

TUTORIAL BOOKLET 2014|

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J. A.
HARGREAVES

TUTORIAL QUESTIONS (2020) AH PHYSICS



Acknowledgement

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Rotational Motion and Astrophysics

Rotational Motion and Astrophysics Numerical questions

Kinematic relationships

1. The displacement, s , in metres, of an object after time t in seconds, is given by

$$s = 90t - 4t^2.$$

- (a) Using a calculus method, find an expression for the object's velocity.
- (b) At what time will the velocity be zero?
- (c) Show that the acceleration is constant and state its value.
2. The displacement, s , in metres of a 3 kg mass is given by $s = 8 - 10t + t^2$, where t is the time in seconds.
- (a) Calculate the object's velocity after:
- 2 s
 - 5 s
 - 8 s.
- (b) Calculate the unbalanced force acting on the object after 4 s.
- (c) Comment on the unbalanced force acting on the object during its journey.

3. The displacement, s , of a car is given by the expression $s = 5t + t^2$ metres, where t is in seconds.

Calculate:

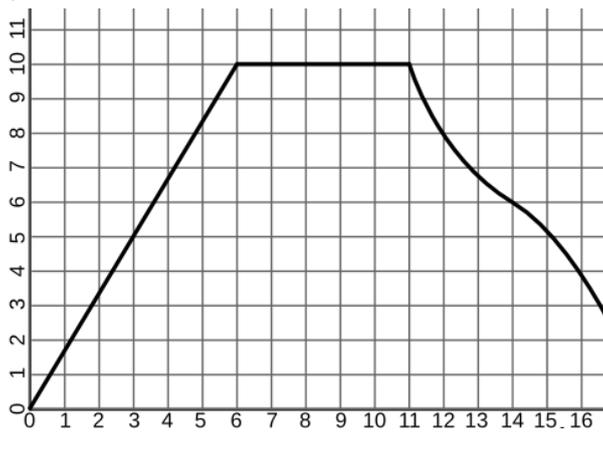
- the velocity of the car when the timing started
 - the velocity of the car after 3 seconds
 - the acceleration of the car
 - the time taken by the car to travel 6 m after the timing started.
4. The displacement, s , of an object is given by the expression $s = 3t^3 + 5t$ metres, where t is in seconds.
- Calculate the displacement, speed and acceleration of the object after 3 seconds.
 - Explain why the unbalanced force on the object is not constant.
5. An arrow is fired vertically in the air. The vertical displacement, s , is given by $s = 34.3t - 4.9t^2$ metres, where t is in seconds.
- Find an expression for the velocity of the arrow.
 - Calculate the acceleration of the arrow.
 - Calculate the initial velocity of the arrow.
 - Calculate the maximum height reached by the arrow.

6. The displacement, s , of an object is given by $s = 12 + 15t^2 - 25t^4$ metres, where t is in seconds.

- (a) Find expressions for the velocity and acceleration of the object.
- (b) Determine the object's initial:
- displacement
 - velocity
 - acceleration.
- (c) At what times is the velocity of the object zero?
7. The displacement, s , of a rocket launched from the Earth's surface is given by
 $s = 2t^3 + 8t^2$ metres for $0 \leq t \leq 30$ seconds.
- Calculate the speed of the rocket after 15 seconds.
 - How far had the rocket travelled in 30 s?
 - Suggest a reason why the expression for displacement is only valid for the first 30 s.
8. A box with a constant acceleration of 4 m s^{-2} slides down a smooth slope. At time $t = 0$ the displacement of the box is 2 m and its velocity is 3 m s^{-1} .
- Use a calculus method to show that the velocity v of the box is given the expression $v = 4t + 3 \text{ m s}^{-1}$.
 - Show that the displacement of the box is given by $s = 2t^2 + 3t + 2$ metres.
9. The velocity, v , of a moving trolley is given by $v = 6t + 2 \text{ m s}^{-1}$. The displacement of the trolley is zero at time $t = 0$.
- Derive an expression for the displacement of the trolley.
 - Calculate the acceleration of the trolley.
 - State the velocity of the trolley at time $t = 0$.

10. The following graph shows the displacement of an object varying with time.

displacement (m)

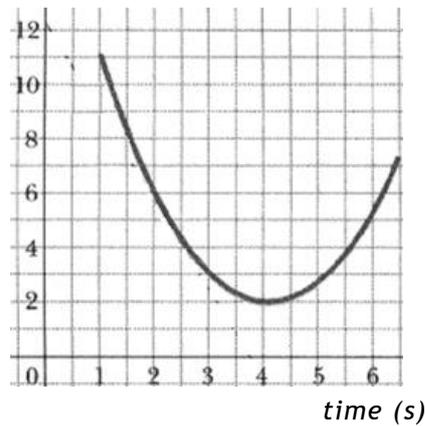


Calculate the velocity of the object at:

- 3 s
- 8 s
- 12 s.

11. The following graph shows how the velocity of an object changes with time.

velocity (m s^{-1})



- Calculate the acceleration of the object at 2 s.
- At what time is the acceleration zero?
- Estimate the distance travelled between 2 s and 5 s.

Angular motion

- Convert the following from degrees into radians:
 180° , 360° , 90° , 60° , 30° , 14° , 1°
- Convert the following from radians to degrees:
 π rad, 2π rad, $\frac{1}{2}\pi$ rad, 1 rad, 5 rad, 0.1 rad, 0.01 rad
- Calculate the angular velocity of each of the following:
 - A bicycle spoke turning through 5.8 rad in 3.6 s.
 - A playground roundabout rotating once every 4 s.
 - An electric drill bit rotating at 3000 revolutions per minute (rpm).
 - An electric drill bit rotating at 40 revolutions per second.
 - The second hand of an analogue watch.
 - The Moon orbiting the Earth with a period of 27.3 days.
 - The Earth spinning about its polar axis.
 - A rotating object whose angular displacement, θ , is given by $\theta = 5t + 4$ radians, where t is the time in seconds.
- A propeller rotates at 95 rpm.
 - Calculate the angular velocity of the propeller.
 - Each propeller blade has a length of 0.35 m.
Calculate the linear speed of the tip of a propeller.
- A CD of diameter 120 mm rotates inside a CD player.

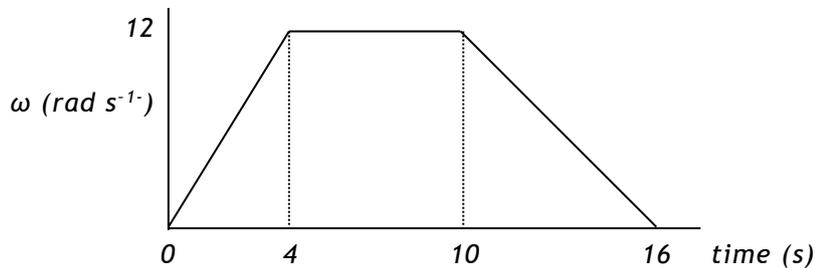


The linear speed of point A on the circumference of the CD is 1.4 m s^{-1} .

Calculate the angular velocity of the CD:

- in rad s^{-1}
 - in rpm.
- A rotating disc accelerates uniformly from 1.5 rad s^{-1} to 7.2 rad s^{-1} in 4 s.
 - Calculate the angular acceleration of the disc.

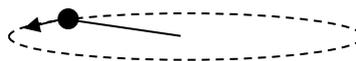
- (b) Calculate the total angular displacement in this time.
 (c) How many revolutions does the disc make in this time?
7. A washing machine drum slows down uniformly from 900 rpm to rest in 15 s.
 (a) Calculate the angular acceleration of the drum.
 (b) How many revolutions does the drum make in this time?
8. A bicycle wheel rotating at 300 rpm makes 120 complete revolutions as it slows down uniformly and comes to rest.
 (a) Calculate the angular acceleration of the wheel.
 (b) Calculate the time taken by the wheel to stop.
9. The graph shows how the angular velocity of a rotating drum varies with time.



- (a) Calculate the initial and final angular acceleration of the drum.
 (b) Calculate the total angular displacement of the drum.
 (c) How many revolutions does the drum make in 16 s?

Centripetal force and acceleration

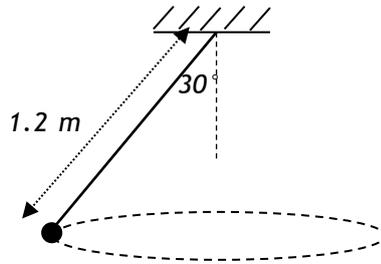
1. A mass of 150 g is attached to a string of length 1.2 m. The string is used to whirl the mass in a horizontal circle at two revolutions per second.
 (a) Calculate the centripetal acceleration of the mass.
 (b) Calculate the centripetal (central) force acting on the mass.
 (c) The string has a breaking force of 56 N. Calculate the maximum angular velocity of the mass.
2. A mass of 0.50 kg is attached to a string of length 0.45 m and rotated in a horizontal circle. The mass has a linear (tangential) speed of 7.6 m s^{-1} .



Calculate the tension in the string.

3. A 3.0 kg mass attached to a string of length 0.75 m rotates in a vertical circle with a steady speed of 8.0 m s^{-1} .
 (a) Calculate the tension in the string when the mass is at the top of the circle.

- (b) Calculate the tension in the string when the mass is at the bottom of the circle.
- (c) Calculate the minimum speed required for the mass to move in this vertical circle.
4. In a space flight simulator an astronaut is rotated horizontally at 20 rpm in a pod on the end of a radius arm of length 5.0 m. The mass of the astronaut is 75 kg.
- (a) Calculate the central force on the astronaut.
- (b) Show that this force is equivalent to a gravitational force of 2.2 g.
- (c) Calculate the rotation rate in rpm that would give a 'simulated' gravity of 3 g.
5. A wet cloth of mass 50 g rotates at 1200 rpm in a spin-dryer drum of diameter 0.45 m.
Calculate the central force acting on the cloth.
6. A small object of mass m revolves in a horizontal circle at a constant speed on the end of a string.



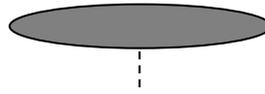
The string has a length of 1.2 m and makes an angle of 30° to the vertical as the mass rotates.

- (a) Name the two forces acting on the mass and draw a diagram showing the two forces acting on the mass.
- (b) Resolve the tension T in the string into a horizontal component and a vertical component.
- (c) (i) Which component of the tension balances the weight of mass m ?
- (ii) Write down an equation which describes this component.
- (d) (i) Which component of the tension provides the central force to keep the mass moving in a circle?
- (ii) Write down an equation using the central force and one of the components of the tension.
- (e) Calculate the radius of the circle using trigonometry.
- (f) Calculate the linear speed of the mass.
- (g) Calculate the period of the motion.

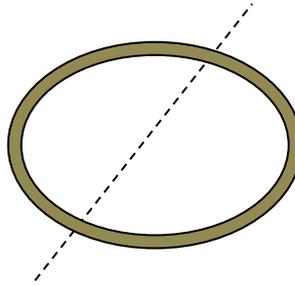
Moment of inertia, torque and angular acceleration

1. Calculate the moment of inertia of:
- (a) a disc of mass 2.3 kg and radius 0.75 m rotating about this axis

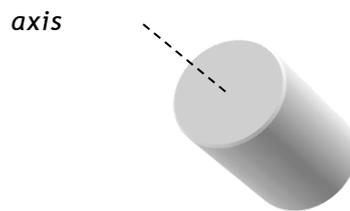
axis



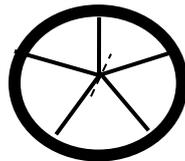
- (b) a rod of mass 0.45 kg and length 0.6 m rotating about its centre
 (c) a rod of mass 1.2 kg and length 0.95 m rotating about its end
 (d) a sphere of mass 12 kg and radius 0.15 m about an axis through its centre
 (e) a point mass of 8.5×10^{-2} kg rotating 7.5×10^{-2} m from the rotation axis
 (f) a metal ring of mass 2.1 kg and radius 0.16 m rotating about its central axis of symmetry



- (g) a solid cylinder of mass 4.5 kg and diameter 0.48 m rotating about the axis shown.



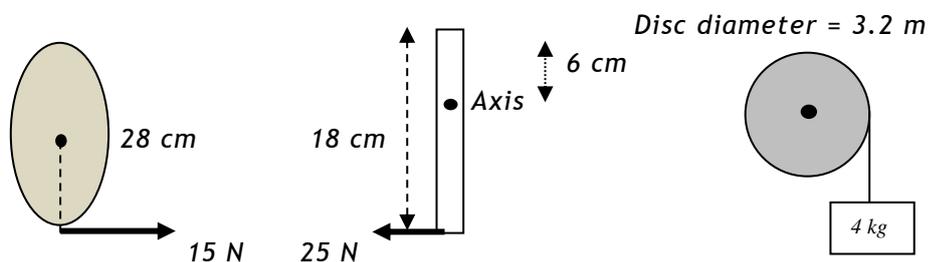
2. A wheel can be represented by a rim and five spokes.



The rim has a mass of 1.5 kg and each spoke has a length of 0.55 m and mass of 0.32 kg.

Calculate the moment of inertia of the wheel, assuming rotation about its axle (dotted line).

3. Calculate the torque applied about the axis in each of the following (the axis of rotation is represented by ●):

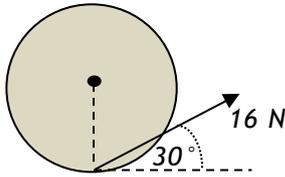


(a)

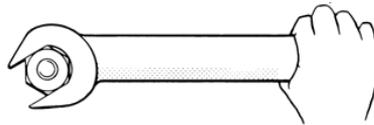
(b)

(c)

4. Calculate the torque applied by the 16 N force to the disc of radius 120 mm rotating about the axis represented by ●.



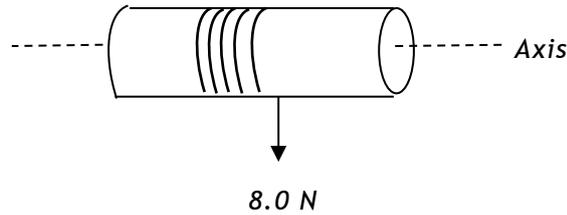
5. An engineer using a spanner of length 22 cm applies a torque of 18 N m to a nut.



Calculate the force exerted by the engineer.

6. A flywheel has a moment of inertia of 1.2 kg m^2 and is acted on by an unbalanced torque of 0.80 N m .
- Calculate the angular acceleration of the flywheel.
 - The unbalanced torque acts for 5 s and the flywheel starts from rest.
Calculate:
 - the angular velocity at the end of the 5 s
 - the number of revolutions made in the 5 s.
7. A hoop of mass 0.25 kg and radius 0.20 m rotates about its central axis. Calculate the torque required to give the hoop an angular acceleration of 5.0 rad s^{-2} .
8. A solid drum has a moment of inertia of 2.0 kg m^2 and radius 0.50 m . The drum rotates freely about its central axis at 10 rev s^{-1} . A constant frictional force of 5.0 N is exerted tangentially to the rim of the drum.
Calculate:
 - the time taken for the drum to come to rest
 - the number of revolutions made during the braking period
 - the heat generated during the braking.
9. A flywheel, with a moment of inertia of 1.5 kg m^2 , is driven by an electric motor which provides a driving torque of 7.7 N m . The flywheel rotates with a constant angular velocity of 52 rad s^{-1} .
- State the frictional torque acting on the flywheel. Give a reason for your answer.
 - The electric motor is now switched off.
Calculate the time taken for the flywheel to come to rest.
State any assumption you have made.

10. A cylindrical solid drum has a rope of length 5.0 m wound round it. The rope is pulled with a constant force of 8.0 N and the drum is free to rotate about its central axis as shown.



The radius of the drum is 0.30 m and its moment of inertia about the axis is 0.40 kg m^2 .

- Calculate the torque applied to the drum.
 - Calculate the angular acceleration of the drum, ignoring any frictional effects.
 - Calculate the angular velocity of the drum just as the rope leaves the drum, assuming the drum starts from rest.
11. A bicycle wheel is mounted so that it can rotate horizontally as shown.



The wheel has a mass of 0.79 kg and radius of 0.45 m, and the masses of the spokes and axle are negligible.

- Show that the moment of inertia of the wheel is 0.16 kg m^2 .
 - A constant driving force of 20 N is applied tangentially to the rim of the wheel.
Calculate the magnitude of the driving torque on the wheel.
 - A constant frictional torque of 1.5 N m acts on the wheel.
Calculate the angular acceleration of the wheel.
 - After a period of 4 s, and assuming the wheel starts from rest, calculate:
 - the total angular displacement of the wheel
 - the angular velocity of the wheel
 - the kinetic energy of the wheel.
 - The driving force is removed after 4 s.
Calculate the time taken for the wheel to come to rest.
12. A playground roundabout has a moment of inertia of 500 kg m^2 about its axis of rotation.



A constant torque of 200 N m is applied tangentially to the rim of the roundabout.

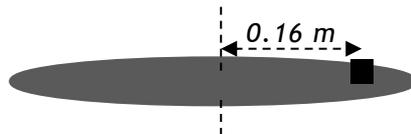
- The angular acceleration of the roundabout is 0.35 rad s^{-2} .

Show that the frictional torque acting on the roundabout is 25 N m.

- (b) A child of mass 50 kg sits on the roundabout at a distance of 1.25 m from the axis of rotation and the 200 N m torque is reapplied.
Calculate the new angular acceleration of the roundabout.
- (c) The 200 N m torque in part (b) is applied for 3 s then removed.
- Calculate the maximum angular velocity of the roundabout and child.
 - The 200 N m torque is now removed. Find the time taken by the roundabout and child to come to rest.

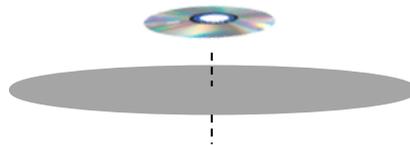
Angular momentum and rotational kinetic energy

- A bicycle wheel has a moment of inertia of 0.25 kg m^2 about its axle. The wheel rotates at 120 rpm. Calculate:
 - the angular momentum of the wheel
 - the rotational kinetic energy of the wheel.
- A turntable of moment of inertia $5.8 \times 10^{-2} \text{ kg m}^2$ rotates freely at 3.5 rad s^{-1} with no external torques. A small mass of 0.18 kg falls vertically onto the turntable at a distance of 0.16 m from the axis of rotation.



Calculate the new angular speed of the turntable.

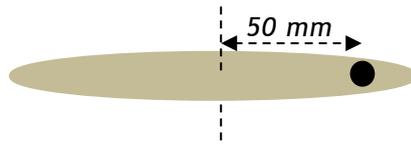
- A turntable rotates freely at 40 rpm about its vertical axis. A small mass of 50 g falls vertically onto the turntable at a distance of 80 mm from the central axis.
The rotation of the turntable is reduced to 33 rpm.
Calculate the moment of inertia of the turntable.
- A CD of mass 0.020 kg and diameter 120 mm is dropped onto a turntable rotating freely at 3.0 rad s^{-1} .



The turntable has a moment of inertia of $5.0 \times 10^{-4} \text{ kg m}^2$ about its rotation axis.

- Calculate the angular speed of the turntable after the CD lands on it. Assume the CD is a uniform disc with no hole in the centre.
 - Will your answer to part (a) be bigger, smaller or unchanged if the hole in the centre of the CD is taken into account? Explain your answer.
- A turntable rotates freely at 100 rpm about its central axis. The moment of inertia of the turntable is $1.5 \times 10^{-4} \text{ kg m}^2$ about this axis.

A mass of plasticine is dropped vertically onto the turntable and sticks at a distance of 50 mm from the centre of the turntable.



The turntable slows to 75 rpm after the plasticine lands on it. Calculate the mass of the plasticine.

6. An ice skater is spinning with an angular velocity of 3.0 rad s^{-1} with her arms outstretched.



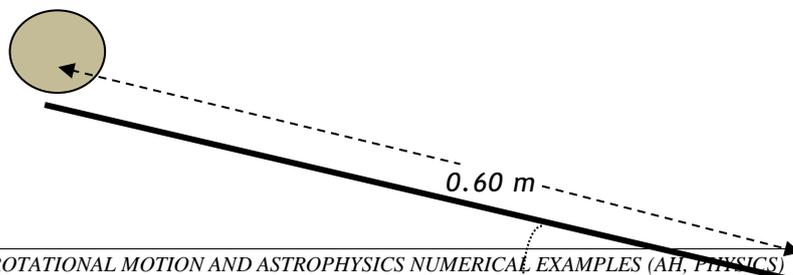
The skater draws in her arms and her angular velocity increases to 5.0 rad s^{-1} .

- Explain why the angular velocity increases.
 - When the skater's arms are outstretched her moment of inertia about the spin axis is 4.8 kg m^2 . Calculate her moment of inertia when her arms are drawn in.
 - Calculate the skater's change in rotational kinetic energy.
 - Explain why there is a change in kinetic energy.
7. A solid sphere of mass 5.0 kg and radius 0.40 m rolls along a horizontal surface without slipping. The linear speed of the sphere as it passes point A is 1.2 m s^{-1} .



As the sphere passes point A calculate:

- the linear kinetic energy of the sphere
 - the angular velocity of the sphere
 - the rotational kinetic energy of the sphere
 - the total kinetic energy of the sphere.
8. A solid cylinder of mass 3.0 kg and radius 50 mm rolls down a slope without slipping.



40°

The slope has a length of 0.60 m and is inclined at 40° to the horizontal.

- Calculate the loss in gravitational potential energy as the cylinder rolls from the top to the bottom of the slope.
- Calculate the linear speed of the cylinder as it reaches the bottom of the slope.

Gravitation

Astronomical data:	mass of Earth = 6.0×10^{24} kg
	radius of Earth = 6.4×10^6 m
	mean radius of Earth orbit = 1.5×10^{11} m
	mass of Moon = 7.3×10^{22} kg
	radius of Moon = 1.7×10^6 m
	mean radius of Moon orbit = 3.84×10^8 m
	mass of Mars = 6.4×10^{23} kg
	radius of Mars = 3.4×10^6 m
	mass of Sun = 2.0×10^{30} kg

- Calculate the gravitational force between two cars each of mass 1000 kg and parked 0.5 m apart.
- Two large ships, each of mass 5.0×10^4 tonnes, are separated by a distance of 20 m.
Show that the force of attraction between them is 417 N (1 tonne = 1000 kg).
- Calculate the force of attraction between the Earth and the Sun.
- The gravitational field strength at the surface of the Earth is 9.8 N kg^{-1} . Calculate the mass of the Earth.
- Calculate the gravitational field strength on the surface of:
 - Mars
 - the Moon.
- The gravitational field strength changes with altitude above sea level. Calculate the gravitational field strength at these locations:
 - at the summit of Ben Nevis (height 1344 m)
 - at the summit of Mount Everest (height 8848 m)
 - on board an aircraft cruising at 12000 m
 - on board the International Space Station orbiting at 350 km above the Earth.
- A satellite of mass m orbits a planet of mass M and radius R .
 - Show that the time for one complete orbit T (called the period of the satellite) is given by the expression

$$T^2 = \frac{4\pi^2}{GM} R^3$$

Is the time T dependent on the mass of the satellite?

8. A satellite orbits the Earth at a height of 250 km above the Earth's surface.
- Calculate the radius of the orbit of this satellite.
 - Calculate the time taken by the satellite to make one orbit of the Earth.
9. A satellite orbits the Earth with a period of 95 min.
Calculate the height of the satellite above the Earth's surface.
10. A geostationary satellite of mass 250 kg orbits the Earth above the Equator.
- State the period of the orbit.
 - Calculate the height of the satellite above the Equator.
 - Calculate the linear speed of the satellite.
 - Calculate the centripetal force acting on the geostationary satellite.
11. The Moon is a satellite of the Earth.
Calculate the period of the Moon's orbit in days.
12. Show by calculation that the Earth takes approximately 365 days to orbit the Sun.
13. The table shows some information about four of Saturn's moons.

Moon name	Titan	Rhea	Dione	Enceladus
Mean orbit radius R (km)	1.22×10^6	5.27×10^5	3.77×10^5	2.38×10^5
Orbit period T (days)	16	4.5	2.7	1.37

Show that T^2 is directly proportional to R^3 .

14. Calculate the gravitational potential at a point:
- on the Earth's surface
 - 800 km above the Earth's surface
 - 100 km above the Moon's surface.
15. Calculate the gravitational potential energy of:
- a 250 kg rocket on the Earth's surface
 - a 500 kg satellite orbiting 350 km above the Earth's surface
 - a 75 kg astronaut on the surface of the Moon.
16. A satellite of mass 450 kg has a gravitational potential energy of -2.3×10^{10} J.
Calculate the height of the satellite above the Earth's surface.
17. A geostationary satellite of mass 2000 kg orbits 3.6×10^7 m above the Earth's surface.
Calculate:

- (a) the gravitational potential energy of the satellite
 (b) the kinetic energy of the satellite
 (c) the total energy of the satellite.
18. A satellite of mass 270 kg orbits the Earth at a height of 320 km above the Earth's surface.
 Calculate the energy required to change the satellite's orbit to a height of 460 km above the Earth's surface.
19. A satellite of mass m orbits a planet of mass M with a radius of R .
 Show that the total energy of the satellite in orbit is $-\frac{1}{2} \frac{GMm}{R}$
20. Derive an expression for the escape velocity from a planet in terms of the mass m and radius r of the planet.
21. Calculate the escape velocity from the surface of:
 (a) the Earth
 (b) the Moon
 (c) Mars.
22. Calculate the escape velocity for a satellite that is in orbit 550 km above the Earth's surface.
23. The escape velocity from the surface of the Moon is $2.4 \times 10^3 \text{ m s}^{-1}$.
 (a) An object is projected from the surface of the Moon with a speed of $2.0 \times 10^3 \text{ m s}^{-1}$.
 Calculate the maximum height reached above the Moon's surface.
 (b) An object is projected from the surface of the Moon with a speed of $2.8 \times 10^3 \text{ m s}^{-1}$.
 Calculate the speed of the object after it leaves the Moon's gravitational field.

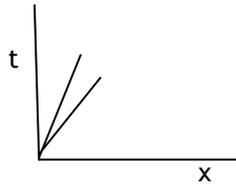
Space and time

1. What is meant by an inertial frame of reference?
2. What is meant by a non-inertial frame of reference?
3. Which frame of reference applies to the theory of special relativity (studied in Higher Physics)?
4. At what range of speeds do the results obtained by the theory of special relativity agree with those of Newtonian mechanics?
5. How does the equivalence principle link the effects of gravity with acceleration?
6. In which part of an accelerating spacecraft does time pass more slowly?

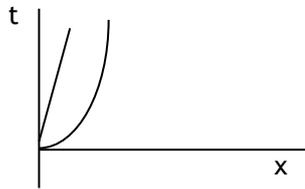
7. Does time pass more quickly or more slowly at high altitude in a gravitational field?
8. How many dimensions are normally associated with space-time?
9. Two space-time diagrams are shown, with a worldline on each. Write down what each of the worldlines describes.



10. The space-time diagram shows two worldlines. Which worldline describes a faster speed?
(These speeds are much less than the speed of light.)

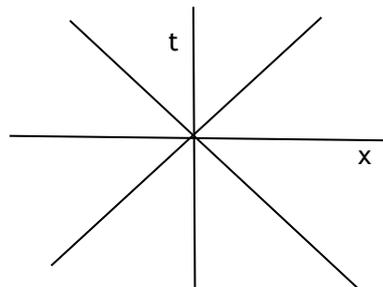


11. Explain the difference between these two worldlines on the space-time diagram.



12. Explain what is meant by the term geodesic.

13. Copy the following space-time diagram.



Insert the following labels onto your diagram:

- the present
- the future

- *the past*
 - $v = c$
 - $v < c$
 - $v > c$.
14. *What effect does mass have on spacetime?*
 15. *Describe two situations where a human body experiences the sensation of force.*
 16. *How does general relativity interpret the cause of gravity?*
 17. *Mercury's orbit around the Sun could not be predicted accurately using classical mechanics. General relativity was able to predict Mercury's orbit accurately. Investigate this using a suitable search engine and write a short paragraph summarising your results.*
 18. *A star of mass 4.5×10^{31} kg collapses to form a black hole. Calculate the Schwarzschild radius of this black hole.*
 19. *A star of mass equivalent to six solar masses collapses to form a black hole. Calculate the Schwarzschild radius of this black hole.*
 20. *If our Sun collapsed to form a black hole, what would be the Schwarzschild radius of this black hole?*
 21. *If our Earth collapsed to form a black hole, what would be the Schwarzschild radius of this black hole?*
 22. *A star is approximately the same size as our Sun and has an average density of 2.2×10^3 kg m⁻³. If this star collapsed to form a black hole, calculate the Schwarzschild radius of the black hole.*

Stellar physics

1. *A star emits electromagnetic radiation with a peak wavelength of 6.8×10^{-7} m.*
 - (a) *Use Wien's law ($\lambda_{max}T = 3 \times 10^{-3}$) to calculate the surface temperature of the star.*
 - (b) *Calculate the power of the radiation emitted by each square metre of the star's surface where the star is assumed to be a black body. Stefan-Boltzmann constant = 5.67×10^{-8} J s⁻¹ m⁻² K⁻⁴.*
2. *The Sun has a radius of 7.0×10^8 m and a surface temperature of 5800 K.*
 - (a) *Calculate the power emitted per m² from the Sun's surface.*
 - (b) *Calculate the luminosity of the Sun.*

- (c) Calculate the apparent brightness of the Sun as seen from the Earth.
3. Three measurements of a distant star are possible from Earth. These measurements are:
- | | |
|------------------------------------|---|
| apparent brightness | $= 4.3 \times 10^{-9} \text{ W m}^{-2}$ |
| peak emitted wavelength | $= 2.4 \times 10^{-7} \text{ m}$ |
| distance to star (parallax method) | $= 8.5 \times 10^{17} \text{ m}$ |
- (a) Use Wien's law ($\lambda_{\text{max}}T = 3 \times 10^{-3}$) to calculate the surface temperature of the star.
- (b) Calculate the energy emitted by each square metre of the star's surface per second.
- (c) Calculate the luminosity of the star.
- (d) Calculate the radius of the star.
4. A star is 86 ly from Earth and has a luminosity of $4.8 \times 10^{28} \text{ W m}^{-2}$. Calculate the apparent brightness of the star.
5. The apparent brightness of a star is $6.2 \times 10^{-8} \text{ W m}^{-2}$. The star is 16 ly from Earth. Calculate the luminosity of the star.
6. A star with luminosity $2.1 \times 10^{30} \text{ W m}^{-2}$ has an apparent brightness of $7.9 \times 10^{-8} \text{ W m}^{-2}$ when viewed from Earth. Calculate the distance of the star from Earth:
- (a) in metres
- (b) in light years.
7. A star with radius $7.8 \times 10^8 \text{ m}$ and surface temperature 6300 K has an apparent brightness of $1.8 \times 10^{-8} \text{ W m}^{-2}$. Calculate its distance from the Earth.
8. A star with radius $9.5 \times 10^9 \text{ m}$ and surface temperature 5900 K is 36 ly from Earth. Calculate the apparent brightness of the star.
9. Show mathematically that the luminosity of a star varies directly with the square of its radius and the fourth power of its surface temperature.
10. Show mathematically that the apparent brightness of a star varies directly with the square of its radius and the fourth power of its surface temperature and varies inversely with the square of its distance from the Earth.
11. Two stars, A and B, are the same distance from the Earth. The apparent brightness of star A is $8.0 \times 10^{-12} \text{ W m}^{-2}$ and the apparent brightness of star B is $4.0 \times 10^{-13} \text{ W m}^{-2}$. Show that star A has 20 times the luminosity of star B.

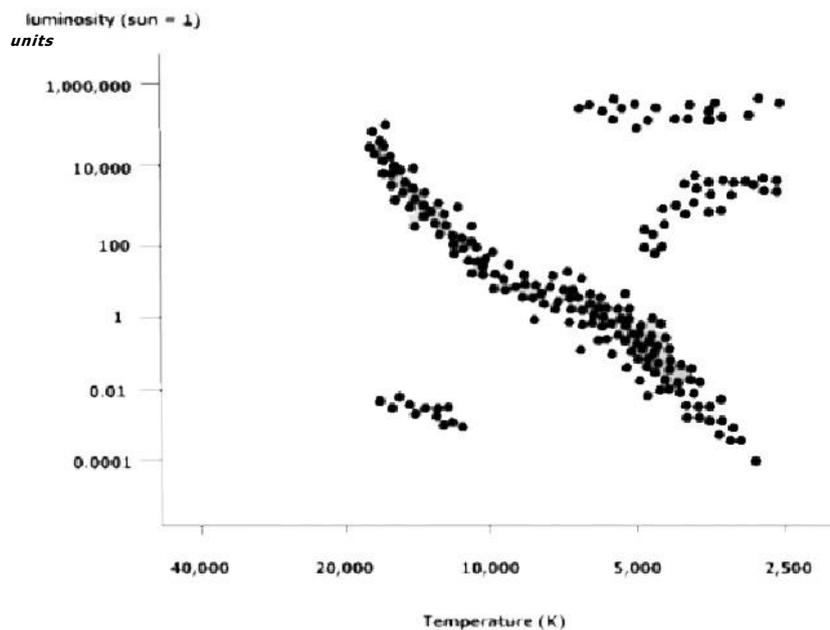
12. A star has half of our Sun's surface temperature and 400 times our Sun's luminosity.
How many times bigger is the radius of this star compared to the Sun?

13. Information about two stars A and B is given below.

surface temperature of star $A = 3 \times$ surface temperature of star B

radius of star $A = 2 \times$ radius of star B

- (a) How many times is the luminosity of star A greater than the luminosity of star B?
- (b) Stars A and B have the same apparent brightness from Earth.
Which star is furthest from Earth and by how many times?
14. The diagram shows one way of classifying stars. Each dot on the diagram represents a star.



- (a) What name is usually given to this type of diagram?
- (b) The stars are arranged into four main regions. Identify the region called:
- the main sequence
 - giants
 - super giants
 - white dwarfs.
- (c) (i) In which of the regions on the diagram is the Sun?
(ii) The surface temperature of the Sun is approximately 5800 K. Explain why the scale on the temperature axis makes it difficult to identify which dot represents the Sun.
- (d) In which region would you find the following:
- a hot bright star
 - a hot dim star
 - a cool bright star
 - a cool dim star?
 -

- (e) A star is cooler than, but brighter than the Sun.
- What can be deduced about the size of this star compared to the size of the Sun?
 - What region would this star be in?
- (f) A star is hotter than, but dimmer than, the Sun.
- What can be deduced about the size of this star compared to the size of the Sun?
 - What region would this star be in?
- (g) The Sun's nuclear fuel will be used up with time. What will then happen to the Sun's position in the above diagram?

Rotational Motion and Astrophysics Numerical answers

Kinematic relationships

- $90 - 8t$
 - 11.25 s
 - -8 m s^{-2}
- -6 m s^{-1}
 - 0
 - 6 m s^{-1}
 - 6 N
 - Constant
- 5 m s^{-1}
 - 11 m s^{-1}
 - 2 m s^{-2}
 - 1 s
- $96 \text{ m}; 86 \text{ m s}^{-1}; 54 \text{ m s}^{-2}$
 - a depends on time t
- $v = 34.3 - 9.8t$
 - -9.8 m s^{-2}
 - 34.3 m s^{-1}
 - 60 m
- $v = 30t - 100t^3; a = 30 - 300t^2$
 - 12 m
 - 0
 - 30 m s^{-2}
 - 0 s and 0.55 s
- 1590 m s^{-1}
 - 61200 m
 - The rocket runs out of fuel.
- $s = 3t^2 + 2t$
 - 6 m s^{-2}
 - 2 m s^{-1}

10. (a) 1.67 m s^{-1}
 (b) Zero
 (c) -1.25 m s^{-1} (gradient of tangent to slope at 12 s)
11. (a) -3.2 m s^{-2}
 (b) 4s (or 4.1 s)
 (c) Approx. 8.75 m (17½ boxes)

Angular motion

1. 3.14 rad; 6.28 rad; 1.57 rad; 1.047 rad; 0.52 rad; 0.244 rad; 0.0174 rad
2. 180° ; 360° 90° ; 57.3° ; 287° ; 5.7° ; 0.57°
3. (a) 1.6 rad s^{-1}
 (b) 1.57 rad s^{-1}
 (c) 314 rad s^{-1}
 (d) 251 rad s^{-1}
 (e) 0.105 rad s^{-1}
 (f) $2.67 \times 10^{-6} \text{ rad s}^{-1}$
 (g) $7.27 \times 10^{-5} \text{ rad s}^{-1}$
 (h) 5 rad s^{-1}
4. (a) 9.9 rad s^{-1}
 (b) 3.5 m s^{-1}
5. (a) 23.3 rad s^{-1}
 (b) 223 rpm
6. (a) 1.4 rad s^{-2}
 (b) 17.4 rad
 (c) 2.8 revolutions
7. (a) -6.28 rad s^{-2}
 (b) 112.5 revolutions
8. (a) -0.65 rad s^{-2}
 (b) 48 s
9. (a) 3 rad s^{-2} , -2 rad s^{-2}
 (b) 132 rad
 (c) 21 revolutions

Centripetal force and acceleration

1. (a) 189 m s^{-2}
 (b) 28.4 N
 (c) 17.6 rad s^{-1}
2. 64 N
3. (a) 227 N
 (b) 285 N
 (c) 2.7 m s^{-1}
4. (a) 1643 N
 (b) $21.9 = 2.2 \times 9.8$
 (c) 23 rpm

5. 177 N
6. (a) Weight of mass, tension in string
 (b) Horizontal component = $T \sin 30^\circ$; vertical component = $T \cos 30^\circ$
 (c) (i) $T \cos 30^\circ$
 (ii) $T \cos 30^\circ = mg$
 (d) (i) $T \sin 30^\circ$
 (ii) $T \sin 30^\circ = mv^2/r$
 (e) 0.6 m
 (f) 1.84 m s^{-1}
 (g) 2.0 s

Moment of inertia, torque and angular acceleration

1. (a) 0.65 kg m^2
 (b) $1.35 \times 10^{-2} \text{ kg m}^2$
 (c) 0.36 kg m^2
 (d) 0.108 kg m^2
 (e) $4.8 \times 10^{-4} \text{ kg m}^2$
 (f) 0.045 kg m^2
 (g) 0.13 kg m^2
2. 0.61 kg m^2
3. (a) 4.2 N m
 (b) 3.0 N m
 (c) 63 N m
4. 1.7 N m
5. 81.8 N
6. (a) 0.67 rad s^{-2}
 (b) (i) 3.3 rad s^{-1}
 (ii) 1.33 revolutions
7. 0.05 N m
8. (a) 50 s
 (b) 251 revolutions
 (c) $3.9 \times 10^3 \text{ J}$
9. (a) 7.7 N m (steady rotational speed, torques balanced)
 (b) 10 s (frictional torque stays constant)
10. (a) 2.4 N m
 (b) 6 rad s^{-2}
 (c) 14 rad s^{-1}
11. (a) 9.0 N m
 (c) 46.9 rad s^{-2}

- (d) (i) 375 rad
(ii) 188 rad s⁻¹
(iii) 2.8 × 10³ J
(e) 20 s
12. (b) 0.30 rad s⁻²
(c) (i) 0.9 rad s⁻¹
(ii) 20.9 s

Angular momentum and rotational kinetic energy

1. (a) 3.14 kg m² rad s⁻¹ (or units could be kg m² s⁻¹)
(b) 19.7 J
2. 3.2 rad s⁻¹
3. 1.5 × 10⁻³ kg m²
4. (a) 2.8 rad s⁻¹
(b) I_{CD} will be bigger as more mass further from axis, angular velocity less.
5. 0.02 kg
6. (a) Her I decreases, so ω increases, as L is conserved.
(b) 2.9 kg m²
(c) 14.7 J increase
(d) Supplied by skater's body (chemical energy).
7. (a) 3.6 J
(b) 3 rad s⁻¹
(c) 1.44 J
(d) 5.04 J
8. (a) 11.3 J
(b) 2.24 m s⁻¹

Gravitation

1. 2.7 × 10⁻⁴ N
3. 3.56 × 10²² N
4. 6.02 × 10²⁴ kg
5. (a) 3.7 N kg⁻¹
(b) 1.7 N kg⁻¹
6. (a) 9.77 N kg⁻¹
(b) 9.74 N kg⁻¹
(c) 9.73 N kg⁻¹
(d) 8.8 N kg⁻¹
7. No

8. (a) $6.65 \times 10^6 \text{ m}$
(b) 90 minutes
9. 508 km
10. (a) 24 h
(b) $3.6 \times 10^7 \text{ m}$
(c) $3.1 \times 10^3 \text{ m s}^{-1}$
(d) 57 N
11. 27.3 days
13. $T^2/R^3 = 1.4 \times 10^{-16}$ (constant) for all four moons
14. (a) $-6.25 \times 10^7 \text{ J kg}^{-1}$
(b) $-5.56 \times 10^7 \text{ J kg}^{-1}$
(c) $-2.7 \times 10^6 \text{ J kg}^{-1}$
15. (a) $-1.56 \times 10^{10} \text{ J}$
(b) $-3.0 \times 10^{10} \text{ J}$
(c) $-2.15 \times 10^8 \text{ J}$
16. $1.43 \times 10^6 \text{ m}$
17. (a) $-1.9 \times 10^{10} \text{ J}$
(b) $9.5 \times 10^9 \text{ J}$
(c) $-9.5 \times 10^9 \text{ J}$
18. $1.6 \times 10^8 \text{ J}$ needed
21. (a) $1.12 \times 10^4 \text{ m s}^{-1}$
(b) $2.4 \times 10^3 \text{ m s}^{-1}$
(c) $5.0 \times 10^3 \text{ m s}^{-1}$
22. $1.07 \times 10^4 \text{ m s}^{-1}$
23. (a) $3.9 \times 10^6 \text{ m}$
(b) $1.45 \times 10^3 \text{ m s}^{-1}$

Space and time

18. $6.67 \times 10^4 \text{ m}$
19. $1.8 \times 10^4 \text{ m}$
20. 3000 m
21. $8.9 \times 10^{-3} \text{ m}$ (8.9 mm)
22. $4.7 \times 10^3 \text{ m}$

Stellar physics

1. (a) 4410 K
(b) $2.1 \times 10^7 \text{ W m}^{-2}$
2. (a) $6.42 \times 10^7 \text{ W m}^{-2}$
(b) $3.95 \times 10^{26} \text{ W}$
(c) $1.4 \times 10^3 \text{ W m}^2$
3. (a) 12500 K
(b) $1.38 \times 10^9 \text{ J (m}^{-2} \text{ s}^{-1}\text{)}$
(c) $3.9 \times 10^{28} \text{ W}$
(d) $1.5 \times 10^9 \text{ m}$
4. $5.8 \times 10^{-9} \text{ W m}^{-2}$
5. $1.8 \times 10^{28} \text{ W m}^{-2}$
6. (a) $1.45 \times 10^{18} \text{ m}$
(b) 153 ly
7. $5.5 \times 10^{16} \text{ m (5.8 ly)}$
8. $5.3 \times 10^{-8} \text{ W m}^{-2}$
9. Show $L = 4\pi r^2 \sigma T^4$
10. Show that apparent brightness = $\sigma r^2 T^4 / d^2$
12. 80
13. (a) 324
(b) Star A; 18 times more distant than star B.

Quanta and Waves

Quanta and Waves Numerical questions

Quantum theory

- The uncertainty in an electron's position relative to an axis is given as $\pm 5.0 \times 10^{-12}$ m.
Calculate the least uncertainty in the simultaneous measurement of the electron's momentum relative to the same axis.
- An electron moves along the x-axis with a speed of 2.05×10^6 m s⁻¹ \pm 0.50%.
Calculate the minimum uncertainty with which you can simultaneously measure the position of the electron along the x-axis.
- An electron spends approximately 1.0 ns in an excited state.
Calculate the uncertainty in the energy of the electron in this excited state.
- The position of an electron can be predicted to within ± 40 atomic diameters. The diameter of an atom can be taken as 1.0×10^{-10} m.
Calculate the simultaneous uncertainty in the electron's momentum.
- Calculate the de Broglie wavelength of:

 - an electron travelling at 4.0×10^6 m s⁻¹
 - a proton travelling at 6.5×10^6 m s⁻¹
 - a car of mass 1000 kg travelling at 120 km per hour.
- An electron and a proton both move with the same velocity of 3.0×10^6 m s⁻¹.
Which has the larger de Broglie wavelength and by how many times larger (to 2 significant figures)?
- Gamma rays have an energy of 4.2×10^{-13} J.

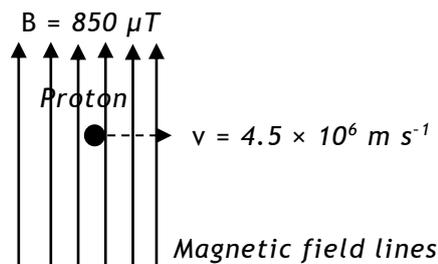
 - Calculate the wavelength of the gamma rays.
 - Calculate the momentum of the gamma rays.
- An electron is accelerated from rest through a p.d. of 200 V in a vacuum.

 - Calculate the final speed of the electron.
 - Calculate the de Broglie wavelength of the electron at this speed.
 - Would this electron show particle or wave-like behaviour when passing through an aperture of diameter 1 mm?
- An electron is accelerated from rest through a p.d. of 2.5 kV.
Calculate the final de Broglie wavelength of this electron.

10. An electron microscope accelerates electrons until they have a wavelength of 40 pm (40×10^{-12} m). Calculate the p.d. in the microscope required to do this assuming the electrons start from rest.
11. Relativistic effects on moving objects can be ignored provided the velocity is less than 10% of the speed of light. What is the minimum wavelength of an electron produced by an electron microscope where relativistic effects can be ignored?
12. An electron moves round the nucleus of a hydrogen atom.
- Calculate the angular momentum of this electron:
 - in the first stable orbit
 - in the third stable orbit.
 - Starting with the relationship $mvv = \frac{nh}{2\pi}$ show that the circumference of the third stable orbit is equal to three electron wavelengths.
 - The speed of an electron in the second stable orbit is 1.1×10^6 m s⁻¹.
 - Calculate the wavelength of the electron.
 - Calculate the circumference of the second stable orbit.

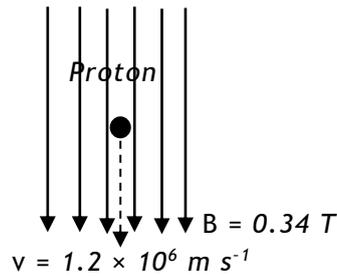
Particles from space

- An electron moves with a speed of 4.8×10^6 m s⁻¹ at right angles to a uniform magnetic field of magnetic induction 650 mT. Calculate the magnitude of the force acting on the electron.
- A proton moves with a speed of 3.0×10^4 m s⁻¹ at right angles to a uniform magnetic field. The magnetic induction is 0.8 T. The charge on the proton is +1e. Calculate the magnitude of the force acting on the proton.
- A neutron moves at right angles to a uniform magnetic field. Explain why the neutron's motion is unaffected by the magnetic field.
- (a) A proton moves through a uniform magnetic field as shown in the diagram.



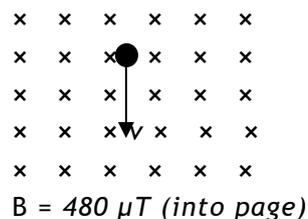
Calculate the magnetic force exerted on the proton.

- Another proton moves through this uniform magnetic field.



What is the magnetic force exerted on the proton? Explain your answer.

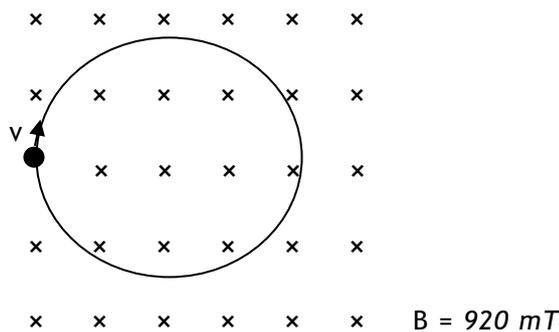
5. An electron experiences a force of $2.5 \times 10^{-13} \text{ N}$ as it moves at right angles to a uniform magnetic field of magnetic induction 350 mT . Calculate the speed of the electron.
6. A muon experiences a force of $1.5 \times 10^{-16} \text{ N}$ when travelling at a speed of $2.0 \times 10^7 \text{ m s}^{-1}$ at right angles to a magnetic field. The magnetic induction of this field is $4.7 \times 10^{-5} \text{ T}$. What is the magnitude of the charge on the muon?
7. An alpha particle is a helium nucleus containing two protons and two neutrons. The alpha particle experiences a force of $1.4 \times 10^{-12} \text{ N}$ when moving at $4.8 \times 10^5 \text{ m s}^{-1}$ at right angles to a uniform magnetic field. Calculate the magnitude of the magnetic induction of this field.
8. An electron moves at right angles to a uniform magnetic field of magnetic induction 0.16 T . The speed of the electron is $8.2 \times 10^6 \text{ m s}^{-1}$.
 - (a) Calculate the force exerted on the electron.
 - (b) Explain why the electron moves in a circle.
 - (c) Calculate the radius of this circle.
9. A proton moves through the same magnetic field as in question 8 with the same speed as the electron ($8.2 \times 10^6 \text{ m s}^{-1}$). Calculate the radius of the circular orbit of the proton.
10. An electron moves with a speed of $3.8 \times 10^6 \text{ m s}^{-1}$ perpendicular to a uniform magnetic field.



Calculate:

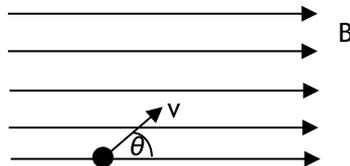
- (a) the radius of the circular orbit taken by the electron
- (b) the central force acting on the electron.

11. An alpha particle travels in a circular orbit of radius 0.45 m while moving through a magnetic field of magnetic induction 1.2 T. The mass of the alpha particle is 6.645×10^{-27} kg. Calculate:
- the speed of the alpha particle in the orbit
 - the orbital period of the alpha particle
 - the kinetic energy of the alpha particle in this orbit.
12. A proton moves in a circular orbit of radius 22 mm in a uniform magnetic field as shown in the diagram.

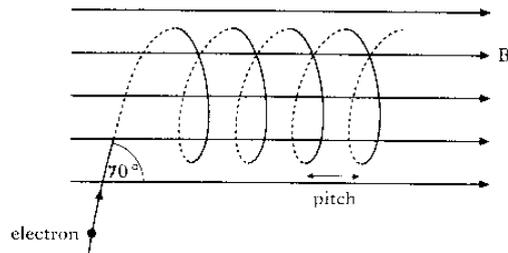


Calculate the speed of the proton.

13. An electron moves with a speed of 5.9×10^5 m s⁻¹ in a circular orbit of radius 5.5 μ m in a uniform magnetic field. Calculate the magnetic induction of the magnetic field.
14. A sub-atomic particle moves with a speed of 2.09×10^6 m s⁻¹ in a circular orbit of radius 27 mm in a uniform magnetic field. The magnetic induction is 0.81 T. Calculate the charge to mass ratio of the sub-atomic particle and suggest a name for the particle. Give a reason for your answer.
15. A charged particle enters a uniform magnetic field with a velocity v at an angle θ as shown.



- Write down an expression for the horizontal component of velocity.
 - Write down an expression for the vertical component of velocity.
 - Which of these components will stay unchanged as the charged particle continues its journey? Give a reason for your answer.
16. An electron travelling at a constant speed of 6.8×10^6 m s⁻¹ enters a uniform magnetic field at an angle of 70° as shown and subsequently follows a helical path.



The magnetic induction is 230 mT.

Calculate:

- the component of the electron's initial velocity parallel to B
- the component of the electron's initial velocity perpendicular to B
- the central force acting on the electron
- the radius of the helix
- the period of electron rotation in the helix
- the pitch of the helix.

17. A proton travelling at $5.8 \times 10^5 \text{ m s}^{-1}$ enters a uniform magnetic field at an angle of 40° to the horizontal (similar to the diagram in question 16). The proton subsequently follows a helical path.

The magnetic induction is 0.47 T.

Calculate:

- the component of the proton's initial velocity parallel to B
- the component of the proton's initial velocity perpendicular to B
- the central force acting on the proton
- the radius of the helix
- the period of proton rotation in the helix
- the pitch of the helix.

18. An electron travelling at $1.3 \times 10^7 \text{ m s}^{-1}$ enters a uniform magnetic field at an angle of 55° and follows a helical path similar to that shown in question 16.

The magnetic induction is 490 mT.

Calculate:

- the radius of the helix
- the pitch of the helix.

19. Explain why most charged particles from the Sun enter the Earth's atmosphere near the north and south poles.

20. Explain what causes the Aurora Borealis to occur.

Simple harmonic motion

1. A particle moves with simple harmonic motion. The displacement of the particle is given by the expression $y = 40\cos 4\pi t$, where y is in millimetres and t is in seconds.

- State the amplitude of the motion.

- (b) Calculate:
- the frequency of the motion
 - the period of the motion.
- (c) Calculate the displacement of the particle when:
- $t = 0$
 - $t = 1.5 \text{ s}$
 - $t = 0.4 \text{ s}$.
2. The displacement, y mm, of a particle is given by the expression $y = 0.44 \sin 28t$.
- State the amplitude of the particle motion.
 - Calculate the frequency of the motion.
 - Calculate the period of the motion.
 - Find the time taken for the particle to move a distance of 0.20 mm from the equilibrium position.
3. An object is moving in simple harmonic motion. The amplitude of the motion is 0.05 m and the frequency is 40 Hz.
- Calculate the period of the motion.
 - Write down an expression which describes the motion of the object if the displacement is zero at $t = 0$.
 - Calculate the acceleration of the object:
 - at the midpoint of the motion
 - at the point of maximum displacement.
 - Calculate the maximum speed of the object.
 - At which displacement in the motion does the maximum speed occur?
4. An object of mass 0.65 kg moves with simple harmonic motion with a frequency of 5.0 Hz and an amplitude of 40 mm.
- Calculate the unbalanced force on the mass at the centre and extremities of the motion.
 - Determine the velocity of the mass at the centre and extremities of the motion.
 - Calculate the velocity and acceleration of the mass when its displacement is 20 mm from the centre.
5. An object of mass 0.50 kg moves with simple harmonic motion of amplitude 0.12 m. The motion begins at +0.12 m and has a period of 1.5 s.
- Calculate the following after the object has been moving for 0.40 s.
 - The displacement of the object.
 - The unbalanced force on the object (magnitude and direction).
 - Calculate the time taken for the object to reach a displacement of -0.06 m after starting.

6. A point on the tip of a tuning fork oscillates vertically with simple harmonic motion.



The displacement y of this point in millimetres is given by
 $y = 2.0 \sin(3.22 \times 10^3 t)$

- (a) Calculate the frequency of the sound created by the tuning fork.
 (b) Calculate the maximum acceleration of the tip of the tuning fork.
 (c) A student states that the period of any object undergoing simple harmonic motion will not change as the motion dies away.
 Which experimental observation of the tuning fork supports the student's statement?
7. An object of mass 0.20 kg oscillates with simple harmonic motion of amplitude 100 mm and frequency 0.50 Hz.
- (a) Calculate the maximum value of the kinetic energy of the object and state where this occurs.
 (b) State the minimum value of the kinetic energy of the object and state where this occurs.
 (c) Calculate the maximum value of the potential energy of the object and state where this occurs.
 (d) State the minimum value of the potential energy of the object and state where this occurs.
 (e) Calculate the potential and kinetic energy of the object when its displacement is:
 (i) 20 mm
 (ii) 50 mm.
 (f) Predict the value of the sum of the kinetic and potential energies of the object at all displacements of its motion.
8. A metal ruler is clamped at one end and is made to vibrate with simple harmonic motion in the vertical plane as shown.



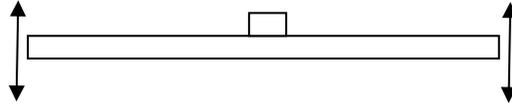
The frequency of vibration is 8.0 Hz.

- (a) (i) One point on the ruler oscillates with an amplitude of 3.0 mm.
 Calculate the maximum downward acceleration of this point.
 (ii) Would a small mass sitting on the ruler at this point lose contact with the surface of the ruler? Explain your answer.
 (b) (i) Another point on the oscillating ruler has an amplitude of 4.0 mm.

Calculate the maximum downward acceleration of this point.

- (ii) Would a small mass sitting on the ruler at this point lose contact with the surface of the ruler? Explain your answer.

9. A horizontal platform oscillates vertically with simple harmonic motion with a slowly increasing amplitude.
A small mass rests on the platform and the period of oscillation is 0.10 s.



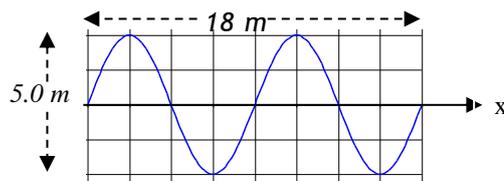
Calculate the maximum amplitude which will allow the mass to always remain in contact with the platform.

10. A vertical spring stretches 0.10 m when a 1.2 kg mass is hung from one end.
The mass is then pulled down a further distance of 0.08 m below the previous equilibrium position and released.
- (a) Show that the spring oscillates with a frequency of 1.6 Hz.
(b) Calculate the total energy of the oscillating system.

Waves

1. A travelling wave is represented by the equation $y = 30 \sin 2\pi(10t - 0.2x)$ where y is in millimetres.
For this wave state or calculate:
- (a) the amplitude
(b) the frequency
(c) the period
(d) the wavelength
(e) the speed.
2. A travelling wave is represented by the equation $y = 0.60 \sin \pi(150t - 0.40x)$ where y is in metres.
- (a) What is the amplitude of this wave?
(b) Calculate the frequency of this wave.
(c) What is the period of the wave?
(d) Calculate the wavelength of the wave.
(e) What is the speed of the wave?
3. A travelling wave is represented by the equation $y = 0.35 \sin(20t - 1.5x)$ where y is in metres.
For this wave calculate:
- (a) the frequency
(b) the wavelength
(c) the wave speed.

4. A plane wave of amplitude 0.30 m, frequency 20 Hz and wavelength 0.50 m travels in the +x direction. The displacement of the wave is zero at $t = 0$.
Write down the equation of this wave.
5. A wave of frequency 40 Hz travels with a speed of 12 m s^{-1} in the +x direction. The amplitude of the wave is 1.5 m.
Write down the equation of this wave.
6. The diagram shows the profile of a wave travelling in the +x direction at 36 m s^{-1} .



Write down the equation of the travelling wave.

7. A travelling wave is represented by the equation $y = 0.20 \sin 2\pi(110t - 15x)$ (x and y are measured in metres).
Write the equation for the displacement y_R of a wave travelling in the opposite direction that has twice the frequency, double the amplitude and the same wavelength as the original wave.
8. A travelling wave is represented by the equation $y_1 = 0.24 \sin(42t - 3.6x)$ (x and y are measured in metres).
- (a) Write down the equation for the displacement y_2 of another wave travelling in the opposite direction to the original wave and with the same amplitude, half the frequency and twice the wavelength.
- (b) Is the new wave faster, slower or the same speed as the original wave? Justify your answer.
9. A travelling wave is represented by the equation $y_1 = 0.40 \sin(8.5t - 0.80x)$ (x and y are measured in meters).
Write down the equation of the displacement y_2 of another wave travelling in the opposite direction to the original wave and with three times the amplitude, twice the frequency and half the speed.
10. The following equation represents a wave travelling in the +x direction:
$$y = A \sin 2\pi \left(ft - \frac{x}{\lambda} \right)$$

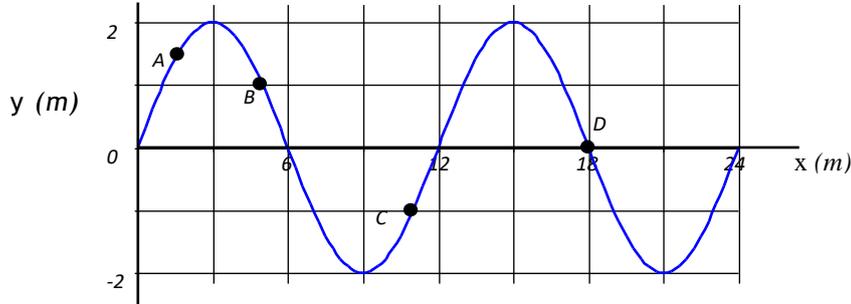
Using the relationships $f = \frac{1}{T}$, $v = f\lambda$, $\omega = 2\pi f$ and $k = \frac{2\pi}{\lambda}$ show that the following are also possible equations for this wave:

- (a) $y = A \sin 2\pi \left(\frac{t}{T} - \frac{x}{\lambda} \right)$
- (b) $y = A \sin(\omega t - kx)$

(c) $y = A \sin 2\pi f \left(t - \frac{x}{v} \right)$

(d) $y = A \sin \frac{2\pi}{\lambda} (vt - x)$

11. The diagram shows the profile of a wave travelling in the +x direction.



Calculate the phase difference between points:

- (a) A and B
 (b) B and C
 (c) A and C
 (d) C and D
 (e) A and D.

12. A wave has a velocity of 350 m s^{-1} and a frequency of 500 Hz.

- (a) Two points on the wave are $\frac{\pi}{3}$ (or 60°) out of phase.

What is the closest horizontal distance between these two points?

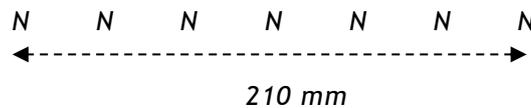
- (b) Another two points on the wave have a phase difference of 0.18 rad.

What is the closest horizontal distance between these two points?

13. A travelling wave has a speed of 24 m s^{-1} and a frequency of 60 Hz. Calculate the phase difference between the leading edge of the wave and the same leading edge of the wave 2.0 ms later.

14. Nodes are 12 cm apart in a standing wave. State the wavelength of the interfering waves.

15. The diagram shows the distance between several nodes in a standing wave.



Calculate the wavelength of the wave.

16. A student sets up a stationary sound wave using the following apparatus.



signal generator

loudspeaker

microphone

metal
reflector

The microphone is used to find the position of the nodes when the reflected wave interferes with the incident wave.

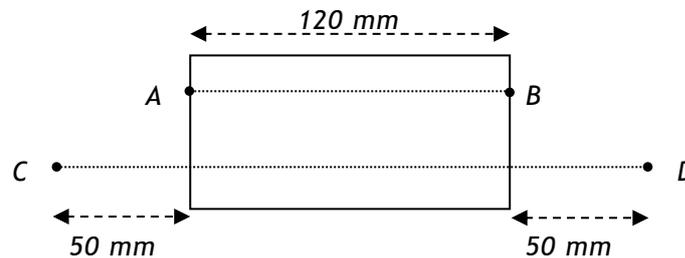
The student notes the following results:

$$\begin{aligned} \text{frequency of sound} &= 700 \pm 50 \text{ Hz} \\ \text{distance between two adjacent nodes} &= 25 \pm 2 \text{ cm} \end{aligned}$$

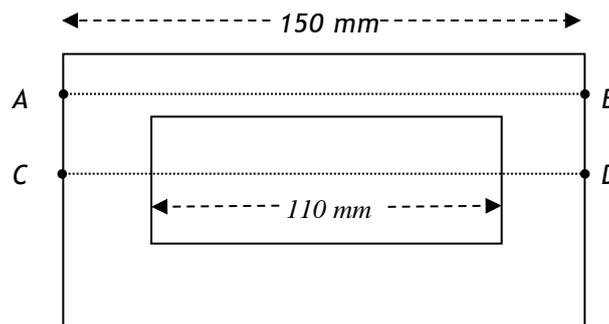
- (a) Using this data calculate:
- the speed of sound
 - the absolute uncertainty in the calculated value for the speed of sound.
- (b) How could the student reduce the absolute uncertainty in the calculated value for the speed of sound?

Interference

1. A glass block of refractive index 1.5 is surrounded by air. Rays of light pass from A to B and from C to D as shown.



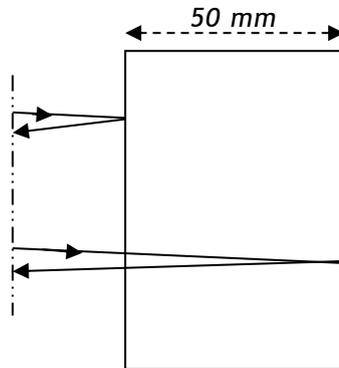
- State the geometric path length AB.
 - Calculate the optical path length AB.
 - What is the geometric path length CD?
 - Calculate the optical path length CD.
2. A hollow air-filled glass block is 150 mm long. The refractive index of the glass is 1.5 and rays of light pass from A to B and from C to D as shown.



Calculate:

- (a) the optical path length AB
- (b) the optical path length CD
- (c) the optical path difference between rays AB and CD.

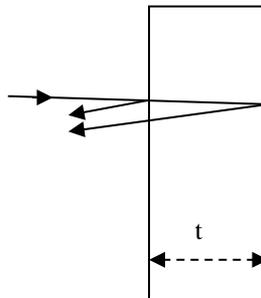
3. A perspex block reflects two rays of light from different surfaces as shown:



The perspex block has a refractive index of 1.47 and a thickness of 50 mm.

Assume both rays have near normal incidence.

- (a) Calculate the optical path difference between the rays.
 - (b) State the phase change undergone by each ray on reflection.
4. A ray of light strikes a thin film of transparent material at near-normal incidence.
The material has refractive index n and thickness t .



The two reflected rays can interfere constructively or destructively.

- (a) Show that the condition for destructive interference between the reflected rays is $2nt = m\lambda$ where the symbols have their usual meanings.
 - (b) Show that the condition for constructive interference between the reflected rays is $2nt = (m + \frac{1}{2})\lambda$ where $m = 0, 1, 2, \dots$
5. A soap film of refractive index 1.3 is illuminated by light of wavelength 650 nm. The light is incident normally on the soap film.
- (a) Calculate the minimum thickness of soap film required to give no reflection.

- (b) White light is now used to illuminate this minimum thickness of soap film. What is the colour of the reflected light? Explain your answer.
6. Light of wavelength 560 nm is incident normally on a thin film of material surrounded by air. The refractive index of the material is 1.5.
- (a) Calculate the minimum thickness of the thin film required to give zero reflection of this wavelength.
- (b) Calculate the minimum thickness of the thin film required to give maximum reflection of this wavelength.
7. A glass lens of refractive index 1.6 is coated with a thin transparent film of refractive index 1.38. The coated lens gives zero reflection of light of wavelength 590 nm. Calculate the minimum thickness of the film to give zero reflection of this wavelength.
8. A camera lens has a thin film of material of refractive index 1.36 applied to its surface. The thin film is designed to give zero reflection of light of wavelength 690 nm.
- (a) Calculate the minimum thickness of film required.
- (b) Calculate the next lowest thickness of film required to give zero reflection of this wavelength.
9. A glass lens is coated with a thin transparent film of thickness 110 nm and refractive index 1.38. What wavelength of light will pass into this coated lens with 100% transmission?
10. An air wedge is formed by two glass slides of length 100 mm in contact at one end. The other ends of the slides are separated by a piece of paper 30 μm thick.



Light of wavelength 650 nm is reflected vertically from the air wedge. Calculate the fringe separation of the interference pattern produced by the air wedge.

11. An air wedge is formed by two glass plates in contact at one end and separated by a length of wire at the other end, as shown.

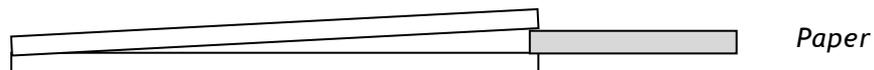


100 mm

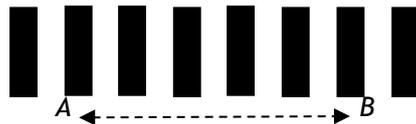
Light of wavelength 690 nm is reflected vertically from the wedge, resulting in an interference pattern. The average fringe separation is 1.2 mm.

- Calculate the diameter of the wire.
- The temperature of the wire increases. What effect will this have on the fringe separation? Explain your answer.

12. An air wedge is formed by two glass slides in contact at one end and separated by a sheet of paper at the other end.



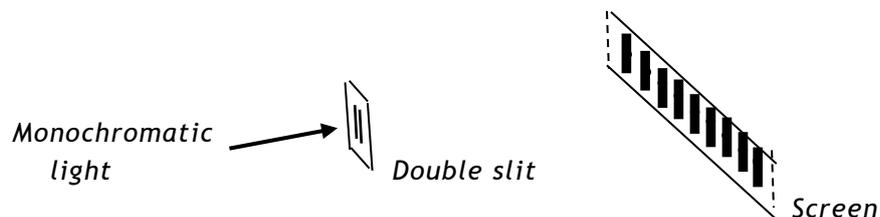
A student observes the following interference pattern from monochromatic light reflected vertically from the air wedge:



The student notes the following measurements/data.

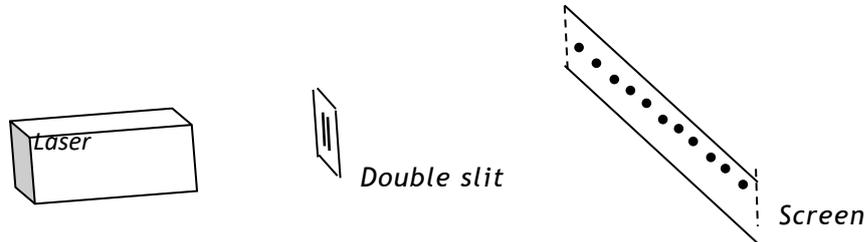
distance AB	=	6.0 ± 0.5 mm
length of glass slides	=	100 ± 0.2 mm
wavelength of light used	=	589 ± 1 nm

- Calculate the thickness of the paper.
 - Calculate the absolute uncertainty in the thickness of the paper.
 - The student suggests in an evaluation that measuring the length of the glass slides more accurately would reduce the uncertainty in the thickness of the paper.
 - Explain why this statement is not correct.
 - How could the uncertainty in the thickness of the paper be reduced?
13. Two parallel slits are separated by a distance of 5.0×10^{-4} m and are illuminated by monochromatic light. An interference pattern is observed on a screen placed 7.2 m beyond the double slit.



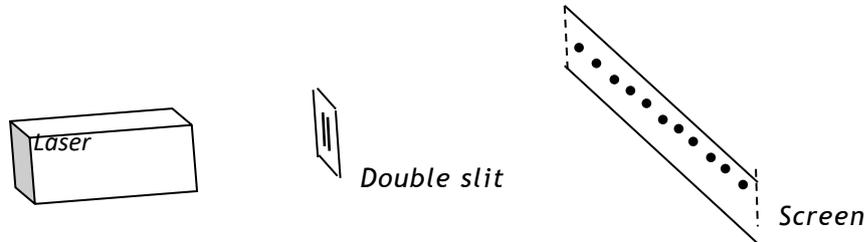
The bright fringes on the screen are separated by a distance of 8.0 mm. Calculate the wavelength of the light.

14. Light of wavelength 695 nm from a laser is shone onto a double slit with a separation of 2.0×10^{-4} m.



Calculate the separation of the bright fringes on a screen placed 0.92 m beyond the double slit.

15. A Young's slits experiment is set up to measure the wavelength of light from a laser.



The measurements taken are:

$$\begin{aligned} \text{distance between adjacent fringes} &= 7.0 \pm 1.0 \text{ mm} \\ \text{separation of double slits} &= 0.20 \pm 0.01 \text{ mm} \\ \text{distance from double slit to screen} &= 2.40 \pm 0.01 \text{ m} \end{aligned}$$

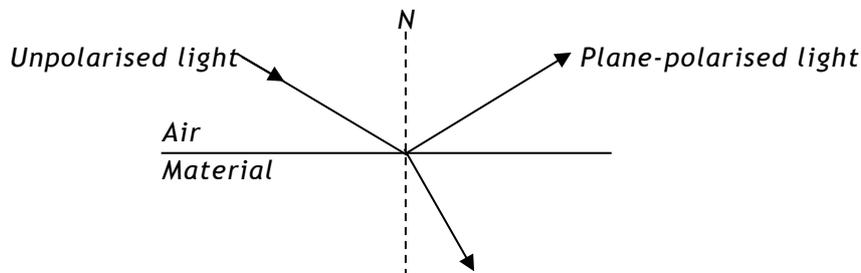
Calculate:

- (a) the wavelength of the laser light
 (b) the absolute uncertainty in the wavelength.
16. Two parallel slits have a separation of 0.24 ± 0.01 mm. Monochromatic light illuminates the slits and an interference pattern is observed on a screen placed 3.80 ± 0.01 m beyond the double slits. The separation between adjacent fringes is 9.5 ± 0.1 mm.
- (a) Calculate the wavelength of the light used, including its absolute uncertainty.
 (b) A student suggests that measuring the fringe separation more accurately will reduce the absolute uncertainty in the wavelength. Explain whether this is true or not.
17. A Young's slits experiment uses yellow monochromatic light to produce interference fringes on a screen. State and explain the effect of the following changes on the spacing between adjacent interference fringes on the screen:

- moving the screen closer to the slits
- reducing the separation of the slits
- replacing the yellow light with red monochromatic light
- replacing the yellow light with blue monochromatic light
- doubling the slits to screen distance and doubling the slit separation.

Polarisation

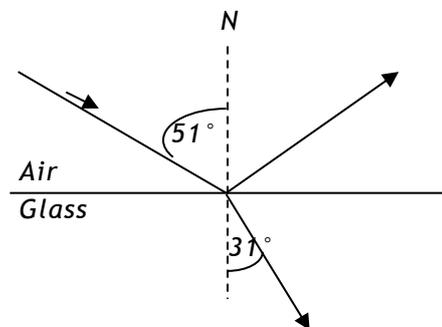
- The refractive index of water is 1.33 for a particular wavelength of light. Calculate the polarising angle of water for this wavelength.
- Brewster's angle for a liquid is 52.0° for a particular wavelength of light. Calculate the refractive index of the liquid for this wavelength.
- An unpolarised light ray in air reflects and refracts on contact with a transparent material of refractive index 1.38.



The reflected light is plane polarised.

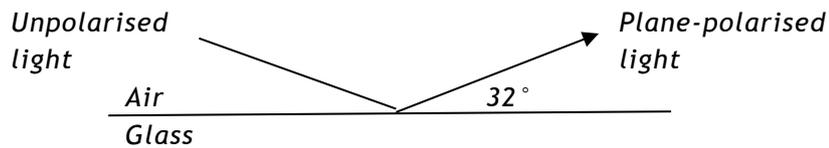
Sketch the diagram and write in the values of all the angles.

- The critical angle of a certain glass is 40.5° for a particular wavelength of light. Calculate the polarising angle for this wavelength in the glass.
- An unpolarised light ray refracts into glass and is also partially reflected as shown.



Is the reflected light plane polarised? You must justify your answer.

- A ray of light reflects off a type of glass in air as shown.



Calculate the refractive index of the glass.

Numerical answers

Quantum theory

1. $\pm 2.1 \times 10^{-23} \text{ kg m s}^{-1}$
2. $\pm 1.1 \times 10^{-9} \text{ m}$
3. $\pm 1.1 \times 10^{-25} \text{ J}$
4. $\pm 2.6 \times 10^{-26} \text{ kg m s}^{-1}$
5. (a) $1.8 \times 10^{-10} \text{ m}$
(b) $6.1 \times 10^{-14} \text{ m}$
(c) $2.0 \times 10^{-38} \text{ m}$
6. The electron has the larger de Broglie wavelength by 1800 times.
7. (a) $4.7 \times 10^{-13} \text{ m}$
(b) $1.4 \times 10^{-21} \text{ kg m s}^{-1}$
8. (a) $8.4 \times 10^6 \text{ m s}^{-1}$
(b) $8.7 \times 10^{-11} \text{ m}$
(c) Particle behaviour
9. $2.5 \times 10^{-11} \text{ m}$ ($2.46 \times 10^{-11} \text{ m}$)
10. 940 V
11. $2.4 \times 10^{-11} \text{ m}$ (24 pm)
12. (a) (i) $1.06 \times 10^{-34} \text{ kg m}^2 \text{ s}^{-1}$ ($1.056 \times 10^{-34} \text{ kg m}^2 \text{ s}^{-1}$)
(ii) $3.2 \times 10^{-34} \text{ kg m}^2 \text{ s}^{-1}$
(b) Show $2\pi r = n\lambda$
(c) (i) $6.6 \times 10^{-10} \text{ m}$
(ii) $1.3 \times 10^{-9} \text{ m}$

Particles from space

1. $5.0 \times 10^{-13} \text{ N}$
2. $3.8 \times 10^{-15} \text{ N}$
3. A neutron has zero charge: $q = 0$
4. (a) $6.1 \times 10^{-16} \text{ N}$ out from page
(b) Zero force, as velocity is parallel to magnetic field.
5. $4.5 \times 10^6 \text{ m s}^{-1}$
6. $1.6 \times 10^{-19} \text{ C}$
7. 9.1 T
8. (a) $2.1 \times 10^{-13} \text{ N}$
(b) This force is a central force at right angles to the direction of motion.
(c) $2.9 \times 10^{-4} \text{ m}$
9. 0.54 m
10. (a) 45 mm
(b) $2.9 \times 10^{-16} \text{ N}$
11. (a) $2.6 \times 10^7 \text{ m s}^{-1}$
(b) $1.1 \times 10^{-7} \text{ s}$

- (c) $2.2 \times 10^{-12} \text{ J}$
12. $1.9 \times 10^6 \text{ m s}^{-1}$
13. 0.61 T
14. $9.56 \times 10^7 \text{ C kg}^{-1}$; proton, q/m for proton = $9.56 \times 10^7 \text{ C kg}^{-1}$
15. (a) $v \cos\theta$
 (b) $v \sin\theta$
 (c) $v \cos\theta$ stays unchanged, as it is parallel to the magnetic field
16. (a) $2.3 \times 10^6 \text{ m s}^{-1}$
 (b) $6.4 \times 10^6 \text{ m s}^{-1}$
 (c) $2.36 \times 10^{-13} \text{ N}$
 (d) $1.6 \times 10^{-4} \text{ m}$
 (e) $1.6 \times 10^{-10} \text{ s}$
 (f) $3.7 \times 10^{-4} \text{ m}$
17. (a) $4.4 \times 10^5 \text{ m s}^{-1}$
 (b) $3.7 \times 10^5 \text{ m s}^{-1}$
 (c) $2.8 \times 10^{-14} \text{ N}$
 (d) $8.2 \times 10^{-3} \text{ m}$
 (e) $1.4 \times 10^{-7} \text{ s}$
 (f) $6.2 \times 10^{-2} \text{ m}$
18. (a) $1.2 \times 10^{-4} \text{ m}$
 (b) $5.4 \times 10^{-4} \text{ m}$

Simple harmonic motion

1. (a) 40 mm
 (b) (i) 2 Hz
 (ii) 0.5 s
 (c) (i) 4 cm
 (ii) 4 cm
 (iii) 1.2 cm
2. (a) 0.44 mm
 (b) 4.5 Hz
 (c) 0.22 s
 (d) 0.017 s (calculator must be in radian mode)
3. (a) 0.025 s
 (b) $y = 0.05 \sin 251t$
 (c) (i) Zero
 (ii) $\pm 3.2 \times 10^3 \text{ m s}^{-2}$
 (d) (i) $\pm 12.6 \text{ m s}^{-1}$
 (ii) Zero displacement
4. (a) Zero; $\pm 26 \text{ N}$
 (b) 1.3 m s^{-1} ; zero
 (c) 1.1 m s^{-1} ; 20 m s^{-2}
5. (a) (i) $-1.26 \times 10^{-2} \text{ m}$
 (ii) -0.11 N
 (b) 0.5 s
6. (a) 513 Hz
 (b) $2.1 \times 10^4 \text{ m s}^{-2}$
 (c) Observing frequency unchanged as vibration dies away.
7. (a) $9.9 \times 10^{-3} \text{ J}$ at centre
 (b) Zero at extremities
 (c) $9.9 \times 10^{-3} \text{ J}$ at extremities

- (d) Zero at centre
 (e) (i) $E_p = 3.9 \times 10^{-4} \text{ J}$; $E_k = 9.5 \times 10^{-3} \text{ J}$
 (ii) $E_p = 2.46 \times 10^{-3} \text{ J}$; $E_k = 7.4 \times 10^{-3} \text{ J}$
 (f) $9.9 \times 10^{-3} \text{ J}$
8. (a) (i) 7.6 m s^{-2}
 (ii) No, as $7.6 < 9.8$
 (b) (i) 10.1 m s^{-2}
 (ii) Yes, as ruler acceleration is greater than 9.8 so ruler accelerates away from the mass.
9. $2.5 \times 10^{-3} \text{ m}$
10. (b) 0.38 J

Waves

1. (a) 30 mm
 (b) 10 Hz
 (c) 0.1 s
 (d) 5 cm
 (e) 50 cm s^{-1}
2. (a) 0.60 m
 (b) 75 Hz
 (c) $1.3 \times 10^{-2} \text{ s}$
 (d) 5 m
 (e) 375 m s^{-1}
3. (a) 3.2 Hz
 (b) 4.2 m
 (c) 13 m s^{-1} (13.4 m s^{-1})
4. $y = 0.30 \sin 2\pi(20t - 2x)$
5. $y = 1.5 \sin(250t - 21x)$
6. $y = 2.5 \sin(25t - 0.70x)$
7. $y_R = 0.40 \sin 2\pi(220t + 15x)$
8. (a) $y_2 = 0.24 \sin(21t + 1.8x)$
 (b) Same speed as $v = f\lambda$ and f halves and λ doubles.
9. $y_2 = 1.2 \sin(17t + 3.2x)$
11. (a) 1.8 rad
 (b) 2.9 rad
 (c) 4.7 rad
 (d) 3.9 rad
 (e) 8.6 rad
12. (a) 0.12 m
 (b) $2.0 \times 10^{-2} \text{ m}$
13. 0.75 rad
14. 24 cm
15. 70 mm
16. (a) (i) 350 m s^{-1}
 (ii) $\pm 40 \text{ m s}^{-1}$ ($\pm 37 \text{ m s}^{-1}$ rounded to 1 significant figure)
 (b) Measure distance between five nodes (uncertainty still $\pm 2 \text{ cm}$).
 This reduces the percentage uncertainty in distance and wavelength.

Interference

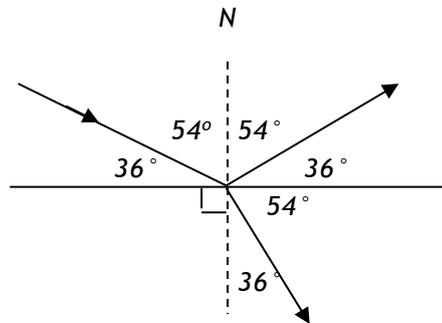
1. (a) 120 mm

- (b) 180 mm
 (c) 220 mm
 (d) 280 mm
2. (a) 225 mm
 (b) 170 mm
 (c) 55 mm
3. (a) 147 mm
 (b) Upper ray has phase change of π on reflection.
 Lower ray has no phase change on reflection.
5. (a) 2.5×10^{-7} m
 (b) Blue/violet. Little red light reflected so more blue reflected or maximum reflection when $m = 1.5$ gives 433 nm reflected strongly.
6. (a) 1.9×10^{-7} m
 (b) 9.3×10^{-8} m
7. 1.07×10^{-7} m
8. (a) 1.27×10^{-7} m
 (b) 3.81×10^{-7} m
9. 6.07×10^{-7} m (607 nm)
10. 1.1 mm
11. (a) 2.9×10^{-5} m
 (b) Fringe separation smaller as diameter of wire increases due to expansion.
 (d increases) and Δx is proportional to $\frac{1}{d}$.
12. (a) 2.5×10^{-5} m
 (b) $\pm 2 \times 10^{-6}$ m
 (c) (i) The percentage uncertainty in L is less than a third of the dominant uncertainty so can be ignored, therefore there is no improvement in uncertainty in d by making L more accurate.
 (ii) Reduce uncertainty in Δx by measuring the width of 10 consecutive fringes rather than five consecutive fringes. If absolute uncertainty is still ± 0.5 mm then the percentage uncertainty in Δx will be halved from 8% to 4%. The calculated uncertainty in d will therefore be reduced.
13. 5.6×10^{-7} m (556 nm)
14. 3.2 mm
15. (a) 580 nm
 (b) ± 90 nm
16. (a) $6.0 \times 10^{-7} \pm 3 \times 10^{-8}$ m
 (b) Not true as percentage uncertainty in Δx is less than a third of the percentage uncertainty in d, so percentage uncertainty in Δx is ignored. Any reduction in percentage uncertainty in Δx will also be ignored.
17. (a) Fringes closer together as $\Delta x \propto D$.
 (b) Fringes further apart as $\Delta x \propto \frac{1}{d}$.
 (c) Fringes further apart as $\lambda_{red} > \lambda_{yellow}$ and $\Delta x \propto \lambda$.
 (d) Fringes closer together as $\lambda_{blue} < \lambda_{yellow}$ and $\Delta x \propto \lambda$.

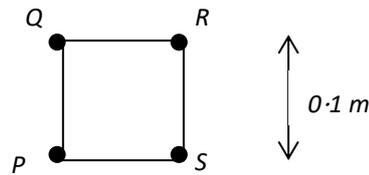
- (e) No change in fringe spacing as $\Delta x = \frac{\lambda D}{d}$ so numerator doubles and denominator doubles, cancelling the overall effect on Δx .

Polarisation

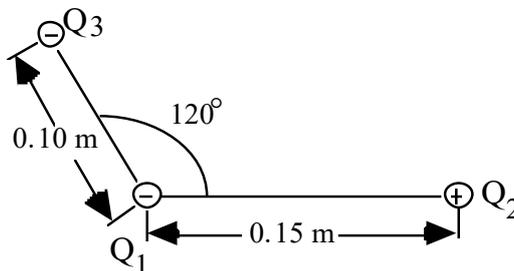
1. 53.1°
2. 1.28
- 3.



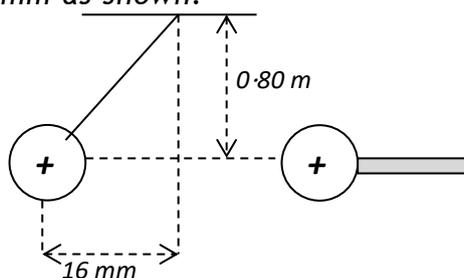
4. 57°
5. No. Show $n = 1.51$ so $i_p = 56^\circ$ not 51° , or angle between reflected and refracted rays is 98° and not 90° .
6. 1.6



- (a) Determine the electrostatic force, magnitude and direction, 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.
7. A proton and an electron have an average separation of $2.0 \times 10^{-10} \text{ m}$. Calculate the ratio of the electrostatic force F_E to the gravitational force F_G acting on the particles. Use $G = 6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2}$.
8. Suppose the Earth (mass $6.0 \times 10^{24} \text{ kg}$) has an excess of positive charge and the Moon (mass $7.3 \times 10^{22} \text{ kg}$) has an equal excess of positive charge. Calculate the size of the charge required so that the electrostatic force between them balances the gravitational force between them.
9. The diagram below shows three charges fixed in the positions shown.



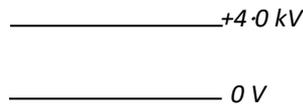
- $Q_1 = -1.0 \times 10^{-6} \text{ C}$, $Q_2 = +3.0 \times 10^{-6} \text{ C}$ and $Q_3 = -2.0 \times 10^{-6} \text{ C}$. Calculate the resultant force on charge Q_1 . (Remember that this resultant force will have a direction as well as magnitude).
10. In an experiment to show Coulomb's law, an insulated, light, charged sphere is brought close to another similarly charged sphere which is suspended at the end of a thread of length 0.80 m . The mass of the suspended sphere is 0.50 g . It is found that the suspended sphere is displaced to the left by a distance of 16 mm as shown.



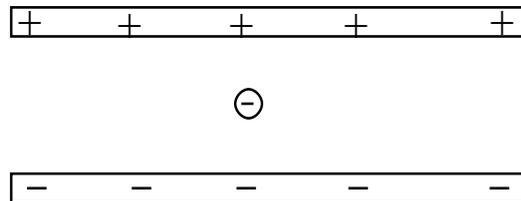
- (a) Make a sketch showing all of the forces acting on the suspended sphere.
- (b) Calculate the electrostatic force acting on the suspended sphere.
11. Two identical charged spheres of mass 0.10 g are hung from the same point by silk threads. The electrostatic force between the spheres causes them to separate by 10 mm . The angle between one of the silk threads and the vertical is 5.7° .
- (a) By drawing a force diagram, find the electrostatic force F_E between the spheres.
- (b) Calculate the size of the charge on each sphere.
- (c) The average leakage current from a charged sphere is $1.0 \times 10^{-11} \text{ A}$.
- Calculate the time taken for the spheres to discharge completely.
- (d) Describe how the two spheres may be given identical charges.

Electric field strength

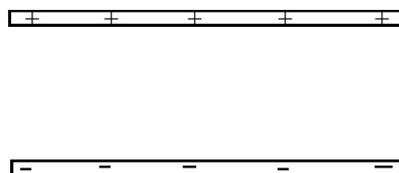
- State the meaning of the term 'electric field strength at a point'.
- State the relationship for the electric field strength, E :
 - at a distance r from a point charge Q
 - between two parallel plates, a distance d apart, when a potential difference (p.d.) V is applied across the plates.
- Calculate the electric field strength at a distance of $1.0 \times 10^{-10} \text{ m}$ from a helium nucleus.
- A small sphere has a charge of $+2.0 \text{ nC}$. At what distance from the sphere is the magnitude of the electric field strength $7.2 \times 10^4 \text{ N C}^{-1}$?
- A point charge of 4.0 nC experiences an electrostatic force of 0.02 N . Calculate the electric field strength at the position of this charge.
- A small charged sphere produces an electric field strength of 1.0 N C^{-1} at a distance of 1.0 m . Calculate the charge on the sphere.
 - State the magnitude of the electric field strength at a distance of 2.0 m from the charged sphere.
- Calculate the electric field strength at a point 5.0 mm from an α -particle.
 - How does the electric field strength calculated in (a) compare with the electric field strength at a point 5.0 mm from a proton?
- Two parallel conducting plates are $2.0 \times 10^{-2} \text{ m}$ apart. A potential difference of 4.0 kV is applied across the plates.



- (a) State the direction of the electric field between the plates.
- (b) Calculate the value of the electric field strength:
- (i) midway between the plates
- (ii) just below the top plate.
9. A small negatively charged sphere, of mass 2.0×10^{-5} kg, is held stationary in the space between two charged metal plates as shown in the diagram below.



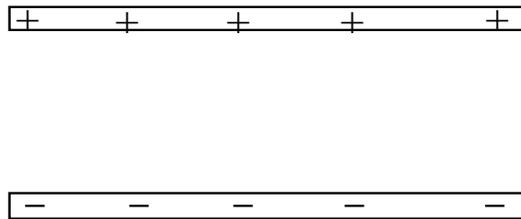
- (a) The sphere carries a charge of -5.0×10^{-9} C. Calculate the size of the electric field strength in the region between the metal plates.
- (b) Make a sketch of the two plates and the stationary charged sphere. Show the shape and direction of the resultant electric field in the region between the plates.
10. Two charges of $+8.0 \times 10^{-9}$ C and $+4.0 \times 10^{-9}$ C are held a distance of 0.20 m apart.
- (a) Calculate the magnitude and direction of the electric field strength at the midpoint between the charges.
- (b) Calculate the distance from the 8.0×10^{-9} C charge at which the electric field strength is zero.
- (c) The 4.0×10^{-9} C charge has a mass of 5.0×10^{-4} kg.
- (i) Calculate the magnitude of the electrostatic force acting on this charge.
- (ii) Calculate the magnitude of the gravitational force acting on this mass.
11. Copy and complete the electric field patterns for:
- (a) the electric field between two parallel conducting plates which have equal but opposite charges



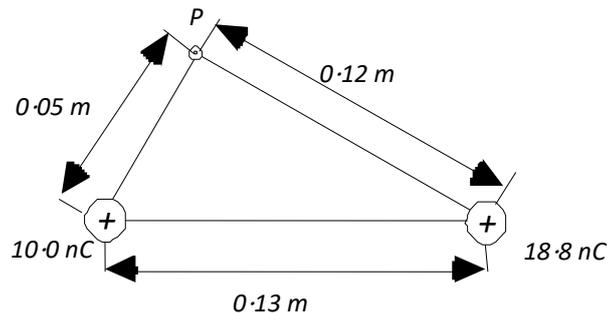
- (b) the electric field around two unequal but opposite point charges.



12. Draw electric field lines and equipotential surfaces for the two oppositely charged parallel conducting plates shown in the sketch below. (Include the fringing effect usually observed near the edge of the plates.)



13. The diagram shows two charges of $+10.0 \text{ nC}$ and $+18.8 \text{ nC}$ separated by 0.13 m .



- (a) Calculate the magnitude of the resultant electric field strength at the point P.
 (b) Make a sketch like the one above and show the direction of the resultant electric field strength at the point P.

Angles are required on your sketch.

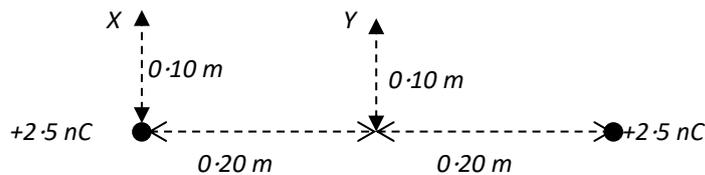
Electric fields and electrostatic potential

- What is meant by the 'electrostatic potential at a point'?
- State the expression for the electrostatic potential at a distance r from a point charge Q .
- Determine the electrostatic potential at a distance of 3.0 m from a point charge of $+4.0 \text{ nC}$.
- Calculate the electrostatic potential at a point P that is at a distance of 0.05 m from a point charge of $+3.0 \times 10^{-9} \text{ C}$.
- Point A is 2.00 m from a point charge of -6.00 nC . Point B is 5.00 m from the same point charge.
 - Determine the potential difference between point A and point B.

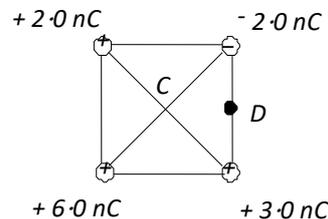
- (b) Does your answer to (a) depend on whether point A, point B and the charge are in a straight line?
6. A hydrogen atom may be considered as a charge of $+1.6 \times 10^{-19} \text{ C}$ separated from a charge of $-1.6 \times 10^{-19} \text{ C}$ by a distance of $5.0 \times 10^{-11} \text{ m}$.
Calculate the potential energy associated with an electron in a hydrogen atom.
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. Using broken dashed lines add lines of equipotential to your sketch.
9. Two point charges of $+4.0 \text{ nC}$ and -2.0 nC are situated 0.12 m apart.
Find the position of the point where the electrostatic potential is zero.
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 point charges each of $+2.5 \text{ nC}$ are situated 0.40 m apart as shown below.



- (a) (i) Calculate the electrostatic potential at point X.
(ii) Calculate the electrostatic potential at point Y.
- (b) Determine the potential difference between points X and Y.
12. Small spherical charges of $+2.0 \text{ nC}$, -2.0 nC , $+3.0 \text{ nC}$ and $+6.0 \text{ nC}$ are placed in order at the corners of a square of diagonal 0.20 m as shown in the diagram.



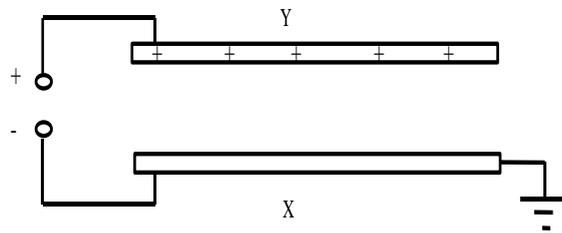
- (a) Calculate the electrostatic potential at the centre, C, of the square
- (b) Show that the length of one side of the square is $\sqrt{0.02} \text{ m}$.
- (c) D is at the midpoint of the side as shown.
Calculate the electrostatic potential difference between point C and point D.
13. Consider an equilateral triangle PQR where $QR = 20 \text{ mm}$. A charge of

$+1.0 \times 10^{-8} \text{ C}$ is placed at Q and a charge of $-1.0 \times 10^{-8} \text{ C}$ is placed at R. Both charges are fixed in place.

- Calculate the electric field strength at point P.
- Calculate the electrostatic potential at point P.

14. Two parallel conducting plates are separated by a distance of 20 mm. The plates have a potential difference of 1500 V between them.
Calculate the electric field strength, in V m^{-1} , between the plates.

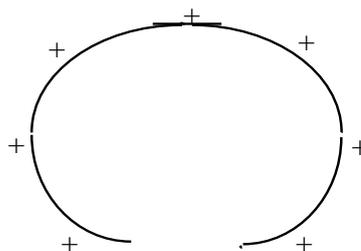
15. The diagram below shows two horizontal metal plates X and Y which are separated by a distance of 50 mm. There is a potential difference between the plates of 1200 V. Note that the lower plate, X, is earthed.



- Draw a sketch graph to show how the potential varies along a line joining the midpoint of plate X to the midpoint of plate Y.
 - Calculate the electric field strength between the plates.
 - Explain how the value for the electric field strength can be obtained from the graph obtained in (a).
16. A metallic sphere has a radius of 0.040 m . The charge on the sphere is $+30 \mu\text{C}$.

Calculate the electric field strength:

- inside the sphere
 - at the surface of the sphere
 - at a distance of 1.0 m from the centre of the sphere.
17. (a) State what is meant by an equipotential surface.
(b) The sketch below shows the outline of the positively charged dome of a Van de Graaff generator.



Copy this sketch and show the electric field lines and equipotential surfaces around the charged dome.

18. Consider the arrangement of point charges shown in the diagrams below. All charges have the same magnitude.



For each of the arrangements of the charges state whether at point P midway between the charges:

- (a) the electric field is zero or non-zero
 (b) the electric potential is zero or non-zero.
19. Consider the arrangement of point charges shown in the diagrams below. All charges have the same magnitude and are fixed at the corners of a square.

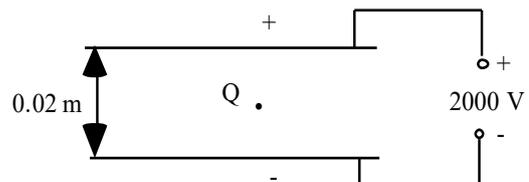


For each of the arrangements of the charges state whether at point P at the centre of the squares:

- (a) the electric field is zero or non-zero
 (b) the electric potential is zero or non-zero.
20. A conducting sphere of radius 0.05 m has a potential at its surface of 1000 V .
- (a) Calculate the charge on the sphere.
 (b) Make a sketch of the first five equipotential lines outside the sphere if there is 100 V between the lines (ie calculate the various radii for these potentials).
21. In a Millikan-type experiment a very small charged oil drop is stationary between the two plates. (Note that one plate is vertically above the other.)

The mass of the oil drop is $4.9 \times 10^{-15}\text{ kg}$.

- (a) Draw a sketch to show the forces acting on the oil drop.
 (b) State the sign of the charge on the oil drop.
 (c) Calculate the size of the charge on the oil drop.
 (d) How many excess electrons are on the oil drop?



Charged particles in motion in an electric field

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



A small particle with a charge $-6.0 \mu\text{C}$ is just at the lower surface of the top plate.

- (a) How much work is done in moving the $-6.0 \mu\text{C}$ charge between the plates?
- (b) Describe the energy transformation associated with the movement of a $-6.0 \mu\text{C}$ charge when it is released from the bottom plate.
2. A p.d. of $3.0 \times 10^4 \text{ V}$ is applied between two parallel conducting plates. The electric field strength between the plates is $5.0 \times 10^5 \text{ N C}^{-1}$.

- (a) Determine the separation of the parallel plates.
- (b) The separation of the plates is reduced to half the value found in (a).

What happens to the magnitude of the electric field strength between the plates?

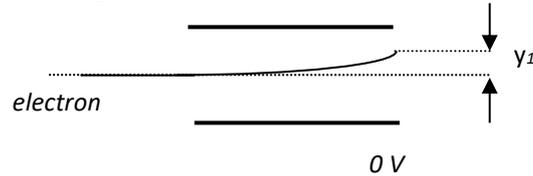
- (c) An electron starts from rest at one plate and is accelerated towards the positive plate.

Show that the velocity v 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, m is the mass of the electron and e is the charge on the electron.

3. A uniform electric field is set up between two oppositely charged parallel conducting metal plates by connecting them to a 2000 V d.c. supply. The plates are 0.15 m apart.
- (a) Calculate the electric field strength between the plates.
- (b) An electron is released from the negative plate.
- (i) State the energy change which takes place as the electron moves from the negative to the positive plate.
- (ii) Calculate the work done by the electric field on the electron as it moves between the plates.
- (iii) Using your answer to (ii) above calculate the speed of the electron as it reaches the positive plate.
4. A proton is now used in the same electric field as in question 3 above. The proton is released from the positive plate.
- (a) Describe the motion of the proton as it moves towards the negative plate.

- (b) (i) Describe how the work done on the proton by the electric field compares with the work done on the electron in question 3.
- (ii) How does the velocity of the proton just as it reaches the negative plate compare with the velocity of the electron as it reaches the positive plate in question 3?
5. An electron is projected along the axis midway between two parallel conducting plates as shown.

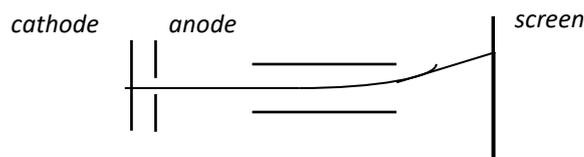


The length of the plates is 0.150 m . The plate separation is 0.100 m .

The initial kinetic energy of the electron is $2.87 \times 10^{-16}\text{ J}$.

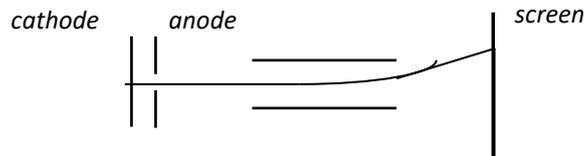
The magnitude of the electric field strength between the plates is $1.40 \times 10^4\text{ N C}^{-1}$.

- (a) Determine the initial horizontal speed of the electron as it enters the space between the plates.
- (b) Calculate the time the electron is between the plates.
- (c) Calculate the unbalanced force on the electron while it is between the plates.
- (d) What is the vertical deflection, y_1 , of the electron?
- (e) Describe the motion of the electron after it leaves the space between the plates.
6. 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 conducting plates as shown.



You may assume that there is no electric field between the anode and the parallel plates and no electric field between the parallel plates and the 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. between 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.
7. In an oscilloscope an electron enters the electric field between two horizontal metal plates.



The electron enters the electric field at a point midway between the plates in a direction parallel to the plates. The speed of the electron as it enters the electric field is $6.0 \times 10^6 \text{ m s}^{-1}$. The electric field strength between the plates is $4.0 \times 10^2 \text{ V m}^{-1}$. The length of the plates is $5.0 \times 10^{-2} \text{ m}$.

- (a) Calculate the time the electron takes to pass between the plates.
 - (b) Calculate the vertical displacement of the electron on leaving the plates.
 - (c) Calculate the angular deflection, from the horizontal, of the electron on leaving the plates.
8. Electrons are accelerated from rest 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 be the correct speed for the electrons?
9. A charged particle has a charge-to-mass ratio e/m of $1.8 \times 10^{11} \text{ C kg}^{-1}$. The particle is initially at rest. It is then accelerated between two points having a potential difference of 250 V. Calculate the final speed of the particle.
10. An electron is initially at rest. It is then accelerated through a potential difference of $7.5 \times 10^5 \text{ V}$.
- (a) Calculate the speed reached by the electron.
 - (b) Why is it not possible for the electron to have this speed?
11. (a) Calculate the acceleration of an electron in a uniform electric field of strength $1.2 \times 10^6 \text{ V m}^{-1}$.
- (b) An electron is accelerated from rest in this electric field.
- (i) What time does it take for the electron to reach a speed of $3.0 \times 10^7 \text{ m s}^{-1}$?
 - (ii) Calculate the displacement of the electron in this time.
12. An α -particle travels at a speed of $5.0 \times 10^6 \text{ m s}^{-1}$ in a vacuum.
- (a) Calculate the minimum size of electric field strength necessary to bring the α -particle to rest in a distance of $6.0 \times 10^{-2} \text{ m}$.
(The mass of an α -particle is $6.7 \times 10^{-27} \text{ kg}$).
 - (b) Draw a sketch of the apparatus which could be used to stop an α -particle in the way described above.
 - (c) Can a α -ray be stopped by an electric field? Explain your answer.
13. An α -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 α -particle is $1.9 \times 10^6 \text{ m s}^{-1}$ and its mass is $6.7 \times 10^{-27} \text{ kg}$. The atomic number of oxygen is 8.

- State an expression for the change in kinetic energy of the α -particle as it approaches the oxygen nucleus and stops.
- State an expression for the change in electrostatic potential energy of the α -particle.
- Using your answers to (a) and (b) show that the distance of closest approach r_c of the α -particle to the nucleus is given by

$$r_c = \frac{2qQ}{4\pi\epsilon_0 mv^2}$$

where q is the charge on the α -particle, Q is the charge on the nucleus, m is the mass of the α -particle and v is the initial speed of the α -particle.

- Calculate the distance of closest approach of the α -particle to the oxygen nucleus.
- The distance of closest approach between an α -particle and an iron nucleus is $1.65 \times 10^{-13} \text{ m}$. The mass of an α -particle is $6.7 \times 10^{-27} \text{ kg}$ and the atomic number of iron is 26. Calculate the initial speed of approach of the α -particle.
 - In the Rutherford scattering experiment α -particles are fired at very thin gold foil in a vacuum. On very rare occasions an α -particle is observed to rebound back along its incident path. This is caused by a particle being repelled by the positively charged gold nucleus.
The α -particles have a typical speed of $2.0 \times 10^7 \text{ m s}^{-1}$.
The atomic number of gold is 79. The mass of the α -particle is $6.7 \times 10^{-27} \text{ kg}$. Calculate the closest distance of approach which an α -particle could make towards a gold nucleus in a head-on collision.
 - Define the unit of energy electron volt, eV.
 - Derive the relationship between electron volts and joules, and show $1 \text{ eV} = 1.6 \times 10^{-19} \text{ J}$.
 - A proton and an α -particle are accelerated from rest through a p.d of 20 V. Calculate the final kinetic energy of
 - the proton in eV
 - the α -particle in eV.
 - An α -particle has a kinetic energy of 4.0 MeV. Calculate its speed.
 - The The Stanford Linear Accelerator (SLAC) can accelerate a beam of electrons to an energy of 40 GeV to strike a target. In one beam

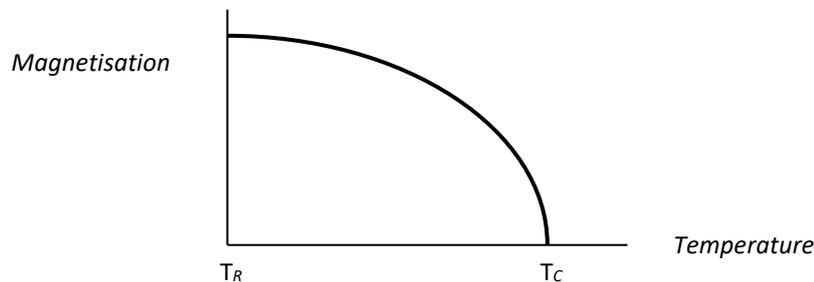
of electrons the number of electrons per second is equivalent to a current of 6.0×10^{-5} A.

- Calculate the number of electrons reaching the target each second.
- Calculate the energy in joules that the beam delivers to the target each second.

Magnetic fields and magnetic induction

Magnetism

- A bar of unmagnetised iron is placed in a solenoid. A d.c supply is connected across the solenoid. The d.c. current in the solenoid is gradually increased.
Explain using domain theory:
 - why the magnetisation of the iron increases
 - why when the current exceeds a certain value it is found that the magnetisation of the iron does not increase.
- A magnetised iron bar is placed in a solenoid. An a.c supply is connected across the solenoid and switched on. The iron bar is then slowly removed from the solenoid. Explain why the iron bar loses its magnetism.
- A sample of ferromagnetic material is heated. The sketch shows how the magnetism of the sample varies with temperature starting from room temperature, T_R .



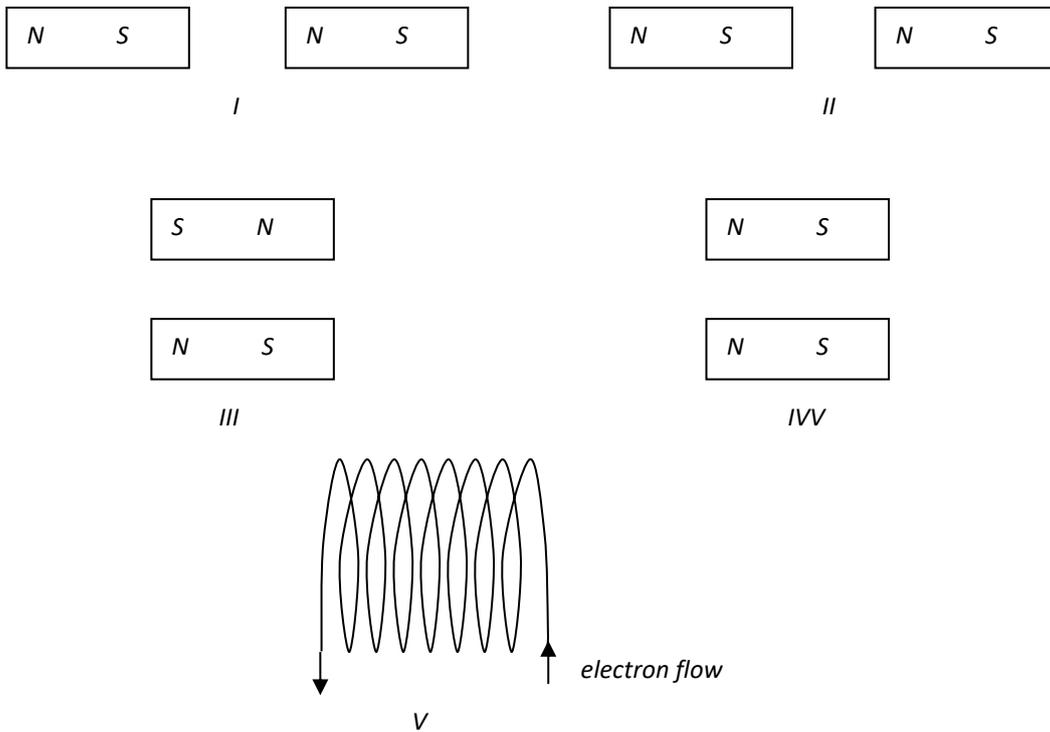
The magnetism of the sample becomes zero at a temperature known as the Curie temperature, T_C .

Explain why the magnetisation of the sample decreases as the temperature decreases.

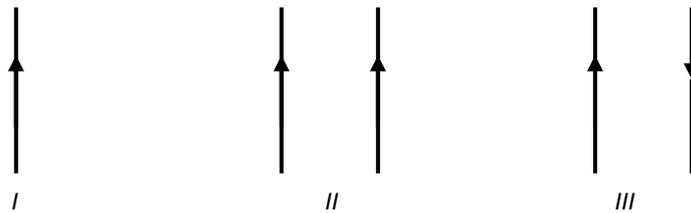
- Explain why a permanent magnet loses its magnetism when it is repeatedly struck with a hammer.

Magnetic field patterns

- Sketch the magnetic field pattern around the following arrangements of permanent magnets and electromagnet.



2. In the following diagrams wires are drawn and the arrow direction shows the direction of the electrons in the wires. Copy the diagrams and on them sketch magnetic field lines around the current-carrying wires.



Magnetic field around a current-carrying wire

1. A long straight wire has a current of 10 A in it. Calculate the magnetic induction at a point at a perpendicular distance of 0.5 m from the wire.

2. A bolt of lightning has a peak current of 20 kA up from the ground.

Calculate the maximum magnetic induction at a perpendicular distance of 2.0 m from the lightning strike.

3. A long straight wire has a resistance of $1\ \Omega$. It is connected to a 12 V battery of negligible internal resistance.

Calculate the magnetic induction at a point 20 mm perpendicular from the wire.

4. A long straight wire has a current in it. At a perpendicular distance of 0.05 m from the wire the magnetic induction caused by the current is $2\ \mu\text{T}$.

Calculate the current in the wire.

Force on a current-carrying conductor

1. (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.

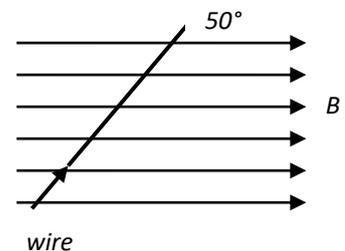
- (c) A straight conductor of length 25 mm is placed in a uniform magnetic field of magnetic induction of $0.70\ \text{T}$. There is a current of $2.0\ \text{A}$ in the conductor and the conductor experiences a force of $95\ \text{mN}$.

Calculate the angle between the direction of the magnetic field and the conductor.

2. A wire is placed in a magnetic field so that it makes an angle of 50° with the field as shown.

The arrow on the wire shows the direction of the electron current in the wire.

The magnetic induction of the field is $0.20\ \text{T}$. The length of the wire, in the field, is $0.05\ \text{m}$ and the current in the wire is $4\ \text{A}$.



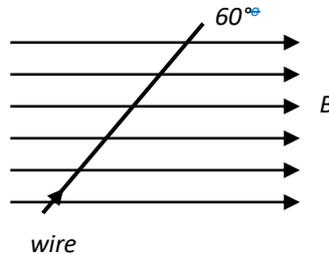
- (a) Calculate the force on the wire.

- (b) What would be the orientation of the wire with respect to the field to achieve a maximum force on the wire? You must justify your answer.

3. A straight wire is placed at right angles to a uniform magnetic field. There is a current of 10 A in the wire. A section of the wire, $0.80\ \text{m}$

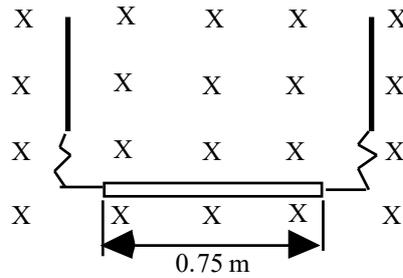
long, has a force of 0.20 N acting on it. Calculate the size of the magnetic induction of the magnetic field.

4. A straight wire, 0.05 m long, is placed in a uniform magnetic field of magnetic induction 0.04 T . The wire carries a current of 7.5 A , and makes an angle of 60° with the direction of the magnetic field.

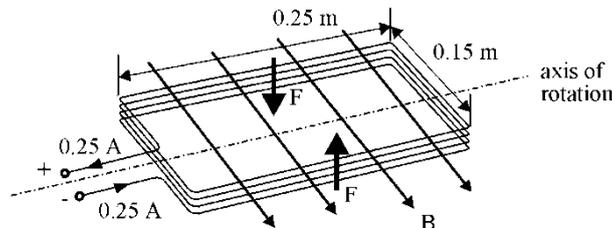


The arrow on the wire shows the direction of the electron current in the wire.

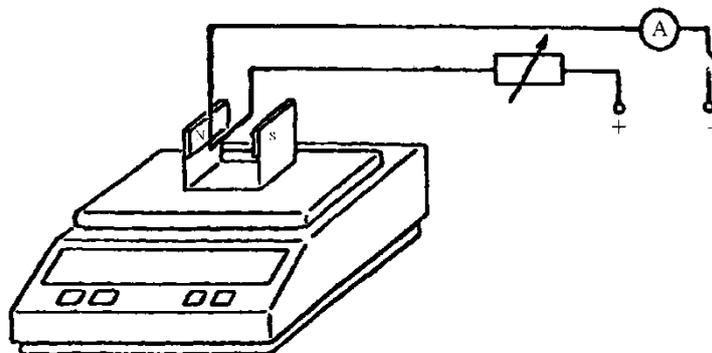
- Calculate the magnitude of the force exerted on the wire.
 - Draw a sketch of the wire in the magnetic field and show the direction of the force.
 - Describe the conditions for this force to be a maximum.
5. A straight conductor of length 50 mm carries a current of 1.4 A . The conductor experiences a force of $4.5 \times 10^{-3} \text{ N}$ when placed in a uniform magnetic field of magnetic induction 90 mT . Calculate the angle between the conductor and the direction of the magnetic field.
6. A straight conductor of length 1.5 m experiences a maximum force of 2.0 N when placed in a uniform magnetic field. The magnetic induction of the field is 1.3 T . Calculate the value of the current in the conductor.
7. A straight wire of length 0.50 m is placed in a region of magnetic induction 0.10 T .
- What is the minimum current required in the wire to produce a force of 0.30 N on the wire?
 - Why is this a minimum value of current?
8. A wire of length 0.75 m and mass 0.025 kg is suspended from two very flexible leads as shown. The wire is in a uniform magnetic field of magnetic induction 0.50 T . As the sketch shows, the magnetic field direction is 'into the page'.



- (a) Calculate the size of the current in the wire necessary to remove the tension in the supporting leads.
- (b) Copy the sketch and show the direction of the electron current which produced this result.
9. The sketch shows the rectangular coil of an electric motor. The coil has 120 turns, is 0.25 m long and 0.15 m wide, and there is a current of 0.25 A in the coil. The coil lies parallel to a magnetic field of magnetic induction 0.40 T . The sketch shows the directions of the forces acting on the coil.



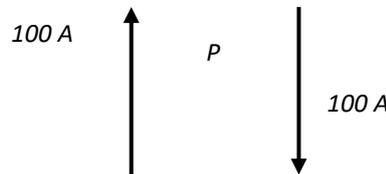
- (a) Calculate the magnitude of the force, F , on each of the wires shown.
- (b) Calculate the torque which acts on the coil when in this position.
- (c) State and explain what will happen to this torque as the coil starts to rotate in the magnetic field.
10. The diagram shows a force-on-a-conductor balance set up to measure the magnetic induction between two flat magnets in which a north pole is facing a south pole.



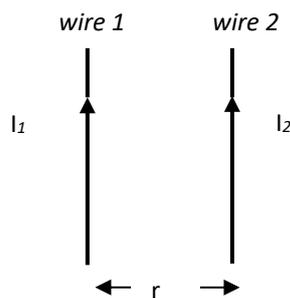
The length of the wire in the magnetic field is 0.06 m .
 When the current in the wire is zero, the reading on the balance is 95.6 g . When the current is 4.0 A the reading on the balance is 93.2 g .

- (a) Calculate the magnitude and direction of the force on the wire from these balance readings.
- (b) Calculate the size of the magnetic induction between the poles of the magnets.
- (c) Suggest what the reading on the balance would be if the connections to the wire from the supply were reversed. Explain your answer.
- (d) Suggest what the reading on the balance would be if one of the magnets is turned over so that the north face on one magnet is directly opposite the north face of the other magnet. Explain your reasoning.

11. Two long straight parallel wires are 0.10 m apart. The current in each wire is 100 A but the currents in the wires are in opposite directions as shown.



- (a) Sketch the magnetic field lines around each of the wires. Use your sketch to determine whether the force between the wires is attractive or repulsive.
- (b) Calculate the magnetic induction at a point P midway between the wires.
12. Two long straight wires are a distance r apart. The current in wire 1 is I_1 and the current in wire 2 is I_2 .



- (a) The current in wire 1 causes a magnetic field at the position of wire 2. Write down the relationship for the magnetic induction B_1 at wire 2 caused by the current in wire 1.
- (b) Wire 2 has a length l . Write down the relationship for the force F on wire 2 as a result of the magnetic induction B_1 .
- (c) Use your answer to (b) to show that the force per unit length on wire 2 is given by

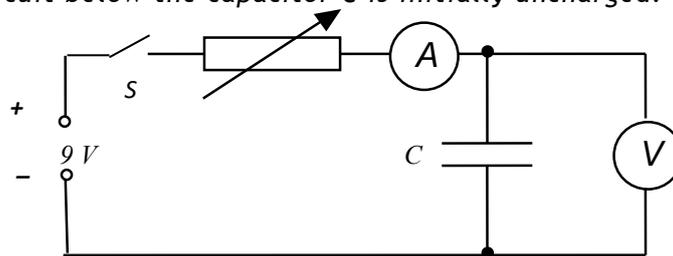
$$\frac{F}{l} = \mu_0 \frac{I_1 I_2}{r}$$

13. In an iron recycling plant there is a heater to melt the iron. Two parallel wires 0.20 m apart are connected to the heater. The wires are 16 m long and there is a current of 2500 A in the wires. The large currents passing into the metal generate enough heat to make the iron melt. It can then be made into new shapes.
- Calculate the force between the wires 16 m long when they each carry a current of 2500 A.
 - Hence explain why these wires are not suspended freely on their route to the iron smelter.

Circuits

Capacitors in d.c. circuits

- A 50 μF capacitor is charged until the p.d. across it is 100 V.
 - Calculate the charge on the capacitor when the p.d. across it is 100 V.
 - The capacitor is now 'fully' discharged in a time of 4.0 ms. Calculate the average current during this time.
 - Why is this average current?
- A capacitor stores a charge of 3.0×10^{-4} C when the p.d. across its terminals is 600 V.
What is the capacitance of the capacitor?
- A 15 μF capacitor is charged using a 1.5 V battery.
Calculate the charge stored on the capacitor when it is fully charged.
- A capacitor stores a charge of 1.2×10^{-5} C when there is a p.d. of 12 V across it. Calculate the capacitance of the capacitor.
 - A 0.10 μF capacitor is connected to an 8.0 V d.c. supply. Calculate the charge stored on the capacitor when it is fully charged.
- In the circuit below the capacitor C is initially uncharged.

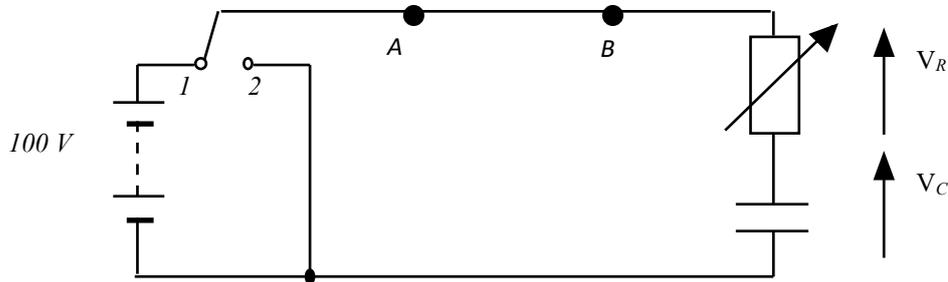


Switch S is now closed. By carefully adjusting the variable resistor R a constant charging current of 1.0 mA is maintained. The reading on the voltmeter is recorded every 10 s. The results are shown in the table.

Time (s)	0	10	20	30	40
V (V)	0	1.9	4.0	6.2	8.1

- (a) Plot a graph of the charge on the capacitor against the p.d. across the capacitor.
 (b) Use the graph to calculate the capacitance of the capacitor.

6. The circuit below is used to charge and discharge a capacitor.



The battery has negligible internal resistance.

The capacitor is initially uncharged.

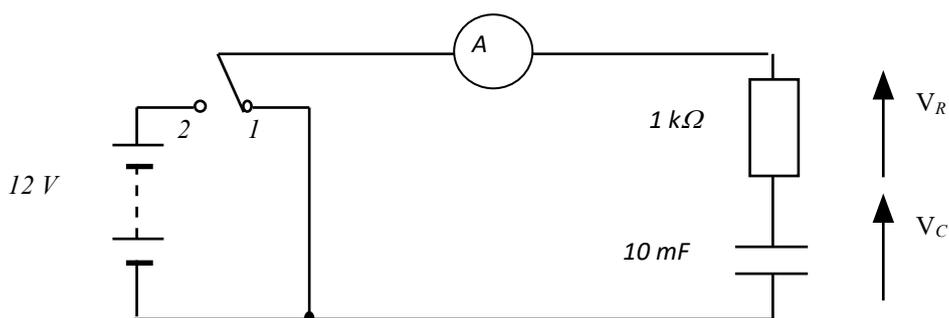
V_R is the p.d. across the variable resistor and V_C is the p.d. across the capacitor.

- (a) Is the position of the switch at 1 or 2
 (i) in order to charge the capacitor
 (ii) in order to discharge the capacitor?
 (b) Sketch graphs of V_R against time for the capacitor charging and discharging. Show numerical values for the maximum and minimum values of V_R .
 (c) Sketch graphs of V_C against time for the capacitor charging and discharging. Show numerical values for the maximum and minimum values of V_C .
 (d) (i) When the capacitor is charging what is the direction of travel of the electrons between points A and B in the wire?
 (ii) When the capacitor is discharging what is the direction of travel of the electrons between points A and B in the wire?
 (e) The capacitor has a capacitance of $4.0 \mu\text{F}$. The resistor has resistance of $2.5 \text{ M}\Omega$.

Calculate:

- (i) the maximum value of the charging current
 (ii) the charge stored by the capacitor when the capacitor is fully charged.

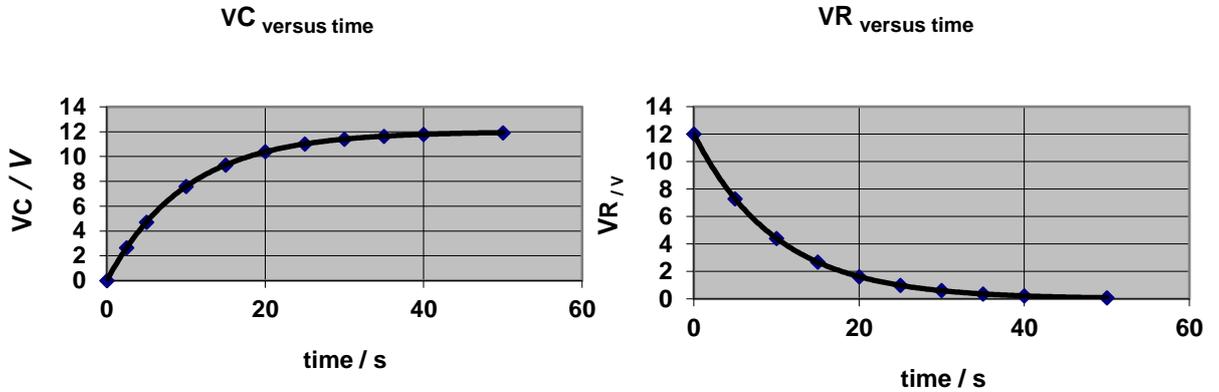
7. The circuit shown is used to investigate the charge and discharge of a capacitor.



The switch is in position 1 and the capacitor is uncharged.

The switch is now moved to position 2 and the capacitor charges.

The graphs show how V_C , the p.d. across the capacitor, and V_R , the p.d. across the resistor, vary with time.



(a) Use these graphs to sketch a graph to show how the current varies with time in the circuit.

(b) The experiment is repeated with the resistance changed to $2\text{ k}\Omega$.

Sketch the graphs above and on each graph sketch the new lines which show how V_C , V_R and I vary with time.

(c) The experiment is repeated with the resistance again at $1\text{ k}\Omega$ but the capacitor replaced with one of capacitance 20 mF . Sketch the original graphs again and on each graph sketch the new lines which show how V_C , V_R and I vary with time.

(d) (i) What does the area under the current against time graph represent?

(ii) Compare the areas under the current versus time graphs in part (a) and in your answers to (b) and (c). Give reasons for any increase or decrease in these areas.

(e) At any instant in time during the charging what should be the value of $(V_C + V_R)$?

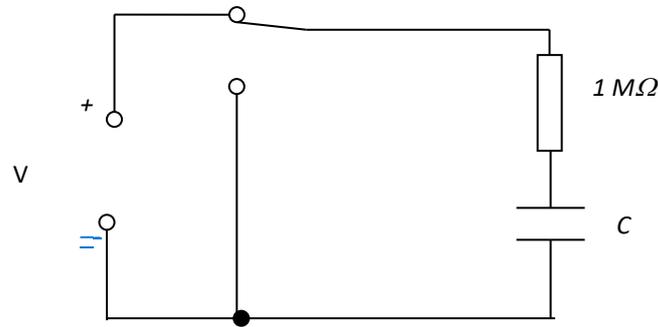
(f) The original values of resistance and capacitance are now used again and the capacitor fully charged. The switch is moved to position 1 and the capacitor discharges.

Sketch graphs of V_C , V_R and I from the instant the switch is moved until the capacitor is fully discharged.

8. State what is meant by the time constant in an RC circuit.

9. In an RC circuit the time constant t is given by the relationship $t = RC$. Show that the product RC has the unit of time.

10. A circuit is made up of a $2 \mu\text{F}$ capacitor and a $4 \text{ k}\Omega$ resistor. Calculate the capacitive time constant.
11. A student sets up a circuit to measure the capacitive time constants for three RC circuits as a capacitor discharges.



C is either a single capacitor or two capacitors in series. The table shows the resistance of R , the capacitor arrangement used and the value of the time constant.

Resistance of R	Capacitor arrangement	Time constant (s)
$1 \text{ M}\Omega$	$1 \mu\text{F}$ only	1
$1 \text{ M}\Omega$	$4 \mu\text{F}$ only	4
$1 \text{ M}\Omega$	$1 \mu\text{F}$ and $4 \mu\text{F}$ in series	0.8

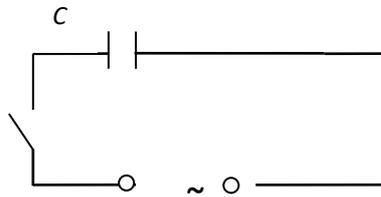
Use the results in the table to show that the total capacitance C_{total} of two capacitors of capacitance C_1 and C_2 in series is given by

$$\frac{1}{C_{\text{total}}} = \frac{1}{C_1} + \frac{1}{C_2}$$

12. A circuit comprises a resistor of resistance R and capacitor of capacitance C connected in series. The capacitor is fully charged then discharged. The p.d. across the capacitor as it discharges is given by $V = V_0 e^{-t/RC}$.
- where V_0 is the p.d. across the capacitor when fully charged.
- (a) Show that at a time equal to the capacitive time constant RC , after the capacitor starts to discharge, the p.d. across the capacitor will be given by $V = 0.37V_0$.
- (b) A $4.0 \mu\text{F}$ capacitor is charged to a p.d. of 12 V . It is then connected across a $2.0 \text{ M}\Omega$ resistor so that it discharges.
- (i) Calculate the capacitive time constant.
- (ii) Calculate the p.d. across the capacitor 4 s after it starts to discharge.

Capacitors in a.c. circuits

1. A capacitor is connected to a variable frequency a.c. supply as shown below. The amplitude of the output voltage from the supply is kept constant.



Variable frequency

- (a) The capacitor has reactance. State what is meant by the term 'reactance'.
- (b) The frequency of the output from the a.c. supply is increased.
- Sketch a graph to show how:
- the reactance of the capacitor varies with the frequency of the supply
 - the current in the circuit varies with the frequency of the supply.

2. A $1.0 \mu\text{F}$ capacitor is connected to 5.0 V a.c. power supply. The frequency of the a.c. supply is 50 Hz .

- Calculate the capacitive reactance of the capacitor.
- Calculate the current in the circuit.

3. A capacitor is connected across a 250 V r.m.s supply having a frequency of 50 Hz . The current in the capacitor is 0.50 A r.m.s.

Calculate:

- the reactance of the capacitor at this frequency
- the capacitance of the capacitor.

4. A 500Ω resistor and a capacitor are connected in series across an a.c. supply. The frequency of the a.c. is 50 Hz . The p.d. across the resistor is 120 V . The p.d. across the capacitor is 160 V .

- Calculate the current in the circuit.
- Calculate the capacitance of the capacitor.

5. A 300Ω resistor and a capacitor are connected in series with an a.c. supply of frequency 100 Hz .

The p.d. across the capacitor is 5.00 V. When the frequency of the output from the supply is 100 Hz the capacitive reactance of the capacitor is 265 Ω

Calculate:

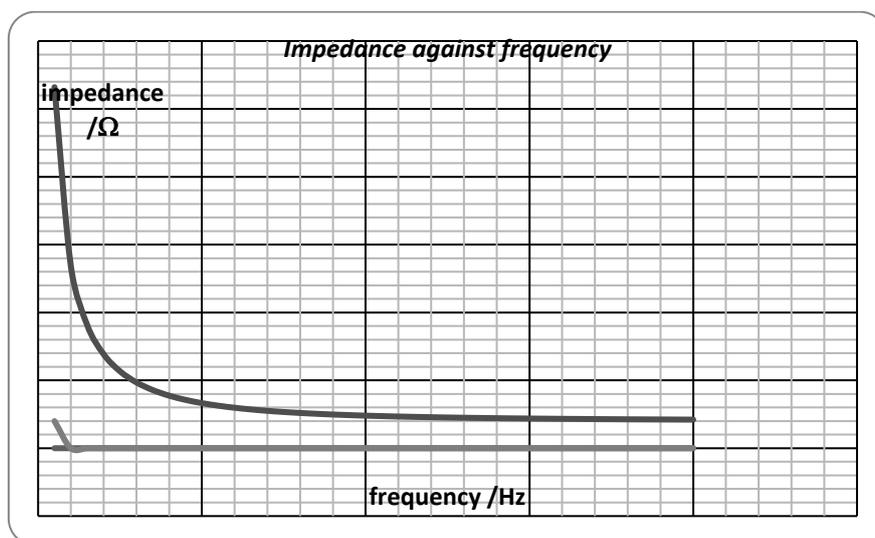
- the capacitance of the capacitor
- the current in the circuit
- the p.d. across the resistor.

6. A resistor and a capacitor are connected in series with a variable frequency constant amplitude a.c. supply. The combined effect of the resistance R and capacitive reactance X_c in series is known as the impedance Z of the circuit where

$$Z = \sqrt{R^2 + X_c^2}$$

Z can be calculated from $Z = V/I$ where V is the voltage of the supply and I is the current in the circuit.

The value of Z is found for different frequencies and the data used to plot the following graph.



Use the graph and knowledge of the relationship for Z and to estimate

- the value of the resistance
- the value of the capacitance.

Inductors

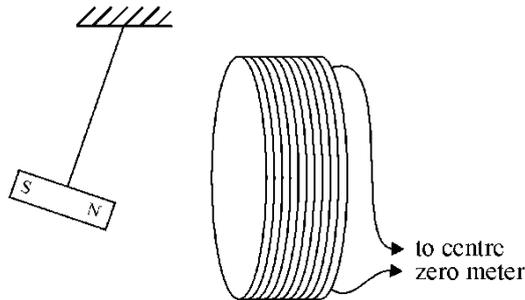
Inductors and induced e.m.f.

- A student is investigating the production of an induced e.m.f. across a coil.

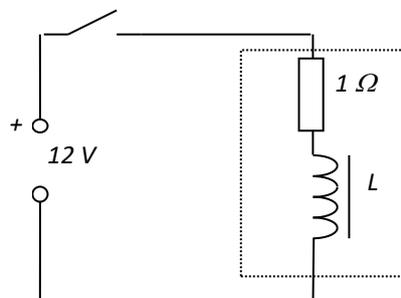
Describe a simple experiment which would allow her to do this.

- (b) State three ways in which the magnitude of the induced e.m.f. across a coil can be increased.

2. The magnet in the sketch below is mounted like a pendulum. It is allowed to swing to and fro into and out of a coil which has N turns.



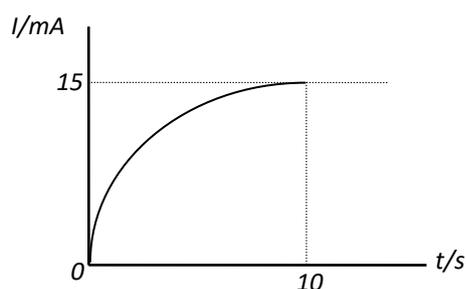
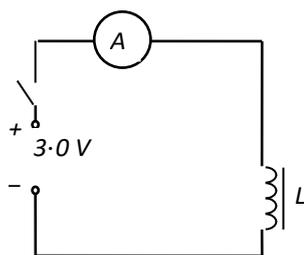
- (a) Sketch a graph to show the variation of induced e.m.f. with time as the pendulum magnet swings to and fro.
- (b) What is the induced e.m.f. when the magnet momentarily stops?
- (c) State what happens to the induced e.m.f. as the magnet reverses its direction of movement.
- (d) What happens to the induced e.m.f. at the positions where the magnet moves fastest?
3. The circuit diagram shows an inductor connected to a 12 V d.c. supply of negligible internal resistance.



The resistance of the inductor coil is 1.0Ω . The switch is now closed.

- (a) When the current in the circuit is 8.0 A , the rate of increase of the current is 400 A s^{-1} . Calculate the induced e.m.f. across the coil.
- (b) Calculate the inductance of the coil.
- (c) Calculate the rate of increase of current immediately after the switch is closed
- (d) A final steady value of current is produced in the coil. Find the value of this current.
- (e) Calculate the final energy stored in the inductor.

4. An inductor with a removable soft iron core is connected in series with a 3.0 V d.c. supply of negligible internal resistance.



A milliammeter is used to monitor the current in the circuit.

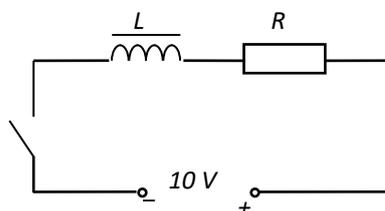
The switch is now closed. The graph shows the variation of current with time.

- (a) (i) Explain why it takes some time for the current to reach its maximum value.
- (ii) Why does the current remain constant after it reaches its maximum value?
- (b) The soft iron core is now partly removed from the coil and the experiment repeated.

Draw a sketch graph showing how the current varies against time for this second experiment. Use the same numerical values on the axes as those in the first graph.

- (c) Calculate the resistance of the coil.
- (d) The iron core is now replaced in the coil. A resistor is added in series with the coil and the experiment repeated. Draw a sketch graph to show how the current varies with time compared with the first experiment.

5. An inductor and resistor are connected in series with a d.c. supply.

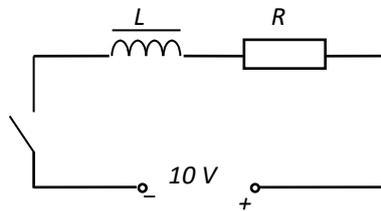


The resistance of resistor R is 40Ω and the inductance of inductor L is 2.0 H . The resistance of the inductor may be neglected. The supply has an e.m.f. of 10 V and negligible internal resistance.

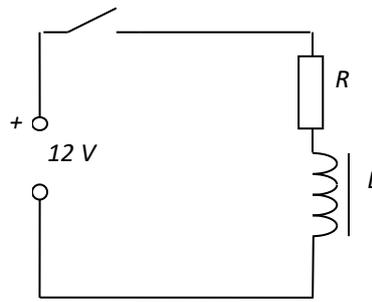
- (a) The switch is now closed.
- (i) State the initial p.d. across the 40Ω resistor.
- (ii) Calculate the initial current in the circuit.

- (iii) State the initial value of the induced e.m.f. across the 2.0 H inductor.
 - (iv) Calculate the energy stored in the inductor immediately after the switch is closed.
- (b) Some time later the current reaches a value of 0.040 A .
- (i) Calculate the p.d. across R at this time.
 - (ii) Calculate the p.d. across the inductor at this time.
 - (iii) Hence calculate the rate of growth of current when the current in the circuit is 0.040 A .
 - (iv) Calculate the energy stored in the inductor.

6. An inductor, resistor and a d.c. supply are connected in series as shown below.



- (a) The inductor has a large number of turns. The switch is now 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 now reduced. The switch is opened and then closed again. Sketch a graph to show how the current varies with time after the switch is closed and note any differences to the graph in answer (a).
7. When the current in 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 in an inductor decreases. Use the conservation of energy to explain the direction of the induced e.m.f.
8. An inductor, resistor and d.c. supply are connected in series.

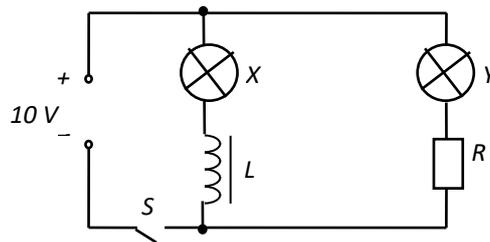


The internal resistance of the d.c. supply is negligible.

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

The switch is now closed.

- (a) Calculate the steady current reached.
 - (b) When the current reaches a steady value, calculate the energy stored in the inductor.
9. (a) Describe what is meant by the self-inductance of a coil.
- (b) The circuit diagram shows a resistor, inductor and two lamps connected to a 10 V d.c. supply.



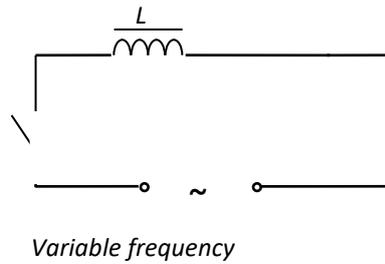
The supply has negligible internal resistance. The rating of each lamp is 6.0 V , 3.0 W .

After the switch is closed each lamp operates at its rated power. It is noticed that lamp Y lights up before lamp X.

- (i) Explain why lamp Y lights before lamp X.
- (ii) Immediately after the switch is closed the current in lamp X increases at a rate of 0.50 A s^{-1} . Calculate the inductance of the coil.
- (iii) Calculate the resistance of the coil.

Inductors and a.c.

1. An inductor is connected to a variable frequency a.c. supply as shown below. The amplitude of the output voltage is kept constant.



- (a) The inductor has reactance. State what is meant by the term 'reactance'.
- (b) The frequency of the a.c. supply is increased. Sketch a graph to show how
- the reactance of the inductor varies with the frequency of the output from the supply
 - the current in the circuit varies with the frequency of the output from the supply.

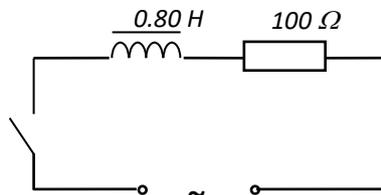
2. A coil has an inductance of 0.80 H and negligible resistance. It is connected to a 30 V a.c. supply of frequency 50 Hz .

- Calculate the reactance of the inductor.
- Calculate the r.m.s current in the inductor.

3. A pure inductor is connected across a 250 V r.m.s supply having a frequency of 50 Hz . The current in the inductance is 0.50 A r.m.s.

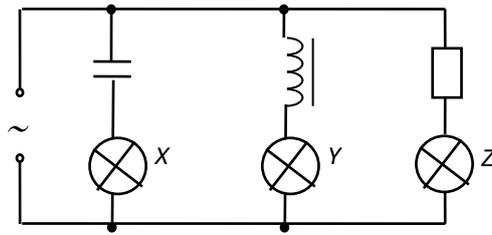
Calculate:

- the inductive reactance of the inductor at this frequency
 - the inductance of the inductor.
4. A pure inductor and resistor are connected across an a.c. supply with a frequency of 50 Hz .



The inductance of the inductor is 0.8 H and the resistor has a resistance of $100\ \Omega$. The p.d. across the resistor is 12 V r.m.s.

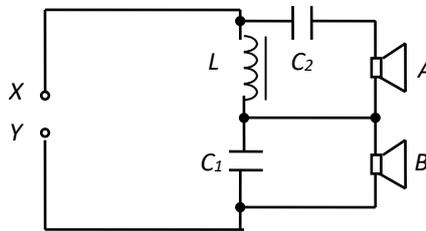
- Calculate the current in the circuit.
 - Calculate the r.m.s voltage across the inductor.
5. A circuit is set up as shown below.



The a.c. supply is of constant amplitude but variable frequency. The frequency of the supply is varied from a very low frequency to a very high frequency.

Explain what you would expect to happen to the average brightness of each of the lamps X, Y and Z as the frequency is increased.

6. The output from an amplifier is connected across XY in the circuit shown below. This is designed to direct low frequency signals to one loudspeaker and high frequency signals to the other loudspeaker.

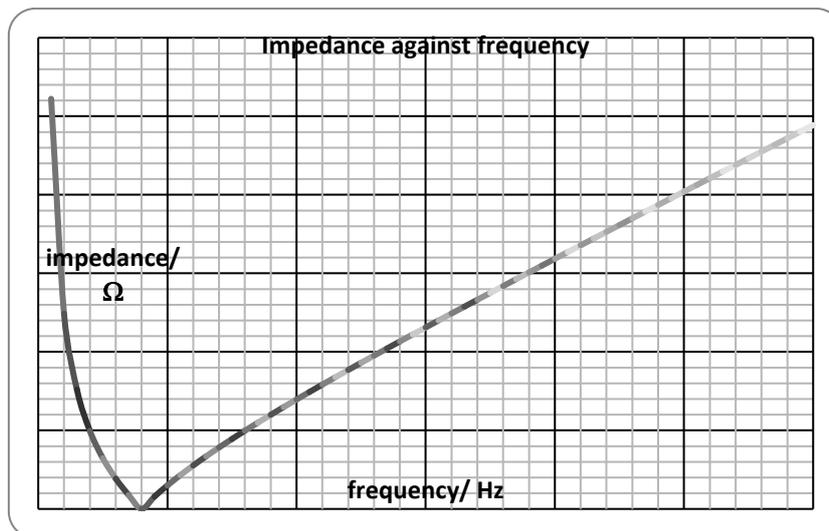


- (a) Suggest which of the loudspeakers A or B is intended to reproduce high-frequency signals.
- (b) Explain how the high- and low-frequency signals are separated by this circuit.
7. In a series circuit containing a resistor, a capacitor and an inductor the combined effect is known as the impedance Z of the circuit where

$$Z = \frac{V}{I} \quad \text{and} \quad Z = \sqrt{R^2 + (X_L - X_C)^2}$$

A series circuit is made of a pure inductor and a capacitor. It is connected across an a.c. supply of constant amplitude but variable frequency.

- (a) Describe how the impedance Z of the circuit can be measured.
- (b) The measurements of Z are used to plot the following graph of Z against frequency.



- (i) Use the graph to estimate the capacitance of the capacitor.
- (ii) Use the graph to estimate the inductance of the inductor.
- (iii) The relationship shows that at a certain frequency the inductive reactance and the capacitive reactance will be equal. At this frequency the impedance will be zero. Use your results from (i) and (ii) to find this frequency and compare it to the value from the graph.

Electromagnetic radiation

1. Electromagnetic waves in a vacuum are said to be transverse. Explain the meaning of transverse in this context.
2. Which of the following cause/s electromagnetic radiation?
 - (a) A stationary electric charge.
 - (b) An electric charge moving with a constant acceleration.
 - (c) An accelerating electric charge.
 - (d) An electric charge in a circular particle accelerator.
 - (e) A charged particle in a linear accelerator.
 - (f) An electron in a Bohr orbit in an atom.
3. The theory of electromagnetic radiation includes the relationship

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

Show that $c = \frac{1}{\sqrt{\epsilon_0 \mu_0}}$ has the units m s^{-1} .

4. The electric field E of an electromagnetic wave is given by

$$E = 4.0 \times 10^2 \sin[3.0 \times 10^6 \pi(x - 3.0 \times 10^8 t)]$$

where E is in V m^{-1} .

Compare this relationship to that for a transverse wave

$$y = A \sin \frac{2\pi}{\lambda}(x - vt)$$

- (a) What is the amplitude of the electric field in the electromagnetic wave?

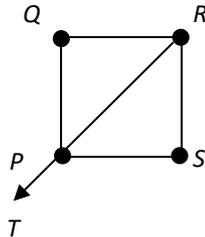
- (b) Calculate the frequency of the electric field in the electromagnetic wave.
- (c) Given that the electric field E is related to the magnetic field B by $E = cB$:
- write down the expression for the magnetic field of the electromagnetic wave
 - what is the amplitude of the magnetic field in the electromagnetic wave?

Solutions

Fields

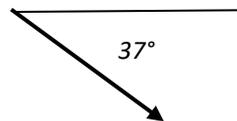
Coulomb's inverse square law

- 1.0×10^{-10} N repulsion
- 4.1×10^{-15} N
- (a) 1.8 N attractive force
(b) 0.27 m
- 7.0×10^{-6} N to the right
- (a) 2.8×10^{-5} N in direction RPT as shown



- (b) 0 N as forces on the central charge are balanced.

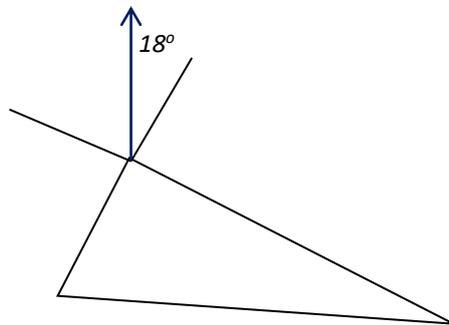
- $F_E/F_G = 2.3 \times 10^{39}$
- 5.7×10^{13} C
- 2.6 N at 37° as shown



- (a) weight (down), tension along thread, electrostatic force to the left
(b) 9.8×10^{-5} N
- (a) 9.8×10^{-5} N
(b) 1.04×10^{-9} C (to 3 sig. figs)
(c) 104 s (to 3 sig. figs)

Electric field strength

3. $2.9 \times 10^{11} \text{ V m}^{-1}$ or N C^{-1} away from the nucleus
4. 0.50 m
5. $5 \times 10^3 \text{ N C}^{-1}$
6. (a) $1.1 \times 10^{-10} \text{ C}$
(b) 0.25 N C^{-1}
7. (a) $1.2 \times 10^{-4} \text{ N C}^{-1}$
(b) $6.0 \times 10^{-5} \text{ N C}^{-1}$ halved
8. (a) vertically down from top plate
(b) (i) $2.0 \times 10^5 \text{ V m}^{-1}$
(ii) $2.0 \times 10^5 \text{ V m}^{-1}$
9. (a) $3.9 \times 10^4 \text{ N C}^{-1}$
10. (a) $3.6 \times 10^3 \text{ N C}^{-1}$ in the direction from the $+8.0 \times 10^{-9} \text{ C}$ charge to the $+4.0 \times 10^{-9} \text{ C}$ charge
(b) 0.12 m
(c) (i) $7.2 \times 10^{-6} \text{ N}$
(ii) $4.9 \times 10^{-3} \text{ N}$
13. (a) $3.8 \times 10^4 \text{ N C}^{-1}$ direction as in diagram

**Electric fields and electrostatic potential**

3. 12 V
4. 540 V
5. (a) 16.2 V where A is negative compared to B
(b) no
6. $4.6 \times 10^{-18} \text{ J}$
9. 0.08 m from $+4.0 \text{ nC}$ charge
10. electrostatic force, electric field strength
11. (a) (i) 280 V
(ii) 201 V to 3 sig. figs

- (b) 79 V
12. (a) 810 V
- (c) +227 V to 3 sig. figs
13. (a) $2 \times 25 \times 10^5 \text{ N C}^{-1}$ parallel to QR and in the direction QR
- (b) 0
14. (a) $7 \times 5 \times 10^4 \text{ V m}^{-1}$
15. (b) $2 \times 4 \times 10^4 \text{ V m}^{-1}$ towards lower plate
16. (a) 0 V m^{-1}
- (b) $1 \times 7 \times 10^8 \text{ V m}^{-1}$ away from sphere
- (c) $2 \times 7 \times 10^5 \text{ V m}^{-1}$ away from sphere
18. (a) I zero, II zero
- (b) I non-zero, II zero
19. (a) I zero, II non-zero
- (b) I non-zero, II zero
20. (a) $5 \times 6 \times 10^{-9} \text{ C}$
- (b) 900 V at 0.056 m, 800 V at 0.063 m, 700 V at 0.071 m, 600 V at 0.083 m, 500 V at 0.10 m
21. (a) electrostatic force up, weight down
- (b) negative
- (c) $4 \times 8 \times 10^{-19} \text{ C}$
- (d) 3

Charged particles in motion in an electric field

1. (a) 6.0 mJ
- (b) electric potential energy to kinetic energy
2. (a) 0.060 m
- (b) field strength doubles
3. (a) $1 \times 33 \times 10^4 \text{ V m}^{-1}$
- (b) (ii) $3 \times 2 \times 10^{-16} \text{ J}$
- (iii) $2 \times 7 \times 10^7 \text{ m s}^{-1}$ ($2 \times 65 \times 10^7 \text{ m s}^{-1}$ to 3 sig. figs)
4. (a) accelerates towards the negative plate
- (b) (ii) $6 \times 2 \times 10^5 \text{ m s}^{-1}$; same as work done = QV with same Q and same V
5. (a) $2 \times 51 \times 10^7 \text{ m s}^{-1}$
- (b) $5 \times 98 \times 10^{-9} \text{ s}$
- (c) $2 \times 24 \times 10^{-15} \text{ N}$
- (c) 0.044 m
- (d) straight line
6. (a) $8 \times 4 \times 10^6 \text{ m s}^{-1}$
- (b) 0.022 m (0.225 m to 3 sig. figs) vertically

7. (a) $8.3 \times 10^{-9} \text{ s}$
 (b) $2.4 \times 10^{-3} \text{ m}$
 (c) 5.6^0 (5.55 to 3 sig. figs)
8. (a) $2.1 \times 10^8 \text{ m s}^{-1}$ this speed is greater than the speed of light
 (b) speed is greater than 10% of speed of light so relativistic effects must be considered
9. $9.5 \times 10^6 \text{ m s}^{-1}$
10. (a) $5.13 \times 10^8 \text{ m s}^{-1}$ (to 3 sig. figs)
 (b) speed greater than the speed of light; would need a relativistic calculation
11. (a) $2.1 \times 10^{17} \text{ m s}^{-2}$
 (b) (i) $1.4 \times 10^{-10} \text{ s}$
 (ii) $2.1 \times 10^{-3} \text{ m}$
12. (a) $4.4 \times 10^6 \text{ N C}^{-1}$
 (c) no, as γ -ray has no electric charge so no electric force on it.
13. (d) $3.0 \times 10^{-13} \text{ m}$
14. $4.7 \times 10^6 \text{ m s}^{-1}$
15. $2.7 \times 10^{-14} \text{ m}$
17. (a) 20 eV
 (b) 40 eV
18. $1.4 \times 10^7 \text{ m s}^{-1}$
19. (a) 3.8×10^{14} (3.75×10^{14} to 3 sig. figs)
 (b) $6.4 \times 10^{-9} \text{ J}$

Magnetic fields and magnetic induction

Magnetic field around a current-carrying wire

1. $4.0 \times 10^{-6} \text{ T}$
2. 2.0 mT
3. 0.1 mT
4. 5.0 A

Force on a current-carrying conductor

1. (c) 16°
2. (a) $3.1 \times 10^{-2} \text{ N}$
3. 25 mT
4. (a) 0.013 N
 (c) $\theta = 90^\circ$ and the full length of the conductor in the magnetic field
5. 46°
6. 1.0 A
7. (a) 6 A

8. (a) 0.65 A
 (b) *right to left*
9. (a) 0.025 N
 (b) 0.45 N m
10. (a) 0.024 N
 (b) 0.1 T
 (c) 98 g
 (d) 95.6 g
11. (b) $8.0 \times 10^{-4} \text{ T}$
13. (a) 100 N

Circuits

Capacitors in d.c. circuits

- (a) $5.0 \times 10^{-3} \text{ C}$
 (b) (i) 1.25 A
 (ii) *current decreases exponentially*
2. $0.5 \mu\text{F}$
3. $2.25 \times 10^{-5} \text{ C}$
4. (a) $1.0 \mu\text{F}$
 (b) $0.8 \mu\text{C}$
5. (b) 4.9 mF
6. (e) (i) $40 \mu\text{A}$
 (ii) $4.0 \times 10^2 \mu\text{C}$ or $4.0 \times 10^{-4} \text{ C}$
7. (e) 12 V
10. 8 ms
12. (b) (i) 8 s
 (ii) 7.3 V

Capacitors in a.c. circuits

2. (a) $3.2 \times 10^3 \mu$
 (b) 1.6 mA
3. (a) 500μ
 (b) $6.4 \mu\text{F}$
4. (a) 0.24 A r.m.s
 (b) $4.8 \mu\text{F}$
5. (a) $6.00 \mu\text{F}$

- (b) 18.9 mA
- (c) 5.66 V
6. (a) $4 \mu\text{F}$
- (b) $2.7 \times 10^{-4} \text{ F}$ (actual values $4 \mu\text{F}$ and $3.0 \times 10^{-4} \text{ F}$)

Inductors

Inductors and induced e.m.f.

3. (a) 4.0 V
- (b) 0.01 H
- (c) 1200 A s^{-1}
- (d) 12 A
- (e) 0.72 J
4. (c) $200 \mu\text{H}$
5. (a) (i) 0 V
- (ii) 0 A
- (iii) 10 V
- (iv) 0 J
- (b) (i) 1.6 V
- (ii) 8.4 V
- (iii) 4.2 A s^{-1}
- (iv) $1.6 \times 10^{-3} \text{ J}$
8. (a) 0.80 A
- (b) 0.13 J
9. (b) (ii) 20 H
- (iii) $8.0 \mu\text{H}$

Inductors and a.c.

2. (a) $250 \mu\text{H}$
- (b) 0.12 A
3. (a) $500 \mu\text{H}$
- (b) 1.6 H
4. (a) 0.12 A
- (b) 30 V
7. (b) (i) $6.4 \times 10^{-6} \text{ F}$

(ii) $2 \times 10^{-6} \text{ H}$ (actual values $6 \times 10^{-6} \text{ F}$ and $2 \times 10^{-6} \text{ H}$)

Electromagnetic radiation

4. (a) $4 \times 10^2 \text{ V m}^{-1}$
(b) $4 \times 10^{14} \text{ Hz}$
(c) (ii) $1 \times 10^{-6} \text{ T}$