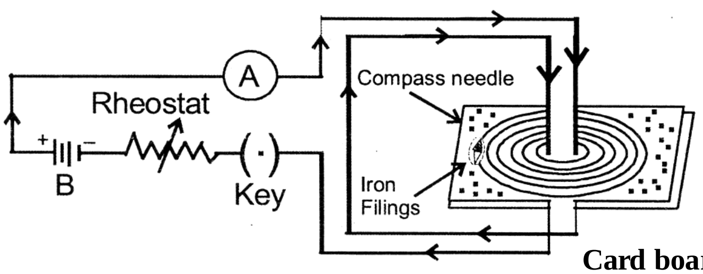
MAGNETIC EFFECT OF ELECTRIC CURRENT
Magnetic Field Due to Current in Circular Path, Magnetic Field in Solenoid

Magnetic Field due to a Straight Current Carrying Wire:

When a current is passed through a conducting wire, a magnetic field is produced around it. The direction of magnetic field due to a straight current carrying wire can be mapped by means of a small compass needle or by iron fillings.
Take a sheet of smooth cardboard with a hole at the center. Place it horizontally and pass a wire vertically through the hole, Sprinkle some iron fillings on the cardboard and pass an electric current through the wire. Gently tap the cardboard. We find that the iron filling arrange themselves in concentric circles around the wire as shown in figure.
If a small compass needle is kept anywhere on the board near the wire, the direction in which the north pole of the needle points gives the direction of the magnetic the magnetic field (i.e., magnetic lines of force) at that point.



The magnetic lines of force form concentric circles near the wire, with their plane perpendicular to the straight conductor and with their centers lying on its axis. if the direction of current in the wire is reversed, the direction of lines of force is also reversed.
On increasing the strength of current in the wire, the lines of force becomes denser and iron fillings are arranged in circles unto a larger distance from the wire, showing that the magnetic field strength has increased.

(i) Magnitude of magnetic field produced by a straight current-carrying conductor:

The magnitude of magnetic field (or strength of magnetic field) **B** produced by an infinitely long conductor in vacuum at a distance **r** from it, it given by :-

$\mathbf{B} = \frac{\mu_0 I}{2\pi r}$ **B =** Magnetic field strength μ_0 = Permeability of vacuum (a constant)

I = Current (flowing in conductor) and

r = Distance from the conductor (where magnetic field is measured).

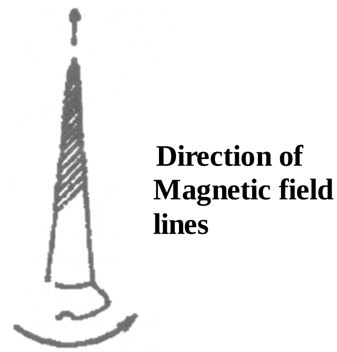
The unit of magnetic field **B** is tesla which is denoted by the symbol **T** (1 tesla is equal to 1 Newton per ampere per meter). Permeability of vacuum μ_0 is $4\pi \times 10^{-7}$ tesla meter per ampere.

(ii) Direction of magnetic field:

The direction of magnetic field (lines of force) produced due to flow of current can be known by the following rules :

(A) Maxwell's cork screw rule:

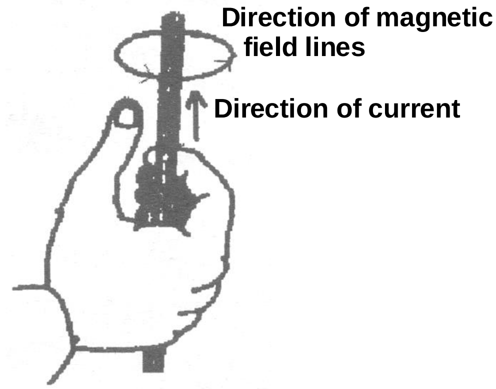
Imagine a right handed cork screw lying with its axis coincides with the current carrying wire. It is now rotated such that it advances in the direction of the current, the direction in which the screw rotates gives the direction for the magnetic lines of force.



Maxwell's cork screw rule

(B)Right hand thumb rule :

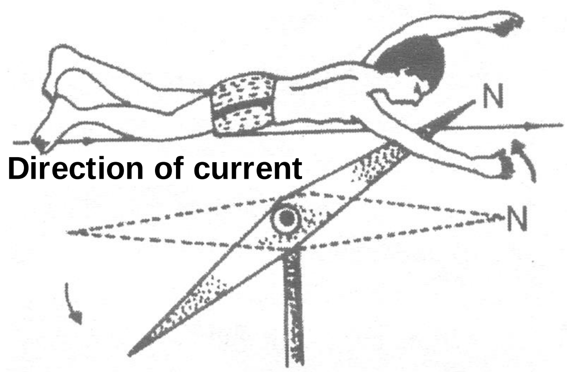
If we hold the current carrying conductor in the right hand such that the thumb points in the direction of current, the fingers encircle the wire in the direction of magnetic lines of force.



Right hand thumb rule

(C) Ampere's swimming rule :

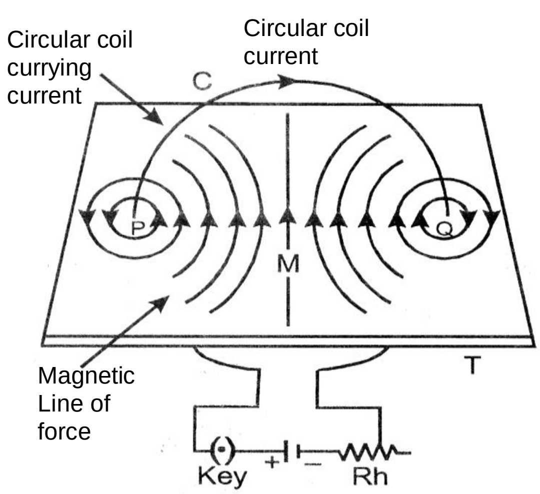
Imagine a man swimming along the wire in the direction of current (such that the current enters at his feet and leaves him at his head) facing towards a magnetic needle kept underneath the wire, then the magnetic field produced in such that the north pole of the needle will be deflected towards his lef



Ampere's Swimming Rule

(b) Magnetic Field due to Circular Coil Carrying Current :

A piece of wire bent in the form of a ring (or coil) is passed through a horizontal cardboard C at two points P and Q at the opposite ends of a diameter of the ring and then some iron fillings are scattered on the cardboard. The ends of the coil are connected to a battery through a rheostat and a key.When a strong electric current is passed through the coil by closing the key and the cardboard is gently tapped we find that the iron filing arrange themselves in a definite pattern representing the magnetic lines of force due to the current carrying coil.



Direction of magnetic field is found by applying the right hand thumb rule to each section of the coil and we find that the concentric lines of force pass through the coil in the same direction. Further more that :

(i) The magnetic lines of force are nearly circular near the wire.

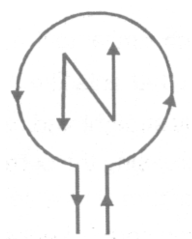
(ii) Within the space enclosed by the wire, the lines of force are in the same direction.

(iii) Near the center of the coil, the lines of force are nearly parallel and the magnetic field may be assumed to be practically uniform for a small space around the centre.

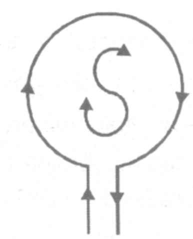
(iv) At the centre, the lines of force are along its axis and at right angle to the plane of the coil.

(v) The magnetic field strength is increased if the number of turns in the coil is increased or the strength of current in the coil is increased.

Since the magnetic lines of force through the coil point in the same direction, hence one face of the coil acts as a large area of north polarity because it is sending out magnetic lines of force and the other face acts as a large area of south polarity as magnetic lines of force are entering it. thus, the coil has a magnetic field similar to a magnetised iron disc of same radius as that of the coil.
The polarity of the faces of the coil depends on the direction of current and is determined by the clock rule. Looking at the face of the coil, if the current around the face is in an anticlockwise direction, the face has north polarity, while if the current at that face is in the clockwise direction, the face has south polarity. This can e tested by using a compass needle.



Anticlockwise Current
(a)



Clockwise Current
(b)

The magnitude of magnetic field **B** produced by a current-carrying circular wire at its center is :

(i) directly proportional to the current **I** passing through the circular wire and

(ii) inversely proportional to the radius **r** of the circular wire.

$$\text{i.e. } B \propto I \qquad \text{and } B \propto \frac{1}{r}$$

$$\text{Magnetic field, } B = \frac{\mu_0 I}{2r}$$

Formula which we have given above is applicable when there is only one turn of a circular wire. If we have circular coil having **N** turns of wire, then the magnetic field will become **N** times. Thus, the magnetic field at the centre of a circular coil of **N** turns having radius **r** and carrying current **I** is given by

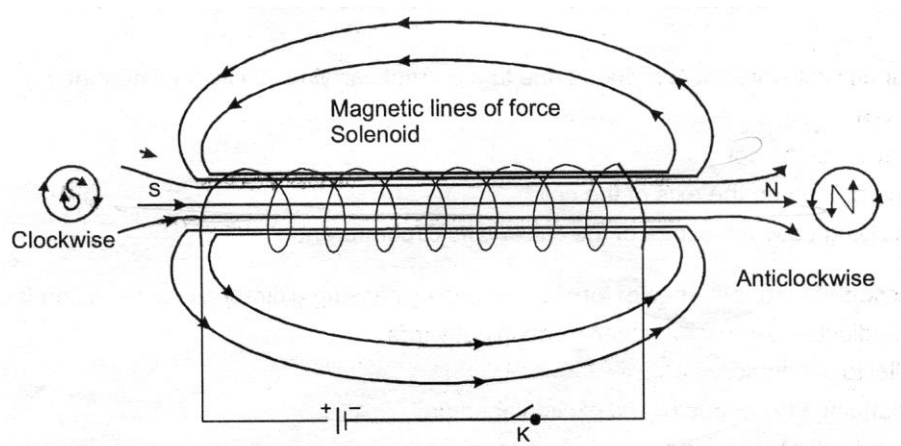
$$B = \frac{N \times \mu_0 \times I}{2r}$$

Magnetic field produced by a circular coil carrying current is directly proportional to both, number of turn (**N**) and current (**I**), but inversely proportional to its radius (**r**). Thus, the strength of magnetic field produced by a current carrying circular coil can be increased by

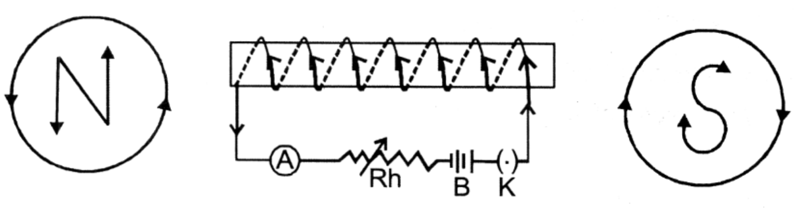
(i) increasing the number of turns of wire in the coil,
(ii) increasing the current following through the coil
(iii) decreasing the radius of the coil.

Magnetic Field due to a Solenoid Carrying Current:

If a conducting wire is wounded in the form of a cylindrical coil whose diameter is less in comparison to the length, then this coil is called a solenoid (it looks like a helical spring).
The magnetic field lines in a solenoid, through which current is passed, are as shown in figure.



The magnetic field, thus produced, is very much similar to that of a bar magnet and one end of the coil acts like a magnetic north pole while the other acts like a south pole.
The lines of force inside the solenoid are nearly straight and parallel to the axis of the solenoid.
A strong magnetic field can be obtained by increasing the current strength.
The magnetic field is increased if the number of turns in the solenoid of given length is increased.
The magnetic field is also increased if soft iron core is kept along the axis of the solenoid.
Thus a current carrying solenoid behaves like a bar magnet with fixed polarities at its ends.



The strength of magnetic field produced by a current carrying solenoid depends upon :

(i) The number of turns in the solenoid : Larger the number of turns in the solenoid, greater will be the magnetic field produced.

(ii) The strength of current in the solenoid : Larger the current passed through solenoid, stronger will be the magnetic field produced.

(iii) The nature of "core material" used in making solenoid : The use of soft iron rod as core in a solenoid produced the strongest magnet.
Magnetic field inside the solenoid is :

$B = \mu_0 n I \ n \mathbf{I}$ [Here in is number of turns per unit length]

At the ends of the solenoid the magnetic field :

$$B_{end} = \frac{1}{2}\mu_0 nI$$

Magnetic Field due to a Current through a Circular Loop:
We have so far observed the pattern of the magnetic field lines produced around a current-carrying straight wire. Suppose this straight wire is bent in the form of a circular loop and a current is passed through it. How would the magnetic field lines look like? We know that the magnetic field produced by a current-carrying straight wire depends inversely on the distance from it.

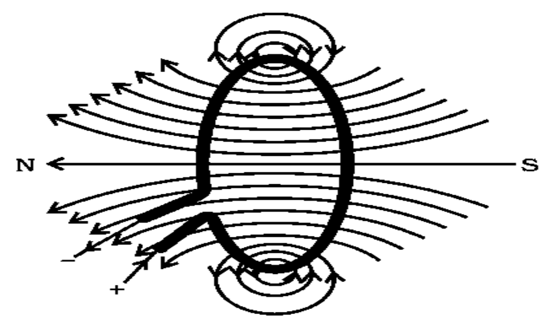


Figure 13.8
Magnetic field lines of the field produced by a current-carrying circular loop

Similarly at every point of a current-carrying circular loop, the concentric circles representing the magnetic field around it would become larger and larger as we move away from the wire . By the time we reach at the center of the circular loop, the arcs of these big circles would appear as straight lines. Every point on the wire carrying current would give rise to the magnetic field appearing as straight lines at the center of the loop. By applying the right-hand rule, it is easy to check that every section of the wire contributes to the magnetic field lines in the same direction within the loop.
We know that the magnetic field produced by a current-carrying wire at a given point depends directly on the current passing through it. Therefore, if there is a circular coil having n turns, the field produced is n times as large as that produced by a single turn. This is because the current in each circular turn has the same direction, and the field due to each turn then just adds up.