Magnetic Fields

- 21. Magnetic Fields
- Content
- 21.1 Concept of magnetic field
- Learning Outcomes
- (a) show an understanding that a magnetic field is an example of a field of force
- produced either by current-carrying conductors or by permanent magnets.
- (b) represent a magnetic field by field lines.

1

History - Magnets

- The term ***magnet*** comes from the ancient Greek city of Magnesia, at which many natural magnets were found.
- We now refer to these natural magnets as **lodestones** (also spelt as loadstone; lode means to lead or to attract) which contain **magnetite**, a natural magnetic material Fe_3O_4
- Chinese as early as 121 AD knew that an iron rod which had been brought near one of these natural magnets would acquire and retain the magnetic property
- Such a rod when suspended from a string would align itself in a north-south direction.
- Use of magnets to aid in navigation can be traced back to at least the eleventh century.

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Magnetic Field

- Gravitational field exists in a region around any mass and, in this region, other masses experience a gravitational force. (always attractive)
- Electric field exists in a region around any charge and, in this region, other charges experience an electric force. (attractive / repulsive)
- Magnetic field exist in a region around any permanent magnets or current-carrying conductor and, in this region, other magnets and magnetic materials experience a magnetic force. (attractive / repulsive)
- Example of magnetic materials are iron, steel, cobalt or nickel
- Magnetic field around a magnet can be represented by using the idea of field lines similar to that of electrical field.

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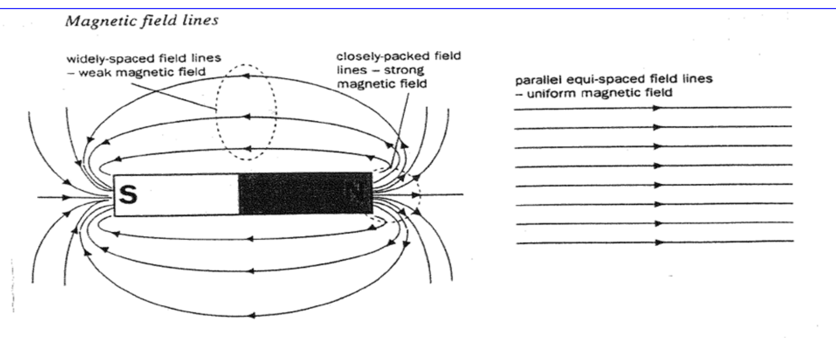
Magnetic field



(a) Non-uniform magnetic field around a bar magnet
(b) Uniform magnetic field

- Parallel field lines indicate a uniform field, whereas converging field lines indicate the field is increasing in strength.
- By ***convention***, we say that the magnetic field lines **leave the North end** of a magnet and **enter the South end** of a magnet.

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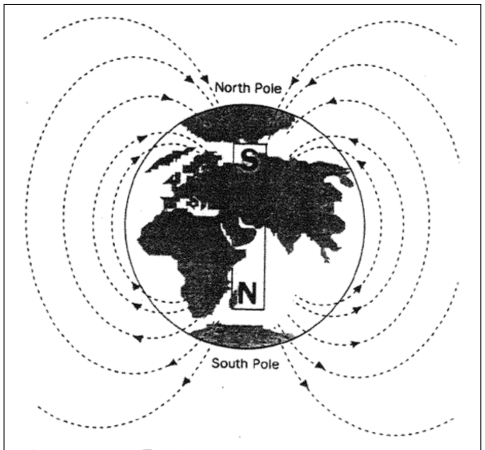
Earth's magnetic field



Earth's magnetic field

- It is now known that the Earth itself is a region of ***weak magnetic field.***
- The earth behaves as though it has a bar of magnet at its center.
- Looking at the field lines pattern, we observe that:

  i.) near equator, lines are parallel to the surface.

  ii.) near the poles, lines are nearly perpendicular to the surface.

- A freely suspended magnet will always align itself with the direction of the local magnetic field.
- This property is used for navigation.

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For every North, there is a South

- Within a magnet, the magnetic effects seems to be concentrated at regions called poles.
- There are 2 types of pole: North pole & South pole.
- If you take a bar magnet and break it into two pieces, each piece will again have a North pole and a South pole.
- If you take one of those pieces and break it into two, each of the smaller pieces will have a North pole and a South pole. No matter how small the pieces of the magnet become, each piece will have a North pole and a South pole.

- Opposite poles exert attractive forces on each other, while similar poles repel each other.
- In the absence of other magnetic fields, a freely suspended magnet will align itself so that 1 pole point towards Earth's North pole, while the other point towards the South pole.

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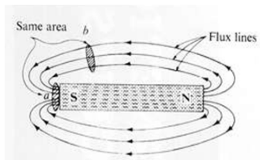
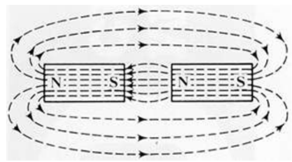
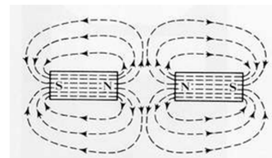
Patterns of Magnetic Field lines / lines of force

- Although the field lines is usually drawn in 2 dimensions, the actual magnetic field is in 3 dimensions. (especially for bar magnet illustration)







- Magnetic field also can be produced around any conductor which carries an electric current.
- The size and shape of the magnetic field depends on the size of the current and the shape or configuration of the conductor through which the current is traveling, e.g.
  i.) straight wire,
  ii.) solenoid,
  iii.) flat circular coil.

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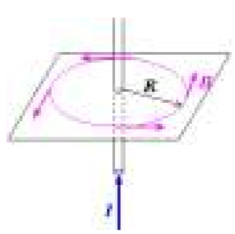
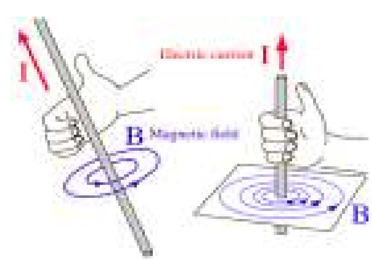
<u>A straight, current-carrying wire</u>

- ***For a straight wire, the field lines are <u>concentric circles</u>*** centred on the middle of the wire.

- ***The separation of the lines increases with distance from the wire indicating that the field is decreasing in strength.***

- The ***strength of the magnetic field is increased*** if
  i) the current flowing through the wire is increased
  ii) the number of wires carrying the current (in same direction) is increased





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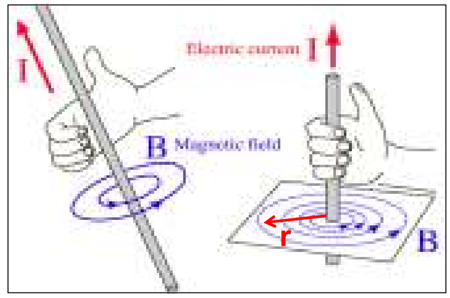
A straight, current-carrying wire

Its Direction…

- The direction of the field lines, indicated by the arrows can be determined using the Right-Hand Grip Rule, which states that if the current carrying wire is grasped with the right hand, with thumb pointing in the direction of conventional current, while the other fingers curled will point in the direction of the magnetic field.



- To calculate the value of magnetic field strength, B at a distance away from the wire, we use the formula:

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

;where $\mu_0 = 4\pi \times 10^{-7}$ Tm/A (permeability of free space)
r = distance from the wire (Radius, m)
I = current in the wire (Ampere, A)
B = magnetic field strength (Tesla, T)

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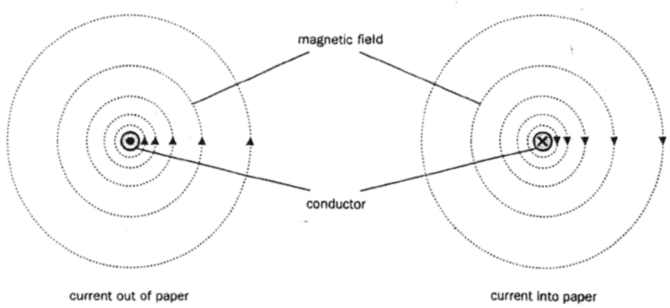
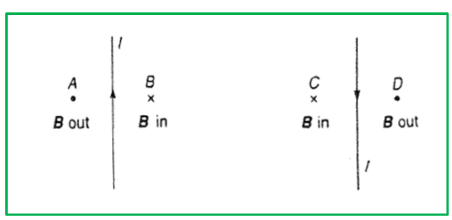
A straight, current-carrying wire

TOP VIEW



'x' represents tail of arrow
'•' represents tip of arrow



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Solenoid

- A solenoid is a long coil made up of several turns of wire like a cylinder through which current flows. It can be thought of as made up of many flat circular coils placed side-by-side.
- The field patterns are identical to that of a bar magnet whereby 2 opposing magnetic poles are formed at the 2 ends of the solenoid.
- ***At the end where the current flows in the clockwise direction or flux lines are entering, it is the S pole.***
- ***At the end where the current flows in the anti-clockwise direction or flux lines are emerging, it is the N pole.***
- The field lines are parallel and equally spaced over the **centre section** of the solenoid indicating that the field is ***uniform.***
- The direction of the field inside a solenoid can be determined using Right Hand Grip Rule. Let your fingers (curled) point in the direction of the current in the solenoid, then your thumb points in the field direction.

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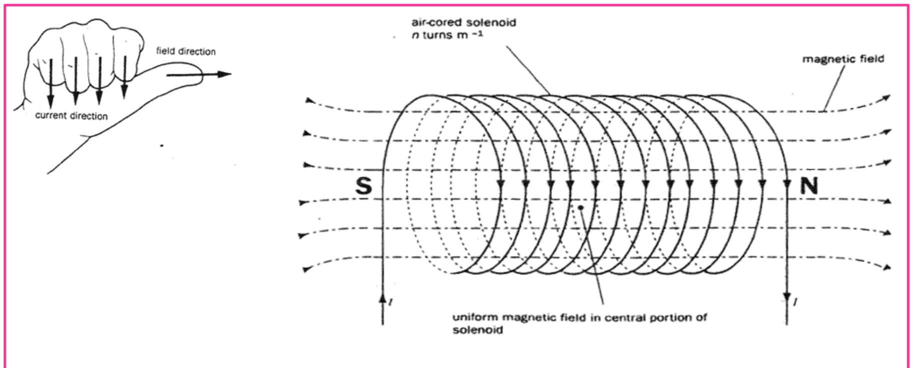
Solenoid



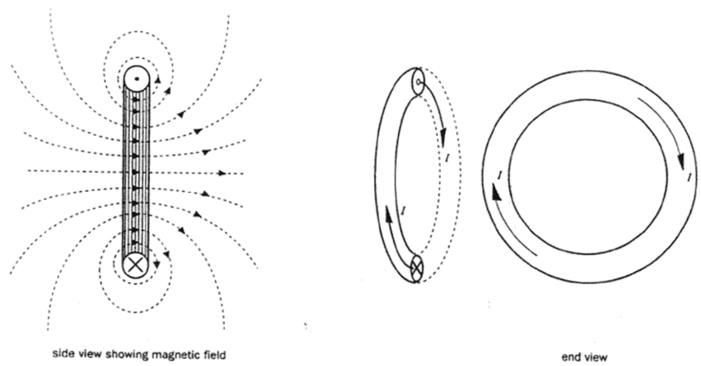
Uniform magnetic field inside a long, air-cored solenoid

$B = \mu_0 nI$;where $\mu_0 = 4\pi \times 10^{-7}$ Tm/A (permeability of free space)
I = current in the wire (Ampere, A)
n = number of turns per unit length (m^{-1})
B = magnetic field strength (Tesla, T)

The value of B calculated is for the field strength inside the solenoid.!

Flat Circular coil

- The magnetic field for a current carrying circular coil is identical to the fields of 2 straight wires, one carrying current upwards and the other downwards.
- It can be thought of as a flat coil.
- In the centre of the coil the field pattern is a straight line while on both sides are curves.



Magnetic field around a flat, circular, current-carrying coil

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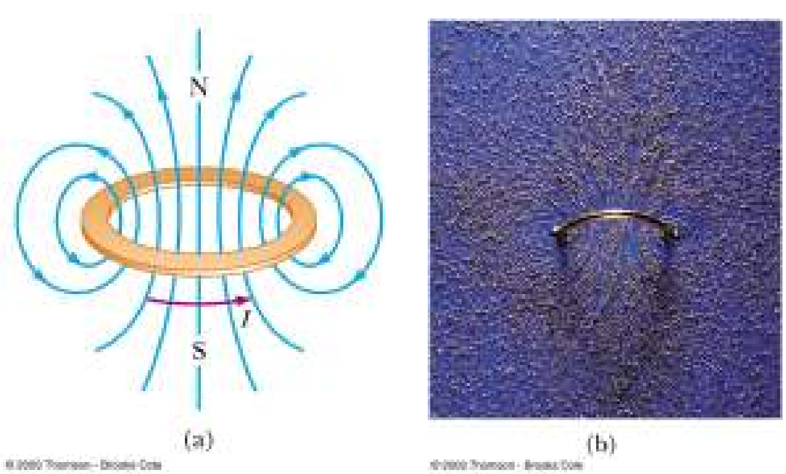
Flat Circular coil



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Principle of the electromagnet .. some facts

- The strength of the magnetic field due to a flat coil or a solenoid may be increased by winding the coil on a bar of ***soft iron*** called the ***core*** of the coil
- The magnetic field is more concentrated because the iron makes a better magnetic path than air
- ***Soft*** means that the iron ***can be magnetised and de-magnetised easily (****not that the iron is soft!)* i.e. the field vanishes quickly when the current is turned off
- Hard iron is a reference to its ability retain its magnetism
- Using soft iron the magnetic strength of an ***electromagnet*** can be increased up to 1000X
- With ferrous alloys i.e. iron alloyed with cobalt or nickel the magnetic strength can be increased by 10,000X
- Transformer cores have a quoted value of how well they 'conduct' a magnetic field known as ***permeability μ***

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Example

- A vertical electric wire in the wall of a building carries a dc current of 25 A upward. What is the magnetic field at a point 10 cm from this wire?

- A thin 10 cm long solenoid is used for fast electromechanical switching which has a total of 400 turns of wire and carries a current of 2.0 A. Calculate the field inside near the center?

  (remember n = number of turns per unit length, m^{-1})