

Exercise walk-through

20.3

Force on a moving charge

A-Level Physics

Force on a moving charge

$$F = BQv\sin\theta$$

Same left-hand rule – the second finger is the motion of a **positive** charge (reverse it for a negative one). In a wire that motion is the electrons' **drift velocity**.

Largest when $v \perp B$; zero when v is along B .

The force is always perpendicular to the velocity, so it does **no work** – it changes direction, never speed.

Circular path in a uniform field

$BQv = mv^2/r$ gives

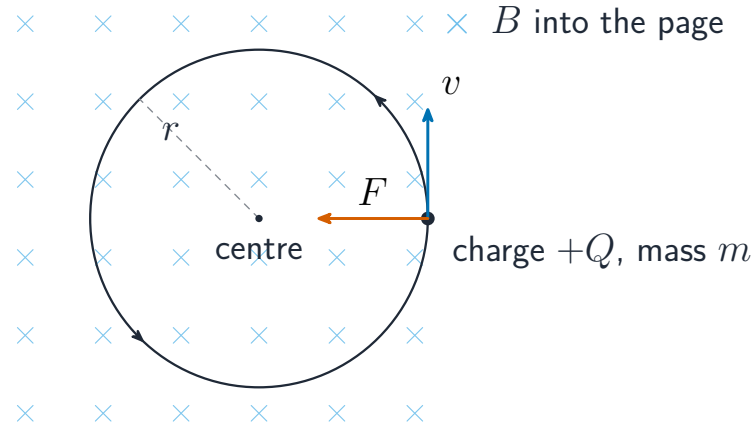
$$r = \frac{mv}{BQ}, \quad T = \frac{2\pi m}{BQ}$$

Here BQv is the **centripetal force**. T does **not** depend on speed – a faster particle goes in a bigger circle but takes the same time per turn, and its **kinetic energy** never changes because the force does no work. A component of v along B is unchanged, so the path is a **helix**.

Proton: $m = 1.7 \times 10^{-27} \text{ kg}$, $v = 2.0 \times 10^6 \text{ m s}^{-1}$, $B = 0.50 \text{ T}$

$$r = \frac{mv}{BQ} \approx 0.043 \text{ m}$$

Circular motion in a uniform field



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

Circular path of a charged particle in a magnetic field

Hall effect – a voltage across a current

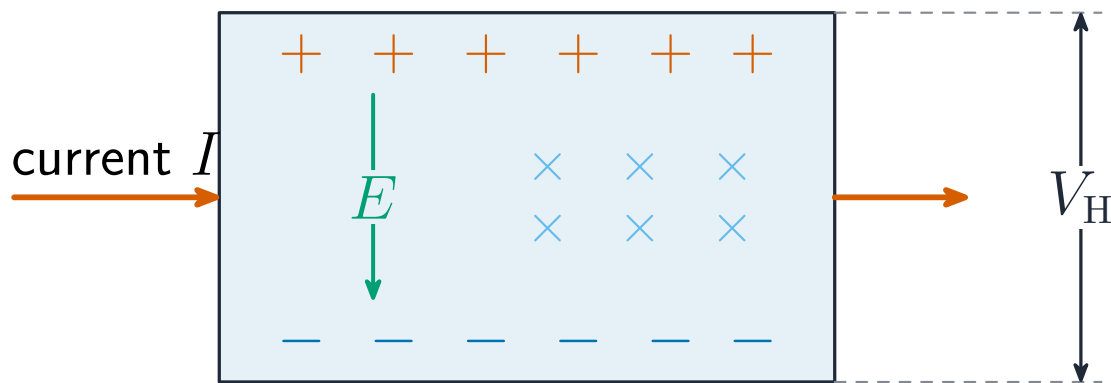
A slab carrying I , in a field B at right angles, develops a **Hall voltage**.
Charges feel Bqv_d , pile up, and make an electric field that opposes further build-up.
At steady state $E = Bv_d$:

$$V_H = \frac{BI}{ntq}$$

A **Hall probe** measures B : known current through a thin semiconductor, read V_H . Largest when the slab is at right angles to B .

Inside the Hall probe

Charges are pushed sideways until the electric field they build up balances the magnetic force – so V_H measures B .



$\times$ B into the page $V_H = \frac{B I}{n t q}$

Exercises 2.1-2.3

2.1 Write the equation for the force on a moving charge. [1]

2.2 A charge of 1.6×10^{-19} C moves at $2.0 \times 10^6 \frac{\text{m}}{\text{s}}$ at right angles to a 0.50 T field. Find the force. [2]

2.3 State the **path** of a charge moving perpendicular to a uniform magnetic field. [1]

Exercises 2.1-2.3

2.1 Write the equation for the force on a moving charge. [1]

2.1

- $F = BQv \sin \theta$

2.2 A charge of 1.6×10^{-19} C moves at $2.0 \times 10^6 \frac{\text{m}}{\text{s}}$ at right angles to a 0.50 T field. Find the force. [2]

2.2

- $F = BQv$

$$F = BQv = (0.50 \text{ T})(1.6 \times 10^{-19} \text{ C})(2.0 \times 10^6 \frac{\text{m}}{\text{s}}) = \mathbf{1.6 \times 10^{-13} \text{ N}}$$

2.3 State the **path** of a charge moving perpendicular to a uniform magnetic field. [1]

2.3

- a **circle**

Exercises 2.4·3.1

2.4 State **why** the magnetic force does **no work** on the moving charge.

[1]

3.1 A charged particle moving **perpendicular** to a uniform field follows:

[1]

☐

A a straight line

B a parabola

C a circle

D a spreading spiral

Exercises 2.4·3.1

2.4 State **why** the magnetic force does **no work** on the moving charge. [1]

2.4

- the force is always **perpendicular** to the velocity, so it does no work (the speed is unchanged)

3.1 A charged particle moving **perpendicular** to a uniform field follows: [1]

☐

A a straight line

B a parabola

C a circle

D a spreading spiral

3.1 C

- a charge moving perpendicular to B follows a **circle**

Exercises 3.2-3.3

3.2 An electron ($m = 9.1 \times 10^{-31}$ kg, $q = 1.6 \times 10^{-19}$ C) moves at $3.0 \times 10^6 \frac{\text{m}}{\text{s}}$ at right angles to a 0.020 T field. Calculate the **radius** of its circular path. [3]

3.3 Explain why the **speed** of the particle stays constant. [2]

Exercises 3.2-3.3

3.2 An electron ($m = 9.1 \times 10^{-31}$ kg, $q = 1.6 \times 10^{-19}$ C) moves at $3.0 \times 10^6 \frac{\text{m}}{\text{s}}$ at right angles to a 0.020 T field. Calculate the **radius** of its circular path. [3]

3.2

- $BQv = mv^2/r \Rightarrow r = mv/(BQ)$

$$r = \frac{mv}{BQ} = \frac{(9.1 \times 10^{-31} \text{ kg})(3.0 \times 10^6 \frac{\text{m}}{\text{s}})}{(0.020 \text{ T})(1.6 \times 10^{-19} \text{ C})} = \mathbf{8.5 \times 10^{-4} \text{ m}}$$

3.3 Explain why the **speed** of the particle stays constant. [2]

3.3

- the magnetic force is always **perpendicular** to the velocity
- so it does **no work** – the kinetic energy and hence speed stay constant

Exercise 3.4

3.4 Describe how a **velocity selector** selects charges of one particular speed. [2]

Exercise 3.4

3.4 Describe how a **velocity selector** selects charges of one particular speed. [2]

3.4

- crossed **electric** and **magnetic** fields exert opposite forces on the charge
- only when they **balance** ($qE = Bqv$, i.e. $v = E/B$) does the charge travel straight through – selecting that speed

Exercise 3.5 (a)

3.5 A narrow beam of electrons, each of charge -1.60×10^{-19} C and mass 9.11×10^{-31} kg, enters a region of uniform magnetic field of flux density 3.5 mT. The electrons travel at $2.4 \times 10^7 \frac{\text{m}}{\text{s}}$ **perpendicular** to the field, and follow a circular path.

(a) **Explain** why the magnetic force makes the electrons move in a **circle** rather than speeding them up. [2]

Exercise 3.5 (a)

3.5 A narrow beam of electrons, each of charge -1.60×10^{-19} C and mass 9.11×10^{-31} kg, enters a region of uniform magnetic field of flux density 3.5 mT. The electrons travel at $2.4 \times 10^7 \frac{\text{m}}{\text{s}}$ **perpendicular** to the field, and follow a circular path.

(a) **Explain** why the magnetic force makes the electrons move in a **circle** rather than speeding them up. [2]

(a) the magnetic force $F = BQv$ is always **perpendicular to the velocity**

- so it does no work on the electron: the speed is unchanged and only the direction turns, which is circular motion

Exercise 3.5 (b)

3.5 A narrow beam of electrons, each of charge -1.60×10^{-19} C and mass 9.11×10^{-31} kg, enters a region of uniform magnetic field of flux density 3.5 mT. The electrons travel at $2.4 \times 10^7 \frac{\text{m}}{\text{s}}$ **perpendicular** to the field, and follow a circular path.

(b) **Determine** the magnitude of the force on one electron.

[2]

Exercise 3.5 (b)

3.5 A narrow beam of electrons, each of charge -1.60×10^{-19} C and mass 9.11×10^{-31} kg, enters a region of uniform magnetic field of flux density 3.5 mT. The electrons travel at $2.4 \times 10^7 \frac{\text{m}}{\text{s}}$ **perpendicular** to the field, and follow a circular path.

(b) **Determine** the magnitude of the force on one electron. [2]

(b) $F = BQv$

$$F = BQv = (3.5 \times 10^{-3} \text{ T})(1.60 \times 10^{-19} \text{ C})(2.4 \times 10^7 \frac{\text{m}}{\text{s}}) = \mathbf{1.3 \times 10^{-14} \text{ N}}$$

Exercise 3.5 (c)

3.5 A narrow beam of electrons, each of charge -1.60×10^{-19} C and mass 9.11×10^{-31} kg, enters a region of uniform magnetic field of flux density 3.5 mT. The electrons travel at $2.4 \times 10^7 \frac{\text{m}}{\text{s}}$ **perpendicular** to the field, and follow a circular path.

(c) **Determine** the radius of the circular path.

[3]

Exercise 3.5 (c)

3.5 A narrow beam of electrons, each of charge -1.60×10^{-19} C and mass 9.11×10^{-31} kg, enters a region of uniform magnetic field of flux density 3.5 mT. The electrons travel at $2.4 \times 10^7 \frac{\text{m}}{\text{s}}$ **perpendicular** to the field, and follow a circular path.

(c) **Determine** the radius of the circular path.

[3]

(c) $BQv = mv^2/r$, so $r = mv/(BQ)$

$$r = \frac{mv}{BQ} = \frac{(9.11 \times 10^{-31} \text{ kg})(2.4 \times 10^7 \frac{\text{m}}{\text{s}})}{(3.5 \times 10^{-3} \text{ T})(1.60 \times 10^{-19} \text{ C})} = \mathbf{3.9 \times 10^{-2} \text{ m}}$$

Exercise 3.5 (d)

3.5 A narrow beam of electrons, each of charge -1.60×10^{-19} C and mass 9.11×10^{-31} kg, enters a region of uniform magnetic field of flux density 3.5 mT. The electrons travel at $2.4 \times 10^7 \frac{\text{m}}{\text{s}}$ **perpendicular** to the field, and follow a circular path.

(d) **Determine** the time for one complete circle, and **state** what happens to that time if the electrons are made to enter at twice the speed. [3]

Exercise 3.5 (d)

3.5 A narrow beam of electrons, each of charge -1.60×10^{-19} C and mass 9.11×10^{-31} kg, enters a region of uniform magnetic field of flux density 3.5 mT. The electrons travel at $2.4 \times 10^7 \frac{\text{m}}{\text{s}}$ **perpendicular** to the field, and follow a circular path.

(d) **Determine** the time for one complete circle, and **state** what happens to that time if the electrons are made to enter at twice the speed. [3]

(d) $T = 2\pi r/v$

$$T = \frac{2\pi r}{v} = \frac{2\pi(0.039 \text{ m})}{2.4 \times 10^7 \frac{\text{m}}{\text{s}}} = 1.0 \times 10^{-8} \text{ s}$$

- doubling the speed doubles the radius as well, so the time is **unchanged** – the period does not depend on the speed

Exercise 3.5 (e)

3.5 A narrow beam of electrons, each of charge -1.60×10^{-19} C and mass 9.11×10^{-31} kg, enters a region of uniform magnetic field of flux density 3.5 mT. The electrons travel at $2.4 \times 10^7 \frac{\text{m}}{\text{s}}$ **perpendicular** to the field, and follow a circular path.

(e) An electric field is now applied in the same region so that the electrons pass through **undeflected**. **Determine** the magnitude of the electric field strength required, and **state** its direction relative to the magnetic force. [3]

Exercise 3.5 (e)

3.5 A narrow beam of electrons, each of charge -1.60×10^{-19} C and mass 9.11×10^{-31} kg, enters a region of uniform magnetic field of flux density 3.5 mT. The electrons travel at $2.4 \times 10^7 \frac{\text{m}}{\text{s}}$ **perpendicular** to the field, and follow a circular path.

(e) An electric field is now applied in the same region so that the electrons pass through **undeflected**. **Determine** the magnitude of the electric field strength required, and **state** its direction relative to the magnetic force. [3]

(e) undeflected means $QE = BQv$

$$E = Bv = (3.5 \times 10^{-3} \text{ T})(2.4 \times 10^7 \frac{\text{m}}{\text{s}}) = \mathbf{8.4 \times 10^4 \text{ V m}^{-1}}$$

- the electric force must act **opposite** to the magnetic force