Magnetic Fields

Name _____ Date _____

By the end of this topic I can…

- sketch magnetic field patterns and use the right-hand grip rule and Fleming's left-hand rule
- use $F = BIL\sin\theta$ and $F = Bqv\sin\theta$, and define magnetic flux density B
- analyse circular motion of charged particles: mass spectrometer, cyclotron, velocity selector
- explain the Hall effect and use $V_H = \frac{BI}{ntq}$

Magnets and magnetic fields

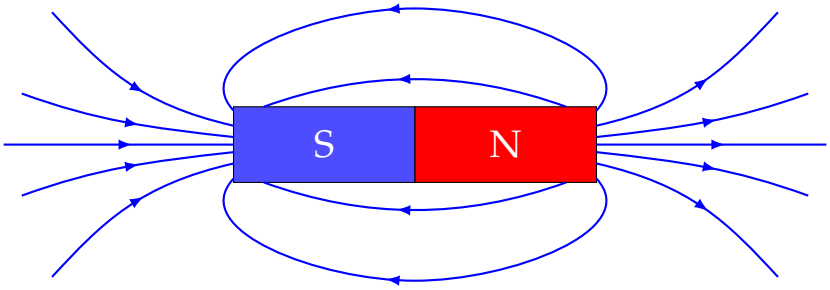
Magnets

A magnet creates a _____. All magnets have a _____ and a _____ (no monopoles at A level). A freely suspended magnet's north pole points to the Earth's geographic north: a _____ pole.

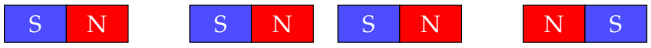
• like poles _____; opposite poles _____

• _____: emerge from the _____ pole and enter the _____ pole. Closely spaced lines mean a _____ field. A small compass lines up along the line, its north pole pointing in the direction of the field.

• the strength of the field is the _____, B (defined in §)



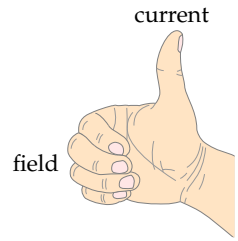
The field of a bar magnet.

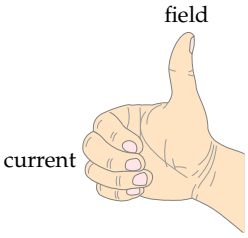


(a) attract (b) repel

Question 25.1 Two identical bar magnets are placed side by side as shown. Sketch the magnetic field lines for each case.

Magnetic field due to currents





Hans Christian Orsted discovered in 1820 that a current deflects a nearby compass: a _____ produces a magnetic field. The direction is given by the **right-hand grip rule**.

- **straight wire**: thumb along the _____, fingers curl in the direction of the _____. Field lines are _____ around the wire.
- **loop or coil**: fingers curl along the _____, thumb points along the _____ inside the loop
- $B \propto I$: a larger current gives a _____ field

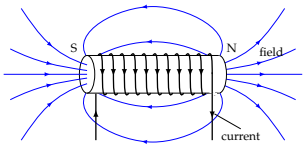
Long straight wire: [ ] where r is the _____ from the wire and $\mu_0 = 4\pi \times 10^{-7}$ T m A^{-1} is the _____.

- at the centre of a long coil of N turns, length L:

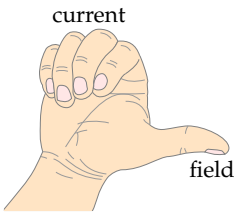
[ ]

- a _____ core strengthens the field: ferromagnetic materials (iron, cobalt, nickel) concentrate the field lines. A material of relative permeability μ_r multiplies B by μ_r.

Solenoids and electromagnets



A current-carrying coil is a _____. Its field is like that of a _____: use the grip rule to find which end is N and which is S. Inside, the field is _____.

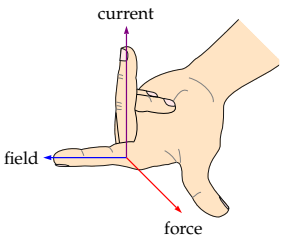


- stronger field with larger _____ I or more _____ N per unit length
- an iron core makes an _____

Question 25.2 Describe the magnetic field due to an alternating current through a solenoid.

Magnetic force

Force on a current-carrying conductor



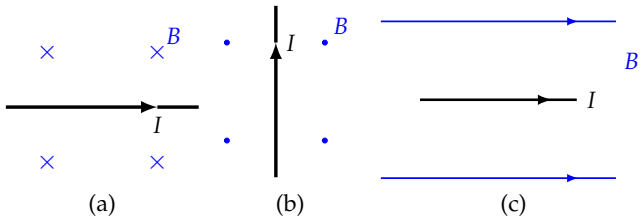
Fleming's left-hand rule.

A wire carrying current in an external field feels a _____, because the wire's field interacts with the external field.

- **Fleming's left-hand rule**: First finger = _____, seCond finger = _____, thuMb = _____ (force). The three are mutually _____.

Force on a conductor of length L: $\quad F = BIL\sin\theta$ θ is the angle between _____.

- $B \perp I$: $F =$ _____ (maximum)
- $B \parallel I$: $F =$ ____
- in general only the _____ contributes, giving the $\sin\theta$. The force is perpendicular to both B and I.



Example 25.1 Use the left-hand rule to find the direction of the magnetic force on each wire. In (a) B is into the page, in (b) B is out of the page, and in (c) B is to the right.

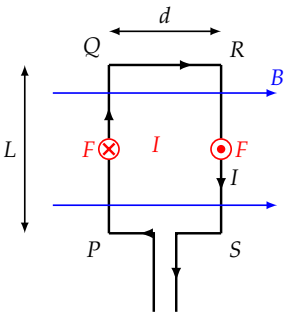
Magnetic flux density

Rearranging $F = BIL\sin\theta$ gives the definition of B:

_____ B is the _____ on a conductor carrying _____ at _____ to the field: _____

- unit: the _____ (T), $1\text{ T} = 1\text{ N A}^{-1}\text{ m}^{-1}$. A 1 m wire at right angles to the field carrying 1 A feels 1 N when $B = 1$ T.
- B is a _____. (A fridge magnet is about 10^{-3} T; an MRI scanner 1–3 T.)

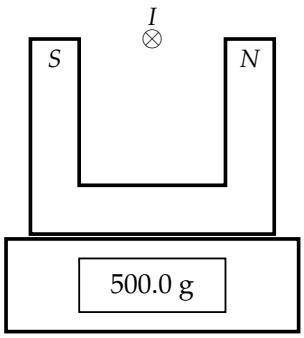
Example 25.2 A wire of length 0.80 m carrying 5.0 A lies at right angles to a magnetic field and experiences a force of 0.60 N. What is the flux density?



Example 25.3 A rectangular frame $PQRS$ carries current I in a uniform field B, with the plane of the frame *parallel* to the field. Explain why it turns.

Question 25.3 If the plane of the frame is at right angles to the field, describe the forces on each side and what happens to the frame.

Example 25.4 A U-shaped magnet sits on a balance reading 500.0 g, with a wire above it carrying 10 A into the page. The flux density between the poles is 0.50 T and 8.0 cm of wire is in the field. What does the balance now read?



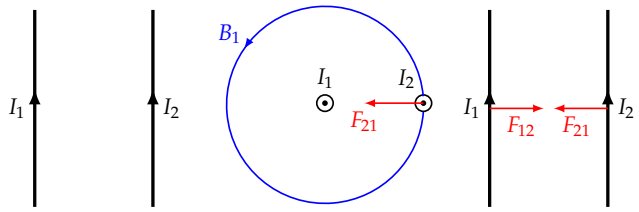
Question 25.4 The current in the example above is replaced by 6.0 A flowing out of the page. What does the balance read?

Force between parallel current-carrying wires

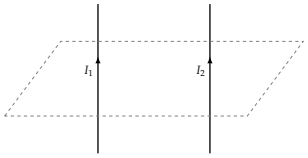
Wire 1 produces a field B_1 at wire 2 (use the grip rule). The left-hand rule then gives the force F_{21} on wire 2 (pointing towards wire 1 for currents in the _____ direction). By Newton's third law F_{12} is equal and _____.

Parallel currents _____; anti-parallel currents _____.

- the ampere is defined using this: two long parallel wires 1 m apart each carrying 1 A experience a force of 2×10^{-7} N per metre



Question 25.5 A light coil of several loops is hung from a fixed point. A current is switched on. State and explain the change in the separation of the loops.



Question 25.6 Two long parallel wires carry $I_1 = 3.0$ A and $I_2 = 5.0$ A in the same direction, 4.0 cm apart. (a) Draw at least three field lines due to I_1. (b) State the direction of the force on I_2. (c) Find the flux density due to I_1 at I_2. (d) Find the force per unit length on I_2. (e) Find the force per unit length on I_1.

Question 25.7 If one of the wires carries an alternating current, the wires should vibrate but are not seen to move. Make reasonable estimates and explain why.

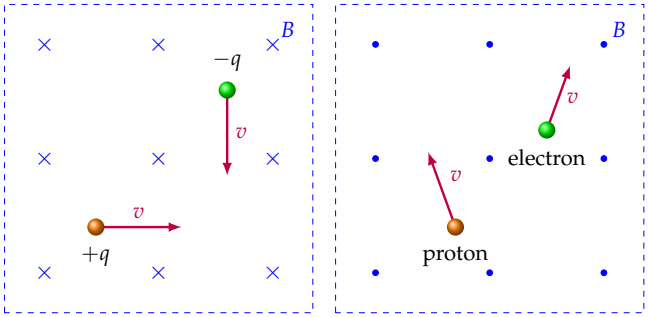
Force on a moving charged particle

A current is moving charges. Substituting $I = nAqv$ into $F = BIL\sin\theta$, and noting that nAL is the number of charge carriers in the wire, the force on _____ charge is

where θ is the angle between $\vec{v}$ and $\vec{B}$.

- direction: left-hand rule. For $+q$ the current is along v; for $-q$ the current is _____ to v
- $v \perp B$: $F =$ _____; $v \parallel B$: $F =$ ____

- F is always _____ to both v and B

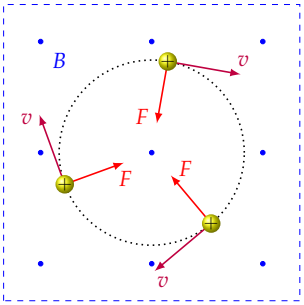


Example 25.5 Find the direction of the magnetic force on each moving charge. In (a) B is into the page and in (b) B is out of the page.

Electric and magnetic fields compared

	electric field	magnetic field
field strength	E	magnetic flux density B
force	$F = Eq$	$F =$ _____
depends on velocity?	no: acts on stationary and moving charges	_____: only moving charges, perpendicular component
direction	along E (same for $+q$, opposite for $-q$)	_____ to B and v
effect on motion	changes speed and direction	changes _____, not speed
work done	yes	_____

Charged particles in magnetic fields



Circular motion in a uniform field

A particle moving at right angles to a uniform field feels a force that is always perpendicular to its velocity and constant in size: it moves in a _____. The magnetic force provides the _____:

$\Rightarrow$

- larger v: _____ radius; larger B: _____ radius; larger m: _____ radius
- the _____ $q/m = \dfrac{v}{Br}$ can be found from measurements
- period: $T = \dfrac{2\pi r}{v}$, so _____, _____ of v and r

Example 25.6 An α-particle travelling at 2.5×10^4 m s^{-1} enters a uniform field of flux density 5.4 mT, normal to its velocity. What is the radius of its path?

Question 25.8 An α-particle and a β^- particle enter the same uniform field at the same speed. Compare the radii of their paths.

Question 25.9 Show that the angular velocity of a charged particle in a uniform field is independent of the radius of its path.

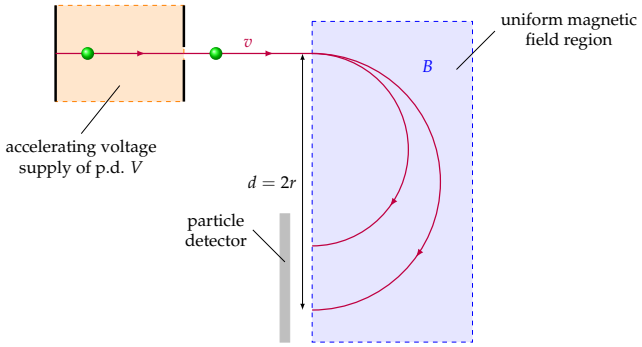
Question 25.10 A charged particle enters a uniform field at an angle $\theta \neq 90°$. State and explain its path.

The mass spectrometer

A mass spectrometer measures the _____ of ions. Particles are accelerated through a p.d. V: $\frac{1}{2}mv^2 = qV$, then move in a semicircle of radius r in the field: $v = \dfrac{Bqr}{m}$.

Eliminating v:

- different particles have different q/m, so different _____, which identifies them



Question 25.11 Two paths of deflected particles are shown in the figure. Give reasons why their radii can differ.

Question 25.12 The particles entering are positively charged and move to the right (as in the figure), curving downwards. In which direction should the field be applied?

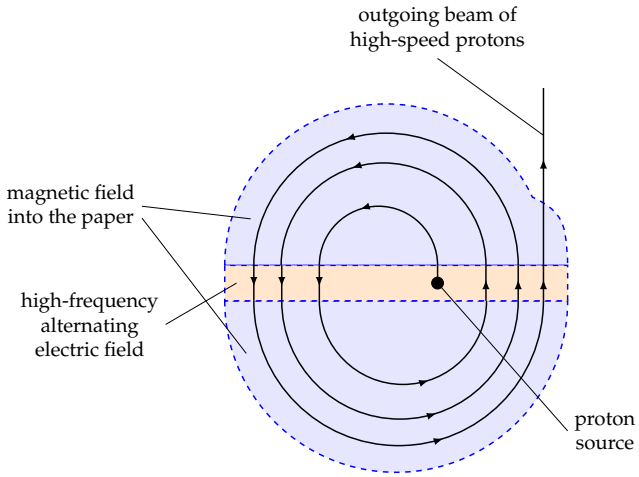
Question 25.13 A particle with charge $+e$ enters a uniform field of 8.8 mT at right angles with speed 1.4×10^5 m s^{-1}. It describes a semicircle of diameter 66 cm. (a) Find its mass. (b) Suggest what it could be.

The cyclotron

A cyclotron is a _____. Particles spiral outwards: in each _____ in the magnetic field the direction is turned round; each time they cross the _____ the alternating electric field accelerates them, adding energy _____.

• period $T = \dfrac{2\pi m}{Bq}$ does not depend on _____, so a fixed-frequency supply stays in step:

(the cyclotron frequency)



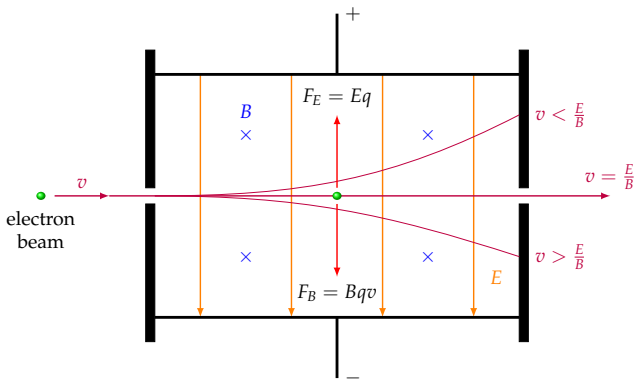
Question 25.14 Protons are accelerated in a cyclotron with a uniform field of 1.5 T and a gap voltage of 20 kV. (a) Find the frequency of the voltage supply needed. (b) How many circles must the protons make to gain 10 MeV?

The velocity selector

Beam of charged particles passes through crossed electric and magnetic fields. Particles of the right speed are _____: the electric and magnetic forces balance:

$$Eq = Bqv \Rightarrow$$

• faster particles: $F_B > F_E$ and they deflect one way; slower particles: $F_B < F_E$ and they deflect the _____ way



Question 25.15 Electrons at speed v pass undeflected through a velocity selector. What happens to α-particles of the same speed?

Question 25.16 A uniform field of 6.0×10^{-2} T is directed out of the page. A beam of protons moves from left to right across the page at 3.5×10^4 m s^{-1}. (a) In which direction do they deflect? (b) What electric field makes them undeviated?

The Hall effect

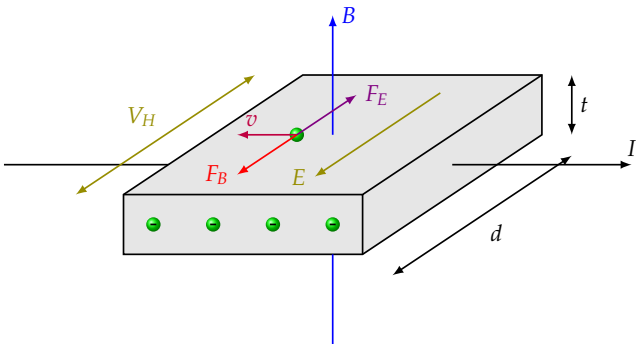
A current in a conductor in a perpendicular field produces a _____, the _____ V_H (Edwin Hall, 1879).

The magnetic force pushes the charge carriers to one side of the conductor. Charge builds up, creating an internal electric field E and p.d. V_H.

- in the steady state $F_E = F_B$: $Eq = Bqv$, with $E = \dfrac{V_H}{d}$ and $I = nAqv$ where $A = td$
- so $\dfrac{V_H}{d} = B\dfrac{I}{nAq}$, giving

where n is the _____ of carriers and t the _____

- a large V_H needs _____ (so use a _____) and a _____ slice
- the sign of V_H depends on whether the carriers are _____ or _____
- at fixed current, $V_H \propto$ ____, so a _____ measures flux density



Question 25.17 Why is it difficult to detect the Hall voltage in a thin slice of copper?

Question 25.18 A Hall probe is near one end of a strong magnet and is rotated through one full revolution. State and explain how the Hall voltage varies.