# Fundamentals of Electrical Circuits

## 1st Stage

## LECTURE 1

## Basic Concepts

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❖ **References**

- *C. K. Alexander*, Fundamentals of Electric Circuits 4th Ed.
- *R. L. Boylestad*, Introductory Circuit Analysis 13th Ed.

❖ **Content**

- Systems of Units
- Charge and Current
- Voltage
- Ohm's Law
- Power and Energy

## 1. Systems of Units

As electrical engineers, we deal with measurable quantities. Our measurement, however, must be communicated in a standard language Such an international measurement language is the ***International System of Units*** (SI). In this system, there are six principal units from which the units of all other physical quantities can be derived. Table 1 shows the six units, their symbols, and the physical quantities they represent.

*Table 1: Six basic SI units*

| Quantity | Basic Unit | Symbol |
|---|---|---|
| Length | Meter | m |
| Mass | Kilogram | kg |
| Time | Second | s |
| Electrical Current | Ampere | A |
| Thermodynamic temperature | Kelvin | K |
| Luminous intensity | Candela | cd |
| Charge | Coulomb | C |

One great advantage of the SI unit is that it uses prefixes based on the power of 10 to relate larger and smaller units to the basic unit. Table 2 shows the SI prefixes and their symbols.

*Table2: The SI prefixes*

| Multiplier | Prefix | Symbol |
|---|---|---|
| $10^{12}$ | Tera | T |
| $10^{9}$ | Giga | G |
| $10^{6}$ | Mega | M |
| $10^{3}$ | Kilo | K |
| $10^{-3}$ | Milli | m |
| $10^{-6}$ | Micro | µ |
| $10^{-9}$ | Nano | n |
| $10^{-12}$ | Pico | p |

For example, the following are expressions of the same distance in meters (m):

600,000,000 mm – 600,000 m – 600 km

## 2. Charge and Current

The most basic quantity in an electric circuit is the *electric charge*. ***Charge is an electrical property of the atomic particles of which matter consists, measured in coulombs (C).***

We know from elementary physics that all matter is made of fundamental building blocks known as atoms and that each atom consists of electrons, protons, and neutrons. We also know that the charge *e* on an electron is ***negative*** and equal in magnitude to **$1.602 \times 10^{-19}$ C**, while a proton carries a positive charge of the same magnitude as the electron. The presence of equal numbers of protons and electrons leaves an atom neutrally charged.

We now consider the flow of electric charges. A unique feature of electric charge or electricity can be transferred from one place to another, where it can be converted to another form of energy.

When a conducting wire is connected to a battery, the charges are compelled to move; positive charges move in one direction while negative charges move in the opposite direction. This motion of charges creates electric current. It is conventional to take the current flow as the movement of positive charges. That is, opposite to the flow of negative charges, as Figure 1 illustrates.

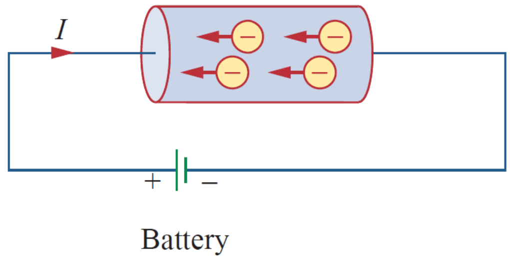



*Figure 1: Electric current due to flow of electronic charge in a conductor*

***Electric current is the time rate of change of charge, measured in amperes (A).***

Mathematically, the relationship between current *i*, charge *q*, and time *t* is:

$$i = \frac{dq}{dt} \tag{1}$$

where current is measured in amperes (**A**), and

**1 ampere = 1 coulomb / second**

The charge transferred between time $t_0$ and $t$ is obtained by integrating both sides of Eq. (1). We obtain

$$Q = \int_{t_0}^{t} i\, dt \qquad (2)$$

The way we define current as $i$ in Eq. (1) suggests that current need not be a constant-valued function. If the current does not change with time, but remains constant, we call it a ***direct current (dc)***.

***A direct current (dc) is a current that remains constant with time.***

By convention the symbol $I$ is used to represent such a constant current.

A time-varying current is represented by the symbol $i$. A common form of time-varying current is the sinusoidal current or ***alternating current (ac)***.

***An alternating current (ac) is a current that varies sinusoidally with time.***

Figure 2 shows direct current and alternating current; these are the two most common types of current.

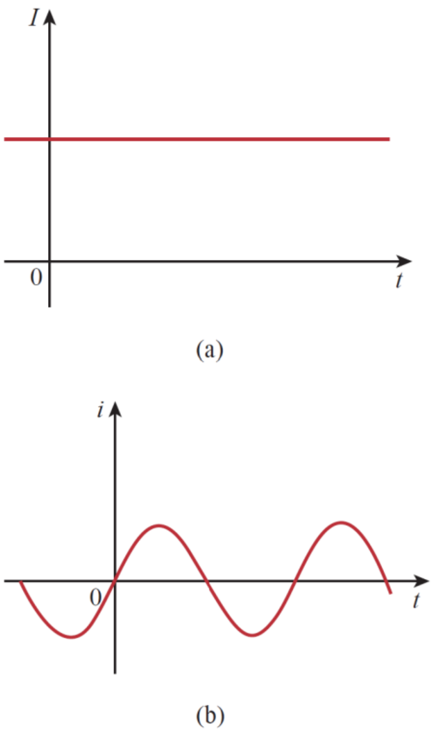



*Figure 2: (a) direct current (dc), (b) alternating current (ac).*

***Example 1:*** How much charge is represented by **4,600** electrons?

***Solution:***

$$-1.602 \times 10^{-19} \times 4600 = -7.369 \times 10^{-16}$$

***Example 2:*** The total charge entering a terminal is given by $\boldsymbol{q = 5t \sin(4\pi t)}$ **mC**. Calculate the current at $\boldsymbol{t = 0.5}$ **s**.

***Solution:***

$$i = \frac{dq}{dt} = \frac{d}{dt}\,(5t\sin(4\pi t)\,mC/s$$

$$i = [5t \times \cos(4\pi t) \times 4\pi] + [\sin(4\pi t) \times 5]$$

$$i = 20\pi t\cos(4\pi t) + 5\sin(4\pi t)\ mA$$

At $t = 0.5$ s

$$i = 20 \times \pi \times 0.5 \times \cos(4 \times 0.5 \times \pi) + 5\sin(4 \times 0.5 \times \pi)$$

$$i = 10\,\pi\cos(2\pi) + 5\sin(2\pi) = 10\pi \times 1 + 0 = \boldsymbol{31.42\ mA}$$

***Example 3:*** Determine the total charge entering a terminal between $\boldsymbol{t = 1}$ **s** and $\boldsymbol{t = 2}$ **s** if the current passing the terminal is $\boldsymbol{i = (3t^2 - t)}$ **A**.

***Solution:***

$$Q = \int_1^2 (3t^2 - t)\,dt = \left(t^3 - \frac{t^2}{2}\right)\Bigg|_1^2$$

$$Q = \left[\left(2^3 - \frac{2^2}{2}\right) - \left(1^3 - \frac{1^2}{2}\right)\right]$$

$$Q = [(8 - 2) - (1 - 0.5)]$$

$$Q = 6 - 0.5 = \boldsymbol{5.5\ C}$$

## 3. Voltage

To move the electron in a conductor in a particular direction requires some work or energy transfer. This work is performed by an external ***electromotive force (emf)***, typically represented by the battery in Figure 1. This emf is also known as ***voltage*** or ***potential difference***. The voltage $v_{ab}$ between two points *a* and *b* in an electric circuit is the energy (work) needed to move a unit charge from *a* to *b*; mathematically,

$$v_{ab} = \frac{dw}{dq} \tag{3}$$

where *w* is energy in ***joules*** (**J**) and *q* is charge in ***coulombs*** **(C)**. The voltage or simply *v* is measured in volts (**V**).

**1 volt = 1 joule / coulomb = 1 newton × meter / coulomb**

***Voltage (or potential difference) is the energy required to move a unit charge through an element, measured in volts (V).***

Figure 3 shows the voltage across an element connected to points *a* and *b*. The plus (+) and minus (–) signs are used to define reference direction or voltage polarity.

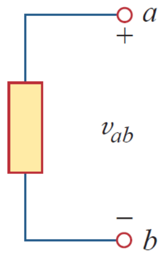



*Figure 3: Polarity of voltage $v_{ab}$*

## 4. Ohm's Law

Materials in general have a characteristic behavior of resisting the flow of electric charge. This is known as resistance and is represented by the symbol *R*. The resistance of any material with a uniform cross-sectional area *A* depends on *A* and its length *l*, as shown in Figure 4.

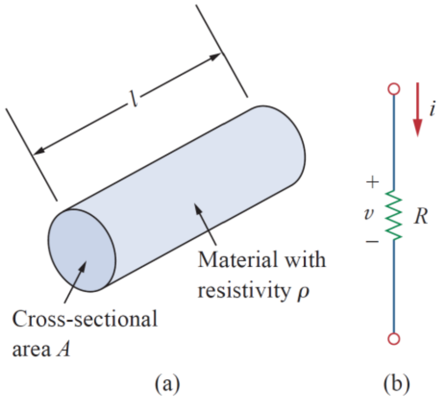



*Figure 4: (a) Resistor, (b) Circuit symbol for resistance*

We can represent resistance in mathematical form as:

$$R = \rho \frac{\ell}{A} \tag{4}$$

Where $\rho$ is known as the resistivity of the material in ohm-meters. Good conductors, such as copper and aluminum, have low resistivities, while insulators, such as mica and paper, have high resistivities. Table 3 presents the values of for some common materials and shows which materials are used for conductors, insulators, and semiconductors.

*Table 3: Resistivities of common materials*

| Material | Resistivity (Ω.m) | Usage |
|---|---|---|
| Silver | $1.64 \times 10^{-8}$ | Conductor |
| Copper | $1.72 \times 10^{-8}$ | Conductor |
| Aluminum | $2.80 \times 10^{-8}$ | Conductor |
| Gold | $2.45 \times 10^{-8}$ | Conductor |
| Carbon | $4 \times 10^{-5}$ | Semiconductor |
| Germanium | $47 \times 10^{-5}$ | Semiconductor |
| Silicon | $6.2 \times 10^{2}$ | Semiconductor |
| Paper | $10^{10}$ | Insulator |
| Mica | $5 \times 10^{11}$ | Insulator |
| Glass | $10^{12}$ | Insulator |
| Teflon | $3 \times 10^{12}$ | Insulator |

***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*. The resistance is a material property which can change if the internal or external conditions of the element are altered, e.g., if there are changes in the temperature. Thus,

$$v = iR \tag{5}$$

***The resistance R of an element denotes its ability to resist the flow of electric current; it is measured in ohms (Ω).***

$$R = \frac{v}{i} \tag{6}$$

so that

**1Ω = 1V/A**

Since the value of *R* can range from ***zero*** to ***infinity***, it is important that we consider the two extreme possible values of *R*. An element with *R* = 0 is called a short circuit, as shown in Figure 5 (a). For a short circuit,

$$v = iR = 0$$

showing that the voltage is zero, but the current could be anything. In practice, a short circuit is usually a connecting wire assumed to be a perfect conductor. Thus,

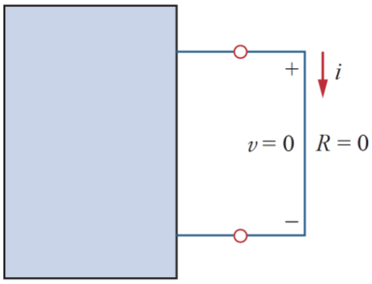
***A short circuit is a circuit element with resistance approaching zero.***

Similarly, an element with *R* = ∞ is known as an open circuit, as shown in Figure 5(b). For an open circuit,

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

indicating that the current is zero though the voltage could be anything. Thus,

***An open circuit is a circuit element with resistance approaching infinity.***



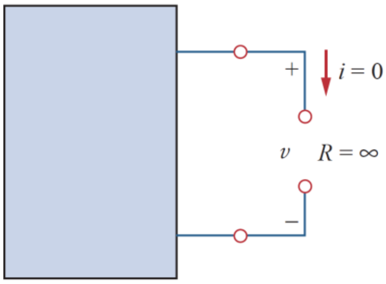




*Figure 5: (a) Short circuit R = 0, (b) Open circuit R = ∞*

A resistor is either fixed or variable. Most resistors are of the fixed type, meaning their resistance remains constant. Variable resistors have adjustable resistance.

***Example 4:*** An electric iron draws **2 A** at **120 V**. Find its resistance.

***Solution:***

$$R = \frac{v}{i} = \frac{120}{2} = \mathbf{60\Omega}$$

## 5. 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. Thus, power and energy calculations are important in circuit analysis.

To relate power and energy to voltage and current, we recall from physics that:

***Power is the time rate of expending or absorbing energy, measured in watts (W).***

We write this relationship as:

$$p = vi \tag{7}$$

The power $p$ in Equation 7 is a time-varying quantity and is called the *instantaneous power*. Thus, the power absorbed or supplied by an element is the product of the voltage across the element and the current through it.

***Energy is the capacity to do work, measured in joules (J).***

The power dissipated by a resistor can be expressed in terms of R.

$$p = i^2 R \tag{8}$$

$$p = \frac{v^2}{R} \tag{9}$$

***Example 5:*** In the circuit shown in Figure 6, calculate the current ***i*** and the power ***p***.

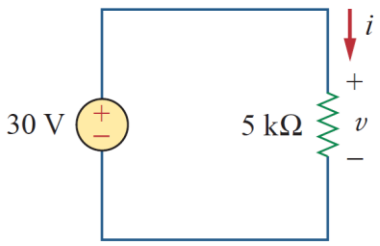



*Figure 6: Example 5*

***Solution:***

$$i = \frac{v}{R} = \frac{30}{5 \times 10^3} = 6 \times 10^{-3} = \mathbf{6\ mA}$$

$$p = iv = 6 \times 10^{-3} \times 30 = 180 \times 10^{-3} = \mathbf{180\ mW}$$

$$p = R \times i^2 = 5 \times 10^3 \times (6 \times 10^{-3})^2 = 5 \times 10^3 \times 36 \times 10^{-6}$$

$$= 180 \times 10^{-3} = \mathbf{180\ mW}$$

$$p = \frac{v^2}{R} = \frac{(30)^2}{5 \times 10^{-3}} = \frac{900}{5 \times 10^{-3}} = 180 \times 10^{-3} = \mathbf{180\ mW}$$