Moving coil galvanometer , ammeter & voltmeter

(and a few applications)

V Vijaykiran
M.Sc., B.Ed., NET
SIGMA Physics Resource Centre
http://www.sigmaprc.in

Note : The notes given in this file is no substitute to the much detailed discussion held in the online/contact classes with active participation of students. It , at best, serves the purpose of ready reference for important concepts/derivations covered in the classes.

Moving charges & magnetism - IV

- Force on a current carrying coil
- Torque on a current carrying coil
- magnetic moment (m)
- magnetic moment of an electron
- Moving coil galvanometer
- Ammeter
- Voltmeter

Force of a current carrying conductor

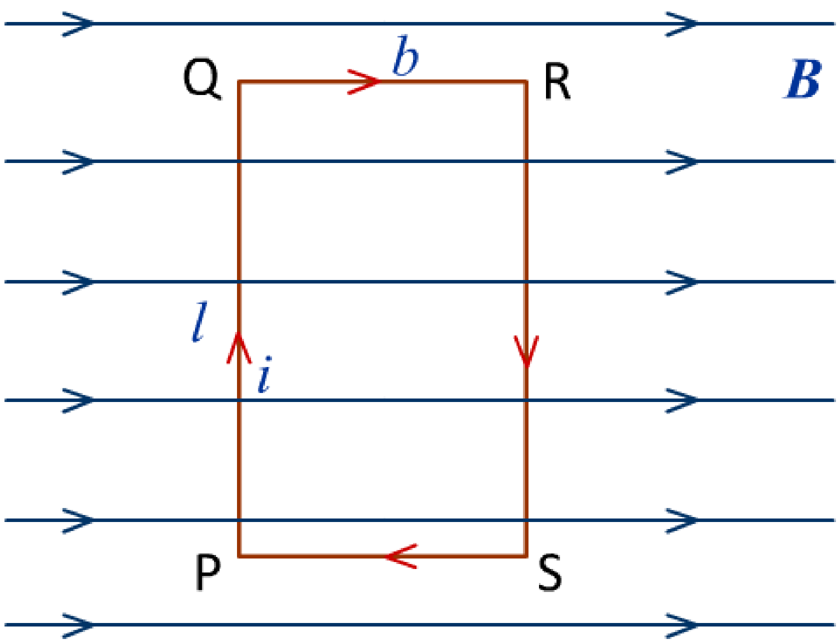
$$\boxed{\overline{F} = i\,\overline{l} \times \overline{B}}$$

$$\boxed{F = B\,i\,l\,\sin(\theta)}$$

- Direction of force is given by the right hand thumb rule.
- Force is maximum when angle between l (taken in the direction of flow of current) and $\boldsymbol{B}$ is 90^o
- Force is zero when l is along $\boldsymbol{B}$ (i.e. θ is 0^o or 180^o)

Force on a current carrying loop in a region of uniform B

- Consider a loop of length l and breath b carrying current i .
- Let the loop be placed in a region of uniform magnetic field of induction B with its plane (initially) parallel to the magnetic field.



Considering the force acting on each edge of the loop

$$F_{PQ} = Bil \quad \text{(inwards)}$$

$$F_{QR} = 0$$

$$F_{RS} = Bil \quad \text{(outwards)}$$

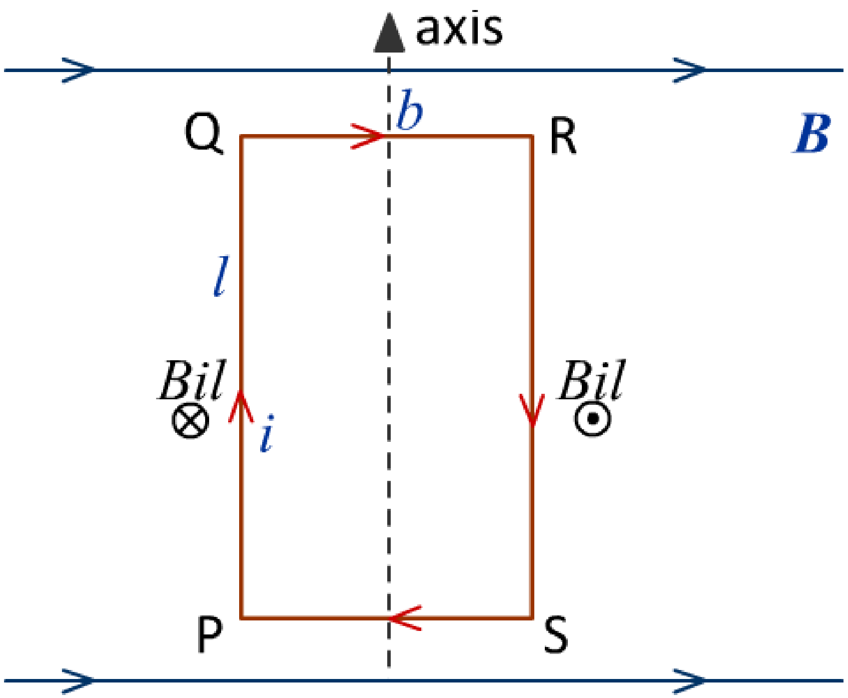
$$F_{SP} = 0$$

$$\boxed{\bar{F}_{net} = 0}$$

Centre of mass of the loop remains in translational equilibrium

Torque on a current carrying loop in a region of uniform B

- Though the net force on the loop is zero, forces acting on the individual segments do not act along the same line. This results in a torque acting on the loop.



$$\bar{\tau} = \bar{r} \times \bar{F}$$

$$\bar{\tau} = Bil \times \frac{b}{2} + Bil \times \frac{b}{2}$$

$$\bar{\tau} = Bilb$$

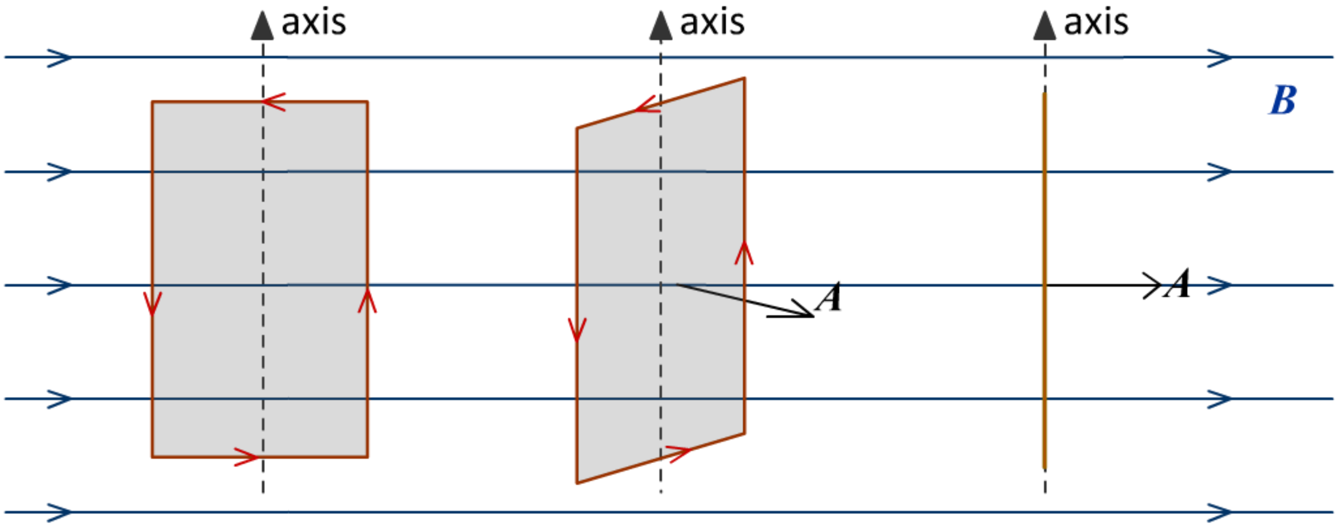
$$\bar{\tau} = BiA$$

For a loop consisting on n turns and when the area vector makes an angle θ w.r.t. the field we get

$$\boxed{\bar{\tau} = ni\,\bar{A} \times \bar{B}}$$

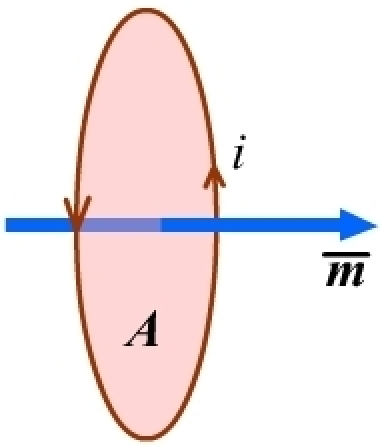
Torque tends to bring the loop to stable equilibrium.

Torque on a current carrying loop in a region of uniform B



- Torque acting on the loop is zero when area vector is along the magnetic field and therefore the loop is in stable equilibrium when $\theta = 0^o$.
- Torque acting on the loop is zero when area vector is opposite the magnetic field The loop is in unstable equilibrium when $\theta = 180^o$.
- Torque acting on the loop is the maximum when area vector is perpendicular to the magnetic field i.e. when $\theta = 90^o$.

Magnetic moment (m)



- Magnetic moment associated with a coil of n turns enclosing area A and carrying current i is given by $\boxed{\boldsymbol{m} = niA}$
- Magnetic moment is a vector quantity. Its direction is given by the right hand thumb rule

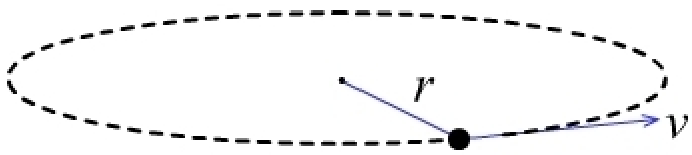
  When fingers of the right hand are curled in the direction of flow of current then the thumb indicates the direction of magnetic moment

  SI unit of magnetic moment is Am^2

  Dimensional formula of magnetic moment is $[\ L^2 A\ ]$

Magnetic moment (μ) of an orbiting electron

Consider an electron of charge e and mass m in a circular orbit of radius r. Let v be the speed of the electron.



Magnetic moment is given by

$$\mu = i\,A$$

$$\mu = \frac{e}{T}\,\pi r^2$$

$$\mu = \frac{e v}{2\pi r}\,\pi r^2$$

$$\mu = \frac{e v}{2}\,r$$

Multiplying and dividing by mass (m) of the electron

$$\mu = \frac{e m v r}{2m}$$

Using Bohr's quantization of angular momentum i.e. $mvr = nh/2\pi$, for $n = 1$ we get

$$\mu = \frac{e h}{2m\,2\pi}$$

$$\mu = \frac{e h}{4 m \pi}$$

The minimum magnetic moment is also called one Bohr magneton.

Gyromagnetic ratio

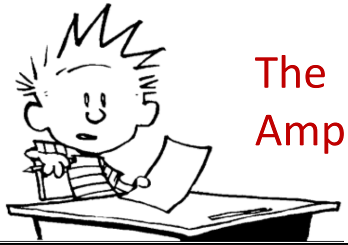
Ratio of magnetic moment to the angular momentum of a particle is called gyromagnetic ratio.

Magnetic moment is given by

$$\mu = \frac{evr}{2}$$

$$\mu = \frac{evr}{2}\frac{m}{m}$$

$$\frac{\mu}{l} = \frac{e}{2m}$$



The fact that even at an atomic level there is a magnetic moment, confirms Ampere's hypothesis of atomic magnetic moments. This explains the magnetic properties of materials.

Moving coil galvanometer

- It is a device to detect the flow of current in a circuit.
- It works on the principle of torque acting on a current carrying coil placed in a region of magnetic field.

<u>Parts of a MCG</u>

- Insulating frame : To support the coil
- Horse shoe magnet : It is used to set up the magnetic field in the region containing the coil.
- Insulated copper coil : When current passes through this coil, it results in a deflecting torque causing the coil to turn
- Phosphor Bronze wire : It is used to suspend the frame holding the coil in the magnetic field. Phosphor-bronze has high young’s modulus (i.e. it does not stretch easily) and low rigidity modulus (i.e. it twists easily)
- Spiral spring : This provides the restoring torque resulting in equilibrium of the coil and also restores the coil to its initial position when current is zero.

Moving coil galvanometer

Deflecting torque acting on the coil of the MCG is

$$\tau_D = nBiA$$ i

Restoring torque due to the spring is

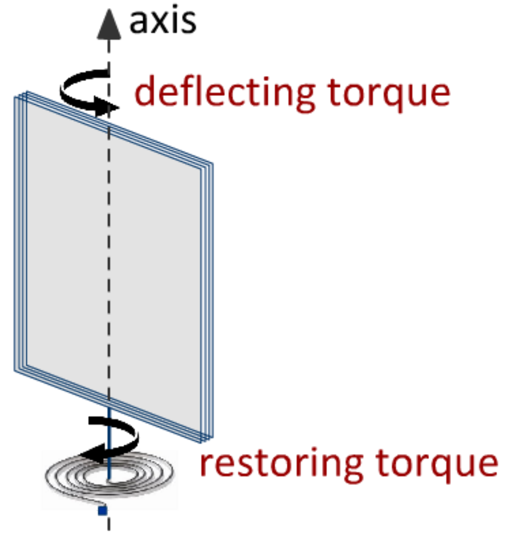
$$\tau_R = C\theta$$ ii

C is couple per unit twist
SI unit Nm rad^{-1}

Under equilibrium τ_R is equal in magnitude and opposite in direction to τ_D

$$C\theta = nBiA$$

$$\boxed{\theta = \frac{nBA}{C} i}$$ iii



Current sensitivity : of a moving coil galvanometer is the deflection per unit current passing through it.

$$\boxed{\frac{\theta}{i} = \frac{nBA}{C}}$$ iv

SI unit of current sensitivity : rad A^{-1}

Figure of merit : It is the inverse of current sensitivity of the galvanometer.

Moving coil galvanometer

Voltage sensitivity : Deflection per unit voltage

From current sensitivity, using $V = iR$, we get

$$\frac{\theta}{V} = \frac{nBA}{C\,R}$$

Increasing current sensitivity does not necessarily increase voltage sensitivity.

Consider a galvanometer in which the current sensitivity is doubled by increasing the number of turns in the coil (thereby increasing the deflecting torque). Therefore

$$\left(\frac{\theta}{i}\right)_{new} = \frac{2 \times nBA}{C}$$

Current sensitivity increases

As the number of turns is increased, the length of the wire required increases and thus R also increases. Therefore

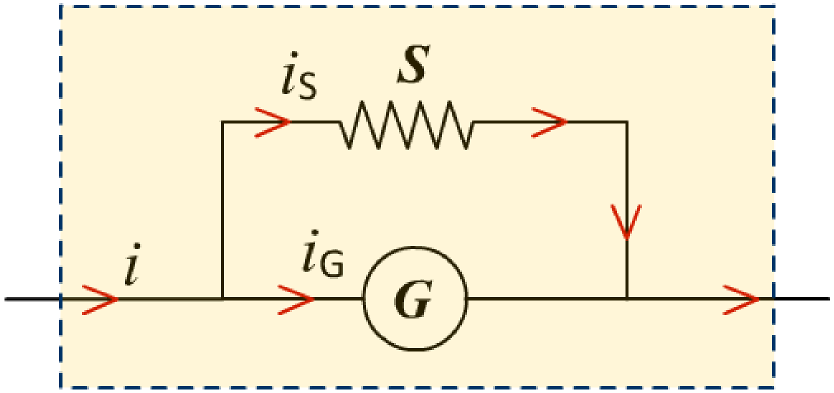
$$\left(\frac{\theta}{V}\right)_{new} = \frac{2 \times nBA}{C 2 \times R}$$

$$\left(\frac{\theta}{V}\right)_{new} = \frac{nBA}{CR}$$

Voltage sensitivity remains same

Ammeter

- It is a device to measure current in a circuit.
- A galvanometer is converted into an ammeter by connecting a small resistance in parallel (also called the shunt resistance) to the galvanometer



Using KLL $i_G G = i_S S$

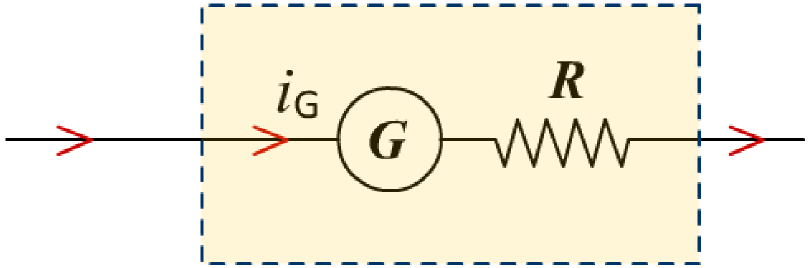
Using KJL $i = i_G + i_S$

$$\boxed{i_G G = (i - i_G)S}$$

- An ammeter is always connected in series in the branch in which the current is to be determined
- An ammeter has a low resistance.
- Resistance of an ideal ammeter is assumed to be zero

Voltmeter

- It is a device to measure potential difference across two points.
- A galvanometer is converted into a voltmeter by connecting a high resistance in series to the galvanometer



$$\boxed{V = i_G(R + G)}$$

- An voltmeter is always connected parallel to the points across which the potential difference is to be determined
- A real voltmeter has a very high resistance.
- Resistance of an ideal voltmeter is assumed to be infinite