# Motion in electromagnetic fields

D.3 · SL

# What shapes the northern lights?

> A magnetic field can steer a moving charge but never speed it up.

- Solar-wind energy enters the magnetosphere and energizes particles, mainly electrons.
- Magnetic guidance and atmospheric collisions help produce auroral light.
- Local uniform-field models explain steering, not the entire auroral system.

# Fields steer charged particles

## Electric field

Force $qE$, even at rest.

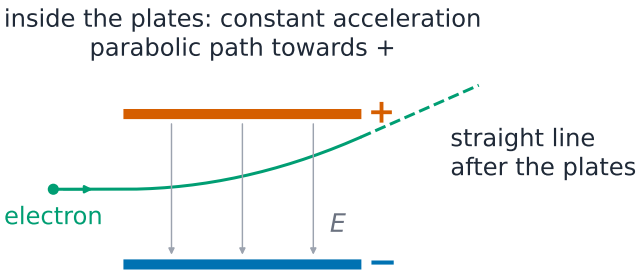
Changes speed and direction.

## Magnetic field

Force only on moving charges.

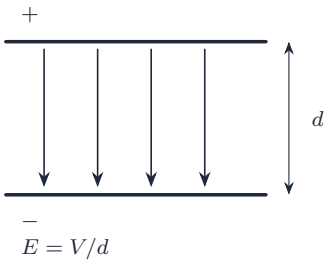
Changes direction only.

# In a uniform electric field




- A proton through 500 V reaches $3.1 \times 10^5$ m s$^{-1}$.
- Across the field the path is a **parabola**, like a projectile.

# The field between parallel plates




A charge feels the same force $qE$ everywhere between them

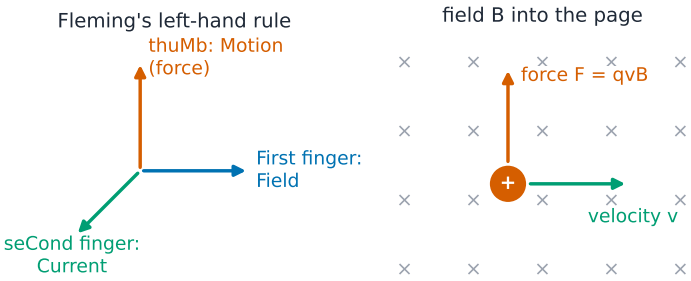
# The magnetic force on a charge

- A proton at $3.0 \times 10^6$ m s$^{-1}$ in 0.20 T feels $9.6 \times 10^{-14}$ N.
- Zero force along the field or at rest.

$$F = |q| v B \sin\theta$$

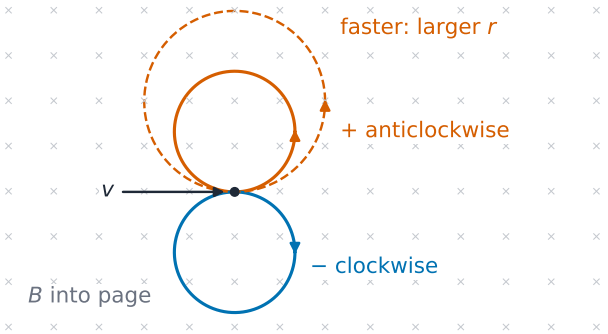
$\theta$ is the angle between the velocity and the field.

# Which way is the force?




- Field, current (positive charge), thumb gives the force.
- Reverse it for electrons.

# Circles in a magnetic field




- No work is done, so the speed stays constant.
- Opposite charges curve opposite ways.

# Radius and period

- The proton above moves on a 0.16 m circle every $3.3 \times 10^{-7}$ s.
- Double the speed and the radius doubles; the period does not change.

$$|q|vB = \frac{mv^2}{r}$$

$$r = \frac{mv}{|q|B} \qquad T = \frac{2\pi m}{|q|B}$$

Perpendicular entry, uniform field and non-relativistic motion.

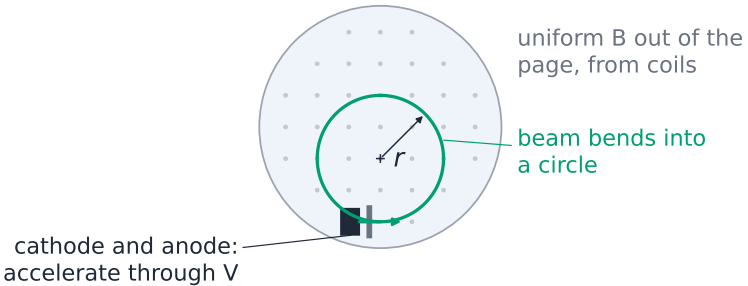
# Check: an alpha particle

## Your turn

An alpha particle has four times a proton's mass and twice its charge magnitude. Both enter the same uniform field perpendicularly at the same speed. How does the alpha particle's radius compare with the proton's?

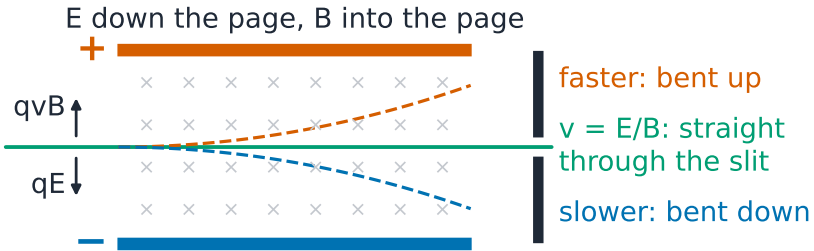
A. Half
B. The same
C. Twice
D. Four times

# Measuring e/m




- Accelerate through $V$, then measure the circle's radius $r$.
- 200 V, 1.0 mT and 4.8 cm give $1.7 \times 10^{11}$ C kg$^{-1}$.

# The velocity selector




- For the stated beam direction, opposite forces balance at $v = E/B$ for any nonzero charge.
- With $E = 3.0 \times 10^4$ V/m and $B = 0.010$ T, selected speed is $3.0 \times 10^6$ m/s.

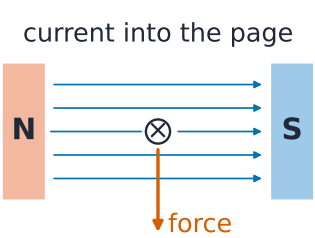
# Force on a wire

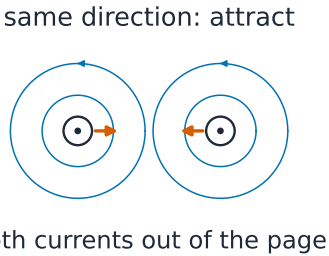
- 5.0 cm carrying 3.0 A at right angles to 0.40 T feels 0.060 N.
- The **motor effect** drives motors and loudspeakers.

$$F = BIL\sin\theta$$

Second finger along the conventional current.

# Parallel wires




- Same direction attract; opposite directions repel.
- 10 A in each, 5.0 cm apart, gives $4.0 \times 10^{-4}$ N m$^{-1}$.

# The force per unit length

- The field of one wire at the other is $\mu_0 I_1/2\pi r$.
- The forces on the two wires are equal and opposite.

$$\frac{F}{L} = \frac{\mu_0 I_1 I_2}{2\pi r}$$

Use current magnitudes; $\mu_0 \approx 4\pi \times 10^{-7}$ T m/A, long wires in vacuum or approximately air.

# Exam tips

> A magnetic force changes direction, not speed, and does no work.

- Derive $r = mv/(|q|B)$ for perpendicular entry; state the classical model.
- Reverse the left-hand rule for electrons.
- No force along the field.

# Check yourself

## Try these

For perpendicular entry, find the radius of a proton at $3.0 \times 10^{6}$ m/s in 0.20 T. Use $m_p = 1.67 \times 10^{-27}$ kg and $e = 1.60 \times 10^{-19}$ C.

Find $e/m$ from 200 V, 1.0 mT and a 4.8 cm radius.

Find force per metre between two long parallel wires carrying 10 A in the same direction, 0.050 m apart. Use $\mu_0 \approx 4\pi \times 10^{-7}$ T m/A.