How do things move without contact?

Fields and interactions

- **describe gravitation, magnetism and electricity using a field model**
- **investigate and compare theoretically and practically gravitational, magnetic and electric fields, including directions and shapes of fields, attractive and repulsive fields, and the existence of dipoles and monopoles**
- **investigate and compare theoretically and practically gravitational fields and electrical fields about a point mass or charge (positive or negative) with reference to:**

  – the direction of the field

  – the shape of the field

  – the use of the inverse square law to determine the magnitude of the field

  – potential energy changes (qualitative) associated with a point mass or charge moving in the field

2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016

Field lines

A field has both magnitude (strength) and direction. The magnitude of the field is the force per unit charge or mass. Fields are vectors, and more than one field will combine using vector addition principles.

When drawing field lines there are four basic principles.

1. Field lines do not touch or cross each other
2. The arrow shows the direction of the field
3. The further the field lines are apart, the weaker the field.
4. Field lines start and end perpendicular to the surface.

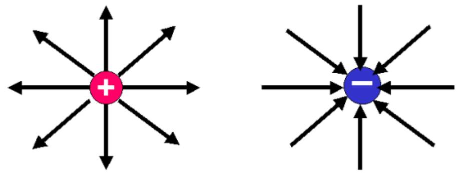
It is often best to draw field lines in pencil, and then, if need be, go over them with pen.

Electrical forces, gravitational forces and magnetic forces act between things that are not in contact with each other. A *force field* exists that influences charged, massive and magnetic bodies respectively.

Electric fields

An electric field **E** is the region around a charged body where another charged body would experience electric forces of attraction or repulsion. We know if a field is present at a particular space because if we place a point charge there, it will experience a force. The stronger the force, the stronger the field. The magnitude of the field is the size of the force it causes to act on a charge of one coulomb. The direction of the electric field is defined as the direction of the force on a positive charge placed in the field. The strength of the field is indicated by the closeness of the field lines.

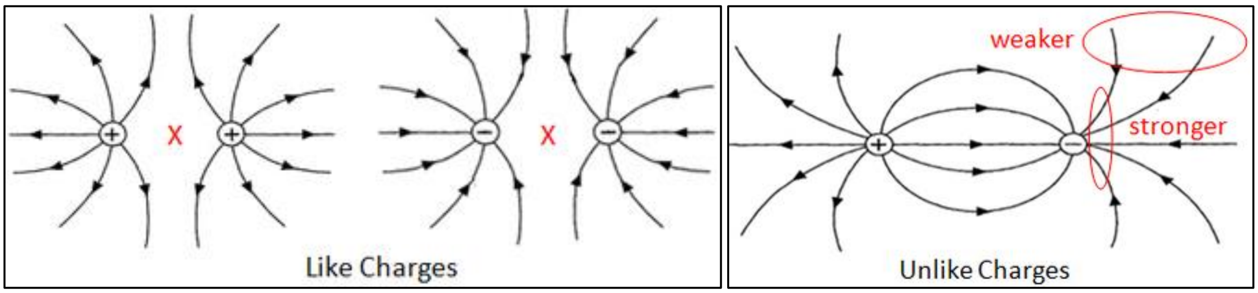
Electric field around positive point charge



Electric field around negative point charge

Electric field lines

Field lines are lines of force, they indicate the direction of the force acting on a unit positive charge at that point. For an isolated charge the lines extend to infinity, for two or more opposite charges we represent the lines as emanating from a positive charge and terminating on a negative charge.



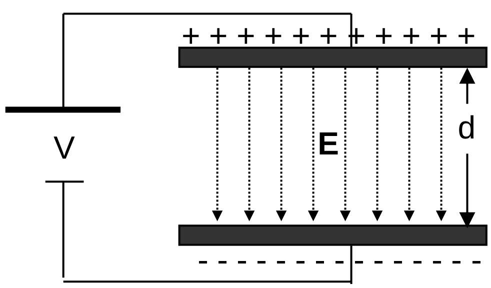
Electric fields between charged plates

In the region between parallel charged plates, the electric field **E** is uniform. The strength of the field depends on the potential difference between the plates and the distance between the plates.

$$\mathbf{E} = \frac{\Delta \mathbf{V}}{\mathbf{d}}$$

Where E = electric field strength (V m^{-1})

ΔV = potential difference (V)
d = distance between plates (m)



A charged oil droplet is stationary between a pair of horizontal parallel plates, X and Y, as in Fig. 1.
The drop carries a charge of 3.2×10^{-19} coulomb, and has a mass of 1.6×10^{-15} kg.
Take g = 10 N kg^{-1}.

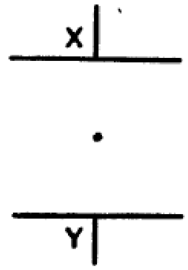


Fig. 1

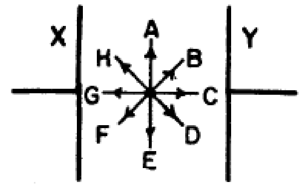


Fig. 2

Example 2.1: 1975 Question 61 (1 mark)

What is the magnitude of the electric field, E, between the plates?

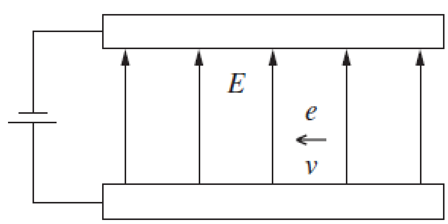
Example 2.2: 1975 Question 62 (1 mark)

The potential difference between the plates is 1 000 Volt.
What is their separation?

Example 2.3: 1975 Question 63 (1 mark)

The plates are turned into a vertical position as in Fig. 2.
In which direction, **(A - H)** will the droplet move?

An electron, *e*, travelling with a velocity, *v*, passes through an electric field, *E*, between two parallel plates.



Example 2.4: NSW 2011 Question 19 (1 mark)

What is the direction of the force that this electric field exerts on the electron?

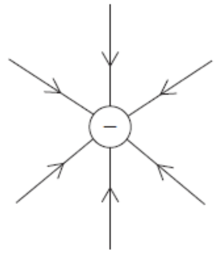
A. ↑

B. ↖

C. ↙

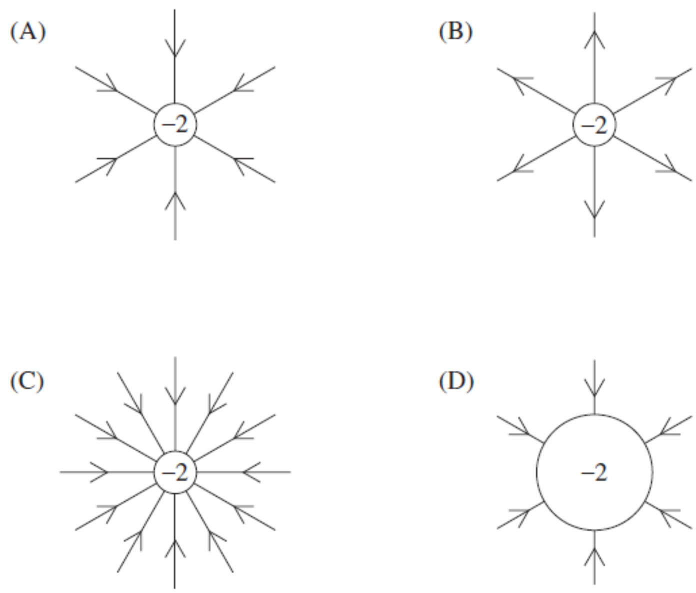
D. ↓

The diagram represents the electric field around a negative charge.

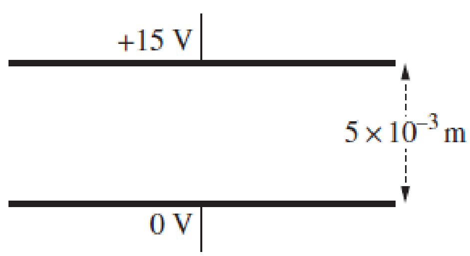


Example 2.5: NSW 2012 Question 6 (1 mark)

If the magnitude of the charge were doubled, which diagram would best represent the new electric field?



The diagram shows two parallel charged plates 5×10^{-3} m apart.



Example 2.6: NSW 2016 Question 5 (1 mark)

What is the magnitude of the electric field between the plates in V m^{-1}?

A. 3.3×10^{-4}

B. 0.33

C. 3

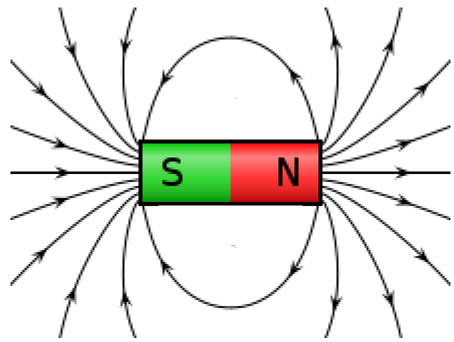
D. 3000

Fields and interactions

- **investigate and apply theoretically and practically a vector field model to magnetic phenomena, including shapes and directions of fields produced by bar magnets, and by current-carrying wires, loops and solenoids**
- **identify fields as static or changing, and as uniform or non-uniform.**

2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
1	1, 2	1	4	1	1, 2	1a, 1b	14	12a	15	12

Magnetic fields



All magnets have two poles. One pole is the North Pole and the other the South Pole. The North-seeking pole, called the North Pole, on a magnet will point towards the Earth's North Pole.

Every magnet is surrounded by a magnetic field, a zone where the magnetic characteristics can be experienced. The direction of the magnetic field is given by the direction of motion of a north monopole at that point.

Recent exam questions have asked you to draw field lines. To do this successfully you need to show the correct polarity (direction), some had to be complete loops, and field lines were not allowed to touch or cross. Students have also had a lot of trouble adding fields as vectors.

Magnetic Field Strength

- The symbol **B** is given to the magnetic field strength
- Its unit is the Tesla (T).
- It is a vector quantity, therefore
  - It has both magnitude and direction.
  - **Two or more magnetic fields need to be added as vectors.**
- Permanent magnets typically have **B** = 10^{-3} to 1 T.
- Earth's magnetic field is about 5×10^{-5} T.

The figure shows a bar magnet

Example 2.7: 2007 Question 1 (2 marks)

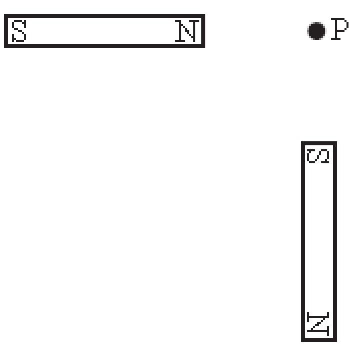
Complete the diagram by sketching five magnetic field lines around the magnet. You must include arrows which show the direction of the magnetic field of the magnet.

Example 2.8: 2007 Question 2 (2 marks)

A second bar magnet is placed next to the original as shown below.

Complete the diagram by sketching magnetic field lines to indicate the shape of the magnetic field around the magnets.

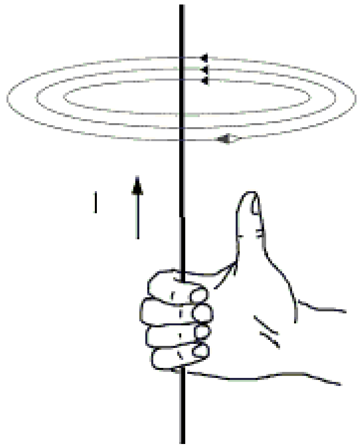
Two identical bar magnets of the same strength are arranged at right angles and are equidistant from point P, as shown below.



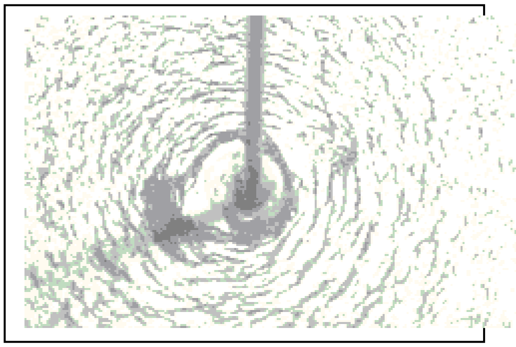
Example 2.9: 2011 Question 1 (1 mark)

At point P on the diagram, draw an arrow indicating the direction of the combined magnetic field of the bar magnets. (Ignore Earth's magnetic field.)

Magnetic Fields around Wires



A conductor carrying an electric current is always surrounded by a magnetic field.



Every current-carrying wire becomes a magnet.

Electromagnetism is a temporary effect caused by the flow of electric current and it disappears when the current flow is stopped.

The magnetic field lines due to the current in a straight wire are concentric circles with the wire at the centre. The direction of the magnetic field can be found using the right-hand screw (grip) rule.

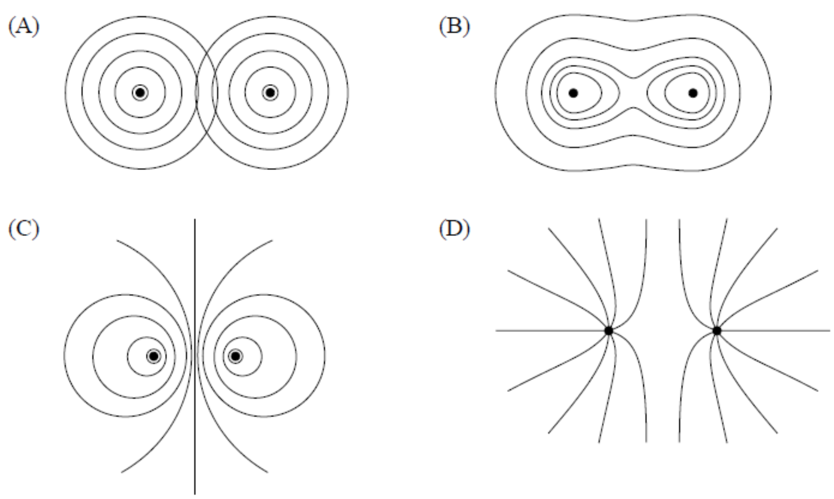
The wire is gripped with the **right** hand so that the thumb lines up with the direction of current flow. The direction of the magnetic field is given by the curl of the fingers.

The strength of the magnetic field caused by the flow of current is given by $\mathbf{B} = \frac{kI}{r}$ (k is a constant).

Two parallel wires carry currents in the same direction. The wires are viewed from the ends as shown in the diagram.

Example 2.10: NSW 1996 Question 11 (3 marks)

Which of the following diagrams best represents the magnetic field in the region near the wires?

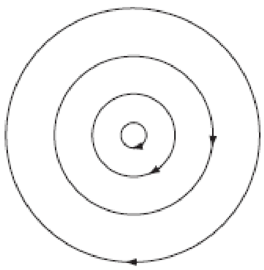


Example 2.11: NSW 1997 Question 24 (3 marks)

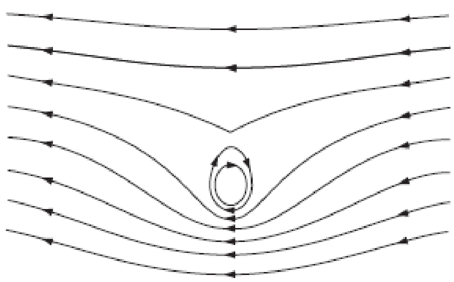
The diagrams below indicate the magnetic fields produced by different arrangements of current-carrying wires. Adjacent to each diagram sketch and label the arrangement of wire(s) that would produce *each* of the fields given, and indicate the direction of the current(s) in *each* case.

(a)

(b)



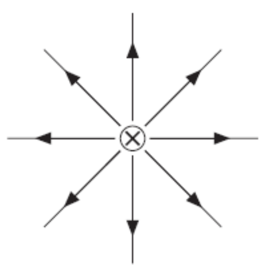
(c)



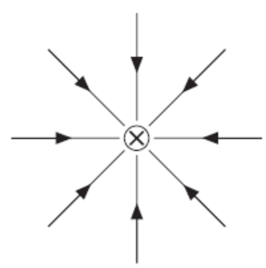
Example 2.12: NSW 2000 Question 10 (1 mark)

Which diagram shows the magnetic field around a straight wire carrying a current *into* the page?

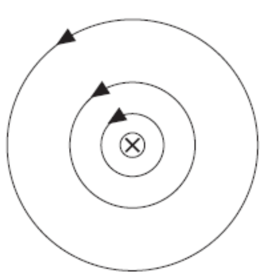
(A)



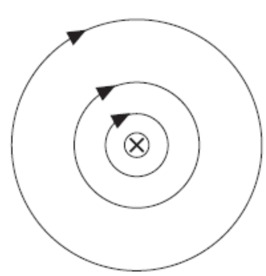
(B)



(C)



(D)



Effects of fields

- **analyse the use of an electric field to accelerate a charge, including:**
  – electric field and electric force concepts: $E = k\frac{Q}{r^2}$ and $F = k\frac{Q_1Q_2}{r^2}$
  – potential energy changes in a uniform electric field: $W = qV$, $E = \frac{V}{d}$
  – the magnitude of the force on a charged particle due to a uniform electric field: *$F = qE$*

Application of field concepts

- **model the acceleration of particles in a particle accelerator (limited to linear acceleration by a uniform electric field and direction change by a uniform magnetic field).**

2006 Synchrotron	2007 Synchrotron	2008 Synchrotron	2009 Synchrotron	2010 Synchrotron	2011 Synchrotron	2012 Synchrotron	2013 Synchrotron	2014 Synchrotron	2015 Synchrotron	2016 Synchrotron
7	2	1	3, 4	1, 2	2	2	1, 2	1	6	2

Coulombs Law (for point charges)

The force of attraction or repulsion between two charges Q_1 and Q_2 a distance 'r' metres apart is proportional to the product of the charges and inversely proportional to the square of the distance between the charges. $F = \frac{kQ_1Q_2}{r^2}$ where F is the force in newtons, Q_1 & Q_2 are measured in coulomb, and 'r' is measured in metres, $k = 9 \times 10^9$ N m^2 C^{-2}. Only used for two charges in air.

Electric forces

Electric forces are given by the product of the electric field and the quantity of charge.

$$\boxed{F_E = q\mathbf{E}}$$

Where F_E = electric force (N), q = charge (C), **E** = electric field (N / C)

Therefore, the direction and magnitude of the electric forces represent the direction and magnitude of the electric field at that point.

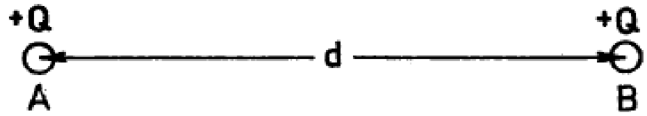
Linear accelerators (linac)

Electrical potential energy is stored in an electric field. An electric field exerts a force on charged particles, this can be used to increase their speed and kinetic energy. The field will do work on the charged particles. An electron will experience a force in the opposite direction to the field, due to its negative charge.

The electric force is F = Eq, and F = ma. Equating these two gives Eq = ma.

The work done is given by W = F × d, (if the force is constant, from a uniform field). The change in KE (typical to assume the particle starts from rest) is the work done.
$\therefore$ W = ΔKE = Eqd, where d is the distance between where the charges enter the field and exit the field.

The work done on a charge is also given by W = qV, and since V = Ed, we get W = qEd.

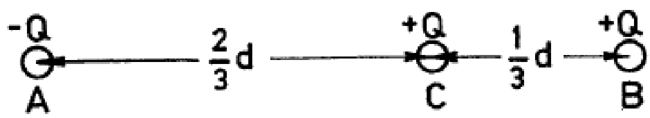


Two small identical metal spheres A and B carry equal positive charges +Q so that they repel each other with a force of 4 x 10^{-5} newton when placed a distance d apart.
A third identical sphere C, also carrying a charge +Q, is placed on the line joining A and B as shown.

Example 2.13: 1970 Question 64 (1 mark)

What is the value of the electrical force on C? Specify the direction of the force.

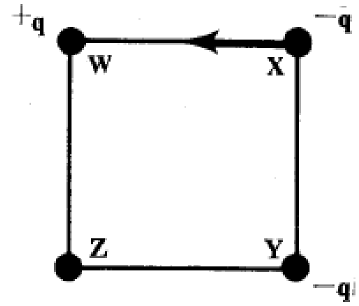
The charge on A is now made equal to -Q.



Example 2.14: 1970 Question 65 (1 mark)

What is the value of the electrical force now on C? Specify the direction of the force.

Three charges +q, -q and -q are placed at the corners W, X, and Y of a square as shown.



A fourth charge, Q, is placed at Z, after which the charge at X experiences a net electrostatic force indicated by the arrow.

Example 2.15: 1982 Question 51 (1 mark)

What is the value of Q?

A. -2.8q

B. -1.4q

C. +1.4q

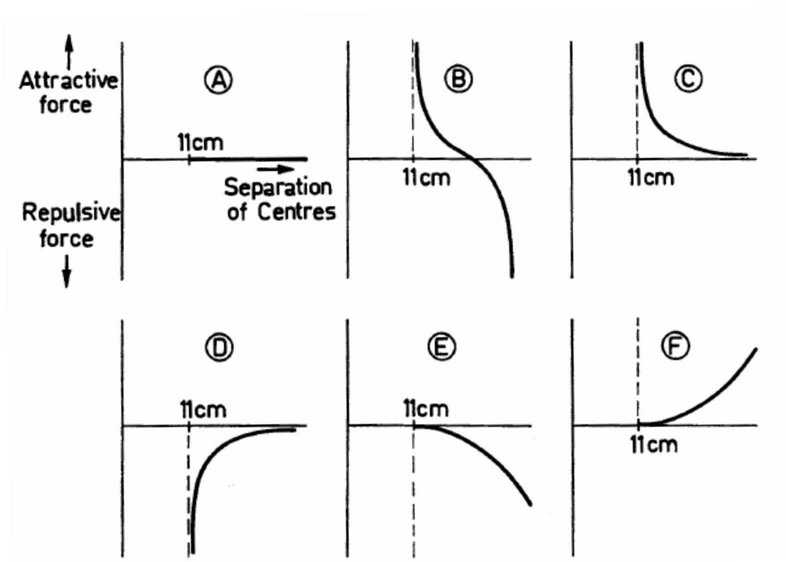
D. +2.8q

E. +4.0q

A large, uncharged metal sphere is moved towards a small, charged metal sphere.

Example 2.16: 1971 Question 67 (1 mark)

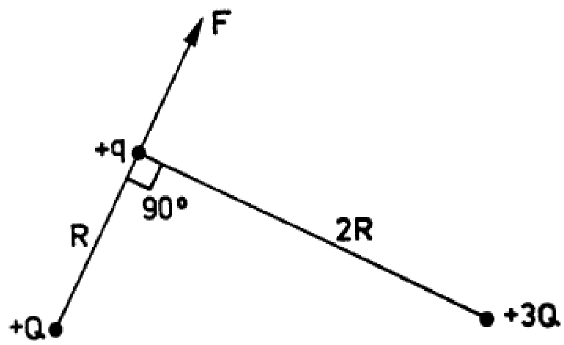
Which graph best represents the relation between the electrical force and the separation between the centres of the spheres?



The two spheres are now touched together.

Example 2.17: 1971 Question 68 (1 mark)

When the spheres are separated, which graph best represents the force-distance relation?

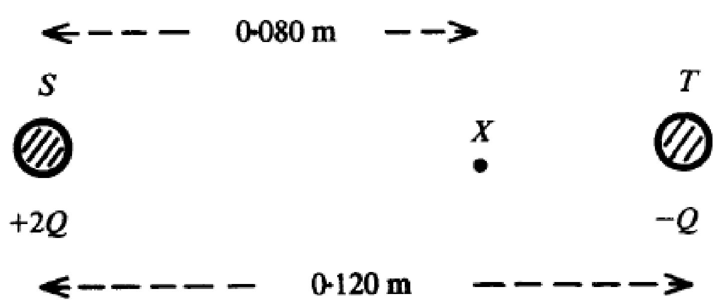


Charges of +q, +Q and +3Q are placed as shown.
The force on +q due to +Q alone is F.

Example 2.18: 1972 Question 63 (1 mark)

In terms of F, what is the magnitude of the resultant force on +q due to both +Q and +3Q?

Two small, identical, conducting spheres carrying charges of +2Q and -Q respectively are placed at S and T with their centres 0.120 m apart as shown. The point X is 0.080 m from S along the line, ST.

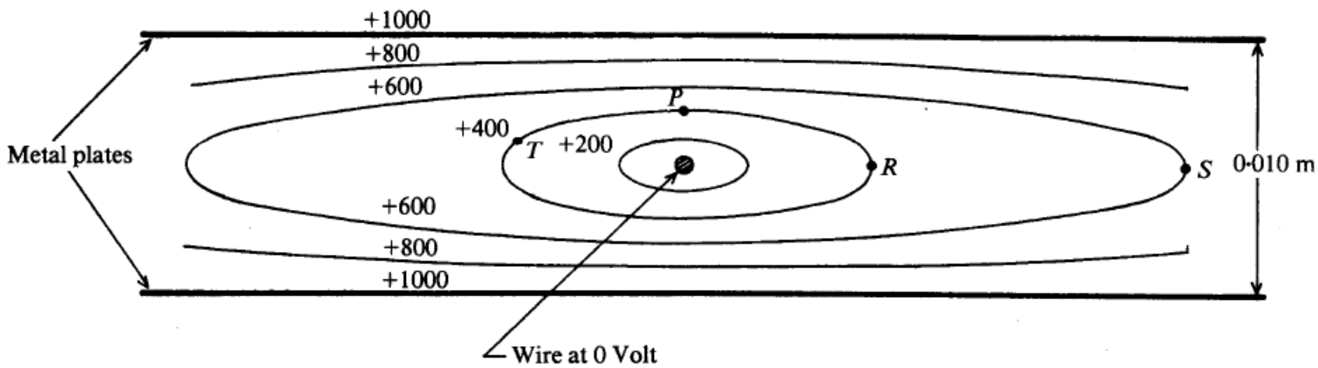


The potential at X due to the charge +2Q at S is *V* volt. Answer must be given in terms of *V*.

Example 2.19: 1986 Question 51 (1 mark)

What is the magnitude of the electric field at X due to the charge +2Q at S?

A region of electric field is set up between two parallel metal plates which are each at +1000 volt, and 0.010 m apart.. A thin wire which passes midway between them is connected to earth. A cross sectional view of the situation is shown in the diagram.
In the-diagram, points of equal potential are joined together and shown as equipotential lines. The potential of each line is indicated on the diagram in volts.



Example 2.20: 1986 Question 53 (1 mark)

Which statement **(A - D)** below, concerning the magnitude of the electric field is correct?

A. The magnitude at R is less than that at S.

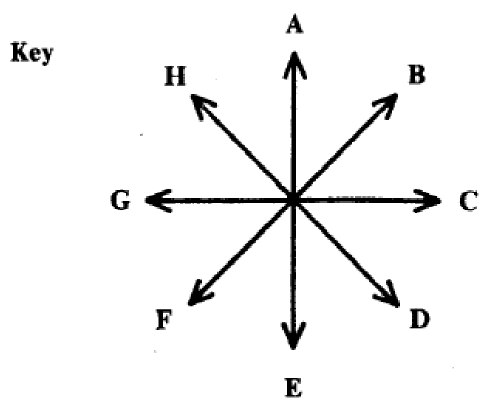
B. The magnitude at R is the same as that at S.

C. The magnitude at P is the same as that at R.

D. The magnitude at P is greater than that at R.

Example 2.21: 1986 Question 54 (1 mark)

Which arrow in the key below, best indicates the direction of the field at point T?



Example 2.22: 1986 Question 55 (1 mark)

An electron is released from rest at point T. Which statement below best describes its subsequent history?

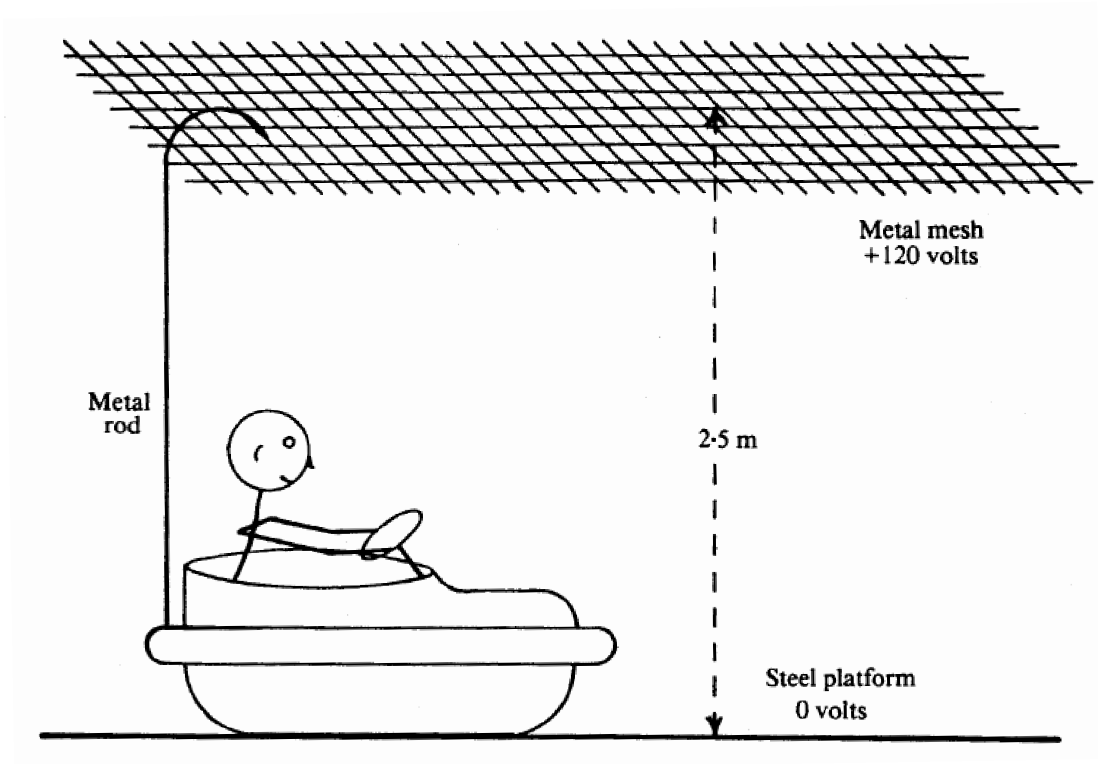
A. It will reach the wire with a kinetic energy of 400 eV.

B. It will reach the top plate with a kinetic energy of 600 eV.

C. It will reach the lower plate with a kinetic energy of 600 eV.

D. It will move **away** from the wire, while travelling parallel to the plates.

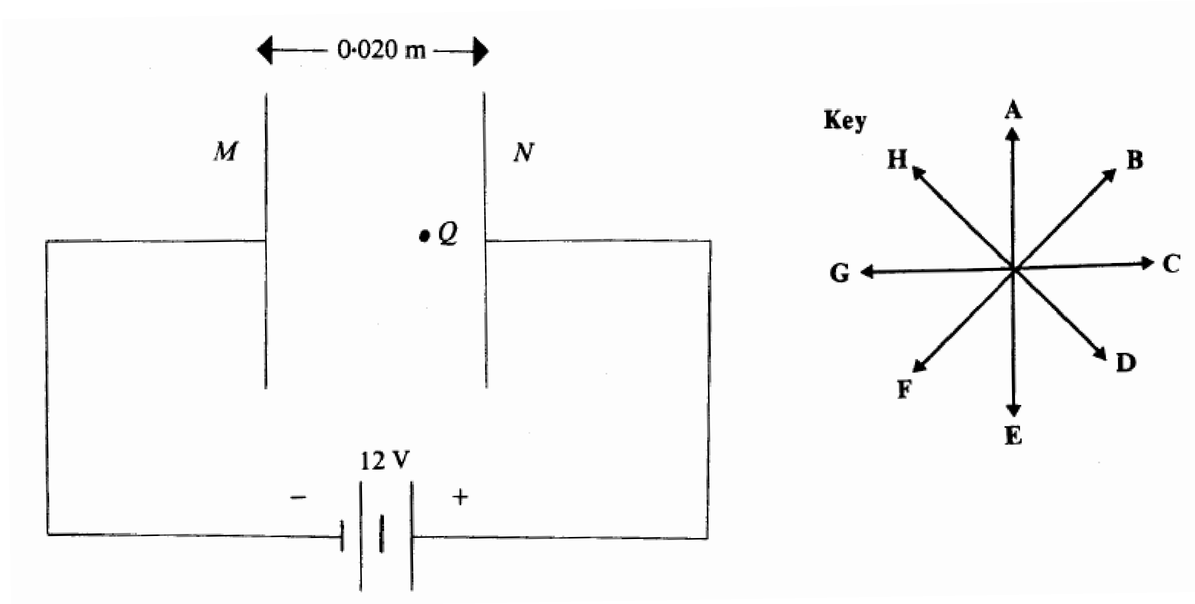
Dodgem cars in an amusement park, represented below, are electrically operated by a DC potential of 120 volts. A metal mesh above the cars is maintained at +120 volts and a steel platform, 2.5 m below the mesh, at 0 volts.



Example 2.23: 1987 Question 57 (1 mark)

What is the electric field strength (assumed constant) between the metal mesh and the steel platform?

Two metal plates M and N, are separated by 0.020 m. They are connected to a 12 V battery as shown below.



Example 2.24: 1987 Question 59 (1 mark)

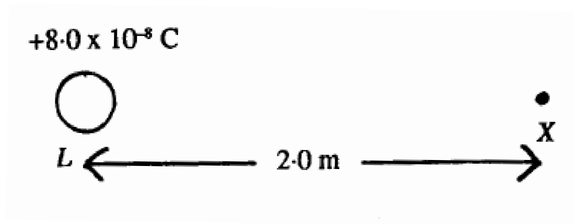
Which of the directions **(A – H)** shown in the key above best shows the direction of the electric field at the point Q?

A dust particle has an electric charge of -8.0×10^{-19} C. It is initially touching plate M.

Example 2.25: 1987 Question 60 (1 mark)

What would be the change in the magnitude of the electric potential energy of the dust particle as it moves from M to N?

In a demonstration of electric fields, two small metal spheres, L and M are used.
(The constant in Coulombs Law, $k = 9.0 \times 10^{9}$ SI units)
In the first demonstration, a charge of $+8.0 \times 10^{-8}$ coulomb is placed on L. X is a point 2.0 m from L as shown below.



Example 2.26: 1988 Question 47 (1 mark)

What is the magnitude of the electric field at X due to L?

With the same charge on L, sphere M, with a charge of -4.0×10^{10} coulomb is placed at X as shown below.

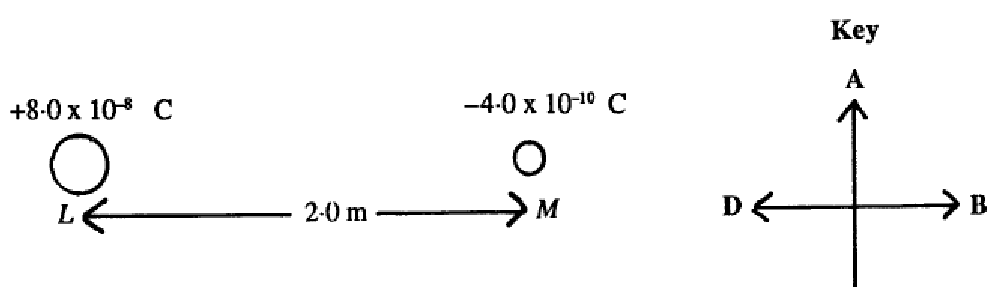


Figure 2

Example 2.27: 1988 Question 48 (1 mark)

What is the magnitude and the direction of the force on M, due to L?
Use the key **A - D** above, to indicate the direction of the force'

The formula for the force between electric charges is $F = \frac{kQ_1Q_2}{r^2}$

Example 2.28: 1989 Question 51 (1 mark)

Which of the following choices **(A - E)** below correctly states the unit of the constant, k?

A. $N^2 C^{-2}$

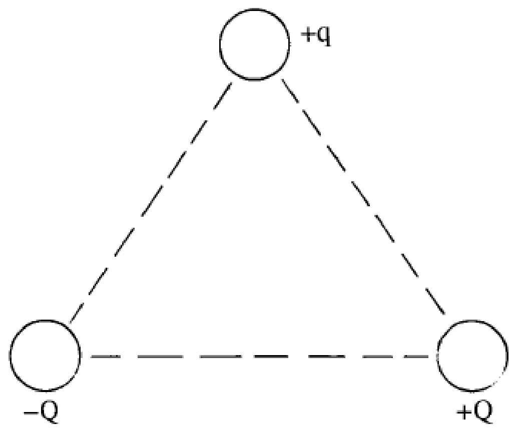
B. $N\ m\ C^{-1}$

C. $N^2 m^2 C^{-2}$

D. $N\ m^2 C^{-2}$

E. $m^2 C^{-2}$

Three electric charges, +Q, -Q and +q are placed at the vertices of an equilateral triangle as shown below.



Example 2.29: 1989 Question 52 (1 mark)

Which of the statements **(A - E)** below correctly describes the direction of the total force exerted on the charge, +q?

A. Its direction is towards charge +Q.

B. Its direction is towards charge -Q.

C. Its direction is away from charge +Q.

D. Its direction is at right angles to the line joining charges +Q and -Q.

E. Its direction is parallel to the line joining charges +Q and -Q.

A helium nucleus contains two protons and two neutrons, and may be pictured at a particular moment as shown in Figure 1 below.
The protons p_1 and p_2 each with a charge of $+1.6 \times 10^{-19}$ C are separated by 1.4×10^{-5} m, and the electrostatic force between them is 118 N.

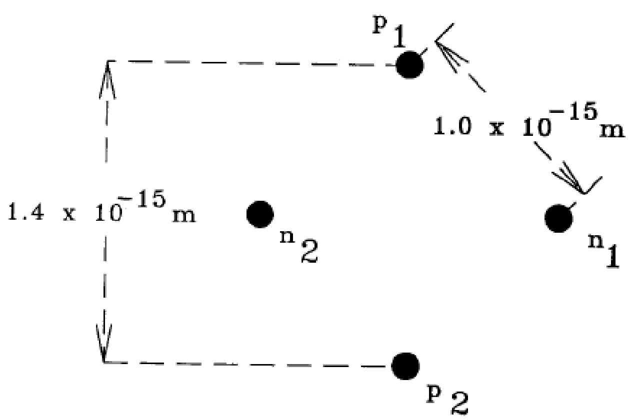


Figure 1

Example 2.30: 1990 Question 46 (1 mark)

What is the magnitude of the electrostatic force between the neutron n_1 and the proton p_1?

Example 2.31: 1990 Question 47 (1 mark)

What is the magnitude of the electric field at proton p_1 due to proton p_2?

Example 2.32: 1990 Question 48 (1 mark)

What is the magnitude of the electric field midway between the two protons?

A beam of protons enters an electrostatic deflection system which consists essentially of two parallel metal separated by 0.50 mm (0.00050 m). The situation is shown in Figure 2 below for a proton.

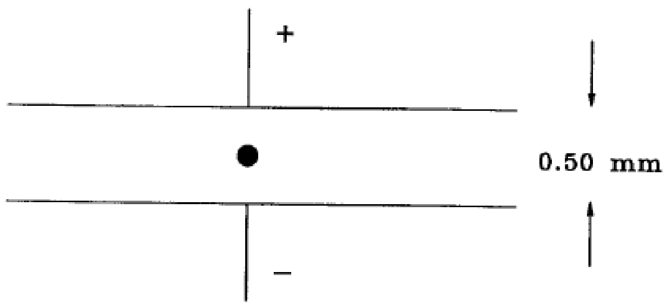


Figure 2

Example 2.33: 1990 Question 49 (1 mark)

If a-potential of 1.0×10^6 V is connected across the plates, which of the choices below gives the best estimate of the ratio $\dfrac{\text{Force on a proton between the deflector plates in Figure 2}}{\text{Force on a proton in the helium nucleus in Figure 1}}$

A. 10^{-12}

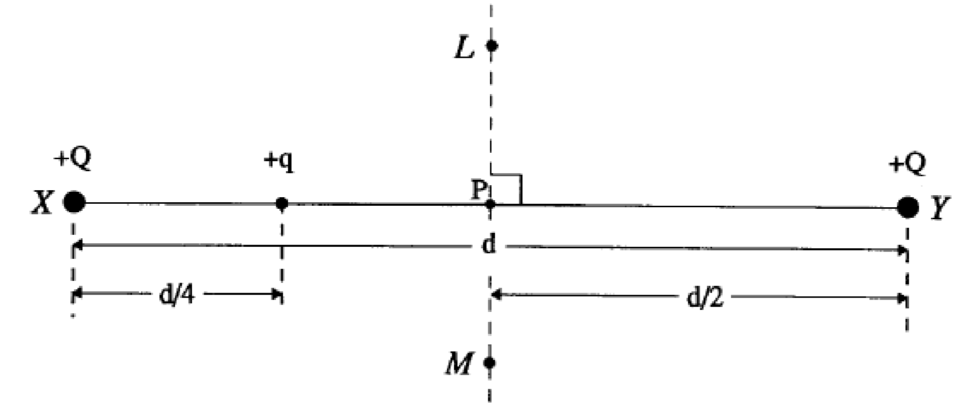
B. 10^{-6}

C. 1

D. 10^{6}

E. 10^{12}

Two equal electric charges, +Q, are placed a distance d apart at X and Y, as shown in the figure. The points L and M are perpendicularly above and below the midpoint of the line joining X and Y.



A small positive charge +q is placed on the line between X and Y, a distance $\frac{d}{4}$ from the charge at X.

Example 2.34: 1991 Question 42 (1 mark)

Which of the following expressions gives the magnitude of the force experienced by the charge, +q? k is the electrostatic constant.

A. $\frac{kQq}{4d^2}$

B. $\frac{kQq}{d^2}$

C. $4\frac{kQq}{d^2}$

D. $16\frac{kQq}{d}$

E. $16\frac{kQq}{d^2}$

F. $\frac{128}{9}\frac{kQq}{d^2}$

Example 2.35: 1991 Question 43 (1 mark)

If the small charge is now placed at point P, precisely midway between X and Y, which of the following expressions best describes the net electrostatic force on it?

A. There is no force on it

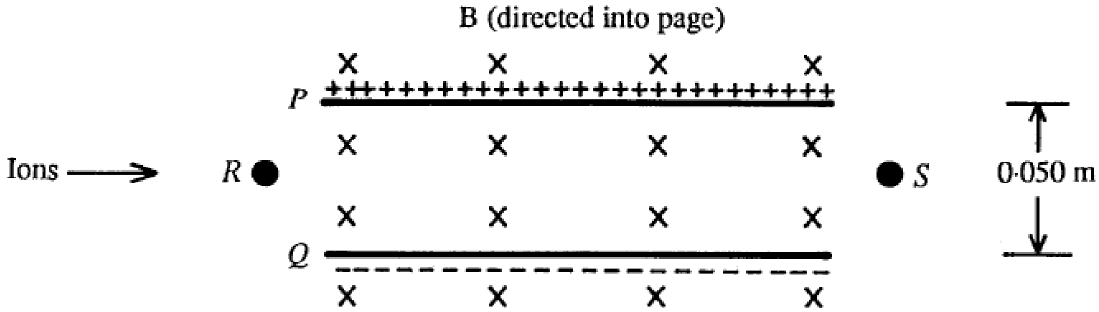
B. There is a force on it towards Y.

C. There is a force on it towards X.

D. There is a force on it towards L.

E. There is a force on it towards M.

The velocity selector of a mass spectrograph is shown below. By adjusting the uniform magnetic field B, (directed into the page), and the uniform electric field between the plates P and Q, ions with a particular velocity can be made to move in a straight line through the region.
(The charge on the electron = 1.6×10^{-19} C.)



In one experiment, singly charged oxygen ions (0^+) enter the region at R.
The potential difference between the plates is 500 V and their separation is 0.050 m.

Example 2.36: 1988 Question 49 (1 mark)

What is the magnitude of the electric field strength in the region between the plates P and Q?

Example 2.37: 1988 Question 50 (1 mark)

What is the magnitude of the force on a single oxygen ion due to the electric field?

In a second experiment, singly charged ions of lithium (Li^+) enter the region at R with a speed of 5.0×10^5 m s^{-1}.
The electric and magnetic fields are adjusted so that the lithium ions travel in a straight line RS.

Example 2.38: 1988 Question 51 (1 mark)

If the electric field strength, E, is adjusted to 2.0×10^4 V m^{-1}, what is the magnitude of the magnetic field strength B, for the ions to travel in this straight line?

The following information relates to Questions 3 and 4.

The first stage of the electrons' path through the synchrotron is the electron-gun injector, in which stationary electrons are initially accelerated by an electric field, E.

In a particular synchrotron, the electric field in the injector is 200 kV m^{-1}.

Example 2.39: 2009 Question 3 (Synchrotron)

Which one of the following best gives the force on a single electron while it is in the field of the injector?

A. 9.1×10^{-31} N

B. 1.6×10^{-19} N

C. 3.2×10^{-14} N

D. 1.8×10^{-25} N

As the electrons leave the injector, they are moving at a speed of 8.4×10^{7} m s^{-1}.

Example 2.40: 2009 Question 4 (Synchrotron)

Which one of the following best gives the length of the accelerating section of the electron-gun?

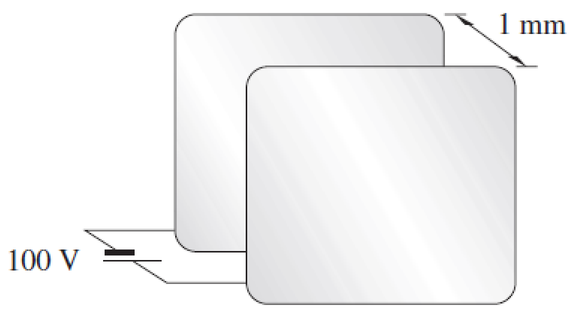
A. 0.01 m

B. 0.1 m

C. 1.0 m

D. 2.0 m

Two parallel metal plates are 1 mm apart. A potential difference of 100 V is applied as shown.



Example 2.41: NSW 2007 Question 11 (1 mark)

What is the magnitude of the uniform electric field between the plates?

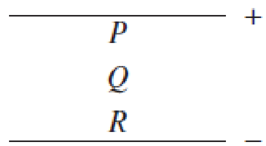
A. 10^{-3} V m^{-1}

B. 10^{-1} V m^{-1}

C. 10^{2} V m^{-1}

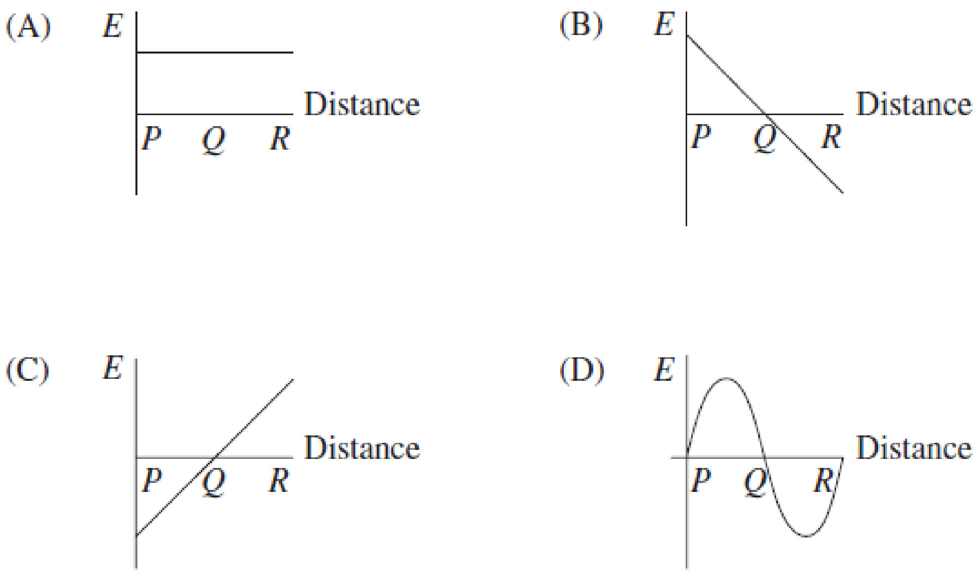
D. 10^{5} V m^{-1}

The diagram shows two parallel plates with opposite charges. *P*, *Q* and *R* represent distances from the positive plate.



Example 2.42: NSW 2009 Question 15 (1 mark)

Which of the following graphs describes the electric field strength, *E*, between the plates?



Example 2.43: NSW 2016 Question 3 (1 mark)

A region of space contains a constant magnetic field and a constant electric field. How will these fields affect an electron that is stationary in this region?

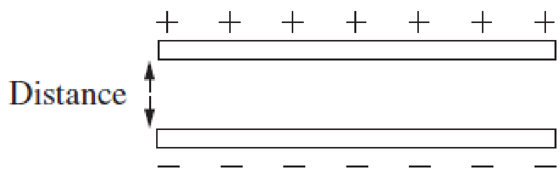
A. Both fields will exert a force.

B. Neither field will exert a force.

C. Only the electric field will exert a force.

D. Only the magnetic field will exert a force.

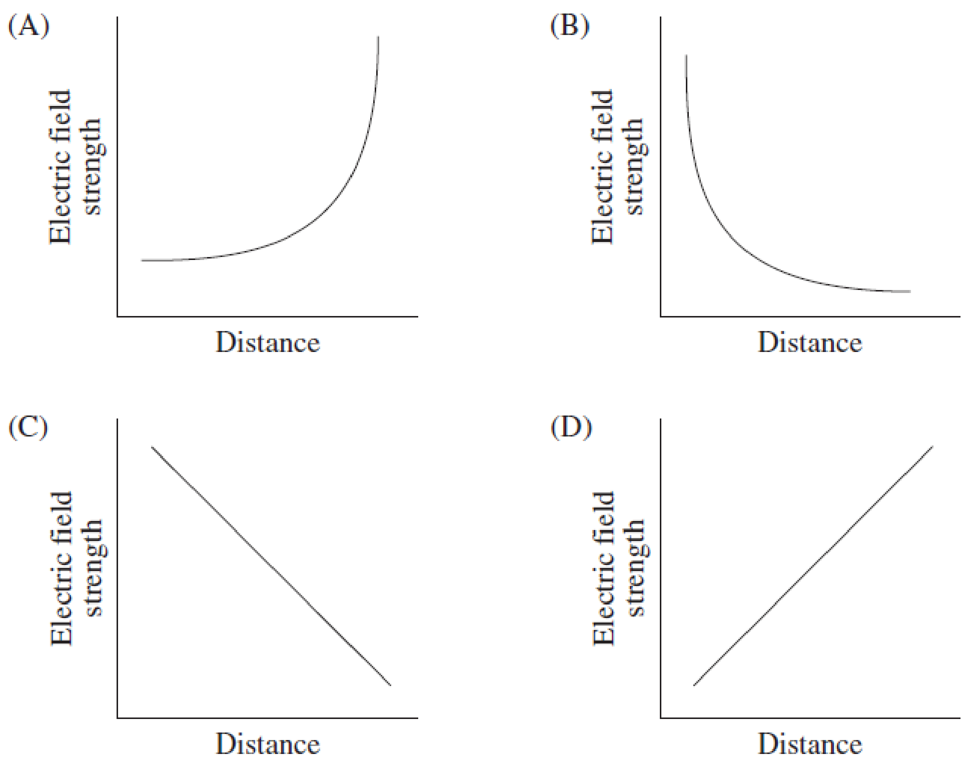
Two charged plates are initially separated by a distance as shown in the diagram.



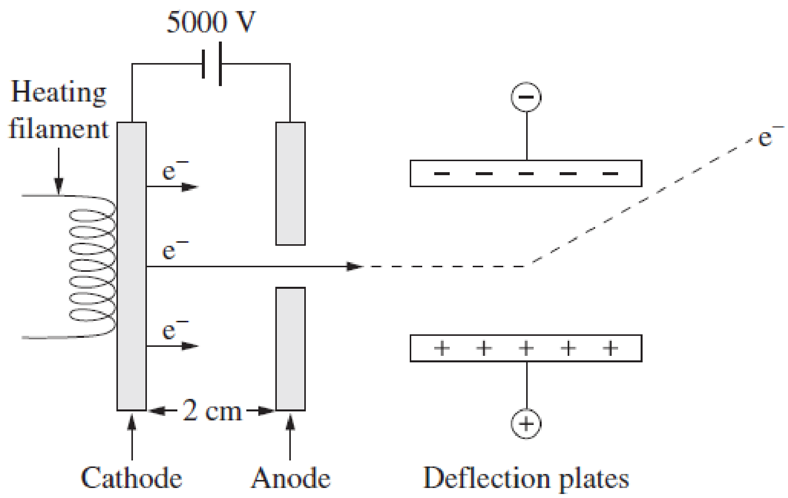
The potential difference between the plates remains constant.

Example 2.44: NSW 2013 Question 14 (1 mark)

Which of the graphs best represents the change in electric field strength as the distance between the two plates is increased?



A part of a cathode ray oscilloscope was represented on a website as shown.



Electrons leave the cathode and are accelerated towards the anode.

Example 2.45: NSW 2016 Question 24a (3 marks)

Explain why the representation of the path of the electron between the deflection plates is inaccurate.

Example 2.46: NSW 2016 Question 24b (2 marks)

Calculate the force on an electron due to the electric field between the cathode and the anode.

Example 2.47: NSW 2016 Question 24c (2 marks)

Calculate the velocity of an electron as it reaches the anode.

Effects of fields

- **analyse the use of a magnetic field to change the path of a charged particle, including:**
  - **– the magnitude and direction of the force applied to an electron beam by a magnetic field: *F* = *qvB*, in cases where the directions of *v* and *B* are perpendicular or parallel**
  - **– the radius of the path followed by a low-velocity electron in a magnetic field:**

$$qvB = \frac{mv^2}{r}$$

Application of field concepts

- **describe the interaction of two fields, allowing that electric charges, magnetic poles and current carrying conductors can either attract or repel, whereas masses only attract each other**

2006 Synchrotron	2007 Synchrotron	2008 Synchrotron	2009 Synchrotron	2010 Synchrotron	2011 Synchrotron	2012 Synchrotron	2013 Synchrotron	2014 Synchrotron	2015 Synchrotron	2016 Synchrotron
8	3, 5	2, 3	5, 6, 7	3, 4	3, 4	3, 4, 5	11	3, 4	5	3, 4

Force on a moving charge

Current is defined as $I = \frac{q}{t}$.

The force on a current is given as F = Bil, which can be considered as $F = \frac{Bql}{t}$.

This can be rewritten as F = Bqv, where v is the speed of the charge given as $\frac{l}{t}$.

Using the right hand rule the direction of the force can be determined.

If an electron is moving to the left, it can be considered as a current to the right. The force will always be perpendicular to the direction of motion, so it will result in circular motion.

Therefore we can equate $F = \frac{mv^2}{r}$ with F = Bqv.

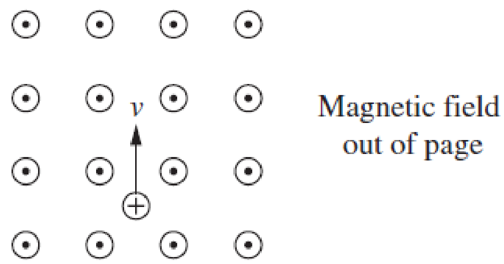
$$\therefore Bqv = \frac{mv^2}{r}.$$

This applies when the velocity is low so that relativistic effects do not need to be taken into consideration.

The equation $Bqv = \frac{mv^2}{r}$ can also be simplified by cancelling v from both sides, this gives

$\therefore Bq = \frac{mv}{r}$, where mv is the momentum of the electron.

At a particular moment, a positively charged particle is moving with velocity *v* in a magnetic field as shown.



Example 2.48: NSW 2001 Question 2 (1 mark)

At this moment, what is the direction of the force on the positively charged particle?

A. To the right

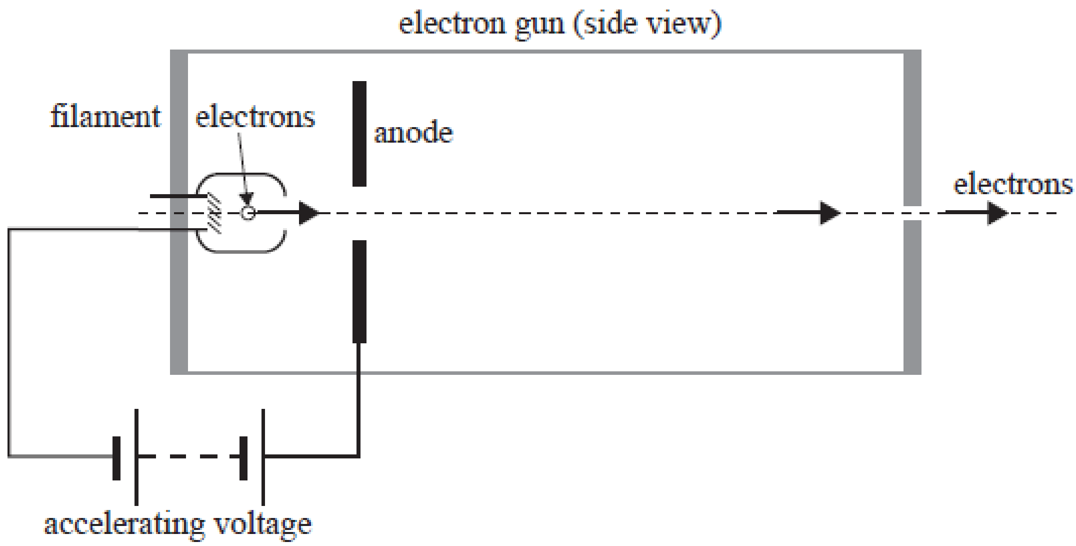
B. To the left

C. Into the page

D. Out of the page

The following information relates to Questions 1–4.

An electron gun is used to inject electrons into the linac of a synchrotron.
The figure shows a schematic diagram of the electron gun.
The mass of the electron is 9.1×10^{-31} kg, and the charge on the electron is 1.6×10^{-19} C.



The electron gun is tested by first operating it at a low voltage.
Using this voltage the acceleration of the electrons is 1.8×10^{15} m s^{-2}.

Example 2.49: 2010 Question 1 (Synchrotron), 2 marks

What is the magnitude of the electric field acting on the electrons?

A. 1 kV m^{-1}

B. 10 kV m^{-1}

C. 100 kV m^{-1}

D. 1000 kV m^{-1}

The accelerating voltage of the electron gun is now increased to its maximum value.
The electrons now reach a speed of 4.6×10^{7} m s^{-1}.

Example 2.50: 2010 Question 2 (Synchrotron), 2 marks

Which of the following best gives the accelerating voltage now?

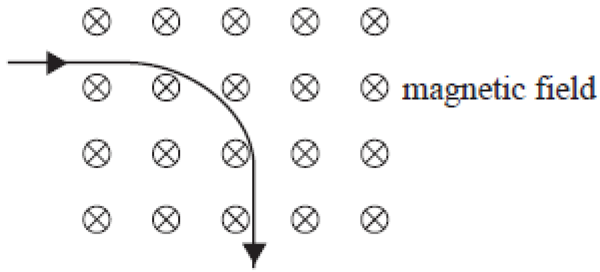
A. 600 V

B. 2 600 V

C. 6 000 V

D. 260 000 V

An electron with a speed of 4.6×10^{7} m s^{-1} then enters a uniform magnetic field and moves in a circular path. The radius of the path is 0.40 m. This is shown below.



Example 2.51: 2010 Question 3 (Synchrotron), 2 marks

What is the magnitude of the magnetic field required to achieve this path?

A. 4.2×10^{-3} T

B. 6.5×10^{-4} T

C. 1.5×10^{3} T

D. 3.0×10^{4} T

The magnetic field is now adjusted to 5.0×10^{-4} T.

Example 2.52: 2010 Question 4 (Synchrotron), 2 marks

Which of the following now best gives the magnetic force on the electron?

A. 4.80×10^{-17} N

B. 3.68×10^{-15} N

C. 2.40×10^{-14} N

D. 3.68×10^{-7} N

Example 2.53: NSW 2006 Question 12 (1 mark)

A charged non-magnetic particle is moving in a magnetic field.
What would NOT affect the magnetic force on the particle?

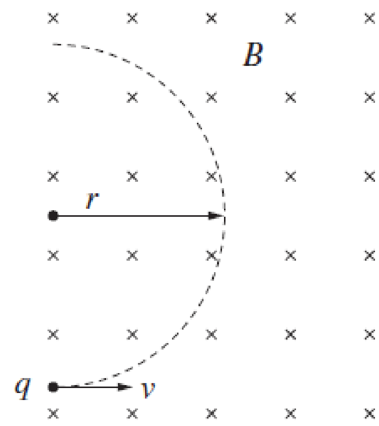
A. The strength of the magnetic field

B. The magnitude of the charge on the particle

C. The velocity component parallel to the magnetic field direction

D. The velocity component perpendicular to the magnetic field direction

A charged particle, *q*, enters a uniform magnetic field *B* at velocity *v*. The particle follows a circular path of radius *r* as shown.



Example 2.54: NSW 2010 Question 15 (1 mark)

If the magnitude of the magnetic field were doubled and the other variables were kept constant, what would the new radius be?

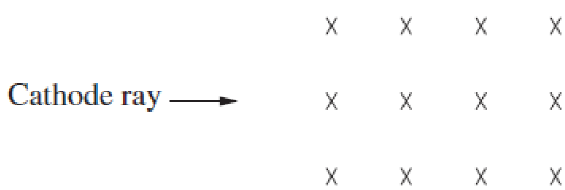
A. $\frac{r}{4}$

B. $\frac{r}{2}$

C. 2r

D. 4r

The diagram shows a cathode ray entering a magnetic field.



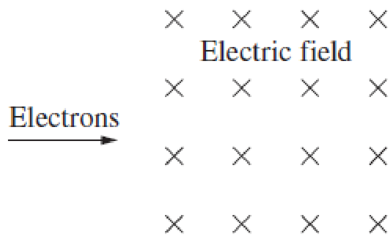
An electric field is applied to cancel the effect of the magnetic field on the cathode ray.

Example 2.55: NSW 2014 Question 18 (1 mark)

Which row of the table correctly describes the direction of the applied electric field, and the direction of the force acting on the cathode ray as a result of the magnetic field?

	Direction of the electric field applied	*Direction of force as result of the magnetic field*
A.	↑	↑
B.	↓	↑
C.	↑	↓
D.	↓	↓

The figure shows electrons travelling in a vacuum at 5.2×10^4 m s^{-1} entering an electric field of 10 V m^{-1}.



Example 2.56: NSW 2016 Question 23b (3 marks)

A magnetic field is applied so that the electrons continue undeflected. What is the magnitude and direction of the magnetic field?

Effects of fields

- **analyse the use of gravitational fields to accelerate mass, including:**

  – gravitational field and gravitational force concepts, $g = \frac{GM}{r^2}$ and $F_g = G\frac{M_1M_2}{r^2}$

  – potential energy changes in a uniform gravitational field: $E_g = mg\Delta h$

  – the change in gravitational potential energy from the area under a force- distance graph and area under a field distance graph multiplied by mass.

2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
15, 16	12, 13	15, 16, 17	13, 14	18, 19 20	21, 22, 23	8a	7a, b	5a, b	7a, b	

Gravitational fields

Newton determined that gravity is a force of attraction that exists between any two bodies. In fact, any two objects that have mass will exert a gravitational force of attraction. Gravitational forces are very weak and only become noticeable when at least one of the objects is extremely massive. The gravitational force can be calculated using the formula below.

The force acts equally on both masses $F = mg = \frac{GMm}{r^2}$

where F = gravitational force on each mass (N)
G = universal gravitational constant
M, m = masses (kg)
r = distance between the centres on the masses (M, m)
The Universal Gravitational constant $G = 6.67 \times 10^{-11}$ N m^2 kg^{-2}

For a body on, or above, the surface of the Earth, the mass of the Earth may be considered to be concentrated at its centre. The gravitational field is found by dividing the gravitational force by the mass of the smaller object.

The gravitational field $g = \frac{GM}{r^2}$

Example 2.57: NSW 2007 Question 4 (1 mark)

The acceleration due to gravity on Earth's surface is *g*. Suppose the radius of Earth was reduced to a quarter of its present value while its mass remained the same. What would be the new value of the acceleration due to gravity on the surface?

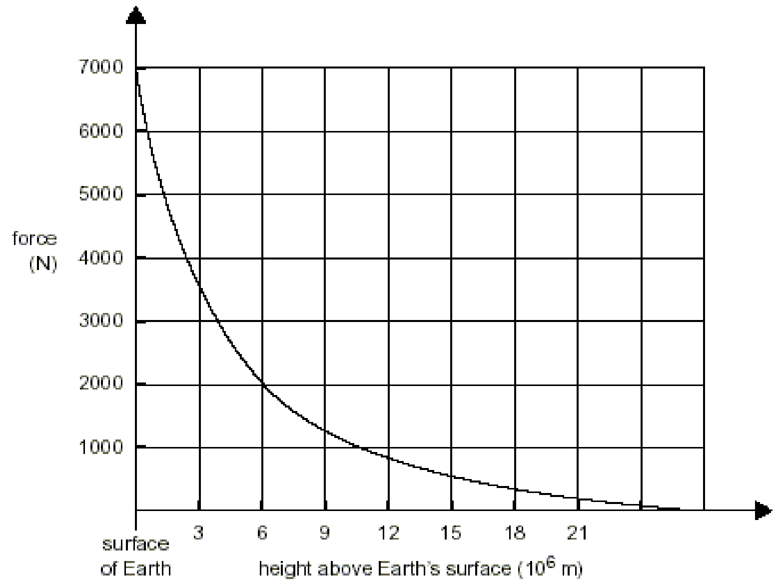
A. $\frac{1}{16}g$

B. $\frac{1}{4}g$

C. 4g

D. 16g

The Mars Odyssey spacecraft was launched from Earth on 7 April 2001 and arrived at Mars on 23 October 2001. The figure below is a graph of the gravitational force acting on the 700 kg Mars Odyssey spacecraft plotted against height above Earth's surface.



Example 2.58: 2002 Question 1 (3 marks)

Estimate the minimum launch energy needed for Mars Odyssey to escape Earth's gravitational attraction.

Application of field concepts

- **apply the concepts of force due to gravity, F_g, and normal reaction force, F_N, including satellites in orbit where the orbits are assumed to be uniform and circular**
- **model satellite motion (artificial, Moon, planet) as uniform circular orbital motion $a = \frac{v^2}{r} = \frac{4\pi^2 r}{T^2}$;**

2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
15, 16	12, 13	15, 16, 17	13, 14	18, 19 20	21, 22, 23	8a	7a, b	5a, b	7a, b	

The moon is the Earth's only natural satellite but there are thousands of artificial satellites orbiting. For a satellite in a stable circular orbit, the only force acting on a satellite is the gravitational attraction between it and the central body. This force acting on it is always perpendicular to its motion. Therefore the energy of the satellite is unchanged as it orbits. The kinetic energy and gravitational potential energy both stay the same. The force of gravity holds the satellites in their orbits and causes them to have acceleration towards the central mass.

Since satellites are in a continual state of free-fall, their acceleration will equal the gravitational field strength at that point.

$$\therefore a = \frac{v^2}{r} \qquad \text{Using } v = \frac{2\pi r}{T} \qquad \therefore a = \frac{4\pi^2 R}{T^2}$$

$$\text{Using } F = \frac{GMm}{R^2} \text{ and } F = mg \qquad \therefore \frac{GM}{R^2} = g$$

The acceleration of the satellite is independent of the mass of the satellite.

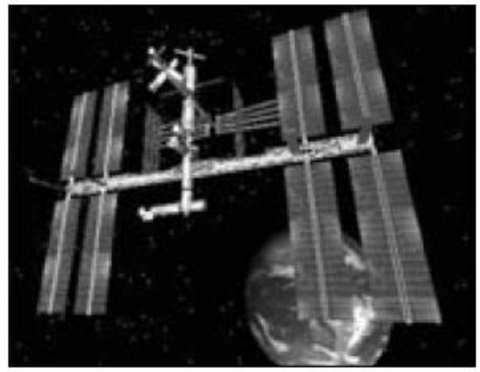
The other sort of question that they ask here is to calculate the speed of the satellite. The two main problems that students have are:
1) Determining the radius/distance (it is always the distance between the two centres of mass) and
2) Managing the powers of ten on their calculator.

To calculate the value of 'g' at the Earth's surface:

$G = 6.67 \times 10^{-11}$ N m^2 kg^{-2},
$M = 6.0 \times 10^{24}$ kg,
$r = 6.4 \times 10^{6}$ m.
$\therefore g = 9.8$ N kg^{-1}.

At the surface of the Earth, the gravitational field strength, g, is 9.8 N kg^{-1}, it becomes weaker further from the Earth. 400 km above the Earth g is 8.7 N kg^{-1}. Any object that is falling freely through a gravitational field will fall with acceleration equal to the gravitational field strength at the point.

The International Space Station (ISS) is in orbit around the Earth at an altitude 380 km.



Radius of Earth = 6.4×10^6 m

Mass of Earth = 6.0×10^{24} kg

Total mass of ISS = 5×10^5 kg

Universal gravitational constant $G = 6.7 \times 10^{-11}$ N m^2 kg^{-2}

Example 2.59: 2004 Pilot Sample Question 12 (1 mark)

What is the period of the ISS in seconds?

Example 2.60: 2004 Pilot Sample Question 13 (3 marks)

Which row of the table (**A – E**) best describes the acceleration and speed of the ISS, and the net force acting on it while in orbit around Earth?

	Acceleration	Speed	Net force
A.	zero	constant	zero
B.	zero	constant	finite
C.	finite	constant	zero
D.	finite	constant	finite
E.	finite	changing	finite

Newton was the first person to quantify the gravitational force between two masses M and m, with their centres-of-mass separated by a distance R as $F = \frac{GMm}{R^2}$ where G is the universal gravitational constant, and has a value of 6.67×10^{-11} N m^2 kg^{-2}.

For a mass *m* **on the surface of Earth** (mass *M*) this becomes F = gm, where $g = \frac{GM}{R^2}$.

Example 2.61: 2005 Question 14 (2 marks)

Which one of the expressions (**A – D**) **does not** describe the term g?

A. g is the gravitational field at the surface of Earth.

B. g is the force that a mass 'm' feels at the surface of Earth.

C. g is the force experienced by a mass of 1 kg at the surface of Earth.

D. g is the acceleration of a free body at the surface of Earth.

The dwarf planet Pluto was discovered in 1930, and was thought to be the outermost member of our solar system. It can be considered to orbit the Sun in a circle of radius 6 billion kilometres (6.0×10^{12} m).

In 2003 a new dwarf planet, Eris, was discovered. It has approximately the same mass as Pluto, but the average radius of its orbit around the Sun is 10.5 billion kilometres (10.5×10^{12} m).

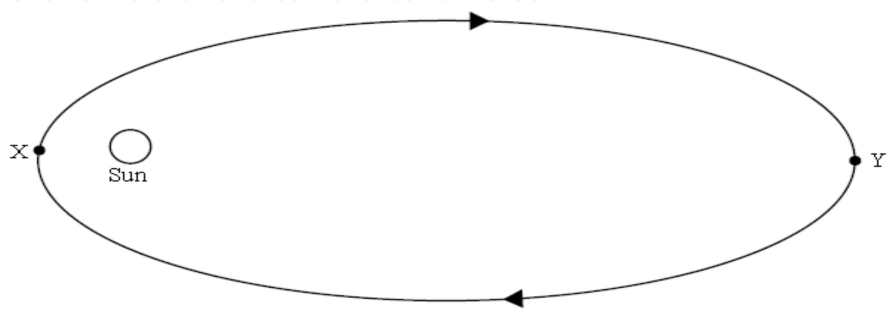
Example 2.62: 2007 Question 12 (2 marks)

Which of the choices **(A – D)** below gives the best estimate of the ratio

$$\frac{\text{gravitational attraction of the Sun on Eris}}{\text{gravitational attraction of the Sun on Pluto}}\ ?$$

A. 0.33 **B.** 0.57 **C.** 1.75 **D.** 3.06

The figure shows the orbit of a comet around the Sun.



Example 2.63: 2008 Question 15 (2 marks)

Describe how the **speed** and **total energy** of the comet vary as it moves around its orbit from X to Y.

The **Jason 2** satellite reached its operational circular orbit of radius 1.33×10^7 m on 4 July 2008 and then began mapping the Earth's oceans.

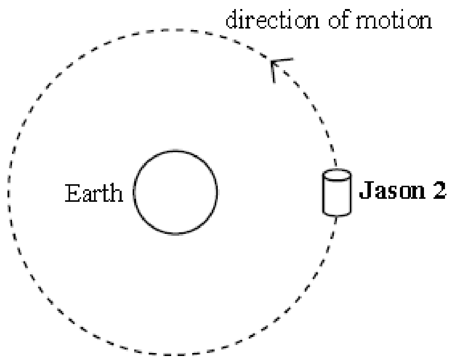
mass of the Earth = 5.98×10^{24} kg

mass of **Jason 2** = 525 kg

$G = 6.67 \times 10^{-11}$ N m^2 kg^{-2}

Example 2.64: 2009 Question 13 (2 marks)

On the figure below, draw one or more labelled arrows to show the direction of any force(s) acting on **Jason 2** as it orbits Earth. You can ignore the effect of any astronomical bodies other than the Earth.



Assume that somewhere in space there is a small spherical planet with a radius of 30 km. By some chance a person living on this planet visits Earth. He finds that he weighs the same on Earth as he did on his home planet, even though Earth is so much larger.

Earth has a radius of 6.37×10^6 m and a mass of 5.98×10^{24} kg. The universal gravitational constant, G, is 6.67×10^{-11} N m^2 kg^{-2}.

The acceleration due to gravity (g), or the gravitational field at the surface of Earth, is approximately 10 N kg^{-1}.

Example 2.65: 2011 Question 21 (1 mark)

What is the value of the gravitational field on the surface of the visitor's planet?

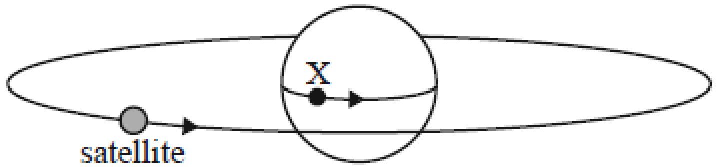
Example 2.66: 2011 Question 22 (2 marks)

What is the mass of the visitor's planet? Explain your answer by showing clear working out.

Example 2.67: 2011 Question 23 (2 marks)

The visitor's home planet is in orbit around its own small star at a radius of orbit of 1.0×10^9 m. The star has a mass of 5.7×10^{25} kg. What would be the period of the orbit of the visitor's planet? Show your working.

A satellite is in a geostationary circular orbit over Earth's equator. It remains vertically above the same point X on the equator, as shown below.



Data

mass of Earth	$M_E = 6.0 \times 10^{24}$ kg
radius of Earth	$R_E = 6.4 \times 10^6$ m
mass of satellite	1000 kg
universal gravitational constant	$G = 6.7 \times 10^{-11}$ N m^2 kg^{-2}

Example 2.68: 2013 Question 7a (1 mark)

Calculate the period of the orbit of the satellite.

Example 2.69: 1970 Question 23 (1 mark)

In terms of the quantities given below, what is the expression for the gravitational field strength, g, at the surface of the earth?

G : universal constant of gravitation.
M : mass of the earth.
R : radius of the earth.

Example 2.70: 1970 Question 24 (1 mark)

Which of the following expressions is correct for the velocity v of a satellite orbiting the earth close to the earth's surface (i.e. the radius of orbit may be taken as R)?

A. $v = Rg$

B. $v = \sqrt{\frac{Rg}{M}}$

C. $v = \sqrt{MRg}$

D. $v = \sqrt{Rg}$

E. $v = R\sqrt{g}$

Example 2.71: 1997 Question 1 (3 marks)

Using Newton's law of universal gravitation show that the radius (***R***) of a satellite's circular orbit around a planet of mass (***M***) is related to its period (***T***) by the relationship:

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

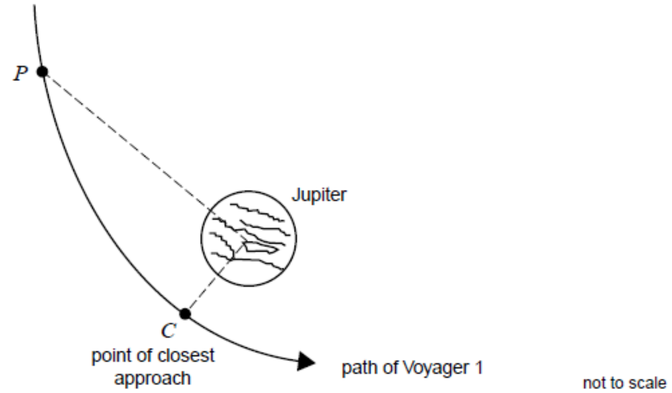
where *G* is the Universal Gravitational Constant (6.67×10^{-11} N m^2 kg^{-2}).

There are many satellites in circular orbit around the Earth. Some, used for communication, remain above a given point on the Earth's equator and are called **geostationary**. They have a period of one day or 8.64×10^4 s.

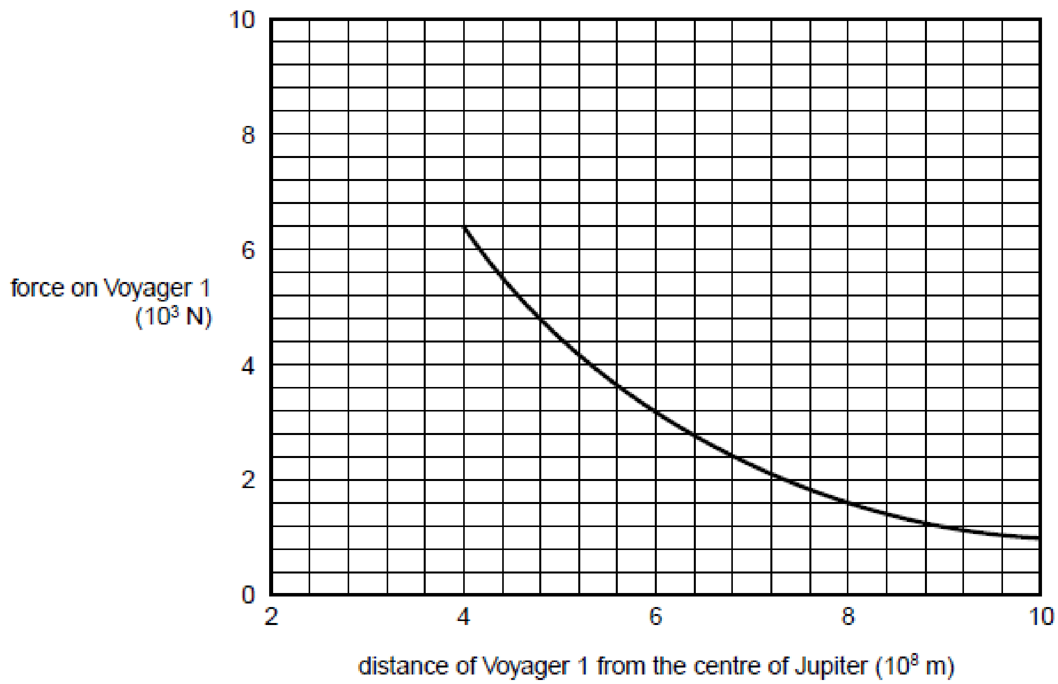
Example 2.72: 1997 Question 2 (2 marks)

Given that the mass of the Earth is 6.0×10^{24} kg, determine the orbital radius of all geostationary Earth satellites.

The path of the Voyager 1 spacecraft in 1979, when it travelled past Jupiter with its engines off, is shown below



The figure below shows how the force that attracted Voyager 1 depended on the distance from the centre of Jupiter.



As Voyager 1 moved from point *P* to point *C* (see above) the kinetic energy changed by 4.0×10^{11} J.

At point *C*, the point of closest approach, the force attracting the spacecraft to Jupiter was 6.4×10^3 N.

Example 2.73: 1997 Question 4 (2 marks)

Find the change in gravitational potential energy of Voyager 1 as it moved from point *P* to point *C*. Indicate in your answer whether this was a **gain** or a **loss** in energy.

Example 2.74: 1997 Question 5 (3 marks)

Explain **how** you would use the information given above to determine the distance of point *P* from the centre of Jupiter. (Note that no numerical answer is required.)

A space shuttle, travelling around Earth in a circular orbit of radius 6.76×10^6 m, docked with a space station. The period of the orbit of the space station was 5.52×10^3 s.

Example 2.75: 1995 Question 1 (1 mark)

Calculate the orbital speed of the space shuttle.

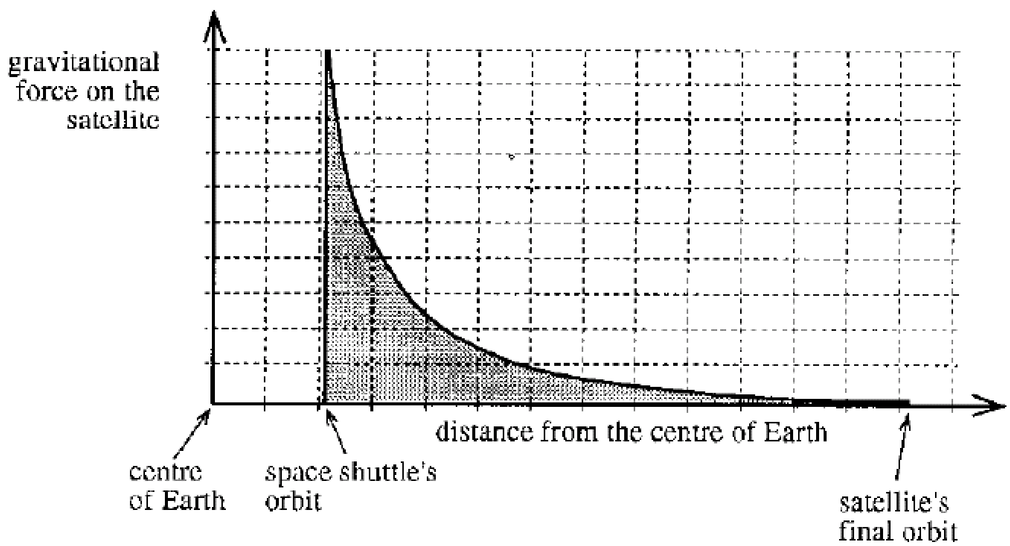
The gravitational force exerted by Earth on the space station is given by $\frac{GMm}{r^2}$,

where $G = 6.67 \times 10^{-11}$ N m^2 kg^{-2}, M = mass of Earth,
m = mass of space station, $r = 6.76 \times 10^6$ m.

Example 2.76: 1995 Question 2 (1 mark)

Using the above equation and the known period of the orbit of the space station, show that the mass of Earth is 6.0×10^{24} kg. Show your working.

A communication satellite was launched from the space shuttle. The figure shows the gravitational force exerted by Earth on the satellite at different distances from the centre of Earth.



Example 2.77: 1995 Question 5 (1 mark)

Which one of the statements (**A - D**) below, correctly describes what the shaded area represents?
It represents

A. the gain in gravitational potential energy when the communication satellite moved from the orbit of the shuttle to its final orbit.

B. the kinetic energy of the communication satellite in its final orbit.

C. the sum of the kinetic energy and the gravitational potential energy of the communication satellite in its final orbit.

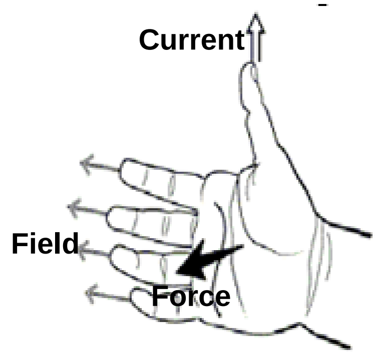
D. the loss in gravitational potential energy when the communication satellite moved from the orbit of the shuttle to its final orbit.

Application of field concepts

- **investigate and analyse theoretically and practically the force on a current carrying conductor due to an external magnetic field, *F* = *nIlB*, where the directions of *I* and *B* are either perpendicular or parallel to each other**

2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
2,3	3	2,3	5, 6, 7	4, 5	4, 5			12b		13a, b

Forces on current carrying conductors



- If a conductor in a magnetic field has a current flowing in it, there is a force acting on it.
- If a current is flowing in a conductor there is an associated magnetic field.

Any conductor that carries electric current will be surrounded by a magnetic field, given by the right-hand grip rule. When this conductor is placed in a magnetic field, the two magnetic fields will interact and a force will be produced.

The direction of the force can be determined by the right hand slap rule.

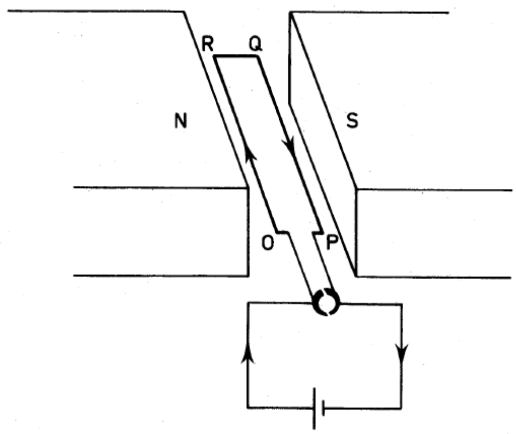
In this rule, the hand is opened flat and the fingers are aligned with the magnetic field. The thumb is pointed in the direction of current flow and the palm is now facing the direction of the force.

The force on a wire carrying a current in a magnetic field is proportional to the current, the length of wire in the field, and the strength of the field.

F = BiL. If there is more than one wire, ‘n’ wires, then F = nBiL.

Electromagnetism is a temporary effect caused by the flow of electric current and it disappears when the current flow is stopped.

If a conductor is connected to an AC power supply the current direction will alternate and so does the direction of the associated magnetic field.



A rectangular loop of wire ORQP carrying a current of 2.0 A is in a uniform magnetic field of induction 0.50 Wb m^{-2}.
OR= QP = 0.10 m, RQ = 0.02 m.

Example 2.78: 1978 Question 64 (1 mark)

What is the magnitude of the force on QP?

Example 2.79: 1978 Question 65 (1 mark)

What is the direction of the force on QP?

A. Vertically upwards.

B. Vertically downwards.

C. To the left.

D. To the right.

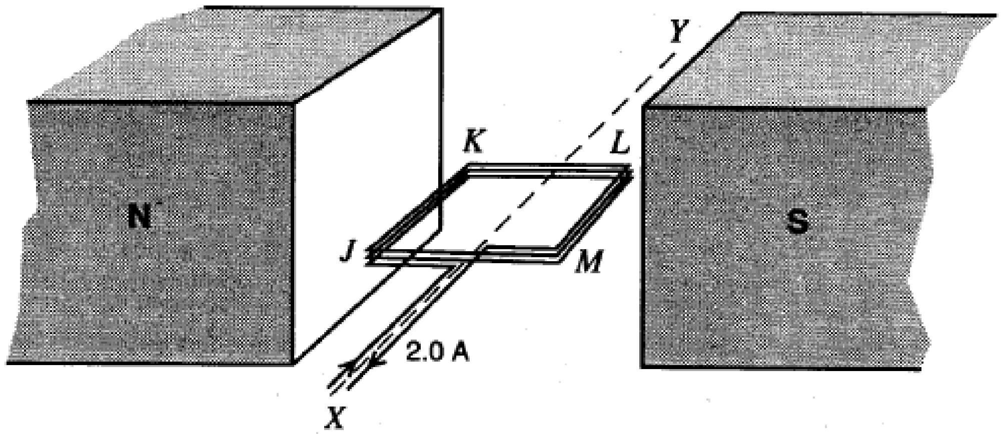
E. In the direction OR.

F. In the direction RO.

Example 2.80: 1978 Question 66 (1 mark)

What is the magnitude of the force on RQ?

A DC electric motor is illustrated below.



The permanent magnet produces a uniform magnetic field of 3.0×10^{-2} T between the pole pieces. The coil JKLM, wound on a square armature of side 0.05 m, consists of 20 turns of wire. There is a current of 2.0 A in each turn of the coil. The armature can rotate about the axis XY.

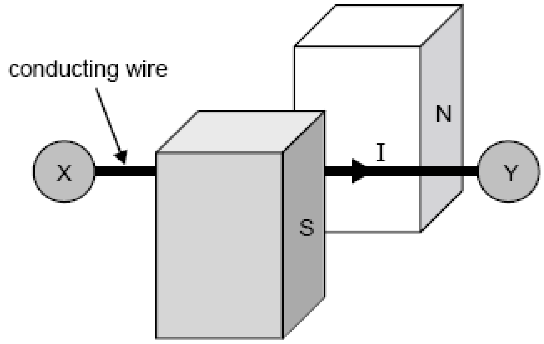
Example 2.81: 1996 Question 7 (1 mark)

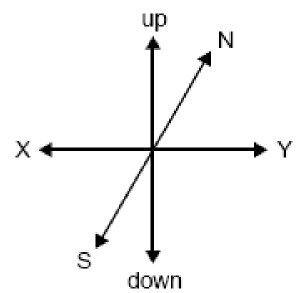
For the coil oriented horizontally, calculate the magnitude of the total force exerted on the 20 turns of side JK.

Example 2.82: 1996 Question 8 (1 mark)

For the coil oriented horizontally, calculate the magnitude of the total force exerted on the 20 turns of side KL.

A 10 mm section of a conducting wire is placed in a uniform magnetic field as shown below.
A DC current of I = 1.0 A produces a force of 0.01 N and stretches the wire.





Example 2.83: 2004 Pilot Question 3 (2 marks)

Calculate the strength of the magnetic field

Example 2.84: 2004 Pilot Question 4 (2 marks)

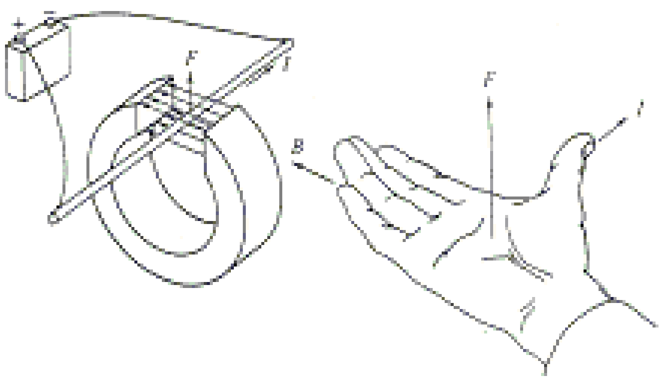
The wire is connected to an AC power source of the same RMS voltage and frequency 100 Hz instead of a DC source. Briefly explain what happens to the wire.

Application of field concepts

- **investigate and analyse theoretically and practically the operation of simple DC motors consisting of one coil, containing a number of loops of wire, which is free to rotate about an axis in a uniform magnetic field and including the use of a split ring commutator**

2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
	4, 5		8		3	2a, 2b	16a, b, c	17a, b, c	12a	14a, b, c

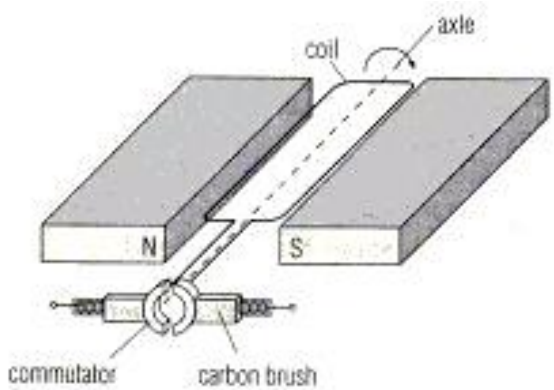
DC motors



A direct current (DC) motor utilises the fact that there is a force between a current carrying conductor and a permanent magnet, and that this force can be arranged to give rise to a rotational motion. The coil has two pairs of equal and opposite forces acting on its sides. These forces tend to rotate the coil. The turning force F is constant in size (F = BIl) but the torque depends on the distance between the parallel turning forces and the axis of rotation.($\tau = F \times r$).

The split ring commutator

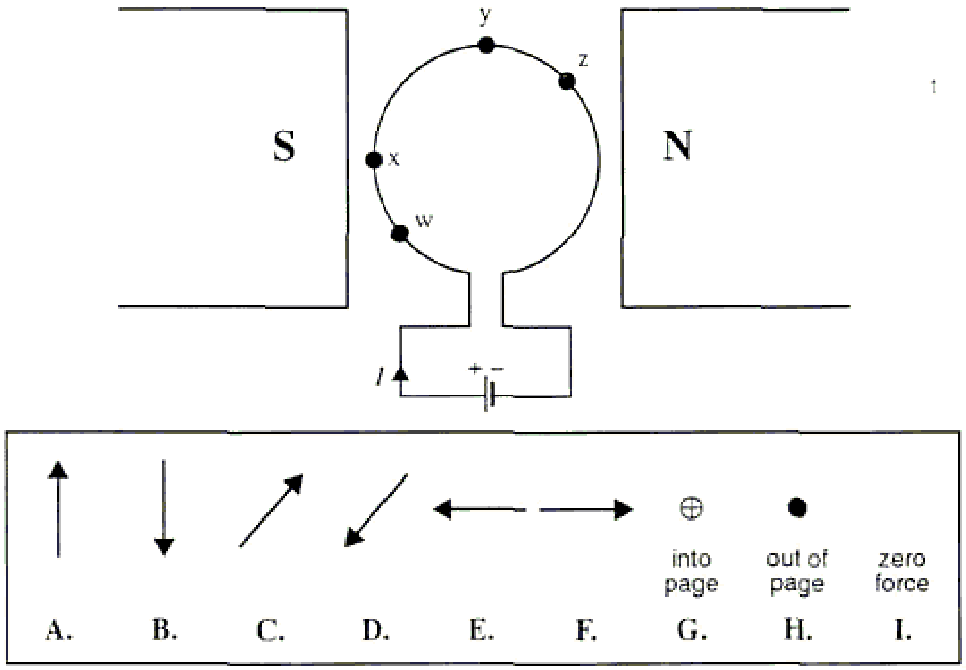
To obtain continuous rotation in a motor, the current in the coil (rotor) is cut just before the plane of the coil is perpendicular to the field, because at this point the forces will act to spread the coil and not to rotate it. The angular momentum of the coil carries it past this position and then the current is switched on again, but the current direction is reversed.



The switching process is carried out automatically by a 'split ring **commutator**' on the motor shaft. A single coil motor would be rather jerky so in most practical motors the magnetic field is provided by an electromagnetic coil, and a radial rather than uniform field is used. This produces a smoother action, ie. a more constant torque.

The role of commutator is to keep the motor rotating in the same direction. It does this by reversing the direction of the current through the coil every half turn when the plane of the coil is perpendicular to the magnetic field.

Thomas is trying to build a simple motor that will operate on DC current. He first decides to study the magnetic forces on a current-carrying wire. He places a single loop of wire in a uniform magnetic field, and connects a battery, as shown below.



Use the answer key above to answer the following questions.

Example 2.85: 2000 Question 9 (2 marks)

Which choice (**A – I**) best indicates the direction of the magnetic force on the wire at point x?

Example 2.86: 2000 Question 10 (2 marks)

Which choice (**A – I**) best indicates the direction of the magnetic force on the wire at point y?

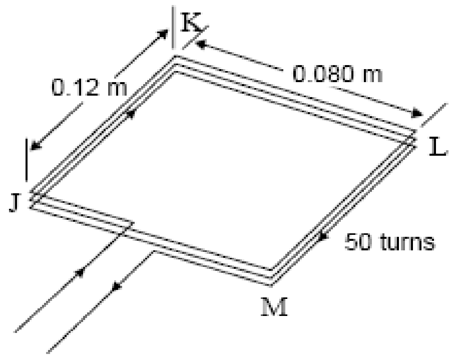
Example 2.87: 2000 Question 11 (2 marks)

Which choice (**A – I**) best indicates the direction of the magnetic force on the wire at point z?

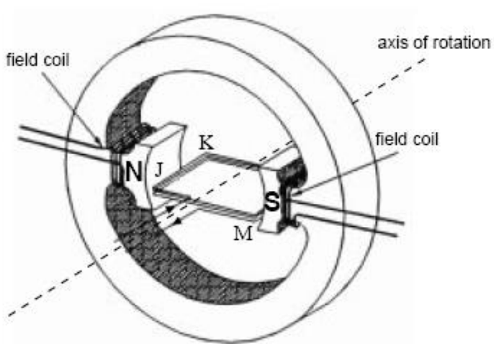
Example 2.88: 2000 Question 12 (2 marks)

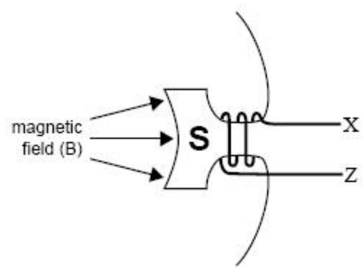
Which choice (**A - I**) best indicates the direction of the magnetic force on the wire at point w?

Two students examine a DC motor. They find that it has an armature consisting of a rectangular coil with 50 turns, which is shown below.



They observe that the armature is in the field of a two-pole magnet, and can rotate about an axis as shown below. The magnetic field is produced by the current flowing through field coils as shown in below. **The armature windings and the field coils are connected in series**, so that the same current flows through each. The current to the armature flows through a commutator which is not shown. When the motor is operating, the current flowing is 1.5 A.





An enlarged diagram of one field coil is shown above.

Example 2.89: 2001 Question 9 (2 marks)

In which direction must the current flow through the field coil to produce a field as indicated by the arrows?

A. in at X and out at Z

B. in at Z and out at X

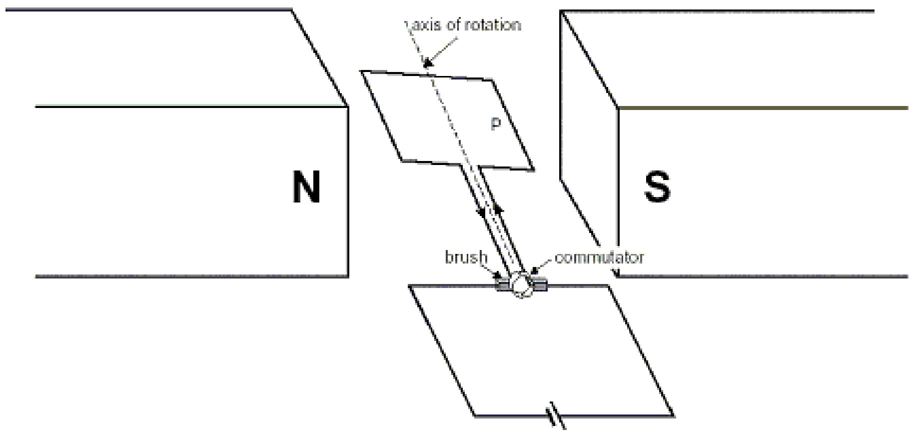
C. it is an AC current, so the direction is always changing

D. in either direction, the field direction does not depend on the current direction

Example 2.90: 2001 Question 10 (2 marks)

With the armature as shown above, the magnetic field in the region of side JK is 0.10 T.
A current of 1.5 A flows through the armature.
What is the magnitude of the force on the side JK of the armature?

The circuit of a simple DC electric motor is shown below. It consists of a current-carrying coil of 50 turns as the armature. The coil is square with sides of 5.0 cm. The coil is in a uniform magnetic field of strength 0.005 T.



A current of 3.0 A flows through the coil in the direction shown above.

Example 2.91: 2002 Question 11 (2 marks)

Calculate the magnitude of the force exerted on the 50 wires of side P of the coil.

Example 2.92: 2002 Question 12 (1 mark)

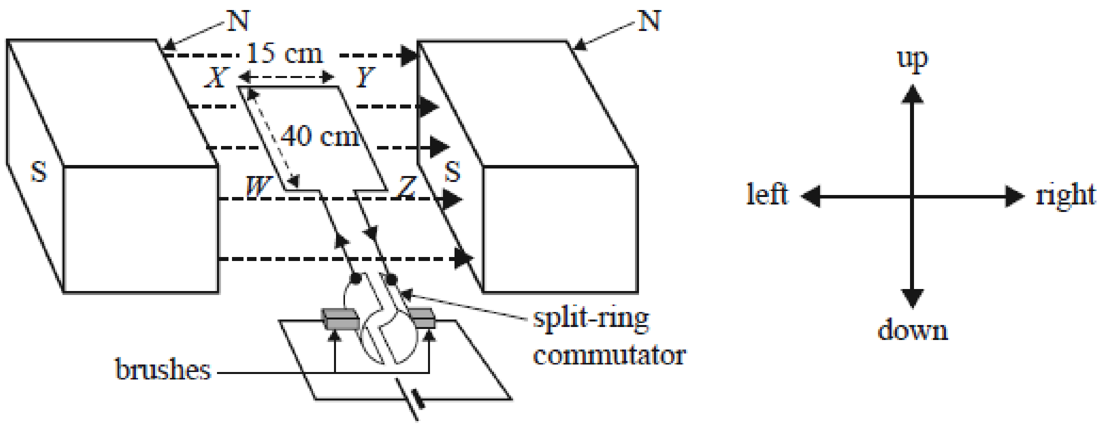
When the coil is in the position shown above, which of the directions (**A – D**) below best shows the direction of the force exerted on side P of the coil?

The ends of the coil are connected to the commutator, as shown above, so that it is free to rotate with the coil.

Example 2.93: 2002 Question 13 (3 marks)

Explain
• why the commutator must be free to rotate in this manner
• how this is fundamental to the operation of the DC electric motor.

A model DC motor using permanent magnets is shown below. The coil of the motor is formed from 75 turns of wire. Each turn is rectangular, having a length of 40 cm (sides WX and YZ) and a width of 15 cm (sides XY and WZ).
The magnetic field is uniform and has a value of 0.020 T. The coil can rotate freely between the magnets.



The axis of the motor and the direction of the magnetic field are shown.

Example 2.94: 2014 Question 17c (2 marks)

The motor is switched on when the coil is stationary in the horizontal position, and the coil starts to rotate.
Explain why this rotation occurs.