A2 Level Physics

Chapter 19 – Electromagnetism

19.2.2 Motion of Charged Particles

Worked Examples

Motion of Charged Particles

Exam Style Question 1

(a) Fig. 2.1 shows a horizontal current-carrying wire placed in a uniform magnetic field.

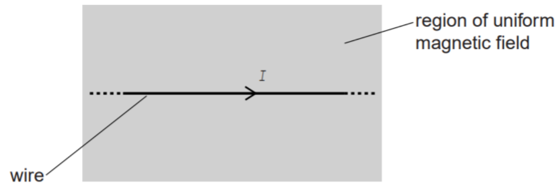


Fig. 2.1

The magnetic field of flux density $0.070\ T$ is at right angles to the wire and into the plane of the paper. The weight of a $1.0\ cm$ length of the wire is $6.8 \times 10^{-5}\ N$. The current, I, in the wire is such that the vertical upward force on the wire due to the magnetic field is equal to the weight of the wire.

(i) Calculate the current I in the wire.

(ii) Suggest why it would be impossible for overhead cables carrying an alternating current to float in the Earth's magnetic field.

(b) A charged particle enters a region of uniform magnetic field. Fig. 2.2 shows the path of this particle.

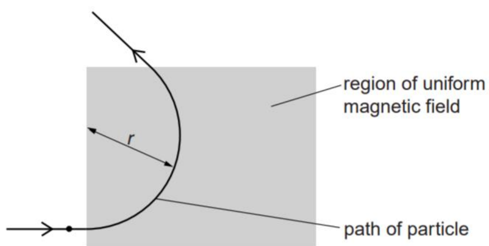


Fig. 2.2

Motion of Charged Particles

Exam Style Question 1

The direction of the field is perpendicular to the plane of the paper. The magnetic field has flux density B. The particle has mass m, charge Q and speed v. The particle travels in a circular arc of radius r in the magnetic field.

(i) Derive an equation for the radius r in terms of B, m, Q and v.

(ii) A thin aluminium plate is now placed in the magnetic field. Fig. 2.3 shows the path of an unknown charged particle.

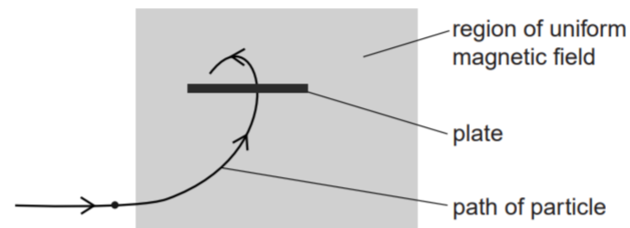


Fig. 2.3

The particle loses some of its kinetic energy as it travels through the plate. The initial radius of the path of the particle before it enters the plate is $4.8\ cm$. After leaving the plate the final radius of the path of the particle is $1.2\ cm$.

Calculate the ratio

$$\frac{initial\ kinetic\ energy\ of\ particle}{final\ kinetic\ energy\ of\ particle}$$

Motion of Charged Particles

Exam Style Question 1

(a) Fig. 2.1 shows a horizontal current-carrying wire placed in a uniform magnetic field.

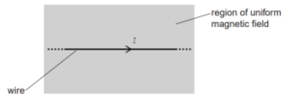


Fig. 2.1

The magnetic field of flux density $0.070\ T$ is at right angles to the wire and into the plane of the paper. The weight of a $1.0\ cm$ length of the wire is $6.8 \times 10^{-5}\ N$. The current, I, in the wire is such that the vertical upward force on the wire due to the magnetic field is equal to the weight of the wire.

(i) Calculate the current I in the wire.

(ii) Suggest why it would be impossible for overhead cables carrying an alternating current to float in the Earth's magnetic field.

(b) A charged particle enters a region of uniform magnetic field. Fig. 2.2 shows the path of this particle.

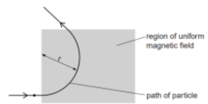


Fig. 2.2

The direction of the field is perpendicular to the plane of the paper. The magnetic field has flux density B. The particle has mass m, charge Q and speed v. The particle travels in a circular arc of radius r in the magnetic field.

(i) Derive an equation for the radius r in terms of B, m, Q and v.

(ii) A thin aluminium plate is now placed in the magnetic field. Fig. 2.3 shows the path of an unknown charged particle.

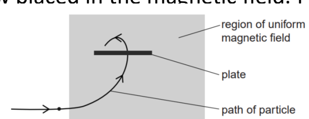


Fig. 2.3

The particle loses some of its kinetic energy as it travels through the plate. The initial radius of the path of the particle before it enters the plate is $4.8\ cm$. After leaving the plate the final radius of the path of the particle is $1.2\ cm$.

Calculate the ratio

$$\frac{initial\ kinetic\ energy\ of\ particle}{final\ kinetic\ energy\ of\ particle}$$

Motion of Charged Particles

Exam Style Question 1

(a) (i) Calculate the current I in the wire.

Use $F = BIL$ and rearrange to find I

$$I = \frac{F}{BL} \dots\dots\dots\dots (1)$$

We know that the vertical upward force on the wire due to the magnetic field is equal to the weight of the wire. So:

$$F = 6.8 \times 10^{-5}$$

Therefore

$$I = \frac{F}{BL} = \frac{6.8 \times 10^{-5}\ N}{(0.070\ T)(0.01\ m)}$$

$$I = 0.097\ A$$

(a) (ii) Suggest why it would be impossible for overhead cables carrying an alternating current to float in the Earth's magnetic field.

Using the statement "The current, I, in the wire is such that the vertical upward force on the wire due to the magnetic field is equal to the weight of the wire" should technically mean that if the cable was in the Earth's magnetic field the upwards force on the wire due to the magnetic field equals the weight of the wire and therefore it should float.

However, the force on the cables will keep changing direction due to the alternating current and therefore it won't float.

(b) (i) Derive an equation for the radius r in terms of B, m, Q and v.

$$magnetic\ force = centripetal\ force$$

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

Therefore:

$$r = \frac{mv}{BQ}$$

Motion of Charged Particles

Exam Style Question 1

(a) Fig. 2.1 shows a horizontal current-carrying wire placed in a uniform magnetic field.

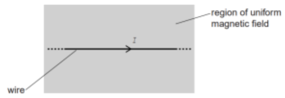


Fig. 2.1

The magnetic field of flux density $0.070\ T$ is at right angles to the wire and into the plane of the paper. The weight of a $1.0\ cm$ length of the wire is $6.8 \times 10^{-5}\ N$. The current, I, in the wire is such that the vertical upward force on the wire due to the magnetic field is equal to the weight of the wire.

(i) Calculate the current I in the wire.

(ii) Suggest why it would be impossible for overhead cables carrying an alternating current to float in the Earth's magnetic field.

(b) A charged particle enters a region of uniform magnetic field. Fig. 2.2 shows the path of this particle.

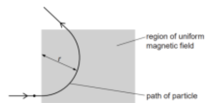


Fig. 2.2

The direction of the field is perpendicular to the plane of the paper. The magnetic field has flux density B. The particle has mass m, charge Q and speed v. The particle travels in a circular arc of radius r in the magnetic field.

(i) Derive an equation for the radius r in terms of B, m, Q and v.

(ii) A thin aluminium plate is now placed in the magnetic field. Fig. 2.3 shows the path of an unknown charged particle.

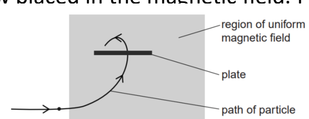


Fig. 2.3

The particle loses some of its kinetic energy as it travels through the plate. The initial radius of the path of the particle before it enters the plate is $4.8\ cm$. After leaving the plate the final radius of the path of the particle is $1.2\ cm$.

Calculate the ratio

$$\frac{initial\ kinetic\ energy\ of\ particle}{final\ kinetic\ energy\ of\ particle}$$

Motion of Charged Particles

Exam Style Question 1

(b) (ii) Calculate the ratio.

Problem with this question is we only have the radius of the path of the particle before and after it leaves the plate. Therefore we need to relate KE of the particle to the radius of the path of the particle and use that to calculate the ratio.

We know $KE = \frac{1}{2}mv^2$ and $v = \frac{rBQ}{m}$

$$\therefore KE = \frac{1}{2}m\left(\frac{rBQ}{m}\right)^2 = \frac{1}{2}m\left(\frac{r^2B^2Q^2}{m^2}\right)$$

Simplifying gives:

$$KE = \frac{1}{2}\frac{r^2B^2Q^2}{m} = \frac{r^2B^2Q^2}{2m}$$

Therefore:

$$KE \propto r^2$$

Now we know KE is proportional to radius squared and as we are trying to find the ratio we can do the below.

So the ratio is:

$$ratio = \frac{4.8^2}{1.2^2} = 16$$

Motion of Charged Particles

Exam Style Question 2

Fig. 2.1 shows the circular path described by a helium nucleus in a region of uniform magnetic field in a vacuum.

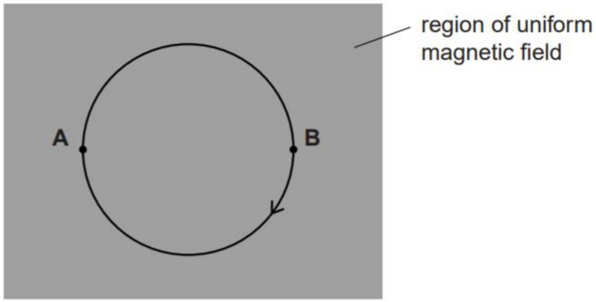


Fig. 2.1

The direction of the magnetic field is perpendicular to the plane of the paper. The magnetic flux density of the magnetic field is 0.20 mT. The radius of the circular path is 15 cm. The helium nucleus has charge $+3.2 \times 10^{-19}$ C and mass 6.6×10^{-27} kg.

(a) Explain why the helium nucleus

(i) Travels in a circular path.

(ii) Has the same kinetic energy at A and B.

(b) Calculate the magnitude of the momentum of the helium nucleus.

(c) Calculate the kinetic energy of the helium nucleus.

(d) A uniform electric field is now also applied in the region shaded in Fig. 2.1. The direction of this electric field is from left to right. Describe the path now followed by the helium nucleus in the electric and magnetic fields.

Motion of Charged Particles

Exam Style Question 2

(a) Explain why the helium nucleus

(i) Travels in a circular path.

A constant force acts at rights angles to the velocity (or motion) of the helium nucleus.

(ii) Has the same kinetic energy at A and B.

No work done by the force and so no acceleration in the direction of motion.

(b) Calculate the magnitude of the momentum of the helium nucleus.

Using $BQv = \frac{mv^2}{r}$ rearrange it to find momentum ($= mv$)

$$BQvr = mv^2$$

$BQvr = m \times v \times v$ (remember $v^2 = v \times v$)

$$\frac{BQvr}{v} = mv$$

$$mv = BQr$$

Therefore

$$momentum = mv = BQr$$

$$momentum = (0.20 \times 10^{-3}\ T)(3.2 \times 10^{-19}\ C)(0.15m)$$

$$momentum = 9.6 \times 10^{-24}\ kg\ m\ s^{-1}$$

(c) Calculate the kinetic energy of the helium nucleus.

Step 1: Use $momentum = mv$ and rearrange to find v

$$v = \frac{momentum}{m} = \frac{9.6 \times 10^{-24}\ kg\ m\ s^{-1}}{6.6 \times 10^{-27}\ kg}$$

$$v = 1454.545 \ldots m\ s^{-1}$$

Step 2: Use $KE = \frac{1}{2}mv^2$

$$KE = \frac{1}{2}(6.6 \times 10^{-27}\ kg)(1454.54 \ldots m\ s^{-1})^2$$

$$KE = 7.0 \times 10^{-21} J$$

Motion of Charged Particles

Exam Style Question 2

Fig. 2.1 shows the circular path described by a helium nucleus in a region of uniform magnetic field in a vacuum.

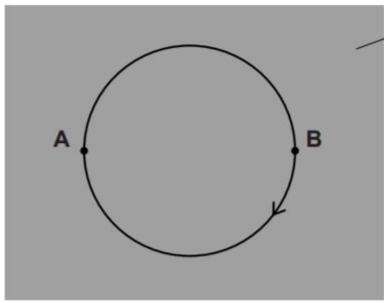


Fig. 2.1

The direction of the magnetic field is perpendicular to the plane of the paper. The magnetic flux density of the magnetic field is $0.20\ mT$. The radius of the circular path is $15\ cm$. The helium nucleus has charge $+3.2 \times 10^{-19}\ C$ and mass $6.6 \times 10^{-27}\ kg$.

(a) Explain why the helium nucleus

(i) Travels in a circular path.

(ii) Has the same kinetic energy at A and B.

(b) Calculate the magnitude of the momentum of the helium nucleus.

(c) Calculate the kinetic energy of the helium nucleus.

(d) A uniform electric field is now also applied in the region shaded in Fig. 2.1. The direction of this electric field is from left to right. Describe the path now followed by the helium nucleus in the electric and magnetic fields.

Motion of Charged Particles

Exam Style Question 2

(d) A uniform electric field is now also applied in the region shaded in Fig. 2.1. The direction of this electric field is from left to right. Describe the path now followed by the helium nucleus in the electric and magnetic fields.

- The helium nucleus moves to the right. (Because the helium has a positive charge and will move to the negative side of the electric field which is to the right).
- The path is still a clockwise curve in the plane of the paper.

Motion of Charged Particles

Exam Style Question 3

Fig. 3.1 shows part of an accelerator used to produce high-speed protons. The protons pass through an evacuated tube that is shown in the plane of the paper.

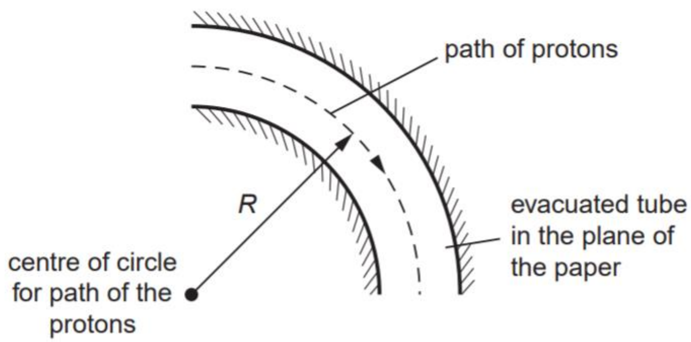


Fig. 3.1

The protons are made to travel in a circle of radius R by a magnetic field of flux density B.

(a) State clearly the direction of the magnetic flux density B that produces the circular motion of the protons.

(b) Show that the relationship between the velocity v of the protons and the radius R is given by $v = \frac{BQR}{m}$ where Q and m are the charge and mass of a proton respectively.

(c) Calculate the magnetic flux density B of the magnetic field needed to keep protons in a circular orbit of radius $0.18\ m$. The time for one complete orbit is $2.0 \times 10^{-8}\ s$.

(d) Explain why the magnetic field does not change the speed of the protons.

Motion of Charged Particles

Exam Style Question 3

(a)State clearly the direction of the magnetic flux density B that produces the circular motion of the protons.

Perpendicular out of plane of paper. (Use Flemings Left Hand rule but remember it is a Proton and not an electron).

(b) Show that the relationship between the velocity v of the protons and the radius R is given by $v = \frac{BQR}{m}$ where Q and m are the charge and mass of a proton respectively.

$$magnetic\ force = centripetal\ force$$

$$BQv = \frac{mv^2}{R}$$

Therefore:

$$BQR = \frac{mv^2}{v}$$

$$v = \frac{BQR}{m}$$

(c) Calculate the magnetic flux density B of the magnetic field needed to keep protons in a circular orbit of radius $0.18\ m$. The time for one complete orbit is $2.0 \times 10^{-8}\ s$.

Use $v = \frac{2\pi r}{T}$

$$v = \frac{2\pi(0.18\ m)}{(2.0 \times 10^{-8}\ s)} = 56548667.76\ ms^{-1}$$

Now use $v = \frac{BQR}{m}$ and rearrange for B

$$B = \frac{vm}{QR} = \frac{(56548667.76\ m\ s^{-1})(1.67 \times 10^{-27}\ kg)}{(1.6 \times 10^{-19}\ C)(0.18\ m)}$$

$$B = 3.28\ T$$

(d) Explain why the magnetic field does not change the speed of the protons.

The force is perpendicular to the motion and therefore no work is done.

Cyclotron (AQA only)

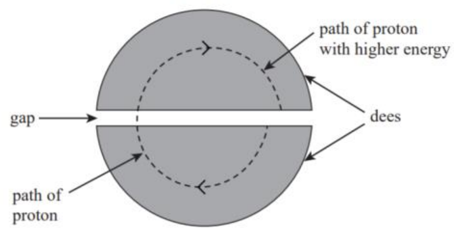
Exam Style Question 4

(a) (i) State two situations in which a charged particle will experience no magnetic force when placed in a magnetic field.

(a) (ii) A charged particle moves in a circular path when travelling perpendicular to a uniform magnetic field. By considering the force acting on the charged particle, show that the radius of the path is proportional to the momentum of the particle.

(b) In a cyclotron designed to produce high energy protons, the protons pass repeatedly between two hollow D-shaped containers called 'dees'. The protons are acted on by a uniform magnetic field over the whole area of the dees. Each proton therefore moves in a semi-circular path at constant speed when inside a dee. Every time a proton crosses the gap between the dees it is accelerated by an alternating electric field applied between the dees. Figure 2 shows a plan view of this arrangement.

Figure 2



(b) (i) State the direction in which the magnetic field should be applied in order for the protons to travel along the semicircular paths inside each of the dees as shown in Figure 2.

(b) (ii) In a particular cyclotron the flux density of the uniform magnetic field is $0.48\ T$. Calculate the speed of a proton when the radius of its path inside the dee is $190\ mm$.

(b) (iii) Calculate the time taken for this proton to travel at constant speed in a semicircular path of radius $190\ mm$ inside the dee.

(b) (iv) As the protons gain energy, the radius of the path they follow increases steadily, as shown in Figure 2. Show that your answer to part (b)(iii) does not depend on the radius of the proton's path.

(c) The protons leave the cyclotron when the radius of their path is equal to the outer radius of the dees. Calculate the maximum kinetic energy, in MeV, of the protons accelerated by the cyclotron if the outer radius of the dees is $470\ mm$.

Cyclotron (AQA only)

Exam Style Question 4

(a)(i) State two situations in which a charged particle will experience no magnetic force when placed in a magnetic field.

1) When charged particle is at rest.
2) When charged particle moves parallel to magnetic field.

(a) (ii) Show that the radius of the path is proportional to the momentum of the particle.

Using $BQv = \frac{mv^2}{r}$ rearrange it to find momentum ($= mv$)

$$BQvr = mv^2$$

$BQvr = m \times v \times v$ (remember $v^2 = v \times v$)

$$\frac{BQvr}{v} = mv$$

$$mv = BQr$$

Therefore

$$momentum = mv = BQr$$

(b) (i) State the direction in which the magnetic field should be applied in order for the protons to travel along the semicircular paths inside each of the dees as shown in Figure 2.

Upwards perpendicular to plane of diagram or "out of the paper".

(b) (ii) Calculate the speed of a proton when the radius of its path inside the dee is 190 mm.

Use $mv = BQr$ and rearrange for v

$$v = \frac{BQr}{m} = \frac{(0.48\ T)(1.60 \times 10^{-19}\ C)(0.19\ m)}{(1.67 \times 10^{-27}\ kg)}$$

$$v = 8.74 \times 10^6\ m\ s^{-1}$$

Cyclotron (AQA only)

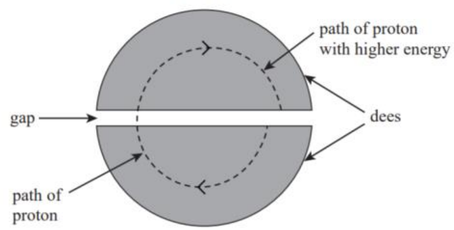
Exam Style Question 4

(a) (i) State two situations in which a charged particle will experience no magnetic force when placed in a magnetic field.

(a) (ii) A charged particle moves in a circular path when travelling perpendicular to a uniform magnetic field. By considering the force acting on the charged particle, show that the radius of the path is proportional to the momentum of the particle.

(b) In a cyclotron designed to produce high energy protons, the protons pass repeatedly between two hollow D-shaped containers called 'dees'. The protons are acted on by a uniform magnetic field over the whole area of the dees. Each proton therefore moves in a semi-circular path at constant speed when inside a dee. Every time a proton crosses the gap between the dees it is accelerated by an alternating electric field applied between the dees. Figure 2 shows a plan view of this arrangement.

Figure 2



(b) (i) State the direction in which the magnetic field should be applied in order for the protons to travel along the semicircular paths inside each of the dees as shown in Figure 2.

(b) (ii) In a particular cyclotron the flux density of the uniform magnetic field is $0.48\ T$. Calculate the speed of a proton when the radius of its path inside the dee is $190\ mm$.

(b) (iii) Calculate the time taken for this proton to travel at constant speed in a semicircular path of radius $190\ mm$ inside the dee.

(b) (iv) As the protons gain energy, the radius of the path they follow increases steadily, as shown in Figure 2. Show that your answer to part (b)(iii) does not depend on the radius of the proton's path.

(c) The protons leave the cyclotron when the radius of their path is equal to the outer radius of the dees. Calculate the maximum kinetic energy, in MeV, of the protons accelerated by the cyclotron if the outer radius of the dees is $470\ mm$.

Cyclotron (AQA only)

Exam Style Question 4

(b) (iii) Calculate the time taken for this proton to travel at constant speed in a semicircular path of radius $190\ mm$ inside the dee.

Use $s = \frac{d}{t}$ and rearrange for t

$$t = \frac{d}{s}$$

The distance d is the length of semi-circle therefore $d = \pi\, r$

Therefore:

$$t = \frac{\pi\, r}{s} = \frac{\pi \times 0.19\ m}{8.74 \times 10^{6}\ m\ s^{-1}}$$

$$t = 6.83 \times 10^{-8}\ s\ (3\ s.f.)$$

(b) (iv) Show that your answer to part (b)(iii) does not depend on the radius of the proton's path.

Use $t = \frac{\pi\, r}{v}$ and $v = \frac{BQr}{m}$ and combine the two equations

$$t = \frac{\pi\, r\, m}{BQr} = \frac{\pi\, m}{BQ}$$

As the r cancels therefore time doesn't depend on r.

(c) Calculate the maximum kinetic energy, in MeV, of the protons accelerated by the cyclotron if the outer radius of the dees is $470\ mm$.

Use $mv = BQr$ and rearrange for v

$$v_{max} = \frac{BQr}{m} = \frac{(0.48\ T)(1.60 \times 10^{-19}\ C)(0.47\ m)}{(1.67 \times 10^{-27}\ kg)}$$

$$v_{max} = 2.161 \ldots \times 10^{7}\ m\ s^{-1}$$

Now use $KE = \frac{1}{2} m v_{max}^2$

$$KE = \left(\frac{1}{2}\right)(1.67 \times 10^{-27}\ kg)(2.16 \ldots \times 10^{7}\ m\ s^{-2})^2$$

$$KE = 3.90 \times 10^{-13}\ J\ (3\ s.f.)$$

Convert into MeV (to convert from J to eV divide by $1.6 \times 10^{-19}\ J$:

$$KE = \frac{(3.90 \times 10^{-13}\ J)}{(1.6 \times 10^{-19}\ J)} = 2437500\ eV = 2.4\ MeV$$

Motion of Charged Particles in Combined Electric and Magnetic Fields

Exam Style Question 5

(a) Fig. 3.1 shows two charged horizontal plates.

Fig. 3.1

The potential difference across the plates is $60\ V$. The separation of the plates is $5.0\ mm$.

(i) On Fig. 3.1 draw the electric field pattern between the plates.

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

(b) Positive ions are accelerated from rest in the horizontal direction through a potential difference of $400\ V$. The charged plates in (a) are then used to deflect the ions in the vertical direction. Fig. 3.2 shows the path of these ions.

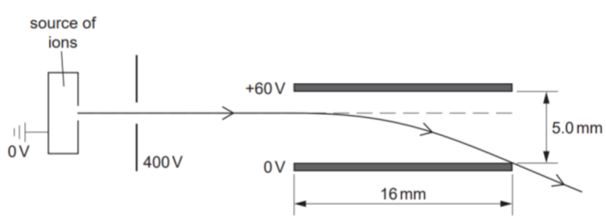


Fig. 3.2

Motion of Charged Particles in Combined Electric and Magnetic Fields

Exam Style Question 5

Each ion has a mass of $6.6 \times 10^{-27}\ kg$ and a charge of $3.2 \times 10^{-19}\ C$.

(i) Show that the horizontal velocity of an ion after the acceleration by the $400\ V$ potential difference is $2.0 \times 10^{5}\ m\ s^{-1}$.

(ii) The ions enter at right angles to the uniform electric field between the plates. Calculate the vertical acceleration of an ion due to this electric field.

(iii) The length of each of the charged plates is $16\ mm$.

1) Show that an ion takes about $8.0 \times 10^{-8}\ s$ to travel through the plates.

2) Calculate the vertical deflection of an ion as it travels through the plates.

(c) A uniform magnetic field is applied in the region between the plates in Fig. 3.2. The magnetic field is perpendicular to both the path of the ions and the electric field between the plates.

Calculate the magnitude of the magnetic flux density of field needed to make the ions travel horizontally through the plates.

(d) Ions of the same charge but greater mass are accelerated by the potential difference of $400\ V$ described in (b). Describe and explain the effect on the deflection of the ions after they have travelled between the plates using the same electric and magnetic fields of (c).

Motion of Charged Particles in Combined Electric and Magnetic Fields

Exam Style Question 5

(a) Fig. 3.1 shows two charged horizontal plates.

Fig. 3.1

The potential difference across the plates is $60\ V$. The separation of the plates is $5.0\ mm$.

(i) On Fig. 3.1 draw the electric field pattern between the plates.

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

(b) Positive ions are accelerated from rest in the horizontal direction through a potential difference of $400\ V$. The charged plates in (a) are then used to deflect the ions in the vertical direction. Fig. 3.2 shows the path of these ions.

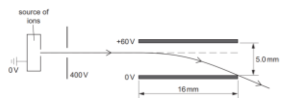


Fig. 3.2

Each ion has a mass of $6.6 \times 10^{-27}\ kg$ and a charge of $3.2 \times 10^{-19}\ C$.

(i) Show that the horizontal velocity of an ion after the acceleration by the $400\ V$ potential difference is $2.0 \times 10^{5}\ m\ s^{-1}$.

(ii) The ions enter at right angles to the uniform electric field between the plates. Calculate the vertical acceleration of an ion due to this electric field.

(iii) The length of each of the charged plates is $16\ mm$.

1) Show that an ion takes about $8.0 \times 10^{-8}\ s$ to travel through the plates.

2) Calculate the vertical deflection of an ion as it travels through the plates.

(c) A uniform magnetic field is applied in the region between the plates in Fig. 3.2. The magnetic field is perpendicular to both the path of the ions and the electric field between the plates.

Calculate the magnitude of the magnetic flux density of field needed to make the ions travel horizontally through the plates.

(d) Ions of the same charge but greater mass are accelerated by the potential difference of $400\ V$ described in (b). Describe and explain the effect on the deflection of the ions after they have travelled between the plates using the same electric and magnetic fields of (c).

Motion of Charged Particles in Combined Electric and Magnetic Fields

Exam Style Question 5

(a) (i) On Fig. 3.1 draw the electric field pattern between the plates.

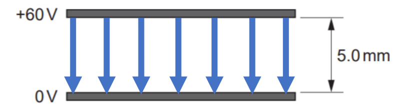


Fig. 3.1

(a) (ii) Calculate the electric field strength between the plates.

Use $E = \frac{V}{d}$

$$E = \frac{60\ V}{5 \times 10^{-3}\ m}$$
$$E = 12000\ V\ m^{-1}$$

(b) (i) Show that the horizontal velocity of an ion after the acceleration by the $400\ V$ potential difference is $2.0 \times 10^{5}\ m\ s^{-1}$.

Use $E = \frac{1}{2}mv^2$ and to calculate energy use $E = qV$

$$\therefore qV = \frac{1}{2}mv^2$$

Rearrange for v

$$v = \sqrt{\frac{qV}{\left(\frac{1}{2}\right)m}} = \sqrt{\frac{2qV}{m}}$$

$$v = \sqrt{\frac{2(3.2 \times 10^{-19}\ C)(400\ V)}{(6.6 \times 10^{-27}\ kg)}}$$
$$v = 1.97 \times 10^{5}\ m\ s^{-1}\ (3\ s.f.)$$

Motion of Charged Particles in Combined Electric and Magnetic Fields

Exam Style Question 5

(a) Fig. 3.1 shows two charged horizontal plates.

Fig. 3.1

The potential difference across the plates is $60\ V$. The separation of the plates is $5.0\ mm$.

(i) On Fig. 3.1 draw the electric field pattern between the plates.

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

(b) Positive ions are accelerated from rest in the horizontal direction through a potential difference of $400\ V$. The charged plates in (a) are then used to deflect the ions in the vertical direction. Fig. 3.2 shows the path of these ions.

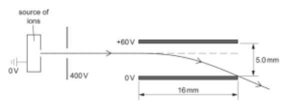


Fig. 3.2

Each ion has a mass of $6.6 \times 10^{-27}\ kg$ and a charge of $3.2 \times 10^{-19}\ C$.

(i) Show that the horizontal velocity of an ion after the acceleration by the $400\ V$ potential difference is $2.0 \times 10^{5}\ m\,s^{-1}$.

(ii) The ions enter at right angles to the uniform electric field between the plates. Calculate the vertical acceleration of an ion due to this electric field.

(iii) The length of each of the charged plates is $16\ mm$.

1) Show that an ion takes about $8.0 \times 10^{-8}\ s$ to travel through the plates.

2) Calculate the vertical deflection of an ion as it travels through the plates.

(c) A uniform magnetic field is applied in the region between the plates in Fig. 3.2. The magnetic field is perpendicular to both the path of the ions and the electric field between the plates.

Calculate the magnitude of the magnetic flux density of field needed to make the ions travel horizontally through the plates.

(d) Ions of the same charge but greater mass are accelerated by the potential difference of $400\ V$ described in (b). Describe and explain the effect on the deflection of the ions after they have travelled between the plates using the same electric and magnetic fields of (c).

Motion of Charged Particles in Combined Electric and Magnetic Fields

Exam Style Question 5

(b) (ii) Calculate the vertical acceleration of an ion due to this electric field.

Use $F = ma$ and rearrange for a

$$a = \frac{F}{m}$$

But we know $F = EQ$ therefore:

$$a = \frac{EQ}{m} = \frac{(12000\ V\,m^{-1})(3.2 \times 10^{-19}\ C)}{(6.6 \times 10^{-27}\ kg)}$$

$$a = 5.82 \times 10^{11}\ m\,s^{-2}\ (3\ s.f.)$$

(b) (iii) The length of each of the charged plates is $16\ mm$.

1)Show that an ion takes about $8.0 \times 10^{-8}\ s$ to travel through the plates.

Use $s = \frac{d}{t}$ and rearrange for t

$$t = \frac{d}{s} = \frac{(16 \times 10^{-3}\ m)}{(1.97 \times 10^{5}\ m\,s^{-1})}$$

$$t = 8 \times 10^{-8}\ s\ (1\ s.f.)$$

2) Calculate the vertical deflection of an ion as it travels through the plates.

Use SUVAT equation $s = ut + \frac{1}{2}at^2$

$$s = (0)(8 \times 10^{-8}\ s) + \left(\frac{1}{2}\right)(5.82 \times 10^{11}\ m\,s^{-2})(8 \times 10^{-8}\ s)^2$$

$$s = 1.86 \times 10^{-3}\ m\ (3\ s.f.)$$

(c) Calculate the magnitude of the magnetic flux density of field needed to make the ions travel horizontally through the plates.

Magnetic force up = electric force down

$$BQv = EQ$$

From which:

$$B = \frac{E}{v}$$

$$B = \frac{(12000\ V\,m^{-1})}{1.97 \times 10^{5}\ m\,s^{-1}}$$

$$B = 0.061\ T\ (3\ d.p.)$$

Motion of Charged Particles in Combined Electric and Magnetic Fields

Exam Style Question 5

(a) Fig. 3.1 shows two charged horizontal plates.

Fig. 3.1

The potential difference across the plates is $60\ V$. The separation of the plates is $5.0\ mm$.

(i) On Fig. 3.1 draw the electric field pattern between the plates.

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

(b) Positive ions are accelerated from rest in the horizontal direction through a potential difference of $400\ V$. The charged plates in (a) are then used to deflect the ions in the vertical direction. Fig. 3.2 shows the path of these ions.

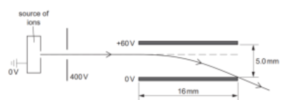


Fig. 3.2

Each ion has a mass of $6.6 \times 10^{-27}\ kg$ and a charge of $3.2 \times 10^{-19}\ C$.

(i) Show that the horizontal velocity of an ion after the acceleration by the $400\ V$ potential difference is $2.0 \times 10^{5}\ m\ s^{-1}$.

(ii) The ions enter at right angles to the uniform electric field between the plates. Calculate the vertical acceleration of an ion due to this electric field.

(iii) The length of each of the charged plates is $16\ mm$.

1) Show that an ion takes about $8.0 \times 10^{-8}\ s$ to travel through the plates.

2) Calculate the vertical deflection of an ion as it travels through the plates.

(c) A uniform magnetic field is applied in the region between the plates in Fig. 3.2. The magnetic field is perpendicular to both the path of the ions and the electric field between the plates.

Calculate the magnitude of the magnetic flux density of field needed to make the ions travel horizontally through the plates.

(d) Ions of the same charge but greater mass are accelerated by the potential difference of $400\ V$ described in (b). Describe and explain the effect on the deflection of the ions after they have travelled between the plates using the same electric and magnetic fields of (c).

Motion of Charged Particles in Combined Electric and Magnetic Fields

Exam Style Question 5

(d) Describe and explain the effect on the deflection of the ions after they have travelled between the plates using the same electric and magnetic fields of (c).

Velocity produced by 400 V is less. Force due to the magnetic field is reduced and force due to the electric field is unchanged. Hence beam deflects down.

Motion of Charged Particles in Combined Electric and Magnetic Fields

Exam Style Question 6

(a) Define electric field strength.

(b) Fig. 3.1 shows two horizontal, parallel metal plates A and B.

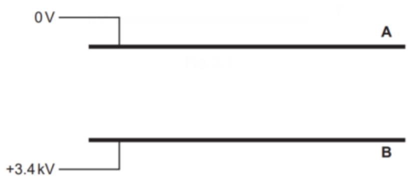


Fig. 3.1

The potential difference across the plates is $3.4\ kV$ and the arrangement provides a uniform electric field between the plates.

On Fig. 3.1 draw at least six lines to represent the electric field between the plates.

(c) A beam of electrons enters between the plates at right angles to the electric field. The horizontal velocity of the electrons is $4.0 \times 10^7\ m\,s^{-1}$. The path of the electrons is shown on Fig. 3.2. The horizontal length of each plate is $0.080\ m$ and the separation of the plates is $0.050\ m$. P is a point $0.040\ m$ from where the beam enters the plates.

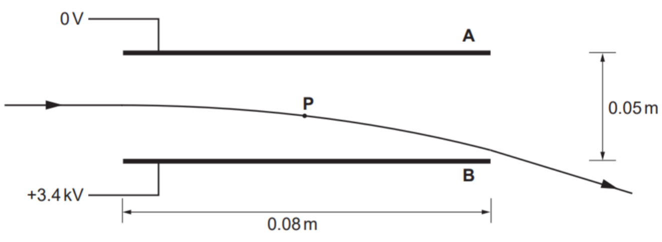


Fig. 3.2

Motion of Charged Particles in Combined Electric and Magnetic Fields

Exam Style Question 6

(i) Draw an arrow on Fig. 3.2 to show the direction of the acceleration of an electron at P.

(ii) Show that the acceleration of an electron between the plates is about $1 \times 10^{16}\ m\,s^{-2}$.

(iii) Calculate the time taken for an electron on entering the plates to reach P.

(iv) Show that the vertical velocity of the electron at P is $1.2 \times 10^7\ m\,s^{-1}$.

(v) Calculate the magnitude of the resultant velocity of the electron at P.

(vi) Calculate the kinetic energy of the electron at P.

tutorpacks.co.uk

Motion of Charged Particles in Combined Electric and Magnetic Fields

Exam Style Question 6

(a) Define electric field strength.

(b) Fig. 3.1 shows two horizontal, parallel metal plates A and B.

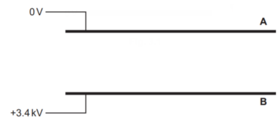


Fig. 3.1

The potential difference across the plates is $3.4\ kV$ and the arrangement provides a uniform electric field between the plates.

On Fig. 3.1 draw at least six lines to represent the electric field between the plates.

(c) A beam of electrons enters between the plates at right angles to the electric field. The horizontal velocity of the electrons is $4.0 \times 10^{7}\ m\ s^{-1}$. The path of the electrons is shown on Fig. 3.2. The horizontal length of each plate is $0.080\ m$ and the separation of the plates is $0.050\ m$. P is a point $0.040\ m$ from where the beam enters the plates.

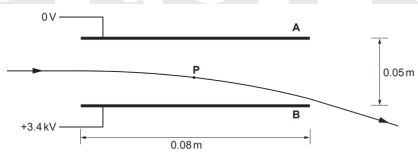


Fig. 3.2

(i) Draw an arrow on Fig. 3.2 to show the direction of the acceleration of an electron at P.

(ii) Show that the acceleration of an electron between the plates is about $1 \times 10^{16}\ m\ s^{-2}$.

(iii) Calculate the time taken for an electron on entering the plates to reach P.

(iv) Show that the vertical velocity of the electron at P is $1.2 \times 10^{7}\ m\ s^{-1}$.

(v) Calculate the magnitude of the resultant velocity of the electron at P.

(vi) Calculate the kinetic energy of the electron at P.

Motion of Charged Particles in Combined Electric and Magnetic Fields

Exam Style Question 6

(a)Define electric field strength.
Electric field strength is the force per units positive charge.

(b) On Fig. 3.1 draw at least six lines to represent the electric field between the plates.

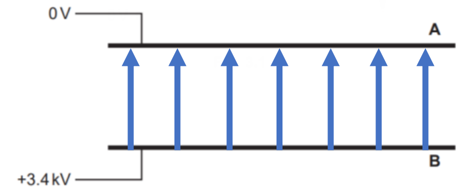


Fig. 3.1

(c) (i) Draw an arrow on Fig. 3.2 to show the direction of the acceleration of an electron at P.

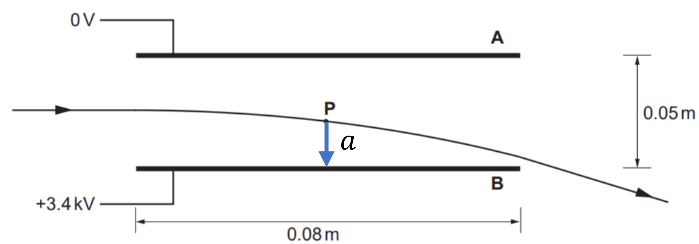


Fig. 3.2

Motion of Charged Particles in Combined Electric and Magnetic Fields

Exam Style Question 6

(a) Define electric field strength.

(b) Fig. 3.1 shows two horizontal, parallel metal plates A and B.

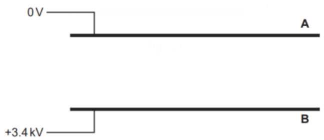


Fig. 3.1

The potential difference across the plates is $3.4\ kV$ and the arrangement provides a uniform electric field between the plates.

On Fig. 3.1 draw at least six lines to represent the electric field between the plates.

(c) A beam of electrons enters between the plates at right angles to the electric field. The horizontal velocity of the electrons is $4.0 \times 10^{7}\ m\ s^{-1}$. The path of the electrons is shown on Fig. 3.2. The horizontal length of each plate is $0.080\ m$ and the separation of the plates is $0.050\ m$. P is a point $0.040\ m$ from where the beam enters the plates.

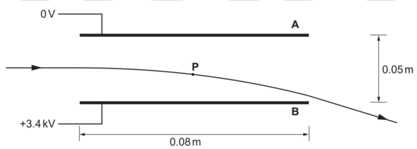


Fig. 3.2

(i) Draw an arrow on Fig. 3.2 to show the direction of the acceleration of an electron at P.

(ii) Show that the acceleration of an electron between the plates is about $1 \times 10^{16}\ m\ s^{-2}$.

(iii) Calculate the time taken for an electron on entering the plates to reach P.

(iv) Show that the vertical velocity of the electron at P is $1.2 \times 10^{7}\ m\ s^{-1}$.

(v) Calculate the magnitude of the resultant velocity of the electron at P.

(vi) Calculate the kinetic energy of the electron at P.

Motion of Charged Particles in Combined Electric and Magnetic Fields

Exam Style Question 6

(c) (ii) Show that the acceleration of an electron between the plates is about $1 \times 10^{16}\ m\ s^{-2}$.

Use $a = \frac{EQ}{m}$ but first calculate E using:

$$E = \frac{V}{d} = \frac{3400\ V}{0.05\ m} = 68000\ V\ m^{-1}$$

$$\therefore a = \frac{(68000\ V\ m^{-1})(1.6 \times 10^{-19}\ C)}{(9.11 \times 10^{-31}\ kg)}$$

$$a = 1.19 \times 10^{16}\ m\ s^{-2}$$

(c) (iii) Calculate the time taken for an electron on entering the plates to reach P.

Use $s = \frac{d}{t}$ and rearrange for t

$$t = \frac{d}{s} = \frac{0.04\ m}{4 \times 10^{7}\ m\ s^{-1}}$$

$$t = 1.0 \times 10^{-9}\ s$$

(c) (iv) Show that the vertical velocity of the electron at P is $1.2 \times 10^{7}\ m\ s^{-1}$.

Use SUVAT equation $v = u + at$ where initial vertical velocity is 0:

$$\therefore v = (0) + (1.19 \times 10^{16}\ m\ s^{-2})(1.0 \times 10^{-9}\ s)$$

$$v = 1.2 \times 10^{7}\ m\ s^{-1}\ (2\ s.f.)$$

Motion of Charged Particles in Combined Electric and Magnetic Fields

Exam Style Question 6

(a) Define electric field strength.

(b) Fig. 3.1 shows two horizontal, parallel metal plates A and B.

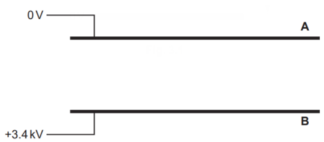


Fig. 3.1

The potential difference across the plates is $3.4\ kV$ and the arrangement provides a uniform electric field between the plates.

On Fig. 3.1 draw at least six lines to represent the electric field between the plates.

(c) A beam of electrons enters between the plates at right angles to the electric field. The horizontal velocity of the electrons is $4.0 \times 10^7\ m\ s^{-1}$. The path of the electrons is shown on Fig. 3.2. The horizontal length of each plate is $0.080\ m$ and the separation of the plates is $0.050\ m$. P is a point $0.040\ m$ from where the beam enters the plates.

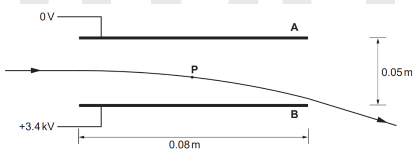


Fig. 3.2

(i) Draw an arrow on Fig. 3.2 to show the direction of the acceleration of an electron at P.

(ii) Show that the acceleration of an electron between the plates is about $1 \times 10^{16}\ m\ s^{-2}$.

(iii) Calculate the time taken for an electron on entering the plates to reach P.

(iv) Show that the vertical velocity of the electron at P is $1.2 \times 10^7\ m\ s^{-1}$.

(v) Calculate the magnitude of the resultant velocity of the electron at P.

(vi) Calculate the kinetic energy of the electron at P.

Motion of Charged Particles in Combined Electric and Magnetic Fields

Exam Style Question 6

(c) (v) Calculate the magnitude of the resultant velocity of the electron at P.

We have the horizontal and vertical velocity of the particle P therefore we can use simple Pythagoras theorem to calculate the resultant velocity:

$$v_{resultant}^2 = v_{horizontal}^2 + v_{vertical}^2$$
$$v_R = \sqrt{(4.0 \times 10^7)^2 + (1.2 \times 10^7)^2}$$
$$v_R = 4.2 \times 10^7\ m\ s^{-1}\ (2\ s.f.)$$

(c) (vi) Calculate the kinetic energy of the electron at P.

Use $KE = \frac{1}{2}mv^2$

$$KE = \left(\frac{1}{2}\right)(9.11 \times 10^{-31}\ kg)(4.2 \times 10^7)^2$$
$$KE = 8.04 \times 10^{-16}\ J\ (3\ s.f.)$$

Please see '19.2.1 Motion of Charged Particles notes' pack for revision notes.

For more revision notes, tutorials and worked examples please visit www.tutorpacks.co.uk.