Potentiometer

Objectives

After going through this module the learner will be able to:

- Interpreting a potential drop per unit length exists in a wire when a potential difference is applied across it.
- Know the design of a potentiometer
- Compare emf of two primary cells, determine the emf of a cell and determine the internal resistance of a cell using a potentiometer

Content Outline

- Unit Syllabus
- Module wise break up of unit syllabus
- Words you must know
- Introduction
- Potentiometer
- Applications of potentiometer
- Sensitivity of potentiometer
- Solved examples
- Problems for practice
- Summary

Unit Syllabus

Electric current, flow of electric charges in a metallic conductor, drift velocity and mobility and their relation with electric current; Ohm's law, electrical resistance, V-I characteristics (linear and nonlinear), electrical energy and power, electrical resistivity and conductivity.

Carbon resistors, colour code for carbon resistors, series & parallel combinations of resistors and temperature dependence of resistance.

Internal resistance of a cell, Potential difference and emf of a cell, combination of cells in series and in parallel

Kirchhoff's laws and simple applications; Wheatstone bridge and metre bridge

Potentiometer- principle and its application to measure potential difference and for comparing emf of two cells; measurement of internal resistance of a cell

Module Wise Distribution

The above unit has been divided into 8 modules for better understanding.

Module 1	• Electric current, • Solids liquids and gases • Need for charge carriers speed of charge carriers in a metallic conductor • Flow of electric charges in a metallic conductor • Drift velocity, • Mobility and their relation with electric current • Ohm's law
Module 2	• Electrical resistance, • V-I characteristics (linear and nonlinear), • Electrical energy and power, • Electrical resistivity and conductivity • Temperature dependence of resistance
Module 3	• Carbon resistors, • Colour code for carbon resistors; • Metallic Wire resistances • Series and parallel combinations of resistors • Grouping of resistances • Current and potential differences in series and parallel circuits
Module 4	• Internal resistance of a cell, • Potential difference and emf of a cell, • Combination of cells in series and in parallel. • Need for combination of cells
Module 5	• Kirchhoff's Rules • Simple applications of Kirchhoff's Rules for calculating current and voltages • Numerical
Module 6	• Wheatstone bridge • Balanced Wheatstone bridge condition derivation using Kirchhoff's Rules

	• Wheatstone bridge and Metre Bridge. • Application of meter bridge
Module 7	• Potentiometer • Principle • Applications to Measure potential difference • Comparing emf of two cells • Measurement of internal resistance of a cell. • Numerical
Module 8	• Numerical • Electrical energy and power

Module 7

Words You Must Know

- **Chemical cell:** An assembly of electrolyte and electrodes which convert chemical energy into electrical energy, for example simple voltaic cell, Daniel cell, Leclanche cell, dry cell.
- **Ohm's law:** The potential difference across a metallic wire is directly proportional to the current passing through it provided the temperature and physical conditions of the metallic wire remain the same. Metals that follow ohm's law over a large range of temperature variation are called ohmic resistances. Electrolytes, semiconductor materials are non ohmic, means do not obey ohm's law: V = IR
- **Resistance:** The obstruction offered by a conducting wire to current whenever a potential difference is applied across it.
- **Potential drop across resistance**: It is the potential difference between ends of a resistance. In Ohm's law V = IR where, V is potential drop across resistance (for details see role of resistance in module 1).
- **Electromotive Force** (EMF): It is the force which makes change to flow in an electrical circuit. It is defined as Work done in moving a unit positive charge once in a closed circuit.
- **EMF of a cell (ε)**: It is the max. Potential difference between electrodes of a cell when no current is being drawn from the cell.
- **TPD of a cell (V)**: It is the max. Potential difference between electrodes of a cell when current is being drawn.

- **Internal resistance of a cell (r)**: It is the resistance offered by electrolyte to current flowing.
- **Galvanometer**: It is the device which detects small currents. A galvanometer can indicate the direction of current and also indicate relative magnitude of current in a circuit or a branch of a circuit.
- **Jockey**: It is a metallic rod whose one end has a knife edge which slides over the wire and the other end is connected.

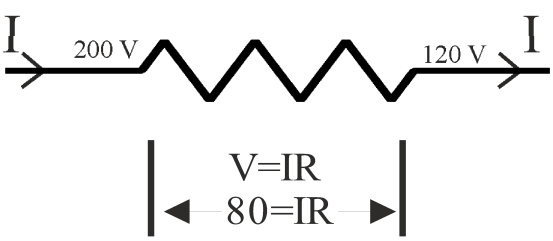
Introduction

In our previous module we have studied basic electrical circuits; the motivation for our study is to recognize series parallel connections of resistances and cells. The cells have internal resistance on account of the electrolyte and the chemicals .The application of basic knowledge to design useful circuits demands thorough and vast knowledge of each of the quantities. We are learning in steps the idea of distribution of currents, as we did using Kirchhoff's rules. We learnt a method of finding the value of an unknown resistance using a meter bridge. The principle of Meter Bridge is Wheatstone bridge and the condition for balanced Wheatstone bridge allows us the simple calculation of resistance of a wire.

In this module we will learn the principle and application of potentiometer.

Think about this, suppose we are given a cell and we wish to know its emf or internal resistance, how shall we measure it?

We need a potentiometer to find an emf or internal resistance of a given cell.We know that resistance is an obstruction in the path of flow of current.From ohms law **we can find the** electric resistance, if our problem is according to the See fig.



The incoming side has say a potential 200V and outgoing end has potential 120V.

- There is a potential drop of 80V. In Ohm's law (V = IR), V is the potential difference between two ends of resistance, hence 80 = IR.
- For this reason we always say "potential drop across resistance".

- A voltmeter connected across R will measure 80V

Electromotive Force (emf) (E)

It is the force which derives the charge in a closed path.

Sources of EMF are:- Cell ,generators ,Dynamos

Question: Why do we need a cell in a circuit?

Answer: Charge can move on its own from higher to lower potential but cannot go on its own from lower to higher potential. So, to run charge in a closed path, we need a source EMF- a cell.

- Don't get confused that emf is force.EMF is not a force but is work done in moving a unit positive charge once in a closed path.
- **EMF of a cell** is defined as the maximum potential difference between the terminals of the cell when no current is being drawn from the cell.

Terminal Potential Difference Of A Cell (TPD) 'V'

It is defined as the maximum potential difference between the terminals of a cell when current is being drawn from the cell.

The basic difference between emf and TPD of a cell is that in emf no current is being drawn from the cell but in TPD current is being drawn from the cell.

Internal Resistance Of A Cell: (r)

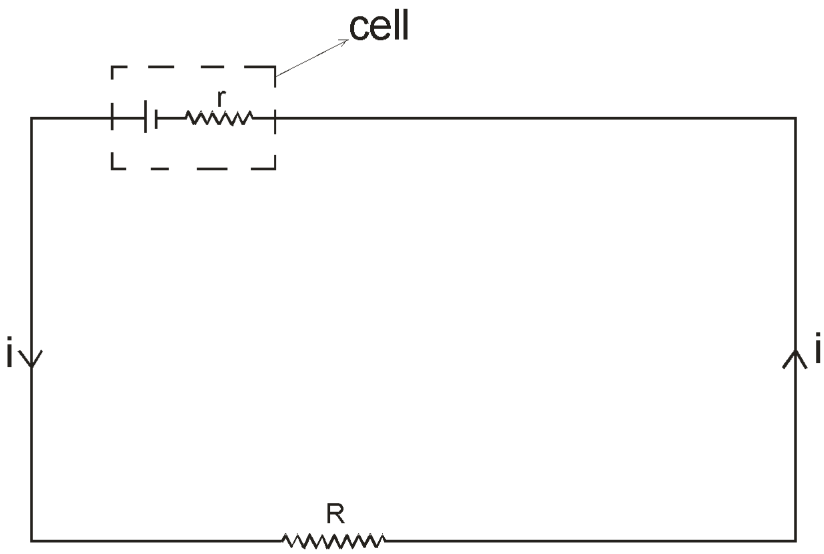
It is the resistance offered by the electrodes and electrolytes of the cell to the current flowing.

The value of internal resistance depends upon:-

- Nature of electrodes
- Nature of electrolyte
- Concentration of electrolyte
- Distance between electrodes ($d \propto r$)
- Area of electrodes emerged in the electrolyte

  Increase area emerged, decrease in internal resistance for this reason, we pour water in cars or inverter batteries.
- Temperature of electrolyte:- Inversely proportional

Relation Between EMF (E) And TPD (V)



V=IR

By applying Kirchhoff's Voltage rule

$$-IR - Ir + E = 0$$

$$-V - Ir + E = 0$$

$V = E - Ir$ . . . . for discharging of cell

$E > V$

The above equation is for discharging of cells. Note that in discharging of cell emf> TPD

Equation for charging of cell is given by:

$V = E + Ir$

$V > E$ . . . . for charging of cell

For charging of cell TPD > emf

Expression for internal resistance(r) of cell

From $V = E - Ir$

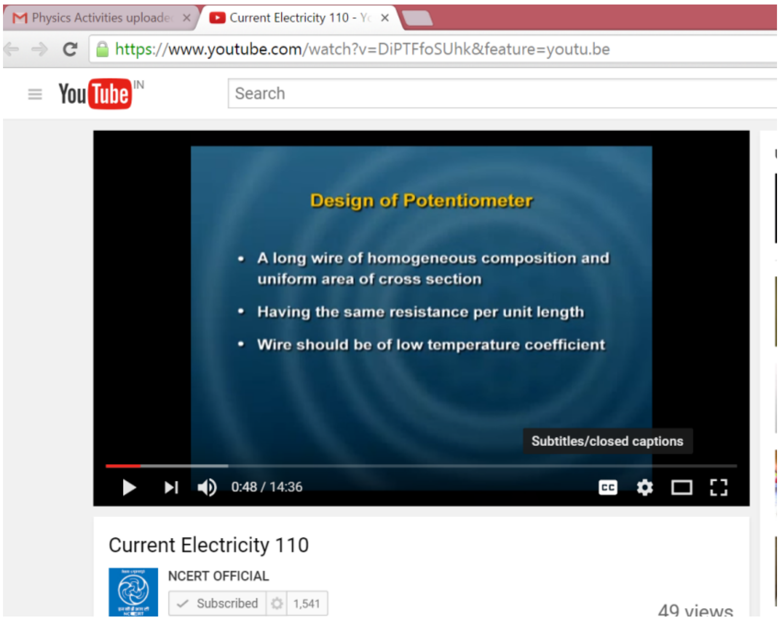
$$Ir = E - V$$

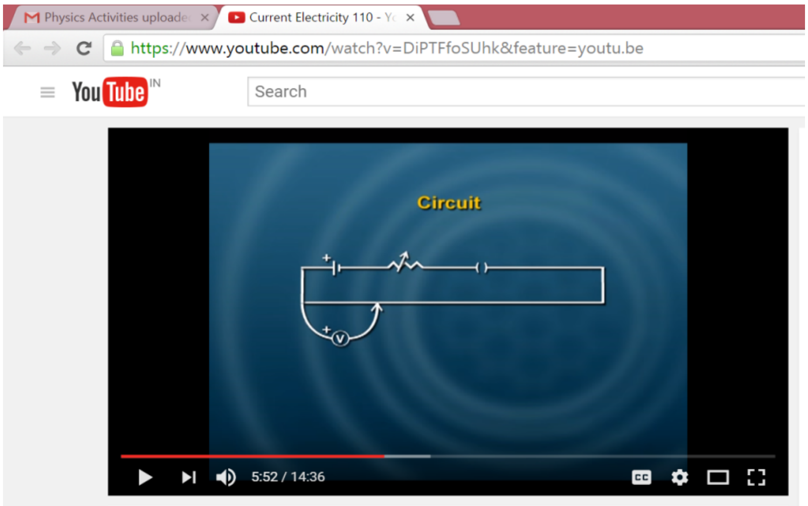
$$r = \left(\frac{E-V}{I}\right)R$$

Potentiometer

It is an electrical device used to accurately measure the emf of a cell or potential difference between two points on an electrical circuit.

Typical potentiomete





https://www.youtube.com/watch?v=DiPTFfoSUhk&feature=youtu.be

Simplified potentiometer

Working principle

Based on the fact that potential drop across a wire is directly proportional to length of that portion, area of cross-section and current through the wire remains constant.

We know $V = IR$

$R = \rho \frac{l}{A}$

$V = I\rho\frac{l}{A}$ $(\frac{I\rho}{A}$ is constant)

$V \propto l$

$V = k\, l$ **Where,** $k = \frac{I\rho}{A}$;

Potential drop per unit length

- $k = \frac{V}{l}$ **is called potential gradient. It is defined as potential drop per unit length of potentiometer wire. Its S.I. unit is volt per meter (Vm^{-1}).**
- **As, k gives potential drop of a unit length of wire. To find potential drop of any length of potentiometer wire, simply multiply that length with k.**
- **Your NCERT book has the potentiometer diagram as shown this is a schematic representation six wire potentiometer, as we said the length of the wire can be chosen for required need of potential drop per cm of potentiometer wire**

Example

Let potential drop per cm is say 0.02 Vcm^{-1}. Therefore k=0.02 Vcm^{-1}. If we wish to find potential drop of 30 cm length, then

$V = k\, l$

$V = 0.02 \times 30V = 0.02\frac{V}{cm} \times 30\, cm$

$V = 0.6V$

To explain the Principle of potentiometer

A current I flows through the wire which can be varied by a variable resistance (rheostat, R) in the circuit. Since the wire is uniform, the potential difference between A and any point at a distance l from A is $V = k\,(l)$ where k as we have said is the potential drop per unit length.

Applications Of Potentiometer

a) To find the emf of a cell.

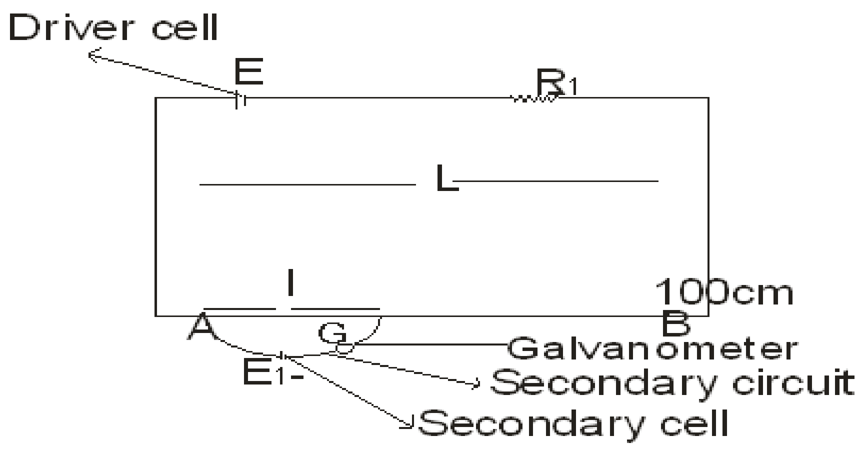
Apparatus required and Circuit connections

You will need:

- **A potentiometer**
- **A galvanometer**
- **A resistance box**

- **A driver cell to create a potential difference across the length of the wire which should be greater than the expected emf of the cell**
- **Connecting wire**

Circuit diagram:



AB is the potentiometer wire; connect the driver cell across it, using suitable resistance from the resistance box.Next connect the positive of the test cell to the terminal connected to the positive of the driver cell .Connect the other terminal of the test cell to the jockey.

- At the balance length l galvanometer shows no deflection means there is no current being drawn from secondary cell E_1. Therefore balance length corresponds to emf.

$$E_1 = kl$$

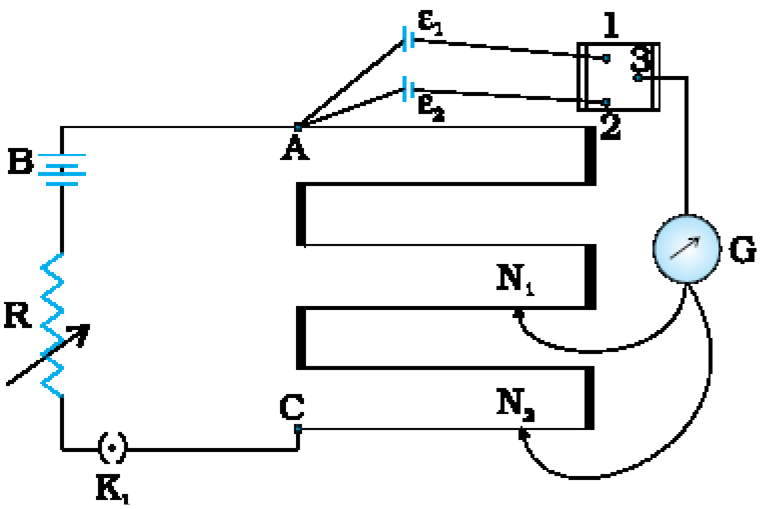
b) To compare emf of two cells

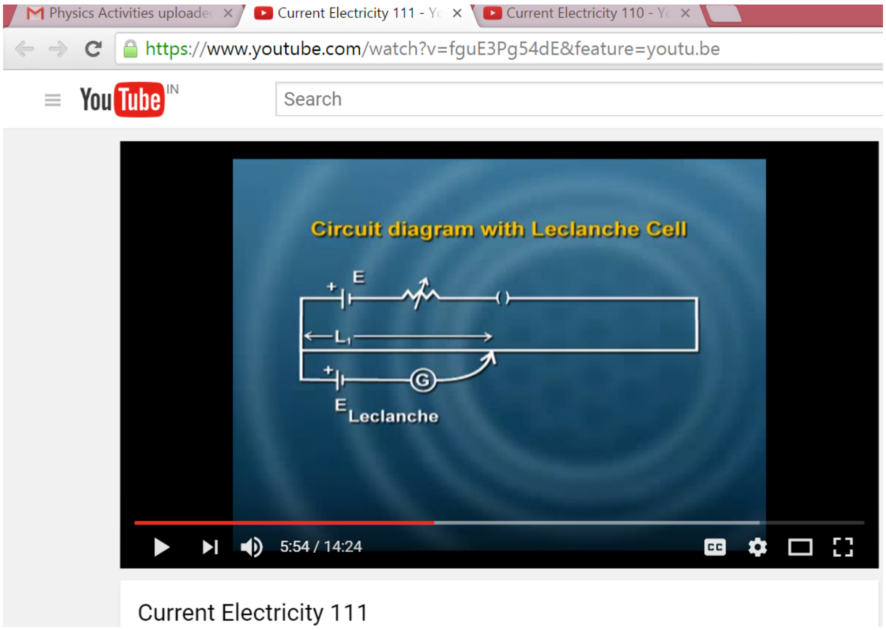
https://www.youtube.com/watch?v=fguE3Pg54dE&feature=youtu.be

Apparatus you will need

- **Potentiometer**
- **Driver cell E**
- **Galvanometer G**
- **The two test cells E_1, E_2**
- **keys and connecting wires**

Circuit connections





Schematic diagram can be given as:

- When key K_1 is closed and K_2 open, balancing length l_1 corresponds to emf E_1.

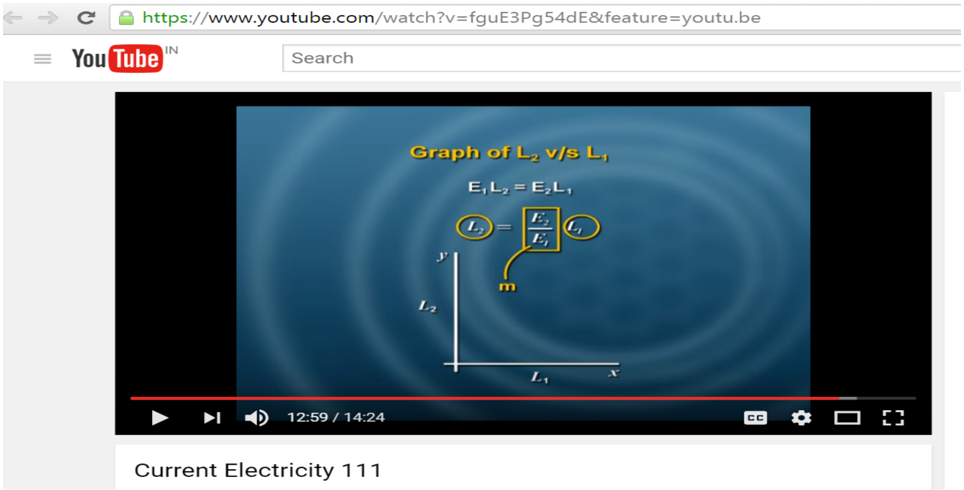
$$E_1 = k\, l_1$$

- When key K_2 is closed and K_1 open, balancing length l_2 corresponds to emf E_2.

$$E_2 = k\, l_2$$

$$\frac{E_1}{E_2} = \frac{l_1}{l_2}$$

Check out the graph between l_2 vs l_1



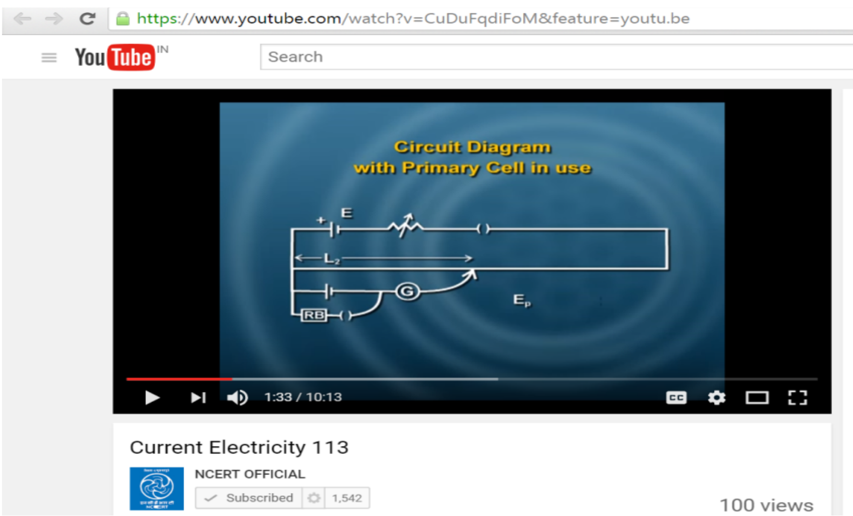
c) **To find internal resistance of a cell**

https://www.youtube.com/watch?v=CuDuFqdiFoM&feature=youtu.be

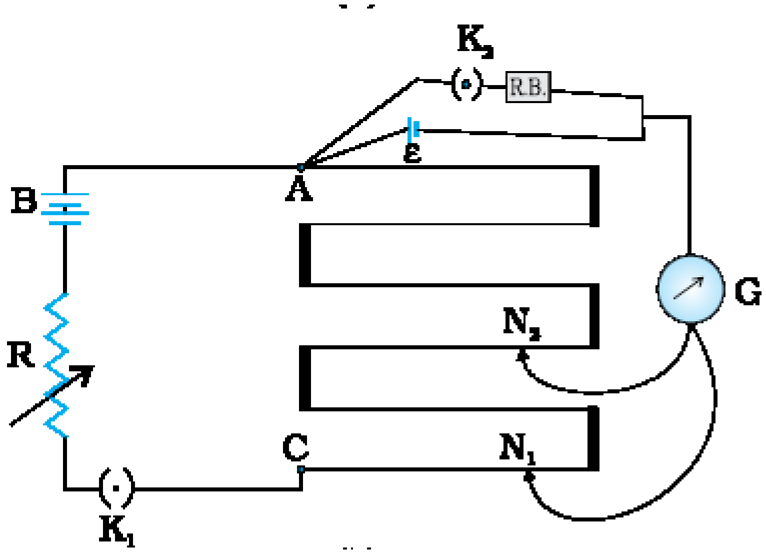
Apparatus used

- **Driver cell**
- **Potentiometer**
- **Test cell**
- **Resistance box**
- **Galvanometer**
- **Jockey**
- **Connecting wires and keys**

Circuit diagram:



So if our balancing length when the galvanometer shows zero deflection is l_1 without resistance R in the circuit or when the circuit is open.



When key k_1 is open, balancing length l_1 at N_1 gives emf E_1.

$E_1 = k\, l_1$

- When key k_1 is closed current is being drawn from cell E_1 therefore balancing length l_2 at N_2 gives TPD (V) of cell E_1.
- Therefore $V = k\, l_2$

$$\frac{E_1}{V} = \frac{l_1}{l_2}$$

- *Expression* for internal resistance (r) is

$$r = \left(\frac{E_1 - V}{V}\right)R$$

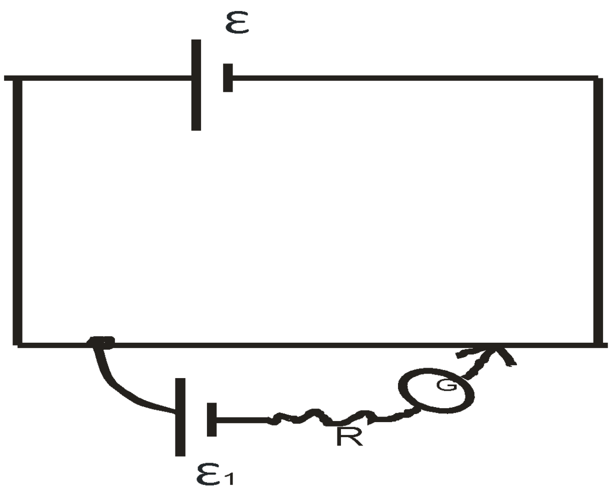
$$r = \left(\frac{E_1}{V} - 1\right)R$$

$$r = \left(\frac{l_1}{l_2} - 1\right)R$$

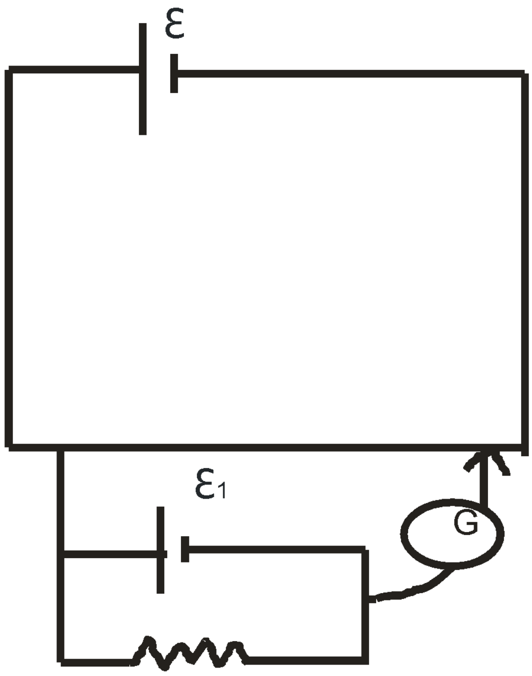
Important Points

- **Current in potentiometer is due to driver cell only. And current in the secondary circuit is due to the secondary cell only.**
- **Emf of the driver cell should be greater than the emf of the secondary cell; otherwise we won't get a balance point on the potentiometer.**

- **A resistance in series with a secondary cell does not affect the balance point because at balance length no current is drawn from the secondary cell. Hence no potential drop in the resistor.**



- **A resistance in parallel to the secondary cell affects the balance point because it draws current from the secondary cell.**



- **If galvanometer shows deflection in one direction, following may be the reason:**
    - **Emf of the secondary cell may be greater than the emf of the primary cell.**
    - **Connections of secondary cells may be losing.**
- **Positive ends of both cells, driver cell and secondary cell, should be connected at zero end of the potentiometer.**

- **Potentiometer is preferred over voltmeter because potentiometer draws no current from the cell, emf of which is being measured. Thus potentiometer is an ideal voltmeter.**

What if your lab does not have a potentiometer?

- **Take a wooden strip**
- **Put a resistance wire tight between the ends using a suitable nail.**
- **You will need a scale and a galvanometer.**
- **You can use dry cells as driver cells. you can find out whether a particular cell is in discharged condition or not.**

Sensitivity of Potentiometer

A potentiometer is said to be sensitive if a small potential drop occurs in larger length.

$$V \alpha\, l$$

$$l = \frac{V}{k}$$

For a given potential, l will be large if k (potential gradient) is small.

For potentiometer to be sensitive its k has to be small, which can be done by:

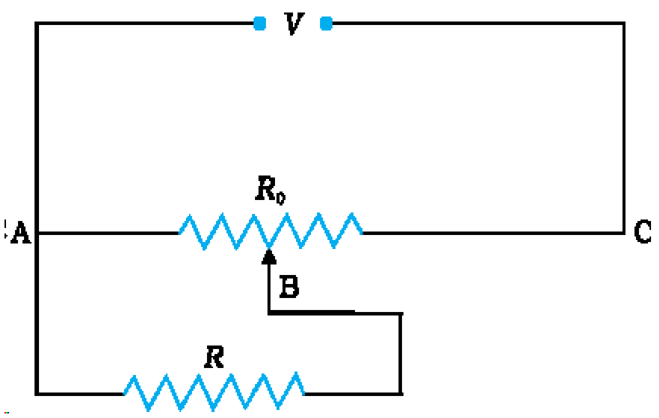
(i) **Increasing length of potentiometer wire since** $k = \frac{V}{l}$

(ii) **Decreasing current in the potentiometer since** $k = \frac{\rho I}{A}$

Solved Examples

Example

Resistance of R Ω is powered from a potentiometer of resistance R_0 Ω. A voltage V is supplied to the potentiometer. Derive an expression of the voltage fed into the circuit when the slide is in the middle of the potentiometer.



Solution

When slide is in the middle of the potentiometer wire, only half of the resistance of potentiometer (=R_o) will be between the points A and B. Hence effective resistances (R_1) between A and B is:

$$\frac{1}{R_1} = \frac{1}{R} + \frac{1}{R_o/2}$$

or

$$R_1 = \frac{R_0 R}{R_0 + 2R}$$

Total resistance between A and $C = R_1 + \frac{R_0}{2}$

Current through the potentiometer wire will be

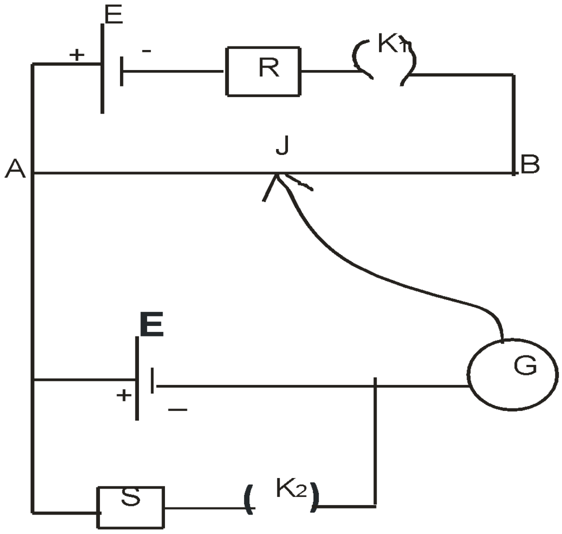
$$I = \frac{V}{R_1 + R_0/2} = \frac{2V}{2R_1 + R_0}$$

The voltage V_1 taken from the potentiometer will be the product of current I and resistance R_1 i.e.

$$V_1 = IR_1 = \frac{2V}{2\left(\frac{R_0 R}{R_0 + R}\right) + R_0} \times \frac{R_0 R}{R_0 + 2R} = \frac{2VR}{2R + R_0 + 2R} = \frac{2VR}{R_0 + 4R}$$

Example

Two students X and Y perform an experiment on potentiometer separately using the circuit given below.



Keeping other parameters unchanged, how will the position of null point be affected if

(i) X increases the value of resistance R in the setup by keeping the key K_1 closed and the key K_2 open.

(ii) Y decreases the value of resistance S in the setup, while the key K_2 remains open and the key K_1 closed.

Solution

(i) Current through potentiometer wire decreases. Thus, potential gradient decreases. As $K = \frac{V}{l}$ with the decrease in potential gradient balancing length increases i.e. null point will shift towards 'B'.

(ii) Current through potentiometer wire remains the same i.e. potential gradient does not change. As a result the null point remains the same.

Example

In a potentiometer arrangement, a cell of emf 1.25 volts gives a balance point at 35 cm length of the wire. If the cell is replaced by another cell and balance point shifts to 63 cm, what is the emf of the second cell?

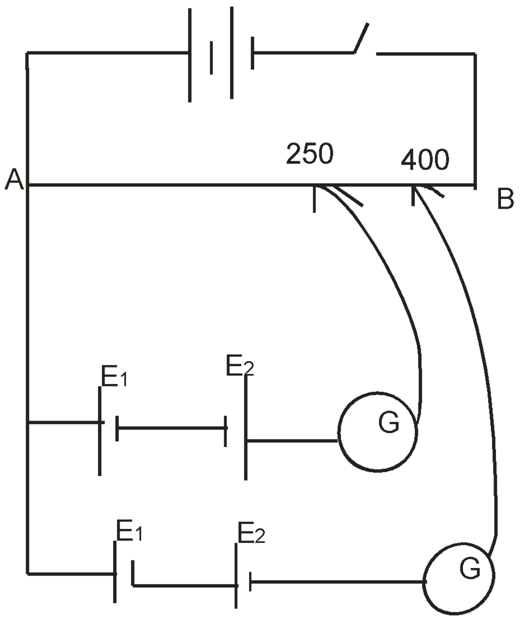
Solution

$$\frac{E_2}{E_1} = \frac{l_2}{l_1}$$

$$E_2 = \frac{63}{35} \times 6 + 1.25 = 2.25\, volt$$

Example

Two primary cells of emf E_1 and E_2 ($E_1 > E_2$) are connected to the potentiometer wire AB as shown in the figure. The balancing lengths for the two combinations of the cells are 250 cm and 400 cm, find the ratio of E_1 and E_2.



Solution

$E_1 + E_2 = k(400)$

$E_1 - E_2 = k(250)$

$\frac{E_1 + E_2}{E_1 - E_2} = \frac{400}{250}$

On solving we get,

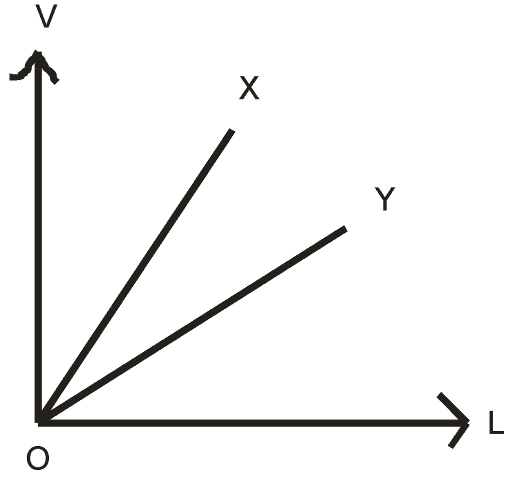
$\frac{E_1}{E_2} = \frac{13}{5}$

Problems For Practice

1. State the principle of potentiometer. With the help of circuit diagrams describe a method to find the internal resistance of a primary cell.
2. What is a potentiometer? Explain its principle of working. How can you compare the emf of two cells using a potentiometer?
3. What is Potential gradient? How is it measured? Explain.
4. Can you express the Potential gradient in terms of specific resistance of the wire? If yes, find the relation.
5. If the emf of the driving cell is decreased, what will be the effect on the position of zero deflection in a potentiometer? Explain.

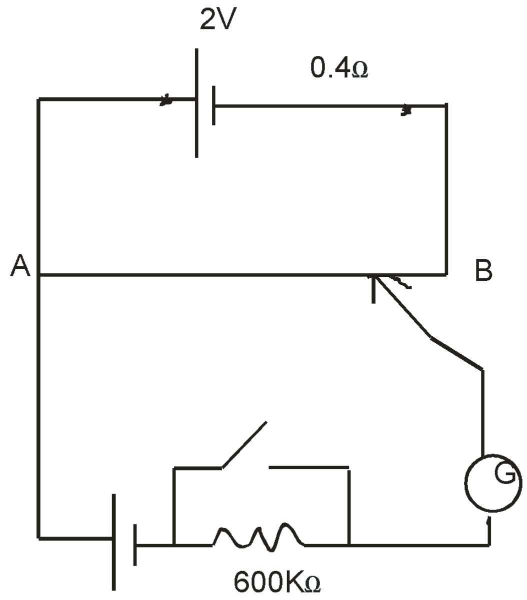
6. A standard cell of emf 1.08V is balanced by the potential difference across 91cm of a metre long wire supplied by a cell of emf 2V through a series resistor of resistance 2Ω. The internal resistance of the cell is zero. Find the resistance per unit length of the potentiometer wire.

7. The variation of potential difference V with length l in case of two potentiometers X and Y is as shown in the figure. Which one of these two will you prefer for comparing emfs of the two cells and why?



8. In a potentiometer arrangement, a cell of emf 1.25 V gives a balance point at 35 cm length of the wire. If the cell is replaced by another cell and the balance point shifts to 63 cm, what is the emf of the second cell?

9. Figure below shows a potentiometer with a cell of 2.0 V and internal resistance 0.40 Ω maintaining a potential drop across the resistor wire AB. A standard cell which maintains a constant emf of 1.02V (for very moderate currents upto a few mA) gives a balance point at 67.3cm length of the wire. To ensure very low currents drawn from the standard cell, a very high resistance of 600 KΩ is put in series with it, which is shorted close to the balance point. The standard cell is then replaced by a cell of unknown emf ε and the balance point found similarly, turns out to be at 82.3 cm length of the wire.



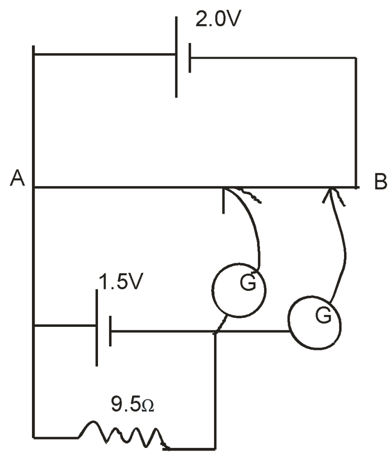
a) What is the value of ε?

b) What purpose does the high resistance of 600 KΩ have?

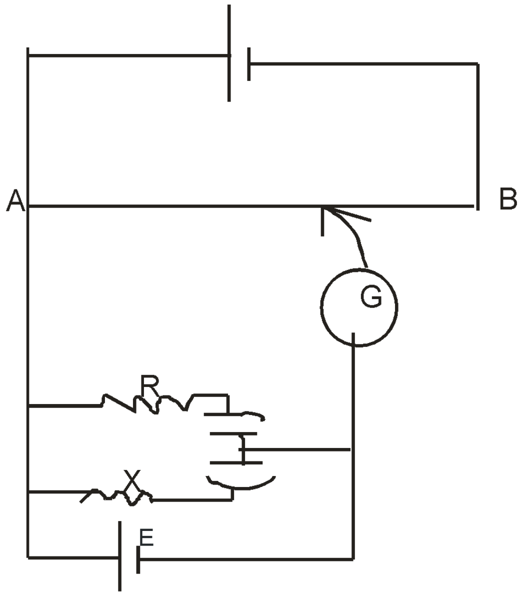
c) Is the balance point affected by the internal resistance of the driver cell?

d) Is the balance point affected by this high resistance?

10. Figure shows a 2.0V potentiometer used for the determination of internal resistance of a 1.5V cell. The balance point of the cell in the open circuit is 76.3cm. When a resistor of 9.5Ω is used in the external circuit of the cell, the balance point shifts to 64.8cm length of the potentiometer wire. Determine the internal resistance of the cell.



11. Figure shows a potentiometer circuit for comparison of two resistances. The balance point with a standard resistor R = 10.0 Ω is found to be 58.3 cm, while that with the unknown resistance X is 68.5cm. Determine the value of X. What might you do if you failed to find a balance point with the given cell of emf ε?



12. If the length of the wire be (i) doubled and (ii) halved, what will be the effect on the position of zero deflection in a potentiometer? Explain.
13. Sometimes balance points may not be obtained on the potentiometer wire. Why?
14. What does the no deflection position in the galvanometer of the potentiometer experiment tell us about the flow of current?
15. Why do we prefer a potentiometer to measure the emf of a cell rather than a voltmeter?
16. What do you understand by sensitiveness of a potentiometer and how can you increase the sensitiveness of a potentiometer.
17. Suggest a method , so that one can use the potentiometer to get a small potential difference say 0.4V for a circuit when the available cells are 1.5 V, 9 V etc.

Summary

In this module you have learnt:

- Principle of potentiometer
- Applications of potentiometer for
  - Finding emf of a cell ,

    - Compare emf of two cells ,
    - Find the internal resistance of a cell
- Potentiometer sensitivity