EECE1001: BASIC ELECTRICAL AND ELECTRONICS ENGINEERING

Unit I

Unit I
Syllabus

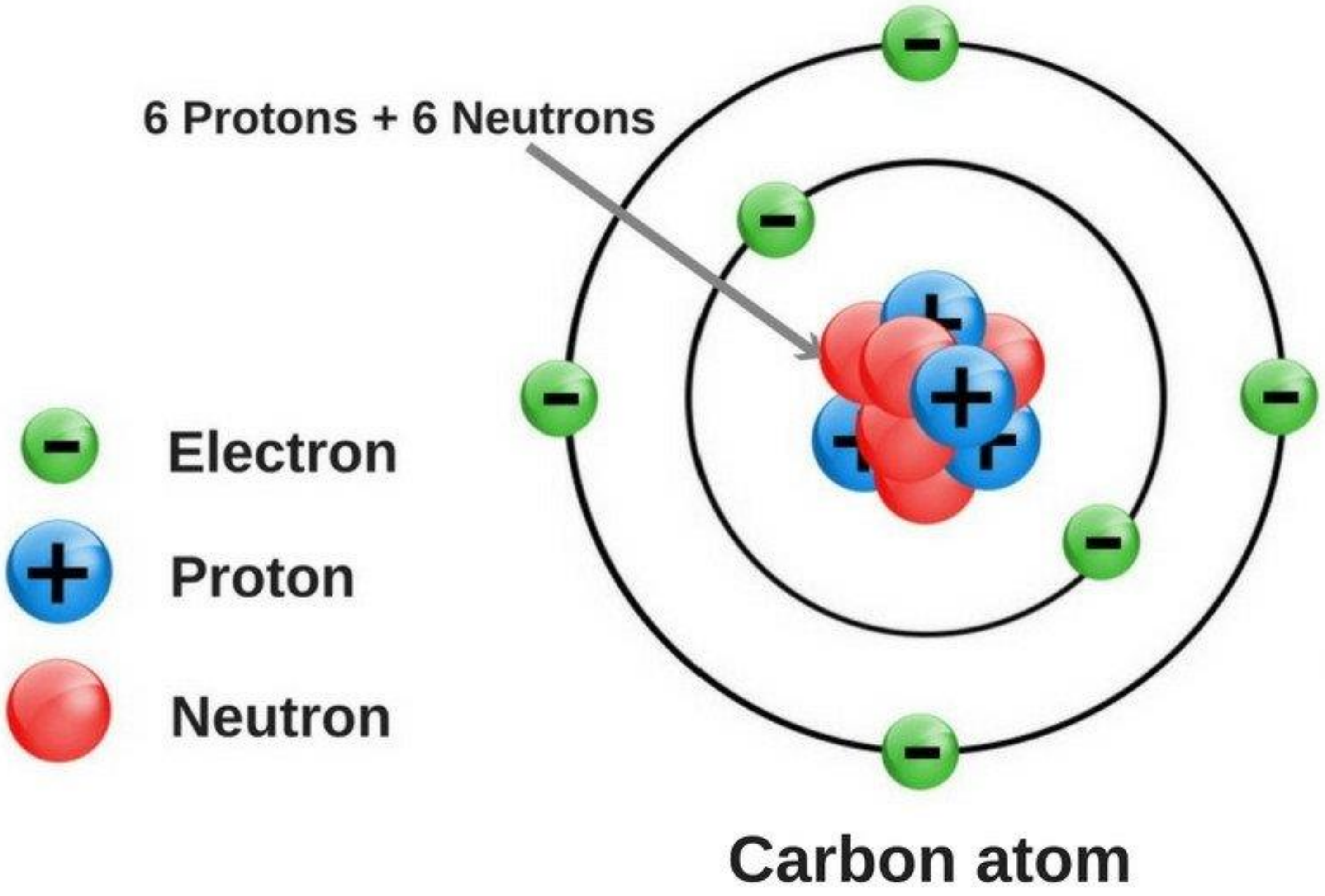
DC Circuits: Basic circuit elements and sources, Ohms law, Kirchhoff's laws, series and parallel connection of circuit elements, Node voltage analysis, Mesh current analysis, Superposition ,Thevenin's and maximum power transfer theorem.

Basis For Comparison	Electrical Device	Electronics Device
Definition	It is defined as the device which uses the electrical energy for performing the work.	The device which controls the flow of electrons for performing the particular task is known as the electronics devices.
Material Used	Metals like copper and aluminium are used for the conduction of current.	Semiconductor material like silicon, germanium etc.
Operating Principle	Convert the electrical energy into other forms of energy.	Uses the electrical energy for performing the particular task.
Current	Alternating Current	Direct Current
Voltage	Works on high voltage.	Works on low voltage
Power consumption	More	Less
Required Space	More	Less
Uses	For doing mechanical work.	For amplifying the weak signal or for coding and decoding the information.
Examples	Transformer, motor, generator etc.	Transistor, diode, microprocessor, flip-flop, amplifier, etc.

Introduction

- In electrical engineering, we are often interested in transferring energy from one point to another point.
- To do this, we require interconnection of electrical devices and such interconnection is known as electric circuit.
- Each component of the electric circuit is known as circuit element.
- A circuit element is a mathematical representation of a simple two terminal electrical device characterized by its specific voltage current relationship. Examples: Resistors, Capacitors, Inductors etc.

Electric Charge



Electric Charge

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- The most basic quantity of electric circuit is electric charge. Charge is the electrical property of atomic particles of which matter consists measured in Coulombs.
- Some important characteristics of electric charge:
- Charge is bipolar and is described in either positive or negative charges.
- The charge that occur in nature are integral multiples of electric charge $e = -1.602 * 10^{-19}$ coulombs.
- Law of conservation of charge states that charge can neither be created nor destroyed, only transferred.

Electric Charge

- How much charge is represented by 6524 electrons?

Solution:

Each electron has $e = -1.602x10^{-19}\ coulombs$

Hence 6524 electrons will have

$$q = -1.602x10^{-19}\frac{coulumbs}{electron} * 6524\ electrons$$

$$q = -1.04514x10^{-15}\ coulombs$$

CURRENT

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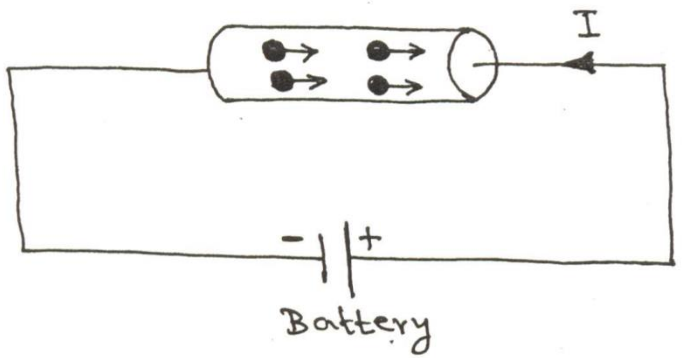
- The unique property of electric charge is that it can be transferred from one place to another, that means it is mobile in nature.
- Charge in motion represents current.
- The convention is to take the current flow as the movement of positive charges. That is, opposite to the flow of negative charges.



Current

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- The electrical effects caused by charge in motion depends on the rate of charge flow.
- The rate of charge flow is known as ‘electric current’.
- The mathematical relation between current, charge and time is $i = \frac{dq}{dt}$ where i is current in Amps

  q is charge in Coulombs

  t is time in seconds

  1 Amp = 1 coulomb/Second

Current

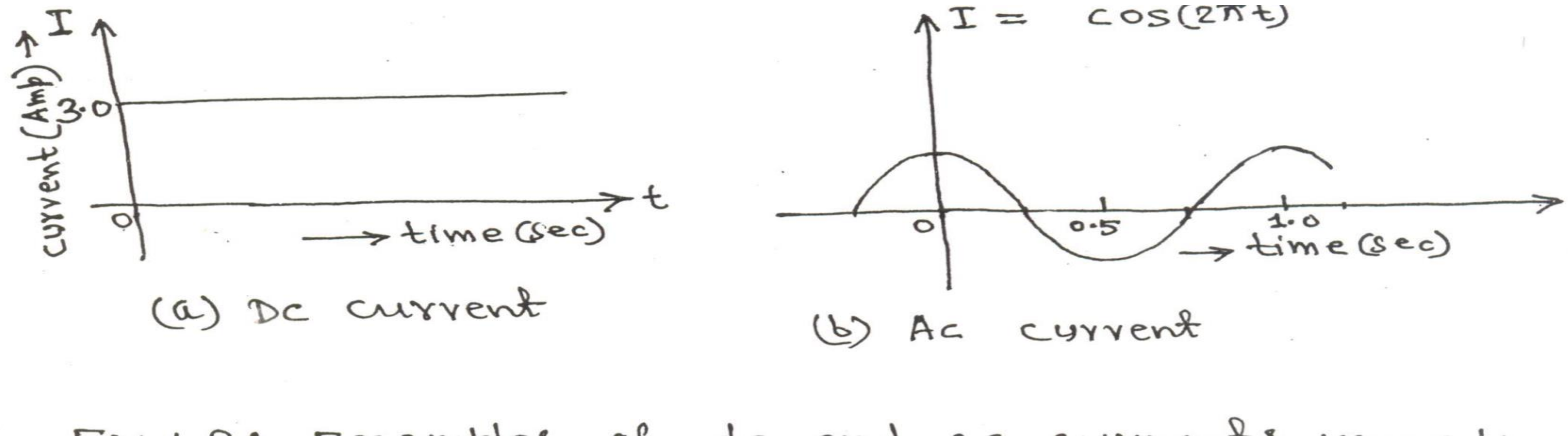
- Charge transferred between time t_o and t is

$$q = \int_{t_o}^{t} i \, dt$$

- Current 'i' need not be a constant value function.
- When a current is constant with time, that is direct current (dc). Thus, a direct current (dc) is a current that remains constant with time.
- A current that varies with time, reversing direction periodically, is called alternating current (ac).
- Thus, an alternating current (ac) is current that varies with time periodically. ac is used in our household to run Fans, bulbs, refrigerators, TV's, air conditioners, water heaters and other electrical appliances.

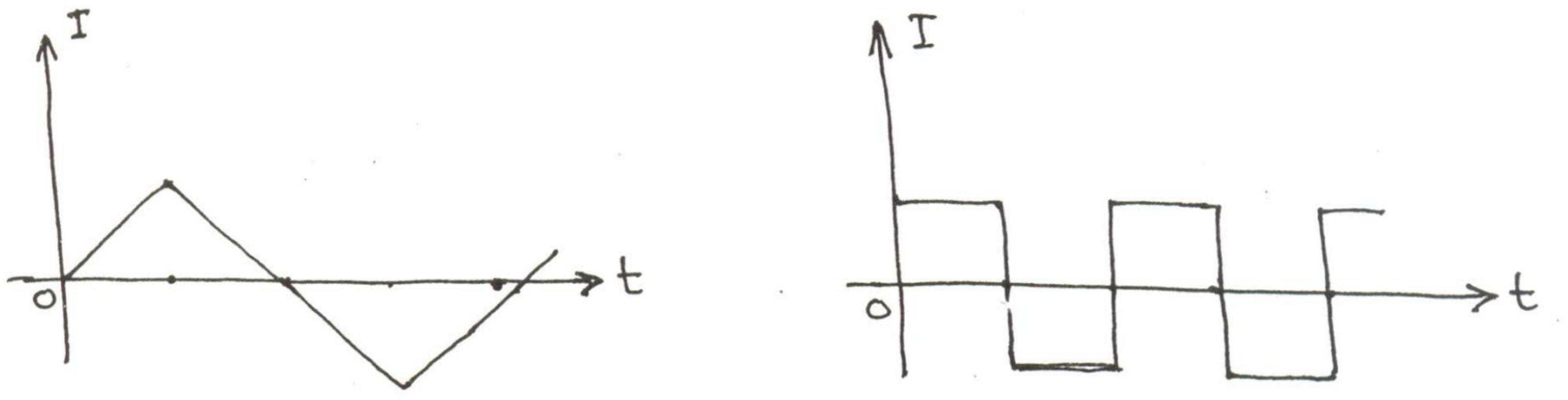
Current

- Figure shows a dc current and a sinusoidal ac current versus time.



Current

- Figure shows other types of time varying currents such as the triangular and square waveforms.



(a) Triangular wave form (b) Square wave form.

Current

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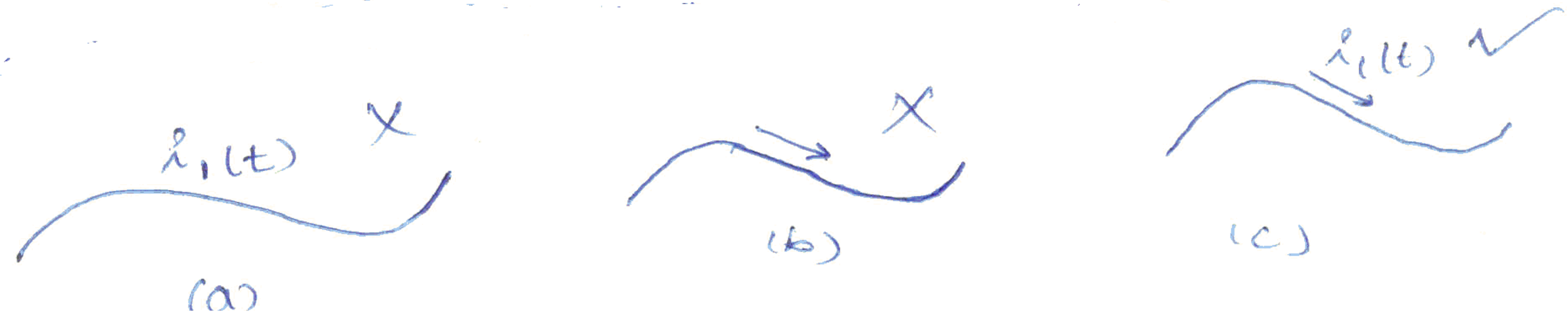
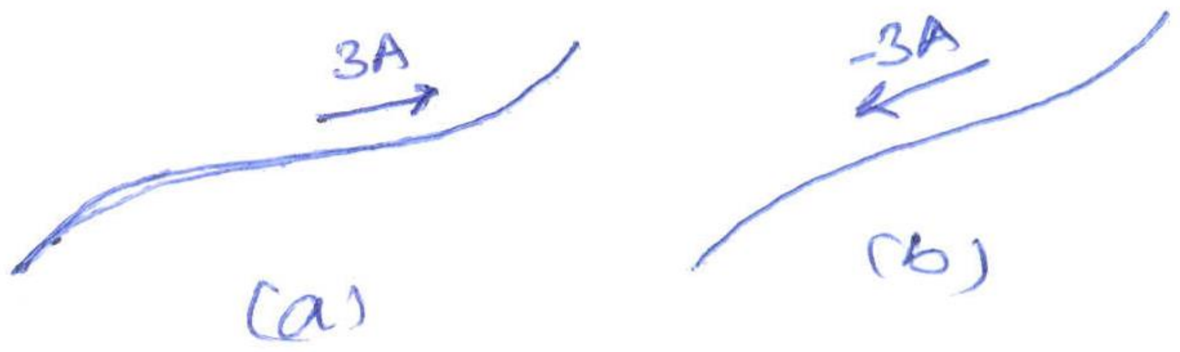
- Graphical representation of current:

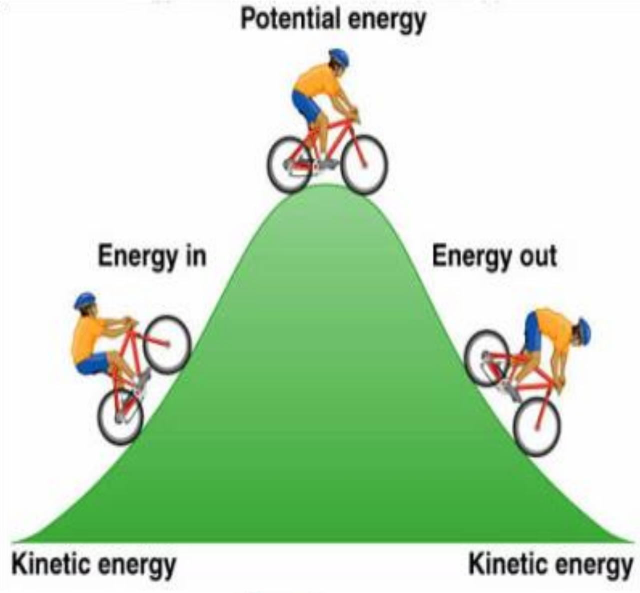


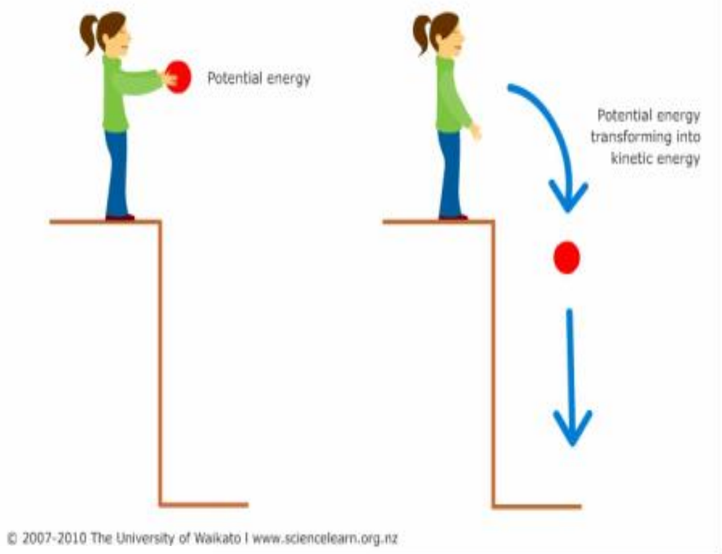
Current

- Graphical representation of current:



VOLTAGE





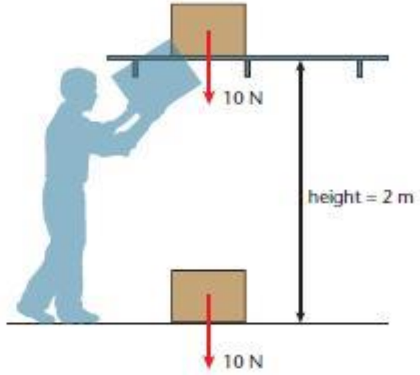
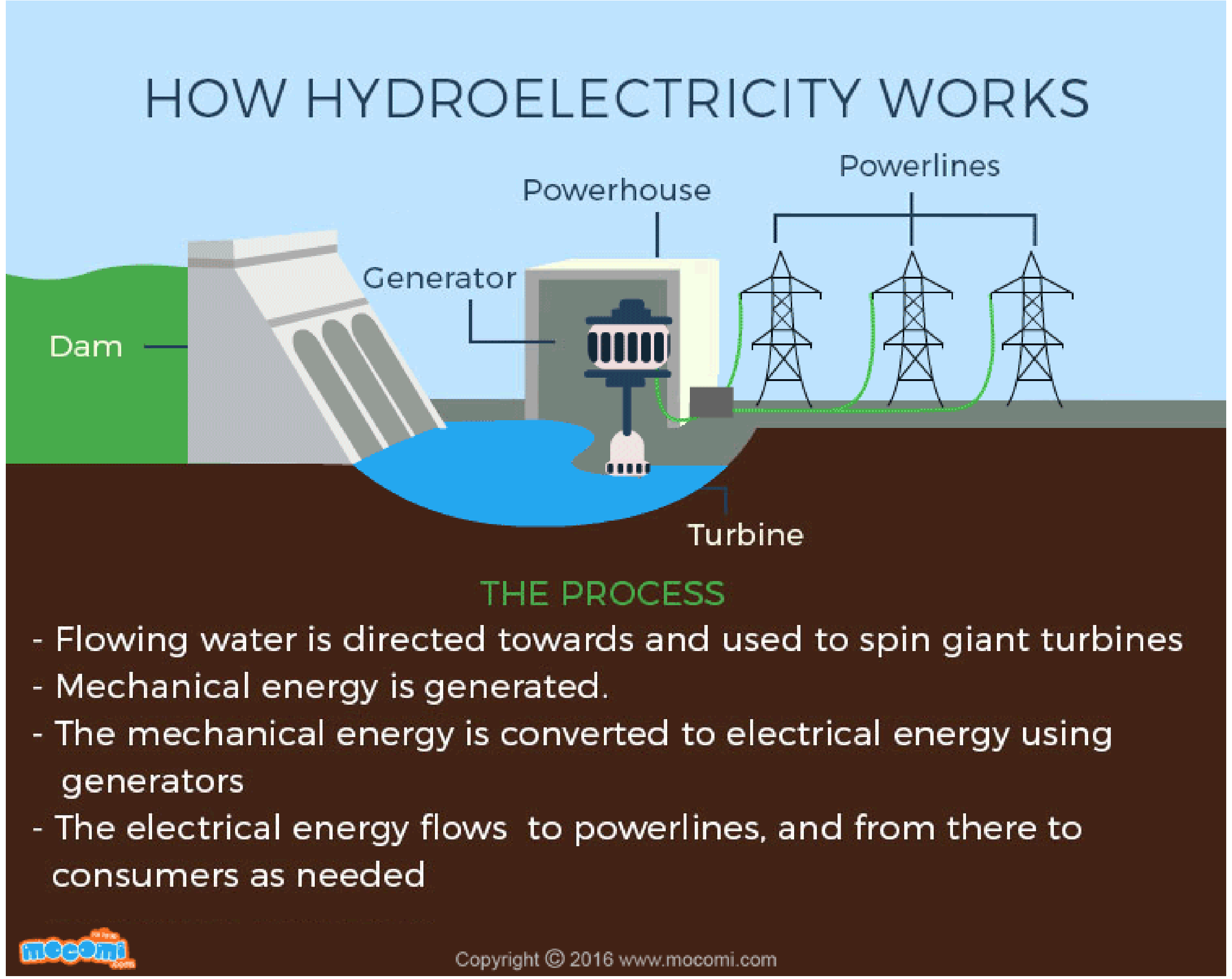


Fig. 9.15 Doing work – increasing the GPE.

Fig. 9.15 shows that when you lift a 10 N weight (a mass of 1 kg) from the floor to a high shelf, a height difference of 2 m, you have done work on the weight. The work done = 10 N × 2 m = 20 J and this is equal to the increase in the GPE of the weight.



Voltage

- To move an electron in a conductor in a particular direction requires some work or energy transfer.
- Work done in moving unit charge in electric field is stored in it in the form of electric potential known as potential difference or voltage.
- Thus the voltage V_{12} between two points 1 and 2 in an electric circuit is the energy or work needed to move a unit charge from 1 to 2.
- The voltage $v = V_{12} = \frac{dw}{dq}$

  w *is energy in joules*

  q *is charge in coulums*

  $v = V_{12}$ *is the voltage in volts*

  1 volt = 1 joule / 1 Coulomb

Voltage

- Voltage has polarity. Plus '+' and minus '-' are used to represent reference direction or voltage polarity.

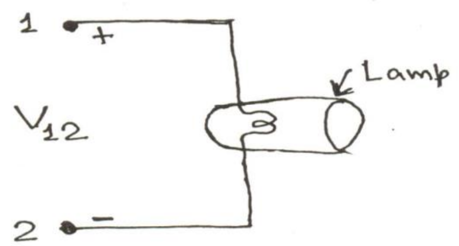


Fig. 1.6 : Polarity of voltage V_{12}

- The Voltage V_{12} can be interpreted as:
  a) Point 1 is at a potential of V_{12} volts higher than point 2.
  Or
  b) potential at point 1 with respect to point 2 is V_{12} volts.
- There fore logically it follows that $V_{12} = - V_{21}$

POWER AND ENERGY

- Power is the time rate of expending or absorbing energy.
- Power is measured in watts (W).
- Power $p = \frac{dw}{dt}$ where p is the power in Watts

  w is the energy in Joules

  $and\ t$ is the time in seconds.

  1 Watt = 1 Joule/ 1 second
- $p = \frac{dw}{dt} = \frac{dw}{dq} * \frac{dq}{dt} = v * i$
- Thus power associated with a basic circuit element is the product of the current in the element and the voltage across it.

Power and Energy

- If the power has + sign, power is delivered to or absorbed by the element.
- On the other hand, if the power has – sign, power is being supplied or delivered by the element.
- Polarity of voltage and direction of current play major role in determining the sign of power.

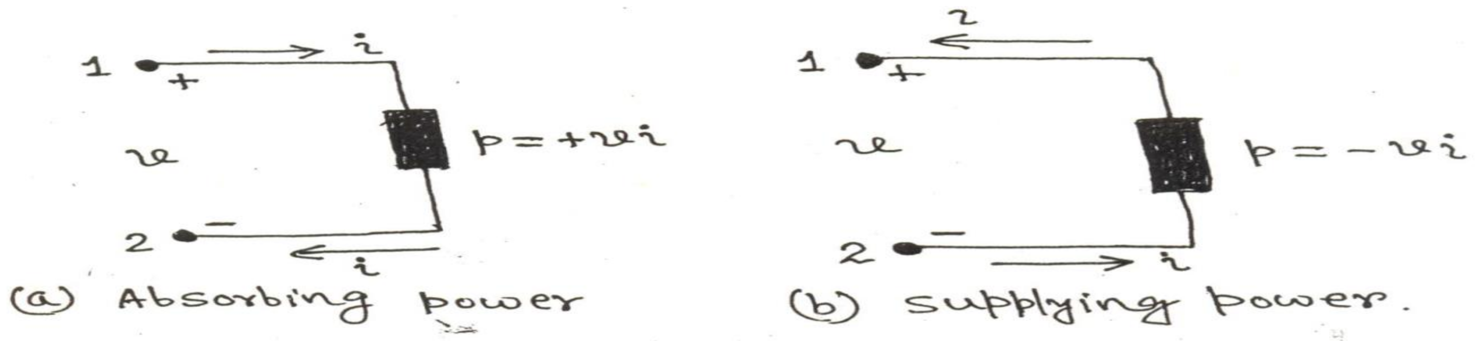


Fig. 1.8: Reference polarities for power using the passive sign convention.

Power and Energy

- According to Passive sign convention:

power absorbed by an element is positive, when current enters through its + terminal.

i.e. p is +ve.

power absorbed by an element is negative when current enters through its –ve terminal.

i.e. p is –ve.

In general Power absorbed = – Power delivered.

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Power and Energy

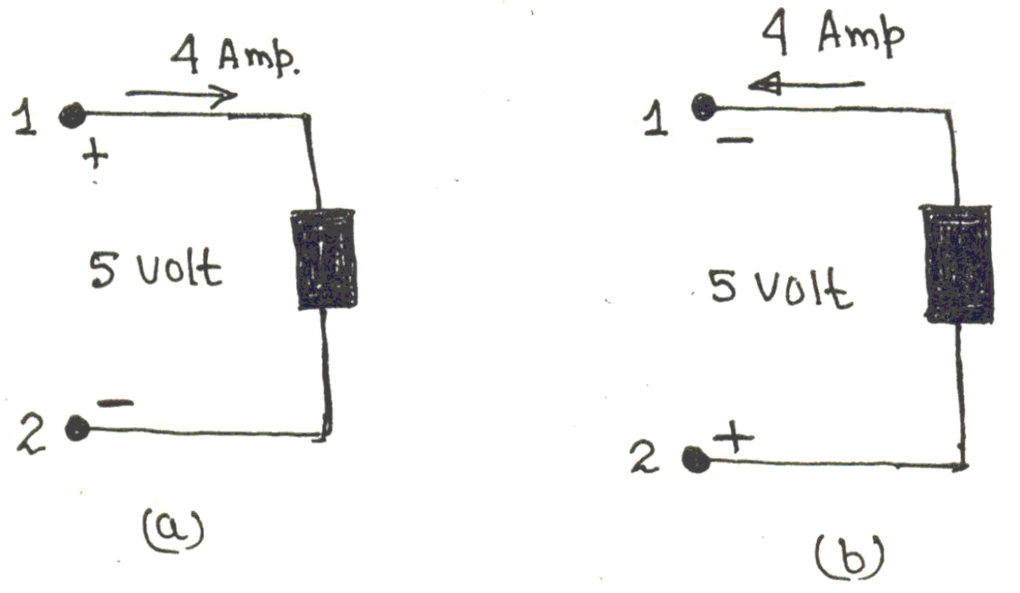

Fig. 1.9: Two cases of an element with an absorbing power ~~of~~ 20W

(a) $p = 5 \times 4 = 20\,W$ (b) $p = 5 \times 4 = 20\,W$

Power and Energy

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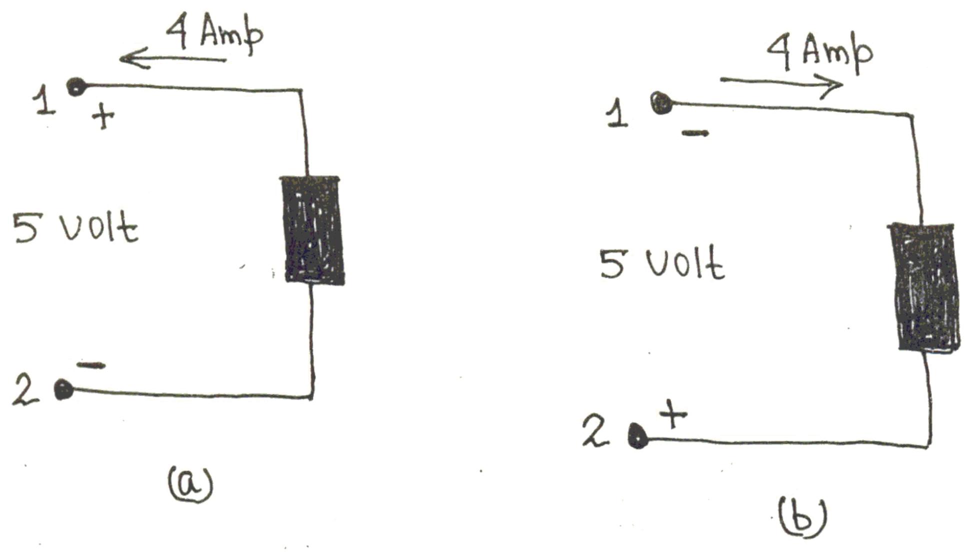

Fig. 1.10: Two cases of an element with a supplying power of 20 W.

(a) $p = 5 \times (-4) = -20\,W$ (b) $p = 5 \times (-4) = -20\,W.$

Power and Energy

- In an electric circuit, law of conservation of energy must be obeyed.
- For this reason, at any instant of time, algebraic sum power must be zero. i.e. $\sum p = 0$.
- i.e. total power supplied to the circuit must balance total power absorbed.

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Power and Energy

- Energy supplied or absorbed by a circuit element between instants t_o and t is

$$E = \int_{t_o}^{t} p\, dt = \int_{t_o}^{t} vi\, dt$$

- Energy is the capacity to do work. Measured in Joules.
- The electric power companies measure energy in Kilo-watt-hours (KWh)
- 1KWh = 36×10^5 Joules.

Active and passive circuit elements

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- There are two types of elements found in electric circuits based on energy delivered to or by them.
- Passive elements are those whose average power delivered is always zero or negative.

Examples: Resistors, inductors, capacitors

- Active elements are those whose average power delivered is always positive.

Examples: Voltage and current sources.

Independent Voltage source

- An independent voltage source is two terminal element that maintains a specific voltage between its terminal.
- The voltage is completely independent of the current through it.
- Sources such as generators and batteries may be regarded as approximations to ideal voltage sources.

(a) Used for constant or time-varying voltage

(b) Used for constant voltage (dc)

Fig. 1.13: Symbols for independent voltage sources.

Independent Current source

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- An independent current source is a two terminal element that provides a specific current independent of voltage across the source.

Fig. 1.14: Symbol for an independent current source.

Dependent sources

- Dependent sources are designated by diamond shaped symbols.

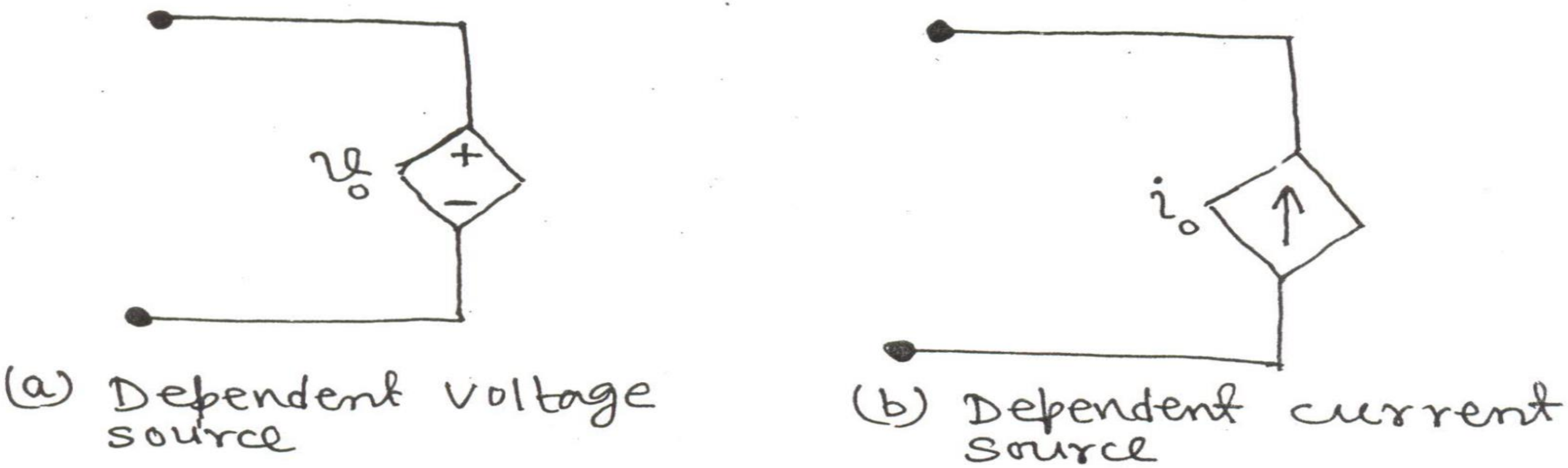

Fig. 1.15: Symbols for dependent sources.

Dependent voltage sources

- In a dependent or controlled voltage source, the voltage across the source terminals is a function of other voltages or currents in the circuit.

(a) Voltage-controlled voltage source

(b) Current-controlled voltage source

Fig. 1.16: Dependent voltage sources or Controlled voltage sources.

Dependent voltage sources

- A voltage controlled voltage source is a voltage source having a terminal voltage equal to a constant times the voltage (v_x) across a pair of terminals elsewhere in the network.
- A current controlled voltage source is a voltage source having a terminal voltage equal to a constant times the current (i_x) through some other element in the circuit.

Dependent current sources

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- The current flowing through a dependent current source is determined by a current or voltage elsewhere in the circuit.

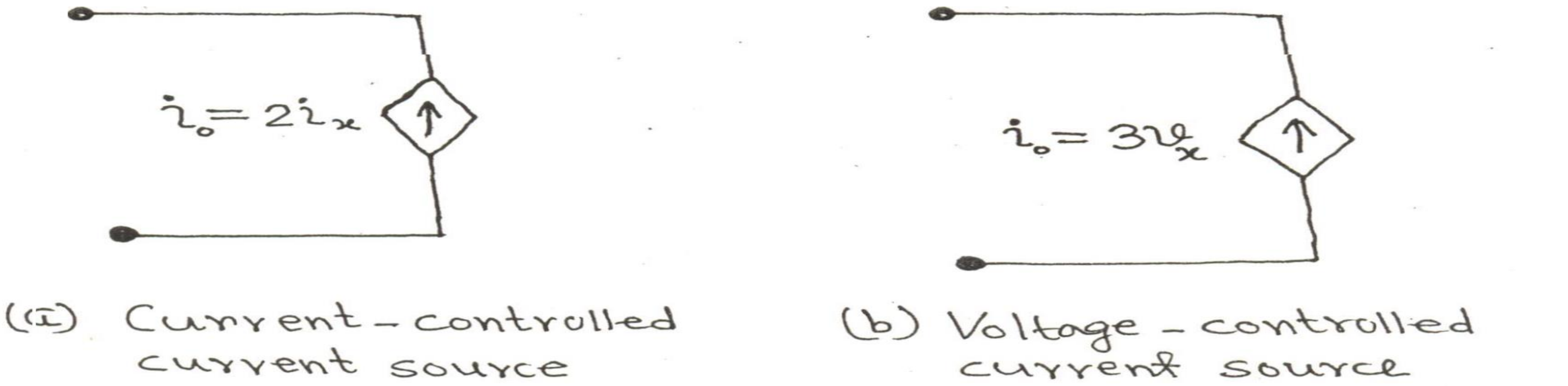

Fig.1.17 : Dependent current sources

Dependent current sources

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- A current controlled current source is a current source having the source current equal to a constant times the current (i_x) through some other element in the circuit.
- A voltage controlled current source is a current source having the source current equal to a constant times a constant times the voltage (v_x) across a pair of terminals elsewhere in the network.

Dependent or controlled sources

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- Controlled voltage and current sources are useful in constructing circuit models for many types of real world devices such as transistors, transformers, electrical machines and electronic amplifiers.
- There are four kinds of controlled sources:

  a) Voltage controlled voltage sources (VCVS)

  b) Current controlled voltage sources (CCVS)

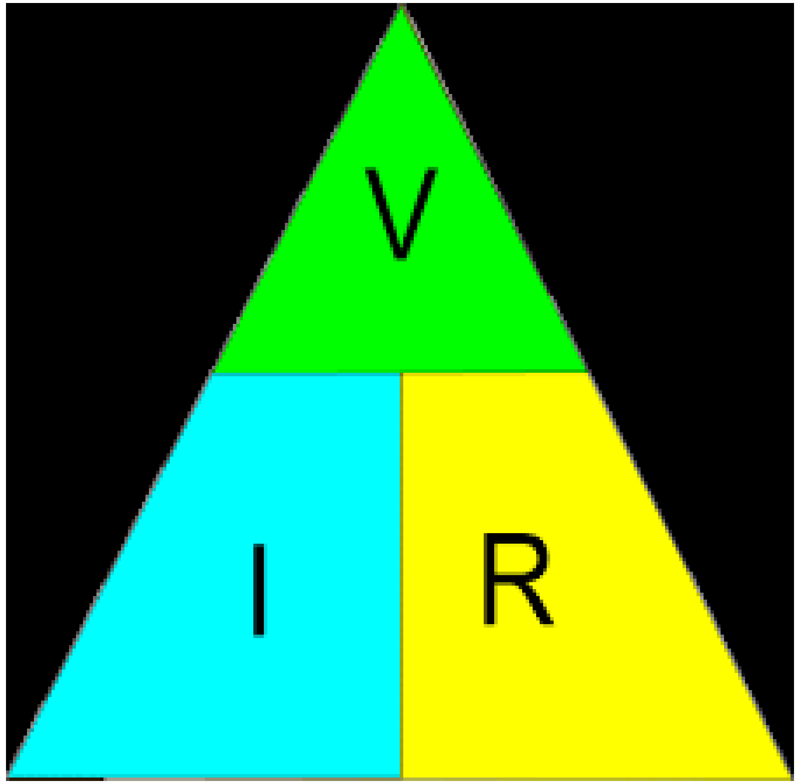
  c) Current controlled current sources (CCCS)

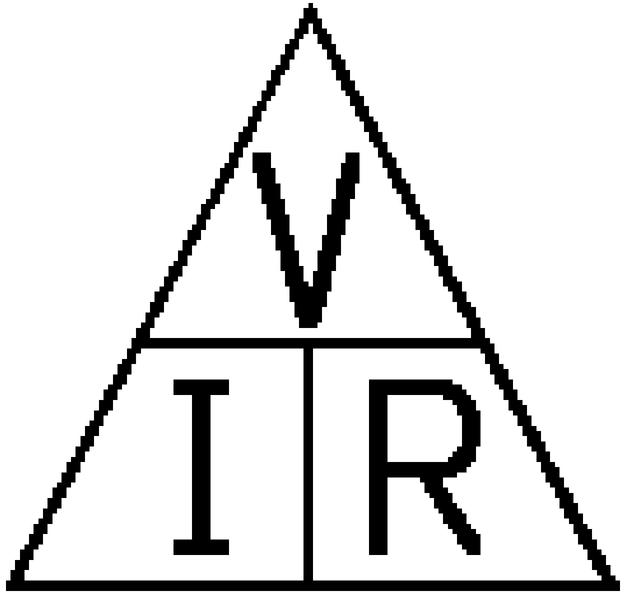
  d) Voltage controlled current sources (VCVS)

Ohms law

- Ohm's law states that the voltage 'v' across an element is directly proportional to the current 'i' flowing through it. i.e. $v \propto i$ or $v = R\,i$. where R is a proportionality constant known as resistance.
- Resistance is the property of the material to restrict the flow of current. It depends on type of material and its dimensions.
- This property is used in many applications such as heaters, irons, toasters and electric stoves.
- In the process of flow of electrons through a material, they loose some of their energy due to the resistive property of materials, resulting in heat generation.

Ohms law





Resistance

Fig. 2.1(a) shows a material with uniform cross-sectional area A, length ℓ and resistivity ρ (ohm-meters).

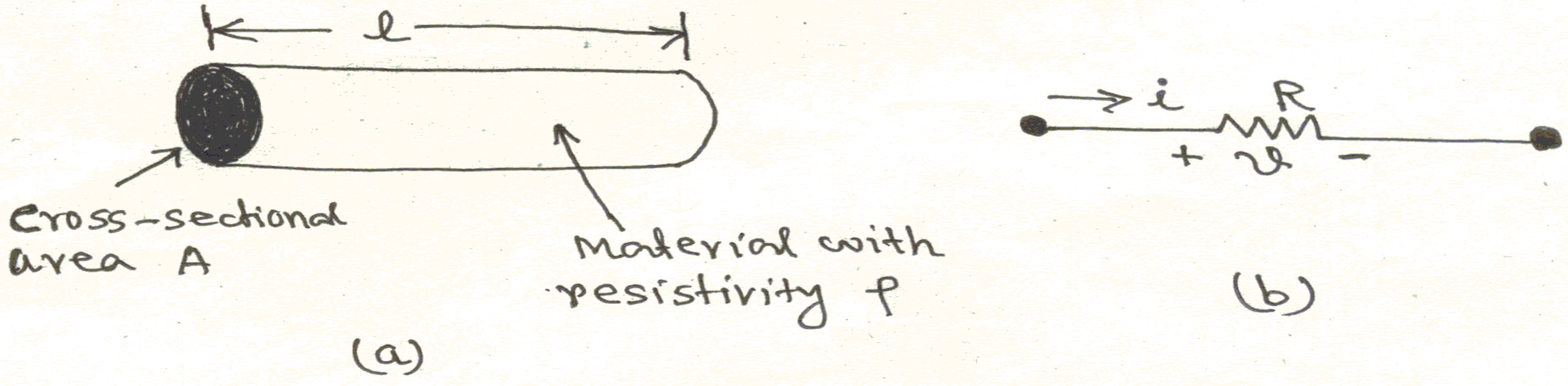


Fig. 2.1 : (a) Resistor (b) Circuit symbol for resistance

Resistance

Fig.2.1(a) shows a material with uniform cross-sectional area A, length l and resistivity ρ (ohm-meters).

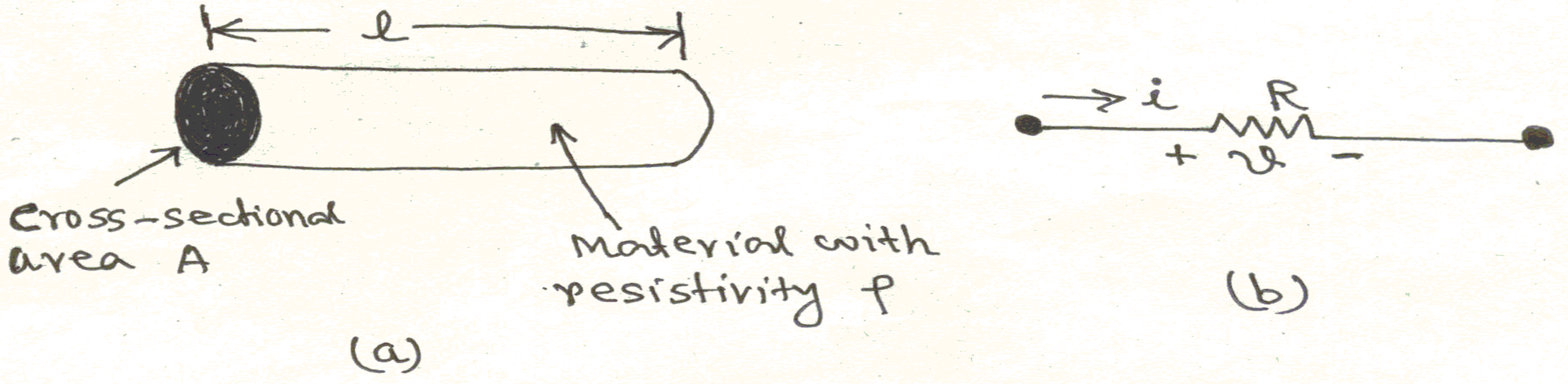


Fig.2.1 : (a) Resistor (b) Circuit symbol for resistance

Resistance

- Resistance of an element, $R = \frac{\rho l}{A}$ and its units are Ohm or Ω
- An element with low resistance is a conductor. Ex. Copper, aluminum, silver etc.
- An element with very high resistance is known as Insulator. Ex. Wood, mica, paper, glass etc.
- An element with R=0 is considered as short circuit.
- An element with R=∞ is considered as open circuit.

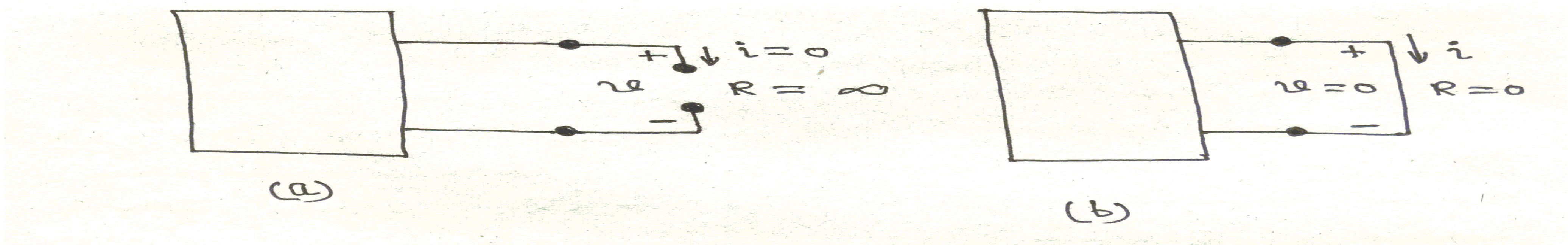


Fig. 2.2: (a) open circuit (b) short circuit

Resistance

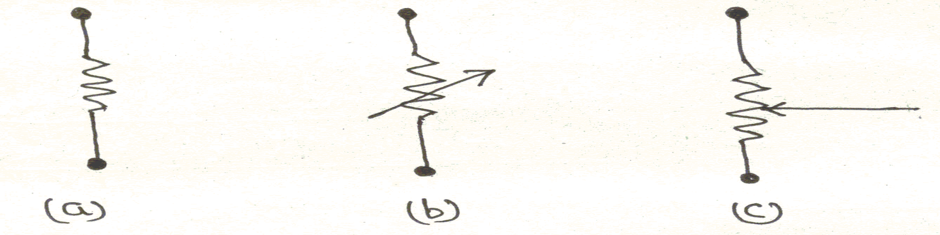


Fig. 2.3: (a) ~~fixed~~ symbol for fixed resistor (b) symbol for variable resistor (c) symbol for potentiometer or pot for short.

- A resistor that obeys Ohm's law is known as linear resistor.
- A resistor that does not obey Ohm's law is known as nonlinear resistor. Ex. Filament in a lamp and diodes

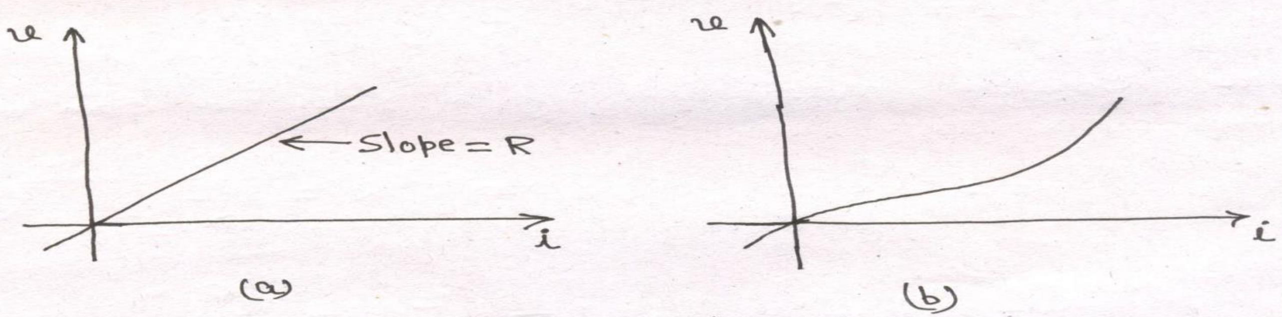


Fig. 2.4: (a) i – v characteristic of a linear resistor (b) i – v characteristic of a nonlinear resistor.

Resistance

Electrical Resistance is the property of a material by virtue of which it opposes the flow of electrons through the material

Resistance restricts the flow of electric current through the material

The Unit of resistance (R) being Ohm Ω

Inductance

Inductance is property of a material by virtue of which it opposes any change of magnitude or direction of electric current passing through the conductor

A pure inductor doesnot dissipate energy but stores energy in the form of electromagnetic form

The Unit of inductance (L) being 'henry' given by faradays laws of electro magnetic induction

Capacitance

Capacitance is property of a material by virtue of which it opposes any sudden change of magnitude electric voltage across the conductor

It is the capability of an element to store electric charge within it

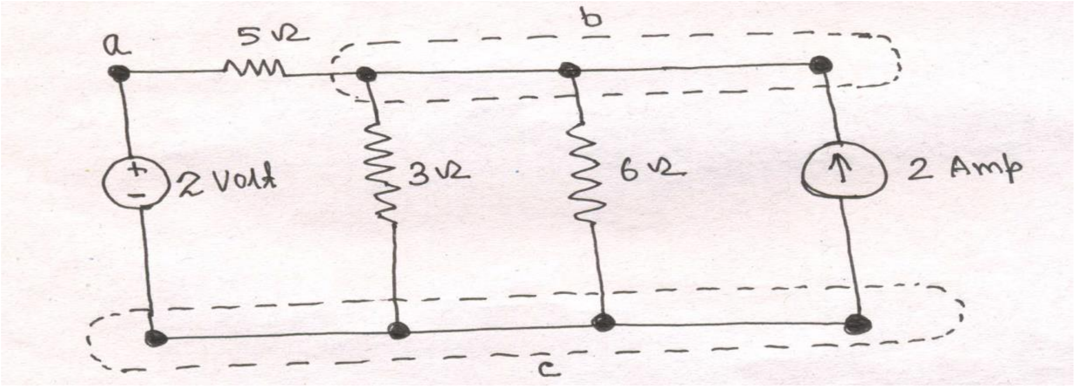
The Unit of Capacitance (C) being ‘farad’ [F]

Voltage-Current Relation ship of Circuit Elements

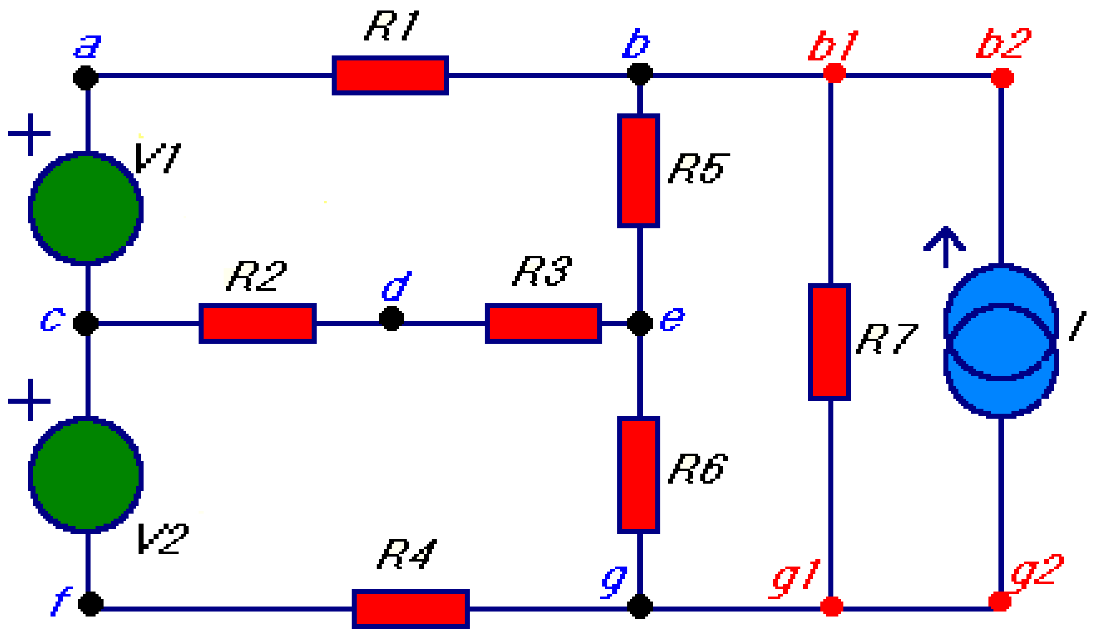
Element	Basic Relation	Voltage across, if Current known	Current through if voltage known	Energy
R	$R = \frac{V}{i}$	$V_R(t) = Ri_R(t)$	$i_R(t) = \frac{1}{R} V_R(t)$	$W = \int_{-\infty}^{t} i_R(t) V_R(t)\,dt$
L	$L = \frac{N\phi}{i}$	$V_L(t) = L\frac{di_L(t)}{dt}$	$i_L(t) = \frac{1}{L}\int_{-\infty}^{t} V_L(t)\,dt$	$W = \frac{1}{2}L[i(t)]^2$
C	$C = \frac{q}{V}$	$V_C(t) = \frac{1}{C}\int_{-\infty}^{t} i_C(t)\,dt$	$i_c(t) = C\frac{dV_C(t)}{dt}$	$w = \frac{1}{2}C[V_C(t)]^2$

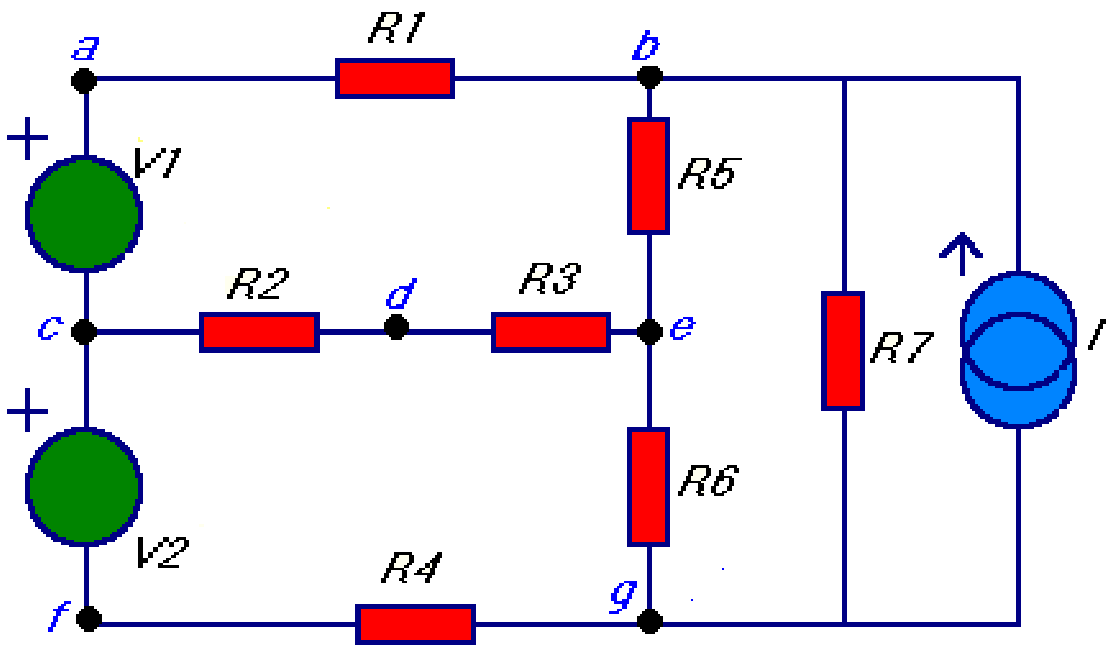
Electric Circuit Terminology

- Elements of electric circuit can be interconnected in several ways.
- Interconnection of two or more circuit elements is known as a **NETWORK**.
- A network having one or more closed paths is known as **ELECTRIC CIRCUIT**.
- A **BRANCH** represents a two terminal element in a circuit.



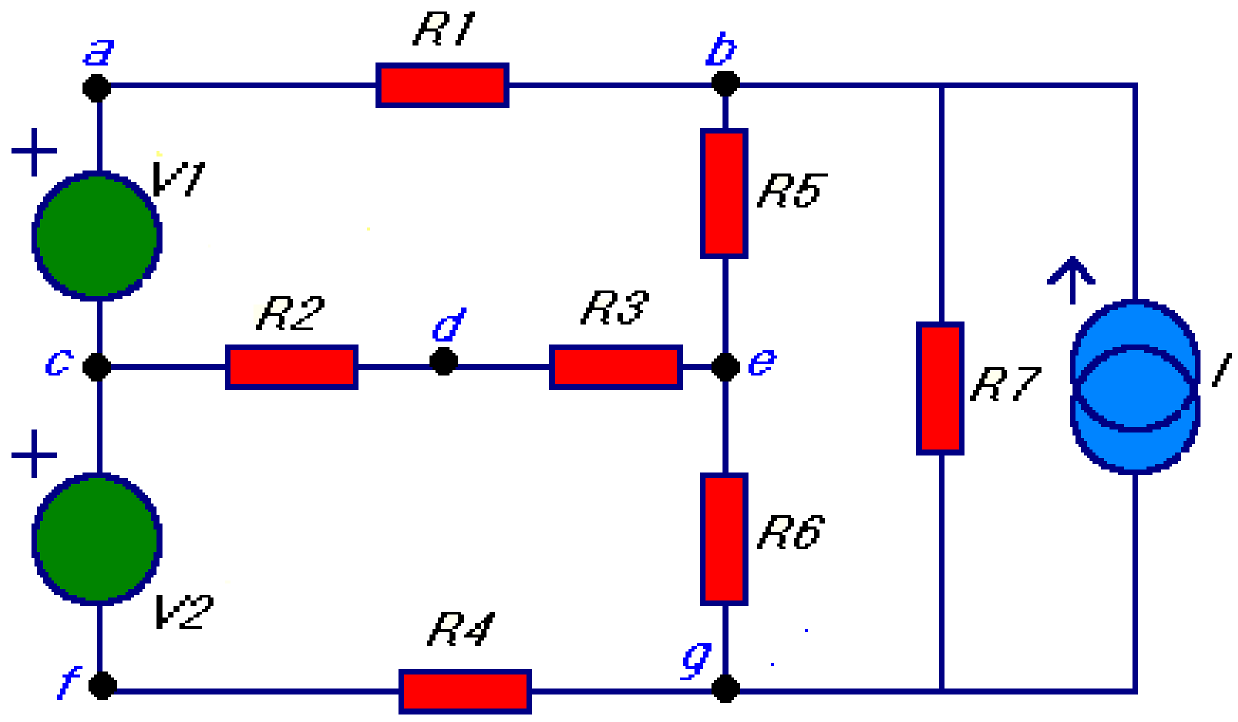
NODE





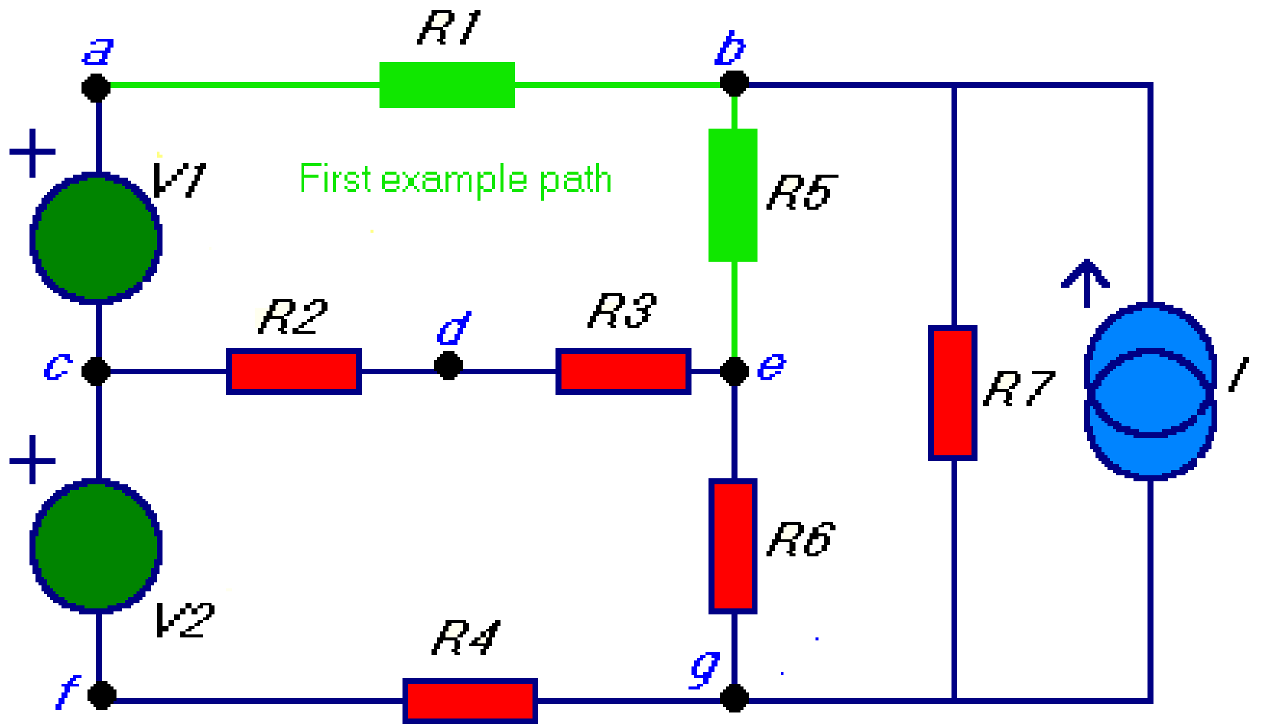
A **NODE** is a point where two or more circuit elements or branches are connected.

Branches



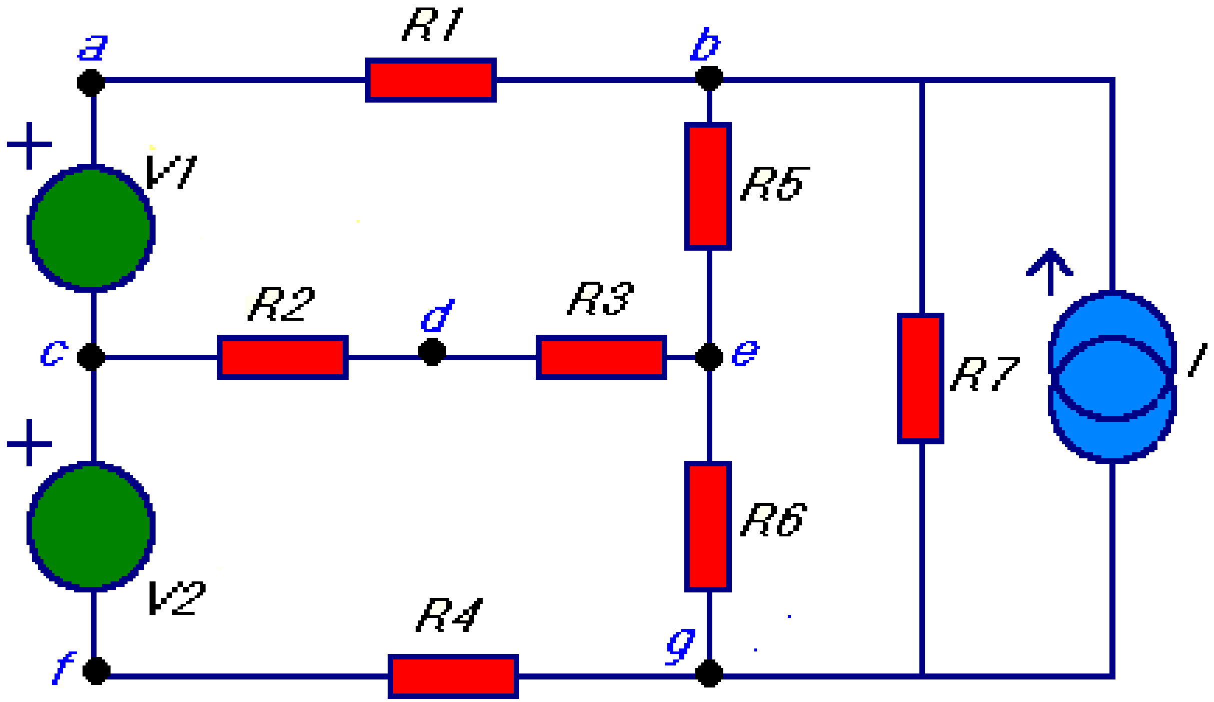
An element or number of elements connected between two nodes constitute a ***BRANCH***

Path



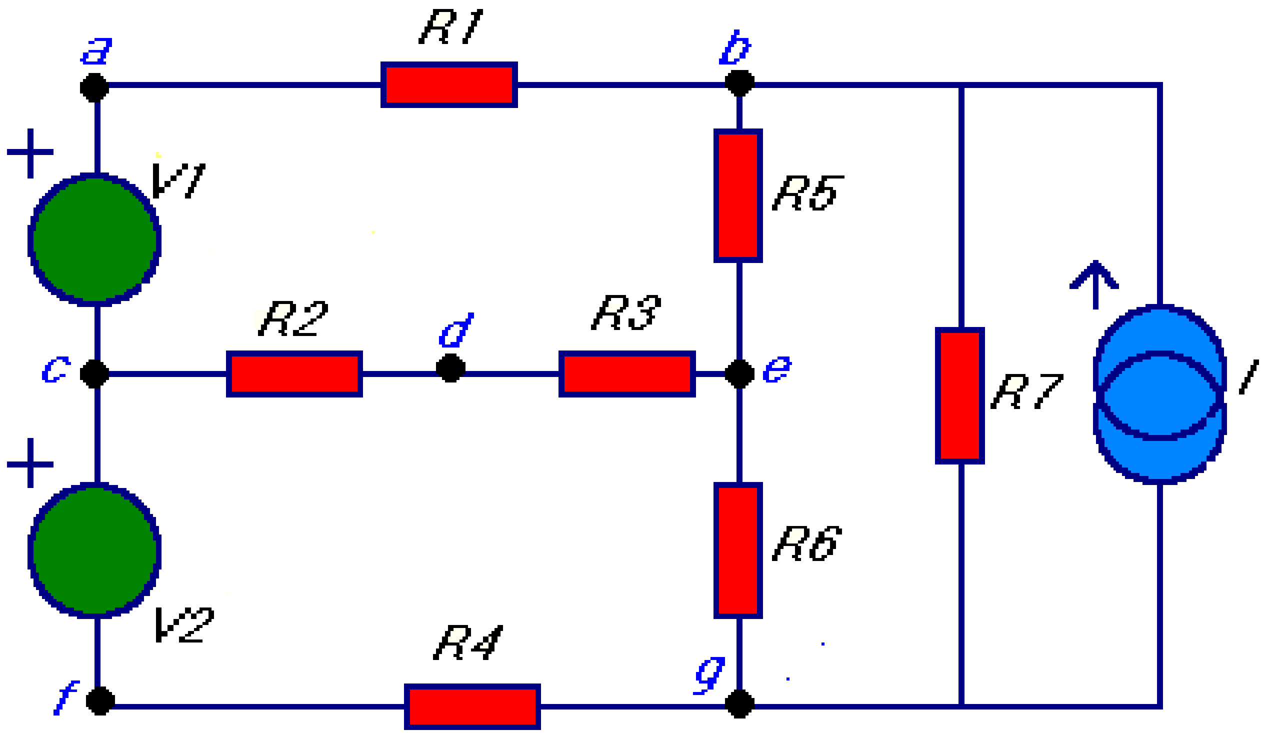
a ***PATH*** is a sequence of nodes

Closed path or Loop



A **LOOP** is a closed path starting at anode and proceeding through circuit elements, eventually returning to the starting node.

Mesh

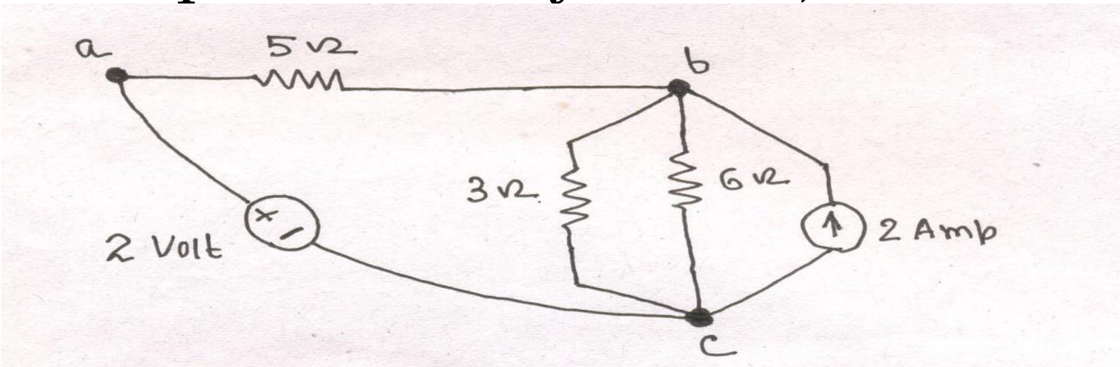


MESH is the most elementary form of a loop and cannot be further divided into other loops.

A loop that do not have any internal loops in it, is a mesh.

Nodes, branches and loops

- A Node is a point where two or more circuit elements or branches are connected.
- Here the nodes are represented by dots a, b and c.



- A loop is a closed path starting at anode and proceeding through circuit elements, eventually returning to the starting node.
- A loop that do not have any internal loops in it, is a mesh.
- Number of meshes $m = b - n + 1$,

  where b – number of branches, n – number of nodes

Kirchhoff's laws

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- Kirchhoff's laws were first introduced in 1847 by the German physicist ***Gustav Robert Kirchhoff.***

➢ Kirchhoff's Current law (KCL)

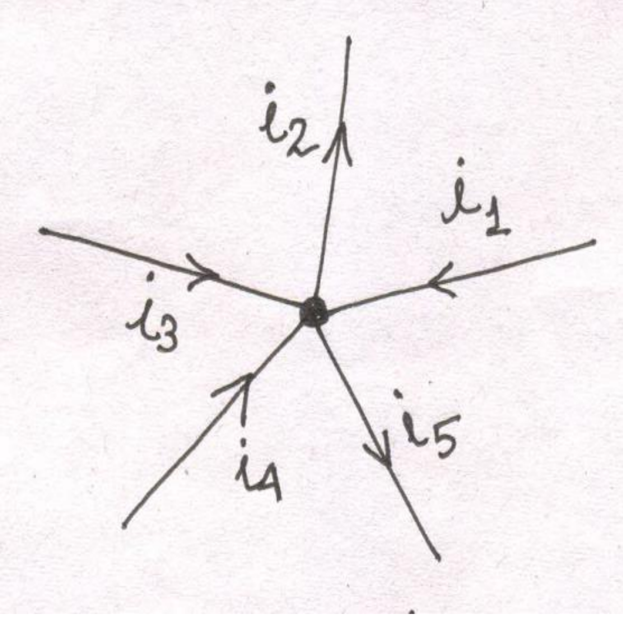
➢ Kirchhoff's Voltage law (KVL)

Kirchhoff's Current law

- **Kirchhoff's current law** (KCL) is based on law of conservation of charge.
- Kirchhoff's current law (KCL) states that the algebraic sum of currents entering a node is zero.
- Mathematically KCL can be written as $\sum_{k=1}^{N} i_k = 0$,

  where N is the number of branches connected to the node k,

  i_k *is* the kth current entering or leaving the node.
- While writing KCL currents entering are taken +ve and leaving –ve.

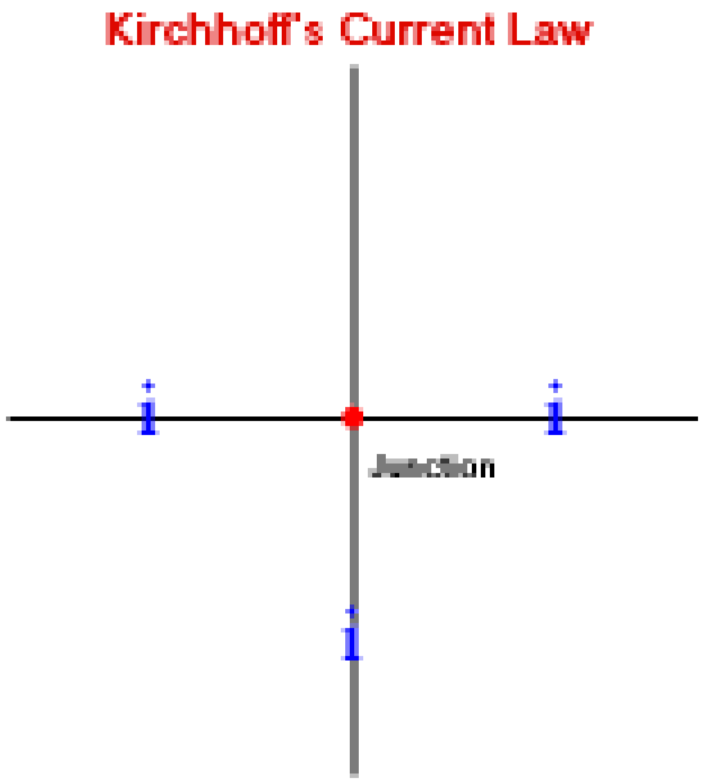


$$i_1 + (-i_2) + i_3 + i_4 + (-i_5) = 0$$

$$i_1 + i_3 + i_4 = i_2 + i_5$$

Thus the sum of currents entering a node is equal to sum of currents leaving the node

Kirchhoff's laws



Kirchhoff's Voltage laws

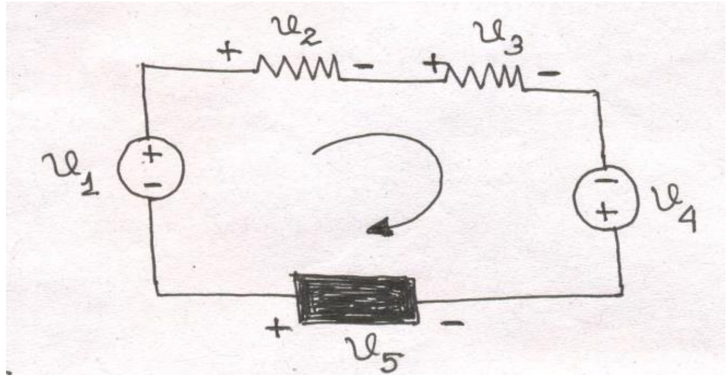
- Kirchhoff's Voltage law (KVL) is based on law of conservation of energy.
- Kirchhoff's Voltage law (KVL) states that algebraic sum of voltages around closed path or a loop is zero.
- KVL can be expressed as $\sum_{p=1}^{M} v_p = 0$, where M is number of branches in the loop and v_p is the corresponding branch voltage.

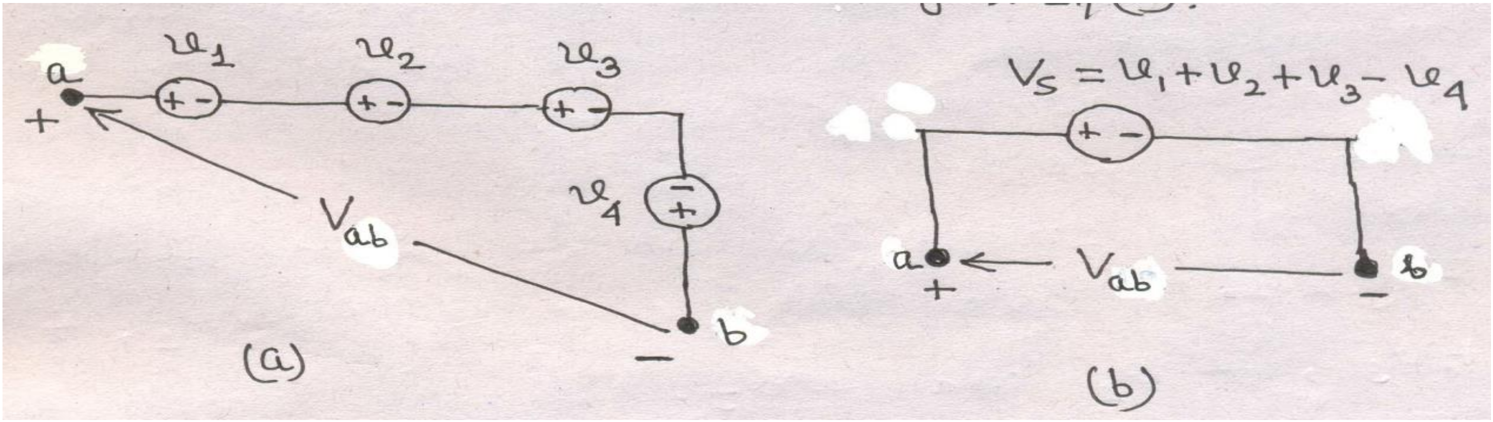
Kirchhoff's Voltage laws

- While writing KVL, we encounter various voltages in the loop. Some of them carry positive sign and other carry negative sign in the algebraic sum.
- While writing KVL, we can start with any branch and go around the loop in either clockwise or counter clockwise.
- The elements that are encountered first with +ve terminal are taken positive voltage and –ve terminal are taken –ve voltage in algebraic sum.

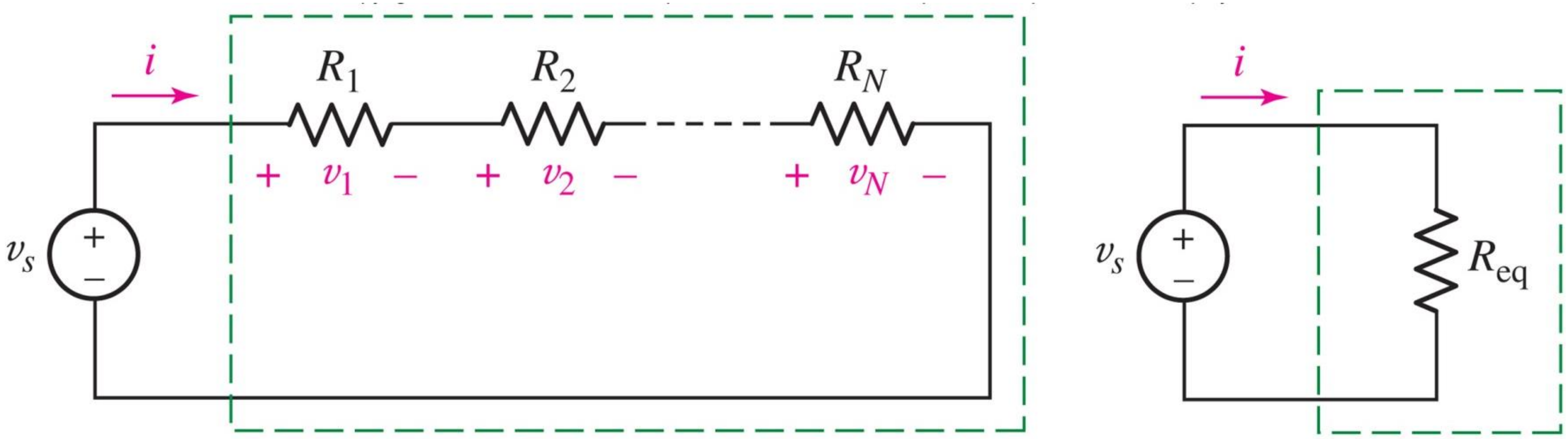
Kirchhoff's laws

- Let us consider this circuit.
- Start moving in clockwise direction in the loop shown with arrow.
- Then voltages will be $+v_2$, $+v_3$, - v_4 , - v_5 *and* – v_1.
- Thus KVL yields $v_2 + v_3 - v_4 - v_5 - v_1 = 0$.
- Rearranging them, $v_2 + v_3 = v_1 + v_4 + v_5$



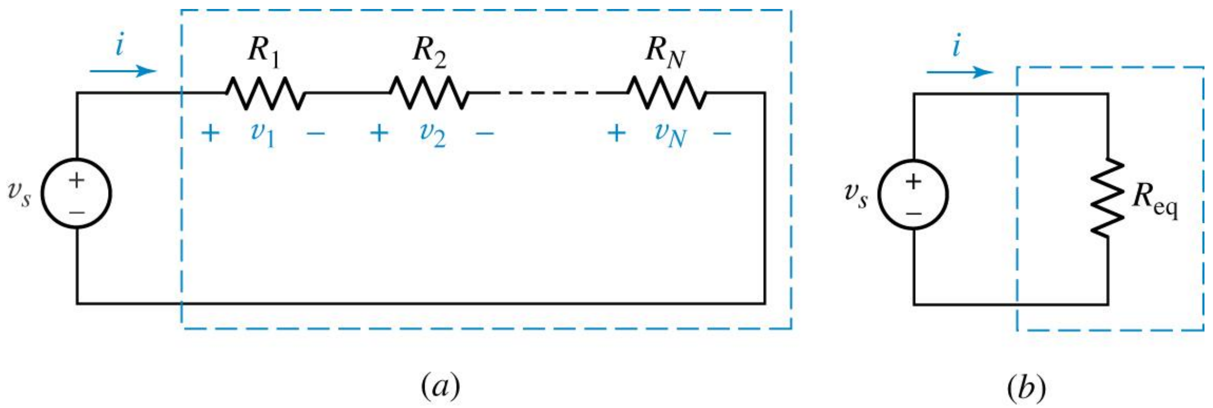


Resistors in Series



Using KVL shows:

$$R_{eq} = R_1 + R_2 + \ldots + R_N$$



(a) Series combination of *N* resistors. (b) Electrically equivalent circuit.

First, apply KVL:

$$v_s = v_1 + v_2 + \cdots + v_N$$

and then Ohm's law:

$$v_s = R_1 i + R_2 i + \cdots + R_N i = (R_1 + R_2 + \cdots + R_N)i$$

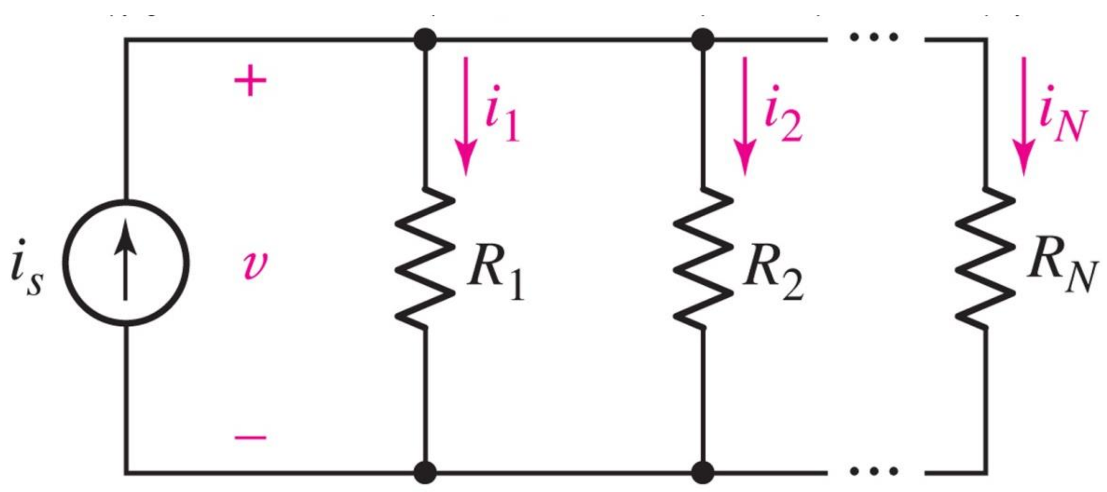
Now compare this result with the simple equation applying to the equivalent circuit shown

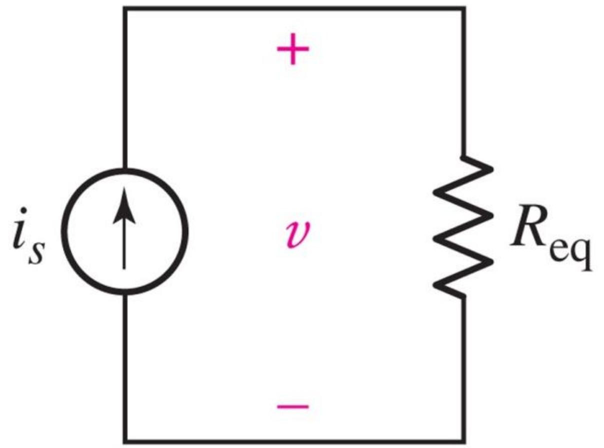
$$v_s = R_{eq} i$$

Thus, the value of the equivalent resistance for N series resistors is

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

Resistors in Parallel





Using KCL shows:

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

Two Resistors in Parallel

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(Estd. u/s 3 of the UGC Act, 1956)

Two resistors in parallel can be combined using the **product / sum** shortcut.

$\therefore I = I_1 + I_2 + I_3$

As all the three resistors have been connected between the same two points A and B, voltage V across each of them is same. By Ohm's law,

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

If R_P be equivalent resistance of parallel combination, then,

$$I = \frac{V}{R_P}$$

But $I = I_1 + I_2 + I_3$

$$\therefore \quad \frac{V}{R_P} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$$

or $$\frac{1}{R_P} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

$$R_{eq} = R_1 \| R_2$$

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

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

Classification of elements

- Classification of a network is done based on the type of elements being used in that network. The operational characteristics of a network depend on the behaviour of its elements.
- Elements which supply the energy to the circuit are known as ***active elements***. A network which contains active elements is known as active networks.

➢ Ex: batteries, generators, transistors etc.

- Elements which absorb the energy are known as ***passive elements***. A network containing only passive elements is known as passive network.

➢ Ex: resistors, inductors and capacitors.

Classification of elements

- An element whose operational behaviour is dependent on the direction of flow of current through is known as ***unilateral elements***. Elements like semiconductor diode, which allow the current to pass through them only in one direction.

- An element whose behaviour is same irrespective of the direction of flow of current through it is known as ***bilateral element***. Passive elements that allow the current to pass through them in both directions are known as bilateral elements.

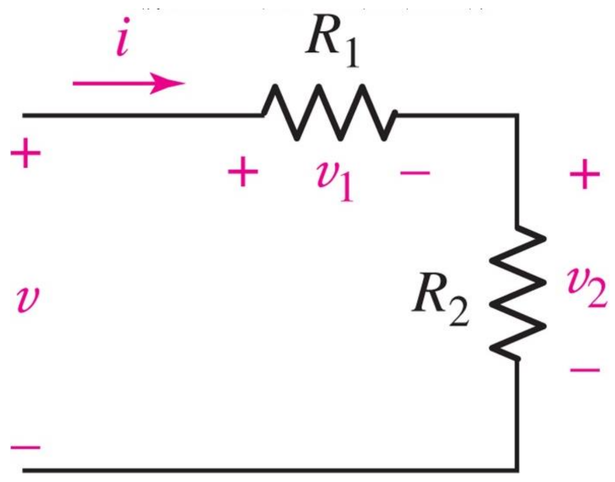
Classification of elements

- Networks consisting of elements which can be physically separated are known as ***lumped networks***. Most of the networks we deal with, are lumped in nature and consists of R, L,C and sources.
- Networks, like transmission lines, having inseparable elements are known as ***distributed networks***

- A ***linear element*** is one which has linear output/input relation and always follows superposition and homogeneity principles. Ohm's can be applied to such networks.
- The element that which does not follow these is known as a ***nonlinear element***. Ohm's law cannot be applied to such networks.

Voltage Division

Resistors in series “share” the voltage applied to them.

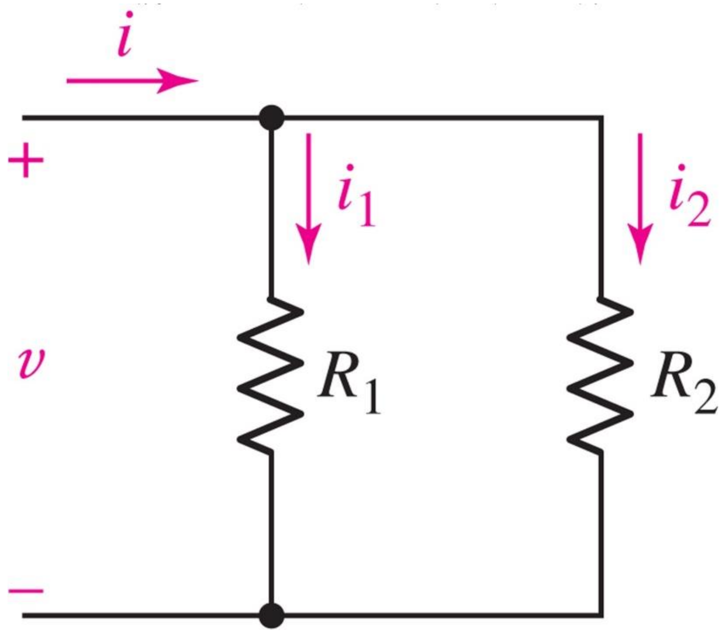


$$v_1 = \frac{R_1}{R_1 + R_2} v$$

$$v_2 = \frac{R_2}{R_1 + R_2} v$$

Current Division

Resistors in parallel “share” the current through them.



$$\boxed{i_1 = i\,\frac{R_2}{R_1 + R_2}}$$

$$\boxed{i_2 = i\,\frac{R_1}{R_1 + R_2}}$$

Source transformation

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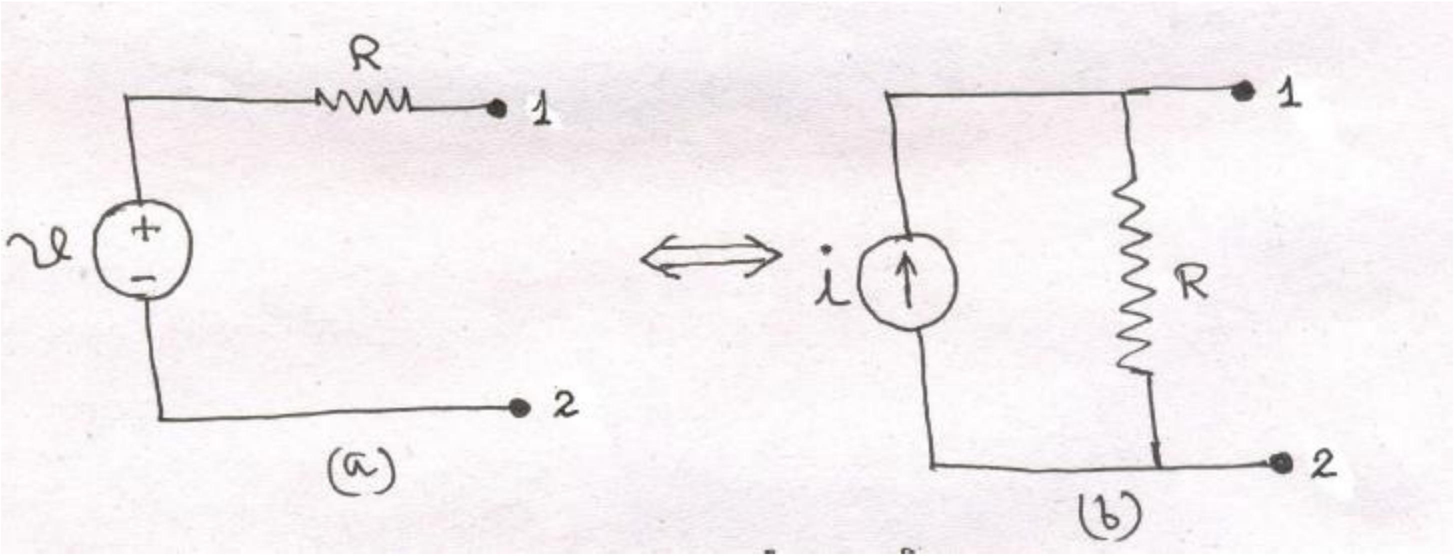
A voltage source can be transformed to its equivalent current source.

$$i = \frac{v}{R}$$

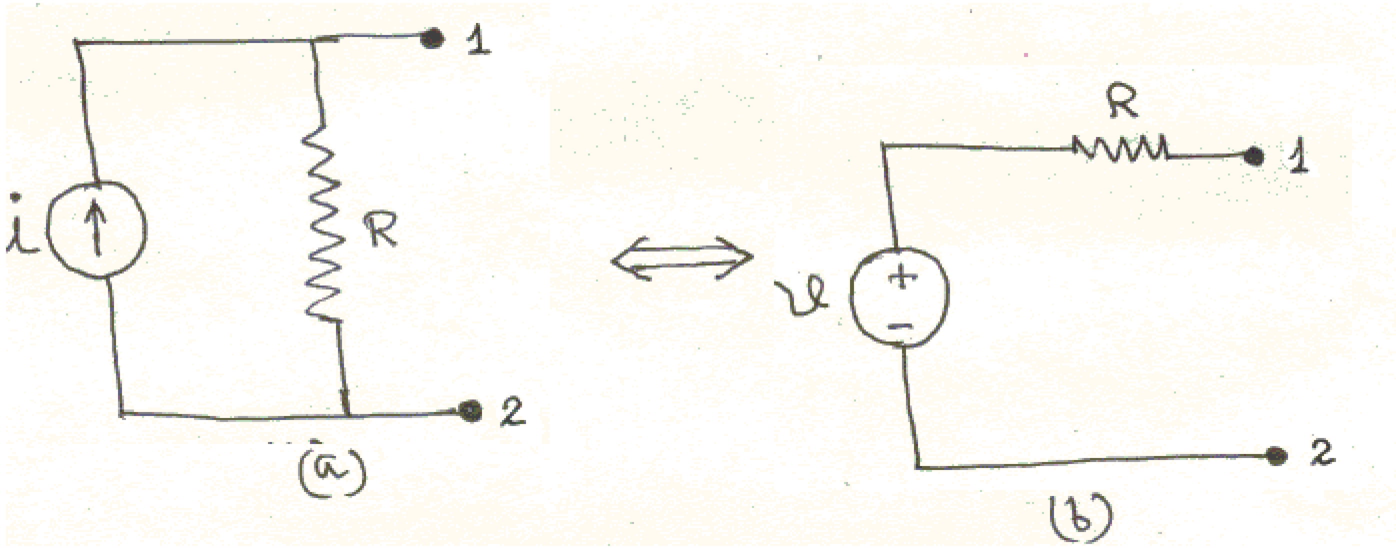


Source Transformation Source transformation is a circuit analysis **technique** in which we transform voltage **source** in series with resistor into a current **source** in parallel with the resistor and vice versa.

Source transformation

A current source can be transformed to its equivalent voltage source.

$$v = iR$$



Nodal and Mesh analysis

- Two powerful techniques that aid in analysis of complex circuits are:

a) Nodal Analysis

b) Mesh analysis

a)Nodal analysis: it is based on systematic application of Kirchhoff's current law.

b) Mesh Analysis: it is based on the systematics application of Kirchhoff's voltage law.

Using above two methods we can solve for voltages and currents in any linear circuit.

Nodal Analysis

- In nodal analysis node voltages are the variables.

Procedure:

- Consider a network without voltage sources.
- Identify the nodes and number them in the network.
- Select one of the node as a reference node.
- Assign the voltages to remaining 'n-1' non reference nodes with respect to the reference node

  as ex: v_1, v_2,v_3,.....v_n.
- Apply KCL at each of the 'n-1' non-reference nodes.
- Express branch current in terms of node voltages using ohms law.
- Solve the simultaneous equations to obtain the node voltages.

Nodal analysis

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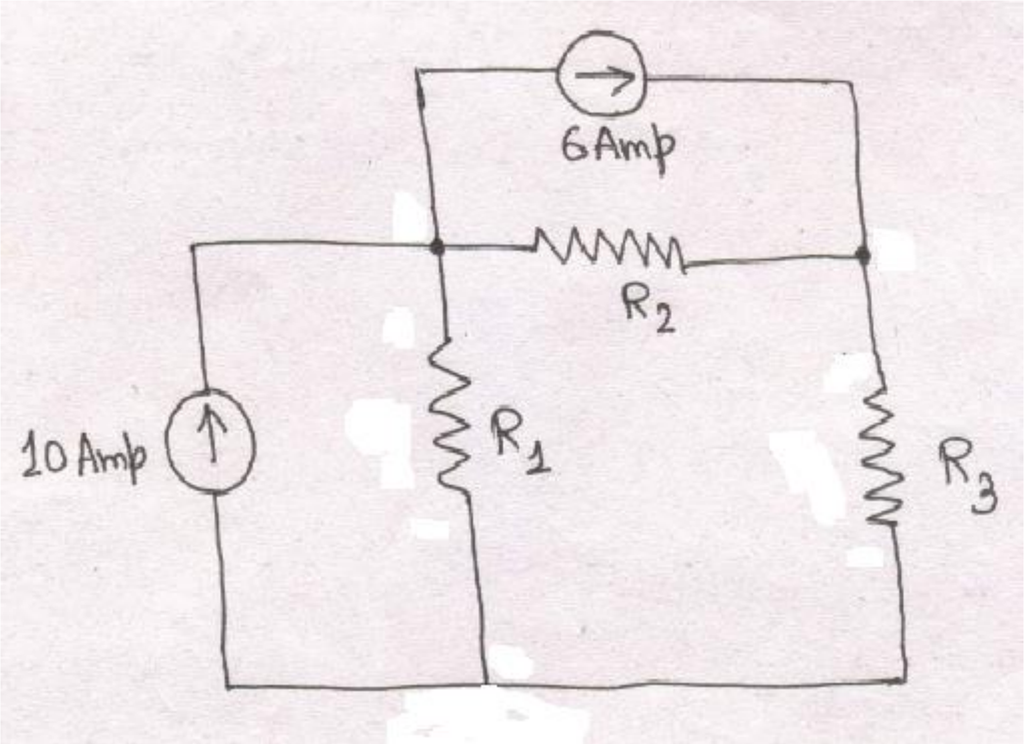
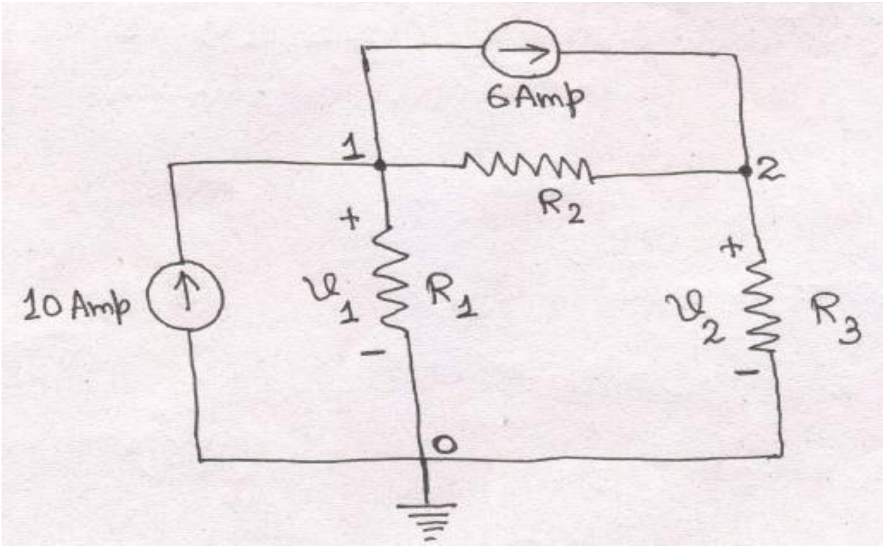
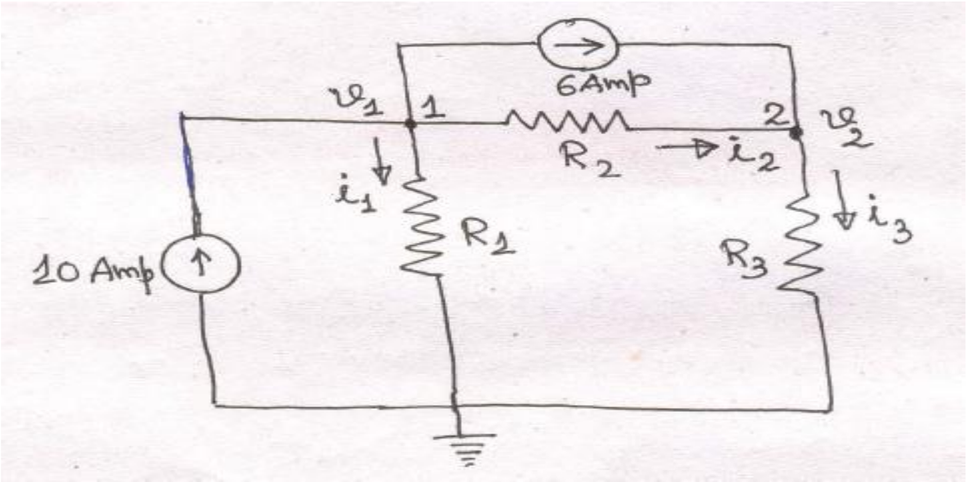
- Determine node voltages for the following circuit



Nodal analysis

- Applying KCL at node1: $10 = i_1 + i_2 + 6$
- Applying KCL at node2: $i_2 + 6 = i_3$,
- Using ohm's law: $i_1 = v_1/R_1$, $i2 = (v_1 - v_2)/R_2$, $i_3 = v_2/R_3$.
- Substituting i_1, i_2 and i_3:
- $10 = \frac{V_1}{R_1} + \left(\frac{V_1 - V_2}{R_2}\right) + 6$
- $\left(\frac{V_1 - V_2}{R_2}\right) + 6 = \frac{V_2}{R_3}$
- Rewriting the equations:
- $v_1\left(\frac{1}{R_1} + \frac{1}{R_2}\right) - v_2\left(\frac{1}{R_2}\right) = 4$
- $-v_1\left(\frac{1}{R_2}\right) + v_2\left(\frac{1}{R_2} + \frac{1}{R_3}\right) = 6$





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Nodal analysis

- Applying KCL at node 1:

$$2.5 = \frac{v_1}{4} + \frac{v_1 - v_2}{8}$$

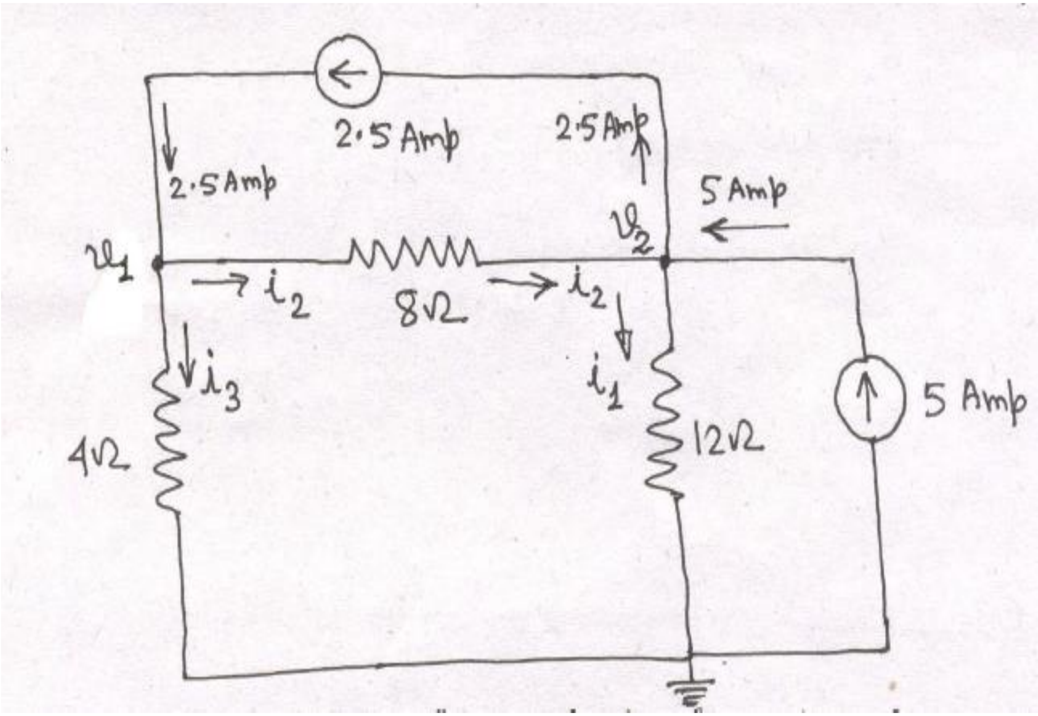
Applying KCL at node 2:

$$5 = \frac{v_2}{12} + \frac{v_2 - v_1}{8} + 2.5$$

$2v_1 + v_1 - v_2 = 20;$ $\quad 3v_1 - v_2 = 20$

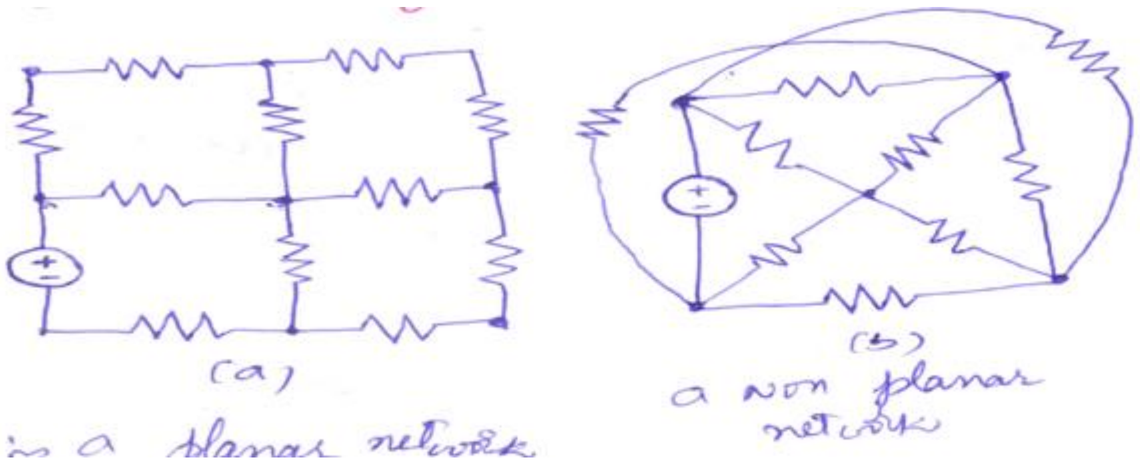
$2v_2 + 3v_2 - 3v_1 = 30$ $\quad -3v_1 + 5v_2 = 30$

Solving, $v_1 = 13.33V\ and\ v_2 = 20V$



Mesh analysis

- Mesh analysis is a general method to analyze electric circuits using mesh currents of the circuit.
- In mesh analysis we apply KVL to obtain unknown currents.
- Mesh analysis is applicable to planar networks.
- A circuit that can be drawn on a plain paper with no branches crossing one another is called a planar circuit.



Mesh analysis

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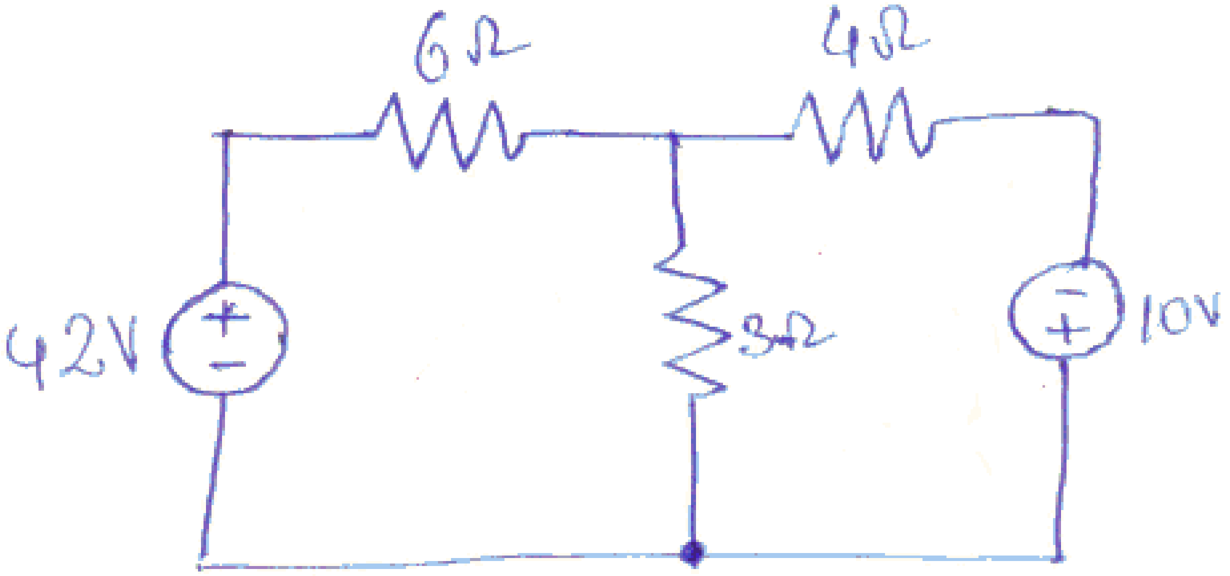
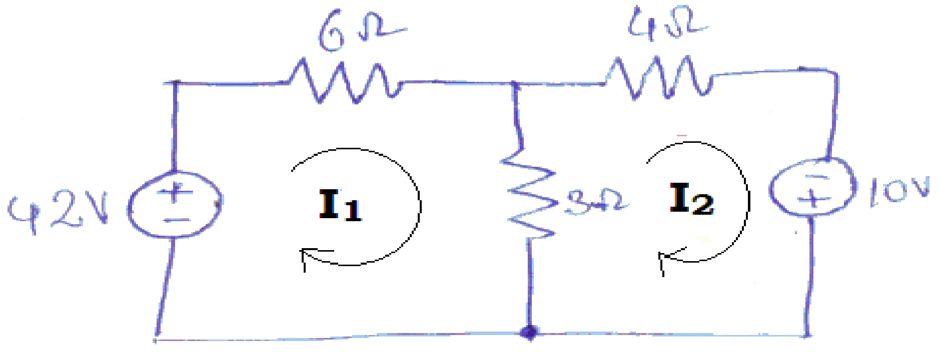
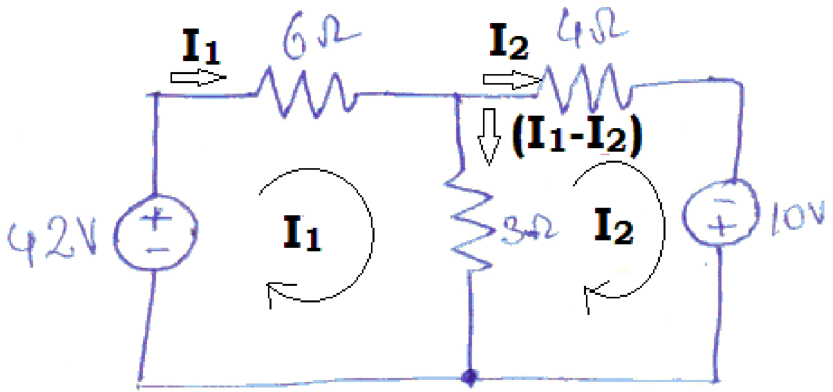
Determine the branch currents for the following circuit.



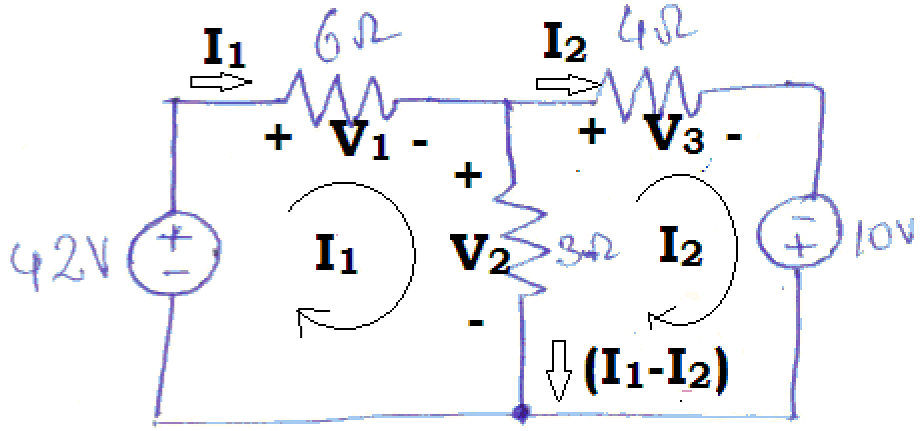
Mesh analysis

- Number of node, n=4
- Number of branches=5
- Number of meshes, m=b-n+1=5-4+1=2





- Applying KVL around mesh 1:
- $-42 + V_1 + V_2 = 0 \Rightarrow -42 + 6I_1 + 3(I_1 - I_2) = 0$
- Applying KVL around mesh 2:
- $V_3 - 10 - V_2 = 0 \Rightarrow 4I_2 - 10 - 3(I_1 - I_2) = 0$
- $9I_1 - 3I_1 - 42 = 0$
- $-3I_1 + 7I_2 - 10 = 0$
- $I_1 = 6A \; and \; I_2 = 4A$



Network Theorem

- We have used Kirchhoff's laws, nodal and mesh analysis to analyze various circuit. The main advantage of using them is, we can analyze a circuit without tampering with its original configuration.
- Major drawback of this approach is, it involves tedious computations for large and complex circuits.
- To handle the complexity of circuits, circuit theorems are developed by engineers to simplify the analysis.
- Such theorems include: Superposition theorem, Thevenin’s, Maximum power transfer theorem

Superposition theorem

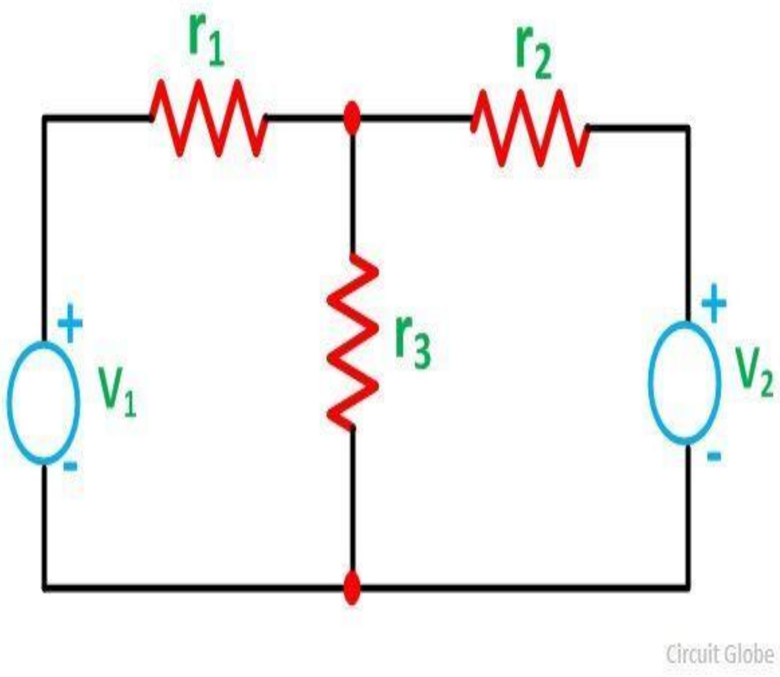
- **Superposition theorem:**

States that current through (voltage across) an element in a linear circuit is the algebraic sum of the currents through (or voltages across) that element due to each independent source acting alone.

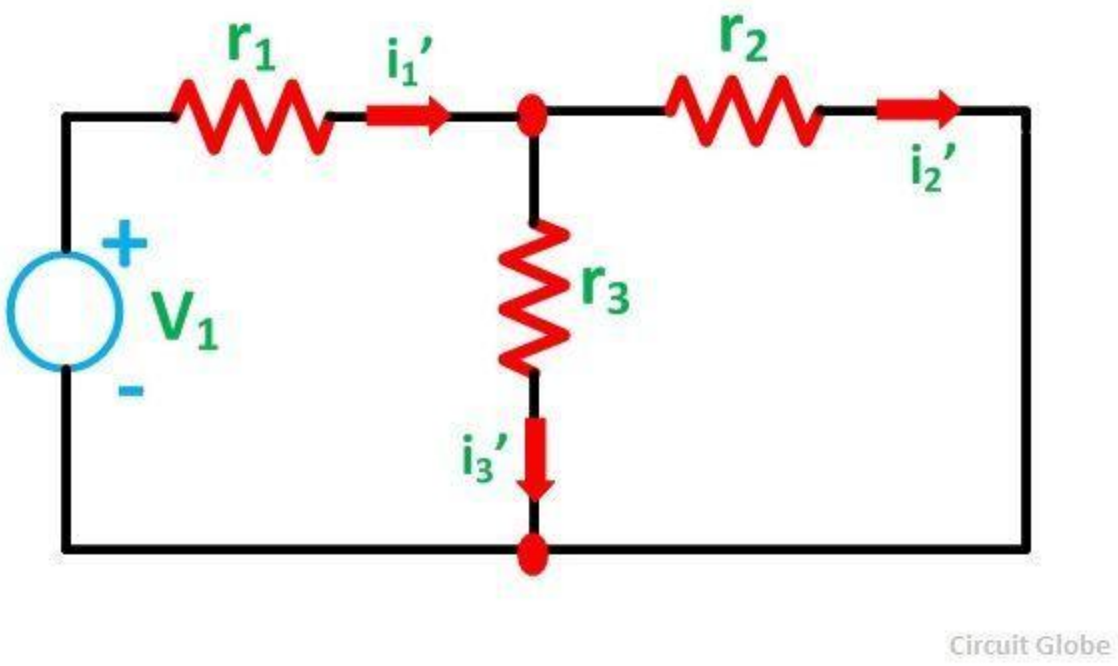
To apply super position theorem:

1. Consider one independent source at a time while all other independent sources are turned off.
2. Dependent sources are controlled by control variables and hence they will be left intact.

Super position theorem



First, take the source V_1 alone and short circuit the V_2 source as shown in the circuit diagram below:



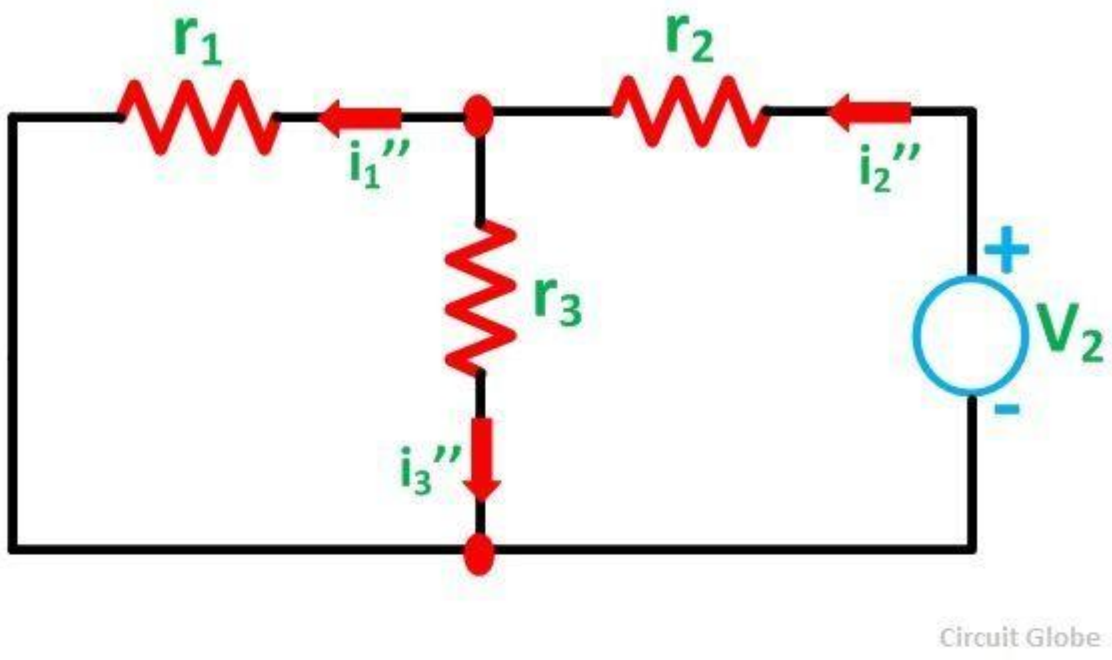
$$i_1' = \frac{V_1}{\frac{r_2 r_3}{r_2 + r_3} + r_1} \quad \dots\dots\dots\dots (1)$$

$$i_2' = i_1' \frac{r_3}{r_2 + r_3} \quad \dots\dots\dots\dots (2)$$

$$i_3' = i_1' - i_2'$$

Super position theorem

Now, activating the voltage source V_2 and deactivating the voltage source V_1 by short-circuiting it, find the various currents, i.e. i_1'', i_2'', i_3'' flowing in the circuit diagram shown below:



$$i_2'' = \frac{V_2}{\frac{r_1 r_3}{r_1 + r_3} + r_2} \quad \text{and} \quad i_1'' = i_2'' \frac{r_3}{r_1 + r_3}$$

$$i_3'' = i_2'' - i_1''$$

Super position theorem

As per the superposition theorem, the value of current i_1, i_2, i_3 is now calculated as:

$$i_3 = i_3' + i_3''$$

$$i_2 = i_2' - i_2''$$

$$i_1 = i_1' - i_1''$$

Super position theorem

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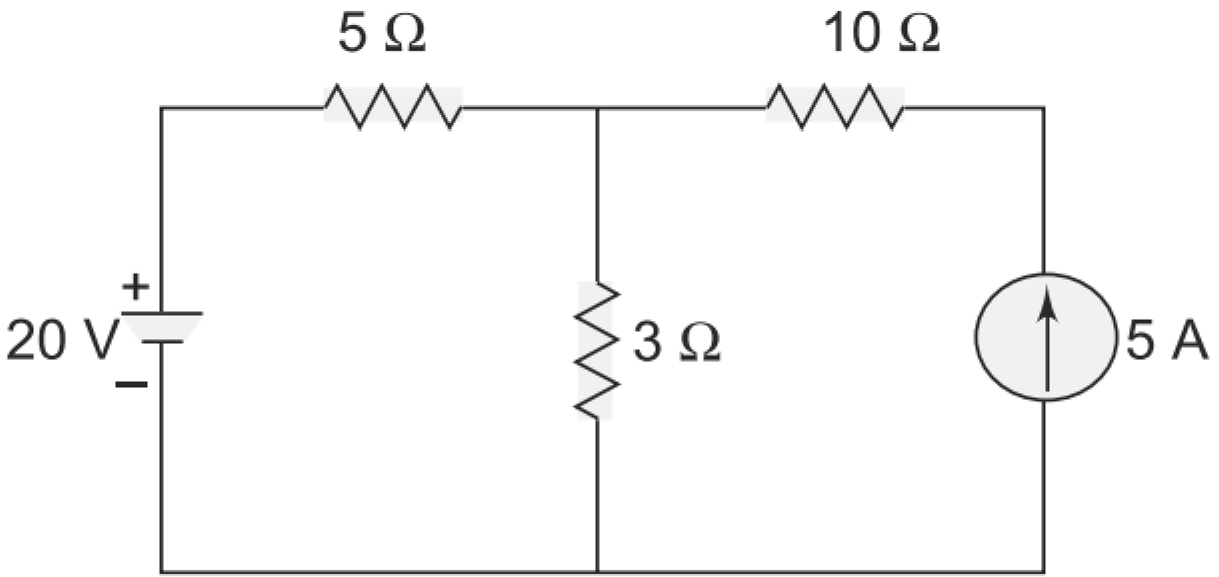
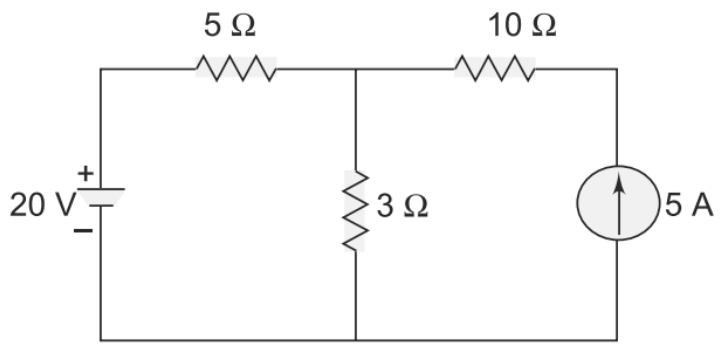
Using super position theorem, determine current flowing through 3ohms resistor for the following circuit.





Step 1

Consider 20V volt. source & open circuit 5A ~~source~~

source

Current flowing through open 10Ω is zero

$I_2 = 20/(5+3) = 2.5A$

Step 2

Consider 5A current source & short circuit 20V volt. source

$I_{3\Omega} = \underbrace{5}_{\text{Total current}}\left(\frac{5}{5+3}\right) = 3.125A$

Total current flowing through 3Ω = 2.5+3.125

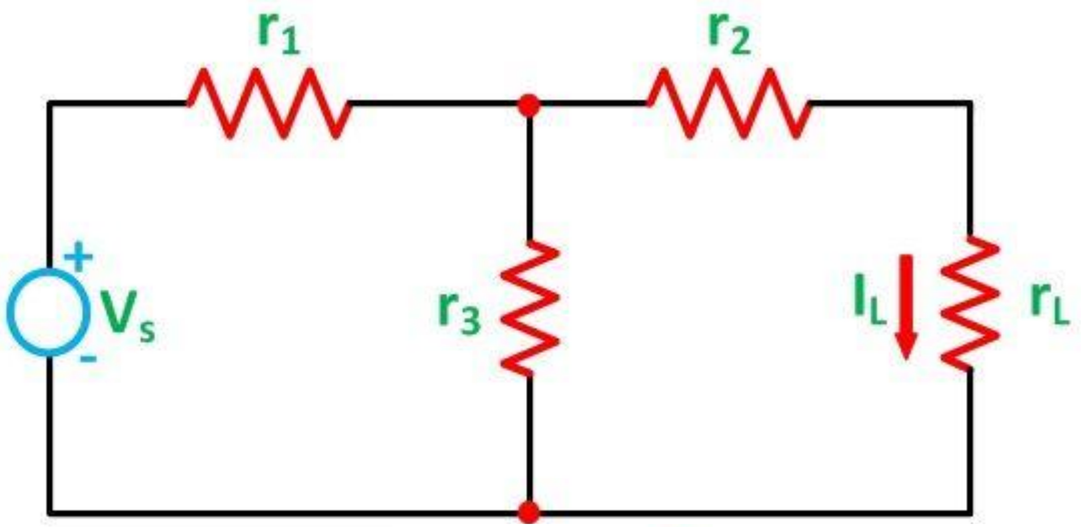
= 5.625A

Thevenin’s theorem

Statement:

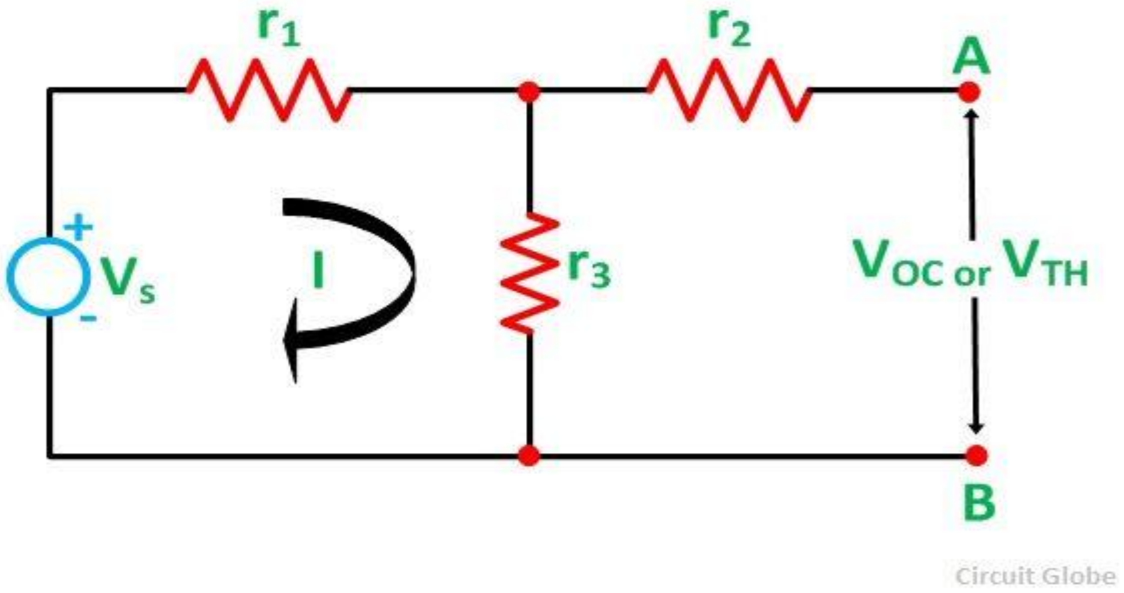
- Thevenin’s theorem states that any two terminal linear network having a number of voltage current sources and resistances can be replaced by a simple equivalent circuit consisting of a single voltage source in series with a resistance.
- The value of the voltage source is equal to the open-circuit voltage across the two terminals of the network,
- Resistance is equal to the equivalent resistance measured between the terminals with all the energy sources are replaced by their internal resistances.

Explanation of Thevenin's Theorem



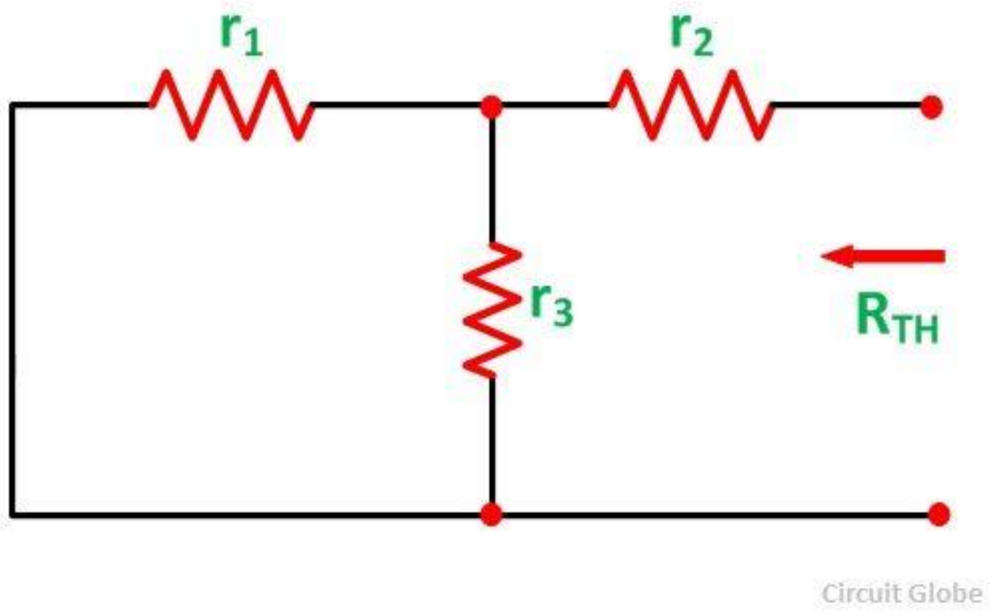
Let us consider a simple DC circuit as shown in the figure above, where we have to find the load current I_L by the Thevenin's theorem.

In order to find the equivalent voltage source, ***r_L is removed from the circuit*** as shown in the figure below and V_{oc} or V_{TH} is calculated.



$$V_{OC} = I\, r_3 = \frac{V_S}{r_1 + r_3}\, r_3$$

- Now, to find the internal resistance of the network (Thevenin's resistance or equivalent resistance) in series with the open-circuit voltage **V_{OC}** , also known as Thevenin's voltage **V_{TH}**, ***the voltage source is removed or we can say it is deactivated by a short circuit***

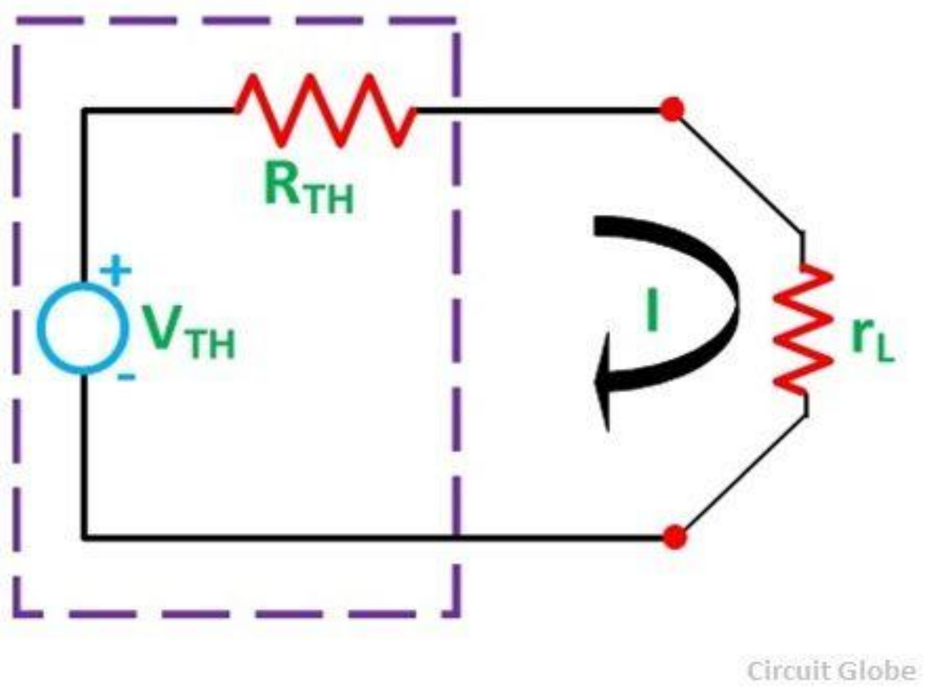


$$R_{TH} = r_2 + \frac{r_1 r_3}{r_1 + r_3}$$

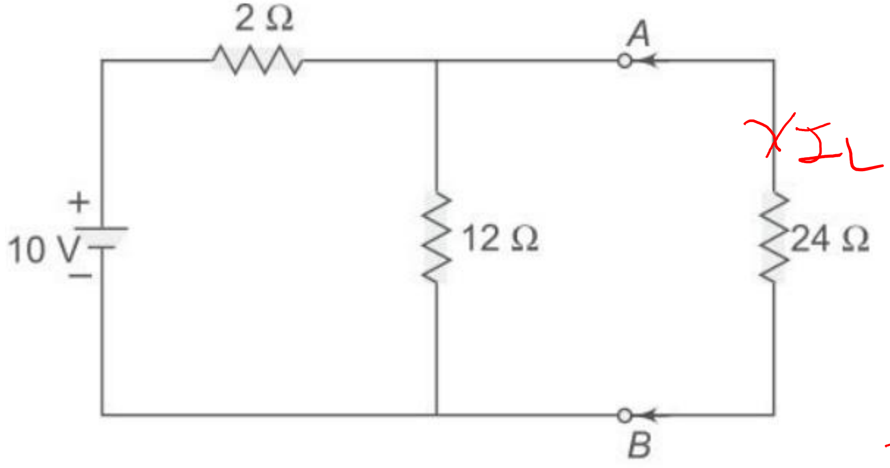
Equivalent Thevenin's circuit

- As per Thevenin's Statement, the load current is determined by the circuit shown above and the equivalent Thevenin's circuit is obtained.
  The load current $\mathbf{I_L}$ is given as:

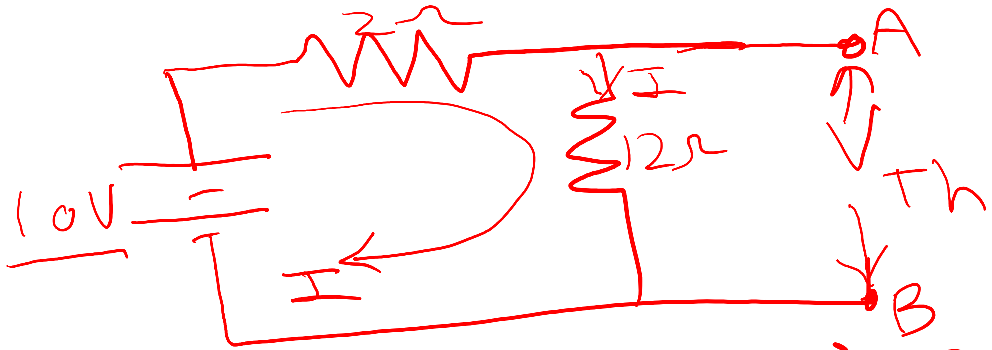
$$I_L = \frac{V_{TH}}{R_{TH} + r_L}$$



Where,
$\mathbf{V_{TH}}$ is the Thevenin's equivalent voltage. It is an open circuit voltage across the terminal AB known as **load terminal**
$\mathbf{R_{TH}}$ is the Thevenin's equivalent resistance, as seen from the load terminals where all the sources are replaced by their internal impedance
$\mathbf{r_L}$ is the **load resistance**



① To find V_{Th}, remove 24Ω resistor



$$I = \frac{10}{2+12} = \underline{0.7142A}$$

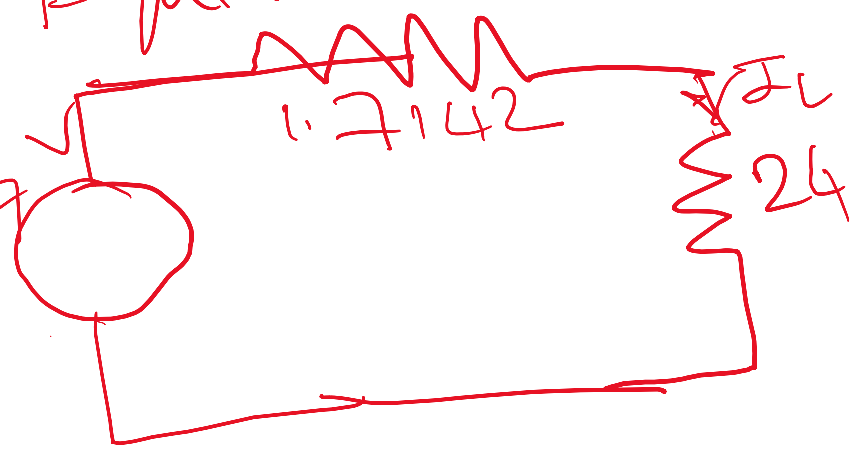
V_{Th} = voltage across 12ohms resistor

$= I(12) = 0.7142 \times 12 = \boxed{8.5704V}$

② To find R_{Th}, remove 24Ω & replace 10V with SC

$$R_{Th} = \frac{12 \times 2}{12+2} = \boxed{1.7142\Omega}$$

③ Equivalent Thevenin's circuit



$$I_L = \frac{8.57}{1.7142+24} = \boxed{0.333A}$$

Maximum power transfer theorem

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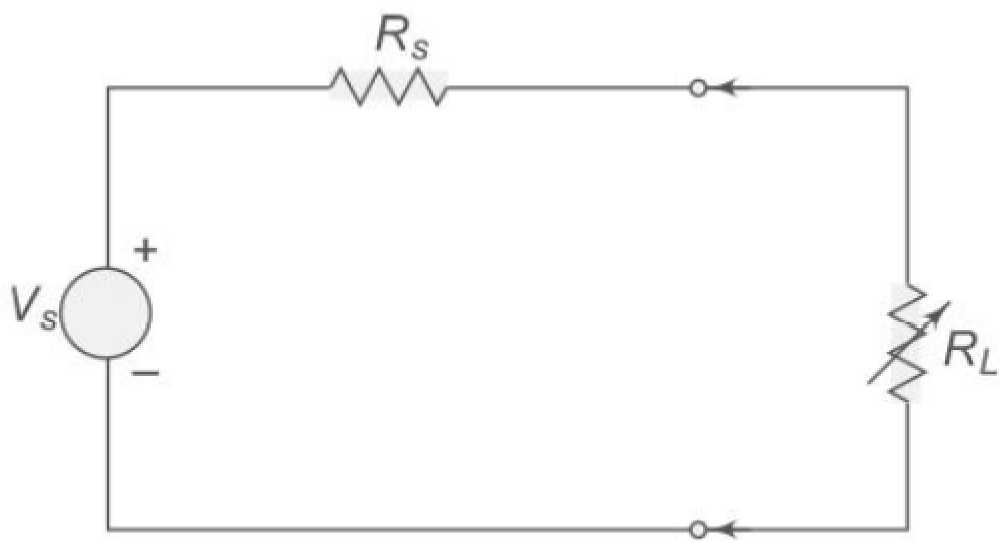
According to Maximum power transfer theorem, power transferred to the load is maximum when the load resistance is equal to source resistance.



Maximum power transfer theorem

Load current, $I_L = \frac{V_S}{R_S+R_L}$

Power absorbed by load, $P_L = {I_L}^2 R_L = \left(\frac{V_S}{R_S+R_L}\right)^2 R_L$

Differentiating P_L with respect to R_L,

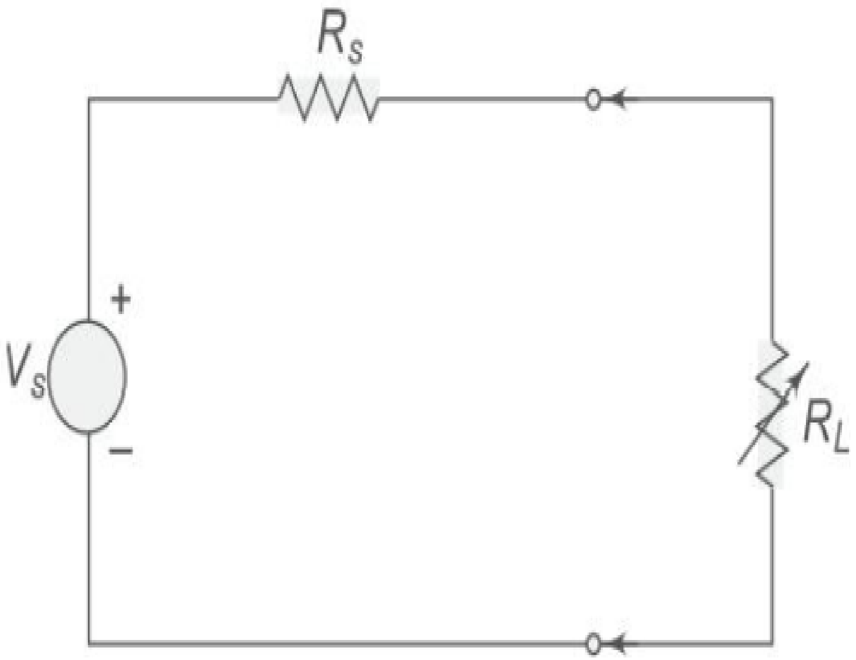
$$\frac{dP}{dR_L} = \frac{d}{dR_L}\left[\frac{V_S^2}{(R_S+R_L)^2} R_L\right]$$

$$= \frac{V_S^2\left\{(R_S+R_L)^2 - (2R_L)(R_S+R_L)\right\}}{(R_S+R_L)^4}$$

$$\therefore \quad (R_S + R_L)^2 - 2R_L(R_S + R_L) = 0$$

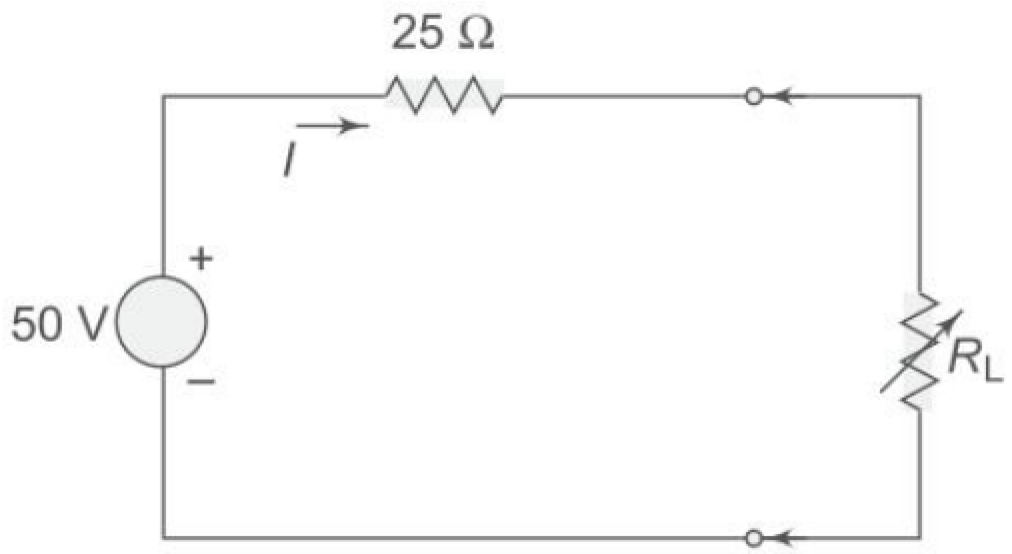
$$R^2{}_S + R^2{}_L + 2R_S R_L - 2R^2{}_L - 2R_S R_L = 0$$

$$\therefore \quad R_S = R_L$$



The amount of maximum power transferred to load is: $P_{Lmax} = \frac{{V_S}^2}{4R_S}$

In the circuit shown determine the value of load resistance when the load resistance draws maximum power. Also find the value of the maximum power



The source delivers the maximum power when load resistance is equal to the source resistance.

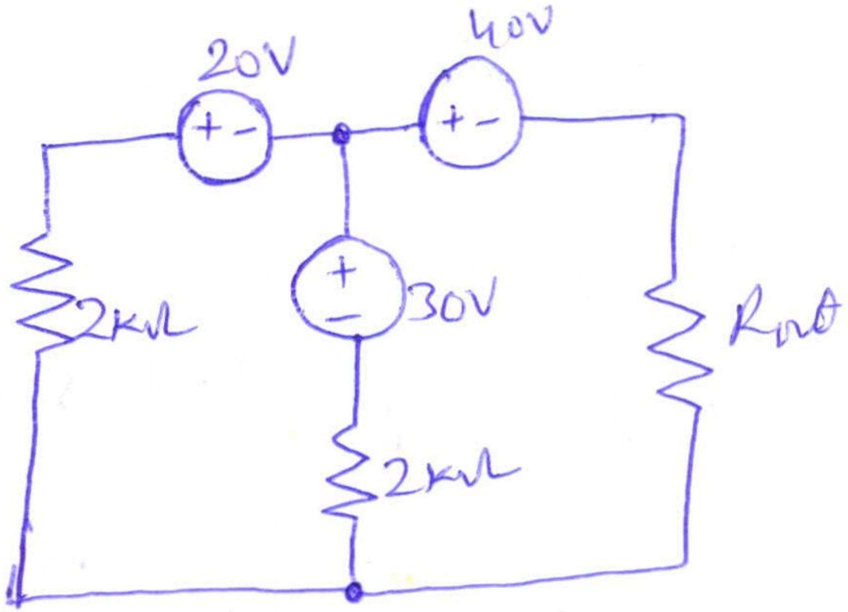
RL = 25 ohms

I = 50/(25 + RL) = 50/50 = 1 A

The maximum power delivered to the load P = I^2R_L = 25 W

Maximum power transfer theorem

Find the maximum power transferred to the load in following circuit.



Maximum power transfer theorem

Assume current ‘i’ ,$20 + 30 + 2000i + 2000i = 0$

$$i = -\frac{50}{4000} = -12.5mA$$

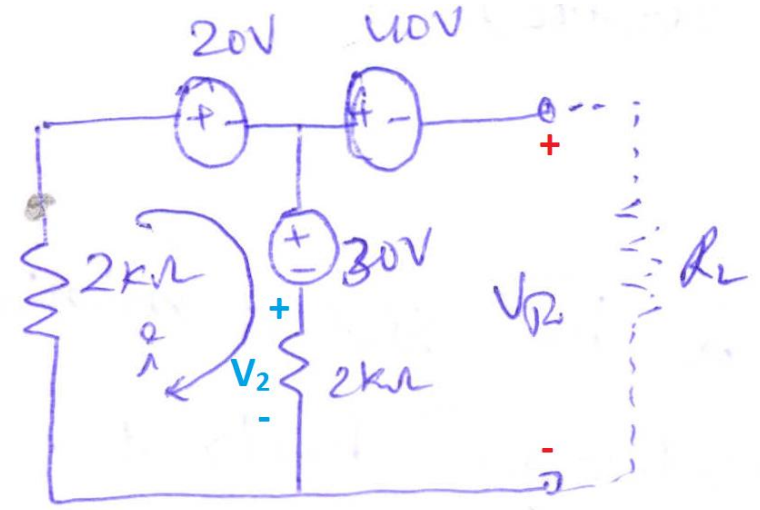
$$V_2 = -12.5m\ x\ 2000 = -25V$$

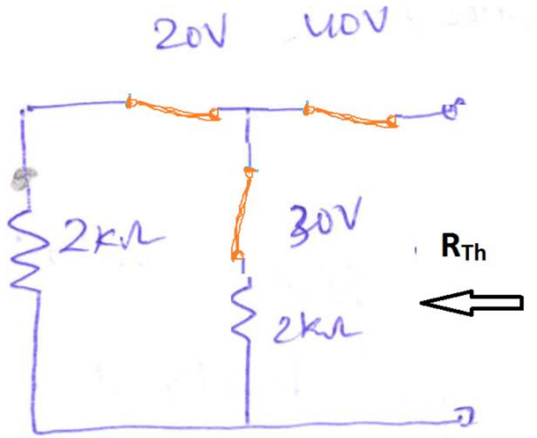
Applying KVL in outer loop:

$$40 + V_{Th} - V_2 - 30 = 0$$

$$V_{Th} = 15V.$$

Thevenin’s resistance: $R_{Th} = 1K\Omega$





Maximum power transfer theorem

Maximum power transferred to load:

$$P_{Lmax} = \frac{{V_{Th}}^2}{4R_{Th}} = \frac{15^2}{4x1000} = 56.25mW$$

$$R_L = R_s = R_{Th} = 1K\Omega$$