Chapter = 15

Electrical Measuring Instruments

The Moving Coil Galvanometer:

The moving coil galvanometer is a basic electrical instrument. It is used for the detection or measurement of small currents.

Principle

When current flows in a rectangular coil placed in a magnetic field it experience a magnetic torque and if it is free to rotate under a controlling torque, it rotates through an angle proportional to the current flowing through it. The rotation or detection thus indicates a current through it.

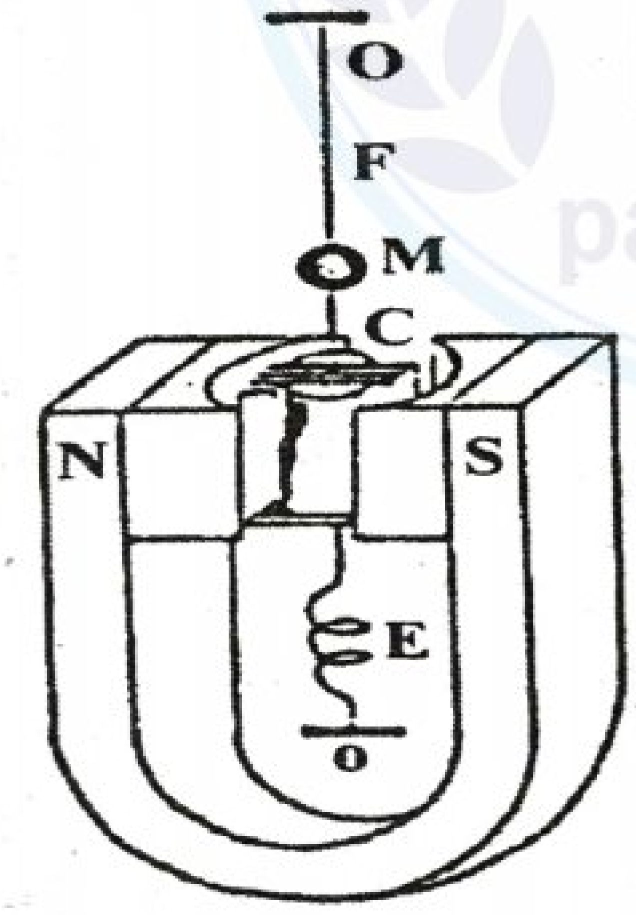
Construction:

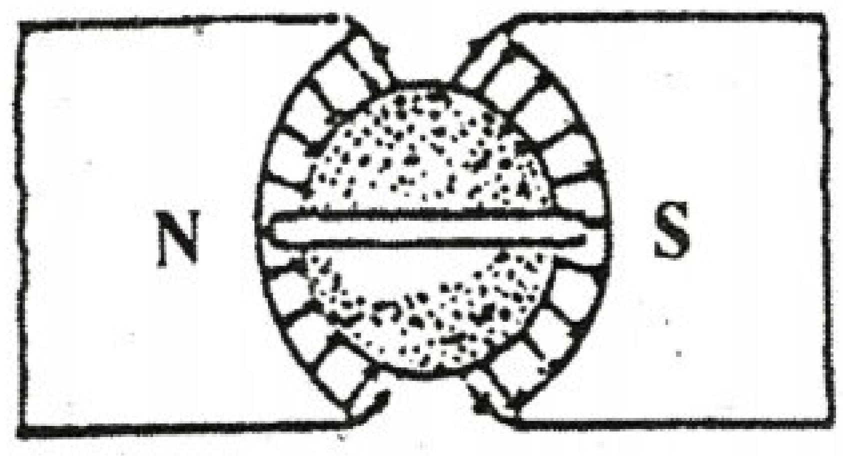
The moving coil galvanometer is usually consists of the following parts:

1. A U-shaped permanent magnet with cylindrical concave pole-pieces to produce radial magnetic field.
2. A flat rectangular coil of thin enamel insulated wire.
3. A soft iron cylinder to make the magnetic field stronger and radial.
4. A scalar lamp and scale arrangement to measure current.
5. A pointer to show deflection.

Working:

When a current passes through the galvanometer coil, it experiences a magnetic deflecting torque, which tends to rotate it from its rest position. As the coil rotates it produces a twist in the suspension strip. The twist in the strip produces an elating restoring torque. The coil rotates until the elastic restoring torque due to which the strip does not equalize and cancel the deflecting magnetic torque and then it attains equilibrium and stops rotating further.





Since the deflection torque on a current carrying rectangular torque is given by

$$\boxed{Deflection\ torque\ =\ BINA\ Cos\alpha}$$

Where

$B\ =\ Strength\ of\ the\ magnetic\ field.$

$I\ =\ Current\ in\ the\ coil.$

$A\ =\ Area\ of\ the\ coil.$

$N\ =\ Number\ of\ turns\ in\ the\ coil.$

$\theta\ =\ The\ angle\ of\ deflection\ of\ the\ coil.$

The restoring elastic torque is proportional to the angle of twist of the suspension strip and according to Hook's Law

$$\boxed{Elastic\ restoring\ torque\ =\ C\theta}$$

Where

$\theta =$ *Angle of twist.*

$C\ =$ *Elasticity constant of spring.*

Under equilibrium condition:

$$Deflecting\ magnetic\ torque = Elastic\ restoring\ torque$$
$$BINA\ Cos\alpha = C\theta$$

$$I\ = \frac{C\theta}{BNACos\alpha} - - - - - (1)$$

In radial magnetic field the plane of the coil is always parallel to the field irrespective of the position of the coil rotates. So the angle between the plane of the coil and direction of the field is always zero i.e. $\alpha = 0°\ and\ cos(0°) = 1$

The equation (1) therefore becomes:

$$I\ = \frac{C\theta}{BNA}$$

Since elastic constant "C", magnetic field "B", area "A" and number of turns "N" are constant for a galvanometer, therefore,

$$I\ = (constant)\theta$$
$$\boxed{I \propto \theta}$$

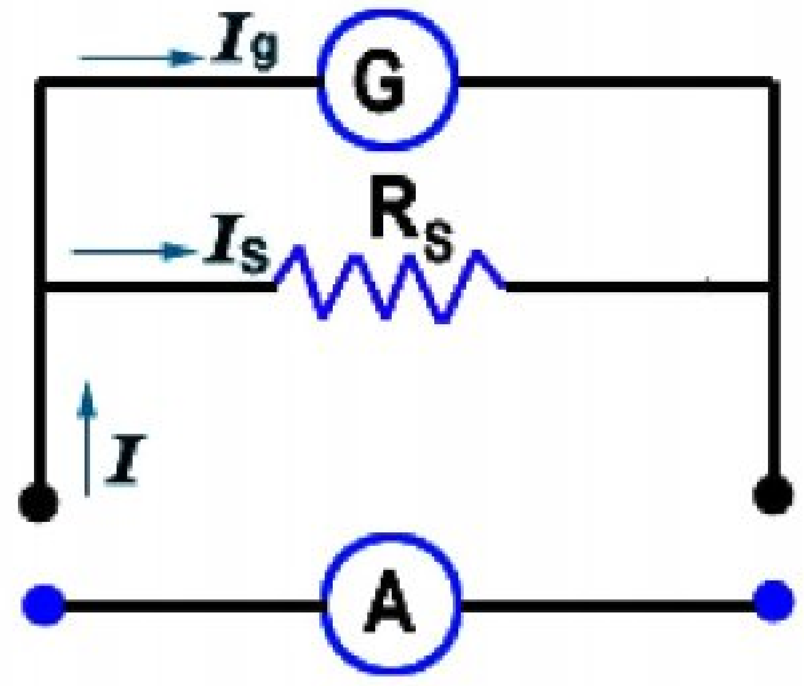
Therefore the current passing through the coil is directly proportional to the angle of twist of the suspension (or deflection).

Ammeter:

An ammeter is an electric instrument, which is used for measuring electric current.

Conversion of Galvanometer into Ammeter:

A galvanometer can be converted into ammeter to measure large amount of current. For this purpose the small resistance called a shunt is connected in parallel with the galvanometer. This resistance allows the large excess current through itself while a fraction of the current passes through the galvanometer coil. The scale of the instrument is so calibrated that it can measure the total input current directly.



Derivation:

Consider a galvanometer "G" whose resistance is R_g and which gives full scale deflection when current "I_g" flows through it. To convert the galvanometer into an ammeter which can measure a maximum current "I", a shunt resistance "R_s" of small resistance is connected in parallel with the galvanometer such that the current "I_s" must flow through the shunt resistance "R_s".

The potential difference "V_g" across the galvanometer is given by

$$Vg = I_g R_g$$

The potential difference "V_s" across the shunt is given by

$$V_s = I_s R_s$$

$$I = I_g + I_s$$

$$I_s = I - I_g$$

$$V_s = (I - I_g) R_s$$

$I_s = I - I_g = current\ through\ the\ shunt.$

Since R_g and R_s are in parallel combination, therefore the potential difference across these resistances will be same

$$V_s = V_g$$

$$(I - I_g) R_s = I_g R_g$$

$$\boldsymbol{R_s = \frac{I_g}{I - I_g} R_g}$$

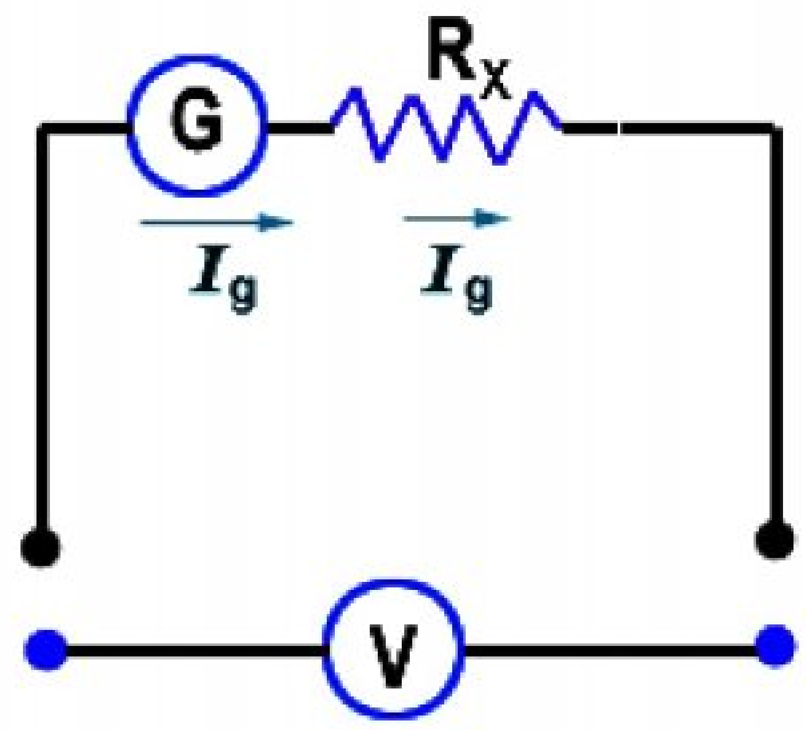
Ammeter is always connected in series with the circuit.

Voltmeter:

Voltmeter is an electric instrument which is used for measuring potential difference.

Conversion of Galvanometer into Voltmeter:

A galvanometer can be converted into voltmeter by connecting a high value resistance in series combination with the galvanometer. This resistance allows the large potential difference drops across it while a fraction of total potential difference drops across galvanometer. The scale of the instrument is so calibrated that it can measure the total voltage directly.



Derivation:

Consider a galvanometer "G" whose resistance is "R_g" and which deflects full scale for the current "I_g". To convert this galvanometer into a voltmeter measuring a potential difference up to "V" volts a high value resistance "R_x" must be connected in series with it. Let "V" is the total potential difference applied across the two ends of the combination. Since the total potential difference is series combination is the sum of the individual potential differences

$$V = V_g + V_x$$

Since we know that the current is same in series combination therefore the current "I_g" must flow through the series combination.

$$V = I_g R_g + I_g R_x$$

$$V = I_g (R_g + R_x)$$

$$V - I_g R_g = I_g R_x$$

$$R_x = \frac{V - I_g R_g}{I_g}$$

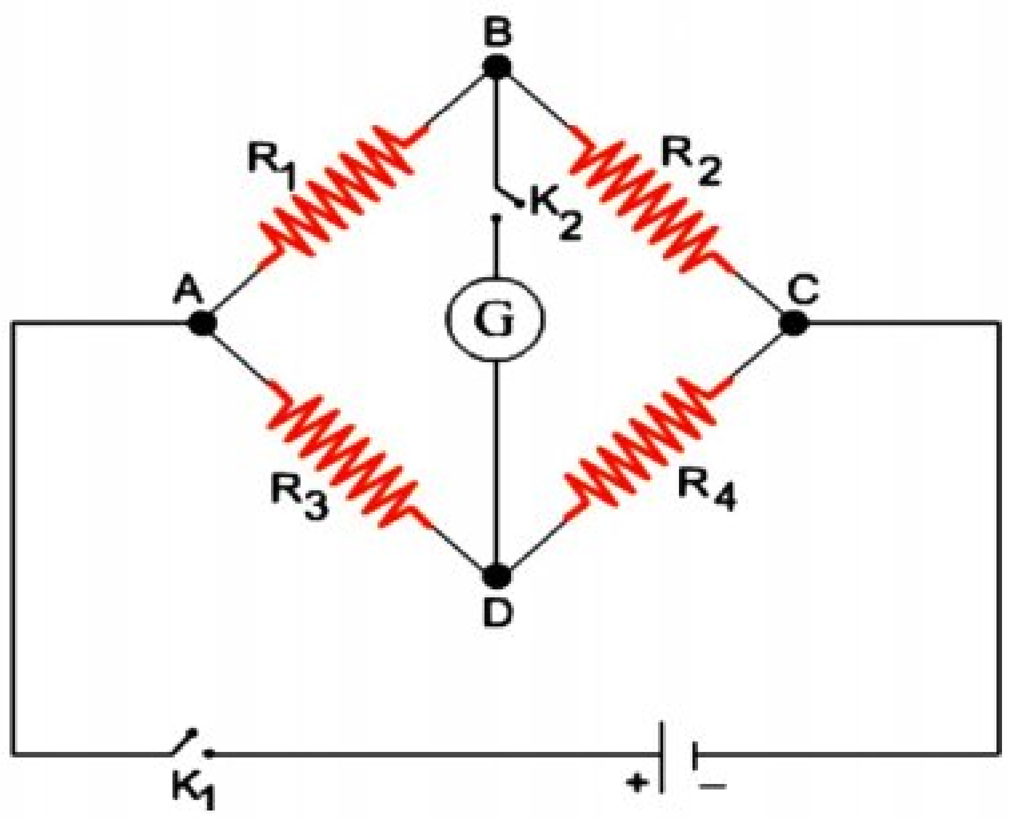
$$R_x = \frac{V}{I_g} - \frac{I_g R_g}{I_g}$$

$$R_x = \frac{V}{I_g} - R_g$$

Voltmeter is always connected in parallel with the circuit.

Wheat Stone Bridge:

If four resistances R_1, R_2, R_3 and R_4 are connected end to end in order to form a closed mesh ABCDA and between one pair of opposite junctions. A and C cell is connected through a key K_1 while between the pair of opposite junctions B and D a sensitive galvanometer "G" is connected through another key K_2. The circuit so formed is called a "Wheatstone-bridge".



Working;

In the above bridge if the key is closed first, some current flows through the cell and the resistance R_1, R_2, R_3 and R_4. If the key K_2 is also closed the current will usually be found to flow through the galvanometer indicated by its deflection. However if the resistance R_1, R_2, R_3 and R_4. (or at least one of them) are adjusted, a condition can always be attached in which the galvanometer show no deflection at all i.e. no current passes through it. Then the potential difference between B & D must be zero i.e. B & D must be at the same potential. This implies that

R_1 & R_2 are connected in series. Reason: (only one path for the flow of current)
R_3 & R_4 are connected in series.
R_1 & R_3 are connected in parallel. Reason: (two paths for the flow of current)
R_2 & R_4 are connected in parallel.
Let current I_1 flows through R_1 & R_2 and I_2 through R_3 & R_4.
When bridge is balanced,
Electric potential of point 'B' = Electric potential of point 'D'
Therefore,

$$V_{AB} = V_{AD}$$

Since according to Ohm's law, V = IR

$$I_1 R_1 = I_2 R_3 ----(1)$$

Similarly,

$$V_{BC} = V_{CD}$$

$$I_1 R_2 = I_2 R_4 ----(2)$$

Dividing equation (1) by equation (2), we get

$$\frac{I_1 R_1}{I_1 R_2} = \frac{I_2 R_3}{I_2 R_4}$$

$$\frac{\boldsymbol{R_1}}{\boldsymbol{R_2}} = \frac{\boldsymbol{R_3}}{\boldsymbol{R_4}}$$

Under balanced condition if any three resistances are known then the fourth can be found easily (i.e. whetstone principle).