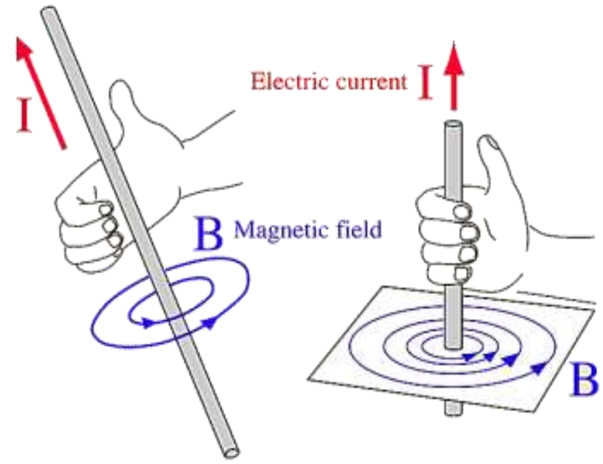
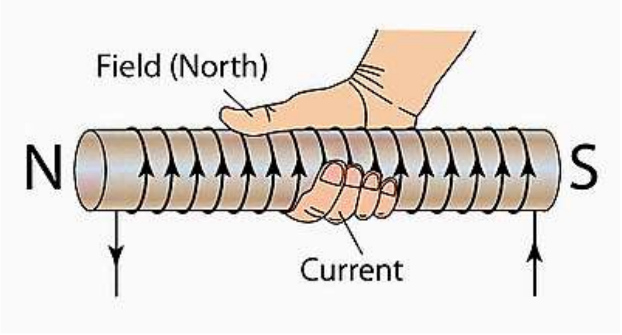
Magnetic Field by Current

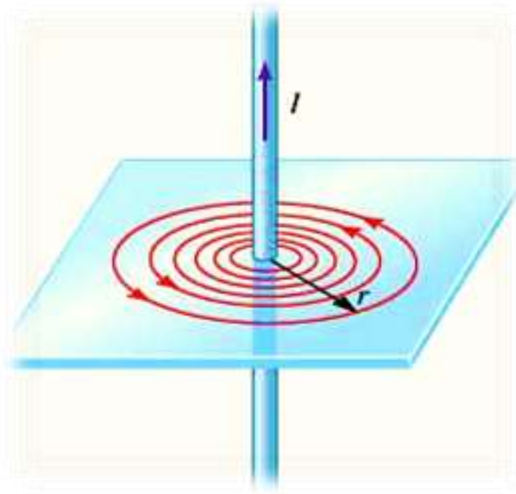




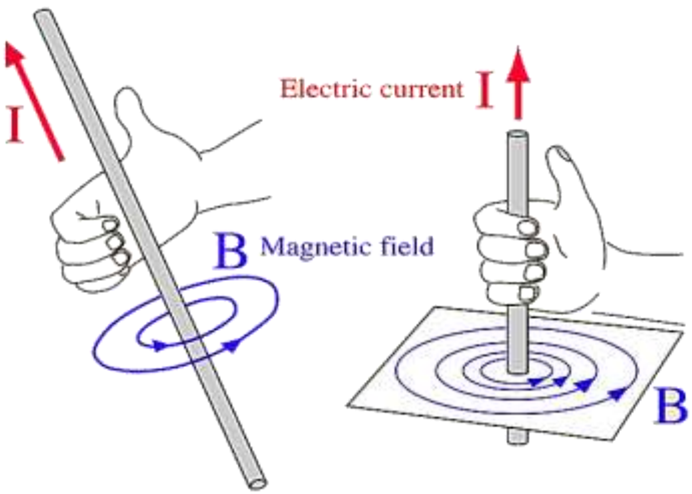
MAGNETIC FIELD BY CURRENT

► Magnetic field due to current in a long straight conductor

When an electric current flown through a long straight conductor (wire), a magnetic field is built up around the conductor itself. This can be seen using a cardboard, iron filing, and a current-carrying conductor. When the conductor passed though the cardboard and the current flowing, iron flowing, iron filings are sprinkled onto the card board. They can be seen arranging themselves in a magnetic field. The magnetic field lines produced by a current in a long straight conductor are in the form of circles with the long straight conductor as its centre. (picture 1).



picture 1



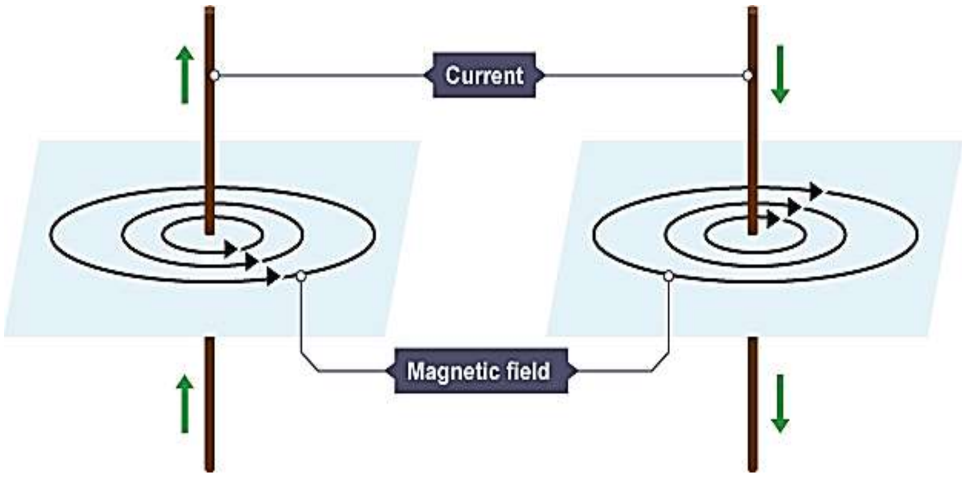
picture 2

The direction of the magnetic field lines is given by a right-hand rule (picture 2). In this rule, point the thumb on your hand in the direction of the current in the conductor. When you curl your fingers, they curl the same way that the magnetic field curls around the conductor.

The magnetic field is strong in the region around the long straight conductor and weakens with increasing distance, i.e., the field lines near the wire are drawn closer to another. With increasing distances, concentric circles are further apart.

Anticlockwise direction of magnetic field lines

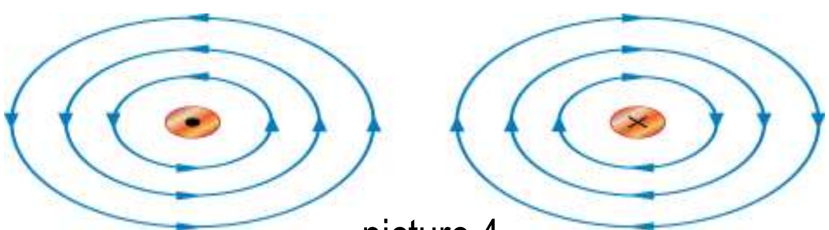
Clockwise direction of magnetic field lines



(a) (b)

picture 3

This picture 3 shows the magnetic fields pattern around a long straight conductor (wire) carrying current. When the direction of current in the conductor is reversed, the direction of magnetic field gets reversed (picture 3-b).



picture 4

If we look at picture 3 from the top view then we use a standard convention (picture 4):

● means the current is pointing at you (out of the cardboard)

X means the current is pointing away from you (into the cardboard)

Biot-Savart law:

The magnitude field strength (magnitude) B at the distance r from a long straight conductor carrying a current of I is given by: :

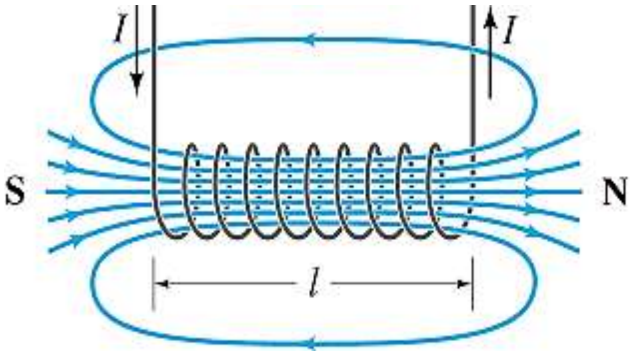
$$\boldsymbol{B = \mu_0 \frac{I}{2\pi r}}$$

$\mu_0 = 4\pi \cdot 10^{-7} \frac{Tm}{A}$ -magnetic permeability of a vacuum

On increasing the current in the conductor, the magnetic field strength gets increased. The magnitude field strength depends on current I in the conductor and distance r from the conductor (not on position along the conductor).

► Magnetic field due to current in a solenoid

Solenoid consists of a length of insulated wire coiled into a cylinder shape (picture 5).

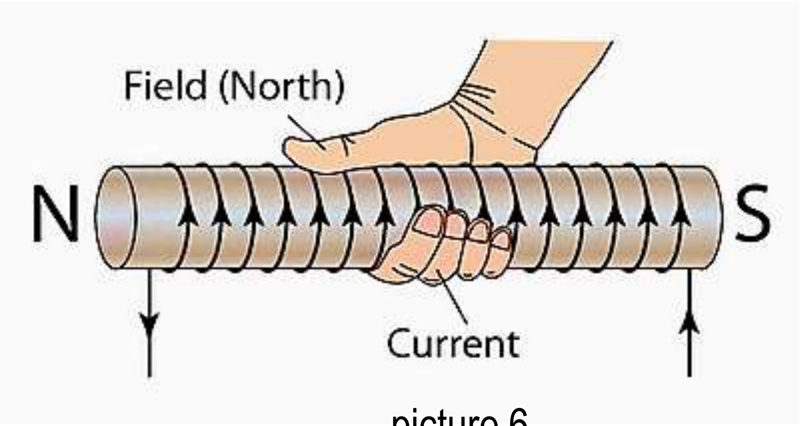


picture 5

- Current in solenoid produces a stronger magnetic field inside the solenoid than outside. The magnetic field lines in this region are parallel and closely spaced showing the magnetic field is highly uniform in strength and direction.
- Field lines outside the solenoid are similar to that of a bar magnet, and it behaves in a similar way – as if it had a north pole at one end and south pole at the other end. Strength of the magnetic field diminishes with distance from the solenoid.

- Strength of the magnetic field can be increased by:
  - increasing the current in the coil
  - increasing the number of turns in the solenoid; and
  - using a soft iron core within the solenoid.
- Reversing the direction of the current reverses the direction of the magnetic field

Right-hand rule can be used to find the direction of the magnetic field. In this case, point the wrapped fingers (along the coil) in the direction of the conventional current. Then, the thumb will point to north pole of the solenoid (picture 6).



picture 6

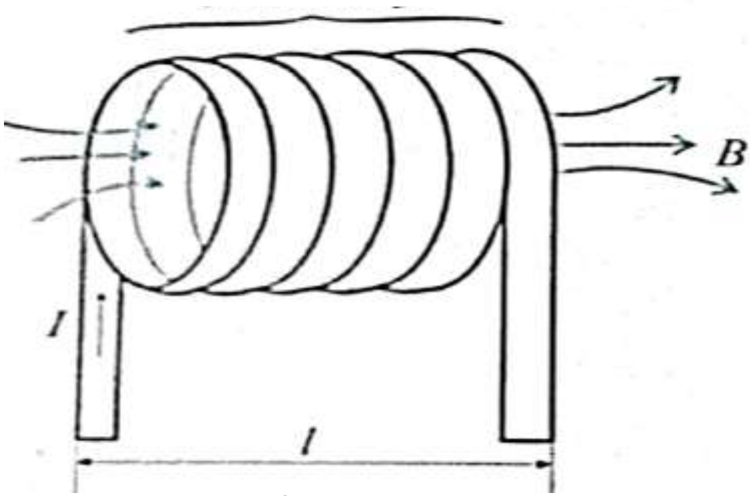
In the interior of the solenoid the magnetic field is uniform.
The magnetic field strength inside a solenoid is given by:

$$B = \frac{\mu_0 N I}{l}$$

where N is the number of turns in the solenoid, l is the length of the solenoid and I is current through it .

The magnitude field strength B inside a solenoid (picture 7) increases with the current I and is proportional to the number of turns per unit length N/l.

N-number of turns in the solenoid



picture 7

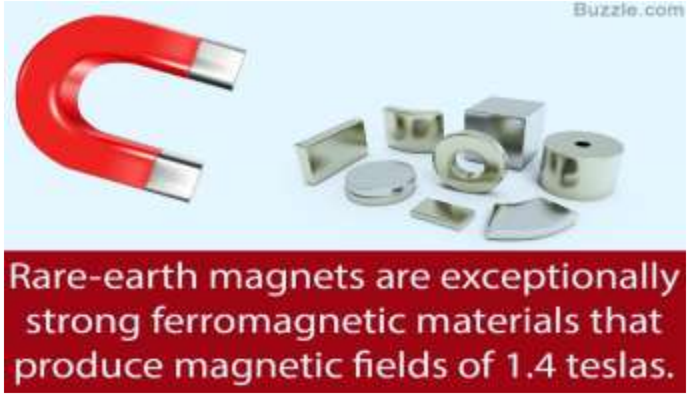
Example: A solenoid 30 cm long consists of 1 000 coils. Find the magnetic induction of the magnetic field inside the solenoid if the current flowing through it is 2 A. Consider the diameter of the solenoid to be small as compared with its length.

FERROMAGNETIC SUBSTANCE

The magnetic permeability is the measure of the ability of a material to support the formation of a magnetic field within itself. Hence, it is the degree of magnetization that a material obtains in response to an applied magnetic field. We assumed that the conductors (solenoids) carrying a current are in vacuum. If the conductors (solenoids) carrying a current are in a medium, the magnetic field changes. The explanation is that any substance is a magnetic. Therefore, we have a new quantity called relative magnetic permeability.

Relative magnetic permeability, denoted by the symbol μ_r. is the ratio of the magnitude field strength of a medium B to the magnitude field strength of a vacuum B_0:

$$\mu_r = \frac{B}{B_O}$$



picture 8

Those substances which when placed in a magnetic field are strongly magnetized in the direction of the applied field are called ferromagnetic substance E.g iron, nickel, cobalt etc (picture 8). When a ferromagnetic substance is placed in a magnetic field, the magnetic field lines tend to crowd into the substance.

The magnetized substance sets up the magnetic field $\vec{B}$ that is superposed onto the fiield $\vec{B}_0$ produced by the currents. Both fields produce the resultant field:

$$\vec{B}_{res} = \vec{B}_0 + \vec{B}$$

Since the strong induced magnetic field is in the direction of the applied field, the resultant magnetic field inside the ferromagnetic material is very large; often thousand times greater than the magnetizing field.
It is clear that relative magnetic permeability μ_r for such substances will be very high of the order of several thousands ($\mu_r \gg 1$).

PROBLEMS

1. Find the magnetic induction at a point M 5cm away from an infinitely long conductor which a current of 5A flows throught?

2. Two long wires (conductors) are arranged parallel to each other at a distance of 5cm. Currents of I_1=I_2=10A flows throught wires in same direction. Find the magnetic induction of magnetic field at a point distant 2cm from the first wire and 3cm from second one.

3. Two parallel wires are 5cm apart, and each carries a current of 30A in the same direction. Find the induction of magnetic field at a point distant 3cm from the first wire, and at a point distant 4cm from the second one.

4. Two long linear conductors are arranged parallel to each other at a distance of 10 cm. Currents of I_1=I_2 =5 A flow through the conductors in opposite directions. Find the magnetic induction at a point 10 cm from each conductor.

5. Two infinitely long rectilinear conductors are arranged perpendicular to each other and are in mutually perpendicular planes Find the magnetic induction at points *M*1 and M_2 if $I_1 = 2\text{A}$ and $I_2 = 3\text{A}$ the distance, $\text{A}M_1$= $\text{A}M_2$=1cm and AB=2cm.