22AIE114 : Introduction to Electrical and Electronic Engineering (2-0-3-3)

Unit 1, Lecture 3

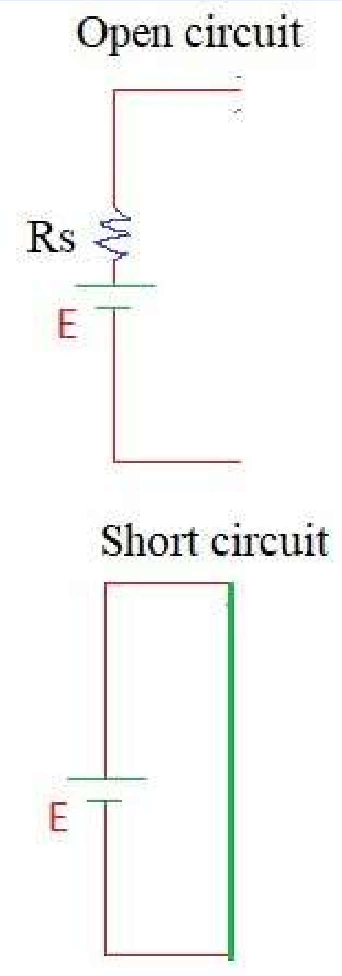
Topic: Basic Circuit Laws

Outline

1. Open and short circuit
2. Source transformation
3. What is Equivalent circuit?
4. Linearity Property
5. Define Ohms Law
6. Define the term equivalent resistance
7. Calculate the equivalent resistance

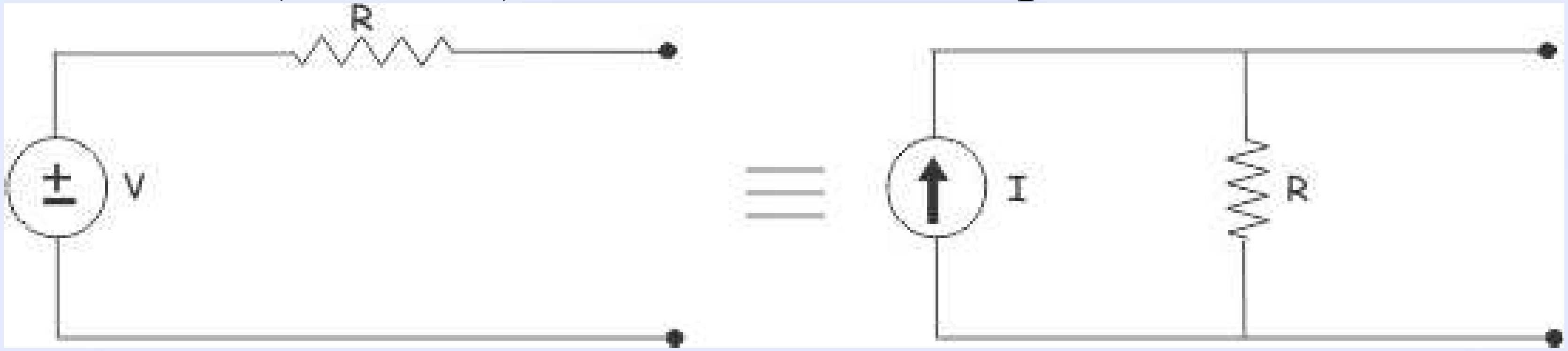
1. OC and SC:

1. Open Circuit (OC)
   a) The circuit is opened between two terminals.
   b) Resistance between open terminal is Infinity.
   c) Current flow = 0 amps
   d) Voltage across terminals may be there.
2. Short Circuit (SC)
   a) The circuit is shorted (with zero resistance conductor)
   b) Hence the current flow will be infinity.
   c) Voltage across the shorted terminal is zero.



2. Source Transformation:

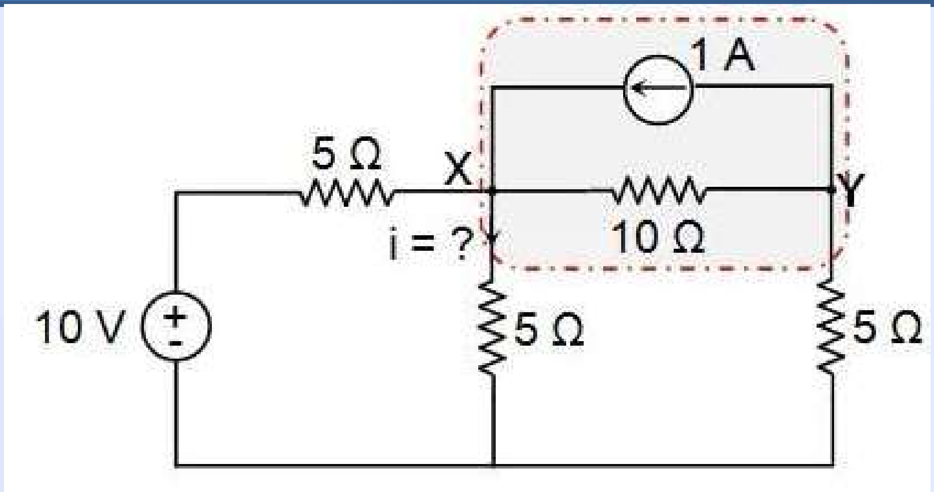
- The source transformation technique is required to simplify an electric circuit for analysis.
- Let us take a simple voltage source along with a resistance connected in series with it.
- This series resistance normally represents the internal resistance of a practical voltage source.
- This circuit can be represented by equivalent current source (I = V/R) with resistance in parallel.



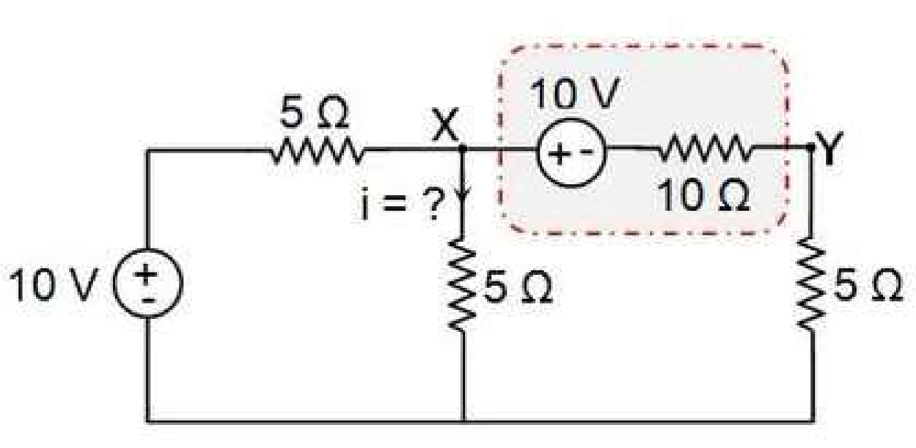
2. Source Transformation:

Example: (I to V)

– Consider the given circuit.



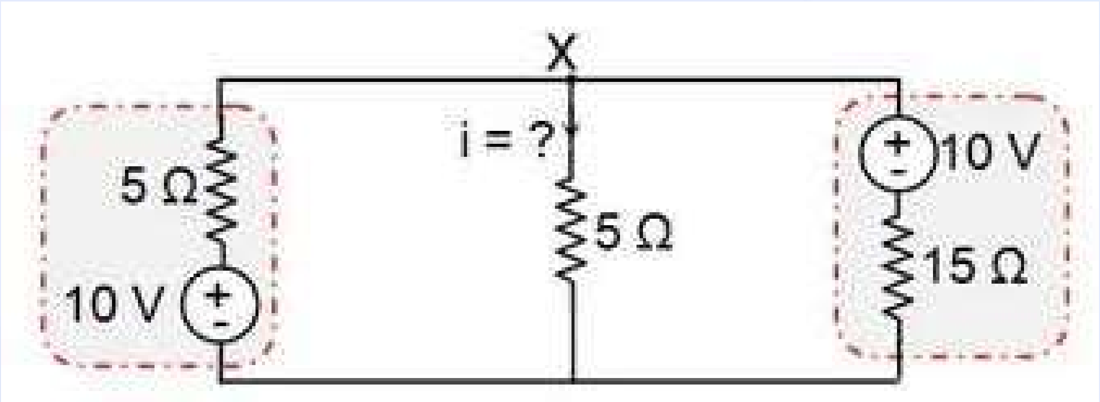
– Convert 1A current source in parallel with 10 Ohms resistor to equivalent voltage source (V = IR = 10V) in series with same resistance.



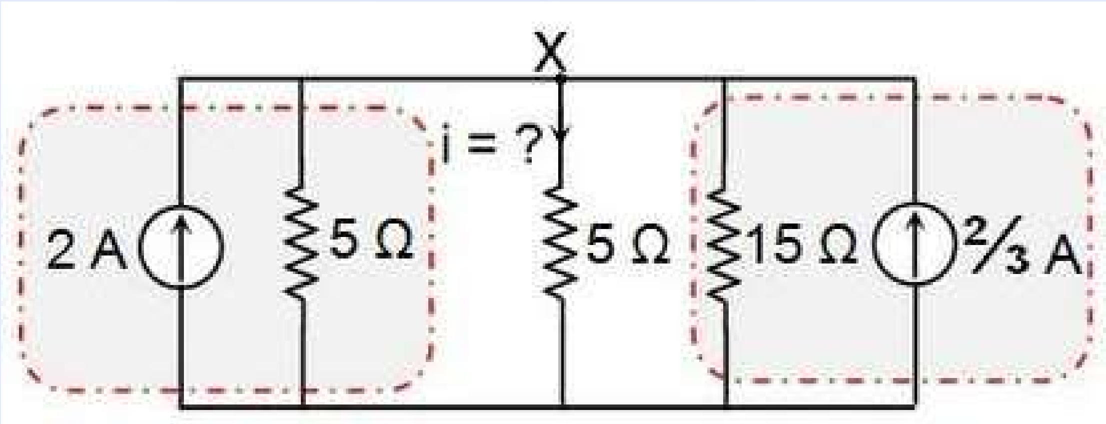
2. Source Transformation:

Example: (V to I)

- Rearrange the circuit.



- Convert voltage source in series with resistor to equivalent current source (I = V/R) in parallel with same resistance.



2. Source Transformation:

Why voltage source has small series internal resistance and current source has large shunt resistance?

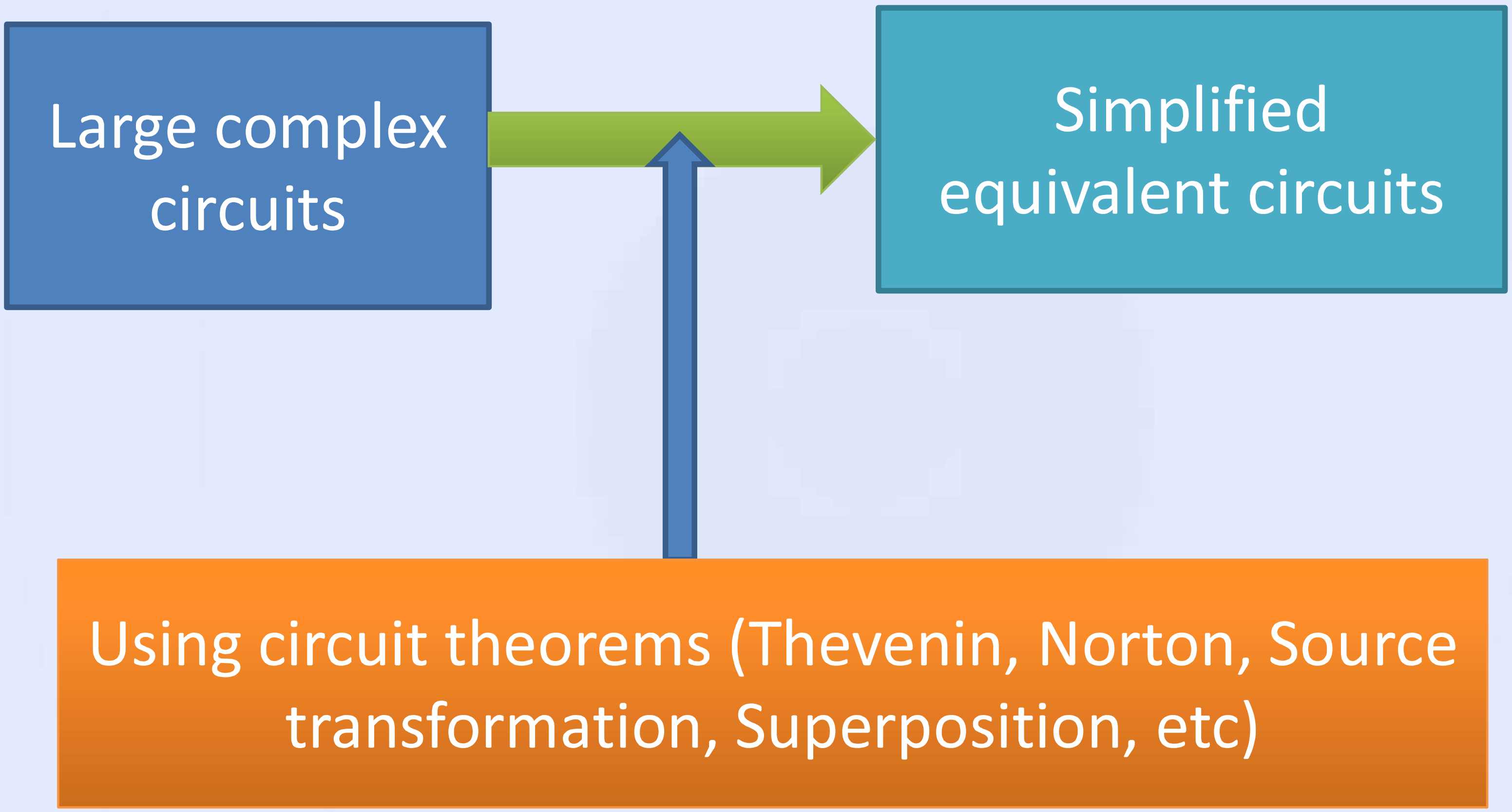
- Internal resistances are not physical resistances intentionally added in the circuit, but are the losses expressed in terms of equivalent resistance. So they are imaginary but they represent that the voltage or current source are not ideal but practical.
- Hence **practical voltage source** has small series internal resistance to represent the drop at terminals when heavy load is connected.
- The output voltage from source is constant always, but the voltage drop is across the series connected internal resistance.

2. Source Transformation:

Why voltage source has small series internal resistance and current source has large shunt resistance?

- Internal resistances are not physical resistances intentionally added in the circuit, but are the losses expressed in terms of equivalent resistance. So they are imaginary but they represent that the voltage or current source are not ideal but practical.
- Hence **practical current source** has larger shunt internal resistance to represent the current diversion path at terminals when heavy load (will take less current) is connected.
- The output current from source is constant always, but the partial current is flowing through shunt connected internal resistance.

3. What is Equivalent circuit?



3. What is Equivalent circuit?

- In any linear circuit, the complicated portion of the network elements can be replaced by a simple equivalent two component representation.
- It is often used to analyze the circuit behavior when the load resistance is changed, without recalculating the whole circuit behavior in original circuit.
- This is possible because of the linear property of the electrical circuit which satisfies $V = a\,I + b$, where a and b are constant depends on circuit element values and configurations.
- Two methods

  (1) Thevenin method   and   (2) Norton method

4. Linearity Property

Any circuit that satisfies the following two properties called as linear circuit.

1. Additive Property:
   a) requires that the response to a sum of inputs is the sum of the responses to each input applied separately.
   b) If $V_1=I_1*R$, $V_2= I_2*R$, applying both currents together, (I_1+I_2)

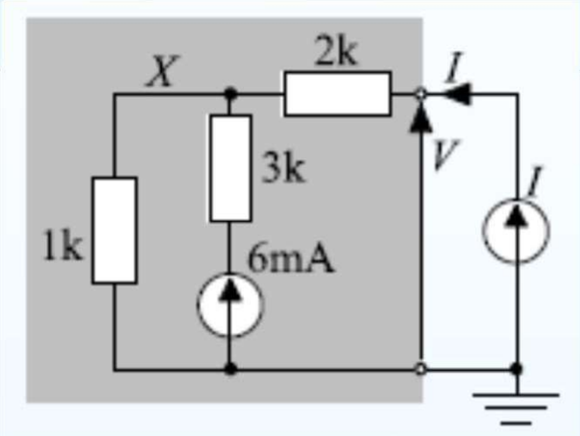
   $V= (I_1+I_2) R = I_{1R}+I_2R = V_1+V_2$

2. Homogeneity:
   a) If you multiply the input (i.e. current) by some constant K, then the output response (voltage) is scaled by the same constant.
   b) If $V_1 = I_{1*}R$

      then $K V_1 = K I_{1*}R$

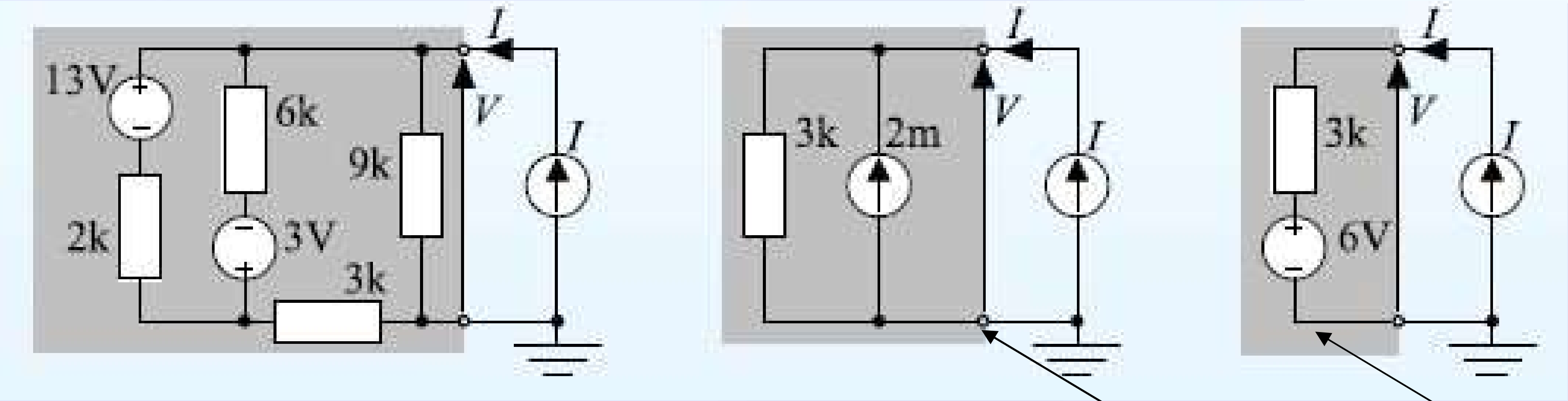
   - Suppose Vs = 20 V gives I = 2 A. According to the linearity principle, when Vs = 10 V will give I = 1 A.

4. Linearity Property



- From Linearity theorem V = a I + b
- Using Nodal analysis, write two nodal equations

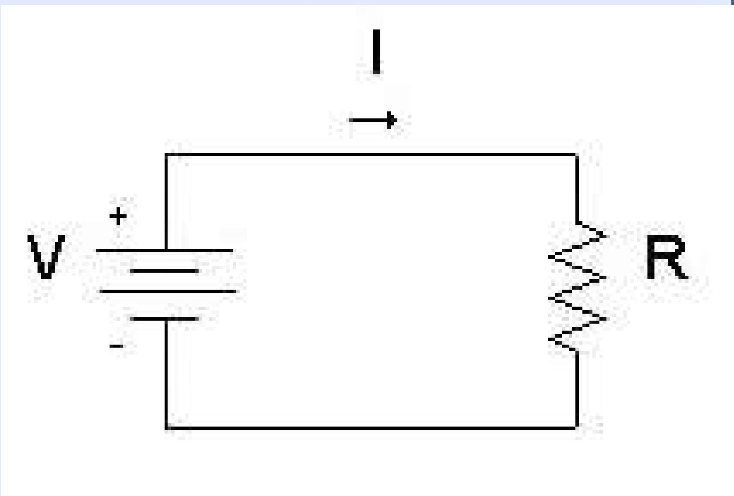
  we get V = 3I +6
- There are many networks provides same value of a and b



- These four shaded networks are equivalent because the relationship between and is exactly the same in each case.
- The last two are particularly simple and are respectively called the Norton and Thévenin equivalent networks.

5. Ohm's Law

- Ohm's Law states that the current flowing through a conductor is directly proportional to the potential difference applied across its ends, provided the temperature and other physical conditions remain unchanged.



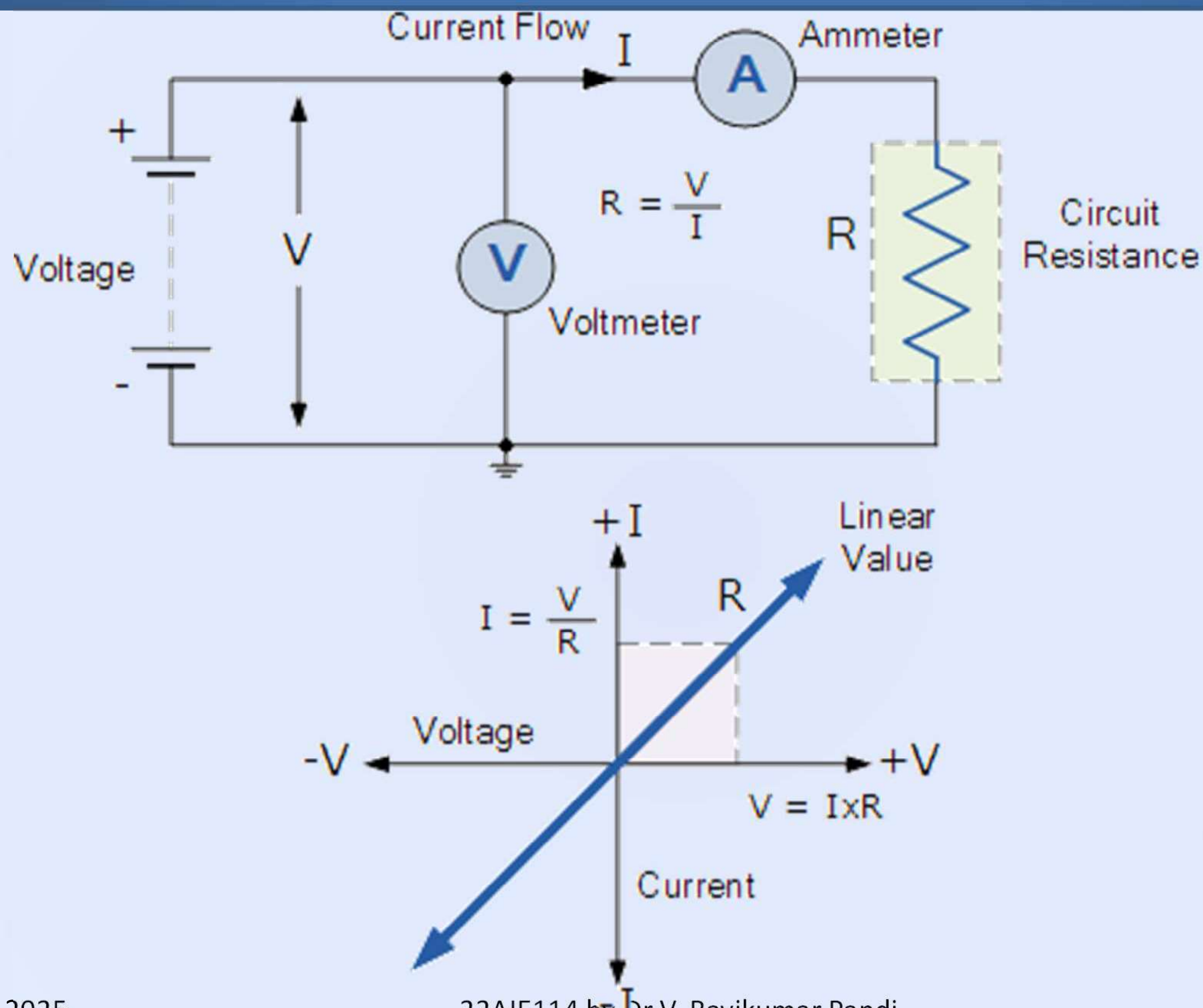
- Mathematically it can be represented as,

Potential difference ∝ Current

$$V \propto I$$

(When the value of V increases the value of I increases simultaneously)

5. Ohm's Law
Linear I-V relationship of the resistor



5. Ohm's Law
Different Applications

- To determine the voltage, resistance or current of an electric circuit.
- Ohm's law is used to maintain the desired voltage drop across the electronic components.
- Conventional Domestic Fan Regulator is one very common device where the current through the fan gets regulated by controlling the resistance of the regulator circuit

5. Ohm’s Law
Limitations

- Ohm’s law is not applicable for unilateral electrical elements like diodes and transistors as they allow the current to flow through in one direction only.
- For non-linear electrical elements with parameters like capacitance, resistance etc. the voltage and current won’t be constant with respect to time making it difficult to use Ohm’s law.

5. Ohm's Law
Units of Measurement

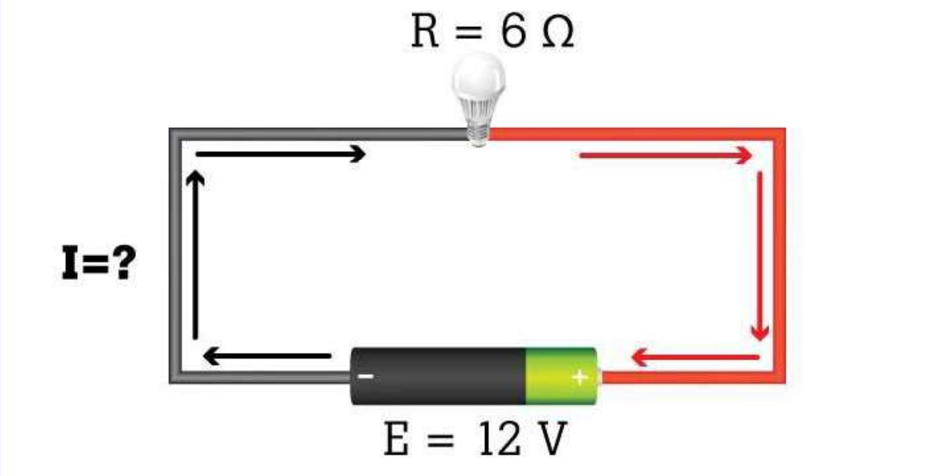
Quantity	Symbol	Unit of Measurement	Unit Abbreviation
Current	I	Ampere ("Amp")	A
Voltage	E *or* V	Volt	V
Resistance	R	Ohm	Ω

To find the Power (P)

[P = V x I]   P (watts) = V (volts) x I (amps)
Also:
[$P = V^2 \div R$]   P (watts) = V^2 (volts) ÷ R (Ω)
Also:
[$P = I^2 \times R$]   P (watts) = I^2 (amps) x R (Ω)

5. Ohm's Law
Example - 1

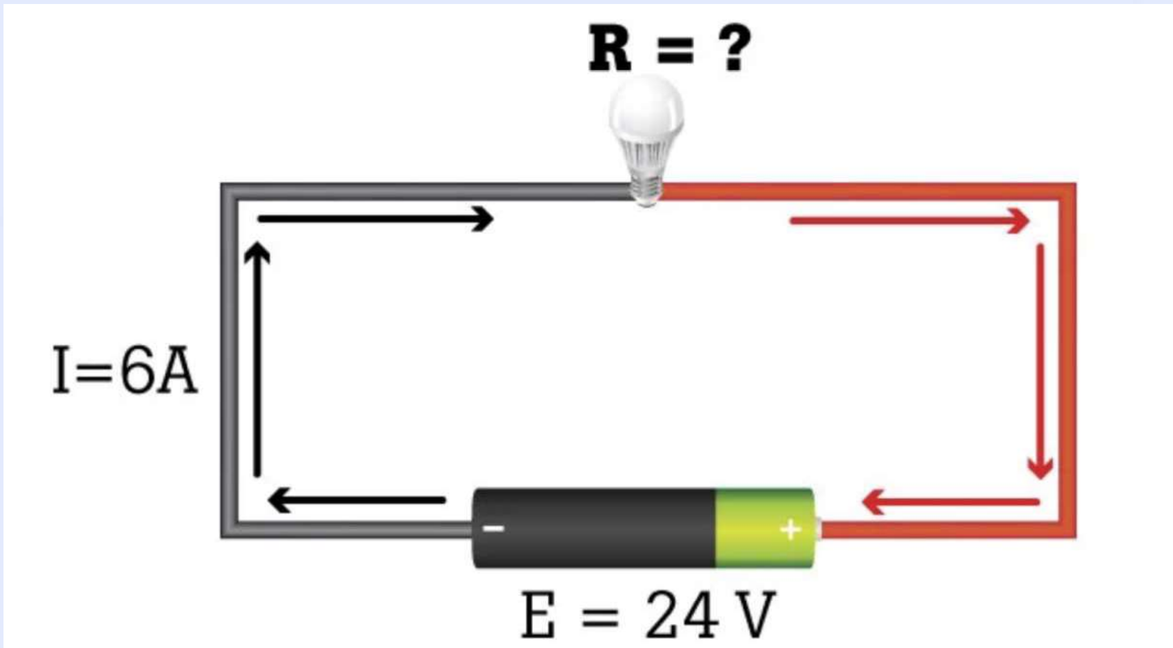
What is the current in the circuit?



$I = E/R = 12V/6\Omega = 2A$

5. Ohm’s Law
Example - 2

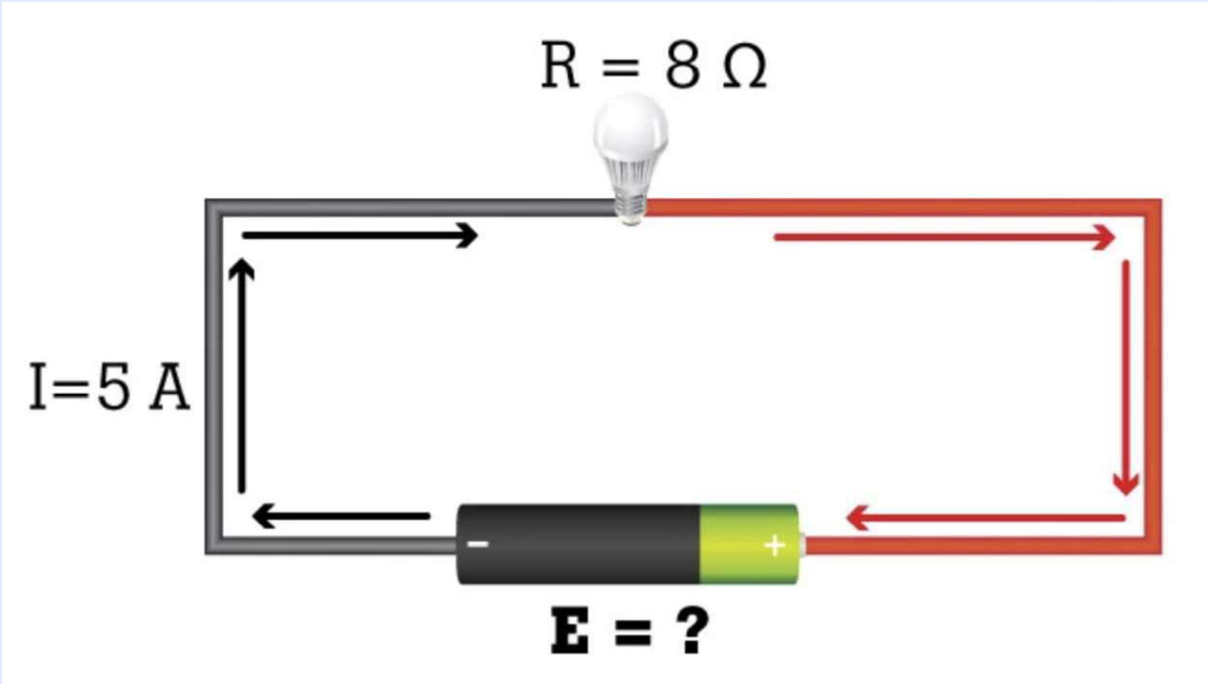
- **What is the resistance offered by the lamp?**



- $R = E/I = 24V/6A = 4\Omega$

5. Ohm's Law
Example - 3

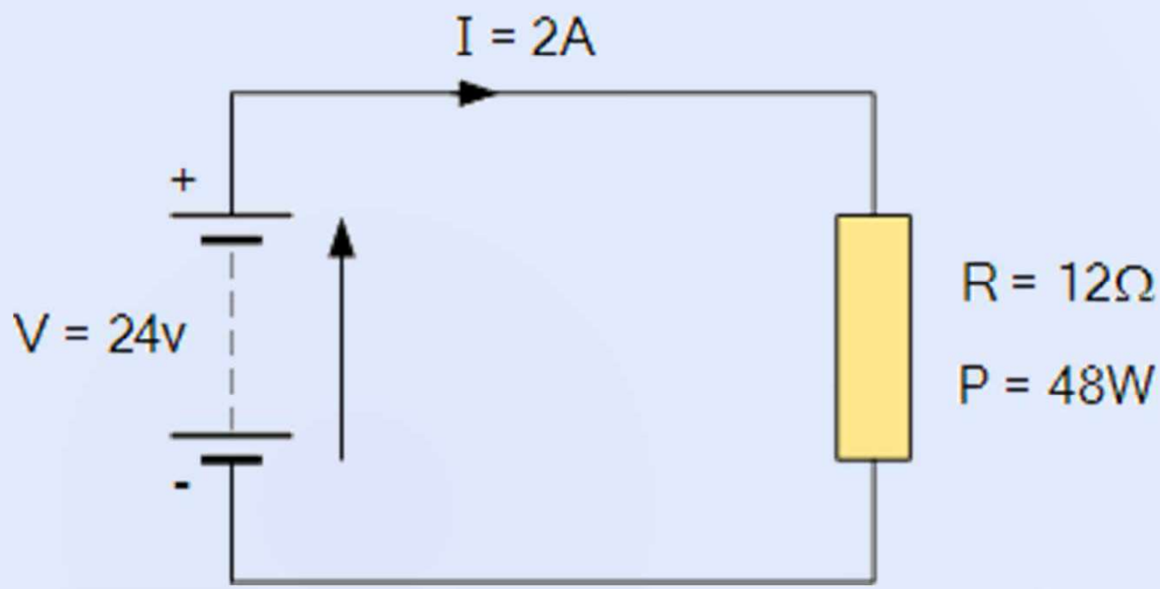
- **What is the voltage in the circuit?**



- $E = I \times R = (5A)(8\Omega) = 40\ V$

5. Ohm's Law
Example - 4

Find the Voltage (V), the Current (I), the Resistance (R) and the Power (P).



Voltage [$V = I \times R$] $= 2 \times 12\Omega = 24V$

Current [$I = V \div R$] $= 24 \div 12\Omega = 2A$

Resistance [$R = V \div I$] $= 24 \div 2 = 12\ \Omega$

Power [$P = V \times I$] $= 24 \times 2 = 48W$

5. Ohm's Law
Example - 5

- What is the resistance of a 60 watt light bulb operated at 120 volts?

$R = 240\ \Omega$

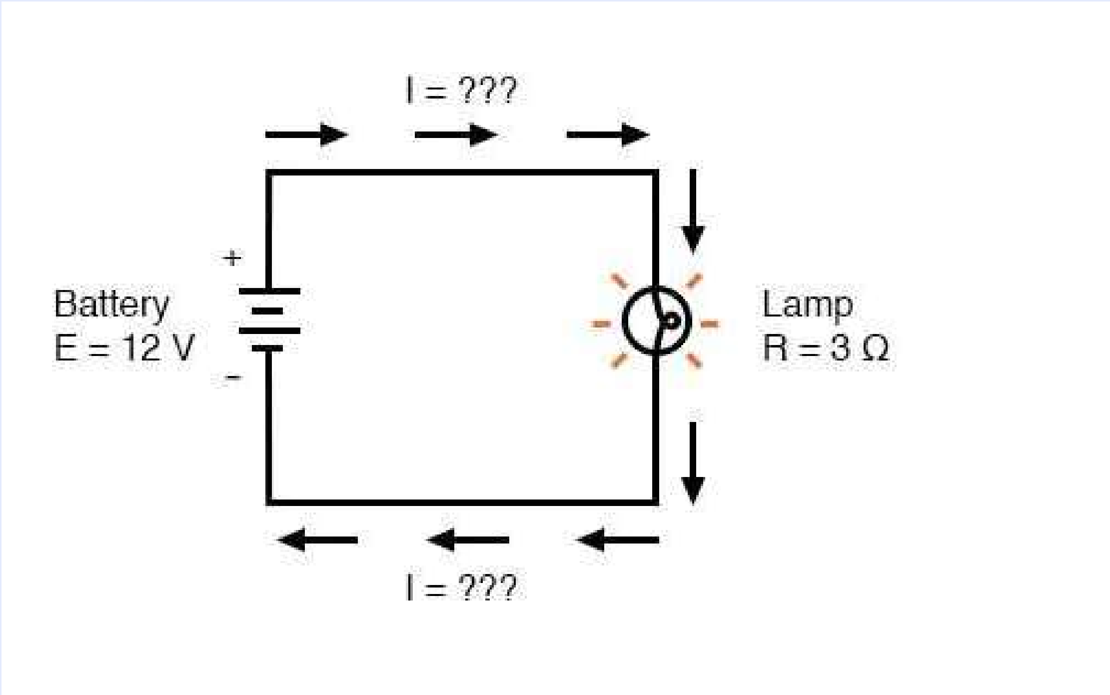
==============================

- A potential drop of 50 volts is measured across a 250 Ω resistor. What is the power consumed by the resistor?

- $P = 10\ W$

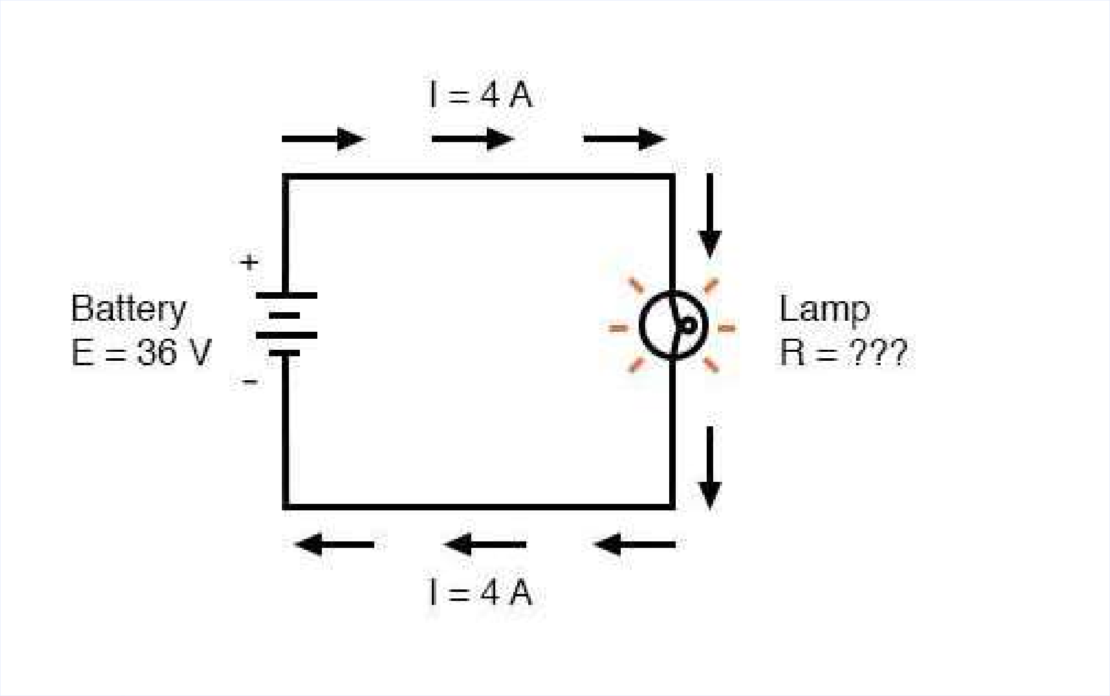
5. Ohm's Law
Example - 6

- **What is the current in the circuit?**



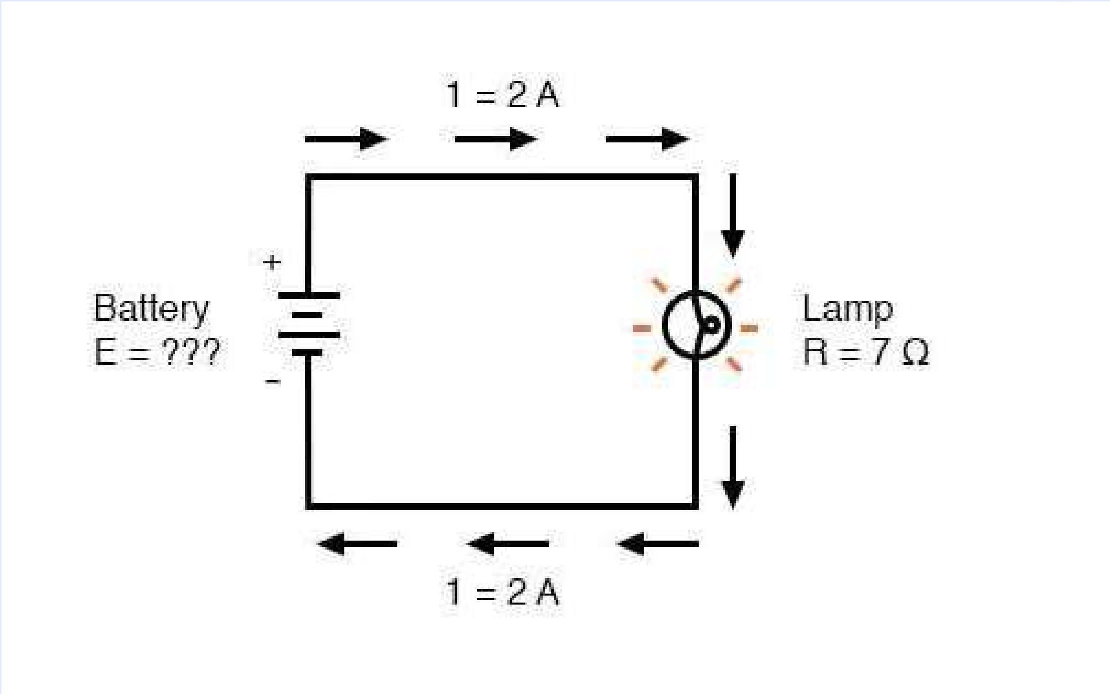
5. Ohm's Law
Example - 7

- calculate the amount of resistance (R) .



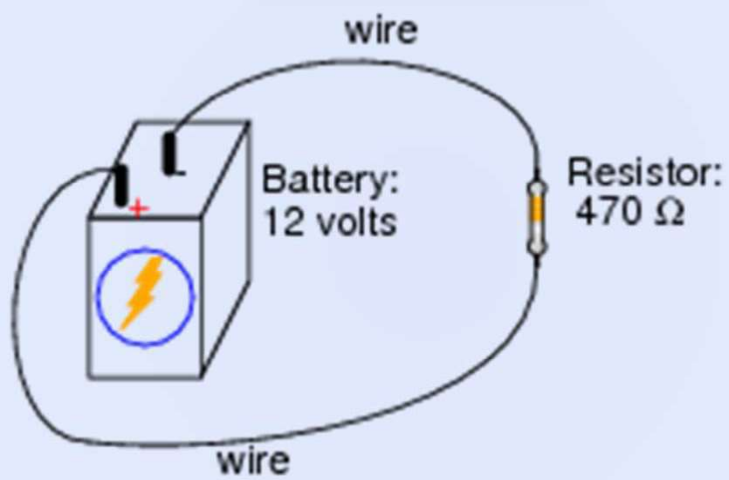
5. Ohm's Law
Example - 8

- Calculate the amount of voltage supplied by a battery



5. Ohm’s Law
Example - 9

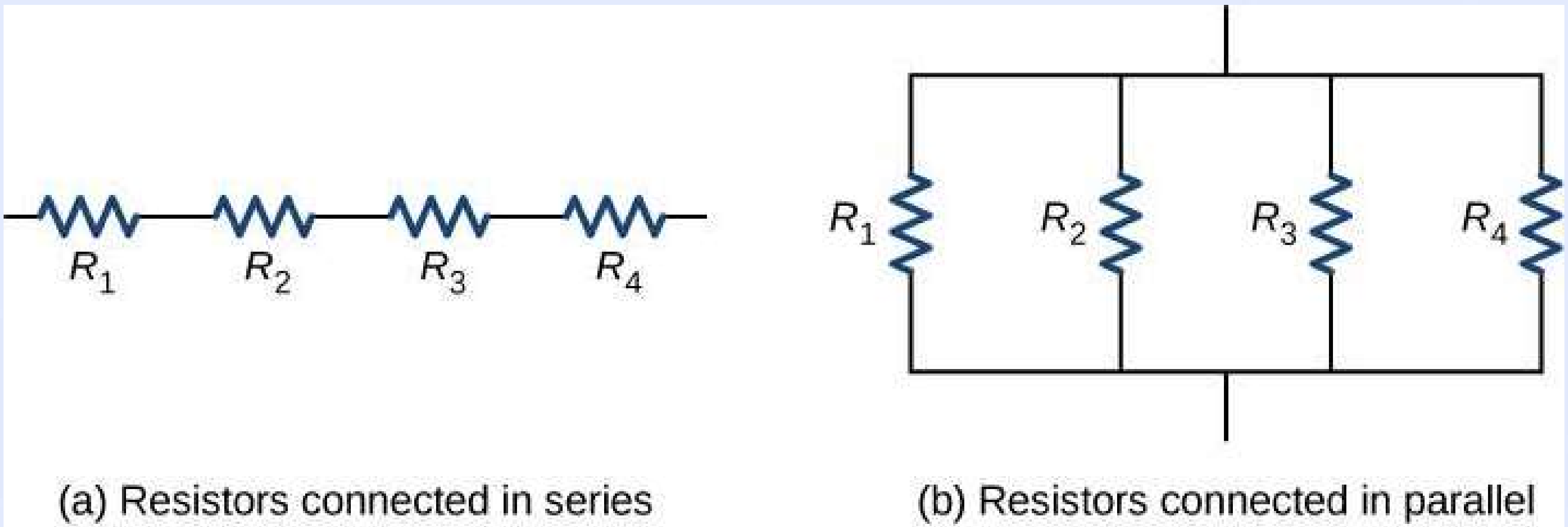
- Calculate the amount of current that will go through the resistor in this circuit.



5. Ohm’s Law
Formulae in Matrix Table

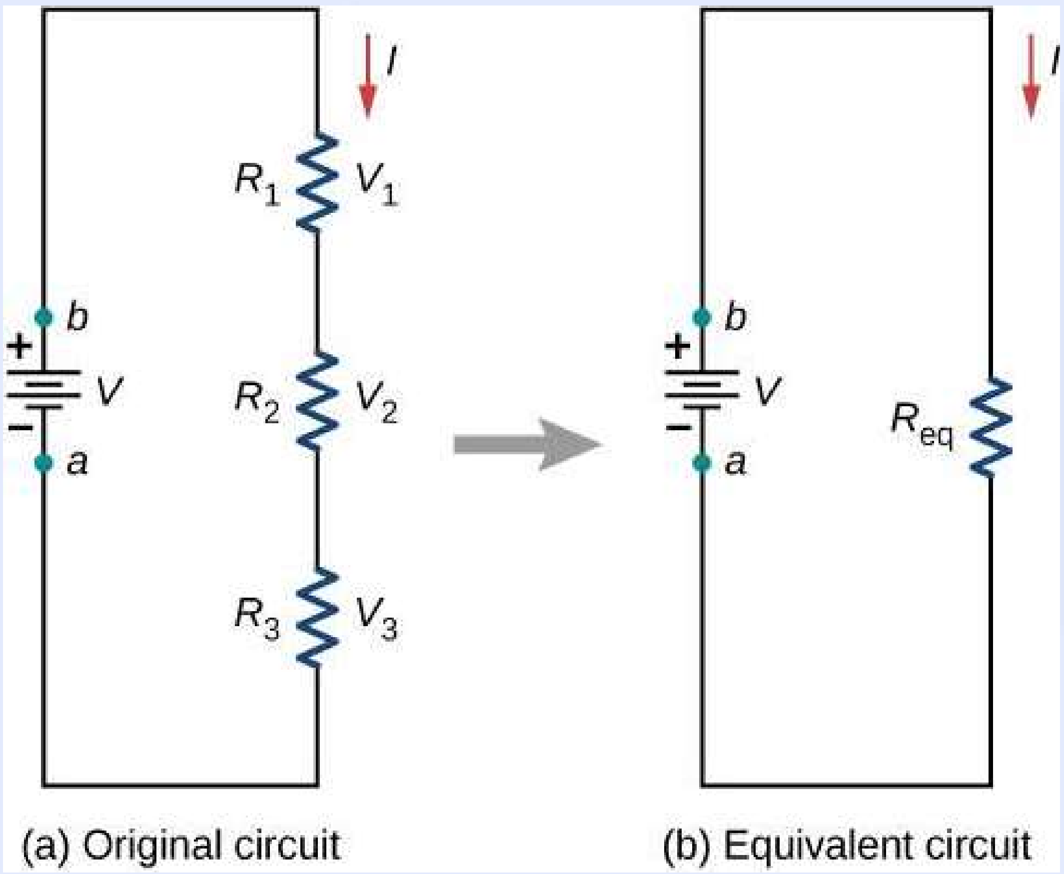
Ohms Law Formulas				
Known Values	Resistance (R)	Current (I)	Voltage (V)	Power (P)
Current & Resistance	---	---	$V = I \times R$	$P = I^2 \times R$
Voltage & Current	$R = \frac{V}{I}$	---	---	$P = V \times I$
Power & Current	$R = \frac{P}{I^2}$	---	$V = \frac{P}{I}$	---
Voltage & Resistance	---	$I = \frac{V}{R}$	---	$P = \frac{V^2}{R}$
Power & Resistance	---	$I = \sqrt{\frac{P}{R}}$	$V = \sqrt{P \times R}$	---
Voltage & Power	$R = \frac{V^2}{P}$	$I = \frac{P}{V}$	---	---

6. Series and Parallel Resistance



6. Series and Parallel Resistance

- A series circuit is a circuit in which resistors are arranged in a chain, so the current has only one path to take.
- Current is the same through each resistor.

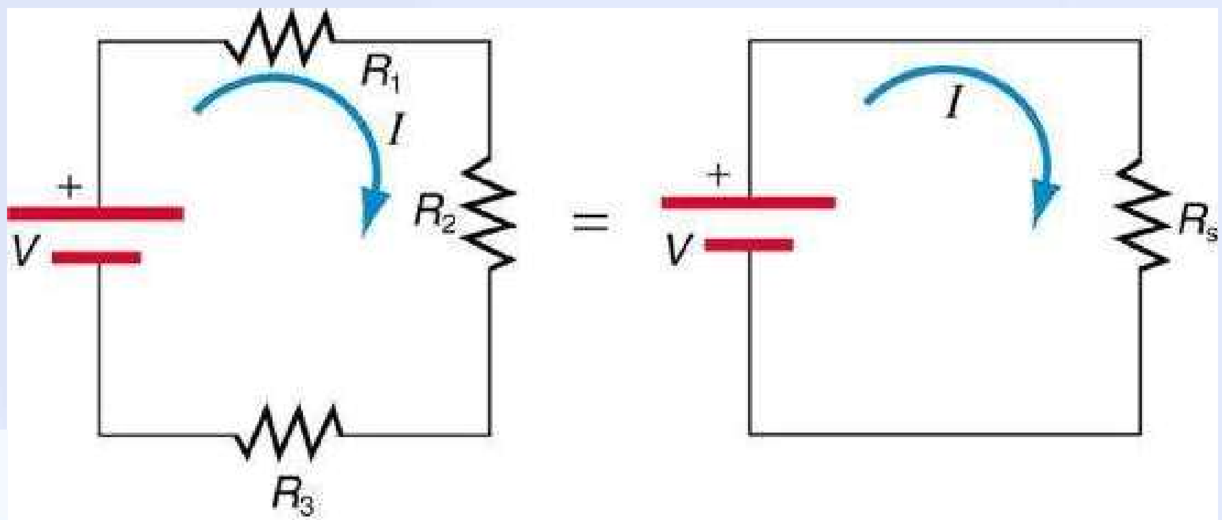


$$V = V_1 + V_2 + V_3,$$
$$= IR_1 + IR_2 + IR_3,$$
$$I = \frac{V}{R_1 + R_2 + R_3} = \frac{V}{R_S}.$$

$$R_S = R_1 + R_2 + R_3$$

6. Series and Parallel Resistance

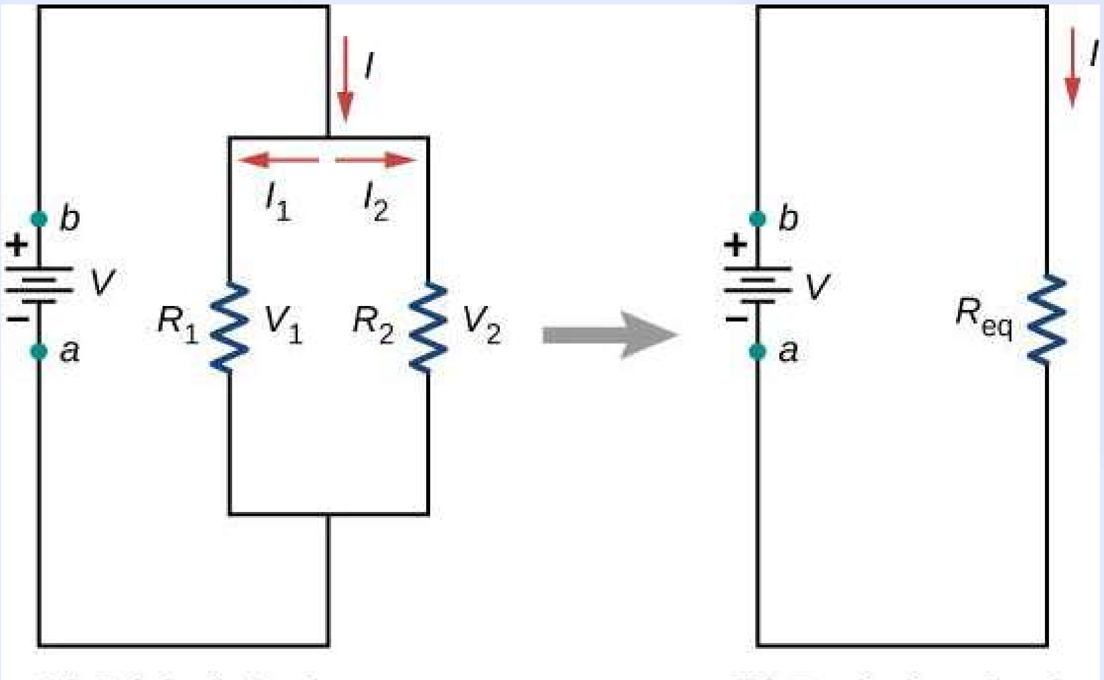
- The same current flows through each resistor in series.
- Individual resistors in series do not get the total source voltage, but divide it.
- Total resistance R_S of a series connection is



$$R_S = R_1 + R_2 + R_3$$

6. Series and Parallel Resistance

- Resistors are in **parallel** when one end of all the resistors are connected by a continuous wire of negligible resistance and the other end of all the resistors are also connected to one another through a continuous wire of negligible resistance.
- Potential drop across each resistor is the same.
- Total resistance Req is less than the smallest of the individual resistances.



(a) Original circuit (b) Equivalent circuit

$$I = I_1 + I_2$$

$$= \frac{V_1}{R_1} + \frac{V_2}{R_2} = \frac{V}{R_1} + \frac{V}{R_2}$$

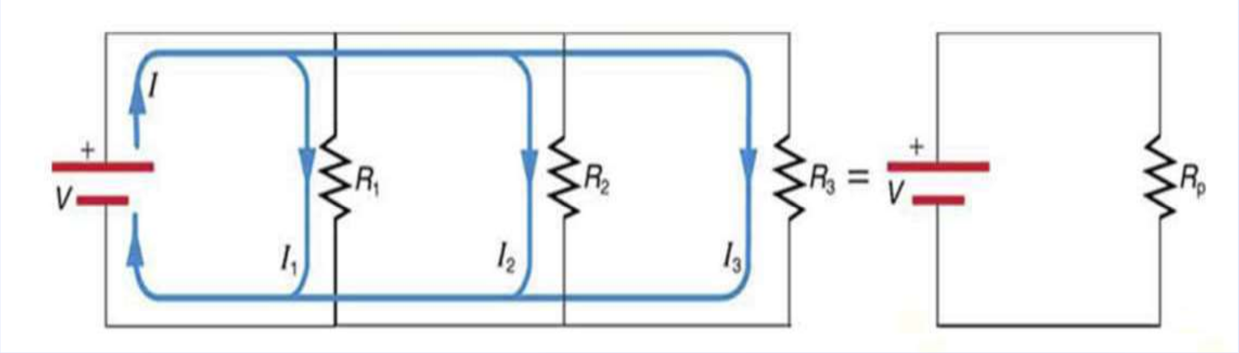
$$= V\left(\frac{1}{R_1} + \frac{1}{R_2}\right) = \frac{V}{R_P}$$

$$R_P = \left(\frac{1}{R_1} + \frac{1}{R_2}\right)^{-1}.$$

Rp = Req

6. Series and Parallel Resistance

- Each resistor in parallel has the same full voltage of the source applied to it.

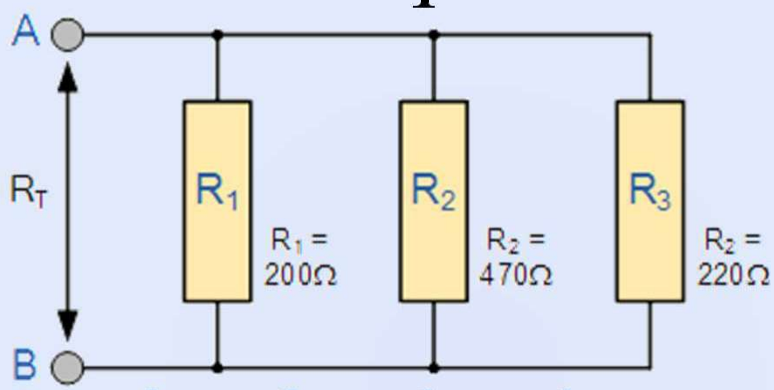


- Total resistance Rp of a parallel connection is related to the individual resistances by

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

Example 10

- Find the total resistance, R_T of the following resistors connected in a parallel network.



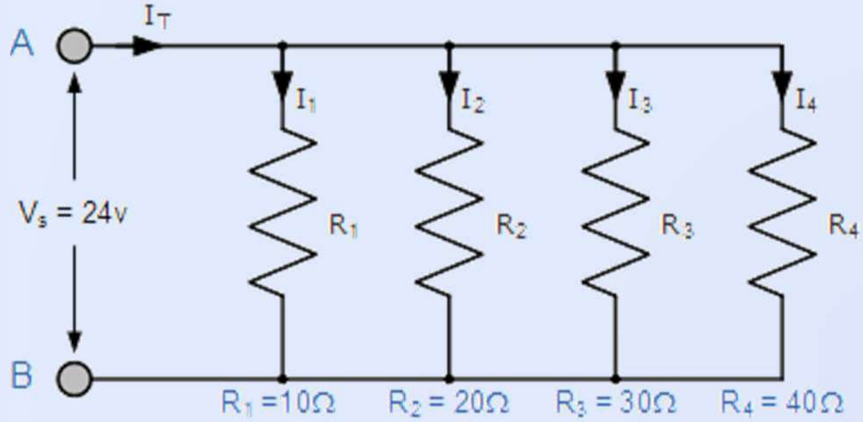
$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

$$= \frac{1}{200} + \frac{1}{470} + \frac{1}{220} = 0.0117$$

$$\text{therefore: } R_T = \frac{1}{0.0117} = 85.67\Omega$$

Example 11

- Calculate the individual branch currents and total current drawn from the power supply.



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

$$\frac{1}{R_T} = \frac{1}{10} + \frac{1}{20} + \frac{1}{30} + \frac{1}{40}$$

$$\frac{1}{R_T} = 0.1 + 0.05 + 0.033 + 0.025$$

$$\therefore R_T = \frac{1}{0.2083} = 4.8\Omega$$

$$I_1 = \frac{V_S}{R_1} = \frac{24V}{10\Omega} = 2.4\text{amps}$$

$$I_2 = \frac{V_S}{R_2} = \frac{24V}{20\Omega} = 1.2\text{amps}$$

$$I_3 = \frac{V_S}{R_3} = \frac{24V}{30\Omega} = 0.8\text{amps}$$

$$I_4 = \frac{V_S}{R_4} = \frac{24V}{40\Omega} = 0.6\text{amps}$$

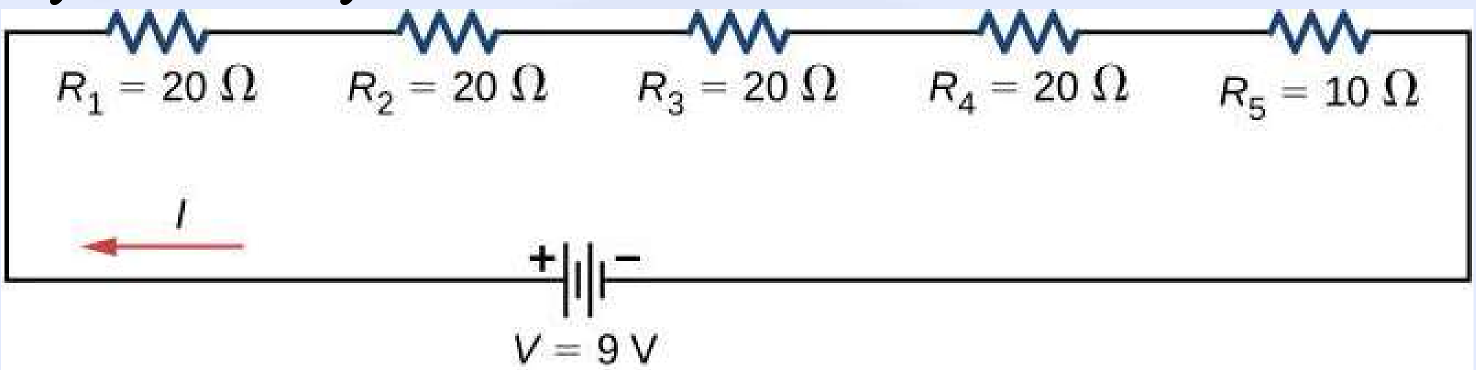
$$I_T = I_1 + I_2 + I_3 + I_4$$

$$I_T = 2.4 + 1.2 + 0.8 + 0.6$$

$$I_T = 5.0 \text{ Amps}$$

Example 12

- (a) Calculate the equivalent resistance of the circuit.
- (b) Calculate the current through each resistor.
- (c) Calculate the potential drop across each resistor.
- (d) Determine the total power dissipated by the resistors and the power supplied by the battery.



$$R_S = R_1 + R_2 + R_3 + R_4 + R_5 = 20\,\Omega + 20\,\Omega + 20\,\Omega + 20\,\Omega + 10\,\Omega = 90\,\Omega.$$

$$I = \frac{V}{R_S} = \frac{9\,V}{90\,\Omega} = 0.1\,A.$$

$$P_1 = P_2 = P_3 = P_4 = (0.1\,A)^2(20\,\Omega) = 0.2\,W,$$

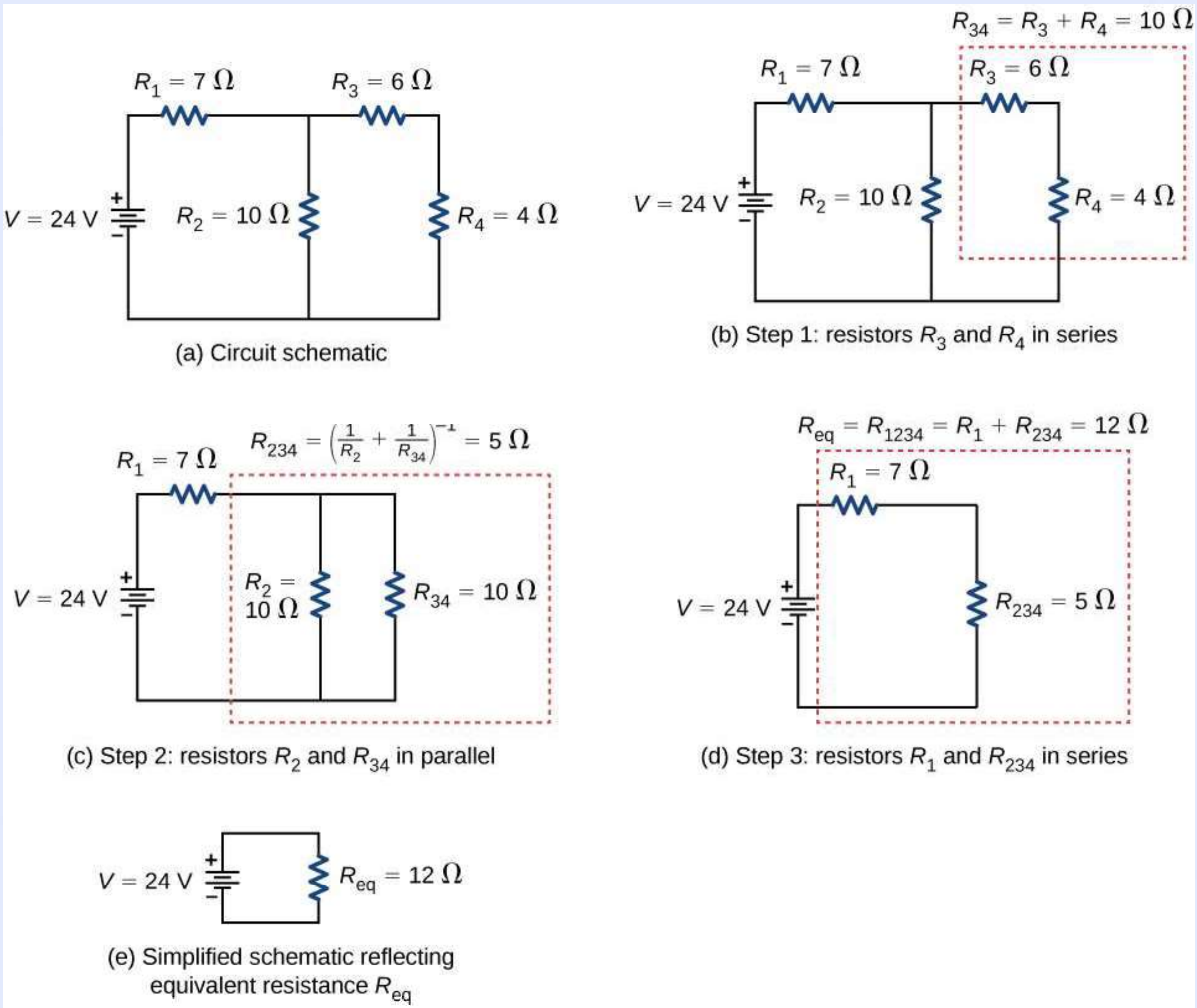
$$P_5 = (0.1\,A)^2(10\,\Omega) = 0.1\,W,$$

$$P_{dissipated} = 0.2\,W + 0.2\,W + 0.2\,W + 0.2\,W + 0.1\,W = 0.9\,W,$$

$$P_{source} = I\epsilon = (0.1\,A)(9\,V) = 0.9\,W.$$

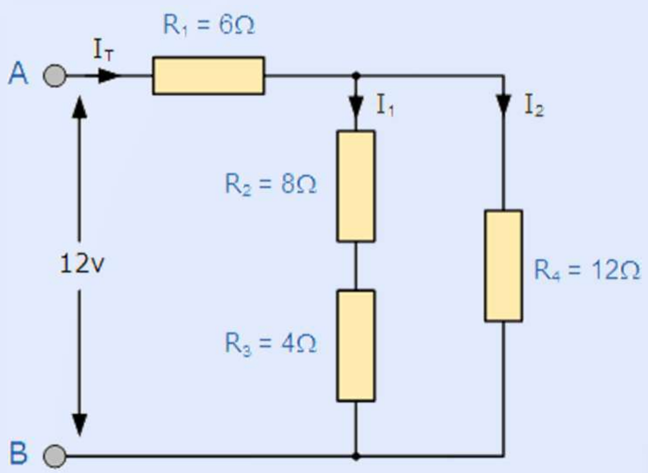
Example 13- **Combinations of Series and Parallel**

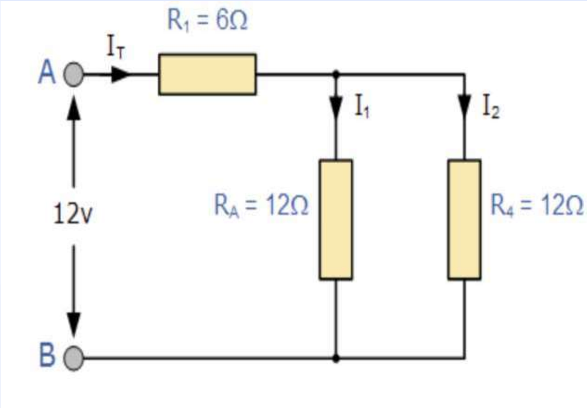
- Find the equivalent resistance.

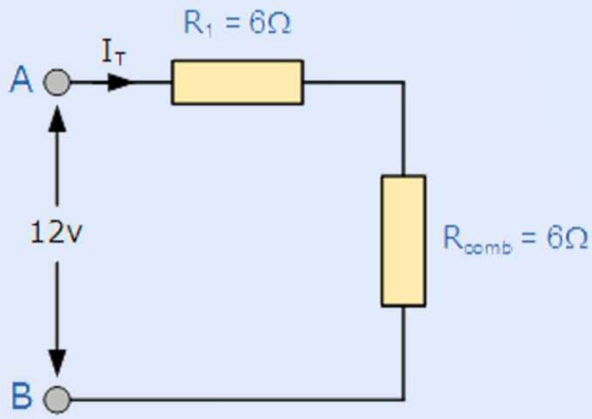


Example 14- Combinations of Series and Parallel

- Find the equivalent resistance.







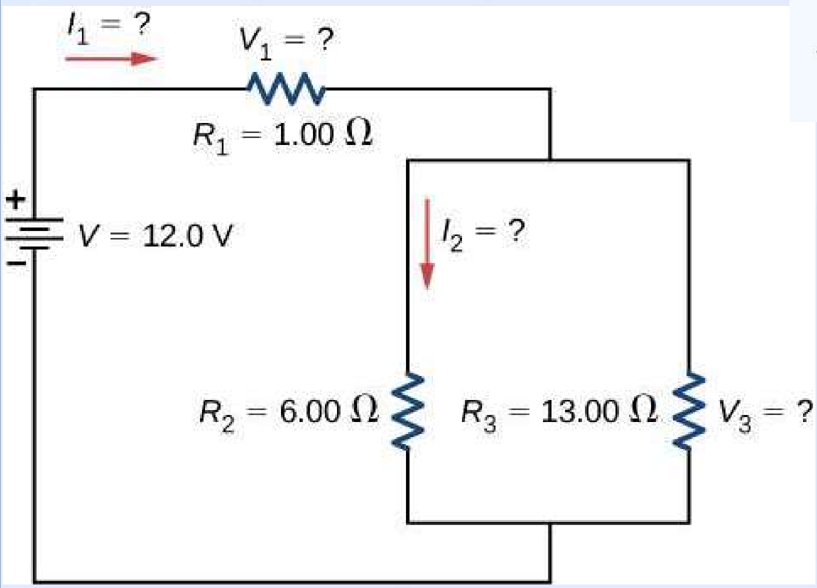
$$R_{(eq)} = \frac{1}{R_A} + \frac{1}{R_4} = \frac{1}{12} + \frac{1}{12} = 0.1667$$

$$R_{(ab)} = R_{comb} + R_1 = 6\Omega + 6\Omega = 12\Omega$$

$$R_{(combination)} = \frac{1}{R_{(eq)}} = \frac{1}{0.1667} = 6\Omega$$

Example 15- **Combinations of Series and Parallel**

(a)Find the equivalent resistance of the circuit. (b) What is the potential drop V1 across resistor R1? (c) Find the current I2 through resistor R2. (d) What power is dissipated by R2?



$$R_{eq} = R_1 + \left(\frac{1}{R_2} + \frac{1}{R_3}\right)^{-1} = 1.00\,\Omega + \left(\frac{1}{6.00\,\Omega} + \frac{1}{13.00\,\Omega}\right)^{-1} = 5.10\,\Omega.$$

$$I_1 = I = \frac{V}{R_{eq}} = \frac{12.0\,V}{5.10\,\Omega} = 2.35\,A.$$

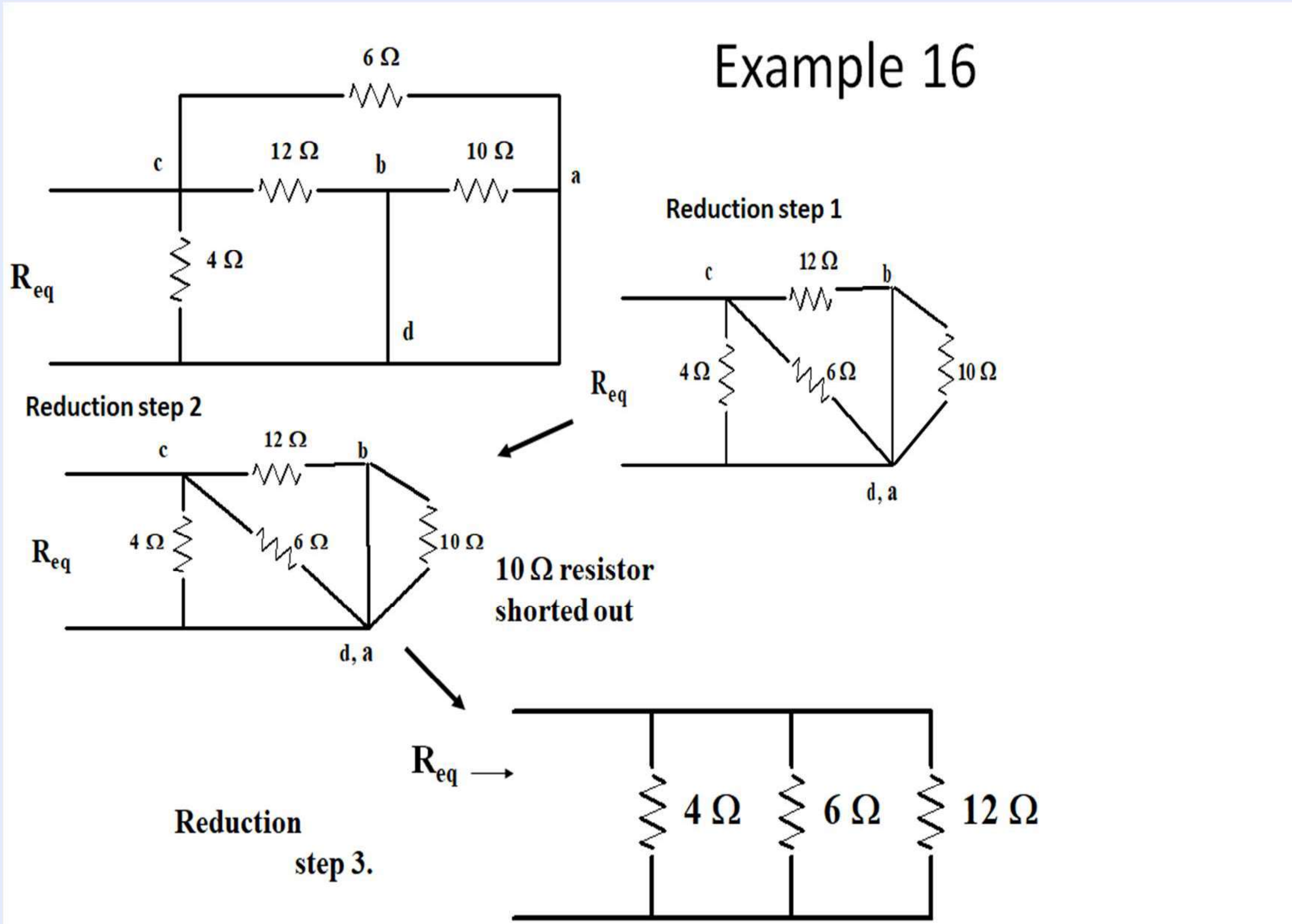
$$V_1 = I_1 R_1 = (2.35\,A)(1\,\Omega) = 2.35\,V$$

$$V_2 = V_3 = V - V_1 = 12.0\,V - 2.35\,V = 9.65\,V$$

$$I_2 = \frac{V_2}{R_2} = \frac{9.65\,V}{6.00\,\Omega} = 1.61\,A.$$

$$P_2 = I_2^2 R_2 = (1.61\,A)^2 (6.00\,\Omega) = 15.5\,W$$

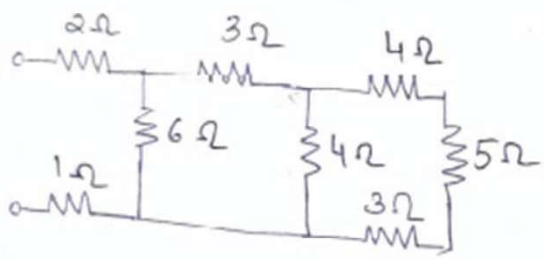
Example 16- **Combinations of Series and Parallel**



Example 17 & 18

- 17

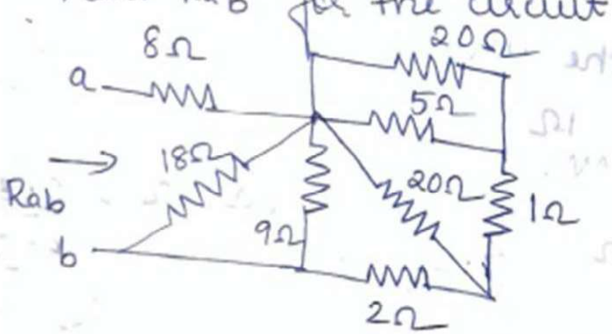
Find Req



Ans: 6Ω

- 18

Find Rab for the circuit



Ans: 11Ω

Review

- If the refrigerator draws 2 A at 200V, what is its resistance?
- The voltage drop across a 100Ω resistor is 10V, what is the power input to the resistor?
- **Find the effective resistance of** $R_1 = 10\ \Omega$ $R_2 = 20\ \Omega$ and $R_3 = 40\ \Omega$. A) if connected in series b) connected in parallel and c) If combination of R1 and R2 in parallel with R3.

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Dr. A.P.J. Abdul Kalam
Former President of India

THANK YOU