Electromagnetism

Magnetic Field – a region of space in which a magnetic pole, current-carrying conductor, or a moving charge experience a magnetic force.

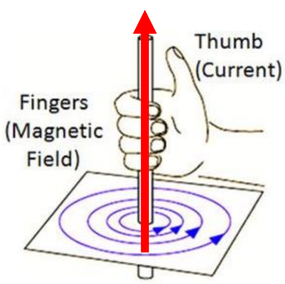
Magnetic Field Lines

- Tangent of the lines points in the direction of the magnetic flux density, *B*
- Closer lines indicate larger *B*
- No two lines intersect one another

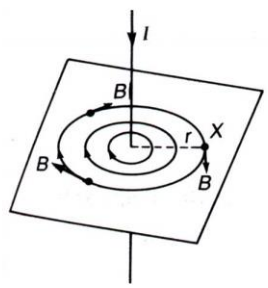
Magnetic Flux Density – at a point is the force per unit current per unit length experienced by a straight current-carrying conductor placed at right angles in a uniform magnetic field.

Tesla – is the magnetic flux density at a point in a magnetic field if a straight conductor carrying a current of one ampere placed at right angle to a uniform magnetic field experiences a force per unit length of one newton per metre.

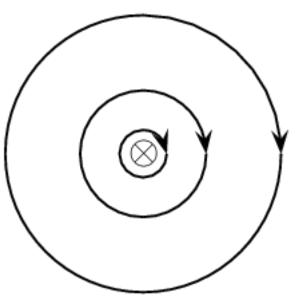
Magnetic Flux Density of a Long Straight Wire



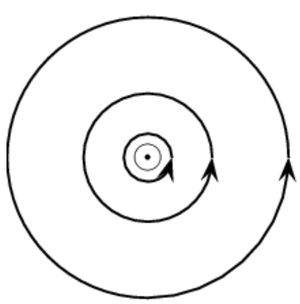
Right-Hand Grip Rule (RHGR). Thumb as current, fingers as field directions



Field direction at each point is tangential to the circular field lines. *Perpendicular to radius*



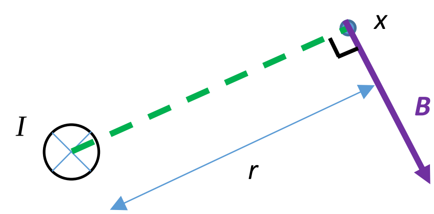
Top View, current into page, clockwise field



Top View, current out of page, anticlockwise field

The magnetic flux density at point *x*, at a perpendicular distance *r* along a plane from the wire carrying current I is,

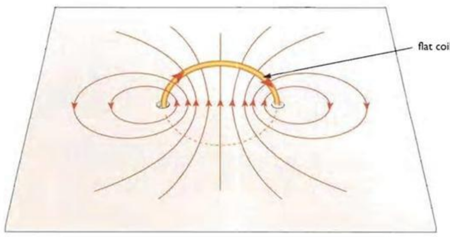
$$B = \frac{\mu_0 I}{2\pi r}$$

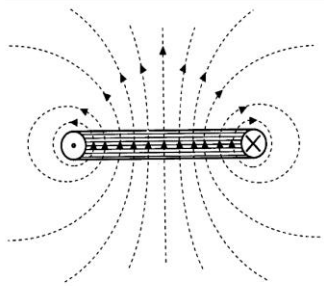


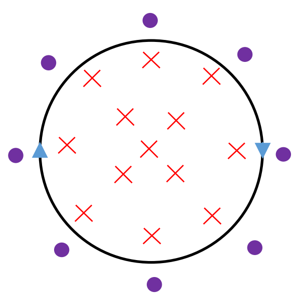
Tip: To determine direction of *B*,

1. Draw a straight line joining the wire to the point in question (Green Line)
2. Use RHGR
   a. Current into page, hence clockwise
3. Hence, as if "turning the green line clockwise", *B* is perpendicular to the green line pointing as shown.

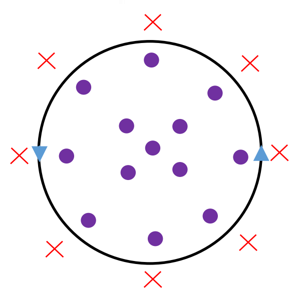
Magnetic Flux Density of a Flat Circular Coil



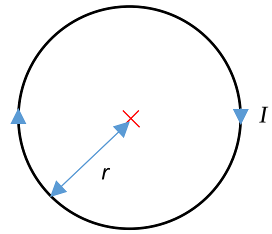




Clockwise current, field into page within coil; out of page not within coil

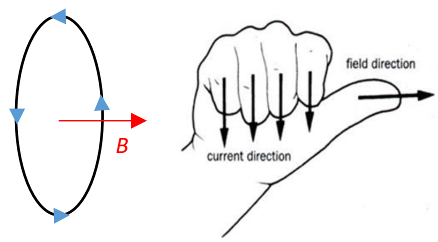


Anticlockwise current, field out of page within coil; into page not within coil



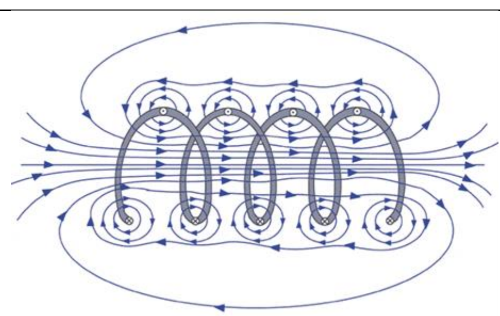
The magnetic flux density at point *x*, which is at the centre of the circular coil of radius, when a current I running through it is,

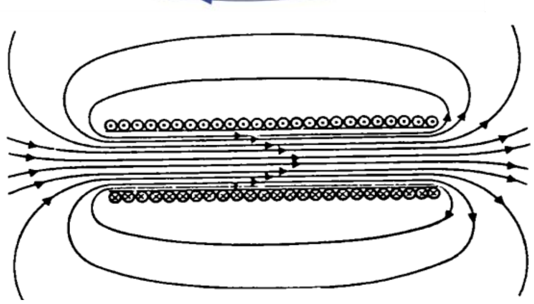
$$B = \frac{\mu_0 NI}{2r}$$

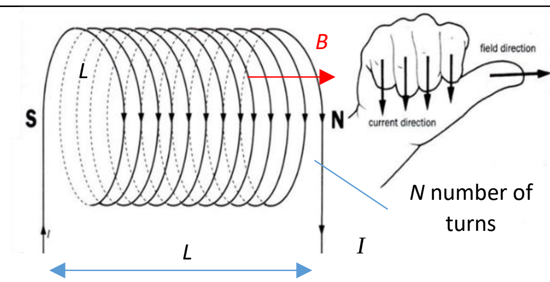


Determine direction of field of a coil, use Right Hand Grip Rule, where now, thumb is the field direction and the fingers as the current direction.

Magnetic Flux Density of a Solenoid







The magnetic flux density within a long solenoid is uniform,

$$B = \mu_0 nI$$

where,

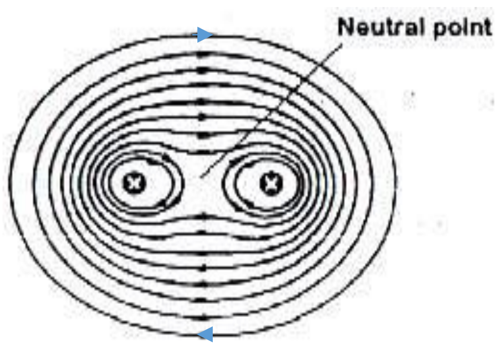
$$n = \frac{N}{L}$$

Ferromagnetic Material in Solenoid

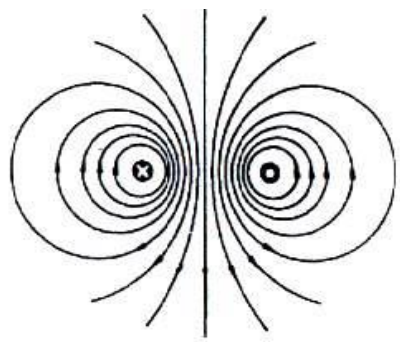
- Examples of ferromagnetic materials are iron, steel, nickel and cobalt
- There are many tiny little magnets called magnetic dipoles within the material
    - Regions of a number of magnetic dipoles are called magnetic domains
- When unmagnetised, the magnetic dipoles are oriented randomly
- Under the influence of an external magnetic field, such as when the ferromagnetic material is placed inside of a solenoid, the magnetic dipoles will align with the field
    - The ferromagnetic material is now magnetised
- The overall effect is that a ferrous core in a solenoid increases the magnetic flux density in and around the solenoid

Other Magnetic Flux Density Patterns

Two Parallel Straight Conductors

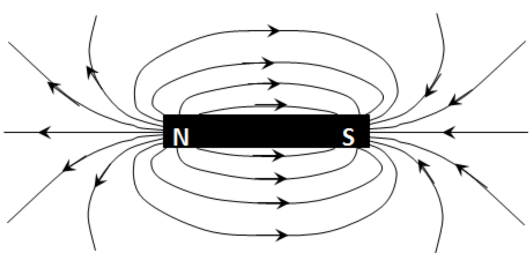


Two conductors with the currents in the same direction, e.g. into the page

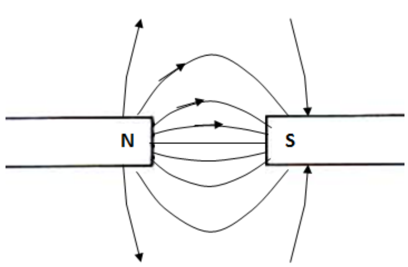


Two conductors with the currents in the opposite direction

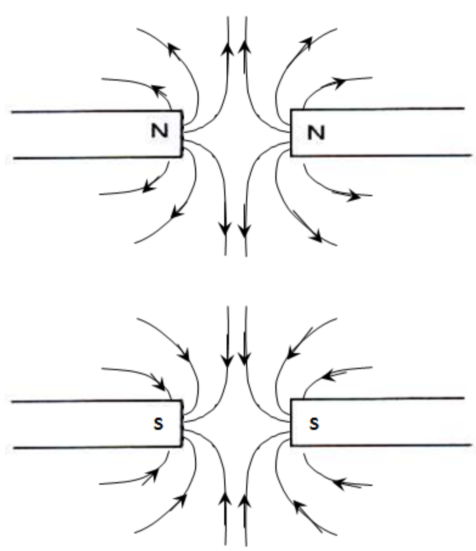
Bar Magnets



Single bar magnet

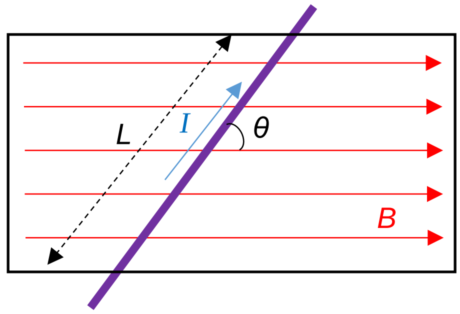


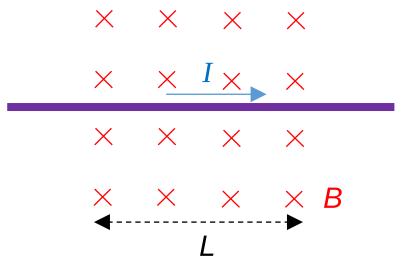
Two unlike-poles



Two like-poles

Magnetic Force on a Straight Current-Carrying Conductor



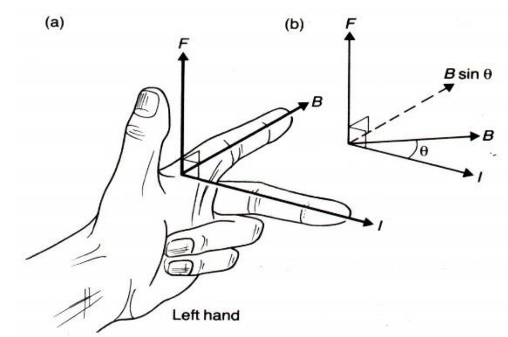


Magnitude of force,

$$F = BIL\sin\theta$$

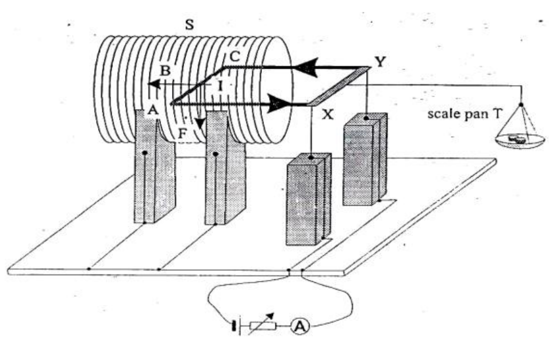
Note:

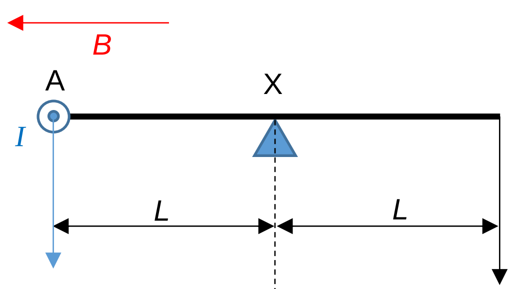
- *L* is the length *within* the field, may not be the whole wire (purple line)
- *B* is the external magnetic field. NOT the flux density by the wire
- Direction of force by Fleming's Left Hand Rule



Current Balance

To measure magnetic flux density





- There are two circuits – one to the solenoid that created the unknown *B* that we want to find, one to frame
- Before any currents are switched on, the frame and the pan are balanced
- When both currents are switched on, additional anticlockwise moment by force on AC needs to be balanced by additional clockwise moments by weight on scale pan,

magnetic force x *L* = *extra* weight added x *L*

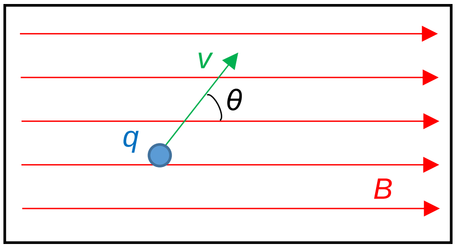
magnetic force = *extra* weight added

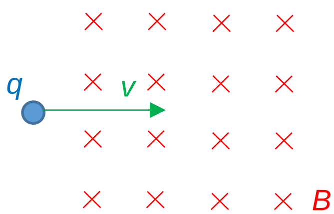
$BIL_{AC} = mg$

$B = mg / IL_{AC}$

Note: I is the current in the frame. The current in the solenoid is usually unknown.

Magnetic Force on a *Moving* Charge





Magnitude of force,

$$F = Bqv\sin\theta$$

Note:

- Direction of force by Fleming's Left Hand Rule
- For positive charge, middle finger (current) points in the motion of the charge
- For negative charge, middle finger (current) points in opposite to the motion of the charge

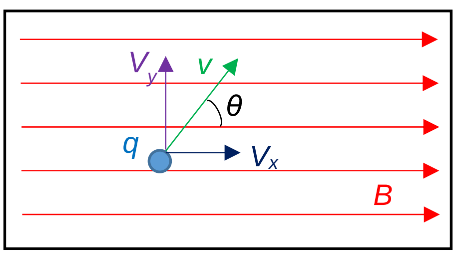
Circular Motion of charge,

Magnetic force provides for centripetal force,

$$bqv = \frac{mv^2}{r} = mr\omega^2$$

$$r = \frac{mv}{bq}$$

Helical Motion

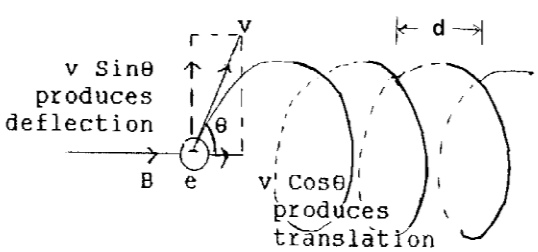


Magnitude of force,

$$F = Bqv\sin\theta = bqv_y$$

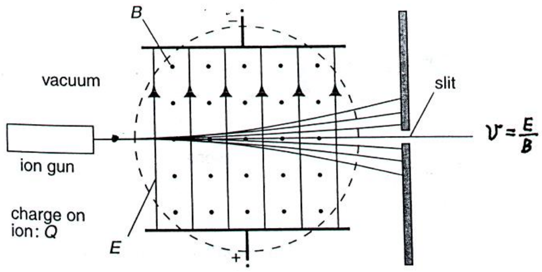
Note:

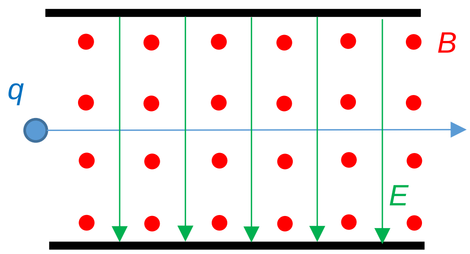
- v_y contributes to the circular motion
- v_x is unaffected by magnetic field
- As the charge goes in circular motion, it moves rightwards → Helical Motion



- Radius of helical motion, $r = \frac{mv_y}{bq}$
  - When radius varies as charge moves, the motion is spiral
- Pitch, *d* affected by v_x
  - If there is an Electric Field in the same direction, v_x changes, *d* changes

Velocity Selector





- Selects charges at a specific velocity
- When the charge is undeflected, by Newton's laws of motion, the electric force on the charge must balance the magnetic force on the charge
- Electric force and magnetic force are opposite in direction

Electric force, F_E = Magnetic force, F_B

$$qE = Bqv$$

$$v = \frac{E}{B}$$

Charges with velocity *E/B* will exit the slit (selected)

- Selection is independent of charge, be it larger or smaller; positive or negative
- Charges only affects which direction the charge will deflects when $E > B$ or $E < B$.