Electromagnetism

Coulomb's Law

1. A charge of $+ 2.0 \times 10^{-8}\ C$ is placed a distance of $2.0\ mm$ from a charge of $-4.0 \times 10^{-8}\ C$.

   (a) Calculate the electrostatic force acting between the charges.

   The distance between the charges is adjusted until the force between the charges is $1.0 \times 10^{-4}\ N$.

   (b) Calculate the new separation between these two charges.

2. A proton and an electron are separated by $2.0 \times 10^{-10}\ m$.

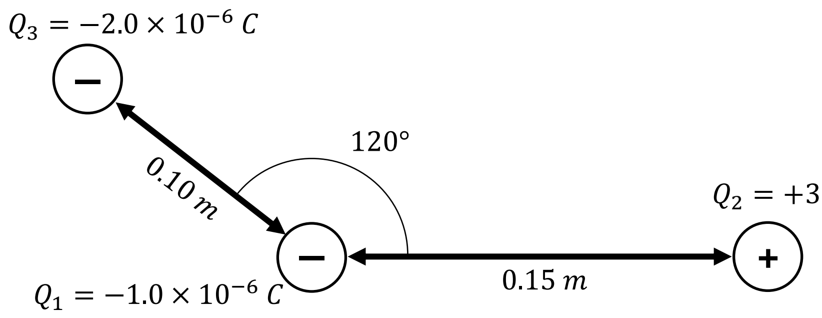
   (a) Calculate the electrostatic force acting between these charges.

   (b) Calculate the gravitational force acting between these two masses.

   (c) Determine the order of magnitude that the electrostatic force is greater than the gravitational force.

3. The Earth and the Moon are attracted by a gravitational force of attraction. If the Earth and the Moon were to gain an equal amount of positive charge such that the electrostatic repulsion balanced the gravitational attraction, calculate the amount of charge gained by either object.

4. The diagram below shows three charges fixed in the position shown.



   Calculate the resultant force (magnitude and direction) on charge Q_1 due to the other two charges.

5. Two like charged spheres of mass $0.10\ g$, hung from the same point by silk threads are repelled from each other to a separation of $1.0\ cm$ by the electrostatic force.
   The angle between one of the silk threads and the vertical is $5.7°$.

   (a) Determine the electrostatic force F_E between the spheres.

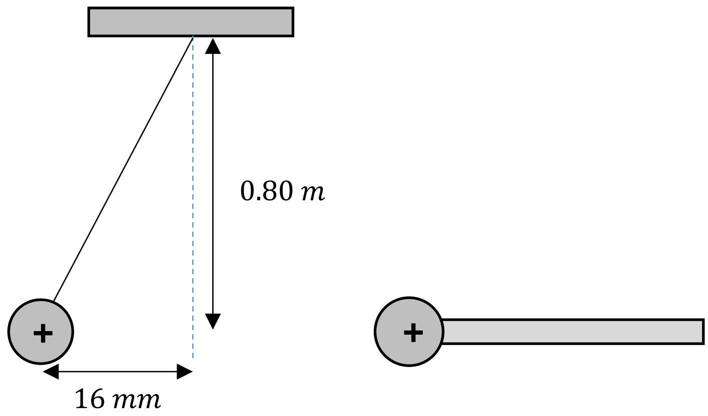
   (b) Calculate the magnitude of the charge on each sphere.

   The average leakage current from a charged sphere is $1.0 \times 10^{-11}\ A$.

   (c) Calculate the time it would take for the charge to leak away from the sphere completely.

6. 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 below.



(a) Create a free-body diagram showing all of the forces acting on the suspended sphere.

(b) Calculate the electrostatic force acting on the suspended sphere.

Electromagnetism

Electric Field Strength

1. Calculate the electric field strength at a point where a small object carrying a charge of $4.0\ \mu C$ experiences a force of $0.02\ N$.

2. A point charge provides an electric field strength of $1.0\ NC^{-1}$ at a distance of $1.0\ m$.

   (a) Calculate the magnitude of the charge.

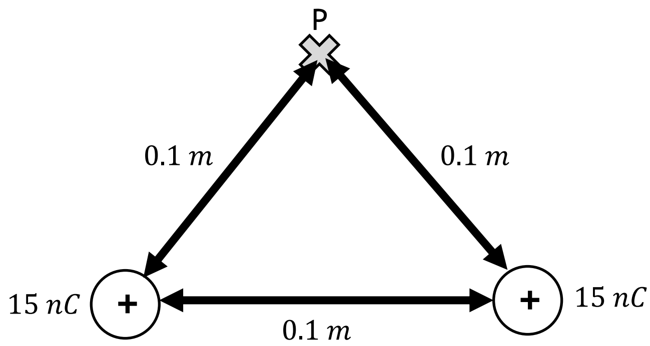
   (b) Determine the magnitude of the electric field strength at a distance of $2.0\ m$ from the point charge.

3. An α-particle can be considered as a point charge.

   (a) Calculate the electric field strength due to an α-particle alone at a point $5.0\ mm$ from the α-particle.

   (b) State how the electric field strength calculated in part (a) would compare with the electric field strength at a point $5.0\ mm$ from a proton.
   You must justify your answer with an appropriate calculation.

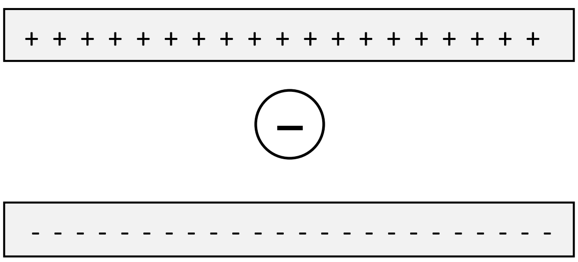
4. The diagram below shows two charges of $+15.0\ nC$, separated by $0.1\ m$.



   (a) Calculate the magnitude of the resultant electric field strength at the point P as shown in the diagram above.

   (b) Determine the direction of the resultant electric field strength at point P.

5. A negatively charged sphere, of mass $2.0 \times 10^{-5}\ kg$, is held stationary in the space between two charged metal plates as shown in the diagram below.



   (a) The sphere carries a charge of $-5.0 \times 10^{-9}\ C$. Calculate the size of the electric field strength in the region between the metal plates.

   (b) Create a diagram of the two metal plates and the stationary charge, showing the electric field lines in the region between the metal plates.

6. 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 mid-point between the charges.

   (b) Calculate the distance from the $+8.0 \times 10^{-9}\ C$ charge at which the electric field strength is zero.

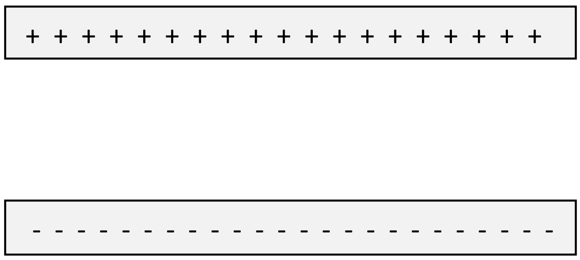
   (c) The $+4.0 \times 10^{-9}\ C$ charge has a mass of $5.0 \times 10^{-4}\ kg$.

      (i) Calculate the magnitude of the electrostatic force acting on the charge.

      (ii) Calculate the magnitude of the gravitational force acting on the mass.

7. The following diagrams show oppositely charged parallel metal plates or point charges.

   (a) Create a diagram showing the electric field lines between the two parallel metal plates shown.



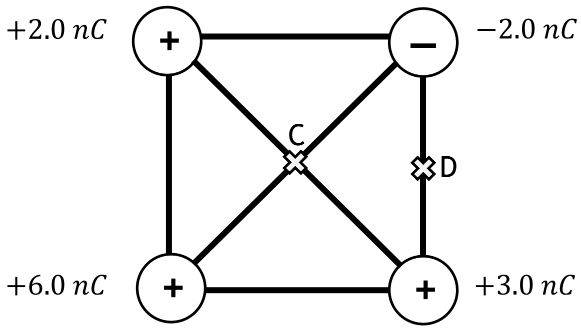
   (b) Create a diagram showing the electric field lines between the two point charges shown.

Electromagnetism

Electric Potential

1. Calculate the electric potential at a point P, which is at a distance of $0.05\ m$ from a point charge of $+3.0 \times 10^{-9}\ C$.

2. Point charges of $+2.0\ nC$, $-2.0\ nC$, $+3.0\ nC$ and $+6.0\ nC$ are placed in order at the corners of a square of diagonal $0.20\ m$ as shown in the diagram below.



   (a) Calculate the electrostatic potential at the centre, C, of the square.

   D is the midpoint of the side, as shown.

   (b) Calculate the electrostatic **potential difference** between point C and point D.

3. A hydrogen atom may be considered to be a charge of $+1.6 \times 10^{-19}\ C$ separated from a charge of $-1.6 \times 10^{-19}\ C$ by a distance of $5.0 \times 10^{-11}\ m$.

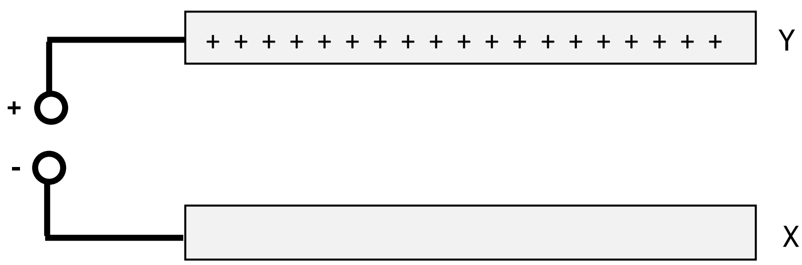
   Calculate the potential energy associated with an electron in a hydrogen atom.

4. Consider an equilateral triangle PQR where $QR = 20\ mm$. A charge of $+1.0 \times 10^{-8}\ C$ is placed at Q and a charge of $-1.0 \times 10^{-8}\ C$ is placed at R. Both charges are fixed in position.

   (a) Calculate the electric field strength at point P.

   (b) Calculate the electrostatic potential at point P.

5. 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.

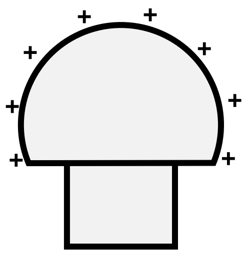


   (a) Create a graph to show how the potential varies along a line joining the midpoint of plate X to the midpoint of plate Y.

   (b) Calculate the electric field strength between the plates.

   (c) Explain how the value for the electric field strength can be obtained from the graph created in part (a).

6. A Van de Graaff generator is charged positively as shown in the diagram below. The surface has an equipotential.



(a) State what is meant by an equipotential surface.

(b) Create a diagram that shows the electric field lines around the charged dome.

7. Two oppositely charged parallel plates have a potential difference of $1500\ V$ between them. If the plates are separated by a distance of $20\ mm$ calculate the electric field strength between the plates.

8. A uniform electric field is set up between two oppositely charged parallel 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 on the electron by the electric field.

(iii) Calculate the velocity of the electron as it reaches the positive plate.

9. A proton is now used in the same electric field as in question 8. The proton is released from the positive plate.

(a) Describe the motion of the proton as it moves towards the negative plate.

(b) Compare your answer to those in question 8.

(i) Describe how the work done on the proton by the electric field compares to the work done on the electron.

(ii) Predict how the velocity of the proton as it reaches the negative plate compares to the velocity of the electron as it reaches the positive plate.

10. A sphere of radius $0.05\ m$ has a potential at its surface of $1000\ V$. Calculate the charge on the surface of the sphere.

11. An electron is accelerated through a potential difference of $1.0 \times 10^6\ V$.

(a) Calculate the final velocity of the electron.

(b) Explain why the value calculated in part (a) cannot be correct.

Electromagnetism

Charges in Electric Fields

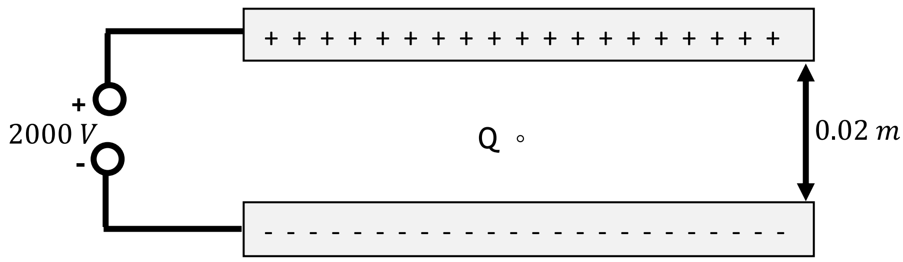
1. An electron is accelerated from rest through a uniform electric field of $1.2 \times 10^6\ NC^{-1}$.

   (a) Calculate the acceleration of the electron.

   (b) Calculate the time taken for the electron to reach a speed of $3.0 \times 10^7\ ms^{-1}$.

   (c) Calculate the displacement of the electron during this time.

2. In a Millikan type experiment a very small oil drop is held stationary between the two charged metal plates.



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

   (a) State the sign of the charge on the oil drop.

   (b) Calculate the size of the charge on the oil drop.

3. An α-particle travels at a speed of $5.0 \times 10^6\ ms^{-1}$ in a vacuum.

   (a) Calculate the minimum size of electric field strength necessary to bring the α-particle to rest in a distance of $6.0 \times 10^{-2}\ m$.

   (b) Explain why a γ-ray cannot be stopped by an electric field.

4. 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 $6.0 \times 10^6\ ms^{-1}$. The electric field strength between the plates is $4.0 \times 10^2\ NC^{-1}$.

   The length of the plates is $5.0 \times 10^{-2}\ m$. The oscilloscope screen is a further $0.20\ m$ beyond the plates.

   (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 final direction of the electron upon leaving the plates.

   (d) Calculate the total vertical displacement of the electron on hitting the oscilloscope screen.

5. Electrons are accelerated through a potential difference of $7.5 \times 10^3\ V$. The electrons are initially at rest.

   Calculate the speed reached, by these electrons. Assuming no relativistic effects take place.

6. 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.

   One α-particle has a speed of $2.0 \times 10^7\ ms^{-1}$. Calculate the closest distance of approach which an α-particle can make towards a stationary gold nucleus in a head-on collision. The atomic number of gold is 79. The mass of the α-particle is 6.7×10^{-27} kg.

7. In Millikan's experiment, a negatively charged oil drop of radius 1.62×10^{-6} m is held stationary when placed in an electric field of strength $1.9 \times 10^5\ NC^{-1}$.

   The density of the oil drop is $870\ kgm^{-3}$.

   (a) Calculate the mass of the oil drop.

   (b) Calculate the charge on the oil drop.

   (c) Determine the number of excess electrons the oil drop has picked up.

8. A charged particle has a charge-to-mass ratio of $1.8 \times 10^{11}\ Ckg^{-1}$.

   Calculate the speed of one such particle when it has been accelerated through a potential difference of 250 V.

Electromagnetism

Force on a Conductor

1. 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 $60°$ to the direction of the magnetic field.

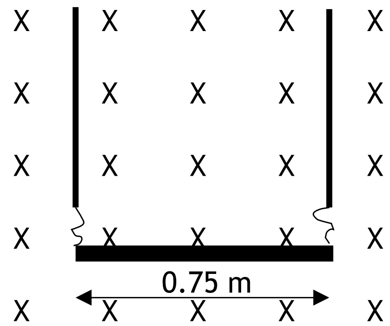
   (a) Calculate the magnitude of the force exerted on the wire.

   (b) Describe the condition(s) needed for this force to be at a maximum.

2. A straight conductor of length $50\ mm$ carries a current of $1.4\ A$. The conductor experiences a force of $4.5 \times 10^{-3}\ N$ 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.

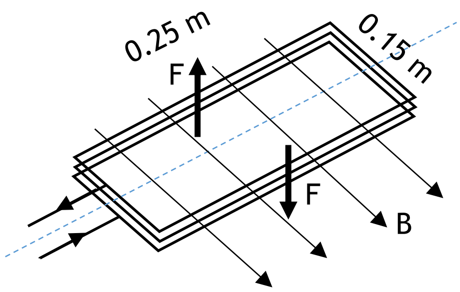
3. A wire of length $0.75\ m$ and mass 0.025 kg is suspended from two very flexible leads as shown below. The wire is in a magnetic field of magnetic induction $0.50\ T$.



   (a) Calculate the magnitude of the current in the wire necessary to remove the tension in the supporting leads.

   (b) State the direction of the current which produced this result.

4. The sketch below shows the rectangular coil of an electric motor. The coil has 120 turns and is $0.25\ m$ long and $0.15\ m$ wide and carries a current of $0.25\ A$. It lies parallel to a magnetic field of magnetic induction $0.40\ T$. The sketch shows the directions of the forces acting on the coil.

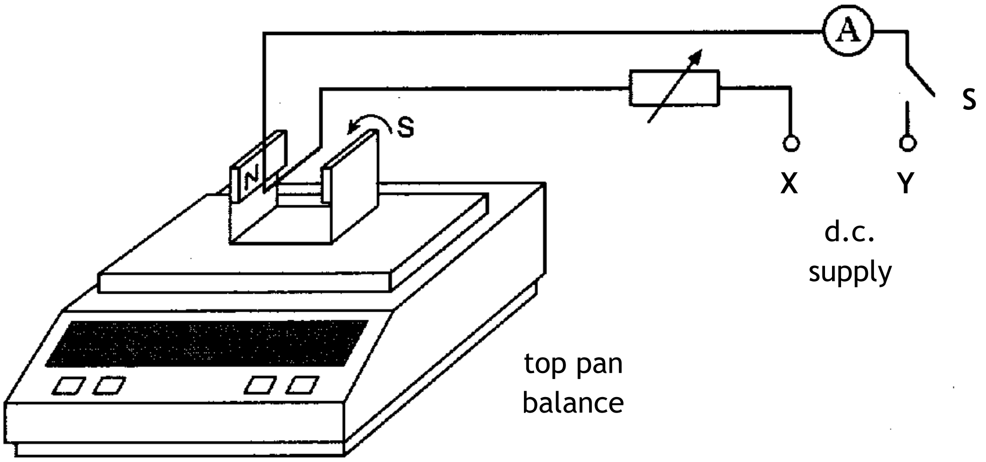


   (a) Calculate the magnitude of the force, F, on each of the wires shown.

   (b) Calculate the torque acting on the coil in this position.

   (c) State what will happen to this torque as the coil starts to rotate in the magnetic field. Justify your answer.

5. The diagram below 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 magnitude of the magnetic induction between the poles of the magnets.

(c) Suggest a value for the reading on the balance if the connections to the supply were reversed. Justify your answer.

(d) Suggest a value for the reading on the balance 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. Justify your answer.

6. Two parallel wires $0.20\,m$ apart carry large direct currents to an iron recycling plant. The large currents passing into the metal generate enough heat to make the iron melt. It can then be made into new shapes.

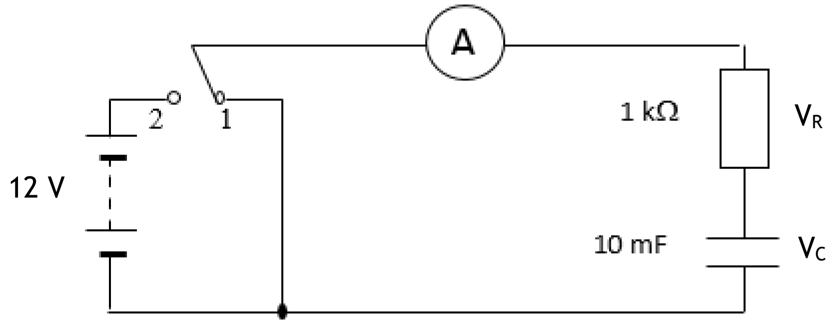
(a) Calculate the forces between two such wires $16\,m$ long if they each carry a current of $2500\,A$.

(b) State why these wires are not suspended freely on their route to the iron smelter.

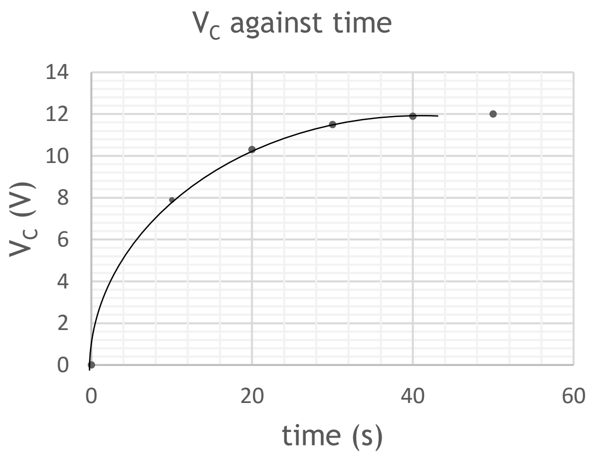
Electromagnetism

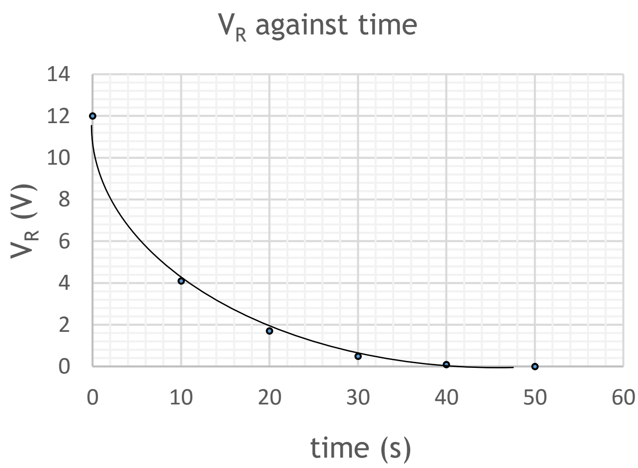
Capacitor Circuits

1. 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 that shows how the current varies with time in the circuit.

The experiment is repeated with the resistance changed to 2 kΩ.

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

The experiment is repeated with the resistance again at 1 kΩ but the capacitor replaced with one of capacitance 20 mF.

(c) 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) State which quantity is represented by the area under the current-time graph.

(e) 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.

(f) State the value of (V_C + V_R), at any instant in time.

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.

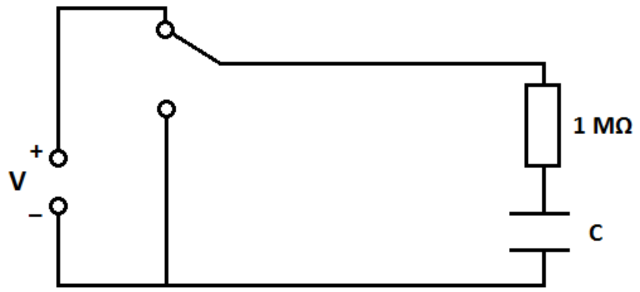
(g) Sketch graphs of V_C, V_R and I from the instant the switch is moved until the capacitor is fully discharged.

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

3. 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.

4. A circuit is made up of a 2 μF capacitor and a 4 kΩ resistor. Calculate the capacitive time constant.

5. 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 (MΩ)	Capacitor arrangement	Time constant (s)
1	1 μF only	1
1	4 μF only	4
1	1 μF and 4 μF 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

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

6. 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

$$V = V_0 e^{-\frac{t}{RC}}$$

   where V_o is the p.d. across the capacitor when fully charged.

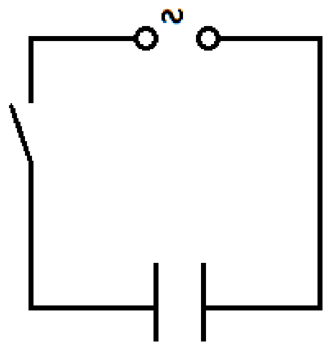
   (a) Show that at a time equal to the capacitive time constant RC, after the capacitor starts to discharge, the p.d. across the capacitor will be given by $V = 0.37V_0$.

   (b) A 4·0 μF capacitor is charged to a p.d. of 12 V. It is then connected across a 2.0 MΩ 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.

7. 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.



(a) The capacitor has reactance. State what is meant by the term ‘reactance’.

The frequency of the output from the a.c. supply is increased.

(b) Sketch a graph to show how:
(i) the reactance of the capacitor varies with the frequency of the supply

(ii) the current in the circuit varies with the frequency of the supply.

8. A 1·0 μF capacitor is connected to 5·0 V a.c. power supply. The frequency of the a.c. supply is 50 Hz.

(a) Calculate the capacitive reactance of the capacitor.

(b) Calculate the current in the circuit.

9. 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:
(a) the reactance of the capacitor at this frequency

(b) the capacitance of the capacitor.

10. A 500 Ω 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.

(a) Calculate the current in the circuit.

(b) Calculate the capacitance of the capacitor.

11. A 300 Ω 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:
(a) the capacitance of the capacitor

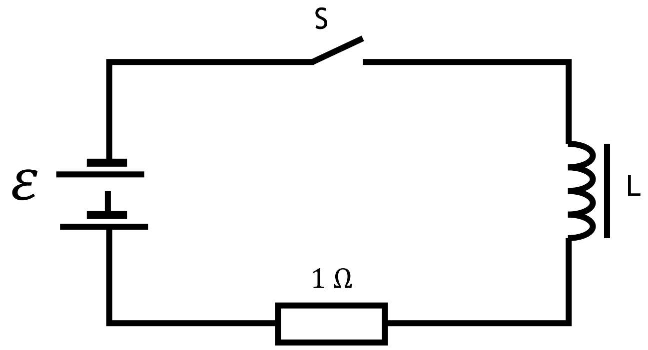
(b) the current in the circuit

(c) the p.d. across the resistor.

Electromagnetism

Inductor Circuits

1. The sketch below shows an inductor connected to a 12 V direct supply of negligible internal resistance. The resistance of the inductor coil is $1\ \Omega$. When switched on the current grows from zero. The rate of growth is $400\ As^{-1}$ when the current is 8.0 A.



(a) Calculate the induced e.m.f. across the coil when the current is 8 A.

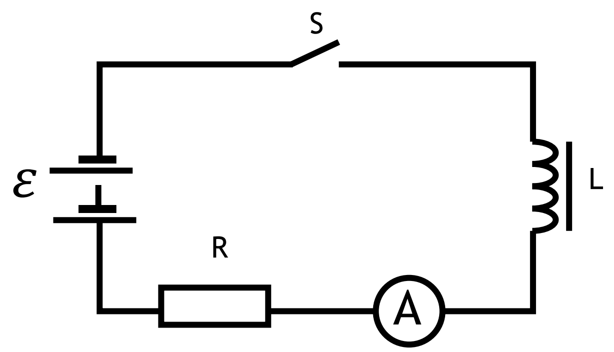
(b) Calculate the inductance of the coil.

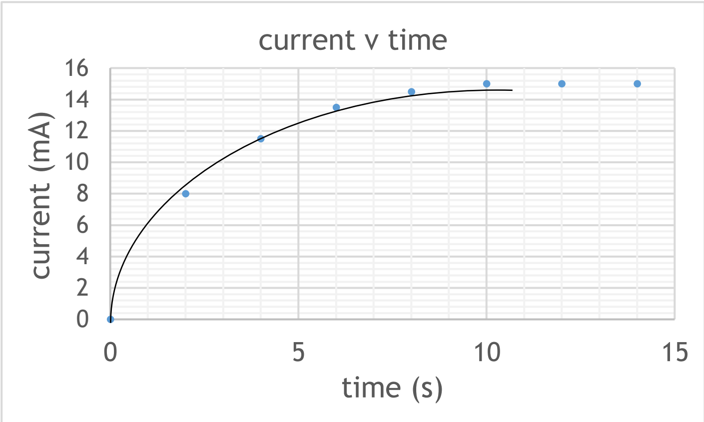
(c) Calculate the rate of increase of current when the switch is closed.

(d) Calculate the maximum current reached in the circuit.

(e) Calculate the maximum energy stored in the inductor.

2. An inductor with a removable soft iron core is connected in series with a 3.0 V direct supply of negligible internal resistance. An ammeter is used to monitor the current in the circuit.





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

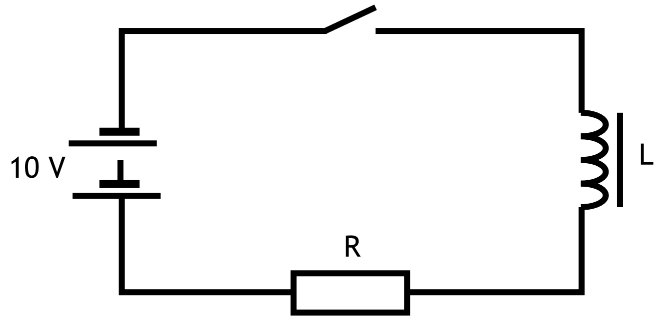
(a) (i) Explain why it takes some time for the current to reach its maximum value.

(ii) State why the current remains constant after reaching its maximum value.

(b) The soft core is then removed from the coil and the experiment repeated.
Create a sketch graph showing how the current varies against time for this second experiment.

(c) Calculate the resistance of the coil.

3. In the circuit shown below, the resistance of the resistor R is $40\ \Omega$ 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 a negligible internal resistance.



(a) Immediately after the switch is closed:

(i) State the potential difference across the $40\ \Omega$ resistor.

(ii) State the magnitude of the current in the circuit.

(iii) State the induced e.m.f. across the 2.0 H inductor.

(iv) Calculate the energy stored by the inductor.

(b) Some time later the current reaches a value of 0.040 A.

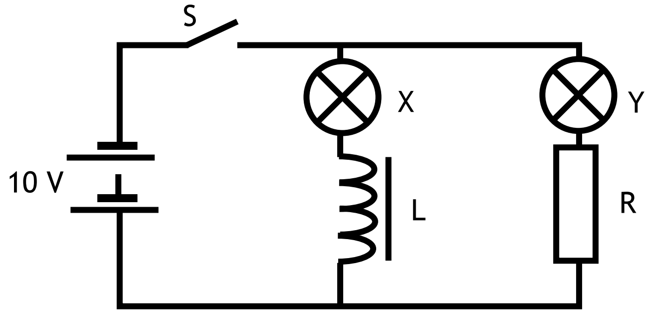
(i) At this time, calculate the potential difference across resistor, R.

(ii) Calculate the potential difference across the inductor, L, at this time.

(iii) Calculate the rate of growth of the current when the current in the circuit is 0.040 A.

(iv) Calculate the energy stored in the inductor.

4. The circuit diagram below shows a resistor, inductor and two lamps connected to a direct supply of 10 V. The supply has negligible internal resistance. The rating of each lamp is 6 V, 3 W.



(a) Describe what is meant by an inductance of 1 Henry.

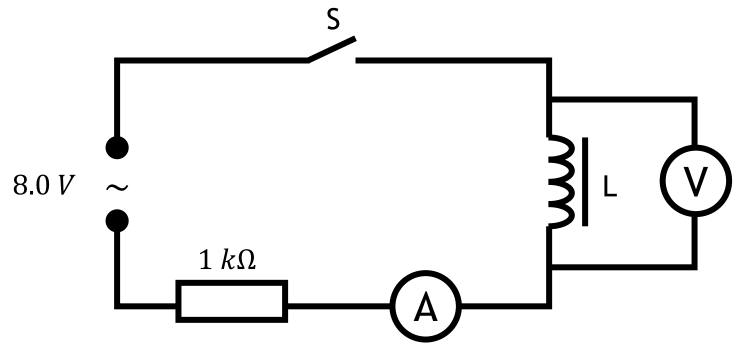
(b) After the switch is closed each lamp operates at its rated power. However, lamp Y lights up before lamp X.

(i) Explain why lamp Y lights before lamp X.

(ii) The current in lamp X grows at a rate of $0.50\ As^{-1}$ just as the switch is closed. Calculate the inductance of the coil.

(iii) Calculate the resistance of the coil.

5. A circuit is set up as shown below.



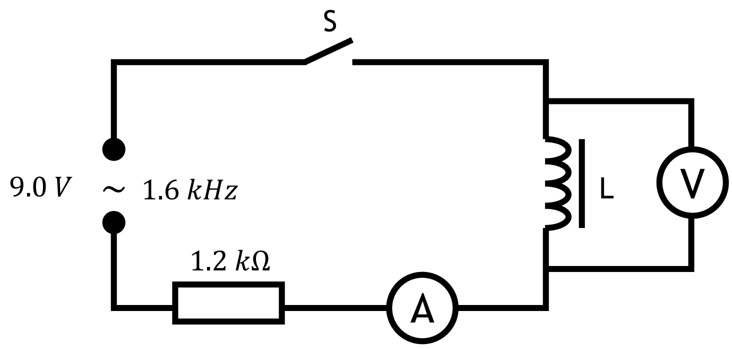
The ammeter reads 5 mA.

(a) Calculate the potential difference across the resistor.

(b) Calculate the potential difference across the inductor.

(c) Calculate the reactance of the inductor.

6. A circuit is set up as shown below.

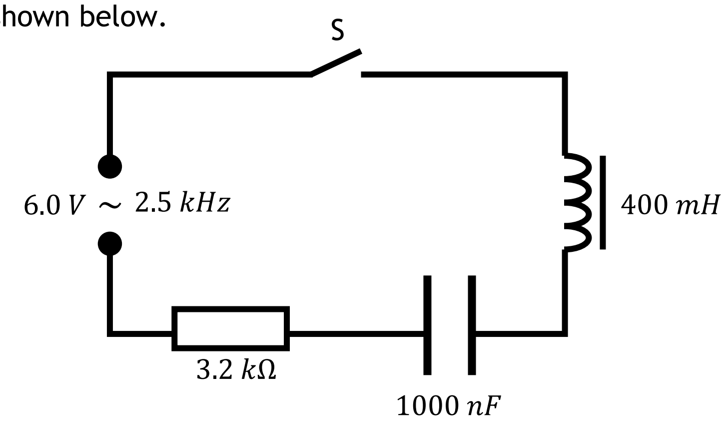


The ammeter reads 4.5 mA. The voltmeter reads 3.6 V.

(a) Calculate the reactance of the inductor.

(b) Calculate the inductance of the inductor.

7. 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.

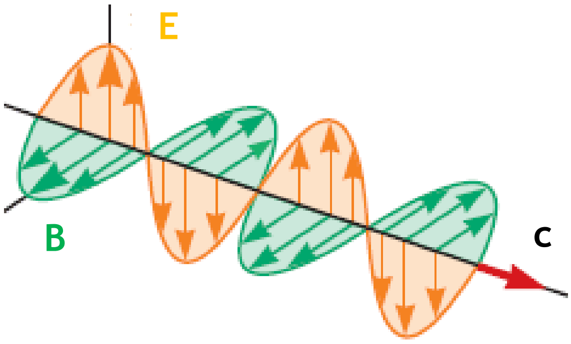
(a) Explain what happens to the voltage across the inductor as the frequency of the supply increases.

(b) Explain what happens to the voltage across the capacitor as the frequency of the supply increases.

Electromagnetism

Electromagnetic Radiation

1. The diagram shows a wave of electromagnetic radiation.



   State what the diagram indicates about waves of electromagnetic radiation.

2. The equation below can be used to determine the speed of light.

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

   Calculate the speed of light, using the equation.