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15.1 GALVANOMETER:

Galvanometer is a basic electromechanical instrument used to detect and measure small amount of current. Galvanometer was first devised by Lord Kelvin and modified for laboratory use by D' Arsonval which is divided in to categories:

(i) Moving coil galvanometer.

(ii) Moving magnet galvanometer.

Edward Weston further modified D' Arsonal's galvanometer, now called as Weston galvanometer.

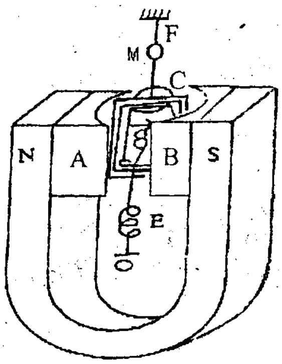
PRINCIPLE:

Galvanometer is based on the interaction between a current and a magnet when a current flows in a rectangular coil placed in a magnetic field, it experiences a magnetic torque and rotates. In this way on electrical energy is converted into mechanical energy.

CONSTRUCTION:

A moving coil galvanometer consists of a coil suspended between the poles of a U-shaped magnet by means of a fine metallic wire (F) which carries a plane mirror (M) The coil consists of a large number of turns of insulated copper wire wound over a rectangular frame of some nonmagnetic material (C) The pole pieces of the magnet are made concave and stronger in the vicinity of the coil. The suspension wire is also used as the first current-lead to the coil (A) (B) The other terminal of the coil is connected to a loose spiral which serves as the second current-lead (E).

WORKING:



When a current "I" is passed through the coil, the coil is acted upon by a couple, called deflecting couple, which tends to rotate the coil. The torque of deflecting couple, i.e. the deflecting torque is given by:

Deflecting torque = BIAN Cosα

The coil, while turning will twist the suspension wire. As a reaction, an opposing torque is developed called the restoring torque, whose magnitude is proportional to the twist in the suspension or the angle of deflection (θ), mathematically……

$$\text{Restoring torque} \propto \theta$$

$$\text{Restoring torque} = C\theta$$

Where "C" is a constant for suspension and is called as the ***couple per unit twist*** of the suspension. At the equilibrium condition, the two torques will balance each other:

$$\text{Deflecting torque} = \text{Restoring torque}$$

$$BIAN \cos\alpha = C\theta$$

$$I = \left(\frac{C}{BAN \cos\alpha}\right)\theta$$

As the coil placed is a radial magnetic, therefore, $\alpha = 0°$ and $\cos\alpha = 1$.

$$\therefore \quad I = \left(\frac{C}{BAN}\right)\theta$$

but the factor $\frac{C}{BAN}$ = constant.

$$\therefore \quad I = \text{Constant} \times \theta$$

OR $I \propto \theta$

It shows that the current passing through a galvanometer is proportional to he deflection of the coil.

SENTIVITY OF GALVANOMETER:

A galvanometer is said to be more sensitive if it gives a large deflection with the same value of current. Sensitivity of a galvanometer is defined as ***the deflection produced per unit micro ampere current.***

$$\text{Sensitivity} = \frac{\text{Deflection}}{\text{Micro ampere current}}$$

$$\text{Sensitivity} = \frac{\theta}{I} \text{ ——— (1)}$$

Also $\frac{1}{C/BAN} = \frac{\theta}{I}$ —— (2)

By comparing eq (1) and (2), we get, sensitivity $= \frac{1}{C/BAN}$

Therefore the reciprocal of factor $\frac{C}{BAN}$ refers to the sensitivity of a galvanometer. In order to make the galvanometer more sensitive, this factor should be made smaller.

15.2 AMMETER:

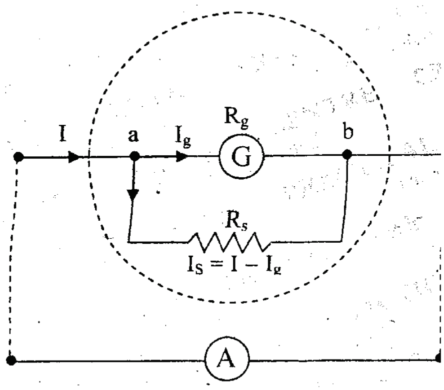
An electrical instrument which is used to measure current passing through a circuit is called ammeter.

PRINCIPLE AND CONSTRUCTION:

Its principle and construction is similar to the moving coil galvanometer.

CONVERSION OF GALVANOMETER INTO AMMETER:

To current a galvanometer into an ammeter a very small resistance is connected in parallel with the galvanometer. This resistance is also called shunt resistance (R_S).



CALCULATION OF Rs:

Suppose we have a galvanometer that gives full scale deflection when a current I_g passed through it. Let the resistance of this galvanometer be R_g. By using ohm's law, the voltage across the galvanometer will be "V_g" when current "I_g" is passed and is given by.

$$V_g = I_g R_g$$

When we connect the shunt resistor, the current "I" distributes at the terminal "a" into I_g and I_s, such that:

$$I = I_g + I_s$$

$$I_s = I - I_g$$

Where I_s is the current passing through the shunt. The potential difference across the shunt, i.e. V_s is giving by:

$$V_s = I_s R_s$$

Since the galvanometer and the shunt are in parallel, therefore,

$$V_s = V_g$$

$$I_s R_s = I_g R_g$$

$$R_s = \frac{I_g R_g}{I_s}$$

OR $$\boxed{R_s = \frac{I_g R_g}{(I - I_g)}}$$

15.3 VOLTMETER:

An electrical instrument which is used to measure potential difference between two points is called Voltmeter.

PRINCIPLE AND CONSTRUCTION:

Its principle and construction is similar to the moving coil galvanometer.

CONVERSION OF GALVANOMETER INTO VOLTMETER:

To convert a galvanometer into a voltmeter, a high resistance is connected in series with the galvanometer.

CALCULATION OF Rx:

In order to convert the galvanometer into a voltmeter of range **"V"** volts, let us suppose "R_g" is the resistance of coil of galvanometer with which a multiplier of resistance "R_x" is connected in series, such that the total resistance of circuit is given by:

$$R = R_g + R_x$$

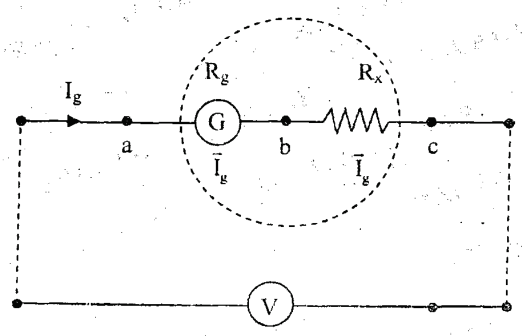
If the galvanometer gives a full scale deflection when a current "I_g" flows through it, then the potential difference V across the end's of voltmeter is:

$$V = I_g R$$

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

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

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



15.4 WHEATSTONE BRIDGE:

An electrical circuit which is used to determine unknown resistance is called "Wheatstone Bridge".

PRINCIPLE:

The condition for which the bridge is balanced and no current flows through the galvanometer is known as wheat stone principle i.e. $\frac{R_1}{R_2} = \frac{R_3}{R_4}$.

CONSTRUCTION:

A Wheatstone bridge consists of four resistances R_1, R_2, R_3 and R_4 joined together to form a bridge or mesh ABCDA. A battery of e.m.f 'E' is connected between the terminals A and C, with a key K_2 and a galvanometer G with key K_1 is connected between the points B and D.

WORKING:

If key K_1 and K_2 are open no current I_g flows through the galvanometer. We can, however arrange conditions under which no current flows through the galvanometer even keys K_1 and K_2 are closed. In this condition the bridge is said to be balanced.

Let us consider the path of the current through different resistors of bridge.

The current I starting from the positive terminal of the battery reaches the terminal A, where it finds two paths, one through resistor R_1 is I_1 and the one through R_3 is $(I_2=I-I_1)$ when the current I_1 reaches the terminal B, it also finds the two paths, the one through the galvanometer which is I_g and the other through the resistor R_2 is $(I_1 - I_g)$. when this current $(I_1 - I_g)$ reaches the terminal C, then it is joined by the current flowing through ADC. The current $(I_2 = I - I_1)$ passing through R_3 when reaches the points D, it is joined by I_g and hence the total current passing through R_4 is $(I - I_1+I_g)$. Thus the current at C is the sum of the currents through ABC and ADC, i.e.

$$I_1 - I_g + I - I_1 + I_g = I$$

When the bridge is balanced, then no current flows through the galvanometer (Ig = o). This means that the potential at B and D are same i.e. $V_{BA} = V_{DA}$, hence.

$$I_1 R_1 = I_2 R_3 \text{ ----------------------(1)}$$

Also the current through R_2 is I_1 and through R_4 is $(I_2 = I - I_1)$

$$I_1 R_2 = I_2 R_4 \text{ ----------------------(2)}$$

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

$$\frac{I_1R_1}{I_1R_2} = \frac{I_2R_3}{I_2R_4}$$

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

This is an important relation true only for a balanced position and is called the Wheatstone principle.

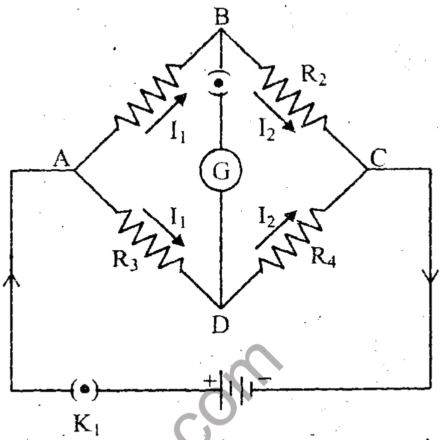
DETERMINE OF UNKNOWN RESISTANCE:

To determine the unknown resistance X, it is connected in the arm containing resistance R_4. The values of R_1, R_2 and R_3 are so adjusted that the bridge is balanced, hence

$$\frac{R_1}{R_2} = \frac{R_3}{X}$$

OR $$X = \frac{R_3}{R_1} \times R_2$$

By knowing the values of R_1, R_2 and R_3 the value of X can be calculated.



15.5 DAMPING:

If the current flowing through a galvanometer is stopped or a current is established suddenly in a galvanometer, the coil comes to rest after vibrating several times. This vibration is not desirable. ***The reduction of amplitude of vibration of the coil before coming to rest is called damping.*** Many artificial methods are used to increase damping and to bring the pointer quickly to its final position, e.g. by electromagnetic induction, external damping resistor, etc.

15.6 METER BRIDGE:

Meter bridge is a practical form of the Wheatstone bridge and is used to determine the value of the unknown resistance.

PRINCIPLE:

It works on the principle of Wheatstone bridge under this condition $\frac{R_1}{R_2} = \frac{R_3}{R_4}$

CONSTRUCTION:

It consists of a thin uniform metallic wire AC of one meter long. It is stretched and fixed to two thick copper strips at A and C and is placed along a meter scale over a wooden board. A jockey J is connected to the terminal D through a galvanometer G. A resistance between A and D, which is a known resistance R can be introduced in the gap AD. The resistance X to be measured is connected between the gap C and D. A cell is connected across A and C through a key K.

To find the value of unknown resistance, the key is closed and a suitable resistance R is taken out of the resistance box. The jockey is moved along the wire till for a certain position at which the galvanometer shows zero deflection called null point and the bridge is in balanced position. Let this point is B, now the position A,B C and D corresponds to the same points as on a Wheatstone bridge. As the slide wire is of uniform density, therefore, from

$$R = \frac{\ell L}{A}$$

Where A is the area of wire and L is, the resistivity of wire remains constant and thus:

$$R \propto L$$

Therefore, let the lengths AB = L_1 and BC = L_2 which corresponds to resistances P and Q respectively. Applying the principle of wheatstone bridge we get.

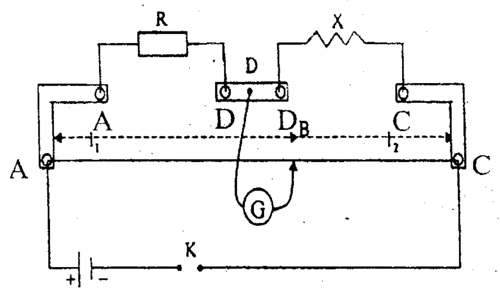
$$\frac{P}{Q} = \frac{R}{X}$$

OR

$$\frac{L_1}{L_2} = \frac{R}{X}$$

OR

$$\boxed{X = R\frac{L_2}{L_1}}$$



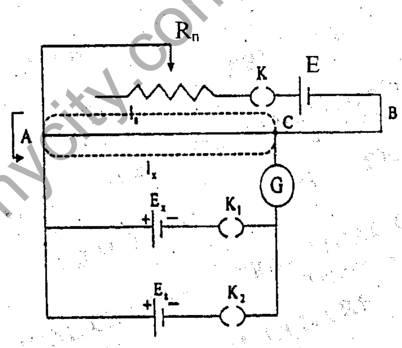
15.7 POTENTIOMETER:

Potentiometer is a simple instrument which can measure and compare potentials of batteries or cells without drawing any current from the circuit.

PRINCIPLE:

The potential difference across any length of a wire of uniform area of cross section is directly proportional to its length when a constant current flows through it.

V α L (at constant current)



CONSTRUCTION:

It consists of a long wire AB of about ten meters long fixed on a wooden board in the form of ten parallel wires, each of one meter long. An electric circuit comprising of a battery of e.m.f E and Galvanometer G, a rheostat R_h a key K are connected between the ends A and B.

WORKING:

When the key K is closed, a constant current flow through the wire AB. This circuit is known as the auxiliary current of the potentiometer. A running point C can be considered on the wire such that the length of the wire AC= L_x and its resistance is r_x. The potential difference between A and C is $V_{AC} = Ir_x$. As C is the running point, therefore, the resistance r_A and V_{AC} change continuously from zero to maximum. The point C thus divides the potential difference V_{AB} into V_{AC} and V_{CB}, therefore, the circuit is called potential divider, which can be used to measure unknown e.m.f. or some other potential difference, or the e.m.f's of two cells. The circuit when used in this way, is called a potentiometer.

The positive terminals of a cell of unknown e.m.f E_x and a standard cell of e.m.f E_s are connected to the terminal A to which the positive terminal of the current driving from the battery of e.m.f. E is connected. The negative terminals of both cells are joined to the jockey through Keys K_1 and K_2 and galvanometer.

Using the key K_1 first, only cell E_x is introduced into the galvanometer circuit and the balancing length Lx for which could be found by obtaining null point at C. As the wire is of uniform density therefore, from:

$$R = \frac{\ell L}{A}$$

As the factor ℓ/A remains constant, therefore

$$R_x = L_x$$

$$E_x = IL_x = \text{----------------------} \textbf{(1)}$$

Now introducing cell E_s in the galvanometer circuit by closing K_2 and the balancing length L_s for which could be found by obtaining null point at C

$$R_s = L_s$$

And $E_s = Ir_s$ ---------------------- **(2)**

Dividing (1) by (2), we get

$$\frac{E_x}{E_s} = \frac{IL_x}{IL_s}$$

$$\boxed{\frac{E_x}{E_s} = \frac{L_x}{L_s}}$$

This equation gives the ratio of the two e.m.f's in terms of the ratio of their balancing lengths. If E_s is known, E_x can easily be computed.

15.8 OHMMETER:

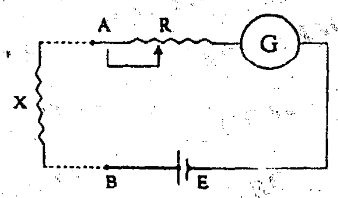
The ohmmeter is a useful device for quick measurement of resistance.

CONSTRUCTION:

A sensitive galvanometer G, adjustable resistor R and a cell of e.m.f E when connected in series forms an ohm meter.

WORKING:

The unknown resistance X to be measured is connected between the terminals A and B as shown in the fig.



The resistance R from the resistance box is so chosen that when the terminal A and B are short circuited (i.e. X=0) the galvanometer gives full scale deflection and when no connection is made between A and B (i.e. X = ∝) the galvanometer shows no deflection called the Null point. For the values of X between 0 and ∝, the deflection is small or large depending on the value of X.

Using different combinations of R in series and different shunts worked by a range is switches. The ohmmeter can be adopted for different accuracies.

15.9 AVOMETER:

An AVO meter is an apparatus which is used to measure current, voltage and resistance. In other words it is an ammeter, voltmeter and ohmmeter.

It consists of galvanometer with different scales graduated in such a way that all the three quantities can be measured to a fair degree of accuracy. A selector switch, by which the quantities to be measured and proper range can be selected, connects the particular electrical circuit to the galvanometer which is suitable for each type of measurement. It has its own battery for its function for operating the electrical circuits so that it is able to measure the quantities. The constant factor is controlled by the range switch. Thus the deflection is proportional to the input current which can be measured from the scale calibrated for this purpose.

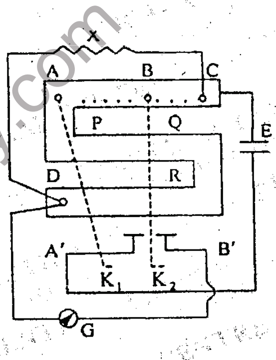
15.10 POST OFFICE BOX:

Post office box is a practical form of Wheatstone bridge. It measure resistance with sufficient accuracy. This was originally designed to measure resistance of telegraph wire, is it was named post office box.

PRINCIPLE:

It works on the principle of Wheatstone bridge under this condition $\frac{R_1}{R_2} = \frac{R_3}{R_4}$

CONSTRUCTION:



It is shown in a simplest form. The arms AB and BC contain resistances P and Q respectively. The arms are called ratio arms. Each of these arms contain resistances of 10Ω, 100Ω and 1000Ω. The third arm AD corresponds to the third resistor R. In this arm, the resistance are arranged in such a way that a resistance of 1Ω or 10,000Ω can be introduced in steps. The unknown resistance X is connected between the terminals C and D. This forms the fourth arm of the Wheatstone bridge. By applying the Wheatstone bridge principle:

$$\frac{X}{R} = \frac{Q}{P} \qquad X = R\frac{Q}{P}$$

The value of X can be found upto the hundredth part of an ohm.

15.11 QUESTIONS FROM PAST PAPERS:

Galvanometer:

Q.1 Give the construction and working of moving coil galvanometer. Show that the current "I" is directly proportional to the angle of twist. On what factors does the sensitivity of galvanometer depends? **(2013, 2011, 2009, 2006,2002 P.E)**

Ammeter and Voltmeter:

Q.2 Describe the conversion of a galvanometer into a voltmeter. **(2007,2011)**

Q.3 With the help of a diagram describe how a galvanometer is converted into an ammeter. Derive the equation for the shunt resistance. **(2005,2004,2003 P.E 2003 P.M)**

Wheatstone Bridge:

Q.4 Describe Wheatstone Bridge. Prove that for a balanced Wheatstone Bridge $\frac{R_1}{R_2} = \frac{R_3}{R_4}$ **(2012,2010,2008,2006,2003 P.E, 2002 P.M)**