Physics
Further Questions (AH)

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HIGHER STILL

Physics

Further Questions

Advanced Higher

Support Materials

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CONTENTS

IMPORTANT NOTICE

This pack contains general tutorial questions and solutions for the Electrical Phenomena (AH) unit and Wave Phenomena (AH) unit.

Questions with solutions for the Mechanics (AH) have already been published

INTRODUCTION

The Advanced Higher student support material contains tutorials for each topic. Many of these questions are of a demanding nature and provide suitable cover of the course content. Full solutions to these tutorials have been provided.

These *General Tutorial Questions* are designed to provide basic practice for each topic. A number of questions are provided for each topic, together with brief solutions. These questions are intended to complement the *Tutorials* in the student material. These questions may be used before or in conjunction with the tutorial questions already published. Solutions are provided.

A set of *Course Questions*, similar to the Course Questions produced at the Higher, Int 2 and Int 1 levels, is published separately. These questions are for use in constructing a prelim or for homework and course revision.

DATA
Common Physical quantities

QUANTITY	SYMBOL	VALUE
Gravitational acceleration	g	9.8 m s^{-2}
Radius of Earth	R_E	6.4 x 10^6 m
Mass of Earth	M_E	6.0 x 10^{24} kg
Mass of Moon	M_M	7.3 x 10^{22} kg
Mean radius of Moon orbit		3.84 x 10^8 m
Universal constant of gravitation	G	6.67 x 10^{-11} m^3 kg^{-1} s^{-2}
Speed of light in vacuum	c	3.0 x 10^8 m s^{-1}
Speed of sound in air	v	3.4 x 10^2 m s^{-1}
Mass of electron	m_e	9.11 x 10^{-31} kg
Charge on electron	e	-1.60 x 10^{-19} C
Mass of neutron	m_n	1.675 x 10^{-27} kg
Mass of proton	m_p	1.673 x 10^{-27} kg
Planck's constant	h	6.63 x 10^{-34} J s
Permittivity of free space	ε_0	8.85 x 10^{-12} F m^{-1}
Permeability of free space	μ_0	4π x 10^{-7} H m^{-1}
Refractive index of water	n	1.33
of perspex	n	1.5

The solutions to the questions use the data values given above.

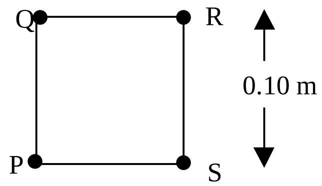
Coulomb's inverse square law and electric field strength

1. State Coulomb's inverse square law for the force between two point charges. State the name and unit for each symbol used in the above equation.

2. Calculate the electrostatic force between two electrons placed 1.5 nm apart.

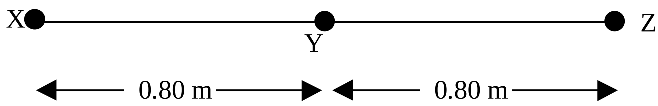
3. The electrostatic repulsive force between two protons in a nucleus is 14 N. Find the separation between the protons.

4. Four charges of +4.0 nC are situated at each of the corners of a square 0.10 m wide as shown below.



   (a) Determine the electrostatic force on charge P.
   (b) What is the electrostatic force on a –1.0 nC charge placed at the centre of the square. You must justify your answer.

5. Three +20 nC charges X, Y, Z are placed on a straight line as shown below.



   Calculate the electrostatic force acting on charge Z.

6. State the meaning of the term 'electric field strength at a point'.

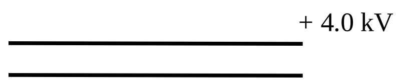
7. State the equation for the electric field strength, E,
   (a) at a distance r from a point charge Q
   (b) between two parallel plates, a distance d apart, when a p.d. V is applied across the plates.

8. Derive the equation stated in 7 (b) above for a uniform electric field.

9. What is the electric field strength at 10^{-10} m from a helium nucleus?

10. A small sphere has a charge of +2.0 μC. At what distance from the sphere is the magnitude of the electric field strength 72 000 N C^{-1}?

11. Two parallel plates are separated by 0.020 m. A potential difference of 4.0 kV is applied across the plates.



   (a) State the direction of the electric field strength between the plates.
   (b) What is the value of the electric field strength
      (i) mid way between the plates
      (ii) just below the top plate.

Electric fields and electrostatic potential

1. A metallic sphere has a radius of 0.040 m. The charge on the sphere is + 30 μC. Determine the electric field strength
   (a) inside the sphere
   (b) at the surface of the sphere
   (c) at a distance of 1.0 m from the centre of the sphere.

2. Describe, with the aid of a diagram, the process of charging by induction.

3. What is meant by the 'electrostatic potential at a point'?

4. State the expression for the electrostatic potential at a distance *r* from a point charge *Q*.

5. Determine the electrostatic potential at a distance of 3.0 m from a point charge of + 4.0 nC.

6. Point A is 2.0 m from a point charge of – 6.0 nC . Point B is 5.0 m from the same point charge. Determine the potential difference between point A and point B.

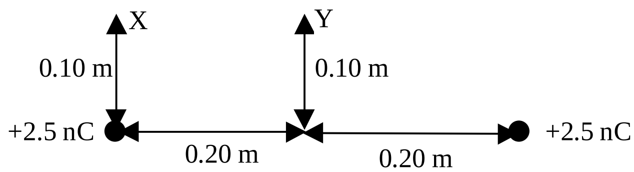
7. What is meant by an equipotential surface.

8. A very small sphere carries a positive charge. Draw a sketch showing lines of electric field for this charge. Add lines of equipotential to your sketch using broken dashed lines.

9. Two charges of + 4.0 nC and –2.0 nC are situated 0.12 m apart. Find the position of the point of zero electrostatic potential.

10. Which of the following are vector quantities: electrostatic force, electric field strength, electrostatic potential, permittivity of free space, electric charge, potential difference.

11. Two charges each of +2.5 nC are situated 0.40 m apart as shown below.

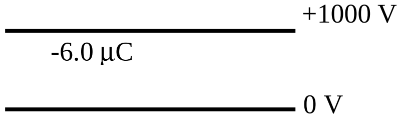


   (a) (i) What is the electrostatic potential at point X?
   What is the electrostatic potential at point Y?
   (b) Determine the potential difference between X and Y.

12. In a uniform electric field an electron gains 10^{-14} J when travelling between two points. What is the p.d. between these two points?

Charges in motion

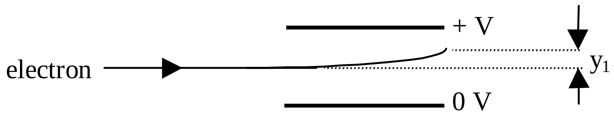
1. Two parallel plates are connected to a 1000 V supply as shown below.



   A –6.0 µC charge is just at the lower surface of the top plate.
   (a) How much work is done in moving the –6.0 µC charge between the plates?
   (b) Describe the energy transformation associated with the movement of a -6.0 µC charge, when it is released from the **bottom** plate.

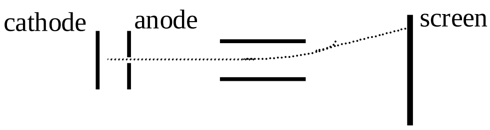
2. A p.d. of 3.0×10^4 V is applied between two large parallel plates. The electric field strength between the plates is 5.0×10^5 N C^{-1}.
   (a) Determine the separation of the parallel plates.
   (b) The separation of the plates is reduced to half the value found in (a). What will happen to the magnitude of the electric field strength between the plates?
   (c) An electron leaves one plate from rest and is accelerated towards the positive plate. Show that the velocity of the electron just before it reaches the positive plate is given by $v = \sqrt{\frac{2Ve}{m}}$ where V is the p.d. between the plates.

3. An electron is projected along the axis midway between two parallel plates as shown below.



   The kinetic energy of the electron is 2.88×10^{-16} J.
   The magnitude of the electric field strength between the plates is 1.4×10^4 N C^{-1}.
   The length of the plates is 0.15 m. The plate separation is 0.10 m.
   (a) Determine the initial horizontal speed of the electron as it enters the space between the plates.
   (b) What is the vertical deflection, y_1, of the electron?
   (c) Describe the motion of the electron after it leaves the space between the plates.

4. A beam of electrons is accelerated from rest at a cathode towards an anode. After passing through the hole in the anode the beam enters the electric field between two horizontal plates as shown below.
   A screen is placed 0.180 m beyond the end of the plates.
   You may assume that there is no electric field between the anode and parallel plates and no electric field between the parallel plates and screen.



   (a) The p.d. between the cathode and anode is 200 V.
   Calculate the speed of each electron as it enters the space between the plates.

(b) The p.d. across the plates is 1.0 kV. The plates are 30 mm long and their separation is 50 mm. Calculate the deflection of an electron on leaving the parallel plates.
(c) Calculate the total deflection on the screen.

5. Electrons are accelerated through a p.d. of 125 kV.
(a) What speed would this give for the electrons, assuming that $qV = \frac{1}{2} mv^2$?
(b) Why is the answer obtained in (a) unlikely to give the correct speed for the electrons?

6. Explain how the results of Millikan's experiment lead to the idea of quantisation of charge.

7. In a Millikan oil drop experiment the oil drop has a mass of 0.01 μg. It is suspended between two plates that are 20 mm apart. The charge on the drop is found to be –5e.
(a) Draw a sketch of the drop showing the forces acting on the drop. The upthrust of the air may be neglected.
(b) Determine the p.d. between the plates.
(c) The p.d. between the plates is increased.
Describe and explain what would happen to the drop?

8. In a Millikan type experiment, a small charged oil drop is held stationary between two plates by adjusting the p.d. between the plates. The experiment is repeated a number of times with different oil drops. The readings below show the mass of each oil drop and the p.d. required to hold it stationary.
The plate separation is 40 mm.

Mass of drop/10^{-15} kg	2.6	1.2	1.6	2.3	4.8	5.9	1.8	3.7
p.d. / V	1592	2940	1960	2818	2940	14455	1470	4533

(a) For each set of readings calculate the number of excess electrons on the oil drop.
(b) Suggest why these readings indicate that charge is quantised.

9. An alpha particle is about to make a head on collision with an oxygen nucleus. When at a large distance from the oxygen nucleus, the speed of the alpha particle was 1.9×10^6 m s^{-1}. The mass of the alpha particle is 6.7×10^{-27} kg.
(a) State an expression for the change in kinetic energy of the alpha particle as it approaches the oxygen nucleus.
(b) State an expression for the change in electrostatic potential energy of the alpha particle.
(c) Using your answers to (a) and (b) derive an expression for the distance, *r*, of closest approach.
(d) Calculate the distance of closest approach for the alpha particle to the oxygen nucleus.

10. The distance of closest approach between an alpha particle and an iron nucleus is 1.65×10^{-13} m. What was the speed of approach of the alpha particle? The mass of an alpha particle is 6.7×10^{-27} kg and the atomic number of iron is 26.

Electromagnetism

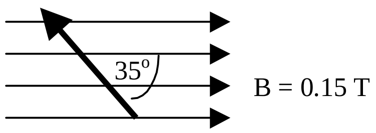
1. (a) State the condition for a magnetic field to exist.
   (b) Under what conditions will a charged particle experience a force in a magnetic field?
   (c) State the definition of the tesla.

2. (a) State the expression for the force on a current carrying conductor placed at an angle θ in a magnetic field.
   (b) Draw a sketch to show the position of this angle θ, the direction of the electron flow in the conductor, the direction of the magnetic induction and the direction of the force.
   (c) A straight conductor of length 25 mm carries a current of 2.0 A. It experiences a force of 9.5 mN when placed in a magnetic field with a magnetic induction of 0.70 T. Calculate the angle between the direction of the magnetic field and the conductor.

3. A wire, carrying a current of 10 A, is placed at right angles to a magnetic field. A straight section of the wire 0.80 m long has a force of 0.20 N acting on it. Calculate the size of the magnetic induction of the magnetic field.

4. A straight wire of length 0.50 m is placed in a region of magnetic induction 0.10 T.
   (a) What is the minimum current required in the wire to produce a force of 0.30 N on the wire?
   (b) Why is this a minimum value?

5. A wire of length 200 mm is placed at an angle of 35^o to a magnetic field of magnetic induction 0.15 T.



Wire showing direction of electron flow

   (a) The current in the wire is 7.0 A.
   Calculate the magnitude of the force on the wire.
   (b) State the direction of this force.

6. State the expression for the magnetic induction at a perpendicular distance r from an infinite straight conductor carrying a current I.

7. Derive the expression $\frac{F}{l} = \frac{\mu_0 I_1 I_2}{2\pi r}$ using the expression stated in question 7.
   State clearly the meaning of all the symbols in this expression.

8. Two long parallel wires are placed 90 mm apart in air. One of the wires is carrying a current of 2.0 A and the force per unit length on the wire is 8.89×10^{-6} N m^{-1}. What is the current in the other wire?

9. A long wire X is fixed horizontally to the ground. A second very thin wire, Y, of weight 0.075 newtons per metre length, runs parallel to wire X. The magnetic repulsion between the wires causes wire Y to be suspended 5.0 mm above wire X. The wires carry the same current, I. Calculate the value of I.

Motion in a magnetic field

1. Derive the expression $F = qvB$ using the relationship $F = Il B\sin\theta$ with $\theta = 90^o$. State clearly the name and unit of all the symbols in this expression.

2. A proton travels at right angles to a magnetic field of magnetic induction 0.80 T. The speed of the proton is 3.0×10^4 m s^{-1}. Determine the force on the proton.

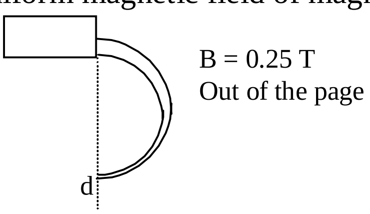
3. An electron is moving at right angles to a magnetic field of magnetic induction 0.50 T. The velocity of the electron is 2.0×10^5 m s^{-1}.
   (a) Calculate the magnitude of the force on the electron.
   (b) State the direction of the force on the electron.
   (c) Determine the radius of the circular path of the electron.

4. The movement of an electron in a uniform magnetic field is found to be helical. Explain how this helical movement arises.

5. 'Crossed' electric and magnetic fields can be used in a velocity selector.
   (a) Explain what is meant by 'crossed' electric and magnetic fields.
   (b) The velocity selector 'selects' charged particles, which pass through the fields without being deflected. By considering the magnetic force and electrostatic force on a charged particle show that the 'selected' velocity is $\frac{E}{B}$
   (c) State, with a reason, if the selected velocity depends on
      (i) the charge of the particle
      (ii) the mass of the particle.
   (d) In a mass spectrometer ions from a velocity selector enter a region that only has a magnetic field. With the aid of a sketch, explain how the ions can be identified by their deflection.

6. In a J J Thomson type experiment the charge to mass ratio is to be determined. Crossed magnetic and electric fields are used to produce an undeflected beam.
   (a) Derive an expression for the velocity of the electrons in this undeflected beam in terms of the magnetic induction, B, the p.d. across the plates, V, and the plate separation, d.
   (b) The magnetic field is then applied by itself and the electron beam moves in a circular path of radius, r.
   By considering the central force on the electrons derive an expression for e/m in terms of the velocity of the electrons and this radius, r.
   (c) Use the expressions stated in (a) and (b) above to show that $\frac{e}{m} = \frac{V}{rB^2d}$.

7. In a mass spectrometer two isotopes of single ionised carbon-13 and carbon-12 ions are accelerated by a p.d. of 4.0 kV. They emerge from a small slit into a uniform magnetic field of magnetic induction 0.25 T as shown below.



Mass of carbon-13 ion = 2.16×10^{-26} kg

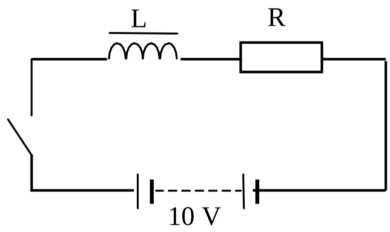
Mass of carbon-12 ion = 1.99×10^{-26} kg

Calculate the separation, d, of the two carbon ions.

Self-inductance

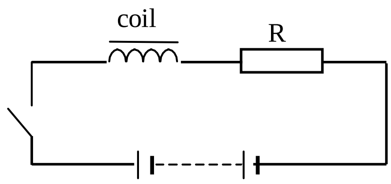
1. (a) A student is investigating the production of an induced e.m.f. across a coil. Describe a simple experiment which would allow her to do this.
   (b) State three ways in which the magnitude of the induced e.m.f. across a coil can be increased.

2. An inductor, resistor and battery are joined in series as shown below.



   (a) The inductor has a large number of turns. The switch is closed. Sketch a graph to show how the current in the circuit varies with time.
   (b) Explain why the current does not reach its maximum value immediately.
   (c) The resistance of the resistor is reduced. How would the shape of the graph alter ?
   (d) The number of turns on the inductor is considerably reduced. State how the graph drawn in part (a) would alter.

3. A circuit is set up as shown below.

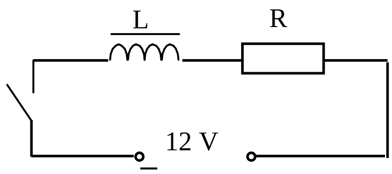


   Explain how an induced e.m.f. is produced across the coil.

4. When the current through an inductor is increasing the induced e.m.f. opposes this increase in current. The current takes time to reach its maximum value.
   (a) Explain what happens when the current through an inductor decreases.
   (b) The current through an inductor decreases. Use the conservation of energy to explain the direction of the induced e.m.f.

5. (a) The current through a coil changes. State the equation for the e.m.f. induced across the coil in terms of the self inductance of the coil.
   (b) State the unit of inductance.
   (c) State the equation for the energy stored in the magnetic field of an inductor.

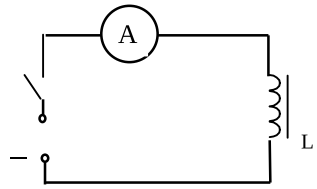
6. An inductor, resistor and d.c. supply are connected in series as shown below. The internal resistance of the d.c. supply is negligible.



The inductance of the inductor is 0.40 H. The resistance of the resistor is 15 Ω. The switch is now closed.

(a) Why does it take a short time for the current to reach its steady value?
(b) Calculate the steady current reached.
(b) When the current reaches a steady value, calculate the energy stored in the inductor.

7. An inductor is connected to an ammeter and an 8.0 V direct supply of negligible internal resistance, as shown below. The resistance of the inductor coil is 20 Ω.

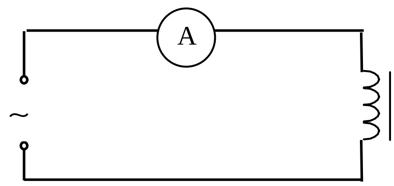


When the reading on the ammeter is 0.10 A, the rate of change of current is 100 A s^{-1}.

(a) Calculate the p.d. across the coil.
(b) Find the induced e.m.f. across the coil.
(c) Calculate the inductance of the coil.
(d) Calculate the energy stored in the inductor.

9. Which of the following are vector quantities:
induced e.m.f., self-inductance, energy stored in an inductor, rate of change of current.

10. An inductor is connected to a variable a.c. supply as shown below.



(a) (i) The frequency of the a.c. supply is increased. Draw a graph to show how the current in the circuit varies with the frequency of the supply.
(ii) The inductor is removed and replaced by a capacitor. Draw another graph to show how the current in the circuit varies with the frequency of the supply.
(b) The inductor has reactance. State what is meant by the term ‘reactance’.

11. Describe an example of the use of an inductor:
(a) as a source of a high e.m.f.
(b) in blocking a.c. signals while transmitting d.c. signals.

Waves

1. (a) State the relationship between the intensity and the amplitude of a wave.
   (b) The amplitude of a wave increases ninefold.
   What is the change in the intensity?

2. 'All waveforms can be described by the superposition of sine or cosine waves'. Explain what is meant by this statement using either a square wave or a sawtooth wave as an example.

3. (a) The relationship $y = a \sin 2\pi(ft - \frac{x}{\lambda})$ represents a travelling wave.
   State clearly the meaning of each symbol in this equation.
   (b) A travelling wave is represented by the relationship
   $$y = 0.60 \sin\pi(150t - 0.40x)$$
   where standard SI units are used throughout.
   (i) What is the amplitude of the wave?
   (ii) Determine the frequency of the wave.
   (iii) State the period of the wave.
   (iv) Calculate the wavelength of the wave.
   (v) What is the wave speed?

4. Two waves are represented by the relationships:
   $y_1 = 4.0 \sin 2\pi(8t - 5x)$ and $y_2 = 4.0 \sin\pi(16t - 21x)$ respectively.
   (a) Which of the following quantities are the same for the two waves: amplitude, frequency, wavelength, period.
   (b) Are the two waves in phase? You must justify your answer.

5. (a) Explain what is meant by a 'stationary wave'.
   (b) Define the terms 'nodes' and 'antinodes'.

6. (a) Describe what is meant by the Doppler effect. Give two examples to illustrate this effect.
   (b) Derive the expression for the apparent frequency detected when a source of sound waves moves relative to an observer.
   (c) Derive the expression for the apparent frequency detected when an observer moves relative to a source of sound waves.

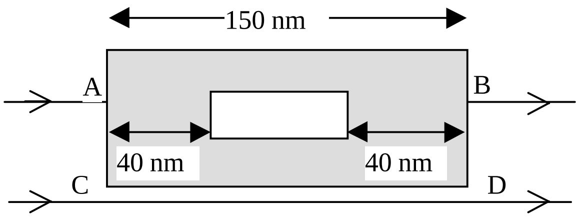
7. An alarm on a stationary car emits waves of frequency 800 Hz.
   (a) What is the frequency heard by a passenger on a bus travelling at 30 m s^{-1} towards the car.
   (b) Calculate the frequency heard by a passenger on the bus when the bus is travelling at 30 m s^{-1} away from the car.

8. While moving at 25 m s^{-1} a car sounds its horn. The frequency of the sound emitted by the horn is 700 Hz. What is the frequency of the sound heard by a pedestrian standing at the side of the road as the car moves away into the distance.

Interference – division of amplitude

1. (a) State the condition for two light beams to be coherent.
   (b) Explain why two light beams, of the same frequency, but from different sources are unlikely to be coherent.
   (c) Can two loudspeakers connected to the same signal generator emit coherent beams of sound waves? Explain your answer.

2. (a) Define the term optical path difference.
   (b) State the relationship between the optical path difference and phase difference.
   (c) A hollow air filled perspex microfibre is shown below. Light of wavelength 700 nm passes through and around the microfibre.



   (i) Determine the optical path length between AB.
   (ii) A ray of light follows the path AB above. Another ray follows the path CD, just outside the block.
   What is the phase difference between the two rays?

3. (a) Light in air is reflected from a glass surface. What is the change in phase of the light waves?
   (b) What change in phase occurs when light in glass is reflected at a glass/water boundary back into the glass.

4. A thin parallel sided film is used to produce interference fringes.
   (a) Using the thin film as an example, explain the term 'interference produced by division of amplitude'. Include a sketch of the path of the light rays through the film
   (b) (i) State the condition for a minimum to be produced in the fringes formed by reflection from the film of monochromatic light of wavelength λ.
   (ii) What is the effect on the fringe pattern when the thickness of the film increases?

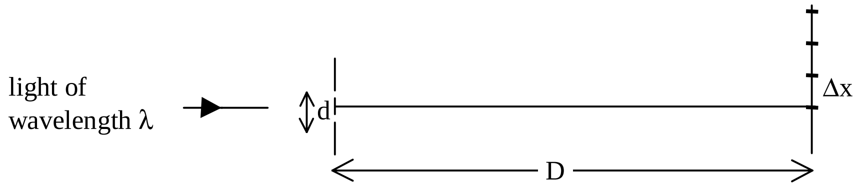
5. (a) Derive the expression for the distance between the fringes which are formed by reflection of light from a thin wedge.
   (b) Two glass slides are 100 mm long. A wedge is formed with the slides by placing the slides in contact at one end. The other ends of the slide are separated by a piece of paper 30 μm thick. Interference fringes are observed using light of wavelength 650 nm. Calculate the separation of the fringes.
   (c) When looking at a slightly different part of the fringe pattern the fringes are observed to be slightly closer together. What does this imply about the paper.
   You must justify your answer.

6. (a) Derive the expression $d = \lambda/4n$ for the thickness of a non-reflecting coating.
   (b) What thickness of coating is required to give non-reflection in green light of wavelength 540 nm for a lens of refractive index 1.53.
   (c) Explain why some lenses with a non-reflective coating appear coloured.

Interference – division of wavefront

1. (a) An interference pattern is obtained by division of wavefront. What is meant by 'division of wavefront'.
   (b) Why must the source be a point source to produce interference by division of wavefront?
   (c) Explain why an extended source can be used to produce an interference pattern by division of amplitude.

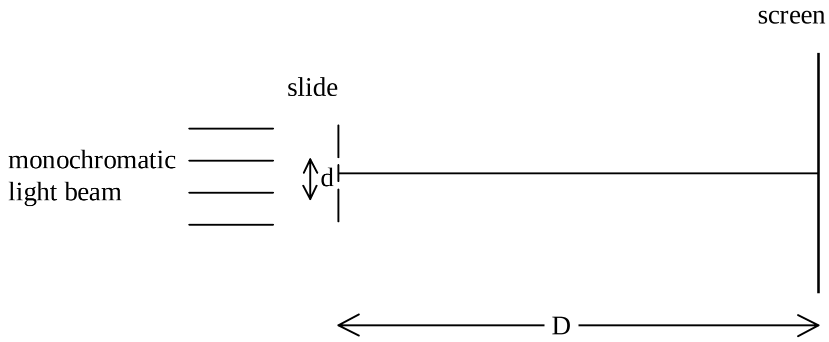
2. The diagram below shows the set up for a Young's double slit experiment.



   (a) Derive the expression $\Delta x = \frac{\lambda D}{d}$ for the fringe spacing.
   (b) State any assumptions made in the above derivation.

3. Two parallel slits have a separation of 0.24 ± 0.01 mm. When illuminated by light an interference pattern is observed on a screen placed 3.8 ± 0.1 m from the double slits. The fringe separation is observed to be 9.5 ± 0.1 mm.
   (a) Calculate the wavelength of the light used.
   (b) Determine the uncertainty in this wavelength.

4. Two slits, of separation d, are made on a slide. The slide is illuminated by monochromatic light as shown below.



   Fringes are observed on the screen.
   (a) The fringe spacing is observed to be too small to make accurate measurements.
   State one way of increasing the fringe spacing using this apparatus.
   (b) The light beam is replaced by one of light of a higher wavelength.
   What effect will this have on the fringe spacing?
   (c) The slide is removed and replaced with another slide. The second slide has two slits with a smaller separation, d.
   What effect does this have on the fringe pattern?
   (d) What can be used to measure the slit separation?
   (e) Describe how the fringe separation could be measured.

Polarisation

1. (a) Explain the difference between linearly polarised and unpolarised waves.
   (b) Describe how an unpolarised wave can be linearly polarised using a polaroid filter.
   (c) Describe how a 'polariser' and 'analyser' can prevent the transmission of light.

2. Monochromatic light is incident at a boundary between air and another medium. The reflected light is found to be polarised.
   (a) What information does this provide about the nature of the medium?
   (b) Derive the expression relating the polarising angle and the refractive index of the medium for this light.
   (c) State the other common name for the polarising angle.

3. Light is incident on a rectangular block of perspex
   (a) Draw a sketch to show the position of the polarising angle for perspex.
   (b) Mark on your sketch for part (a) the value of the polarising angle.

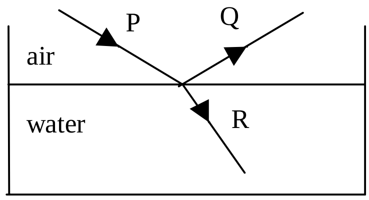
4. Explain how sunglasses can remove glare.

5. The refractive index of a liquid is 1.45.
   (a) Calculate the polarising angle for this liquid.
   (b) Determine the value of the angle of refraction for this polarising angle.

6. The critical angle in a certain glass is 40.5^o.
   What is the polarising angle for this glass?

7. A spectrum can be produced by a prism because the refractive index changes with the frequency of light.
   What effect will an increase in the frequency of light have on the polarising angle?
   You must justify your answer.

8. Light is incident on a water surface as shown below.



   The angle between the ray Q and R is 90^o.

   (a) The ray Q is observed through a sheet of polaroid. The polaroid is rotated. Describe and explain what is observed.
   (b) Calculate the polarising angle for water.
   (c) Copy the diagram and label in the correct places the values of the angle of incidence and angle of refraction.

SOLUTIONS

In many cases the data in the question is given to two significant figures, hence the final answer is given to two significant figures. Any interim calculation should retain more significant figures. Where possible a calculator is used *once* to obtain a final numerical answer.

Note:

$\frac{1}{4\pi\varepsilon_0}$ is 8.99 x 10^9 to three significant figures, or the more commonly used 9.0 x 10^9 to two significant figures. The answers to the solutions have used 9.0 x 10^9.]

Coulomb's inverse square law and electric field strength

1. $F = \frac{Q_1 Q_2}{4\pi\varepsilon_0 r^2}$

   where F - force between the two charges (N), Q_1 and Q_2 – charges (C)
   ε_0 – permittivity of free space (F m^{-1}), r – separation of charges (m)

2. $F = \frac{Q_1 Q_2}{4\pi\varepsilon_0 r^2}$ $\quad F = 9 \times 10^9 \times \frac{1.6 \times 10^{-19} \times 1.6 \times 10^{-19}}{(1.5 \times 10^{-9})^2}$

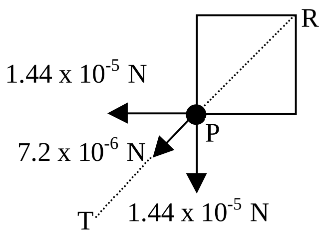
   $F = 1.0 \times 10^{-10}$ N repulsion [the direction must be stated]

3. $14 = 9 \times 10^9 \times \frac{1.6 \times 10^{-19} \times 1.6 \times 10^{-19}}{r^2}$ giving $r = 4.1 \times 10^{-15}$ m

4. (a) Magnitude of F due to charge Q = $9 \times 10^9 \times \frac{4 \times 10^{-9} \times 4 \times 10^{-9}}{0.1^2}$

   $= 1.44 \times 10^{-5}$ N

   Magnitude of F due to charge S = 1.44×10^{-5} N (same separation)
   Magnitude of F due to charge R = 7.2×10^{-6} N (r = 0.1414 m)
   Total force on charge is determined by vector addition.



   Combining the two 1.44×10^{-5} N forces gives a force of 2.04×10^{-5} N in the same direction as the 7.2×10^{-6} N force.

   Hence total force on P is $= (2.04 + 0.72) \times 10^{-5}$ N
   $F = 2.8 \times 10^{-5}$ N
   in the direction RPT, shown on the diagram.

   (b) zero. The two 4.0 nC charges at opposite ends of a diagonal will exert an equal and opposite force on the –1.0 nC charge at the centre, hence the resultant force will be zero.

5. $F = 9 \times 10^9 \times \dfrac{20 \times 10^{-9} \times 20 \times 10^{-9}}{0.8^2} + 9 \times 10^9 \times \dfrac{20 \times 10^{-9} \times 20 \times 10^{-9}}{1.6^2}$

$F = 7.0 \times 10^{-6}$ N to the right

6. The electric field strength is the electrostatic force on one coulomb of charge placed at that point.

7. (a) $E = \dfrac{Q}{4\pi\varepsilon_0 r^2}$ (b) $E = \dfrac{V}{d}$

8. See Student Material page 5.

9. $E = \dfrac{Q}{4\pi\varepsilon_0 r^2} = 9 \times 10^9 \times \dfrac{2 \times 1.6 \times 10^{-19}}{(1 \times 10^{-10})^2}$

$= 2.88 \times 10^{11}$ V m^{-1} (or N C^{-1}) away from the nucleus

10. $E = \dfrac{Q}{4\pi\varepsilon_0 r^2}$; $72\,000 = 9 \times 10^9 \times \dfrac{2 \times 10^{-6}}{r^2}$ $r = 0.50$ m

11. (a) Towards the bottom plate, perpendicular to the plates.

(b) (i) $E = \dfrac{V}{d} = \dfrac{4.0 \times 10^3}{0.02}$ $= 2.0 \times 10^{-5}$ V m^{-1}

(ii) The same $E = 2.0 \times 10^{-5}$ V m^{-1}, the field is uniform between the plates.

Electric fields and electrostatic potential

1. (a) zero

(b) $E = \dfrac{Q}{4\pi\varepsilon_0 r^2} = 9 \times 10^9 \times \dfrac{30 \times 10^{-6}}{0.04^2} = 1.7 \times 10^8$ V m^{-1} away from the sphere.

(c) $E = 2.7 \times 10^5$ V m^{-1} [as above with r = 1 m] away from the sphere.

2. See Student Material page 6. Notice that the object charged by induction, the electroscope, is not touched by the charging object, the negatively charged rod.

3. The electrostatic potential at a point is the work done to bring one coulomb of charge from infinity to that point.

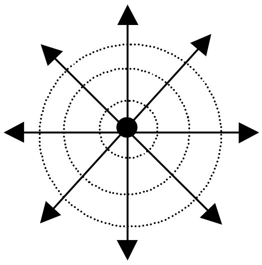
4. $V = \dfrac{Q}{4\pi\varepsilon_0 r}$

5. $V = \dfrac{Q}{4\pi\varepsilon_0 r} = 9 \times 10^9 \times \dfrac{4 \times 10^{-9}}{3} = 12$ V

6. $V_A = 9 \times 10^9 \times \dfrac{6 \times 10^{-9}}{2} = 27$ V and $V_B = 9 \times 10^9 \times \dfrac{-6 \times 10^{-9}}{5} = -10.8$ V

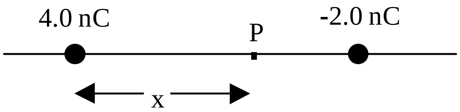
Potential difference $V_{AB} = 16.2$ V where A is negative compared to B

7. A surface on which the potential is the same at all points. No work would be done to move a charge between two points on the surface.

8. 

The field lines are full lines and the lines of equipotential are broken lines.

Notice that the field lines and lines of potential are perpendicular to each other.

9. 

For zero potential at point P: V(due to 4.0 nC) + V(due to -2.0 nC) = 0

$9 \text{ x } 10^9 \text{ x } \frac{4 \text{ x } 10^{-9}}{x} + 9 \text{ x } 10^9 \text{ x } \frac{-2 \text{ x } 10^{-9}}{(0.12 - x)} = 0$

4(0.12 –x) - 2x = 0 and 0.48 – 4 x – 2x = 0 giving x = 0.08 m

10. Electrostatic force, electric field strength.

11. (a) $V_X = 9 \text{ x } 10^9 \text{ x } \frac{2.5 \text{ x } 10^{-9}}{0.1} + 9 \text{ x } 10^9 \text{ x } \frac{2.5 \text{ x } 10^{-9}}{0.412} = 280 \text{ V}$

$V_Y = 2 \text{ x } (9 \text{ x } 10^9 \text{ x } \frac{2.5 \text{ x } 10^{-9}}{0.224}) = 201 \text{ V}$

(b) $V_{XY} = 79 \text{ V}$

12. Energy = VQ $10^{-14} = V \text{ x } 1.6 \text{ x } 10^{-19}$ giving V = 62.5 kV

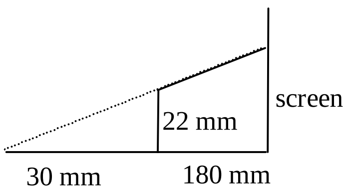
Charges in motion

1. (a) Work = p.d. x charge = 1000 x 6.0 x 10^{-6} = 6.0 mJ
   (b) Electrostatic potential energy is transformed into kinetic energy as the charge is accelerated towards the top plate.

2. (a) V = Ed 3.0 x 10^4 = 5.0 x 10^5 x d giving d = 0.060 m or 60 mm
   (b) The electric field strength will double.
   (c) change in E_k = change in electrical energy
   $\frac{1}{2} mv^2 - 0 = VQ$ where V is the p.d.
   $v = \sqrt{\frac{2Ve}{m}}$ where e is the charge, and m the mass, of an electron.

3. (a) In the horizontal direction: velocity of electron entering the plates
   $\frac{1}{2} mv^2 = 2.88 \times 10^{-16}$ thus v = 2.51 x 10^7 m s^{-1}.
   (b) In the horizontal direction:
   Time taken to travel pass plates at 0.15 m long = 5.98 x 10^{-9} s
   In the vertical direction: time = 5.98 x 10^{-9} s initial velocity = 0
   Force on electron due to electric field = EQ = 1.4 x 10^4 x 1.6 x 10^{-19} N
   Acceleration = $\frac{F}{m} = \frac{1.4 \times 10^4 \times 1.6 \times 10^{-19}}{9.11 \times 10^{-31}}$ = 2.46 x 10^{15} m s^{-2}
   Using $s = ut + \frac{1}{2} at^2$ deflection = 0.044 m
   (c) The electron will travel in a straight line. There is no unbalanced force on the electron because there is no electric field outside the plates.

4. (a) $\frac{1}{2} mv^2 = Ve$ $\frac{1}{2} \times 9.11 \times 10^{-31} \times v^2 = 200 \times 1.6 \times 10^{-19}$
   thus v = 8.38 x 10^6 m s^{-1}
   (b) In the horizontal direction, time taken = $\frac{\text{length of plates}}{\text{horizontal speed}}$ = 3.58 x 10^{-9} s
   In the vertical direction, a = $\frac{F}{m} = \frac{1.0 \times 10^3 \times 1.6 \times 10^{-19}}{50 \times 10^{-3} \times 9.11 \times 10^{-31}}$ = 3.51 x 10^{15} m s^{-2}
   Initial velocity vertically = 0 hence using $s = ut + \frac{1}{2} at^2$ gives s = 0.022 m

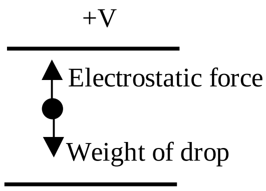
   (c)


   The electron travels in a straight line after leaving the plates.
   By proportion $\frac{\text{deflection}}{22} = \frac{210}{30}$
   Giving the deflection on the screen = 154 mm

5. (a) 1.6 x 10^{-19} x 125 x 10^3 = ½ x 9.11 x 10^{-31} x v^2 gives v = 2.09 x 10^8 m s^{-1}
   (b) This speed is more than 60% of the speed of light. Relativistic effects must be considered when speeds are greater than 10 % of the speed of light.

6. Millikan determined the charge on a number of small charged drops. He noticed that the charges were all multiples of a certain smallest charge, 1.6 x 10^{-19} C. This suggested that it was not possible to obtain a charge with a fraction of this value.

7. (a)



(The charge on the drop is negative)

(b) weight down = electrostatic force upwards

$$mg = EQ = \frac{VQ}{d}$$

$$0.01 \times 10^{-9} \times 9.8 = \frac{V \times 5 \times 1.6 \times 10^{-19}}{20 \times 10^{-3}}$$

$$V = 2.45 \times 10^{6}\ V$$

(c) The drop would accelerate upwards, since the electrostatic force is now greater than the weight of the drop. The drop will accelerate in the direction of the resultant force.

8. (a) Excess charge on each drop is calculated using $Q = \frac{mgd}{V}$ and gd = 0.392

Mass of drop/10^{-15} kg	2.6	1.2	1.6	2.3	4.8	5.9	1.8	3.7
p.d. / V	1592	2940	1960	2818	2940	14455	1470	4533
Charge/ 10^{-19} C	6.4	1.6	3.2	3.2	6.4	1.6	4.8	3.2
No. excess electrons	4	1	2	2	4	1	3	2

(b) These are all whole numbers. No fractional charges were found.

9. (a) Change in $E_k = \frac{1}{2} mv^2 - 0$ with zero E_k at the distance of closest approach.

(b) Change in electrostatic $E_p = \frac{qQ}{4\pi\varepsilon_0 r} - 0$ [potential energy = V x charge]

where q and Q are the charges on the alpha particle and oxygen atom.

(c) At closest approach change in E_k = change in E_p

$$\tfrac{1}{2} mv^2 - 0 = \frac{qQ}{4\pi\varepsilon_0 r} - 0$$

rearranging gives $r = \frac{2qQ}{4\pi\varepsilon_0 mv^2}$

(d) $r = 9 \times 10^{9} \times \frac{2 \times (2 \times 1.6 \times 10^{-19}) \times (8 \times 1.6 \times 10^{-19})}{6.7 \times 10^{-27} \times (1.9 \times 10^{6})^2} = 3.0 \times 10^{-13}$ m

10. From above $v^2 = \frac{2qQ}{4\pi\varepsilon_0 mr} = 9 \times 10^{9} \times \frac{2 \times (2 \times 1.6 \times 10^{-19}) \times (26 \times 1.6 \times 10^{-19})}{6.7 \times 10^{-27} \times 1.65 \times 10^{-13}}$

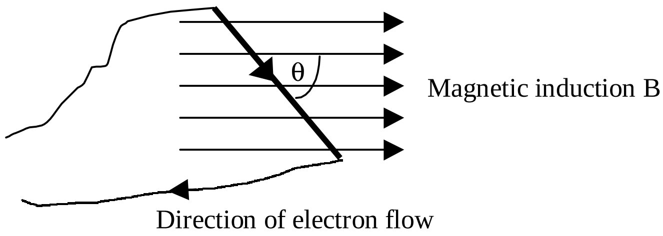
and $v = 4.7 \times 10^{6}$ m s^{-1}

Electromagnetism

1. (a) A magnetic field is produced around moving charges.
   (b) The charge must be moving across the magnetic field, or the magnetic field must be changing relative to the position of the charge.
   (c) One tesla is the magnetic induction of a magnetic field in which a conductor of length one metre, carrying a current of one ampere perpendicular to the field, is acted on by a force of one newton.

2. (a) $F = I l B \sin\theta$

   (b) For a current in the direction shown, the force on the wire is directed into the page.



   (c) $F = I l B \sin\theta$ giving $9.5 \times 10^{-3} = 2 \times 25 \times 10^{-3} \times 0.70 \times \sin\theta$
   $\theta = 16^{o}$

3. $F = I l B \sin\theta$ $\quad 0.20 = 10 \times 0.8 \times B$ $\quad (\sin\theta = 1$ since θ is $90^{o})$
   $B = 25$ mT $\quad (0.025$ T$)$

4. (a) $F = I l B \sin\theta$ $\quad 0.30 = I \times 0.50 \times 0.10$ $\quad$ for θ at 90^{o} and $\sin\theta = 1$
   $I = 6$ A
   (b) If θ is less than 90^{o}, $\sin\theta$ will be less than 1, and a larger current I will be required.

5. (a) $F = I l B \sin\theta$ $\quad F = 7.0 \times 200 \times 10^{-3} \times 0.15 \times \sin 35$ $\quad F = 0.12$ N
   (b) Out of the page, perpendicular to both the magnetic field and the wire.

6. Magnetic induction $B = \dfrac{\mu_0 I}{2\pi r}$

7. See Student Material page 20
   B is magnetic induction (T)
   μ_o is the permeability of free space (H m^{-1})
   I_1 and I_2 are the currents in the conductors (A) r is the distance between them (m)
   F/l is the force per unit length (N m^{-1})

8. $\dfrac{F}{l} = \dfrac{\mu_0 I_1 I_2}{2\pi r}$ $\quad$ giving $\quad 8.89 \times 10^{-6} = \dfrac{4\pi \times 10^{-7} \times 2.0 \times I_2}{2\pi \times 90 \times 10^{-3}}$ $\quad I_2 = 2.0$ A

9. Weight per m length = magnetic force per m length
   $0.075 = \dfrac{4\pi \times 10^{-7} \times I^2}{2\pi \times 5.0 \times 10^{-3}}$
   Current in each wire = 43 A

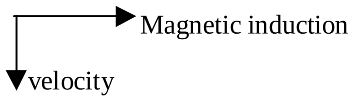
Motion in a magnetic field

1. See Student Material page 22.

2. $F = qvB \qquad F = 1.6 \times 10^{-19} \times 3 \times 10^{4} \times 0.80 = 3.8 \times 10^{-15}$ N

3. (a) $F = qvB \quad F = 1.6 \times 10^{-19} \times 2.0 \times 10^{5} \times 0.50 = 1.6 \times 10^{-14}$ N

   (b) The force is perpendicular to both the velocity and the magnetic field.



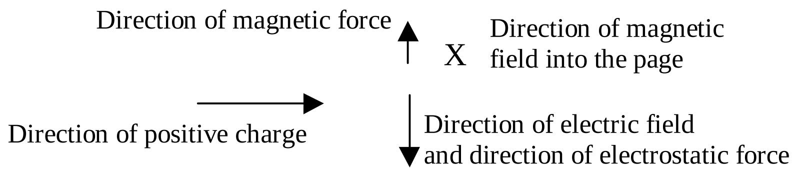
For these directions of v and B the force is vertically into the page.

   (c) Central force $F = \dfrac{mv^2}{r}$ giving $qvB = \dfrac{mv^2}{r}$ and $r = \dfrac{mv}{qB}$

$$r = \frac{9.11 \times 10^{-31} \times 2 \times 10^{5}}{1.6 \times 10^{-19} \times 0.5} = 2.3 \times 10^{-6} \text{ m}$$

4. The direction of the velocity of the electron must make an angle with the direction of the magnetic field.
   The component of velocity perpendicular to the field causes the electron to move in a circle.
   The component of velocity parallel to the field causes the electron to move along the direction of the field.

5. (a) Electric and magnetic fields arranged so their forces on a charged particle oppose each other. The electric and magnetic field must be perpendicular to each other.

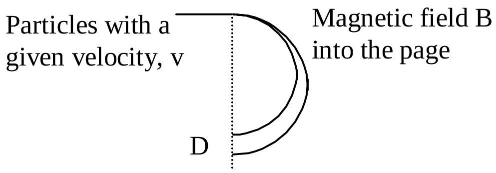


   For the example shown above, a magnetic field is directed into the page and an electric field acts down the page. The magnetic force and the electrostatic force on a positive charge oppose each other. These fields are then said to be ‘crossed’.
   The fields are often adjusted such that the two forces are equal in magnitude, $F_e = F_m$. The velocity of the positive charge would then remain constant.

   (b) $F_e = F_m$ also $F_e = Eq$ and $F_m = qvB$ giving $Eq = qvB$ and $v = \dfrac{E}{B}$.

   (c) From the above equation the velocity does not depend on the mass or the charge of the particle but only on the values of E and B.

   (d) Charged particles enter the region with the magnetic field only, at right angles to the field. The particle will move in a circle with a radius given by $r = \dfrac{mv}{qB}$.



The particles all have the same velocity hence the radius will depend on the mass and charge of each particle. Different ions will meet a detector at D in different places.

6. (a) From the question above $v = \frac{E}{B} = \frac{V}{Bd}$

(b) $qvB = \frac{mv^2}{r}$ or $evB = \frac{mv^2}{r}$ giving $\frac{e}{m} = \frac{v}{rB}$

(c) $\frac{e}{m} = \frac{v}{rB} = \frac{V}{rB^2 d}$

7. Velocity of each ion is given by $\frac{1}{2}mv^2 = qV$

giving $v^2 = \frac{2qV}{m}$ - - - - - - - - - - - - - {1}

radius of curved path $r = \frac{mv}{qB}$ - - - - - - - - - - - - - {2}

and $r^2 = \frac{m^2 v^2}{q^2 B^2}$ thus $r^2 = \frac{m^2}{q^2 B^2}\left(\frac{2qV}{m}\right)$ substituting for v^2

giving $r = \sqrt{\frac{2Vm}{qB^2}}$

The difference in the two radii $r_{13} - r_{12} = \sqrt{\frac{2V}{qB^2}}\left(\sqrt{m_{13}} - \sqrt{m_{12}}\right)$

$= 5 \times 10^{-3}$ m

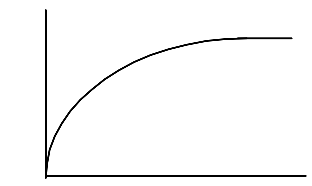
Hence d = 0.01 m (Because of the subtraction above the answer is to one significant figure only.)

[Alternatively the velocity of each ion can be calculated using {1} above to give v_{13} and v_{12}. Then equation {2} used to give the difference in the radii $r_{13} - r_{12} = \frac{1}{qB}(m_{13}v_{13} - m_{12}v_{12})$. This involves more calculations and potential loss in accuracy.]

Self-inductance

1. (a) A magnet is moved in and out a coil. The coil is connected to a voltmeter and a deflection is observed when the magnet is moving relative to the coil, see Electrical Phenomena - Student Material page 27.
   (b) Increase the relative speed of the magnet and coil, increase the magnetic induction of the magnet, increase the number of turns on the coil.

2. (a)



   (b) When the switch is closed the current increases from zero. The magnetic field through the inductor will increase. An e.m.f. is induced across the inductor due to the changing magnetic field through the inductor. This induced e.m.f. acts against the current preventing the current reaching its maximum value immediately.
   (c) The current would reach its steady value quicker, see Electrical Phenomena – Student Material page 28.

3. When a steady current is passed through a coil a constant magnetic field is established through the coil. When the current through the coil changes, the magnetic field through the coil will change. A changing magnetic field will cause and induced e.m.f. through the coil.
   [**Note**: The induced e.m.f. will act in a direction to oppose the change causing it. Thus the induced e.m.f. produced when the current increases will act in a direction as to oppose the increase. It will act **against** the current direction.]

4. (a) When the current decreases the magnetic field will decrease and an e.m.f. will be induced.
   (b) The induced e.m.f. will act in the **same** direction as the current, that is it will try to keep the current steady and stop the change in the magnetic field.
   The energy needed to do this comes from the energy which was stored in the magnetic field. When the magnetic field decreases this energy is released and to conserve energy work has to be done.

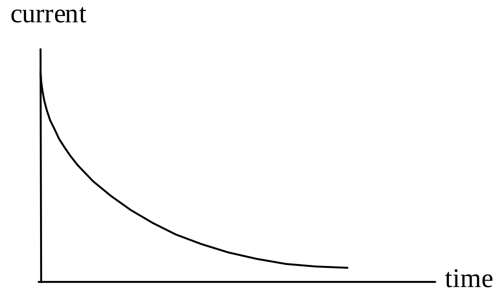
5. (a) $\mathcal{E} = -L\frac{dI}{dt}$
   (b) The unit of inductance is henry (H)
   (c) Energy = $\frac{1}{2} LI^2$

6. (a) As the current increases the magnetic field through the inductor increases. An e.m.f. is induced against the direction of the current. Thus the current takes time to reach its maximum value.
   (b) Using V = I R steady current = 12/15 = 0.8 A
   (c) Energy = $\frac{1}{2} LI^2 = \frac{1}{2} \times 0.40 \times 0.8^2 = 0.13$ J

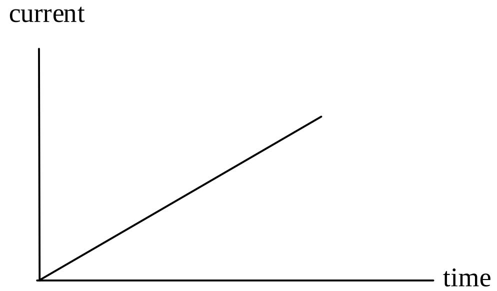
7. (a) p.d. = I R = 0.1 x 20 = 2 V
   (b) induced e.m.f. = 8 – 2 = 6 V
   (c) $\mathcal{E} = -L\frac{dI}{dt}$ 6 = -L x (-100)   L = 0.06 H
   (d) Energy = ½ LI^2 = ½ x 0.06 x 0.10^2 = 0.30 mJ

8. None

9. (a) (i)



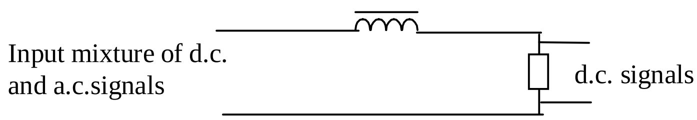
(ii)



   (b) The reactance of the inductor is the opposition of the inductor to the alternating current. It is given by reactance $X_L = \frac{V}{I}$.

11. (a) When a switch in opened in a circuit containing an inductor the current will fall rapidly to zero. There will be a large change in the magnetic field through the inductor and this will cause a large induced e.m.f. at the switch terminals.

   (b)



The inductor has a large opposition to a.c. signals. For d.c. signals the only opposition is the resistance of the coil. Assume that the resistance of the resistor is much larger than the resistance of the inductor. The p.d. across the inductor will be due to the a.c. signals and the p.d. across the resistor will be due to the d.c. signals. The inductor blocks the a.c.

Waves

1. (a) intensity $\propto$ (amplitude)^2
   (b) an increase of 81 times

2. Any waveform can be represented by a series of sine or cosine expressions.
   See Wave Phenomena – Student Material page 3 or SCCC Staff Guide page 122.
   [The student is not expected to recall and draw these wave patterns but only to understand the principle of superposition.]

3. (a) y – displacement in transverse direction
   a – amplitude f – frequency t – time
   x – distance of a particle from the origin λ - wavelength

   (b) (i) 0.06 m
   (ii) 75 Hz [using $2\pi f = \pi \times 150$]
   (iii) 13 ms [using $T = 1/f$]
   (iv) 5 m [using $2\pi/\lambda = \pi \times 0.40$
   (v) 375 m s^{-1} [using $v = \lambda f$]

4. (a) amplitude, frequency, period
   (b) no, at time t = 0 the displacements are different.

5. (a) A stationary wave does not travel to the left or the right, but particle displacements do still take place. The particle displacements increase or decrease in unison. In some places there are maximum amplitudes in other places zero amplitude and no vibration.
   (b) A node is a position of zero amplitude.
   An antinode is a position of maximum amplitude.

6. (a) The Doppler effect is the change in frequency observed when a source of sound waves is moving relative to an observer.
   (b) See Wave Phenomena – Student Material page 6.
   (c) See Wave Phenomena – Student Material page 7.

7. (a) $f_{obs} = f_s \dfrac{v + v_o}{v}$ $\quad f_{obs} = 800 \text{ x } \dfrac{340 + 30}{340} = 871 \text{ Hz}$
   (b) $f_{obs} = f_s \dfrac{v - v_o}{v}$ $\quad f_{obs} = 800 \text{ x } \dfrac{340 - 30}{340} = 729 \text{ Hz}$

8. $f_{obs} = f_s \dfrac{v}{v + v_s}$ $\quad f_{obs} = 700 \text{ x } \dfrac{340}{340 + 25} = 652 \text{ Hz}$

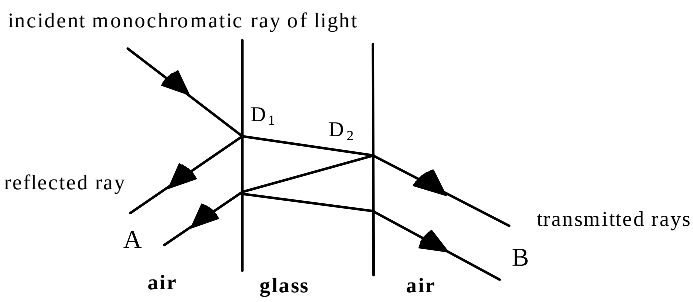
Interference – division of amplitude

1. (a) Constant phase difference.
   (b) Light is produced when electrons, which have been excited, return to a lower energy state. This is a random process in that two separate sources will not emit light beams which have a constant phase difference, even if they have the same frequency.
   (c) yes, both loudspeakers are driven by the same single source. Any change in phase from the single source occurs simultaneously at the loudspeakers.

2. (a) Optical path difference = geometric path difference x refractive index
   (b) phase difference = $\frac{2\pi}{\lambda}$ x optical path difference
   (c) (i) optical path AB = (80 x 1.5) + (150 – 80) = 190 nm
       (ii) optical path difference = 190 - 150 = 40 nm
       phase difference = $\frac{2\pi}{700 \times 10^{-9}} \times 40 \times 10^{-9}$ = 0.36 radians

3 (a) π radians (or 180^{o})
   (b) None, the water has a smaller refractive index than the glass.

4. (a) Light incident on the film. The amplitude of the ray is divided. The light is partially reflected and partially refracted at D_1.
   The reflected rays at A have a different path difference so will interfere when brought together, similarly for the transmitted rays at B.



   (b) (i) $2nt = m\lambda$ for destructive interference
       (ii) When t increases the value of λ needed to produce constructive interference will increase. The colour of the pattern will move towards the red end of the spectrum.

5. (a) See Wave Phenomena – Student Material page 12.
   (b) $\Delta x = \frac{\lambda L}{2D} = \frac{650 \times 10^{-9} \times 100 \times 10^{-3}}{2 \times 30 \times 10^{-6}}$ = 1.1 mm
   (c) The thickness of the paper has increased. The wavelength and length of the plates are constant.

6. (a) See Wave Phenomena – Student Material page 13.
   (b) $d = \frac{\lambda}{4n} = 8.8 \times 10^{-8}$ m
   (c) The non-reflective coating will only give complete cancellation for one particular wavelength. For a coating giving cancellation for green light, the blue and red would be partially reflected and the lens would appear purple.

Interference – division of wavefront

1. (a) When light is incident on two small slits, the wavefront is divided and each slit acts as a secondary source. Interference takes place between the two secondary sources.
   (b) With an extended source each part of the wave would be incident on the slit at a different angle which could produce overlapping fringes and the interference pattern would be lost. A point source (or a line source parallel to the slits) must be used.
   (c) With division of amplitude the beam is split at a point with partial reflection and transmission.

2. (a) See Wave Phenomena – Student Material page 14.
   (b) x << D giving θ a small angle and $\sin\theta = \theta = \tan\theta$

3. (a) $\Delta x = \dfrac{\lambda D}{d}$ giving $\lambda = 6.0 \times 10^{-7}$ m
   (b) % uncertainty in: Δx is 1.1%; d is 4.2%; D is 2.6%
   The 1.1% can be neglected since less than one third of 4.2%
   Total uncertainty = $\sqrt{4.2^2 + 2.6^2}$ = 4.9%
   Uncertainty in the wavelength = 0.3×10^{-7} m
   $\lambda = (6.0 \pm 0.3) \times 10^{-7}$ m

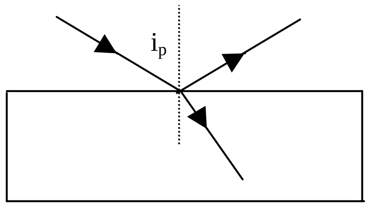
4. (a) Increase the slide to screen distance D.
   (b) Fringes are further apart.
   (c) The fringes are further apart.
   (d) A travelling microscope
   (e) Measure the distance across a number of fringes, for example ten, then calculate the fringe spacing.

Polarisation

1. (a) With linearly polarised light the oscillations of the electric field strength vector are restricted to one plane. With unpolarised light the electric filed strength vector oscillates in all directions perpendicular to the direction of wave propagation.
   (b) A polaroid filter will only transmit vibrations of the electric field vector in one plane.
   (c) A polariser and analyser are placed at right angle to each other. They are both placed perpendicular to the direction of transmission. The polariser will only transmit vibrations of the electric field vector in one plane, the analyser will absorb these vibrations since they are all perpendicular to its axis of tranmission. See top diagram, Wave Phenomena – Student Material page 16.

2. (a) The medium is an electric insulator.
   (b) See Wave Phenomena – Student Material page 17.
   (c) Brewster's angle

3. (a)



   (b) $n = \tan i_p$ $\quad i_p = 56^o$

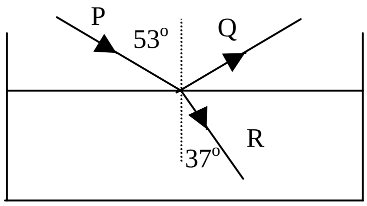
4. When light is reflected from a horizontal surface, such as water, the light will be polarised. The polariod in the sunglasses acts as an analyser and cuts out a large part of the reflected light. (Note that the light is only completely polarised at the Brewster's angle.)

5. (a) $n = \tan i_p$ $\quad i_p = 55^o$
   (b) angle of refraction = 90 – 55 = 35^o

6. $n = 1/\sin\theta_C = 1.54$ $\qquad n = \tan i_p$ $\quad i_p = 57^o$

7. When the frequency increases the refractive index increases. Hence the polarising angle will increase slightly.

8. (a) The intensity of the light observed through the polaroid decreases to a minimum, at the polarising angle, then increases again.
   (b) $n = \tan i_p$ $\quad i_p = 53^o$
   (c) Angle between ray Q and R is 90^o



CORRECTION PAGE

(AH): Mechanics – Student Materials

IMPORTANT NOTICE

The text at the top of page 7 has been corrected.

Page 8 has been provided so that this page, with text on both sides, can be inserted in place of the previous page in your pack. There are no corrections on page 8.

Angular acceleration and linear component of tangential acceleration a_t

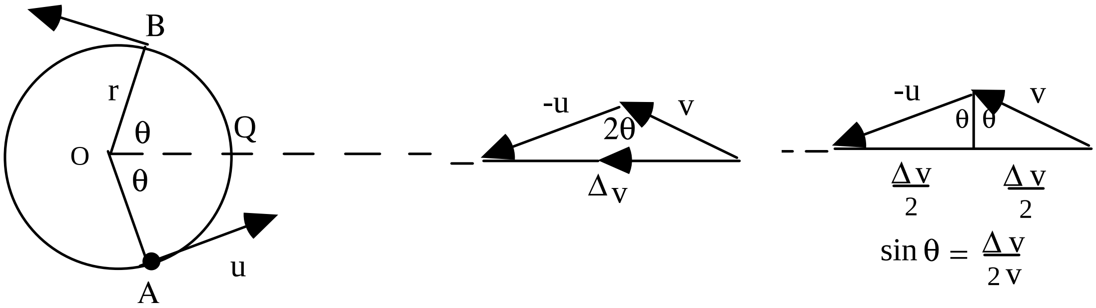
The angular acceleration $\alpha = \dfrac{d\omega}{dt}$ and the linear tangential acceleration $a_t = \dfrac{dv}{dt}$, when the rotational speed v is *changing*.

Since $v = r\omega$ at any instant, then $\dfrac{dv}{dt} = r\dfrac{d\omega}{dt}$ giving

$$\boxed{a_t = r\,\alpha}$$

where the direction of a_t is at a tangent to the circular path of radius r.

Radial Acceleration



$\sin\theta = \dfrac{\Delta v}{2v}$

The particle travels from A to B in time Δt and with speed v, thus $|u| = |v|$ and $\Delta v = v + (-u)$ which is $\Delta v = v - u$

$$\Delta t = \frac{\text{arc } AB}{v} = \frac{r\,(2\theta)}{v}$$

$$\text{average radial acceleration, } a_{av} = \frac{\Delta v}{\Delta t} = \frac{2v\sin\theta}{\Delta t}$$

$$= \frac{2v\sin\theta}{r\,2\theta / v} = \frac{v^2}{r}\cdot\frac{\sin\theta}{\theta}$$

As $\theta \to 0$, $a_{av} \to$ instantaneous acceleration at point Q:

$$\text{radial acceleration} = \frac{v^2}{r}\left[\lim_{\theta\to 0}\frac{\sin\theta}{\theta}\right] \quad \text{but} \left[\lim_{\theta\to 0}\frac{\sin\theta}{\theta}\right] = 1$$

when θ is small and is measured in radians $\sin\theta = \theta$.

$$\boxed{\text{Radial acceleration} = \frac{v^2}{r} = \omega^2 r} \qquad \text{since } v = r\omega$$

The **direction** of this acceleration is always towards the **centre** of the circle.

Note: This is **not** a constant acceleration. Radial acceleration is fixed only in **size**. Compare this with angular acceleration, which **is** constant for problems in this course.

Thus any object performing circular orbits at uniform speed must have a **centre-seeking** or **central** force responsible for the motion. This force produces a radial acceleration of $\dfrac{v^2}{r}$ or $\omega^2 r$.

Central Force

Does a rotating body really have an inward acceleration (and hence an inward force)?

Argument Most people have experienced the sensation of being in a car or a bus which is turning a corner at high speed. The feeling of being 'thrown to the outside of the curve' is very strong, especially if you slide along the seat. What happens here is that the friction between yourself and the seat is insufficient to provide the central force needed to deviate you from the straight line path you were following before the turn. In fact, instead of being thrown outwards, you are, in reality, continuing in a straight line while the car moves inwards. Eventually you are moved from the straight line path by the inward (central) force provided by the door.

Magnitude of the Force

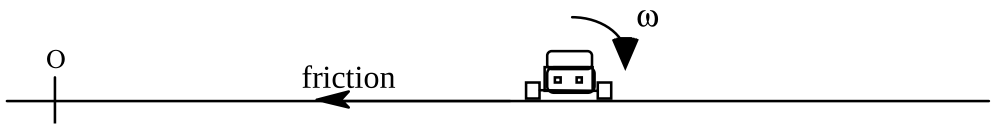
$$F = m a \qquad \text{but} \quad a = \frac{v^2}{r} \quad \text{or} \quad a = \omega^2 r$$

Thus central force, $\boxed{F = m\frac{v^2}{r} \quad \text{or} \quad F = m r \omega^2}$ since $v = r\omega$

Examples

1. A Car on a Flat Track

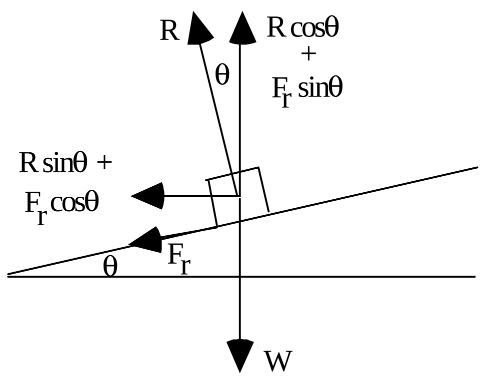
If the car goes too fast, the car 'breaks away' at a tangent. The force of friction is not enough to supply an adequate central force.



2. A Car on a Banked Track

For tracks of similar surface properties, a car will be able to go faster on a banked track before going off at a tangent because there is a component of the normal reaction as well as a component of friction, F_r, supplying the central force.

The central force is $R \sin\theta + F_r \cos\theta$ which reduces to $R \sin\theta$ when the friction is zero. The analysis on the right hand side is for the friction F_r equal to **zero**.



R is the 'normal reaction' force of the track on the car.

In the vertical direction there is no acceleration:

$$R \cos\theta = mg \quad \text{........ 1}$$

In the radial direction there is a central acceleration:

$$R \sin\theta = \frac{mv^2}{r} \quad \text{........ 2}$$

Divide Eq. 2 by Eq. 1:

$$\tan\theta = \frac{v^2}{gr} \qquad \text{(assumes friction is zero)}$$

(This equation applies to all cases of 'banking' including aircraft turning in horizontal circles)