

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

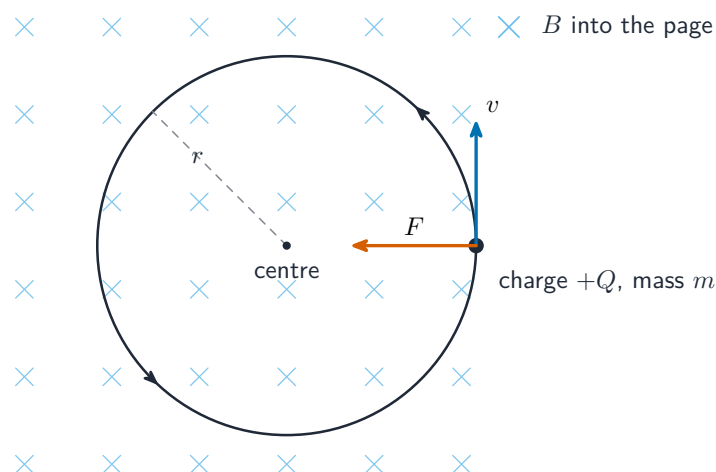
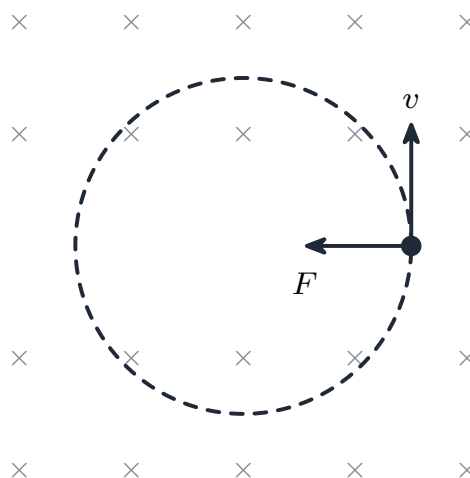
$$F = BQv \sin \theta.$$

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**):

B into page



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

A moving charge curves in a magnetic field

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

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
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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

2.1 $F = BQv \sin \theta$.

2.2 $F = BQv = (0.50)(1.6 \times 10^{-19})(2.0 \times 10^6) = 1.6 \times 10^{-13} \text{ N}$.

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 circle.

3.2 $BQv = \frac{mv^2}{r} \Rightarrow r = \frac{mv}{BQ} = \frac{(9.1 \times 10^{-31})(3.0 \times 10^6)}{(0.020)(1.6 \times 10^{-19})} = 8.5 \times 10^{-4} \text{ m}$.

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 exactly the condition for circular motion.

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

(c) The magnetic force provides the centripetal force: $BQv = \frac{mv^2}{r}$, so $r = \frac{mv}{BQ} = \frac{9.11 \times 10^{-31} \times 2.4 \times 10^7}{3.5 \times 10^{-3} \times 1.60 \times 10^{-19}} = 3.9 \times 10^{-2} \text{ m}$.

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

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