Jimma University
College of Natural Sciences
Department of Physics

***Lecture Notes** : Electronics I (Phys 2062)*

Chapter One: Network theories and equivalent circuits

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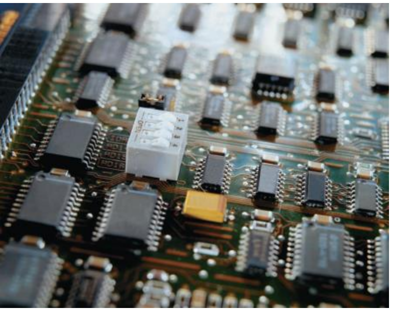


April 2020

Learning outcomes of the course

- **Upon completion of this course students should be able to:**
  - *Apply Kirchhoff's laws to solve circuit problems*
  - *Apply Thévenin's theorem to reduce any two-terminal, series-parallel network with any number of sources*
  - *Become familiar with Norton's theorem and how it can be used to reduce any two-terminal, series parallel network*
  - Explain charge carrier generation in intrinsic and extrinsic semi-conductors;
  - Explain formation and application of a P-N junction;
  - Design and analyze diode circuits (e.g. power supply circuits);
  - Explain how a Bipolar Junction Transistor(BJT) works;
  - Design and analyze basic BJT circuits in various configurations Explain how a Junction Field Effect Transistor(JFET) works(some theory);
  - Explain the construction of the operational amplifier;
  - Manipulate numbers in various bases (2,8,10,16);
  - Apply Boolean algebra in design of logic circuits;

Chapter One: Network theories and equivalent circuits

❑ *Chapter Objective*

➢ ***After studying this chapter you should be able to:***

- ✓ *State* Kirchhoff's current law.
- ✓ *State Kirchhoff's voltage law.*
- ✓ *Use* the method of branch currents to solve for all voltages and currents in a circuit containing two or more voltage sources in different branches.
- ✓ *Use* node-voltage analysis to solve for the unknown voltages and currents in a circuit containing two or more voltage sources in different branches.
- ✓ *Use* the method of mesh currents to solve for the unknown voltages and currents in a circuit containing two or more voltage sources in different branches.

Outline of the Chapter

- **Introduction**
- **Kirchhoff's rules**
- **Mesh analysis**
- **Norton's theorem**
- **Thevenin's Equivalent circuits**
- **Conversion of Thevenin's to Norton's equivalent circuits**
- **Delta and Y Network**

Introduction: Basic Electrical Principles

- **Conductors** - keep loose grip on their electrons and allow electrons to move freely. Metals are usually good conductors.
- **Insulators** - keep close hold of their electrons and do not allow free movement of electrons. Glass, wood, plastic, mica, fiberglass and air are good insulators.
- **Electromotive Force (EMF)-** is the force that moves electrons through conductors. Its unit of measure is the Volt.
- **Voltage Source** - has two terminals (+ and -). Some examples are car batteries (12 volts DC)
- **Current** - is the flow of electrons. It is measured in amperes.
- **Resistance (ohms, Ω)**- is the ability to oppose an electrical current.

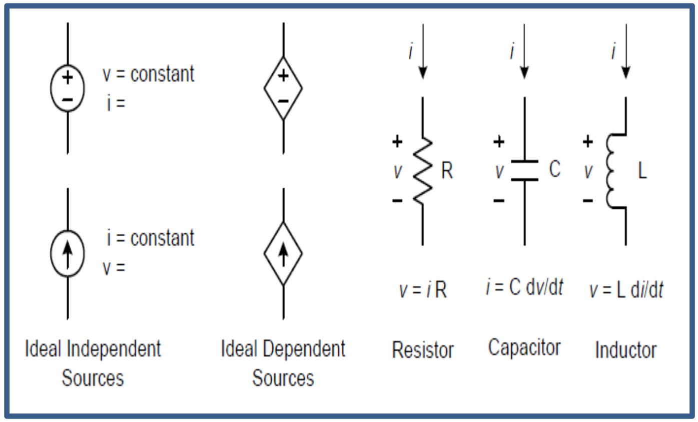


Fig. some basic circuit elements

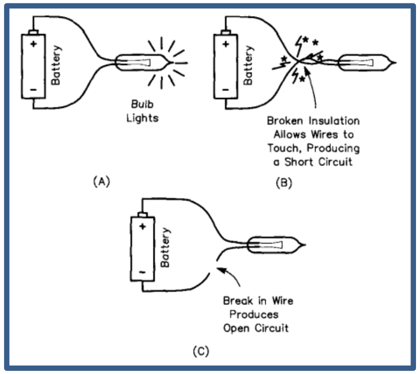


Fig. different circuit e

Introduction: Circuits and Networks

- By convention everything in a circuit is assumed to happen in the elements of a circuit, the lines just show the interconnections. The figure represents a general circuit composed of elements *e1 … e5*.
- The elements could be any two terminal devices (voltage source, current source, resistor, capacitor, inductor, etc).
- The terminals of the various elements are connected together forming the nodes *n1 … n4* as indicated in the figure
- The connection between two elements is called a branch and the loops *l1, l2* and *l3* are closed connections of branches.

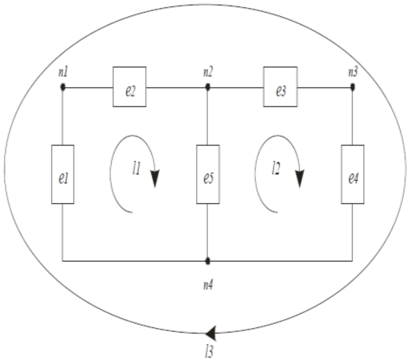


Fig. circuit e

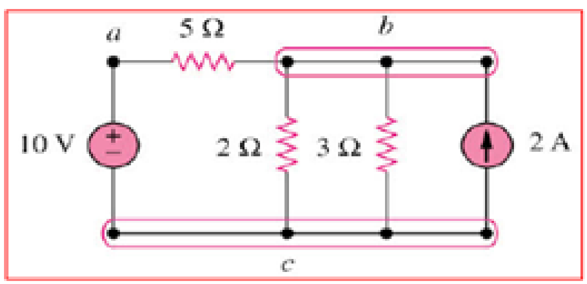
- A network is a combination of components, such as resistances and voltage sources, interconnected to achieve a particular end result

Introduction: Branches, Nodes, Loops

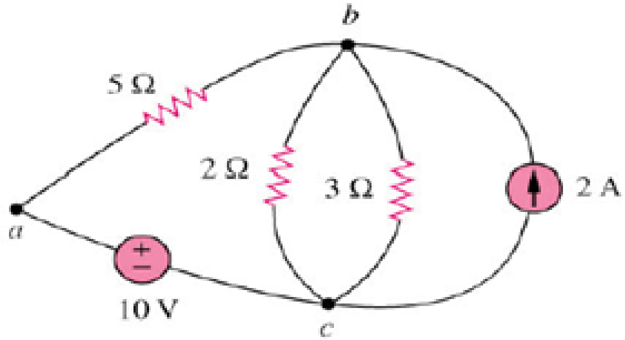
- A **branch** represents a single element such as a voltage source or a resistor
- A **node** is the point of connection between two or more branches
- A **loop** is any closed path in a circuit
- A network with ***b*** branches, ***n*** nodes and ***l*** independent loops will satisfy the fundamental theorem of network topology:

$$b = l + n - 1$$

Example 1



Original circuit



Network schematics or graph

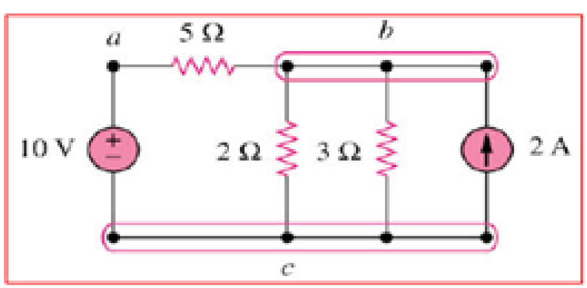
How many branches, nodes and loops are there?

Introduction: Branches, Nodes, Loops

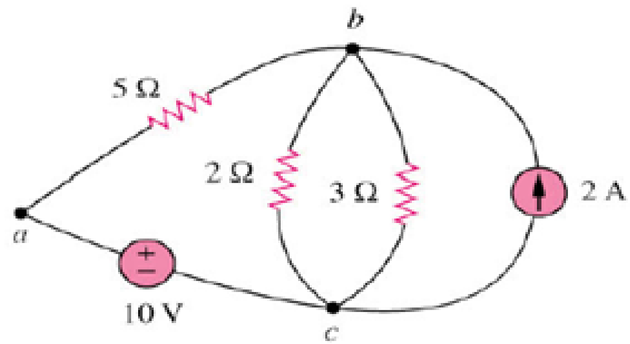
- Things we need to know in solving any resistive circuit with current and voltage source are:

	no. of equations required
✓ Ohm's law	b
✓ Kirchhoff's Current Laws (KCL)	$n-1$
✓ Kirchhoff's Voltage Laws (KVL)	$b-(n-1)$

Example 1



Original circuit

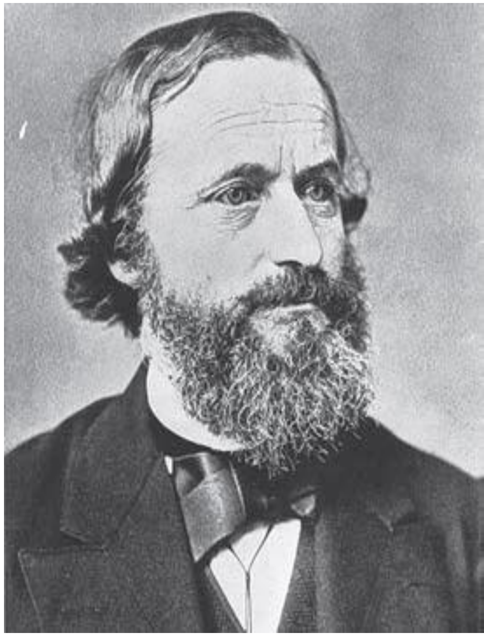


Network schematics or graph

How many branches, nodes and loops are there?

Kirchhoff's Rules (Laws)

- Networks generally need more than the rules of series and parallel circuits for analysis
- Kirchhoff's laws can always be applied for any circuit connections.
- The network theorems, though, usually provide shorter methods for solving a circuit
- Kirchhoff's laws known as Kirchhoff's Current Law (KCL) and Kirchhoff's Voltage Law (KVL)
- They are based respectively on the conservation of charge (KCL) and the conservation of energy (KVL)
- They are derived from Maxwell's equations.
- They along with Ohm's law present the fundamental tools for circuit analysis.



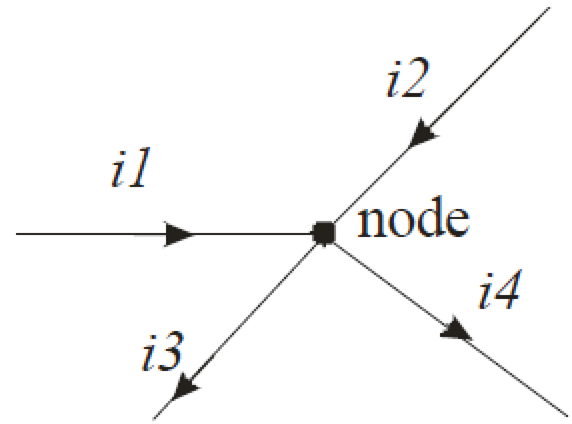
Kirchhoff's Current Law (KCL)

➢ States

✓ The algebraic sum of the currents entering and leaving any point in a circuit must equal zero.

Or

✓ stated another way, *the algebraic sum of the currents into any point of the circuit must equal the algebraic sum of the currents out of that point*



Mathematically, $$\sum_{n=1}^{N} i_n = 0$$

❖ Otherwise, charge would accumulate at the point, instead of having a conducting path.

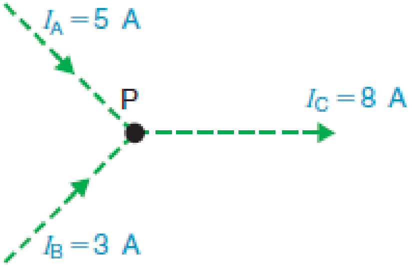
❖ An *algebraic sum* means combining positive and negative values

Kirchhoff’s Current Law (KCL)

Algebraic Signs

- ✓ In using Kirchhoff’s laws to solve circuits, it is necessary to adopt conventions that determine the algebraic signs for current and voltage terms.
- ✓ A convenient system for currents is to *consider all currents into a branch point as positive and all currents directed away from that point as negative.*

Example: *Current* I_c goes out from point p

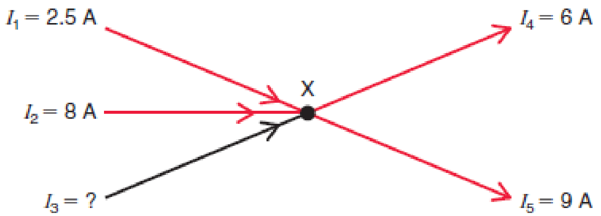


$$I_A + I_B - I_c = 0$$

$$I_c = 3A + 5A = 8A$$

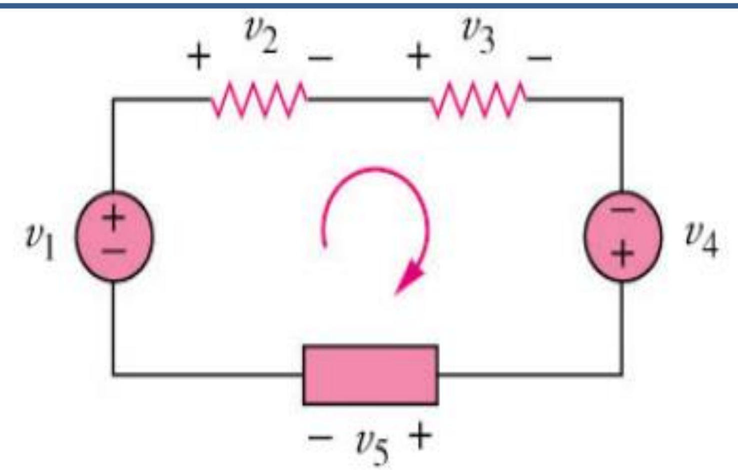
- Currents I_A and I_B are positive terms because these currents flow in to P, but I_C , directed out, is negative.

Exercise: Solve for the unknown current I_3



Kirchhoff's Voltage Law (KVL)

- **States :** The algebraic sum of the voltages around any closed path is zero.
  - ✓ If you start from any point at one potential and come back to the same point and the same potential, the difference of potential must be zero
  - ✓ where M is the number of voltages in the loop.
  - ✓ The number of voltages is equal to the number of elements encountered as we go around the loop.



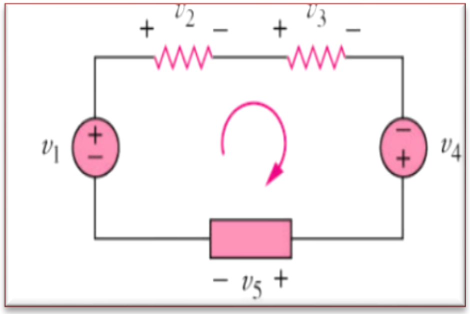
Mathematically, $\sum_{m=1}^{M} v_n = 0$

❖ Any closed path is called a *loop* . A loop equation specifies the voltages around the loop.

Kirchhoff's Voltage Law (KVL)

❖ Algebraic Signs

- ✓ In determining the algebraic signs for voltage terms in a KVL equation, first **mark the polarity** of each voltage as shown in Figure.
- ✓ A convenient system is to *go around **any closed** path and consider any voltage whose negative terminal is reached first as a negative term and any voltage whose positive terminal is reached first as a positive term.*
- ✓ This method applies to *IR voltage drops* (voltage drop on a resistor) and voltage sources
- ✓ The direction can be clockwise or counterclockwise.
- ✓ Remember that electrons flowing into a resistor make that end negative with respect to the other end.
- ✓ For a voltage source, the direction of electrons returning to the positive terminal is the normal direction for electron flow, which means that the source should be a positive term in the voltage equation.
- ✓ When you go around the closed path and come back to the starting point, the algebraic sum of all the voltage terms must be zero.
- ✓ There cannot be any potential difference for one point.



Voltage and current divider rule

Series Circuit and Voltage Division (1)

- Series: Two or more elements are in series if they are cascaded or connected sequentially and consequently carry the same current.
- The equivalent resistance of any number of resistors connected in a series is the sum of the individual resistances.

$$R_{eq} = R_1 + R_2 + \cdots + R_N = \sum_{n=1}^{N} R_n$$

- The voltage divider can be expressed as

$$v_n = \frac{R_n}{R_1 + R_2 + \cdots + R_N} v$$

Voltage and current divider rule

Parallel Circuit and Current Division (1)

- Parallel: Two or more elements are in parallel if they are connected to the same two nodes and consequently have the same voltage across them.

- The equivalent resistance of a circuit with N resistors in parallel is:

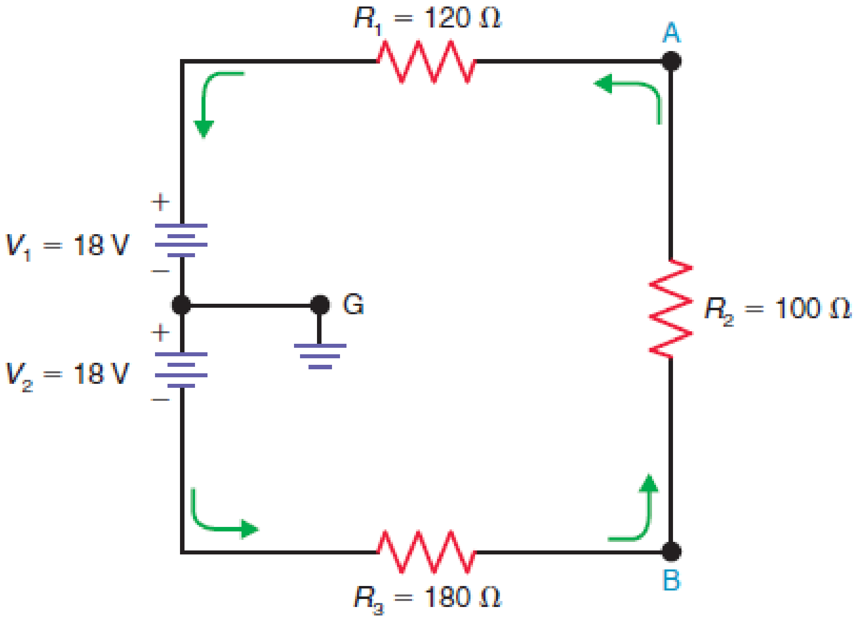
$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots + \frac{1}{R_N}$$

- The total current i is shared by the resistors in inverse proportion to their resistances. The current divider can be expressed as:

$$i_n = \frac{v}{R_n} = \frac{i \cdot R_{eq}}{R_n}$$

Kirchhoff's Rules (Laws)

Example: In Figure a , apply Kirchhoff's voltage law to solve for the voltages V_{AG} $and V_{BG}$.



(a)

Solution

$$V_T = V_1 + V_2 = 18\text{ V} + 18\text{ V} = 36\text{ V}$$

$$R_T = R_1 + R_2 + R_3 = 120\ \Omega + 100\ \Omega + 180\ \Omega = 400\ \Omega$$

$$I = \frac{V_T}{R_T} = \frac{36\text{ V}}{400\ \Omega} = 90\text{ mA}$$

$$V_{R_1} = I \times R_1 = 90\text{ mA} \times 120\ \Omega = 10.8\text{ V}$$

$$V_{R_2} = I \times R_2 = 90\text{ mA} \times 100\ \Omega = 9\text{ V}$$

$$V_{R_3} = I \times R_3 = 90\text{ mA} \times 180\ \Omega = 16.2\text{ V}$$

- **See the text book for the detil**

Kirchhoff's Rules (Laws)

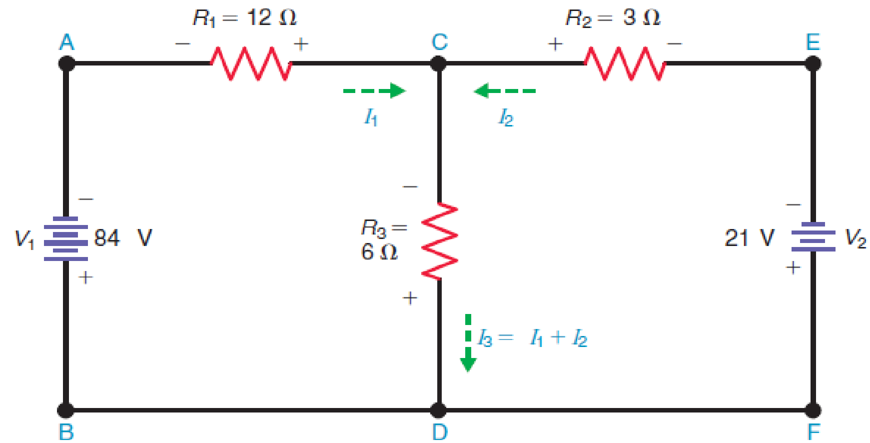
Example: Solve for the unknown currents $I_1, I_2 \; and I_3$.

Solution: For the loop with V_1 , $start\ at\ point\ B, at\ the\ bottom\ left\ and\ go\ clockwise\ through\ V_1$, $V_{R1}\ and\ V_{R2}$. The equation for

$$84 - V_{R_1} - V_{R_3} = 0$$

For the loop with V_2 , $start\ at\ point\ F, at\ thelower\ rightnd\ go\ counter\ clockwise\ through\ V_2$, $V_{R2}\ and\ V_{R3}$. The equation for loop 1 is (Why)

$$21 - V_{R_2} - V_{R_3} = 0$$



With Ohms law (Show how)

$$V_{R_1} = I_1 R_1 = I_1 \times 12 = 12 I_1$$
$$V_{R_2} = I_2 R_2 = I_2 \times 3 = 3 I_2$$
$$V_{R_3} = (I_1 + I_2) R_3 = 6(I_1 + I_2)$$

Substituting

$$84 - 12 I_1 - 6(I_1 + I_2) = 0$$

Also in loop 2

$$21 - 3 I_2 - 6(I_1 + I_2) = 0$$

The two equations become (Show how)

$$-18 I_1 - 6 I_2 = -84$$
$$-6 I_1 - 9 I_2 = -21$$

$$3 I_1 + I_2 = 14$$
$$2 I_1 + 3 I_2 = 7$$

$$9 I_1 + 3 I_2 = 42$$
$$2 I_1 + 3 I_2 = 7$$

S $2(5) + 3 I_2 = 7 \qquad I_1 = 5\ \mathrm{A} \qquad I_2 = -1\ \mathrm{A}$

❑ **See the text book for the detail**

Mesh and Node Analysis

- We have seen that using Kirchhoff's laws and Ohm's law we can analyze any circuit to determine the operating conditions (the currents and voltages).

- The challenge of formal circuit analysis is to derive the smallest set of simultaneous equations that completely define the operating characteristics of a circuit.

- In this section we will develop two very powerful methods for analyzing any circuit: The **node method** and the **mesh method**.

- These methods are based on the systematic application of Kirchhoff's laws.

Mesh Analysis

- A mesh is defined as a loop which does not contain any other loops

- Mesh analysis provides a general procedure for analyzing circuits using mesh currents as the circuit variables

- The procedure for obtaining the solution

  Step 1. Clearly label all circuit parameters and distinguish the unknown parameters from the known.

  Step 2. Identify all meshes of the circuit.

  Step 3. Assign mesh currents and label polarities.

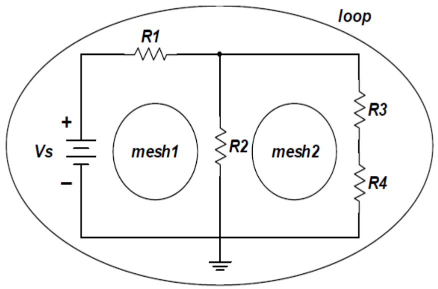
  Step 4. Apply KVL at each mesh and express the voltages in terms of the mesh currents.

  Step 5. Solve the resulting simultaneous equations for the mesh currents.

  Step 6. Now that the mesh currents are known, the voltages may be obtained from Ohm's law.

Node Analysis

- The node method or the node voltage method, is a very powerful approach for circuit analysis and it is based on the application of KCL, KVL and Ohm's law
- t provides a general procedure for analyzing circuit using node voltages as the circuit variables
- Steps:



1. Clearly label all circuit parameters and distinguish the unknown parameters from the known.
1. Identify all nodes of the circuit.
2. Select a node as the reference node also called the ground and assign to it a potential of 0 Volts. All other voltages in the circuit are measured with respect to the reference node.
3. Label the voltages at all other nodes.
4. Assign and label polarities.
5. Apply KCL at each node and express the branch currents in terms of the node voltages.
6. Solve the resulting simultaneous equations for the node voltages.
7. Now that the node voltages are known, the branch currents may be obtained from Ohm's law.

Mesh Analysis application

Example: Solve for the unknown currents I_A *and* I_B.

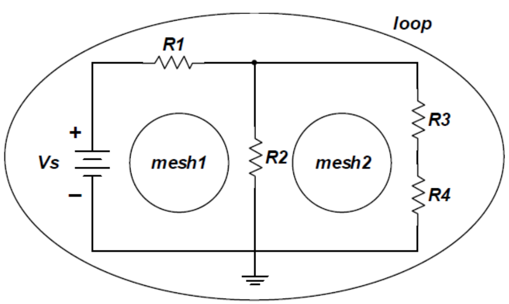
- The equation for the two meshes become (Why)

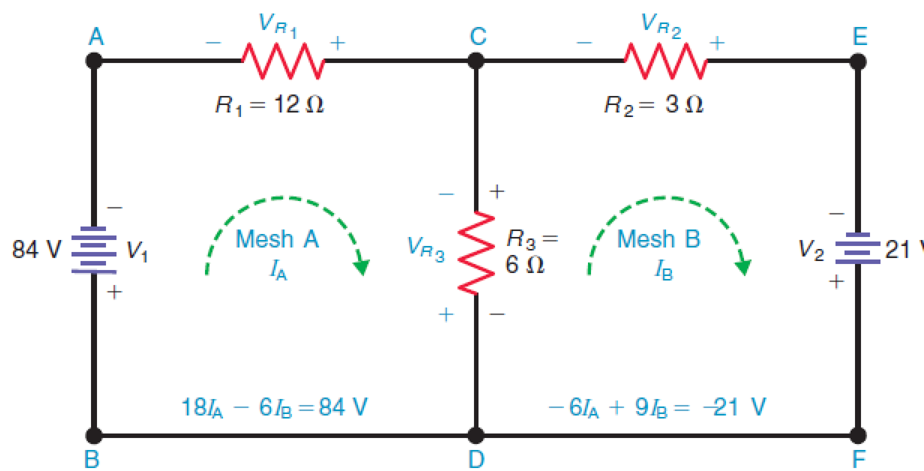
$$18I_A - 6I_B = 84$$
$$-6I_A + 9I_B = -21$$

- Solving the simultaneous equation

$$I_A = 5\text{ A}$$

And





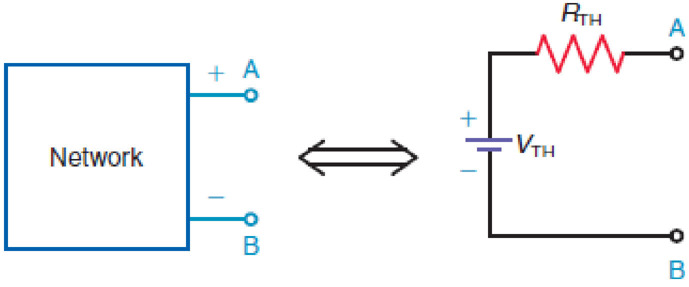
❑ **See the text book for the detail**

THÉVENIN'S THEOREM

- The next theorem to be introduced, **Thévenin's theorem,** is probably one of the most interesting in that it permits the reduction of complex networks to a simpler form for analysis and design.
- In general, the theorem can be used to do the following:
  - ✓ ***Analyze networks with sources that are not in series or parallel.***
  - ✓ **Reduce the number of components required to establish the same characteristics at the output terminals.**
  - ✓ ***I*nvestigate the effect of changing a particular component on the behavior of a network without having to analyze the entire network after each change**

- **Thévenin's theorem states the following:**
  - ✓ ***Any two-terminal dc network can be replaced by an equivalent circuit consisting solely of a voltage source V_{Th} and a series resistor R_{Th} as shown***

- This circuit is known as the **Thevenin Equivalent Circuit**



- With these two measurements we are able to replace the complex network by a simple equivalent circuit.

THÉVENINIZING A CIRCUIT

➢ Thévenin's Theorem Procedure

❖ *Preliminary:*

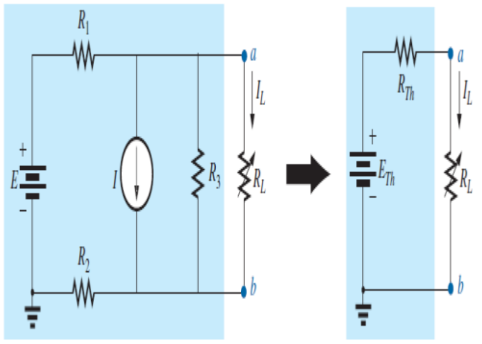
- ✓ Remove that portion of the network where the Thévenin equivalent circuit is found. In Fig.(a), this requires that the load resistor R_L be temporarily removed from the network.
- ✓ Mark the terminals of the remaining two-terminal network.

$\mathbf{R_{Th}}$:

- ✓ Calculate R_{Th} by first setting all sources to zero (voltage sources are replaced by short circuits and current sources by open circuits) and then finding the resultant resistance between the two marked terminals

V_{Th} :

- ✓ Calculate V_{Th} by first returning all sources to their origina position and finding the open-circuit voltage between the marked terminals



(a) (b)

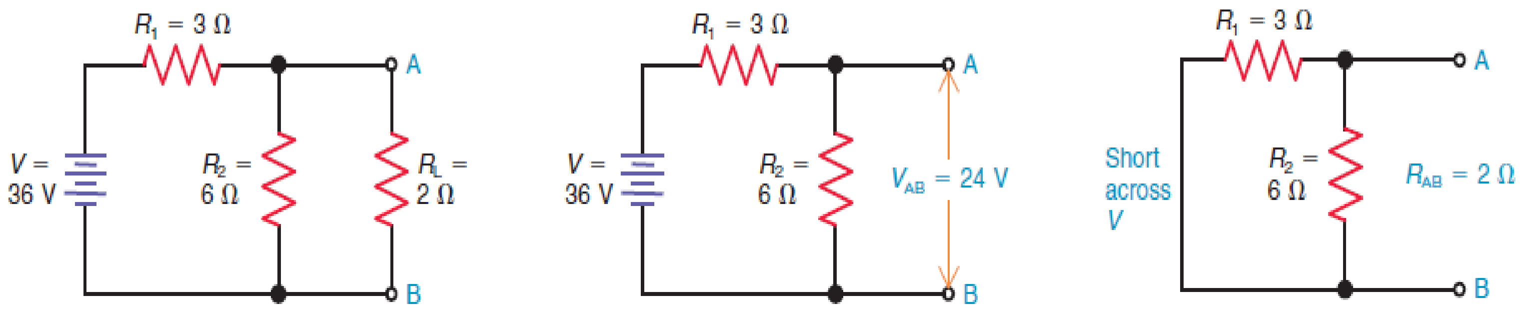
❖ *Conclusion:*

- ✓ Draw the Thévenin equivalent circuit with the portion of the Circuit previously removed replaced between the terminals of the equivalent circuit. This step is indicated by the placement of the resistor R_L between the terminals of the Thévenin equivalent Circuit as shown in Fig. b.

THÉVENINI's Theorem Application

Example : In the figure below find the voltage *V* L across the 2Ω - R_L and its current I_L *by appluing Theenin's therem*

Solution: To use Thevenin's theorem, mentally disconnect R_L .



(a) (b) (c)

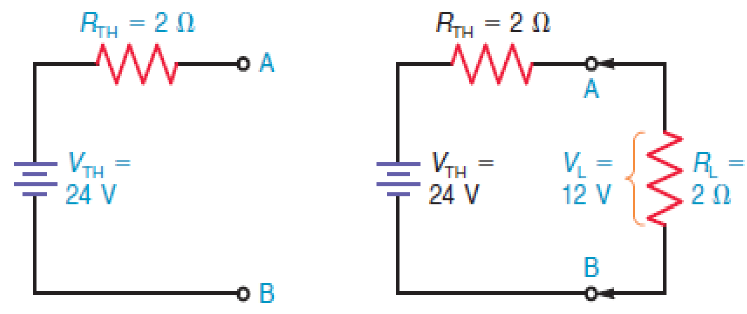
- ✓ Using the voltage divider formula (How ?)

$$V_{R_2} = \frac{6}{9} \times 36 \text{ V} = 24 \text{ V}$$

$$V_{R_2} = V_{\text{AB}} = V_{\text{TH}} = 24 \text{ V}$$

- ✓ The Thevenini's resistance becomes (How ?)

$$R_{\text{TH}} = \frac{18}{9} = 2 \ \Omega$$



(d) (e)

❑ **See the text book for the detail**

Example2: Find the Thévenin equivalent circuit for:

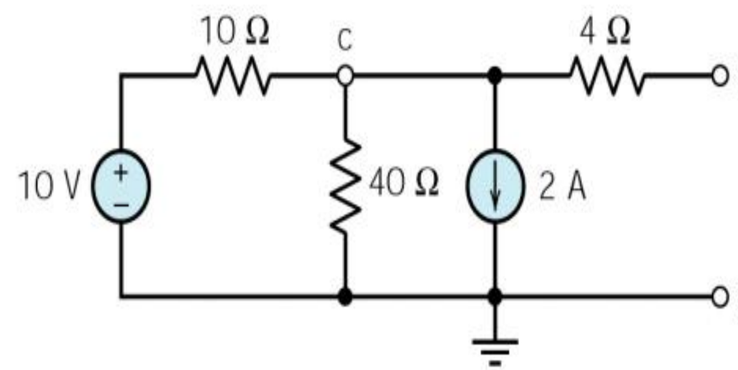
Keep in mind:

- **The Thévenin equivalent circuit involves three parameters:**

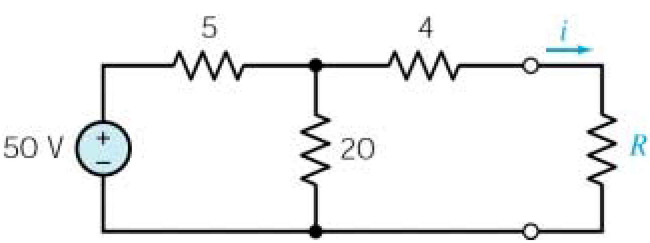
(a) the open-circuit voltage, V_{oc},

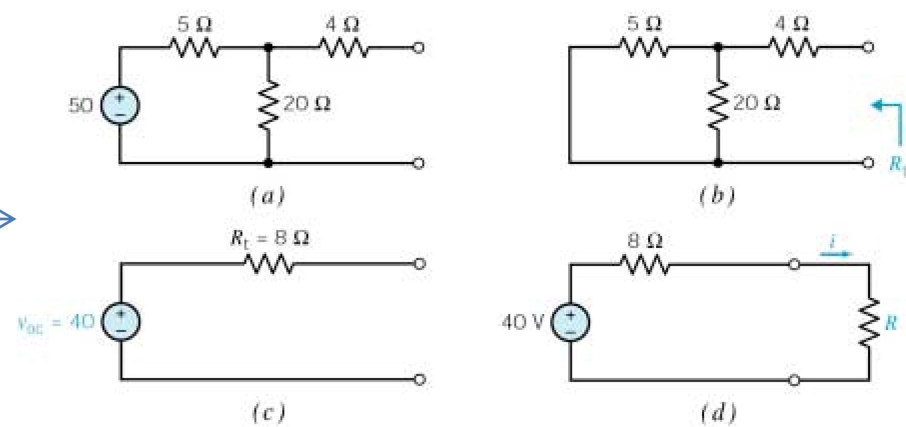
(b) the short-circuit current I_{sc}, and

(c) the Thévenin resistance, R_{Th}.



Exercise: Find current *i* using Thévenin's Theorem in the circuit below



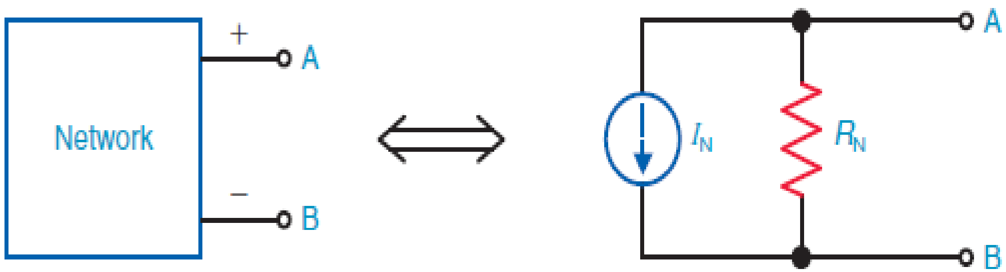


NORTON'S THEOREM

- A linear one port network can be replaced by an equivalent circuit consisting of a current source I_N in parallel with a resistor R_N.
- The current I_N is equal to the short circuit current through the terminals of the port and the resistance R_N is equal to the open circuit voltage V_{OC} divided by the short circuit current I_N.

The theorem states the following:

- ✓ ***Any two-terminal linear bilateral dc network can be replaced by an equivalent circuit consisting of a current source and a parallel resistor, as shown***



Norton's Theorem Procedure

❖ ***Preliminary:***

- ✓ Remove that portion of the network across which the network across which the Norton's equivalent circuit is found
- ✓ Mark the terminals of the remaining two-terminal network.

$\mathbf{R_N}$:

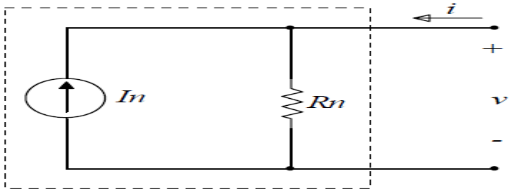
- ✓ Calculate R_N by first setting all sources to zero (voltage sources are replaced by short circuits and current sources with open circuits) and then finding the resultant resistance between the two marked terminals. Since $R_N = R_{Th}$, the procedure and value obtained using the approach described for Thevenin's theorem will determine the proper value R_N.

$\boldsymbol{I_N}$:

- ✓ Calculate $\boldsymbol{I_N}$ by first returning all sources to their original position and then finding the short-circuit current between between the marked terminals. It is the same current that would be measured by an ammeter placed between marked terminals.

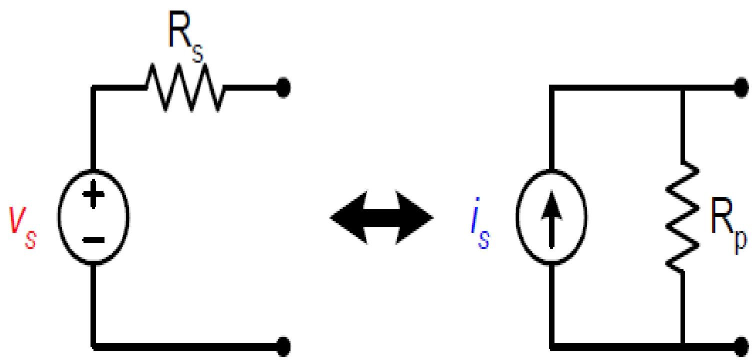
❖ ***Conclusion:***

- ✓ Draw the Norton's equivalent circuit with the portion of the Circuit previously removed replaced between the terminals of the equivalent circuit. This step is indicated by the placement of the resistor R_L between the terminals of the equivalent Circuit as shown.



Thevenin Nortorn conversion

- Thevenin's theorem says that any network can be represented by a voltage source   and series resistance, and Norton's theorem says that the same network can be represented by a current source and shunt resistance.
- It must be possible, therefore, to convert directly from a Thevenin form to a Norton form and vice versa. Such conversions are often useful.
- **Norton equivalent is simply the source transformation of the Thévenin equivalent**



Thevenin ←→ Norton

- **Conversion Formulas**

Thevenin from Norton:

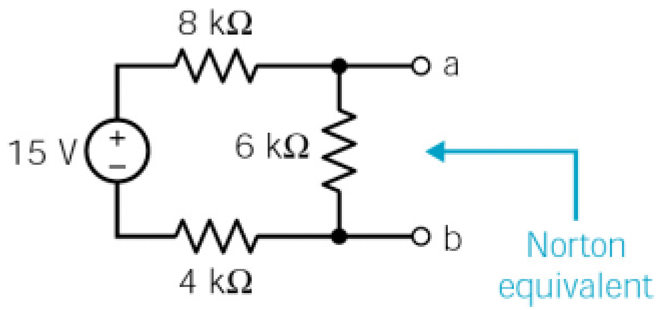
$$R_{TH} = R_N$$
$$V_{TH} = I_N \times R_N$$

Norton from Thevenin:

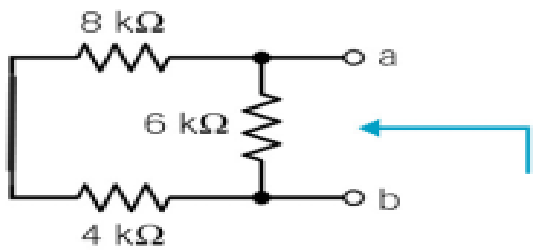
$$R_N = R_{TH}$$
$$I_N = V_{TH}/R_{TH}$$

Norton’s Theorem Application

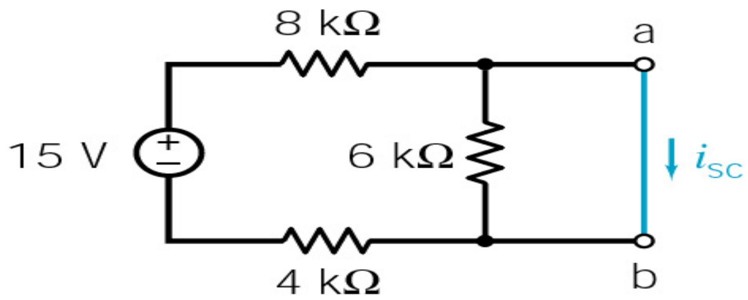
- Example1: Find the Norton Equivalent Circuit for



✓ Find *Rn* by replacing the voltage source with a short circuit



✓ Find the short circuit current *i*sc,



❑ **See the text book for the detail**

T or Y and π or Δ Connections

- The circuit in Fig (a) called a T (tee) or Y (wye) network, as suggested by the shape. They are different names for the same network; the only difference is that the *R* 2 and *R* 3 legs are shown at an angle in the Y.
- The circuit in Fig. (b) is called a (pi) or (delta) network because the shape is similar to these Greek letters Δ

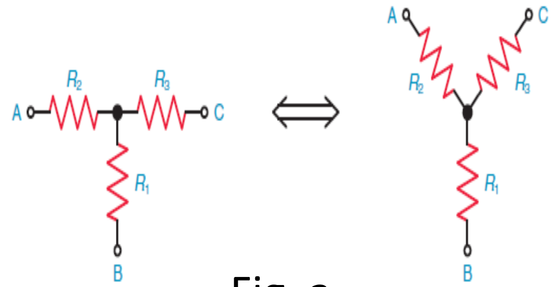


Fig. a

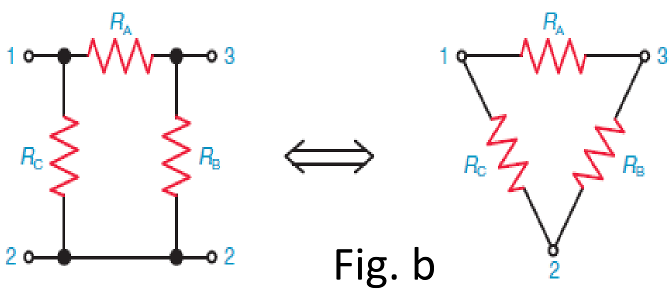


Fig. b

Conversion of Y to Δ

$$R_A = \frac{R_1R_2 + R_2R_3 + R_3R_1}{R_1}$$

$$R_B = \frac{R_1R_2 + R_2R_3 + R_3R_1}{R_2}$$

$$R_C = \frac{R_1R_2 + R_2R_3 + R_3R_1}{R_3}$$

or

$$R_\Delta = \frac{\Sigma \text{ all cross products in Y}}{\text{opposite } R \text{ in Y}}$$

Conversion of Δ to Y

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

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

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

or

$$R_Y = \frac{\text{product of two adjacent } R \text{ in } \Delta}{\Sigma \text{ all } R \text{ in } \Delta}$$

Thank you