Chapter-3

27/7/21

Current Electricity

Exercises

3.1 Emf of battery, $\mathcal{E} = 12V$
Internal resistance of battery, $r = 0.4\,\Omega$
Max. Current from battery = ?
Ohm's law say - $\mathcal{E} = Ir$

$$I = \mathcal{E}/r$$

$$\Rightarrow 12/0.4 = 30A$$

30A is the maximum current drawn from the battery.

3.2 Emf of battery, $\mathcal{E} = 10V$
Internal resistance of the battery $= 3\Omega$
Current in circuit $= 0.5A$
Resistance = ?
Relation for current using Ohm's law

$$I = \frac{\mathcal{E}}{R+r}$$

$$R+r = \mathcal{E}/I = 10/0.5 = 20\Omega$$

$$R = 20-3 = 17\Omega$$

Terminal voltage of the resistance
According to Ohm's law,

$$V = IR = 0.5 \times 17$$
$$= 8.5V$$

$\therefore$ Resistance $= 17\Omega$ and terminal voltage $= 8.5V$

3.3 (a) 3 resistance $1\Omega, 2\Omega, 3\Omega$ are in series.

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Total resistance $= 1+2+3 = 6\Omega$

(b) Current $= I$

Emf of the battery, $\varepsilon = 12V$

Total resistance, $R = 6\Omega$

According to Ohm's law,

$$I = \varepsilon/R$$
$$= 12/6 = 2A$$

Potential drop across 1st resistance $= V_1$

From Ohm's law, the value of V_1 can be obtained V_1

$$= 2\times1 = 2V \quad \text{— (I)}$$

Potential drop across V_2

$$\therefore V_2 = 2\times2 = 4V \quad \text{— (II)}$$

Potential drop across V_3

$$\therefore V_3 = 3\times2 = 6V \quad \text{— (III)}$$

So, potential drop across V_1, V_2, V_3 is 2V, 4V and 6V

3.4 3 resistors of resistance

$$\Rightarrow R_1 = 2\Omega,\ R_2 = 4\Omega,\ R_3 = 5\Omega$$

Total resistance in parallel combination

$$\Rightarrow 1/R = 1/R_1 + 1/R_2 + 1/R_3$$

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$\Rightarrow 1/R = 1/2 + 1/4 + 1/5$

$= \frac{10+5+4}{20} = 19/20$

$\therefore R = 20/19\ \Omega$

(b) Emf be of the battery, $V = 20V$
I_2 flowing through R_2 resistor

$I_2 = V/R_2 = 20/4 = 5A$

Current I_3 flowing through resistor R_3 is given by,

$I_3 = V/R_3$

$= 20/5 = 4A$

Total current $\Rightarrow I = I_2 + I_1 + I_3$

$= 10+5+4$

$= 19A$.

3.5 Room Temperature, $T = 27°C$
Resistance of heating substance $= 100\Omega$

Let, T_1 = increased temperature of the fialment
Resistance of the heating element at T_1, $R_1 = 117\Omega$

Temp. co-efficient of the ~~fil~~ material of the

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the fialment,

$$\lambda = 1.70 \times 10^{-4}\,°C^{-1}$$

$$\lambda = \frac{R_1 - R}{R(T_1 - T)}$$

$$\Rightarrow T_1 - T = \frac{R_1 - R}{R\alpha}$$

$$\Rightarrow T_1 - 27 = \frac{117 - 100}{100(1.70 \times 10^{-4})}$$

$$\Rightarrow T_1 = 1000 + 27$$

$$\Rightarrow T_1 = 1027°C$$ at resistance $117\,\Omega$

3.6 Length of the wire, $l = 15\,m$
Area of cross section of the wire, $a = 6.0 \times 10^{7}\,m^2$
Resistance $= 5.0\,\Omega = R$
Resistivity of the material $= \rho$
Resistance related resistivity as

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

$$\rho = \frac{RA}{l}$$

$$= \frac{5 \times 6 \times 10^{-7}}{15} = 2 \times 10^{-7}\,\Omega m.$$

3.7 Temperature, $T_1 = 27.5°C$
Resistance of wire at T_1, $R_1 = 2.1\,\Omega$
Temperature, $T_2 = 100°C$

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Resistance $= 2.7\,\Omega = R_2$

Temp. co-efficient of silver $= a$
It is related with temp. and resistance

$$\alpha = \frac{R_2 - R_1}{R_1(T_2 - T_1)}$$

$$= \frac{2.7 - 2.1}{2.1(100 - 27.5)}$$

$$= \frac{0.5}{2.1(72.5)}$$

$$= 0.0039\,°C^{-1}$$

3.8 Supply voltage $= V = 230V$
I_1 = Initial current drawn $= 3.2A$
R_1 = Initial resistance $= V/I$

$$= \frac{230}{3.2} = 71.87\,\Omega$$

Steady state value of the current be $= 2.8A$

$$R_2 = \frac{230}{2.8} = 82.14\,\Omega$$

Temp. co-efficient of nichrome, $a = 1.70 \times 10^{-4}\,C^{-1}$.

Initial temp. of nichrome, $T_1 = 27°C$.

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Steady state temp. reached by nichrome = T_2

T_2 can be obtained by the relation of a,

$$\alpha = \frac{R_2 - R_1}{R_1(T_2 - T_1)}$$

$$T_1 = -27°C = \frac{82.14 - 71.87}{71.87 \times 1.7 \times 10^{-4}} = 840.5$$

$$T_2 = 840.5 + 27$$
$$= 867.5°C$$

3.9 For closed ~~circuit~~ circuit ABDA,

Potential = 0,

$$10I_2 + 5I_4 - 5I_3 = 0$$
$$I_3 = 2I_2 + I_4 \quad \text{—— (1)}$$

For closed circuit BCDB,

Potential = 0

$$5(I_2 - I_4) - 10(I_3 + I_4) - 5I_4 = 0$$
$$\Rightarrow 5I_2 - 10I_3 - 20I_4 = 0$$
$$I_2 = 2I_3 + 4I_4 \quad \text{—— (2)}$$

For closed circuit ABCFEA,

Potential = 0

$$-10 + 10(I_2) + 10(I_2) + 5(I_2 - I_4) = 0$$
$$\Rightarrow 10 = 15I_2 + 10I_1 - 5I_4$$
$$\Rightarrow 3I_2 + 2I_1 - I_4 = 2 \quad \text{—— (3)}$$

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From (1) and (2)

$\Rightarrow I_3 = 2(2I_3 + 4I_4) + I_4$

$\Rightarrow I_3 = 4I_3 + 8I_4 + I_4$

$\Rightarrow 3I_3 = 9I_4$

$\Rightarrow -3I_4 = I_3$ —— (4)

Putting Eq^n's (4) in (1),

$I_3 = 2I_2 + I_4$

$-4I_4 = 2I_2$

$I_2 = -2I_4$ —— (5)

It is evident that

$I_1 = I_3 + I_2$ —— (6)

Putting Eq^n's (6) in (1)

$3I_2 + 2(I_3 + I_2) - I_4 = 2$

$5I_2 + 2I_3 - I_4 = 2$ —— (7)

Putting Eq^n's (4) and (5) in (7)

$5(-2I_4) + 2(-3I_4) - I_4 = 2$

$\Rightarrow -10I_4 - 6I_4 - I_4 = 2$

$\Rightarrow 17I_4 = -2$

$\Rightarrow I_4 = -2/17\ A$

Eq^n (4) reduces to

$I_3 = -3(I_4)$

$= -3(-2/17) = 6/17\ A$

$\Rightarrow I_2 = -2(I_4)$

$= -2(-2/17) = 4/17\ A$

$\Rightarrow I_2 - I_4 = 4/17 - (-2/17) = 6/17\ A$

$\Rightarrow I_3 + I_4 = 6/17 + (-2/17) = 4/17\ A$

$I_1 = I_3 + I_2 = 16/17 + 4/17 = 10/17\ A$

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∴ Current branch $AB = 4/17$ A

$BC = 6/17$ A

$CD = -4/17$ A

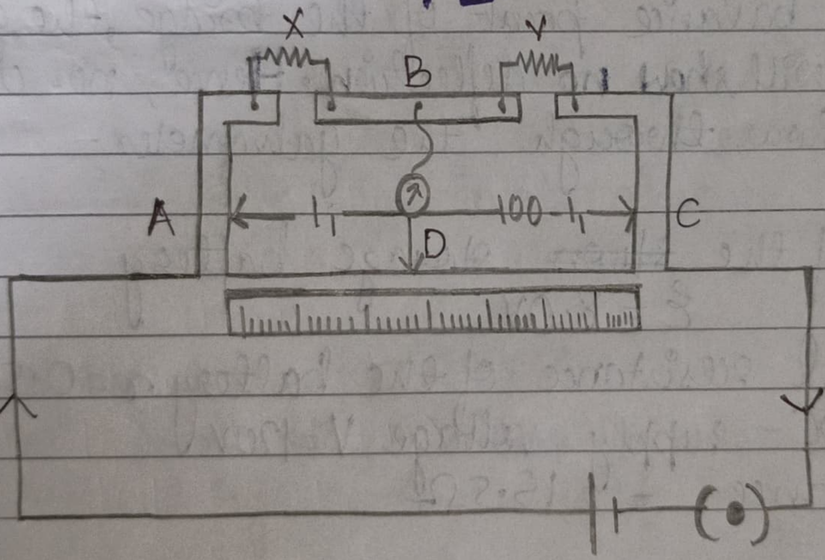
$AD = 6/17$ A

$BD = -2/17$ A

Total current $= 4/17 + 6/17 + 6/17 - 4/17 - 2/17$

$= 10/17$ A.

3.10



(a) Balance point from end A, $l_1 = 39.5$ cm
Resistance of the resistor $Y = 12.5\,\Omega$
Condition for balance given

$\Rightarrow X/Y = \dfrac{100 - l_1}{l_1}$

$\Rightarrow X = \dfrac{100 - 39.5}{39.5} \times 12.5 = 8.2\,\Omega$ ⇒ resistance

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The connection between resistors in a wheel stone ~~or~~ metre bridge is made of thick copper strips to minimize the resistance, which isn't taken to consideration in the bridge formula.

(b) If X and Y are interchanged then, l_1 and $100-l_1$ get interchanged.

The balance point of the bridge will be $100-l_1$ from A

$100-l_1 = 100 - 39.5 = 60.5$ cm.

(c) When the galvanometer and cell are interchanged at the balance point of the bridge, the galvanometer will show no deflection. Hence, no current would flow through the galvometer.

3.11 Emf of the ~~stron~~ storage battery

$\mathcal{E} = 8.0V$

Internal resistance of the battery $r = 0.5\,\Omega$

DC supply voltage $V = 120V$

Resistance $= 15.5\,\Omega$

Effective voltage in the circuit $= V$

R is connected to the storages battery in series. Hence, it can be written as

$V' = V - \mathcal{E}$

$V' = 120 - 8 = 112V$

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Current flowing in the circuit = I

$$I = \frac{V}{R+r} = \frac{112}{15.5+0.5} = \frac{112}{16} = 7A$$

Voltage across resistor R is given by product IR
$= 7 \times 15.5 = 105.5V$

DC supply voltage = Terminal voltage of battery and voltage drop across R

Terminal voltage of battery $= 120 - 108.5$
$= 11.5 V$

3.12 A series resistor in a charging circuit limits the current drawn from the external source. The current will be extremely high in its absence. This is very dangerous

Emf of the cell, $\varepsilon_1 = 1.25V$
Balance point to potentiometer, $l_1 = 35 cm$
Cell replaced by another cell of Emf, ε_2

New Balance point to the potentiometer $l_2 = 63 cm$
The balance condition is given by the relation,

$$\frac{\varepsilon_1}{\varepsilon_2} = \frac{l_1}{l_2}$$

$$\Rightarrow \varepsilon_2 = \frac{\varepsilon_1 \times l_2}{l_1}$$

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$= 1.25 \times \frac{63}{35}$

$= 2.25V$ 2nd cell Emf

3.13 No. of density electrons in a copper conductor, $n = 8.5 \times 10^{28}\ m^{-3}$.

Length of wire of copper $= l \Rightarrow 3.0\ m$
Area of cross section of the wire,
$A = 2.0 \times 10^{-6}\ m^2$.
Current carried by the wire, $I = 3.0A$
given by relation, $I = nAeVd$

where, e = electric charge $= 1.6 \times 10^{-19} C$

$= \frac{\text{length of the wire } (l)}{\text{Time taken to cover } l\ (t)}$

Vd = Drift velocity
$I = nAe\, l/t$

$t = \frac{nAel}{I}$

$= \frac{3 \times 8.5 \times 10^{28} \times 2 \times 10^{-4} \times 1.6 \times 10^{-19}}{3}$

$= 2.7 \times 10^{4}\ s$

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3.14 Surface charge density on the earth, $\sigma = 10^{-9} cm^{-2}$
Current over the entire globe, $I = 1800 A$
Radius of earth, $r = 6.37 \times 10^6 m$

Surface area of the earth
$A = 4\pi r^2$
$= 4\pi (6.37 \times 10^6)^2$
$= 5.09 \times 10^{14} m^2$

Charge on earth surface
$q = \sigma \times A$
$= 10^{-9} \times 5.09 \times 10^{14}$
$= 5.09 \times 10^5 C$

Time taken to neutralize the earth's surface $= t$
$\Rightarrow I = q/t$

Current, $t = q/I = \dfrac{5.09 \times 10^5}{1800} = 282.775$

3.15 (a) No. of secondary cell, $n = 6$
Emf of each secondary cell, $E = 2.0V$
Internal resistance of each, $= 0.015 \Omega$

$\Rightarrow$ Series resistor; Resistance $R = 8.5 \Omega$
current drawn $= I$
$\Rightarrow I = \dfrac{nE}{R + nr}$

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$$= \frac{6 \times 2}{8.5 + 6 \times 0.015}$$

$$= \frac{12}{8.59} = 1.39\,A$$

Terminal voltage, $V = IR = 1.39 \times 8.5$
$= 11.87\,A$

(b) After long use, emf would be, $\varepsilon = 1.9V$

Internal resistance, $r = 380\Omega$

$$= \varepsilon / r = \frac{1.9}{380} = 0.005\,A$$

Max. current = 0.005A

Since a large amount of current is require to start a motor of a car, the cell cann't be used to start a motor.

3.16 Resistivity of aluminium of A $= 2.63 \times 10^{-8}\,\Omega$
Relative density, $d_1 = 2.7$
Let, l_1 = length and m_1 = mass
Resistance = R_1
Area of cross-section = A_1

Resistivity of copper, $\rho_{cu} = 1.72 \times 10^{-8}\,\Omega$
Relative density of copper, $d_2 = 8.9$
Let, l_2 = length and m_2 be in mass
Resistance = R_2
Area of cross-section = A_2

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$$\therefore R_1 = \rho_1 \frac{l_1}{A_1} \quad \text{—— (I)}$$

$$R_2 = \rho_2 \frac{l_2}{A_2} \quad \text{—— (II)}$$

It is given that, $R_1 = R_2$

$$\rho_1 \frac{l_1}{A_1} = \rho_2 \frac{l_2}{A_2}$$

And $l_1 = l_2$

$$\therefore \frac{\rho_1}{A_1} = \frac{\rho_2}{A_2}$$

$$\frac{A_1}{A_2} = \frac{\rho_1}{\rho_2}$$

$$= \frac{2.63 \times 10^{-8}}{1.72 \times 10^{-8}} = \frac{2.63}{1.72}$$

Mass of aluminium

m_1 = volume × density

$\Rightarrow A_1 l_1 \times d_1 = A_1 l_1 d_1$ —— (3)

Mass of copper $= A_2 l_2 d_2$ —— (4)

Dividing (3) by (4).,

$$\frac{m_1}{m_2} = \frac{A_1 l_1 d_1}{A_2 l_2 d_2}$$

for $l_1 = l_2$

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$$\frac{m_1}{m_2} = \frac{A_1 d_1}{A_2 d_2}$$

for $\frac{A_1}{A_2} = \frac{2.63}{1.72}$

$$\frac{m_1}{m_2} = \frac{2.63}{1.72} \times \frac{2.7}{8.9}$$

$$= 0.46$$

⇒ We can infer that m_1 is less than m_2, so aluminium is lighter than copper. hence it is preffered for overhead power cables.

3.17 We can conclude that, ratio of voltage with current is a constant which = 19.7. Hence, managanism is an ohmic conductor i.e., an alloy that obeys ohm's law, i.e., voltage and current ratio is the resistance of the conductor. It's resistance = 19.7 Ω.

3.18 (a) When a steady current flows in a metallic conductor of non-uniform cross-section, the current flowing through it is constant. Current density, electric field and drift speed are inversely proportional to the area of cross-section. They aren't constant.

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(b) Ohm's law isn't universally applicable for all conducting elements. Vacuum diode semi-conductor ~~is~~ is a non-ohmic conductor. Ohm's law isn't valid for it.

(c) Ohm's law states $V = IR$,
R = resistance
$I = V/R$

If V is low, then R must be very low, so high current can be drawn from source.

(d) To prohibit the current exceeding safety limit, a high tension supply must have a high internal resistance. If it isn't large, current drawn can exceed safety limits and can hence cause a short circuit.

3.19 (a) Alloys of metals usually have greater resistivity than that of their constituent metal.

(b) Alloys have lower temperature co-efficient of resistance than pure metal.

(c) The resistivity of the alloy magnetic is nearly independent of increase of temperature.

(d) The resistivity of a typical insulator is greater than that of a metal by a factors of order 10^{22}.

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3.20 (a) Total no. of resistors $= n$

Resistance of each $= R$

(i) When n resistor are connected in series, effective resistance R_1, is the maximum, given product nR.

$$\therefore R_1 = nR$$

(ii) n-resistors are connected in parallel, the effective resistance R_2 is the minimum by ratio $= R/n$

(iii) minimum resistance $R_1 = R/n$

Ratio of max. to min. resistor.

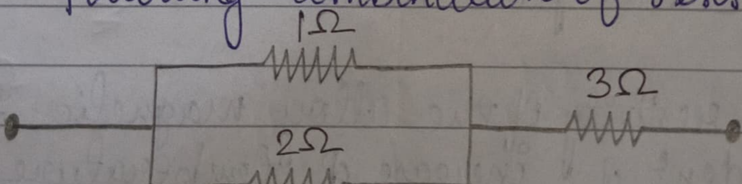
$$R_1/R_2 = nR/R/n = n^2$$

(b) Resistance of given resistors.

$$R_1 = 1\Omega,\ R_2 = 2\Omega,\ R_3 = 3\Omega$$

$$R = 11/3\,\Omega$$

(i) Consider following combination of resistor.



Equivalent resistance

$$\Rightarrow R = \frac{2 \times 1}{2+1} + 3 = \frac{2}{3} + 3 = 11/3\,\Omega$$

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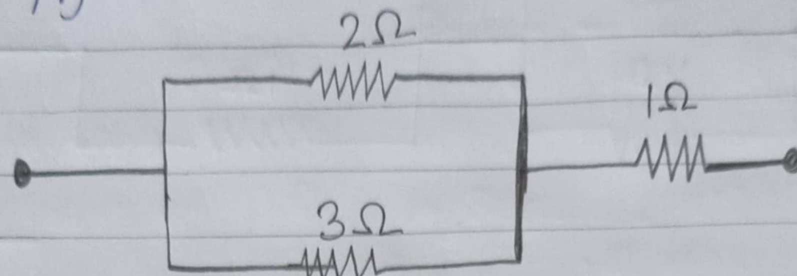
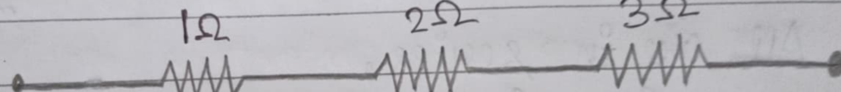
(ii) $R = 11/5\,\Omega$

$\Rightarrow$ 

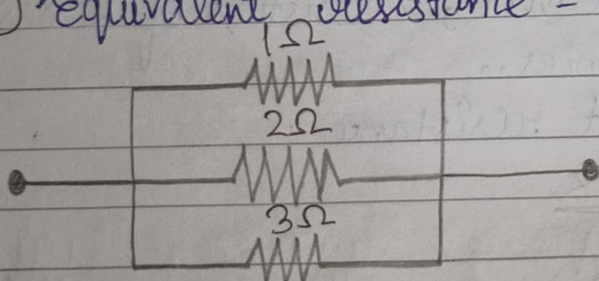
$$R = \frac{2\times 3}{2+3} + 1 = \frac{6}{5} + 1 = 11/5\,\Omega$$

(iii) $6\Omega = R$

$\therefore \Rightarrow$ 

$$R = 1+2+3 = 6\Omega$$

(iv) Equivalent resistance $= R = 6/11\,\Omega$



$$R = \frac{1\times 2 \times 3}{1\times 2\times 3 + 3\times 1} = 6/11\,\Omega$$

(c) (i) It can be observed from circuit that in 1st small loop, 2 resistance of 1Ω are is series,

$$R = 1+1 = 2\Omega$$

and are 2 resistor of 2Ω resistance are in series.,

$$\therefore R = 2+2 = 4\Omega$$

$\therefore$ Circuit can be drawn.,

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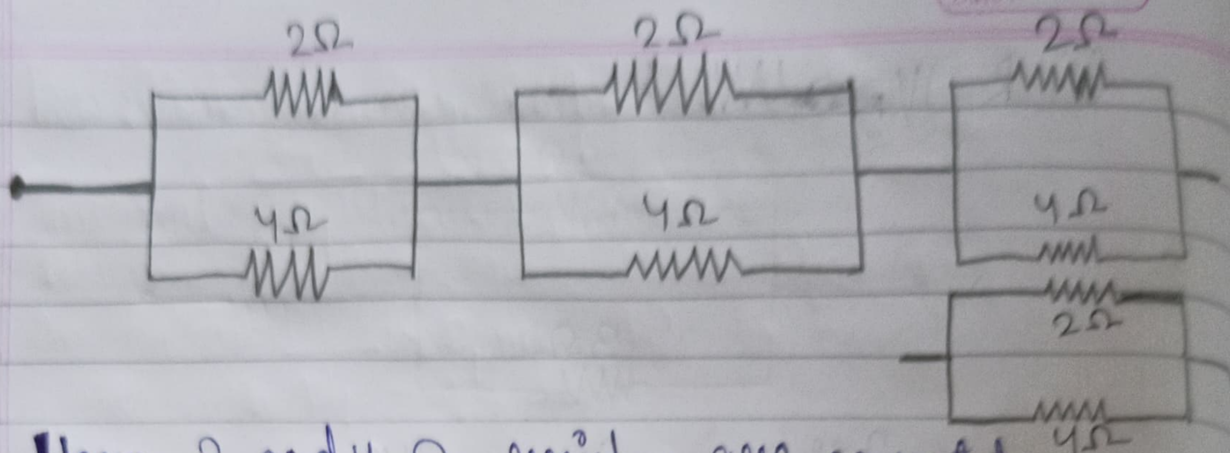

Here 2 and 4 Ω resistors are connected in parallel.,

$\therefore$ $(R)'$ of each loop $= R = \frac{2\times4}{2+4} = 4/3\,\Omega$

All are in series,

Equivalence Resistance of the given resistance $= 4/3 \times 4 = 16/3\,\Omega$

(ii) It can be observed, 5 resistors of R resistance are connected in series.,

Hence, equivalent resistance

$= \underline{5R}$

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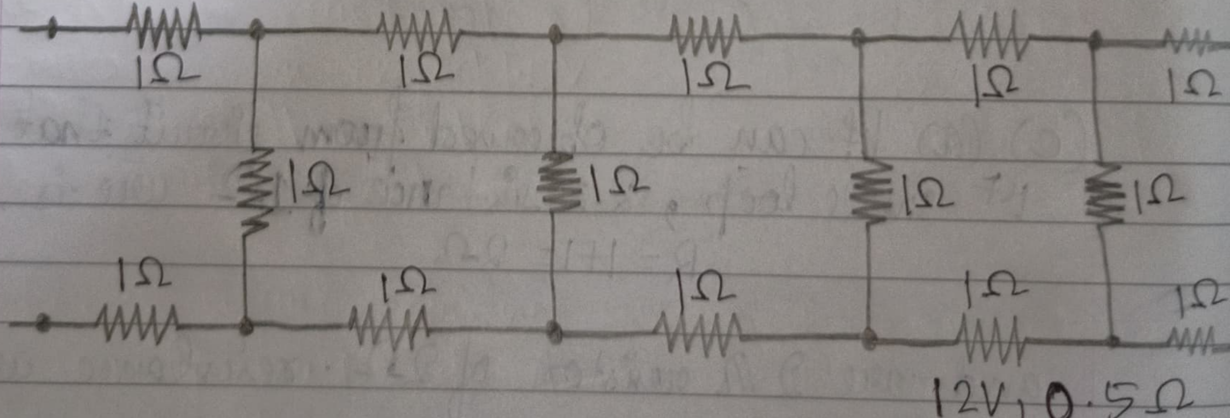

Resistance of each resistor = 1 Ω

Equivalent resistance = R'

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Net work is infinite. Hence, equivalent resistance is given by the relation

$$\therefore R = 2 + \frac{R}{(R'+1)}$$

$$\Rightarrow (R')^2 - 2R - 2 = 0$$

$$\Rightarrow R^2 - 2R - 2 = 0$$

$$R' = \frac{2 \pm \sqrt{4+8}}{2}$$

$$= \frac{2 \pm \sqrt{12}}{2} = 1 + \sqrt{3}$$

Negative of R' can't be accepted

$$\therefore R' = (1+\sqrt{3}) = 1 + 1.73$$
$$= 2.73\,\Omega$$

Internal resistance $r = 0.5\,\Omega$

Hence, total resistance of given circuit $= 2.73 + 0.5 = 3.23\,\Omega$

$V = 12V$

$\therefore$ Current (Ohm's law) $= V/R = 12/3.23 = 3.72\,A$

3.29 (a) Constant Emf of the given standard cell, $E_1 = 1.02$

Balance point on the wire $= l_1 = 67.3$ cm

Cell of unknown Emf, E replaced the standar cell.

$\therefore$ New balance point on wire $l = 82.3$ cm

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Relation connecting Emf, and balance point

$$\frac{\mathcal{E}_1}{l_1} = \frac{\mathcal{E}}{l}$$

$$\mathcal{E} = \frac{l}{l_1} \times \mathcal{E}_1$$

$$= \frac{82.3}{67.3} \times 1.02$$

$$= 1.247\,V$$

3.23

(b) It is to reduce the current through galvanometer when the movable constant is far from the balance point.

(c) No, balance point isn't affect by high resistance.

(d) Point is not affected by internal resistance of the driver shell.

(e) Method would not work if driver cell of potentiometer had in Emf of 1.0V instead 2.0V, because it is less than Emf of the other cell, there would be no balance point on the wire.

(f) The circuit would not work well for determining extremely small Emf. As the circuit would be unstable, the balance point would be close to end A. So there would be a large % error.

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The given circuit can be modified if a series resistance is connected with AB metre. Potential drop across AB is slightly greater than emf measured. The % error would be small.

3.23 Resistance of Standard resistance
$R = 10.0\,\Omega$

Balance point, $l_1 = 58.3$ cm
Current of potentiometer wire $= i$
Hence, potential drop across, R, $E_1 = iR$

Resistance of unknown resistance $= X$
Its balance point $= 68.5\text{ cm} = l_2$
It's potential drop across X, $E_2 = iX$

The relation connecting balance point and Emf is

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

$$\Rightarrow \frac{iR}{iX} = \frac{l_1}{l_2}$$

$$\Rightarrow X = \frac{l_1}{l_2} \times R = \frac{68.5}{58.3} \times 10 = 11.749\,\Omega$$

If we fail to find balance point, with given cell of emf, E = ; then potential drop across R and X must be reduced by putting a resistance in series with it. Only if the potential drop across R or X is smaller than the potential drop, across wire

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AB, a balance is obtained.

3.24 Internal resistance of cell = r,
Balance point of the cell in open circuit, $l_1 = 76.3$
An external resistance (R) is connected to the circuit with $R = 9.5\,\Omega$

New balance point of the circuit, $l_2 = 64.8$ cm
Current flowing through the circuit = I

The relation connecting resistance and Emf is

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

$$= \frac{76.3 - 64.8}{64.8} \times 9.5$$

$$= 1.68\,\Omega$$ (Internal resistance of the cell).