Motion in electromagnetic fields

International Baccalaureate · IB Diploma · Physics · SL

Scope and prerequisites

This handout covers selected SL topics for the course first assessed in 2025; it is not the whole syllabus.

Prerequisites: read the stated quantities and units, and use arithmetic and the model conditions below.

The examples are original and fictional: they are not real measurements or real student investigations.

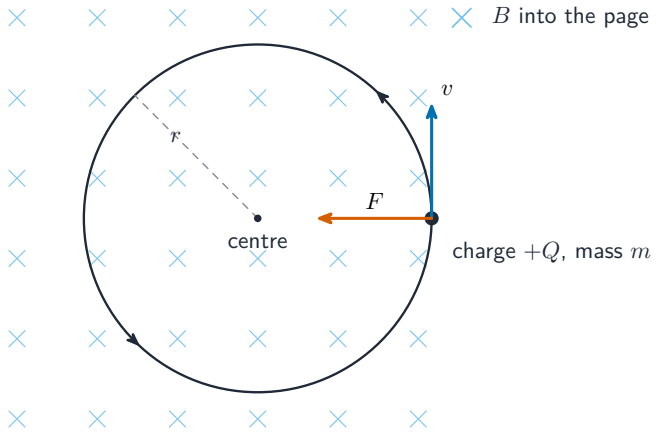
Magnetic forces: turn velocity without increasing speed

What would explain this observation?

- A charged particle curves in a uniform magnetic field. Its direction changes although the **magnetic force** alone does not increase its kinetic energy.

Build the model

- The magnetic force magnitude is F = |q|vB sinθ.
- It is perpendicular to velocity and magnetic field, with direction determined by charge sign.
- For perpendicular entry into a uniform field, it can provide the centripetal force for circular motion.
- magnetic force: Force due to a magnetic field on a moving charge or current.
- **momentum** : Mass multiplied by velocity in the classical model.



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

The magnetic force is always perpendicular to v, so it bends the path into a circle: r = mv/(qB)

Choose evidence that can test it

- Equate magnetic force with mv^2/r to obtain r = mv/(|q|B) for perpendicular motion.
- A stronger field makes a smaller radius at fixed momentum.
- Parallel entry gives zero magnetic force in this model.

In the lab: Draw velocity, field and force as separate arrows using stated into/out-of-page conventions. Use supplied beam data or a simulation. Do not treat a current-carrying wire direction as identical to electron-motion direction.

Work from known quantities

- Known: a particle has m = 2.0×10^{-27} kg, v = 3.0×10^{6} m/s, |q| = 1.0×10^{-19} C and B = 0.20 T. r = mv/(|q|B) = 0.30 m.
- The calculation assumes non-relativistic motion and perpendicular entry.

Your turn: Use r = mv/(|q|B). For m=2×10^{-27} kg, v=2×10^{6} m/s, |q|=1×10^{-19} C and B=0.20 T, find r.

■ Check the conclusion and its limits

- A magnetic force can change momentum direction without doing work.
- Adding an electric field can change the energy, so conclusions about a magnetic field alone do not cover every combined-field apparatus.

Not true: A magnetic force alone continuously increases the kinetic energy of a charged particle. A force perpendicular to the velocity does no work (work = force x distance ALONG the force), so a magnetic field alone cannot change a particle's kinetic energy - only its direction. Speeding up needs a field component along the motion, which only an electric field provides.

Key:

- The magnetic force magnitude is F = |q|vB sinθ.
- Equate magnetic force with mv^2/r to obtain r = mv/(|q|B) for perpendicular motion.
- Watch for: A magnetic force can change momentum direction without doing work.

■ Write from an orbital radius of 0.50 m

- Use r = mv divided by the product of charge magnitude and magnetic field.
- Take m = 2 times 10 to the minus 27 kg, v = 2 times 10 to the 6 metres per second, charge magnitude 1 times 10 to the minus 19 coulomb and B = 0.08 T. A magnetic force perpendicular to the velocity does no work.

■ Write from a doubled radius

- The same particle enters the same field at half the strength.
- r = mv ÷ (qB), so halving B DOUBLES the radius – the spiral loosens as the field weakens.

■ Write from a speed-independent period

- A fast and a slow particle of equal mass orbit in the same field.
- T = 2πm ÷ (qB) contains no v: the faster one travels a larger circle in the SAME time.