RAMAIAH UNIVERSITY OF APPLIED SCIENCES

Chapter 1
DC and AC Fundamentals

Topics

- Circuit elements
- Active elements
- Passive elements
- Voltage and current
- Resistance, capacitance and inductance
- Ohm’s law
- Kirchoff’s laws

Objectives

At the end of this lecture, student will be able to:

- Classify Circuit Elements
- Identify basic active and passive elements
- Define current, voltage, Resistance, Capacitance and inductance
- State and Illustrate Ohm's law
- State and solve Kirchoff's law
- Explain Generation of Sinusoidal quantity
- Define Fundmentals of Alternating quantities, definitions and drivations
- Explain relation of voltage and current in prue passive elements

Introduction

Why Study Electrical Engineering?

- To operate and maintain electrical systems
- To communicate with electrical engineering consultants
- To distribute and convert energy between various forms
- To design projects in your own field

What Do You Infer From This Figures?

cave

Hut

Building

What Do You Infer From This Figures?

Candle

Bulb

C F L

What do you infer from this figures?

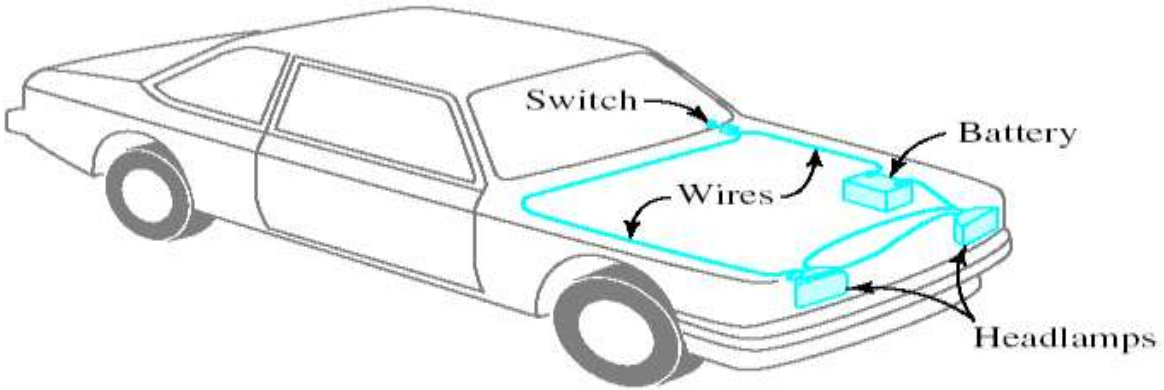
Walking man

Bike

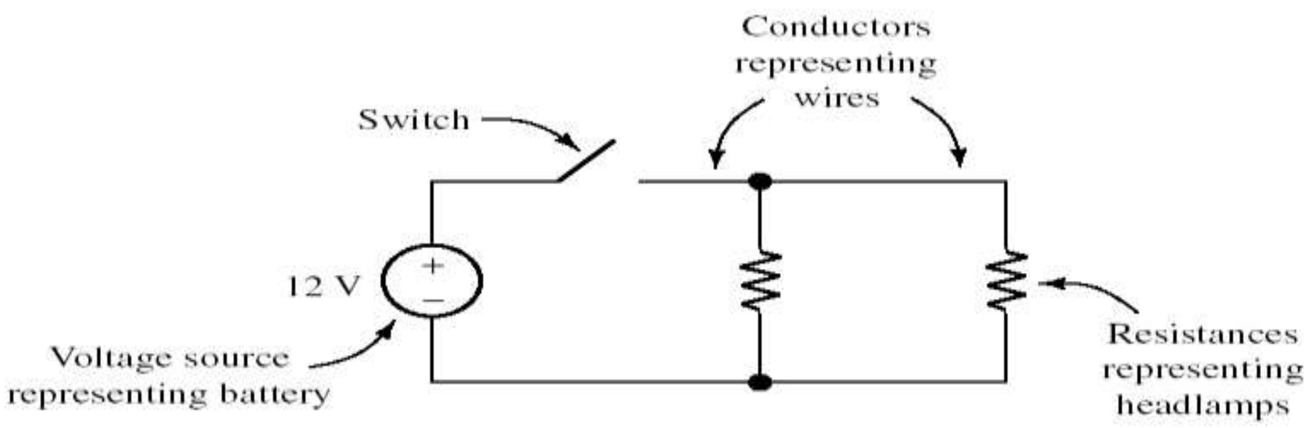
Airplane

Car

Application Example: Headlight Circuit



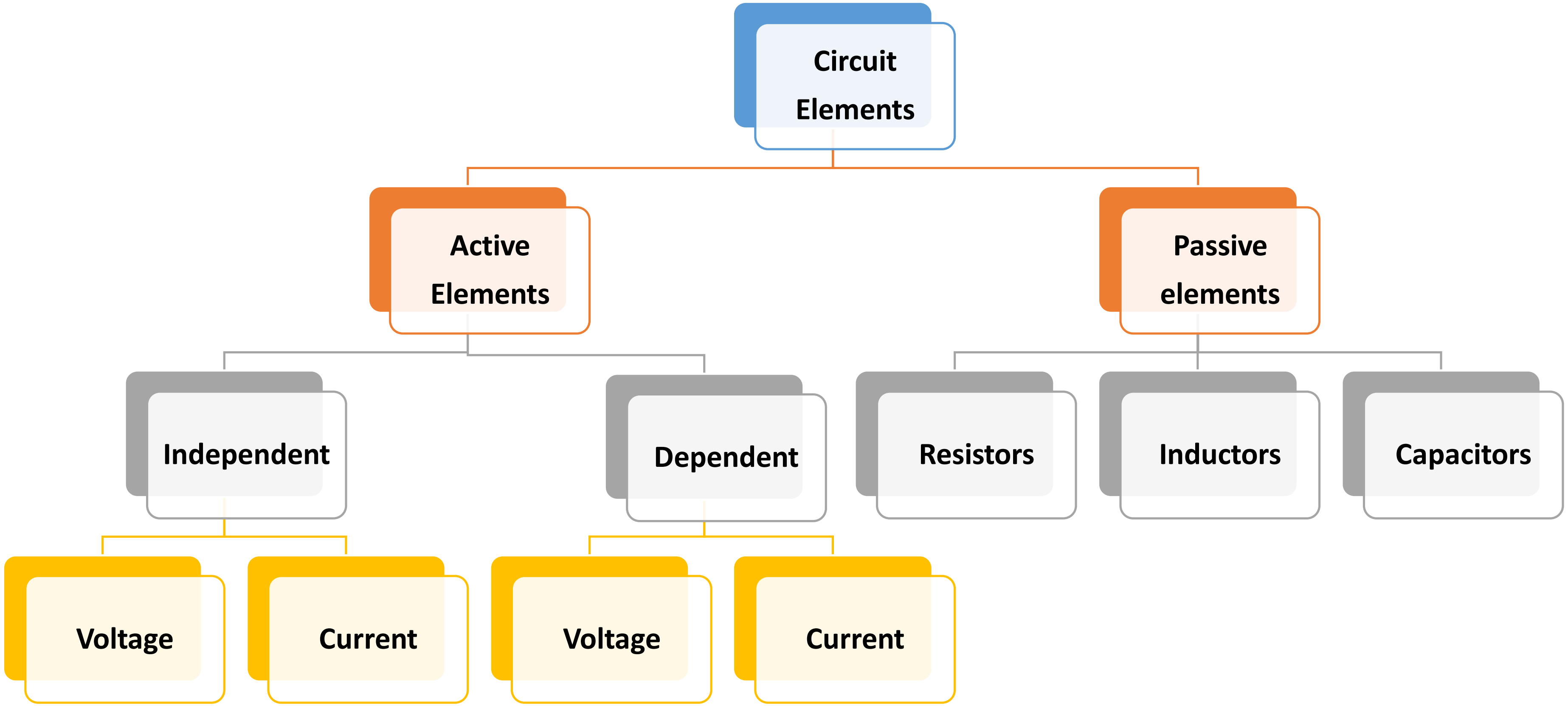
(a) Physical configuration



(b) Circuit diagram

Basic Circuit Elements

- Circuit elements mainly consists of active and passive elements and categorized as shown



Circuit Elements

- Active elements are capable of generating electrical energy
- Passive elements are incapable of generating electrical energy
- Electrical source is a device that can convert non-electrical energy into electrical energy
- Example: Battery

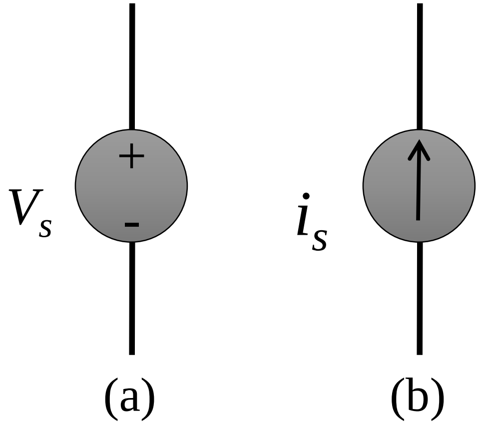
  Generator

Active Element

- Sources is categorized as
  - ✓ **Independent sources** where generated voltage or current does not depend on the other circuit elements
  - ✓ **Dependent Sources** where the generated voltage or current depends on another circuit voltage or current

Active Element

- Independent voltage source provides a specified voltage
- Independent voltage source (or current source), the terminal voltage (or current) would depend only on the loading and the internal source quantity
- But not on any other circuit variable
- The circle is used as the circuit symbol for independent sources are as shown



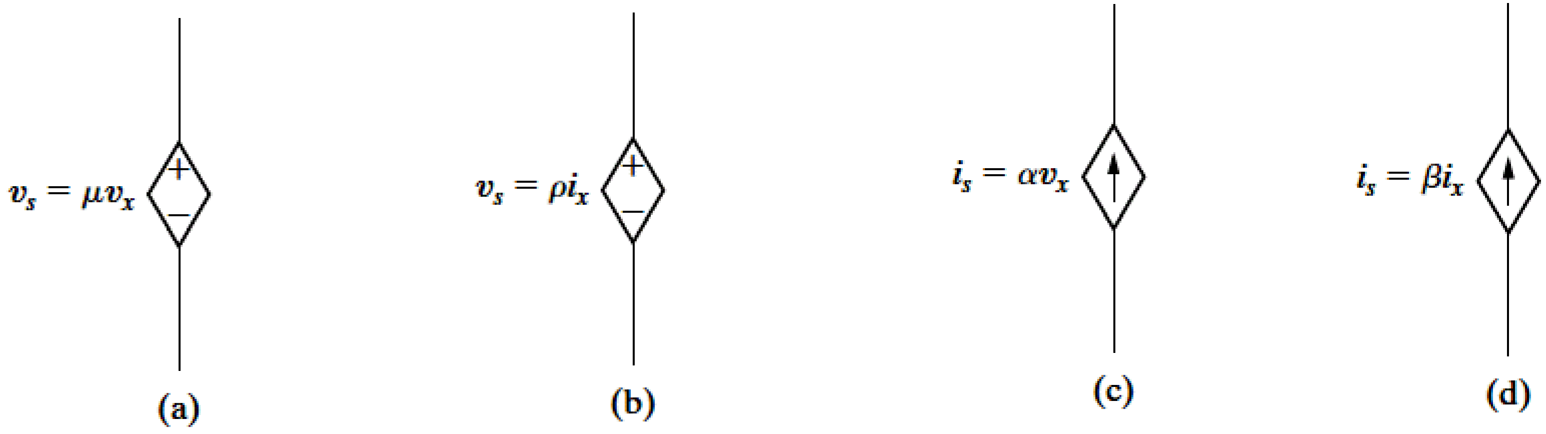
The circuit symbols for (a) an ideal independent voltage source and (b) an ideal independent current source

Active Element

- Dependent source is a voltage or current generator whose source quantity depends on another circuit variable (current or voltage)
- There are a total of four variations of dependent sources
  - VCVS, VCCS, CCVS, CCCS
- Dependent sources are also called **controlled sources**

Active Element

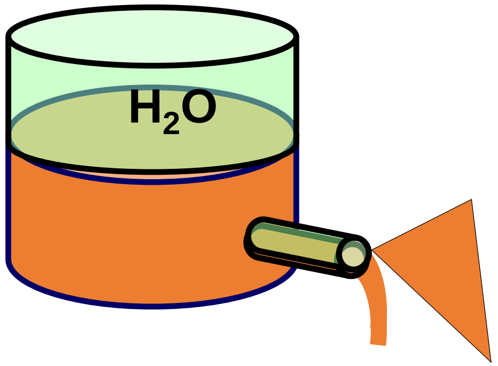
- Diamond is used to represent a dependent source



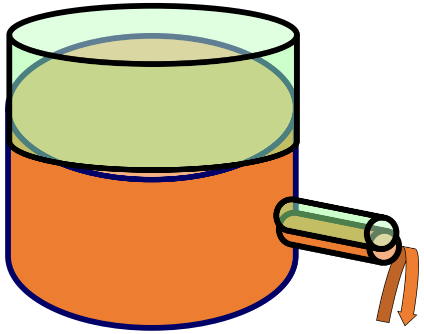
The circuit symbols for (a) voltage-controlled voltage source, (b) current-controlled voltage source, (c) voltage-controlled current source, and (d) current-controlled current source.

What is Voltage?

V = "Electrical pressure" - measured in ***volts.***



High Pressure

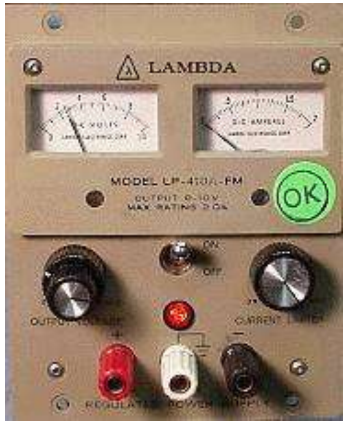


Low Pressure

What Produces Voltage?

V = “Electrical pressure”

Lab Power Supply

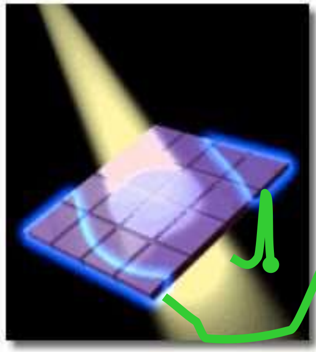


A Battery

9 V

1.5 V

Solar Cell



A few Volts

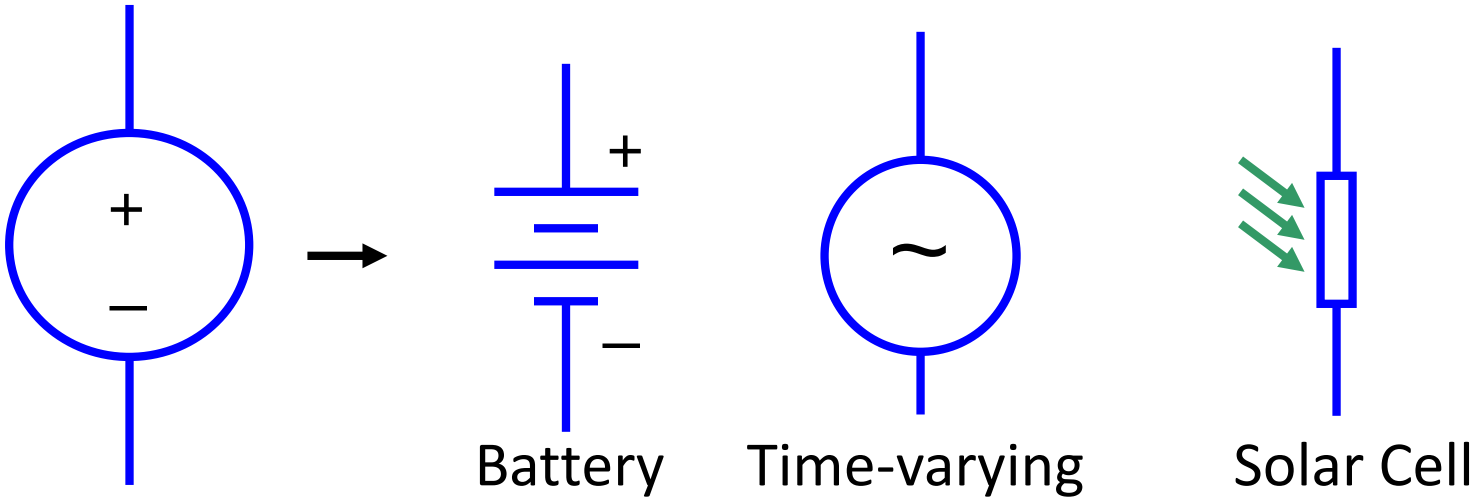
Electric Power Plant

13,500 V

Nerve Cell

A few millivolts when activated by a synapse

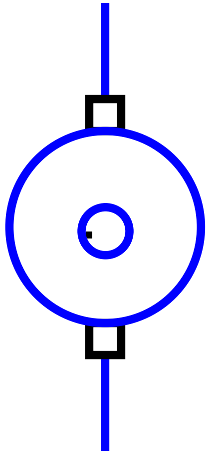
Other Symbols Used for Specific Voltage Sources



Battery

Time-varying source

Solar Cell



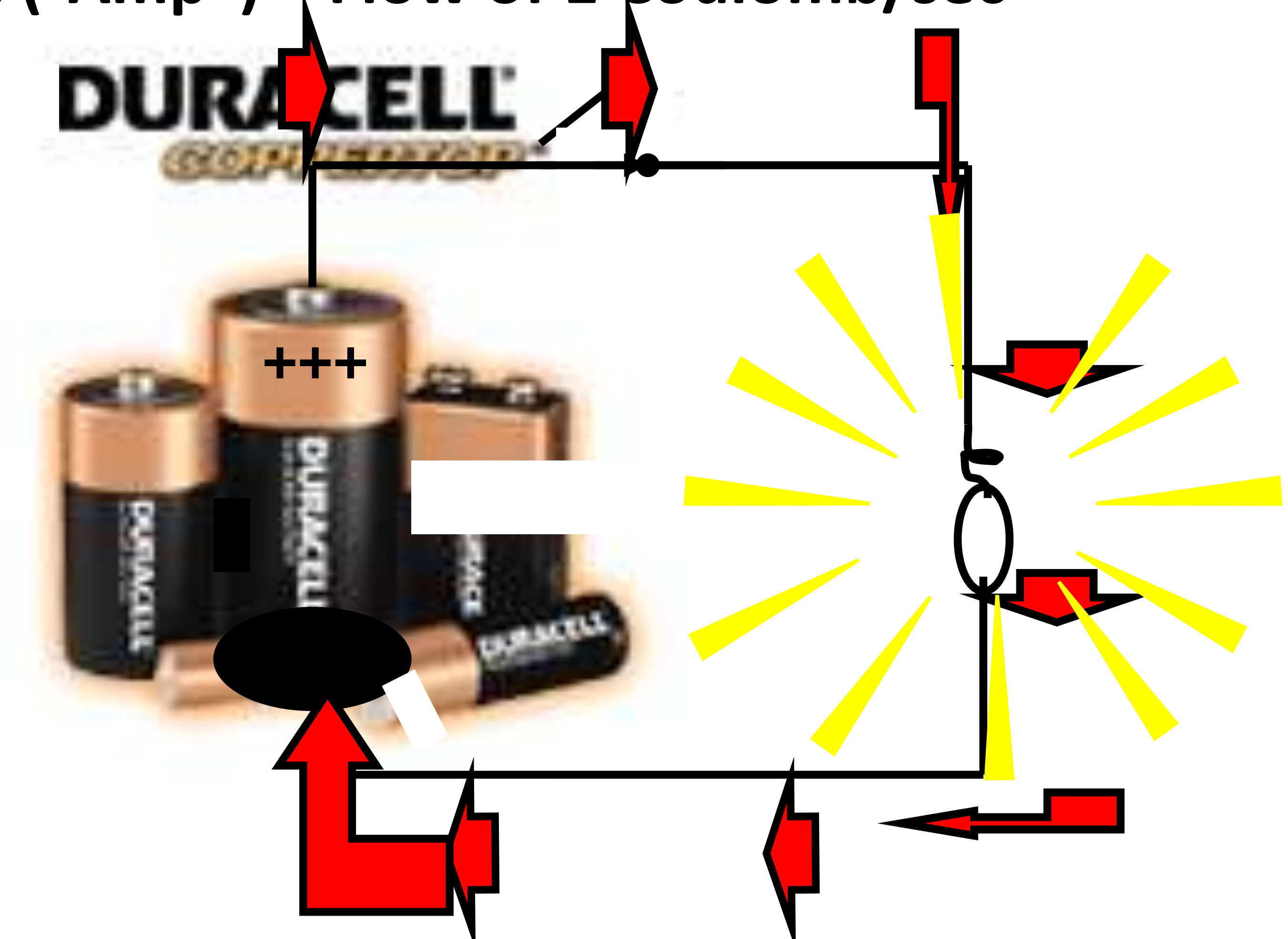
Generator
(power plant)

These are all…

Voltage Sources

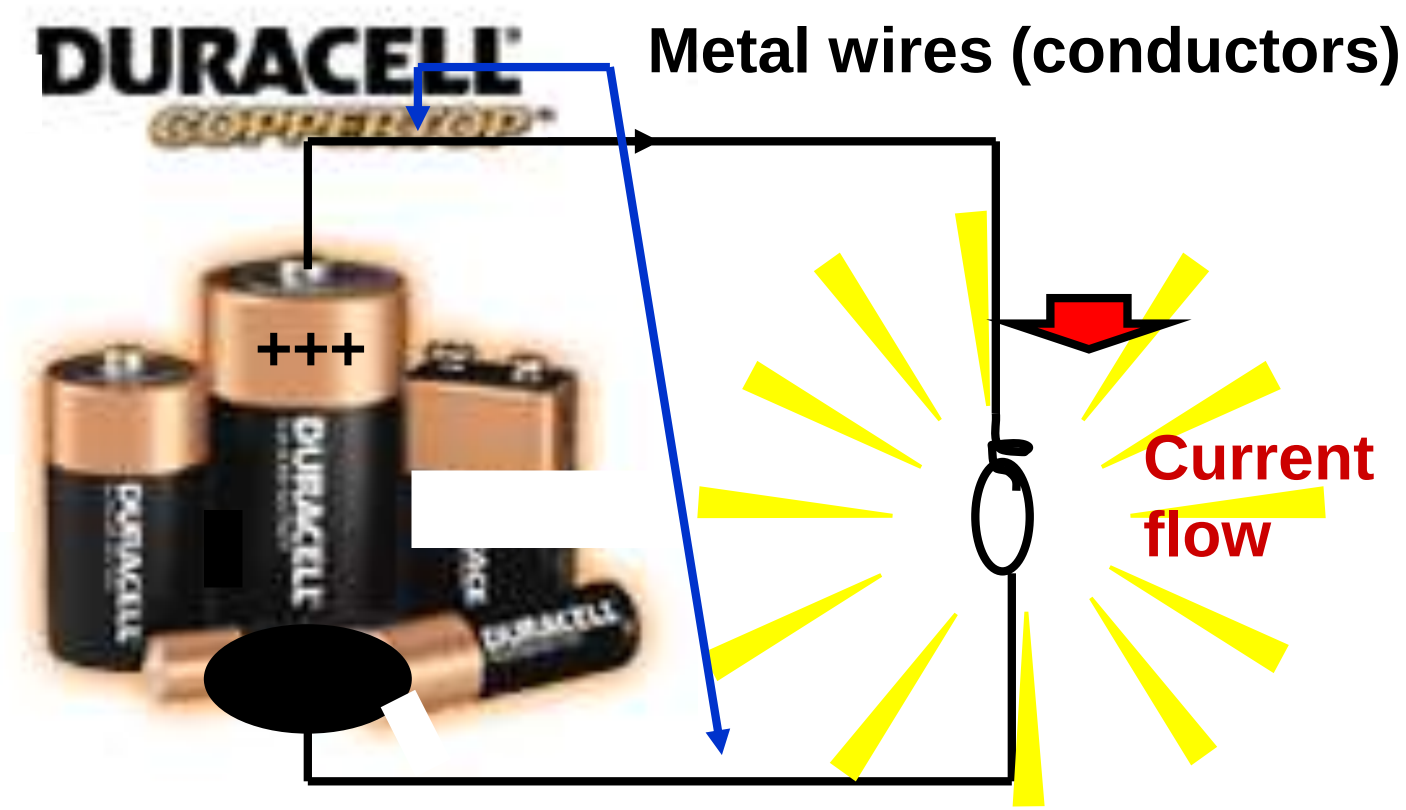
What is Current?

- Current is the flow of charge from a voltage source
- 1 Ampere ("Amp") = Flow of 1 Coulomb/sec



How Does Current Flow?

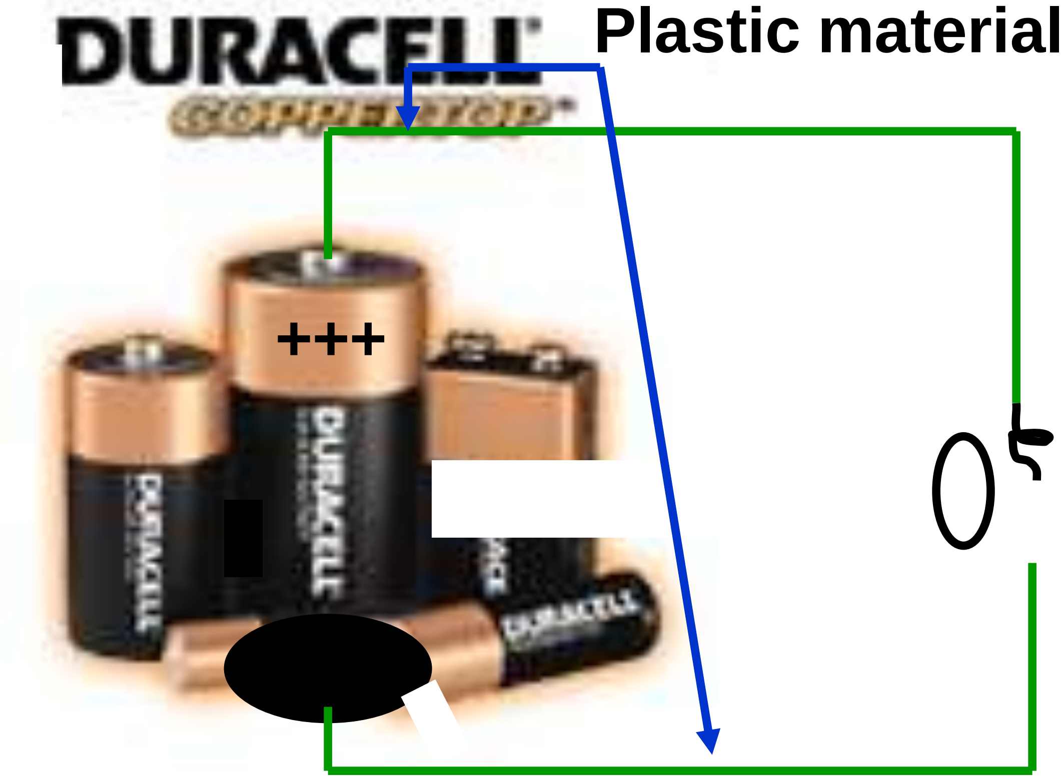
Current can only flow through conductors



When Does Current *NOT* Flow?

Current cannot flow through insulators

Plastic material (insulators)



No current flow

What is Current?

- Electricity flows when electrons travel through a conductor.
- We call this flow "current."
- Only some materials have free electrons inside.

YES!

Conductors:

silver
copper
gold
aluminium
iron
steel
brass
bronze
mercury
graphite
dirty water
concrete

NO!

Insulators:

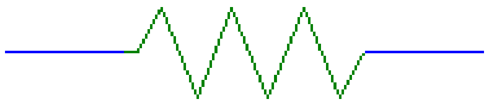
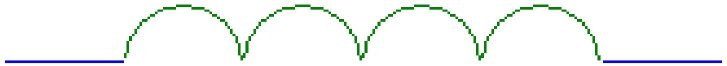
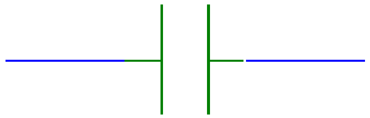
glass
rubber
oil
asphalt
fiberglass
porcelain
ceramic
quartz
(dry) cotton
(dry) paper
(dry) wood
plastic
air
diamond
pure water

No free electrons = No current

Current and Voltage

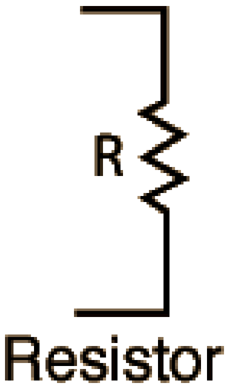
	Current	Voltage
Definition	Rate of flow of electric charge	Potential difference between two points in the circuit
Symbol	I	V
Units	A or Amps	V or Volts
Measuring Instrument	Ammeter	Voltmeter
Field created	Magnetic Field	Electrostatic Field
In series connection	Current is same through all components connected in series	Voltage over components connected in series gets distributed
In parallel connection	Current gets distributed over components when connected in parallel	Voltage is same over all the components when connected in parallel

Passive Components

Component	Symbol	Basic Measure (Unit)
Resistor		Ohm (Ω)
Inductor		Henry (H)
Capacitor		Farad (F)

Resistance

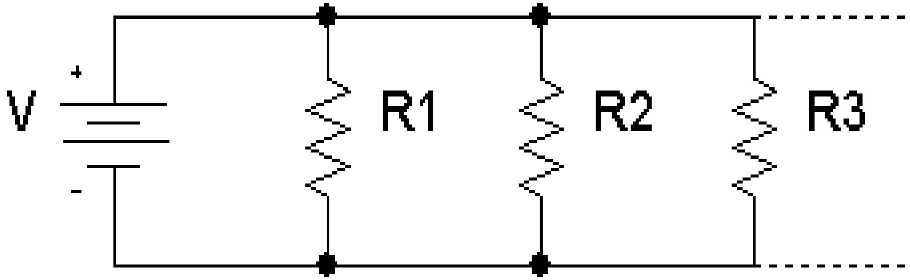
- Resistor is an electrical component that reduces the electric current.
- Resistor's ability to reduce the current is called resistance
- Unit of resistance is ohms (symbol: Ω)



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

Equivalent Resistance

- Resistors in parallel

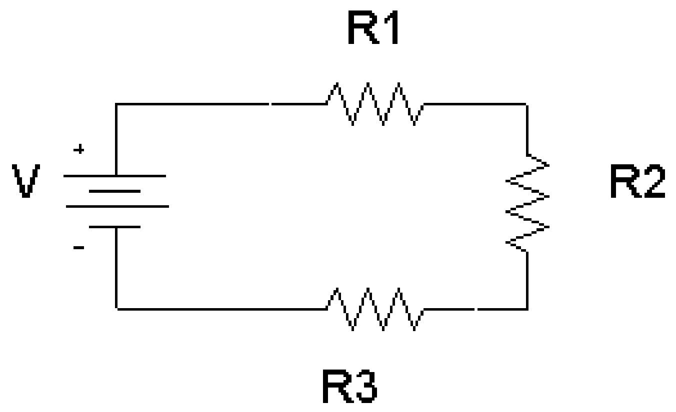


- Total resistance or equivalent resistance is given by

$$\frac{1}{R_{Total}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots$$

Equivalent Resistance

- Resistors in series



- Total resistance or equivalent resistance is given by

$$R_{total} = R_1 + R_2 + R_3 + \dots$$

- Value of resistance increases when connected in series

Resistor color code

- The resistance of the resistor and its tolerance are marked on the resistor with color code bands that denotes the resistance value.
- There are 3 types of color codes:
  I. 4 bands: digit, digit , multiplier, tolerance.
  II. 5 bands: digit, digit, digit , multiplier, tolerance.
  III. 6 bands: digit, digit, digit , multiplier, tolerance, temperature coefficient.

Resistor color code

- Resistance calculation of 4 band resistor is given by

$$R = (10 \times digit_1 + digit_2) \times multiplier$$

- Resistance calculation of 5 band and 6 band resistor is given by

$$R = (100 \times digit_1 + 10 \times digit_2 + digit_3) \times multiplier$$

Resistor Color Code Table

	1st Digit	2nd Digit	3rd Digit	Multiplier	Tolerance	Temperature Coefficient
4bands	1	2		3	4	
5bands	1	2	3	4	5	
6bands	1	2	3	4	5	6
Black	0	0	0	$\times 10^0$		
Brown	1	1	1	$\times 10^1$	±1%	100 ppm/ºK
Red	2	2	2	$\times 10^2$	±2%	50 ppm/ºK
Orange	3	3	3	$\times 10^3$		15 ppm/ºK
Yellow	4	4	4	$\times 10^4$		25 ppm/ºK
Green	5	5	5	$\times 10^5$	±0.5%	
Blue	6	6	6	$\times 10^6$	±0.25%	10 ppm/ºK
Violet	7	7	7	$\times 10^7$	±0.1%	5 ppm/ºK
Grey	8	8	8	$\times 10^8$	±0.05%	
White	9	9	9	$\times 10^9$		
Silver				$\times 10^{-2}$	±10%	
Gold				$\times 10^{-1}$	±5%	
None					±20%	

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How to remember Color Codes ?

B **B** **R** **O** **Y** of **G**reat **B**ritain has **V**ery **G**orgeous **W**ife

Black

Brown

Red

Orange

Yellow

Green

Blue

Violet

Gray

White

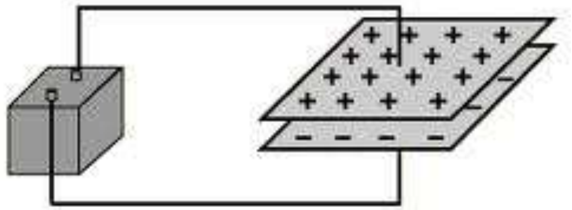
Inductance

- Inductor is a passive electronic component that stores energy in the form of a magnetic field.
- In its simplest form, an inductor consists of a wire loop or coil.
- Inductance is directly proportional to the number of turns in the coil.
- Inductance also depends on the radius of the coil and on the type of material around which the coil is wound.

Capacitance

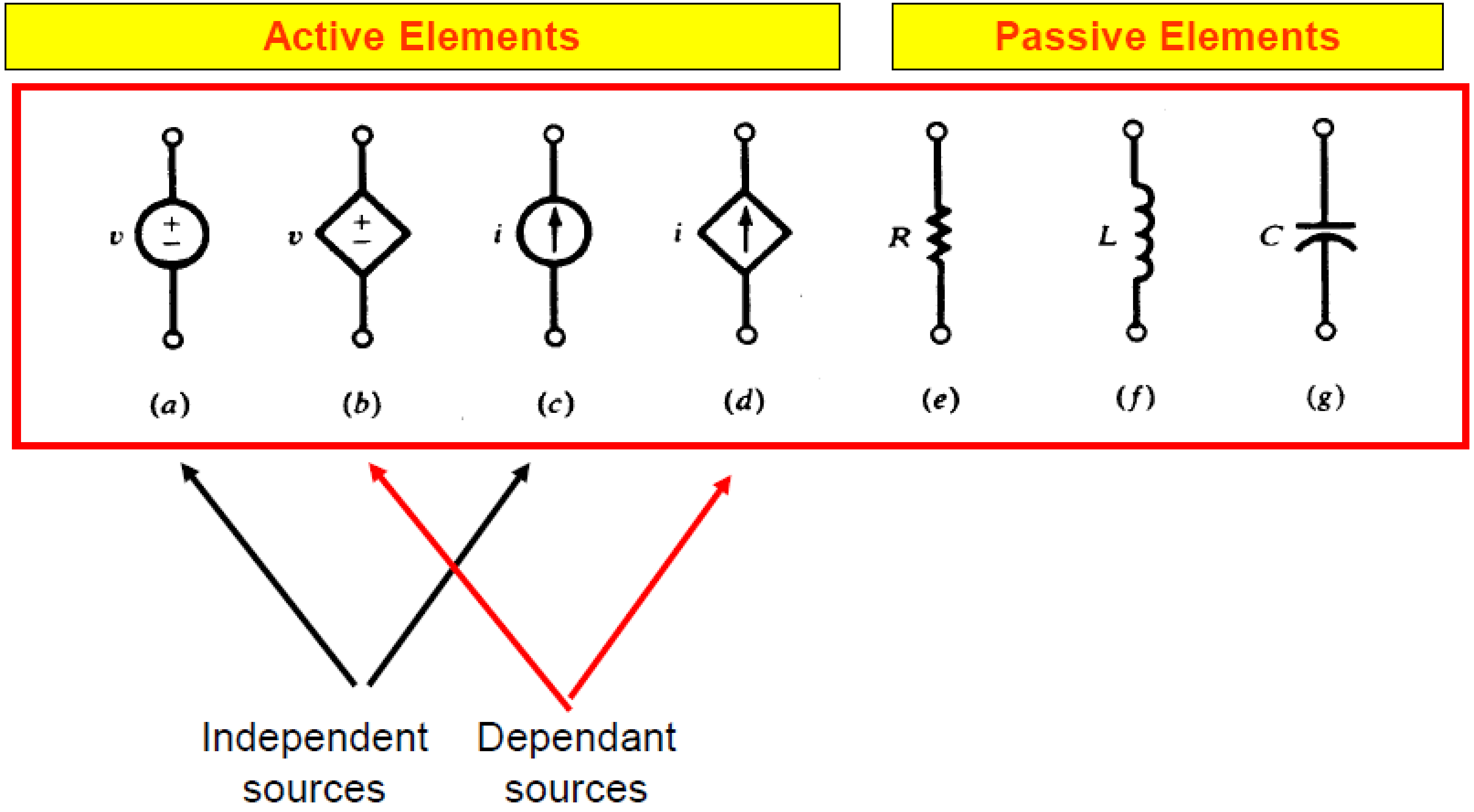
- When a voltage is applied across a **capacitor**, a positive charge is deposited on one plate and a negative charge on the other and the capacitor is said to store a charge
- The charge stored is directly proportional to the applied voltage

$$q = C \cdot V$$

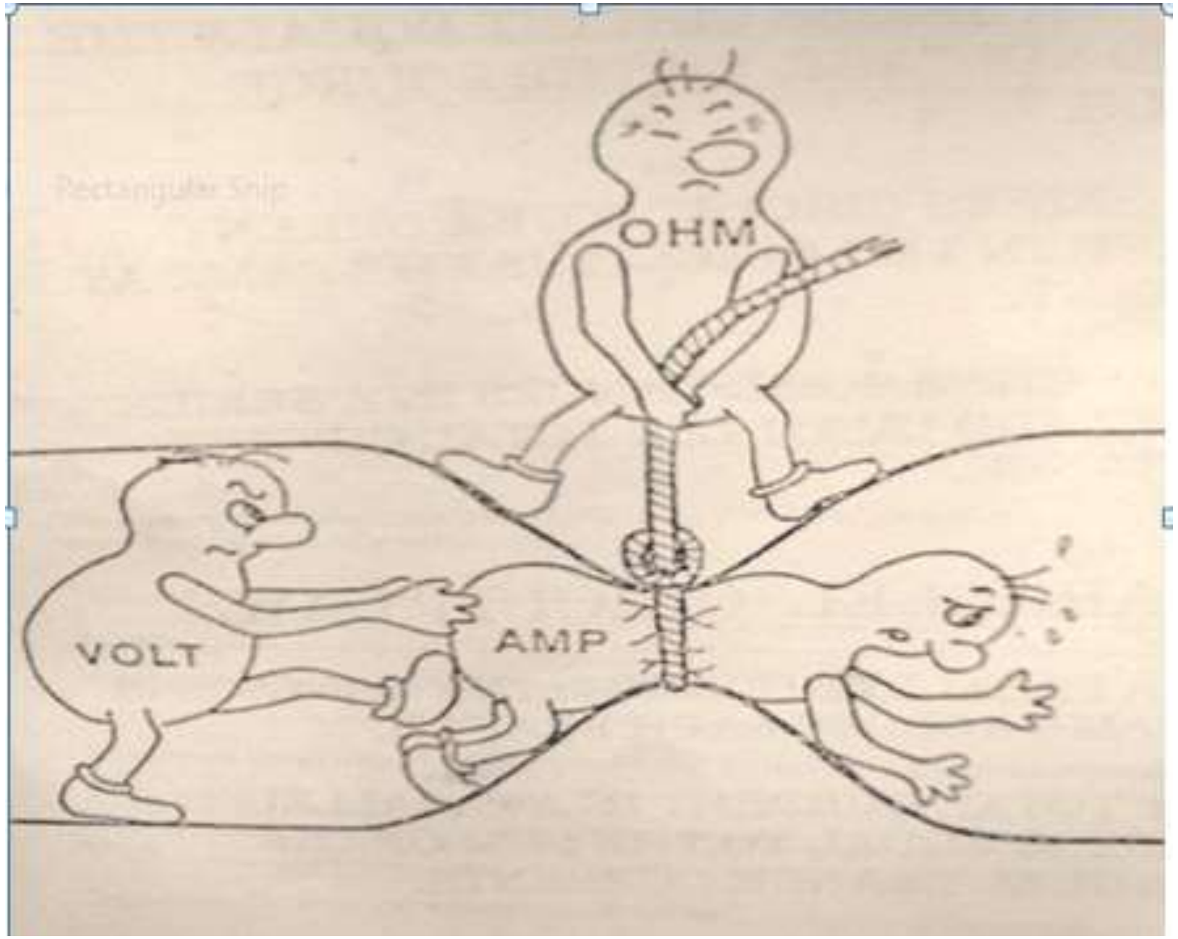


A battery will transport charge from one plate to the other until the voltage produced by the charge buildup is equal to the battery voltage.

Circuit Elements



Pictorial Representation of Ohms Law



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Conductance

Conductance is the reciprocal of resistance

Symbol: G

Units: Siemens (S) or mho (℧)

Example:

Consider a 10 W resistor. What is its conductance?

Power Calculation for a Resistor

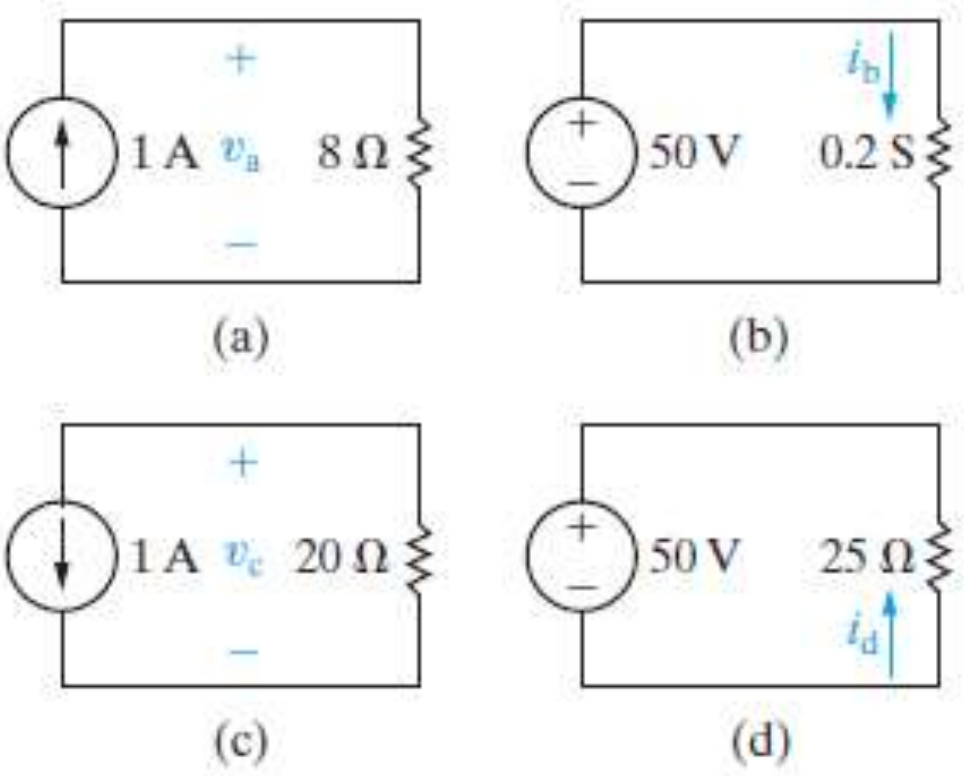
- To calculate power across the resistor

$$P = V * i = (iR) * i = i^2 R$$

- Other method of expressing the power at the terminals of a resistor is in terms of the voltage and resistance.

$$P = \frac{V^2}{R}$$

Calculating Voltage, Current, and Power for a Simple Resistive Circuit



- Calculate the values of *v and i.*
- Determine the power dissipated in each resistor

Kirchoff

- In 1845, German physicist Gustav Robert Kirchoff first described two laws that became central to electrical engineering. The laws were generalized from the work of Georg Ohm. The laws can also be derived from Maxwell’s equations

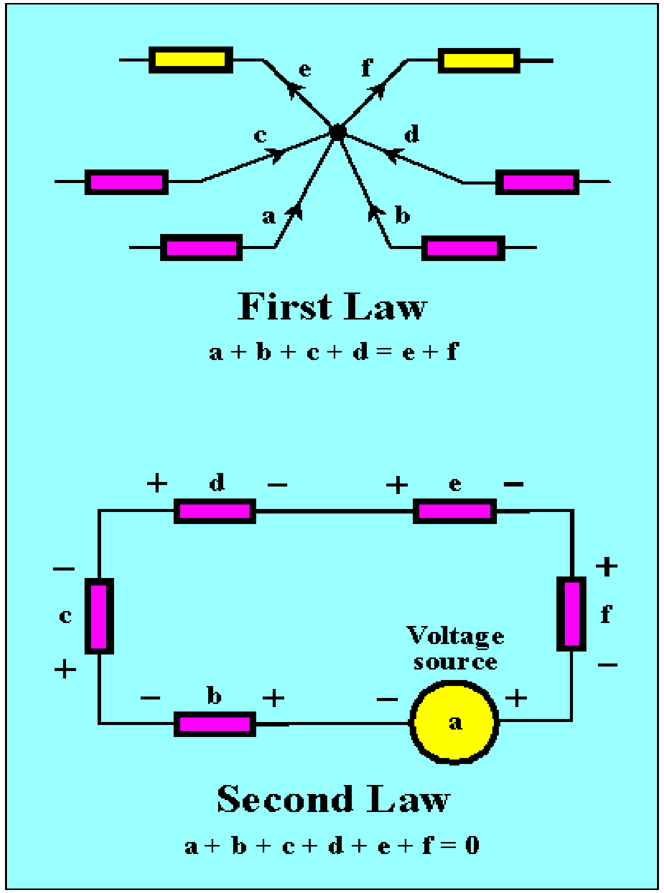
Kirchoff's laws

•Kirchoff's First Law(Current Law)

In any network of wires carrying currents, the algebraic sum of all he currents at a Point is zero.

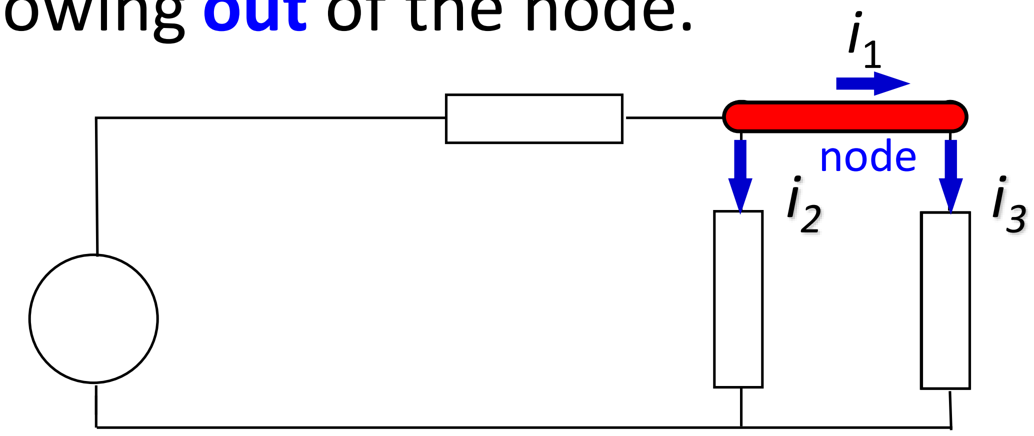
•Kirchoff's Second Law(Voltage Law)

In any closed circuit or mesh, the algebraic sum of EMF’s plus voltage drops the algebraic sum of product of current and resistance in the circuit is zero



Kirchhoff's Current Law

- The sum of currents flowing **into** a node must be balanced by the sum of currents flowing **out** of the node.



i_1 flows **into** the node

i_2 flows **out** of the node

i_3 flows **out** of the node

$$\boxed{i_1 = i_2 + i_3}$$

Gustav Kirchoff

was an 18th century German mathematician

$$\sum i = 0$$

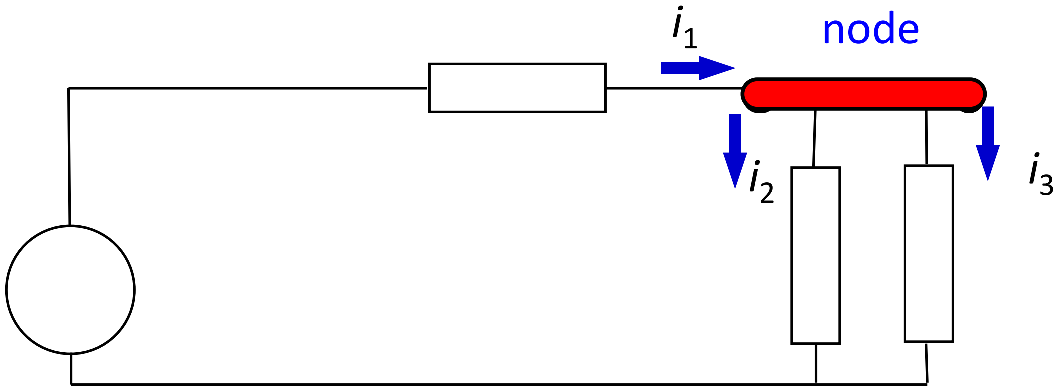
Kirchhoff’s Current Law

Kirchhoff’s Current Law:

$$i_1 = i_2 + i_3$$

- This equation can also be written in the following form:

$$i_1 - i_2 - i_3 = 0$$



A formal statement of **Kirchhoff’s Current Law**:

The sum of *all* the currents **entering** a node is zero.

(i_2 and i_3 **leave** the node, hence currents $-i_2$ and $-i_3$ **enter** the node.)

Kirchhoff’s Current Law

Sometimes Kirchhoff’s Current Law is abbreviated just by

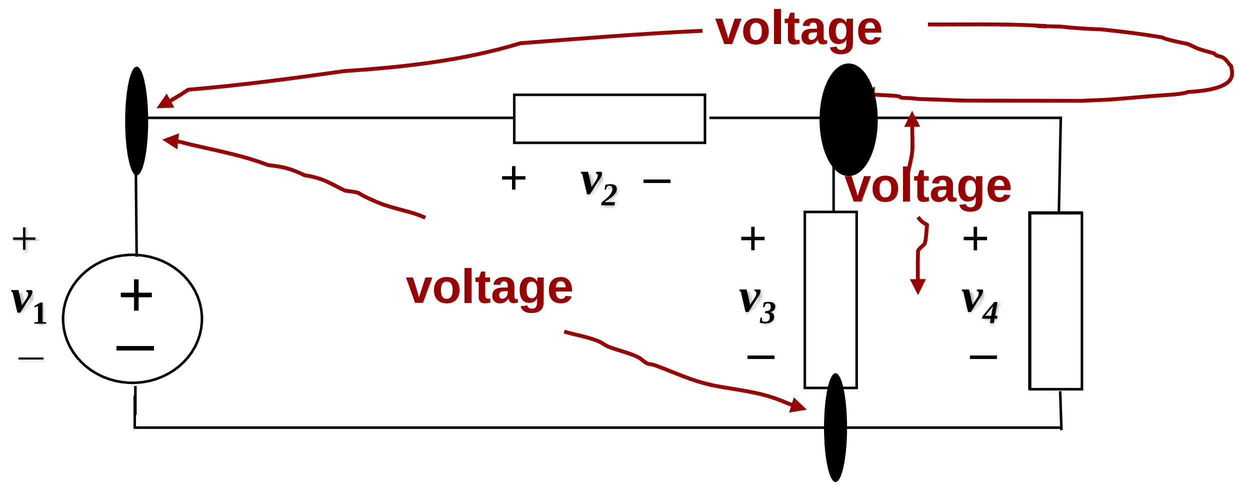
KCL

Review: Different ways to state KCL:

- ✓ The sum of *all* currents **entering** a node must be zero.
- ✓ The net current entering a node must be zero.

Kirchhoff's Voltage Law

- The voltage measured between any two nodes does not depend of the path taken.



Example of KVL: $v_1 = v_2 + v_3$

Similarly: $v_1 = v_2 + v_4$

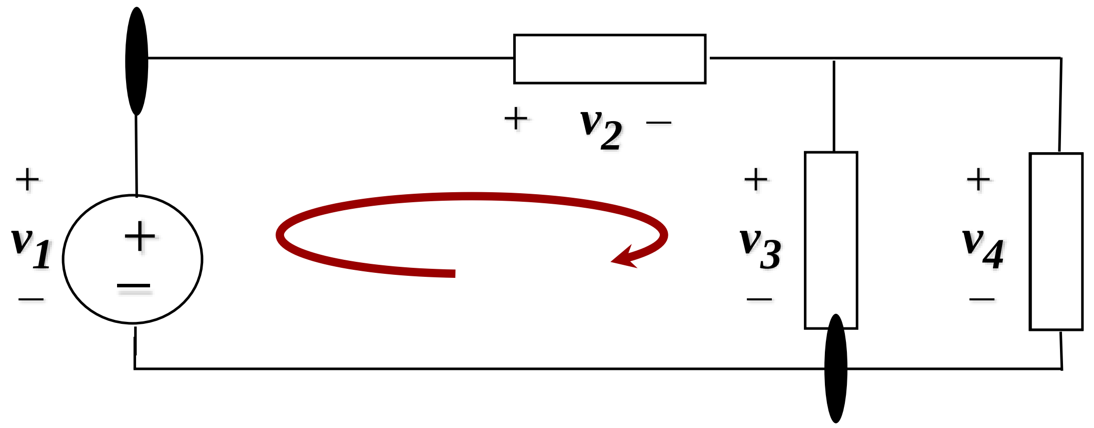
and: $v_3 = v_4$

Kirchhoff's Voltage Law

Kirchhoff's Voltage Law:

$$v_1 = v_2 + v_3$$

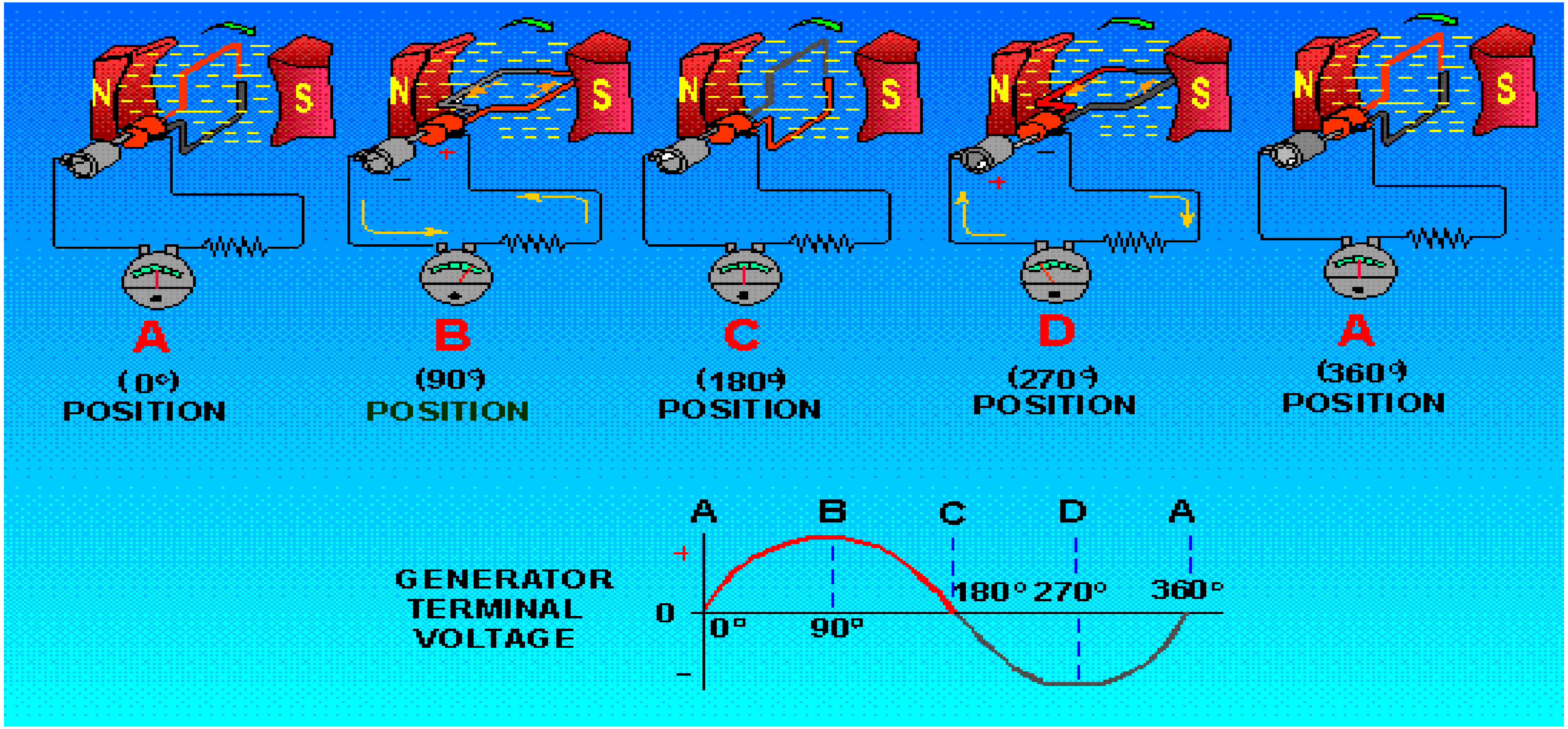
$$-v_1 + v_2 + v_3 = 0$$



A formal statement of **Kirchhoff's Voltage Law**:

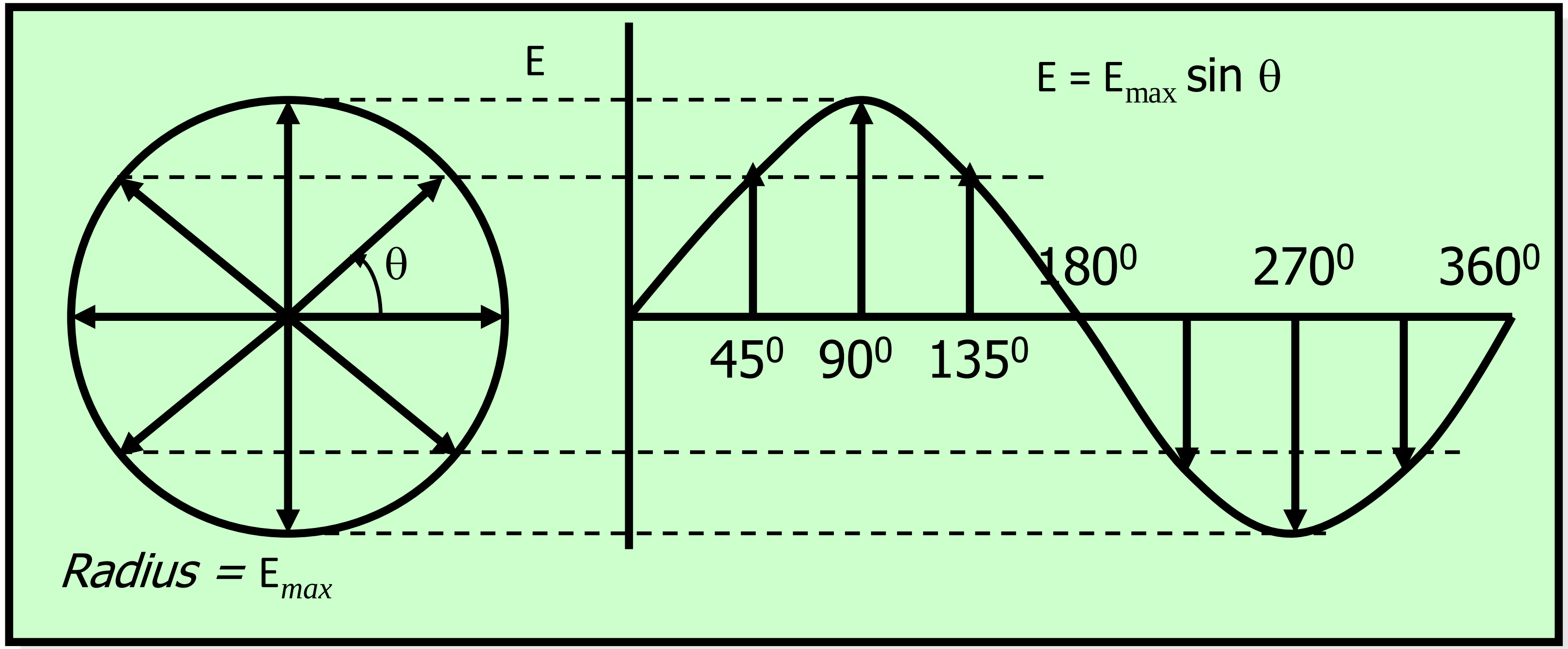
The sum of voltages around a **closed loop** is zero.

Generation of Alternating E.M.F

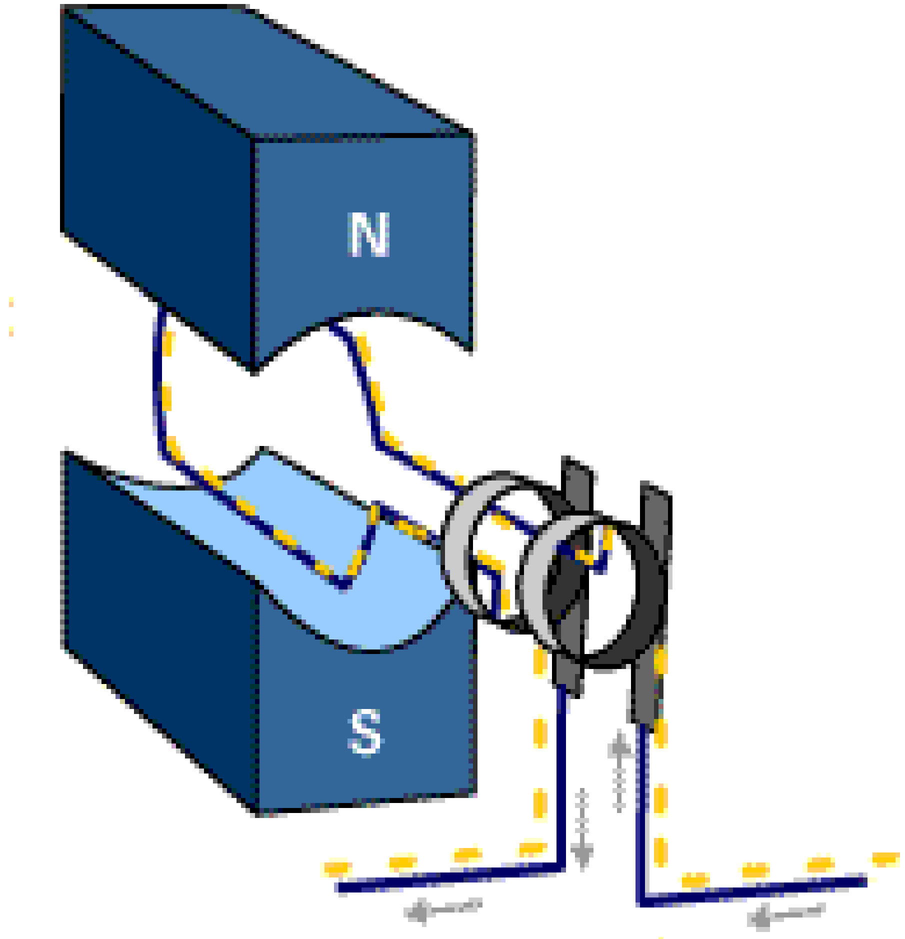


Rotating Vector Description

The coordinate of the emf at any instant is the value of E_{max} sin θ. Observe for incremental angles in steps of 45^0. Same is true for *i*.

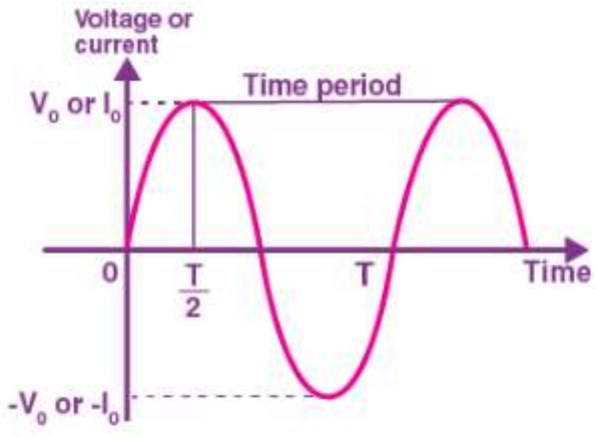


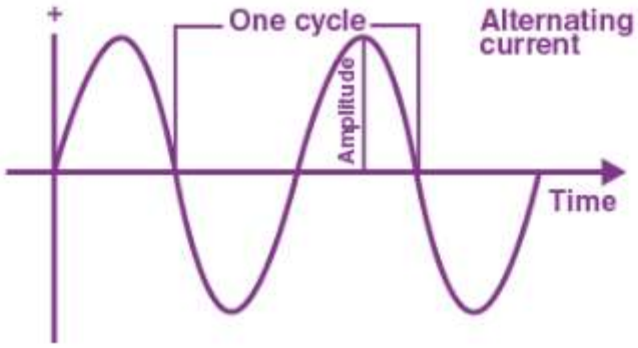
Generation of ALTERNATING E.M.F



Alternating Current Waveform

- The time interval between a definite value of two successive cycles is the period.
- The number of cycles or number of periods per second is frequency.
- The maximum value in both directions is the amplitude.





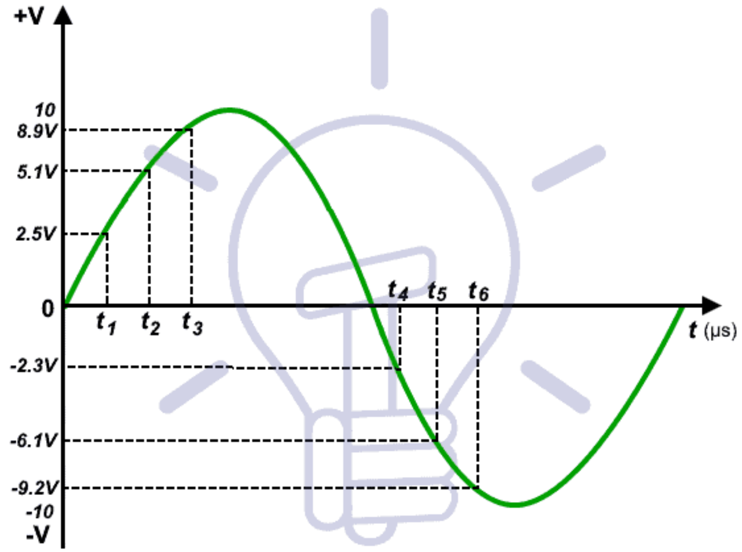
Alternating Current Waveform

Instantaneous Value : The value attained by an alternating quantity at any instant is known as instantaneous value. It is denoted by “i” and e.

Or

in other words, the value of an alternating current or voltage at any particular moment us called an instantaneous value.

Example: different instantaneous values of voltages or currents are shown at specific point and time period. The value of instantaneous current or voltage are “+” in the positive cycle and “-” in negative cycle in a sinusoidal wave. The curves are showing the values of different instantaneous voltages while the same curve can be drawn for current as well. In the fig 7, the value of instantaneous voltages are 2.5V at 1µs, 5.1V at 2µs, 8.9V at 3µs. While it is -2.3V at 4µs, -6.1V at 5µs and -9.2V at 6µs.

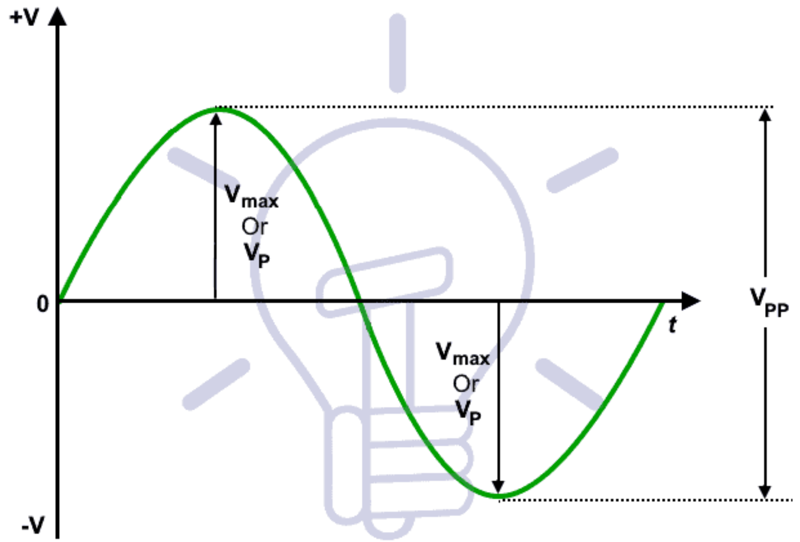


Alternating Current Waveform

Peak Voltage or Maximum Voltage Value: Peak value is also known as Maximum Value, Crest Value or Amplitude. It is the maximum value of alternating current or voltage from the "0" position no matter positive or negative half cycle in a sinusoidal wave as shown in fig. Its expressed as I_M and E_M or V_P and I_M.

Or

In other words, It is the value of voltage or current at the positive or the negative maximum (peaks) with respect to zero. In simple words, it is the instantaneous value with maximum intensity.



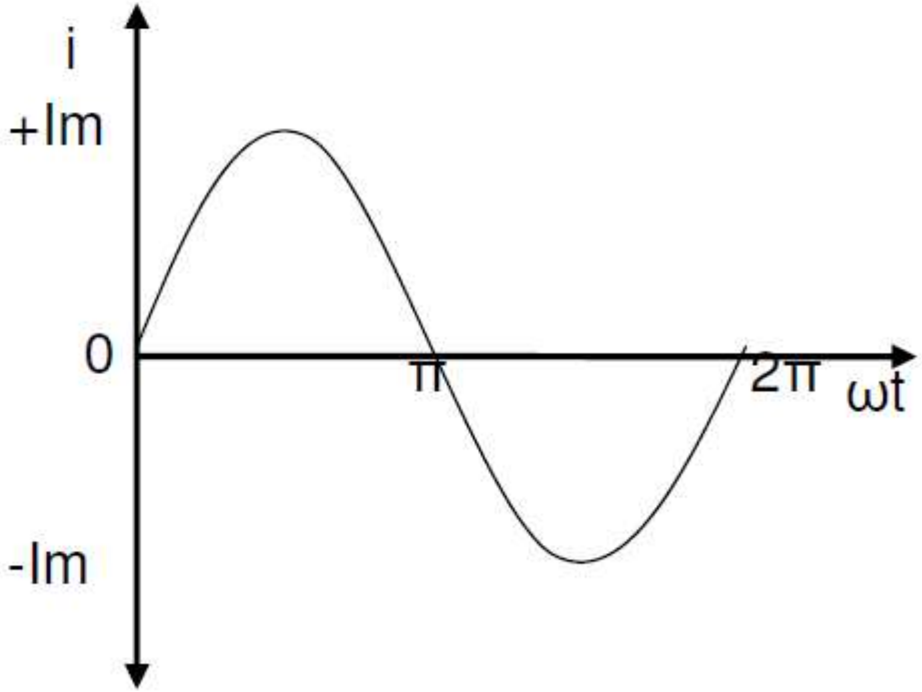
Average value of a sinusoidal current

- The average value is usually defined as the average of the instantaneous values of alternating current over a complete cycle. The positive half cycle of asymmetrical waves such as a sinusoidal voltage or current waveform will be equal to the negative half cycle. This implies that the average value after the completion of a full cycle is equal to zero.

- Since, both the cycles do some work the average value is obtained by avoiding the signs. Therefore, the average value of alternating quantities of sinusoidal waves can be considered by taking the positive cycle only.

Average value of a sinusoidal current

$$\text{Average value} = \frac{\text{Area under one half cycle}}{\text{Base}}$$



$$i = I_m \sin \omega t$$

$$I_{av} = \frac{1}{\pi}\int_0^{\pi} i\,d(\omega t)$$

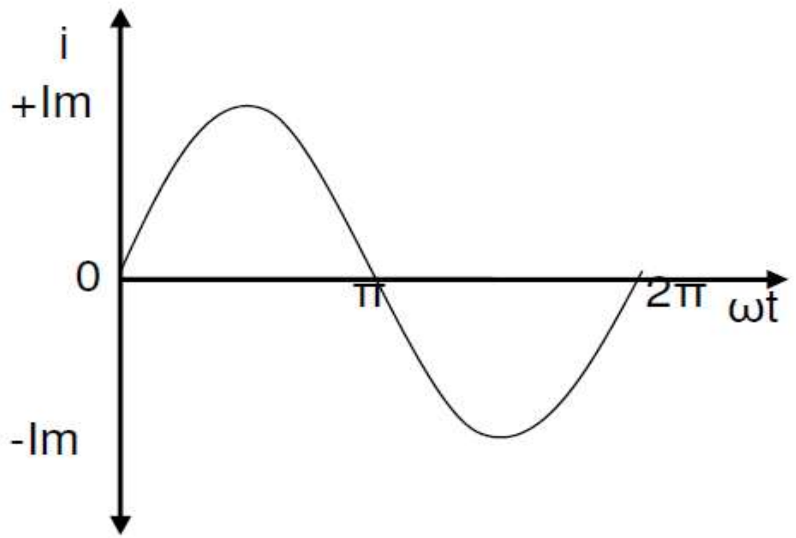
$$I_{av} = \frac{1}{\pi}\int_0^{\pi} I_m \sin \omega t\,d(\omega t)$$

$$I_{av} = \frac{2I_m}{\pi} = 0.637\,I_m$$

RMS value of a sinusoidal current

RMS value is defined as the square root of means of squares of instantaneous values. It can also be described as the amount of AC power that generates the same heating effect as an equivalent DC power.

$$RMS = \sqrt{\frac{\text{Area under squared curve}}{base}}$$



$$i = I_m \sin \omega t$$

$$I_{rms} = \sqrt{\frac{1}{2\pi}\int_0^{2\pi} i^2 d(\omega t)}$$

$$I_{rms} = \sqrt{\frac{1}{\pi}\int_0^{\pi} I_m^2 \sin^2 \omega t d(\omega t)}$$

$$I_{rms} = \frac{I_m}{\sqrt{2}} = 0.707 I_m$$

Peak factor & Form factor

Peak Factor:

- It is also known as Crest Factor or Amplitude Factor.
- It is the ratio between maximum value and RMS value of an alternating wave.

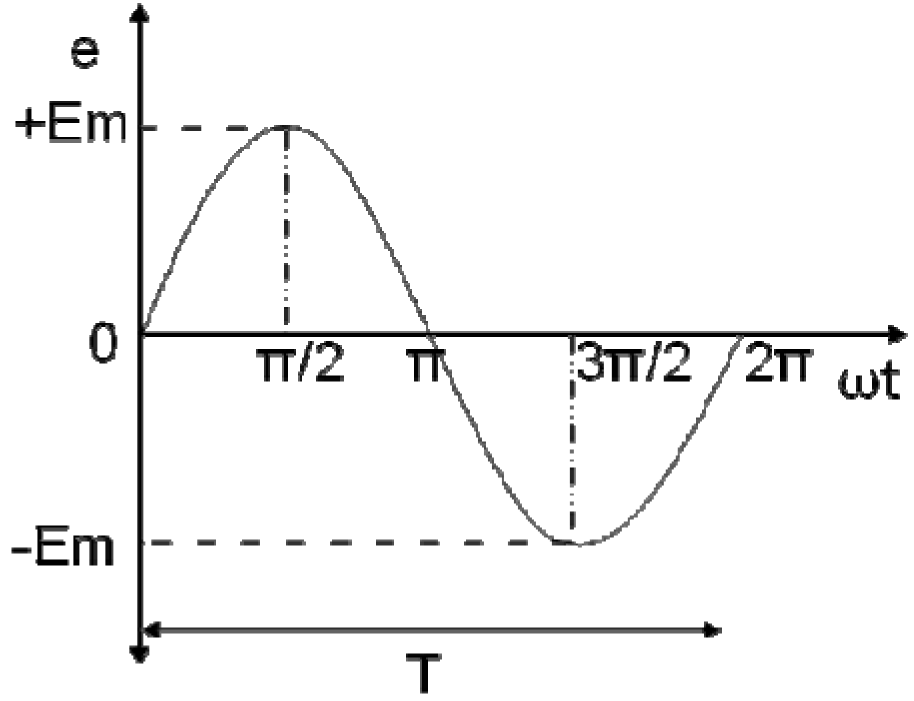
$$\textbf{Peak Factor} = \frac{\text{Maximum Value}}{\text{R.M.S Value}}$$

Form Factor:

- The ratio between RMS value and Average value of an alternating quantity (Current or Voltage) is known as Form Factor.

$$\textbf{Form Factor} = \frac{\text{RMS Value}}{\text{Average Value}}$$

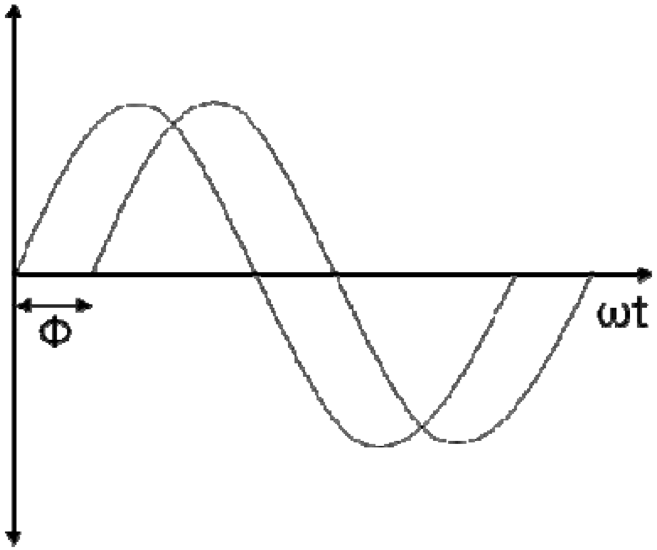
Phase



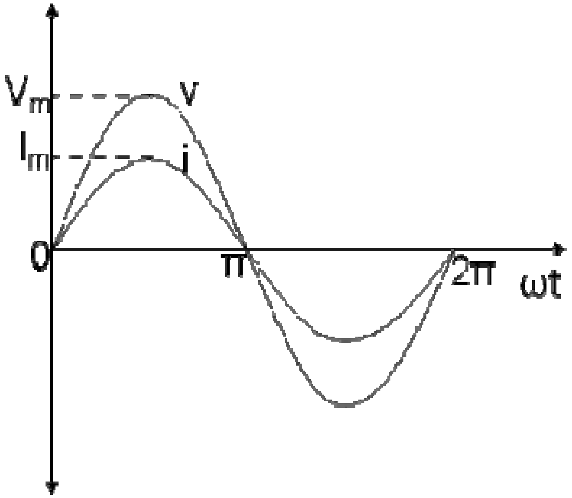
Phase of $+E_m$ is $\pi/2$ rad or $T/4$ sec

Phase of $-E_m$ is $3\pi/2$ rad or $3T/4$ sec

Phase Difference



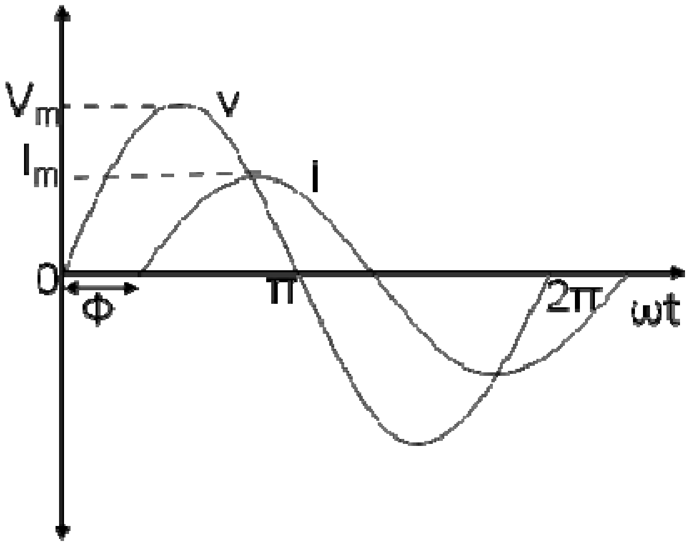
In Phase

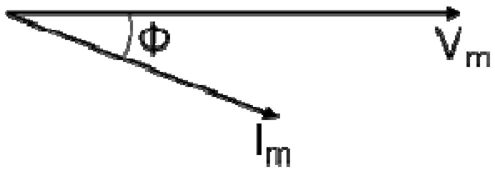


$$v = V_m \sin \omega t$$

$$i = I_m \sin \omega t$$

Lagging

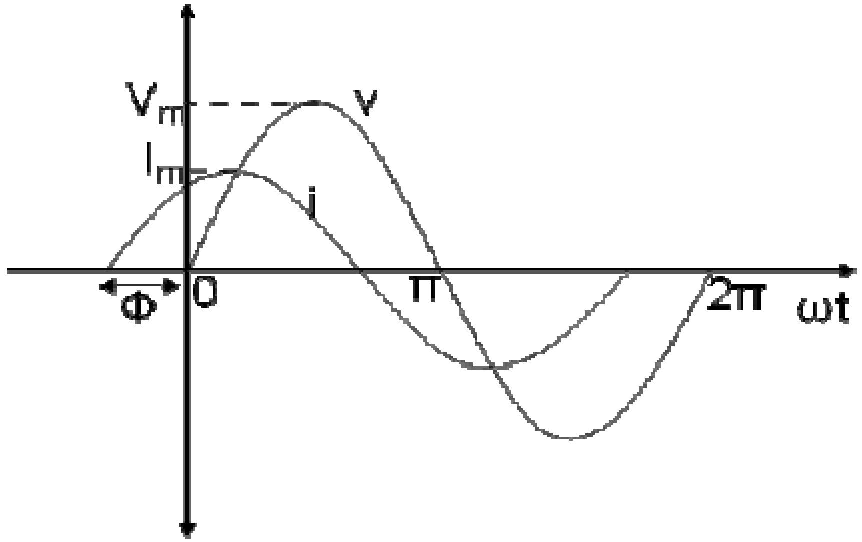


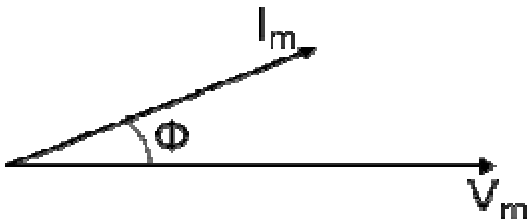


$$v = V_m \sin \omega t$$

$$i = I_m \sin(\omega t - \Phi)$$

Leading





$$v = V_m \sin \omega t$$

$$i = I_m \sin(\omega t + \Phi)$$

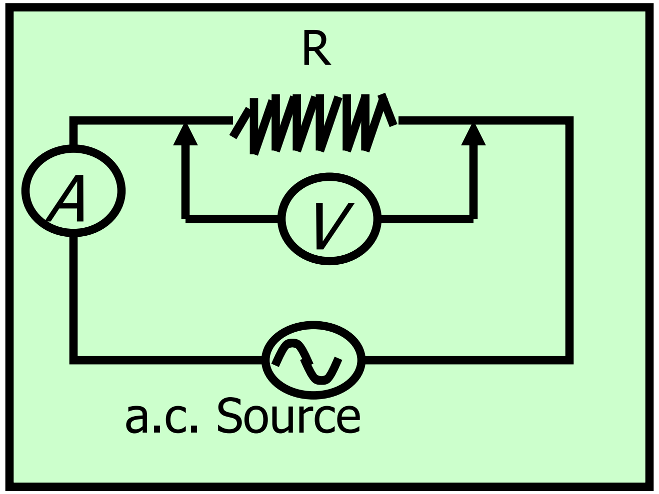
AC circuit with a pure resistance

$$v = V_m \sin \omega t \qquad \text{----------- (1)}$$

$$i = \frac{v}{R} = \frac{V_m \sin \omega t}{R}$$

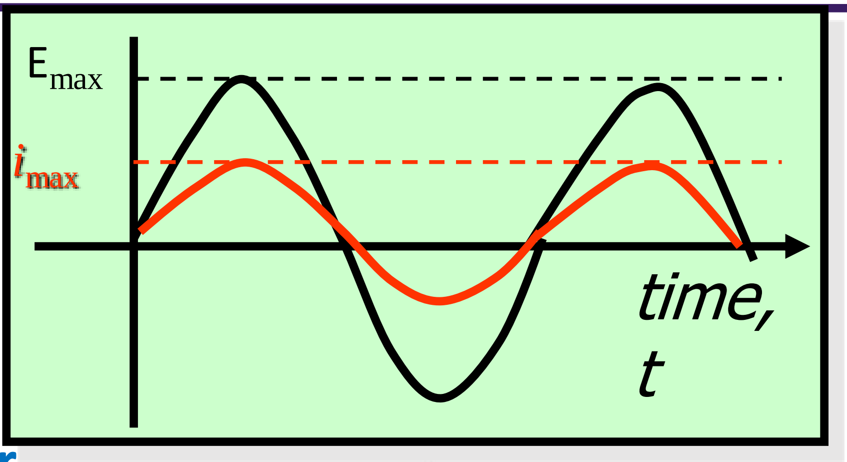
$$i = I_m \sin \omega t \qquad \text{---------------(2)}$$

Where $I_m = \dfrac{V_m}{R}$



From equation (1) and (2) we conclude that in a pure resistive circuit, the voltage and current are in phase.

AC circuit with a pure resistance



Instantaneous power

$$p = vi$$

$$p = (V_m \sin \omega t)(I_m \sin \omega t)$$

$$p = V_m I_m \sin^2 \omega t$$

$$p = \frac{V_m I_m}{2}(1 - \cos 2\omega t)$$

$$p = \frac{V_m I_m}{2} - \frac{V_m I_m}{2}\cos 2\omega t$$

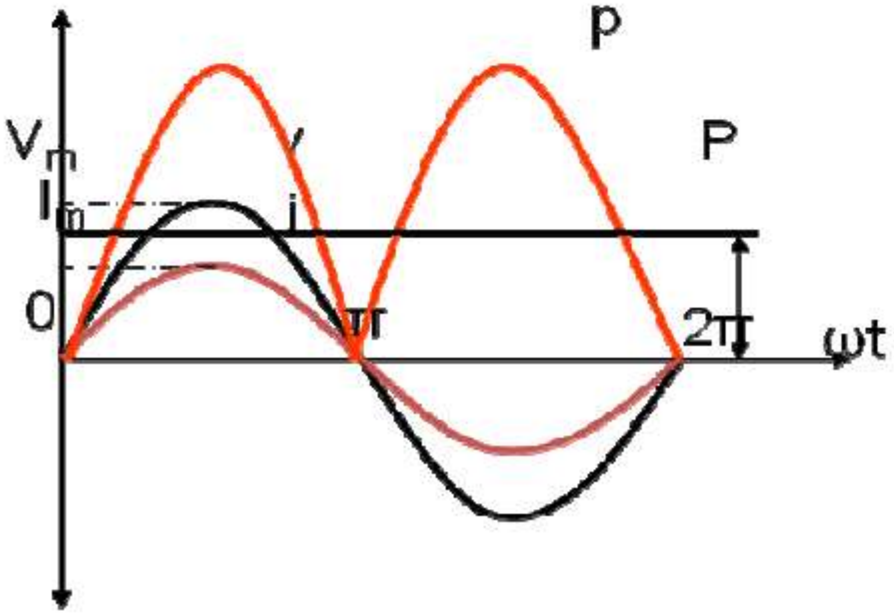
Average power

$$P=\frac{1}{2\pi}\int_0^{2\pi}\left[\frac{V_mI_m}{2}-\frac{V_mI_m}{2}\cos 2\omega t\right]d\omega t$$

$$P=\frac{V_mI_m}{2}-\frac{1}{2\pi}\int_0^{2\pi}\left[\frac{V_mI_m}{2}\cos 2\omega t\right]d\omega t$$

$$P=\frac{V_mI_m}{2}=\frac{V_m}{\sqrt{2}}\frac{I_m}{\sqrt{2}}$$

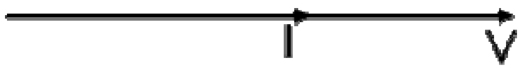
$$P=V.I$$

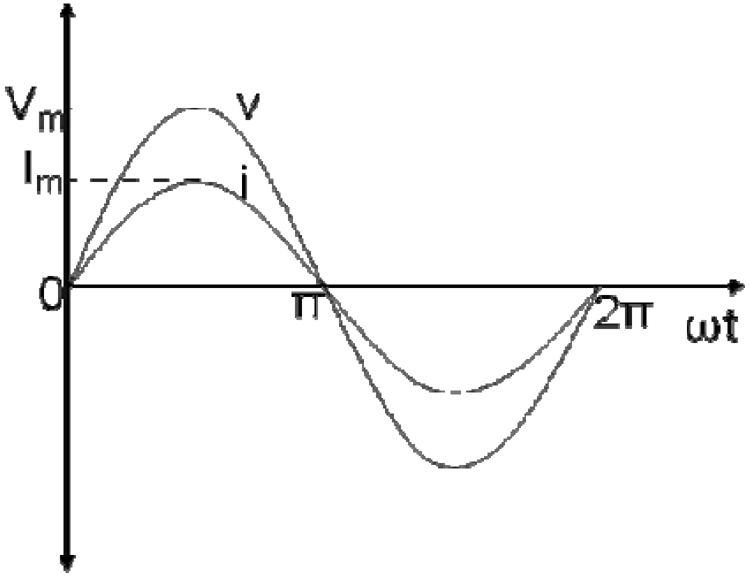


Phasor Algebra for a pure resistive circuit

$$\overline{V} = V\angle 0^\circ = V + j0$$

$$\overline{I} = \frac{\overline{V}}{R} = \frac{V + j0}{R} = I + j0 = I\angle 0^\circ$$





AC circuit with a pure inductance

$$v = L\frac{di}{dt}$$

$$V_m \sin \omega t = L\frac{di}{dt}$$

$$di = \frac{V_m}{L}\sin \omega t dt$$

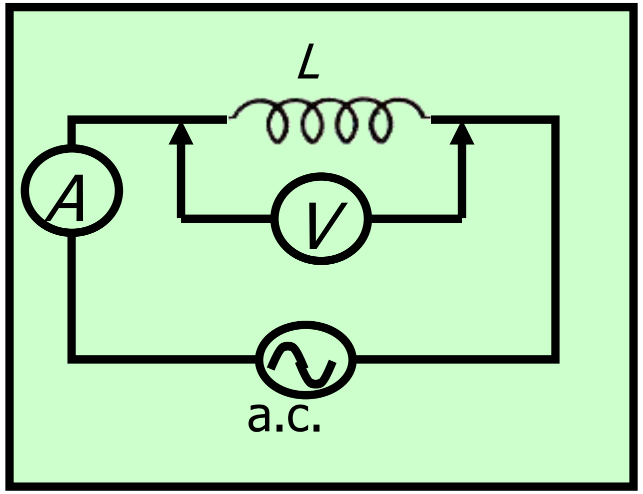
$$i = \frac{V_m}{L}\int \sin \omega t dt$$

$$i = \frac{V_m}{\omega L}(-\cos \omega t)$$

$$i = \frac{V_m}{\omega L}\sin(\omega t - \pi/2)$$

$$i = I_m \sin(\omega t - \pi/2)$$

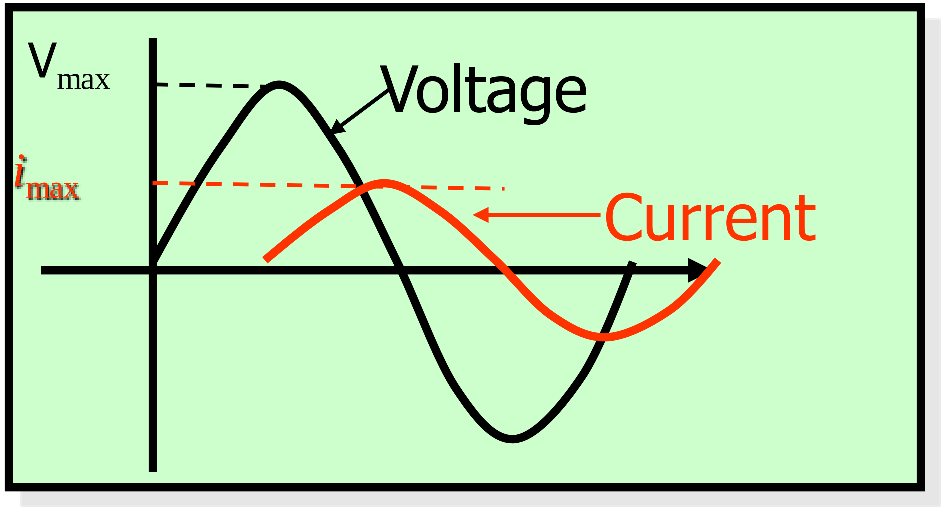
Where $I_m = \frac{V_m}{\omega L}$



$$v = V_m \sin \omega t \quad \text{---------- (1)}$$

$$i = I_m \sin(\omega t - \pi/2) \quad \text{------------------(2)}$$

AC circuit with a pure inductance



Instantaneous power

$$p = vi$$

$$p = (V_m \sin \omega t)(I_m \sin(\omega t - \pi / 2))$$

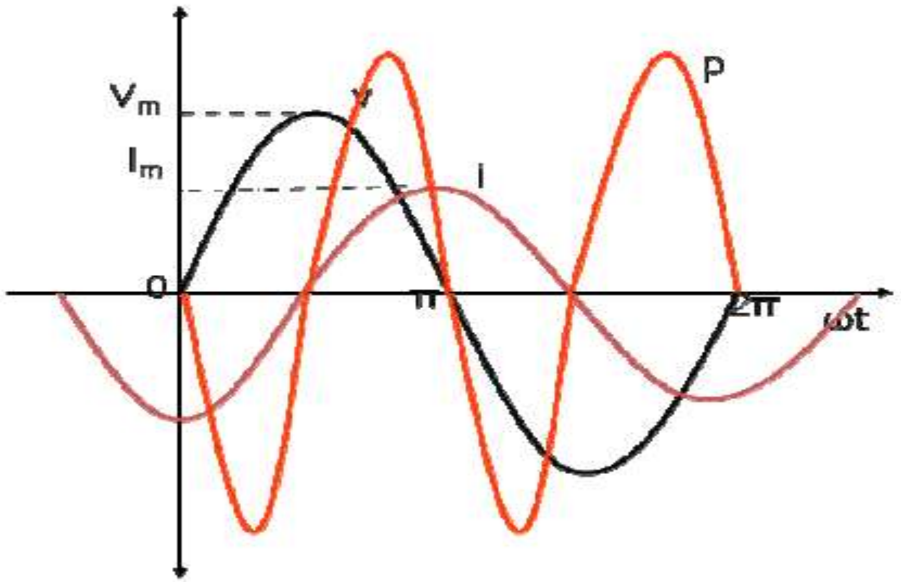
$$p = -V_m I_m \sin \omega t \cos \omega t$$

$$p = -\frac{V_m I_m}{2} \sin 2\omega t$$

Average power

$$P = \frac{1}{2\pi}\int_0^{2\pi} -\frac{V_m I_m}{2}\sin 2\omega t \, d\omega t$$

$$P = 0$$



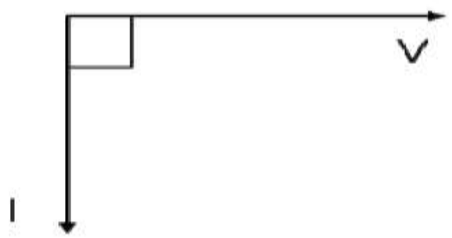
Phasor Algebra for a pure inductive circuit

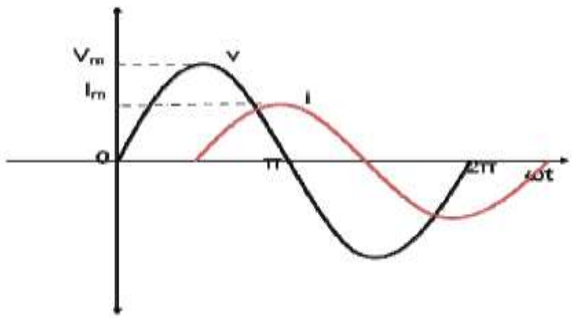
$$\overline{V} = V\angle 0^\circ = V + j0$$

$$\overline{I} = I\angle -90^\circ = 0 - jI$$

$$\frac{\overline{V}}{\overline{I}} = \frac{V\angle 0^\circ}{I\angle -90} = X_L\angle 90^\circ$$

$$\overline{V} = \overline{I}(jX_L)$$





AC circuit with a pure capacitive

$$q = Cv$$

$$q = CV_m \sin \omega t$$

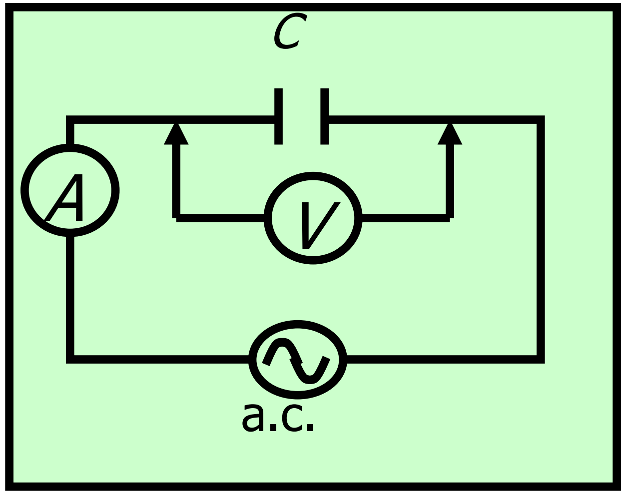
$$i = \frac{dq}{dt}$$

$$i = CV_m \omega \cos \omega t$$

$$i = \omega CV_m \sin(\omega t + \pi/2)$$

$$i = I_m \sin(\omega t + \pi/2)$$

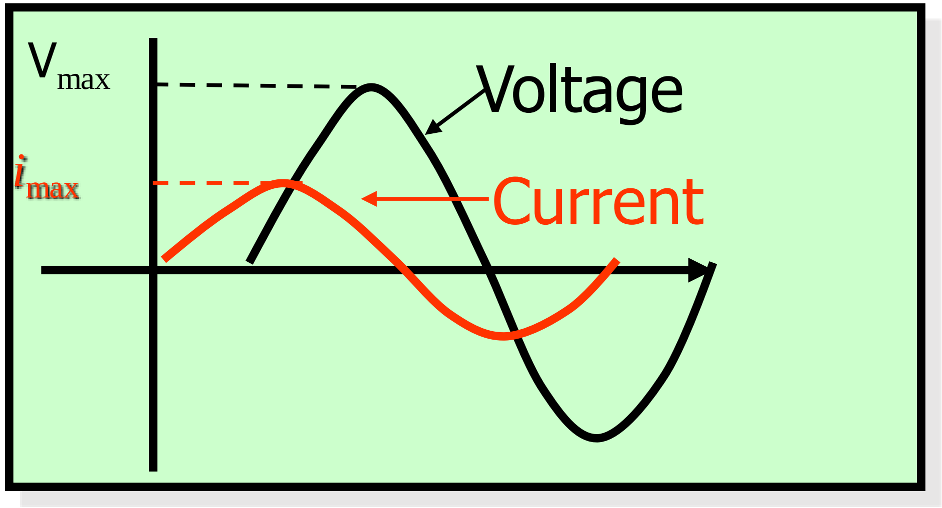
Where $I_m = \omega CV_m$



$$v = V_m \sin \omega t \quad \text{----------} \ (1)$$

$$i = I_m \sin(\omega t + \pi/2)$$

AC circuit with a pure capacitive



Instantaneous power

$$p = vi$$

$$p = (V_m \sin \omega t)(I_m \sin(\omega t + \pi / 2))$$

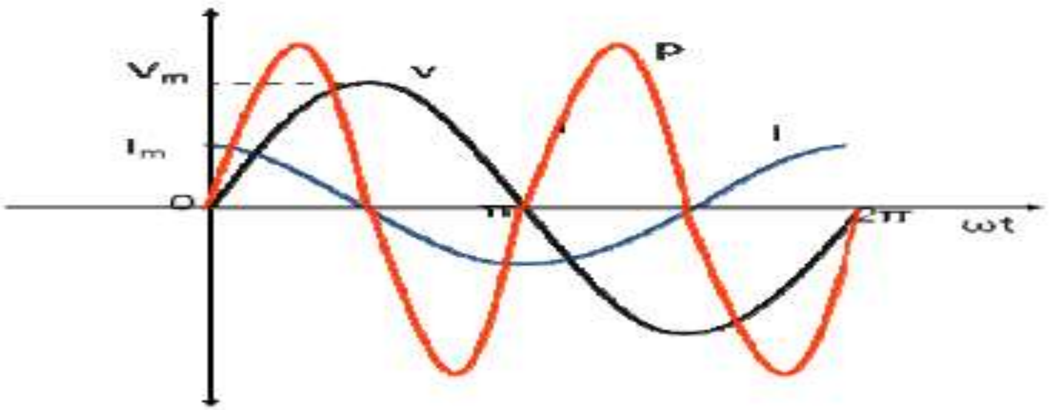
$$p = V_m I_m \sin \omega t \cos \omega t$$

$$p = \frac{V_m I_m}{2} \sin 2\omega t$$

Average power

$$P = \frac{1}{2\pi}\int_0^{2\pi}\frac{V_m I_m}{2}\sin 2\omega t \, d\omega t$$

$$P = 0$$



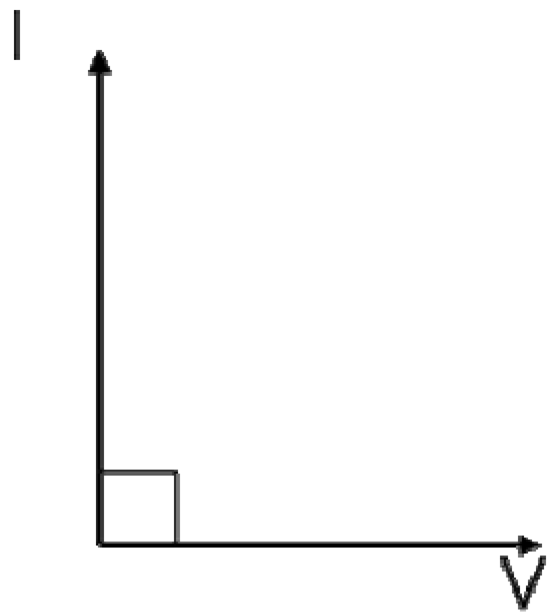
Phasor Algebra for a pure capacitive circuit

$$\overline{V} = V\angle 0^\circ = V + j0$$

$$\overline{I} = I\angle 90^\circ = 0 + jI$$

$$\frac{\overline{V}}{\overline{I}} = \frac{V\angle 0^\circ}{I\angle 90} = X_C\angle -90^\circ$$

$$\overline{V} = \overline{I}(-jX_C)$$



Problem

An alternating current i is given by

$i = 141.4 \sin 314t$

Find i) The maximum value

ii) Frequency

iii) Time Period

iv) The instantaneous value when t=3ms

Problem on R Circuit

An ac circuit consists of a pure resistance of 10 and is connected

to an ac supply of 230 V, 50 Hz.

Calculate the

(i) current

(ii) power consumed and

(iii)equations for voltage and current.

Problem on L Circuit

A pure inductive coil allows a current of 10A to flow from a 230V, 50 Hz supply. Find

(i) Inductance of the coil

(ii) power absorbed and

(iii) equations for voltage and current.

Problem on Capacitor Circuit

A 318μF capacitor is connected across a 230V, 50 Hz system.

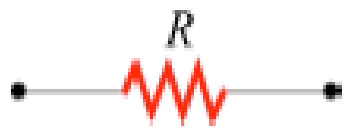
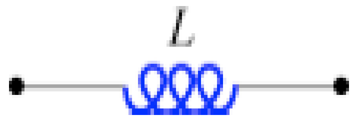
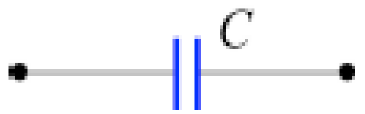
Find

(i) the capacitive reactance

(ii) rms value of current and

(iii) equations for voltage and current.

Summary of R, L and C

Circuit Elements	Resistance /Reactance	Current Amplitude	Phase constant ϕ
	R	$I_{R0} = \frac{V_0}{R}$	0
	$X_L = \omega L$	$I_{L0} = \frac{V_0}{X_L}$	$\pi / 2$ current lags voltage by $90°$
	$X_C = \frac{1}{\omega C}$	$I_{C0} = \frac{V_0}{X_C}$	$-\pi / 2$ current leads voltage by $90°$

Reference

- https://www.electricaltechnology.org/2019/05/rms-value-average-value-peak-value-instantiations-value-form-factor-peak-factor.html

- https://byjus.com/jee/alternating-current/#:~:text=An%20alternating%20current%20can%20be,single%20direction%20as%20shown%20below.

Summary

- Circuit elements are classified active and passive elements
- Active elements are capable of generating electrical energy
- Passive elements are incapable of generating electrical energy
- Basic active elements are voltage and current sources and passive circuit elements are the resistance, inductance and capacitance
- Ohms law states that “Voltage V across a resistor is directly proportional to the current I flowing through the resistor”
- Kirchoff's First Law States that “In any network of wires carrying currents, the algebraic sum of all he currents at a Point is zero”
- Kirchoff's Second Law states that “Algebraic sum of the voltages across any set of branches in a closed loop is zero”