Introduction

This is a learning as well as an exam preparation video.

At the end of the video are practice assignments for you to attempt.

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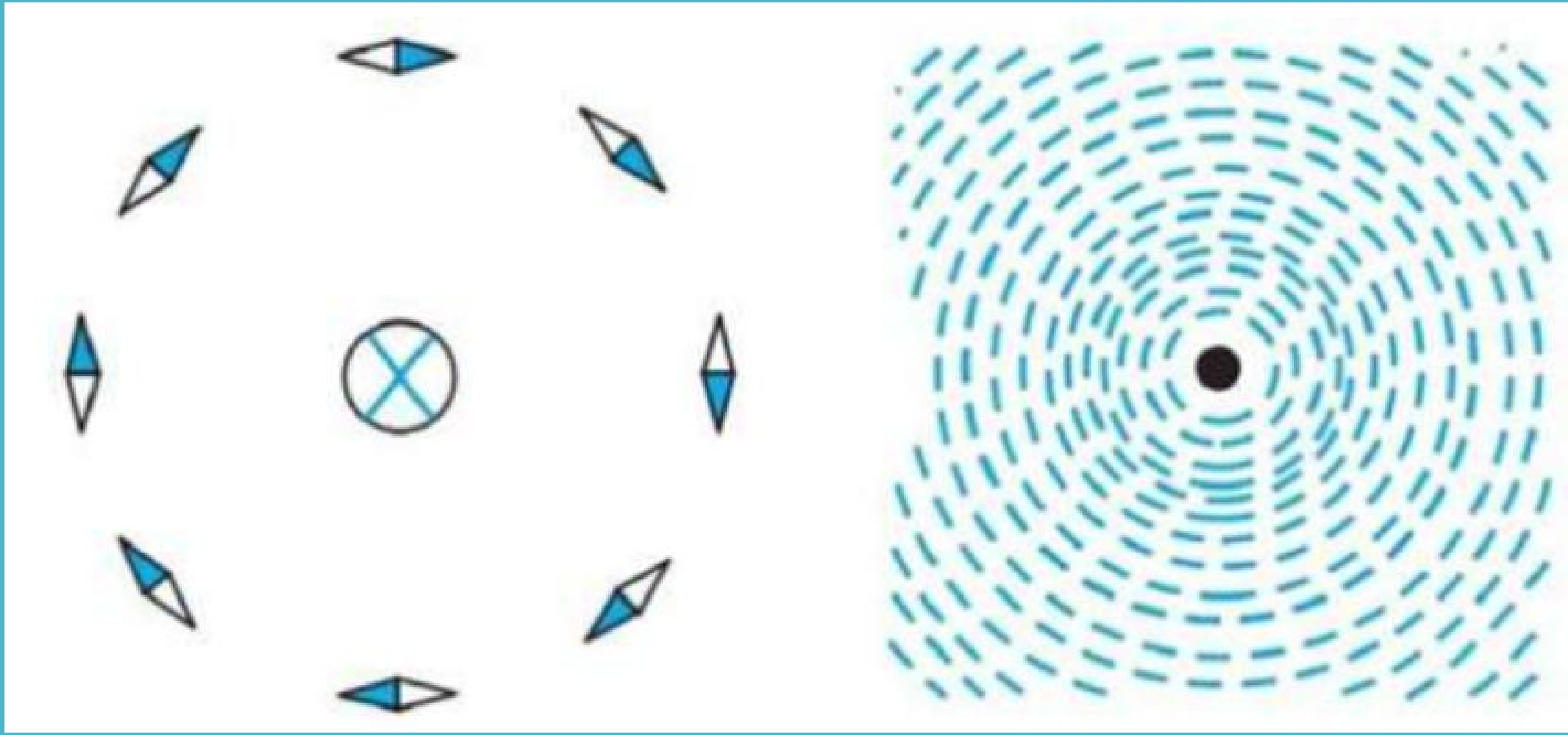
Chapter 4: Moving Charges And Magnetism

Chapter 4: Moving Charges and Magnetism

Magnetic Field:



Chapter 4: Moving Charges and Magnetism

Magnetic Feild

We have discussed that a stationary charge creates electric field in its surrounding space, similarly a moving charge creates a field in its surrounding space which exerts a force on a moving charge this field is known as magnetic field which is a vector quantity and represented by B.

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Motion of charged particle in a Magnetic Field:

When a charged particle q is thrown in magnetic field B∡$^{\rightarrow}$ with a velocity v then the force acting on the particle is given by $F = qvB.\sin\theta$, where θ is the angle between the velocity and the magnetic field. As the magnetic force on a charged particle is perpendicular to the velocity, it does not do any work on the particle. Hence, the kinetic energy or the speed of the particle doesn't change due to the magnetic force.

Case I: $\theta = 0°$ or $180°$

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Motion of charged particle in a Magnetic Field:

Path followed: Straight line

If a charged particle is thrown parallel or antiparallel to magnetic field it does not experience any magnetic force as the angle θ between v and B will be zero or 180°. So, it will continue to move in a straight line with constant velocity.

Case II: $\theta = 90°$

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Motion of charged particle in a Magnetic Field:

Path followed: Circular

When a charged particle is projected perpendicular to a uniform magnetic field, its path is a circle. The magnetic Lorentz force acts as the centripetal force causing the charged particle to move in a circular path of radius R with constant speed.

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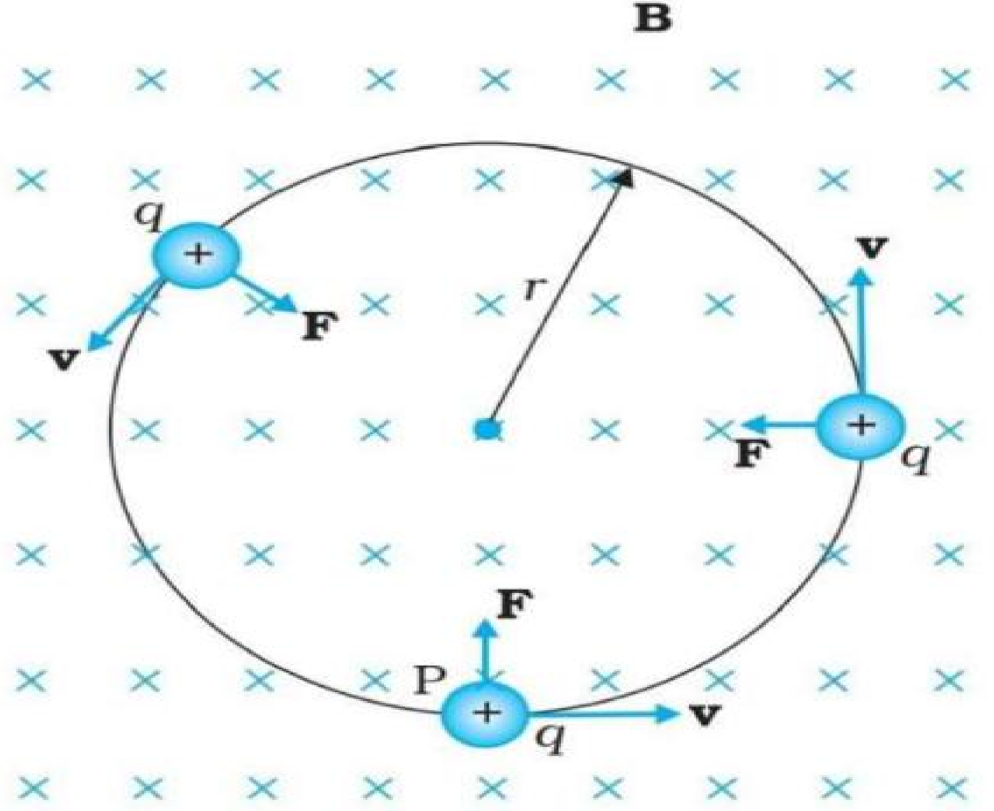
Motion of charged particle in a Magnetic Field:



$$F = qvB = \frac{mv^2}{R}$$

$$\Rightarrow R = \frac{mv}{qB}$$

$$F = qvB = \frac{mv^2}{R}$$

$$\Rightarrow R = \frac{mv}{qB}$$

Angular velocity $(\omega) = \frac{v}{R} = \frac{qB}{m}$

Time period of revolution $T = \frac{2\pi}{\omega} = \frac{2\pi m}{qB}$

Frequency of revolution $= \frac{1}{T} = \frac{qB}{q2\pi m}$

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Biot-Savart Law:

Consider an infinitesimal element dl of the conductor. The magnetic field dB due to this element

is to be determined at a point P which is at a distance r from it. Let θ be the angle between dl

and the position vector r. The direction of dl is same as the direction of current.

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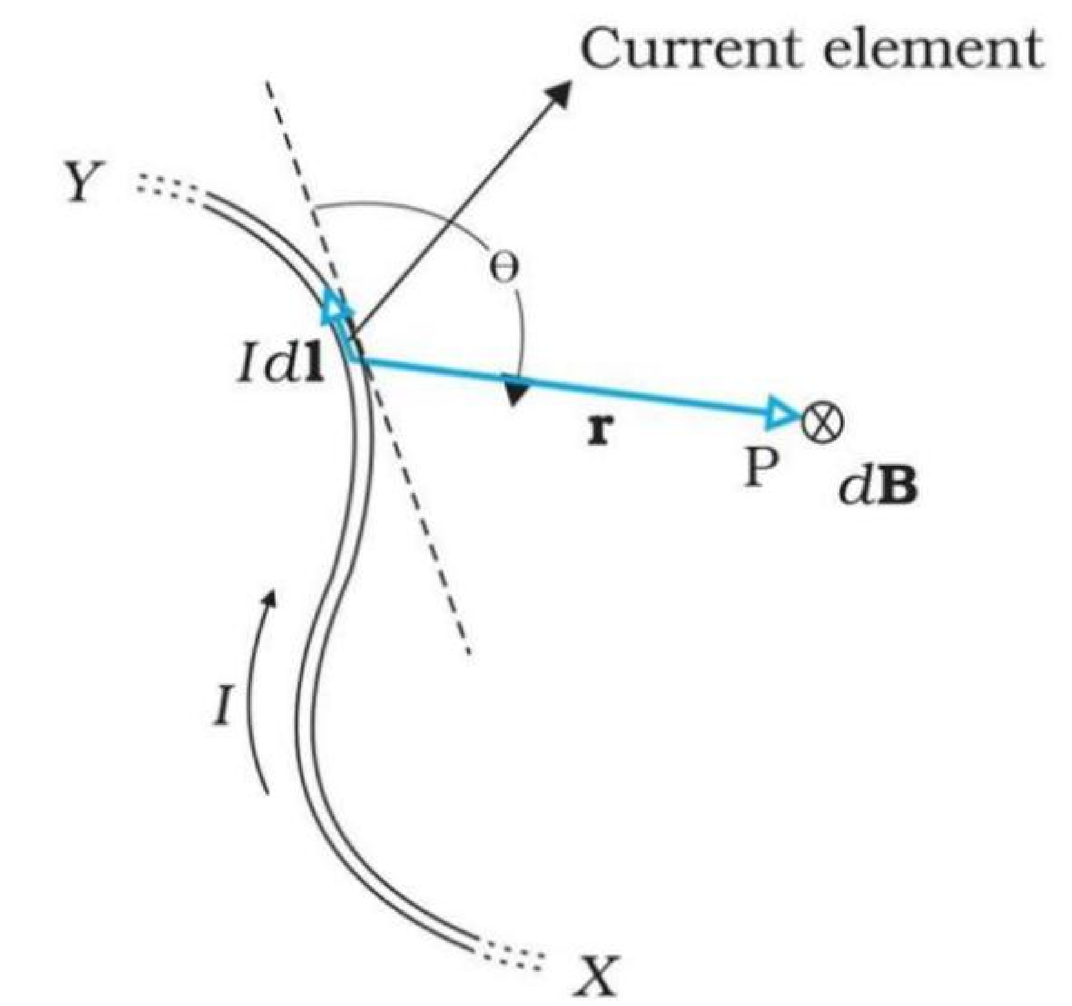
Biot-Savart Law:



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Biot-Savart Law:

According to Biot-Savart law, the magnitude of the magnetic field dB is proportional to the current I, the element length dl is inversely proportional to the square of the distance r. Its direction is perpendicular to the plane containing dl and r. Thus in vector notation,

$$d\vec{B} \propto \frac{Id\vec{l}\sin\theta}{r^2}$$

$$d\vec{B} = \frac{u_0}{4\pi}\frac{Id\vec{l}\sin\theta}{r^2}$$

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Biot-Savart Law:

Where, $\frac{u_0}{4\pi}$ is a constant of proportionality. The above expression holds when the medium is vacuum. The proportionality constant in SI unit has value, $\frac{u_0}{4\pi} = 10^{-7} T - \frac{m}{A}$. We call u_0 the permeability of free space.

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Magnetic Field due to a Loop of Current:

Magnetic field lines due to a loop of wire are shown in the figure. The direction of magnetic field on the axis of current loop can be determined by right hand thumb rule. If the fingers of right hand are curled in the direction of current, the stretched thumb is in the direction of magnetic field.

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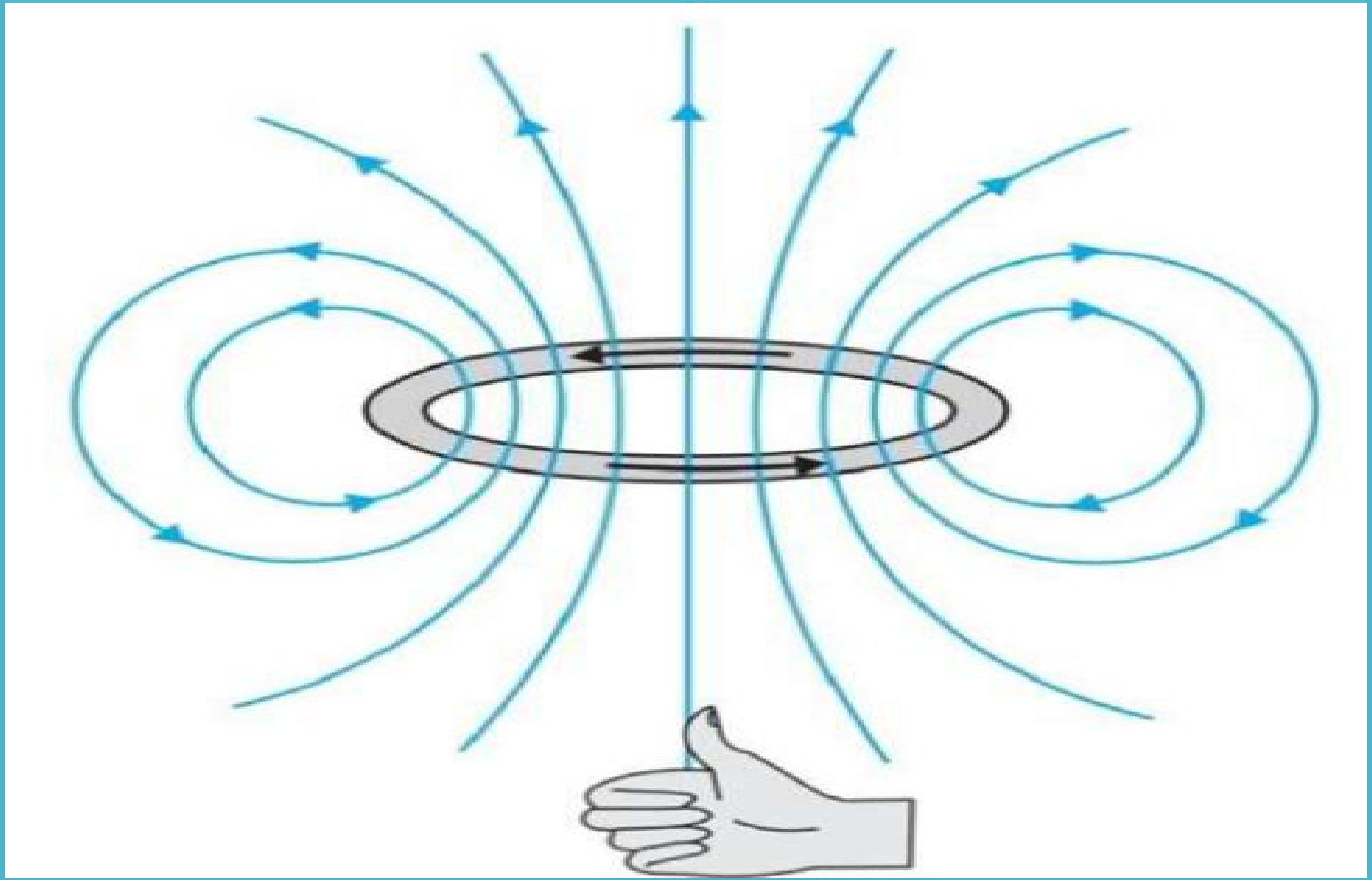
Magnetic Field due to a Loop of Current:



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Magnetic Field due to a Loop of Current:

Consider a current loop placed in plane carrying current i in anticlockwise sense. Due to a small current element i.dl shown in the figure, the magnetic field is given by

$$dB = \frac{\mu_0}{4\pi} \frac{idl.\sin 90}{r^2}$$

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Magnetic Field due to a Loop of Current:

Strength of Magnetic Field at the center of loop,

$$\int dB = \int \frac{\mu_0}{4\pi} \frac{idl.\sin 90}{r^2}$$

$$B = \frac{\mu_0}{4\pi} \frac{i.\sin 90}{r^2} \int dl$$

$$B = \frac{\mu_0}{4\pi} \frac{i}{r^2} 2\pi r$$

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

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Magnetic Field due to a Loop of Current:

If the loop has n round of wire,

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

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Magnetic Field due to a Loop of Current:

Relation between μ and ε

Relation between μ_0 and ε_0

$$\frac{1}{4\pi\varepsilon_0} = 9 \times 10^9 \ldots (1)$$

$$\frac{\mu_0}{4\pi} = 10^{-7} \ldots (2)$$

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Magnetic Field due to a Loop of Current:

Dividing by eq. (2) to eq. (1)

$$\frac{\frac{\mu_0}{4\pi}}{\frac{1}{4\pi\varepsilon_0}} = \frac{10^{-7}}{9 \times 10^9}$$

$$\frac{\mu_0}{4\pi} \times \frac{4\pi\varepsilon_0}{1} = \frac{1}{9 \times 10^{9+7}}$$

$$\mu_0\varepsilon_0 = \frac{1}{(3 \times 10^8)^2}$$

$$\mu_0\varepsilon_0 = \frac{1}{c^2}$$

$$c = \frac{1}{\sqrt{\mu_0\varepsilon_0}}$$

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Ampere's Circuital Law:

Ampere's circuital law states that line integral of steady magnetic field over a closed loop is

equal to μ0 times the total current (Ie) passing through the surface bounded by the loop i.e.,

$\int B. dl = \mu \quad I_e$

where Ie is enclosed current

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Magnetic Force:

It is observed that when charge is at rest it experiences almost no force. However, if the charge q is given a velocity v in the direction of current, it is deflected towards the wire. Hence, we conclude that magnetic field exerts a force on a moving charge particle. The combination of electric and magnetic force on a point charge is known as Lorentz Force. Consider a point charge q moving with velocity v located at position vector r at a given time t. If an electric field E and a magnetic field B exist at that point, then force on the electric charge q is given by

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Magnetic Force:

$$\vec{F} = q[\vec{E} + \vec{v} \times \vec{B}]$$

This force was first given by H. A. Lorentz; hence it is called Lorentz force.

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Fleming's left-hand rule:

If we stretch the thumb and first two fingers of our left hand in mutually perpendicular directions such that forefinger points along B and middle finger points along v, then the thumb points along F.

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Cyclone Frequency:

A charge c completes a circular orbit on a plane normal to B which is the uniform magnetic field.

The uniform circular motion frequency is known as cyclone frequency. This frequency is unaffected by the radius and speed of the particle. It can be determined with the help of a machine known as cyclotron which is used to accelerate the particles which are charged.

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Current Loop as a Magnetic Dipole:

A current carrying loop behaves like a magnetic dipole. It has two poles viz north and south like

that of a bar magnet. Following figures show magnetic field lines due to a bar magnet and a current carrying loop.

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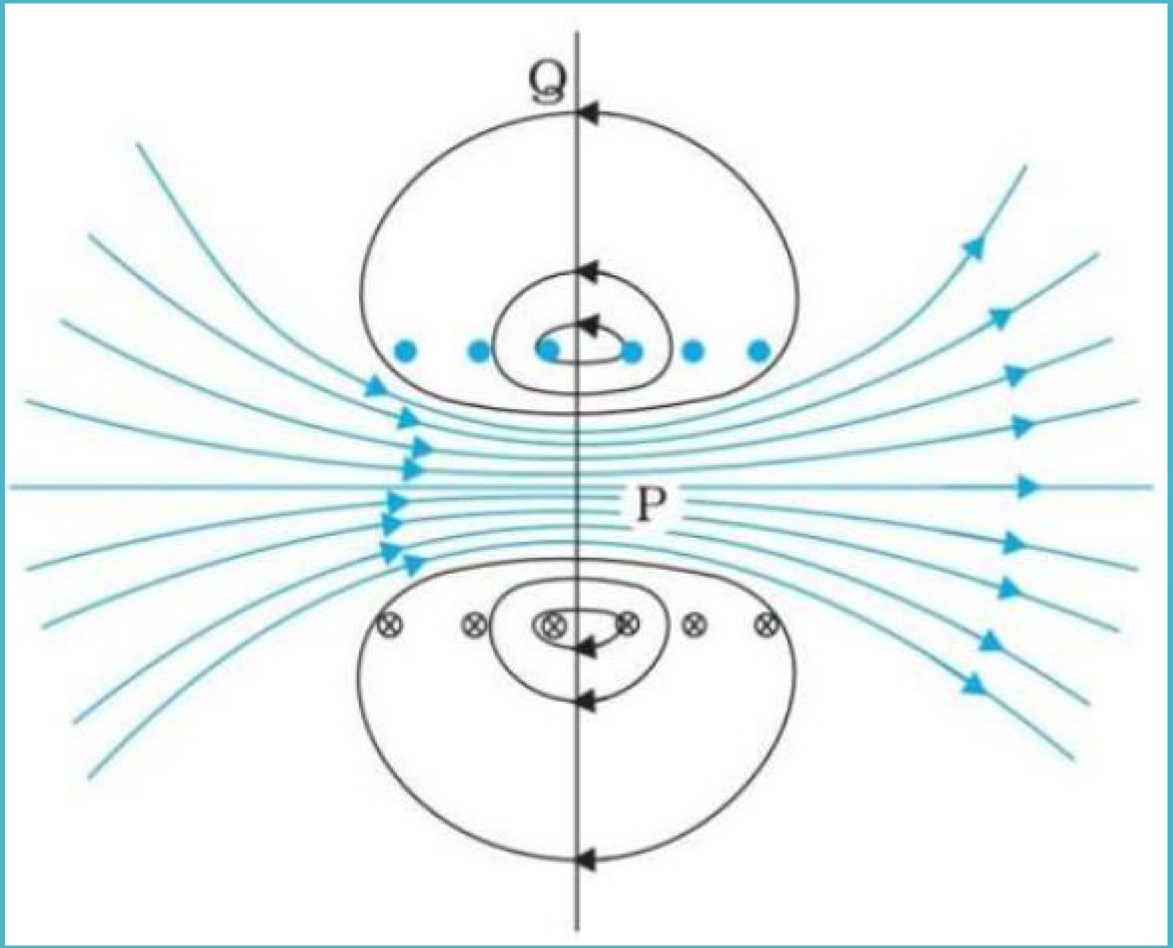
Current Loop as a Magnetic Dipole:



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Current Loop as a Magnetic Dipole:

The magnetic dipole moment vector for a current loop is given by

$$\vec{M} = Ni\vec{A},$$

where, N = number of loops or turns

i = current through each turn

A = area of each turn

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Current Loop as a Magnetic Dipole:

Current sensitivity:

It is defined as the deflection produced per unit current passed through the galvanometer.

Voltage sensitivity:

It is defined as the deflection produced per unit voltage applied across the galvanometer.

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Current Loop as a Magnetic Dipole:

Galvanometer as Ammeter:

The galvanometer cannot as such be used as an ammeter to measure the value of the current in a given circuit. This is for two reasons.

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Current Loop as a Magnetic Dipole:

- Galvanometer is a very sensitive device. It gives a full-scale deflection for a current of the order of µA.

- For measuring currents, the galvanometer has to be connected in series, and as it has a large resistance, this will change the value of the current in the circuit.

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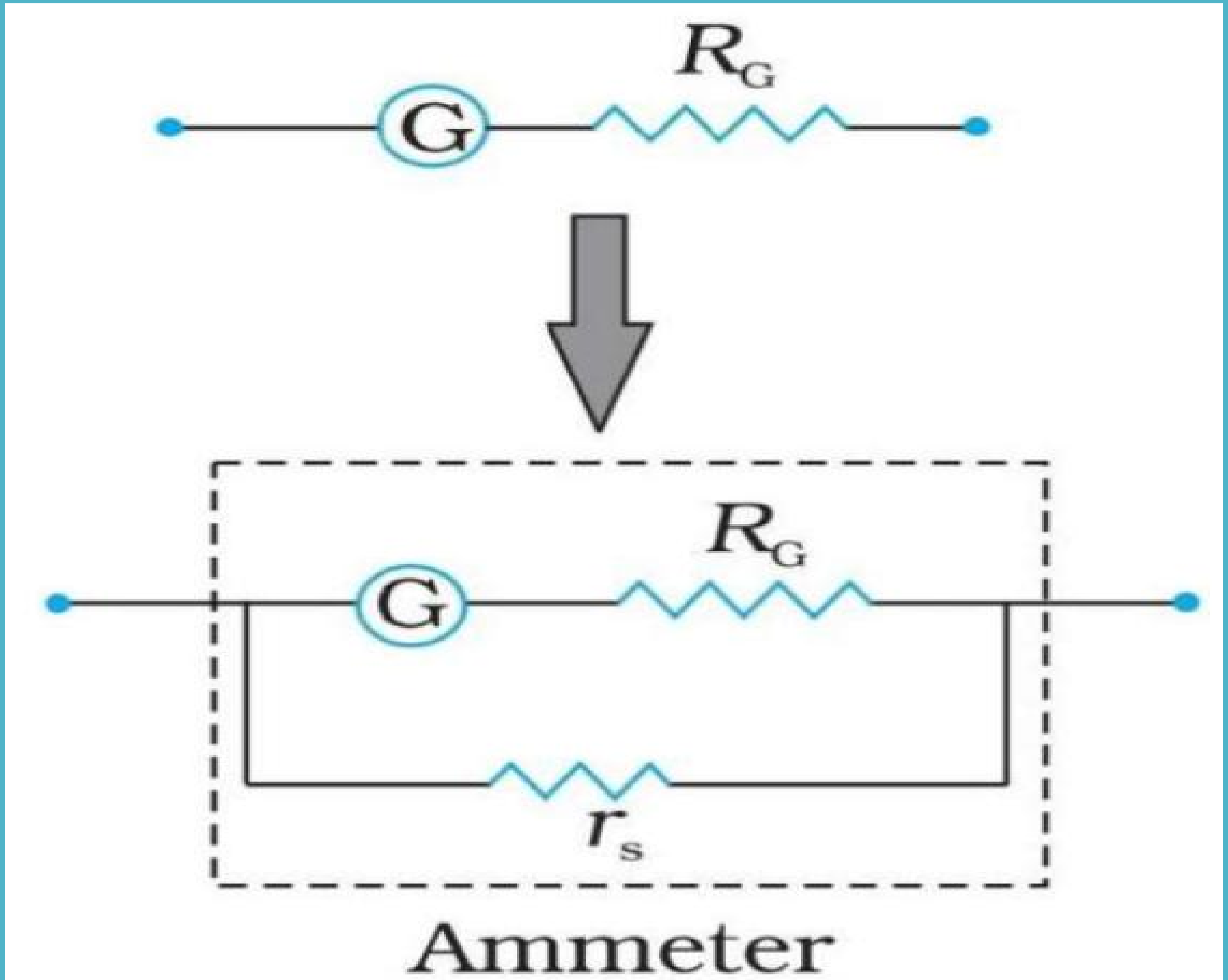
Current Loop as a Magnetic Dipole:



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Current Loop as a Magnetic Dipole:

To overcome these difficulties, one attaches a small resistance rs called shunt resistance, in parallel with the galvanometer coil, so that most of the current passes through the shunt. The resistance of this arrangement is.

$$\frac{R_G r_s}{R_G + r_s} = r_s$$

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Current Loop as a Magnetic Dipole:

We define the current sensitivity of the galvanometer as the deflection per unit current. Thus

$$\frac{\phi}{i} = \frac{NAB}{K}$$

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Galvanometer as Voltmeter:

To use galvanometer to find the potential difference between a section of a circuit, it must be connected in parallel to that section of the circuit. Further, it must draw very small current, otherwise the voltage measurement will disturb the original setup by an amount which is very large. Usually, we like to keep the disturbance due to the measuring device below one percent. To ensure this, a large resistance R is connected in series with the galvanometer.

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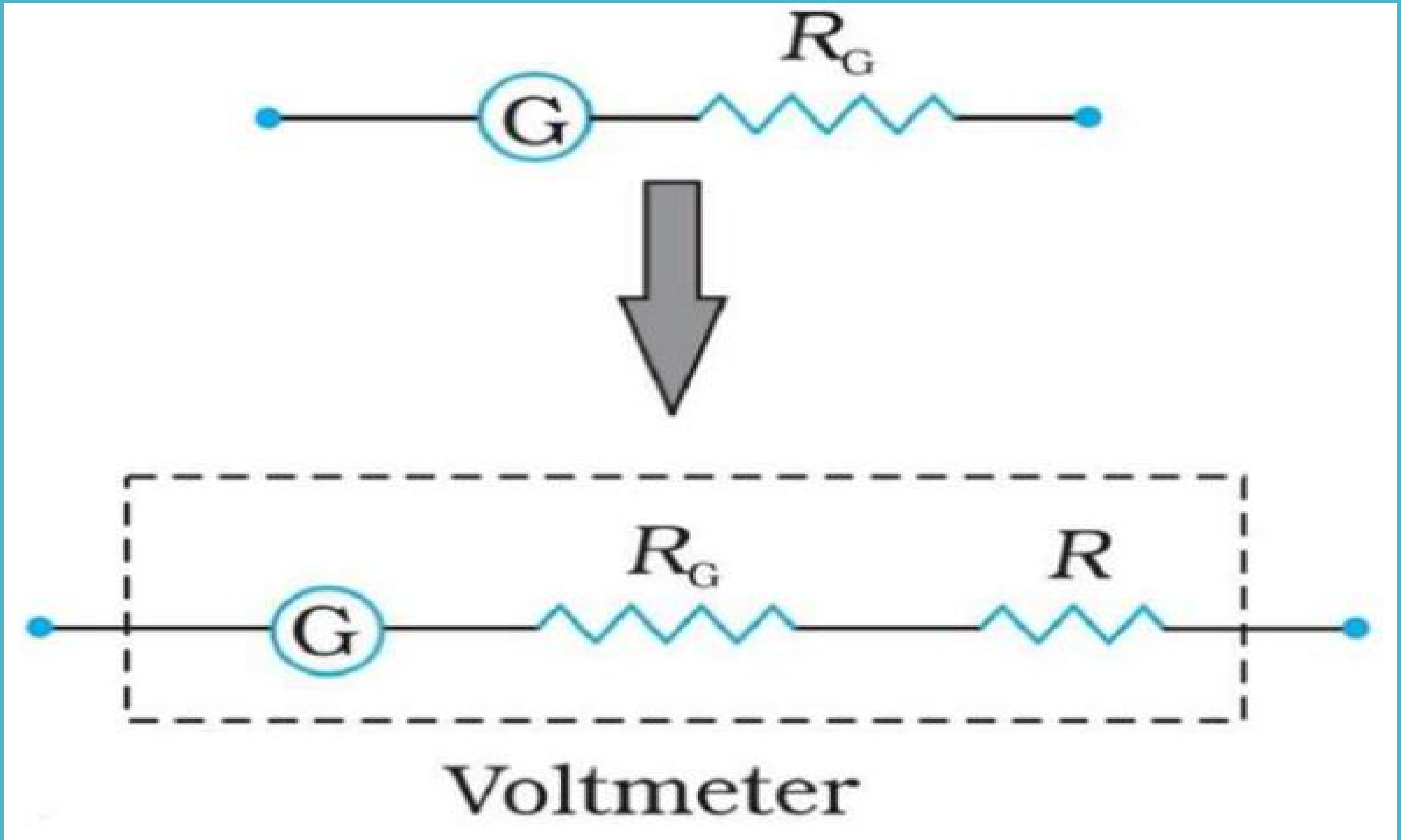
Galvanometer as Voltmeter:



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Galvanometer as Voltmeter:

We define voltage sensitivity as the deflection per unit voltage.

$$\frac{\phi}{V} = \left(\frac{NAB}{K}\right)\frac{i}{v}$$

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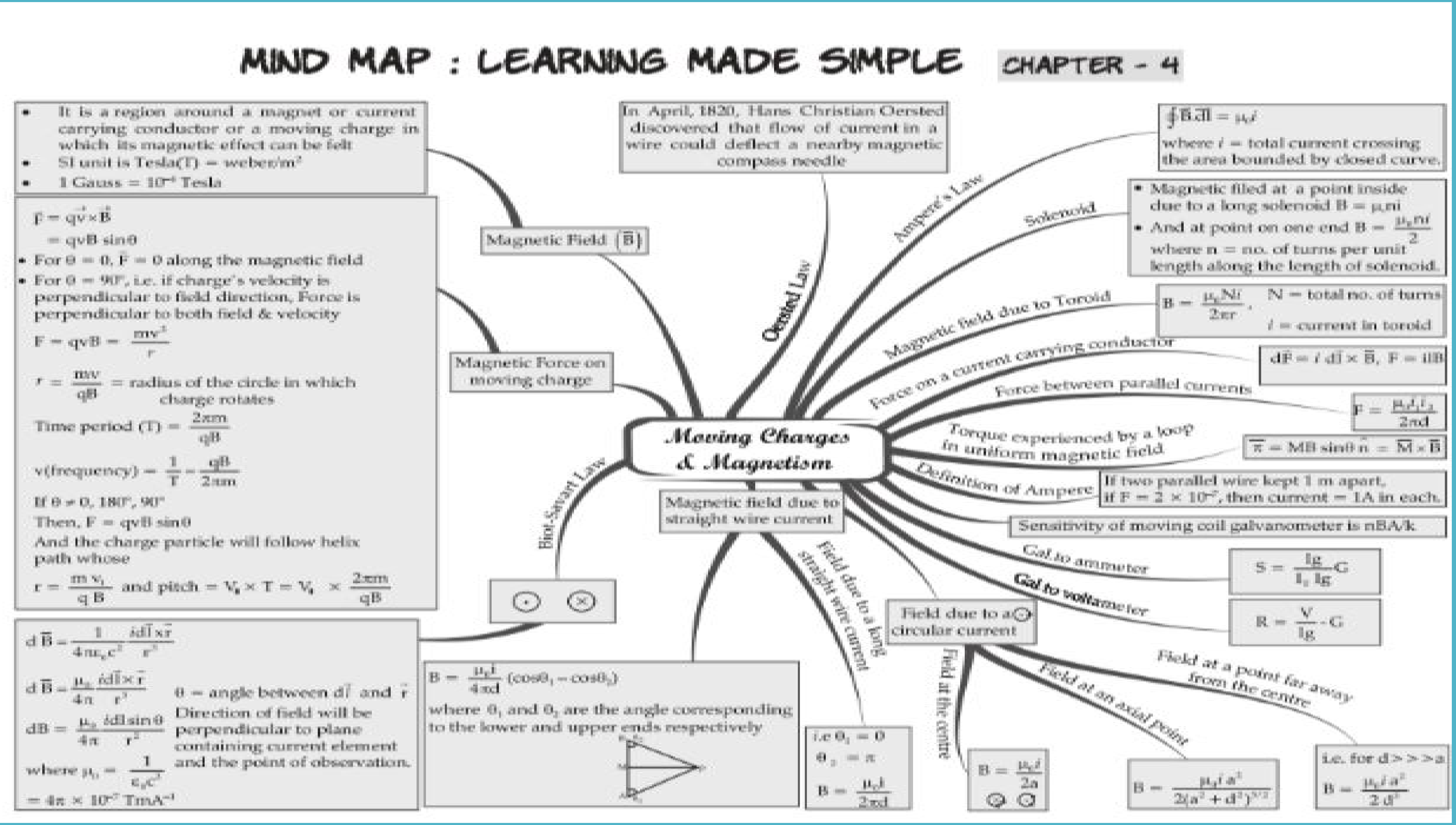

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