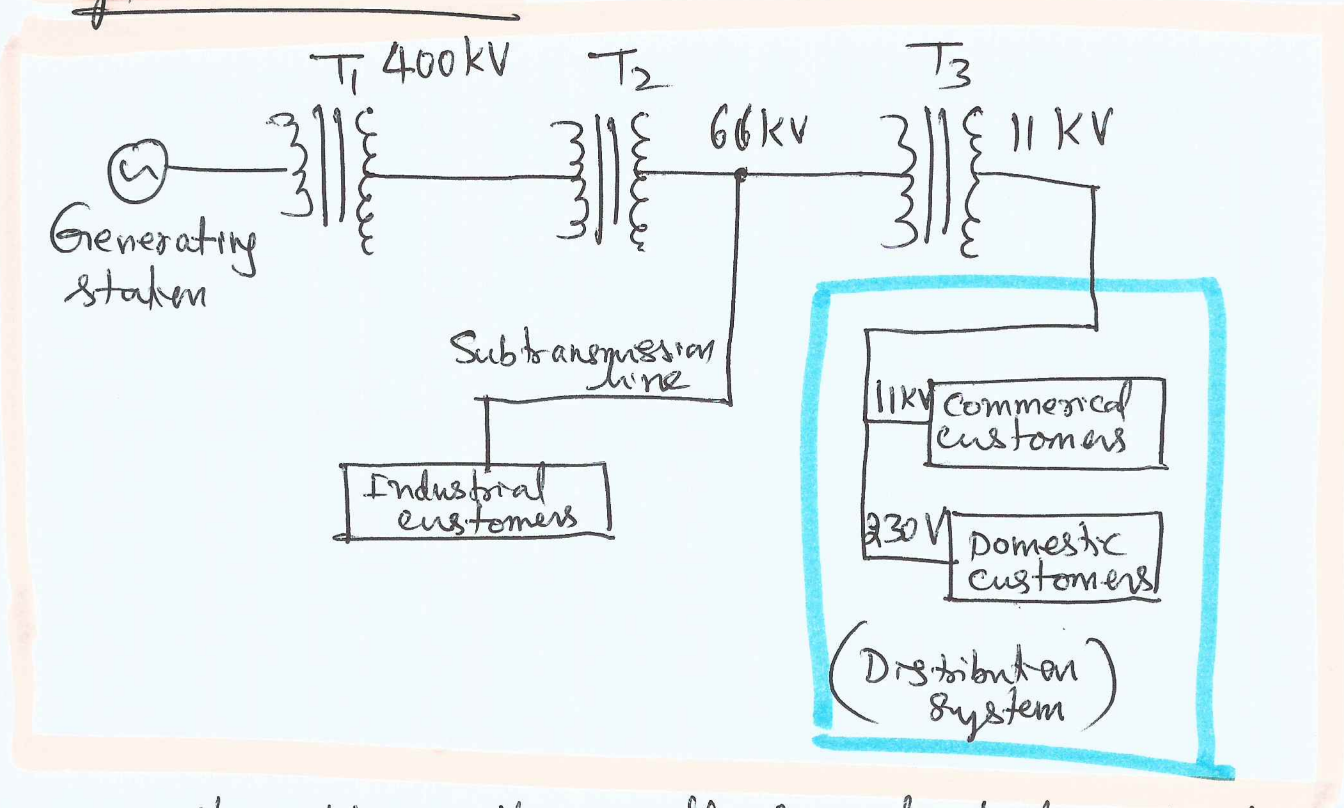
Typical distribution.

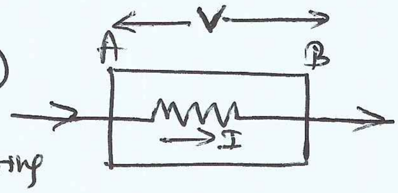


presently, this is the method adopted in India where generating station produces very high voltages before transmission over long distances and using step-down transformers, required voltage will be supplied to customers.
Whereas the current drawn is dependent on the load.

From other book

Electric Energy and power.

→ **Electric energy**: In general, the work done by a source to maintain a current in an electrical circuit is known as electric energy.



- Consider an electric device (eg. lamp, heater etc) thro' which current I flows from A to B for time ~~dt~~ t. Let q be the charge ~~from~~ flowing from A to B in time t. $q = It$
- If V is pd betn A and B, then work done to carry the charge q from A to B is given by

$$W = Vq = VIt \longrightarrow (1)$$

This work done is equal to the electrical energy E consumed in the circuit and is given by

$$E = VIt \longrightarrow (2)$$

we know that $V = IR$

$$\boxed{E = (IR)It = I^2Rt}$$

⇒ This is the form of energy which is converted into heat energy.

~~Also (2)~~ $\boxed{E = \frac{V^2}{R}t}$

SI unit of electrical energy

1 joule = 1 volt × 1 Ampere × 1 s = 1 VAs

→ **Electric power** → rate of doing work

$$\therefore P = \frac{\text{energy produced}}{\text{time}} = \frac{\cancel{R}E}{t} = \frac{I^2Rt}{t} = I^2R$$

$$\therefore \boxed{P = I^2R \quad \text{or} \quad P = \frac{V^2}{R} \quad \text{or} \quad P = VI}$$

unit = Watt = 1 A × 1 V

1 horse power = 746 W

※ IMP (1) $P = VI$ applies to rate of electric energy transfer from a source (say a cell or battery)

(2) $P = I^2R$ or $P = \frac{V^2}{R}$ applies to the rate of transfer of electric energy to thermal or heat energy in resistance R.

→ Commerical unit 1 unit = 1 KW·h = 1000 Wh

$$1\,\text{kW·h} = 1000\,\frac{J}{\cancel{s}} \cdot 3600\,\cancel{s} = 3.6 \times 10^6\,J$$

Q: Which of the 2 has higher R: a 1000 W heater or a 100 W bulb both @ 230 V?

$$P = \frac{V^2}{R}; \quad R = \frac{V^2}{P}$$

$$R_{heater} = \frac{23\cancel{0} \times 23\cancel{0}}{10\cancel{00}} = 52.9\,\Omega$$

$$R_{bulb} = \frac{23\cancel{0} \times 23\cancel{0}}{\cancel{100}} = 529\,\Omega$$

Q!: A 500 W lamp gives light for 10 hrs @ 230 V_{rms}. Find the cost of electric consumption for 30 days if cost of energy is Rs 3/— per unit.

→ Energy Consumed per day $= p \times t = 500 \times 10h = 5000 Wh$

$= 5 kW \cdot h = 5$ units.

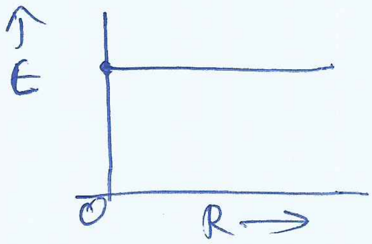
For 30 days $= 30 \times 5 = 150$ units.

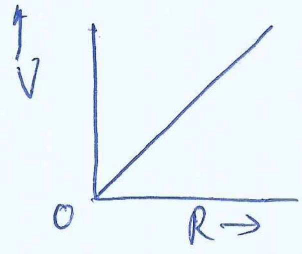
Cost of energy $= 150 \times$ Rs. 3 $=$ Rs 450/—

* tips :-

(1) emf of a cell does not change with external Resistance R connected across the cell. On the other hand, terminal p.d. V of a cell is directly $\propto$ to R connected across the cell.

$\Rightarrow E$ independent of R and $V \propto R$.



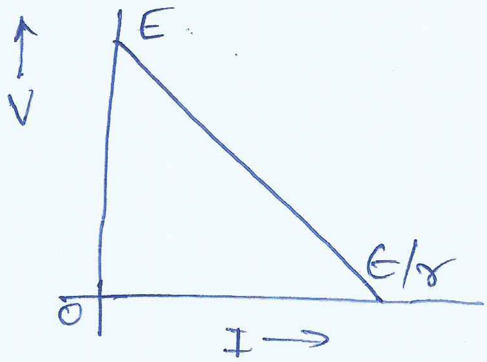


(2) The variation of V of the cell with current I is shown below

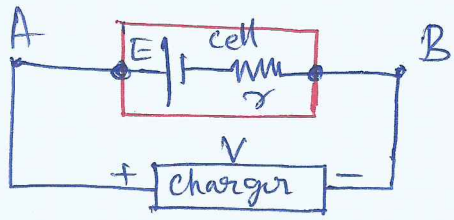
eqn is $y = mx + c$

$\Rightarrow V = -Ir + E$; Comparing

E = intercept and slope $= -r$



(3) <u>Charging battery</u> : when a battery is to be charged, the charger voltage V is kept equal or more than E of the cell. In this case, net p.d. $= V - E$



This net p.d. is equal to voltage dropped (Ir) in the internal resistance (r) of the cell, then

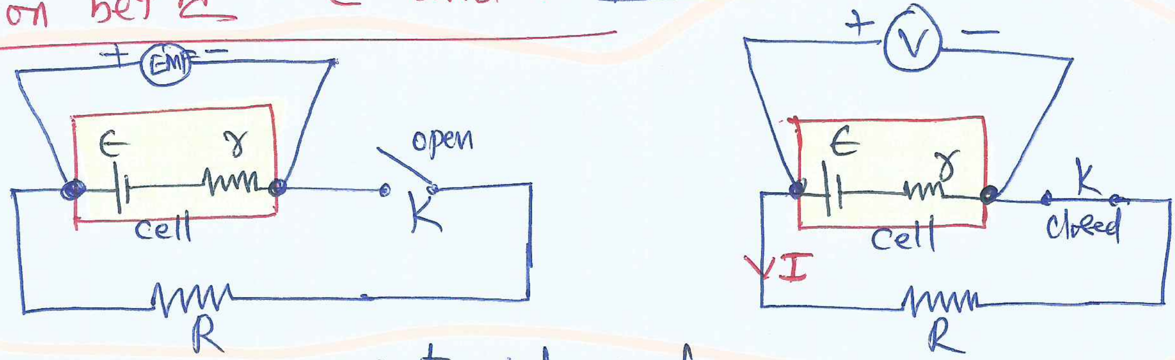
$$V - E = Ir$$

$$\boxed{V = E + Ir}$$

X. Comparison betⁿ EMF and V

$\mathcal{E}$ (emf)	V (Terminal p.d)
1. The difference of potentials betⁿ the two terminals of a cell when no current is drawn from the cell (i.e. when circuit is open) is called emf of the cell	1. The difference of potentials betⁿ the two terminals of a cell when current is drawn from the cell (i.e. when circuit is closed) is called terminal p.d. of the cell
2. The emf of a cell is independent of external resistance in the circuit. It depends upon the type of a cell	2. p.d. ~~betⁿ~~ between any two points of a circuit is proportional to the resistance betⁿ these two points.
3. The emf of a cell > the p.d. betⁿ the two terminals of the cell.	3. p.d. ~~of~~ between the two terminals of the cell is < the emf of the cell when current is drawn from the cell.
4. The word emf is reserved for the p.d. of an electric Source	4. The word p.d. is used for the measurement made between any two points of the electric circuit.
5. It is a special term which is related to "Source" of electric current.	5. It is a general term which indicates the ~~ef~~ effect of electric current

Relation betn ϵ and V



- Key K is open, no current is drawn from the cell. So, voltmeter connected across the cell gives value emf ϵ.
- when K is closed, current I flows thro' R and r

$$\therefore I = \frac{\epsilon}{R+r} \implies \epsilon = IR + Ir$$

Since external R is connected in parallel to the ~~cell~~ "electrodes" of the cell, so the "terminal p.d" of the cell is equal to p.d. across R.

$$\therefore V = IR$$

$$\therefore \epsilon = V + Ir \qquad \therefore \boxed{V = \epsilon - Ir}$$

$\implies$ Terminal p.d. of a cell < emf of the cell.

$\implies$ voltmeter connected across the cell reads V < emf value.

- If circuit is open $I = 0$ $\therefore$ $V = \epsilon$. Thus, terminal p.d. betn the electrodes of the cell is equal to the emf of the cell in an open circuit.

~~$V = \epsilon - Ir$~~

- $I = \dfrac{\epsilon}{R+r}$ using this in $V = IR$, we get

$$V = \frac{\epsilon R}{R+r} \implies VR + Vr = \epsilon R$$

$$\therefore Vr = \epsilon R - VR = (\epsilon - V)R$$

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

$$\therefore \boxed{r = \left(\frac{\epsilon}{V} - 1\right)R}$$

$\therefore$ Knowing ϵ, V, R, one can determine r.

From another book

Cells, emf, Terminal voltage (p.d) & internal resistance (r)

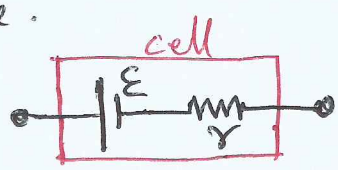
- A cell is a device which provides the necessary p.d. to an electric circuit to maintain a steady flow of current in it. (—|⊢—)
- **EMF**: of a cell is defined as the p.d. betⁿ the terminals of the cell when no current is drawn from the cell.
  → The work done by a cell to bring a unit positive charge from one terminal to the other terminal of the cell is called the electromotive force (emf)
  → unit of emf = Joule per coulomb = Volt (V), which is also the unit of electric potential and p.d.
- **Terminal p.d. or Terminal Voltage**:
  → Terminal p.d. of a cell is defined as the p.d. betⁿ its terminals in a closed circuit (i.e. when current is drawn from the cell)
  → SI unit → volt (V)
- **Internal Resistance of a cell (r)**:
  → r is defined as the opposition offered by ~~an~~ the electrolyte and electrodes of a cell to the flow of current thro' it.
  r mainly depends on nature of electrolyte & electrodes of a cell.
  → SI unit → ohm (Ω)

- **Tips**:

① Conventional current direction is opposite the electron current direction.

② Direction of conventional current inside a cell is from −ve to +ve electrode, whereas outside the cell it is from +ve to −ve electrode.

③ Representation:



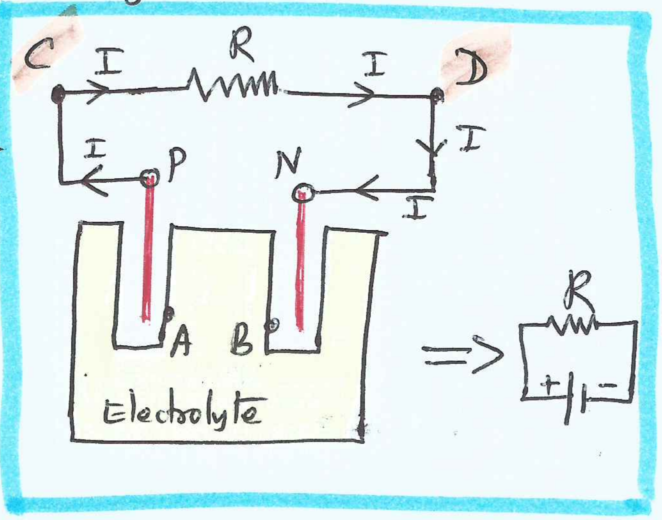
④ r of a cell increases with passage of time and usage of the cell.

⑤ r of a cell increases with the decrease in temperature.

p.T.O

Cells, EMF, Terminal p.d and Internal Resistance

→ A simple device to maintain a steady current in an electric circuit is the electrolytic cell.



→ Electrodes P and N are immersed in an electrolytic solution. Dipped in the solution, the electrodes exchange charges with the electrolyte.

→ P has p.d. V_+ (>0) betn itself and A.

→ N ~~has p.d.~~ develops a −ve potential $-(V_-)$ (>0) betn itself and B

→ When there is no current:
- the electrolyte has the same potential throughout, so that
- p.d. betn P and N is $V_+ - (-V_-) = V_+ + V_-$
- This difference is called Electromotive Force (EMF) of the cell, denoted by $\mathcal{E}$.
- Thus $\mathcal{E} = V_+ + V_- > 0$.
- Note that $\mathcal{E}$ is p.d. and not a force. The name is used because of historical reasons ~~and~~ was given name when phenomenon is not understood properly.

→ Resistance R connected across cell to make it a closed loop.
- Steady current flows thro' R from C to D
- Within electrolyte, same steady current is maintained ~~from~~ and flowing from N to P (Note thro' R it is from P to N)
- The electrolyte thro' which current flows has a finite resistance r, called the "internal resistance".

→ Consider R is infinite; $R >>> r$
- V = p.d. betn P & A + p.d. betn A & B + p.d. betn B & N

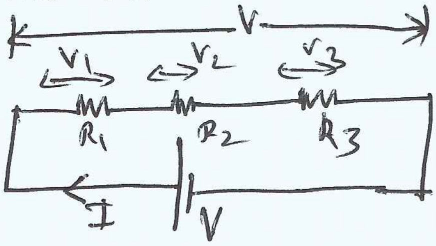
$V = \mathcal{E}$ ⟹ Thus emf $\mathcal{E}$ is the p.d. betn +ve and −ve electrodes in an open circuit. i.e. when no current is drawn from the cell (or no current flows thro' the cell)

→ R is finite:
- p.d. between P and N is $V = V_+ + V_- - Ir = \mathcal{E} - Ir$
- Note −ve sign in Ir, since current flows from B to A in the electrolyte.
- We know that $V = IR$; $IR = \mathcal{E} - Ir$ ∴ $\boxed{I = \dfrac{\mathcal{E}}{R+r}}$

→ *tips: The internal resistance of dry cells >> Common electrolyte cells.

Resistors in Series and parallel:

① **Series**: Two or more resistors are said to be in series if they are connected one after the other such that the same current flows through all the resistors when voltage is applied across the combination.



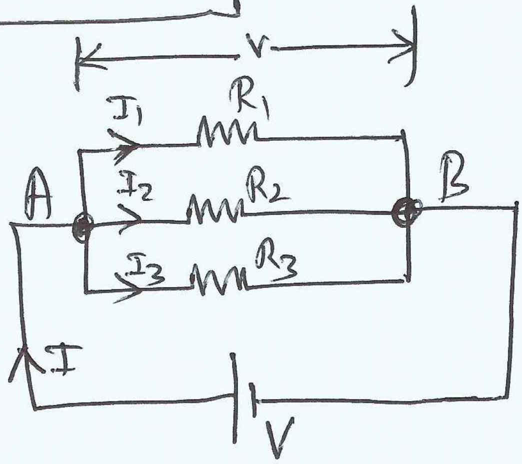
$$\boxed{V = V_1 + V_2 + V_3}$$

$V_1 = IR_1$; $V_2 = IR_2$; $V_3 = IR_3$

$$V = I(R_1 + R_2 + R_3) = I R_{eqs}$$

$$\therefore \boxed{R_{eqs} = R_1 + R_2 + R_3 - - - - + R_n}$$

② **parallel**



$$I = I_1 + I_2 + I_3$$

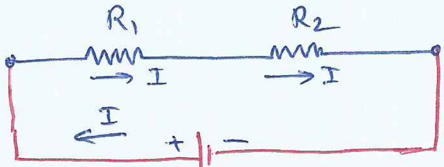
$I_1 = \frac{V}{R_1}$; $I_2 = \frac{V}{R_2}$; $I_3 = \frac{V}{R_3}$

$$I = V\left[\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right]$$

$I = V/R_p$ where $\boxed{\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + - - - \frac{1}{R_n}}$

* In parallel circuit, vol. across each resistor is same and equal to the applied voltage (generally)

Resistors in Series and parallel:



- Consider two resistors R_1 and R_2 in series connection. The charge which leaves R_1 must enter R_2.
- Since current is rate of flow of charge, this means that the same current I flows thro' R_1 & R_2.
- By Ohm's law, p.d. across R_1 = $V_1 = IR_1$

  p.d. —— R_2 = $V_2 = IR_2$

  p.d. across R_1 and R_2 $= V = V_1 + V_2 = IR_1 + IR_2$
  $= I(R_1 + R_2)$

$$\therefore V = V_1 + V_2 = I(R_1 + R_2)$$

$$V = I(R_1 + R_2) \longrightarrow (1)$$

Eqn (1) is as if the combination had an equivalent resistance R_{eq}, which by Ohm's law is $R_{eq} \equiv \frac{V}{I} = (R_1 + R_2)$

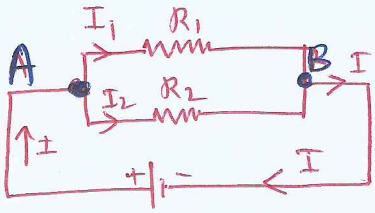
- If we had 3 resistors connected in series, then similarly

$$V = IR_1 + IR_2 + IR_3 = I(R_1 + R_2 + R_3)$$

- This obviously can be extended to a series combination of any number of resistors $R_1, R_2 \ldots R_n$. The equivalent resistance

$$\boxed{R_{eq} = R_1 + R_2 + \cdots R_n}$$

- Consider parallel combination as shown in figure.
- The charge that flows in at A flows out partly thro' R_1 and partly thro' R_2.
- The currents I, I_1, I_2 shown in figure are the rates of flow of charges at the point indicated.



Hence $I = I_1 + I_2 \longrightarrow (1)$

- p.d. betn A and B ~~applied~~ is given by Ohm's law applied to R_1 is

  $V = I_1 R_1 \longrightarrow$ $\quad \therefore \boxed{I_1 = V/R_1} \longrightarrow (2)$

- Similarly, Ohm's law applied to R_2 gives

  $V = I_2 R_2 \longrightarrow$ $\quad \therefore \boxed{I_2 = V/R_2} \longrightarrow (3)$

Inserting (2) and (3) in eqn (1), we get

$$I = \frac{V}{R_1} + \frac{V}{R_2} = V\left[\frac{1}{R_1} + \frac{1}{R_2}\right]$$

$\Longrightarrow$ This is similar to ~~equi~~ replacing eq. resistance as

$$I = V\frac{1}{R_{eq}} \qquad \therefore \frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2}$$

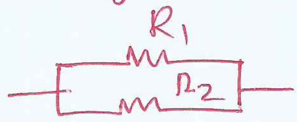
$\rightarrow$ It can be extended $\rightarrow$ $\boxed{\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots\cdots + \frac{1}{R_n}}$

Tips: for calculating fast parallel Resistors.

① R's in series → easy to handle → just add them up.

② R's in parallel

ⓐ if there are only 2 resistors in parallel

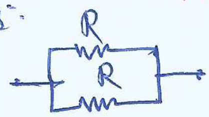


~~Req~~ =

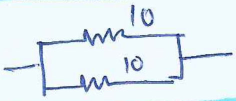
$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} = \frac{R_1 + R_2}{R_1 R_2}$$

$$\therefore R_{eq} = \frac{R_1 R_2}{R_1 + R_2} = \frac{\text{product of 2 resistors}}{\text{Sum of 2 resistors}}.$$

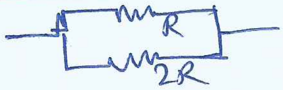
Examples: ~~eg~~:



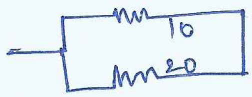
$$\Rightarrow \frac{\text{product of 2 R's}}{\text{Sum of 2 R's}} = \frac{R \times R}{2R} = \frac{R}{2}$$



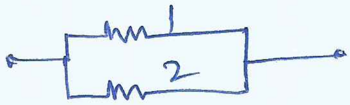
$$\Rightarrow \frac{\cancel{10}^{5} \times 10}{\cancel{20}_{2}} = 5\,\Omega.$$



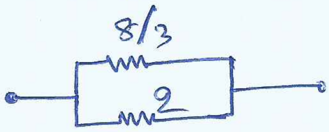
$$\Rightarrow \frac{\cancel{2}R \times 2R}{3R} = \frac{2}{3}R = 0.67\,R\,\Omega$$



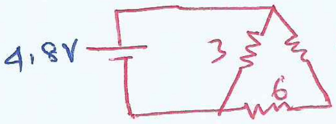
$$\Rightarrow \frac{\cancel{10} \times 20}{30\ 3} = \frac{20}{3} = 6.67\,\Omega$$



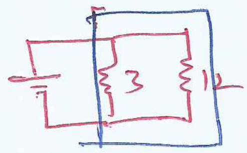
$$\Rightarrow \frac{1 \times 2}{3} = \frac{2}{3} = 0.67\,\Omega.$$



$$\Rightarrow \frac{8/3 \times 2}{8/3 + 2} = \frac{16/3}{\frac{8+6}{3}} = \frac{\overset{8}{\cancel{16}}/\cancel{3}}{\cancel{14}_{7}/\cancel{3}} = \frac{8}{7}\,\Omega$$



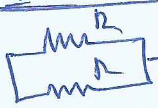
$\Rightarrow$



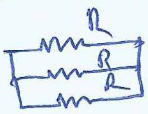
$$\Rightarrow \frac{3 \times 12}{15} = 2.4\,\Omega$$

$$\therefore I = \frac{4.8}{2.4} = 2\,A.$$

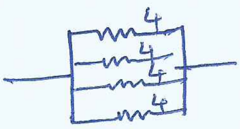
• If all resistors are same and parallel.



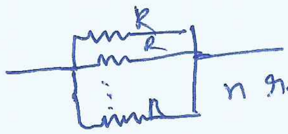
$$\rightarrow \frac{R \times R}{2R} \Longrightarrow \frac{\text{each } R}{\text{No. of } R\text{s}} = \left(\frac{R}{2}\right)$$



$$\rightarrow \frac{\text{each } R}{\text{No. of } R\text{s}} = \frac{R}{3}$$



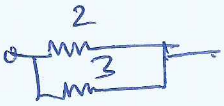
$$\rightarrow \frac{\text{each } R}{\#\text{ of } R\text{s}} = \frac{4}{4} = 1\,\Omega$$



$$= \frac{R}{n}$$

P.T.O

Contd...



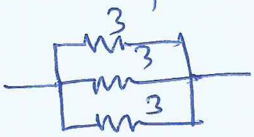
$\Rightarrow \frac{2\times 3}{5} = \frac{6}{5}\,\Omega$

∴ For two different (or same) resistors, we can use fast calculation $= \dfrac{\text{product of Resistors}}{\text{Sum of Resistors}}$

→ If R's are same, then $\dfrac{\text{each R}}{\text{\# of R's}}$

Note that for different resistances, more than 2 in parallel, this rule will not apply.

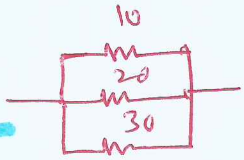
eg.



$\Rightarrow \frac{3\times 3\times \cancel{3}}{\cancel{9}\,3} = 3\,\Omega$ which is not correct

Correct answer is $\dfrac{\text{each R}}{\text{\# of R's}} = \dfrac{3}{3} = 1\,\Omega$

eg.

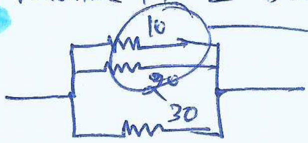


$= \frac{10\times \cancel{20}\times \cancel{30}^{\,10}}{\cancel{60}\,2} = 100\,\Omega \rightarrow$ not correct

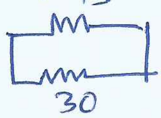
So, more than 2 resistors in parallel, this trick will not help.

Somehow, in a complicated circuit, ~~to~~ try getting 2 resistors in parallel (2 only) and then you can do the trick $= \dfrac{\text{product of Resistors}}{\text{Sum of Resistors}}$

Make it 2 steps



$\frac{\cancel{10}\times 20}{\cancel{30}\,3} = 20/3 =$



$\Rightarrow \frac{20/3 \times 30}{20/3 + 30}$

$= \frac{(20\times 30)/\cancel{3}}{(20+90)/\cancel{3}} = \frac{60\cancel{0}}{11\cancel{0}} \simeq 5.6\,\Omega$

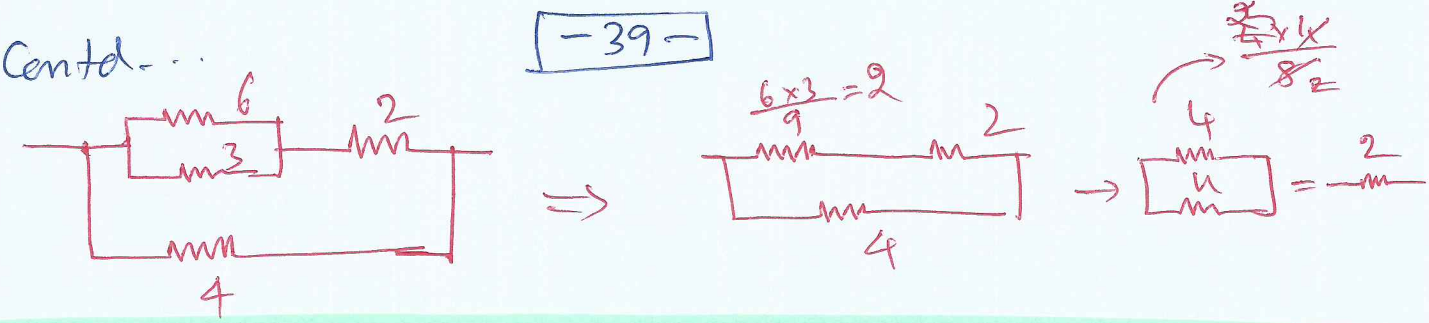
$\frac{1}{Req} = \frac{1}{10} + \frac{1}{20} + \frac{1}{30}$

$= \frac{6+3+2}{60} = \frac{11}{60}$

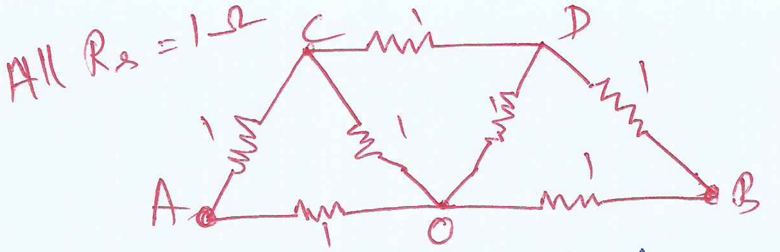
$\therefore Req = \frac{60}{11} = 5.6\,\Omega$

P.T.O

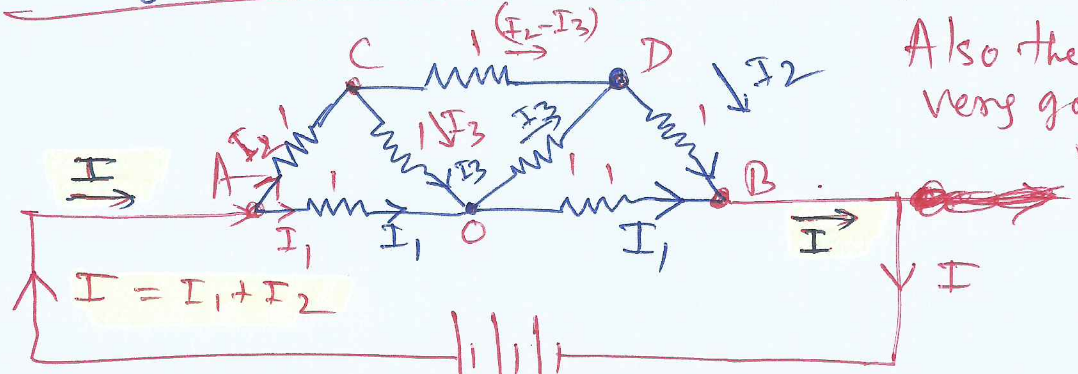
— Contd...



8: All $R_s = 1\,\Omega$ — EQ. R betn A & B = ?



If we drive the above circuit from a source, current entering junction A ≡ current exiting junction B.



Also there is a very good symmetry in circuit resistors

→ I is split at junction A into 2 currents I_1 and I_2

→ Current leaving junction B also should be I

∴ [Current from D to B should be I_2 and current from O to B should be I_1 in the direction as indicated in circuit.

∴ Current from O to D should be I_3

At junction D, as per K' junction rule

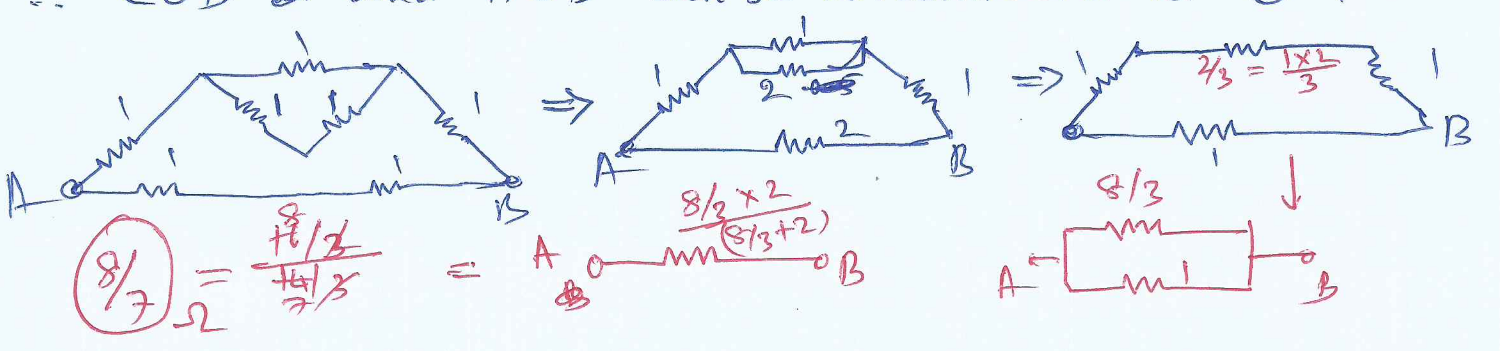
$$(I_2 - I_3) + I_3 - I_2 = 0$$

$$I_2 \cancel{- I_3 + I_3} = I_2$$

∴ Current from D to B = I_2

∴ Current from C to O will completely flow into OD

∴ COD and AOB can be disconnected at O.



$$\frac{8}{7}\,\Omega = \frac{16/3}{14/3}$$