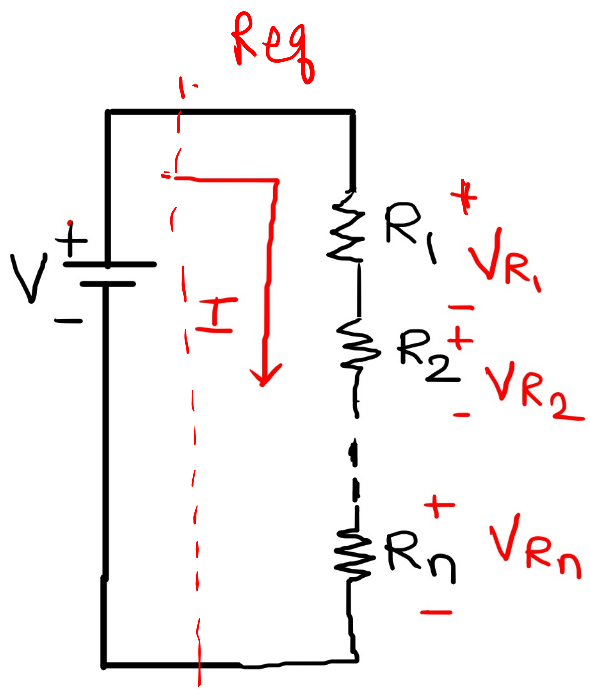
Series Combination of Resistors (Current is same in all resistor)



Applying KVL

$$V - V_{R_1} - V_{R_2} - \cdots - V_{R_n} = 0$$

$$V = V_{R_1} + V_{R_2} + \cdots + V_{R_n}$$

$$V = IR_1 + IR_2 + \cdots + IR_n$$

$$V = I(R_1 + R_2 + \cdots + R_n)$$

$$\frac{V}{I} = R_1 + R_2 + \cdots + R_n \quad \text{also } I = \frac{V}{R_1 + R_2 + \cdots + R_n}$$

$$\boxed{R_{eq} = R_1 + R_2 + \cdots + R_n} \qquad R_{eq} = \sum_{i=1}^{n} R_i$$

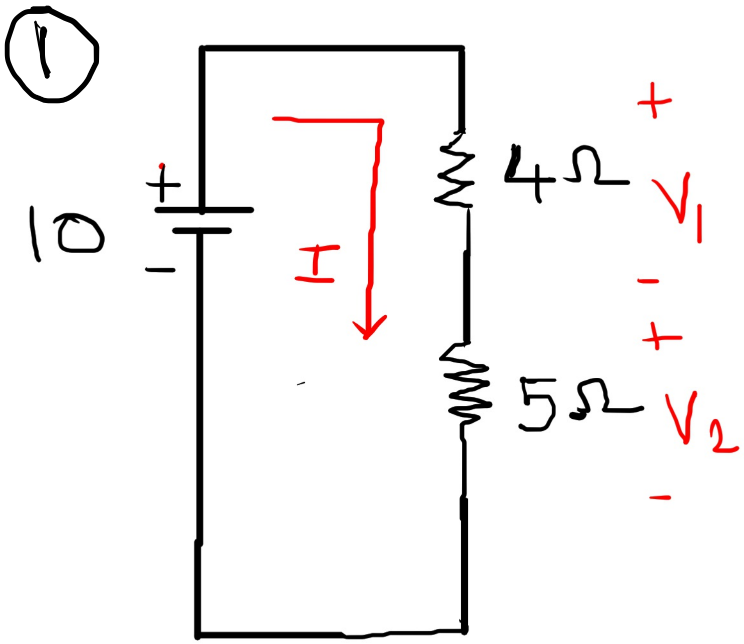
Voltage Division Formula

$$V_{R_1} = IR_1 = \frac{R_1 \times V}{R_1 + R_2 + \cdots + R_n}, \quad V_{R_2} = I \cdot R_2 = \frac{R_2 \times V}{R_1 + R_2 + \cdots + R_n} \;\&\; V_{R_n} = IR_n = \frac{R_n \times V}{R_1 + R_2 + \cdots + R_n}$$

[Voltage across any resistor in a Series Combination] = applied Voltage × (Resistance of the Same branch / Sum of all Resistances)

Series Combination of Resistors (Current is same in all resistor)

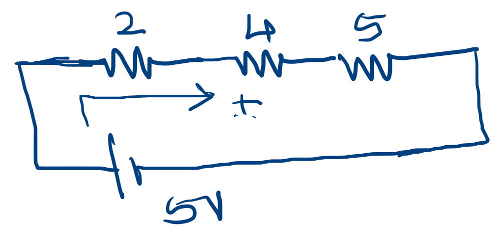
1



$$V_1 = \frac{4}{4+5} \times 10 = \frac{40}{9}$$

$$V_2 = \frac{5}{5+4} \times 10 = \frac{50}{9}$$

2



$$V_{2\Omega} = \frac{2}{2+4+5} \times 5 = \frac{10}{11} \checkmark$$

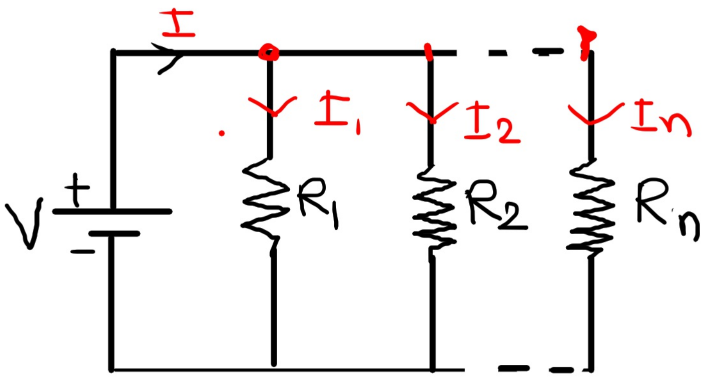
$$V_{4\Omega} = \frac{4}{2+4+5} \times 5 = \frac{20}{11} \checkmark$$

$$V_{5\Omega} = \frac{5}{2+4+5} \times 5 = \frac{25}{11} \checkmark$$

Voltage Division Formula

[Voltage across any resistor in a Series Combination] = applied Voltage × (Resistance of Same branch / Sum of resistances in Series)

Parallel Combination of Resistors (Voltage Across all resistors is Same)



Current Division formula

Applying KCL

$$I = I_1 + I_2 + \cdots + I_n$$

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

$$\frac{I}{V} = \left[\frac{1}{R_1} + \frac{1}{R_2} + \cdots + \frac{1}{R_n}\right] = \frac{1}{R_{eq}}.$$

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

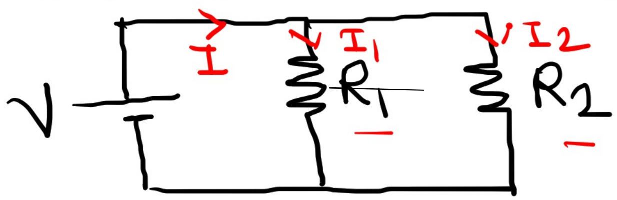
$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots + \frac{1}{R_n}$$

$$I_n = \frac{I \times \frac{1}{R_n}}{\frac{1}{R_{eq}}}$$

$$I_1 = \frac{V}{R_1} = \frac{1}{R_1}\left[\frac{I}{\frac{1}{R_1} + \frac{1}{R_2} + \cdots + \frac{1}{R_n}}\right] = \left(\frac{\frac{1}{R_1} \times I}{1/R_{eq}}\right) = \left(\frac{\frac{1}{R_1} \times I}{\frac{1}{R_1} + \frac{1}{R_2} + \cdots + \frac{1}{R_n}}\right)$$

For two Resistors in parallel

⇒



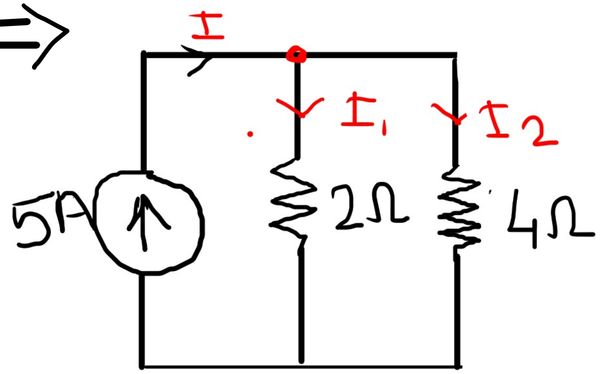
$$I_1 = \frac{\frac{1}{R_1} \times I}{\frac{1}{R_1} + \frac{1}{R_2}} = \frac{\frac{1}{\cancel{R_1}} \times I}{\frac{R_1 + R_2}{\cancel{R_1} R_2}} = \frac{R_2 \times I}{R_1 + R_2}$$

$$I_2 = \frac{R_1 \times I}{R_1 + R_2}$$

Current Through a resistor(in parallel = combination of two) resistors)

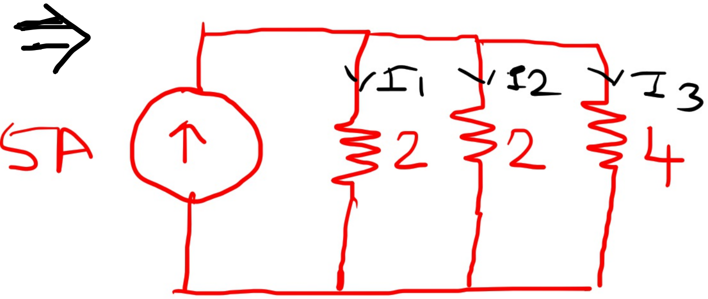
Total Current X (Resistance of other branch / Sum of Resistances

Parallel Combination of Resistors (Voltage Across all resistors is Same)



Current Division formula

$$\boxed{\begin{aligned} I_1 &= \frac{5 \times 4}{4+2} = \frac{20}{6} \\ I_2 &= \frac{5 \times 2}{2+4} = \frac{10}{6} \end{aligned}}$$



$$I_1 = \frac{\frac{1}{2} \times 5}{\frac{1}{2} + \frac{1}{2} + \frac{1}{4}} \checkmark$$

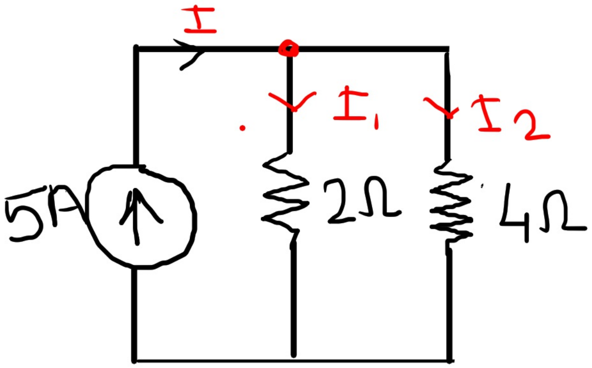
$$I_3 = \frac{5 \times \frac{1}{4}}{\frac{1}{2} + \frac{1}{2} + \frac{1}{4}} \checkmark$$

$$I_2 = \frac{\frac{1}{2} \times 5}{\frac{1}{2} + \frac{1}{2} + \frac{1}{4}} \checkmark$$

Current Through a resistor(in parallel = combination of two) resistors)

Total Current X (Resistance of other branch / Sum of Resistances

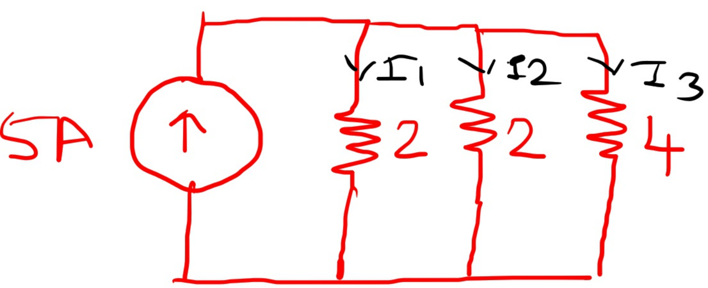
Parallel Combination of Resistors (Voltage Across all resistors is Same)



$$I_1 = \frac{5 \times 4}{4+2} = \frac{20}{6}$$

$$I_2 = \frac{5 \times 2}{2+4} = \frac{10}{6}$$

Current Division formula



$$I_1 = \frac{\frac{1}{2} \times 5}{\frac{1}{2}+\frac{1}{2}+\frac{1}{4}}$$

$$I_3 = \frac{5 \times \frac{1}{4}}{\frac{1}{2}+\frac{1}{2}+\frac{1}{4}}$$

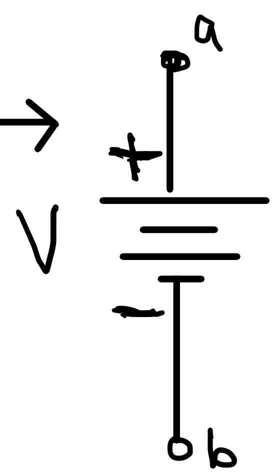
$$I_2 = \frac{\frac{1}{2} \times 5}{\frac{1}{2}+\frac{1}{2}+\frac{1}{4}}$$

Current Through a resistor(in parallel = combination of two) resistors)

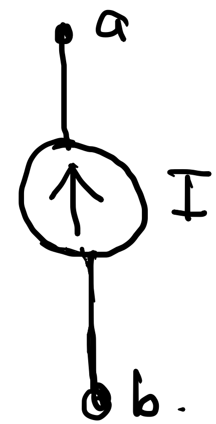
Total Current X (Resistance of other branch / Sum of Resistances

Energy Sources

Voltage & Current Sources	Direct Current (DC) Sources Vs Alternating Current (AC) Sources	Ideal Vs Practical	Dependent Vs Independent



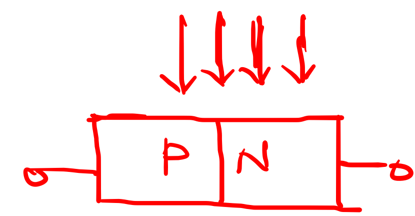
Voltage Source

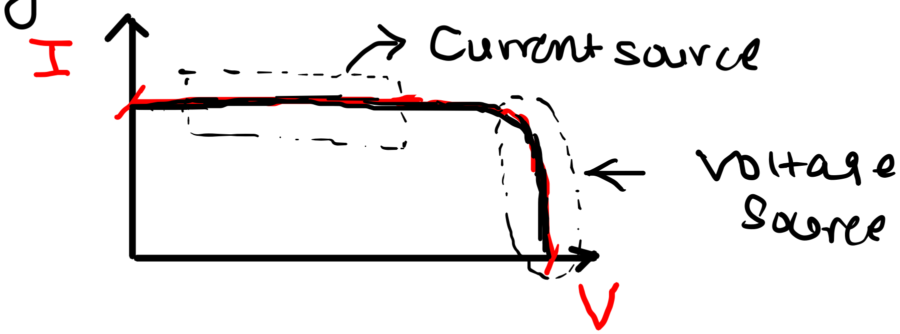


Current Source

e.g. Electro-chemical cell.

e.g. Solar cell

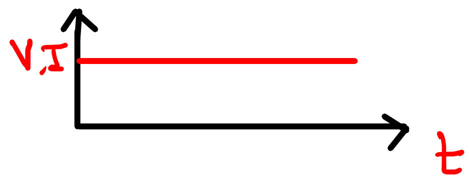




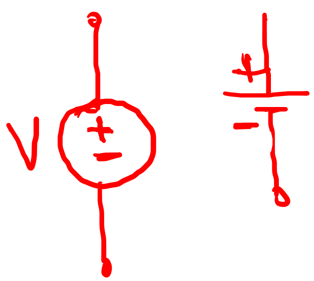
Energy Sources

- Voltage & Current Sources
- Direct Current (DC) Sources Vs Alternating Current (AC) Sources
- Ideal Vs Practical
- Dependent Vs Independent

DC Sources

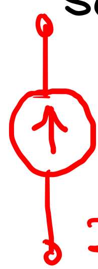


Voltage source



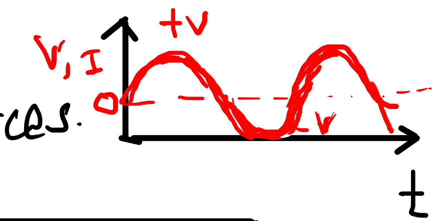
e.g. V = 10V

Current source



e.g. I = 5A

AC Sources



Voltage source

e.g. rms = 230 V
frequency = 50Hz

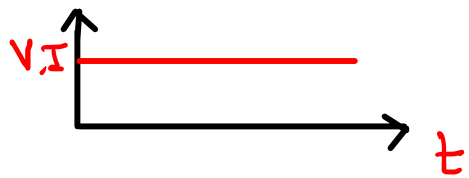
Current source

DC output (5V, 12V) 1A ← Mobile / Laptop Battery charger ← AC input (230V, 50Hz)

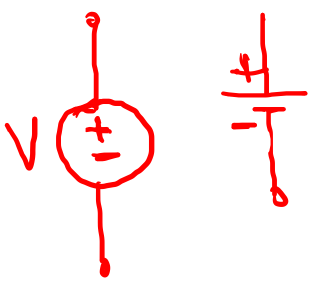
Energy Sources

- Voltage & Current Sources
- Direct Current (DC) Sources Vs Alternating Current (AC) Sources
- Ideal Vs Practical
- Dependent Vs Independent

DC Sources

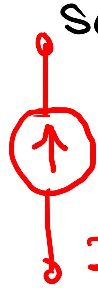


Voltage source



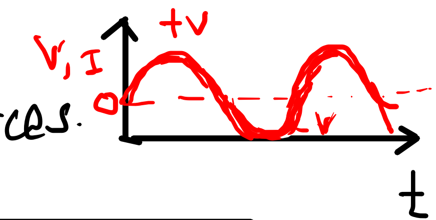
e.g. V = 10V

Current source



e.g. I = 5A

AC Sources



Voltage source

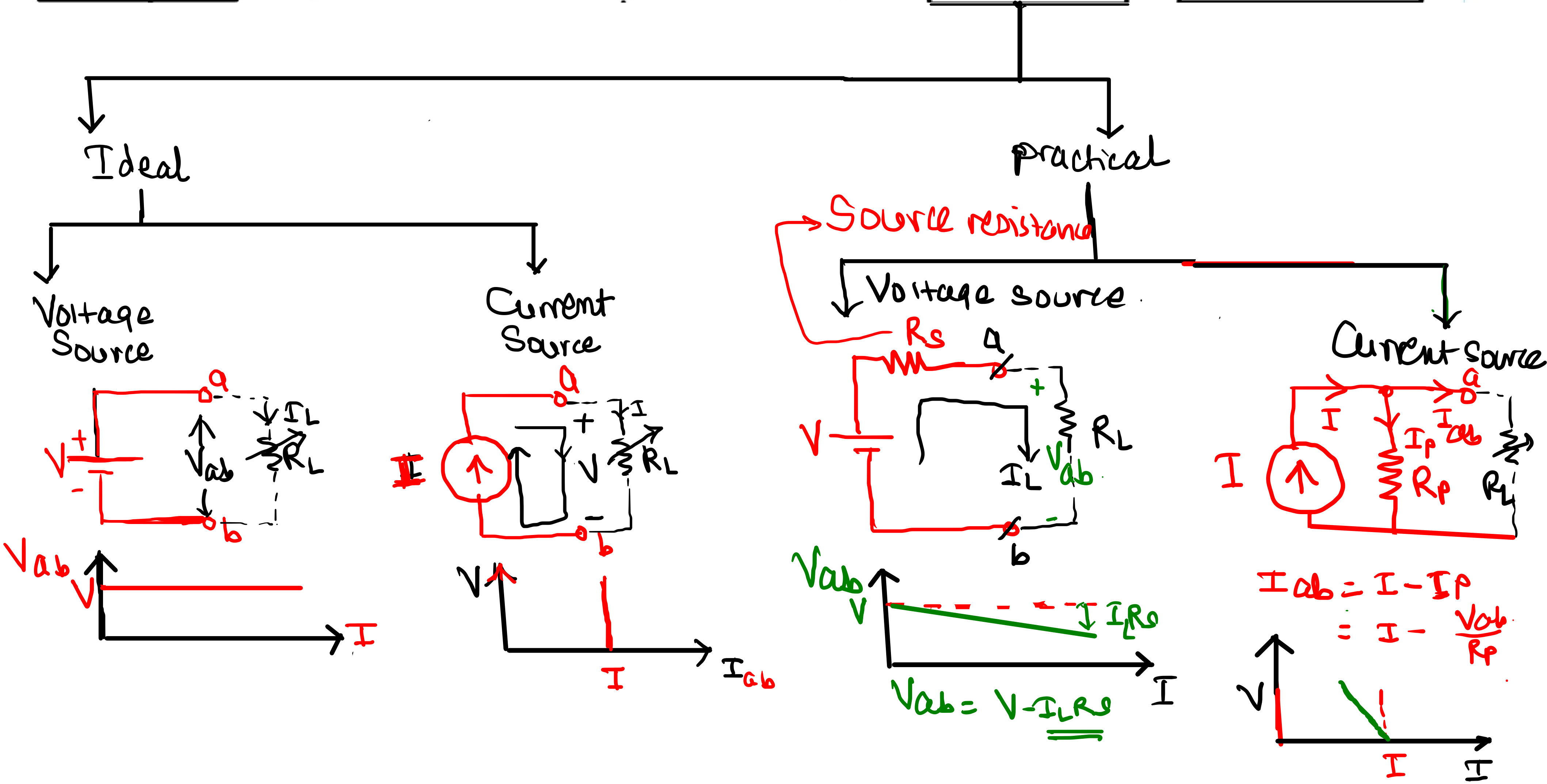
e.g. rms = 230V
frequency = 50Hz

Current source

DC output (5V, 12V) 1A ← Mobile/Laptop Battery charger ← AC input (230V, 50Hz)

Energy Sources

Voltage & Current Sources	Direct Current (DC) Sources Vs Alternating Current (AC) Sources	Ideal Vs Practical	Dependent Vs Independent

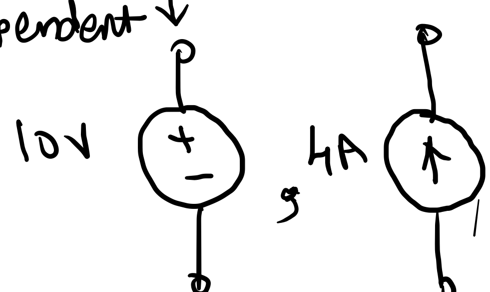


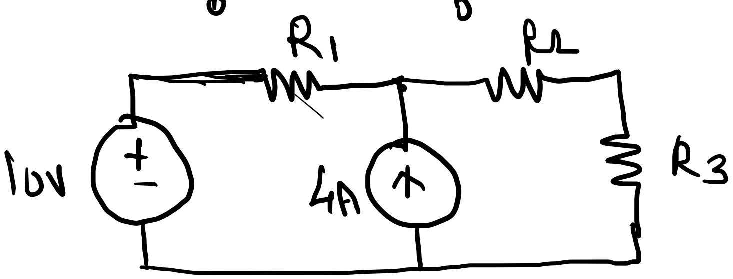
Energy Sources

Voltage & Current Sources	Direct Current (DC) Sources Vs Alternating Current (AC) Sources	Ideal Vs Practical	Dependent Vs Independent

(Uncontrolled)

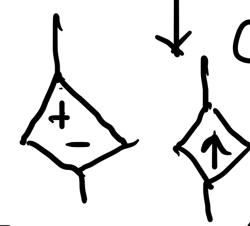
Independent



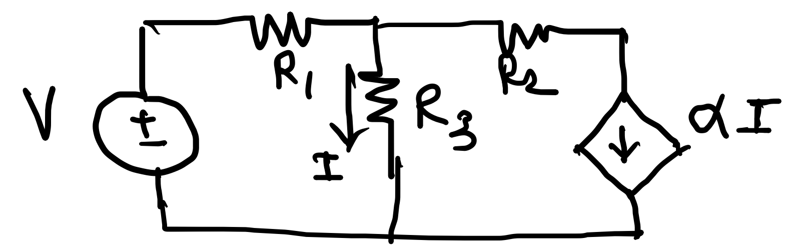


Independent (voltage/current) source is the one whose value is independent of any other parameters in the network

Controlled/dependent



The value of source will depend on other parameters in the circuit.



→ Current controlled current source

Energy Sources

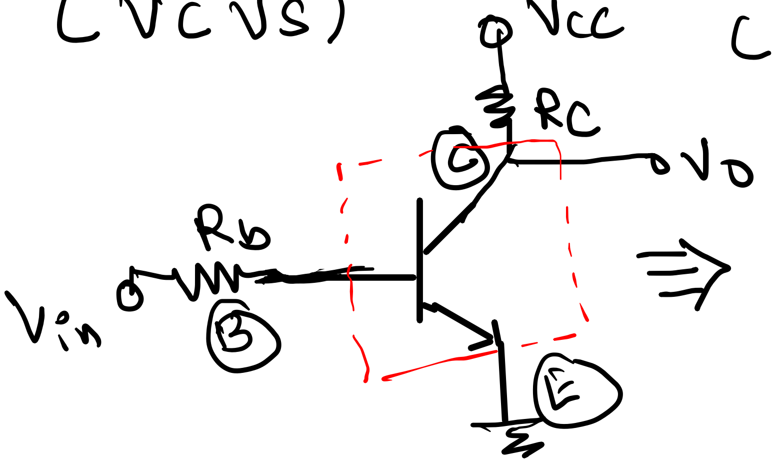
Voltage & Current Sources

Direct Current (DC) Sources Vs Alternating Current (AC) Sources

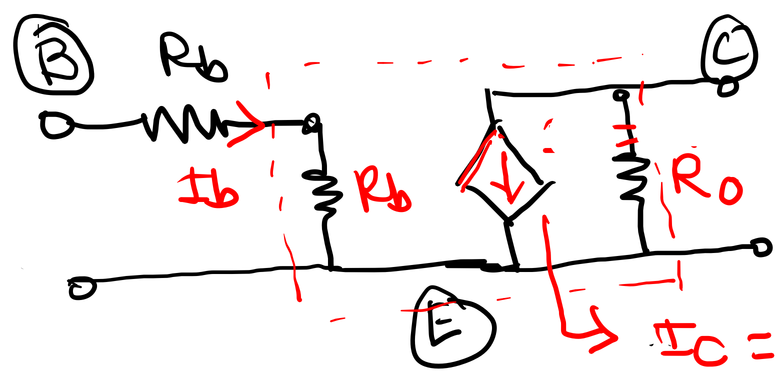
Ideal Vs Practical

Dependent Vs Independent

1. Voltage Controlled Voltage Source (CVCVS)
2. Voltage Controlled Current source (VCCS)
3. Current Controlled Current Source (CCCS)
4. Current Controlled Voltage Source (CCVS)



⇒



$I_C = \alpha I_b$

CCCS

Energy Sources

Voltage & Current Sources

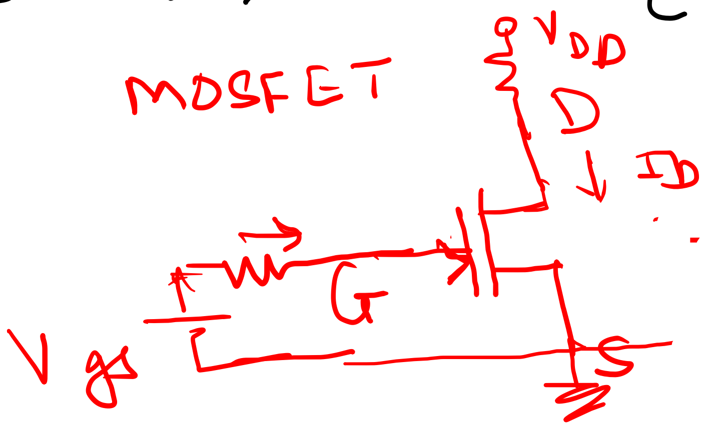
Direct Current (DC) Sources
Vs
Alternating Current (AC) Sources

Ideal
Vs
Practical

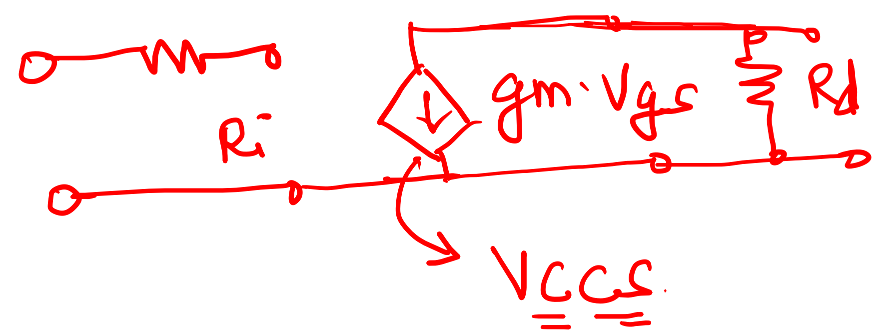
Dependent
Vs
Independent

1. Voltage Controlled Voltage Source (VCVS)
2. Voltage Controlled Current source (VCCS)
3. Current Controlled Current Source (CCCS)
4. Current Controlled Voltage source

MOSFET



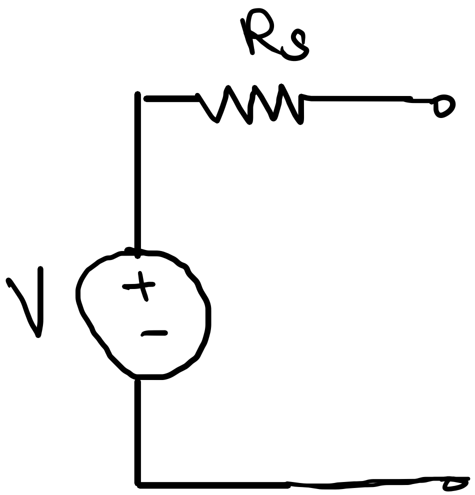
⇒



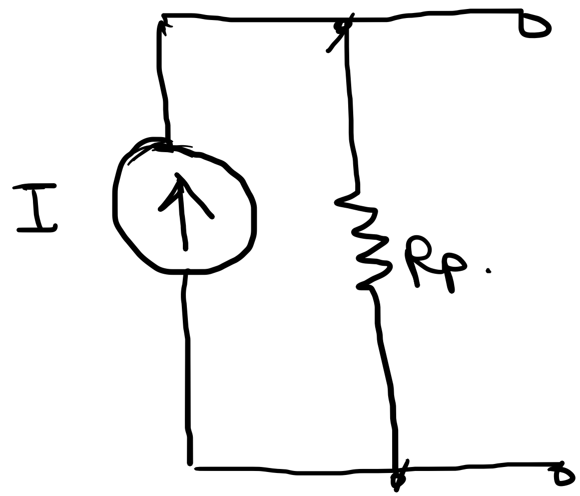
Source Transformation

[Transforming / Converting

Voltage source → Current source
Current source → Voltage source.

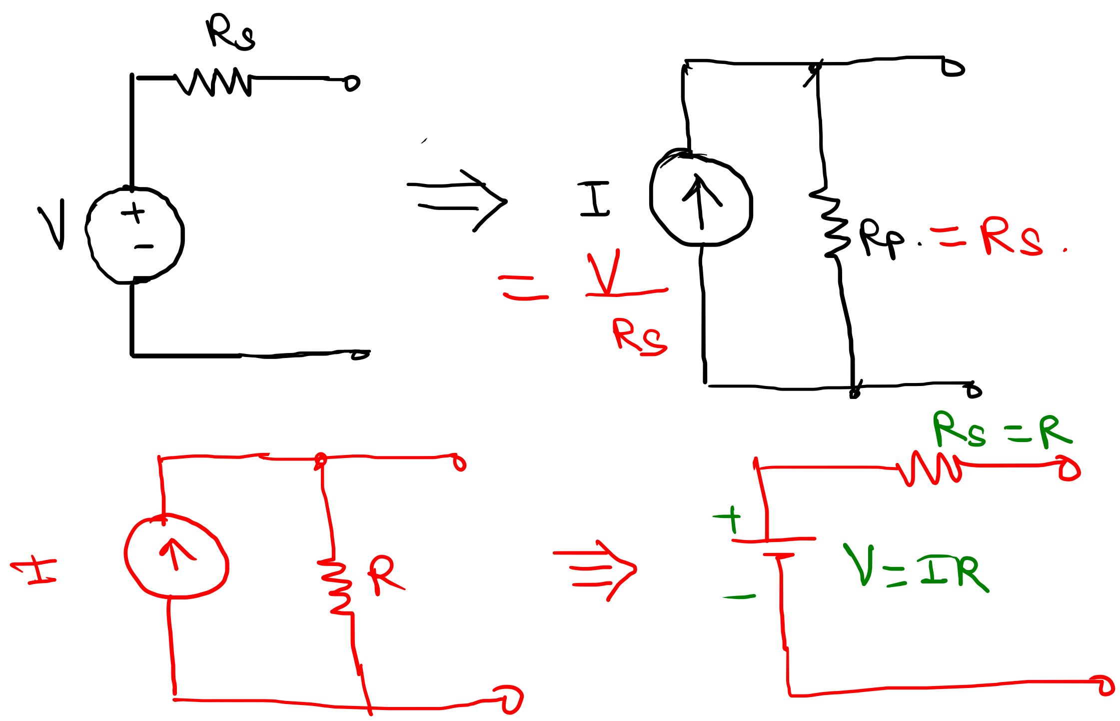


practical voltage source



practical Current source.

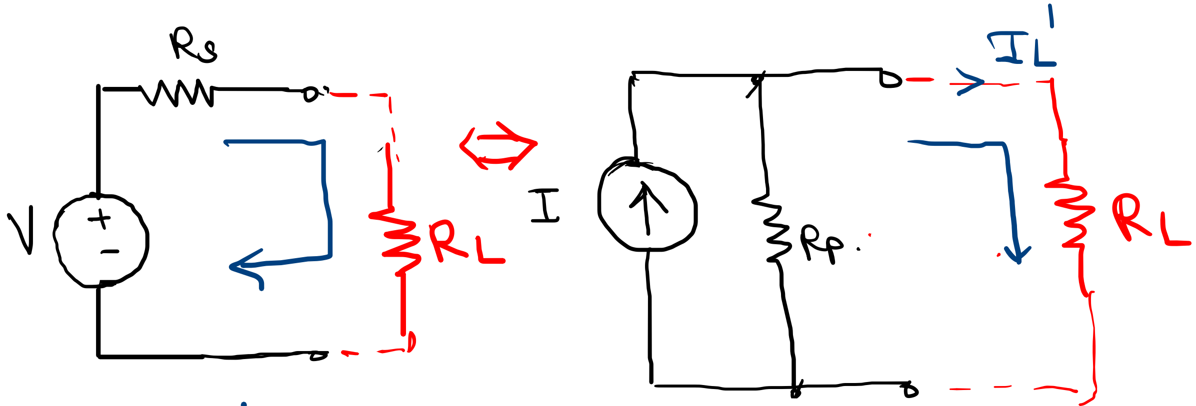
Source Transformation



⇒ Voltage source in series with resistance can be converted into equivalent current source in parallel with resistance

⇒ Current source in parallel with resistance can be converted into equivalent voltage source in series. with resistance

Source Transformation



$$I_L = \frac{V}{R_s + R_L}$$

$$I_L' = \frac{I \cdot R_s}{R_p + R_L}$$

To maintain electrical equivalence

$$I_L = I_L'$$

$$\frac{V}{R_s + R_L} = \frac{I \cdot R_s}{R_p + R_L}$$

$V = I \cdot R_s$ So $I = \frac{V}{R_s}$

$R_s + \cancel{R_L} = R_p + \cancel{R_L}$

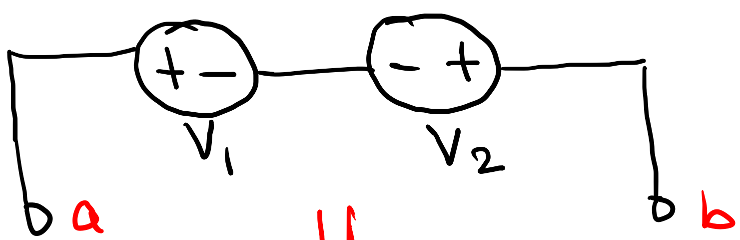
$R_s = R_p$.

Interconnection of energy sources

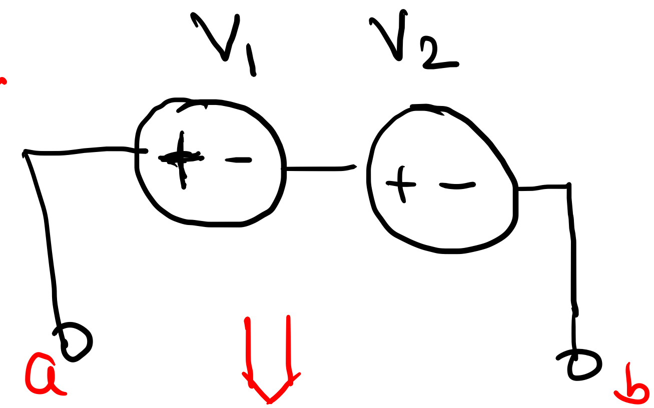
Voltage Source

Current Source

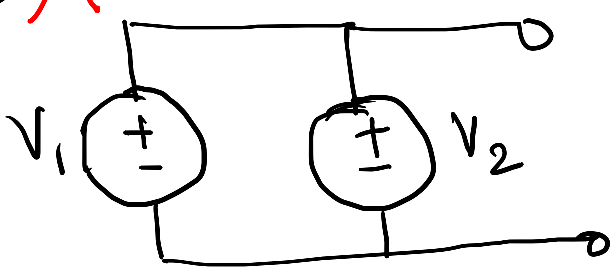
① In series



③



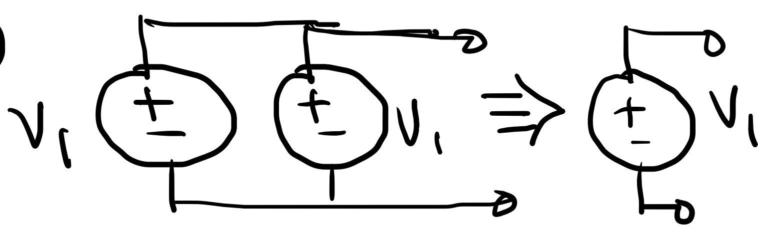
② X



$\Rightarrow$ If $V_1 \neq V_2$

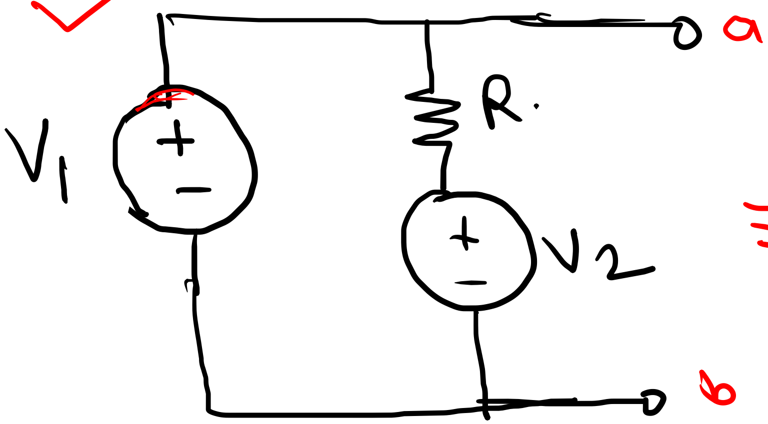
$\frac{V_1 - V_2}{0} = \infty$

④

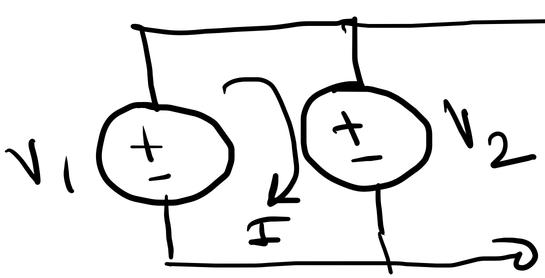


Interconnection of energy sources

Voltage source



⇒



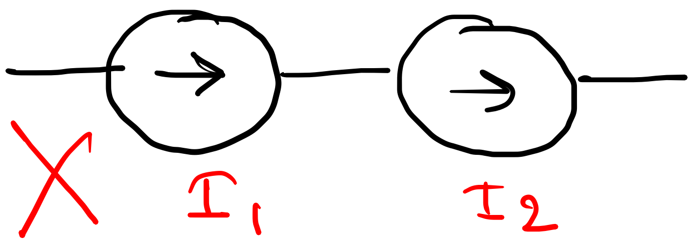
$V_1 > V_2$

$I = \frac{V_1 - V_2}{0} = \infty$

Heat $= I^2R = \infty$

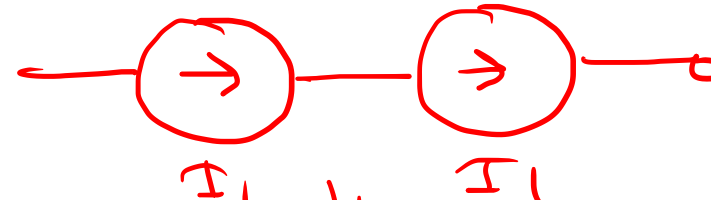
Current source

1

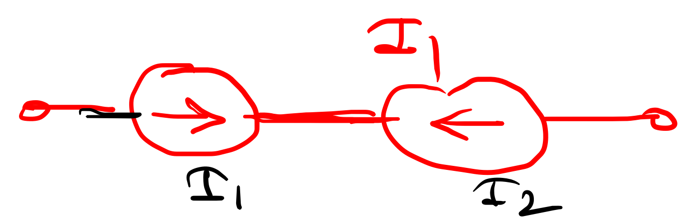


If $I_1 \neq I_2$

2

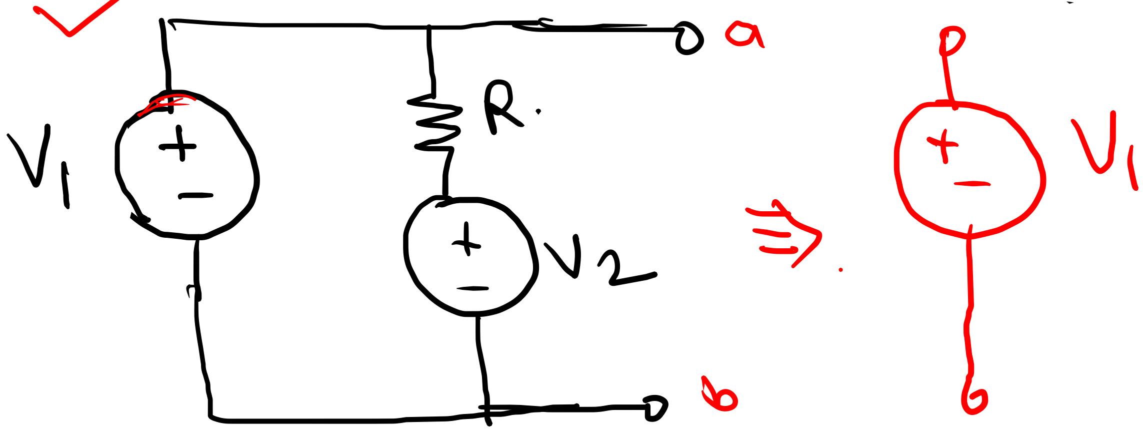


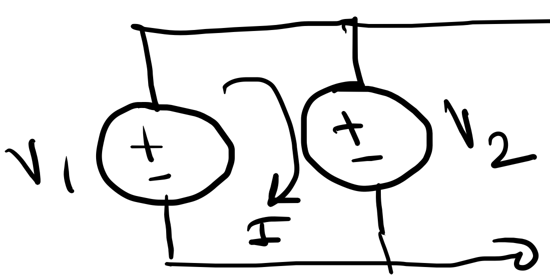
3



Interconnection of energy sources

Voltage Source



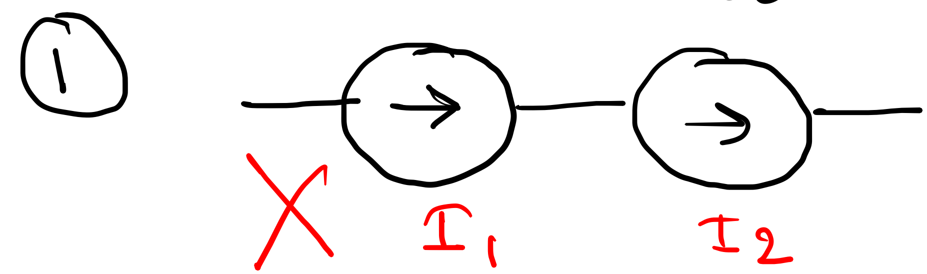


$V_1 > V_2$

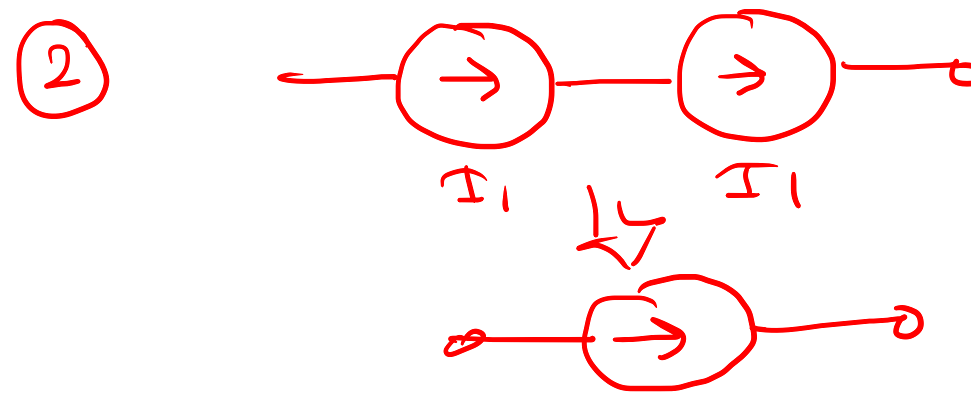
$$I = \frac{V_1 - V_2}{0} = \infty$$

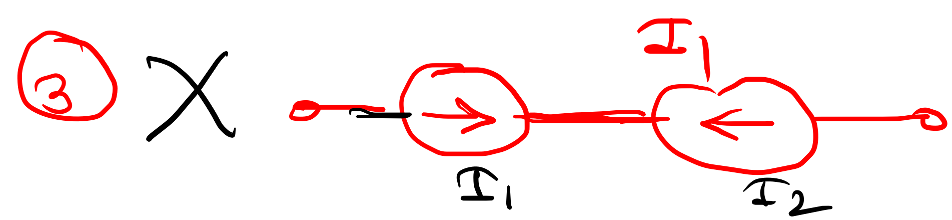
$$\text{Heat} = I^2R = \infty$$

Current source



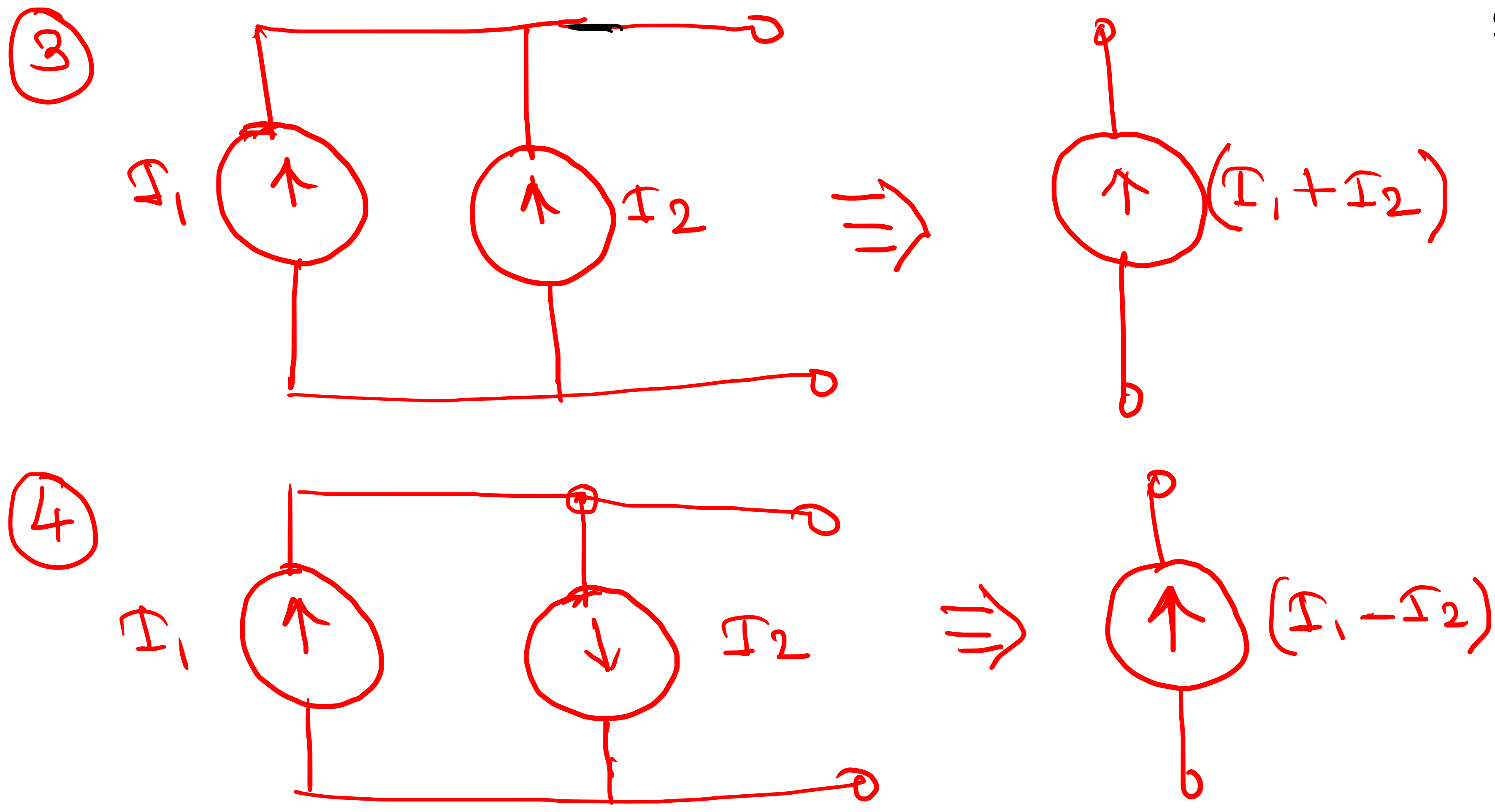
If $I_1 \neq I_2$





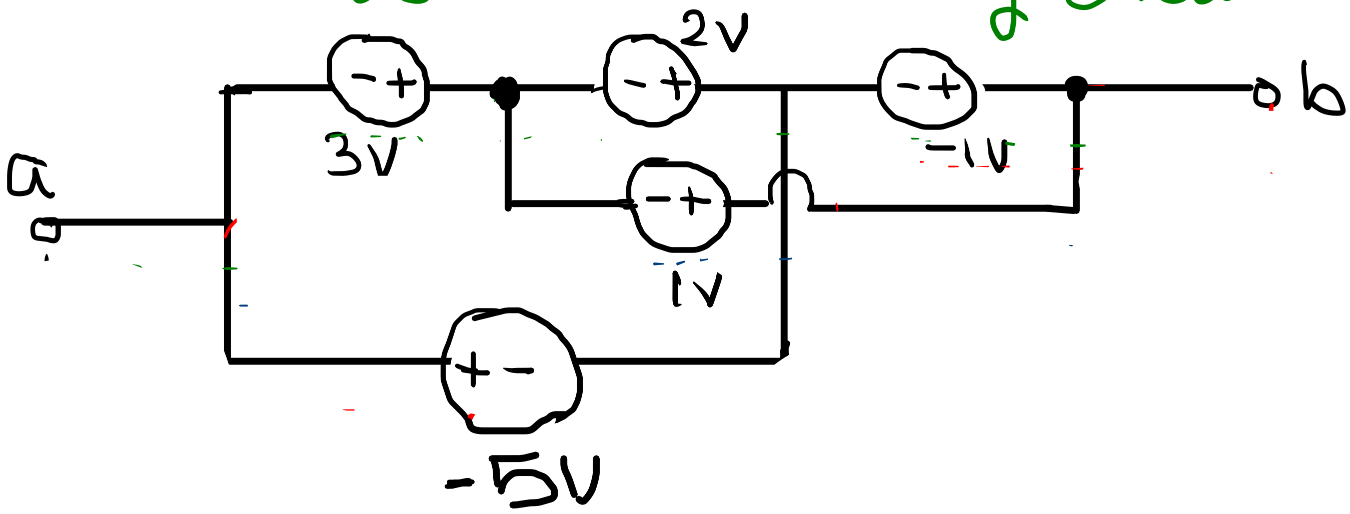
Interconnection of energy sources

Current source

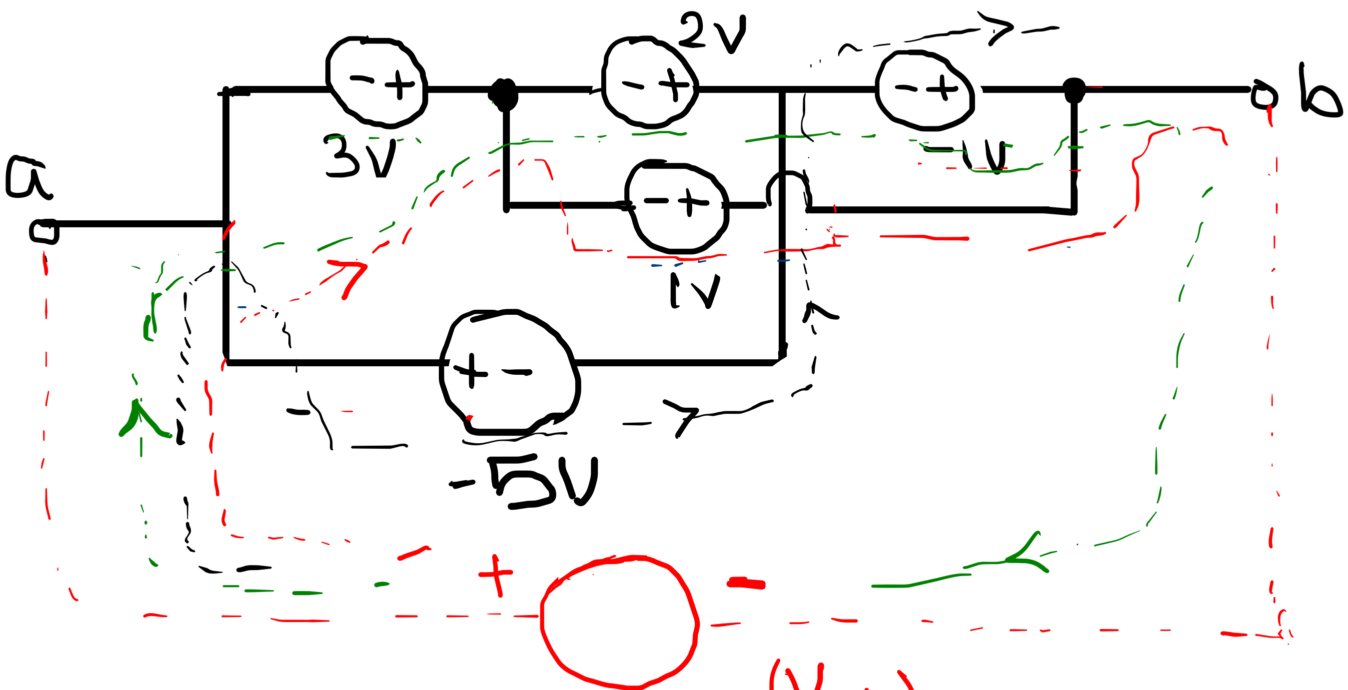


1

⇒ Find V_{ab} in the following circuit.



⇒



Using KVL

$V_{ab} + 3 + 2 + (-1) = 0$

$V_{ab} + 4 = 0$

$\boxed{V_{ab} = -4V}$

OR

$V_{ab} + 3 + 1 = 0$

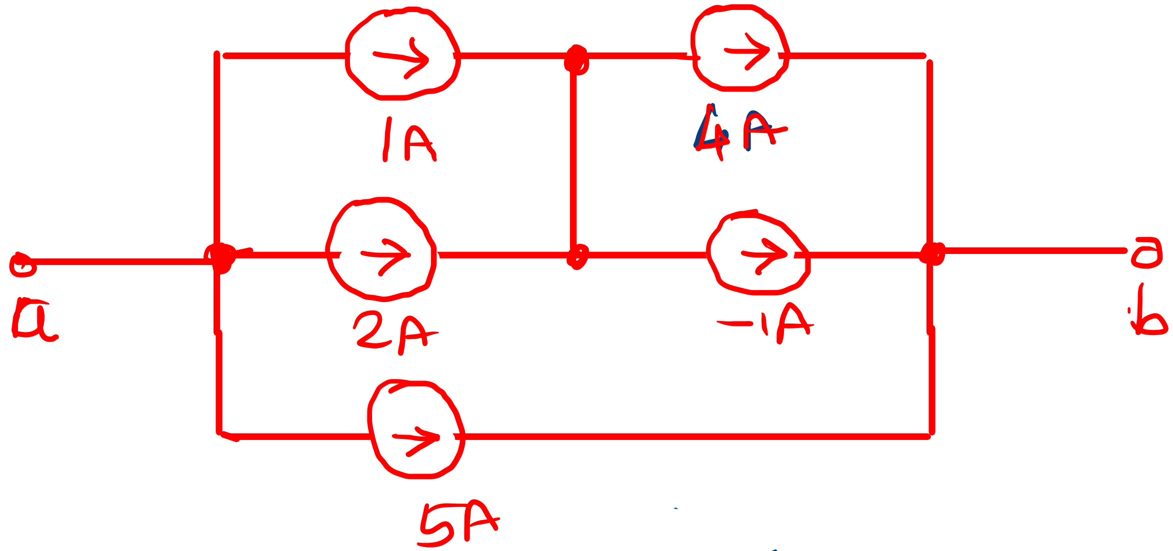
$\boxed{V_{ab} = -4V}$

$V_{ab} - (-5) + (-1) = 0$

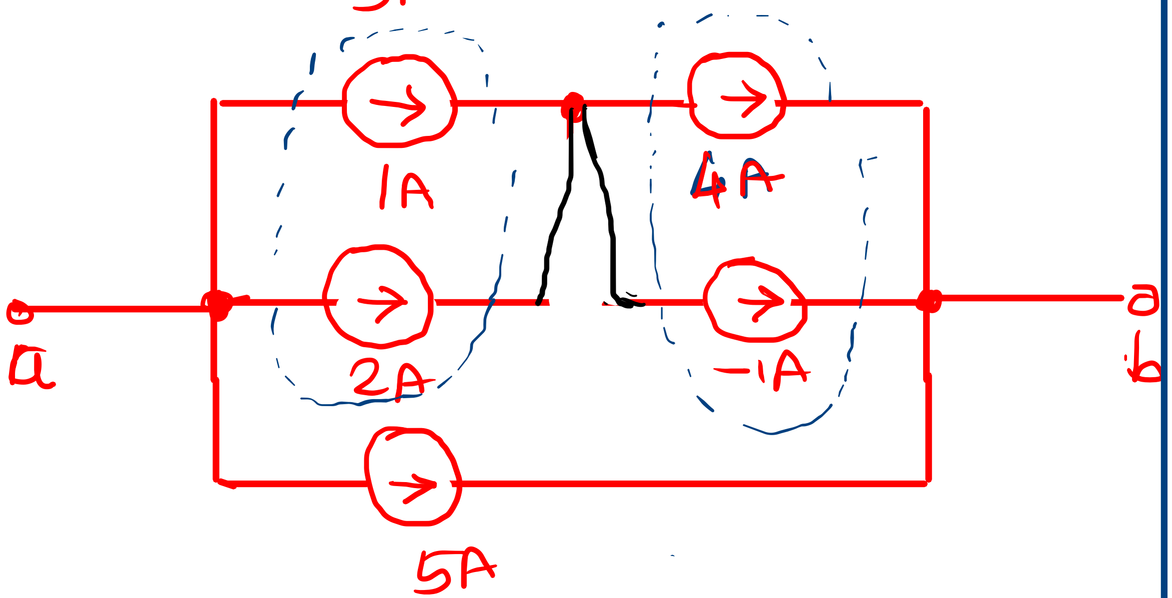
$V_{ab} + 5 - 1 = 0$

$\boxed{V_{ab} = -4V}$

② Find I_{ab}

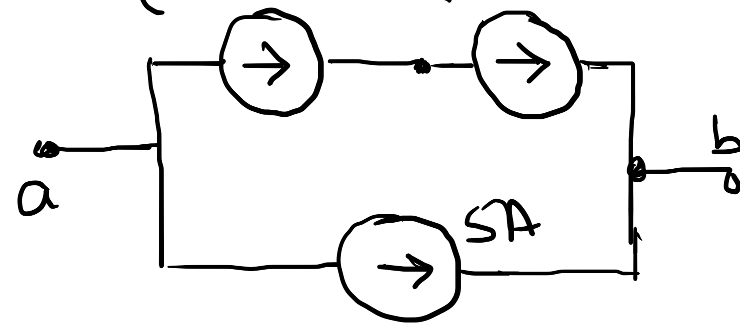


⇒

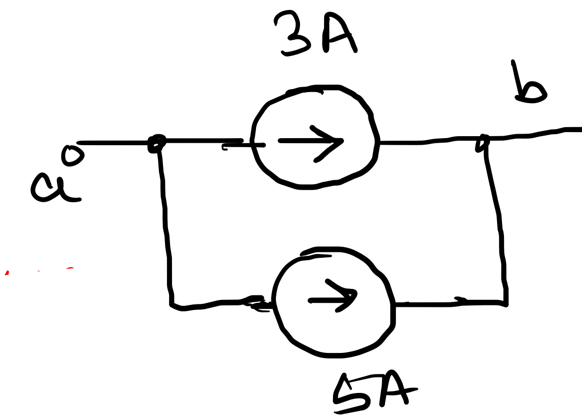


$(2+1)=3A \quad (4-1)=3A$

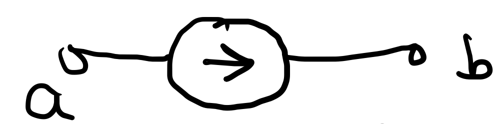
⇒



⇒



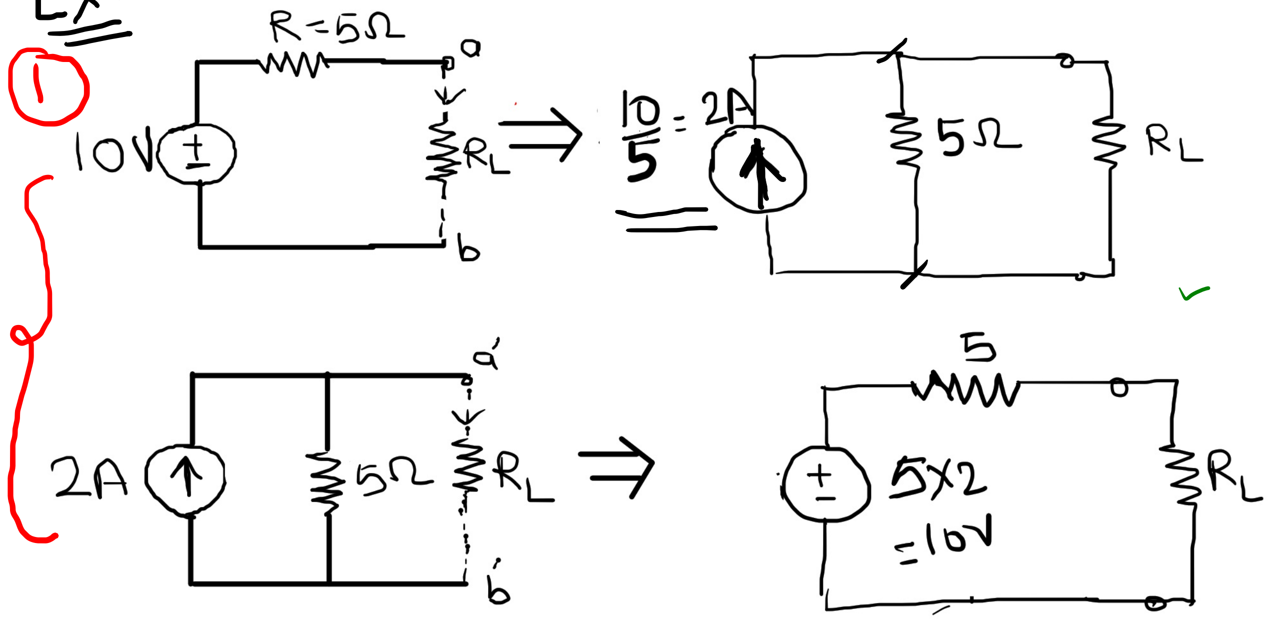
⇒

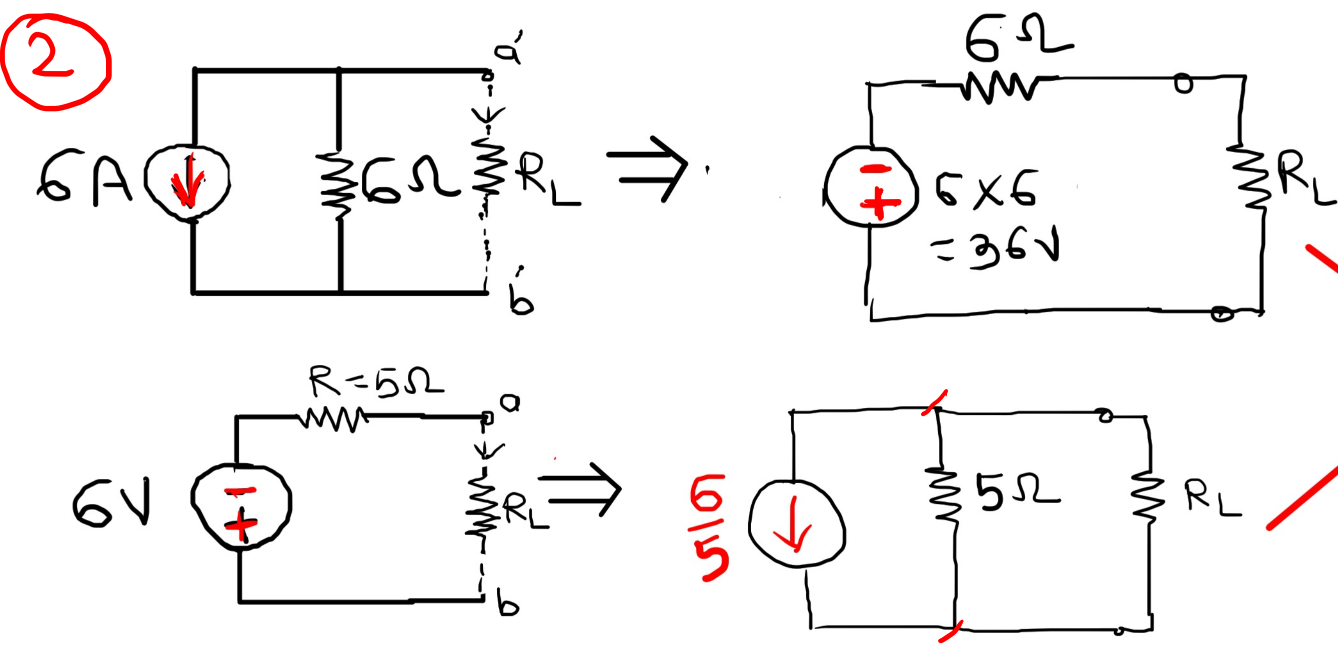


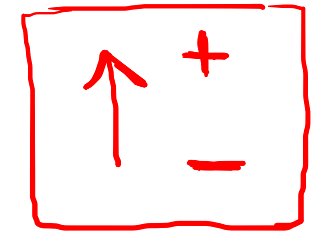
$(5+3)=8A$

Source Transformation Examples

Ex.

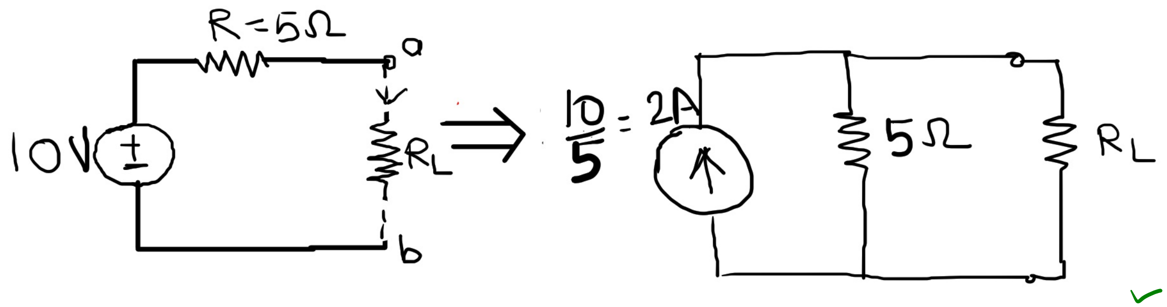


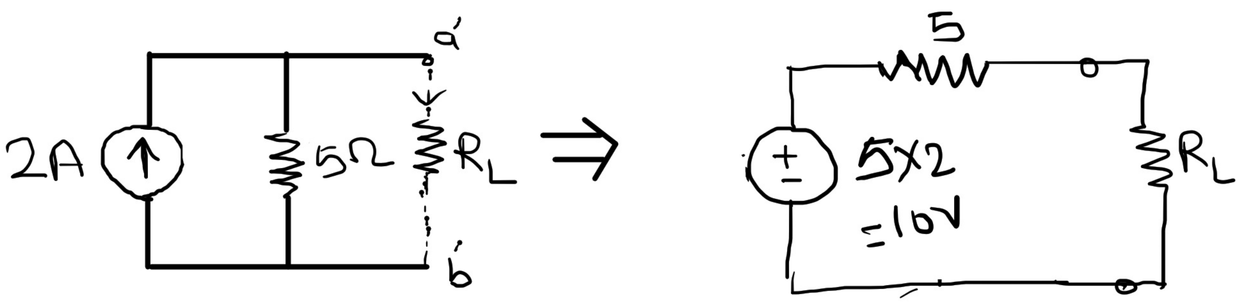


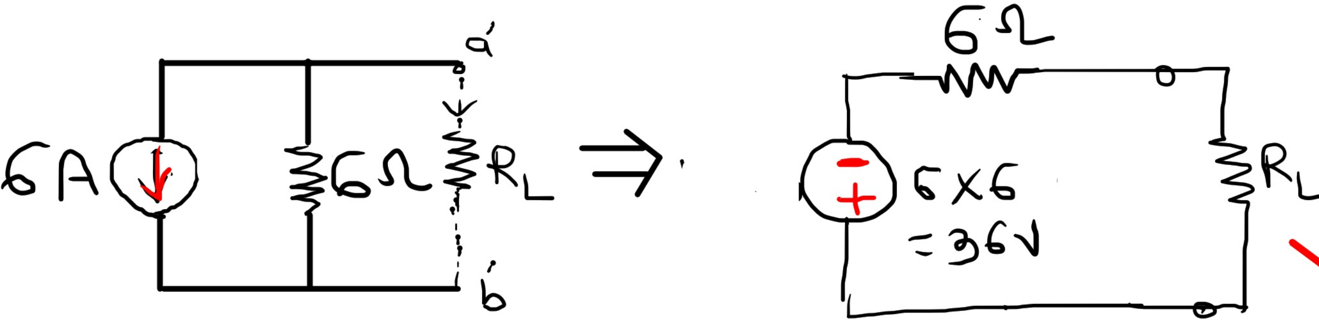


Note the direction of current source & polarity of Voltage Source

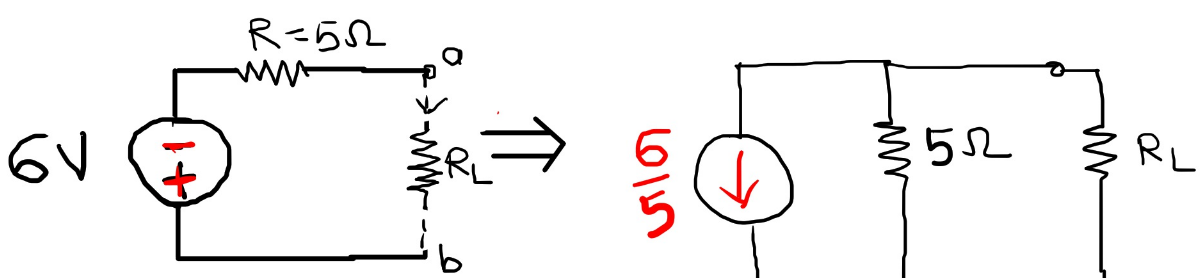
Source Transformation Examples



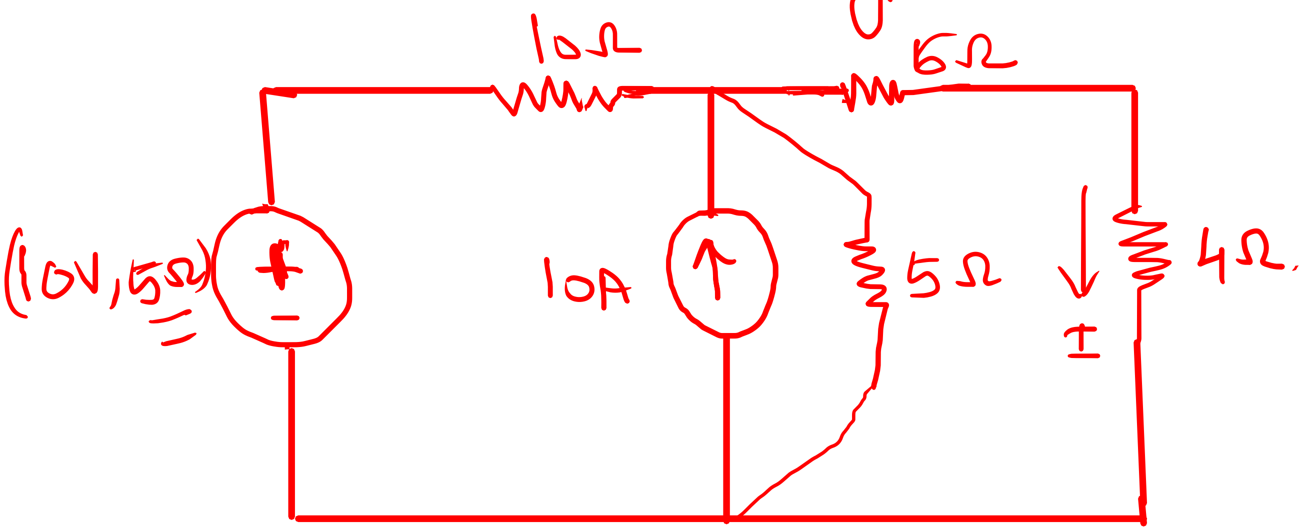




Note the direction of current source & polarity of Voltage Source

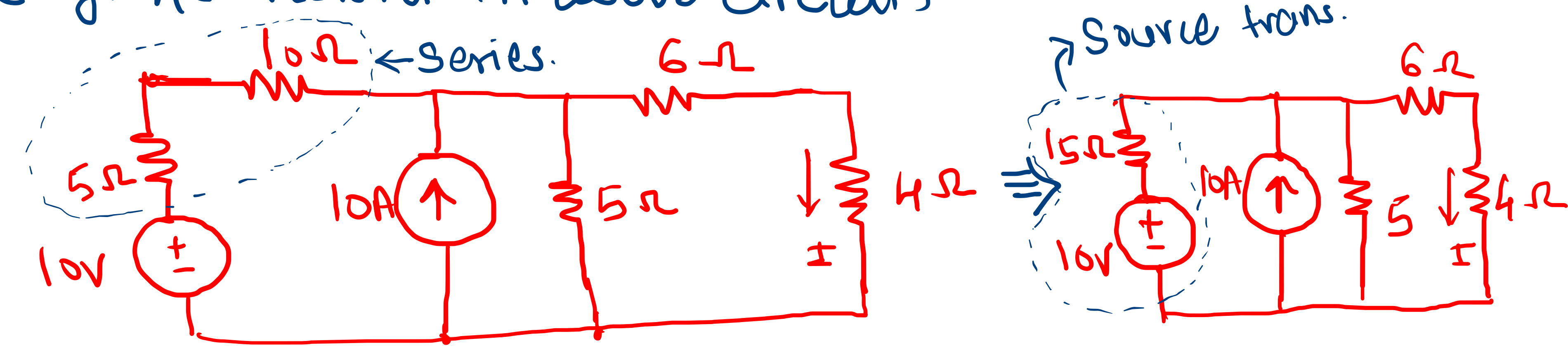


⇒ Find current I using source transformation.



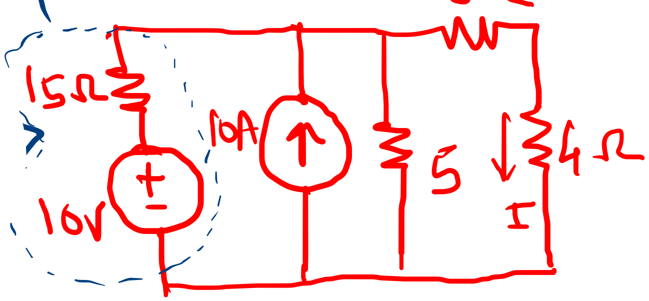
Note: Never take resistance for source transformation across which (through which) the voltage (current) to be found. (e.g. 4Ω resistor in above circuit)

⇒

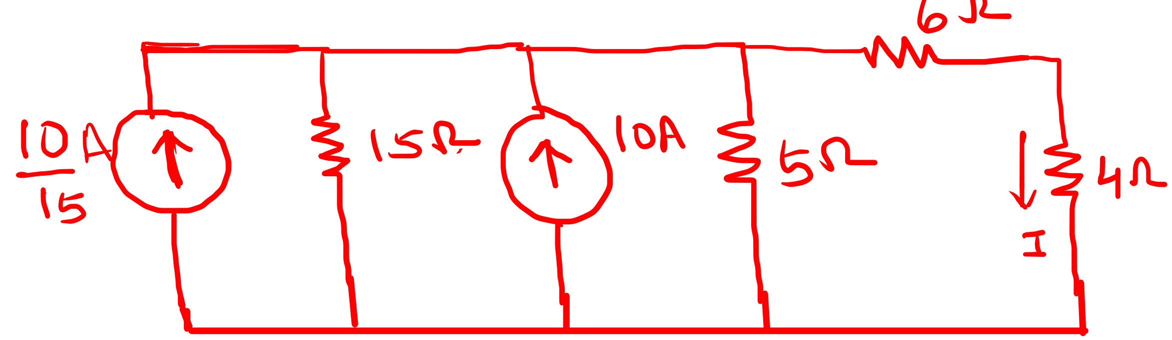


⇒ Find current I using source transformation.

Source trans.



⇒



(0.67A || 10A).

(10 + 0.67 = 10.67A↑)

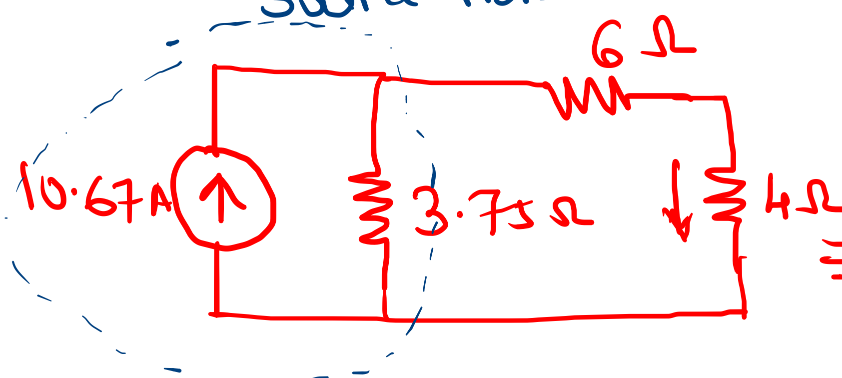
(15Ω || 5Ω)

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

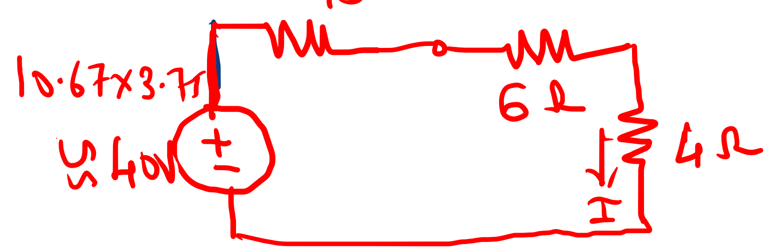
$$R_{eq} = \frac{R_1 R_2}{R_1+R_2} = \frac{15\times 5}{15+5} = \left(\frac{75}{20}\right)\Omega$$

$R_{eq} = 3.75\Omega$

Source trans.



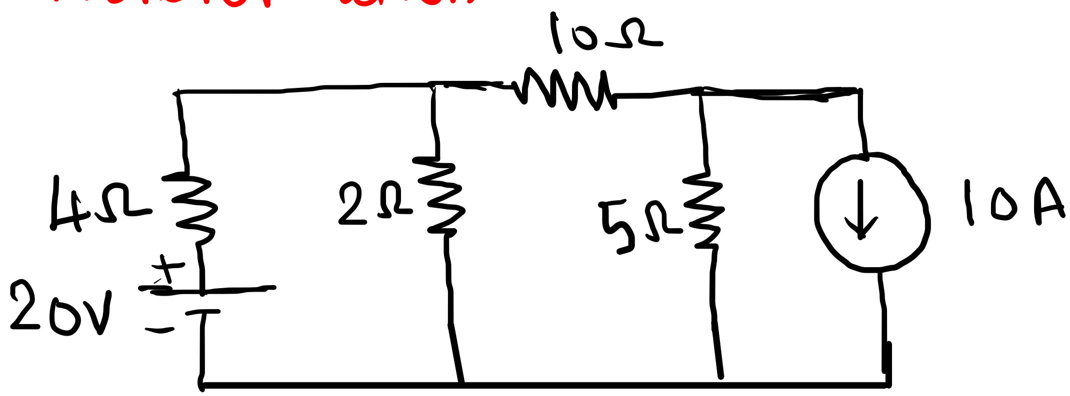
⇒



$$I = \frac{40}{(3.75+6+4)}$$

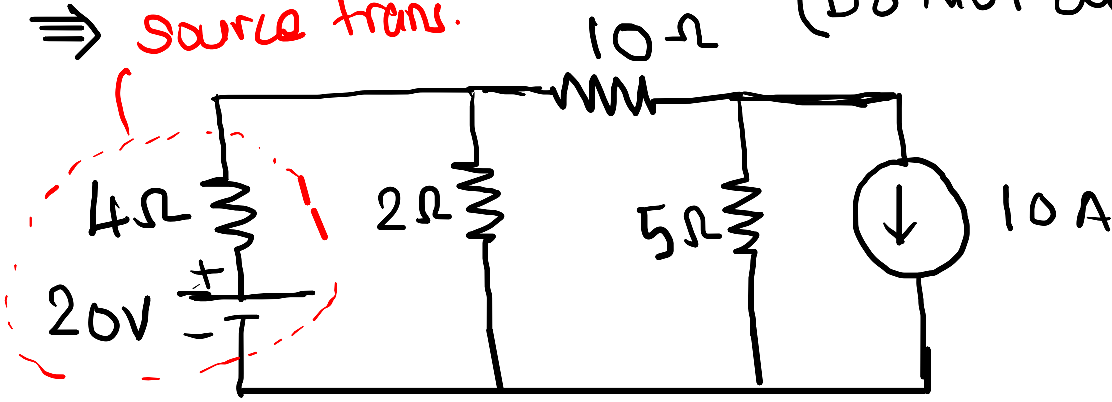
$$I = \frac{40}{13.75} = 2.91A$$

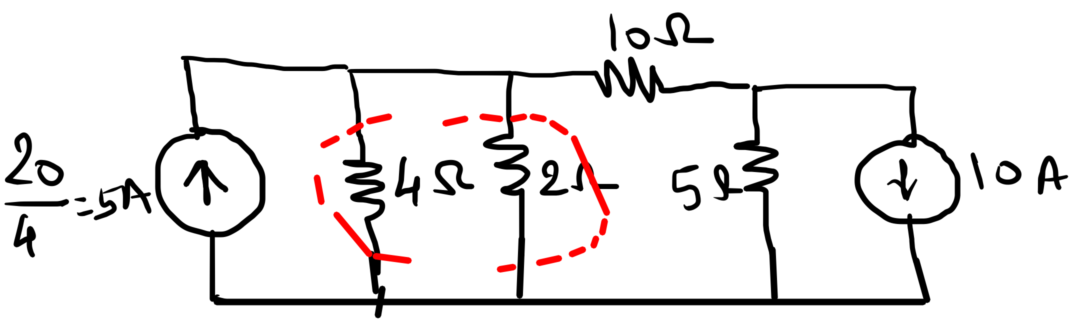
Ex (2) Find voltage across 10Ω resistor using source transformation



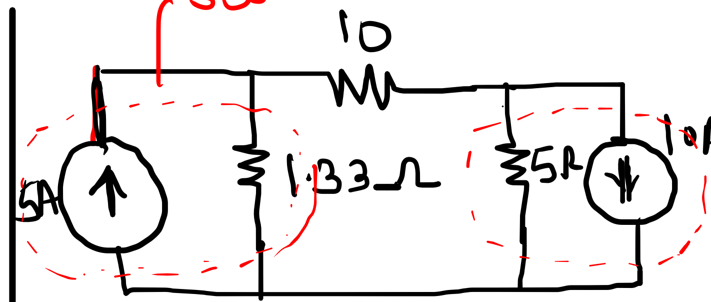
(Do Not disturb 10Ω)

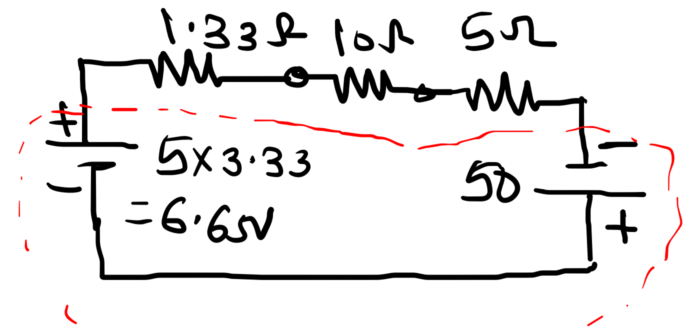
⇒ source trans.

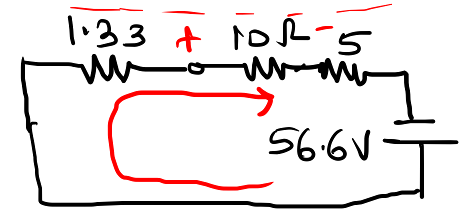




source trans.







Using voltage division formula.

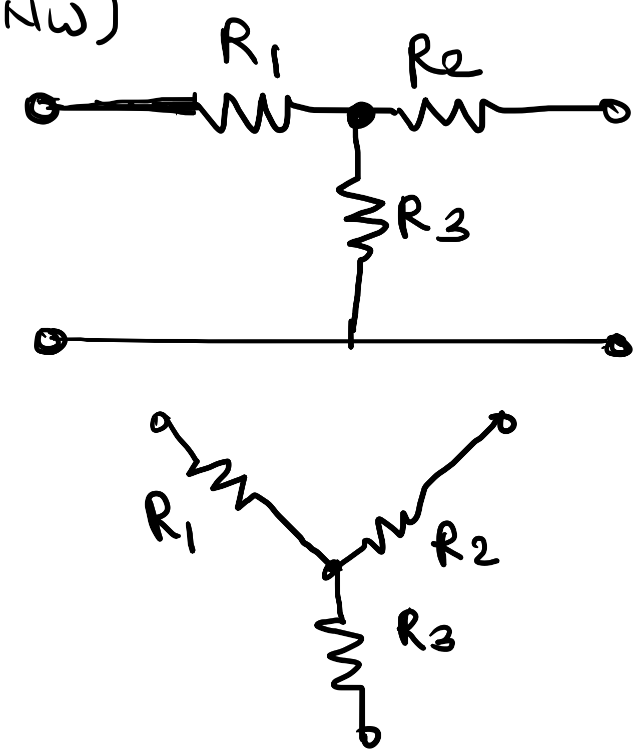
$$V_{10\Omega} = \frac{10 \times (56.6)}{1.33 + 10 + 5}$$

$$V_{10\Omega} = (34.69)\,V$$

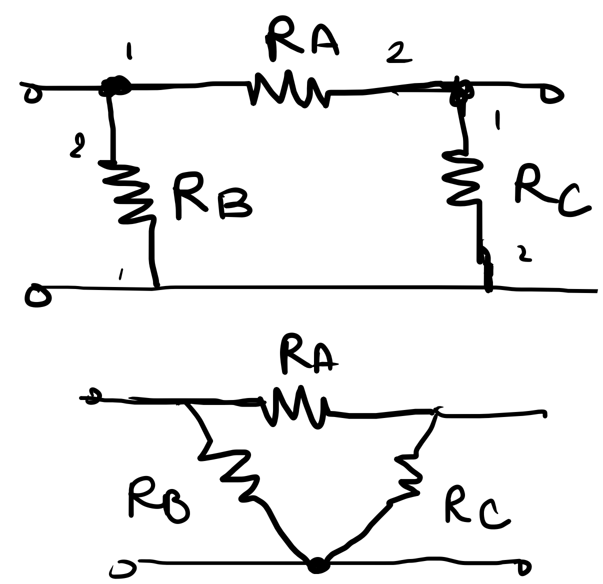
Resistive network simplification using star-delta transformsation

1. Series Combination of resistors ⇒ Equivalent $R_{eq} = R_1 + R_2 + \cdots + R_n$
2. Parallel Combination of resistor ⇒ $\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots + \frac{1}{R_{eq}}$

⇒ Star Network (Y)
(T-NW)

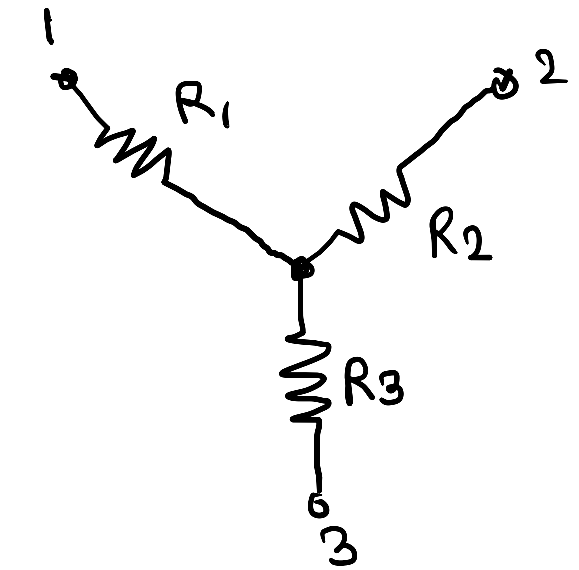


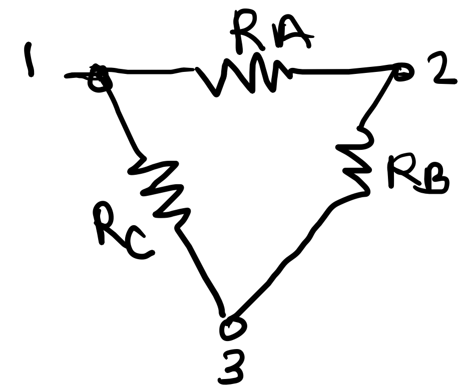
⇒ Delta Network (π)
(Mesh network)



Resistive network simplification using star-delta transformsation

Star network $\rightleftarrows$ Equivalent Delta





$$R_{12Y} = R_1 + R_2$$

$$R_{23Y} = R_2 + R_3$$

$$R_{31Y} = R_1 + R_3$$

$$R_{12\Delta} = R_A \parallel (R_B + R_C)$$

$$R_{23\Delta} = R_B \parallel (R_A + R_C)$$

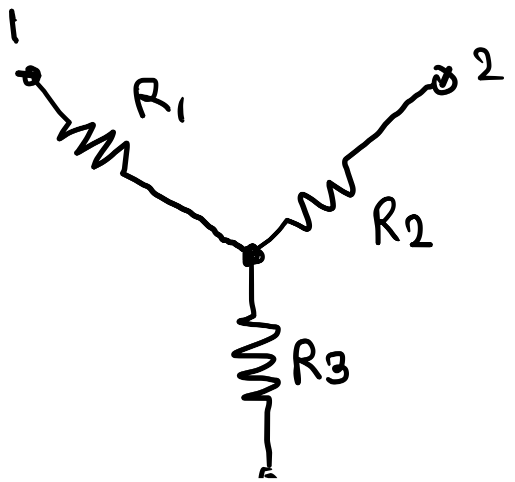
$$R_{31\Delta} = R_C \parallel (R_A + R_B)$$

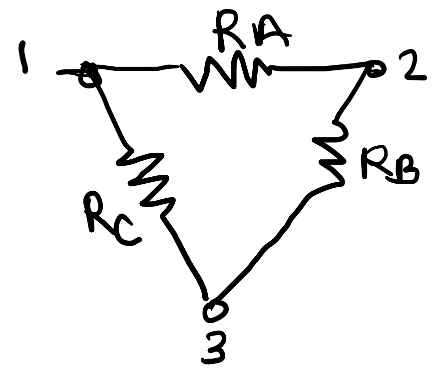
Two networks will be equivalent when

$$R_{12Y} = R_{12\Delta}$$
$$R_{23Y} = R_{23\Delta}$$
$$R_{31Y} = R_{31\Delta}.$$

Resistive network simplification using star-delta transformsation

Star network $\rightleftarrows$ Equivalent Delta





Delta ⟶ Star network

$$R_1 + R_2 = R_A \parallel (R_B + R_C)$$

$$R_1 + R_2 = \frac{R_A(R_B + R_C)}{R_A + R_B + R_C} \quad \text{--- (i)}$$

$$R_2 + R_3 = \frac{R_B(R_A + R_C)}{R_A + R_B + R_C} \quad \text{--- (ii)}$$

$$R_3 + R_1 = \frac{R_C(R_A + R_B)}{R_A + R_B + R_C} \quad \text{--- (iii)}$$

Equation (i) + (ii) − (iii)

$$R_1 + R_2 + R_2 + R_3 - R_3 - R_1$$

$$= \frac{R_A(R_B + R_C) +}{R_A + R_B + R_C}$$

Resistive network simplification using star-delta transformsation

Delta $\longrightarrow$ star network

$$R_1 + R_2 = R_A \parallel (R_B + R_C)$$

$$R_1 + R_2 = \frac{R_A(R_B + R_C)}{R_A + R_B + R_C} \quad \text{---} \; (i)$$

$$R_2 + R_3 = \frac{R_B(R_A + R_C)}{R_A + R_B + R_C} \quad \text{---} \; (ii)$$

$$R_3 + R_1 = \frac{R_C(R_A + R_B)}{R_A + R_B + R_C} \quad \text{---} \; (iii)$$

Adding (i) + (ii) − (III)

$$\cancel{R_1} + R_2 + R_2 + \cancel{R_3} - \cancel{R_3} - \cancel{R_1} = \frac{R_A(R_B + R_C) + R_B(R_A + R_C) - R_C(R_A + R_B)}{R_A + R_B + R_C}$$

$$2R_2 = \frac{R_A R_B + \cancel{R_A R_C} + R_A R_B + \cancel{R_B R_C} - \cancel{R_A R_C} - \cancel{R_B R_C}}{R_A + R_B + R_C}$$

$$\cancel{2}R_2 = \frac{\cancel{2}\, R_A R_B}{R_A + R_B + R_C}$$

$$\boxed{R_2 = \frac{R_A R_B}{R_A + R_B + R_C}}$$

Resistive network simplification using star-delta transformsation

Delta $\longrightarrow$ Star network

$R_1 + R_2 = R_A \| (R_B + R_C)$

$$R_1 + R_2 = \frac{R_A(R_B + R_C)}{R_A + R_B + R_C} \quad \text{--- (i)}$$

$$R_2 + R_3 = \frac{R_B(R_A + R_C)}{R_A + R_B + R_C} \quad \text{--- (ii)}$$

$$R_3 + R_1 = \frac{R_C(R_A + R_B)}{R_A + R_B + R_C} \quad \text{--- (iii)}$$

Adding (I) + (III) $-$ (II)

$$2R_1 = \frac{2 R_A \cdot R_C}{R_A + R_B + R_C}$$

$$\boxed{R_1 = \frac{R_A R_C}{R_A + R_B + R_C}}$$

Simillarly

(II) + (III) $-$ (I)

$$2R_3 = \frac{2 R_B R_C}{R_A + R_B + R_C}$$

$$\boxed{R_3 = \frac{R_B R_C}{R_A + R_B + R_C}}$$

Resistive network simplification using star-delta transformsation

Star $\longrightarrow$ Delta

$$R_1 = \frac{R_A R_C}{R_A + R_B + R_C}$$

$$R_2 = \frac{R_A R_B}{R_A + R_B + R_C}$$

$$R_3 = \frac{R_B R_C}{R_A + R_B + R_C}$$

$$R_1 R_2 = \frac{R_A^2 R_B R_C}{(R_A + R_B + R_C)^2}$$

$$R_2 R_3 = \frac{R_A R_B^2 R_C}{(R_A + R_B + R_C)^2}$$

$$R_3 R_1 = \frac{R_A R_B R_C^2}{(R_A + R_B + R_C)^2}$$

$$\Sigma R = R_1 R_2 + R_2 R_3 + R_3 R_1 = \frac{R_A^2 R_B R_C + R_A R_B^2 R_C + R_A R_B R_C^2}{(R_A + R_B + R_C)^2}$$

$$\Sigma R = \frac{R_A R_B R_C \cancel{(R_A + R_B + R_C)}}{(R_A + R_B + R_C)^{\cancel{2}}}$$

$$\Sigma R = \frac{R_A R_B R_C}{R_A + R_B + R_C} \quad --- \quad 4$$

$$\frac{\Sigma R}{R_1} = \frac{\cancel{R_A} R_B \cancel{R_C}}{\cancel{(R_A + R_B + R_C)}} \times \frac{\cancel{(R_A + R_B + R_C)}}{\cancel{R_A R_C}} = R_B$$

$$\frac{\Sigma R}{R_2} = \frac{\cancel{R_A R_B} R_C}{\cancel{R_A + R_B + R_C}} \times \frac{\cancel{(R_A + R_B + R_C)}}{\cancel{R_A R_B}} = R_C$$

$$\frac{\Sigma R}{R_3} = \frac{R_A R_B R_C}{R_A + R_B + R_C} \times \frac{(R_A + R_B + R_C)}{R_B R_C} = R_A$$

Resistive network simplification using star-delta transformsation

Delta → Star

$$R_1 = \frac{R_A R_C}{R_A+R_B+R_C}$$

$$R_2 = \frac{R_A R_B}{R_A+R_B+R_C}$$

$$R_3 = \frac{R_B R_C}{R_A+R_B+R_C}$$

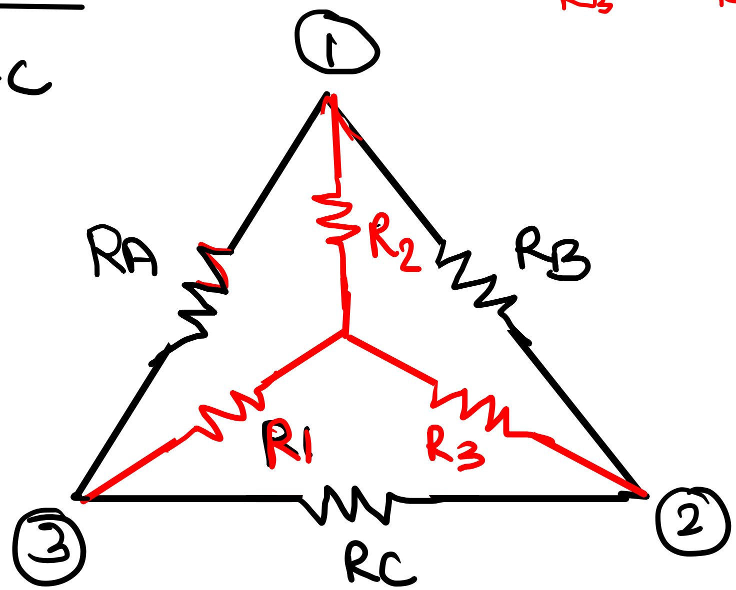
Star — Delta

$$\Sigma R = \frac{R_A R_B R_C}{R_A+R_B+R_C} \quad \text{----} \quad (4)$$

$$\frac{\Sigma R}{R_1} = \frac{\cancel{R_A} R_B \cancel{R_C}}{\cancel{(R_A+R_B+R_C)}} \times \frac{\cancel{(R_A+R_B+R_C)}}{\cancel{R_A R_C}} = R_B$$

$$\frac{\Sigma R}{R_2} = \frac{\cancel{R_A R_B} R_C}{\cancel{R_A+R_B+R_C}} \times \frac{\cancel{(R_A+R_B+R_C)}}{\cancel{R_A R_B}} = R_C$$

$$\frac{\Sigma R}{R_3} = \frac{R_A R_B R_C}{R_A+R_B+R_C} \times \frac{(R_A+R_B+R_C)}{R_B R_C} = R_A$$



$$R_A = \frac{\Sigma R}{R_3}$$

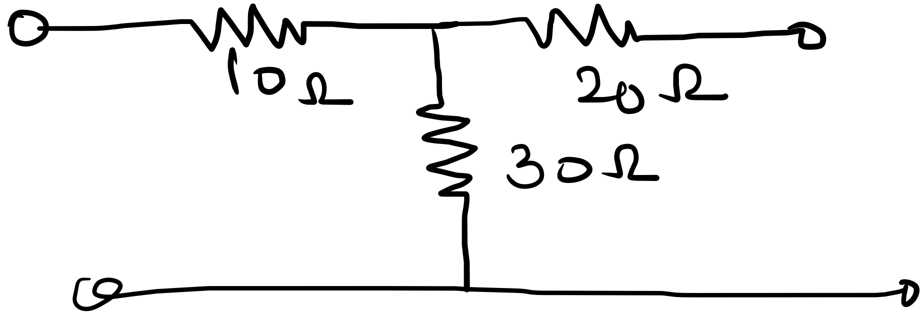
$$R_B = \frac{\Sigma R}{R_1}$$

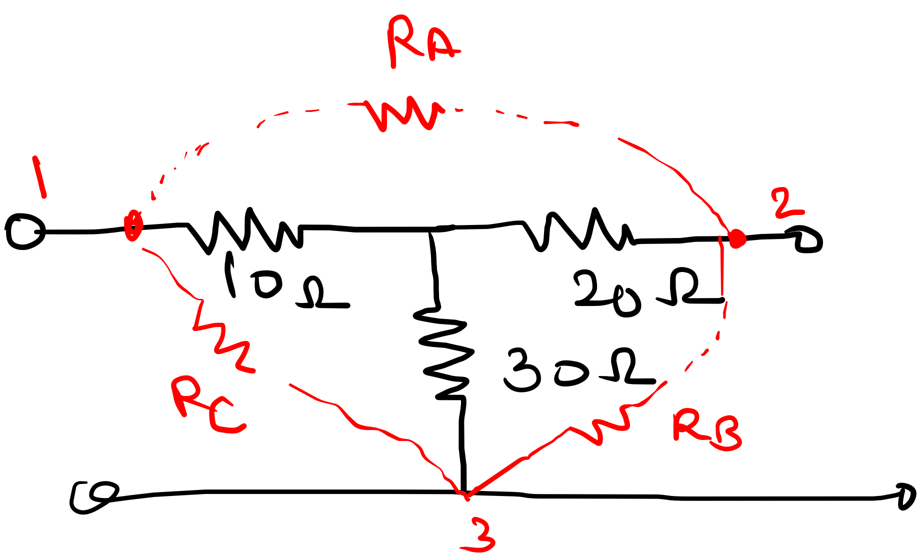
$$R_C = \frac{\Sigma R}{R_2}$$

$$\Sigma R = R_1R_2 + R_2R_3 + R_1R_3$$

Resistive network simplification using star-delta transformsation

Ex. 1 Convert to equivalent Delta





$$\Sigma R = R_1R_2 + R_2R_3 + R_3R_1$$

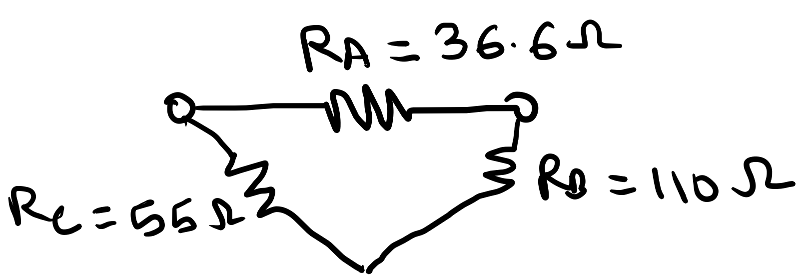
$$\Sigma R = 10\times20 + 20\times30 + 30\times10$$

$$\Sigma R = 200 + 600 + 300 = 1100$$

$$R_A = \frac{\Sigma R}{30} = \frac{1100}{30} = \frac{110}{3} = 36.66\,\Omega$$

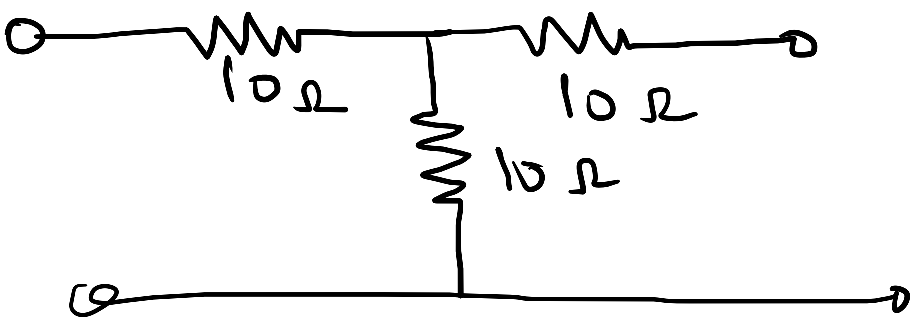
$$R_B = \frac{\Sigma R}{10} = \frac{1100}{10} = 110\,\Omega$$

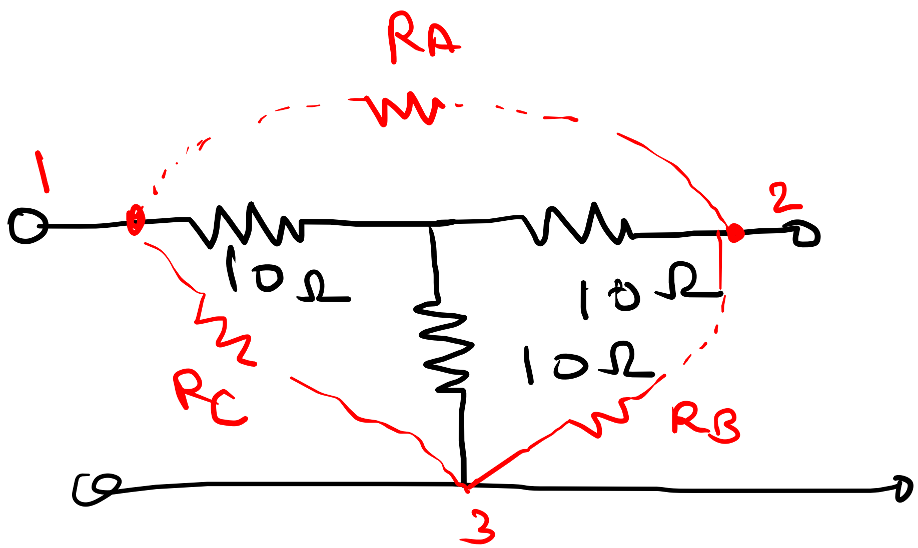
$$R_C = \frac{\Sigma R}{20} = \frac{110}{20} = 55\,\Omega$$



Resistive network simplification using star-delta transformsation

Ex. (ii) Convert to equivalent Delta



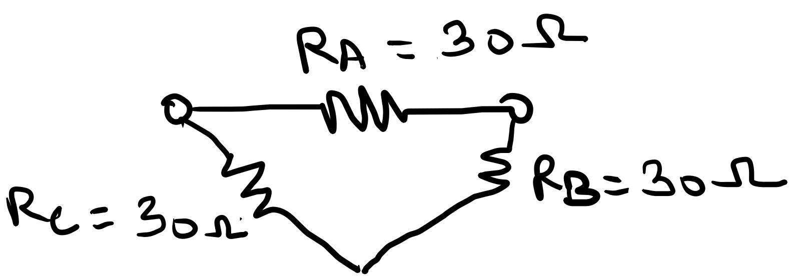


$\Sigma R = R_1R_2 + R_2R_3 + R_3R_1$

$\Sigma R = 10\times10 + 10\times10 + 10\times10 = 300$

$R_A = \frac{\Sigma R}{10} = \frac{300}{10} = 30\ \Omega$

$R_B = R_C = \frac{\Sigma R}{10} = 30\Omega$

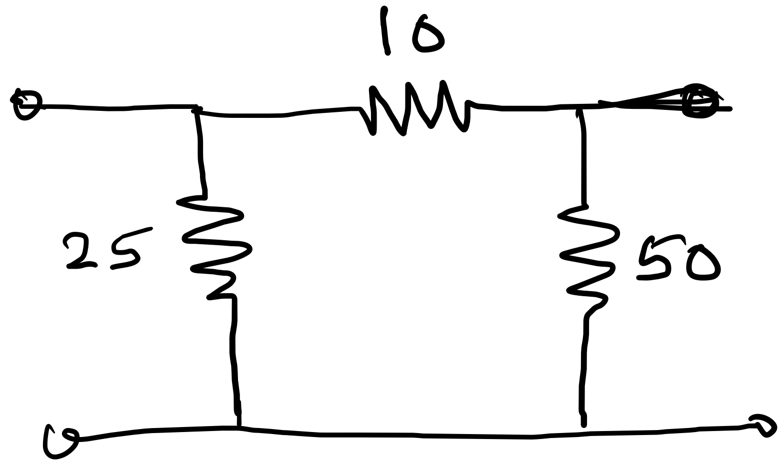


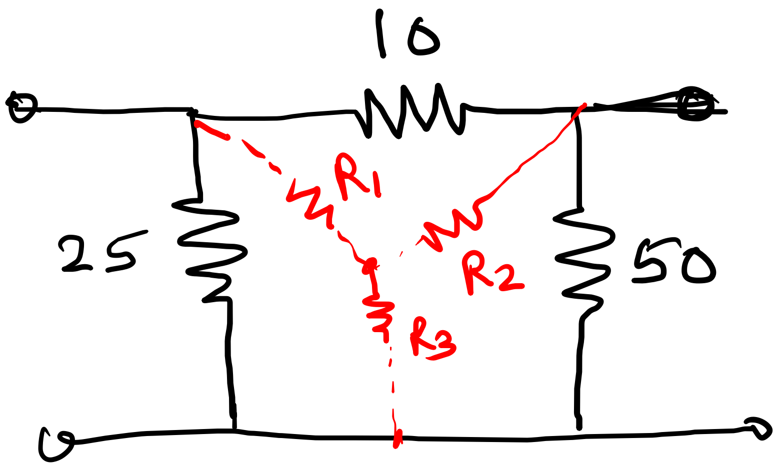
Delta Resistances = 3 X Star resistance

if all resistances in Star are same.

Resistive network simplification using star-delta transformsation

Ex. (iii) Convert following network into equivalent star.





$R_A + R_B + R_C = 10 + 50 + 25 = 85$

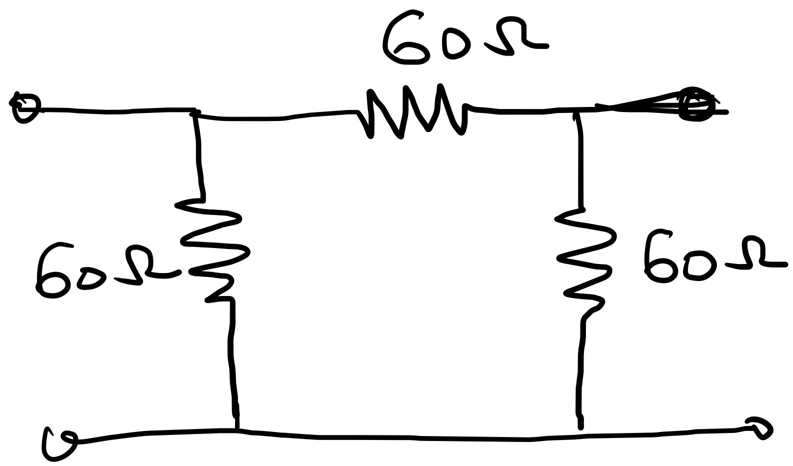
$R_1 = \dfrac{25 \times 10}{85} = 2.94\,\Omega$

$R_2 = \dfrac{10 \times 50}{85} = 5.88\,\Omega$

$R_3 = \dfrac{25 \times 50}{85} = 14.7\,\Omega$

Resistive network simplification using star-delta transformsation

Ex(N) Convert following network into equivalent star.

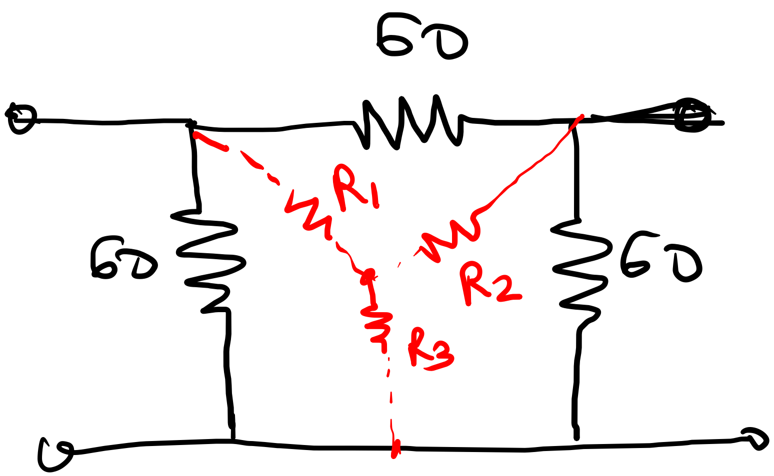


$R_A+R_B+R_C = 60+60+60$

$R_A+R_B+R_C = 180$

$R_1 = R_2 = R_3 = \dfrac{60\times 60}{180}$

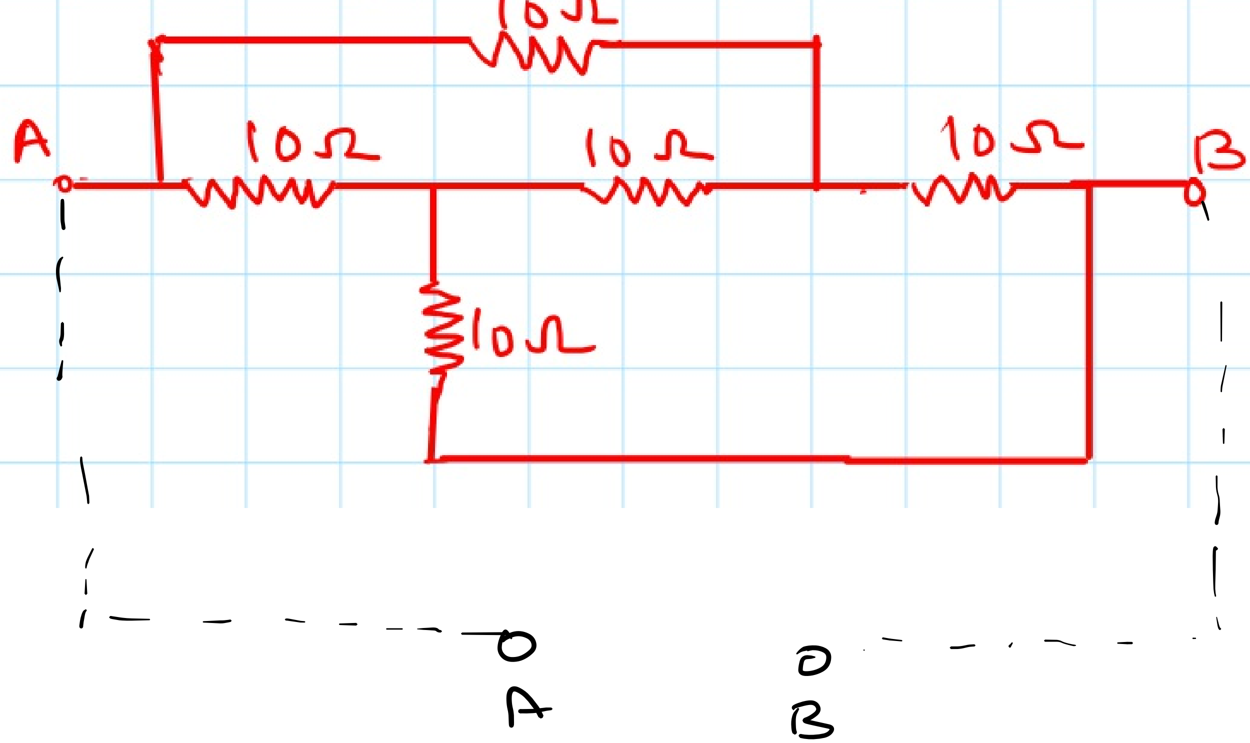
$R_1 = R_2 = R_3 = 20\Omega$



If all Delta network resistances are same then

Star n/w equivalent $= \frac{1}{3} \times$ Delta resistance

Example: 2 Find resistance R_{AB}



Example (3)

$\Rightarrow$ Find resistance R_{AB} in the following network