Potentiometer-Principle and its applications to measure P.D and for comparing EMF of two cells

CLASS-XII

SUBJECT : PHYSICS
CHAPTER NUMBER: 03
CHAPTER NAME : CURRENT ELECTRICITY

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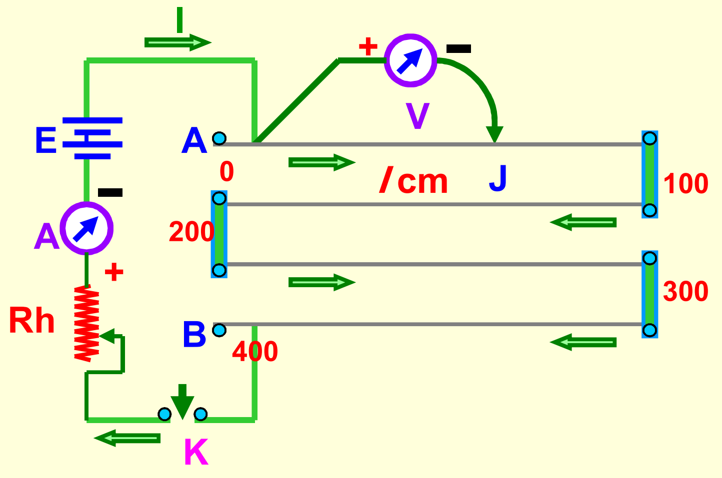
Potentiometer:

Principle:

$V = I R$

$= I \rho l/A$

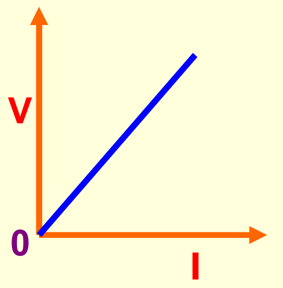
If the constant current flows through the potentiometer wire of uniform cross sectional area (A) and uniform composition of material (ρ), then



$V = Kl$ or $V \propto l$

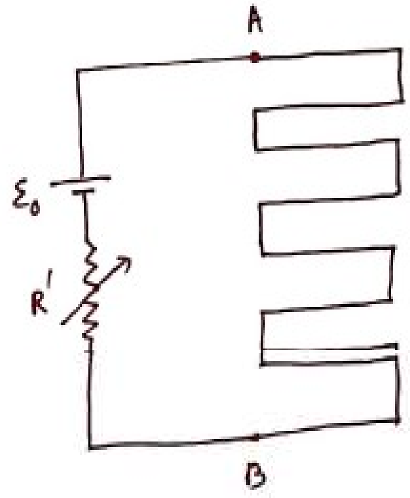
V / l is a constant.

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



The expression for potential drop per unit length :

It contains a long wire AB of length (l_0) and uniform cross-section of area A connected across a cell called as driver cell of emf $(\xi_0)$and a variable resistor of resistance R



So the resistance of potentiometer wire is

$$R_0 = \rho \frac{l_0}{A}$$

Where ρ = resistivity of potentiometer wire

Current in the driver circuit is

$$I_0 = \frac{\xi_0}{R\prime + R_0} = \frac{\xi_0}{R\prime + \frac{\rho l_0}{A}} = \frac{A\xi_0}{AR\prime + \rho l_0} \text{........(ii)}$$

The potential difference across potentiometer wire is

$V_0 = I_0 R_0$

So potential drop per unit length is $K = \frac{V_0}{l_0} = \frac{I_0 R_0}{l_0} = \frac{I_0 \rho}{A}$ (Using equation (i)) ...(iii)

Sensitivity:

It is a measure of how small voltage be measured by the potentiometer . For this K should be very small

As $K = \frac{I_0 \rho}{A} = \frac{A\xi_0}{AR\prime + \rho l_0} \frac{\rho}{A} = \frac{\rho \xi_0}{AR\prime + \rho l_0}$ (Using equation (ii))

So potentiometer will be more sensitive or φ should be very small if

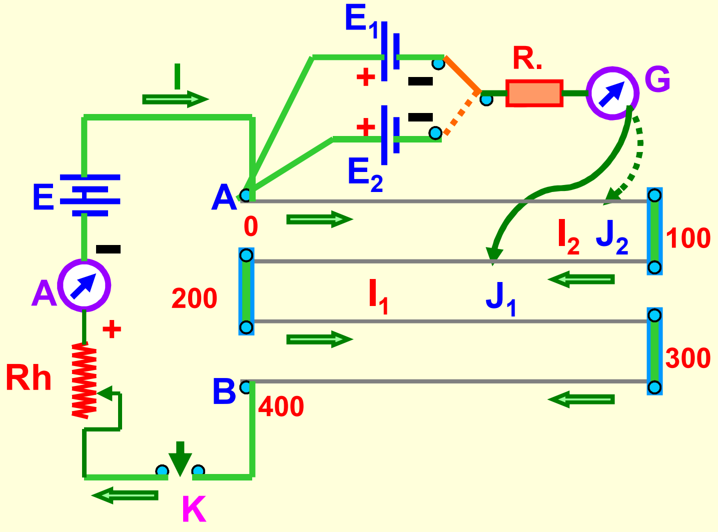
(i) the resistance of the driver circuit is very high

(ii) length of potentiometer wire should be very large

(iii) the wire should be thick.

The advantage of the potentiometer in comparison to a voltmeter is that potentiometer doesn't draw any current from the element where the voltmeter draws. So potentiometer measures the exact voltage of the element where the voltmeter measures smaller voltage.

Comparison of emf's using Potentiometer:



The balance point is obtained for the cell when the potential at a point on the potentiometer wire is equal and opposite to the emf of the cell.

$$E_1 = V_{AJ_1} = I \rho l_1 / A$$

$$E_2 = V_{AJ_2} = I \rho l_2 / A$$

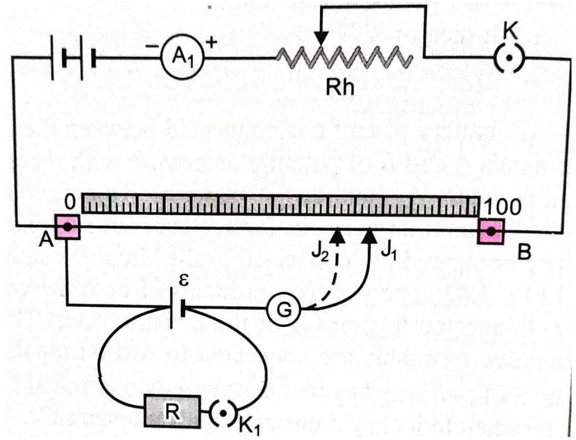
$$E_1 / E_2 = l_1 / l_2$$

Note:

The balance point will not be obtained on the potentiometer wire if the fall of potential along the potentiometer wire is less than the emf of the cell to be measured.

The working of the potentiometer is based on null deflection method. So the resistance of the wire becomes infinite. Thus potentiometer can be regarded as an ideal voltmeter.

Determination of internal resistance of a cell



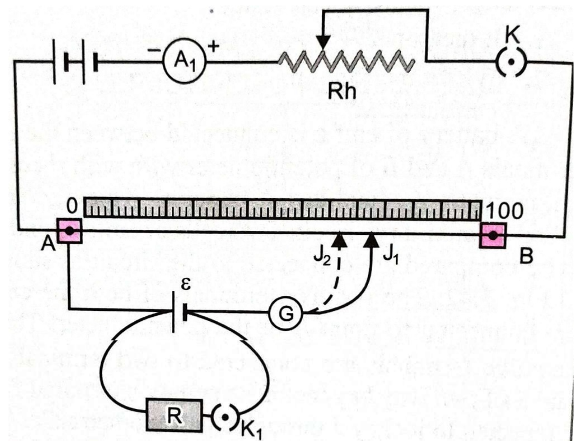
Determination of internal resistance of a cell

When switch K2 is open there is no current in the second circuit at the null point position.

If null point length at this condition is l_1 ,

then $\xi = Kl_1$ ....(i)

When switch K2 is closed there is a current I through the second circuit.



So potential difference across the cell is

$V = IR = \xi - Ir$ ....(ii)

$\Rightarrow \xi = I(R + r)$ ....(iii)

Now null point distance is l_2. So $V = Kl_2$

Dividing equation(i) by equation (iv) we get $\frac{\xi}{V} = \frac{Kl_1}{Kl_2} = \frac{l_1}{l_2}$

Now using equations (ii) and (iii)

$$\frac{I(R+r)}{IR} = \frac{l_1}{l_2}$$

$\Rightarrow \frac{R+r}{R} = \frac{l_1}{l_2} \Rightarrow R + r = \frac{l_1}{l_2}R \Rightarrow r = \frac{l_1}{l_2}R - R = R\left(\frac{l_1}{l_2} - 1\right)$ r is the internal resistance of the cell and R is the resistance connected across the cell

Numerical

Question: A potentiometer circuit uses a driver cell of emf 2 V with internal resistance 0.5Ω and potentiometer wire of resistance 7.5Ω with a length of 400 cm.

a) Calculate the potential drop per unit length

b) Find balancing length for a cell of emf 1 V.

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Solution :

$$a)\ \mathrm{I_0} = \frac{\xi_0}{\mathrm{r+R_0}} = \frac{\mathrm{2V}}{0.5\Omega+7.5\Omega} = \frac{1}{4}\mathrm{A}$$

$$\therefore K = \frac{V_0}{l_0} = \frac{I_0 R_0}{l_0} = \frac{0.25\times7.5}{4} V/m = 0.47 V m^{-1}$$

$$\text{b)}\ \mathrm{l} = \frac{\mathrm{V}}{\mathrm{K}} = \frac{\mathrm{1V}}{\mathrm{0.47Vm^{-1}}} = 2.13\mathrm{m} = 213\mathrm{cm}$$

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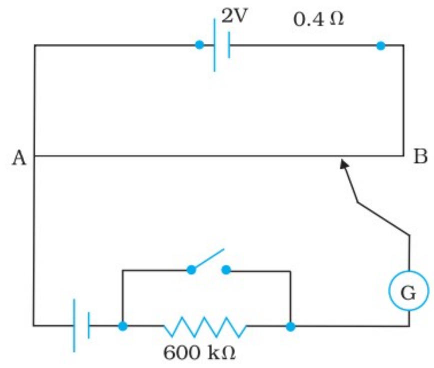
Numerical

Question: The figure shows a potentiometer with a cell of 2.0 V and internal resistance 0.40Ω maintaining a potential drop across the resistor wire AB. A standard cell which maintains a constant emf of 1.02 V (for very moderate currents up to a few mA) gives a balance point at 67.3 cm length of the wire. To ensure very low currents drawn from the standard cell, 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 ξ and the balance point found similarly, turns out to be at 82.3 cm length of the wire.



a) What is the value of ξ?

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

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

d) Would the method work in the above situation if the driver cell of the potentiometer had an emf of 1.0V instead of 2.0V?

e) Would the circuit work well for determining an extremely small emf, say of the order of a few mV (such as the typical emf of a thermo-couple)? If not, how will you modify the circuit? (NCERT)

Numerical

Solution :

(a) Since $\frac{\xi_1}{\xi_2} = \frac{l_1}{l_2} \Rightarrow \xi_2 = \frac{\xi_1 l_2}{l_1} = \frac{1.02 \times 82.3}{67.3} V = 1.247V$

(b) The purpose of using high resistance $600 k\Omega$ is to protect the galvanometer by ensuring low current to pass through it when the balance point is achieved.

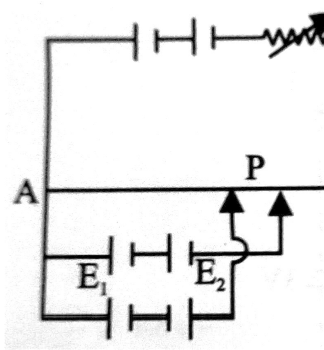
(c) No, the balance point is not affected by the presence of this resistance.

(d) No, the emf of the driver cell must be more than the emf of the cells.

(e) For the measurement of small emf, this circuit will not work well. The length of the potentiometer wire should be increased to have a very small potential drop per unit length. So that the small voltage source can have a considerable balancing length.

Numerical

Question: The figure shows a long potentiometer wire AB with a constant potential gradient. The null points for the two primary cells of EMFs $\mathrm{E_1}$ and $\mathrm{E_2}$ $(\mathrm{E_1} > \mathrm{E_2})$ connected in the manners shown are obtained at distances 250 cm and 400cm from A respectively.



Calculate

(i) $\frac{\mathrm{E_1}}{\mathrm{E_2}}$

(ii) position of a null point when $\mathrm{E_1}$ is connected only

Numerical

Solution :

From the figure, $E_1 - E_2 = 250cm \times K$ ....(i)

$E_1 + E_2 = 400cm \times K$ ......(ii)

Adding equations (i) and (ii) we have , $2E_1 = 650cm \times K$

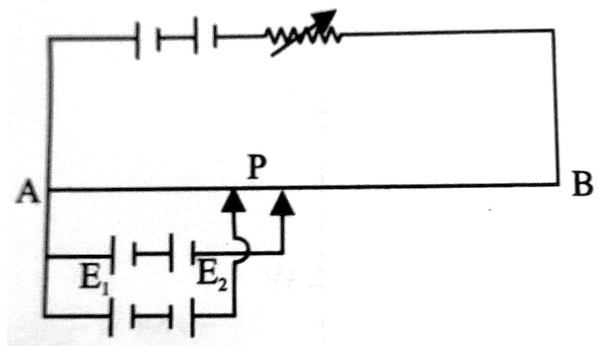
$E_1 = 325cm \times K$ ....(iii)

Using equation (iii) in (ii) we have

$E_2 = 400cm \times K - 325cm \times K = 75cm \times K$ ....(iv)

(i) $\frac{E_1}{E_2} = \frac{325cm \times K}{75cm \times K} = \frac{13}{5}$

(ii) From equation (iii) we have the null point length of E_1 alone is 325 cm .



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