A-LEVEL PHYSICS • EXERCISE SHEET

20.3 Force on a moving charge

Name: ____________ Class: ________ Date: __________ **Total: 26 marks**

KEY WORDS velocity 速度 • velocity selector 速度选择器 • uniform field 匀强场 • hall voltage 霍尔电压 • magnetic field 磁场

Objective

Build the skills to answer exam questions on the **force on a moving charge** in a magnetic field.

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**

1 Worked examples

Study these first. Each one shows the method for a question type used later — follow the steps and you can do the Practice and Exam-style questions yourself.

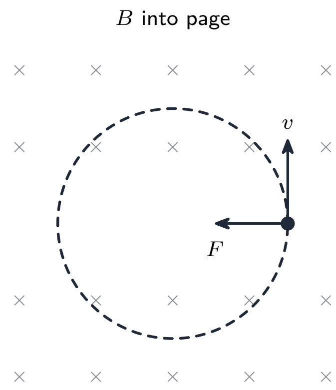
■ Force on a moving charge

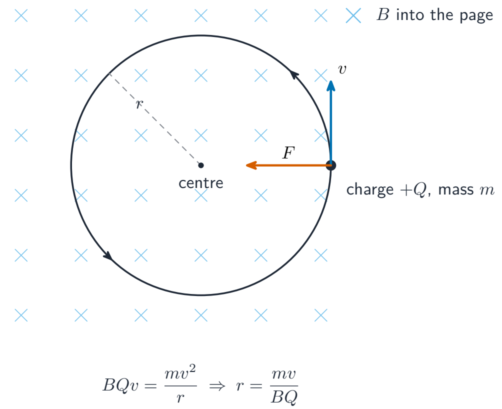
$$F = BQv\sin\theta.$$

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

■ 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**):





A moving charge curves in a magnetic field

Set magnetic force = centripetal force: $BQv = \dfrac{mv^2}{r}$, so $r = \dfrac{mv}{BQ}$.

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

2 Practice

Now apply the methods above.

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 2.0×10^{6} m s^{-1} 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]

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

3 Exam-style questions

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

3.2 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. [3]

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

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

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 2.4×10^{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. [2]

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

(c) **Determine** the radius of the circular path. [3]

(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]

(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]

Solutions

Each answer shows the steps, then the **result**.

2.1

- $F = BQv \sin\theta$

2.2

- $F = BQv$

$$F = (0.50\text{ T})(1.6 \times 10^{-19}\text{ C})(2.0 \times 10^{6}\text{ m s}^{-1}) = \mathbf{1.6 \times 10^{-13}}\text{ N}$$

2.3

- a **circle**

2.4

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

3.1 C

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

3.2

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

$$r = \frac{(9.1 \times 10^{-31}\text{ kg})(3.0 \times 10^{6}\text{ m s}^{-1})}{(0.020\text{ T})(1.6 \times 10^{-19}\text{ C})} = \mathbf{8.5 \times 10^{-4}}\text{ m}$$

3.3

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

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

3.5

(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

(b) $F = BQv$

$$F = (3.5 \times 10^{-3}\text{ T})(1.60 \times 10^{-19}\text{ C})(2.4 \times 10^{7}\text{ m s}^{-1}) = \mathbf{1.3 \times 10^{-14}}\text{ N}$$

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

$$r = \frac{(9.11 \times 10^{-31}\ \text{kg})(2.4 \times 10^{7}\ \text{m s}^{-1})}{(3.5 \times 10^{-3}\ \text{T})(1.60 \times 10^{-19}\ \text{C})} = \mathbf{3.9 \times 10^{-2}}\ \text{m}$$

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

$$T = \frac{2\pi(0.039\ \text{m})}{2.4 \times 10^{7}\ \text{m s}^{-1}} = \mathbf{1.0 \times 10^{-8}}\ \text{s}$$

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

(e) undeflected means $QE = BQv$

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

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