Exercise walk-through

Force on a moving charge ▪ 20.3

eXercise

You must be able to

- use $F = BQv\sin\theta$ and find the force direction
- describe the **circular motion** of a charge in a uniform field
- explain the **Hall voltage** and **velocity selection**

Method — Force on a moving charge

$$F = BQv\sin\theta.$$

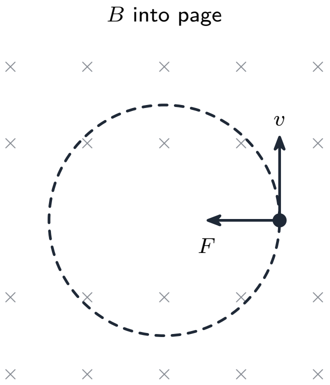
Maximum when v is at right angles to B; zero when v is along B.

Method — Circular motion

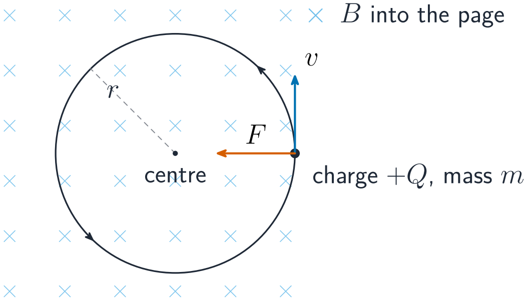
A charge moving **perpendicular** to a uniform field feels a force at right angles to v — so it moves in a **circle** at constant speed (the force does **no work**): Set magnetic force = centripetal force:

$$BQv = \frac{mv^2}{r}, \text{ so } r = \frac{mv}{BQ}.$$

A **velocity selector** uses crossed electric and magnetic fields: only charges with $v = E/B$ (where the forces balance) pass straight through.



Method — Circular motion



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

A moving charge curves in a magnetic field

Practice 2.1 ▪ 1 mark

Write the equation for the force on a moving charge.

Solution 2.1

Worked steps

$F = BQv\sin\theta$ **B1**.

Practice 2.2 ▪ 2 marks

A charge of 1.6×10^{-19} C moves at 2.0×10^{6} m s^{-1} at right angles to a 0.50 T field. Find the force.

Solution 2.2

Method: Circular motion

Worked steps

$F = BQv = (0.50)(1.6 \times 10^{-19})(2.0 \times 10^{6}) = 1.6 \times 10^{-13}$ N **M1** **A1**.

Practice 2.3 ▪ 1 mark

State the **path** of a charge moving perpendicular to a uniform magnetic field.

Solution 2.3

Method: Circular motion

Worked steps

A **circle** B1.

Practice 2.4 ▪ 1 mark

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

Solution 2.4

Method: Circular motion

Worked steps

The force is always **perpendicular** to the velocity, so it does no work (the speed is unchanged) B1.

Exam-style 3.1 ▪ 1 mark

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

- **A** a straight line
- **B** a parabola
- **C** a circle
- **D** a spreading spiral

Solution 3.1

Method: Circular motion

A a straight line

B a parabola

C a circle ✓

D a spreading spiral

Worked steps

C — a circle.

Exam-style 3.2 ▪ 3 marks

An electron ($m = 9.1 \times 10^{-31}$ kg, $q = 1.6 \times 10^{-19}$ C) moves at 3.0×10^{6} m s^{-1} at right angles to a 0.020 T field. Calculate the **radius** of its circular path.

Solution 3.2

Method: Circular motion

Worked steps

$BQv = \frac{mv^2}{r} \Rightarrow r = \frac{mv}{BQ} = \frac{(9.1 \times 10^{-31})(3.0 \times 10^6)}{(0.020)(1.6 \times 10^{-19})}$ **M1** **M1** $= 8.5 \times 10^{-4}$ m **A1**.

Exam-style 3.3 ▪ 2 marks

Explain why the **speed** of the particle stays constant.

Solution 3.3

Method: Circular motion

Worked steps

The magnetic force is always **perpendicular** to the velocity B1, so it does **no work** — the kinetic energy and hence speed stay constant B1.

Exam-style 3.4 ▪ 2 marks

Describe how a **velocity selector** selects charges of one particular speed.

Solution 3.4

Method: Circular motion

Worked steps

Crossed **electric** and **magnetic** fields exert opposite forces on the charge **B1**; only when they **balance** ($qE = Bqv$, i.e. $v = E/B$) does the charge travel straight through — selecting that speed **B1**.

Exam-style 3.5 ▪ 2 marks

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 2.4×10^{7} m s^{-1} **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.

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

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

(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.

Solution 3.5

Method: Circular motion

Worked steps

(a) The magnetic force $F = BQv$ is always **perpendicular to the velocity** B1, so it does no work on the electron: the speed is unchanged and only the direction turns, which is exactly the condition for circular motion B1.

(b) $F = BQv = 3.5 \times 10^{-3} \times 1.60 \times 10^{-19} \times 2.4 \times 10^{7}$ M1 $= 1.3 \times 10^{-14}$ N A1.

(c) The magnetic force provides the centripetal force: $BQv = \dfrac{mv^2}{r}$ M1, so

$$r = \frac{mv}{BQ} = \frac{9.11 \times 10^{-31} \times 2.4 \times 10^{7}}{3.5 \times 10^{-3} \times 1.60 \times 10^{-19}}$$ M1 $= 3.9 \times 10^{-2}$ m A1.

Solution 3.5

(d) $T = \frac{2\pi r}{v} = \frac{2\pi(0.039)}{2.4 \times 10^7}$ **M1** $= 1.0 \times 10^{-8}$ s **A1**. Doubling the speed doubles the radius as well, so the time is **unchanged** — the period does not depend on the speed **B1**.

(e) Undeflected means the electric force balances the magnetic one: $QE = BQv$ **M1**, so $E = Bv = 3.5 \times 10^{-3} \times 2.4 \times 10^7 = 8.4 \times 10^4$ V m^{-1} **A1**, and the electric force must act **opposite** to the magnetic force **B1**. (This is a velocity selector: only electrons at 2.4×10^7 m s^{-1} pass straight through.)