$\therefore 140\,V = V_{R_1} + V_{R_2} \Rightarrow V_{R_1} = 140 - 100 = 40\,V$

$\therefore R_1 = \frac{V_{R_1}}{I} = \frac{40\,V}{20\,mA} = 2\,k\Omega$

$\because 180 = V_{R_2} + V_{R_3} \Rightarrow V_{R_3} = 180 - 100 = 80\,V$

$\therefore R_3 = \frac{V_{R_3}}{I} = \frac{80\,V}{20\,mA} = 4\,k\Omega$

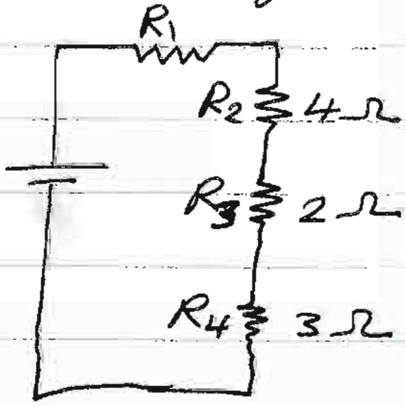
Home Work :-

Q1) Three resistors R_1, R_2 and R_3 are connected in series to a $100\,V$ supply. If $R_1 = 100\,\Omega$, $I_2 = 250\,mA$ and $V_3 = 40\,V$, calculate a) V_1 b) R_2 c) R_3.

(Ans: $25\,V$, $140\,\Omega$, $160\,\Omega$)

Q2) Determine the voltage across R_3 if the voltage across $(R_2 + R_3 + R_4) = 27\,V$.

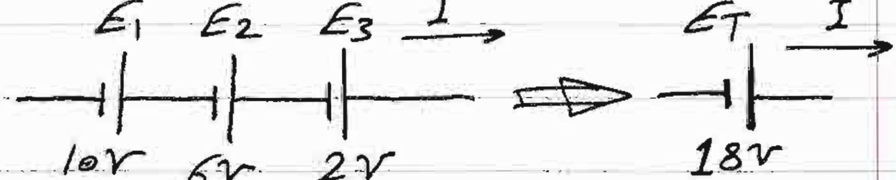
(Ans: $6\,V$)



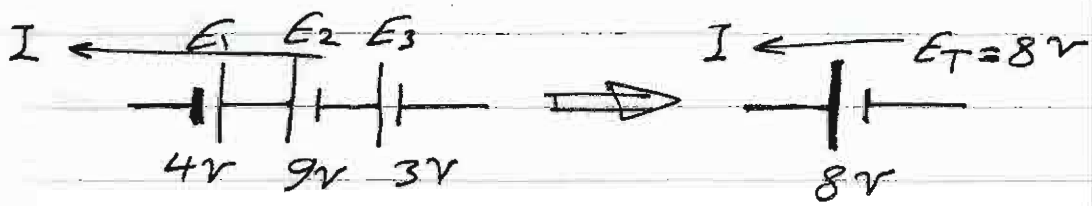
Voltage Sources in Series :⇒

Voltage sources can be connected in series to increase or decrease the total voltage applied to a system.
The net voltage is determined by summing the sources with the same polarity and subtracting the total of the sources with opposite "pressure". The net polarity is the polarity of the larger sum.

Example:



Here, the sources are all "pressuring" current to the right,
$\therefore E_T = E_1 + E_2 + E_3 = 10 + 6 + 2 = 18\ V$



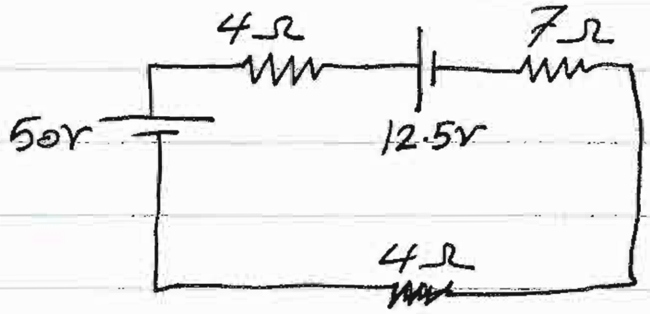
In this connection, the greater "pressure" is to the left

$$E_T = E_2 + E_3 - E_1 = 9 + 3 - 4 = 8V$$

Interchanging Series Elements :⇒

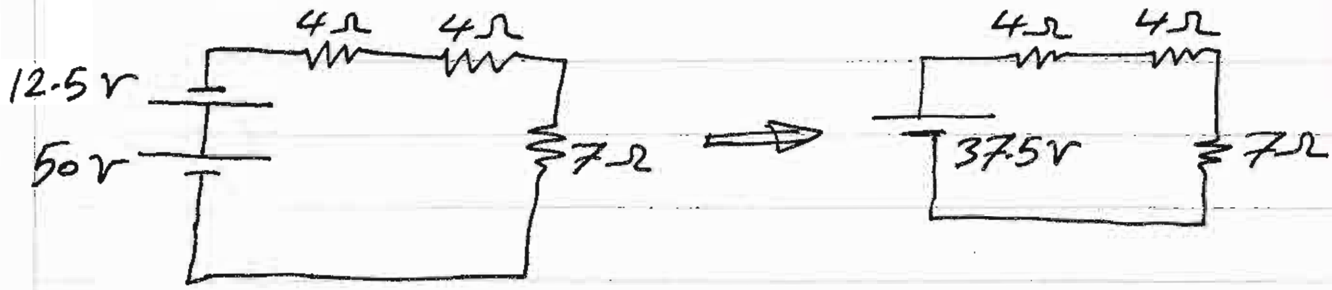
The elements of a series circuit can be interchanged without affecting the total resistance, current, or power to each element.

Example: Determine I and the voltage across the $7\text{-}\Omega$ resistor for this fig.



Sol.)

We can re-draw the network as follows:



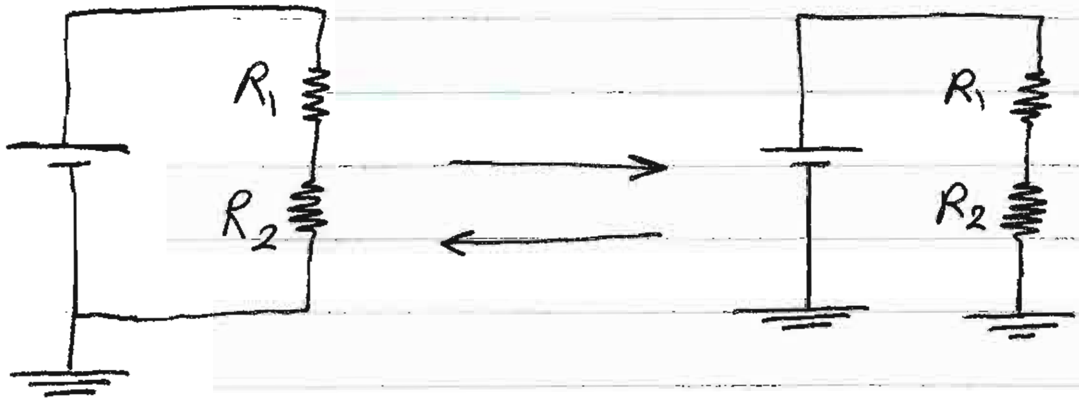
$\because R_T = (2)(4) + 7 = 15\,\Omega$

$\therefore I = \frac{E}{R_T} = \frac{37.5}{15} = 2.5\,A \Rightarrow \therefore V_{7\Omega} = IR = 2.5 * 7 = 17.5\,V$

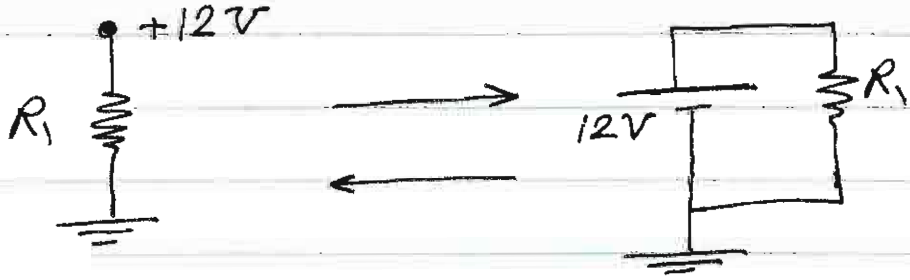
Notation:-

The symbol for the ground connection appears in the following figure, with its defined potential level - zero volts.

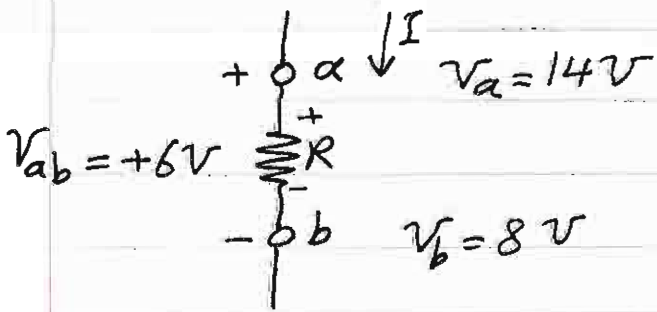
The following figures show a grounded supply:



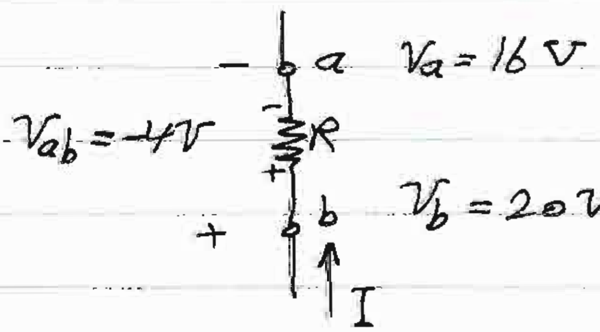
In either case, it is understood that the negative terminal of the battery and the bottom of the resistor R_2 are at ground potential.



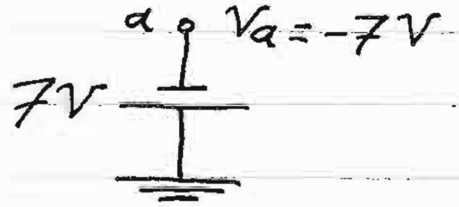
The notation V_{ab} (double-subscript notation) for the potential difference appearing in the following fig. specifies that the potential at a is higher than that at b by 6V.

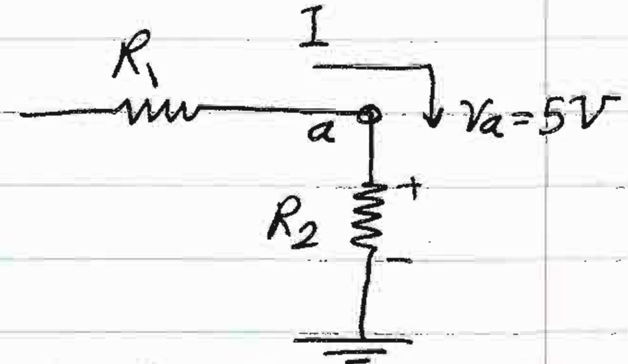


While for this fig.,



If a single-subscript notation such as (V_a) is used, it is understood that V_a is the potential from point a to ground.





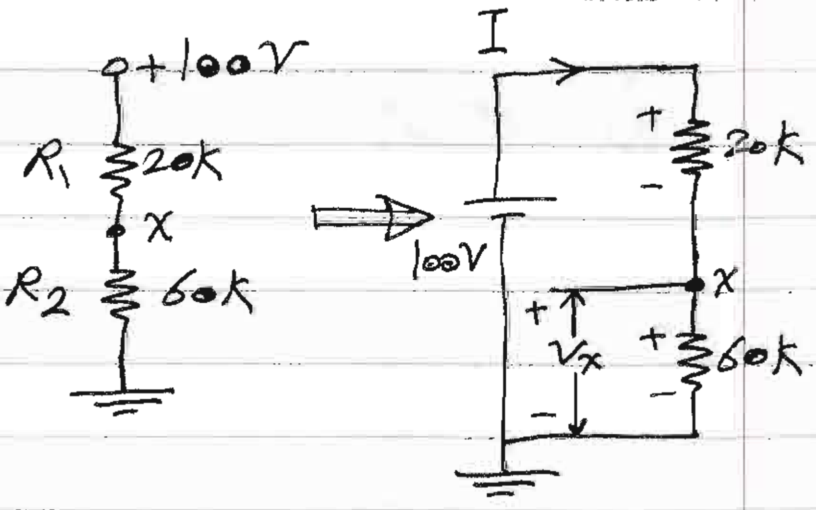
Example: For the following circuit, find the voltage at point x.

Sol:)

By VDR:

$$V_{60k} = 100 * \frac{60k}{20k + 60k}$$

$$\therefore V_{60k} = V_x = 75V$$



Example: For the following circuit, find the voltage V_x with respect to ground.

Sol:)

$$E_T = 60 + 100 = 160V$$

$$V_{R_1} = V_{R_2} = \frac{160}{2} = 80V$$

By KVL for Loop 1:

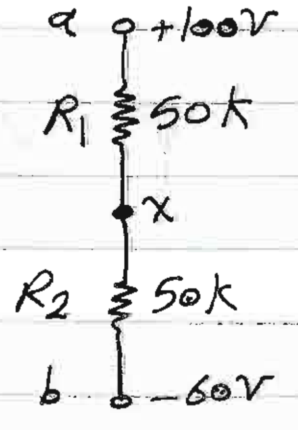
$$-V_x + 100 - 80 = 0$$

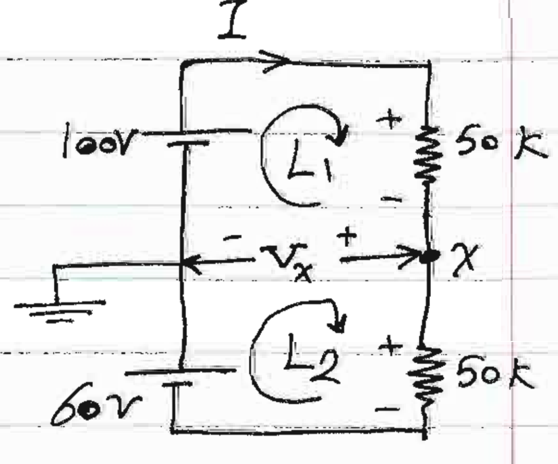
$$\therefore V_x = 100 - 80 = 20V$$

By KVL for loop 2:

$$-80 + 60 + V_x = 0$$

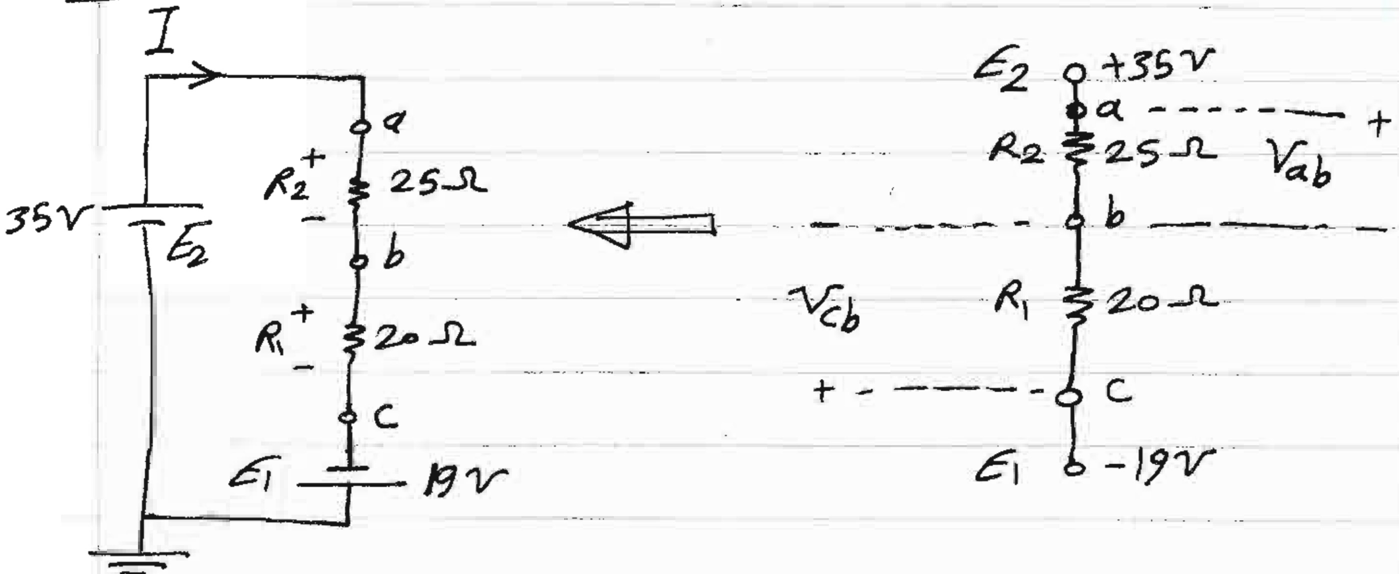
$$\therefore V_x = 80 - 60 = 20V$$





Example: Determine V_{ab}, V_{cb} and V_c for this network.

Sol:



$$I = \frac{35+19}{45\,\Omega} = 1.2A$$

$$\therefore V_{ab} = IR_2 = (1.2)(25) = 30V$$

$$V_{cb} = -IR_1 = -(1.2)(20) = -24V$$

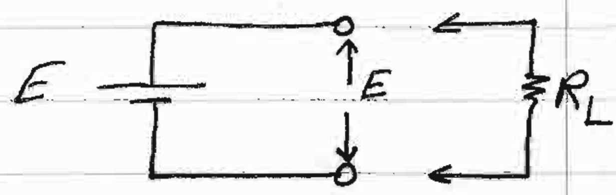
$$V_c = -E_1 = -19V$$

Internal Resistance of Voltage Sources :⇨

Every source of voltage will have some internal resistance.

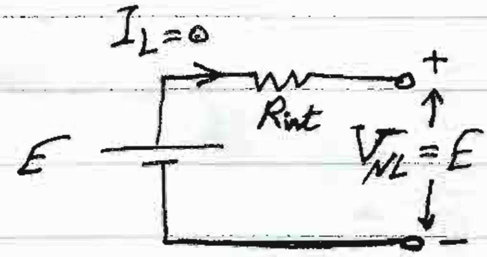
Case 1 :⇨

For ideal voltage source,
which has no internal resistance,
the output voltage = E
with load and with no load.



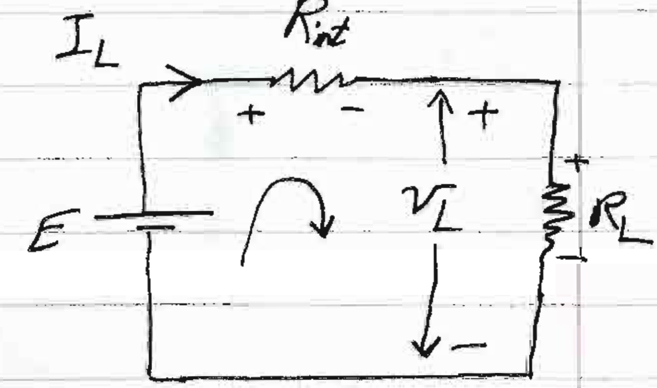
Case 2 :⇨

For non ideal voltage source,
which has internal resistance,
the output voltage = E
with no load.



Case 3 :⇨

For non ideal voltage source,
the output voltage will decrease
due to the voltage drop across
the internal resistance.



For case 3, by applying KVL around the indicated loop:

$$E = I_L R_{int} + V_L$$

$$\because E = V_{NL} \Longrightarrow V_{NL} = I_L R_{int} + V_L$$

$$\therefore \boxed{V_L = V_{NL} - I_L R_{int}} \quad (\text{volt})$$

To find the power delivered to the load, multiply by I_L

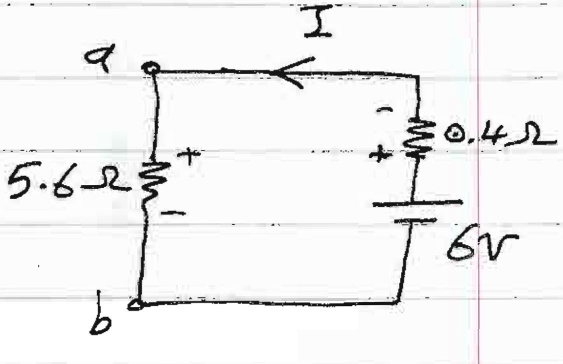
$$I_L * V_L = I_L * V_{NL} - I_L^2 * R_{int}$$

power to load — power from the battery — power loss in the form of heat.

Example: A Lamp having a resistance of 5.6 Ω is connected across the battery in the following circuit, calculate:

a) The current drawn from the battery.
b) The internal voltage drop across its internal resistance.
c) The terminal voltage of the battery.
d) The power dissipated internally within the battery.
e) The power delivered to the load.
f) The total power generated by the battery.
g) The efficiency of the battery.

Sol.:



a) $I = \frac{E}{R_T} = \frac{E}{R_{int} + R_L} = \frac{6}{5.6 + 0.4} = 1A$

b) $V_{R_{int}} = I * R_{int} = 1 * 0.4 = 0.4\,V$

c) $V_L = I_L R_L = 1 * 5.6 = 5.6\,V$

OR $V_L = E - V_{R_{int}} = 6 - 0.4 = 5.6\,V$

d) $P_{int} = I^2 * R_{int} = 1^2 * 0.4 = 0.4\ W$

e) $P_L = I^2 * R_L = 1^2 * 5.6 = 5.6\ W$

f) $P_T = P_L + P_{int} = 0.4 + 5.6 = 6W$

or $P_T = EI = I^2 R_T = E^2 / R_T = 6W$

g) $\eta = \frac{P_o}{P_{in}} = \frac{5.6\,\cancel{W}}{6\,\cancel{W}} = 0.933 * \frac{100}{100} = 93.3\ \%$

Voltage Regulation :-

A measure of how close a supply will come to ideal conditions, where the ideal conditions dictate that for all range of load demand (I_L), the terminal voltage remain fixed in magnitude.

$$\text{Voltage regulation (VR) \%} = \frac{V_{NL} - V_{FL}}{V_{FL}} \times 100\%$$

For ideal conditions, $V_{FL} = V_{NL}$ and $VR\% = 0$. Therefore, the smaller the voltage regulation, the less the variation in terminal voltage with change in load.

$\because V_{FL} = I_L R_L$ & $V_{NL} = I_L (R_{int} + R_L)$

$$\therefore V_R \% = \frac{\cancel{I_L} R_{int} + \cancel{I_L R_L} - \cancel{I_L R_L}}{\cancel{I_L} R_L} * 100\%$$

$$\therefore VR\% = \frac{R_{int}}{R_L} * 100\%$$

Home Work :-

Q1) A series circuit consists of three resistors $R_1 = 25\,k\Omega$, $R_2 = 65\,k\Omega$, $R_3 = 80\,k\Omega$. If the voltage drop across R_1 is 10V, calculate the:

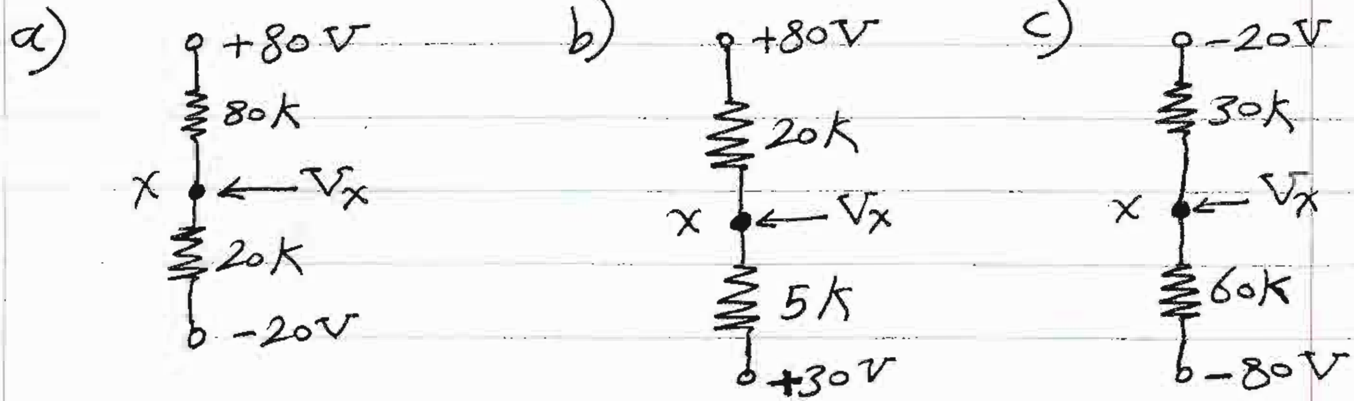
a) supply voltage

b) Voltage drop across R_3

c) power dissipated by R_2

(Ans: 68 V, 32 V, 10.4 mW).

Q2) Calculate the voltage V_x with respect to ground for the circuits shown:



(Ans: 0 V, 40 V, −40 V).

Q3) Two voltmeters are connected in series across a 1200 V supply. The internal resistances of the voltmeters are 75 kΩ and 120 kΩ, respectively. Calculate the:

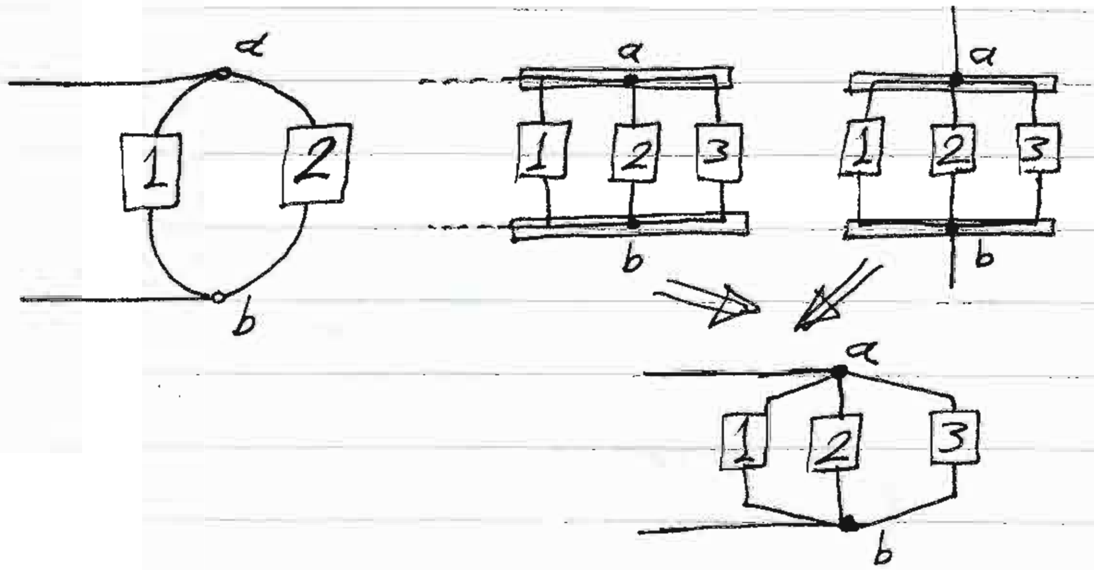
a) Voltage reading of the lower resistance voltmeter.
b) " " " " higher " ".
c) Current in each. (Ans: 461.5 V, 738.5 V, 6.154 mA).

Q4) A dc generator delivers 40 A to a load when its terminal voltage is 120 V. When the load is increased to 60 A, the terminal voltage drops to 116 V. Calculate:

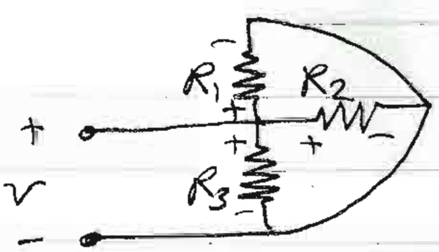
a) open circuit voltage E of the generator.
b) Internal resistance of the generator.
c) Voltage regulation of the generator if its rated voltage is 115 V.
d) current delivered by the generator at rated voltage. (Ans: 128 V, 0.2 Ω, 11.3 %, 65 A).

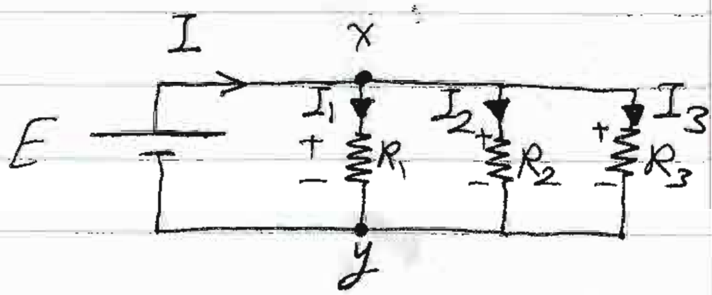
Parallel Circuits:

Two elements, branches, or networks are in parallel if they have two points in common.

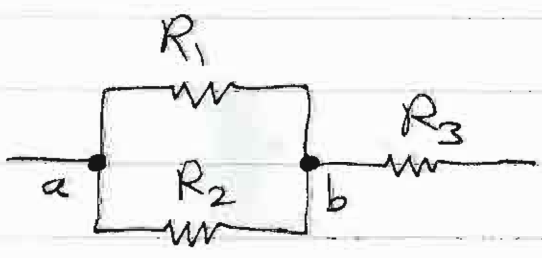


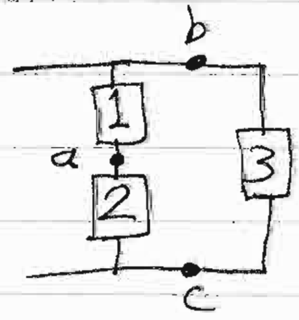
In other words, components are connected in parallel when they have the same potential applied across their terminals. Or any two (or more) networks are in parallel if they have two points in common.





« 3 parallel circuits »





For parallel elements:

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

$$\therefore R_{eq} = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \cdots + \frac{1}{R_N}} \quad (\Omega) \text{ ohms}$$

$\because G = \frac{1}{R}$

$\therefore$ The total ~~resistance~~ conductance of a parallel network is equal to:

$$G_T = G_1 + G_2 + \cdots + G_N \quad \text{(in Siemens)}$$

Note that the total resistance of parallel resistors is <u>always</u> less than the value of the smallest resistor. [We can use this fact for checking purposes in parallel ccts]

Example: Determine the total resistance for the following cct.

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} = \frac{1}{2} + \frac{1}{4} + \frac{1}{5} = 0.5 + 0.25 + 0.2$$
$$= 0.95$$

$$\therefore R_T = \frac{1}{0.95} = 1.053\ \Omega$$

For equal resistors in parallel (for (N) equal resistors)

$$\frac{1}{R_T} = \underbrace{\frac{1}{R} + \frac{1}{R} + \cdots + \frac{1}{R}}_{N} = N\left(\frac{1}{R}\right)$$

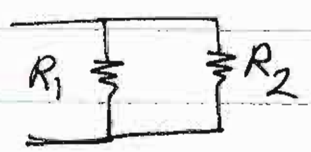
$$\therefore \boxed{R_T = \frac{R}{N}} \quad (\Omega) \text{ ohms}$$

The conductance G of equal resistors is:

$$G = \frac{1}{R} \Longrightarrow G_T = \frac{1}{R_T} = \frac{1}{R/N} = \frac{N}{R} = \frac{1}{R}N = GN$$

$$\therefore \boxed{G_T = G * N} \quad \text{siemens}$$

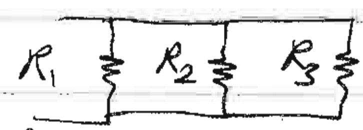
For two parallel resistors:



$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} = \frac{R_2 + R_1}{R_1 R_2}$$

$$\therefore R_T = \frac{R_1 R_2}{R_1 + R_2} \quad (\Omega)$$

For three parallel resistors:



$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} = \frac{R_2 R_3 + R_1 R_3 + R_1 R_2}{R_1 R_2 R_3}$$

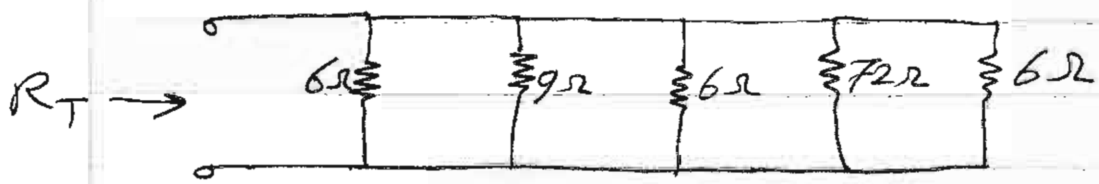
$$\therefore R_T = \frac{R_1 R_2 R_3}{R_2 R_3 + R_1 R_3 + R_1 R_2} \quad (\Omega)$$

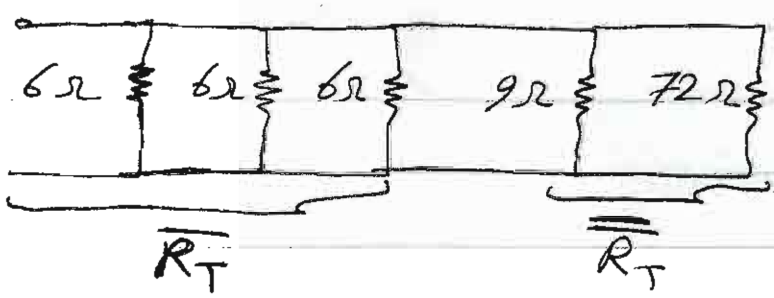
OR Let $R_A = R_1 \parallel R_2 = \frac{R_1 R_2}{R_1 + R_2}$

Then $R_T = R_A \parallel R_3 = \frac{R_A R_3}{R_A + R_3}$

Recall that series elements can be interchanged without affecting the magnitude of the total resistance or current.

In parallel networks, parallel elements can be interchanged without changing the total resistance or input current.
Note in the next example how we can benefit from this point:
Example: Calculate the total resistance for the cct.:

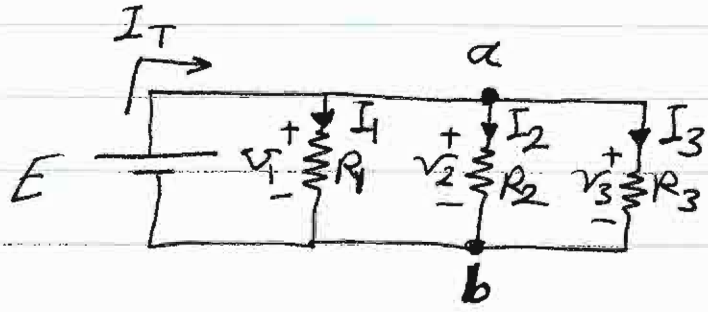




$$\overline{R_T} = \frac{R}{N} = \frac{6}{3} = 2\,\Omega \quad \& \quad \overline{\overline{R_T}} = \frac{(9)(72)}{9+72} = 8\,\Omega$$

$$\therefore R_T = \overline{R_T} \parallel \overline{\overline{R_T}} = \frac{(2)(8)}{2+8} = \frac{16}{10} = 1.6\,\Omega$$

In parallel circuits,



Since the terminals of the battery are connected directly across the resistors R_1, R_2 and R_3

$\therefore$ The voltage across parallel elements is the same.

$\therefore E = V_1 = V_2 = V_3$

From Ohm's law:

$$I_1 = \frac{V_1}{R_1} = \frac{E}{R_1}$$

$$I_2 = \frac{V_2}{R_2} = \frac{E}{R_2}$$

$$I_3 = \frac{V_3}{R_3} = \frac{E}{R_3}$$

$\because \frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$ (multiply both sides by E)

$$\therefore \frac{E}{R_T} = \frac{E}{R_1} + \frac{E}{R_2} + \frac{E}{R_3}$$

$$\therefore I_T = I_1 + I_2 + I_3$$

* The power dissipated by the resistors are:

$P_1 = V_1 I_1 = I_1^2 R_1 = \frac{V_1^2}{R_1} = \frac{E^2}{R_1}$ (watt)

$P_2 = V_2 I_2 = I_2^2 R_2 = \frac{V_2^2}{R_2} = \frac{E^2}{R_2}$ (watt)

$$P_3 = V_3 I_3 = I_3^2 R_3 = \frac{V_3^2}{R_3} = \frac{E^2}{R_3} \quad \text{(watt)}$$

The power delivered by the source is given by:

$$P_s = P_1 + P_2 + P_3 \quad \text{(watt)}$$

or $$P_s = E I_T = I_T^2 R_T = \frac{E^2}{R_T} \quad \text{(watt)}$$

Example: Six resistors connected in parallel have the following values: 120 kΩ, 60 kΩ, 40 kΩ, 5 kΩ, 4 kΩ and 2 kΩ, calculate the:

a) Equivalent conductance of the parallel combination.
b) Equivalent resistance of the " " .
c) Circuit voltage if 20 mW is dissipated by the 5 kΩ resistor.
d) Current in the 40 kΩ resistor.
e) Total current drawn from the supply.
f) Total power drawn from the supply.

Sol:

a) $$G_T = \frac{1}{120k} + \frac{1}{60k} + \frac{1}{40k} + \frac{1}{5k} + \frac{1}{4k} + \frac{1}{2k}$$

$$\therefore \; G_T = 0.001 \text{ S} = 1 \text{ mS}$$

b) $$R_T = 1/G_T = 1/0.001 = 1 \text{ k}\Omega$$

c) $$20\text{mW} = \frac{E^2}{5k} \Rightarrow E^2 = 100 \Rightarrow E = 10 \text{ V}$$

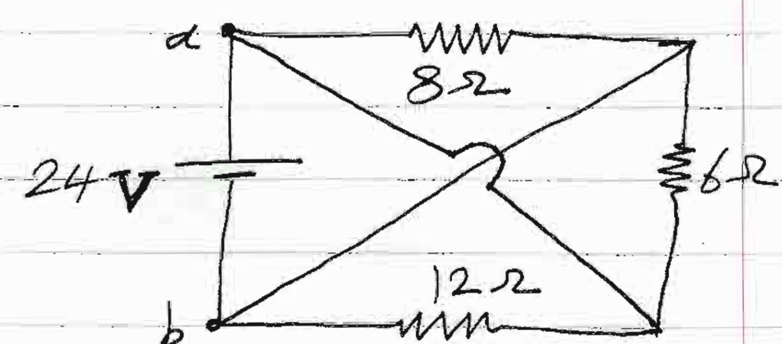
d) $$= I_{40k} = \frac{E}{40k} = \frac{1\cancel{0}\text{ v}}{4\cancel{0}k} = 0.25 \text{ mA}$$

e) $I_T = \frac{E}{R_T} = \frac{10\,V}{1\,k\Omega} = 10\ mA$ OR $I_T = E\,G_T =$
$= 10 * 1\,mS = 10\ mA$

f) $P_T = I_T * E = 10\,mA * 10 = 100\ mW$

Example: Calculate the total circuit resistance and battery current for the following circuit. prove that the power delivered to the circuit is equal to the power dissipated in each resistor.

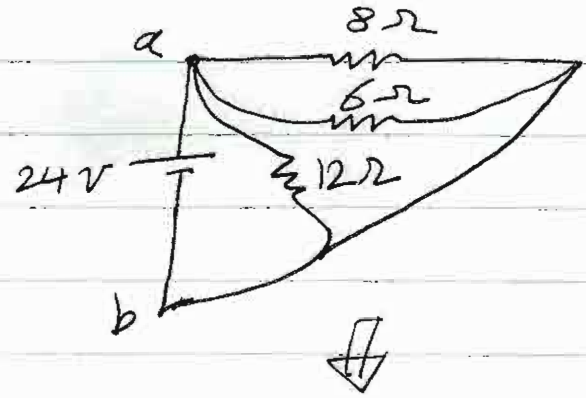
Sol:



$R_T = 8 \,//\, 6 \,//\, 12$

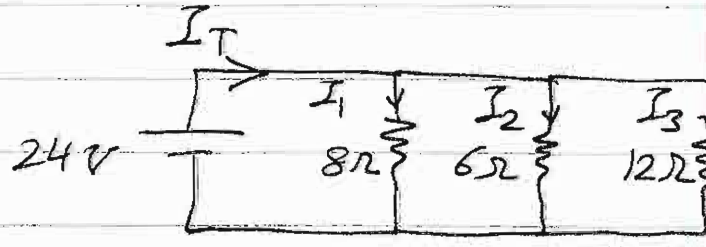
$= \frac{8*6*12}{8*6+8*12+6*12}$

$= \frac{576}{216} = 2.667\ \Omega$



$\therefore I_T = \frac{E}{R_T} = \frac{24}{2.667} \approx 9A$

$P_T = 24 * 9 = 216\ W$



$P_1 = \frac{E^2}{8} = \frac{(24)^2}{8} = 72\ W$

$P_2 = \frac{E^2}{6} = 96\ W$

$P_3 = \frac{E^2}{12} = 48\ W$

$\therefore P_T \overset{?}{=} P_1 + P_2 + P_3$

$216 \overset{?}{=} 72 + 96 + 48 \rightarrow \therefore 216 = 216$ (Watt)

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Kirchhoff's Current Law:

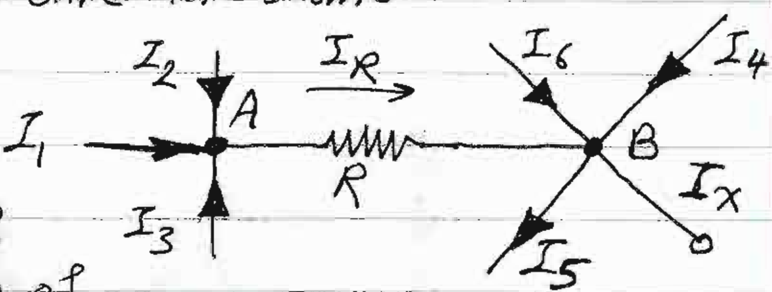
States that the algebraic sum of all currents entering and leaving a node is zero.

$$\sum I_{entering} - \sum I_{leaving} = 0$$

or $\sum I_{entering} = \sum I_{leaving}$ amperes (A)

Example: In the following fig. the known currents are $I_1 = 4A$, $I_2 = 3A$, $I_3 = 2A$, $I_4 = 5A$, $I_5 = 1A$ and $I_6 = 2A$, each having the current direction shown.

Calculate:



a) Current in resistor R, I_R

b) Current and direction of I_x.

Sol:)

a) At node A:

$$\sum I_{entering} = \sum I_{leaving}$$

$$\therefore I_1 + I_2 + I_3 = I_R \Longrightarrow 4+3+2 = I_R \Longrightarrow I_R = 9A$$

b) At node B:

$$\sum I_{entering} = \sum I_{leaving}$$

$$I_R + I_6 + I_4 \stackrel{?}{=} I_5 \Longrightarrow 9+2+5 \stackrel{?}{=} 1$$

$16 \stackrel{?}{=} 1 + I_x \Rightarrow I_x = 16 - 1 = 15A$ leaving point B (why?)