Advanced Higher Physics

Electromagnetism

Questions and solutions

James Page

Education Scotland
Foghlam Alba

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Section 1 : **Fields**

Coulomb's inverse square law

1. State the relationship for Coulomb's inverse square law for the force between two point charges.

   State the name and unit for each quantity used in the relationship.

2. Two electrons are placed 1.5 nm apart. Calculate the electrostatic force acting on each electron.

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

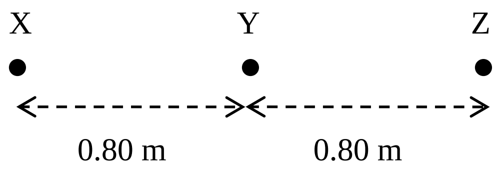
   Calculate the separation between the protons.

4. A point charge of + 2.0×10^{-8} C is placed a distance of 2.0 mm from a point charge of -4.0×10^{-8} C.

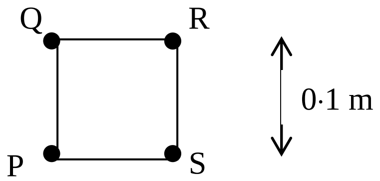
   (a) Calculate the electrostatic force between the charges.
   (b) The distance between the same charges is adjusted until the force between the charges is 1.0×10^{-4} N.
   Calculate this new distance between the charges.

5. Three point charges X, Y and Z each of +20 nC are placed on a straight line as shown.

   Calculate the electrostatic force acting on charge Z.



6. Four point charges P, Q, R and S each of +4.0 nC are situated at each of the corners of a square of side 0.10 m.



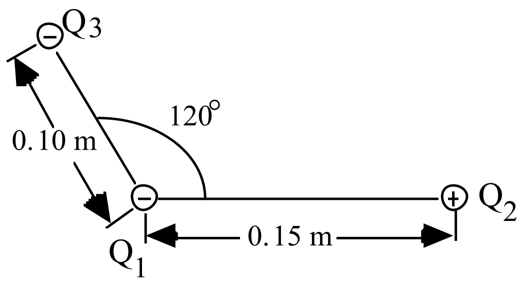
(a) Determine the electrostatic force, magnitude and direction, on charge P.

(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 2.0×10^{-10} m. Calculate the ratio of the electrostatic force F_E to the gravitational force F_G acting on the particles. Use $G = 6.67 \times 10^{-11}$ N m^2 kg^{-2}.

8. Suppose the Earth (mass 6.0×10^{24} kg) has an excess of positive charge and the Moon (mass 7.3×10^{22} 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.

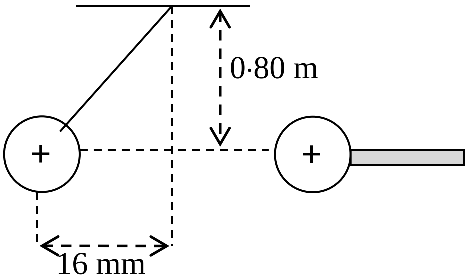


$Q_1 = -1.0 \times 10^{-6}$ C, $Q_2 = +3.0 \times 10^{-6}$ C and $Q_3 = -2.0 \times 10^{-6}$ C.

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 1.0×10^{-11} 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

1. State the meaning of the term ‘electric field strength at a point’.

2. State the relationship for the electric field strength, E:

(a) at a distance r from a point charge Q

(b) between two parallel plates, a distance d apart, when a potential difference (p.d.) V is applied across the plates.

3. Calculate the electric field strength at a distance of 1.0×10^{-10} m from a helium nucleus.

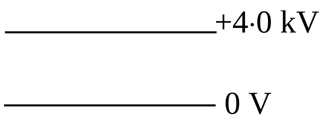
4. A small sphere has a charge of +2.0 μC. At what distance from the sphere is the magnitude of the electric field strength 7.2×10^{4} N C^{-1}?

5. A point charge of 4.0 μC experiences an electrostatic force of 0.02 N. Calculate the electric field strength at the position of this charge.

6. (a) 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.
   (b) State the magnitude of the electric field strength at a distance of 2.0 m from the charged sphere.

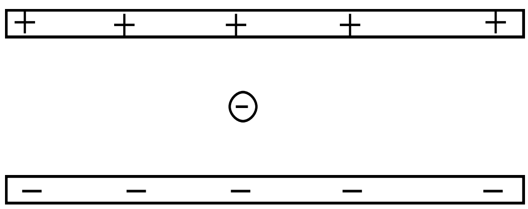
7. (a) Calculate the electric field strength at a point 5.0 mm from an α-particle.
   (b) How does the electric field strength calculated in (a) compare with the electric field strength at a point 5.0 mm from a proton?

8. Two parallel conducting plates are 2.0×10^{-2} 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.



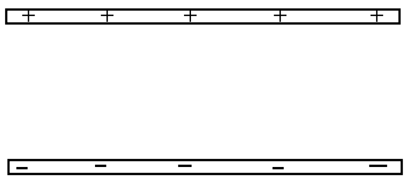
   (a) The sphere carries a charge of -5.0×10^{-9} C. Calculate the size of the electric field strength in the region between the metal plates.
   (b) Make a sketch of the two plates and the stationary charged sphere. Show the shape and direction of the resultant electric field in the region between the 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.

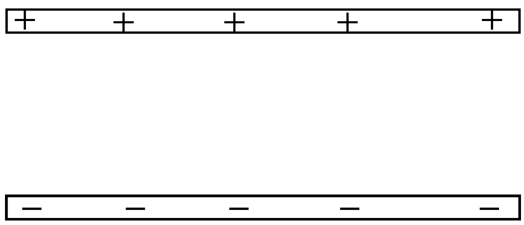
11. Copy and complete the electric field patterns for:

    (a) the electric field between two parallel conducting plates which have equal but opposite charges

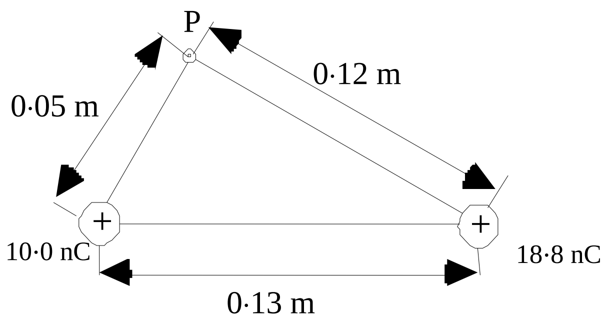


    (b) the electric field around two *unequal* but opposite point charges.

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 nC and +18.8 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

1. What is meant by the ‘electrostatic potential at a point’?

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

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

4. Calculate the electrostatic potential at a point P that is at a distance of 0.05 m from a point charge of + 3.0×10^{-9} C.

5. 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.

(a) 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 + 1.6×10^{-19} C separated from a charge of -1.6×10^{-19}C by a distance of 5.0×10^{-11} m.
Calculate the potential energy associated with an electron in a hydrogen atom.

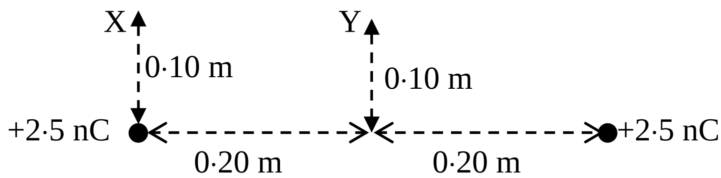
7. What is meant by an equipotential surface?

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 nC and –2.0 nC are situated 0.12 m apart. Find the position of the point where the electrostatic potential is zero.

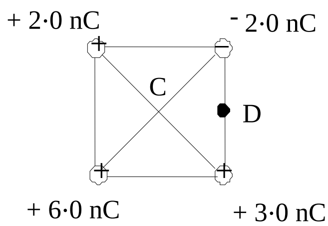
10. Which of the following are vector quantities?
electrostatic force, electric field strength, electrostatic potential, permittivity of free space, electric charge, potential difference

11. Two point charges each of +2.5 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 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.



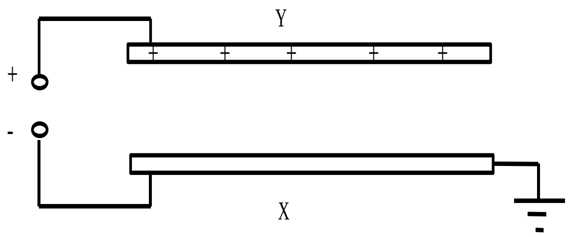
(a) Calculate the electrostatic potential at the centre, C, of the square
(b) Show that the length of one side of the square is $\sqrt{0.02}$ m.
(c) D is at the midpoint of the side as shown.
Calculate the electrostatic potential *difference* between point C and point D.

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

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



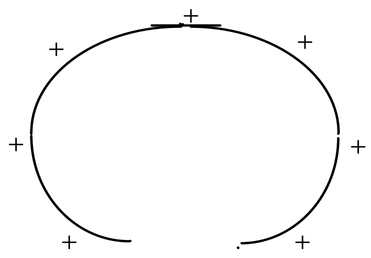
(a) Draw a sketch graph to show how the potential varies along a line joining the midpoint of plate X to the midpoint of plate Y.
(b) Calculate the electric field strength between the plates.
(c) Explain how the value for the electric field strength can be obtained from the graph obtained in (a).

16. A metallic sphere has a radius of 0.040 m. The charge on the sphere is +30 μC.
Calculate the electric field strength:

(a) inside the sphere
(b) at the surface of the sphere
(c) at a distance of 1.0 m from the centre of the sphere.

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.

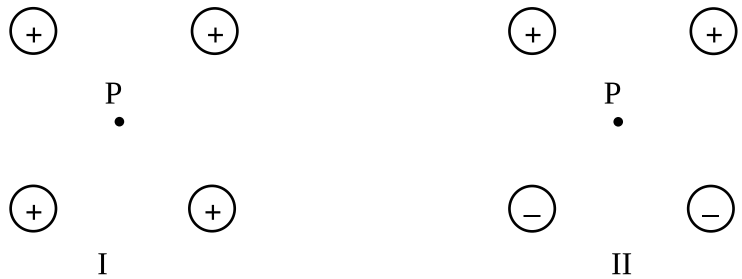
18. Consider the arrangement of point charges shown in the diagrams below. All charges have the same magnitude.

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

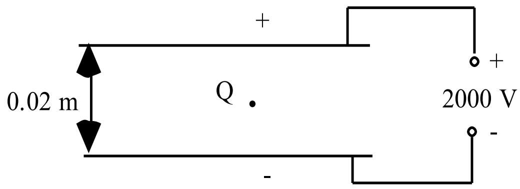
(b) the electric potential is zero or non-zero.

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.)

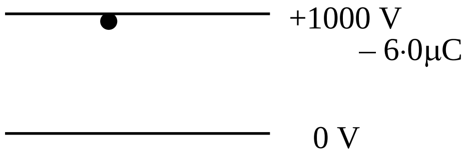
    The mass of the oil drop is 4.9×10^{-15} kg.



    (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 μC is just at the lower surface of the top plate.

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

2. A p.d. of 3.0×10^4 V is applied between two parallel conducting plates. The electric field strength between the plates is 5.0×10^5 N C^{-1}.

(a) Determine the separation of the parallel plates.

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

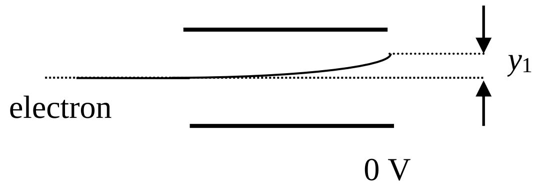
4. A proton is now used in the *same* electric field as in question 3 above. The proton is released from the positive plate.

(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?

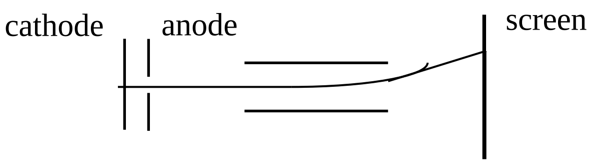
5. An electron is projected along the axis midway between two parallel conducting plates as shown.



The length of the plates is 0.150 m. The plate separation is 0.100 m.
The initial kinetic energy of the electron is 2.87×10^{-16} J.
The magnitude of the electric field strength between the plates is 1.40×10^{4} 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.
(c) What is the vertical deflection, y_1, of the electron?
(d) Describe the motion of the electron after it leaves the space between the plates.

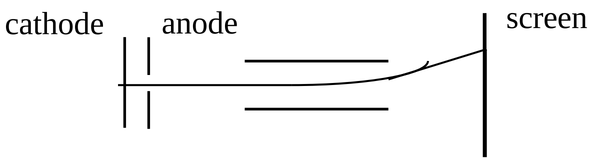
6. A beam of electrons is accelerated from rest at a cathode towards an anode. After passing through the hole in the anode the beam enters the electric field between two horizontal conducting plates as shown.



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 6.0×10^6 m s^{-1}. The electric field strength between the plates is 4.0×10^2 V m^{-1}. The length of the plates is 5.0×10^{-2} 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 1.8×10^{11} 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 7.5×10^5 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 1.2×10^6 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 3.0×10^7 m s^{-1}?

(ii) Calculate the displacement of the electron in this time.

12. An α-particle travels at a speed of 5.0×10^6 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 6.0×10^{-2} m. (The mass of an α-particle is 6.7×10^{-27} kg).

(b) Draw a sketch of the apparatus which could be used to stop an □-particle in the way described above.

(c) Can a □-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 1.9×10^6 m s^{-1} and its mass is 6.7×10^{-27} kg. The atomic number of oxygen is 8.

(a) State an expression for the change in kinetic energy of the □-particle as it approaches the oxygen nucleus and stops.

(b) State an expression for the change in electrostatic potential energy of the α-particle.

(c) 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

$$r_c = \frac{2qQ}{4\pi\varepsilon_o m v^2}$$

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.

(d) Calculate the distance of closest approach of the α-particle to the oxygen nucleus.

14. The distance of closest approach between an α-particle and an iron nucleus is 1.65×10^{-13} m. The mass of an α-particle is 6.7×10^{-27} kg and the atomic number of iron is 26.
Calculate the initial speed of approach of the α-particle.

15. 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 2.0×10^{7} m s^{-1}.
    The atomic number of gold is 79. The mass of the α-particle is 6.7×10^{-27} kg. Calculate the closest distance of approach which an α-particle could make towards a gold nucleus in a head-on collision.

16. (a) Define the unit of energy electron volt, eV.
    (b) Derive the relationship between electron volts and joules, and show 1 eV = 1.6×10^{-19} J.

17. A proton and an α- particle are accelerated from rest through a p.d of 20 V. Calculate the final kinetic energy of

    (a) the proton in eV
    (b) the α-particle in eV.

18. An α-particle has a kinetic energy of 4.0 MeV. Calculate its speed.

19. 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.

    (a) Calculate the number of electrons reaching the target each second.
    (b) Calculate the energy in joules that the beam delivers to the target each second.

Section 2: Magnetic fields and magnetic induction

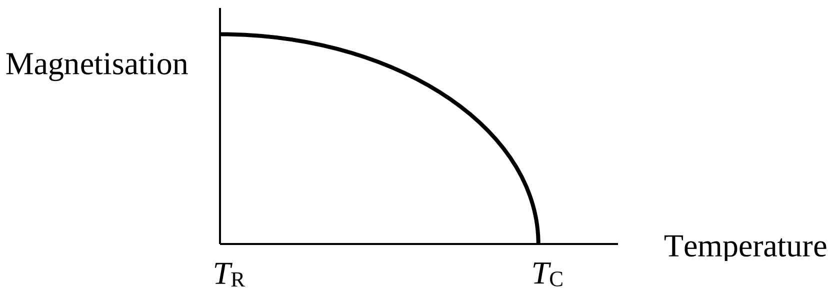
Magnetism

1 A bar of un-magnetised 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:

(a) why the magnetisation of the iron increases
(b) why when the current exceeds a certain value it is found that the magnetisation of the iron does not increase.

2. 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.

3. 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.

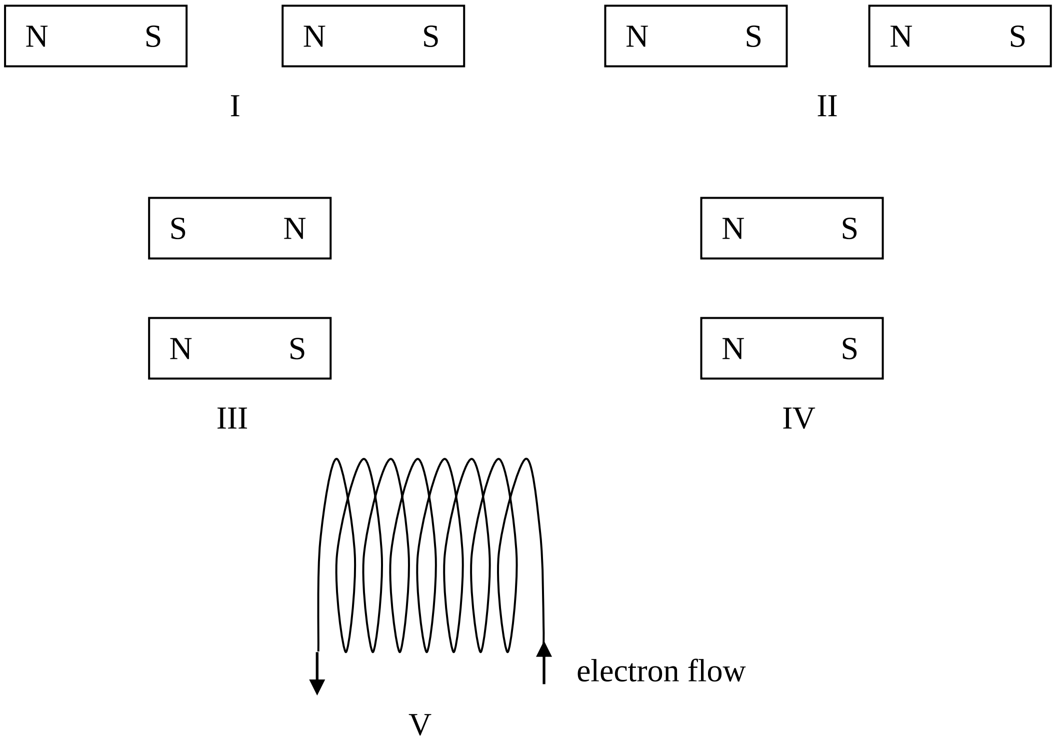


The magnetism of the sample becomes zero at a temperature known as the Curie temperature, T_C.
Explain why the magnetisation of the sample decreases as the temperature decreases.

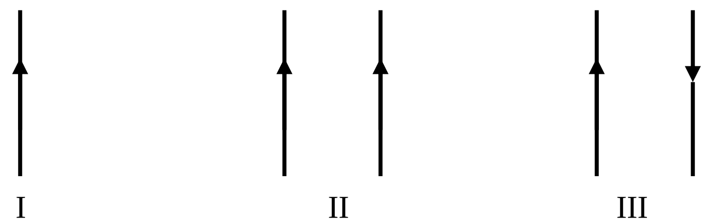
4. Explain why a permanent magnet loses its magnetism when it is repeatedly struck with a hammer.

Magnetic field patterns

1. 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 1.2 Ω. 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 2.0×10^{-5} T.
Calculate the current in the wire.

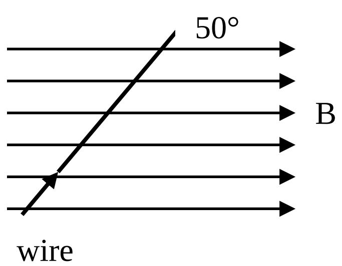
Force on a current-carrying conductor

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 T. There is a current of 2.0 A in the conductor and the conductor experiences a force of 9.5 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.

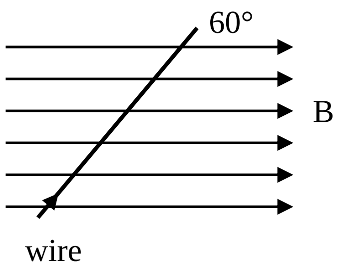


The arrow on the wire shows the direction of the electron current in the wire.
The magnetic induction of the field is 0.20 T. The length of the wire, in the field, is 0.05 m and the current in the wire is 4.0 A.

(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 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.

(a) Calculate the magnitude of the force exerted on the wire.
(b) Draw a sketch of the wire in the magnetic field and show the direction of the force.
(c) Describe the conditions for this force to be a maximum.

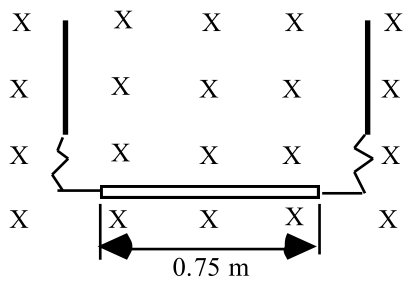
5. A straight conductor of length 50 mm carries a current of 1.4 A. The conductor experiences a force of 4.5×10^{-3} N when placed in a uniform magnetic field of magnetic induction 90 mT.
Calculate the angle between the conductor and the direction of the magnetic field.

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.

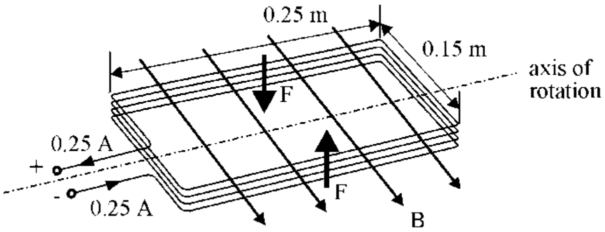
(a) What is the minimum current required in the wire to produce a force of 0.30 N on the wire?
(b) Why is this a minimum value of current?

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.

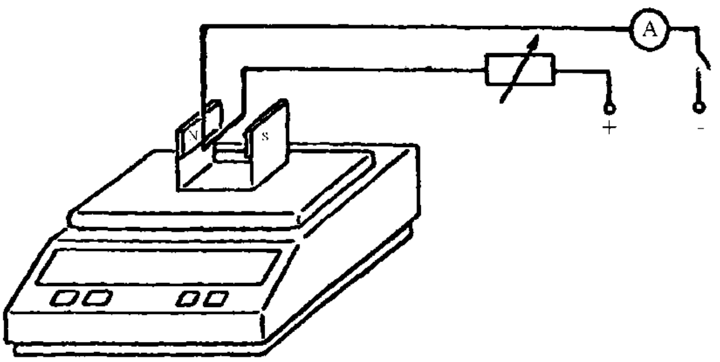


(a) Calculate the magnitude of the force, F, on each of the wires shown.

(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.

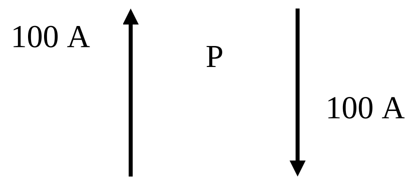
(a) Calculate the magnitude and direction of the force on the wire from these balance readings.

(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.

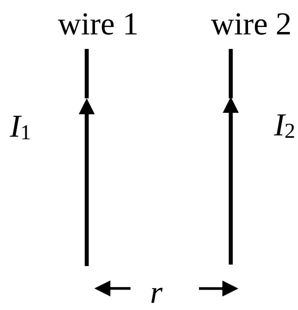
11. Two long straight parallel wires are 0·10 m apart. The current in each wire is 100 A but the currents in the wires are in opposite directions as shown.



(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.

(a) Calculate the force between the wires 16 m long when they each carry a current of 2500 A.

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

Section 3: Circuits

Capacitors in d.c. circuits

1. A 50 μF capacitor is charged until the p.d. across it is 100 V.

   (a) Calculate the charge on the capacitor when the p.d. across it is 100 V.

   (b) (i) The capacitor is now ‘fully’ discharged in a time of 4·0 ms. Calculate the average current during this time.

   (ii) Why is this average current?

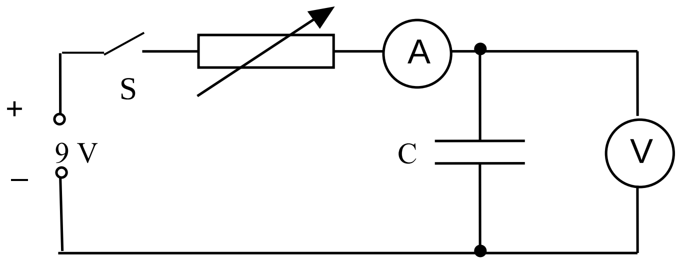
2. A capacitor stores a charge of $3{\cdot}0 \times 10^{-4}$ C when the p.d. across its terminals is 600 V.
   What is the capacitance of the capacitor?

3. A 15 μF capacitor is charged using a 1·5 V battery.
   Calculate the charge stored on the capacitor when it is fully charged.

4. (a) A capacitor stores a charge of $1{\cdot}2 \times 10^{-5}$ C when there is a p.d. of 12 V across it. Calculate the capacitance of the capacitor.

   (b) 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.

5. In the circuit below the capacitor C is initially uncharged.

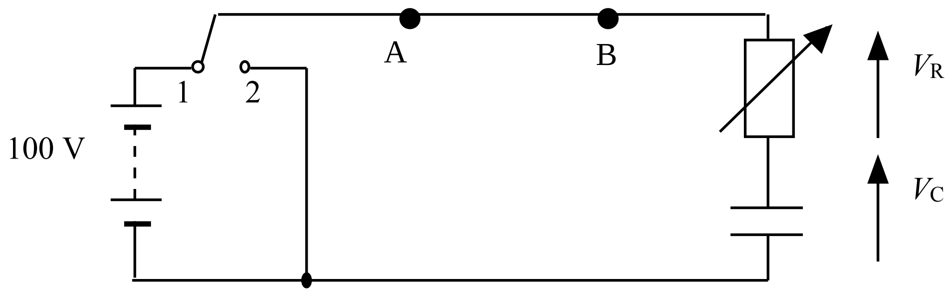


Switch S is now closed. By carefully adjusting the variable resistor R a constant charging current of 1·0 mA is maintained.
The reading on the voltmeter is recorded every 10 s. The results are shown in the table.

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.

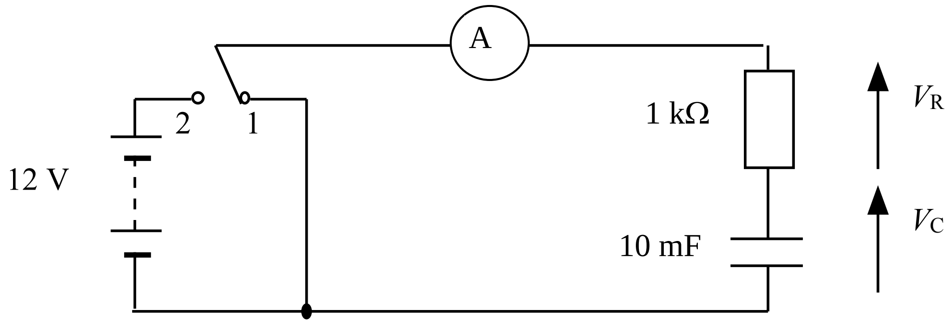
(c) Sketch graphs of V_C against time for the capacitor charging and discharging. Show numerical values for the maximum and minimum values of V_C.

(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?

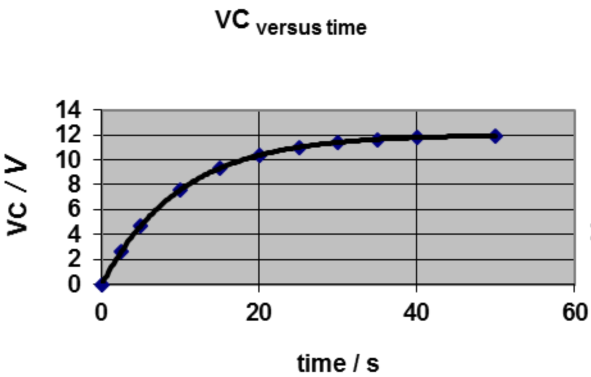
(e) The capacitor has a capacitance of 4·0 μF. The resistor has resistance of 2·5 MΩ.

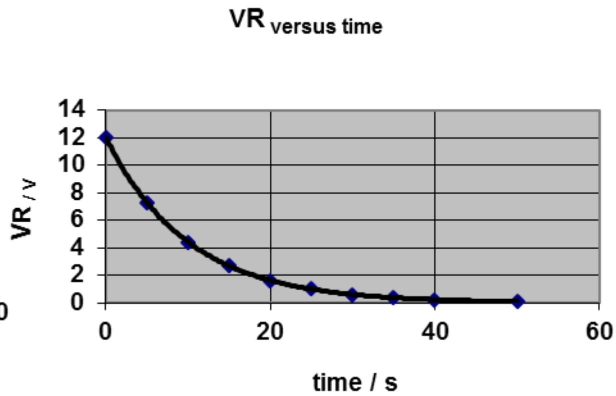
Calculate:
(i) the maximum value of the charging current
(ii) the charge stored by the capacitor when the capacitor is fully charged.

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 kΩ. 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 kΩ 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.

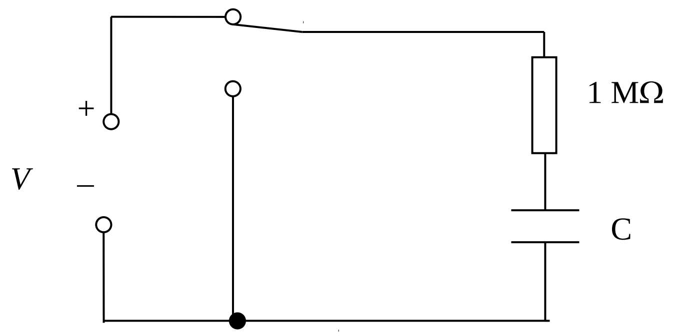
Sketch graphs of V_C, V_R and I from the instant the switch is moved until the capacitor is fully discharged.

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 μF capacitor and a 4 kΩ 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 MΩ	1 μF only	1
1 MΩ	4 μF only	4
1 MΩ	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

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

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 $V = V_o e^{-t/RC}$ 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 $V = 0.37V_o$.

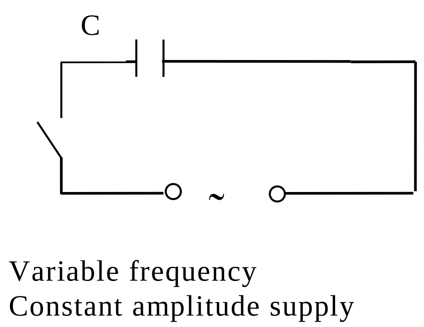
(b) A 4·0 μF capacitor is charged to a p.d. of 12 V. It is then connected across a 2.0 MΩ resistor so that it discharges.

(i) Calculate the capacitive time constant.

(ii) Calculate the p.d. across the capacitor 4 s after it starts to discharge.

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.



(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:

(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.

2. 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.

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:

   (a) the reactance of the capacitor at this frequency
   (b) the capacitance of the capacitor.

4. 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.

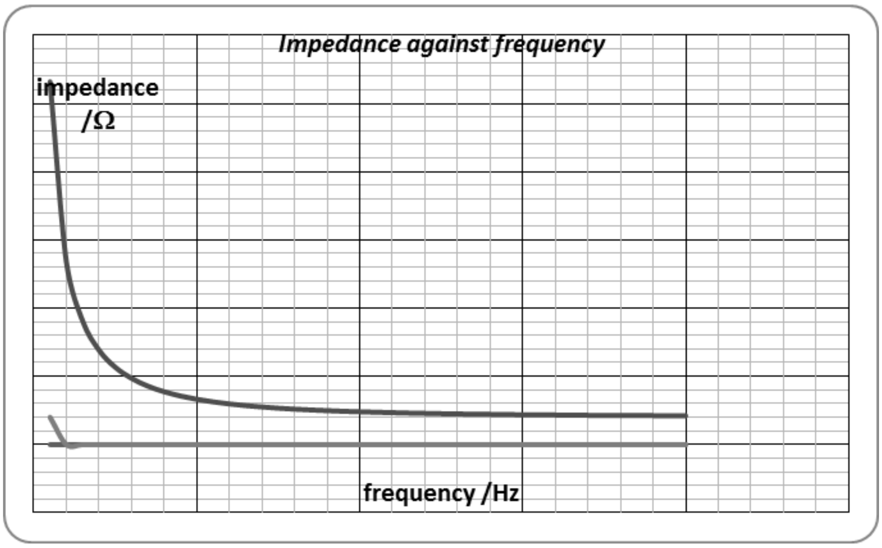
5. A 300 Ω resistor and a capacitor are connected in series with an a.c. supply of frequency 100 Hz.
   The p.d. across the capacitor is 5.00 V. When the frequency of the output from the supply is 100 Hz the capacitive reactance of the capacitor is 265 Ω.
   Calculate:

   (a) the capacitance of the capacitor
   (b) the current in the circuit
   (c) the p.d. across the resistor.

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

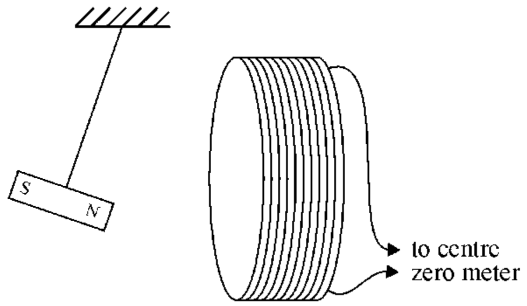
(a) the value of the resistance
(b) the value of the capacitance.

Section 4: Inductors

Inductors and induced e.m.f.

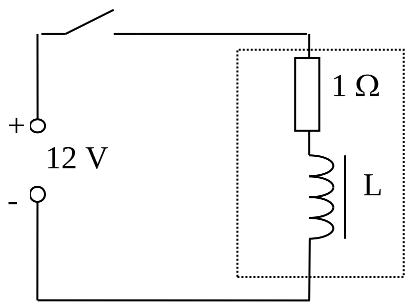
1. (a) A student is investigating the production of an induced e.m.f. across a coil.
   Describe a simple experiment which would allow her to do this.
   (b) State three ways in which the magnitude of the induced e.m.f. across a coil can be increased.

2. 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 1·0 Ω. 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.

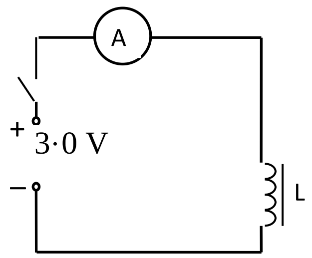
(b) Calculate the inductance of the coil.

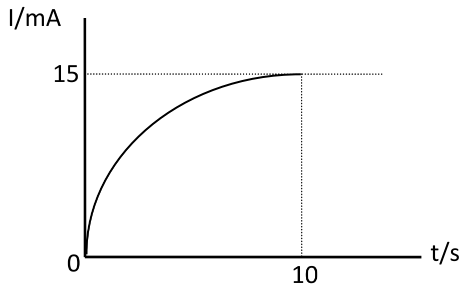
(c) Calculate the rate of increase of current immediately after the switch is closed

(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.

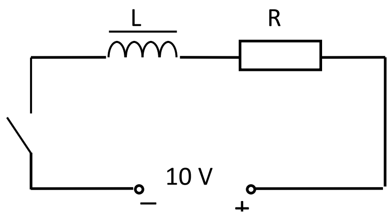
(ii) Why does the current remain constant after it reaches its maximum value?

(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.

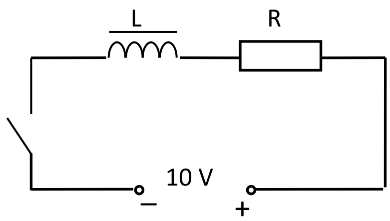


The resistance of resistor R is 40 Ω and the inductance of inductor L is 2·0 H. The resistance of the inductor may be neglected. The supply has an e.m.f. of 10 V and negligible internal resistance.

(a) The switch is now closed.
   (i) State the initial p.d. across the 40 Ω 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.



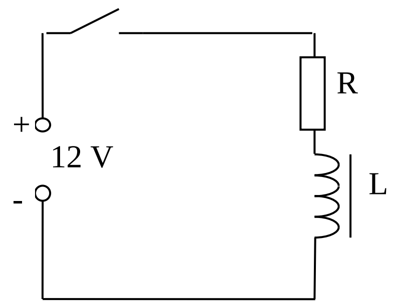
(a) The inductor has a large number of turns. The switch is now closed. Sketch a graph to show how the current in the circuit varies with time.
(b) Explain why the current does not reach its maximum value immediately.
(c) The resistance of the resistor is now reduced. The switch is opened and then closed 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.

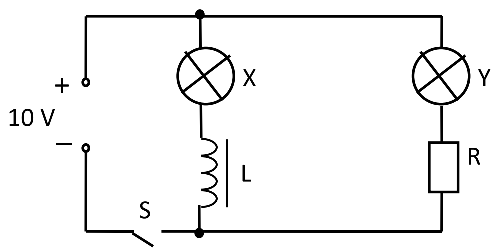
8. An inductor, resistor and d.c. supply are connected in series.



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 15 Ω.
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.

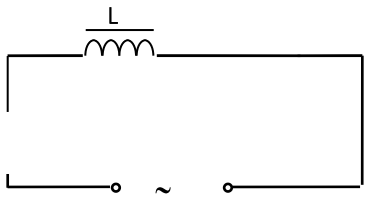


The supply has negligible internal resistance. The rating of each lamp is 6·0 V, 3·0 W.
After the switch is closed each lamp operates at its rated power. It is noticed that lamp Y lights up before lamp X.

(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.



Variable frequency
Constant amplitude supply

(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
(i) the reactance of the inductor varies with the frequency of the output from the supply
(ii) the current in the circuit varies with the frequency of the output from the supply.

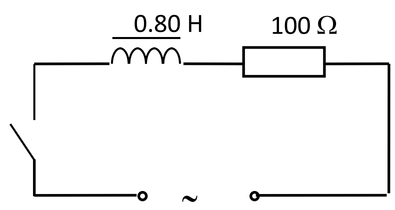
2. A coil has an inductance 0f 0.80 H and negligible resistance. It is connected to a 30 V a.c. supply of frequency 50 Hz.

(a) Calculate the reactance of the inductor.
(b) 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:

(a) the inductive reactance of the inductor at this frequency
(b) the inductance of the inductor.

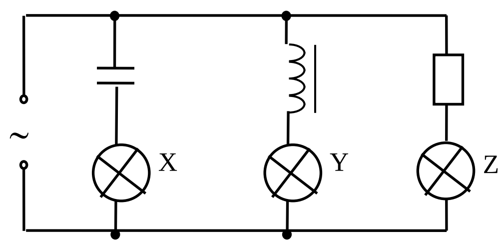
4. A pure inductor and resistor are connected across an a.c. supply with a frequency of 50 Hz.



The inductance of the inductor is 0·8 H and the resistor has a resistance of 100 Ω. The p.d. across the resistor is 12 V r.m.s.

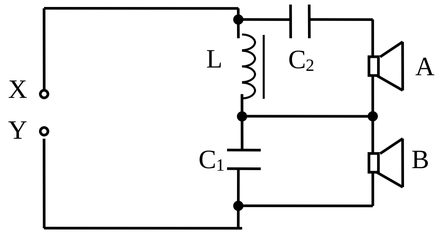
(a) Calculate the current in the circuit.
(b) Calculate the r.m.s voltage across the inductor.

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.

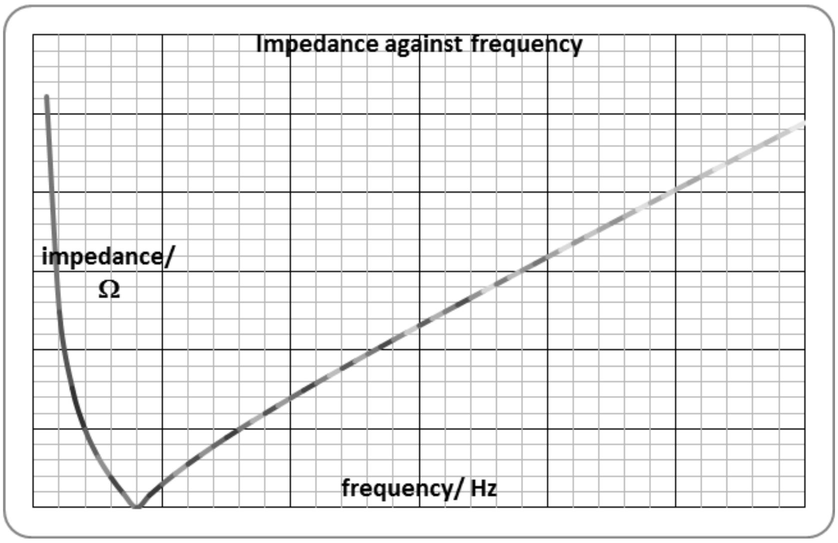
7. In a series circuit containing a resistor, a capacitor and an inductor the combined effect is known as the impedance Z of the circuit where

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

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

$$c = \frac{1}{\sqrt{\varepsilon_o \mu_o}}$$

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

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

$$E = 4 \cdot 0 \times 10^2 \sin[3 \cdot 0 \times 10^6 \pi (x - 3 \cdot 0 \times 10^8 t)]$$

   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 $E = cB$:

(i) write down the expression for the magnetic field of the electromagnetic wave

(ii) what is the amplitude of the magnetic field in the electromagnetic wave?

Numerical solutions

Section 1: Fields

Coulomb's inverse square law

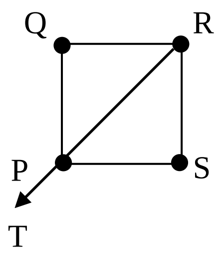
2. $1{\cdot}0 \times 10^{-10}$ N repulsion

3. $4{\cdot}1 \times 10^{-15}$ N

4. (a) 1·8 N attractive force
   (b) 0·27 m

5. $7{\cdot}0 \times 10^{-6}$ N to the right

6. (a) $2{\cdot}8 \times 10^{-5}$ N in direction RPT as shown

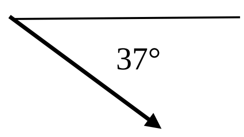


   (b) 0 N as forces on the central charge are balanced.

7. $F_E/F_G = 2{\cdot}3 \times 10^{39}$

8. $5{\cdot}7 \times 10^{13}$ C

9. 2·6 N at 37° as shown



10. (a) weight (down), tension along thread, electrostatic force to the left
    (b) $9{\cdot}8 \times 10^{-5}$ N

11. (a) $9{\cdot}8 \times 10^{-5}$ N
(b) $1{\cdot}04 \times 10^{-9}$ C (to 3 sig. figs)
(c) 104 s (to 3 sig. figs)

Electric field strength

3. 2.9×10^{11} V m^{-1} or N C^{-1} away from the nucleus

4. 0.50 m

5. 5×10^{3} N C^{-1}

6. (a) 1.1×10^{-10} C
(b) 0.25 N C^{-1}

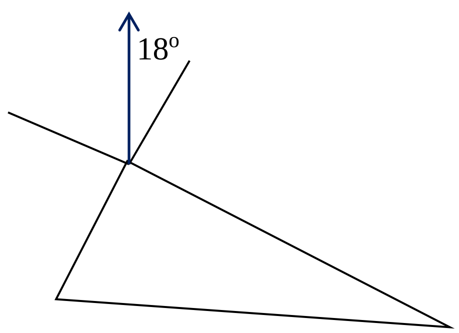
7. (a) 1.2×10^{-4} N C^{-1}
(b) 6.0×10^{-5} N C^{-1} halved

8. (a) vertically down from top plate
(b) (i) 2.0×10^{5} V m^{-1}
(ii) 2.0×10^{5} V m^{-1}

9. (a) 3.9×10^{4} N C^{-1}

10. (a) 3.6×10^{3} N C^{-1} in the direction from the $+8.0 \times 10^{-9}$ C charge to the $+4.0 \times 10^{-9}$ charge
(b) 0.12 m
(c) (i) 7.2×10^{-6} N
(ii) 4.9×10^{-3} N

13. (a) 3.8×10^{4} 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. 4.6×10^{-18} J

9. 0.08 m from +4.0 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) 2.25×10^{5} N C^{-1} parallel to QR and in the direction QR
    (b) 0

14. (a) 7.5×10^{4} V m^{-1}

15. (b) 2.4×10^{4} V m^{-1} towards lower plate

16. (a) 0 V m^{-1}
    (b) 1.7×10^{8} V m^{-1} away from sphere
    (c) 2.7×10^{5} 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) 5.6×10^{-9} 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) 4.8×10^{-19} 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) 1.33×10^{4} V m^{-1}
   (b) (ii) 3.2×10^{-16} J
   (iii) 2.7×10^{7} m s^{-1} (2.65×10^{7} m s^{-1} to 3 sig. figs)

4. (a) accelerates towards the negative plate
   (b) (ii) 6.2×10^{5} m s^{-1}; same as work done = QV with same Q and same V

5. (a) 2.51×10^{7} m s^{-1}
   (b) 5.98×10^{-9} s
   (c) 2.24×10^{-15} N
   (c) 0.044 m
   (d) straight line

6. (a) 8.4×10^{6} m s^{-1}
   (b) 0.022 m (0.225 m to 3 sig. figs) vertically

7. (a) 8.3×10^{-9} s
   (b) 2.4×10^{-3} m
   (c) 5.6° (5.55 to 3 sig. figs)

8. (a) 2.1×10^{8} 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. 9.5×10^{6} m s^{-1}

10. (a) 5.13×10^{8} m s^{-1} (to 3 sig. figs)
    (b) speed greater than the speed of light; would need a relativistic calculation

11. (a) 2.1×10^{17} m s^{-2}
(b) (i) 1.4×10^{-10} s
(ii) 2.1×10^{-3} m

12. (a) 4.4×10^{6} N C^{-1}
(c) no, as γ-ray has no electric charge so no electric force on it.

13. (d) 3.0×10^{-13} m

14. 4.7×10^{6} m s^{-1}

15. 2.7×10^{-14} m

17. (a) 20 eV
(b) 40 eV

18. 1.4×10^{7} m s^{-1}

19. (a) 3.8×10^{14} (3.75×10^{14} to 3 sig. figs)
(b) 6.4×10^{-9} J

Section 2: Magnetic fields and magnetic induction

Magnetic field around a current-carrying wire

1. 4.0×10^{-6} T

2. 2.0 mT

3. 0.1 mT

4. 5.0 A

Force on a current-carrying conductor

1. (c) 16°

2. (a) 3.1×10^{-2} N

3. 25 mT

4. (a) 0.013 N
   (c) θ = 90° 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) 8.0×10^{-4} T

13. (a) 100 N

Section 3: Circuits

Capacitors in d.c. circuits

1. (a) 5.0×10^{-3} C
   (b) (i) 1.25 A
   (ii) current decreases exponentially

2. 0.5 μF

3. 2.25×10^{-5} C

4. (a) 1.0 μF
   (b) 0.8 μC

5. (b) 4·9 mF

6. (e) (i) 40 μA
   (ii) 4.0×10^{2} μC or 4.0×10^{-4} C

7. (e) 12 V

10. 8 ms

12. (b) (i) 8 s
    (ii) 7.3 V

Capacitors in a.c. circuits

2. (a) 3.2×10^{3} Ω
   (b) 1.6 mA

3. (a) 500 Ω
   (b) 6.4 μF

4. (a) 0.24 A r.m.s
   (b) 4.8 μF

5. (a) 6.00 μF
   (b) 18.9 mA
   (c) 5.66 V

6. (a) 4 Ω
   (b) 2.7×10^{-4} F (actual values 4 Ω and 3.0×10^{-4} F)

Section 4: 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 ⍰

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) 1.6×10^{-3} J

8. (a) 0.80 A
   (b) 0.13 J

9. (b) (ii) 20 H
   (iii) 8.0 Ω

Inductors and a.c.

2. (a) 250 Ω
   (b) 0.12 A

3. (a) 500 Ω
   (b) 1.6 H

4. (a) 0.12 A
   (b) 30 V

7. (b) (i) 6.4×10^{-6} F
   (ii) 2.6 H (actual values 6.0×10^{-6} F and 2.6 H)

Electromagnetic radiation

4. (a) 4.0×10^{2} V m^{-1}
   (b) 4.5×10^{14} Hz
   (c) (ii) 1.3×10^{-6} T