Magnetism:

Magnetism is a class of physical phenomena that are mediated by magnetic fields. Electric currents and the magnetic moments of elementary particles give rise to a magnetic field. The most familiar effects occur in ferromagnetic materials, which are strongly attracted by magnetic fields and can be magnetized to become permanent magnets, producing magnetic fields themselves. The most common ones are iron, nickel and cobalt and their alloys. Permanent magnetism was first observed in lodestone, a form of natural iron ore called magnetite, Fe_3O_4. The magnetic state or magnetic phase of a material depends on temperature and other variables such as pressure and the applied magnetic field.

Magnetic Field:

The magnetic field is the central concept used in describing magnetic phenomena.A region or a space surrounding a magnetized body or current-carrying circuit in which resulting magnetic force can be detected.

A magnetic field consists of imaginary lines of flux coming from moving or spinning electrically charged particles. Examples include the spin of a proton and the motion of electrons through a wire in an electric circuit.

In a vaccum, $B= \mu_0 H$

Magnetic Force:

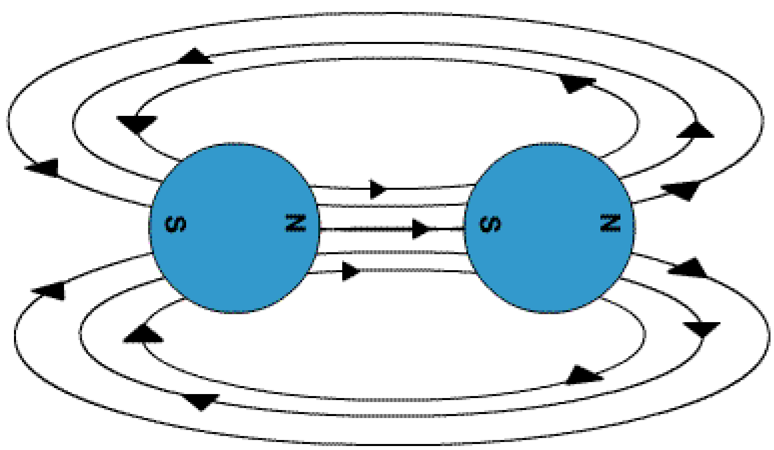
The magnetic field of an object can create a magnetic force on other objects with magnetic fields. When a magnetic field is applied to a moving electric charge, such as a moving proton or the electrical current in a wire, the force on the charge is called a Lorentz force.

The Biot–Savart law describe the origin and behavior of the fields that govern these forces. Therefore, magnetism is seen whenever electrically charged particles are in motion, for example, from movement of electrons in an electric current, or in certain cases from the orbital motion of electrons around an atom's nucleus.

When a charged particle moves through a magnetic field **B**, it feels a Lorentz force **F** given by the cross product:[17]

$F = q(V \times B)$

Where q is the electric charge of the particle, and V is the velocity vector of the particle.



Lorentz Force

If a charged particle moves through a region where both an electric and magnetic field are present, then the resultant force is given by

$$F = q_o \vec{E} + q_o (\vec{V} \times \vec{B})$$

$$= q_o [\vec{E} + (\vec{V} \times \vec{B})]$$

This resultant force is called Lorentz force.

Electromagnet:

An electromagnet is a type of magnet in which the magnetic field is produced by an electric current.The magnetic field disappears when the current is turned off. Electromagnets usually consist of a large number of closely spaced turns of wire that create the magnetic field. The wire turns are often wound around a magnetic core made from a ferromagnetic or ferrimagnetic material such as iron; the magnetic core concentrates the magnetic flux and makes a more powerful magnet.

The main advantage of an electromagnet over a permanent magnet is that the magnetic field can be quickly changed by controlling the amount of electric current in the winding. However, unlike a permanent magnet that needs no power, an electromagnet requires a continuous supply of current to maintain the magnetic field.

Electromagnets are widely used as components of other electrical devices, such as motors, generators, relays, solenoids, loudspeakers, hard disks, MRI machines, scientific instruments, and magnetic separation equipment.

BiotSavart Law:

BiotSavart showed that, the strength of the magnetic field dB at a point due to the current element dl is,

(1) Proportional to the length dl of the element.

(2) Inversely Proportional to the square of the distance r of the point from the element.

(3) Proportional to the sine of the angle '**θ**' between the directions of the element and the line joining the midpoint of the element to the point end.

(4) Proportional to the strength 'I' of the current.

Mathematically, $dB \propto \frac{idl\sin\theta}{r^2}$

$$dB = Km \frac{idl\sin\theta}{r^2}$$

$$dB = \frac{\mu_0}{4\pi} \frac{idl\sin\theta}{r^2} \quad ....(1)$$

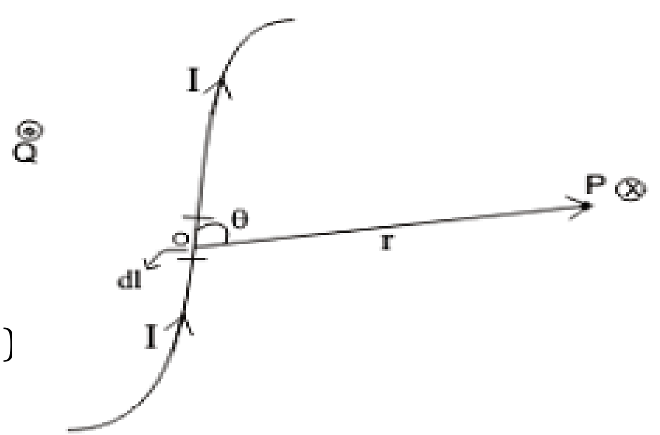


Figure 1. Field at point P is perpendicular to the plane of paper pointing into it

Where, μ_0 is permeability constant, has the value $4\pi\times10^{-7}$ Tm/A. The permeability constant plays an important role in calculating magnetic fields.

$$dB = \frac{\mu_0}{4\pi}\frac{\mathrm{idlsin\theta \times r}}{r^2 \times r}$$

$$dB = \frac{\mu_0}{4\pi}\frac{\mathrm{idlsin\theta r}}{r^3}$$

$$dB = \frac{\mu_{0\,i}}{4\pi}\frac{\mathrm{dl\times r}}{r^3}\text{............(2)}$$

This is the vector form of Biot Savart Law.

The resultant field at "p" due to the complete circuit is found by integrating equation (2),

$$B=\int dB=\oint\frac{\mu_{0\,i}}{4\pi}\ \frac{\mathrm{dl\times r}}{r^3}$$

Applications of Biot Savart Law:

Biot Savart law can be applied to calculate:

(1) Magnetic field at the center of a circular current carrying conductor

(2) Magnetic Field due to a long straight wire.

(3) Magnetic force on two parallel current carrying conductors

Magnetic field at the center of a circular current carrying conductor:

Let a circular coil of radius r carrying a steady current I. For simplicity, let dl is a small element of the coil.

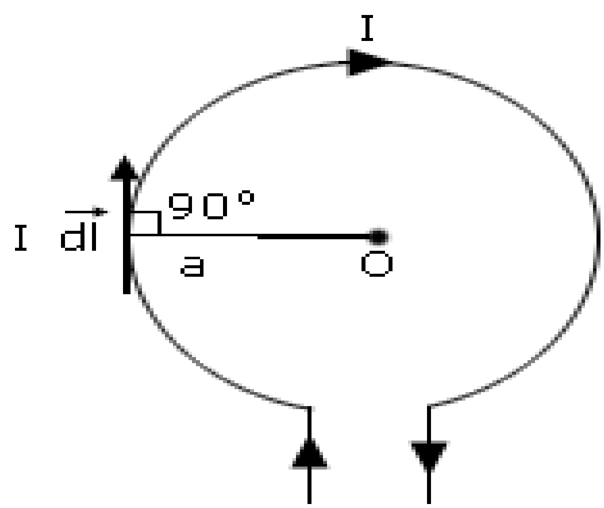
According to Biot Savart law, the magnitude of the magnetic field at the center of the coil due to the flow of current through the element is obtained as,

$$dB = \frac{\mu_0}{4\pi}\frac{idl\sin\theta}{r^2} \quad ....(1)$$

But here $\theta = 90^0$ and $\sin 90^0 = 1$, equation (1) becomes,

$$dB = \frac{\mu_0}{4\pi}\frac{idl}{r^2} \quad ....(2)$$

The total field at the center of the coil is Obtained by integrating equation (2) in the limit of L=0 to L=2πr.



$$B = \frac{\mu_0}{4\pi}\frac{i}{r^2}[l]_0^{2\pi r}$$

For any medium,

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

For "n' number of turns in a circular coil, the magnetic field is at its center is,

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

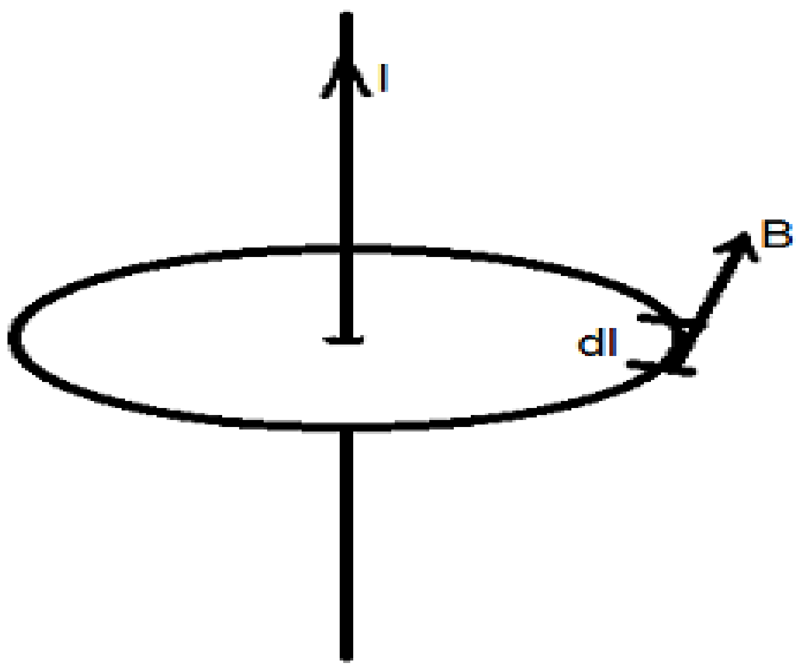
Ampere's law:

Ampere's law states that, the line integral of B around a closed path is equal to μ_0 times the current enclosed by the path.

Let us consider, C is a circle of radius r centered on the wire. In this case, the magnetic field-strength is the same at all points on the loop. In fact,

$$\oint B.dl = \mu_0 i$$

The field is everywhere parallel to the line elements which make up the loop.



Magnetic induction at a point due to a long straight wire carrying current:

Suppose a long and straight wire and current *i* is flowing through it. Magnetic induction or magnetic field at a point X at a distance r from the wire is to be determined. Let a very small section of that wire be taken. Let its length be dl.

Suppose the distance from the point of that portion to the point X is r and angle ϴ. So, applying Biot-Savart's law, we get the magnetic field

$$dB = \frac{\mu o}{4\pi} \frac{i\, dl \sin\Theta}{r^2} \quad \ldots\ldots\ldots\ldots\ldots(1)$$

Now, from the right-angled triangle ΔOQX, we get

$$\text{Cosec}\ \Theta = \frac{r}{a}$$

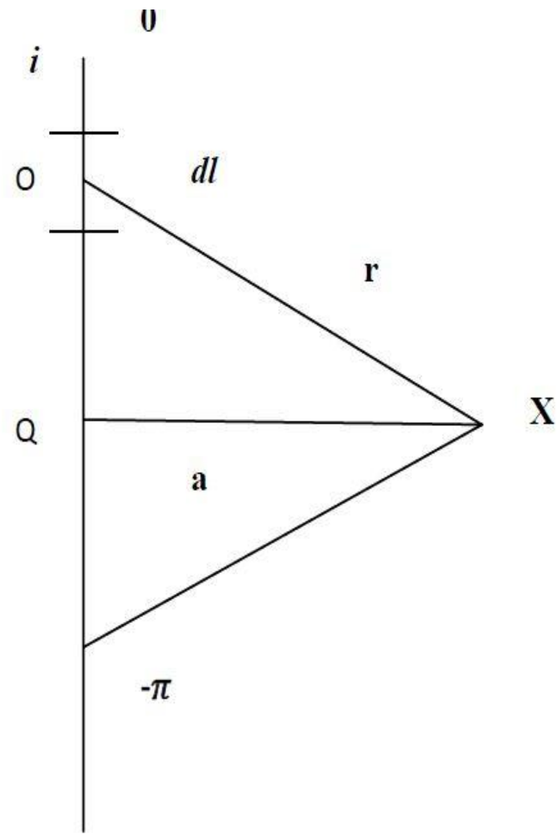
$$\text{or, } r = a \text{ cosec}\ \Theta \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Again, let OQ = l

Then, $l = a \cot\Theta$ $\quad\quad$ ($\cot\Theta = \frac{l}{a}$)

By differentiating, we get

$$dl = -\ a\ \text{cosec}^2\Theta\ d\Theta \quad \ldots\ldots\ldots\ldots\ldots\ldots(3)$$



Now, inserting the value of r and dl in equation

$$dB = -\ \frac{\mu o}{4\pi} \frac{i\ a\ cosec^{\,2}\theta\ sin\theta\ \ d\theta}{a^2\ cosec^{\,2}\theta}$$

$$= \frac{\mu o\ i}{4\ \pi\ a} \quad \sin\Theta\ d\Theta$$

If the wire PQ is infinitely long, then the total magnetic induction at point X due to the whole conductor is

$$B = \int_0^{\pi} - \frac{\mu o\, i}{4 \pi a} \sin\Theta \, d\Theta$$

$$\text{Or, } B = - \frac{\mu o\, i}{4 \pi a} \left[-\cos \Theta \right]_0^{\pi}$$

$$\boxed{\text{Finally, } B = \mu o \frac{i}{2 \pi a}}$$