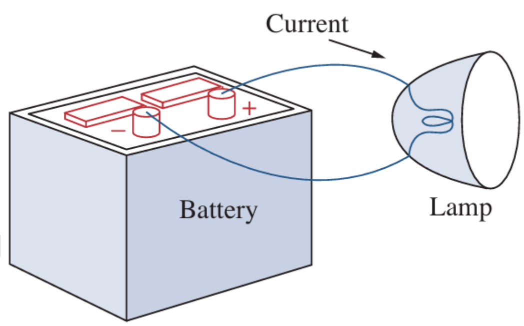
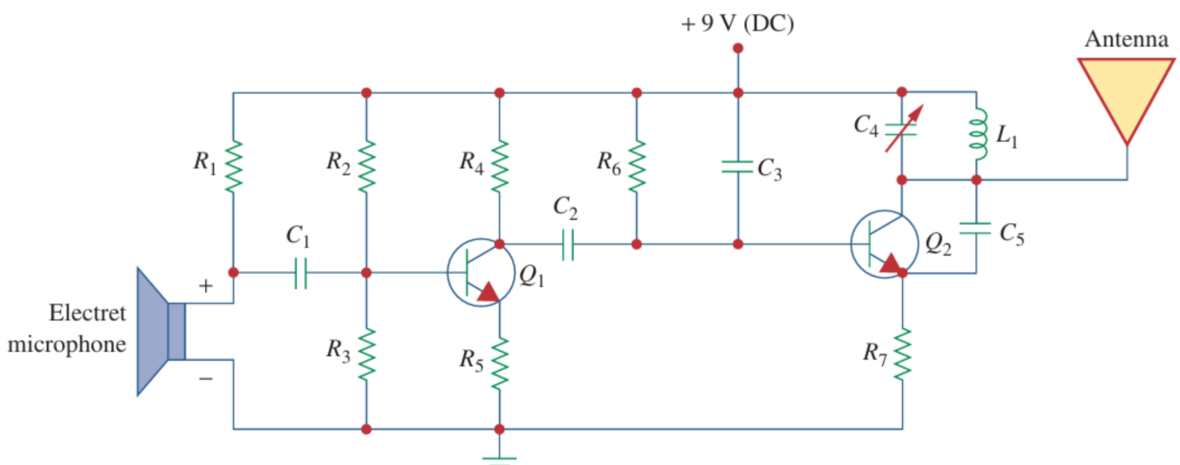
DC Circuit

Why we study circuits?

Electric circuit theory and electromagnetic theory are the two fundamental theories upon which all branches of electrical engineering are built. Many branches of electrical engineering, such as power, electric machines, control, electronics, communications, and instrumentation, are based on electric circuit theory. Therefore, the basic electric circuit theory course is the most important course for an electrical engineering student, and always an excellent starting point for a beginning student in electrical engineering education. Circuit theory is also valuable to students specializing in other branches of the physical sciences because circuits are a good model for the study of energy systems in general, and because of the applied mathematics, physics, and topology involved. In electrical engineering, we are often interested in communicating or transferring energy from one point to another. To do this requires an interconnection of electrical devices. Such interconnection is referred to as an electric circuit, and each component of the circuit is known as an element



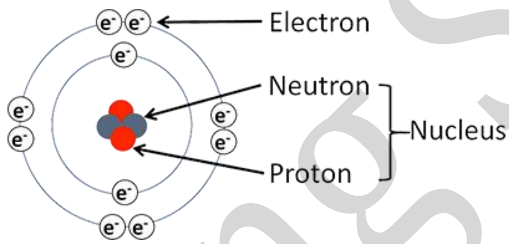


DC Circuit

Fundamentals: -

Atomic Structure Terms

- Electrons: Minute mass compared to protons and neutrons
  Under normal conditions, an atom has equal numbers of electrons and neutrons
- Free electrons: An electron with sufficient energy to break away from its parent atom
- Valence electron: An electron in the outermost orbit of an atom
- Ion: An atom that has lost or gained an electron is a positive ion
  an atom that has gained an electron is negative ion



Classes of Materials

- Material can be classified by their ability to pass electrical current
- Materials are classified as
  1. Conductors
  2. Insulators
  3. Semiconductors
  4. Super conductors

1.Conductors

- Materials with loosely bound valence electrons where little energy is required to free them
- In particular, silver, copper, gold, and aluminum are excellent conductors
- Of these, copper is the most widely used. Not only is it an excellent conductor, it is in expensive and easily formed into wire
- Aluminum, although it is only about 60% as good a conductor as copper, is also used, mainly in applications where light weight is important

2.Insulators

- Materials that have few free valence electrons and don't conduct electricity well (ex: air, glass, porcelain, plastic, rubber and so on)
- Insulators don't conduct because they have full or nearly full valence orbits and thus their electrons are tightly bound
- However, when high enough voltage is applied, the force is so great that electrons are literally torn from their parent atoms, causing the insulation to break down and conduction to occur

3.Semiconductors

- Materials that are neither good insulators nor food conductors' typical semiconductors have four valence electrons and are represented by germanium and silicon
- The most important material is silicon.
  It is used to make transistors, diodes, IC and other electronic devices

4.Super conductors

Materials that offer no opposition to current flow essentially being perfect conductors

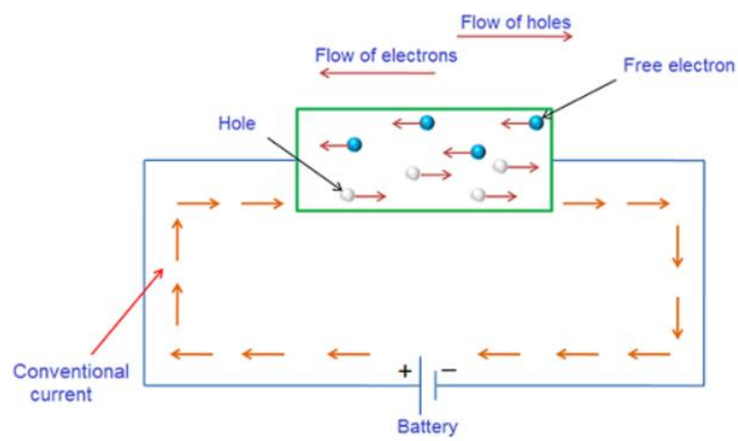
DC Circuit

Voltage (Potential Difference)

- The voltage across an element is the work (energy) required to move a unit positive charge from the +ve terminal to the -ve terminal
- Electrons won't flow through a circuit unless the are given some energy to help send them on their way. that "push" is measured in volts
- The units of voltage are volts (V), which are equivalent to joules per coulomb(J/C)

Electrical Current

- Electrical current is the time rate of flow of electrical charge through a conductor or circuit element
- The unit is Ampere (A), which is equivalent to coulombs per second (C/Sec)
  $i = \frac{dq}{dt}\ , i \equiv flow\ rate(ampere), q \equiv charge(coulomb), t \equiv time(\text{sec})$
- Current direction
  $Conventional\ Current\ \equiv flow\ of\ holes \equiv form + ve\ to - ve$
  $Actual\ Current\ \equiv flow\ of\ electrons\ \equiv form - ve\ to + ve$



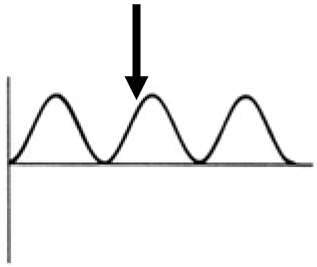
DC Circuit

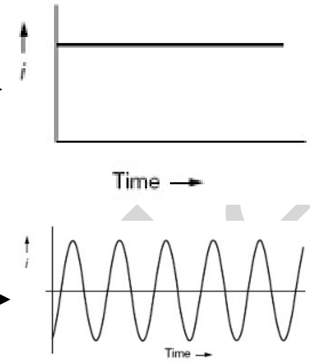
- Types of current

  $DC \equiv Direct\ Current\ (constant)$

  $AC \equiv Alternating\ Current(variable)$

  $Unidirectional\ Current$





Energy & Power

- Energy is the capacity to do work measured in joules (J)
- Power is the time rate of expanding or absorbing energy, measured in Watts (W)
- If the power has a + sign, power is being delivered to or absorbed by the element.

  If on the other hand, the power has a – sign, power is being supplied by the element.

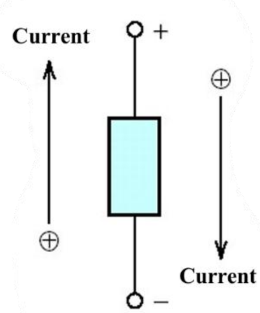
  $$Power(P) = \frac{dEnergy(W)}{dt}$$

  $$P = \frac{dW}{dt} = \frac{dW}{dq}\frac{dq}{dt} = VI$$

  $$P = Voltage\ \times Current\ (Watt)$$

  $$W = Voltage\ \times Current\ \times time(Joule \equiv watt.sec)$$

Energy supplied
by the element
P is -ve



Energy absorbed
by the element
P is +ve

DC Circuit

Elements of Electric Circuit

Electrical Network

A combination of various electric element
(Resistor, Inductor, Capacitor, Voltage Source, Current Source)

Connected in any manner what so ever is called an electrical network.

We may classify circuit elements in two categories

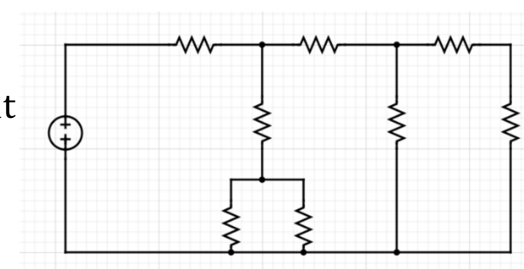
i. Passive elements
The elements which receive energy (absorb energy) and then either converts it into heat (R) or stored it in an electric (C) or magnetic (L) field is called passive elements
ii. Active elements
The elements that supply energy to the circuit is called active element
EX: Voltage Source, Current Source & generators

Node: A node in an electric circuit is a point where three or more components are connected together

Branch: A branch is a conducting path between two nodes in a circuit containing the electric elements. These elements could be sources, resistances, or other elements.

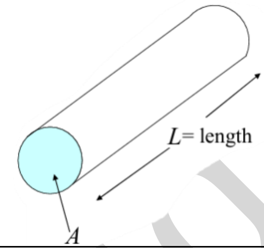
Loop: is any closed path in the circuit

Mesh: is the shortest closed path in the circuit



Passive element (Resistance)

The resistance "R" of an element denotes its ability to resist the flow of electric current; it measured in ohms

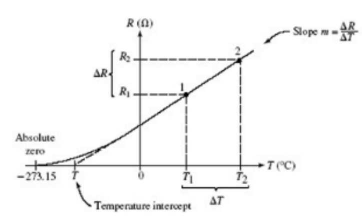


$$R = \rho \frac{L}{A}\ (ohm\ \Omega) \qquad (conductance\ G = \frac{1}{R})$$

Resistivity

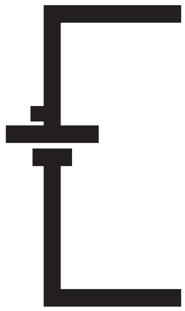
Material	$Resistivity(\Omega.m)$	Usage
Silver	1.64×10^{-8}	Conductor
Copper	1.72×10^{-8}	Conductor
Aluminum	2.8×10^{-8}	Conductor
Gold	2.45×10^{-8}	Conductor
Carbon	4×10^{-5}	Semiconductor
Germanium	47×10^{-2}	Semiconductor
silicon	6.4×10^{2}	Semiconductor
Paper	10^{10}	Insulator
Mica	5×10^{11}	Insulator
Glass	10^{12}	Insulator
Teflon	3×10^{12}	Insulator

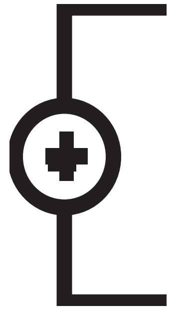
Temperature effects

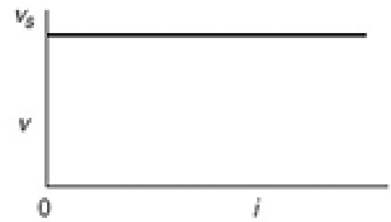


- The resistance of the conductor won't be constant with all temperature
- As temperature increases, more electrons will escape their orbits, causing additional collisions within the conductor
- For most conducting material, the increase in the number of collisions translates into a relatively linear increase in resistance
- The rate at which the resistance of material changes with a variation in temperature is called the temperature coefficient of material (α)
- Some materials have only very slight changes in resistance, while other materials demonstrate dramatic changes in resistance with a change in temperature
- Any material for which resistance increase as temperature increases is said to have a positive temperature coefficient
- For semiconductors an increase in temperature results in decrease in resistance. consequently, these materials are referred to as having negative temperature coefficients

Independent Voltage source





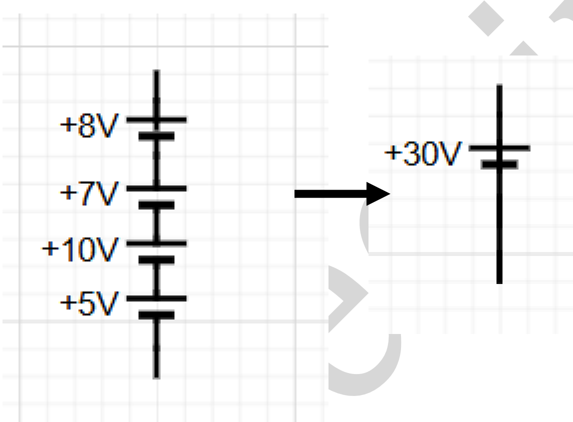


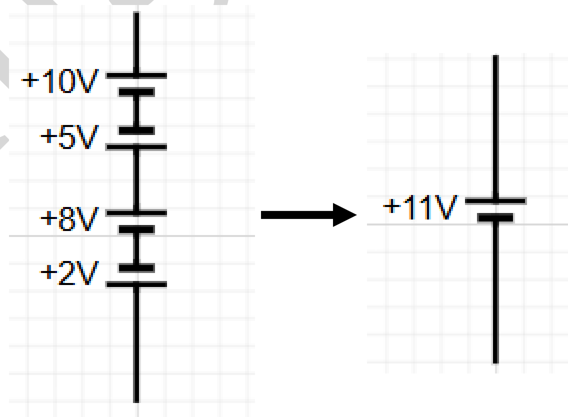
Voltage Source
Constant "DC"

Voltage Source
Time varying "AC"

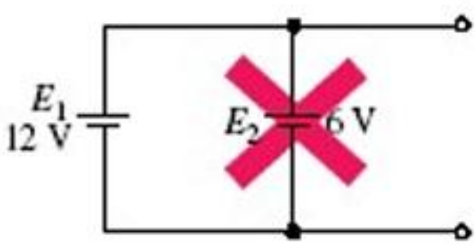
An independent voltage source maintains a specified voltage between its terminals regardless of the circuit it connected to the voltage across the source is completely independent of the current through the source
This voltage is called electromotive force "emf"

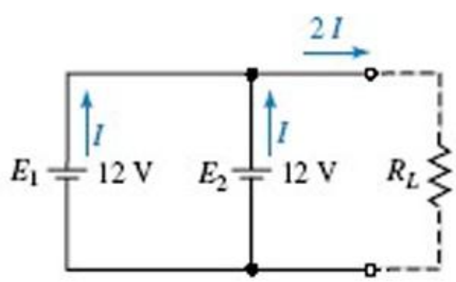
Voltage source in series



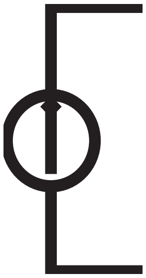


Voltage source in parallel

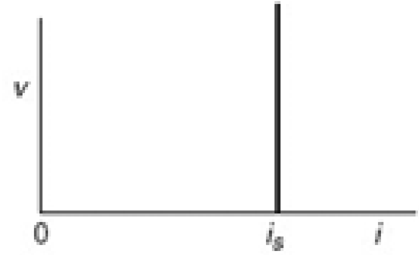




Independent Current Source

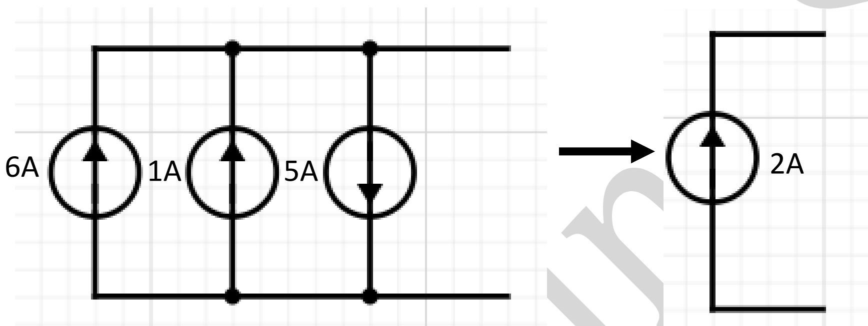


Current Source

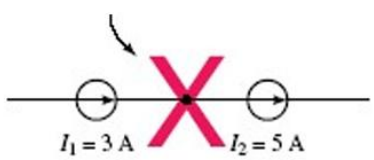


An independent current source maintains a specified current flowing through its terminals regardless of the circuit it connected to it. the current through the source is completely independent of the voltage across the source

Current Sources in Parallel



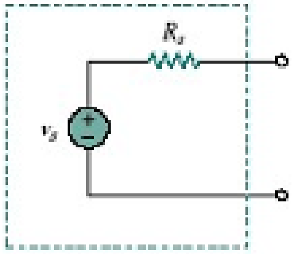
Current Source in Series

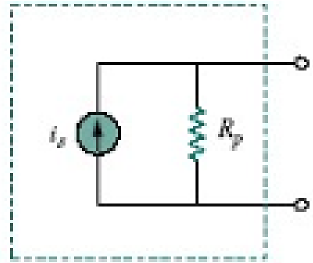


Practical voltage and current sources

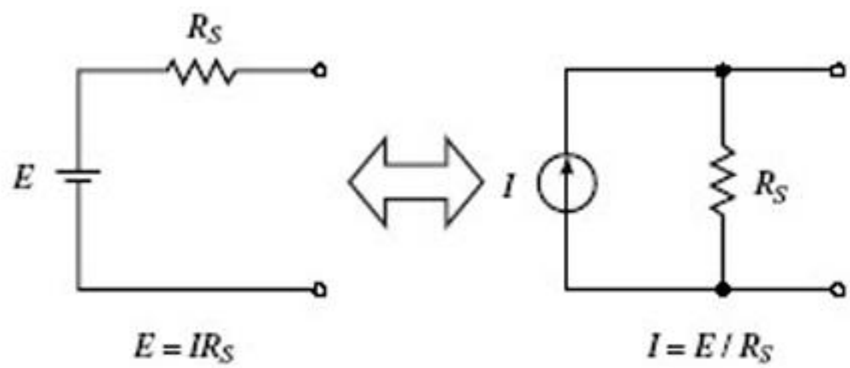
$Practical\ voltage\ \&\ current\ sources\ are\ not\ ideal\ , due\ to\ their\ internal\ resistance$

$R_s \& R_P. they\ become\ ideal\ as\ R_s \rightarrow 0\ \& R_P \rightarrow \infty$



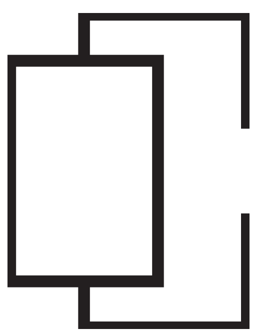


Source transformation

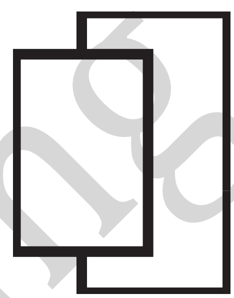


Process of replacing a voltage source “E” in series with a resistor “R_s” by Current source “I” is in parallel with a resistor “R_s” or vice versa

Short Circuit & Open Circuit



Open Circuit
$R = \infty$
$I = 0$



Short Circuit
$R = 0$
I
$= \infty\ theoritical$
$Actual\ \neq \infty$

These are all fundamental of circuit

Reference used:
Fundamental Of Circuit Charles K. Alexander |Matthew N.O. Sadiku

DC Circuit

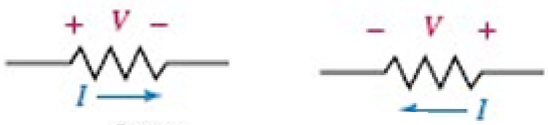
Basic laws

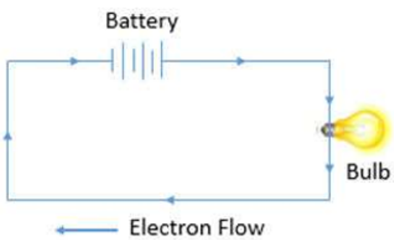
Ohm's law

$V = IR$ $\qquad$ $V: Voltage\ , I: Current\ , R: Resistance$

Ohm determined experimentally that current in a resistive circuit is directly proportional to its applied voltage and inversely proportional to its resistance

Current flows from a higher potential to a lower potential in a resistor.

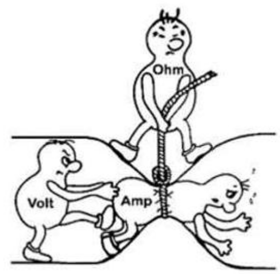




Resistance (R)=Bulb

Current (I)=Flow of electron

Voltage(V)=Battery



Power

Using Ohm's law, and substituting

$V = IR$

$P = VI$

Thus, power can also be expressed as: $P = \frac{V^2}{R}$ $or\ I^2R$

Kirchhoff's Law

- Kirchhoff current law (KCL)

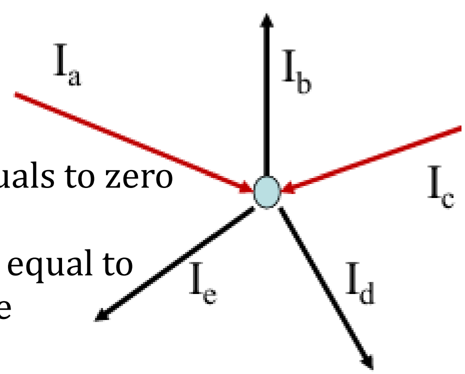
  $\sum I = 0 \quad , \sum I_{in} = \sum I_{out}$

  The summation of the current at any node equals to zero

  $I_a + I_c - I_b - I_d - I_e = 0$

  The summation of current entering to node is equal to the summation of the current leaving the node

  $I_a + I_c = I_b + I_d + I_e$



- Kirchhoff voltage law (KVL)

  $\sum V = 0$

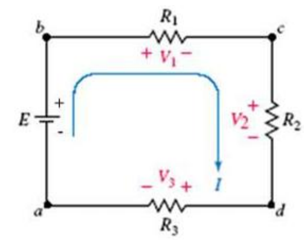
  The algebraic summation of all the voltages around any loop, in a circuit equals zero

  $\sum V.D = \sum emf$

  The summation of emf is equal to the summation of voltage drops around any loop.

DC Circuit

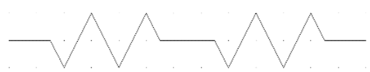
$$E - V_1 - V_2 - V_3 = 0$$
$$E = V_1 + V_2 + V_3$$



Resistor Connections

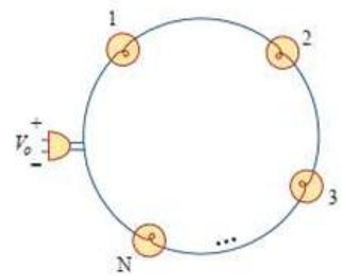
1. Series connection
2. Parallel connection
3. Star connection
4. Delta connection

1.Series Connection "+"



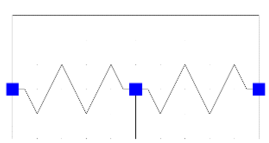
The end of the first is the begin of the second

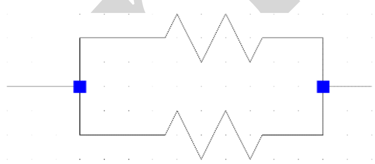
Same current flow through the resistances



$$R_{eq} = R_1 + R_2 + R_3 + \ \dots = \sum R_i$$

2.Parallel connection "//"

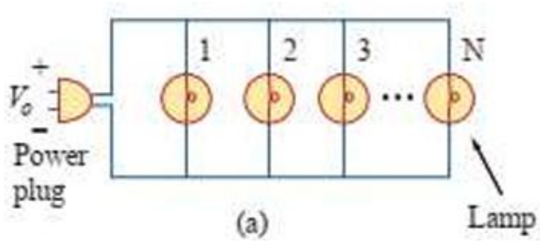




Same Start → Same End

Same voltage between the two terminals of the resistances

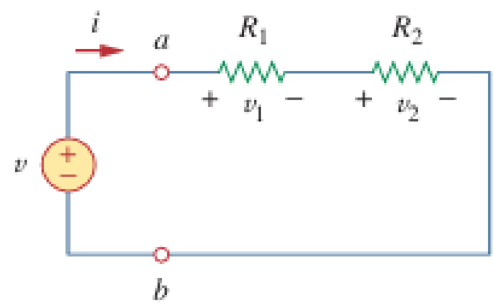
$$R_{eq} = \frac{1}{R_1^{-1} + R_2^{-1} + R_3^{-1} + \ \dots} = \frac{1}{\sum R_i^{-1}}$$



In case of 2 parallel resistance

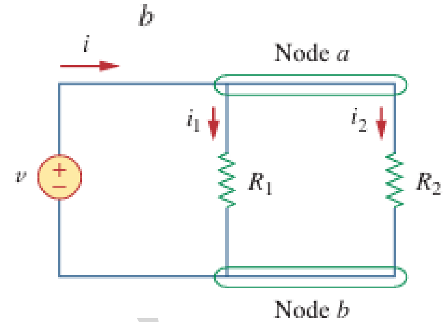
$$R_1 // R_2 = \frac{R_1 R_2}{R_1 + R_2}$$

Voltage Divider



$$v_1 = \frac{R_1}{R_1 + R_2} v$$
$$v_2 = \frac{R_2}{R_1 + R_2} v$$
$$v_n = \frac{R_n}{R_1 + R_2 + R_3 + R_4 + \ \dots + R_n} v$$

Current Divider

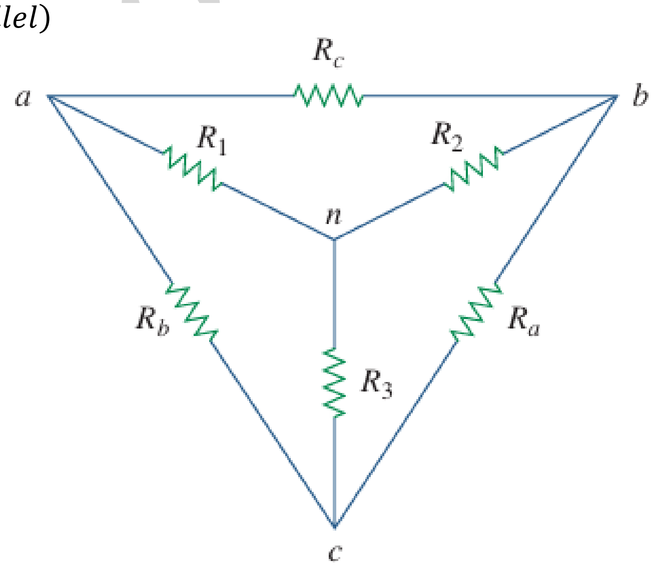


$$i_1 = \frac{R_2}{R_1 + R_2} i$$
$$i_2 = \frac{R_1}{R_1 + R_2} i$$

3.Star connection
4.Delta connection

$Delta(\Delta) \& \ Star(Y)(not\ series\ or\ parallel)$

1. Define
2. Strategy
3. Rule



$$\Delta\ to\ Y : R_1 = \frac{R_b \times R_c}{R_a + R_b + R_c} = R_Y$$

If all resistors are equal $R_Y = \frac{R_\Delta}{3}$

$$Y\ to\ \Delta : R_a = R_2 + R_3 + \frac{R_2 \times R_3}{R_1}$$

If all resistors are equal $R_\Delta = 3R_Y$

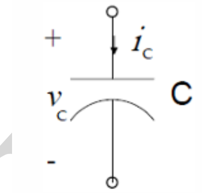
We took about first thing in passive elements

Passive Elements

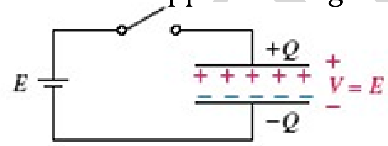
1. Resistance
2. Capacitors
3. Inductors

2.Capacitor

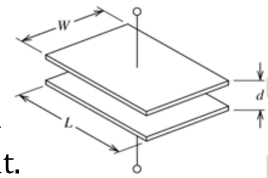
- A capacitor is a passive element designed to store energy in its electric field or to store electrical charge
- If you connect a dc voltage source to a capacitor for example the capacitor will "charge" to the voltage of the source



- If you disconnect the source, the capacitor will remain charged
- The amount of charge Q that a capacitor can store depends on the applied voltage
- A capacitor consists of two conducting plates separated by an insulator (or dielectric)



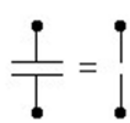
- $Capacitance(C) = \frac{\varepsilon A}{d} Farad$
  $A = WL \quad \varepsilon = permitivity$
  $\varepsilon = \varepsilon_r \varepsilon_0 \quad \varepsilon_0 = 8.85 \times 10^{-12} F/m$
  Farad, however, is a very large unit.
  Most practical capacitors range size from picofarads (PF or$10^{-12}F$) to micro farads($\mu F \; or \; 10^{-6}F$).



- The Current-Voltage relationship for a capacitor
- $q = CV \;, i = \frac{dq}{dt}$

$$i_c = C\frac{dV_C}{dt} \qquad V = \frac{1}{C}\int i\,dt$$

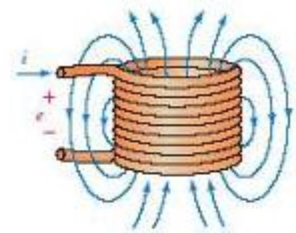
- $C_{eq} \; is \; inverse \; R_{eq} \; in \; connection$
  Series connection
  $$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \cdots + \frac{1}{C_n}$$
  $$C_{eq} = \frac{1}{\sum_{i=0}^{n} C_i^{-1}}$$
  Parallel connection
  $$C_{eq} = C_1 + C_2 + C_3 + \ \ldots + C_n$$
  $$C_{eq} = \sum_{i=0}^{n} C_i$$
  Star as Delta
  Delta as Star
  In DC,$\frac{dV}{dt} = 0, i = 0$



  Open Circuit

3.Inductor

- An inductor is a passive element designed to store energy in its magnetic field
- In its simplest form an inductor is simply a coil of wire
- Ideally, inductors have only inductance.
  However, since they are made of wire, practical inductors also have resistance
- 'L' is the self-inductance of the coil
- 'L' is measured in Henry
- It is the ratio of voltage induced in a coil to the rate of change of current producing it

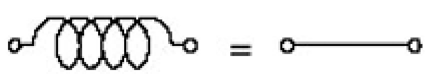


$$V = L\frac{di}{dt} \ ,i = \frac{1}{L}\int V\,dt$$

$$L = \frac{\mu A N^2}{l} Henry \qquad \mu = permeability$$

$$\mu = \mu_r \mu_0 \qquad \mu = 4\pi \times 10^{-7} H/m$$

- $L_{eq} is\ same\ R_{eq} in\ connection$
  Series connection
  $$L_{eq} = L_1 + L_2 + L_3 + \ \dots = \sum L_i$$
  Parallel connection
  $$L_{eq} = \frac{1}{L_1^{-1} + L_2^{-1} + L_3^{-1} + \ \dots} = \frac{1}{\sum L_i^{-1}}$$
  Star same star in resistance
  Delta same delta in resistance
  In DC,$V = L\frac{di}{dt} = L.0 = 0$



DC Circuit

DC Circuit Analysis

All available methods:
(Main tech)

- Nodal
- Mesh

(Tools)

- Source transformation
- Superposition

(eq circuit)

- Thevenin
- Norton   Can get max P transfer

Main techniques
Nodal Steps
1.Select a node as the reference node. Assign voltage $v_1, v_2, \ldots., v_{n-1}$ to the remaining $n-1$ nodes. The voltage is referenced with respect to the reference node.
2. Apply KCL to each of the $n\ -1$, nonreference nodes. Use Ohm's law to express the branch currents in terms of node voltages.
3. Solve the resulting simultaneous equations to obtain the unknown node voltages.

مش فاهم حاجة؟؟؟!
اول حاجة حدد ال Ref node
تاني حاجة اعمل KCLعلى كل Node
تالت حاجة لو في Super node خلي بالك منها
اخر حاجة حل المعدلات الي طلعتها

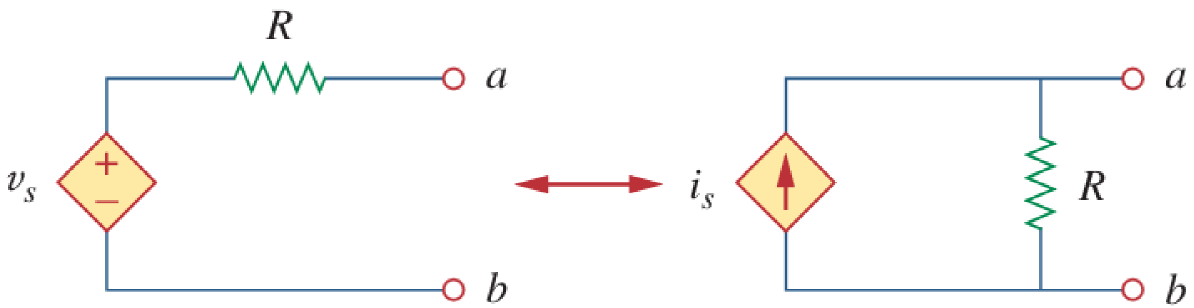
Mesh Steps
1.Assign mesh current $i_1, i_2, .. i_n$ to the n meshes.
2.Apply KVL to each of the n meshes.
Use Ohm's law to express the voltage in terms of the mesh current
3.Solve the resulting n simultaneous equations to get the mesh currents

مش فاهم حاجة ؟؟؟!
اول حاجة حدد اتجاه كل تيار في Mesh
تاني حاجة اعمل KVL على كل mesh
تالت حاجة لو في Super mesh خلي بالك منها
اخر حاجة حل المعدلات الي طلعتها

خلاصه ازاي احل سواء Mesh or Nodal Analysis
الا لو فيها Dependent Source**

Tools

Source transformation



R is series with source R is parallel with source

$$v_s = i_s R$$

$$i_s = \frac{v_s}{R}$$

Note:

- $V = IR$
- Same R value
- +ve of VS is corresponding to the head of CS

Superposition (use only to get V or I not P)

Steps to apply superposition

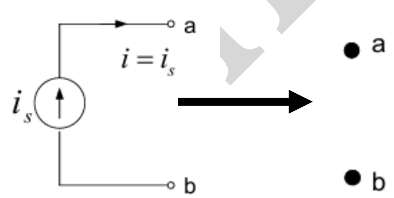
1.Turn off all independent source except one source
  Find the output (voltage or current) due to that active source using
  the techniques covered in the pervious part.

2.Repeat step 1 for each of the other independent source.

3.Find the total contribution by adding algebraically all the contribution due to
  The independent sources.

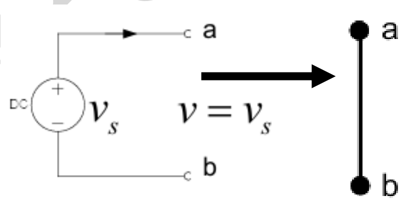
Sources in superposition

Current source:



Open-circuit representation

Voltage source:



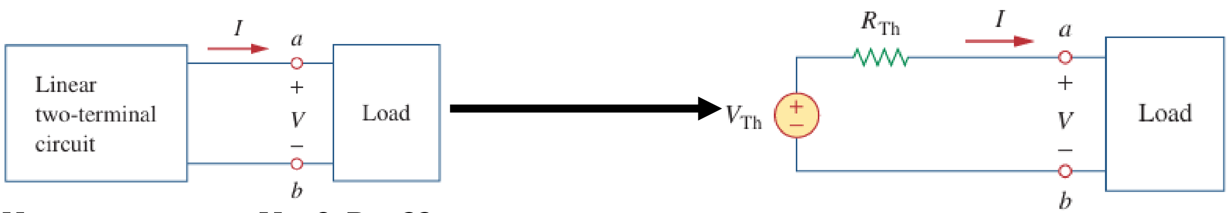
Short-circuit representation

Eq circuit

Thevenin 's theorem

States that a linear two-terminal circuit can be replaced by an equivalent circuit consisting of voltage source V_{th} in series with a resistor R_{th}

Where V_{th} is the open circuit voltage at the terminal and R_{th} is the input or equivalent resistance at the terminals when the independent sources are turned off

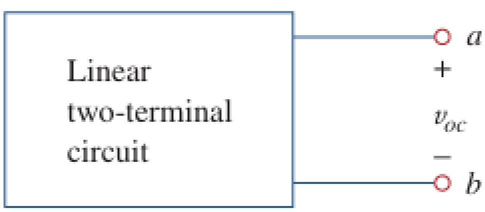


How can we get V_{th} & R_{th} ??

Get R_{eq} of the circuit and equating it with R_{th}

Get the voltage difference between the two point that you want

EX

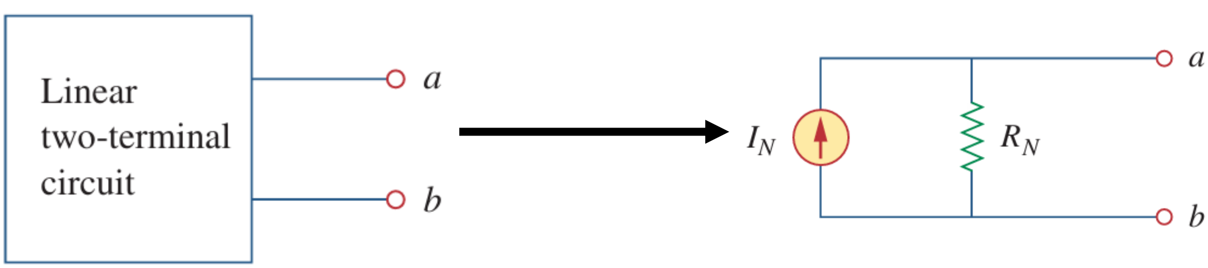


Let a & b as open circuit, assume polarity & solve the circuit using any method to get

$V_{th} = V_{oc} = V_a - V_b$ (*diff between the 2 points*)

Norton's theorem

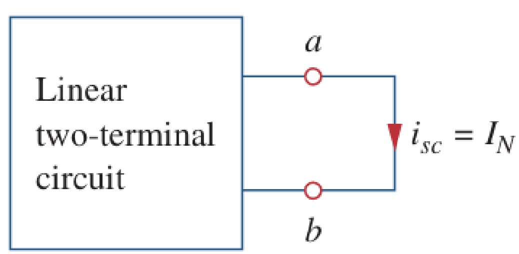
States that a linear two-terminal circuit can be replaced by an equivalent circuit consisting of a current source I_N in parallel with a resistor R_N, where I_N is the short-circuit current through the terminals and RN is the input or equivalent resistance at the terminals when the independent sources are turned off.



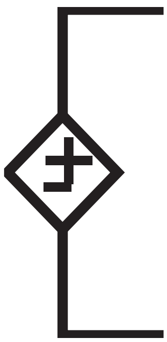
How can we get I_N & R_N ??

Get R_{eq} of the circuit and equating it with R_N

Get the S.C current in the wire by solving The circuit

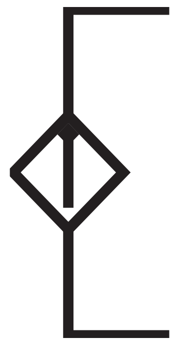


Dependent Source
Usage: represent as Op-amp, transistor, or any integrated circuits



Voltage Controlled Voltage Source

Voltage Controlled Current Source



Current Controlled Voltage Source

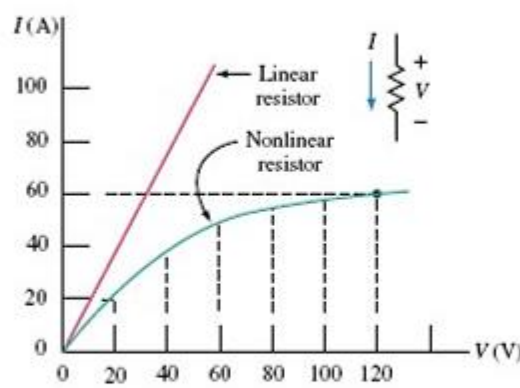
Current Controlled Current Source

In solving problem:

- Dependent source like independent source in all thing (mesh, nodal, super mesh, super node)
- But: if the method needs to source off sources
  Means to off independent source only (superposition, R_{th}, R_N)
  If the dependent current or voltage is zero; off the dependent source

Nonlinear and dynamic Resistances

- All resistors considered so far have constant values that don't change with voltage or current.
  Such resistors are termed linear or ohmic since their current voltage (I-V) plot is a straight line
- However, the resistance of some materials changes with voltage or current. These materials are termed nonlinear because their I-V plot is curved



Linear and nonlinear resistance Characteristics