Lecture-2

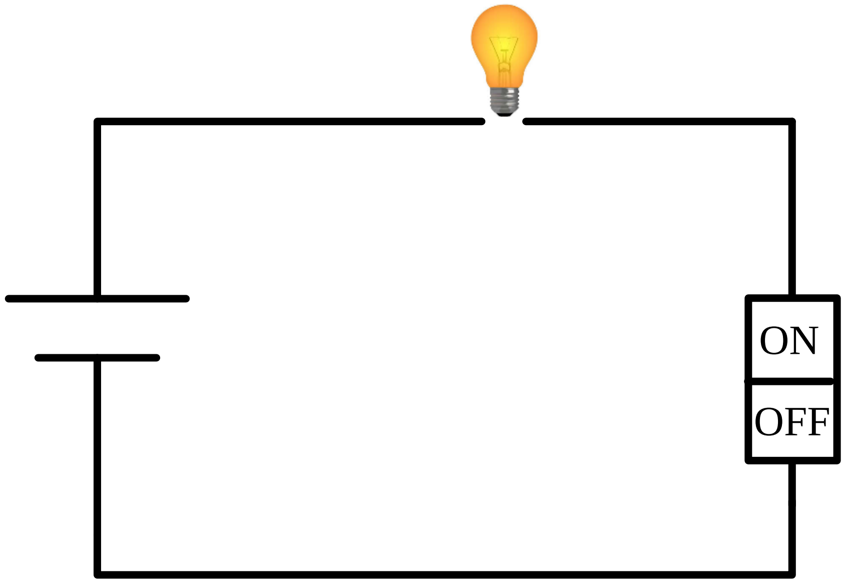
On

INTRODUCTION TO ELECTRICAL ENGINEERING (ESO203)

- Electric charge.
- Current.
- Voltage.
- Power and energy.
- Resistance and Conductance.

ELECTRIC CURRENT

- The battery acts as a source of electromotive force (emf).
- Connecting a conducting wire to a battery causes the electrons to move in one direction.
- This motion of charges create an electric current.
- Although, the current in a metallic conductor is due to the flow of electrons it is conventional to take the current as the net flow of positive charge in a direction opposite to the flow of electrons. (Benjamin Franklin and Joseph Thompson)



ELECTRIC CURRENT (Cont…)

- Hence, electric current can be defined as the time rate of change of charge.
- Mathematically, the relationship between charge, q and current, i can be expressed as,

$$\boxed{i \triangleq \frac{dq}{dt}}$$

- The unit of current is ampere (A), where 1 ampere = 1 coulomb / second.
- The charge transferred between time t_0 and t is evaluated by integrating the above equation.

$$\boxed{Q \triangleq \int_{t_0}^{t} i \, dt}$$

ELECTRIC CURRENT (Cont…)

❑ Example:

- The total charge entering a terminal is given by q=5tsin4πt mC. Calculate the current at t=0.5 s?

❑ Solution:

$$i = \frac{dq}{dt} = \frac{d}{dt}(5t \sin 4\pi t) = 5 \sin 4\pi t + 20\pi t \cos 4\pi t$$

At t=0.5

$$i = 5 \sin 2\pi + 10\pi \cos 2\pi = 0 + 10\pi = 31.42\text{mA}.$$

❑ Example:

- Determine the total charge entering a terminal between t=1s and t=2s if the current passing the terminal is i=(3t^2-t) A?

❑ Solution:

$$Q = \int_{t=1}^{2} i dt$$

$$= \int_{t=1}^{2} (3t^2 - t) dt$$

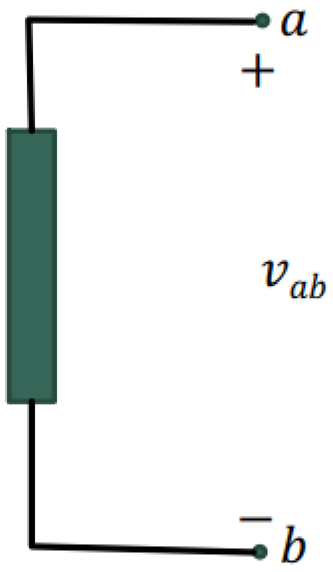
$$= \left(t^3 - \frac{t^2}{2}\right)\Big|_1^2$$

$$= 5.5\text{C}$$

VOLTAGE

- Energy transfer or work is needed to move electrons in a particular direction.
- This work is performed by an external emf generally provided by the battery.
- The emf is also known as voltage or potential difference.
- Voltage is defined as the energy required to move a unit charge through an element.
- It is expressed mathematically as,

$$\boxed{v_{ab} \triangleq \frac{dw}{dq}}$$



- Here, v_{ab} is the voltage between two points a and b, w is the energy in joules (J), and q is the charge in coulombs (C).

VOLTAGE (Cont..)

- Voltage is measured in volts (V).
- Here, 1 volt = 1 joule / coulomb = 1 newton-meter / coulomb.
- The +ve and –ve signs are used to represent the voltage polarity or the reference direction.
- It follows logically that v_{ab} = -v_{ba}.
- Current and voltage are considered as the two basic variables in the electric circuit.

POWER AND ENERGY

- Although current and voltage are the two basic variables in an electric circuit, they are not sufficient by themselves.
- For practical purposes, we need to know how much power an electric device can handle.
- When we pay our bills to the electric utility companies, we are paying for the electric energy consumed over a certain period of time.
- Thus, power and energy calculations are also important in circuit analysis.

POWER AND ENERGY (Cont…)

- To relate power and energy to voltage and current, we recall from physics the following:
- Power is the time rate of expending or absorbing energy and can be expressed as

$$p \triangleq \frac{dw}{dt}$$

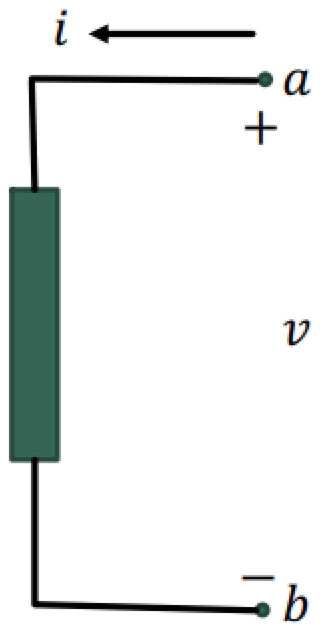
- Power, p, is measured in watts (W), w is the energy in joules (J), and t is the time in seconds (s).
- Using the previous equations:-

$$p = \frac{dw}{dt} = \frac{dw}{dq} \cdot \frac{dq}{dt} = v.i$$

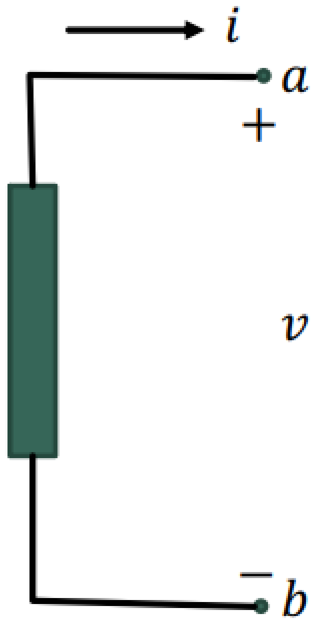
- Thus, the power absorbed or supplied by an element is the product of the voltage across the element and the current through it.
- The power p in the above equation is a time-varying quantity and is called the **instantaneous power**.

POWER AND ENERGY (Cont…)

- If the power has a +ve sign, power is being delivered to or absorbed by the element.
- If, on the other hand, the power has a -ve sign, power is being supplied by the element.
- Current direction and voltage polarity play a major role in determining the sign of power.



$$p = v.i$$



$$p = -v.i$$

POWER AND ENERGY (Cont…)

- It is therefore important that we pay attention to the relationship between current and voltage.
- The voltage polarity and current direction must conform with those shown in in the previous figure in order for the power to have a positive sign.
- This is known as the **passive sign** convention.
- Passive sign convention is satisfied when the current enters through the positive terminal of an element and $p = vi$.
- If the current enters through the negative terminal, $p = -vi$.

POWER AND ENERGY (Cont…)

- Law of conservation of energy must be obeyed in any electric circuit.
- For this reason, the algebraic sum of power in a circuit, at any instant of time, must be zero:

$$\sum p = 0$$

- This again confirms the fact that the total power supplied to the circuit must balance the total power absorbed.
- Using energy power equation, the energy absorbed or supplied by an element from time t_0 to time t is

$$w = \int_{t_0}^{t} p\,dt = \int_{t_0}^{t} vi\,dt$$

- Energy is, thus, defined as the capacity to do work and is measured in joules (J).

❑ Example:

- An energy source forces a constant current of 2 A for 10 s to flow through a light bulb. If 2.3 kJ is given off in the form of light and heat energy, calculate the voltage drop across the bulb.

❑ Solution:

The total charge is

$$\Delta q = i\Delta t = 2 * 10 = 20\text{C}$$

The voltage drop is

$$v = \frac{\Delta w}{\Delta q} = \frac{2.3 * 10^3}{20} = 115\text{V}$$

POWER AND ENERGY (Cont…)

❑ Example:

- Find the power delivered to an element at $t = 3\text{ms}$ if the current entering its positive terminal is $i = 5\cos 60\pi t$ A and the voltage is $v = 3i$?

❑ Solution:

The voltage is

$$v = 3i = 15\cos 60\pi t$$

Hence, power

$$p = vi = 75\cos^2 60\pi t \text{ W}$$

At t = 3ms

Power $p = 75\cos^2(60\pi * 3 * 10^{-3}) = 53.48\text{ W}$

POWER AND ENERGY (Cont…)

Example:

- For the previous problem find the power at t = 3ms if the voltage is v = 3di/dt?

Solution:

The voltage is

$$v = 3\frac{di}{dt} = 3(-60\pi)5\sin 60\pi t = -900\pi \sin 60\pi t$$

Hence, power

$$p = vi = -4500 \sin 60\pi t \cos 60\pi t \text{ W}$$

At t = 3ms

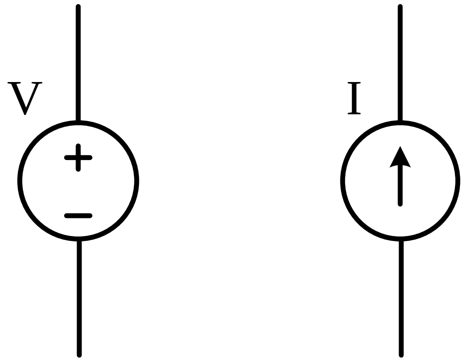
Power $p = -4500 \sin(60\pi * 3 * 10^{-3}) \cos(60\pi * 3 * 10^{-3}) = -6.396 \text{ kW}$

CIRCUIT ELEMENTS

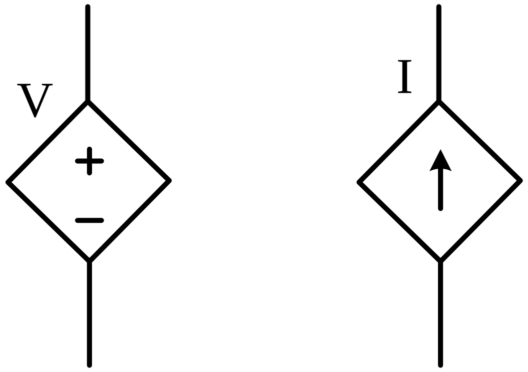
- There are two types of elements found in electric circuits: **passive elements** and **active elements**.
- An active element is capable of generating energy while a passive element is not.
- Examples of passive elements are resistors, capacitors, and inductors.
- Typical active elements include generators, batteries, and operational amplifiers.
- The most important active elements are voltage or current sources that generally deliver power to the circuit connected to them.

CIRCUIT ELEMENTS (Cont…)

- There are two kinds of sources: independent and dependent sources.
- An ideal independent source provides a specified voltage or current that is completely independent of other circuit elements.
- An ideal independent voltage source delivers to the circuit whatever current is necessary to maintain its terminal voltage.
- Physical sources such as batteries may be regarded as approximations to ideal voltage sources.
- In an ideal dependent (or controlled) source, source quantity is controlled by another voltage or current.



Independent sources



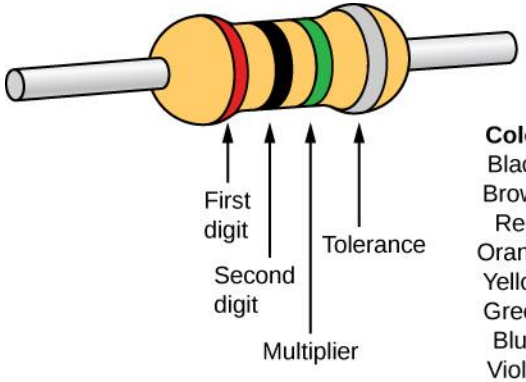
Dependent sources

CIRCUIT ELEMENTS (Cont…)

❑ Resistance:

- A physical property or ability of an element to resist the current, is known as resistance and is represented by the symbol R, and is measured in ohms.
- The resistance of any material with a uniform cross-sectional area A depends on A and its length, l.
- It is expressed mathematically as, $\boxed{R = \rho l/A}$

  where, ρ is known as the resistivity of the material in ohm-meters.
- The common circuit symbol used for a resistor is as shown in the figure below:



$R = 20 \times 10^5\ \Omega \pm 10\%$
$R = 2.0M\ \Omega \pm 0.2M\ \Omega$

Color	Digit	Multiplier
Black	0	10^0
Brown	1	10^1
Red	2	10^2
Orange	3	10^3
Yellow	4	10^4
Green	5	10^5
Blue	6	10^6
Violet	7	10^7
Gray	8	10^8
White	9	10^9

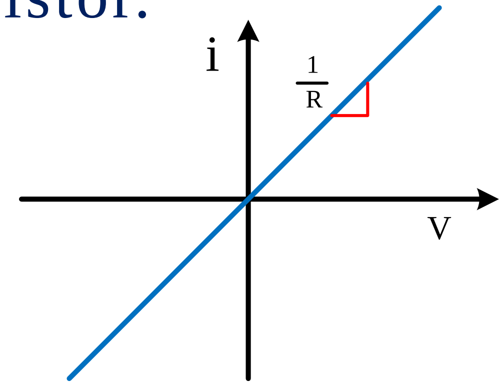
Tolerance

Gold	5%
Silver	10%

CIRCUIT ELEMENTS (Cont…)

❑Resistance (Cont..):

- Georg Simon Ohm (1787–1854), a German physicist, developed the relationship between current and voltage for a resistor.
- This relationship is known as Ohm's law.
- Ohm's law states that the voltage v across a resistor is directly proportional to the current i flowing through the resistor.



- Ohm defined the constant of proportionality for a resistor to be the resistance, R.

$$v = iR$$

- From the above equation,

$$R = \frac{v}{i} \quad \Rightarrow \quad 1\Omega = 1\frac{\text{V}}{\text{A}}$$

CIRCUIT ELEMENTS (Cont…)

❑Resistance (Cont..):

- The value of R can range from zero to infinity.
- An element with $R = 0$ is called a short circuit.
- For a short circuit,

$$\boxed{v = iR = 0}$$

- The short circuit voltage across an element is zero.
- Similarly, an element with $R = \infty$ is known as open circuit.
- For an open circuit,

$$\boxed{i = \lim_{R \to \infty} \frac{v}{R} = 0}$$

- Thus, for an open circuit the current through the element is zero.

CIRCUIT ELEMENTS (Cont…)

❑Conductance:

- Another useful element in circuit analysis is the reciprocal of resistance R, known as conductance G.
- It is defined as a measure of how well an element can conduct electric current.
- The unit of conductance is siemens (S) or mho (℧).
- It can be expressed mathematically as,

$$\boxed{G = \frac{1}{R} = \frac{i}{v}}$$

- Thus, the unit of conductance can be expressed as,

$$\boxed{1\text{S} = 1\mho = 1\text{A/V}}$$

- The same resistance can be expressed in terms of ohms or siemens. For example, 10 Ω is same as 0.1 ℧.


THANKS
FOR YOUR
ATTENTION