

CURRENT ELECTRICITY

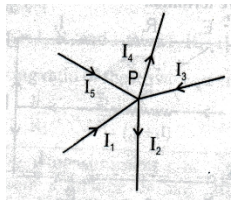
KIRCHHOFF'S LAWS

Kirchhoff's first law (Current Law or Junction Law):

The algebraic sum of electric current at any junction is always equal to zero. $\Sigma I = 0$

The current flowing towards the junction is positive and current flowing away from the junction is negative
 $I_1 + I_3 + I_5 - I_2 - I_4 = 0$ OR $I_1 + I_3 + I_5 = I_2 + I_4$

NOTE: This law is in accordance with law of conservation of charge



Precautions or How to minimize the errors:

1. Use a wire of uniform cross section
2. The R value should be chosen in such a way that the null point (D) should be close to the centre of the wire
3. Repeat the experiment by interchanging X and R in order to minimize the effect of contact resistance
4. The jockey should be tapped on the wire and not slid.

Kirchhoff's second Law (Voltage law or loop theorem): In a closed loop of electrical network, the algebraic sum of potential differences for all components plus the algebraic sum of all E.M.F. is equal to zero.

$$\Sigma IR + \Sigma E = 0$$

In the direction of conventional current flow the potential difference across the resistances is negative otherwise positive. For EMF if we travel from negative to positive terminal then we take it positive otherwise negative.

WHEATSTONE'S NETWORK

For accurate measurement of unknown resistance 4 resistors connected to form a quadrilateral ABCD. A battery of E volts is connected between A & C. A galvanometer is connected between the ends B and C having resistance G.

Network is said to be balanced if $V_B = V_D$, hence $I_g = 0$

(current through galvanometer is zero, called NULL POINT)

Proof: Applying KVL to ABGD

$$-I_1 P + I_2 S = 0, \text{ thus, } I_1 P = I_2 S$$

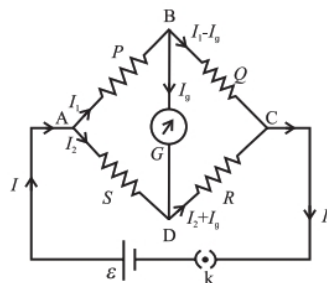
Applying KVL to BCDGB

$$-I_2 Q + I_1 R = 0, \text{ thus, } I_1 Q = I_2 R$$

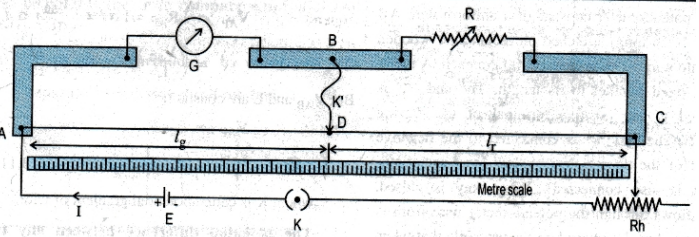
Dividing we get $P/Q = S/R$, alternately, $PR = QS$

This is the balancing condition.

NOTE: If the bridge is balanced $I_g = 0$, Thus P and Q are in series and so is S and R. Thus, total resistance of circuit is $(P+Q)/(S+R)$



KELVIN'S Method to determine Galvanometer Resistance:



[Construction & setup own words]

With some suitable resistance R you should be able to get opposite side deflections in G when jockey is touched at A and C (indicating there is a null point somewhere in between A and C).

Now without the jockey attached to the wire measure the current in G. Now touch the jockey on wire to find a point D such that the galvanometer shows the same current as when the jockey was not attached. This point D is the null point and the bridge is balanced.

Thus, $G \cdot (100 - l_1) = R \cdot l_1$, which gives $G \cdot l_1 = R \cdot l_2$ which implies $G = R(l_2/l_1)$

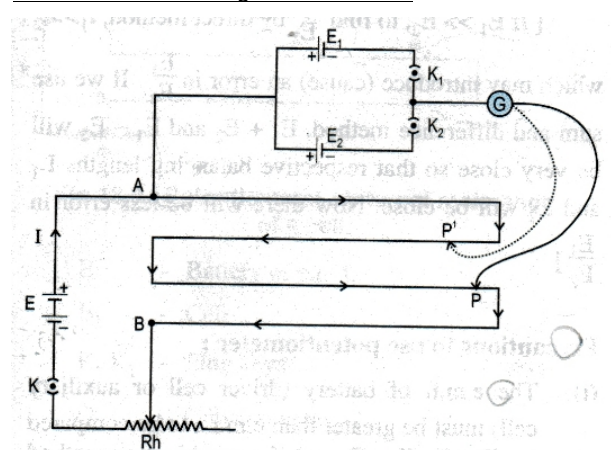
$$G = R \left(\frac{l_2}{100 - l_1} \right)$$

- G - Galvanometer
- R - Resistance from resistance box
- AC - Metal wire one metre long
- Rh - Rheostat
- E - Cell
- K - Plug key
- K' - Jockey

POTENTIOMETER:

Principle: The fall in potential per unit length (called potential gradient) of the wire is constant.

COMPARE TWO EMF using POTENTIOMETER:



Construction refer GTB (pg 221-222)

With key K1 closed and K2 open find the NULL point P. Thus, $V_{AP} = E_1$ and potential gradient will be E_1/L_{AP}

Now with K1 open and K2 closed find NULL point P'. Thus, $V_{AP'} = E_2$ and potential gradient will be $E_2/L_{AP'}$

But potential gradient in a potentiometer is constant.

$$\text{Thus, } \frac{E_1}{L_{AP}} = \frac{E_2}{L_{AP'}}$$

Precautions:

- (i) $E_1 > E_2$, $E_1 > E_2$
- (ii) E1 and/or E2 positive end should be connected to the potentiometer where the positive end of E is connected
- (iii) The potentiometer wire must be uniform
- (iv) The resistance of the potentiometer wire must be high

DETERMINATION OF UNKNOWN RESISTANCE BY METER BRIDGE

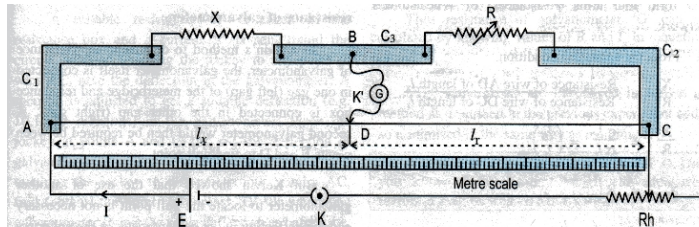


Fig. 13.4 : Wheatstone's meter bridge

- | | |
|----------------------------|-------------------------------------|
| AC - 1 m long uniform wire | C1, C2, C3 - Metal strips, E - Cell |
| X - Unknown resistance | D - Null point |
| R - Resistance box | K' - Sliding key (jockey) |
| G - Galvanometer | Rh - Rheostat |

[Construction refer GTB or write in own words]

A suitable resistance is selected for R such that a point D is obtained on the wire showing zero (null) deflection in the galvanometer. If I is the steady current flowing in the circuit and ρ is the specific resistance of the wire AC. Then, by Wheatstone balanced bridge condition

$$X \cdot R_{DC} = R \cdot R_{AD}$$

$$X \cdot (\rho \cdot l_2) / A = R \cdot (\rho \cdot l_1) / A \quad \text{that is } X \cdot l_2 = R \cdot l_1 \quad \text{that is } X = R (l_1/l_2) \text{ or}$$

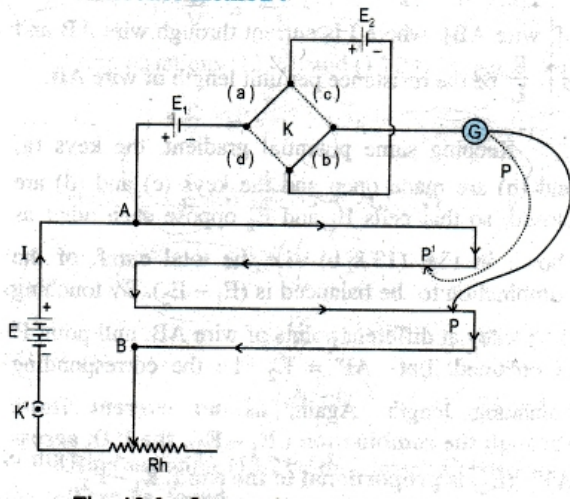
$$X = R \left(\frac{l_1}{100 - l_1} \right)$$

NOTE: The resistance calculated is not a function of applied voltage or current.

Error while using Meter Bridge:

1. Wire may not have uniform cross-section
2. At the ends (A and C) contact resistances will be developed
3. The ends of the wire may not coincide with the 0 and 100 mark on the scale hence readings of length may not be accurate

E1/E2 BY SUM AND DIFFERENCE METHOD (COMBINATION METHOD)



[Construction and setup refer GTB pg 222]

With switches aligned along a and b we get E1+E2 and when aligned along c and d we get E1-E2

For E1+E2 configuration we find the balancing length AP

Thus potential gradient = $(E1+E2)/L_{AP}$

For E1 - E2 we find balancing length as AP'

Thus potential gradient = $(E1 - E2)/L_{AP'}$

For a potentiometer the potential gradient will be same

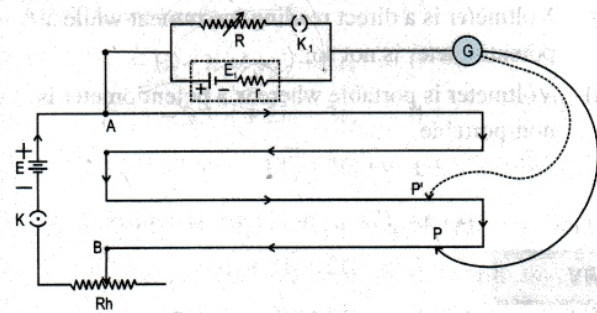
$(E1+E2)/(E1 - E2) = L_{AP}/L_{AP'}$

Thus, $\frac{E1}{E2} = \frac{L_A + L_A r}{L_A - L_A r}$

Precautions:

- (i) $E > (E1+E2)$, $E > E1$, $E > E2$, $E1 > E2$
- (ii) E1 and/or E2 positive end should be connected to the potentiometer where the positive end of E is connected
- (iii) The potentiometer wire must be uniform
- (iv) The resistance of the potentiometer wire must be high

DETERMINATION OF INTERNAL RESISTANCE OF A CELL



- E - Battery of e.m.f.
- E1 - Cell
- K, K1 - Plug keys
- G - Galvanometer
- P, P' - Null points
- R - Resistance box
- r - Internal resistance of cell E1
- AB - Potentiometer wire
- Rh - Rheostat

[Refer GTB for construction]

With K1 open find NULL point at P. Thus balancing length for E1 is AP

Thus, potential gradient = $E1 / L_{AP}$

with key K1 plugged in the new balancing length is AP'

Now the potential gradient is $(E1 - Ir)/L_{AP'}$ or $IR/L_{AP'}$

Potential gradient remains the same, thus,

$\frac{E1}{L_A} = \frac{E1 - I r}{L_A r}$ $I = \frac{E1}{R + r}$

$\frac{E1}{L_A} = \frac{E1 - \frac{E1 r}{R + r}}{L_A r}$

$E1 \left(\frac{L_A r}{L_A} \right) = E1 \left(1 - \frac{r}{R + r} \right)$

$\frac{L_A r}{L_A} = \frac{R}{R + r}$, reciprocating we get

$\frac{L_A}{L_A r} = 1 + \frac{r}{R}$

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

ADVANTAGE OF POTENTIOMETER OVER VOLTMETER:

- (i) Voltmeter can only measure terminal PD of the cell while a potentiometer can measure small PD as well as EMF of cell
- (ii) Accuracy of a potentiometer can be increased by increasing the length of the wire
- (iii) Potentiometer can measure small PD also accurately unlike a voltmeter as its resistance is high but not infinite
- (iv) Internal resistance of a cell can be measured by a potentiometer and not by a voltmeter

DISADVANTAGE OF POTENTIOMETER

- (i) Voltmeter is a direct reading instrument while a potentiometer is not
- (ii) Voltmeter is easily portable as compared to a potentiometer which is not that portable.

APPLICATIONS OF POTENTIOMETER

Voltage Divider

It can continuously change the output voltage by changing the length by using a slider.

Audio Control

A sliding volume control (faders) or a rotary knob for frequency attenuation is common in audio devices for loudness control and controlling other characteristics of audio signals in modern day low - power audio systems

As a sensor

Can be used as a motion sensor, where a sliding potentiometer can be attached to the moving part of the machine. When it moves will cause the slider to move and hence cause changes in potential which can be amplified and calibrated in terms of the displacement of the moving part to know how much it moved.

Extra:

- 1) $I = Q/t$ and $Q = ne$
- 2) $V = IR$
- 3) $P = VI = I^2 R = V^2/R$
- 4) $H = Pt = VIt = I^2 Rt = (V^2/R)t$
- 5) If n is the number of electrons per unit volume the $Q = (nAL)e$ and $I = nALe/t$ BUT $t = L/V_d$ where L is the length and V_d the drift velocity
Thus, $I = n.e.A.V_d$
Current density = $J = I/A = n.e.V_d$
NOTE: current density is a vector directed in same direction as E
- 6) $R = \rho L/A$
- 7) $R = R_0(1 + \alpha\theta)$ if PTC and $R = R_0(1 - \alpha\theta)$ if NTC

*Galvanometer, Voltmeter and Ammeter will be part of MEEC notes.