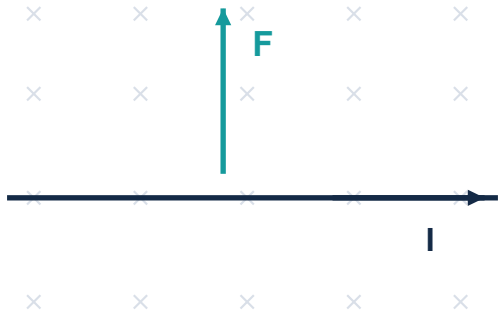
LESSON 4.2.2

Magnetic Fields and Forces on Charges or Currents

A magnetic field can exert a sideways force on a moving charge or a current-carrying wire. Work out the force magnitude and direction separately.

CURRENT TO THE RIGHT; FIELD INTO THE PAGE



Crosses show B into the page.

A FORCE AT RIGHT ANGLES

The force is perpendicular to both the field and the conventional current. Here it points upwards.

Outside a magnet, field lines point from north to south. Closer lines indicate a stronger field.

$$F = BI\ell \sin\theta$$

B: magnetic flux density (tesla, T); I: conventional current (A). Script ell denotes wire length inside the uniform field (m). The angle is between the current direction and B.

$$\text{At } 90°\text{: } B = \frac{F}{I\ell} \qquad 1\ \text{T} = 1\ \text{N A}^{-1}\ \text{m}^{-1}$$

WORKED EXAMPLE: A WIRE AT 30° TO THE FIELD

B = 0.250 T, I = 3.00 A and ℓ = 0.200 m.

$$F = (0.250)(3.00)(0.200)\sin 30° = 0.0750\ \text{N}$$

Parallel or antiparallel: zero force. Perpendicular: maximum force.

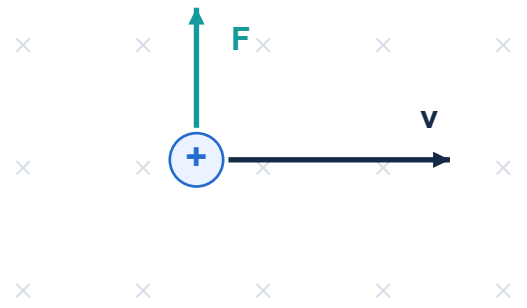
1 Charge sign changes force direction

Use the magnitude of charge to calculate the force, then handle its sign when finding direction.

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

q: charge (C); v: speed (m/s). The angle is between velocity and B. A stationary charge, a neutral particle, or a charge moving parallel to B has no magnetic force.

POSITIVE CHARGE



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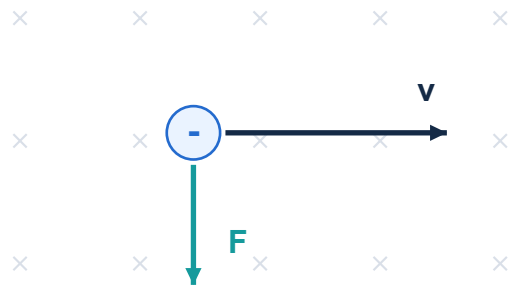
NEGATIVE CHARGE



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FLEMING'S LEFT-HAND RULE

1. First finger: magnetic field B. Second finger: conventional current, or the velocity of a positive charge. Thumb: force. Hold all three at right angles.

2. For an electron, use conventional current opposite to its motion, or find the positive-charge force and reverse it. Do not reverse both.

WORKED EXAMPLE: ELECTRON MOVING PERPENDICULARLY TO B

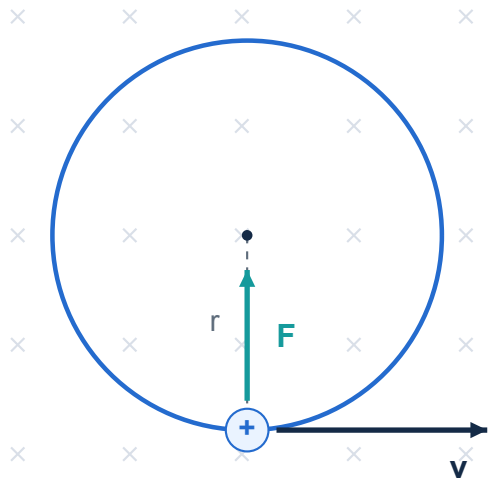
$$F = (0.0400)(1.60 \times 10^{-19})(3.00 \times 10^{6})$$

$$F = 1.92 \times 10^{-14}\ \text{N}$$

With motion to the right and B into the page, the electron force is downwards. Reversing B or the direction of motion reverses the force; reversing both leaves it unchanged.

2 A sideways force bends the path

In a uniform magnetic field, motion perpendicular to B is circular if the magnetic force acts alone.



B into page; positive charge

MAGNETIC FORCE DOES NO WORK

Force is always perpendicular to velocity. It changes direction, not speed or kinetic energy. The force provides the inward resultant.

NOT ALWAYS A CIRCLE

A component of velocity along B is unchanged. Combined with the circular component, it produces a helix. Parallel motion alone stays straight.

$$B|q|v = \frac{mv^2}{r} \qquad r = \frac{mv}{B|q|} = \frac{p}{B|q|}$$

Here v is perpendicular to B and p = mv for non-relativistic motion.

WORKED EXAMPLE: PROTON IN A 0.200 T FIELD

$$m = 1.67 \times 10^{-27}\ \text{kg} \qquad v = 2.00 \times 10^{6}\ \text{m/s}$$

$$r = \frac{(1.67 \times 10^{-27})(2.00 \times 10^{6})}{(0.200)(1.60 \times 10^{-19})} = 0.104\ \text{m}$$

The radius is 10.4 cm, not the diameter. Doubling B halves r at fixed momentum.

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

T is the orbital period, not the tesla unit here. At non-relativistic speeds it is independent of speed. For a helical path, use the perpendicular speed to calculate the radius.

Source: Pearson IAL Physics, Unit 4 pp. 30-31, points 105-107 and 115.

Course lesson numbering. Flux and induction continue in Lesson 4.2.3.