

PHYSICS ADVANCED HIGHER

Unit 3 Electromagnetism Homework

DATA SHEET

COMMON PHYSICAL QUANTITIES

Quantity	Symbol	Value	Quantity	Symbol	Value
Gravitational acceleration on Earth	g	9.8 m s^{-2}	Mass of electron	m_e	$9.11 \times 10^{-31} \text{ kg}$
Radius of Earth	R_E	$6.4 \times 10^6 \text{ m}$	Magnitude of charge on electron	e	$1.60 \times 10^{-19} \text{ C}$
Mass of Earth	M_E	$6.0 \times 10^{24} \text{ kg}$	Mass of neutron	m_n	$1.675 \times 10^{-27} \text{ kg}$
Mass of Moon	M_M	$7.3 \times 10^{22} \text{ kg}$	Mass of proton	m_p	$1.673 \times 10^{-27} \text{ kg}$
Mean Radius of Moon Orbit		$3.84 \times 10^8 \text{ m}$	Mass of alpha particle	m_α	$6.645 \times 10^{-27} \text{ kg}$
Universal constant of gravitation	G	$6.67 \times 10^{-11} \text{ m}^3 \text{ kg}^{-1} \text{ s}^{-2}$	Planck's constant	h	$6.63 \times 10^{-34} \text{ J s}$
Speed of light in vacuum	c	$3.0 \times 10^8 \text{ m s}^{-1}$	Permittivity of free space	ϵ_0	$8.85 \times 10^{-12} \text{ F m}^{-1}$
Speed of sound in air	v	$3.4 \times 10^2 \text{ m s}^{-1}$	Permeability of free space	μ_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	<i>Lasers</i>		
	397	Ultraviolet	<i>Element</i>	<i>Wavelength/nm</i>	<i>Colour</i>
	389	Ultraviolet	Carbon dioxide	9550	Infra red
Sodium	589	Yellow		10590	Infra red
			Helium-neon	633	Red

PROPERTIES OF SELECTED MATERIALS

Substance	Density/ kg m^{-3}	Melting Point/ K	Boiling Point/ K	Specific Heat Capacity/ $\text{J kg}^{-1} \text{ K}^{-1}$	Specific Latent Heat of Fusion/ J kg^{-1}	Specific Latent Heat of Vaporisation/ J kg^{-1}
Aluminium	2.70×10^3	933	2623	9.02×10^2	3.95×10^5	....
Copper	8.96×10^3	1357	2853	3.86×10^2	2.05×10^5	....
Glass	2.60×10^3	1400	....	6.70×10^2	....	....
Ice	9.20×10^2	273	....	2.10×10^3	3.34×10^5	....
Glycerol	1.26×10^3	291	563	2.43×10^3	1.81×10^5	8.30×10^5
Methanol	7.91×10^2	175	338	2.52×10^3	9.9×10^4	1.12×10^6
Sea Water	1.02×10^3	264	377	3.93×10^3	....	....
Water	1.00×10^3	273	373	4.19×10^3	3.34×10^5	2.26×10^6
Air	1.29	....	....	....	....	....
Hydrogen	9.0×10^{-2}	14	20	1.43×10^4	....	4.50×10^5
Nitrogen	1.25	63	77	1.04×10^3	....	2.00×10^5
Oxygen	1.43	55	90	9.18×10^2	....	2.40×10^5

The gas densities refer to a temperature of 273 K and a pressure of $1.01 \times 10^5 \text{ Pa}$

2. 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.

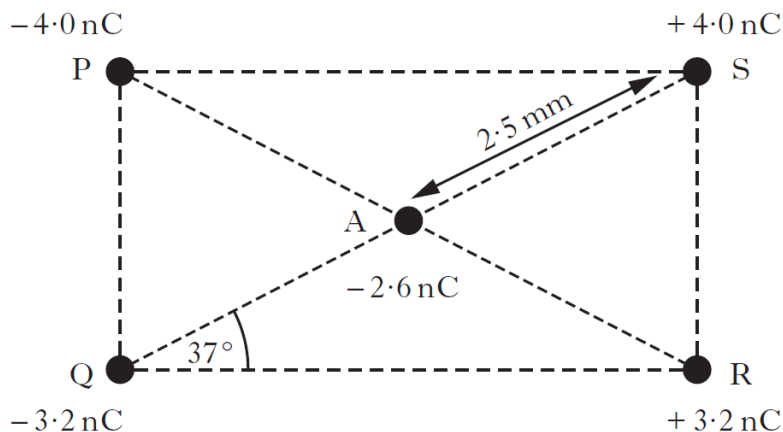


Figure 2A

- (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.

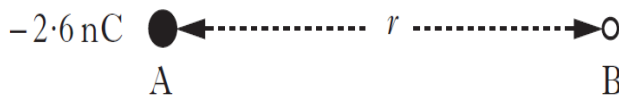


Figure 2B

- (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.

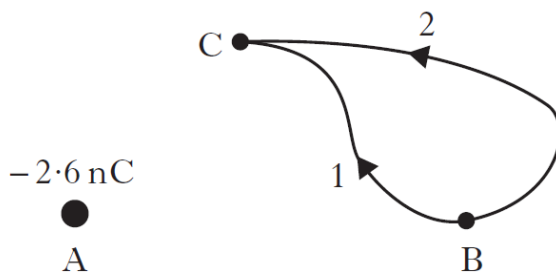


Figure 2C

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

(12)

3. A helium filled metal foil balloon with a radius of 0.35 m is charged by induction. The charge on the balloon is $+120 \mu\text{C}$. The balloon is considered to be perfectly spherical.

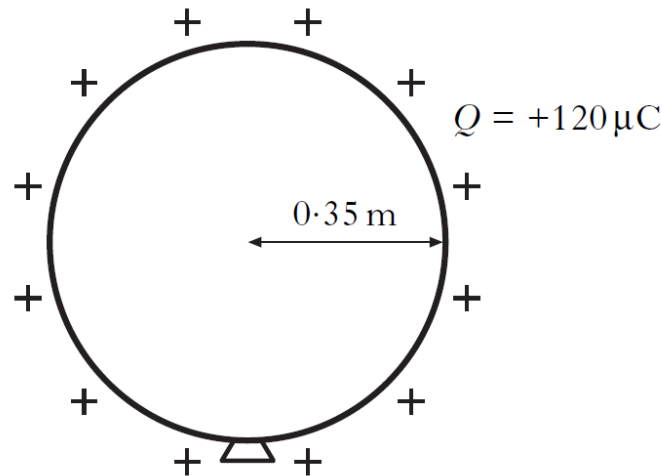


Figure 3A

- (a) (i) Using diagrams or otherwise, describe a procedure to charge the balloon by induction so that an evenly distributed positive charge is left on the balloon. **4**
- (ii) Calculate the Electric Field Strength at the surface of the balloon. **3**
- (iii) 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.

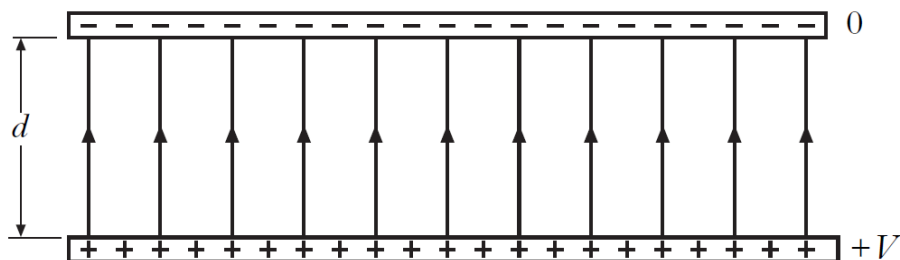


Figure 3B

- (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**

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Cont.

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

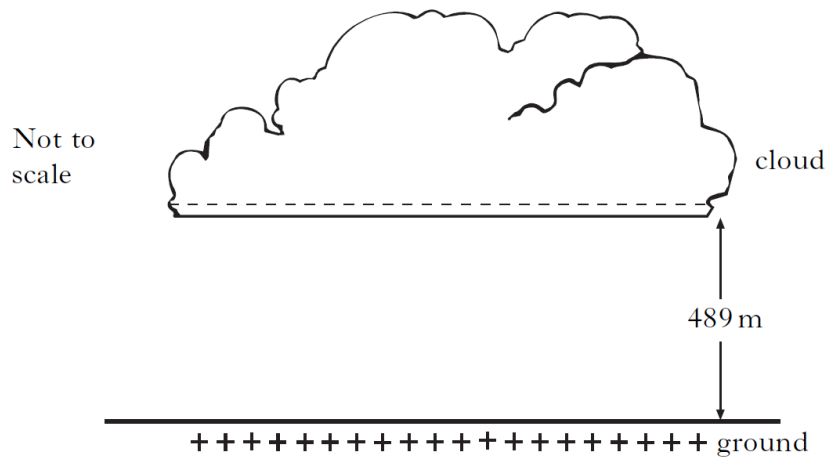


Figure 3C

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

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.

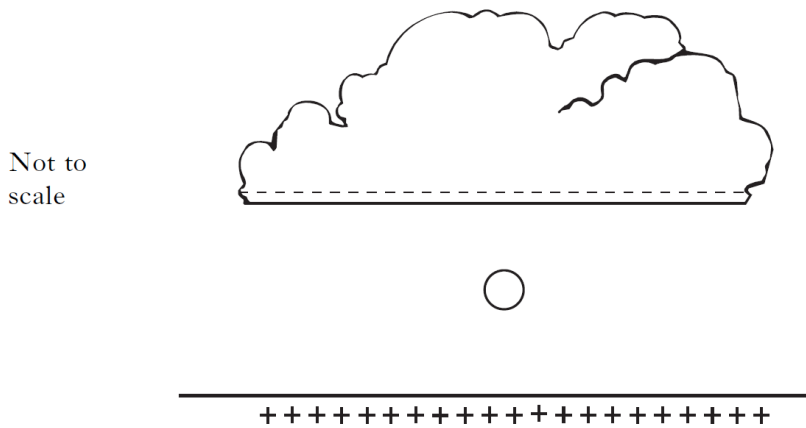


Figure 3D

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

2

(20)

4. 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.

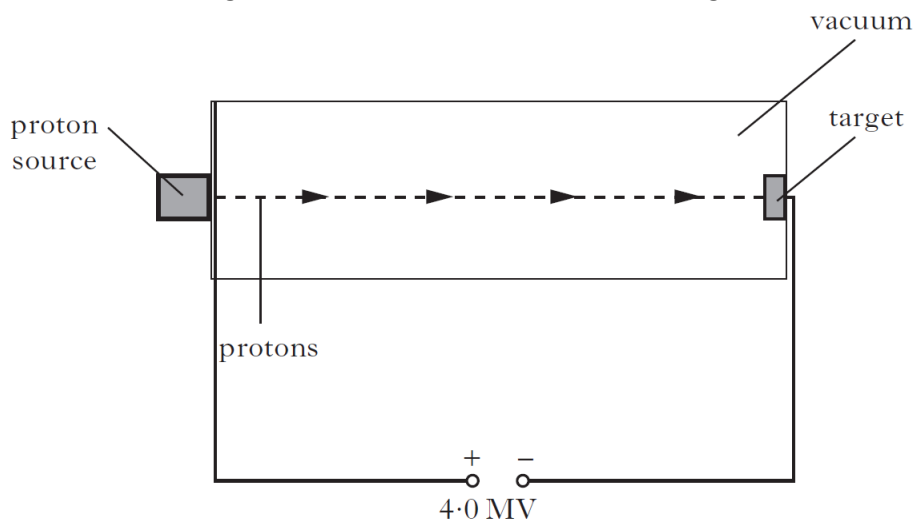


Figure 4A

- (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

$$r = \frac{qQ}{2\pi\epsilon_0 mv^2} \quad \mathbf{1}$$

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

(7)

5. Two long parallel wires are suspended from 1 m long threads and each carry equal currents in opposite directions such that the wires are repelled by one another.

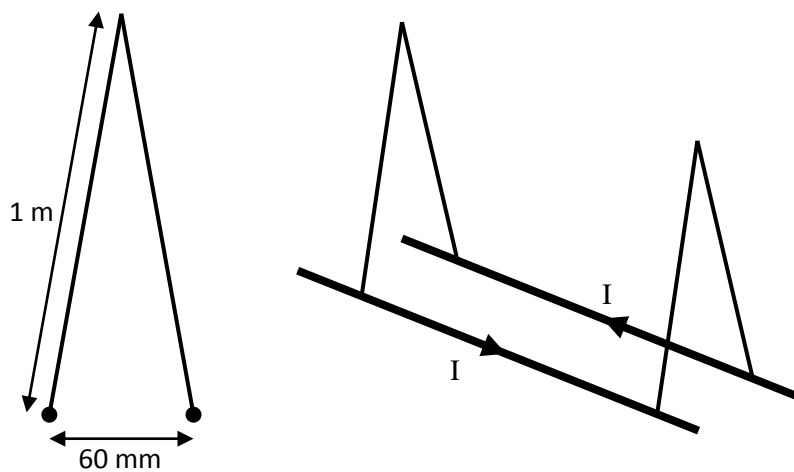


Figure 5

The wires are in equilibrium and are separated by a distance of 60 mm as shown in figure 5 (which is not drawn to scale).

The wires each have a mass per unit length of $12 \times 10^{-3} \text{ kg m}^{-1}$.

- (a) Draw a diagram showing all the forces acting on one of the wires by name. 2
- (b) By considering the horizontal and vertical forces acting on the wire separately, calculate the force of repulsion per unit length of wire. 4
- (c) Derive an expression for the force per unit length of repulsion between two parallel current carrying conductors carrying currents I_1 and I_2 respectively separated by a distance r . 3
- (d) Hence calculate the current flowing in the wires in figure 5. 3

(12)

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

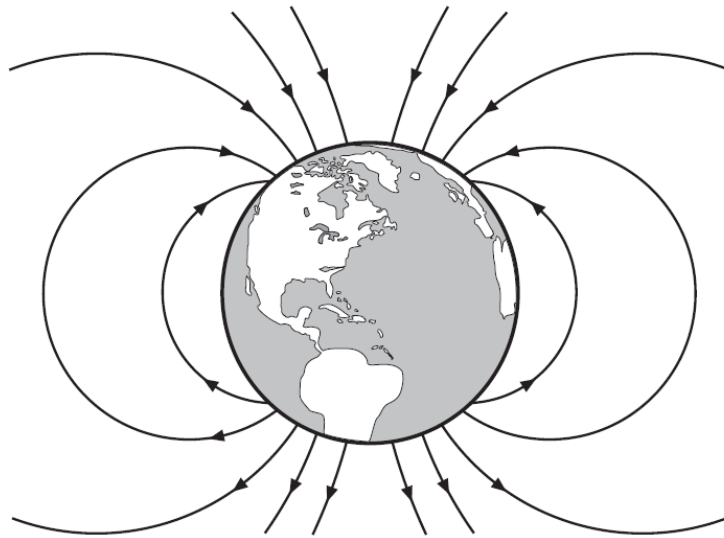


Figure 6A

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

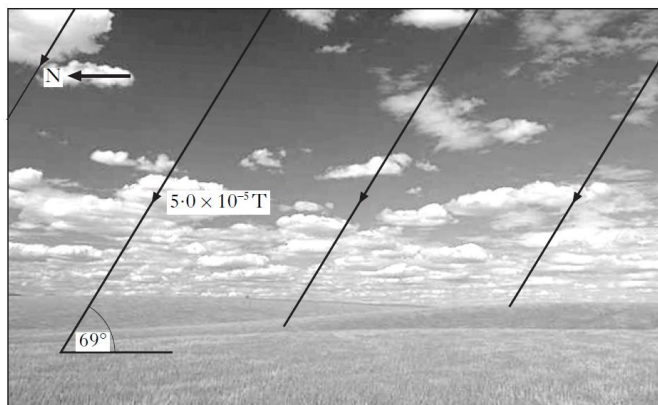


Figure 6B

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

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.

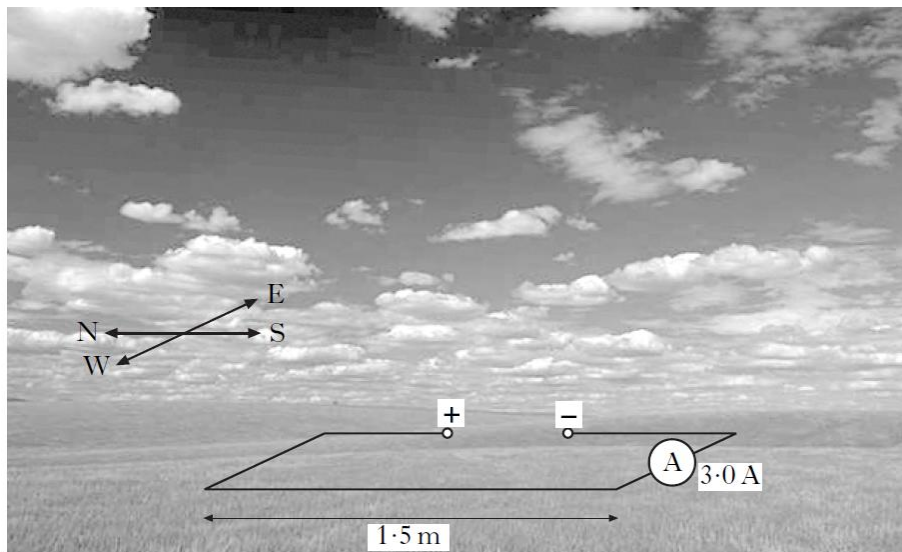


Figure 6C

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 5.0×10^{-5} T. **2**
- (ii) Describe the shape of this magnetic field. **1**
- (8)**

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

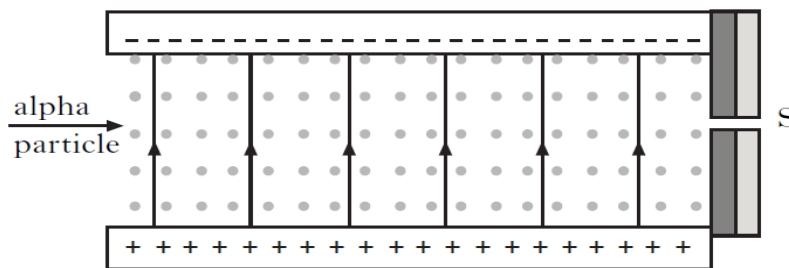


Figure 7A

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 5.0×10^{-11} N.

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

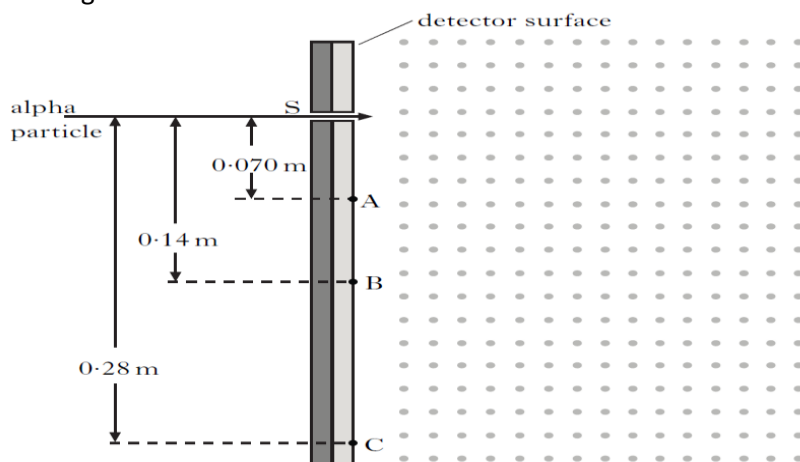


Figure 7B

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)

8. (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

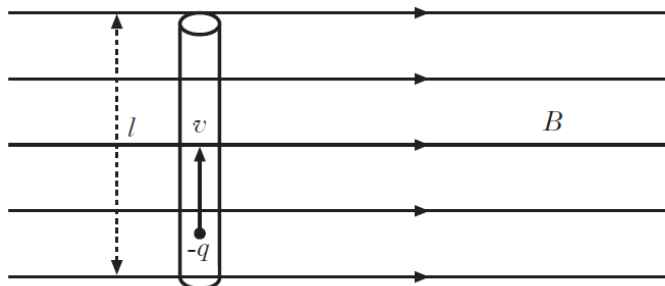


Figure 8A

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

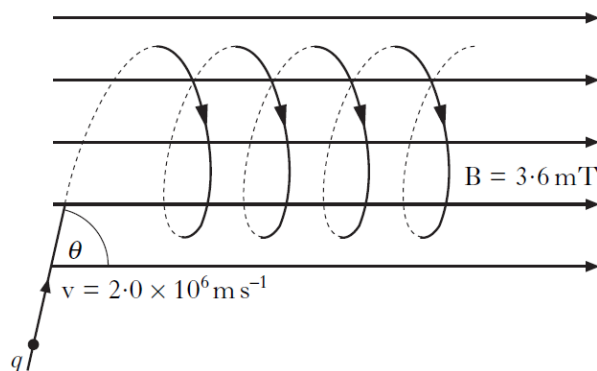


Figure 8B

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)

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

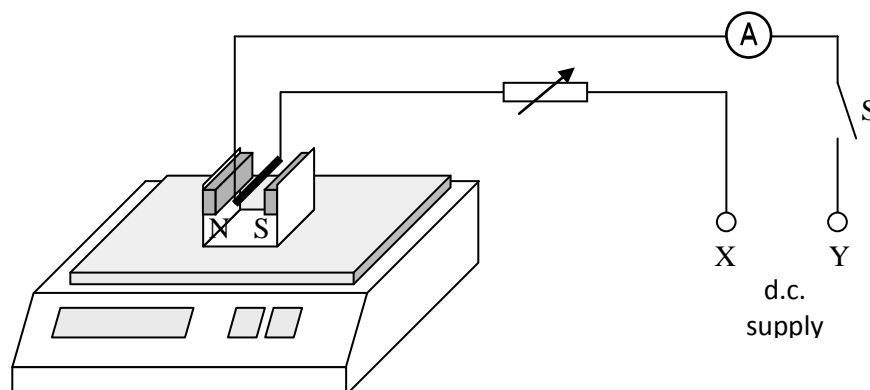


figure 9A

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. State the polarity of X and Y on the d.c. supply. 1
- (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]

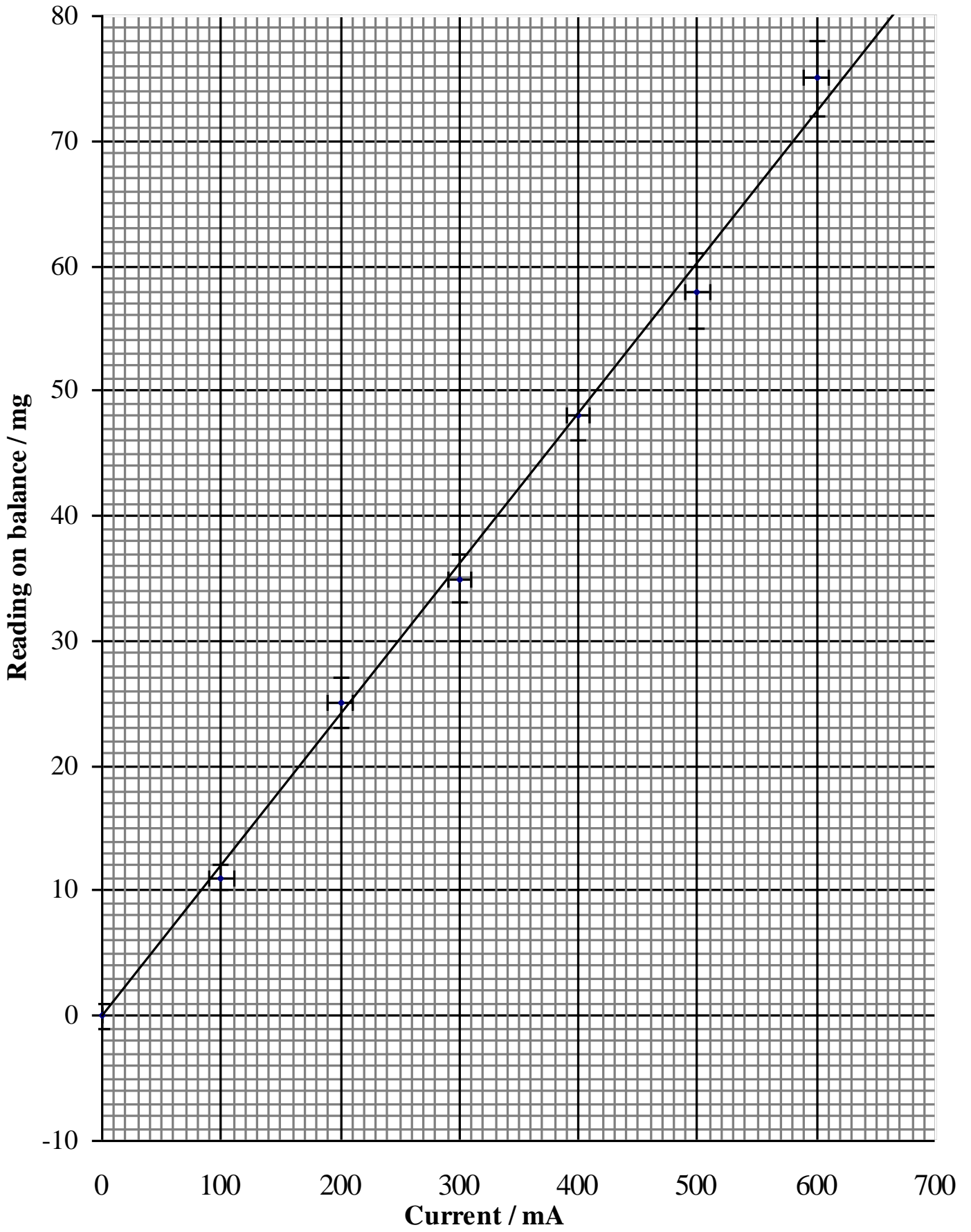


figure 9B

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

1

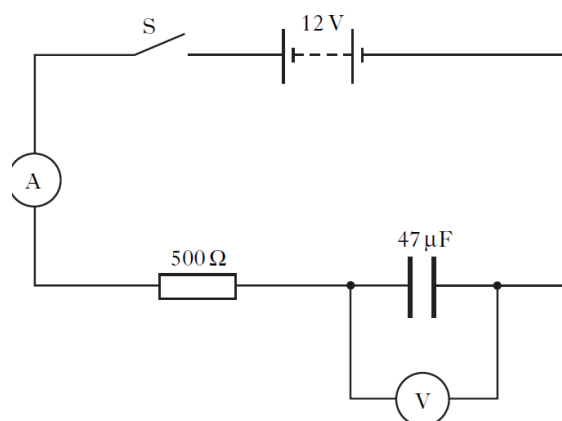


Figure 10

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.
- (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.

1

5

(6)

11. The relationship $\mathcal{E} = -L \frac{dI}{dt}$ 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**
- (d) A coil of self inductance L and negligible resistance is connected in series with a resistor of resistance 25Ω as shown in figure 11. The supply has an emf of 12 V and negligible internal resistance.

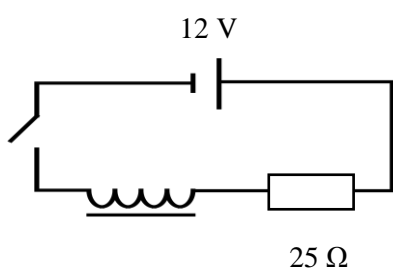


Figure 11

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)

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

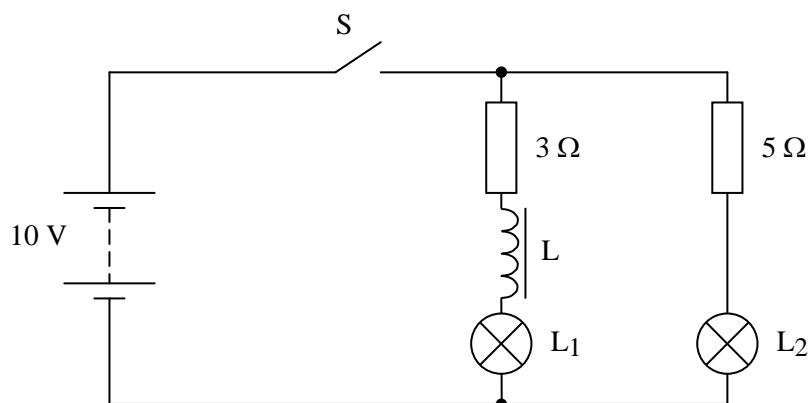


figure 12 A

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 inductor L is removed. Switch S is then closed.

Describe how any time delay in lamps L_1 and L_2 turning on compares with that observed in part (a). Justify your answer. 2

[Turn over]

12.

(continued)

Marks

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

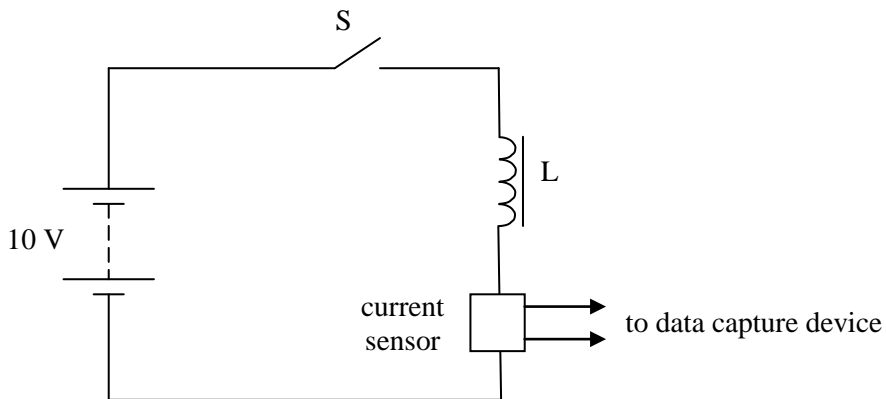


Figure 12 B

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.

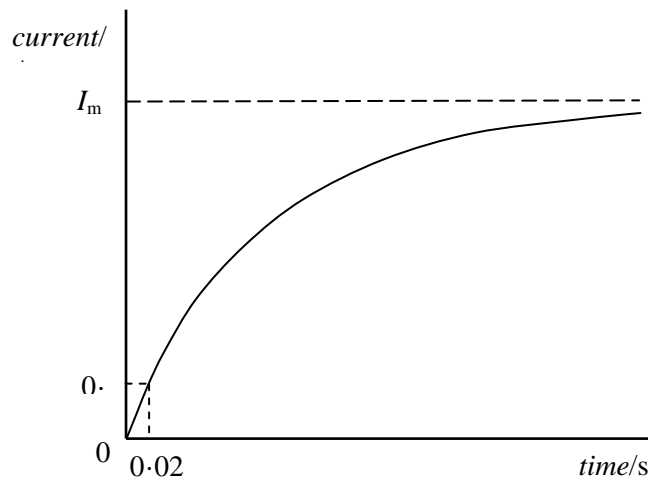


figure 12 C

- (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)**

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

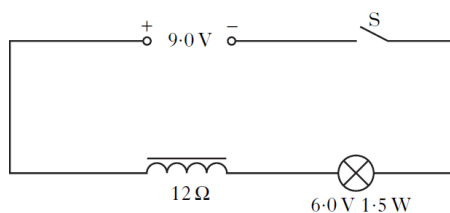


Figure 13 A

The inductor consists of a coil of wire with a resistance of $12\ \Omega$.

The lamp is rated at $6\ \text{V}\ 1.5\ \text{W}$.

The $9.0\ \text{V}$ 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 $75\ \text{mJ}$.
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 $1.5\ \text{V}$ cell.

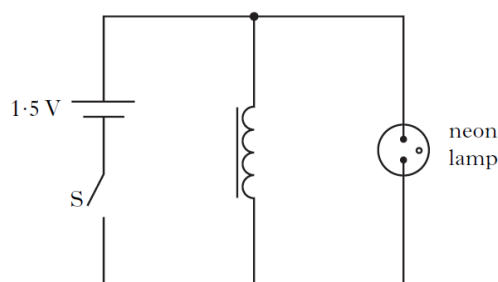


Figure 13 B

A neon lamp needs a potential difference of at least $80\ \text{V}$ 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)

14. (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. Marks

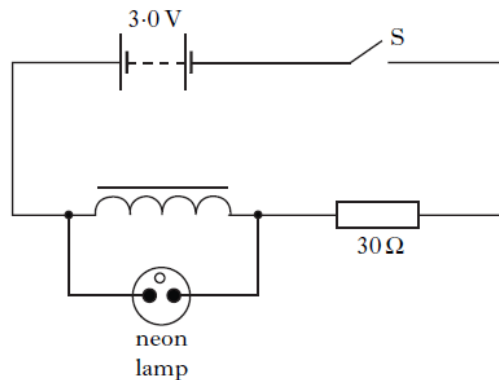


Figure 14 A

- (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]

14. cont

Marks

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

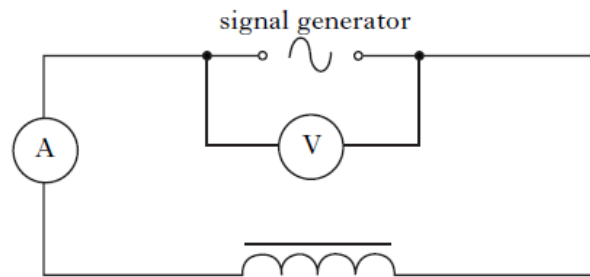


Figure 14B

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.

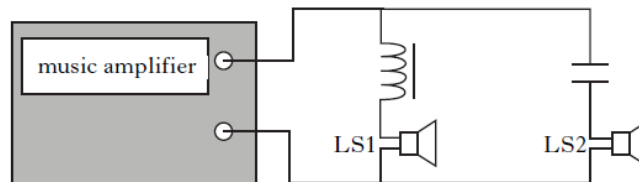


Figure 14C

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)

Marks

15. (a) Describe an experiment that demonstrates light behaving as a wave.
- (b) Describe an experiment that demonstrates light behaving as a particle.
- (c) Name the quantities and their units in the equation

2

2

$$c = \frac{1}{\sqrt{\epsilon_0 \mu_0}}$$

3

(7)