
☐ A	PQ	BIl to the left
☐ B	QR	BIl to the right
☐ C	RS	BIl upwards
☐ D	SP	BIl downwards

(Total for Question 6 = 1 mark)

5 A positron produced a track in a detector, as shown.



(Source: © Science Source/SCIENCE PHOTO LIBRARY)

Which of the following is the direction of the magnetic field in this detector?

- ☐ A down the page
- ☐ B into the page
- ☐ C out of the page
- ☐ D up the page

(Total for Question 5 = 1 mark)

- 3 In the 19th century experiments with magnetic and electric field deflections were used to determine the charge to mass ratio of electrons.
Later experiments showed the diffraction of electrons as they passed through thin metal foils.
Deduce what these experiments tell us about electrons.

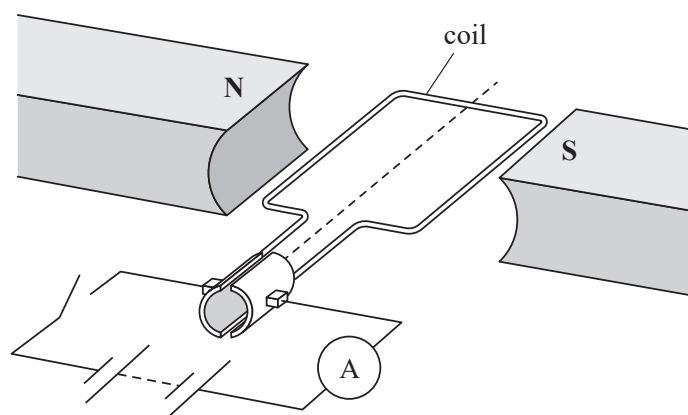
(3)

(Total for Question 3 = 3 marks)

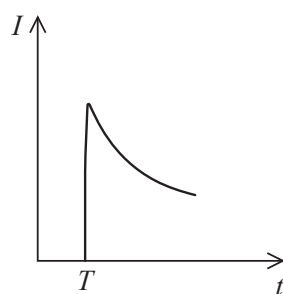


*12 A simple electric motor consists of a coil that is free to rotate in a magnetic field.

A student connects the motor to an ammeter and a battery.



The graph shows how the current I in the coil varies with time t . The switch is closed at time T .



Explain why the current rises to a maximum then decreases.
Your answer should include a reference to Faraday and Lenz's laws.

(6)

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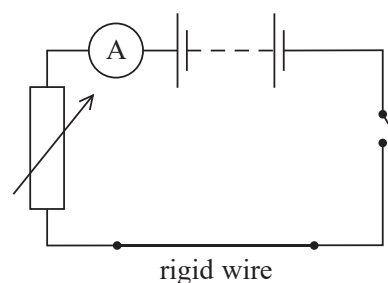
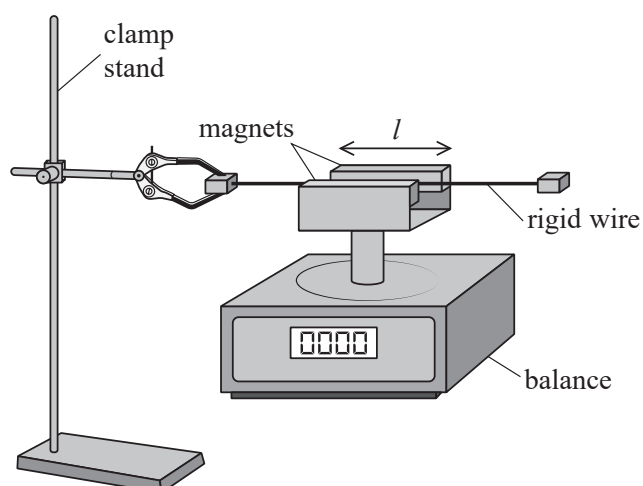
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(Total for Question 12 = 6 marks)



- 1 A student set up the apparatus shown. A length of rigid wire was held horizontally by a clamp in a uniform magnetic field of flux density B . The circuit connected to the rigid wire is also shown.



With the switch open, the balance was set to zero. When the switch was closed a current I in the circuit was recorded by the ammeter and the reading on the balance increased.

- (a) The length l of wire in the magnetic field was 15.5 cm. When the current in the circuit was 4.55 A, the reading on the balance increased by 5.65 g.

Calculate the magnetic flux density B in the region of the rigid wire.

(3)

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$B =$

(b) The student wrote the following statement

“The balance could read to the nearest 0.01 g, which makes my values for the magnetic force both accurate and precise.”

Comment on this statement.

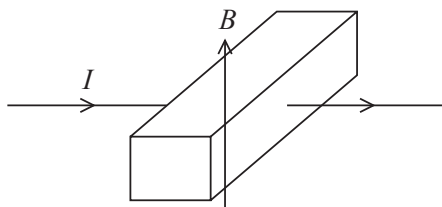
(3)

(Total for Question 1 = 6 marks)



- 14 Some liquids conduct electricity. This property can be used to pump these liquids through pipes.

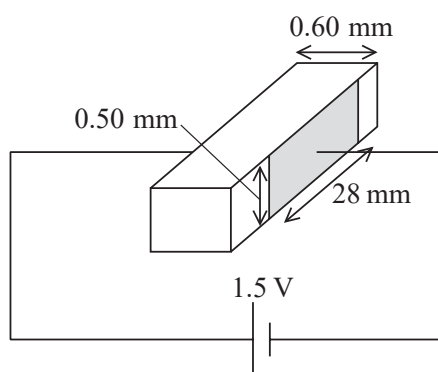
A short section of a rectangular pipe containing a liquid is shown in the diagram. The pipe is placed in a magnetic field of flux density B and a current I is passed through the liquid as shown.



- (a) Add an arrow to the diagram above to show the direction in which the liquid will move. (1)

- (b) A practical demonstration of this principle used two rectangular electrodes, opposite each other on either side of the pipe, a distance of 0.60 mm apart. The dimensions of the electrodes are shown in the diagram.

The electrodes were connected to a 1.5 V cell. Salt water was pumped using a magnetic field of magnetic flux density 0.40 T.



- (i) Show that the current through the salt water is about 20 mA.

resistivity of salt water = $1.6 \, \Omega \, \text{m}$

(4)

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(ii) Hence calculate the force on the salt water.

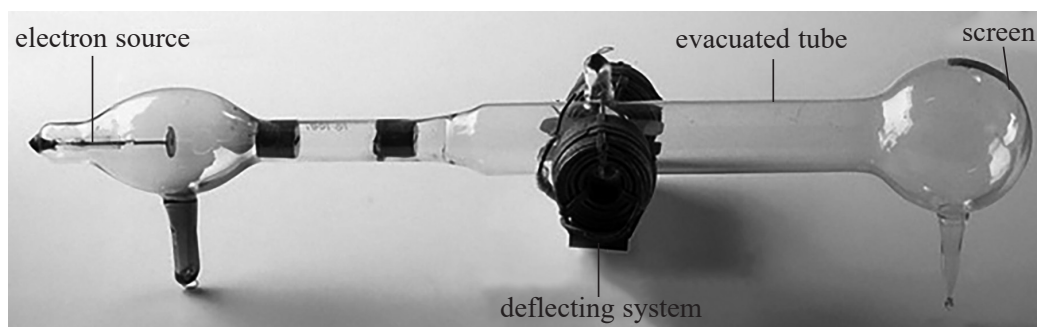
(2)

Force = ...

(Total for Question 14 = 7 marks)



- 7 At the end of the 19th century, J.J. Thompson used electric and magnetic fields to deflect beams of charged particles. A photograph of his apparatus is shown.



© Science Museum London

Electrons were accelerated through a potential difference to produce a beam of high-energy electrons. The beam was then deflected in perpendicular directions by the magnetic and electric fields. The final position of the beam on the screen was determined by the charge and mass of the electrons.

- (a) Explain how electrons from the source become a beam of high-energy electrons.

(2)

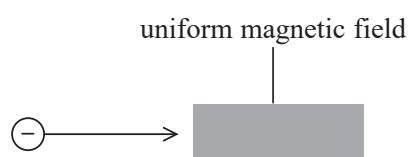
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- (b) An electron is travelling left to right and enters a region of uniform magnetic field as shown below. The direction of the magnetic field is perpendicular to the direction of travel of the electron.



- (i) The magnetic field deflects the electron in the direction up the page.

Explain the direction of the magnetic field that would produce this deflection.

(2)

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- (ii) Explain why the electron would travel in a circular path if no other forces acted on it.

(2)

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- (c) In a modern version of Thompson's experiment, a uniform electric field of electric field strength E is applied so that the electric and magnetic forces on the electrons are equal and in opposite directions.

- (i) Show that for electrons to be undeflected their velocity must be given by

$$v = \frac{E}{B}$$

where B is the magnetic flux density of the magnetic field.

(2)

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- (ii) The beam is produced by accelerating electrons through a potential difference of 250 V. The electric field strength is $1.4 \times 10^4 \text{ V m}^{-1}$. The magnetic flux density is $1.5 \times 10^{-3} \text{ T}$.

Calculate the value of the specific charge e/m for the electron using this data.

(3)

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$e/m =$



- (d) In his original experiments, Thompson determined the specific charge of a range of particles. His results indicated that the specific charge of an electron is about 2000 times bigger than that for a hydrogen ion.

Deduce what conclusion can be made from this information.

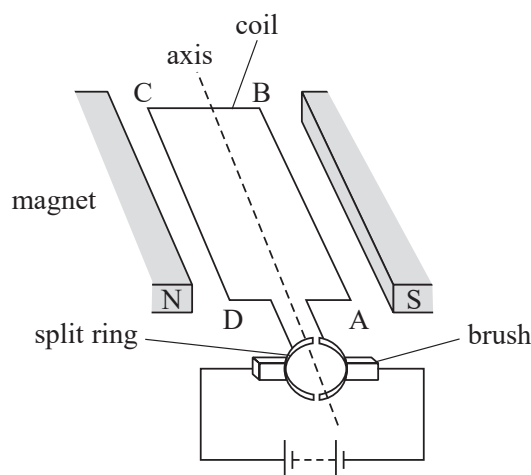
(1)

(Total for Question 7 = 12 marks)



- 16 Electric vehicles use a direct current (d.c.) electric motor powered by a battery for propulsion. A simplified diagram of a d.c. electric motor is shown.

A split ring consists of two semi-circular sections that are attached to a coil. The coil is labelled ABCD. Two brushes, made of carbon, rub against and make electrical contact with the split ring.



*(a) Describe how this arrangement can lead to the coil rotating.

(6)

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(b) An advert for an electric car has the following information:

- electric motor can develop up to 390 kW output power
- car achieves a velocity of 28 m s^{-1} from rest in 4.0 s at maximum power

Calculate the work done by resistive forces when the car accelerates to a velocity of 28 m s^{-1} from rest in 4.0 s.

mass of car = 1950 kg

(3)

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Work done by resistive forces = ...

(c) A website suggests that ‘fast-charging’ the battery in an electric vehicle can increase the internal resistance of the battery.

Explain why an increase in internal resistance of a battery is a disadvantage.

(3)

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(Total for Question 16 = 12 marks)



- 10** The Shanghai Maglev Train is the first commercially operated high-speed magnetic levitation train in the world, connecting the airport and central Shanghai.



- (a) The total distance travelled is 29.9 km and the total journey time is 440 s. The train starts from rest and reaches a speed of 97 m s^{-1} in 120 s.

- (i) Calculate the average acceleration of the train during the first 120 s.

(2)

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Average acceleration of train = ...

- (ii) Calculate the average speed of the train for the period following the 120 s acceleration.

(3)

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Average speed of train = ...

- (b) Electromagnetic forces enable the train to levitate above a steel rail.

Explain why magnetic levitation is an advantage for a high-speed transport system.

(2)

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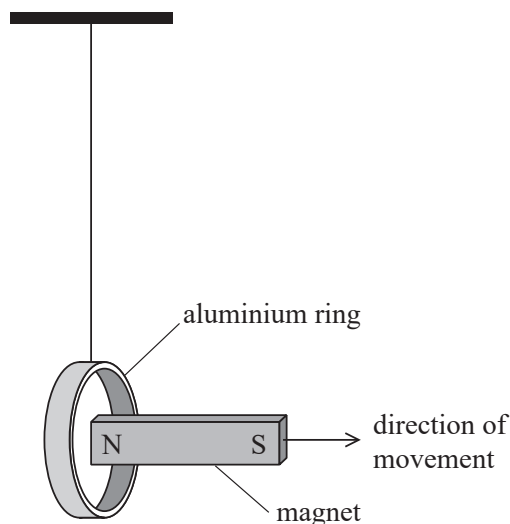
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- *(c) A linear induction motor provides the force to accelerate the train forwards. A current flows in sequence through coils of wire mounted in the track. The train is dragged along as the magnetic field progresses along the coils of wire in the track. This is similar to moving a permanent magnetic field away from a conductor.

A teacher demonstrates this effect by quickly removing one end of a bar magnet from a suspended aluminium ring.



When the magnet is removed from the ring, the ring moves in the same direction as the magnet.

Explain, using the laws of electromagnetic induction, why the ring moves in the direction of the magnet.

(6)

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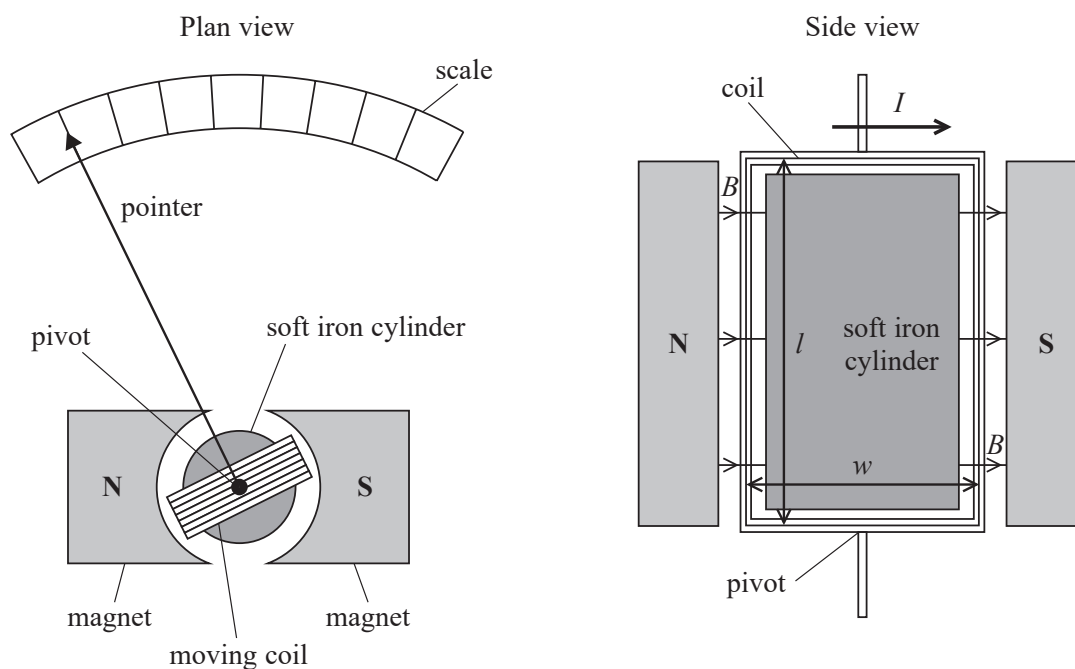
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(Total for Question 10 = 13 marks)

17 The diagrams show the plan view and side view of a moving coil ammeter.



The fixed soft iron cylinder and magnets produce a uniform magnetic field of magnetic flux density B . The coil is able to rotate within this magnetic field. The coil has width w and length l . There is a current I in the coil in the direction shown in the side view diagram.

(a) (i) Explain which way the coil will rotate.

(2)

- (ii) Show that the moment M on the coil about the pivot, due to the magnetic field, is given by

$$M = BAIN$$

where

A is the cross-sectional area of the coil

N is the number of turns of wire on the coil.

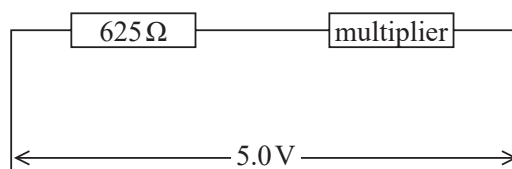
(4)



- (b) An ammeter of this type has a resistance of $625\ \Omega$ and will measure a maximum current of $1.6\ \text{mA}$.

The ammeter can be adapted to measure potential difference by adding a resistor in series with the ammeter. This resistor is known as a multiplier.

The ammeter is adapted so that it can measure potential differences up to $5.0\ \text{V}$ as shown.



The following multipliers are available:

$200\ \Omega$ $2500\ \Omega$ $3125\ \Omega$ $3750\ \Omega$

Deduce which multiplier should be used.

(3)

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- (c) The coil within a very sensitive moving coil ammeter can be damaged when the ammeter is transported. The two ends of the coil are connected together when the ammeter is transported. This reduces the movement of the coil and makes it less likely to be damaged.

A student suggests that this is due to Faraday's law and Lenz's law.

Explain how these laws apply to this situation.

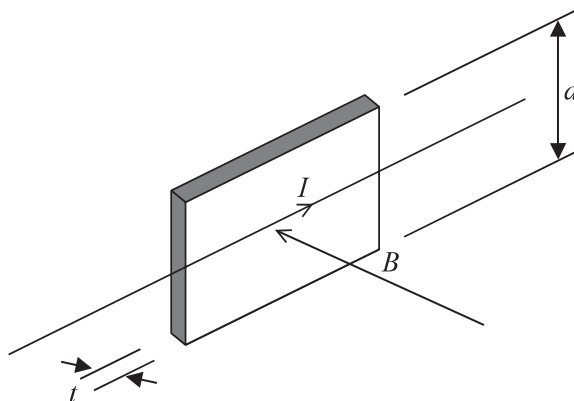
(4)

(Total for Question 17 = 13 marks)



- 17 Tiny sensors in smartphones could be used to determine the position of the phone on the Earth's surface by measuring the Earth's magnetic flux density.

A current I and a magnetic field of flux density B are applied to a slice of semiconductor as shown. The slice has thickness t and depth d .



Electrons collect at the top edge of the slice and the bottom edge becomes positively charged. As a result a potential difference known as a Hall voltage V_{HALL} develops.

- (a) Explain why electrons will collect at the top edge of the slice.

(2)

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- (e) The table gives the values of n and t for a number of material samples.

material	n/m^{-3}	t/m
copper	8.47×10^{28}	110×10^{-6}
germanium	2.25×10^{19}	1.10×10^{-6}
silicon	1.44×10^{16}	120×10^{-6}

Deduce which sample would result in the largest Hall voltage for a particular current and magnetic field.

(2)

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- (f) Two sensors in the smartphone were used to determine the horizontal component B_{H} and the vertical component B_{V} of the Earth's magnetic flux density.

Calculate the angle of the Earth's magnetic field to the horizontal.

$$B_{\text{H}} = 19.0 \mu\text{T}$$

$$B_{\text{V}} = 49.0 \mu\text{T}$$

(2)

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Angle = ...

(Total for Question 17 = 14 marks)



11 Particle accelerators produce beams of high speed charged particles which are used to investigate particle collisions. New particles are created during the collisions.

(a) In the Large Hadron Collider (LHC), protons are maintained in a circular path by the force exerted on the protons due to a magnetic field.

(i) The magnetic flux density required to maintain the protons in a circular path increases as the kinetic energy of the protons increases.

Explain why.

(2)

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(ii) Calculate the magnetic flux density required to maintain the protons in the LHC when the protons are travelling at a speed of $3.0 \times 10^7 \text{ m s}^{-1}$.

circumference of LHC = 27 km

(4)

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Magnetic flux density = ...

- (iii) A maximum of 13 600 GeV of energy is available to create a new particle.

Calculate the theoretical maximum mass, in kg, of the new particle.

(3)

Maximum mass = ... kg

- *(b) Fifty years ago, fixed-target collision experiments were carried out at the Stanford Linear Accelerator Centre (SLAC). In these experiments, high speed particles were made to collide with a stationary target.

Currently, colliding beam experiments are carried out at SLAC. In these experiments, high speed particles travelling in opposite directions are made to collide head-on.

For a given total energy in the collision, colliding beam experiments allow particles to be created with a larger mass than could be created in a fixed-target experiment.

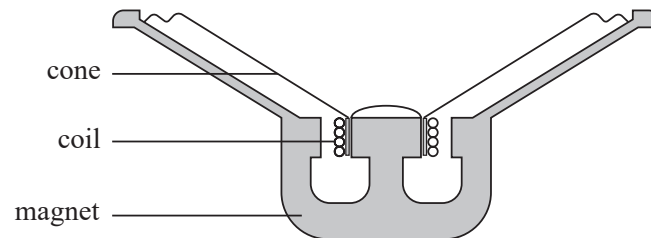
Explain why colliding beam experiments allow a new particle with the larger mass to be created. You should consider how the conservation of energy and the conservation of momentum apply to each type of collision.

(6)

(Total for Question 11 = 15 marks)



- 9 A simple loudspeaker consists of a cone, a coil of wire and a magnet. The cone and coil are attached to each other and are free to move. An alternating current in the coil causes the cone to oscillate. The loudspeaker is mounted in a wooden box. A cross-section through the loudspeaker is shown.



A student made the following observations:

- when an alternating potential difference (p.d.) is applied to the coil, the cone oscillates
- the frequency of oscillation is the same as the frequency of the p.d.
- at particular frequencies, the box vibrates with a large amplitude.

*(a) Explain these observations.

(6)

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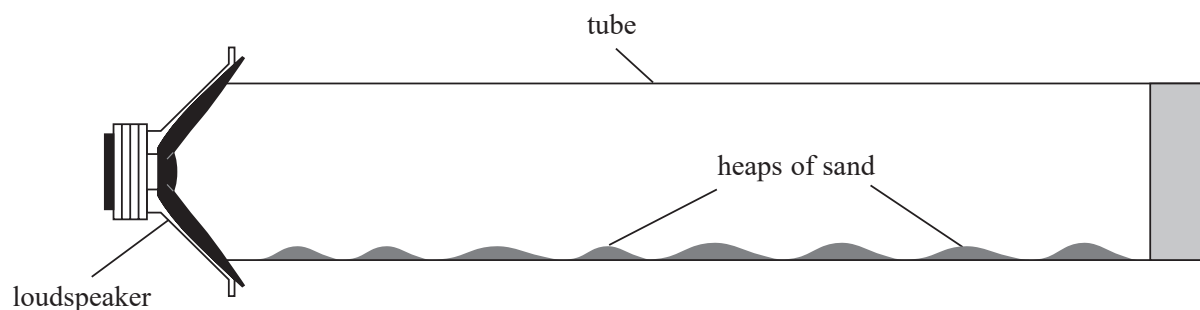
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- (b) The student connected a signal generator to the loudspeaker, and placed the loudspeaker near to one end of a long tube containing sand. The student adjusted the signal generator until the sand collected in small heaps as shown.



- (i) Explain why the sand collects in heaps.

(4)

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- (ii) The student determined the distance d between the centres of adjacent heaps.

Describe the procedure she should follow to determine an accurate value for d .

(3)

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- (iii) Assess whether the experimental data is consistent with a value for the speed of sound of 340 m s^{-1} .

signal generator frequency = 3.25 kHz .

$d = 5.1 \text{ cm}$

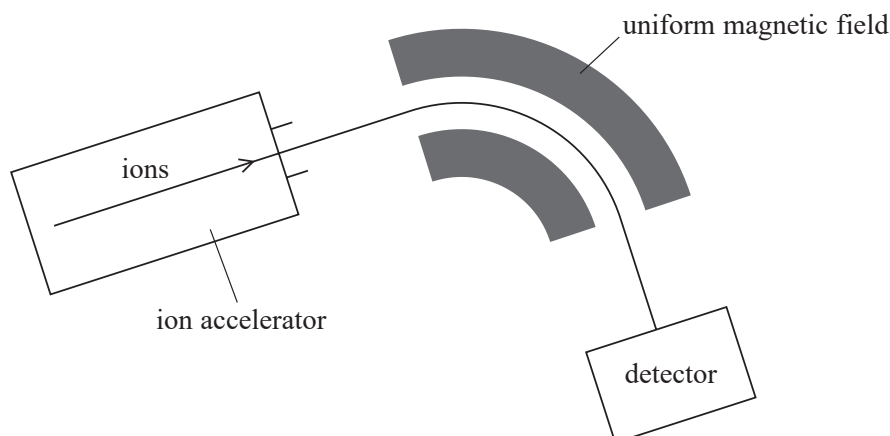
(3)

(Total for Question 9 = 16 marks)



13 Mass spectrometry is a technique used to separate ions based on their charge to mass ratio.

The atoms in a sample are ionised and then accelerated and formed into a fine beam. This beam is passed into a region of uniform magnetic field and the ions are deflected by different amounts according to their mass.



Analysis of mass spectrometer data shows that chlorine exists in nature as two isotopes, chlorine-35 and chlorine-37.

(a) State what is meant by isotopes.

(1)

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(b) In a mass spectrometer, chlorine-35 ions are accelerated through a potential difference of 8.50 kV to produce an ion beam.

Show that the speed of singly ionised chlorine-35 atoms is about $2.2 \times 10^5 \text{ m s}^{-1}$.

mass of an ion of chlorine-35 = 34.97 u

(4)

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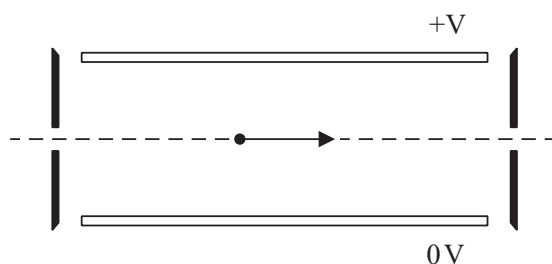
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- (c) In most mass spectrometers the ions are passed through a velocity selector, after being accelerated, to produce a beam of ions of a particular velocity. The velocity selector consists of a pair of parallel plates, across which a potential difference (p.d.) is applied to create an electric field.



In one mass spectrometer the plates are 2.5 cm apart and a p.d. of 135 V is applied.

A magnetic field is also applied to produce a force on the ions in the opposite direction to the force from the electric field. For one particular speed the ions travel in a straight line and emerge from the selector.

- (i) Add to the diagram to indicate the directions of the electric field and the magnetic field. (2)
- (ii) The magnetic flux density applied to the velocity selector is 24.5 mT.

Deduce whether this magnetic flux density is suitable to produce a beam of chlorine-35 ions of speed $2.2 \times 10^5 \text{ m s}^{-1}$.

(4)

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(d) After passing through the velocity selector the ion beam enters a region of uniform magnetic flux density 0.35 T with the ions travelling at right angles to the field direction.

(i) Explain why the ions travel in a circular path.

(2)

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(ii) Calculate the radius of the circular path.

(2)

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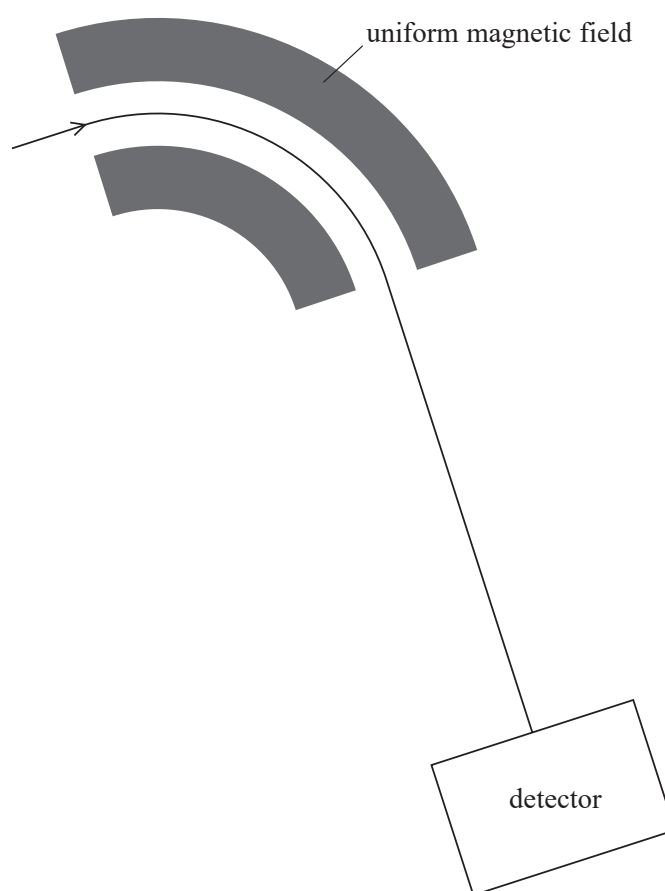
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Radius = ...



- (iii) The diagram shows the path of the chlorine-35 ions in the field. Chlorine-37 ions enter the magnetic field with the same velocity.



1. Add another line to the diagram to show the path of these chlorine-37 ions.

(1)

2. Explain any differences in the paths.

(2)

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(Total for Question 13 = 18 marks)

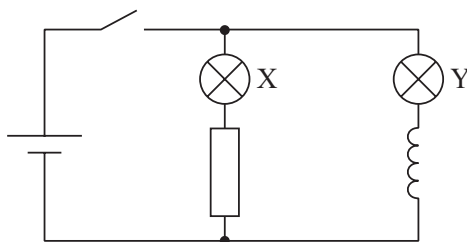
SUB-TOPIC 7.4

ELECTROMAGNETIC INDUCTION AND ALTERNATING CURRENT

Sub-topic 7.4 · 16 questions · 120 marks · lowest tariff first



- 7 A circuit is set up as shown in the diagram. Lamps X and Y are identical. The coil has a soft iron core. The resistor and the coil have the same resistance.



The switch is closed and lamp X lights instantly.

Which statement best describes lamp Y after the switch is closed?

- ☐ A Lights after a delay with a final brightness less than X
- ☐ B Lights after a delay with a final brightness the same as X
- ☐ C Lights instantly with less brightness than X
- ☐ D Lights instantly with the same brightness as X

(Total for Question 7 = 1 mark)

8 A wire carries an alternating current of peak value 3 A.

Which of the following is the root-mean-square value of this current?

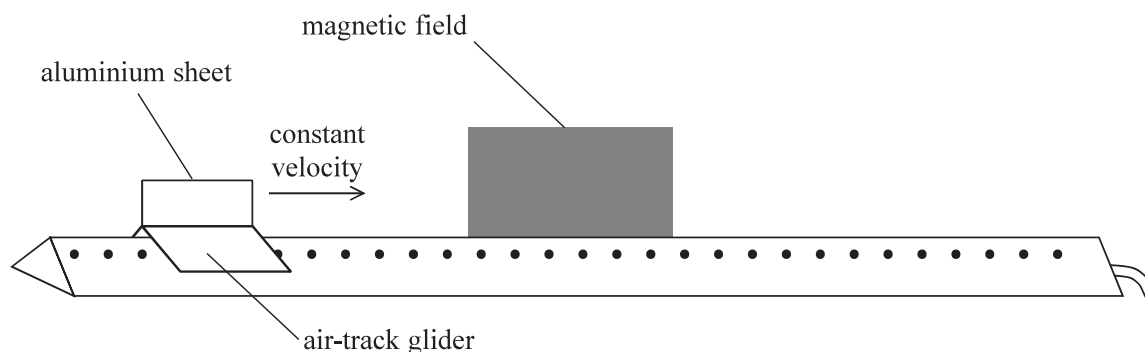
- ☐ A 1.5 A
- ☐ B 2.1 A
- ☐ C 4.2 A
- ☐ D 9.0 A

(Total for Question 8 = 1 mark)



- 9 A rectangular sheet of aluminium is attached to an air-track glider as shown.

The glider moves towards a region of uniform magnetic field at a constant velocity. When the glider enters the magnetic field, the magnetic flux is perpendicular to the aluminium sheet.

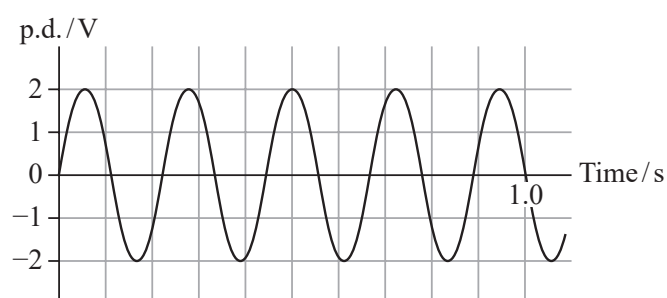


Which row of the table describes the velocity of the glider as it enters the magnetic field, when it is completely within the magnetic field and as it leaves the magnetic field?

	Enters the magnetic field	Within the magnetic field	Leaves the magnetic field
☐ A	constant	decreasing	constant
☐ B	decreasing	constant	increasing
☐ C	decreasing	constant	decreasing
☐ D	decreasing	decreasing	decreasing

(Total for Question 9 = 1 mark)

- 1 The graph shows how a potential difference (p.d.) varies with time.



Which of the following is correct?

- ☐ A The frequency is 4.5 Hz.
- ☐ B The peak value is 4.0 V.
- ☐ C The period is 0.20 s.
- ☐ D The root mean square value of p.d. is 1.0 V.

(Total for Question 1 = 1 mark)

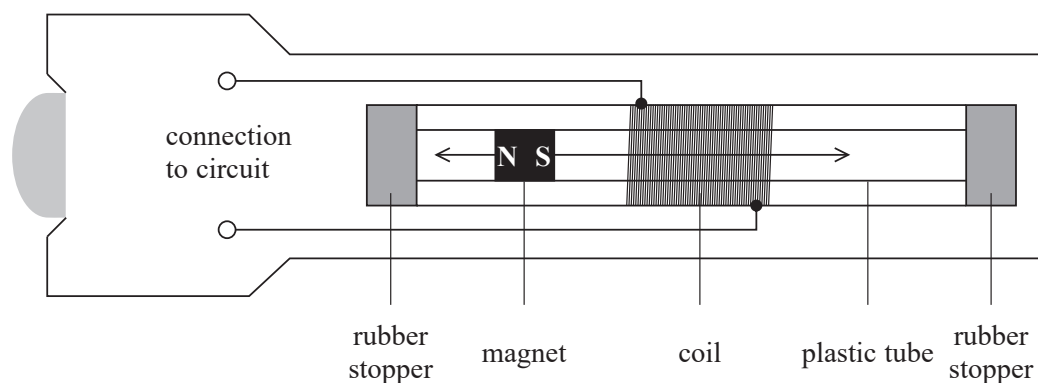
10 Which of the following is a unit of magnetic flux?

- ☐ **A** NC^{-1}
- ☐ **B** Tm^{-2}
- ☐ **C** Vs
- ☐ **D** Wbm^2

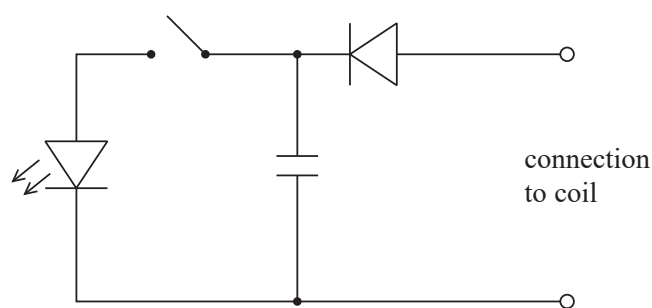
(Total for Question 10 = 1 mark)



- *5 The diagram shows a 'shaker torch'. When the torch is shaken, a strong magnet moves forwards and backwards through a copper coil, powering a light-emitting diode (LED).



Each time the magnet moves through the coil a current pulse is generated. The coil is connected to a capacitor via a diode, as shown.



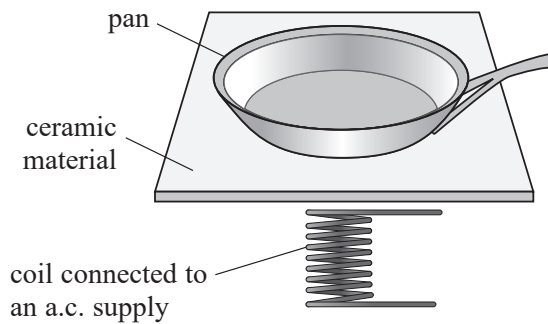
Once the torch has been shaken for a few minutes the switch is closed and the LED lights for a short while.

Explain how the shaker torch is able to light the LED.

(Total for Question 5 = 6 marks)



- 11 An induction hob consists of a coil beneath a sheet of ceramic material. The coil is connected to an alternating current (a.c.) supply as shown.



- (a) A steel pan containing water is placed on the induction hob.

Explain why the pan becomes hot when the supply is switched on.

(4)

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- (b) The a.c. supply to the coil in an induction hob has a much higher frequency than normal mains frequency.

Explain why this is an advantage in this case.

(2)

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(Total for Question 11 = 6 marks)

14 Power supplies provide either alternating or direct currents and potential differences.

(a) A power supply produces an alternating potential difference (p.d.). The p.d. has a period of 0.02 s and a peak value of 4.0 V.

(i) Calculate the frequency of the supply.

(1)

Frequency = ...

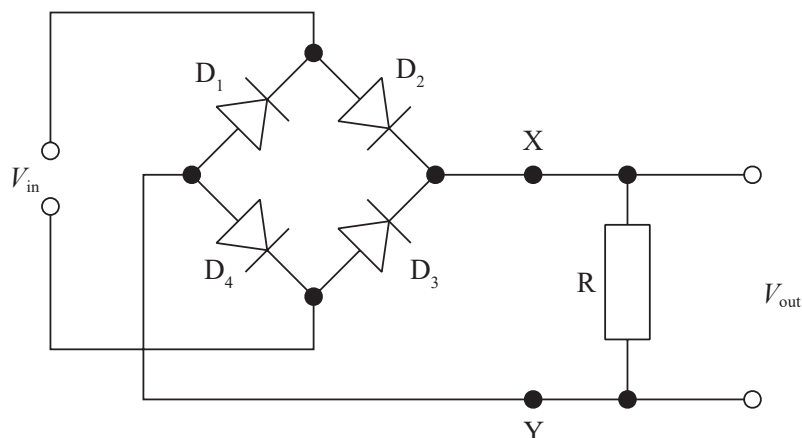
(ii) Calculate the root-mean-square p.d.

(1)

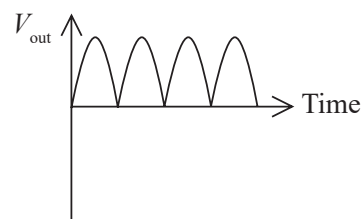
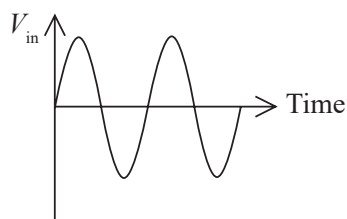
Root-mean-square p.d. = ...

(b) It is possible to convert alternating currents and p.d.s, to direct currents and p.d.s using diodes.

The power supply provides an input V_{in} to the circuit shown. The circuit includes four diodes D_1 , D_2 , D_3 and D_4 and a resistor R . The circuit produces an output potential difference V_{out} .



A graph of V_{in} against time and a corresponding graph of V_{out} against time are shown below.



- (i) Explain the operation of this circuit. Your answer should refer to D_1 , D_2 , D_3 and D_4 .

(3)

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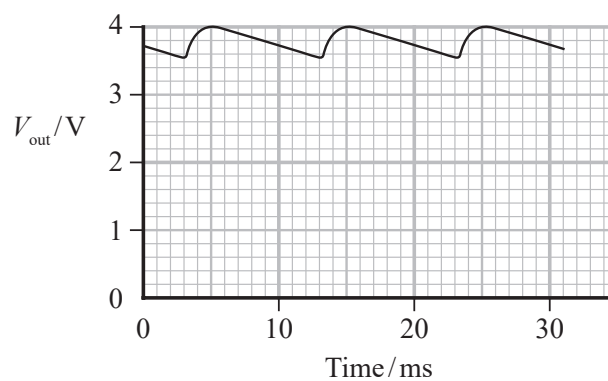
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- (ii) A capacitor is added between points X and Y in the circuit.

The new graph of V_{out} against time is shown below.



Determine a value for the capacitance of the capacitor.

resistance of $R = 2.2 \text{ k}\Omega$

(3)

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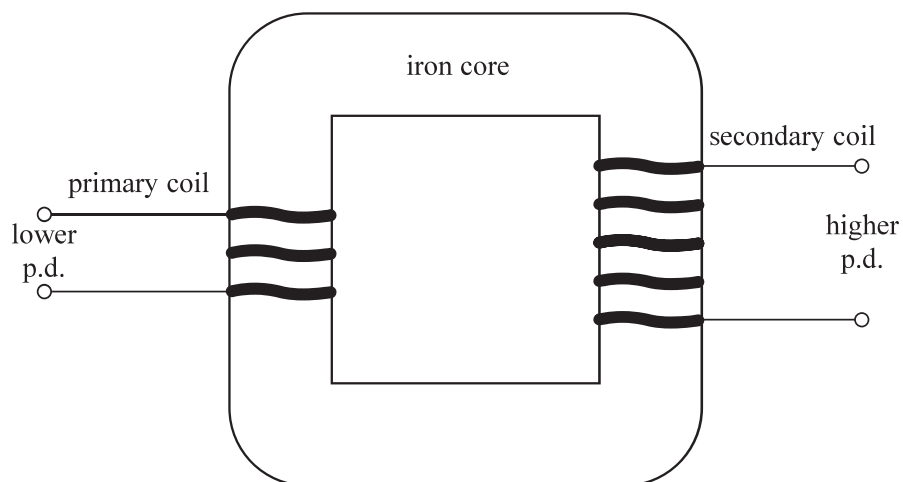
Capacitance = ...

(Total for Question 14 = 8 marks)



- 12** Electrical transmission systems are used to transmit electrical power from place to place. Transformers are used to change potential differences (p.d.) and power transmission cables are used to transmit power.

(a) The diagram shows a step-up transformer.



A step-up transformer is used to convert a lower p.d. to a higher p.d. An alternating p.d. is applied to the primary coil.

Explain how a higher p.d. is produced across the secondary coil.

(4)

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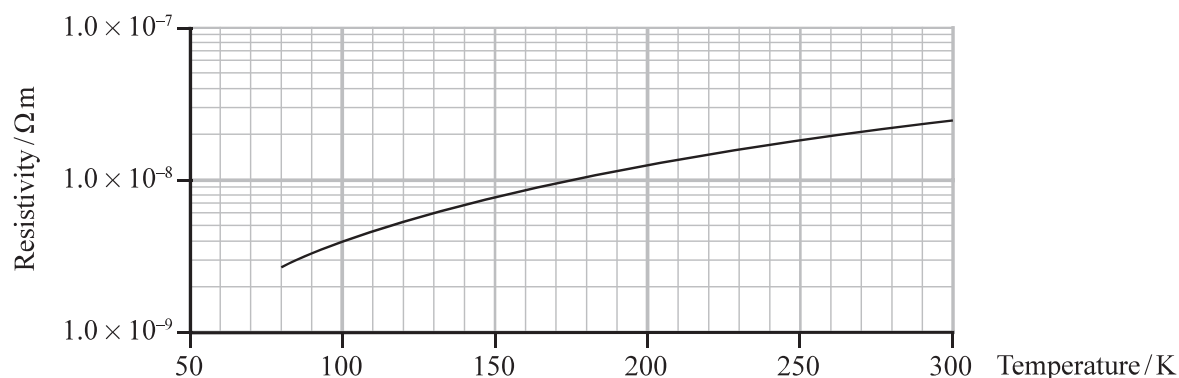
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- (b) Efficient electrical transmission systems are being developed using superconductors. Superconductors have zero resistance at low temperatures, and therefore no power is wasted by transfer to thermal energy unlike copper cable systems.

In one project a 1.05 km length of copper cable at a temperature of 270 K has been replaced by a superconductor. The superconductor has a cooling system which requires power.

The graph shows the variation of resistivity with temperature for copper.



Deduce whether the power requirement of the superconductor cooling system is less than the power losses in the copper cable.

transmission power = 40 MW

transmission potential difference = 110 kV

cross-sectional area of copper cable = 145 mm²

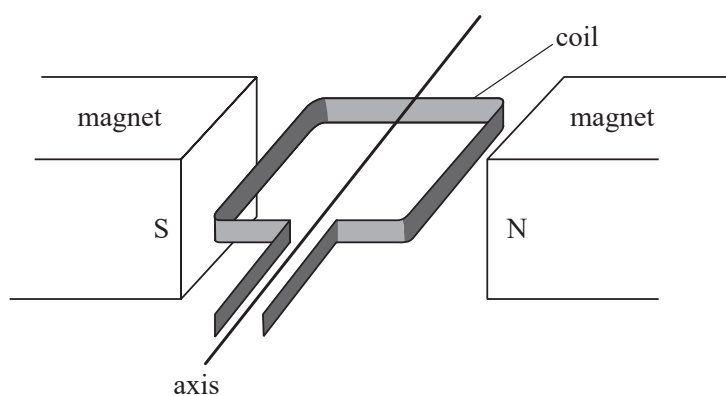
power requirement of cooling system for the superconductor = 7 kW

(5)

(Total for Question 12 = 9 marks)



- 17 Hybrid electric vehicles (HEV) use the same device both as a generator to charge the car battery and as an electric motor to support the propulsion system. A simplified diagram of the device is shown. The coil can rotate freely around the axis.



*(a) Describe how the device can be used as both a generator and an electric motor.

(6)

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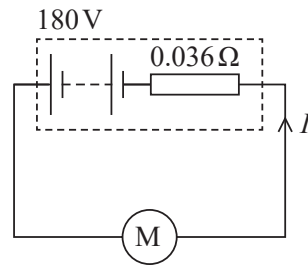
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- (b) The circuit diagram shows a car battery connected to an electric motor for a HEV. The battery has an electromotive force (e.m.f.) 180 V and internal resistance $0.036\ \Omega$.



The motor has a maximum power of 88 kW .

- (i) Show that the current I drawn by the electric motor when operating at this power would be given by the equation

$$0.036I^2 - 180I + 88\,000 = 0$$

(3)

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- (ii) Solving the equation above produces an answer of $I = 550\text{ A}$. At maximum power, the car can accelerate from rest to sixty miles per hour in under 7 s .

The maximum charge capacity of the battery within this HEV is 6.1 amp-hour .

Deduce whether the battery could maintain this current for up to 7 s .

(2)

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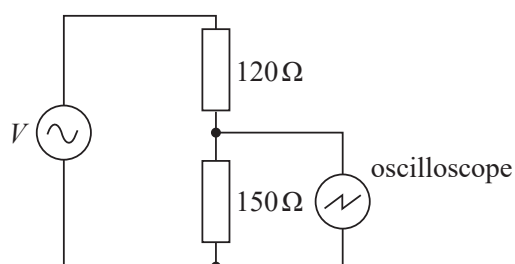
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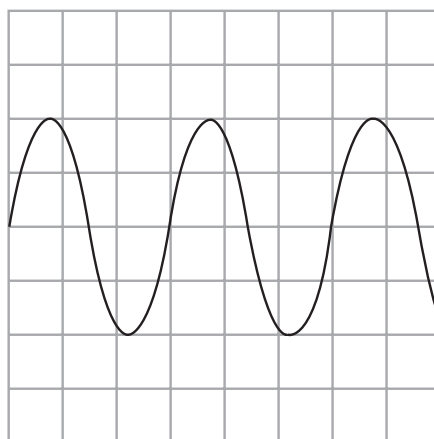
(Total for Question 17 = 11 marks)

- 7 A student connected the output from a source of alternating potential difference (p.d.) to a series resistor combination.

She connected an oscilloscope across the 150Ω resistor as shown.



- (a) The trace obtained on the oscilloscope is shown below.



- (i) Determine the peak p.d. across the 150Ω resistor.

y-sensitivity of oscilloscope = 2.0 V per division

(2)

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Peak p.d. across 150Ω resistor = ...

(ii) Calculate the root mean square (r.m.s.) value of the current in the circuit.

(3)

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r.m.s. value of current = ...

(iii) Calculate the power dissipated in the circuit.

(3)

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Power dissipated in circuit = ...

(b) Another student suggested that a voltmeter would be more accurate than using an oscilloscope to determine the magnitude of the p.d.

Comment on this suggestion.

(3)

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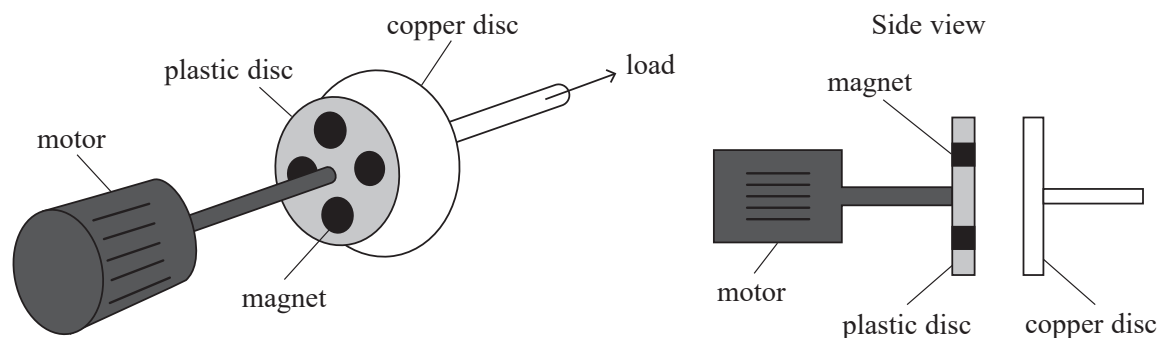
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(Total for Question 7 = 11 marks)



- 16** A device called a clutch can be used to connect a motor to a load. The diagram shows a design called an eddy current clutch.



Several magnets are embedded in the plastic disc and it is rotated by the motor.

- (a) (i) Explain why a current is induced in the copper disc when the motor is switched on.

(2)

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- (ii) Explain, using Lenz's law, why the copper disc rotates.

(3)

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- (b) The motor rotates at 500 revolutions per minute.

Calculate the angular speed ω of the motor.

(2)

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$\omega =$

- (c) The table shows how the turning effect exerted on a load varies with ω for a particular distance between the copper disc and the plastic disc.

$\omega / \text{rad s}^{-1}$	Turning effect / N cm
52.4	1.0
104.7	2.0
157.1	2.8

Explain the trend shown by the data.

(4)

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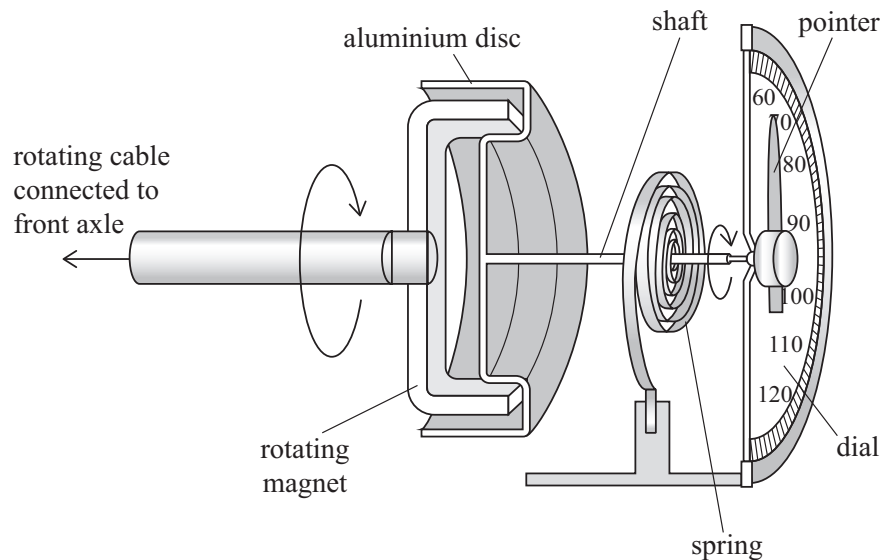
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(Total for Question 16 = 11 marks)



- 17 The diagram shows a section through the components of a speedometer for a bicycle. The front wheel axle of the bicycle is connected to a cable. The cable rotates as the bicycle wheel rotates. The other end of the cable is connected to a magnet which also rotates, as shown.



An aluminium disc is shaped so that it is close to, but not touching, the magnet. The disc is connected to a pointer by a shaft. A spring prevents the disc and shaft from freely rotating.

- *(a) Explain why the aluminium disc rotates in the same direction as the magnet.

(6)

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- 10** The potential difference (p.d.) from a power pack alternates at a frequency of 50 Hz. The root-mean-square (r.m.s.) value of the output p.d. is measured to be 8.5 V using an a.c. voltmeter.

The output from the power pack is connected to a resistor of resistance $1.5\ \Omega$.

- (a) Show that the rate of power dissipation in the resistor is about 48 W.

(2)

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- (b) A lab technician used the resistor to heat $1.25 \times 10^{-4}\text{ m}^3$ of milk in a beaker.

Calculate the time taken for the milk to increase in temperature by 12°C .

specific heat capacity of milk = $3930\text{ J kg}^{-1}\text{ K}^{-1}$

density of milk = 1050 kg m^{-3}

(4)

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Time = ...



- (c) The lab technician used an oscilloscope to determine the supply frequency and check the r.m.s. output p.d. displayed by the voltmeter.

Describe the methods the technician should use.

(6)

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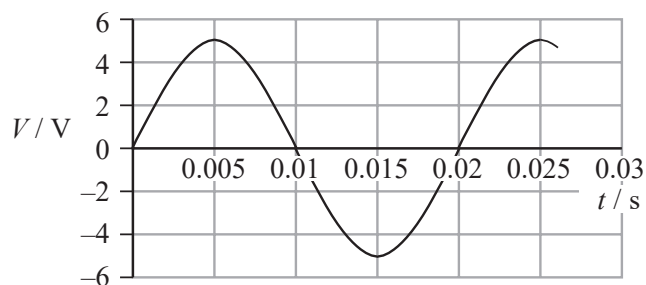
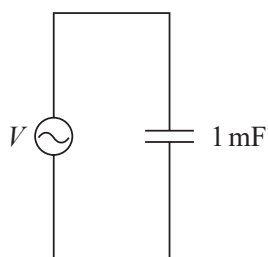
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(Total for Question 10 = 12 marks)



- 18** The circuit shows a 1 mF capacitor connected to an a.c. supply. The graph shows how the potential difference V varies with time t .



- (a) (i) Calculate the root-mean-square potential difference.

(1)

Root-mean-square potential difference = ...

- (ii) The formula used to generate this graph is $V = 5 \sin(100\pi t)$

Explain why this formula leads to the graph above.

(3)

- (b) A spreadsheet is used to model how the current I in the 1 mF capacitor varies with t . Six rows of the spreadsheet are shown below.

	A	B	C	D	E	F	G
	t / s	$\Delta t / \text{s}$	V / V	$Q_{\text{initial}} / \text{C}$	$Q_{\text{final}} / \text{C}$	$\Delta Q / \text{C}$	I / A
7	0.0050	0.0010	5.00	0.00476	0.00500	0.00024	0.24
8	0.0060	0.0010	4.76	0.00500	0.00476	-0.00024	-0.24
9	0.0070	0.0010	4.05	0.00476	0.00405	-0.00071	-0.71
10	0.0080	0.0010	2.94	0.00405	0.00294	-0.00111	-1.11
11	0.0090	0.0010	1.55	0.00294	0.00155	-0.00139	-1.39
12	0.0100	0.0010	0	0.00155	0.00000	-0.00155	-1.55

- (i) Explain how cell E10 has been calculated.

(2)

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- (ii) State the formula used to calculate cell G11.

(1)

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- (iii) Calculate the maximum energy stored on the capacitor.

(2)

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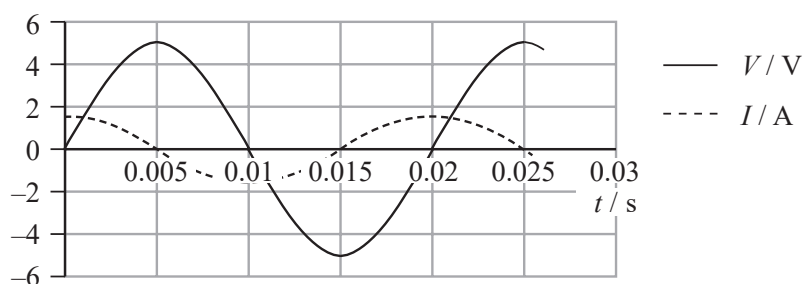
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Maximum energy stored on the capacitor = ...



- (c) The spreadsheet data are used to plot a graph to show how I varies with t . This is shown as a dashed line below.



The corresponding graph of V against t is also shown as a continuous line.

Deduce whether the capacitor dissipates power over one cycle of the a.c. supply.

(4)

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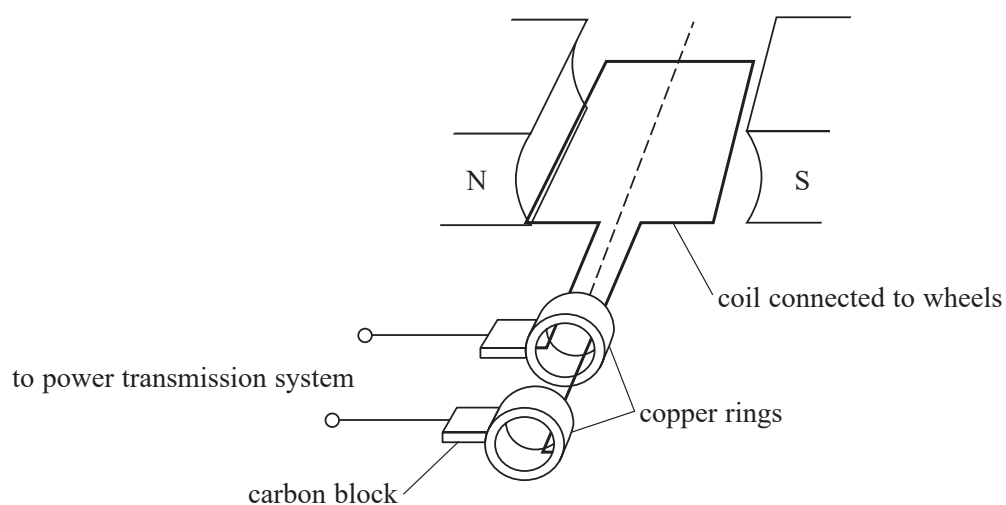
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(Total for Question 18 = 13 marks)

- 18** Regenerative braking supplies a current back to the power transmission system whilst slowing a vehicle. The arrangement shown can be used as a regenerative braking system on a train.



The coil rotates with the wheels of the train. Two copper rings are connected to the ends of the coil. The rings rotate with the coil and two carbon blocks make electrical contact with the rings as they rotate.

- (a) Describe how this arrangement can be used as a regenerative brake.

(4)

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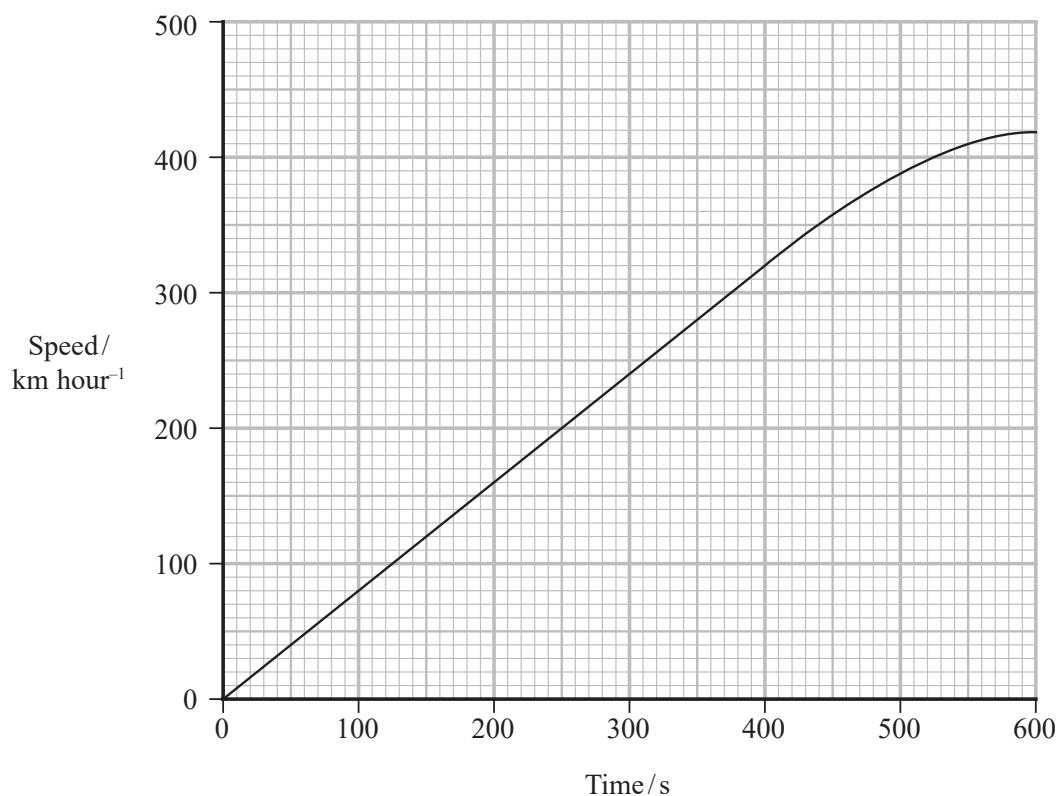
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- (b) A specification for a new train states that the train should be able to accelerate to a speed of 360 km hour^{-1} from rest, and that this acceleration should be completed within 40 km of level track.

The graph shows the performance of the train on a test run.



- (i) Calculate the acceleration of the train as it accelerates to a speed of 360 km hour^{-1} .

(3)

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Acceleration of train = ...



- (ii) Deduce whether the performance of the train met the specification on this test run.

(3)

- (c) On curved tracks there is a maximum safe speed for the train.

- (i) Explain why there is a maximum safe speed for a train travelling on a curved track.

(4)

- (ii) When the train travels at 200 km hour^{-1} , the minimum safe radius of curvature of the track is 1800 m.

Calculate the minimum safe radius of curvature for a speed of 360 km hour^{-1} .

(2)

Minimum safe radius of curvature = ...

(Total for Question 18 = 16 marks)



MARK SCHEMES

official mark schemes



7	The only correct answer is B <i>A is not correct because this is a uniform field so F constant</i> <i>C is not correct because this is a uniform field so F constant</i> <i>D is not correct because this is a uniform field so F constant</i>	F	1
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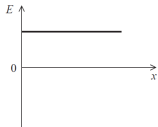


Question Number	Acceptable answers	Additional guidance	Mark
7	D		1



Question Number	Acceptable answers	Additional guidance	Mark
3	The only correct answer is D $\frac{F}{4}$	A,B and C do not show an inverse square	1



Question Number	Acceptable answers	Additional guidance	Mark
6	The only correct answer is A 	B,C and D are not the negative potential gradient	1



8	The only correct answer is C A is not correct as $E_{\text{initial}} = F/Q = 10F$, if d halved then $E_{\text{after}} = 20F$ B is not correct as $E_{\text{initial}} = F/Q = 10F$, if d halved then $E_{\text{after}} = 20F$ D is not correct as $E_{\text{initial}} = F/Q = 10F$, if d halved then $E_{\text{after}} = 20F$		1
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Question Number	Acceptable answers	Additional guidance	Mark
6	The only correct answer is C <i>A is not correct because the E is equal to $-\text{gradient of the graph of } V$ against r</i> <i>B is not correct because the E is equal to $-\text{gradient of the graph of } V$ against r</i> <i>D is not correct because the E is equal to $-\text{gradient of the graph of } V$ against r</i>		1



8	The only correct answer is A <i>B is not correct because field direction is correct but equipotential lines will become further apart as distance increases as $V \propto 1/r$</i> <i>C is not correct because field direction is incorrect</i> <i>D is not correct because field direction is incorrect</i>		1
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Question Number	Acceptable answers	Additional guidance	Mark
4	The only correct answer is A B is not the correct answer, as force on sphere is repulsion. C is not the correct answer, as tension in thread direction is incorrect. D is not the correct answer, as force on sphere is repulsion and tension direction is incorrect.		1

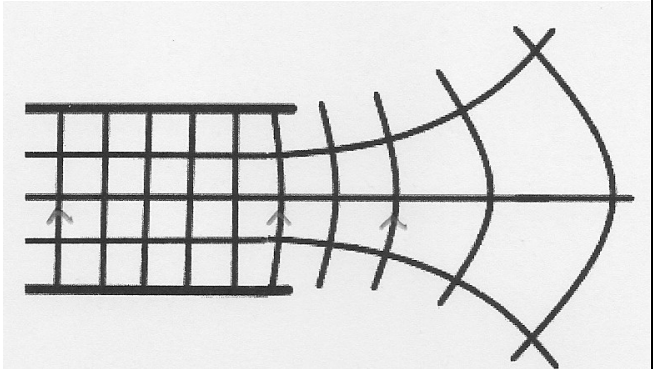


Question Number	Acceptable answers	Additional guidance	Mark
5	The only correct answer is B A is not the correct answer, as $2Q/(2d)^2$ simplifies to $F/2$. C is not the correct answer, as $2Q/(2d)^2$ simplifies to $F/2$. D is not the correct answer, as $2Q/(2d)^2$ simplifies to $F/2$.		1



6	The only correct answer is C (P to Q ; increased) A is not the correct answer, as the field direction is towards the plate connected to the negative terminal and the field strength is increased B is not the correct answer, as the field direction is towards the plate connected to the negative terminal and the field strength is increased D is not the correct answer, as the field direction is towards the plate connected to the negative terminal and the field strength is increased		1
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Question Number	Acceptable answers	Additional guidance	Mark
13(a)	- Arrow upwards on at least one line. (1) Uniform section: - at least 3 parallel, perpendicular straight lines, equispaced (1) Non-uniform: - at least 2 lines perpendicular to equipotentials (1) - spacing getting larger (1)		4
13(b)	- Use of $\ln V = \ln V_0 - \frac{t}{RC}$ (1) - Or Draws initial tangent to curve and uses $T = RC$ (1) - Or Determines t when V has decreased to approx. 37% (1) - Conversion hours to seconds (1) - Calculates resistance in range 2.4×10^{11} to $2.8 \times 10^{11} \Omega$ (1) - Use of $R = \rho \frac{l}{A}$ (1) - Resistivity in range $2.2 \times 10^{15} \Omega \text{ m}$ to $2.6 \times 10^{15} \Omega \text{ m}$ so yes above $10^{14} \Omega \text{ m}$ (1)	<u>Example of calculation:</u> $R = \frac{20 \times 3600 \text{ s}}{0.1 \times 10^{-6} \text{ F} \times \ln 2}$ $R = 2.6 \times 10^{11} \Omega$ $R = \frac{\rho l}{A}$ $2.6 \times 10^{11} \Omega = \frac{\rho \times 0.6 \times 10^{-3} \text{ m}}{5.6 \times 10^{-6} \text{ m}^2}$ $\rho = 2.4 \times 10^{15} \Omega \text{ m}$ Resistivity = $2.4 \times 10^{15} \Omega \text{ m}$ Using $T = RC$ $7 \times 3600 \text{ s} = 0.1 \times 10^{-6} \text{ F} \times R$	5

		$R = 2.5 \times 10^{11} \Omega$ (allow T in range 7 – 8 hour)	
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(Total for Question 13 = 9 marks)



Question number	Acceptable Answers	Additional guidance	Mark
16a	- At least 4 radial lines (1) - arrow pointing outwards (1) - straight, symmetrical and equally distributed (1)	Ignore dotted lines	3
16b	- tangent at correct point (1) - triangle with base at least 0.4 m (1) $5.3 \times 10^6 \text{ (Vm}^{-1}\text{)}$ (range 4.9×10^6 to 6.1×10^6) (1)	Example of calculation: Gradient = $3200000 / 0.6$ $E = 5.3 \times 10^6 \text{ V m}^{-1}$	
	- So would ionise as value greater than 3×10^6 (1) Alternative: - Correct value of V at 30 cm (1) - Use of $E = k \frac{Q}{r^2}$ and $V = k \frac{Q}{r}$ (1) $5.3 \times 10^6 \text{ (Vm}^{-1}\text{)}$ (1) - So would ionise as value greater than 3×10^6 (1)	MP4 to be consistent with calculated value $V = 1.6 \times 10^6 \text{ V m}^{-1}$	4
16c	Maximum 3 marks - There cannot be a p.d. across his body (1) - Electric field strength inside cage is zero (1) - As no potential gradient (1) - Current/electrons/charge would conduct through suit (1) Or the current would not pass through body	Accept reference to Faraday cage for MP2	3max

(Total for Question 16 = 10 marks)



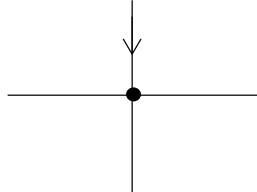
Question mark	Acceptable Answers	Additional Guidance	Mark
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Question Number	Acceptable answers	Additional guidance	Mark
15(a)(i)	- At least three straight horizontal parallel lines (1) - Equispaced (1) - Arrow to indicate direction to the right (1)		3
15(a)(ii)	- As no current drawn from supply (1) - Terminal potential difference is equal to e.m.f. Or no potential difference across internal resistance (1)	Accept no “lost volts”	2
15(b)(i)	- Use of $E = V / d$ (1) $V = 6000 \text{ V}$ (1)	<u>Example of calculation</u> $3 \times 10^6 \text{ V m}^{-1} = V / 0.002 \text{ m}$ $V = 6000 \text{ V}$	2
15(b)(ii)	(A spark is) a current (drawn from the supply) (1) - A potential difference is produced across the internal resistance of the supply (1) - According to $V = E - Ir$ V decreases Or (the decrease in V) is large because the internal resistance is large (1)	Accept “lost volts” are present/increases Accept reduces the terminal potential difference which is shown on the voltmeter	3

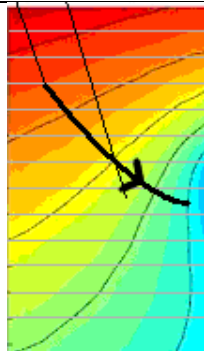
(Total for Question 15 = 10 marks)



Question Number	Acceptable Answer	Additional Guidance	Mark
14(a)	- At least four straight equispaced lines (1) - Arrow on at least one line pointing to the charge (1)	<u>Example</u> 	2
14(b)(i)	- Use of $V = Q/4\pi\epsilon_0 r$ (1) - Converts to nC (1) $Q = (-) 0.11$ (nC) (1)	<u>Example of calculation</u> $-16 \text{ V} = \frac{Q}{4\pi \times 8.85 \times 10^{-12} \text{ F m}^{-1} \times 0.06 \text{ m}}$ $Q = -1.07 \times 10^{-10} \text{ C}$ $Q = -0.11 \text{ nC}$	3
14(b)(ii)	- Use of $E = Q/4\pi\epsilon_0 r^2$ (1) - Either calculates $r = 0.091$ (m) using $E = 120 \text{ V m}^{-1}$ or $E = 99 \text{ (V m}^{-1})$ using $r = 0.10 \text{ m}$ (Show that value gives $r = 0.087$ (m) using $E = 120 \text{ V m}^{-1}$ or $E = 90 \text{ (V m}^{-1})$ using $r = 0.10 \text{ m}$) (1) - Comparison of student's answer for distance with $r = 10$ (cm) and an opinion about the statement Or Comparison of student's answer for field strength with the field strength = $120 \text{ (V m}^{-1})$ and an opinion about the statement (1)	<u>Example of calculation</u> $(-)120 \text{ V m}^{-1} = \frac{(-) 1.1 \times 10^{-10} \text{ C}}{4\pi \times 8.85 \times 10^{-12} \text{ F m}^{-1} \times r^2}$ $r = 0.091 \text{ m}$ Or calculates the field strength $E = \frac{(-) 1.1 \times 10^{-10} \text{ C}}{4\pi \times 8.85 \times 10^{-12} \text{ F m}^{-1} \times 0.10^2}$ $E = 99 \text{ V m}^{-1}$ Accept statement is incorrect because the bee can detect the field at 9.1 (cm) or less Or Accept statement is incorrect because the bee cannot detect the field at 10 (cm)	3
14(c)	- Hair must be charged (1) - As an electric field exerts a force on a charge (1)	Accept “negative” or “positive” Accept as like charges repel Or opposite charges attract	2

(Total for Question 14 = 10 marks)



Question Number	Acceptable answers	Additional guidance	Mark
13(a)	A region where a charged particle experiences a force/acceleration		(1)
13(b)(i)	- States a value of ΔV - Uses $\Delta V/\Delta d$ with a difference in distance $E = 560 \text{ V m}^{-1}$ allow range 500-560 V m^{-1}	Example of calculation: $E = \frac{(80-75)\text{V}}{0.009\text{m}} = 556 \text{ V m}^{-1}$ (Alt: 5.6 V cm^{-1})	(3)
13(b)(ii)	- Line perpendicular to a least 2 equipotential lines - Arrow pointing towards flower		(2)

13(b)(iii)	- States $V \propto r = \text{constant}$ (1) - One corresponding pair of values of V and r (1) - At least two pairs of values used to show that the product is not constant therefore not radial (1) (MP3 dependent on MP2)	Example of calculation: Using $V = 95$ and $r = 2.0 - 2.2$: $Vr = 190 - 209$ $V = 90$ and $r = 2.1 - 2.5$: $Vr = 189 - 225$ $V = 85$ and $r = 2.5 - 2.8$: $Vr = 212 - 238$ $V = 80$ and $r = 3.5 - 3.8$: $Vr = 280 - 304$ $V = 75$ and $r = 4.3 - 4.7$: $Vr = 323 - 353$ $V = 70$ and $r = 5.8 - 6.2$: $Vr = 406 - 434$ Using $r = 3$ and $V = 82 - 83$: $Vr = 246 - 249$ $r = 4$ and $V = 77 - 78$: $Vr = 308 - 312$ $r = 5$ and $V = 72 - 73$: $Vr = 360 - 365$	(3)
13(c)	Charged particle/hair attracts/repels (1) Or charged/hair experiences a force		(1)
13(d)	Equipotential lines would be further apart (1)		(1)

(Total for Question 13 = 11 marks)



Question Number	Acceptable Answer	Additional Guidance	Mark
9(a)(i)	- Bottom plate marked positive Or bottom terminal of power supply marked positive	Accept top plate marked negative or top terminal of power supply marked negative	1
9(a)(ii)	- Calculates volume of oil drop - Use of $\rho = \frac{m}{V}$ - Use of $E = \frac{V}{d}$ - Use of $F = mg$ and $F = Eq$ - Use of $N = \frac{q}{e}$ $N = 4.2$ so student's expectation not supported by data Or $N = 4.2$ which is not a whole number Or $N = 4.2$ so taking experimental error into account student's expectation may be supported by data	(1) <u>Example of calculation</u> (1) $V = \frac{4}{3}\pi \times (1.78 \times 10^{-6} \text{ m})^3 = 2.36 \times 10^{-17} \text{ m}^3$ (1) $m = 2.36 \times 10^{-17} \text{ m}^3 \times 920 \text{ kg m}^{-3} = 2.17 \times 10^{-14} \text{ kg}$ (1) $E = \frac{4870 \text{ V}}{1.55 \times 10^{-2} \text{ m}} = 3.14 \times 10^5 \text{ V m}^{-1}$ (1) $q = \frac{2.17 \times 10^{-14} \text{ kg} \times 9.81 \text{ N kg}^{-1}}{3.14 \times 10^5 \text{ N C}^{-1}} = 6.78 \times 10^{-19} \text{ C}$ (1) $N = \frac{6.78 \times 10^{-19} \text{ C}}{1.60 \times 10^{-19} \text{ C}} = 4.23$ (1)	6



9(b)(i)	An explanation that makes reference to max two of the following points: - The oil drop initially accelerates Or it takes time for the oil drop to reach terminal velocity (1) (Initially) weight of oil drop not balanced by the drag force (+ upthrust) Or Weight of oil drop must be balanced by the drag force (+ upthrust) (1) (If measurements are taken immediately) the calculated velocity will be less than the terminal velocity (1)	Accept use of standard symbols	2
9(b)(ii)	- Positions from scale used to determine displacement (1) - Use of $v = \frac{s}{t}$ (1) $v = 3.4 \times 10^{-5} \text{ m s}^{-1}$ $3.5 \times 10^{-5} \text{ m s}^{-1}$ (1)	<u>Example of calculation</u> Displacement = 6.65 mm – 2.50 mm = 4.15 mm $v = \frac{4.15 \times 10^{-3}}{2 \times 60 \text{ s}} = 3.46 \times 10^{-5} \text{ m s}^{-1}$	3
9(c)	- The maxima are for charges of e, 2e, 3e etc. Or 24 drops had charge as (an integer) multiple of e (1) - But there is a significant number of non-integer charged oil drops Or comment related to only $\frac{24}{50}$ having integer value Or comment related to only 48% having integer value (1) - The evidence from the bar chart is inconclusive Or Reference variation due to experimental uncertainties (1)	MP2: Accept just less than half the drops have an integer multiple of charge	3

(Total for Question 9 = 15 marks)



Question Number	Acceptable answers	Additional guidance	Mark
5	D uses $W = \frac{1}{2} CV^2$ so if V is doubled W is 4×	4W	1
	A divides the energy by 4 (rather than multiply) B forgets to square the potential difference and divides C forgets to square the potential difference		



Question Number	Acceptable answers	Additional guidance	Mark
8	A		1

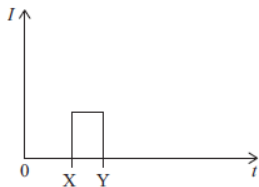


9	The only correct answer is C A is not correct as the increase in energy is the change in the area under the graph line : rectangle area $V_0 \times \Delta Q$		1
	B is not correct as the increase in energy is the change in the area under the graph line : rectangle area $V_0 \times \Delta Q$ D is not correct as the increase in energy is the change in the area under the graph line : rectangle area $V_0 \times \Delta Q$		



Question Number	Acceptable answers	Additional guidance	Mark
3	The only correct answer is D A is not the correct answer, as $-\frac{t}{T} = \ln \frac{1}{2}$ B is not the correct answer, as $-\frac{t}{T} = \ln \frac{1}{2}$ C is not the correct answer, as $-\frac{t}{T} = \ln \frac{1}{2}$		1

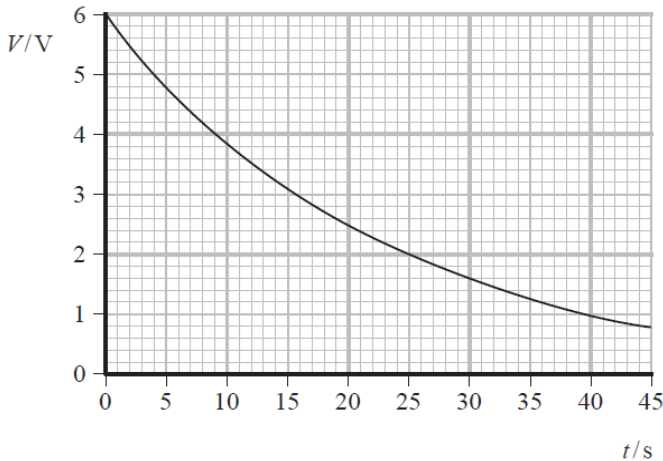


7	The only correct answer is C  A is not the correct answer, as current is only present when capacitor changes so charges or discharges B is not the correct answer, current is only present when capacitor changes and charges or discharges D is not the correct answer, as current is only present when capacitor changes and charges or discharges		1
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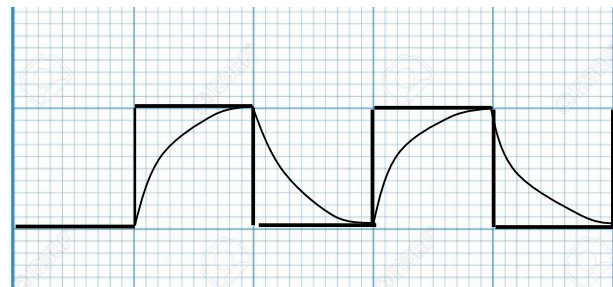
8	The only correct answer is B $\frac{2}{\ln 3}$ A is not the correct answer, as Time constant $RC = t/\ln 3$ C is not the correct answer, as Time constant $RC = t/\ln 3$ D is not the correct answer, as Time constant $RC = t/\ln 3$		1
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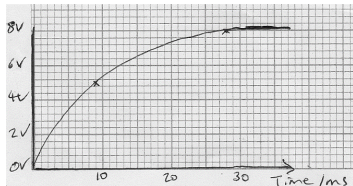
Question Number	Acceptable Answer	Additional Guidance	Mark
8(a)	- A pair of corresponding V and t values read from graph (1) - Use of $V = V_0 e^{-\frac{t}{RC}}$ (1) Or Use of time constant $= RC$ (1) $C = 270 \mu\text{F}$ (1) - Use of $\pm 20\%$ with $220 \mu\text{F}$ [Largest $C = 264 \mu\text{F}$, smallest $C = 176 (\mu\text{F})$] (1) - Comparison of $264 (\mu\text{F})$ [$176 (\mu\text{F})$ if their calculated C is too low] with calculated value of C from graph and conclusion consistent with this (1)	 Allow use of tangent at $t = 0$ to determine intercept on x-axis and obtain value for time constant; then calculate C gives MP1, MP2 and MP3 MP3: Value should be correct and have units <u>Example of calculation</u> $1.0 = 6.0 e^{-\frac{40 \text{ s}}{82 \times 10^3 \Omega \times C}}$ $\therefore \ln\left(\frac{1.0 \text{ V}}{6.0 \text{ V}}\right) = -\frac{40 \text{ s}}{82 \times 10^3 \Omega \times C}$ $\therefore C = \frac{-40 \text{ s}}{-1.79 \times 82 \times 10^3 \Omega} = 2.72 \times 10^{-4} \text{ C}$ Largest value of capacitance $= 1.2 \times 220 \mu\text{F} = 264 \mu\text{F}$	5

8(b)	- The data has to be collected in a short time Or Data logger has high sampling rate Or Data logger enables readings to be taken more frequently (1) - It would be difficult to read the voltmeter and stopwatch simultaneously (1) - So the suggestion is correct [dependent on MP1 or MP2] (1)	MP1: Data logger can take more readings in the time for capacitor to discharge	3
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(Total for Question 8 = 8 marks)

Question Number	Acceptable answers	Additional guidance	Mark
15a	- p.d. across capacitor increases Or p.d. across resistor decreases (1) - p.d. across capacitor increases to 5V (1) - p.d. across resistor starts at 5V and reduces to 0V (1) - Exponentially (1)		4
15b	- Time axis: one cycle = 50 OR two cycles = 100 (1) - Use of time constant = RC (1) - Charging curve, from 25 ms to 50 ms, just about reaching 5V as shown (ecf from their T) (1) - One corresponding discharge curve (1) - Curve should look exponential (1)	<u>Example of calculation</u> $T = 1/f = 1/20 \text{ Hz} = 0.050 \text{ s}$ Two cycles = $2 \times 0.050 \text{ s} = 0.10 \text{ s} = 100 \text{ ms}$ Time Constant = $100 \times 50 \times 10^{-6} = 0.005 \text{ s}$ In half a cycle (0.025 s) there are $0.025 \text{ s} / 0.005 \text{ s} = 5$ Time constants Ignore anything drawn in the first half cycle  Time period should be marked 50 ms or equivalent	5

(Total for Question 15 = 9 marks)

Question Number	Acceptable answers	Additional guidance	Mark
15a	- line approximately exponential curve starting at 0 and increasing potential (1) - beginning to flatten off at a maximum of 8 V (at 30 ms above 7.5 V) (1) - Use of time constant RC (1)	 This can be evidenced with an exponential curve passing through about 5 V at 9 ms Or approximately 2/3 of their maximum	3
15bi	- Use of $\ln V = \ln V_0 - \frac{t}{RC}$ (1) - Substitution $V = 2.0$ V and $V_0 = 8.0$ V (1) $t = 5.6(1)$ ms (1)	Alternative use of $V = V_0 e^{-\frac{t}{RC}}$ Rearrange to $\ln 4 = t / 2700 \Omega \times 1.5 \times 10^{-6} F$ <u>Example of calculation</u> $t = 2700 \Omega \times 1.5 \times 10^{-6} F (\ln 8 - \ln 2)$ $t = 5.61 \text{ ms}$	3
15bii	- Use of $W = \frac{1}{2} CV^2$ (1) $W = 3.0 \times 10^{-6} \text{ J}$ (1)	<u>Example of calculation</u> $W = \frac{1}{2} 1.5 \times 10^{-6} F \times 2^2 V^2 = 3.0 \times 10^{-6} \text{ J}$	2

Question Number	Acceptable answers	Additional guidance	Mark
15c	- Deduce the p.d. across the total resistance (1) - Use of $P = I^2 R$ or V^2/R (1) $P = 3.3 \times 10^{-3} \text{ W}$ (1)	<u>Example of calculation</u> $I = \frac{6 \text{ V}}{3.3 \text{ k}\Omega + 2.7 \text{ k}\Omega} = 1.0 \text{ mA}$ $P = (1.0 \text{ mA})^2 \times 3300 \Omega = 3.3 \times 10^{-3} \text{ W}$ Alternative $V = 6 \text{ V} \times \frac{3.3}{3.3 + 2.7} = 3.3 \text{ V}$ $P = \frac{3.3^2 \text{ V}^2}{3300 \Omega} = 3.3 \times 10^{-3} \text{ W}$	3

(Total for Question 15 = 11 marks)

Question Number	Acceptable answers	Additional guidance	Mark
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9	The only correct answer is B <i>A is not correct because a cyclotron uses a magnetic field</i> <i>C is not correct because a LINAC uses an electric field</i> <i>D is not correct because a LINAC does not use a magnetic field</i>	Cyclotron accelerated	1
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Question Number	Acceptable answers	Additional guidance	Mark
5	The only correct answer is D <i>A is not correct because FLHR gives the direction as OQ</i> <i>B is not correct because FLHR gives the direction as OQ</i> <i>C is not correct because FLHR gives the direction as OQ</i>		1



Question Number	Acceptable answers	Additional guidance	Mark
6	The only correct answer is C A is not the correct answer, as force is downwards. B is not the correct answer, as there is no force. D is not the correct answer, as there is no force.		1



5	The only correct answer is B (into the page) A is not the correct answer, as the positron is anticlockwise, the force is to the centre of the spiral and use of Flemings left hand rule C is not the correct answer, as the positron is anticlockwise, the force is to the centre of the spiral and use of Flemings left hand rule D is not the correct answer, as the positron is anticlockwise, the force is to the centre of the spiral and use of Flemings left hand rule		1
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Question Number	Acceptable Answer	Additional Guidance	Mark
3	- The deflection/fields experiments indicate that electrons have a mass (and a charge) Or the deflection/fields experiments indicate that electrons have particle behaviour. (1) - The diffraction experiments indicate that electrons must have a wave nature (1) - Idea that a model of electron behaviour must include wave-particle duality (1)	In MP1 allow a description of deflection e.g. electrons are deflected by (electric and magnetic) fields indicating that they have a mass (and charge)	3

(Total for Question 3 = 3 marks)



*12	This question assesses a student's ability to show a coherent and logically structured answer with linkages and fully-sustained reasoning. Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning. The following table shows how the marks should be awarded for indicative content. Indicative content: (Maximum/Initial) current is equal to battery emf divided by R Or current as switch closed Or current as complete circuit Or current due to battery - Coil rotates (movement of) coil “cuts/changes” (magnetic) flux (linkage) / field - Which induces an emf (according to Faraday's law) - Opposes original emf/current according to Lenz's law Or current reduced as effect opposes change - The faster the coil rotates the larger this (back) emf/effect the smaller the current	<table> <tr> <th>IC points</th><th>IC mark</th><th>Max linkage mark available</th><th>Max final mark</th></tr> <tr> <td>6</td><td>4</td><td>2</td><td>6</td></tr> <tr> <td>5</td><td>3</td><td>2</td><td>5</td></tr> <tr> <td>4</td><td>3</td><td>1</td><td>4</td></tr> <tr> <td>3</td><td>2</td><td>1</td><td>3</td></tr> <tr> <td>2</td><td>2</td><td>0</td><td>2</td></tr> <tr> <td>1</td><td>1</td><td>0</td><td>1</td></tr> <tr> <td>0</td><td>0</td><td>0</td><td>0</td></tr> </table> ic3 needs a link to coil moving ic4 depends on ic3	IC points	IC mark	Max linkage mark available	Max final mark	6	4	2	6	5	3	2	5	4	3	1	4	3	2	1	3	2	2	0	2	1	1	0	1	0	0	0	0	6
IC points	IC mark	Max linkage mark available	Max final mark																																
6	4	2	6																																
5	3	2	5																																
4	3	1	4																																
3	2	1	3																																
2	2	0	2																																
1	1	0	1																																
0	0	0	0																																

(Total for question 12 = 6 Marks)



Question Number	Acceptable Answer	Additional Guidance	Mark
1(a)	- Use of $F = BIl \sin \theta$ (1) - Use of $F = mg$ (1) $B = 0.0786 \text{ T}$ (1)	Example of calculation: $BIl = mg$ $\therefore B = \frac{5.65 \times 10^{-3} \text{ kg} \times 9.81 \text{ N kg}^{-1}}{4.55 \text{ A} \times 15.5 \times 10^{-2} \text{ m}} = 0.07859 \text{ T}$	3
1(b)	MAX 3 A comment that makes reference to the following points: - High precision means a small spread of values (1) - High accuracy means close to the true value (1) - The student is actually referring to the resolution of the balance (1) (The student should have stated) there was a low uncertainty in the value of the force Or a high resolution doesn't guarantee accuracy/precision (1)		3

(Total for Question 1 = 6marks)



Question Number	Acceptable answers	Additional guidance	Mark
14(a)	Direction out of page (1)	The arrow needs to be parallel to the length of the pipe by eye.	1
14(b)(i)	- Use of $R = \rho l / A$ (1) - Using $A = 0.5 \times 28 (\times 10^{-6} \text{ m}^2)$ (1) - Use of $V = IR$ (1) $I = 22 \text{ (mA)}$ (1)	<u>Example of calculation</u> $R = \frac{1.6 \Omega \text{m} \times 0.6 \times 10^{-3} \text{ m}}{0.5 \times 10^{-3} \text{ m} \times 28 \times 10^{-3} \text{ m}}$ $R = 68.6 \Omega$ $1.5 \text{ V} = I \times 68.6 \Omega$ $I = 1.5 \text{ V} / 68.6 \Omega$ $I = 0.022 \text{ A} = 22 \text{ mA}$	4
14(b)(ii)	- Use of $F = BIL$ ecf values from (b)(i) (1) - Force = $5.3 \times 10^{-6} \text{ N}$ (1)	Use of show that values gives $4.8 \times 10^{-6} \text{ N}$ <u>Example of calculation</u> $F = 0.40 \text{ T} \times 0.022 \text{ A} \times 0.6 \times 10^{-3} \text{ m}$ $F = 5.3 \times 10^{-6} \text{ N}$	2

(Total for Question 14 = 7 marks)

Question Number	Acceptable Answer	Additional Guidance	Mark
7(a)	An explanation that makes reference to the following points: - The potential difference creates an electric field - An (electric) field/force does work on the electrons (increasing their kinetic energy) Or an (electric) field/force accelerates the electrons (increasing their velocity)		2
7(b)(i)	(Perpendicularly) out of the page - The force is perpendicular to the magnetic field and the direction of (conventional) current Or an application of Fleming's Left-Hand Rule	Accept movement of electrons for current	2
7(b)(ii)	An explanation that makes reference to the following points: - There would be a force (of constant magnitude) on the electron perpendicular to its direction of motion - Causing an acceleration towards the centre of a circle	Accept reference to centripetal force for MP1	2
7(c)(i)	- Use of $F = BQv$ and $F = EQ$ - Algebra to show $v = \frac{E}{B}$		2
7(c)(ii)	- Use of $W = QV$ and $E_k = \frac{1}{2}mv^2$ - Use of $v = \frac{E}{B}$ $\frac{e}{m} = 1.7 \times 10^{11} \text{ C kg}^{-1}$	<u>Example of calculation:</u> $v = \frac{E}{B} = \frac{1.4 \times 10^4 \text{ V m}^{-1}}{1.5 \times 10^{-3} \text{ T}} \quad \frac{e}{m} = \frac{v^2}{2V}$ $\frac{e}{m} = \frac{(9.33 \times 10^6 \text{ m s}^{-1})^2}{2 \times 250 \text{ V}} = 1.74 \times 10^{11} \text{ C kg}^{-1}$	3
7(d)	- The hydrogen ion must be (about 2000 times) more massive than the electron Or the electron must be (about 2000 times) less massive than the hydrogen ion	Accept "proton" for "hydrogen ion"	1

(Total for Question 7 = 12 marks)



Question Number	Acceptable answers	Additional guidance	Mark																																
*16(a)	This question assesses a student's ability to show a coherent and logically structured answer with linkages and fully-sustained reasoning. Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning. The following table shows how the marks should be awarded for indicative content. Indicative content: - Current direction is D to C in coil Or Current direction is B to A (1) - There is a force due to current (carrying conductor) within a magnetic field (1) - The force is vertically down on side DC Or The force is vertically up on side BA (1) - Moment of force (around axis) produces rotation (in an anticlockwise direction) (1) - as coil moves through half a turn split ring ensures the current switches direction (for a particular side) (1) - This results in the coil continuing to rotate (in the same direction) (1)	<table border="1"> <thead> <tr> <th>IC points</th><th>IC mark</th><th>Max linkage mark available</th><th>Max final mark</th></tr> </thead> <tbody> <tr> <td>6</td><td>4</td><td>2</td><td>6</td></tr> <tr> <td>5</td><td>3</td><td>2</td><td>5</td></tr> <tr> <td>4</td><td>3</td><td>1</td><td>4</td></tr> <tr> <td>3</td><td>2</td><td>1</td><td>3</td></tr> <tr> <td>2</td><td>2</td><td>0</td><td>2</td></tr> <tr> <td>1</td><td>1</td><td>0</td><td>1</td></tr> <tr> <td>0</td><td>0</td><td>0</td><td>0</td></tr> </tbody> </table> Arrows could be added to the diagram Accept $F = BIl$ allow ecf if current direction is defined/indicated in the opposite direction	IC points	IC mark	Max linkage mark available	Max final mark	6	4	2	6	5	3	2	5	4	3	1	4	3	2	1	3	2	2	0	2	1	1	0	1	0	0	0	0	6
IC points	IC mark	Max linkage mark available	Max final mark																																
6	4	2	6																																
5	3	2	5																																
4	3	1	4																																
3	2	1	3																																
2	2	0	2																																
1	1	0	1																																
0	0	0	0																																



16(b)	- Use of $P = W/t$ (1) - Use of $E_k = \frac{1}{2}mv^2$ (1) Or use of SUVAT, $F = ma$ and $W = Fs$ - Work done = 8.0×10^5 J (1)	<u>Example of calculation</u> Work done by motor = $390 \times 10^3 \text{ W} \times 4.0 \text{ s} = 1.56 \times 10^6 \text{ J}$ $E_k = \frac{1}{2} 1950 \text{ kg} \times 28^2 (\text{m s}^{-1})^2 = 764400 \text{ J}$ Work done by resistive forces = $1.56 \times 10^6 \text{ J} - 764400 = 795600 \text{ J}$ Second example of MP2 $a = \frac{28 \text{ m s}^{-1} - 0}{4.0 \text{ s}} = 7.0 \text{ m s}^{-2}$ Resultant force = $1950 \text{ kg} \times 7.0 \text{ m s}^{-2} = 13650 \text{ N}$ $s = \frac{0 + 28 \text{ m s}^{-1}}{2} \times 4.0 \text{ s} = 56 \text{ m}$ Work to increase velocity = $13650 \text{ N} \times 56 \text{ m} = 764400 \text{ J}$ Work done by resistive forces = $1.56 \times 10^6 \text{ J} - 764400 = 795600 \text{ J}$	3
16(c)	An explanation that makes reference to the following points: Energy Argument: - More energy transferred in the battery (rather than the motor) (1) - The battery/car will be less efficient (1) - Therefore the battery will need charging more often Or journey will be shorter (1) Force/Power Argument: - Increased internal resistance reduces terminal p.d. (1) - reduces the current (in the circuit) (1) - So acceleration of car is reduced Or less power Or battery will take longer to charge (1)	Accept reference to heating effect in the battery	3

(Total for Question 16 = 12 marks)



Question Number	Acceptable Answer	Additional Guidance	Mark
10(a)(i)	- Use of $v = u + at$ (1) $a = 0.81 \text{ m s}^{-2}$ (1)	<u>Example of calculation</u> $a = \frac{v - u}{t} = \frac{97 \text{ m s}^{-1}}{120 \text{ s}} = 0.808 \text{ m s}^{-2}$	2
10(a)(ii)	- Use of $s = ut + \frac{1}{2}at^2$ Or $v^2 = u^2 + 2as$ Or $s = \left(\frac{v+u}{2}\right)t$ (1) - Use of $v_{\text{av}} = \frac{s}{t}$ with $t = 320 \text{ s}$ (1) $v_{\text{av}} = 75 \text{ m s}^{-1}$ (1)	Ecf acceleration from (a)(i) <u>Example of calculation</u> $s = ut + \frac{1}{2}at^2 = 0.5 \times 0.808 \text{ m s}^{-2} (120 \text{ s})^2 = 5820 \text{ m}$ $s_2 = 29900 \text{ m} - 5820 \text{ m} = 24\,080 \text{ m}$ $t = 440 \text{ s} - 120 \text{ s} = 320 \text{ s}$ $v_{\text{av}} = \frac{24\,080 \text{ m}}{320 \text{ s}} = 75.3 \text{ m s}^{-1}$	3
10(b)	An explanation that makes reference to the following: (Magnetic levitation) reduces frictional forces (acting on the train as it moves) (1) - This reduces the work done against friction Or this makes it more efficient Or there is less time to reach maximum speed Or there is a higher maximum speed (1)	MP1: accept removes/no frictional forces MP2: accept there is less fuel used Or less energy is wasted	2



*10(c)

This question assesses a student’s ability to show a coherent and logically structured answer with linkages and fully sustained reasoning.

Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning.

The table shows how the marks should be awarded for indicative content and structure and lines of reasoning.

Number of indicative marking points seen in answer	Number of marks awarded for indicative marking points
6	4
5–4	3
3–2	2
1	1
0	0

	Number of marks awarded for structure of answer and sustained line of reasoning
Answer shows a coherent and logical structure with linkages and fully sustained lines of reasoning demonstrated throughout	2
Answer is partially structured with some linkages and lines of reasoning	1
Answer has no linkages between points and is unstructured	0

Indicative content:

1. Removing the magnet from the ring changes the magnetic flux (linked with the ring)
2. This induces an e.m.f. (in the ring)
3. E.m.f. causes a current in the ring
4. Which produces a magnetic field
5. The magnetic fields interact/combine
6. This opposes the change, causing an attractive force to act

IC Points	IC Mark	Max linkage mark avail.	Max final mark
6	4	2	6
5	3	2	5
4	3	1	4
3	2	1	3
2	2	0	2
1	1	0	1
0	0	0	0

IC1: accept references to flux cutting

Alternative indicative content for IC4 – IC5

4. The current is in the magnetic field produced by the magnet
5. The current experiences a magnetic force

6

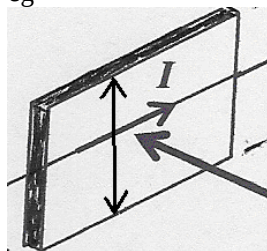
(Total for Question 10 = 13 marks)

Question Number	Acceptable Answers	Additional Guidance	Mark
17 (a)(i)	An explanation that makes reference to the following points: - Fleming left hand rule force will cause force on left hand side of coil into page (1) Or right hand side of coil out of page - The coil will turn clockwise as shown in the plan view (1) (MP2 dependent on MP1)	allow 1 mark for statement “rotates clockwise because of FLHR”	2
17 (a)(ii)	- Moment of F around pivot = $F \times w/2$ (1) - Use of $F = BIl$ (1) - Moment due to F on both sides = $2 \times BIl \times w/2$ (1) - As N turns and $l \times w = A$; Total moment = $BAIN$ (1)	alt: Use of Torque of a couple = $F \times w$ then MP1 and 3 This equation should be substituted into a product with a “distance” to be awarded ‘use of’	4
17(b)	- Use of $V = IR$ (1) - Use of $V_{\text{total}} = V_{\text{meter}} + V_{\text{multiplier}}$ (1) - Choice of $R = 2500 \Omega$ (1)	<u>Example of calculation</u> V across meter = $0.0016 \text{ A} \times 625 \Omega = 1.0 \text{ V}$ V across multiplier = $5.0 \text{ V} - 1.0 \text{ V} = 4.0 \text{ V}$ $R_{\text{multiplier}} = \frac{4.0 \text{ V}}{0.0016 \text{ A}} = 2500 \Omega$ MP3 dependent on MP1 or MP2	3
17(c)	An explanation that makes reference to the following points: This is because there is a change of flux (linkage) as the meter is moved (1)		4

	• An emf is induced which will produce a current in the coil (as both ends of the coil are connected) (1) • Current-carrying conductor within a magnetic field (1) experiences a force • These forces oppose the coil's motion (reducing it) (1)		
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(Total for Question 17 = 13 marks)



Question Number	Acceptable answers	Additional guidance	Mark
17(a)	- The current and magnetic field are perpendicular (1) - By (Flemings) left hand rule the force on the electrons is upwards (1)	alt. force results from current not parallel to a magnetic field	(2)
17(b)	indication at top and bottom of conductor (1)	eg 	(1)
17(c)	- Equates $F = Bev$ and $F = eE$ (1) - Substitutes $E = V/d$ (1) - Or $F = eV/d$ seen - Replaces v with I/neA (1) - Substitute $A = d \times t$ and leads to given equation (1) Alternative: - Equates $F = BIl$ and $F = QE$ with Q identified as total charge (1) - Substitutes $E = V/d$ (1) - Or $F = QV/d$ seen	Example of derivation: $Bev = eE$ $Bev = eV/d$ $\frac{BI}{neA} = \frac{V_H}{d}$ $V_H = \frac{BI}{net}$ Alternative: $BIl = QE$ Total charge $Q = neAl$ $BIl = neAlE$ $BI = neAV_H/d$ $V_H = BI/net$	(4)

	- Substitutes $Q = neAl$ and cancels l - Substitute $A = d \times t$ and leads to given equation		
17(d)	- Uses $V = J/C$ (1) Or $V = Nm/C$ Or $V = Wb s^{-1}$ - Use of $T = N/Cms^{-1}$ (1) Or $T = N/Am$ Or $T = Wb m^{-2}$ Or Sub of $B=F/IL$ and cancels I's - Uses units of $n = m^{-3}$ and completes agreement (1) Alternative with base units: - Uses base unit of force = $kg m s^{-2}$ (1) Or base unit of energy = $kg m^2 s^{-2}$ - Uses base unit of charge = $A s$ (1) Or uses $A = Cs^{-1}$ Or Sub of $B=F/IL$ and cancel I's or A's - Uses base units of $n = m^{-3}$ and completes agreement (1)	Example of unit simplification: J/C should equal $\frac{N}{Am} \times A \div m^{-3} Cm$ $= \frac{Nm}{C} = \frac{J}{C}$	(3)



17(e)	- Calculates a product nt for at least one sample (1) (Largest value of V_H) smallest value of nt which is silicon (1) Or - Calculates $1/nt$ for at least one sample (1) (Largest value of V_H) largest value of $1/nt$ which is silicon (1)	Example of calculation of nt: Copper = $8.47 \times 10^{28} \times 110 \times 10^{-6} = 9.31 \times 10^{24}$ Germanium = $2.25 \times 10^{19} \times 1.10 \times 10^{-6} = 2.48 \times 10^{13}$ Silicon = $1.44 \times 10^{16} \times 120 \times 10^{-6} = 1.73 \times 10^{12}$ Example of calculation of $1/nt$: Copper = 1.07×10^{-25} Germanium = 4.03×10^{-14} Silicon = 5.79×10^{-13}	(2)
17(f)	- Uses $\tan \theta = B_V \div B_H$ (1) Or uses $\tan \theta = B_H \div B_V$ - Angle = 69° (1)	Example of calculation: $\tan \theta = 49/19$ $\theta = 68.8^\circ$ Accept use of vector triangle as alternative to calculation	(2)

(Total for Question 17 = 14 marks)



Question Number	Acceptable Answer	Additional Guidance	Mark
11(a)(i)	An explanation that makes reference to the following points: - The velocity/momentum increases as the energy of the protons increases (1) $r = \frac{p}{Bq}$ and $p=mv$ so the magnetic flux density must increase (to keep r constant). - Or $r = \frac{p}{Bq}$ and $E_k = \frac{p^2}{2m}$ so the magnetic flux density must increase (to keep r constant). - Or $F = \frac{mv^2}{r}$ and $F = Bqv$ so the magnetic flux density must increase (to keep r constant) (1)		2



11(a)(ii)	- Radius calculated - Use of $F = \frac{mv^2}{r}$ - Use of $F = Bqv$ $B = 7.3 \times 10^{-5} \text{ T}$	(1) (1) Allow use of $p = mv$ for MP2 (1) and use of $r = \frac{p}{Bq}$ for MP3 (1) <u>Example of calculation</u> $r = \frac{\text{circumference}}{2\pi} = \frac{27 \times 10^3 \text{ m}}{2\pi} = 4.30 \times 10^3 \text{ m}$ $F = \frac{1.67 \times 10^{-27} \text{ kg} \times (3.0 \times 10^7 \text{ m s}^{-1})^2}{4.30 \times 10^3 \text{ m}} = 3.50 \times 10^{-16} \text{ N}$ $B = \frac{3.50 \times 10^{-16} \text{ N}}{1.6 \times 10^{-19} \text{ C} \times 3.0 \times 10^7 \text{ m s}^{-1}} = 7.28 \times 10^{-5} \text{ T}$	4
11(a)(iii)	- Conversion to joule - Use of $\Delta E = c^2 \Delta m$ $m = 2.4 \times 10^{-23} \text{ (kg)}$	(1) <u>Example of calculation</u> (1) $E = 13\,600 \times 10^9 \text{ eV} \times 1.6 \times 10^{-19} \text{ J eV}^{-1} = 2.18 \times 10^{-6} \text{ J}$ (1) $m = \frac{2.18 \times 10^{-6} \text{ J}}{(3.0 \times 10^8 \text{ m s}^{-1})^2} = 2.42 \times 10^{-23} \text{ kg}$	3

*11(b)	This question assesses a student’s ability to show a coherent and logical structured answer with linkage and fully-sustained reasoning Indicative content: IC1 In a fixed target collision there is momentum before the collision so there is momentum after the collision IC2 So particle(s) created must have some kinetic energy IC3 So not all kinetic energy converted to mass IC4 In a colliding beam experiment total initial momentum is zero (if the colliding particles have the same mass and speed) IC5 Momentum after the collision will be zero IC6 So (almost) all of the kinetic energy is converted to mass	Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning. The following table shows how the marks should be awarded for indicative content. <table><tr><th>Number of indicative marking points seen in answer</th><th>Number of marks awarded for indicative marking points</th></tr><tr><td>6</td><td>4</td></tr><tr><td>5–4</td><td>3</td></tr><tr><td>3–2</td><td>2</td></tr><tr><td>1</td><td>1</td></tr><tr><td>0</td><td>0</td></tr></table> <table><tr><th></th><th>Number of marks awarded for structure of answer and sustained line of reasoning</th></tr><tr><td>Answer shows a coherent and logical structure with linkages and fully sustained lines of reasoning demonstrated throughout</td><td>2</td></tr><tr><td>Answer is partially structured with some linkages and lines of reasoning</td><td>1</td></tr><tr><td>Answer has no linkages between points and is unstructured</td><td>0</td></tr></table> Total marks awarded is the sum of marks for indicative content and the marks for structure and lines of reasoning. <table><tr><th>IC points</th><th>IC mark</th><th>Max linkage mark</th><th>Max final mark</th></tr><tr><td>6</td><td>4</td><td>2</td><td>6</td></tr><tr><td>5</td><td>3</td><td>2</td><td>5</td></tr><tr><td>4</td><td>3</td><td>1</td><td>4</td></tr><tr><td>3</td><td>2</td><td>1</td><td>3</td></tr><tr><td>2</td><td>2</td><td>0</td><td>2</td></tr><tr><td>1</td><td>1</td><td>0</td><td>1</td></tr><tr><td>0</td><td>0</td><td>0</td><td>0</td></tr></table>	Number of indicative marking points seen in answer	Number of marks awarded for indicative marking points	6	4	5–4	3	3–2	2	1	1	0	0		Number of marks awarded for structure of answer and sustained line of reasoning	Answer shows a coherent and logical structure with linkages and fully sustained lines of reasoning demonstrated throughout	2	Answer is partially structured with some linkages and lines of reasoning	1	Answer has no linkages between points and is unstructured	0	IC points	IC mark	Max linkage mark	Max final mark	6	4	2	6	5	3	2	5	4	3	1	4	3	2	1	3	2	2	0	2	1	1	0	1	0	0	0	0
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5–4	3																																																					
3–2	2																																																					
1	1																																																					
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3	2	1	3																																																			
2	2	0	2																																																			
1	1	0	1																																																			
0	0	0	0																																																			

6

(Total for Question 11 = 15 marks)



Question Number	Acceptable Answer				Additional Guidance	Mark																				
9(a)	IC points	IC mark	Max linkage mark	Max final mark	This question assesses a student’s ability to show a coherent and logically structured answer with linkages and fully sustained reasoning. Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning. The table shows how the marks should be awarded for indicative content and structure and lines of reasoning. <table><tr><th>Number of indicative marking points seen in answer</th><th>Number of marks awarded for indicative marking points</th></tr><tr><td>6</td><td>4</td></tr><tr><td>5–4</td><td>3</td></tr><tr><td>3–2</td><td>2</td></tr><tr><td>1</td><td>1</td></tr><tr><td>0</td><td>0</td></tr></table> <table><tr><th></th><th>Number of marks awarded for structure of answer and sustained line of reasoning</th></tr><tr><td>Answer shows a coherent and logical structure with linkages and fully sustained lines of reasoning demonstrated throughout</td><td>2</td></tr><tr><td>Answer is partially structured with some linkages and lines of reasoning</td><td>1</td></tr><tr><td>Answer has no linkages between points and is unstructured</td><td>0</td></tr></table> Alternative to first 3 indicative content points: IC1 Current in coil causes a magnetic field IC2 Current is alternating so field changes direction with current (same frequency) IC3 Field interacts with permanent magnet's field so coil experiences oscillating force IC6 Resonance occurs and the amplitude of vibration of the box increases	Number of indicative marking points seen in answer	Number of marks awarded for indicative marking points	6	4	5–4	3	3–2	2	1	1	0	0		Number of marks awarded for structure of answer and sustained line of reasoning	Answer shows a coherent and logical structure with linkages and fully sustained lines of reasoning demonstrated throughout	2	Answer is partially structured with some linkages and lines of reasoning	1	Answer has no linkages between points and is unstructured	0	
	Number of indicative marking points seen in answer	Number of marks awarded for indicative marking points																								
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5	3	2	5																							
4	3	1	4																							
3	2	1	3																							
2	2	0	2																							
1	1	0	1																							
0	0	0	0																							
Indicative content:																										
IC1 Alternating p.d. causes an alternating current in the coil																										
IC2 Current carrying conductor in a magnetic field experiences a force																										
IC3 Current is alternating, so force changes direction with current (same frequency)																										
Or the alternating current drives the cone at the frequency of the p.d.																										
IC4 The loudspeaker forces the box into oscillation																										
IC5 (At certain frequencies) the frequency of oscillation equals the natural frequency of oscillation of the air in the box																										
IC6 Maximum energy is transferred and the amplitude of vibration of the box increases																										

6

9(b)(i)	- A standing wave is set up in the tube Or interference (of sound waves) takes place in the tube (1) - Where constructive interference occurs the amplitude is a maximum Or at antinodes the amplitude is a maximum (1) - Where destructive interference occurs the amplitude is a minimum Or at nodes the amplitude is zero/minimum (1) - Sand is displaced from points of max amplitude to points of min amplitude Or sand is displaced from antinodes to nodes (1)		4
9(b)(ii)	- Measure over at least 3 heaps (1) - Divide by the number of gaps between the heaps (1) - Repeat measurement and calculate average (1)	i.e at least 2 gaps	3
9(b)(iii)	- Use of $d = \frac{\lambda}{2}$ (1) - Use of $v = f\lambda$ (1) $v = 330 \text{ (m s}^{-1}\text{)}$ and a comment on consistency with 340 m s^{-1} (1)	<u>Example of calculation:</u> $\lambda = 2d = 2 \times 5.1 \times 10^{-2} \text{ m} = 0.102 \text{ m}$ $v = 3.25 \times 10^3 \text{ Hz} \times 0.102 \text{ m} = 332 \text{ m s}^{-1}$	3

(Total for Question 9 = 16 marks)



Question Number	Acceptable Answer	Additional Guidance	Mark
13(a)	(isotopes are atoms/nuclides with the) same number of protons but different numbers of neutrons/nucleons (in the nucleus) (1)	Ignore references to the number of electrons in the atoms Do not credit mass number or atomic number	1
13(b)	- Use of $W = QV$ (1) - Use of $KE = \frac{1}{2}mv^2$ (1) - Use of $1u = 1.66 \times 10^{-27} \text{ kg}$ (1) $v = 2.16 \times 10^5 \text{ (m s}^{-1}\text{)}$ (1)	Example of calculation: $\frac{1}{2}mv^2 = eV$ $\therefore v = \sqrt{\frac{2 \times 1.6 \times 10^{-19} \text{ C} \times 8.5 \times 10^3 \text{ V}}{(34.97 \times 1.66 \times 10^{-27}) \text{ kg}}} = 2.16 \times 10^5 \text{ ms}^{-1}$	4
13(c)(i)	- Electric field vertically downwards (from top plate to bottom plate) (1) - Magnetic field into paper (1)		2
13(c)(ii)	- Use of $E = \frac{V}{d}$ (1) - Use of $F_E = EQ$ (1) - Use of $F_M = BQv$ (1) - Show that these forces are equal (if v is $2.2 \times 10^5 \text{ m s}^{-1}$) and hence state that B is suitable (1)	Do not award MP4 if incorrect ion charge used Example of calculation: $E = \frac{V}{d} = \frac{135 \text{ V}}{2.5 \times 10^{-2} \text{ m}} = 5400 \text{ V m}^{-1}$ $F = EQ = 5400 \text{ V m}^{-1} \times 1.6 \times 10^{-19} \text{ C} = 8.6 \times 10^{-16} \text{ N}$ $F = BQv = 24.5 \times 10^{-3} \text{ T} \times 1.6 \times 10^{-19} \text{ C} \times 2.2 \times 10^5 \text{ ms}^{-1}$ $= 8.6 \times 10^{-16} \text{ N}$	4



13(d)(i)	- The ions experience a force perpendicular to their velocity (and the magnetic field) (1) - The (resultant) force on the ions causes an acceleration at right angles to their velocity (1) Or There is a magnetic force acting towards the centre of the path (1)	For velocity accept direction of motion or direction of travel	2
13(d)(ii)	- Use of $r = \frac{mv}{BQ}$ (1) $r = 0.23 \text{ m}$ (1)	<u>Example of calculation:</u> $r = \frac{mv}{BQ}$ $= \frac{(34.97 \times 1.66 \times 10^{-27}) \text{ kg} \times 2.2 \times 10^5 \text{ ms}^{-1}}{0.35 \text{ T} \times 1.6 \times 10^{-19} \text{ C}} = 0.228 \text{ m}$	2
13(d)(iii)1	path drawn with less curvature (less overall deflection) (1)	MP1 awarded for path in the magnetic field	1
13(d)(iii)2	- ions are more massive (1) - ions have the same charge so the radius of the path would be greater (1)		2

(Total for Question 13 = 18 marks)



7	B The induced emf in the coil will oppose the cell emf and cause a delay in the current to lamp Y	Lights after a delay with a final brightness the same as X		1
	A assumes the resistance of the coil is more than the resistor C ignores the magnetic effect of the coil and assumes the resistance of the coil is more than the resistor D ignores the magnetic effect of the coil			



8	The only correct answer is B <i>A is not correct because it is 3 divided by 2</i> <i>C is not correct because it is $3 \times \text{root } 2$</i> <i>D is not correct because it is 3^2</i>	2.1 A	1
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Question Number	Acceptable answers	Additional guidance	Mark
9	C		1



Question Number	Acceptable answers	Additional guidance	Mark
1	The only correct answer is A B is not correct as the peak value is 2 V C is not correct as the period is 0.22 s D is not correct as r.m.s. value of p.d. is 1.4 V		1



10	The only correct answer is C A is not correct as this is a unit of electric field strength B is not correct as units T m^2 could be used as a unit of flux D is not correct as Wb is a unit of flux		1
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(Total for Multiple Choice Questions = 10 marks)



Question Number	Acceptable Answer	Additional Guidance	Mark																																																				
*5	This question assesses a student’s ability to show a coherent and logical structured answer with linkage and fully-sustained reasoning. Indicative content: IC1 As the magnet moves through the coil there is a change in magnetic flux linkage (with coil) Or as the magnet moves through the coil the coil cuts (lines of) magnetic flux Or as the magnet moves through the coil the coil cuts magnetic field lines IC2 An <u>e.m.f.</u> is induced across the coil IC3 This generates a current in the (capacitor) circuit IC4 The diode only allows current in one direction IC5 So capacitor is charged (repeatedly) IC6 When switch is closed capacitor discharges through the LED	Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning. The following table shows how the marks should be awarded for indicative content. <table><tr><th>Number of indicative marking points seen in answer</th><th>Number of marks awarded for indicative marking points</th></tr><tr><td>6</td><td>4</td></tr><tr><td>5–4</td><td>3</td></tr><tr><td>3–2</td><td>2</td></tr><tr><td>1</td><td>1</td></tr><tr><td>0</td><td>0</td></tr></table> <table><tr><th></th><th>Number of marks awarded for structure of answer and sustained line of reasoning</th></tr><tr><td>Answer shows a coherent and logical structure with linkages and fully sustained lines of reasoning demonstrated throughout</td><td>2</td></tr><tr><td>Answer is partially structured with some linkages and lines of reasoning</td><td>1</td></tr><tr><td>Answer has no linkages between points and is unstructured</td><td>0</td></tr></table> Total marks awarded is the sum of marks for indicative content and the marks for structure and lines of reasoning <table><tr><th>IC points</th><th>IC mark</th><th>Max linkage mark</th><th>Max final mark</th></tr><tr><td>6</td><td>4</td><td>2</td><td>6</td></tr><tr><td>5</td><td>3</td><td>2</td><td>5</td></tr><tr><td>4</td><td>3</td><td>1</td><td>4</td></tr><tr><td>3</td><td>2</td><td>1</td><td>3</td></tr><tr><td>2</td><td>2</td><td>0</td><td>2</td></tr><tr><td>1</td><td>1</td><td>0</td><td>1</td></tr><tr><td>0</td><td>0</td><td>0</td><td>0</td></tr></table>	Number of indicative marking points seen in answer	Number of marks awarded for indicative marking points	6	4	5–4	3	3–2	2	1	1	0	0		Number of marks awarded for structure of answer and sustained line of reasoning	Answer shows a coherent and logical structure with linkages and fully sustained lines of reasoning demonstrated throughout	2	Answer is partially structured with some linkages and lines of reasoning	1	Answer has no linkages between points and is unstructured	0	IC points	IC mark	Max linkage mark	Max final mark	6	4	2	6	5	3	2	5	4	3	1	4	3	2	1	3	2	2	0	2	1	1	0	1	0	0	0	0	6
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(Total for Question 5 = 6 marks)



Question Number	Acceptable answers	Additional guidance	Mark
11(a)	An explanation that makes reference to the following points: (1) - current (in coil) produces a magnetic field/flux (1) (a.c.) leads to changing (magnetic) field/flux through <u>pan</u> (1) <u>induces</u> an <u>emf</u> in pan (1) - leads to current (in pan because it is an electrical conductor) (1) MP4 dependent on MP2	MP2 – 4 must relate to the pan	4
11(b)	An explanation that makes reference to the following points: - high frequency means that flux/field is changing quickly Or increases rate of change of flux/field (1) - leads to increased (induced) emf (in pan) Or leads to increase in (induced) current (in pan) (1) MP2 dependent on MP1		2

(Total for Question 11 = 6 marks)



Question Number	Acceptable answers	Additional guidance	Mark
14a(i)	Frequency = 50 Hz (1)	<u>Example of calculation</u> $f = \frac{1}{0.02 \text{ s}} = 50 \text{ Hz}$	1
14a(ii)	Root mean square potential difference = 2.8 V (1)	<u>Example of calculation</u> $V_{\text{rms}} = \frac{4}{\sqrt{2}} = 2.83 \text{ V}$	1
14b(i)	An answer which makes reference to: - Diode only lets current through in one direction (1) (In positive half cycle of input) D2 and D4 conduct Or In positive half cycle of input D2 conducts Or (In negative half cycle of input) D3 and D1 conduct Or negative half cycle D3 conducts (1) - Current towards X Or down through R Or X to Y (1)		3
14b(ii)	- Read off corresponding values of V and t from graph (1) - Use of $\ln V = \ln V_0 - \frac{t}{RC}$ (1) $C = 3.5 \times 10^{-5} \text{ F}$ (1) range $2.7 \times 10^{-5} \text{ F}$ to $3.5 \times 10^{-5} \text{ F}$ Alternate method - Use of $I = V/R$ - Use of $Q = It$ and $C = \Delta Q / \Delta V$ $C = 2.7 \times 10^{-5} \text{ F}$ to $3.5 \times 10^{-5} \text{ F}$	eg this can be any t (in ms) and corresponding V <u>Example of calculation</u> $\ln 3.5 = \ln 4 - \frac{0.008 \text{ s}}{2200 \Omega \times C}$ $C = 2.7 \times 10^{-5} \text{ F}$ Alternate: $I = 3.8 \text{ V} / 2.2 \text{ k}\Omega = 1.73 \text{ mA}$ $Q = 1.73 \text{ mA} \times 8 \text{ ms} = 13.8 \times 10^{-6} \text{ C}$ $C = 13.8 \times 10^{-6} \text{ C} / 0.4 \text{ V} = 3.4 \times 10^{-5} \text{ F}$	3

(Total for Question 14 = 8 marks)



Question Number	Acceptable answers	Additional guidance	Mark
12(a)	- Alternating current/a.c. (in primary) produces changing/alternating magnetic flux/field (1) - The magnetic flux/field is linked to the secondary coil by the iron core (1) - The changing magnetic flux/field induces an emf in the secondary coil (1) - More turns on the secondary (will increase the rate of change of flux linkage according to Faraday's law). (1)	alt. to changing magnetic flux is $\Delta N\phi$ alt. quote of $V_1/V_2 = N_1/N_2$	(4)
12(b)	270K corresponds to a resistivity of $2 \times 10^{-8} (\Omega \text{ m})$ (1) - Use of $P=VI$ (1) - Use of $R=\rho l/A$ (1) - Use of $P=I^2R$ (1) - Power losses from copper cables 19 kW so more than 7 kW and that the superconductor would save energy. MP5 dependant on MP2,3,4 (1) (Acceptable range for Power losses: 9.6 kW to 34 kW)	range allow $2 \times 10^{-8} \Omega \text{ m}$ to $2.1 \times 10^{-8} \Omega \text{ m}$ Example of calculation: $40 \times 10^6 \text{ W} = 110 \times 10^3 \text{ V} \times I$ $I = 364 \text{ A}$ $R = \frac{2 \times 10^{-8} \Omega \text{ m} \times 1.050 \times 10^3 \text{ m}}{145 \times 10^{-6} \text{ m}^2} = 0.145 \Omega$ $P = 364^2 \text{ A}^2 \times 0.145 \Omega = 19.2 \text{ kW}$	5

(Total for Question 12 = 9 marks)



Question Number	Acceptable answers	Additional guidance	Mark																																
*17(a)	This question assesses a student's ability to show a coherent and logically structured answer with linkages and fully-sustained reasoning. Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning. The following table shows how the marks should be awarded for indicative content. Indicative content: Generator: - coil has to be rotated - cuts magnetic flux Or rate of change of flux linkage - induces an emf Motor: - current provided to coil - Force on sides of coil that are perpendicular to magnetic field - rotate coil as forces provide a moment	<table border="1"> <thead> <tr> <th>IC points</th><th>IC mark</th><th>Max linkage mark available</th><th>Max final mark</th></tr> </thead> <tbody> <tr> <td>6</td><td>4</td><td>2</td><td>6</td></tr> <tr> <td>5</td><td>3</td><td>2</td><td>5</td></tr> <tr> <td>4</td><td>3</td><td>1</td><td>4</td></tr> <tr> <td>3</td><td>2</td><td>1</td><td>3</td></tr> <tr> <td>2</td><td>2</td><td>0</td><td>2</td></tr> <tr> <td>1</td><td>1</td><td>0</td><td>1</td></tr> <tr> <td>0</td><td>0</td><td>0</td><td>0</td></tr> </tbody> </table>	IC points	IC mark	Max linkage mark available	Max final mark	6	4	2	6	5	3	2	5	4	3	1	4	3	2	1	3	2	2	0	2	1	1	0	1	0	0	0	0	6
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17(b)(i)	- Use of $P = IV$ (1) - Use of $V = \varepsilon - Ir$ Or $V = 180 - 0.036I$ (1) - Converts kW to W and rearranges equation to that shown (1)	Example of derivation: $88 \text{ kW} = I \times V$ $88 \text{ kW} = I \times (180 - 0.036I)$ $88000 = 180I - 0.036I^2$ $0.036I^2 - 180I + 88000 = 0$	3																																
17(b)(ii)	- Use of $Q = It$ (1) - Time that batteries can deliver this power = 40 s so more than 7 s (1)	Example of calculation: $6.1 \text{ A h} = 550 \text{ A} \times t$ $t = 0.011 \text{ h} = 40 \text{ s}$	2																																

(Total for Question 17 = 11 marks)



Question Number	Acceptable Answer	Additional Guidance	Mark
7(a)(i)	- Use of y-sensitivity value (1) $V_0 = 4.0 \text{ V}$ (1)	<u>Example of calculation:</u> $V_0 = 2 \times 2.0 \text{ V} = 4.0 \text{ V}$	2
7(a)(ii)	- Use of $I = \frac{V}{R}$ (1) - Use of $I_{\text{rms}} = \frac{I_0}{\sqrt{2}}$ (1) - Or use of $V_{\text{rms}} = \frac{V_0}{\sqrt{2}}$ (1) $I_{\text{rms}} = 0.019 \text{ A}$ ECF from(i) (1)	<u>Example of calculation</u> $I_0 = \frac{4.0 \text{ V}}{150 \Omega} = 0.0267 \text{ A}$ $I_{\text{rms}} = \frac{0.0267 \text{ A}}{\sqrt{2}} = 0.0189 \text{ A}$	3
7(a)(iii)	- Use of $R = R_1 + R_2$ (1) - Use of $P = I^2 R$ (or other valid power equation) (1) $P = 0.096 \text{ W}$ ECF from(i) and (ii) (1)	<u>Example of calculation:</u> $R = 150 \Omega + 120 \Omega = 270 \Omega$ $P = I^2 R = (0.019 \text{ A})^2 \times 270 \Omega = 0.0964 \text{ A}$	3
7(b)	MAX 3 - Voltmeter must measure alternating p.d.s Or voltmeter would indicate zero for a.c. (1) - A.C. voltmeter would give an r.m.s. p.d. directly (1) - Voltmeter may draw current and affect the circuit it was connected to Or oscilloscope would have little effect on the circuit it was connected to (1) - Accuracy would depend upon the calibration of the voltmeter (1) - A (digital) voltmeter would give better resolution than measuring trace height on an oscilloscope. (1)	Accept “voltmeter reading would change too fast to measure”	3

(Total for Question 7 = 11 marks)



Question Number	Acceptable answers	Additional guidance	Mark
16(a)(i)	- change in magnetic flux (linkage as motor rotates) (1) Or (copper disc is) cutting magnetic flux/field - therefore there is an <u>induced e.m.f.</u> (according to Faraday's law) (1)	Accept flux linkage for magnetic flux	2
16(a)(ii)	- copper disc rotates in the same direction (1) - because it reduces the rate of magnetic flux change (1) - so as to oppose the change that produces it (1)	Accept induced current produces magnetic fields Or force on current in a magnetic field for MP2 Accept alternatives to flux as in a(i)	3
16(b)	- convert to radians (1) $\omega = 52 \text{ rad s}^{-1}$ (1)	<u>Example of calculation</u> $\omega = \frac{500 \times 2\pi}{60}$ $\omega = 52.4 \text{ radians s}^{-1}$	2
16(c)	- The relationship between ω and turning effect is (approximately) proportional (1) - As speed increases rate of change/cut of magnetic flux increases (1) - this increases the induced current in the copper disc (1) - this will lead to an increase in force (on the copper disc as it is within a magnetic field/flux) (1)	Accept attempt to find a constant ratio and relevant conclusion Accept alternatives to flux as in a(i) accept ref. to emf rather than current Dependent on MP2 or 3	4

(Total for Question 16 = 11 marks)



Question Number	Acceptable Answer	Additional Guidance	Mark																																																				
*17(a)	This question assesses a student’s ability to show a coherent and logically structured answer with linkages and fully-sustained reasoning. Total marks awarded is the sum of marks for indicative content and the marks for structure and lines of reasoning. <table><tr><th>IC points</th><th>IC mark</th><th>Max linkage mark</th><th>Max final mark</th></tr><tr><td>6</td><td>4</td><td>2</td><td>6</td></tr><tr><td>5</td><td>3</td><td>2</td><td>5</td></tr><tr><td>4</td><td>3</td><td>1</td><td>4</td></tr><tr><td>3</td><td>2</td><td>1</td><td>3</td></tr><tr><td>2</td><td>2</td><td>0</td><td>2</td></tr><tr><td>1</td><td>1</td><td>0</td><td>1</td></tr><tr><td>0</td><td>0</td><td>0</td><td>0</td></tr></table> Indicative content: IC1 There is a change in the (magnetic) field/flux (linkage with aluminium disc) Or (disc is) cutting (magnetic) field/flux IC2 So an <u>e.m.f.</u> is <u>induced</u> IC3 There is a current (in the disc) IC4 Force acts on the disc, as there is a current in a magnetic field Or Field due to current in disc interacting with field due to magnet to cause force on disc IC5 The disc moves to reduce the change in field/flux IC6 According to Lenz’s law	IC points	IC mark	Max linkage mark	Max final mark	6	4	2	6	5	3	2	5	4	3	1	4	3	2	1	3	2	2	0	2	1	1	0	1	0	0	0	0	Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning. The following table shows how the marks should be awarded for indicative content. <table><tr><th>Number of indicative points seen in answer</th><th>Number of marks awarded for indicative points</th></tr><tr><td>6</td><td>4</td></tr><tr><td>5-4</td><td>3</td></tr><tr><td>3-2</td><td>2</td></tr><tr><td>1</td><td>1</td></tr><tr><td>0</td><td>0</td></tr></table> <table><tr><th></th><th>Number of marks awarded for structure and lines of reasoning</th></tr><tr><td>Answer shows a coherent and logical structure with linkage and fully sustained lines of reasoning demonstrated throughout</td><td>2</td></tr><tr><td>Answer is partially structured with some linkages and lines of reasoning</td><td>1</td></tr><tr><td>Answer has no linkage between points and is unstructured</td><td>0</td></tr></table> IC4 Accept reference to $F = BIl$ if current in disc has been mentioned IC6 dependent on IC5	Number of indicative points seen in answer	Number of marks awarded for indicative points	6	4	5-4	3	3-2	2	1	1	0	0		Number of marks awarded for structure and lines of reasoning	Answer shows a coherent and logical structure with linkage and fully sustained lines of reasoning demonstrated throughout	2	Answer is partially structured with some linkages and lines of reasoning	1	Answer has no linkage between points and is unstructured	0	6
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17(b)	(The speedometer reading is proportional / related to) angular velocity of axle/cable (1) - As $v = r\omega$ different radii / r will lead to different (road) speeds (1) Or (different diameter) therefore circumference of wheels are different Or one rotation leads to a different distance travelled Or different number of rotations over a set distance (1) - So the angular velocity is different for the same speed Or the velocity is different for the same angular velocity (1)	Accept angular frequency Or frequency of rotations	2
17(c)	- Use of $P = W/t$ and $\Delta W = F\Delta s$ (1) - Use of $\Delta E_{\text{grav}} = mg\Delta h$ (1) - Use of principle of conservation of energy [MP3 dependent on MP2] (1) - Velocity = $5.5 \text{ (m s}^{-1}\text{)}$ so speedometer reading slightly inaccurate Or Velocity = $5.5 \text{ (m s}^{-1}\text{)}$ so speedometer reading is quite accurate Or Total power = 334 (W) so speedometer reading must have been correct (1)	<u>Example of calculation</u> $190 \text{ W} = F \times 8.3 \text{ m s}^{-1}$ $F = 22.9 \text{ N}$ Power loss due to friction and air resistance = $22.9 \text{ N} \times v$ Gain in G.P.E. / second = $75 \text{ kg} \times 9.81 \text{ m s}^{-2} \times \frac{v}{20}$ $330 \text{ W} = 22.9 \text{ N} \times v + 75 \text{ kg} \times 9.81 \text{ m s}^{-2} \times \frac{v}{20}$ $330 \text{ W} = 22.9v + 36.79v = 59.7v$ $v = 5.53 \text{ m s}^{-1}$ Alternative resulting on comparison of power: $190 \text{ W} = F \times 8.3 \text{ m s}^{-1}$ $F = 22.9 \text{ N}$ Gain in G.P.E. / second = $75 \text{ kg} \times 9.81 \text{ m s}^{-2} \times \frac{5.6}{20} \text{ m s}^{-1}$ Gain in G.P.E. / second = 206 W Power loss due to friction and air resistance = $22.9 \text{ N} \times 5.6 \text{ m s}^{-1} = 128 \text{ W}$ Total power = 334 W	4



	Alternative based on resolving forces: • Use of $P = W/t$ and $\Delta W = F\Delta s$ • Determines a component of force • Determines total force along the slope • Velocity = 5.5 m s^{-1} so (speedometer reading) slightly inaccurate Or Velocity = 5.5 m s^{-1} so (speedometer reading) is accurate Or Total power = 334 (W) so (speedometer reading) must be correct	Alternative based on resolving forces: $190 \text{ W} = F \times 8.3 \text{ m s}^{-1}$ $F = 22.9 \text{ N}$ Component of weight along slope = $75 \text{ kg} \times 9.81 \text{ m s}^{-2} \times \frac{1}{20}$ as $\sin \theta \sim \tan \theta = 1/20$ Force up slope from cyclist = $22.9 \text{ N} + 75 \text{ kg} \times 9.81 \text{ m s}^{-2} \times \frac{1}{20} = 59.7 \text{ N}$ So velocity of cyclist = $\frac{330 \text{ W}}{59.7 \text{ N}} = 5.53 \text{ m s}^{-1}$ Or Cyclist Power = $59.7 \text{ N} \times 5.6 \text{ m s}^{-1} = 334 \text{ W}$	
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(Total for Question 17 = 12 marks)



Question Number	Acceptable Answer	Additional Guidance	Mark
10(a)	- Use of $P = \frac{V^2}{R}$ $P = 48.2 \text{ (W)}$	(1) <u>Example of calculation</u> (1) $P = \frac{(8.5 \text{ V})^2}{1.5 \Omega} = 48.2 \text{ W}$ Bald answer of 48.2 can score MP2 only Bald answer of 48 scores 0	2
10(b)	- Use of $\rho = \frac{m}{V}$ - Use of $\Delta E = mc\Delta\theta$ - Use of $P = \frac{\Delta W}{\Delta t}$ - Time = 128 s (ecf from (a))	(1) <u>Example of calculation</u> (1) $m = 1.25 \times 10^{-4} \text{ m}^3 \times 1050 \text{ kg m}^{-3} = 0.131 \text{ kg}$ (1) $t = \frac{0.131 \text{ kg} \times 3930 \text{ J kg}^{-1} \text{ K}^{-1} \times 12 \text{ K}}{48.2 \text{ W}} = 128 \text{ s}$ (1) Allow 130s Show that value gives 129 s	4



10(c)	• (Connect oscilloscope to the a.c. supply and) adjust time base so that a complete wave can be seen on the screen (1) • Measure the (horizontal) distance from peak to peak (1) • Use the time base setting $\times$ distance between peaks (to determine the time for one cycle) (1) • Use $f = \frac{1}{T}$ to calculate the supply frequency (1) • Use the voltage sensitivity and amplitude (of a peak to determine the peak p.d.) (1) • Use $V_{\text{rms}} = \frac{V_0}{\sqrt{2}}$ (to calculate the r.m.s. p.d. and compare with the voltmeter reading) (1)	Accept several complete cycles for MP1, but in that case require measurement across several cycles for MP2.	6
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(Total for Question 10 = 12 marks)



Question Number	Acceptable answers	Additional guidance	Mark
18(a)(i)	$V_{\text{rms}} = 3.5 \text{ V}$ (1)	<u>Example of calculation</u> $V_{\text{rms}} = \frac{5}{\sqrt{2}} = 3.54 \text{ V}$	1
18(a)(ii)	An explanation that makes reference to the following points: “5” is the peak value (of pd) (1) - Use of $T = 1/f$ Or $\omega = 2\pi/T$ Or $\omega = 2\pi f$ (1) - Uses $\omega = 100\pi$ to show that the time period should be 0.02 s Or Uses $f = 50$ to show that $\sin 2\pi f t$ is $\sin 100\pi t$ (1) - Uses $T = 0.02$ to show that $100\pi \cdot 0.02 = 2\pi$	Accept max for peak Alternative MP2: recognises that one period/cycle of the sine wave is an angle of 2π	3
18(b)(i)	$Q = CV$ Or $E_{10} = C_{10} \cdot C$ (1) - where $C = 0.001 \text{ (F)}$ (1) MP2 dependent on MP1		2
18(b)(ii)	$I = \Delta Q / \Delta t$ Or $G_{11} = F_{11} / B_{11}$ (1)		1
18(b)(iii)	- Use of $W = \frac{1}{2} CV^2$ Or $W = \frac{1}{2} QV$ Or $W = \frac{1}{2} \frac{Q^2}{C}$ (1) $W = 0.0125 \text{ J}$ (1)	<u>Example of calculation</u> $W = \frac{1}{2} 0.001 \text{ F} \times 5^2 \text{ V}^2 = 0.0125 \text{ J}$ $W = \frac{1}{2} 0.005 \text{ C} \times 5 \text{ V} = 0.0125 \text{ J}$	2
18(c)	- States $P = IV$ (1) - any two corresponding values of I and V used to calculate a value of P (1) - observation that at different times P is negative or positive (1) - Overall power dissipated by capacitor is zero (1)	Graph could be marked with values/lines/power curve Alternative MP2: recognise the symmetry of either quarter or half cycles of the graphs	4

(Total for Question 18 = 13 marks)



Question Number	Acceptable answers	Additional guidance	Mark
18(a)	- There is a (rate of) change of flux (linkage)/field with the (moving coil) (1) - Induces an emf (and current) (1) - To oppose the change that created (the induced current) (1) - Wheels will slow down/not turn as fast (1) MP4 dependent on MP3	Accept magnetic field (due to induced current) will oppose original field	4
18(b)(i)	- Converts speed to m s^{-1} Or converts time to hours (1) - Determines gradient of graph Or uses appropriate equation of motion (1) - Acceleration = 0.22 m s^{-2} Or 2800 km h^{-2} (1) range 2800-2900 km h^{-2}	<u>Example of calculation</u> $360 \text{ km/h} = 360000 \text{ m} / 3600 \text{ s} = 100 \text{ m s}^{-1}$ $a = \frac{100 \text{ m s}^{-1}}{450 \text{ s}} = 0.222 \text{ m s}^{-2}$	3
18(b)(ii)	- Determines area under graph for a time of 450 s. Or use of appropriate equation of motion (1) - Distance = 22.5 km (1) 22.5 km is less than 40 km so meets specification (1) Or - Use of appropriate equation of motion to calculate v - velocity = 130 m s^{-1} 130 m s^{-1} is more than 100 m s^{-1} so meets specification Or - Use of appropriate equation of motion to calculate a	<u>Example of calculation</u> $s = \frac{(0+100 \text{ m s}^{-1})}{2} \times 450 \text{ s} = 22.5 \text{ km}$ Or $v^2 = 2 \times 0.22 \text{ m s}^{-2} \times 40000 \text{ m}$ $v = 133 \text{ m s}^{-1}$ Or $(3600 \text{ km h}^{-1})^2 = 2 \times a \times 40 \text{ km}$ $a = 1620 \text{ km h}^{-2}$	3



	$a = 1620 \text{ km h}^{-2}$ 1620 km h^{-2} is less than 2800 km h^{-2} so meets specification		
18(c)(i)	- If the track is curved then a centripetal force is required (1) - This force provided by reaction force between wheel and rails (1) - The centripetal force is given by $F = mv^2/r$ (1) - There will be a maximum speed at which the train will leave the track (and the train must travel at less than this speed) as there is a maximum value of reaction/friction (between wheels and rails) (1)	Accept Force towards the centre Accept This force is provided by friction (between rail and wheels) Accept Train slips off track if centripetal force is larger than reaction/friction can provide	4
18(c)(ii)	- Use of constant $= v^2/r$ (1) $r = 5800 \text{ m}$ (1)	<u>Example of calculation</u> As $v^2/r = \text{constant } (k)$ $k = 200^2 (\text{km h}^{-1})^2 / 1800 \text{ m} = 22.22$ $r = 360^2 (\text{km h}^{-1})^2 / 22.22 \text{ m} (\text{km h}^{-1})^{-2}$ $r = 5840 \text{ m}$	2

(Total for Question 18 = 16 marks)

