3. Moving Coil Galvanometer

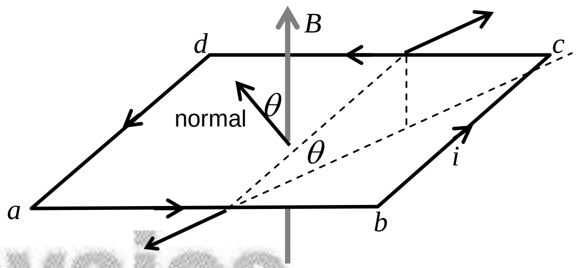
1.Find the expression for torque on a current loop in magnetic field.

▶ Let there be a rectangular loop *abcd* carrying current i placed in a uniform magnetic field *B*. The normal to the plane of the loop makes angle θ with $\vec{B}$. Force on sides *bc* and *da* are equal and opposite and the line of action of forces are also the same. Hence there is no rotatory and translatory effect of this force pair. Force on sides *ab* and *cd* are $F_1 = i(ab)B$ and $F_2 = i(cd)B$ respectively. The two forces are also equal and opposite because *ab* = *cd*. Hence $F_1 = F_2 = i(ab)B$.

Lines of action of forces are at a perpendicular distance $bc\sin\theta$.

Therefore the two forces constitute a couple whose moment (or torque) is $\tau = i(ab)(bc)B\sin\theta$. Since $(bc \times ab) = S$ = area of the loop.

Therefore $\tau = iS\,B\sin\theta$.



$\because$ θ is angle between normal to the plane of loop ($\hat{n}$) and $\vec{B}$, therefore considering the area to be a vector in the direction of the normal, $\vec{\tau} = i\vec{S} \times \vec{B}$.

Vector quantity $i\vec{S}$ is called **magnetic dipole moment** of the current loop denoted as $\vec{P}_m$ $\therefore$ $\boxed{\vec{\tau} = \vec{P}_m \times \vec{B}}$.

Hence *torque on a current loop is cross product of dipole moment and field vector irrespective of the shape of the loop*.

? Is it possible for a current loop to stay without rotating in a uniform magnetic field? If yes what should be the orientation of the loop?
Ans: Yes. If the loop's plane is perpendicular to the field it will stay without rotating.

? The torque on a current loop is zero if the angle between the positive normal and the magnetic field is either θ = 0 or θ = 180°. In which of the orientations the equilibrium is stable.
Ans: When θ = 0.

2.Moving coil Galvanometer:

▶ **Principle:** When a current carrying coil is placed in a magnetic field it experiences a torque which is proportional to the current flowing in the coil. The torque on the coil is proportional to the deflection of the coil.

Therefore $i \propto \theta$. Hence measuring the deflection, current can be measured.

Construction: A rectangular coil is wound on a frame and it is pivoted between the *semi cylinder* shaped poles of a *horse shoe magnet* through two *spiral springs*. End of the coil is joined to the suspension springs which serve as leads also.

A cylindrical soft iron core is placed between poles of the magnet and is detached from the coil so that coil may rotate freely around it.

Semi cylindrical poles provide almost 'radial' and strong field lines of $\vec{B}$ in presence of the iron core. Due to the radial nature of magnetic field, $\vec{B}$ is always in the plane of the coil, i.e., dipole moment of the coil $\vec{m}$ is perpendicular to the $\vec{B}$.

A pointer is attached to the coil which can move on a graduated dial to show the deflection.

Working: Supposed the coil has number of turns *N* and its area is *S*.

Since magnetic field is radial therefore the plane of the coil is always parallel to the direction of field. Therefore the angle between the dipole moment of the coil and magnetic field is 90°.

Therefore, when a current i is flown through the coil, the torque on the coil is

$$\tau = iNSB\sin 90^\circ = iNSB.$$

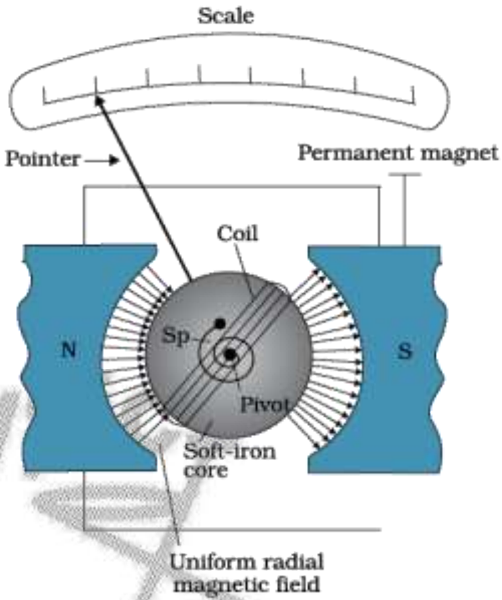
This torque rotates the coil. Due to rotation spring is twisted and an elastic restoring torque in the spring develops which establishes equilibrium.

If ϕ is deflection in equilibrium, the restoring torque developed in the suspension wire is $\tau_r = C\phi$, where C = spring constant of the spring.

In equilibrium, $\tau = \tau_r$. $\Rightarrow$ $N\,i\,S\,B = C\phi$.

$\Rightarrow i = (c/NAB)\phi$. $\therefore$ $i \propto \phi$.

Here, $c/NAB = G$ is a constant for a given galvanometer and it is called "*galvanometer constant*" or *figure of merit.*



3.Sensitivity of a galvanometer?

▶ Sensitivity of a galvanometer is defined as the deflection per unit change of current. $\Rightarrow$ Sensitivity = θ/I.

It is measured in divisions /μA or divisions /*m*A.

***Current Sensitivity*:** Change in defection deflection per unit current change, i.e. $d\phi/di$, is called *sensitivity* or *current sensitivity* of a galvanometer. $\therefore (d\phi/di) = (NSB/C) = G$.

To increase the current sensitivity the number of turns *N* is increased.

***Voltage Sensitivity*:** deflection per unit pd applied to the coil, $d\phi/dV$ is called *voltage sensitivity*.

$\because$ $V = iR$ where *R* is resistance of the coil of the galvanometer, therefore $V = (CR/NSB)\ \phi$.

$\Rightarrow$ $\phi = (NSB/CR)V$. $\therefore$ $d\phi/dV = (NSB/CR) = (G/R)$.

4.Increasing the current sensitivity of the galvanometer also increases the voltage sensitivity or not? Explain.

▶ Increasing the current sensitivity doesn't necessarily increase the voltage sensitivity. To increase the current sensitivity number of turns is increased. For example to double the current sensitivity, *N* number of turns) is also doubled. Now the resistance is also proportional to *N* so the resistance becomes 2*R*.

Therefore voltage sensitivity $d\phi/dV = (2NSB/C2R) = NSB/CR$.

So the voltage sensitivity is unchanged.

5.State the underlying principle of working of a moving coil galvanometer. Write two reasons why a galvanometer can not be used as such to measure current in a given circuit. Name any two factors on which the current sensitivity of a galvanometer depends.

▶ If a coil of area *A*, number of turns *N* carrying current *I* is placed in a perpendicular magnetic field B then torque acting on it is $\tau = (NAB)I$

This torque tends to rotate the coil; if coil is attached to a rigid spiral spring of tortional rigidity *c* then is equilibrium, for small twist or deflection θ, $\tau = c\theta$ $\therefore c\theta = (NAB)I$ $\therefore \theta = \left(\frac{NAB}{c}\right)I$

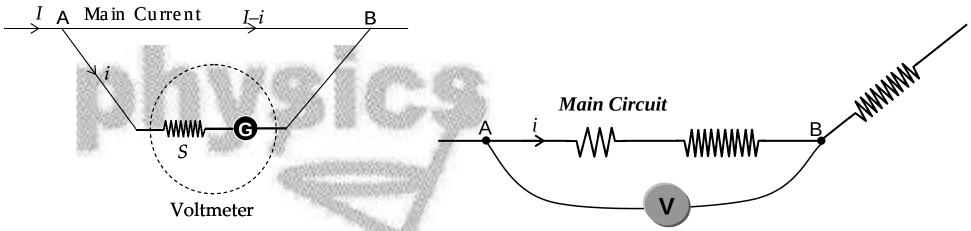
∴ By measuring θ we can measure the current flowing through the coil.
This is the principle of galvanometer.
Galvanometer can not be used as such because:
(i) resistance of the coil is less and large value of current can damage it.
(ii) it increases the total resistance of the of the circuit when joined in series with the circuit hence alter the current to be measured.
Therefore after modification it is used as ammeter to measure the current. Current sensitivity is $S_C = \frac{NSB}{c}$. Hence current sensitivity depends upon:
(i) Number of turns in the coil and **(ii)** Area of the coil.

6.Shunt:

▶ Shunt is a resistance which is used to reduce current through a galvanometer. It is either connected to the galvanometer in series or in parallel.

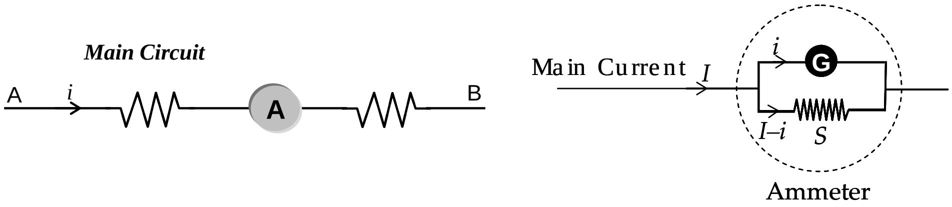
7.*Voltmeter* and *ammeter*:

▶ **Voltmeter**: A galvanometer with a high value shunt in series is called *voltmeter*. It is used to measure potential difference between two points in a circuit.
It is joined between the points in parallel with the other elements in the main circuit.



Voltmeter measuring pd between AB

Working and range: Let G is the resistance of galvanometer and i_g is the maximum current that can be flown through the galvanometer without damaging its coil.
Supposed S is value of shunt, then total resistance of the voltmeter is $G+S \approx S$, as $G<<S$. Value of S is so high that negligibly small current flows through the galvanometer (voltmeter) and main current is unaffected. If i is the current through the voltmeter then potential difference between the points to which the voltmeter is connected is $V = i\,S$ .Therefore maximum voltage that can be measured between the points to which the galvanometer is connected, will be $\boxed{V_{\max} = i_g S}$.
Ammeter: A galvanometer with very low value of shunt in parallel is called an ammeter. It is used to measure current in a given circuit.
It is joined in series with the other elements of the circuit through which the current is to be measured.



Ammeter measuring current through branch AB

Working and range: Let G is the resistance of galvanometer and i_g is the maximum current that can be flown through the galvanometer without damaging the coil. Value of shunt S is so small that negligibly small current flows through the galvanometer and almost all of the main current passes through the shunt unaffected. If i is the current through the galvanometer and I is the main current, then,

$$i = \frac{SI}{G+S}, \Rightarrow I = \frac{G\,i}{S}, \text{ because } G >> S.$$

Therefore the maximum current that can be measured by the ammeter will be,

$$\boxed{I_{\max} = \frac{G i_g}{S}}.$$

8.Increasing the range of an ammeter & voltmeter:

▶ **Ammeter:** Maximum current that can be measured by an ammeter is $I_{\max} = \frac{G i_g}{S}$. i_g can not be increased, so range is increased by decreasing *S*, by adding more resistances in parallel. Let range is increased *n* times by adding S_a in parallel. Then $n I_{\max} = G i_g \left(\frac{1}{S} + \frac{1}{S_a}\right)$.

$\Rightarrow n\frac{G i_g}{S} = G i_g \left(\frac{1}{S} + \frac{1}{S_a}\right)$. $\Rightarrow \frac{1}{S_a} = \left(\frac{n}{S} - \frac{1}{S}\right) = \frac{n-1}{S}$. $\Rightarrow \boxed{S_a = \frac{S}{n-1}}$.

Voltmeter: Maximum voltage that can be measured by a voltmeter is $V_{\max} = i_g S$. If the range is to be increased *n* times then the value of shunt is increased. Let S_a is the additional resistance added to the voltmeter in series, then $nV_{\max} = i_g (S + S_a)$. $\Rightarrow n i_g S = i_g (S + S_a)$. $\therefore \boxed{S_a = (n-1)S}$.[4]

9.Current sensitivity and voltage sensitivity of a moving coil galvanometer:

▶ Current sensitivity $S_I = \frac{\theta}{I} = \frac{NAB}{c}$.

Voltage sensitivity, $S_V = \frac{\theta}{V} = \frac{\theta}{IR} = \frac{NAB}{cR}$.

To increase the current sensitivity, if number of turns is increased, then length of the coil also increases in the same proportion.
That is if *N* is made *m* times greater, resistance *R* also becomes *mR*.

Therefore new current sensitivity $S_I' = \frac{mNAB}{c}$ and new voltage sensitivity $S_V' = \frac{mNAB}{cmR} = \frac{NAB}{cR} = S_V$.

Thus the voltage sensitivity doesn't increase if current sensitivity is increased by increasing number of turns in the coil. If *B* is increased then both can increase.
Hence it is concluded that increasing current sensitivity, not necessarily increase the voltage sensitivity.

? A galvanometer has a resistance 30Ω. It gives full scale deflection with a current of 2 mA. Calculate the value of the resistance needed to convert it into an ammeter of range 0 to 0.3 A.

Ans: Full scale deflection current is I_G = 2mA. Galvanometer resistance G = 30Ω. Maximum current to be measured *I* = 0.3 A.

If shunt required is S then, $I_G = \frac{SI}{S+G}$, or $\frac{I_G}{I - I_G} = \frac{S}{G}$. $\Rightarrow S = \frac{I_G G}{I - I_G}$.

Placing the values we have: $S \approx \frac{2\times10^{-3}\times30}{0.3}$ =0.2Ω.

? In an ammeter (consisting of a galvanometer and a shunt), 0.5% of the main current passes through the galvanometer. Resistance of the galvanometer coil is G. Calculate the resistance of the shunt in terms of G.

Ans: For an ammeter $S = \frac{I_G G}{I - I_G}$. $\Rightarrow S = \frac{0.005IG}{I - 0.005I}$ =0.005G.

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[4] If S is comparable to G then the needed value of resistance is (*n*–1) of the equivalent.