# Advanced Higher Physics

# Electromagnetism

# Homework

**DATA SHEET**

COMMON PHYSICAL QUANTITIES

| *Quantity* | *Symbol* | *Value* | *Quantity* | *Symbol* | *Value* |
|---|---|---|---|---|---|
| Gravitational acceleration on Earth | $g$ | $9{\cdot}8\ \text{m s}^{-2}$ | Mass of electron | $m_e$ | $9{\cdot}11 \times 10^{-31}$ kg |
| Radius of Earth | $R_E$ | $6{\cdot}4 \times 10^{6}$ m | Magnitude of charge on electron | $e$ | $1{\cdot}60 \times 10^{-19}$ C |
| Mass of Earth | $M_E$ | $6{\cdot}0 \times 10^{24}$ kg | Mass of neutron | $m_n$ | $1{\cdot}675 \times 10^{-27}$ kg |
| Mass of Moon | $M_M$ | $7{\cdot}3 \times 10^{22}$ kg | Mass of proton | $m_p$ | $1{\cdot}673 \times 10^{-27}$ kg |
| Mean Radius of Moon Orbit | | $3{\cdot}84 \times 10^{8}$ m | Mass of alpha particle | $m_\alpha$ | $6{\cdot}645 \times 10^{-27}$ kg |
| Universal constant of gravitation | $G$ | $6{\cdot}67 \times 10^{-11}\ \text{m}^3\,\text{kg}^{-1}\,\text{s}^{-2}$ | Planck's constant | $h$ | $6{\cdot}63 \times 10^{-34}$ J s |
| Speed of light in vacuum | $c$ | $3{\cdot}0 \times 10^{8}\ \text{m s}^{-1}$ | Permittivity of free space | $\varepsilon_0$ | $8{\cdot}85 \times 10^{-12}\ \text{F m}^{-1}$ |
| Speed of sound in air | $v$ | $3{\cdot}4 \times 10^{2}\ \text{m s}^{-1}$ | Permeability of free space | $\mu_0$ | $4\pi \times 10^{-7}\ \text{H m}^{-1}$ |

REFRACTIVE INDICES

The refractive indices refer to sodium light of wavelength 589 nm and to substances at a temperature of 273 K.

| *Substance* | *Refractive index* | *Substance* | *Refractive index* |
|---|---|---|---|
| Diamond | 2·42 | Glycerol | 1·47 |
| Glass | 1·51 | Water | 1·33 |
| Ice | 1·31 | Air | 1·00 |
| Perspex | 1·49 | Magnesium fluoride | 1·38 |

SPECTRAL LINES

| *Element* | *Wavelength*/nm | *Colour* | *Element* | *Wavelength*/nm | *Colour* |
|---|---|---|---|---|---|
| Hydrogen | 656 | Red | Cadmium | 644 | Red |
| | 486 | Blue-green | | 509 | Green |
| | 434 | Blue-violet | | 480 | Blue |
| | 410 | Violet | *Lasers* | | |
| | 397 | Ultraviolet | | | |
| | 389 | Ultraviolet | *Element* | *Wavelength*/nm | *Colour* |
| | | | Carbon dioxide | 9550 | Infra red |
| Sodium | 589 | Yellow | | 10590 | Infra red |
| | | | Helium-neon | 633 | Red |

PROPERTIES OF SELECTED MATERIALS

| *Substance* | *Density*/ $\text{kg m}^{-3}$ | *Melting Point*/ K | *Boiling Point*/ K | *Specific Heat Capacity*/ $\text{J kg}^{-1}\,\text{K}^{-1}$ | *Specific Latent Heat of Fusion*/ $\text{J kg}^{-1}$ | *Specific Latent Heat of Vaporisation*/ $\text{J kg}^{-1}$ |
|---|---|---|---|---|---|---|
| Aluminium | $2{\cdot}70 \times 10^{3}$ | 933 | 2623 | $9{\cdot}02 \times 10^{2}$ | $3{\cdot}95 \times 10^{5}$ | . . . . |
| Copper | $8{\cdot}96 \times 10^{3}$ | 1357 | 2853 | $3{\cdot}86 \times 10^{2}$ | $2{\cdot}05 \times 10^{5}$ | . . . . |
| Glass | $2{\cdot}60 \times 10^{3}$ | 1400 | . . . . | $6{\cdot}70 \times 10^{2}$ | . . . . | . . . . |
| Ice | $9{\cdot}20 \times 10^{2}$ | 273 | . . . . | $2{\cdot}10 \times 10^{3}$ | $3{\cdot}34 \times 10^{5}$ | . . . . |
| Glycerol | $1{\cdot}26 \times 10^{3}$ | 291 | 563 | $2{\cdot}43 \times 10^{3}$ | $1{\cdot}81 \times 10^{5}$ | $8{\cdot}30 \times 10^{5}$ |
| Methanol | $7{\cdot}91 \times 10^{2}$ | 175 | 338 | $2{\cdot}52 \times 10^{3}$ | $9{\cdot}9 \times 10^{4}$ | $1{\cdot}12 \times 10^{6}$ |
| Sea Water | $1{\cdot}02 \times 10^{3}$ | 264 | 377 | $3{\cdot}93 \times 10^{3}$ | . . . . | . . . . |
| Water | $1{\cdot}00 \times 10^{3}$ | 273 | 373 | $4{\cdot}19 \times 10^{3}$ | $3{\cdot}34 \times 10^{5}$ | $2{\cdot}26 \times 10^{6}$ |
| Air | 1·29 | . . . . | . . . . | . . . . | . . . . | . . . . |
| Hydrogen | $9{\cdot}0 \times 10^{-2}$ | 14 | 20 | $1{\cdot}43 \times 10^{4}$ | . . . . | $4{\cdot}50 \times 10^{5}$ |
| Nitrogen | 1·25 | 63 | 77 | $1{\cdot}04 \times 10^{3}$ | . . . . | $2{\cdot}00 \times 10^{5}$ |
| Oxygen | 1·43 | 55 | 90 | $9{\cdot}18 \times 10^{2}$ | . . . . | $2{\cdot}40 \times 10^{5}$ |

The gas densities refer to a temperature of 273 K and a pressure of $1{\cdot}01 \times 10^{5}$ Pa

# 3.1 Fields

*Marks*

**1.** (a) A point charge of + 4.0 µC is shown in figure 1A.

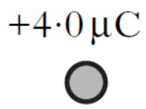



Figure 1 A

Copy figure 1 and draw the electric field lines around this charge. **1**

(b) A - 2.0 µC is now placed a t a distance of 0.1 m from the first charge as shown in figure 1B.

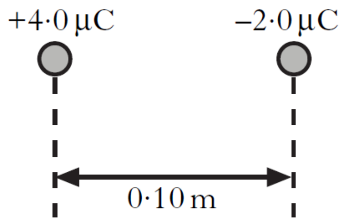



Figure 1B

Explain why the electric field strength is **not zero** at any point between these 2 charges. **2**

(c) Point P is 0.24 m to the right of the second charge as shown in figure 1C.

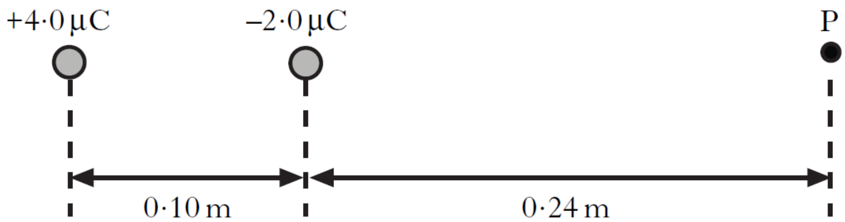



Figure 1C

Calculate the Electric field strength at point P.

**5**

**(8)**

2 (*a*) Two point charges with values $+4{\cdot}0\,\mu C$ and $-6{\cdot}0\,\mu C$ are placed $5{\cdot}0$ m apart. Point X lies on the line between the charges as shown in Figure 7.

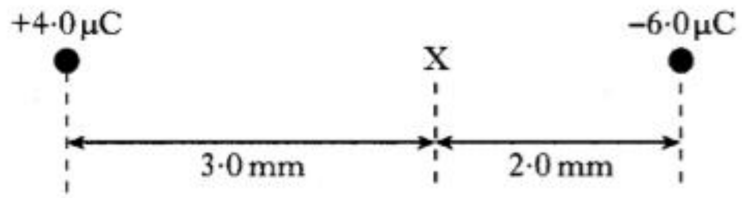



Figure 7

(i) Calculate the magnitude of the electric field strength at point X. 3

(ii) State the direction of the electric field at point X. 1

(*b*) A hollow uncharged metal cylinder is placed midway between two parallel plates which are connected to a d.c. power supply as shown in Figure 8.

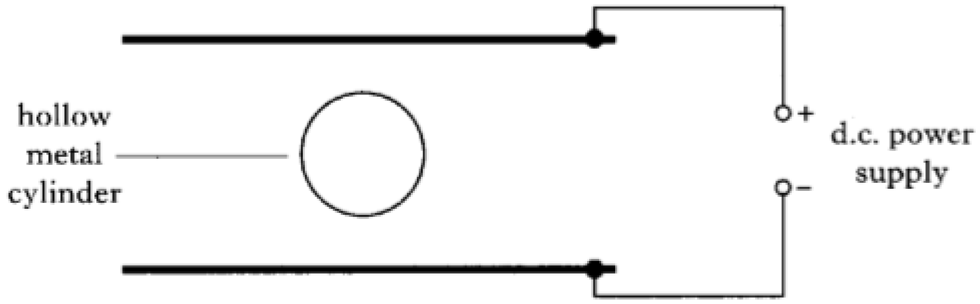



Figure 8

(i) Copy and complete the above diagram showing:

(A) the electric field lines in the space between the parallel plates; 2

(B) the charge distribution induced on the cylinder. 1

(ii) Coaxial cable consists of a central wire surrounded by a metal mesh, as shown in Figure 9.

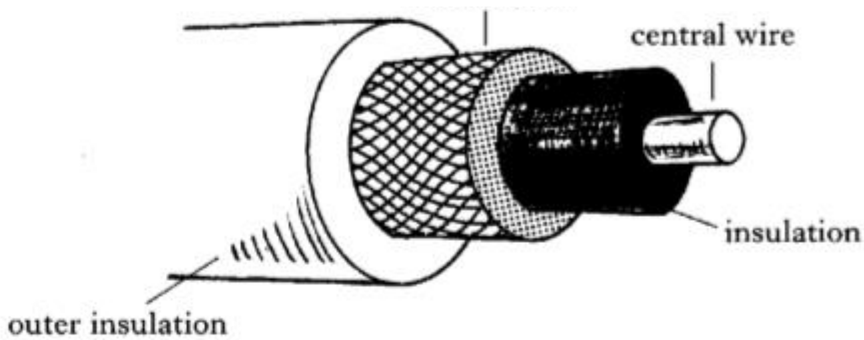



Figure 9

Explain why coaxial cable is designed in this way. **1**

**(8)**

*Marks*

**3.** Four point charges P, Q, R and S are fixed in a rectangle array. Point charge A is placed in the centre of the rectangle, 2.5 mm from each of the other charges, as shown in figure 2A.

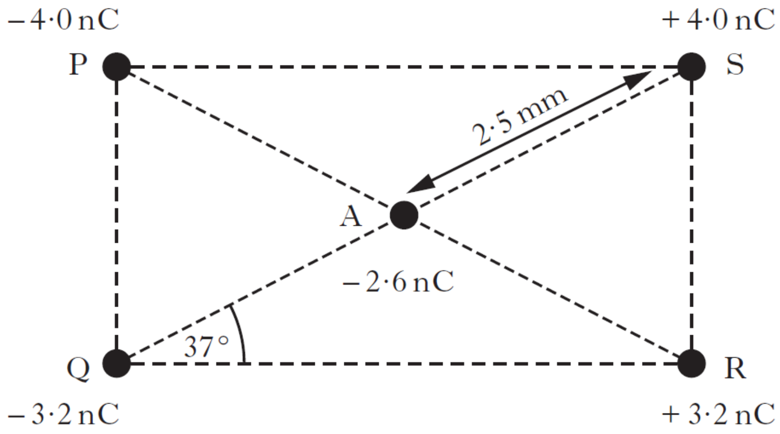



Figure 2A

(a) (i) Calculate the magnitude of the force exerted on charge A due to charge P. **3**

(ii) The magnitude of the Force exerted on charge A due to charge Q is 0.012 N. Calculate the **resultant force** acting on charge A due to all the fixed charges. **5**

(b) The four fixed charges are now removed and charge A is now fixed. Position B is at a distance *r* from charge A, as shown in figure 2B.

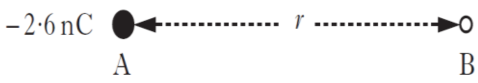



Figure 2B

(i) The electrostatic potential at B is – 37 V. Calculate the distance r. **3**

(ii) A charge may be moved from B to position C along two possible paths, 1 and 2, as shown in figure 2C.

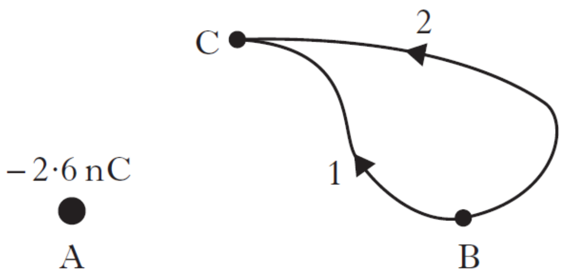



Figure 2C

Compare the work done in moving the charge by the two different routes. **1**

**(12)**

4 (*a*) Two point charges $Q_1$ and $Q_2$ each has a charge of $-4\cdot0\,\mu C$. The charges are $0\cdot60\,m$ apart as shown in Figure 7.

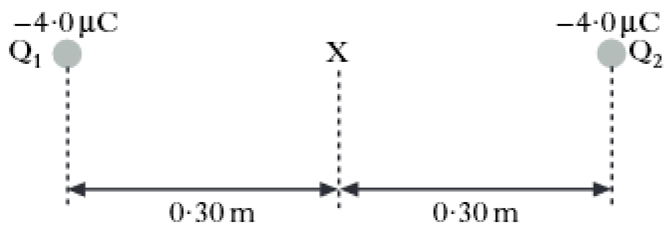



Figure 7

(i) Draw a diagram to show the electric field lines between charges $Q_1$ and $Q_2$. **1**

(ii) Calculate the electrostatic potential at point X, midway between the charges. **2**

(*b*) A third point charge $Q_3$ is placed near the two charges as shown in Figure 8.

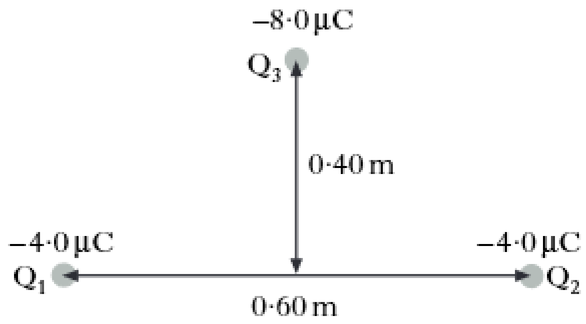



Figure 8

(i) Show that the force between charges $Q_1$ and $Q_3$ is $1\cdot2\,N$. **2**

(ii) Calculate the **magnitude** and **direction** of the resultant force on charge $Q_3$ due to charges $Q_1$ and $Q_2$. **2**

**(7)**

5 (a) $Q_1$ is a point charge of +12 nC. Point Y is 0·30 m from $Q_1$ as shown in Figure 13A.

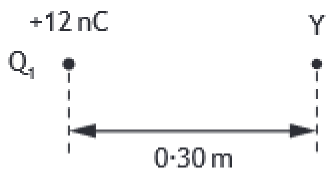



Figure 13A

Show that the electrical potential at point Y is +360 V. **2**

(b) A second point charge $Q_2$ is placed at a distance of 0·40 m from point Y as shown in Figure 13B . The electrical potential at point Y is now zero.

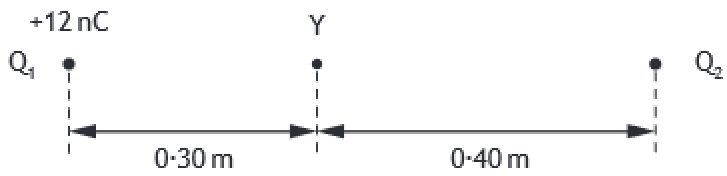



Figure 13B

(i) Determine the charge of $Q_2$. **3**

(ii) Determine the electric field strength at point Y. **4**

(iii) Sketch the electric field pattern for this system of charges. 2

(11)

*Marks*

6 A student is investigating the electrical potential around a point charge Q. Point P is at a distance of (0·65 ± 0·02) m from Q as shown in Figure 12. The potential at point P is (2·1 ± 0·1) V.

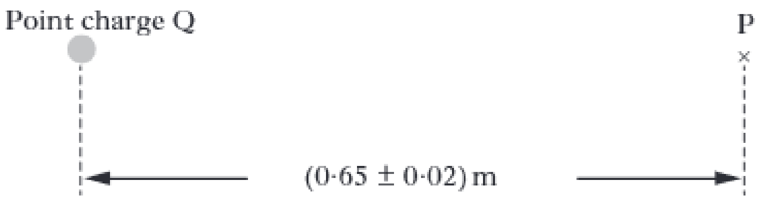



Figure 12

(*a*) Calculate the value of the point charge Q. 3

(*b*) Calculate the absolute uncertainty in the charge. 3

**(4)**

7 (*a*) (i) Define the term *electric field strength*. 1

(ii) Two parallel plates are separated by distance $d$. The potential difference between the plates is $V$.

Derive the expression for the electric field strength $E$ between the plates in terms of $V$ and $d$. 4

(*b*) The electric field pattern between two parallel metal plates is shown in Figure 6.

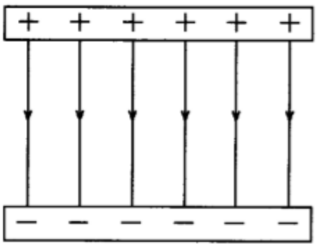



Figure 6

An uncharged, conducting sphere is placed between the plates as shown in Figure 7.

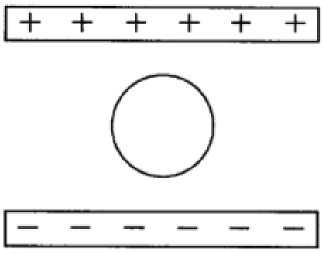



Figure 7

(i) Copy and complete Figure 7 to show the electric field pattern between the plates. 2

(ii) On your diagram, show the charge distribution on the sphere. 1

(iii) State the value of the electric field strength inside the sphere. 1

(9)

8. (*a*) A teacher investigates the electric field between two parallel metal plates X and Y using the apparatus shown in Figure 10A.

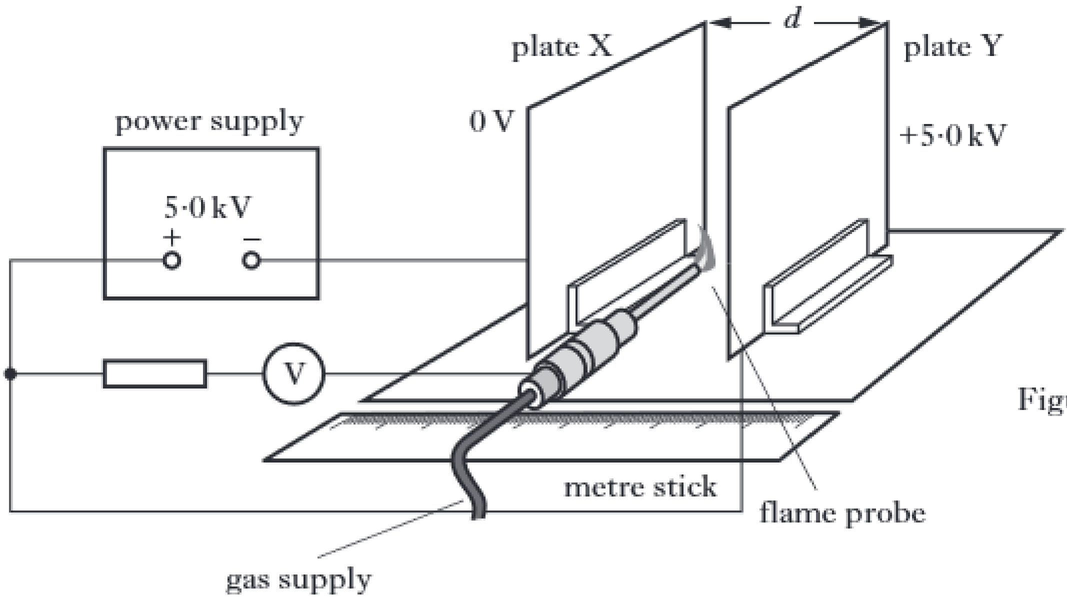



Figure 10A

The plates are connected to a 5·0 kV supply and are separated by a distance *d*.

A calibrated flame probe and voltmeter measure the potential relative to plate X. The probe is placed at different points between the plates. The distance from plate X and the potential at each point are measured.

The results are used to plot the graph shown in Figure 10B.

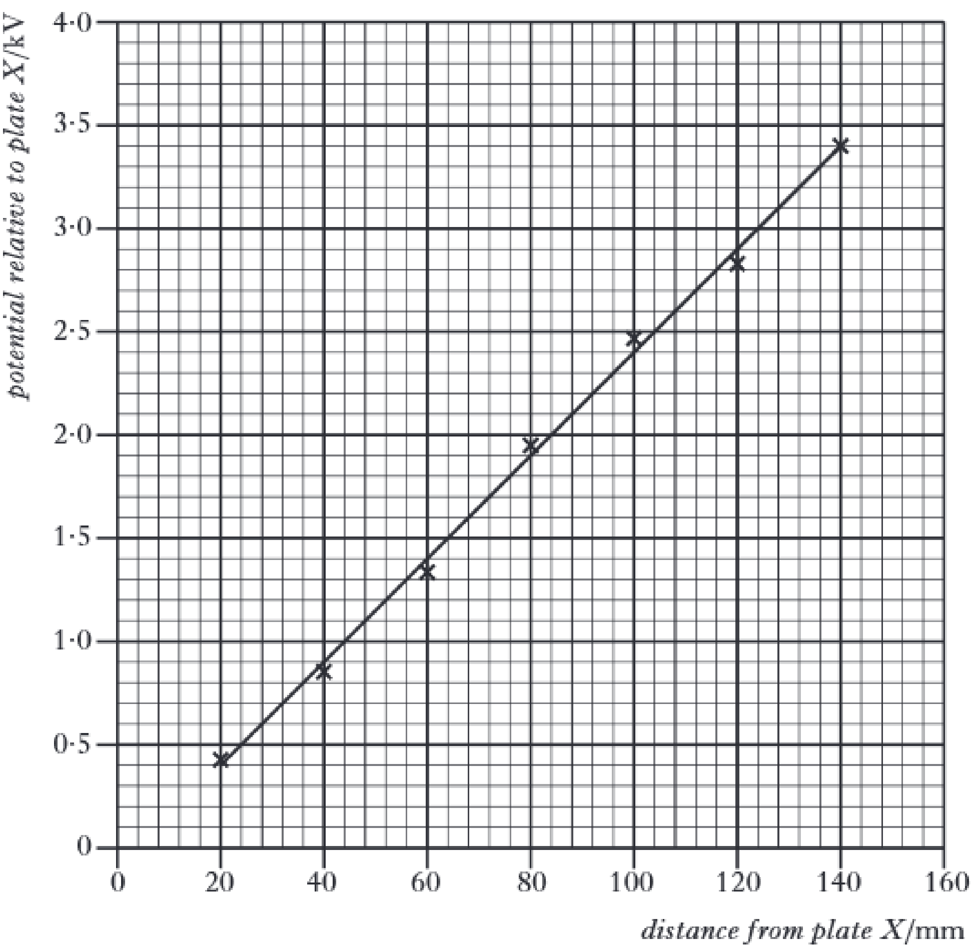



Figure 10B

(i) The electric field strength in the region between the plates is considered to be uniform. Explain the meaning of the term *uniform electric field*. **1**

(ii) Using information from the graph, determine the electric field strength between the plates. 3

(iii) Calculate the separation *d* of the plates. 3

(iv) In theory the best fit line for this graph should pass through the origin. Suggest why the line on the graph in Figure 10B does not pass through the origin. **1**

**(8)**

**9.** A helium filled metal foil balloon with a radius of 0.35 m is charged by induction. The charge on the balloon is +120 μC. The balloon is considered to be perfectly spherical.

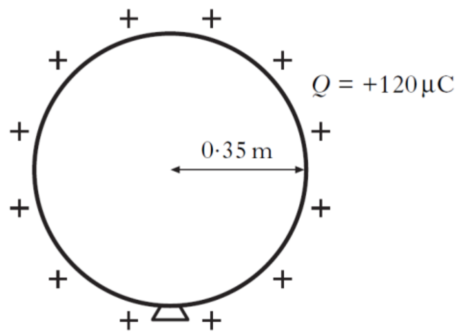



Figure 3A

(a) (i) Calculate the Electric Field Strength at the surface of the balloon. **3**

(ii) Sketch a graph of the electric field strength against distance from the centre of the balloon to well beyond the balloons surface.
No numerical values are required. **2**

(b) Two parallel charged plates are separated by a distance, d. The potential difference between the plates is *V*.
Lines representing the electric field between the plates are shown in figure 3B.

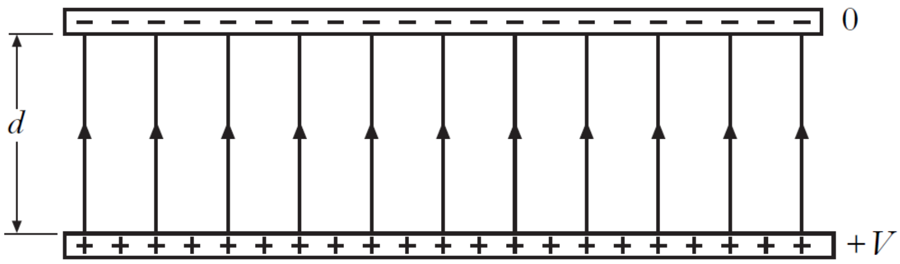



Figure 3B

(i) By considering the work done in moving a point charge q between the plates, derive an expression for the electric field strength *E* between the plates in terms of *V* and *d*. **4**

**[Turn over]**

*Cont.* (ii) The base of a thundercloud is 489 m above an area of open flat ground as shown in figure 3C.


Figure 3C

The uniform electric field strength between the cloud and the ground is $7.23 \times 10^4$ $NC^{-1}$.
Calculate the potential difference between the cloud and the ground. **2**

(iii) During a lightning strike a charge of 2.0 C passes between the cloud and the ground in a time of 348 μs. The strike has negligible effect on the potential of the cloud. Calculate the average power of the strike lightning. **3**

(c) An uncharged metal foil balloon is released and floats between the thundercloud and the ground, as shown in figure 3D.

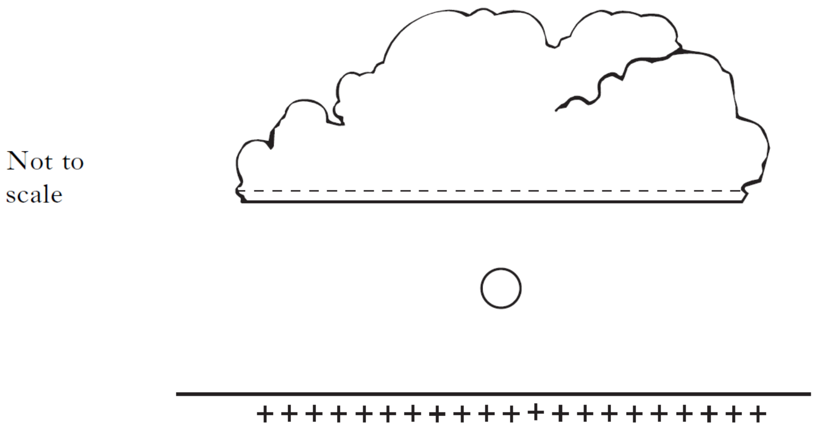



Figure 3D

Draw a diagram showing the charge distribution on the balloon and the resulting electric field around the balloon. **2**

**(16)**

*Marks*

**10.** A research physicist is investigating collisions between protons and the nuclei of metallic elements. Protons are accelerated **from rest** across a potential difference of 4.0 MV. The protons move through a vacuum and collide with a metal target as shown in figure 4A.

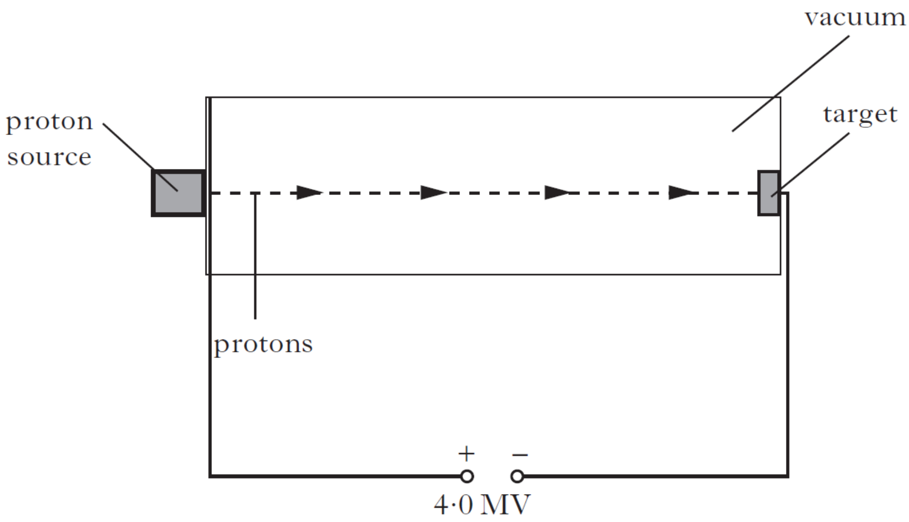



Figure 4A

(*a*) Calculate the maximum speed of the protons as they hit the target. **3**

(b) In one test the researcher uses zirconium as the target. A proton of charge *q* and velocity *v* travels directly towards a zirconium nucleus as shown in figure 4B. The zirconium has a charge *Q*.


Figure 4B

Show that the distance of the closest approach is given by

$$r = \frac{qQ}{2\pi\varepsilon_o m v^2}$$ **2**

Where the symbols have their usual meaning.

(c) Calculate the distance of closest approach for a proton travelling towards a zirconium nucleus in the target. **3**

**(8)**

11. A charged oil drop of mass $1{\cdot}2 \times 10^{-14}$ kg is stationary between two horizontal parallel plates.

There is a potential difference of $4{\cdot}9$ kV between the parallel plates.

The plates are 80 mm apart as shown in Figure 7.

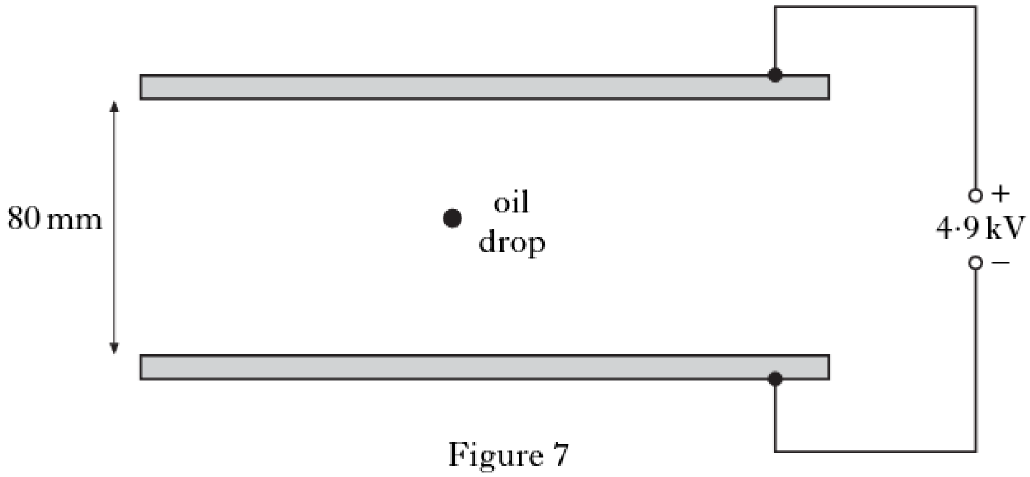



Figure 7

(i) Draw a labelled diagram to show the forces acting on the oil drop. **2**

(ii) Calculate the charge on the oil drop. **5**

(iii) How many excess electrons are on the oil drop? **1**

The results of Millikan's oil drop experiment led to the idea of quantisation of charge.

A down quark has a charge of $-5{\cdot}3 \times 10^{-20}$ C. Explain how this may conflict with Millikan's conclusion. **1**

**(9)**

## 3.2 Magnetic Fields & induction

**1.** A single rectangular loop of wire is arranged vertically in the uniform magnetic field between the poles of a magnet as shown in Figure 10. The loop is free to spin about axis XY. *Marks*

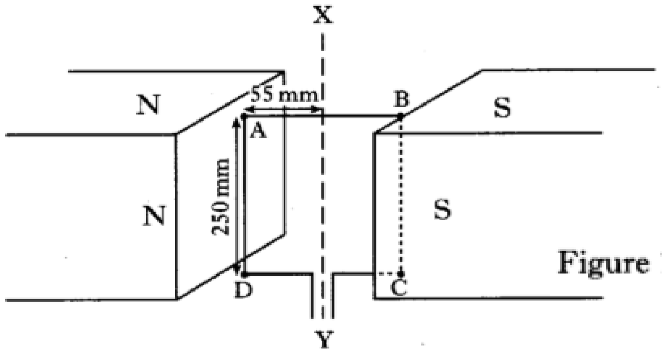


Figure 10

Sides AD and BC of the rectangle are 250 mm in length and each is 55 mm from the axis of rotation.

The loop of wire carries a current of 0·40 A.

The magnetic induction of the field is 0·60 T.

(*a*) Calculate the size of the magnetic force acting on side AD. 3

(*b*) Figure 11 shows the loop when **viewed from above**.

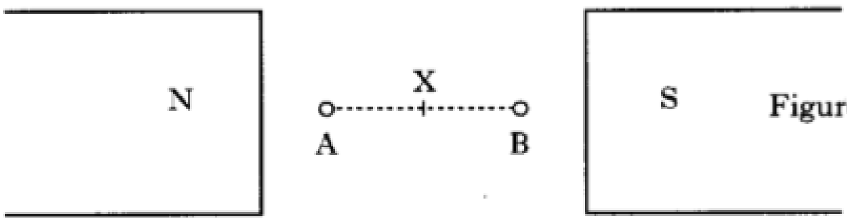


Figure 11

Calculate the magnitude of the torque acting on the loop.

(*c*) The loop is turned through 30 ° to the position shown in Figure 12.

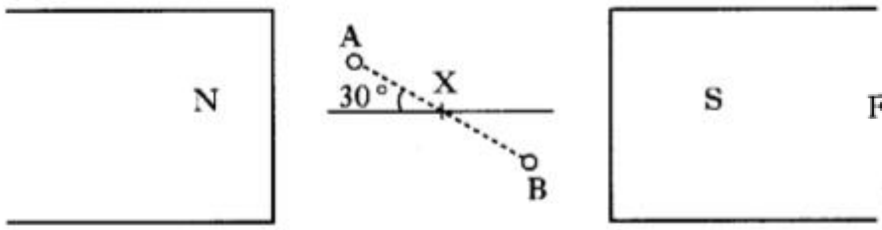


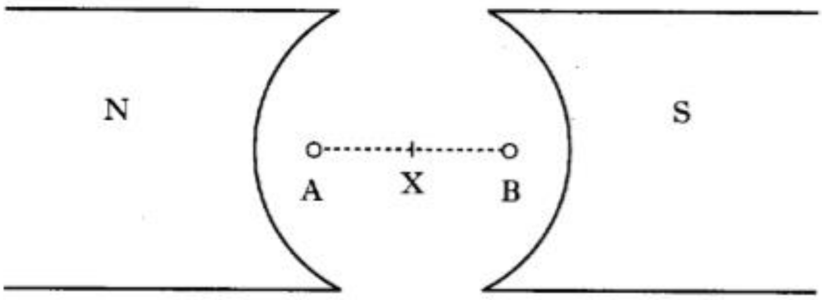
Figure 12

**view from above**

Calculate the magnitude of the torque now acting on the loop. 3

**(continued)**

**(*d*) The magnet is replaced by another magnet with the poles shaped as shown in Figure 13.**




**view from above**

**Explain how this arrangement reduces variation in the torque as the loop turns.** 1

(10)

**2.** In a nuclear power station liquid sodium is used to cool parts of the reactor. An electromagnetic pump keeps the coolant circulating. The sodium enters a perpendicular magnetic field and an electric current, $I$, passes through it. A force is experienced by the sodium causing it to flow in the direction shown in Figure 11.

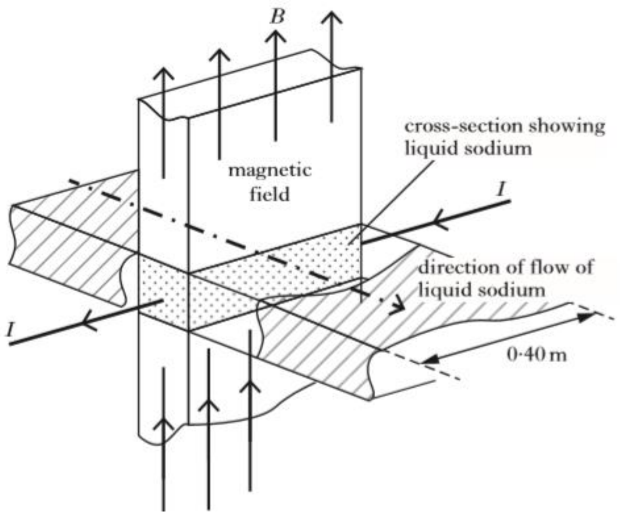



Figure 11

The magnetic induction $B$ is 0·20 T. The current $I$ in the sodium is 2·5 A and is perpendicular to the magnetic field.

(*a*) Calculate the force acting on the 0·40 m length of sodium within the magnetic field. 3

(*b*) The pump is moved during maintenance and as a result the direction of the magnetic field is changed so that it is no longer perpendicular to the current. What effect does this have on the rate of flow of sodium passing through the pump?

You **must** justify your answer. 3

(*c*) An engineer must install a long, straight, current carrying wire close to the pump and is concerned that the magnetic induction produced may interfere with the safe working of the pump. 3

The wire is 750 mm from the pump and carries a current of 0·60 A. (9)

Show by calculation that the magnetic induction at this distance is negligible.

**3.** A long thin horizontal conductor AB carrying a current of 25 A is supported by two fine threads of negligible mass. The tension in each supporting thread is T as shown in Figure 8A.

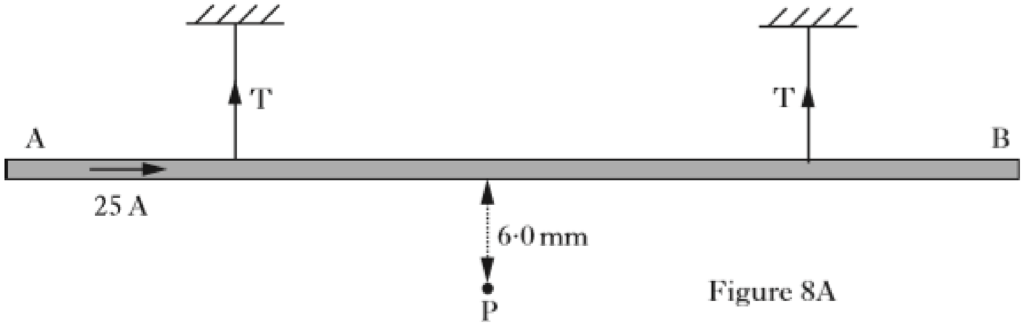
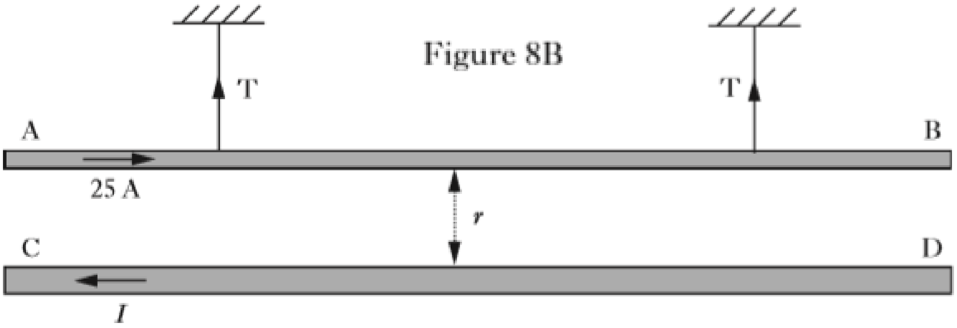


Figure 8A

(*a*) Calculate the magnetic induction at a point P, 6·0 mm directly below conductor AB. 3

(*b*) A second conductor CD carrying current $I$ is now fixed in a position a distance $r$ directly below AB as shown in Figure 8B. CD is unable to move.

Figure 8B




Explain why there is a force of repulsion between conductors AB and CD. 2

(5)

*Marks*

**4.** The shape of the Earth's magnetic field is shown in figure 6A.

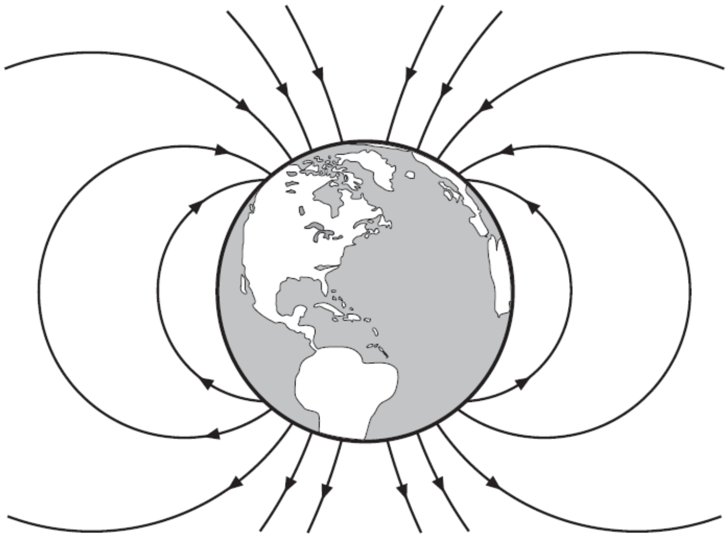


*Figure 6A*

At a particular location in Scotland the field has a magnitude of $5.0 \times 10^{-5}$ T directed into the Earth's surface at an angle of 69° as shown in figure 6B.


*Figure 6B*

(a) Show that the component of the field perpendicular to the Earth's surface is $4.7 \times 10^{-5}$ T. **2**

**[Turn over]**

(b) At this location a student sets up a circuit containing a straight length of copper wire lying horizontally in the North – South direction as shown in figure 6C.

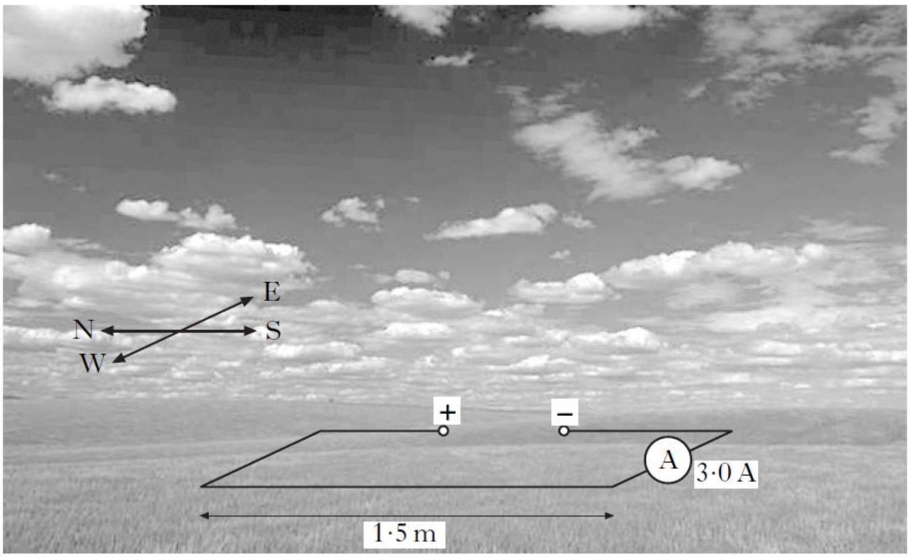



*Figure 6C*

The length of wire is 1.5 m and the Current is 3.0 A.

(i) Calculate the magnitude of the force acting on the wire due to the Earth's magnetic field. **3**

(ii) State the direction of this force. **1**

(c) The wire is now tilted through an angle of 69° so that it is parallel to the direction of the Earth's magnetic field.
Determine the force on the wire due to the Earth's magnetic field. **1**

(d) A long straight current carrying wire produces a magnetic field. The current in this wire is 3.0 A.

(i) Calculate the distance from the wire at which the direction of the magnetic field is $5.0 \times 10^{-5}$ T. **2**

(ii) Describe the shape of this magnetic field. **1**

**(10)**

5 (a) Alpha particles are accelerated to a speed of $5 \cdot 0 \times 10^6\ \text{m s}^{-1}$.

The alpha particles are then injected into a magnetic field. The path of the alpha particles is perpendicular to the magnetic field lines.

The magnetic induction is $1 \cdot 7\ \text{T}$.

The alpha particles follow the circular path shown in Figure 10A.

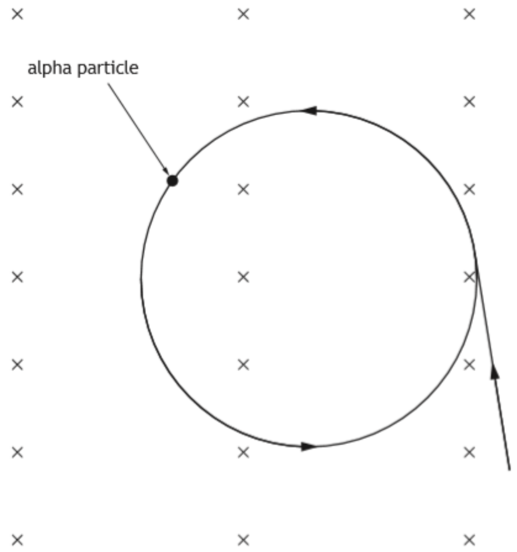



**Figure 10A**

(i) (A) Calculate the magnitude of the magnetic force acting on an alpha particle. **3**

(B) This magnetic force provides the centripetal force that causes the alpha particles to follow the circular path.

Calculate the radius of the circular path. **3**

(ii) The alpha particles are now replaced by protons.

The protons also travel at $5 \cdot 0 \times 10^6\ \text{m s}^{-1}$, and are injected into the magnetic field at the same point and in the same direction as the alpha particles.

**Sketch the path followed by the path of the protons after they enter the magnetic field.** **3**

(b) Cosmic rays travel through space towards Earth.

Approximately 9% of cosmic rays are alpha particles.

Alpha particles entering the magnetic field of the Earth follow a **helical**, rather than a **circular** path.

Explain why alpha particles travelling through the magnetic field of the Earth follow a helical path. **2**

**(11)**

*Marks*

**6.** (a) Figure 8A shows a current carrying wire of length l, perpendicular to a magnetic field, B. A single charge $-q$ moves with constant velocity $v$ in the wire. Using the relationship for the force on a current carrying conductor placed in a magnetic field, derive the relationship $F = qvB$ for the magnitude of the force acting on charge $q$. **4**

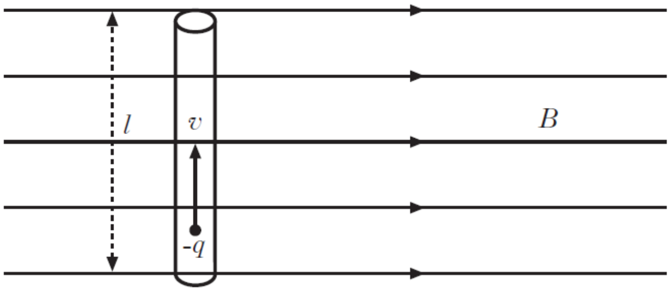



*Figure 8A*

(b) An electron with a speed of $2.0 \times 10^{6}$ $ms^{-1}$ enters a uniform magnetic field at an angle θ. The electron follows a helical path as shown in figure 8B.

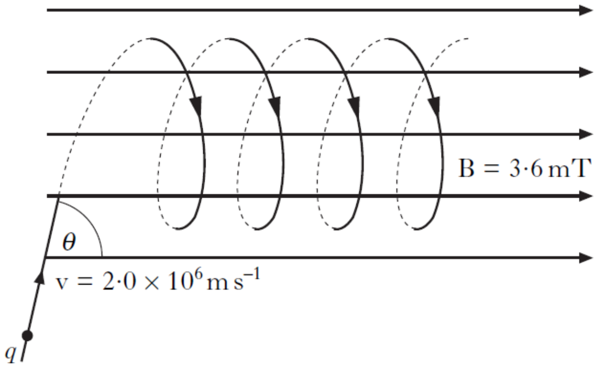



*Figure 8B*

The uniform magnetic induction is 3.6 mT and the radius of the helical path is 2.8 mm. Calculate the value of the angle θ. **4**

(c) A second electron travelling at the same speed enters the field at a smaller angle θ. Describe how the path of the second electron differs from the first. **2**

**(10)**

7. An alpha particle passes through a region that has perpendicular magnetic and electric fields as shown in figure 7A.

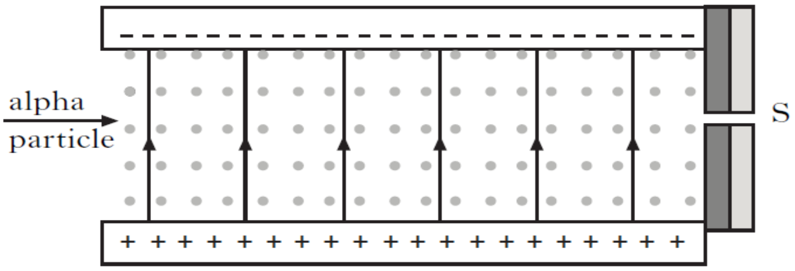



*Figure 7A*

The magnetic induction is 6.8 T and directed out of the page.
The force on the alpha particle due to the magnetic field is $5.0 \times 10^{-11}$ N.

(a) Show that the velocity of the alpha particle is $2.3 \times 10^{7}$ $ms^{-1}$. **3**

(b) In order that the alpha particle exits through slit S, it must pass through the region undeflected.
Calculate the strength of the electric field that ensures the alpha particle passes through slit S. **3**

(c) After passing through slit S, the alpha particle enters a region where there is the same uniform perpendicular magnetic field but no electric field as shown in figure 7B.

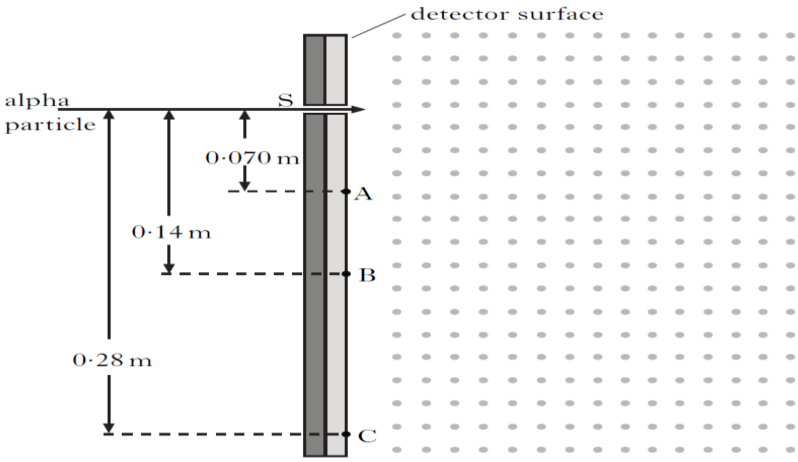



*Figure 7B*

This magnetic field causes the alpha particle to travel in a semi-circular path and hit the detector surface.
Points A, B and C are at distances of 0.070 m, 0.14 m and 0.28 m respectively from slit s.
Show, by calculation, which point on the detector surface is hit by the alpha particle. **5**

(d) An electron travelling at the same speed as the alpha particle passes through slit S into the region of the uniform magnetic field.
State two differences in the semi-circular path of the electron compared to the path of the alpha particle. Justify your answer. **4**

**(15)**

*Marks*

**8.** The force on a current carrying conductor in a magnetic field can be measured using an electronic balance.

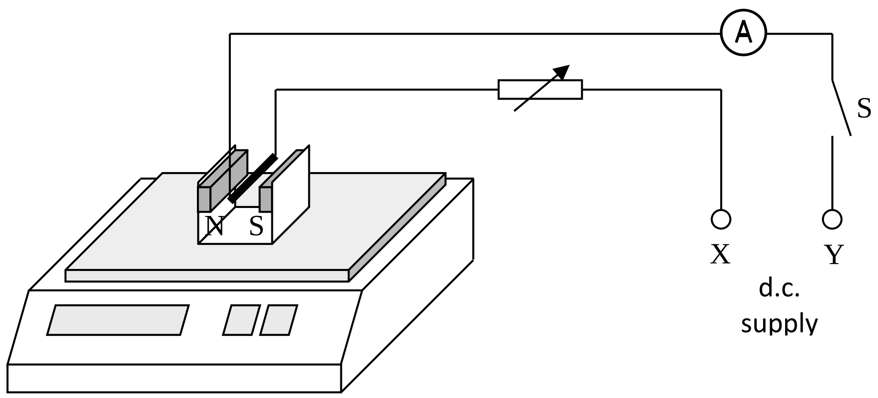



figure 9A

A magnet is placed on the balance, which is then zeroed. A rigid copper wire is then clamped in place in a fixed position between the poles as shown in figure 9A.

(a) The reading on the balance increases when the switch is closed. **1**
State the polarity of X and Y on the d.c. supply.

(b) The reading on the balance is recorded for several values of current. These readings and their associated uncertainties are shown in the following table.

| Current / mA | 0 | 100±10 | 200±10 | 300±10 | 400±10 | 500±10 | 600±10 |
|---|---|---|---|---|---|---|---|
| Reading on balance / mg | 0±1 | 11±1 | 25±2 | 35±2 | 48±2 | 58±3 | 75±3 |

Figure 9B on the following page shows a graph of this data. A line of best fit has been drawn.

(i) Calculate the gradient of the best fit line.

(ii) Calculate the absolute uncertainty in this gradient. **5**

(c) The horizontal part of the rigid copper wire in the magnetic field has a length of 0.060 m. It is fixed at right angles to the magnetic field.

Use the information calculated in part (b) to calculate the magnitude of the magnetic induction between the poles of the magnet. **3**
An uncertainty in the magnetic induction is **not** required.

**(9)**

**[Turn over]**

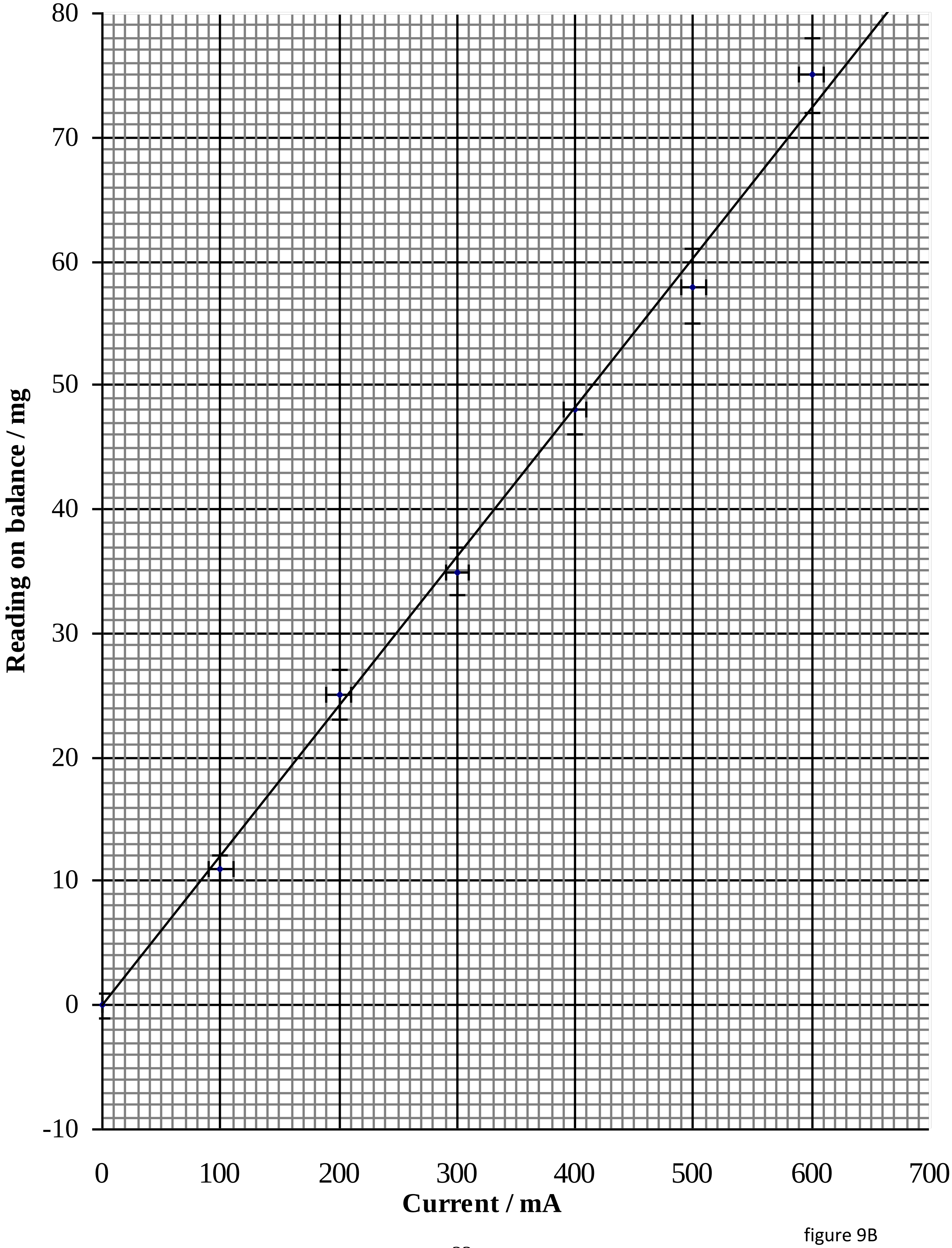

80
70
60
50
40
30
20
10
0
-10
Reading on balance / mg
0
100
200
300
400
500
600
700
Current / mA

figure 9B

**9** A student carries out an experiment to determine the charge to mass ratio of the electron. The apparatus is set up as shown in figure 14 A *Marks*

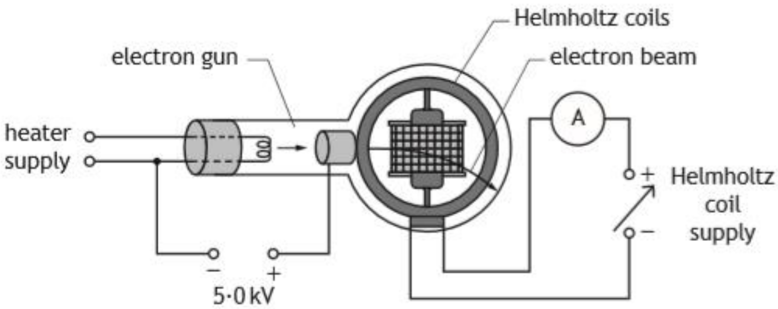



Figure 14A

An electron beam is produced using an electron gun attached to a 5.0kV supply. A current *I* in the Helmholtz coil produces a uniform magnetic field.

The electron beam enters the magnetic field.

The path of the electron between points O and P can be considered to be an arc of constant radius r. This is shown in figure 14 B.

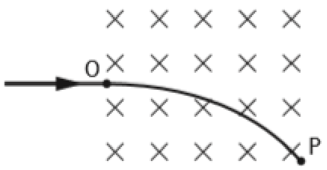



Figure 14B

The student records the following results.

| | |
|---|---|
| Electron gun supply voltage, $V$ | 5·0 kV (±10%) |
| Current in the Helmholtz coils, $I$ | 0·22 A (±5%) |
| Radius of curvature of the path of the electron beam between O and P, $r$ | 0·28 m (±6%) |

The manufacturer's instruction sheet states that the magnetic field strength B at the centre is given by

$$B = 4{\cdot}20 \times 10^{-3} \times I$$

(a) Calculate the magnitude of the magnetic field strength at the centre of the apparatus. 1

(b) The charge to mass ratio of the electron is calculated using the following relationship

$$\frac{q}{m} = \frac{2V}{B^2 r^2}$$

(I) Using the measurements recorded by the student, calculate the charge to mass ratio of the electron. 2

(ii) Determine the absolute uncertainty in the charge to mass ratio of the electron. 4

(c) A second student uses the same equipment to find the charge to mass ratio of the electron and analyses their measurements differently.

The current in the Helmholtz coils is varied to give a range of values for magnetic field strength. This produces a corresponding range of measurements of the radius of curvature.
The student then draws a graph and uses the gradient of the line of best fit to determine the charge to mass ratio of the electron .
Suggest which quantities the student chose for the axes of the graph. 1

**(d)** The graphical method of analysis used by the second student should give a more reliable measure of the charge to mass ratio of the electron than the value obtained by the first student.
Use your knowledge of experimental physics to explain why this is the case. **3**

**(11)**

## 3.3 Circuits

**1.** A 12 V battery of negligible internal resistance is connected in a circuit as shown in figure 10.

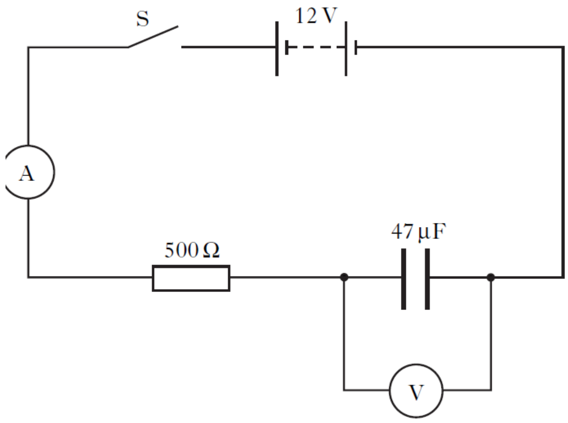



*Figure 10*

The capacitor is initially uncharged. Switch S is then closed and the capacitor starts to charge.

(a) Sketch a graph of the current against time from the instant switch S is closed. Numerical values are not required. **1**

(b) At one instant on the charging of the capacitor the reading on the Ammeter is 5.0 mA .
Calculate the reading on the voltmeter at this instant. **4**

**(5)**

**2.** A student is investigating the charging and discharging of a capacitor. The circuit used is shown in figure 16 A.

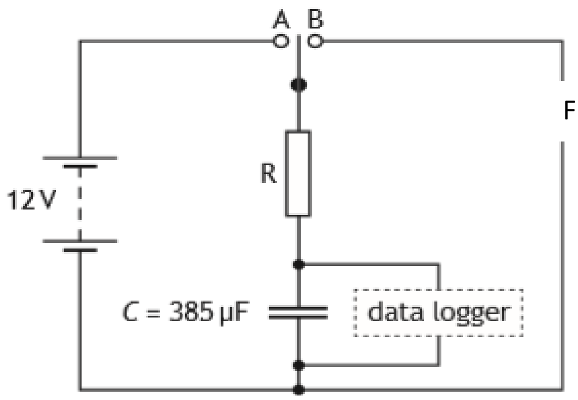
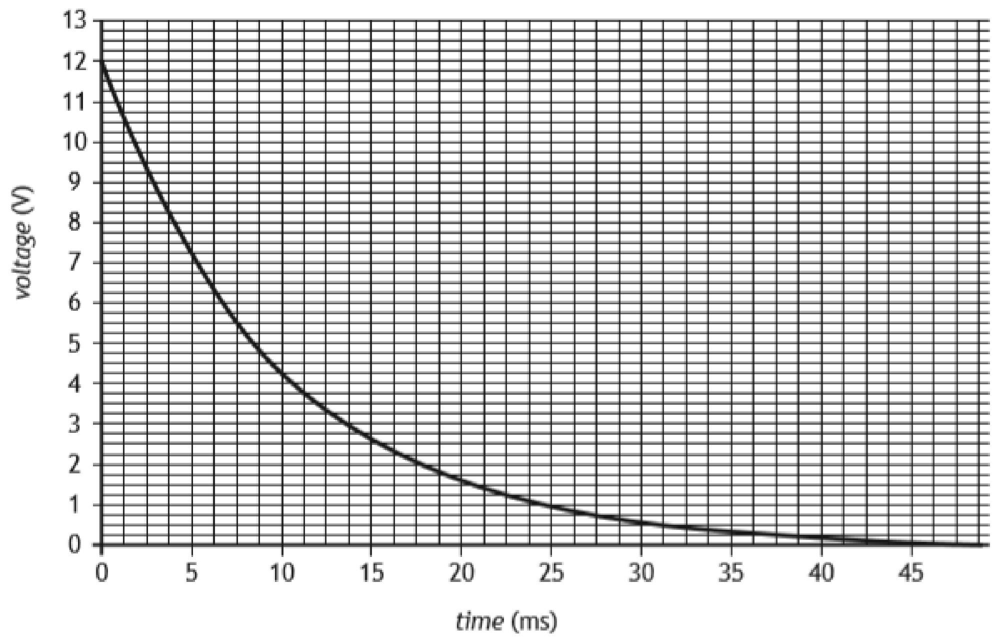



Figure 16 A

With the switch in position A the capacitor charges. To discharge the capacitor the switch is moved to position B. The data logger measures the voltage across the capacitor.

The graph in figure 16 B shows the how the voltage across the capacitor changes during the discharge of the capacitor.

Figure 16B




**(a)** Determine the time constant for the graph. **2**

**(b)** Calculate the resistance of resistor R. **3**

**(5)**

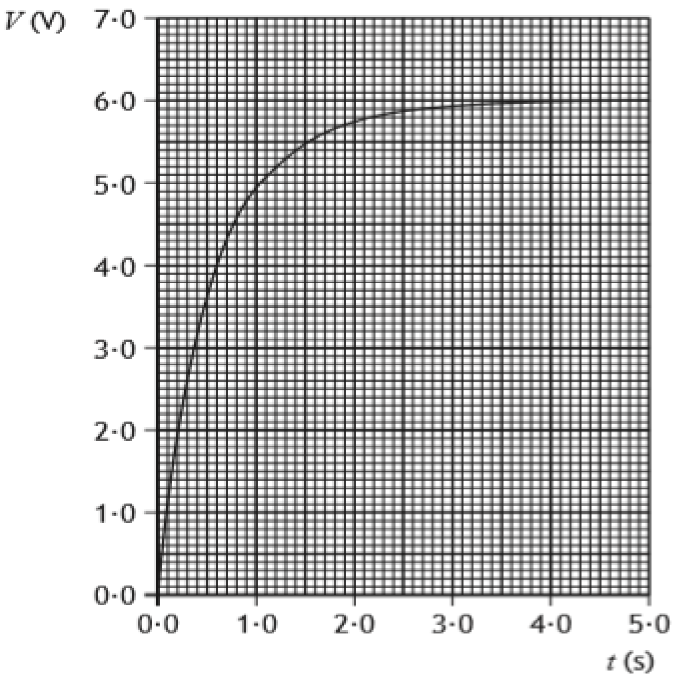
**3.** (a) A technician finds an unlabelled capacitor and carries out an experiment to determine its capacitance.
The technician builds a circuit using a battery, a 2.7kΩ resistor, a voltmeter and the unlabelled capacitor. The technician constructs the circuit so that the potential difference of the capacitor can be measured as it charges.

(i) Draw a diagram of a circuit that would enable the technician to carry out this experiment. **1**

(ii) The data obtained from the experiment are used to draw the graph of potential difference V against time t show in figure 16A.
Use the graph to determine the time constant of the circuit. **2**

(iii) Calculate the capacitance of the unlabelled capacitor. **3**

Figure 16A



**4.** A student carries out a series of experiments to investigate the properties of capacitors in ac circuits.

(a) The student connects a 5μF capacitor to an AC supply of $15V_{rms}$ and negligible internal resistance as shown in figure 14 A

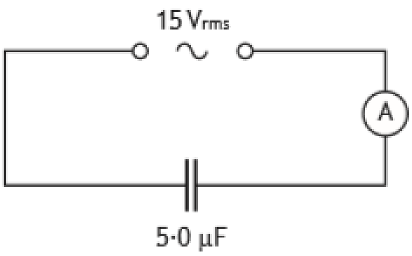



**Figure 14A**

The frequency of the AC supply is 65 Hz.

(i) Calculate the reactance of the capacitor. **3**

(ii) Calculate the current in the circuit. **3**

**(6)**

(b) The student uses the following circuit to determine the capacitance of a second capacitor.

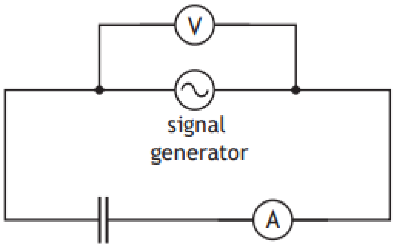



**Figure 14B**

The student obtains the following data.

| $X_c$ (Ω) | $f$ (Hz) |
|---|---|
| $1{\cdot}60 \times 10^6$ | 10 |
| $6{\cdot}47 \times 10^5$ | 40 |
| $2{\cdot}99 \times 10^5$ | 100 |
| $1{\cdot}52 \times 10^5$ | 200 |
| $6{\cdot}35 \times 10^4$ | 500 |
| $3{\cdot}18 \times 10^4$ | 1000 |

(i) On the square-ruled paper on *page 37*, plot a graph of $X_c$ against $\frac{1}{f}$. **3**

(ii) Use your graph to determine the capacitance of this capacitor. **3**

**5.** In an experiment a magnetised iron rod is placed into a coil of wire as shown in Figure 12B **1**

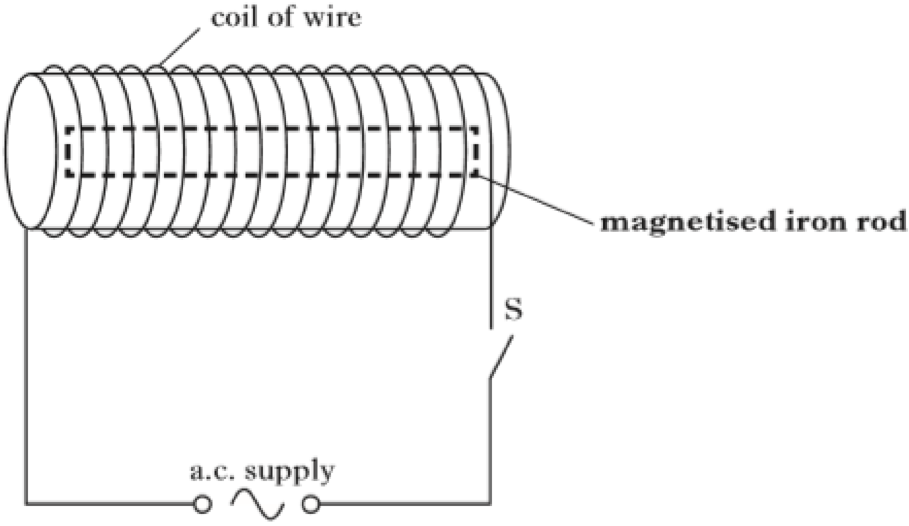



Figure 12B

Switch S is closed for a short time, passing an alternating current through the coil.

State the effect on the iron rod's magnetic field.

You must justify your answer. **3**

**6.** The relationship $\varepsilon = -L\frac{dI}{dt}$ arises in electromagnetic induction

(a) Comment on the significance of the minus sign in the relationship. **1**

(b) Define the Henry, the unit of inductance in an inductor. **1**

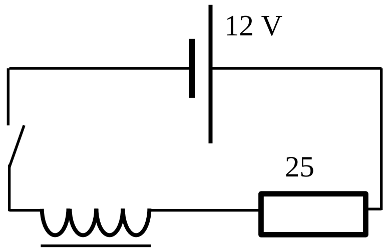
(c) Sketch a graph showing how current varies with time after the switch is closed in a d.c. circuit containing an inductor. **1**

**Contd over**

**6.** contd

(d) A coil of self-inductance L and negligible resistance is connected in series with a resistor of resistance 25 Ω as shown in figure 11.
The supply has and emf of 12 V and negligible internal resistance.

Figure 11




A short time after closing the switch, the current is 0.22 A and the rate of change of current in the circuit is 0.90 As-1.
Calculate the inductance of the coil. **5**

**(8)**

**7.** The circuit shown in figure 12 A is set up to illustrate the effect of an inductor.

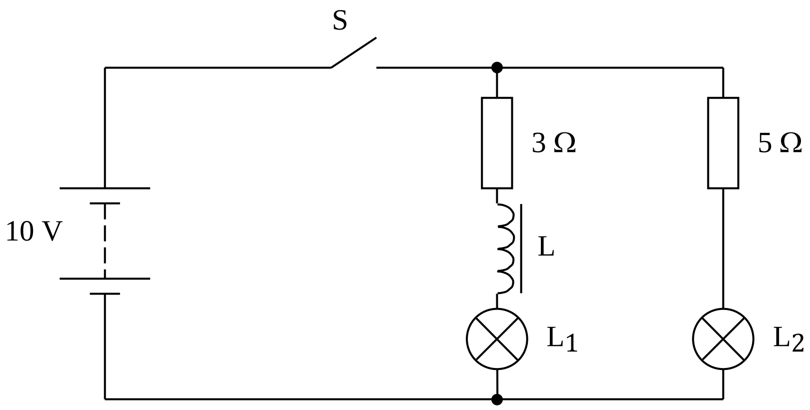



*figure 12 A*

The two lamps $L_1$ and $L_2$ are identical. When switch S is closed the lamps take different times to reach their maximum brightness.

(*a*) State the order in which the lamps light. Justify your answer. **2**

(*b*) The final brightness of $L_1$ equals that of $L_2$. Calculate the resistance of inductor L. **1**

(*c*) Switch S is then opened and the iron core in the centre of the inductor is removed. Switch S is then closed.

Describe how any time delay in turning on lamps L1 and L2 compares with that observed in part (a). Justify your answer. **2**

**7.** **(continued)** *Marks*

(*d*) Inductor L, with its iron core replaced, is now connected in the circuit shown in figure 12 B.

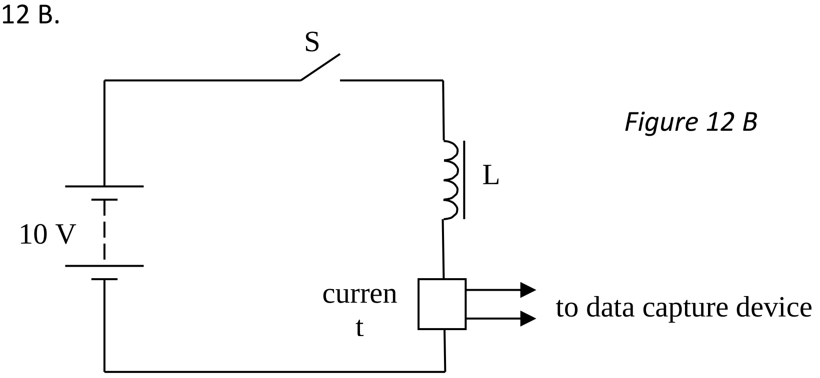



*Figure 12 B*

The battery and current sensor have negligible internal resistance. Switch S is closed and the data capture device collects sufficient data to plot the graph shown in figure 12 C.

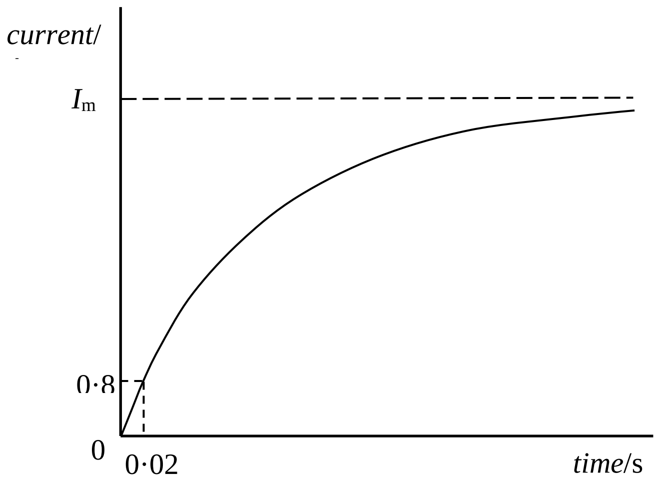



*figure 12 C*

(i) Calculate the maximum current $I_{max}$. **1**

(ii) Use the values given at the start of the graph to calculate the inductance of inductor L. **3**

(iii) Calculate the energy stored in the inductor at its maximum current. **3**

**(12)**

**8.** (*a*) Figure 13 A shows a d.c. power supply in series with a switch, lamp and inductor.

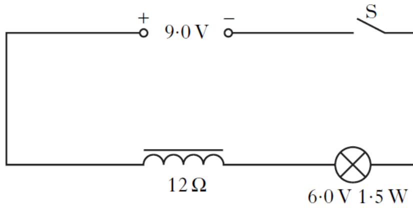



*Figure 13 A*

The inductor consists of a coil of wire with a resistance of 12 Ω.
The lamp is rated at 6 V 1.5 W.
The 9.0 V d.c. power supply has negligible internal resistance.

(i) Explain why the lamp does not reach its maximum brightness immediately after the switch is closed. **3**

(ii) When the lamp reaches its maximum brightness it is operating at its stated power rating.
Calculate the Current in the circuit. **1**

(iii) The maximum energy stored in the inductor is 75 mJ.
Calculate the inductance of the inductor. **3**

(iv) The inductor in figure 13 A is replaced by another inductor which has the same type of core and wire but twice as many turns.
State the effect this has on:

A The maximum current.

B The time to reach maximum current.

**2**

(b) Figure 13 B shows a neon lamp connected to an inductor, switch and 1.5 V cell.

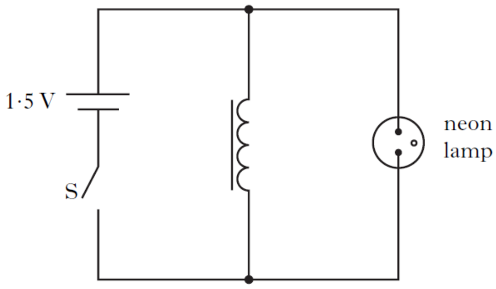
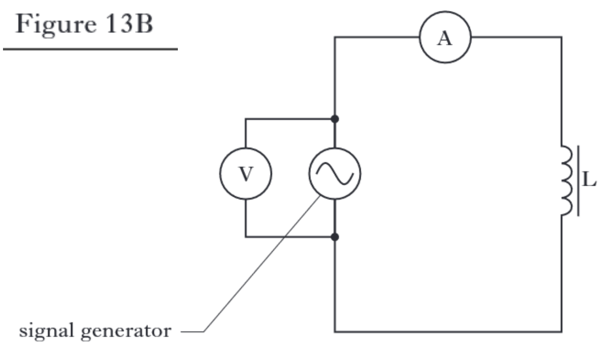



*Figure 13 B*

A neon lamp needs a potential difference of at least 80 V across it before it lights.
The switch is closed for 5 seconds.
The switch is then opened and the lamp flashes briefly.
Explain this observation. **2**

**(11)**

**9.** A 4.0 H inductor is connected in the circuit shown in figure 13B.




The output voltage is set at 6.0V. the reading in the ammeter is 5.0 mA.
Calculate the output frequency of the signal generator. **3**

**10.** (a) A 3.0 V battery is connected in series with a switch, a resistor and an inductor of negligible resistance. A neon lamp is connected across the inductor as shown in figure 14 A.

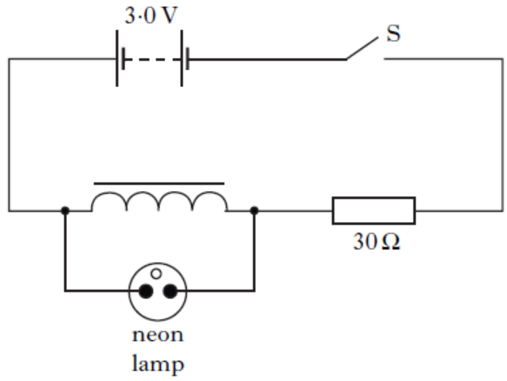



Figure 14 A

(i) Sketch a graph to show how the current in the inductor varies with time from the instant the switch is closed.
Appropriate numerical values are required on the current axis. **4**

(ii) The neon lamp requires a potential difference of at least 110 V across it before it lights.
Explain why the lamp does not light when the switch is closed. **1**

(iii) After a few seconds the switch is opened and the lamp flashes.
Explain, in terms of the magnetic field, why the lamp flashes as the switch is opened. **2**

(iv) The neon lamp has an average power of 1.2 mW and a flash that lasts 0.25 s.
Assuming all the energy stored by the inductor is transferred to the lamp, calculate the inductance of the inductor. **4**

**[Turn over]**

**10.** *cont* *Marks*

(b) Figure 14B shows a circuit used to investigate the relationship between the current in an inductive circuit and the supply frequency.

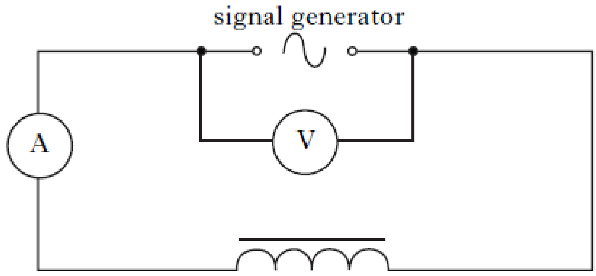



Figure 14B

The reading on the ammeter is noted for different values of supply frequency.

(i) State the purpose of the voltmeter. **1**

(i) Describe how the data obtained should be analysed to determine the relationship between the current in the inductive circuit and the supply frequency. **1**

(iii) State the expected relationship. **1**

(c) A loudspeaker system is connected to a music amplifier. The system contains a capacitor, inductor and two loudspeakers, LS1 and LS2, as shown in figure 14C.

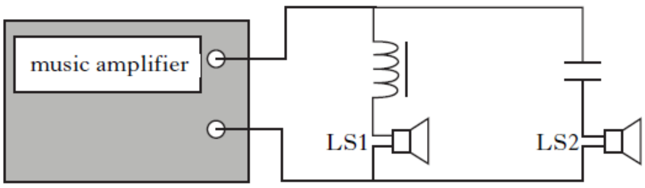



Figure 14C

The circuit is designed so that one loudspeaker emits low frequency sounds while the other emits high frequency sounds.
By comparing the capacitive and inductive reactances, describe the operation of this system. **3**

**(17)**

**11.** (*a*) Describe an experiment that demonstrates light behaving as a wave. **2**

(*b*) Describe an experiment that demonstrates light behaving as a particle. **2**

(c) Name the quantities and their units in the equation

$$c = \frac{1}{\sqrt{\varepsilon_0 \mu_0}}$$ **3**

**(7)**

**12.** As part of a physics project a student carried out experiments to obtain values for the permeability of free space and the permittivity of free space.

The results obtained by the student were

permeability of free space, $\mu_0 = (1{\cdot}32 \pm 0{\cdot}05) \times 10^{-6}\ \mathrm{Hm^{-1}}$

permittivity of free space, $\varepsilon_0 = (8{\cdot}93 \pm 0{\cdot}07) \times 10^{-12}\ \mathrm{Fm^{-1}}$

(a) State the number of significant figures in the value of each result. **1**

(b) Use these results to determine a value for the speed of light. **3**

(c) (i) Determine which of the uncertainties obtained by the student is more significant for the calculation of the speed of light.

You must justify your answer by calculation. **3**

(ii) Calculate the absolute uncertainty in the value obtained for the speed of light. **2**

**(9)**