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)

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** $\dfrac{I_0}{e}$

☒ **B** $\dfrac{I_0}{2}$

☒ **C** $I_0 e^{-RC}$

☒ **D** $I_0 \ln \dfrac{1}{e}$

(Total for Question 8 = 1 mark)

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.

iron core

secondary coil

primary coil
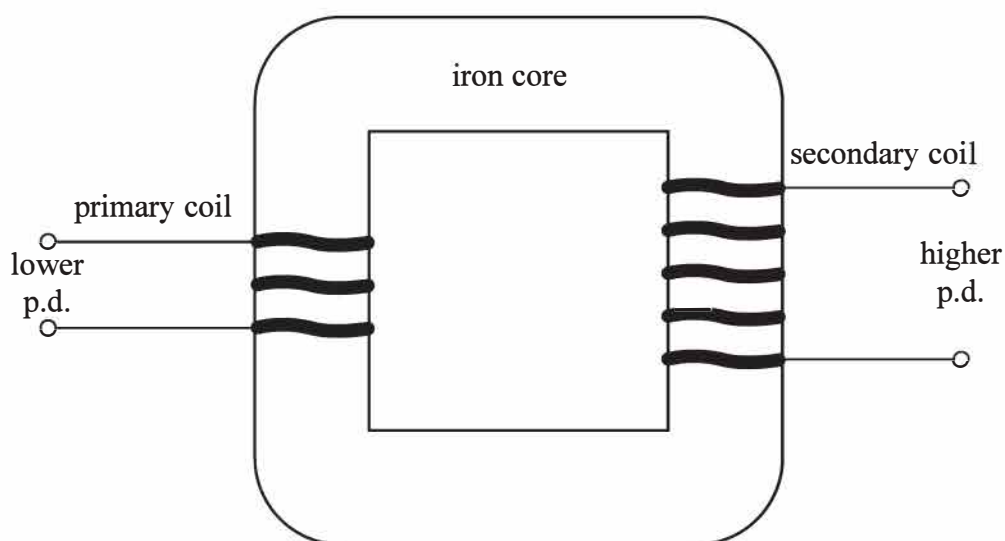
lower
p.d.

higher
p.d.

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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(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In one project a 1.05 km length of copper cable at a temperature of 270 K has been replaced by a superconductor.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.
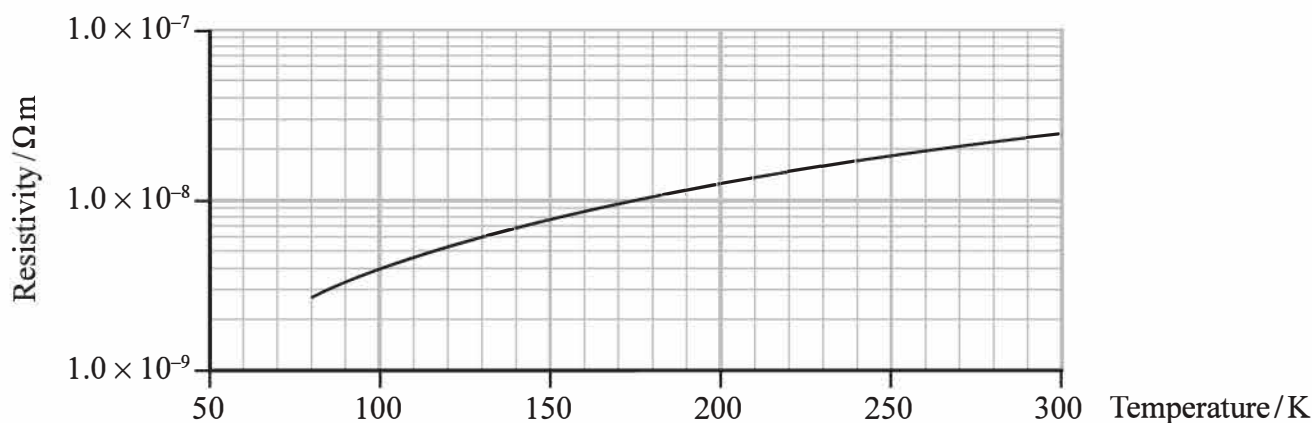
Deduce whether the power requirement of the superconductor cooling system is less than the power losses in the copper cable.

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)

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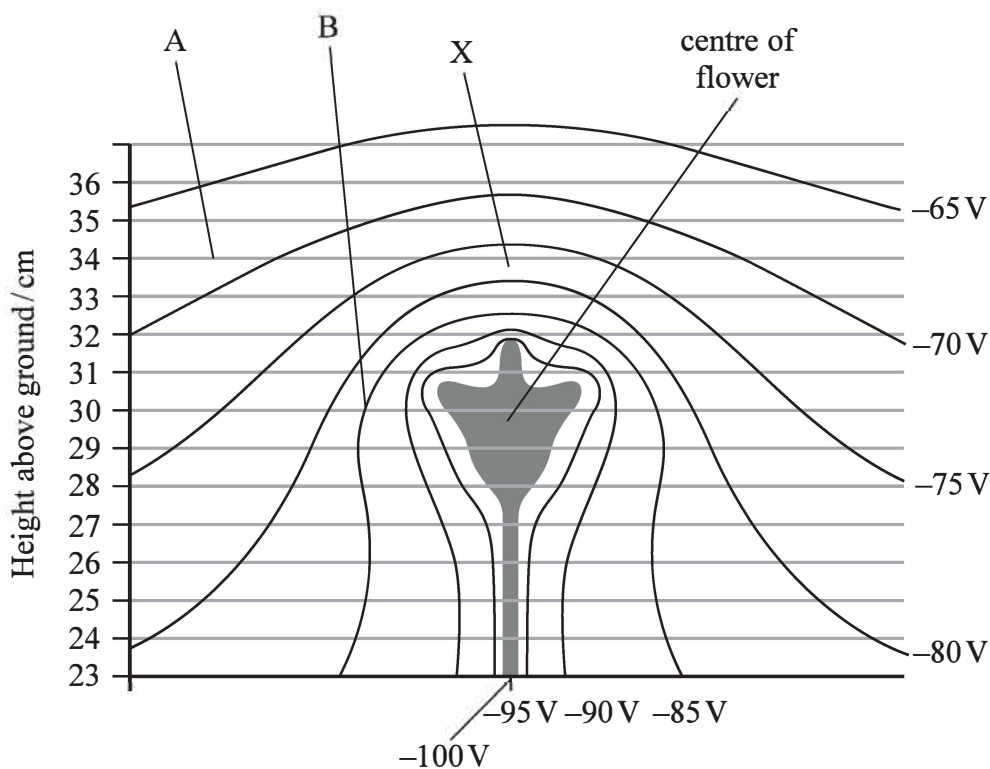**(Total for Question 12 = 9 marks)**

P 5 8 3 5 8 A 0 1 1 2 8

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)

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

(i) Determine the electric field strength at X.

(3)

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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

$$V = \frac{Q}{4\pi\varepsilon_0 r}$$

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)

(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)

(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)

(Total for Question 13 = 11 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.
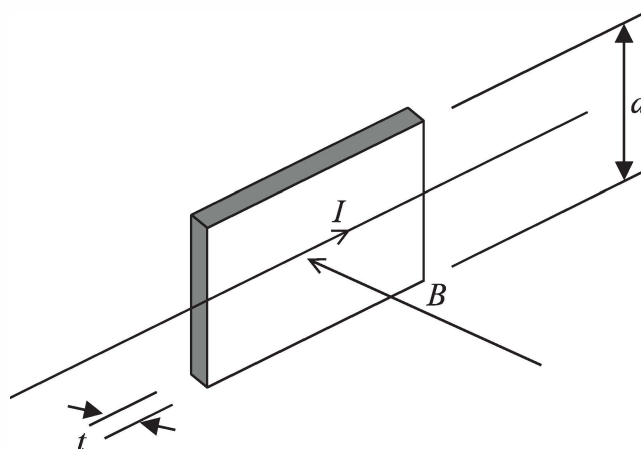
Electrons collect at the top edge of the slice and the bottom edge becomes positively charged. As a result a potential difference known as a Hall voltage V_{HALL} develops.

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

(2)

P 5 8 3 5 8 A 0 2 0 2 8

(b) Add to the diagram to show clearly two points between which V_{HALL} develops.

(1)

(c) Electrons continue to collect at the top edge of the slice, until the force on a moving electron due to the magnetic field is equal to the force on the electron due to the electric field.

Derive the following equation for V_{HALL}:

$$V_{HALL} = \frac{BI}{nte}$$

where n is the number of charge carriers per unit volume of the semiconductor.

(4)

(d) Show that the units are the same on each side of the equation

$$V_{HALL} = \frac{BI}{nte}$$

(3)

(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)

(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)

Angle = ...

(Total for Question 17 = 14 marks)

TOTAL FOR PAPER = 90 MARKS

Answer All questions.

All multiple choice questions must be answered with a cross ⊠ in the box for the correct answer from A to D. If you change your mind about an answer, put a line through the box ⊠ and then mark your new answer with a cross ⊠.

1   Which of the following is an example of a scalar quantity?

   ⊠   **A** displacement

   ⊠   **B** energy

   ⊠   **C** momentum

   ⊠   **D** velocity

(**Total for Question 1 = 1 mark**)

2   Which row of the table summarises the mass and charge of an antineutron?

	Mass / u	Charge / e
⊠ **A**	0	0
⊠ **B**	0	−1
⊠ **C**	1	0
⊠ **D**	1	+1

(**Total for Question 2 = 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** $\dfrac{F}{2}$

   ⊠   **C** $\dfrac{F}{3}$

   ⊠   **D** $\dfrac{F}{4}$

(**Total for Question 3 = 1 mark**)

6 The graph shows how an electric potential V varies with distance x.
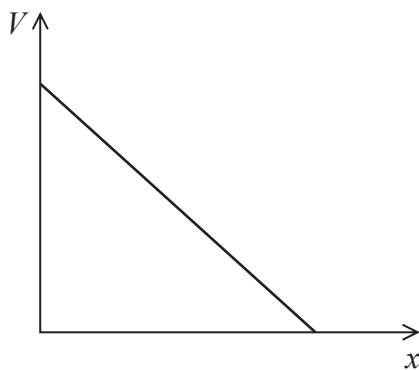
Which of the following shows the corresponding variation of electric field strength E with x?
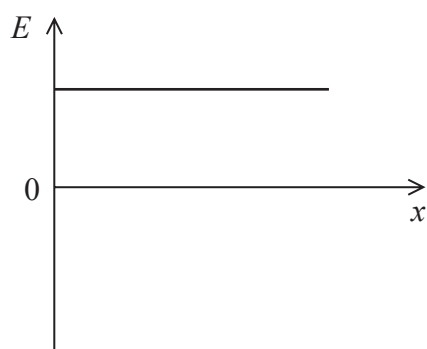
⊠ **A**
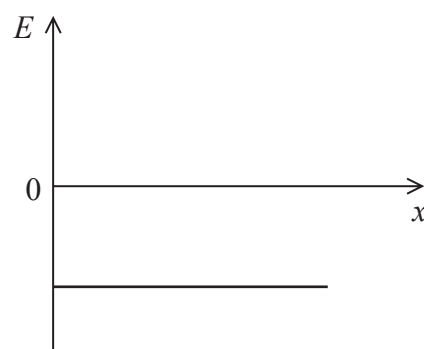
⊠ **B**
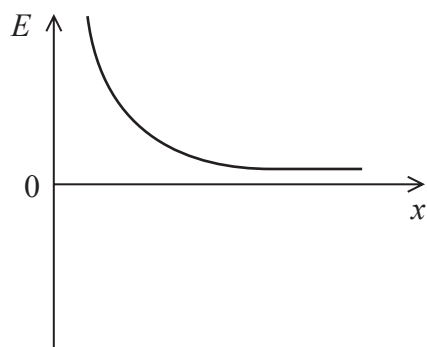
⊠ **C**
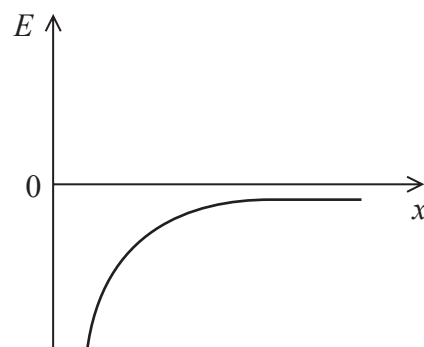
⊠ **D**

(Total for Question 6 = 1 mark)

14 The diagram shows a model used to demonstrate alpha particle scattering. A ball bearing is set rolling on a wooden track. The track is positioned so that the ball bearing rolls onto a metal sheet with a curved surface known as a 'hill'.
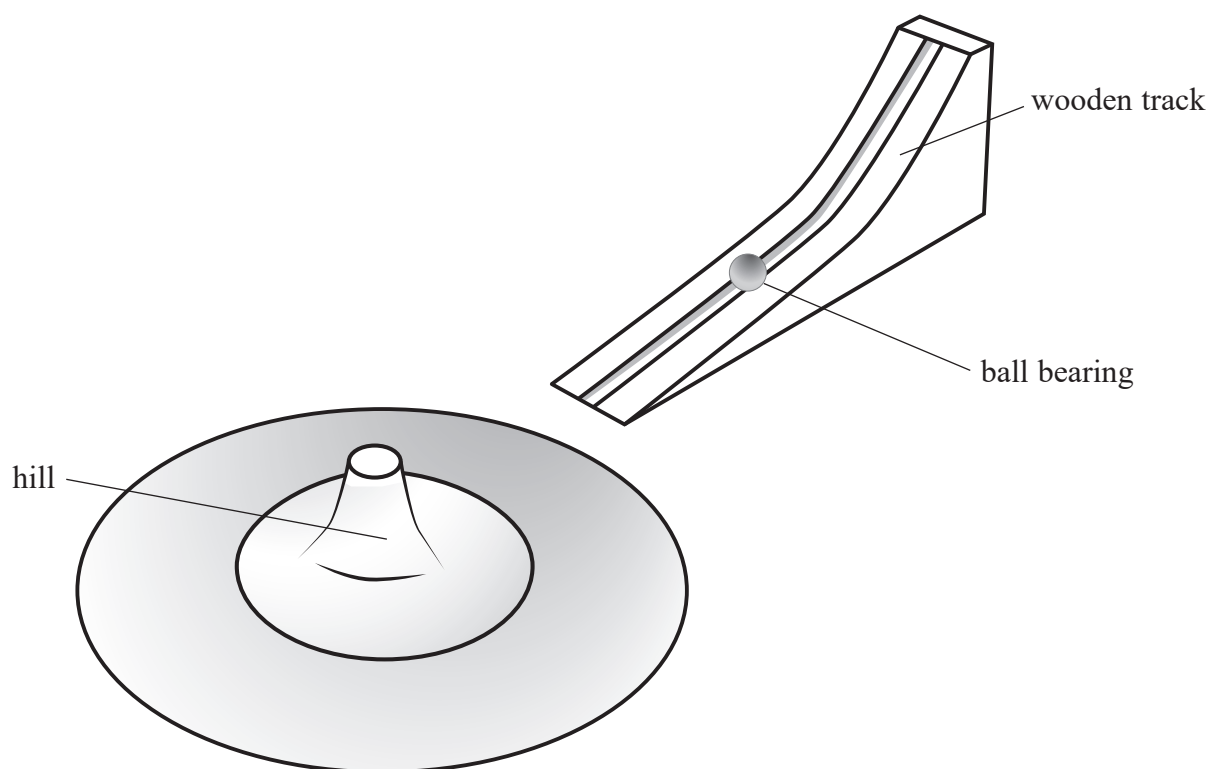
The diagram shows a vertical cross-section through the hill. The surface is curved so that the height of a point h on the curved surface is inversely proportional to the distance r from the centre of the hill.
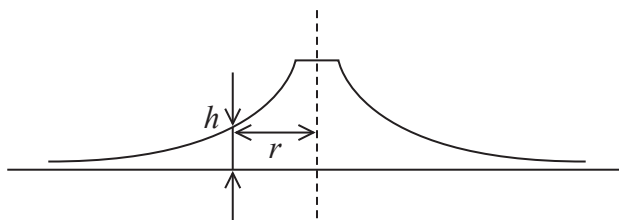
(a) Explain why the hill is suitable as a model for the electric field surrounding the nucleus of an atom.

(3)

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(b) A plan view of the arrangement is shown.
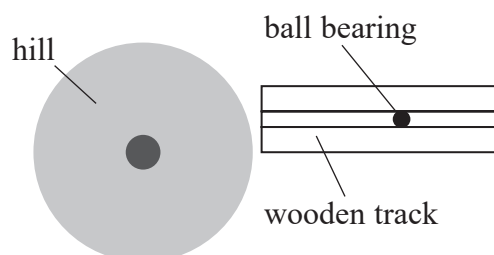
The wooden track is moved to different positions and the ball bearing is released.

Describe the results of the alpha particle scattering experiment and how these can be demonstrated by moving the wooden track to different positions.

(4)

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(Total for Question 14 = 7 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.
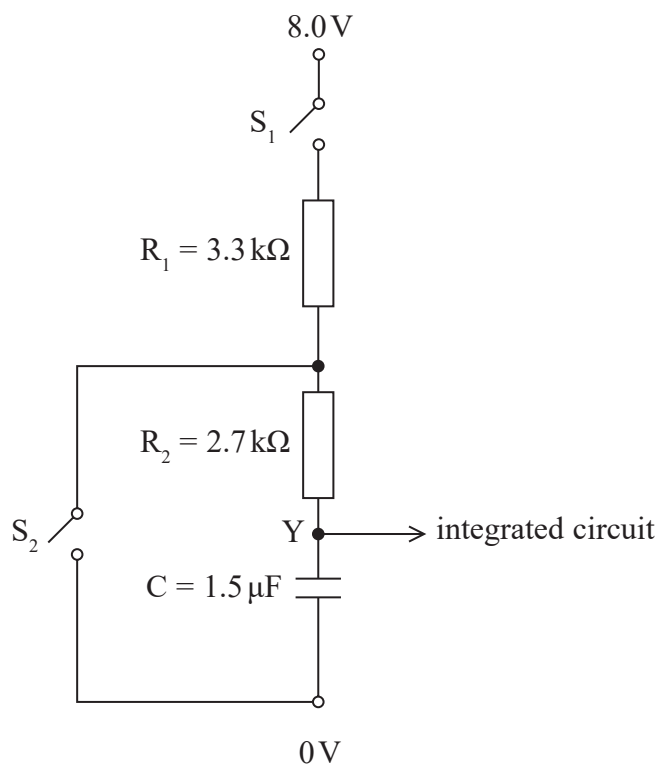
(a) Initially the capacitor is uncharged. The switch S_1 is closed.

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

(3)

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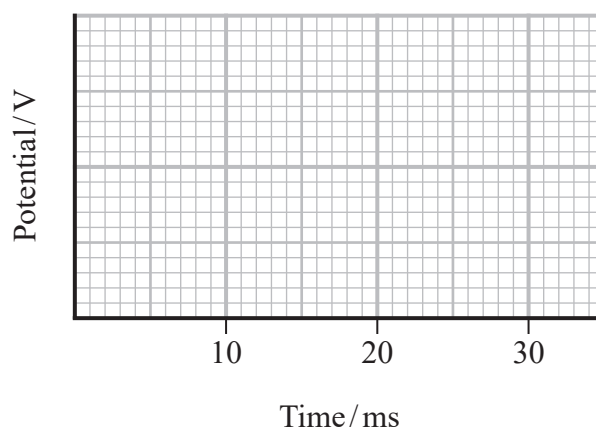
(b) When the potential at Y is 8.0 V, the switch S_2 is closed.

(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)

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.
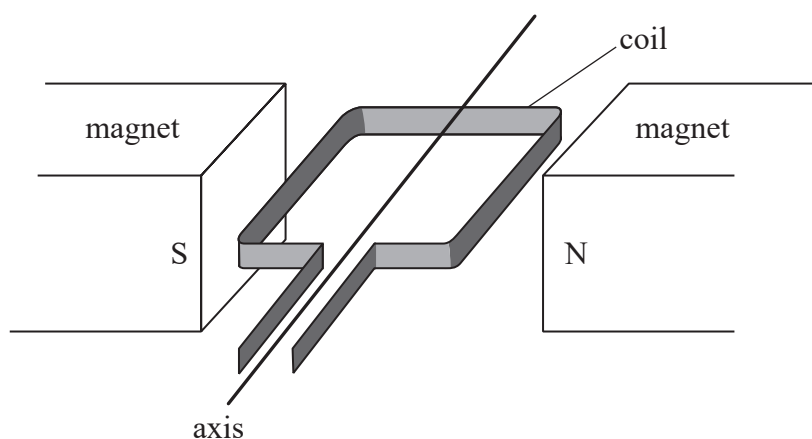

*(a) Describe how the device can be used as both a generator and an electric motor.

(6)

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(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 Ω.

180 V

0.036 Ω

↑ I

M
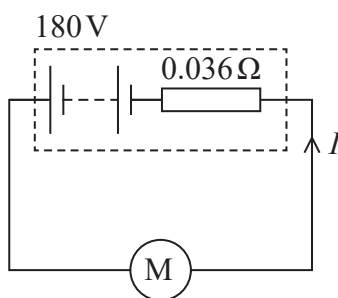
The motor has a maximum power of 88 kW.

(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 $I = 550$ A. At maximum power, the car can accelerate from rest to sixty miles per hour in under 7 s.

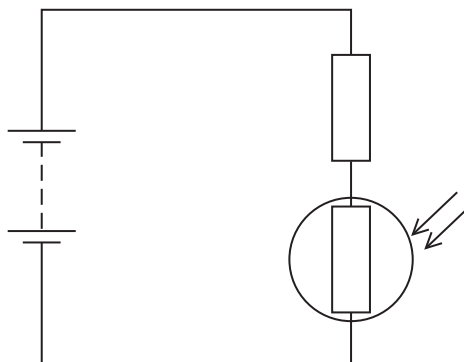The maximum charge capacity of the battery within this HEV is 6.1 amp-hour.

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

(2)

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(Total for Question 17 = 11 marks)

7 A light dependent resistor (LDR) and a resistor are connected to a battery, as shown.

The intensity of light incident on the LDR increases.

Which row of the table describes the change in the resistance of the LDR and the change in the potential difference across the resistor?

	Resistance of LDR	Potential difference across the resistor
☒ **A**	decreases	decreases
☒ **B**	decreases	increases
☒ **C**	increases	decreases
☒ **D**	increases	increases

(Total for Question 7 = 1 mark)

8 A potential difference is applied across two parallel plates. A particle carrying a charge of +0.1 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)

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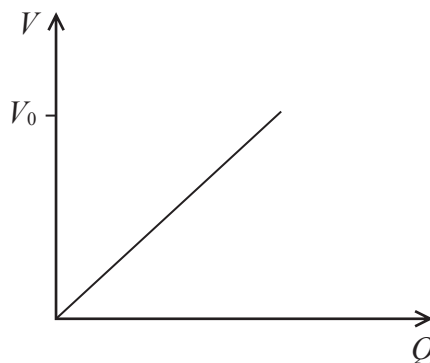
At a potential difference V_0 a small charge ΔQ is added to the capacitor. This results in a small increase in potential difference ΔV across the capacitor.

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** $\dfrac{\Delta V \times \Delta Q}{2}$

☒ **C** $V_0 \times \Delta Q$

☒ **D** $\dfrac{V_0 \times \Delta Q}{2}$

(Total for Question 9 = 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)

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

0V ——— metal plate

+100V ——— metal plate
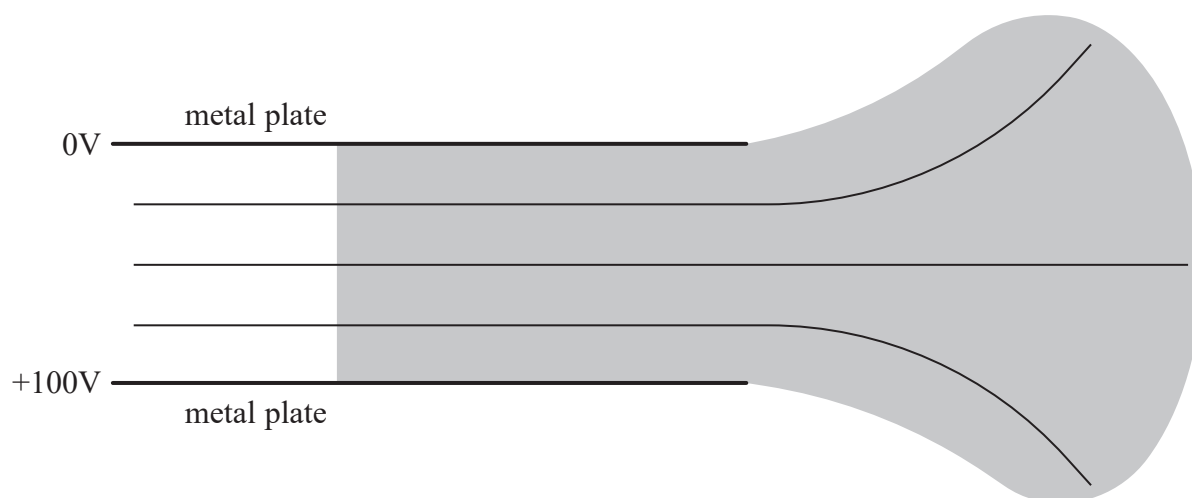
(a) Draw lines to represent the electric field in the shaded area.

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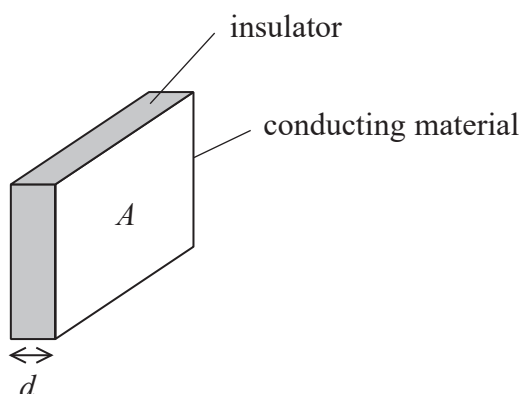
The capacitor has a capacitance $0.1\,\mu F$ and is charged to a p.d. of $100\,V$ by connecting it to an electrical supply.

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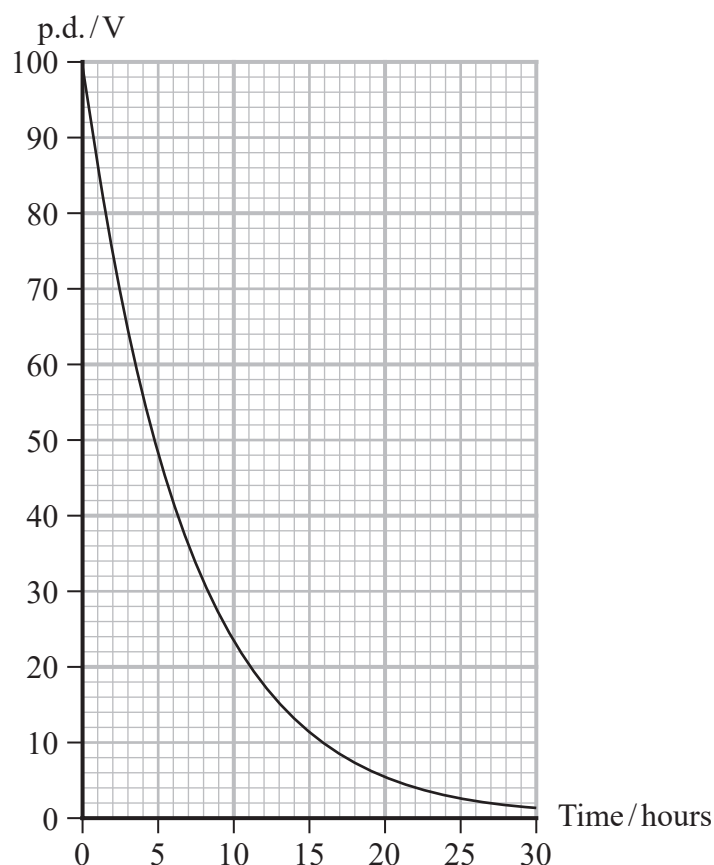
The insulator is a type of plastic and should have a resistivity greater than $10^{14}\,\Omega\,\mathrm{m}$.

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

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

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

(5)

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(Total for Question 13 = 9 marks)

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

Plan view

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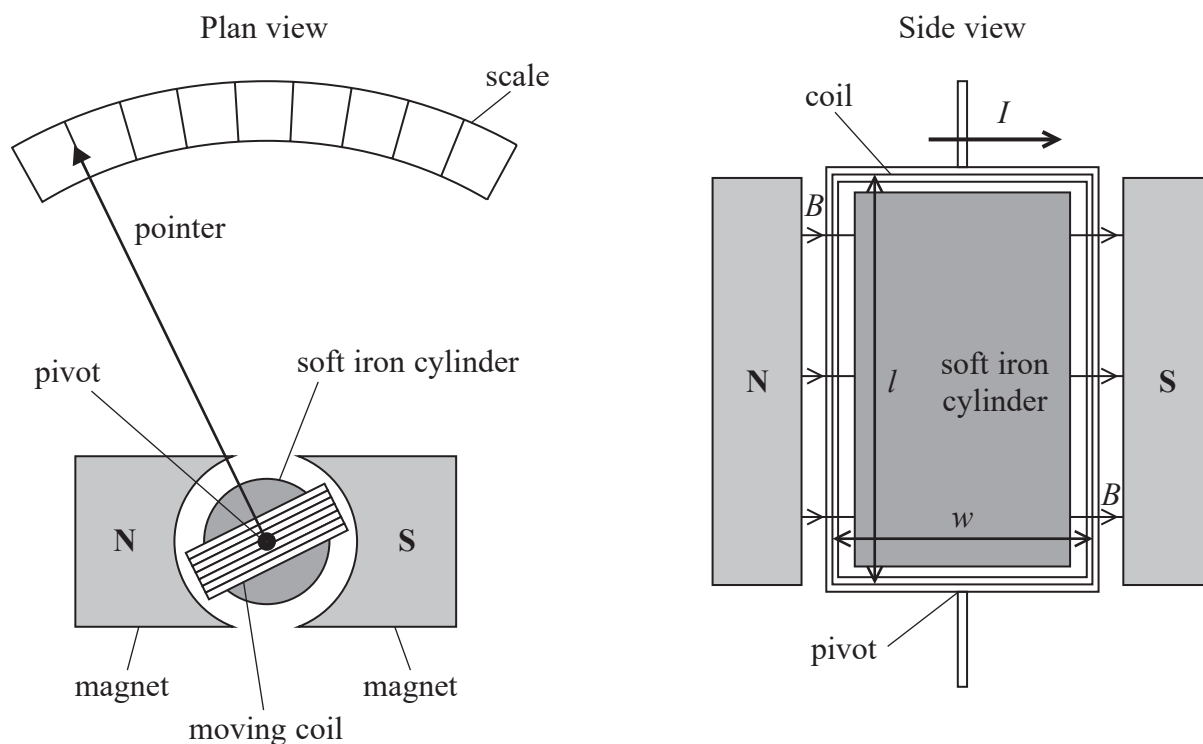
The fixed soft iron cylinder and magnets produce a uniform magnetic field of magnetic flux density B. The coil is able to rotate within this magnetic field. The coil has width w and length l. There is a current I in the coil in the direction shown in the side view diagram.

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

(2)

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(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)

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(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.
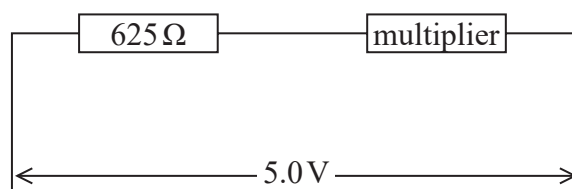
The following multipliers are available:

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

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)

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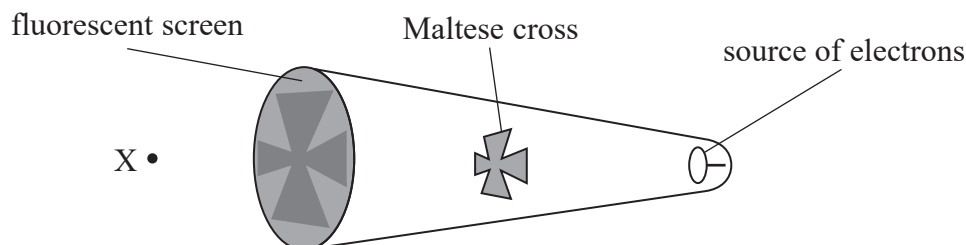**(Total for Question 17 = 13 marks)**

TOTAL FOR PAPER = 90 MARKS

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.

4 The electrons are produced by heating a metal filament.

Which of the following is the name of this process?

⊠ **A** ionisation

⊠ **B** scattering

⊠ **C** the photoelectric effect

⊠ **D** thermionic emission

(Total for Question 4 = 1 mark)

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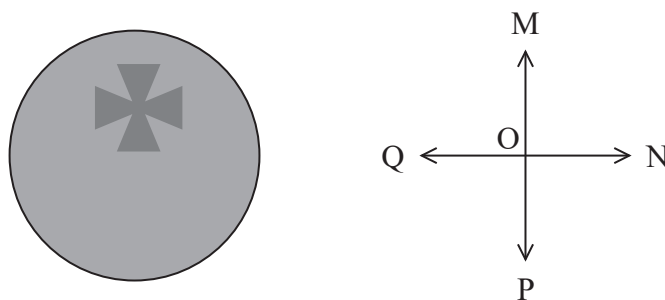
In which of the following directions is the magnetic field acting as seen by this observer?

⊠ **A** OM

⊠ **B** ON

⊠ **C** OP

⊠ **D** OQ

(Total for Question 5 = 1 mark)

6 The graph shows how the potential V varies with distance d in an electric field.
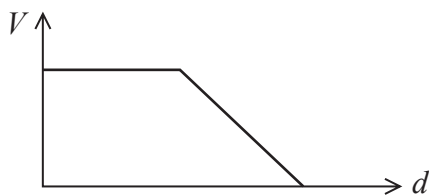
Which of the following shows the corresponding variation in electric field strength E?

☒ **A**

☒ **B**

☒ **C**

☒ **D**
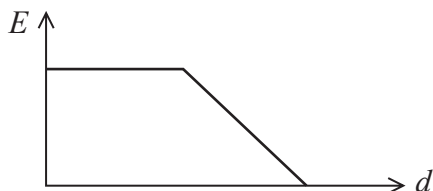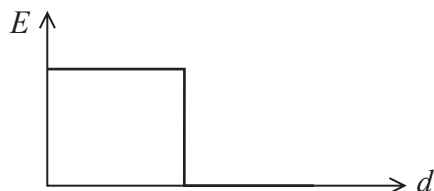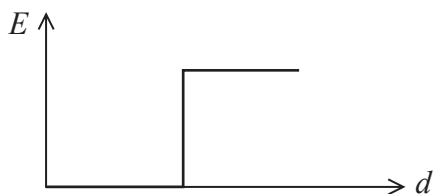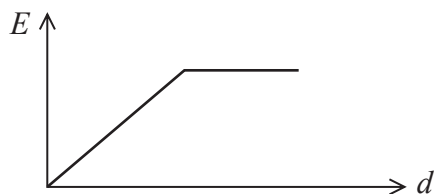
(Total for Question 6 = 1 mark)

7 Which of the following quantities is a vector?

☒ **A** charge

☒ **B** mass

☒ **C** momentum

☒ **D** time

(Total for Question 7 = 1 mark)

P 6 9 3 0 6 A 0 4 2 8

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**
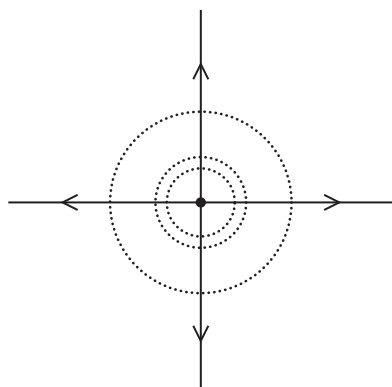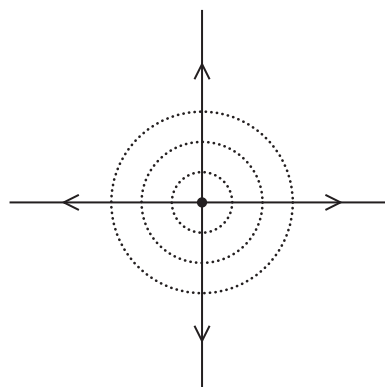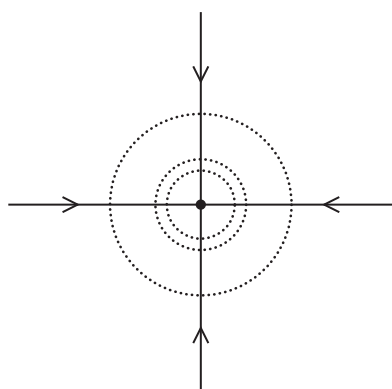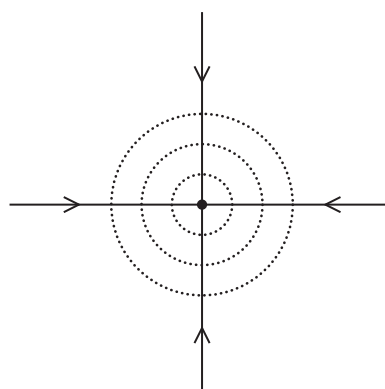
(Total for Question 8 = 1 mark)

Questions 9 and 10 refer to the information below.

Alpha particle scattering investigations were first carried out in the early part of the 20th century.

9 An alpha particle with initial kinetic energy 8.8×10^{-13} J approaches a nucleus of a gold $\left(^{197}_{79}\text{Au}\right)$ atom.

Which of the following is an equation for the closest distance r, in metres, between the alpha particle and the nucleus?

☒ **A** $r = 8.99 \times 10^9 \left(\dfrac{2 \times 1.6 \times 10^{-19} \times 79 \times 1.6 \times 10^{-19}}{8.8 \times 10^{-13}} \right)$

☒ **B** $r = \dfrac{2 \times 1.6 \times 10^{-19} \times 197 \times 1.6 \times 10^{-19}}{8.99 \times 10^9 \times 8.8 \times 10^{-13}}$

☒ **C** $r = 8.99 \times 10^9 \left(\dfrac{8.8 \times 10^{-13}}{4 \times 1.6 \times 10^{-19} \times 79 \times 1.6 \times 10^{-19}} \right)$

☒ **D** $r = 8.99 \times 10^9 \left(\dfrac{2 \times 79}{8.8 \times 10^{-13}} \right)$

(Total for Question 9 = 1 mark)

10 Which of the following conclusions could **not** be made as a result of these investigations?

☒ **A** The atom is mostly empty space.

☒ **B** The atom is neutral.

☒ **C** The nucleus is charged.

☒ **D** The nucleus is very small compared to the atom.

(Total for Question 10 = 1 mark)

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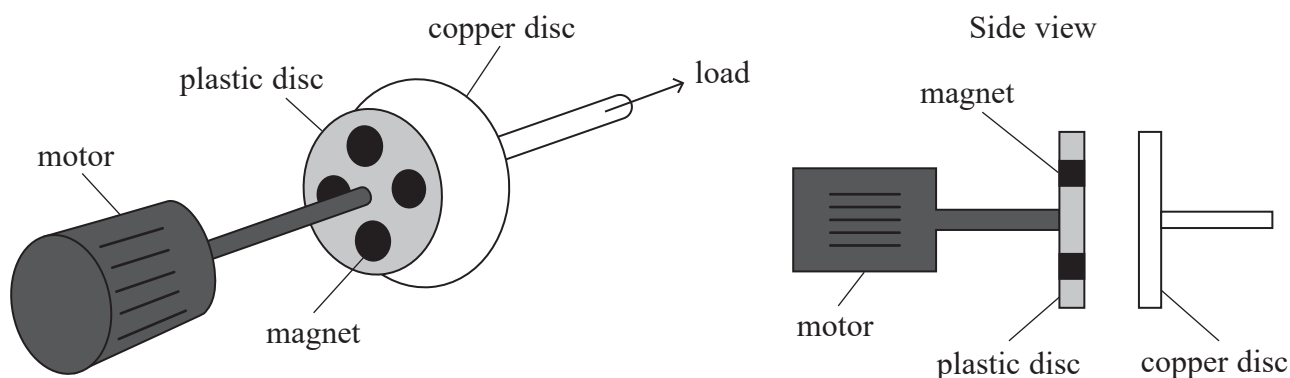
Several magnets are embedded in the plastic disc and it is rotated by the motor.

(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.

ω / 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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(Total for Question 16 = 11 marks)

Answer ALL questions.

All multiple choice questions must be answered with a cross in the box ⊠ for the correct answer from A to D. If you change your mind about an answer, put a line through the box ⊠ and then mark your new answer with a cross ⊠.

1 One isotope of oxygen is $^{17}_{8}\text{O}$.

Which row of the table shows the number of neutrons and the number of protons in a nucleus of $^{17}_{8}\text{O}$?

		Number of neutrons	Number of protons
⊠	**A**	8	9
⊠	**B**	8	17
⊠	**C**	9	8
⊠	**D**	17	8

(Total for Question 1 = 1 mark)

2 A subatomic particle consists of the quark combination u s̄.

Which of the following is the classification for this particle?

⊠ **A** baryon

⊠ **B** lepton

⊠ **C** meson

⊠ **D** nucleon

(Total for Question 2 = 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** $t = \dfrac{\ln 2}{T}$

⊠ **B** $t = \ln \dfrac{1}{2T}$

⊠ **C** $t = T \ln \dfrac{1}{2}$

⊠ **D** $t = T \ln 2$

(Total for Question 3 = 1 mark)

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.

pan

ceramic
material

coil connected to
an a.c. supply
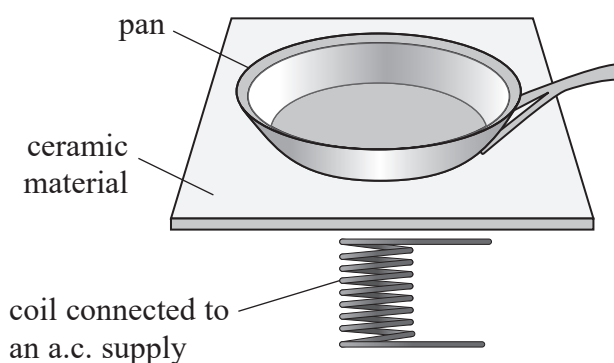
(a) A steel pan containing water is placed on the induction hob.

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)

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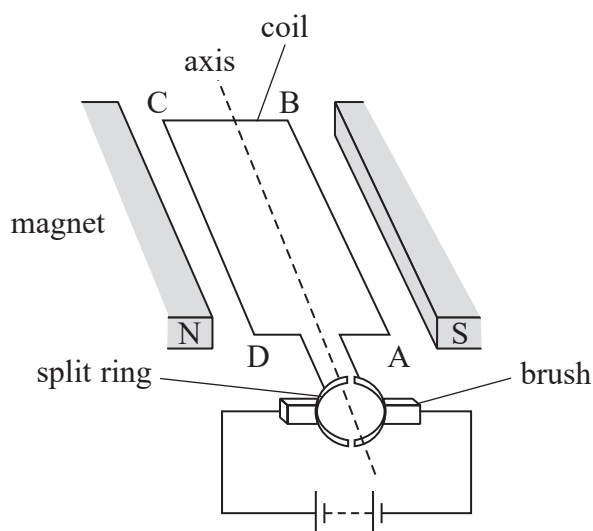
*(a) Describe how this arrangement can lead to the coil rotating.

(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 $28\,\text{m s}^{-1}$ from rest in 4.0 s at maximum power

Calculate the work done by resistive forces when the car accelerates to a velocity of $28\,\text{m s}^{-1}$ 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)

P 7 1 9 1 5 A 0 1 7 2 8