Unit-III

Potentiometers:

Potentiometer: An instrument used to measure unknown emf by comparing it with a standard known emf

- Accuracy is high

Two types:

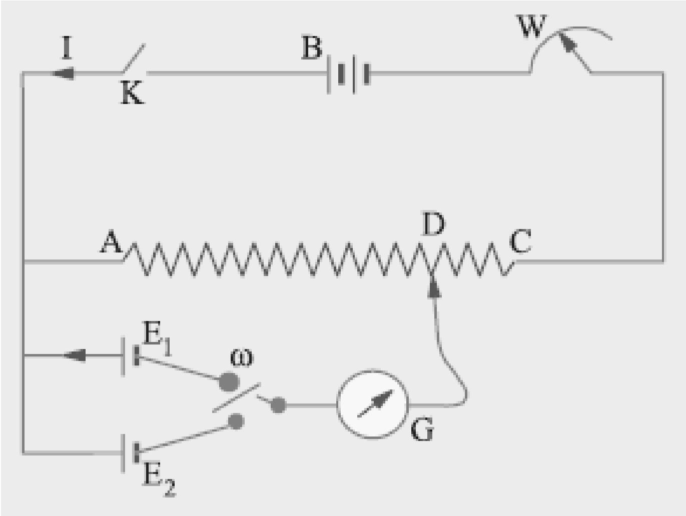
- DC potentiometer
- AC potentiometer

Uses:

- Measurement of small e.m.f up to 2 V
- Comparison of e.m.f. of 2 cells
- Measurement of resistance
- Measurement of current Calibration of ammeter
- Calibration of voltmeter

D.C. Potentiometer

A potentiometer is used for measuring and comparing the e.m.f.s. of different cells and for calibrating and standardizing voltmeters, ammeters etc. In its simplest from, it consists of a German silver or manganin wire usually one meter long and stretched between two terminals as shown in Fig.



This wire is connected in series with a suitable rheostat and battery *B* which sends a steady current through the resistance wire *AC.* As the wire is of uniform cross-section throughout, the fall in potential across it is uniform and the drop between any two points is proportional to the distance between them. As seen, the battery voltage is spread over the rheostat and the resistance wire *AC.* As we go along *AC*, there is a progressive fall of potential. If ρ is the resistance/cm of this wire, *L* its length, then for a current of *I* amperes, the fall of potential over the whole length of the wire is ρ *LI* volts.

The two cells whose e.m.f.s are to be compared are joined as shown in above Figure always remembering that positive terminals of the cells and the battery must be joined together. The cells can be joined with the galvanometer in turn through a two-way key. The other end of the galvanometer is connected to a movable contact on AC. By this movable contact, a point like D is found when there is no current in and hence no deflection of G. Then, it means that the e.m.f. of the cell just balances the potential fall on AD due to the battery current passing through it.

Suppose that the balance or null point for first cell of e.m.f. E1 occurs at a length L1 as measured from point A. The E1 = ρ L_1I.

Similarly, if the balance point is at L2 for th other cell, then E2 = ρ L_2I.

Dividing one equation by the other, we have

$$\frac{E_1}{E_2} = \frac{\rho L_1 I}{\rho L_2 I} = \frac{L_1}{L_2}$$

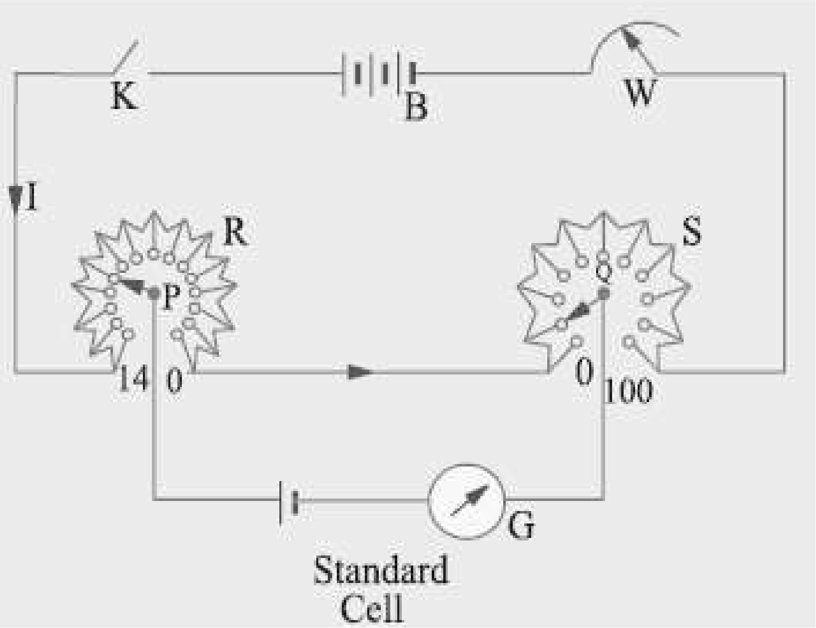
If one of the cells is a standard cell, the e.m.f. of the other cell can be found

Applications of DC Potentiometer:

- Calibration of Ammeter
- Calibration of voltmeter
- Measurement of Power
- Measurement of Resistance
- Calibration of Wattmeter

Direct-reading Potentiometer:

The simple potentiometer described above is used for educational purposes only. But in it commercial form, it is so calibrated that the readings of the potentiometer give the voltage directly, thereby eliminating tedious arithmetical calculations and so saving appreciable time. Such a direct-reading potentiometer is shown in Figure. The resistance *R* consists of 14 equal resistances joined in series, the resistance of each unit being equal to that of the whole slide were *S* (which is divided into 100 equal parts). The battery current is controlled by slide wire resistance *W*.



Standardizing the Potentiometer:

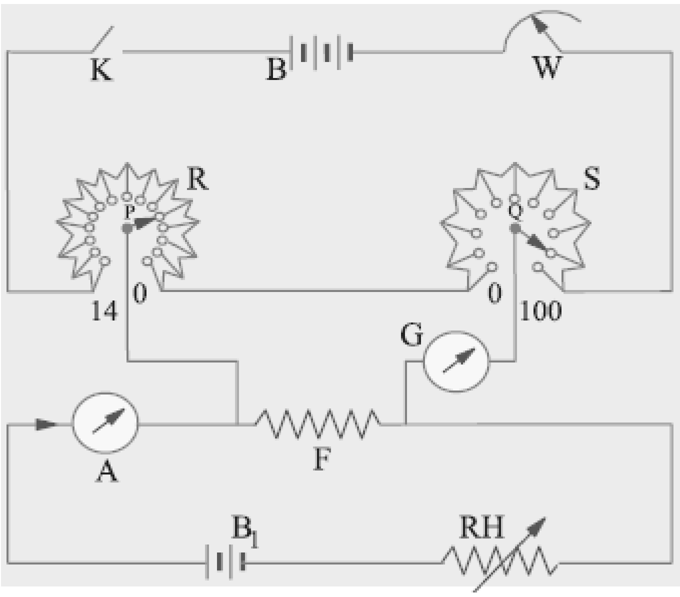
A standard cell i.e. Weston cadmium cell of e.m.f. 1.0183 V is connected to sliding contacts P and Q through a sensitive galvanometer G. First, P is put on stud No. 10 and Q on 18.3 division on S and then W is adjusted for zero deflection on G. In that case, potential difference between P and Q is equal to cell voltage i.e. 1.0183 V so that potential drop on each resistance of R is 1/10 = 0.1 V and every division of S represents 0.1/100 = 0.001 V. After standardizing this way, the position of W is not to be changed in any case otherwise the whole adjustment would go wrong. After this, the instrument becomes direct reading. Suppose in a subsequent experiment, for balance, P is moved to stud No. 7 and Q to 84 division, then voltage would be

$= (7 \times 0.1) + (84 \times 0.001) = 0.784$ V.

It should be noted that since most potentiometers have fourteen steps on *R*, it is usually not possible to measure p.ds. exceeding 1.5 V. For measuring higher voltages, it is necessary to use a volt box

Calibration of Ammeters:

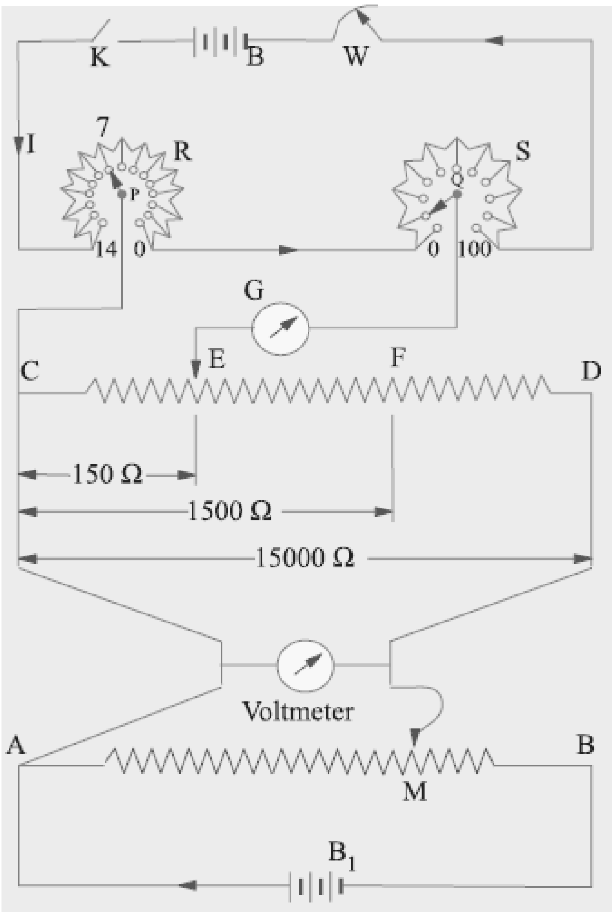
The ammeter to be calibrated is connected in series with a variable resistance and a standard resistance F, say, of 0.1 Ω across battery B1 of ample current capacity as shown in Figure shown below. Obviously, the resistance of F should be such that with maximum current flowing through the ammeter A, the potential drop across F should not exceed 1.5 V. Some convenient current, say



6 amperes (as indicated by A) is passed through the circuit by adjusting the rheostat RH. The potential drop across F is applied between P and Q as shown. Next the sliding contacts P and Q are adjusted for zero deflection on G. Suppose P reads 5 and Q reads 86.7. Then it means that p.d. across F is 0.5867 V and since F is of 0.1 Ω, hence true value of current through F is 0.5867/0.1 = 5.867 amperes. Hence, the ammeter reads high by (6 − 5.867) = 0.133 A. The test is repeated for various values of current over the entire ranges of the ammeter.

Calibration of Voltmeters:

As Stated above, a voltage higher than 1.5 cannot be measured by the potentiometer directly, the limit being set by the standard cell and the type of the potentiometer (since it has only 14 resistances on *R* as in Figure (direct potentiometer)).However, with the help of a volt-box which is nothing else but a voltage reducer, measurements of voltage up to 150 V or 300 V can be made, the upper limit of voltage depending on the design of the volt-box. The diagram of connections for calibration of voltmeters is shown in Fig. 10.81. By calibration is meant the determination of the extent of error in the reading of the voltmeter throughout its range. A high value resistor *AB* is connected across the supply terminals of high voltage battery *B*1 so that it acts as a voltage divider. The volt box consists of a high resistance *CD* with tapings at accurately determined points like *E* and *F* etc. The resistance *CD* is usually 15,000 to 300 Ω. The two tappings *E* and *F* are such that the resistances of portions *CE* and *CF* are 1/100th and 1/10th the resistance *CD*. Obviously, whatever the potential drop across *CD*, the corresponding potential drop across *CE* is 1/100th and that across *CF*, 1/10th of that across *CD*. If supply voltage is 150 V, then p.d. across *AB* is also 150 V and if *M* coincides with *B*, then p.d. across *CD* is also 150 V, so across *CF* is 15 volts and across *CE* is 1.5 V. Then p.d. across *CE* can be balanced over the potentiometer as shown in Fig. 10.81. Various voltages can be applied across the voltmeter by moving the contact point *M* on the resistance *AB*.



Suppose that M is so placed by voltmeter V reads 70 V and p.d. across CE is balanced by adjusting P and Q. If the readings on P and Q to give balance are 7 and 8.4 respectively, then p.d. across CE is 0.7084 V. Hence, the true p.d. across AM or CD or voltmeter is

$0.7048 \times 100 = 70.84$ V (because resistance of CD is 100 times greater than that of CE)

In other words, the reading of the voltmeter is low by 0.84 V. By shifting the position of M and then balancing the p.d. across CE on the potentiometer, the voltmeter can be calibrated throughout its range. By plotting the errors on a graph, a calibration curve of the instrument can also be drawn.

A.C. Potentiometer:

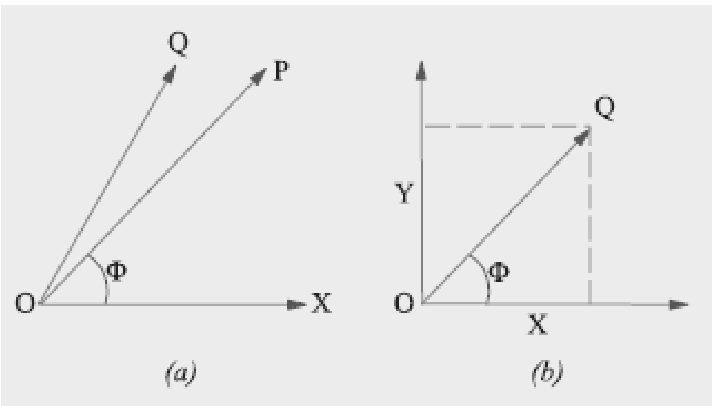
An A.C. potentiometer basically works on the same principle as a D.C. potentiometer. However there is one very important difference between the two. In D.C. potentiometer, only the magnitudes of the unknown e.m.f. and slide-wire voltage drop are made equal for obtaining balance. But in an a.c. potentiometer, not only the magnitudes but phases as well have to be equal for obtaining balance. Moreover, to avoid frequency and waveform errors, the a.c. supply for slide-wire must be taken from same source as the voltage or current to be measured. A.C. potentiometers are of two general types differing in the manner in which the value of the unknown voltage is presented by the instrument dials or scales.

The two types are:

(*i*) Polar potentiometers in which the unknown voltage is measured in polar form *i.e.* in terms of magnitude and relative phase.

(*ii*) Co-ordinate potentiometers which measure the rectangular co-ordinates of the voltage under Test.

The two products are illustrated in Fig. 10.82. In Fig. 10.82 (*a*), vector *OQ* denotes the test voltage whose magnitude and phase are to be imitated. In polar potentiometer, the length *r* of the vector *OP* can be varied with the help of a sliding contact on the slide wire while its phase φ is varied independently with the help of a phase-shifter. Drysdale potentiometer is of this type.



In co-ordinate type potentiometers, the unknown voltage vector *OQ* is copied by the adjustment of 'in phase' and 'quadrature' components *X* and *Y*. Their values are read from two scales of the potentiometer. The magnitude of the required vector is = *X* 2 + *Y* 2 and its phase is given

$$\text{By } \varphi = \tan^{-1} (X/Y).$$

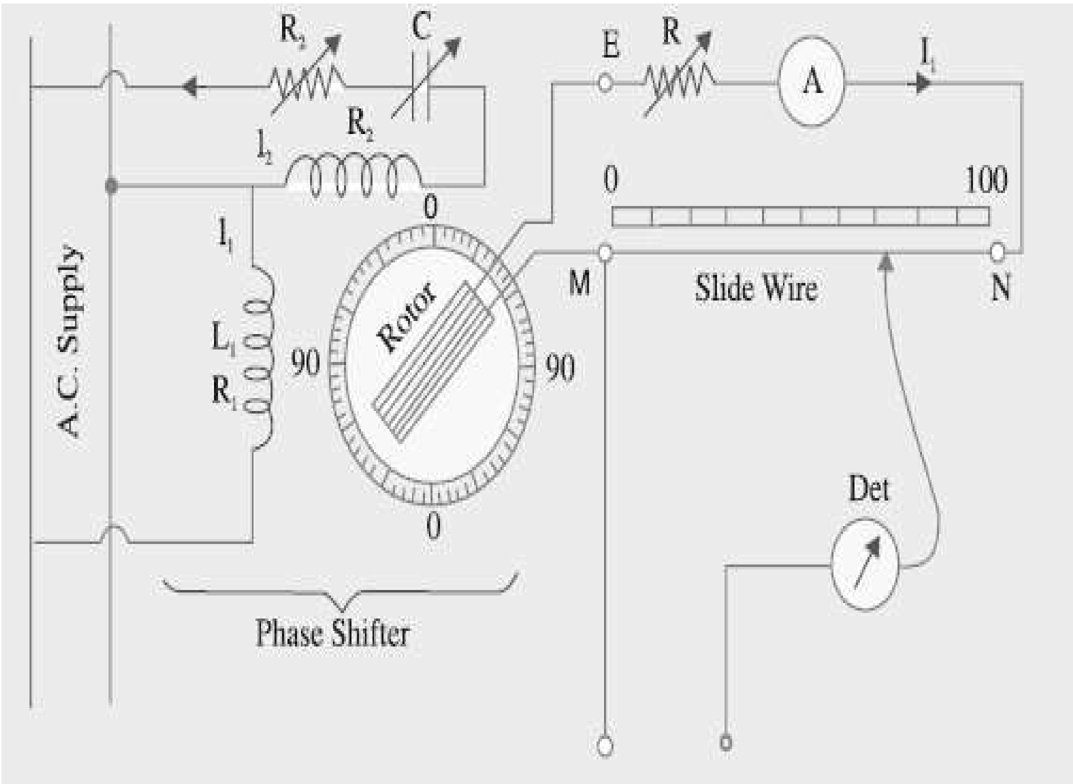
Examples of this type are

(i) Gall potentiometer and

(ii) Campbell-Larsen potentiometer.

Drysdale Polar Potentiometer:

As shown in Figure shown below for a.c. measurements, the slide-wire *MN* is supplied from a phase shifting circuit so arranged that magnitude of the voltage supplied by it remains constant while its phase can be varied through 360°.Consequently, slide-wire current *I* can be maintained constant in magnitude but varied in phase. The phase-shifting circuit consists of



(i) Two stator coils supplied from the same source in parallel. Their currents *I*1 and *I*2 are made to differ by 90° by using well-known phase-splitting technique.

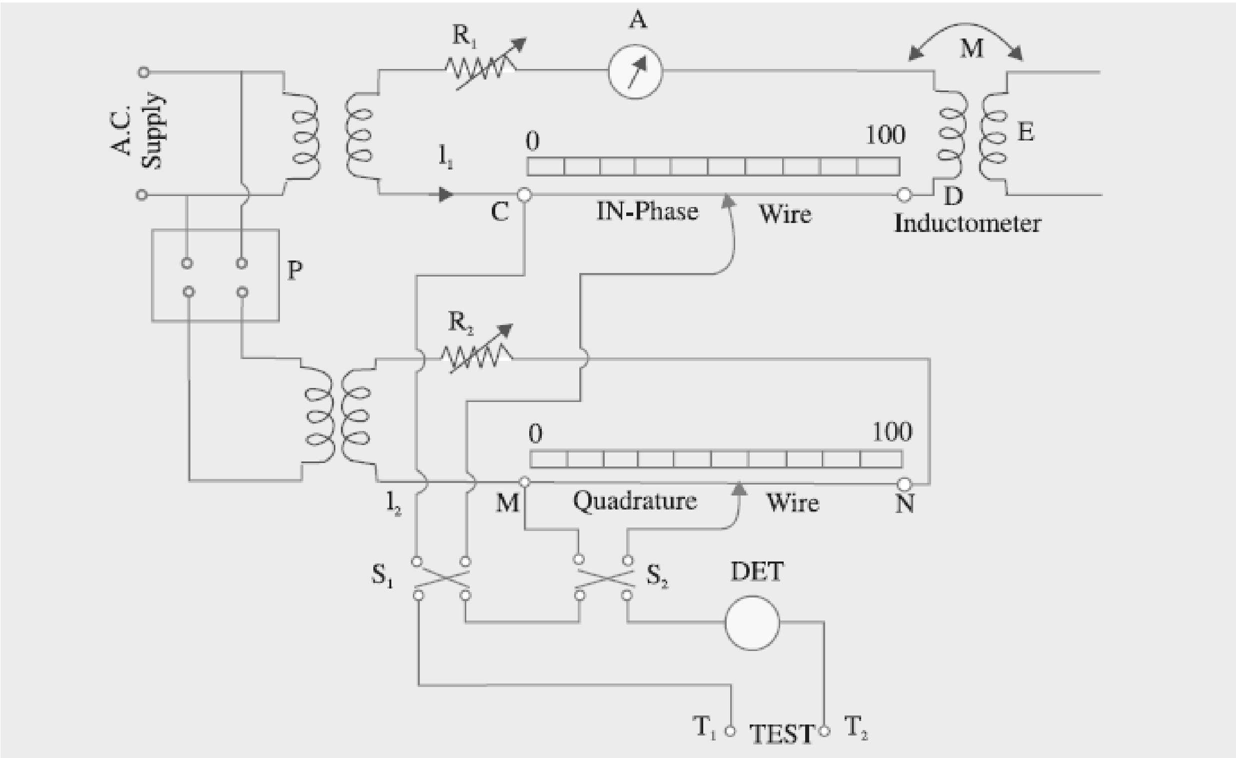
(ii) The two windings produce a rotating flux which induces a secondary e.m.f. in the rotor winding which is of constant magnitude but the phase of which can be varied by rotating the rotor in any position either manually or otherwise. The phase of the rotor e.m.f. is read from the circular graduated dial provided for the purpose.

The ammeter *A* in the slide-wire circuit is of electrodynamic of thermal type. Before using it for a.c. measurements, the potentiometer is first calibrated by using D.C. supply for slide wire and a standard cell for test terminals *T*1 and *T*2.

The unknown alternating voltage to be measured is applied across test terminals *I*2 and *T*2 balance is affected by the alternate adjustment of the slide-wire contact and the position of phase-shifting rotor. The slide-wire reading represents the magnitude of the test voltage phase-shifter reading gives its phase with reference to an arbitrary reference vector.

Gall Co-ordinate Potentiometer:

This potentiometer uses two slide-wires *CD* and *MN* with their currents *I*1 and *I*2 (Figure below) having a mutual phase difference of 90°. The two currents are obtained from the single phase supply through isolating transformers, the circuit for 'quadrature' slide wire *MN* incorporating a phase shifting arrangement.



Before use, then current I_1 is first standardized as described for Drysdale potentiometer. Next, current I_2 is standardized with the help of the mutually induced e.m.f. E in inductometer secondary. This e.m.f. $E = \omega MI_1$ and is in quadrature phase with I_1. Now, E is balanced against the voltage drop on slide-wire MN. This balance will be obtained only when I_2 is of correct magnitude and is in exact quadrature with I_1. Balance is achieved with the help of the phase-shifter and rheostat R_2. The unknown voltage is applied across the test terminals T_1 and T_2. Slide-wire MN measures that component of the unknown voltage which is in phase with I_2. Similarly, slide-wire CD measures that component of the unknown voltage which is in phase with I_1. Since I_1 and I_2 are in quadrature, the two measured values are quadrature components of the unknown voltage. If V_1 and V_2 are these values, then

$$V = \sqrt{V_1^2 + V_2^2}$$

and $\varphi = \tan^{-1}(V_2/V_1)$ —with respect to I_1

Reversing switches S_1 and S_2 are used for measuring both positive and negative in-phase and quadrature components of the unknown-voltage.

Applications of AC Potentiometer:

- Calibration of voltmeter
- Calibration of Ammeter
- Calibration of Watt meter
- Measurement of self inductance

Advantages of AC Potentiometer:

- Very versatile instrument. By using shunts and volt- ratio boxes its use may be extended to cover current, voltage and resistance measurements over a wide range of values
- The fact that phase, as well as magnitude, is measured leads to such applications as measurement of power, inductance and phase angle of the coil etc.
- Used in special measurement circuits

Disadvantages of AC Potentiometer:

- A very small difference in reading of reflecting dynamometer instrument either in DC or AC calibration introduces error in the AC current to be set at standard value

- The mutual inductance between various parts of the instruments affects the normal value of mutual inductance. Due to this, a slight difference is introduced on the magnitude of the current of quadrature wire compared to that in the in phase POT wire.

  The inter capacitance and mutual inductance affect the potential gradient of the wires
- The inaccuracy in the measured value of frequency will also result in the quadrature POT wire current to differ from that of in-phase POT wire.
- Because the standardization is done on the basis of RMS value and balance is obtained depending upon the fundamental only, the presence of harmonics in the waveform introduces operating troubles and the vibration galvanometer tuned to the fundamental may not show full null position at all.