Heating Effect of Electric Current.

The phenomenon of production of heat in a resistor by the flow of an electric current through it is called heating effect of electric current. or Joules heating effect.

According to Joule, the amount of heat produced in a resistor of resistance R is

$H \propto I^2$ (square of current flowing through the conductor)

$\propto R$ (Resistance of the conductor)

$\propto t$ (time for which current passes through conductor)

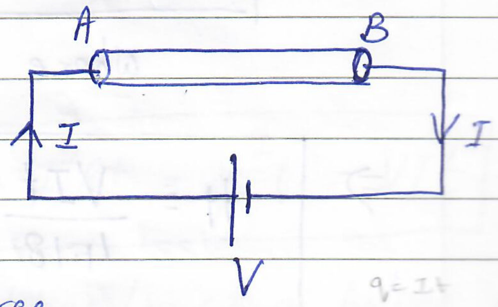
$\Rightarrow H \propto I^2Rt$

$\Rightarrow \boxed{H = \frac{I^2Rt}{J}}$ where J is Joule's mechanical equivalent of heat.

Cause of heating effect of electric current ↦ when a pot. diff. is applied across a conductor, the free e^-s get drifted towards the +ve terminal of battery. while doing so, these electrons suffer frequent collisions with the +ve ions of the conductor and transfer their energies to the ions. Thus avg. K.E. of the ions increases hence temp. of the conductor also increases.

In other words electrical energy of source of emf get converted into heat energy.

Expression for heat produced by electric current ↦



Consider a conductor AB of resistance R, connected to a battery of pot. diff. V volts. If I is the current flowing through the resistor, then charge flown through the conductor in time t is

$q = It$ —— ①

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Thus workdone by the battery in sending
q from A to B is:

$$W = q(V_B - V_A) \qquad \left\{ \because \frac{W_{AB}}{q_0} = \right.$$

$$\Rightarrow W = qV$$

$$W = VIt \qquad \{\text{using } ①\}$$

This workdone should appear in the form
gain in K.E. of the free electrons. But we kn
e^-s flow through the conductor with constant
velocity. It means this entire energy is han
by e^-s to the ions of the conductor durin
~~Thus~~ and appears in the form of heat in the

Thus heat produced

$\cancel{H = I^2Rt}$

$\cancel{H = I}$

$$\boxed{H = VIt \text{ joules} \quad \text{or} \quad H = I^2Rt \text{ joules} \quad H = \frac{V^2t}{R}}$$

or $$\boxed{H = \frac{VIt}{J} = \frac{I^2Rt}{J} = \frac{V^2t}{RJ} \text{ cal.}}$$

where $J = 4.18$ joule cal^{-1}

$$\Rightarrow \boxed{H = \frac{VIt}{4.18} \text{ cal} = \frac{I^2Rt}{4.18} \text{ cal} = \frac{V^2t}{4.18R} \text{ c}}$$

Important!! ie $H \propto R$ if I is constant {in series
and $H \propto \frac{1}{R}$ if V is constant {in $\parallel$ ci

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Electric power ↦ The rate at which work is done by a source of emf (battery) in maintaining an electric current through a circuit is called electric power of the circuit.

ie $P = \frac{W}{t} = \frac{VIt}{t} = VI$

$\Rightarrow \boxed{P = VI}$ or $\boxed{P = I^2R}$ or $\boxed{P = \frac{V^2}{R}}$

Units :- SI unit is watt.

if $V = 1$ Volt and $I = 1$ Amp.

then $P = 1\,VA = 1$ Watt.

Thus power is said to be 1 watt, if 1A of current flows through the circuit on applying a pot. diff. of 1 Volt.

Bigger unit $1\,KW = 1000$ watt.

$1\,MW = 10^6$ watt.

Commercial Unit

1 Horse Power = 746 watt.

Electric Energy ↦

The total workdone by a source of emf in maintaining electric current through a circuit is called electric energy.

ie $E = W = VIt$

or $\boxed{E = Pt.}$ or $\boxed{E = I^2Rt = \frac{V^2}{R}t = VIt}$

Thus electrical energy depends upon power of electrical appliance used and the time for which it is used.

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Unit ↦

$$E = Pt$$
$$= \text{watt. sec.}$$
$$= \text{Volt Amp sec.}$$

Commercial unit of electric energy ↦

The commercial or Board of Trade (BOT) unit of electrical energy is 1Kw hour. (unit used by electricity board for measuring the energy consumed the home appliances)

Energy consumed ~~by an~~ is said to be 1 Killo watt hour (1Kwh) if an appliance of power 1 Kilo watt runs for an hour.

$$1\,Kwh = 1\,Kwatt \times 1\,hour.$$
$$= 1000\,Watt \times 3600\,sec.$$
$$= 3.6 \times 10^6\ watt\,sec.$$

$$\Rightarrow \boxed{1\,Kwh = 3.6 \times 10^6\ joules}$$

Note ↦ $P = VI$

or $P = \frac{V^2}{R}$ ie $P \propto \frac{1}{R}$ if voltage is constant

or $P = I^2 R$ ie $P \propto R$ if current is constant

Generally the home applicance are manufactured for constant supply of voltage (ie 220V in India is supplied to the houses by the electricity board)

Thus for home appliances.

$P = \frac{V^2}{R}$ ie $P \propto \frac{1}{R}$

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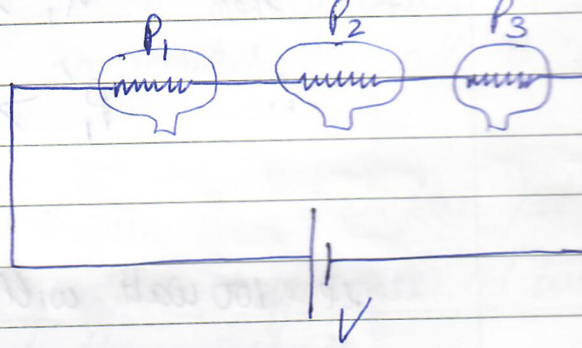
ie appliance of higher power (wattage) will have smaller value of resistance. and vice versa.

ie a bulb of ~~200~~ Power 200 W will have lesser resistance than a bulb of power 100 W.

And since home appliance are connected in || in a house there for 200 W bulb will draw more current than 100 watt bulb.

Power consumed by a series combination of appliances ↦

Consider ~~3~~ a series combination of 3 bulbs of powers P_1, P_2 & P_3 manufactured for applied voltage V volts (220 Volts say)



Thus

$$R_1 = \frac{V^2}{P_1} \quad \text{———} (1)$$

$$R_2 = \frac{V^2}{P_2} \quad \text{———} (2)$$

$$R_3 = \frac{V^2}{P_3} \quad \text{———} (3)$$

if R, P are effective resistance, power of the combination.

the $R = \frac{V^2}{P}$ ——— (4)

Also $R = R_1 + R_2 + R_3$

$$\Rightarrow \frac{V^2}{P} = \frac{V^2}{P_1} + \frac{V^2}{P_2} + \frac{V^2}{P_3}$$

$$\Rightarrow \boxed{\frac{1}{P} = \frac{1}{P_1} + \frac{1}{P_2} + \frac{1}{P_3}}$$

ie eff. power consumed will be less than least po bulb connected in series.

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And current flowing through each bulb will be

$$I = \frac{V}{R} = \frac{V}{R_1 + R_2 + R_3}$$

The brightness of the bulbs will depend upon power dissipated by each bulb and is given a

$P_1' = I^2 R_1$, $P_2' = I^2 R_2$, $P_3' = I^2 R_3$

since for a given voltage $R \propto \frac{1}{P}$

~~⇒~~ ie $P_1 < P_2 < P_3$ (eg $100w < 200w$

then $R_1 > R_2 > R_3$ (ie $R_{100} > R_{200} >$

∴ $P_1' > P_2' > P_3'$ (ie brightness or p dissipated of $100w > 200w >$

ie 100 watt will glow brightes of all three conn in series.

Power consumed by a || combination ↦

Consider three bulbs of power P_1, P_2 so that $P_1 < P_2 < P_3$ are connected in || acro battery of pot. diff. V volts.

Since power is rated for constant applied pot. V (220V volts say)

∴ $R_1 = \frac{V^2}{R}$ —①

$R_2 = \frac{V^2}{P_2}$ —②

$R_3 = \frac{V^2}{P_3}$ —③

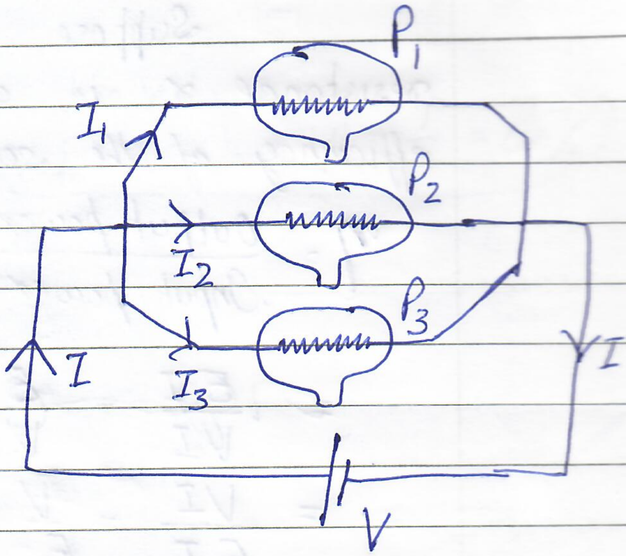
~~her~~ Note here $P_1 < P_2 < P_3$

$\therefore R_1 > R_2 > R_3$

DATE $\therefore I_1 < I_2 < I_3$

if R and P are the effective resistance and power of the ∥ combination then

$$R = \frac{V^2}{P} \quad \text{——} \quad (4)$$



also $\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$

$$\Rightarrow \frac{P}{V^2} = \frac{P_1}{V^2} + \frac{P_2}{V^2} + \frac{P_3}{V^2}$$

$$\Rightarrow \boxed{P = P_1 + P_2 + P_3}$$

ie effective power consumed in the ∥ combination is equal to sum of the powers consumed by all three connected in ∥

Since bulbs are connected in ∥ therefore pot. diff. across each is same. Thus brightness of bulbs or power dissipated by the bulbs will be:

$$P_1' = \frac{V^2}{R_1}, \quad P_2' = \frac{V^2}{R_2} \quad \text{and} \quad P_3' = \frac{V^2}{R_3}$$

comparing with (1), (2) and (3)

$$P_1' = P_1, \quad P_2' = P_2 \quad \text{and} \quad P_3' = P_3$$

ie power dissipated = power rated

Hence ~~bulb~~ 100 W bulb having higher value of resistance will glow lesser than 500 Watt bulb.

ie there brightness will be as per their rated power.

* mean one reading

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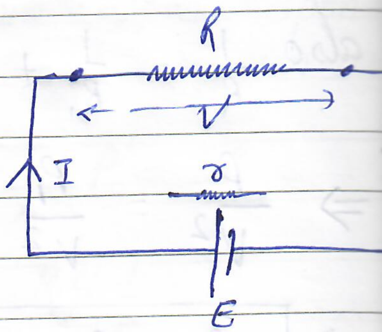
* Efficiency of a source of EMF ↦ It is d/o the ratio output power to the input power.

Suppose a source of emf E and internal resistance r is connected to a load resistance R efficiency of the source is



$$\eta = \frac{\text{Output power}}{\text{Input power}}$$

$$\cancel{= \frac{EI}{VI} = \frac{E}{V} = E}$$

$$= \frac{VI}{EI} = \frac{V}{E} = \frac{IR}{I(R+r)}$$

$$\boxed{\eta = \frac{R}{R+r}}$$

* Maximum power Theorem ↦ It states that output of the source is maximum, when external re[sistance] of the circuit is equal to the internal resista[nce] of the source

ie $P_{out} = VI = I^2R = Max.$ when $R = r$.

Proof ↦

Consider a source of emf E and int. res[istance] r is connected to ext. load resistance R.

Thus

$$E = IR + Ir = I(R+r)$$

$$\therefore I = \frac{E}{R+r} \quad \text{—— (1)}$$

Thus output power of the devise will be

$$P = VI = I^2R = \frac{E^2}{(R+r)^2} \cdot R \quad \text{—— (2)}$$ { using

$$P = \frac{E^2R}{(R-r)^2 + 4Rr}$$

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clearly P will be max,
when $(R-r)^2 = 0$ (∵ denominator is minimum)

$\Rightarrow \boxed{R = r}$ hence proved.

And for max power $\eta = \frac{r}{r+r}$ {∵ $R=r$} $\Rightarrow \eta = \frac{1}{2} = 50\%$

from eqn no. (2)

$$P_{max} = \frac{E^2 r}{(r+r)^2} = \frac{E^2 r}{4r^2}$$

$$\Rightarrow \boxed{P_{max} = \frac{E^2}{4r}} \quad \text{——— (A)}$$

Note :- This is the experession for max power of device in which entire ~~power is dis~~ electrical energy is converted into heat. ie pure resistive device eg bulb or heater etc.

* Efficiency of an electric device ↦ (say electric motor) ↦
It is d/a the ratio of output power to the input power.

In an electric motor, power supplied to it is used in two ways.

1. in performing the mechanical work.
2. power lost in the form of heat.

Thus it efficiency,

$$\eta = \frac{\text{Output power}}{\text{Input power}} = \frac{\text{Output mechanical ~~work~~ power}}{\text{Input electric power}}$$

$$= \frac{\text{Mech. power}}{\text{Mech. power + Heat loss.}}$$

*Ques. Q. Show that out mech. power of the source is max when current drawn by the motor is $E/2r$.

Ans ↦ We know that

Input mech. power = Output power + ~~Heat loss~~ Power lost as heat

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$\therefore$ Output mech. power = Input mech. power $-$ ^power^ Heat

$\Rightarrow \quad P = EI - I^2 r$

we know that P is max, when

$$\frac{dP}{dI} = 0$$

$\Rightarrow \quad E - 2Ir = 0$

$\Rightarrow \quad 2Ir = E$

~~or $I = r$~~

or $\boxed{I = \frac{E}{2r}}$ hence proved

* Ques 6 $\mapsto$ Show that output power of electric is max when back emf is one half source emf, provided resistance of the is negligible.

Ans ~~Let E is emf of the source of conn~~

Let a source of emf E is connected motor whose resistance $R \approx 0$. If E' is back emf produced. Then,

Net emf $= E - E'$

and Net resistance $= R + r = r$ [!

$\therefore$ Current drawn by the motor

$$I = \frac{\text{Net emf}}{\text{Net resistance}} = \frac{E - E'}{r} \quad \text{--- (1)}$$

Now, we know that

Output power = Input power $-$ Power lost

 PAGE

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$$\Rightarrow P = EI - I^2 r$$

Also output power will be max if

$$I = \frac{E}{2r} \quad \text{--- (2)}$$

from (1) and (2)

$$\frac{E - E'}{r} = \frac{E}{2r}$$

$$\Rightarrow E - E' = \frac{E}{2}$$

$$\therefore E' = E - E/2$$

$$\Rightarrow \boxed{E' = \frac{E}{2}} \quad \text{--- (B)}$$ hence proved.

* Note :- Both Eqn A and eqn B ~~are~~ gives the condition for max. output power, but the difference is that eqn A. is pure resistive circuit for which entire energy appears in the form of heat where as eqn B is for non passive resistor (eg electric motor) in which electric energy mainly changes into mech. work and remaining part appears in the form of heat.

Applications of Heating effects of current ↦

(1) All heating devices like heaters, toaster, iron, gyser etc. works on the heating effect of current.

(2) In incandescent bulb heat produced in the filament of bulb appears in the form of light.

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3. A fuse wire of high resistivity and low meltin[g] is connected in series with the live supply to protect costly electric devices from dam[age]

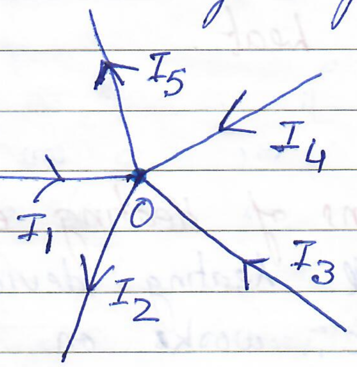
4. A large amount of power get wasted in the from of [heat] during transmission through cables from one place to [another]. This heat loss is given as

$$H = I^2 R t$$

To reduce heat loss either R or I ha[s to] be reduced. But reducing R is a costly as it requires wires of large area of cross-[section]. Thus by using step up transformers, voltage [is] increased and hence current is reduced [to] a large extent.

Kirchhoff's first law or junction rule ↦

According to Kirchhoff's first law or junction [rule], the algebraic sum of currents at any junction [is] equal to zero
Or, the sum of current entering a junction [is] equal to the sum of currents leaving the junc[tion].



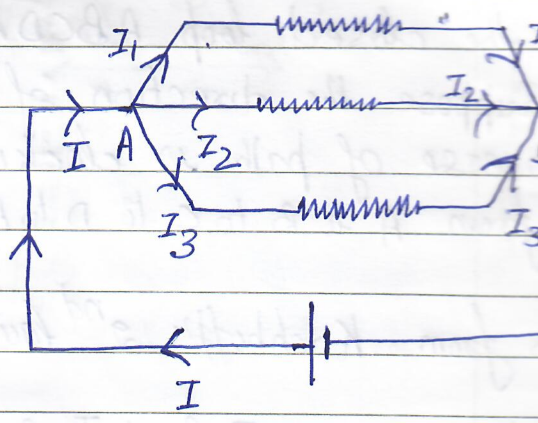
ie. $I_1 + (-I_2) + I_3 + I_4 + (-I_5) = 0$

{∵ By taking the sign convention that currents towards the junction/point are taken as +ve and away from the junction are taken as −ve)

$\Rightarrow \quad I_1 + I_3 + I_4 = I_2 + I_5$

$\Rightarrow$ current entering the junction = Currents leaving the junction.

Even in the circuit of resistance in parallel.
By applying the junction rule at junction A we have



$$I = I_1 + I_2 + I_3$$

and even at junction B

$$I_1 + I_2 + I_3 = I$$

Kirchhoff second law or Loop law :→

According to Kirchhoff's second law, the alge-braic sum of emfs in a closed loop is equal to sum of products of resistances and respective va[lues] of currents flowing through them.

Mathematically

$$\Sigma E = \Sigma IR$$

or $$\Sigma \Delta V = 0$$

While applying the Kirchhoff's 2nd law we use following sign conventions.

First of all select the direction of traverse path ie either clockwise or anticlockwise.

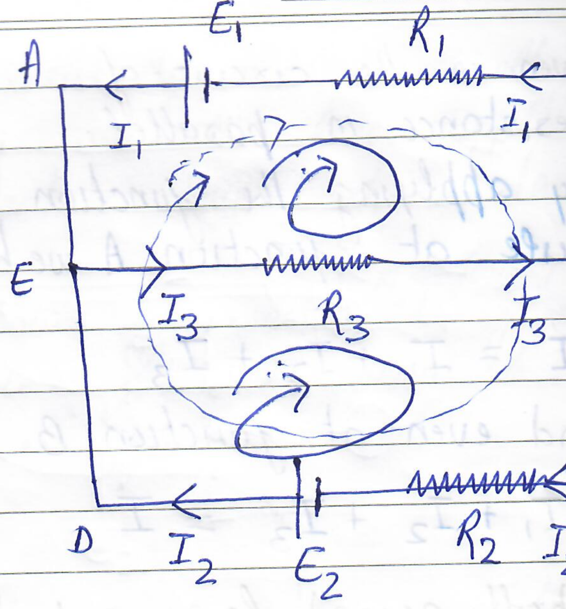
(1) While traversing the path if −ve terminal of ~~a~~ battery is encountered first then emf is [taken] as +ve, otherwise −ve.

(2) If the direction of flow of current is same [as] that of direction of traverse of path then cu[rrent] ~~one~~ is taken as +ve, otherwise −ve.

<u>Illustration</u>

Consider a closed loop ABCDA shown.

For the closed loop ABCDA ↦
Suppose the direction of traverse of path is clockwise ie from A to B to C to D to A.



thus from Kirchhoff's 2^{nd} law

$$-E_1 + E_2 = -I_1R_1 + I_2R_2$$

or $E_2 - E_1 = I_2R_2 - I_1R_1$

$||^{ly}$ for closed loop ABFEA
ie from A to B to F to E to A.

$$-E_1 = -I_1R_1 - I_3R_3$$

or $E_1 = I_1R_1 + I_3R_3$

$||^{ly}$ for closed loop EFCDE
ie from E to F to C to D to E

$$E_2 = I_3R_3 + I_2R_2$$

We can have the same results if we sel[ect] anticlockwise direction of traverse of path.

Potentiometer ↦ Potentiometer is a device used [to] measure emf or potential difference [...]

Principle ↦ Potentiometer is based on the princip[le] when constant current flows a wire of un[iform] area of cross-section then potential drop a[cross] any portion of the wire is directly pro[portional] to the length of that portion.

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We know that

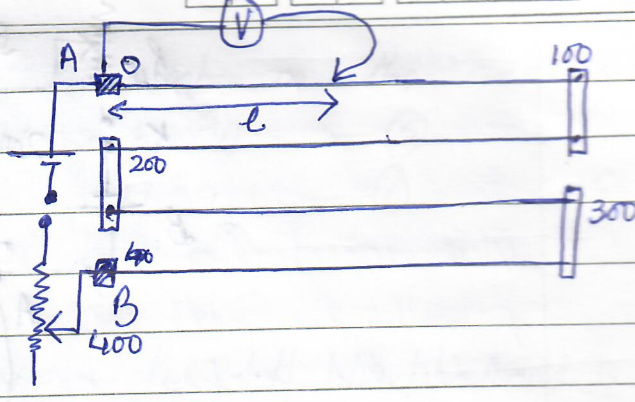
$$V = IR$$

$$\Rightarrow V = I\rho\frac{l}{A}$$

for I, A to be const.

$$V = \text{Const}\ l$$

$$\Rightarrow \boxed{V \propto l}$$



Construction ↦ Potentiometer consist of long wire AB of unifo area of cross-section fixed on a wooden board as shown. A metre scale is fixed ∥ to wire to measure the length of wire used. A constant cu is passed through the wire with the help of battery and rehostat. The potential of battery gradually falls from A to B.

In a potentiometer the fall of potential pe distance ~~is const.~~ (ie potential gradient) is cons

we know that

$$V = \text{Const} \times l$$

$$\Rightarrow \frac{V}{l} = \text{Const}$$

$$\Rightarrow \text{Potential Gradient} = \text{Const.}$$

Applications of Potentiometer :→

① Comparison of emfs of two primary cells ↦

In order to compare the emfs of the two primary ~~cell~~ cell, ~~we~~ connect the ~~o~~ instr as shown in the circuit diagram.

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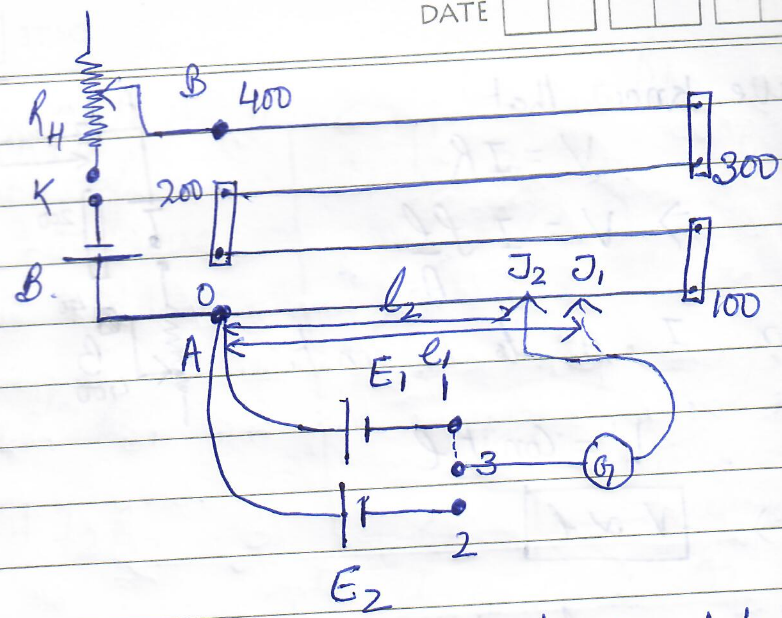

A const. current is passed through the potentio
wire AB with the help of Battery B, key K an
rehostat RR.

~~Now~~ Now bring the ~~cc~~ Ist cell of emf
the circuit by inserting the key b/w points 1
and slide the jockey on the potentiometer w
to find out the balance point ie zero read
the galvanometer. Let it comes at point J_1
that length $AJ_1 = l_1$

Since there is no current in the arm

∴ Pot. of positive term. of cell E_1 = Pot. of pt. A —

and " " -ve " " " E_1 = Pot. of pt J_1 —

Subtract ② from ①

Difference in pot. b/w the two terminals of E_1 = Diff. in pot. b/

emf of the cells $E_1 = Kl_1$ ——— ③

~~Hen~~. Now remove the key from ~~⊗~~ 1 and
insert b/w 2 and 3 to bring the cell E_2
circuit. Again slide the jockey to find the
point. Let it comes at point J_2, so that

$AJ_2 = l_2$

Since there is no current in the arm AE

$\therefore$ Pot. of +ve term. of E_2 = Pot. of pt. A —⑤

" " −ve " " E_2 = " " pt. J_2 —⑥

⑤ − ⑥ gives

Pot. diff. b/w the two terminals of E_2 = Pot diff. b/w pt. A and J_2

$\Rightarrow$ emf of cell $E_2 = Kl_2$ ——— ⑦

Dividing ③ by ⑦

$$\frac{E_1}{E_2} = \frac{Kl_1}{Kl_2}$$

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

Knowing the values of l_1 and l_2, the emf of the two cell can be compared.

② Determination of internal resistance of the cell :→

Arrange the circuit as shown in the diagram. A const. current is passed through the potentiometer wire AB with the help of battery B, key and rehostat Rh.

Keep the key K_1 open and slide the jockey on the potentiometer wire to find the balance point. Let it comes at point J_1 so that length AJ_1 =

Since there is no current in the arm AEG

Pot. of +ve term. of cell E = Pot. of pt. A —①

" " −ve " " " E = Pot. of pt. J_1 —②

① − ② gives.

Diff. in pot. b/w the two terminals of cell E = Diff. in pot. b/w pt. A and J_1

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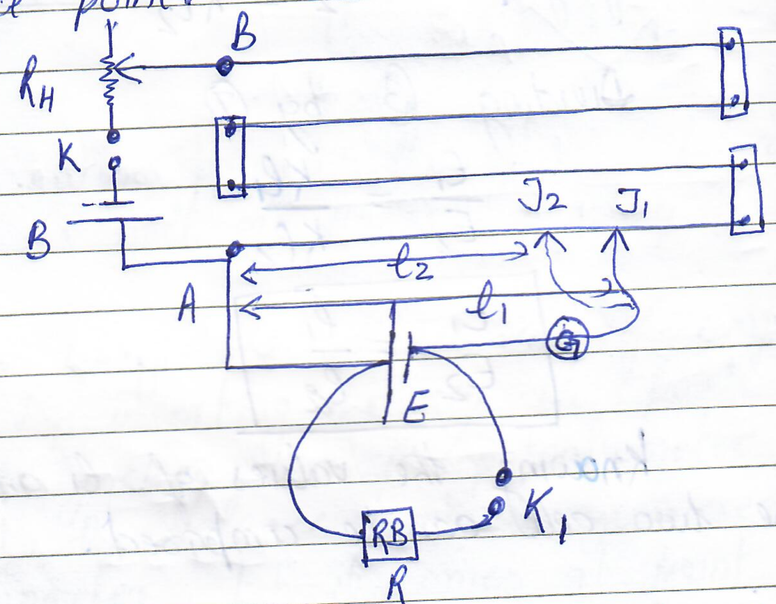
$\Rightarrow \quad E = Kl_1$ — (3) { ∵ $V \propto l$ and key K... open i.e. no current drawn from the ce...

Now insert the key K_1 and apply suitable res... R with the help of resistance box RB. and aga... slide the jockey on the potentiometer wire to f... out the balance point.

Let it come at J_2 so that $AJ_2 = l_2$



Since there is no current in the arm A E...

∴ Pot. of +ve term. of E = Pot. of pt A

and " " −ve " " E = " " " J_2

∴ Pot. diff. b/w ~~pt~~ two terminals of cell E = Pot diff. b/w pt. A a...

$\Rightarrow \quad V = Kl_2$ — (4) { ∵ key K_1 is ... and current flo... ~~arm~~ the loop E...

Now we know that internal resistance of the cell

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

$$\Rightarrow \quad r = \left(\frac{Kl_1}{Kl_2} - 1\right) R$$ { using (...

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

Knowing the values of l_1, l_2 and R (resistance removed from the resistance box.) internal resistance of the cell can be calculated.

Superiority of a potentiometer to a voltmeter ↦ Potentiometer is a null method device. At null point or balance point no current is drawn from the cell. Thus it can measure the emf of the cell.

where as voltmeter draws small current for its operation. Thus it is capable of measuring only the Pot Diff. ~~of the~~ b/w two terminals of the cell or b/w two points.

Moreover a potentiometer is much more sensitive than a voltmeter and its senstivity can further be increased by using long wire potentiometers or by decreasing the pot. gradient (ie pot. drop per unit l) and pot. gradient for a given potentiometer can be reduced by lowering the value of current passed through the wire.

Wheatstone Bridge :→ It is an arrangement of four resistance connected to each other so as to form a bridge. In wheatstone bridge, one unknown resistance can be calculated if the value of other three resistances is known to us.

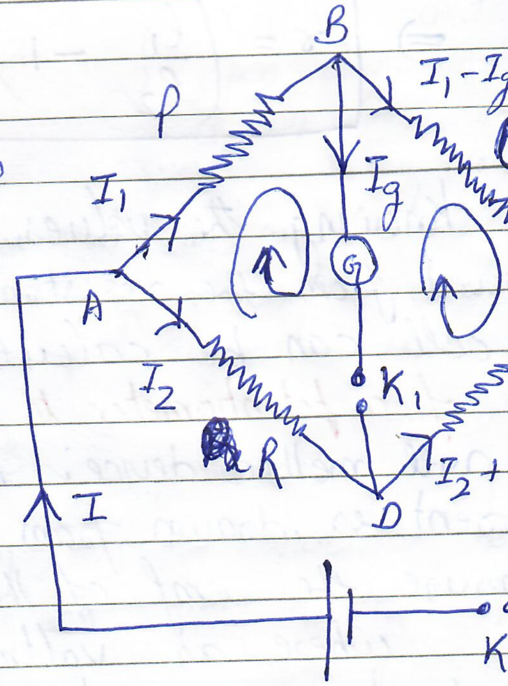
Principle ↦ According to wheatstone bridge principle when no current flows through the galvanometer then bridge is said to be in balanced state. And at ~~bla~~ balanced state,

$$\frac{P}{Q} = \frac{R}{S}.$$

Proof →

Consider a wheatstone bridge consisting of four resistances P, Q, R and S connected to a battery and key as shown.

The various currents flowing through the resistance can be determined using Kirchhoff's first law.



Applying Kirchhoffs second law in closed loop

$$I_1 P + I_g G - I_2 R = 0 \quad \text{—— (1)}$$

||ly for closed loop BCDD.

$$(I_1 - I_g) Q - (I_2 + I_g) S - I_g G = 0 \quad \text{—— (}$$

For balance state of the bridge, $I_g = 0$

thus - eqn (1) and (2) becomes

$$I_1 P - I_2 R = 0 \quad \Rightarrow \quad I_1 P = I_2 R \quad \text{——}$$

$$I_1 Q - I_2 S = 0 \quad \Rightarrow \quad I_1 Q = I_2 S \quad \text{——}$$

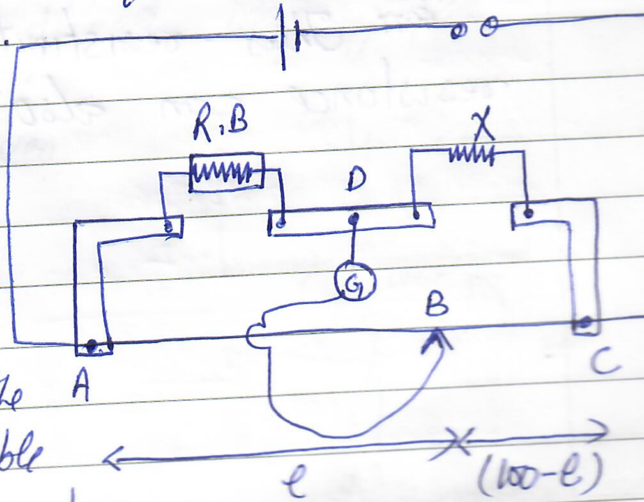
Dividing (3) by (4) we get

$$\boxed{\frac{P}{Q} = \frac{R}{S}}$$

Hence proved.

Meter Bridge or Slide Wire Bridge ↦ Slide wire bridge is the practical application of wheatstone bridge.

In slide wire bridge, a one meter lo[ng] manganin wire is fixed on the wooden board. A resistance box $\boxed{RB}$ and unknown resistance X a[re] attached b/w the two gaps of the copper strip as shown. A constant current is passed through the circ[uit] with the help of a battery.



A (G) and a jockey are attached b/w point D and B as shown.

~~Now remove a suitable resistance from~~

Now remove a key from the RB to introduce a suitable resistance R in the first gap and slide a jockey on the ~~potentriometer wire~~ wire to find out the balance point. Let it comes at point B so that

$AB = l \quad \therefore BC = 100 - l.$

~~If r is the resistance per unit length~~

Since bridge is in balanced state.

$$\therefore \frac{l r}{(100-l) r} = \frac{R}{X}$$

where r is resi[stance] per unit length of wire.

$$\Rightarrow \boxed{X = \frac{(100-l)R}{l}}$$

knowing the value of balancing length l, [and] from RBox R, the value of unknown re[sistance] X can be calculated.

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Also $X = \frac{\rho l'}{A'}$ $\left[R = \rho \frac{l}{A} \right.$

where l', A' are the length and area of cross section of the wire of unknown resistance.

$\therefore \rho = X \frac{A'}{l'}$

~~on~~ Thus resistivity of the material of resistance can also be determined.

classmate