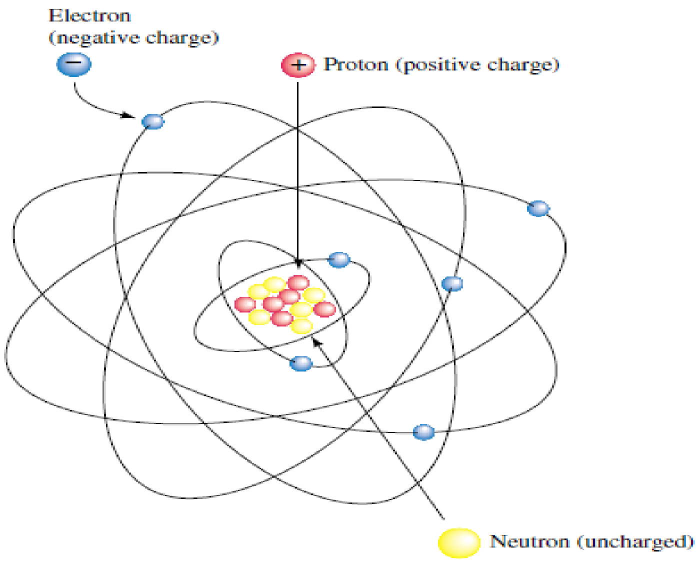
Introductory concepts

1.1 Atomic Theory Review

The basic structure of an atom consists of a nucleus of protons (positively charged (+)) and neutrons (uncharged) surrounded by a group of orbiting electrons (negatively charged (-)). Each atom (in its normal state) has an equal number of electrons and protons, and since their charges are equal and opposite, they cancel, leaving the atom electrically neutral with zero net charge.



1.2 Conductors, Insulators, and Semiconductors

Electrically, materials are classified as conductors, insulators, or semiconductors.

1.2.1 Conductors

- Materials through which charges move easily are termed conductors.
- The most familiar examples are metals. Good metal conductors have large numbers of free electrons that are able to move about easily.
- In particular, silver, copper, gold, and aluminum are excellent conductors.
- Copper is the most widely used. it is an excellent conductor, inexpensive and easily formed into wire.
- Aluminum, although it is only about 60% as good a conductor as copper.
- Silver and gold are too expensive for general use.

1.2.2 Insulators

- Materials that do not conduct are termed **insulators.**
- Their electrons are tightly bound.
- Examples: glass, porcelain, plastic, rubber, and so on.
- The covering on electric lamp cords, for example, is an insulator. It is used to prevent the wires from touching and to protect us from electric shock.

1.2.3 Semiconductors

- Silicon and germanium are thus neither good conductors nor good insulators.
- They have unique electrical properties that make them important to the electronics industry.
- It is used to make transistors, diodes, integrated circuits, and other electronic devices.

1.3 Electrical Charge (*Q*)

The term charge denotes an imbalance between the number of electrons and protons present in the atom. This charge is denoted by the letter ***Q***, and its unit is the coulomb. The charge on one electron is

$$Q_e = 1.60 \times 10^{-19}\ \text{C}$$

Example 1: An initially neutral body has 1.7 µC of negative charge removed. Later, 18.7 x 10^{11} electrons are added. What is the body's final charge?

When 1.7 mC of electrons is removed, the body is left with a positive charge of 1.7 µC.

$Q_{\text{added}} = 18.7 \times 10^{11} \times 1.60 \times 10^{-19} = 0.3\mu\text{C}$

The final charge on the body is

$Q_f = Q_{initial} + Q_{\text{added}} = 1.7\ \mu\text{C} - 0.3\ \mu\text{C} = +1.4\ \mu\text{C}$

H.W 1: After 10.61 x10^{13} electrons are added to a metal plate, it has a negative charge of 3 μC. What was its initial charge in coulombs? (Answer = +14 μC)

1.4 Voltage

When charges are detached from one body and transferred to another, a *potential difference* or *voltage* results between them. In general, the amount of energy required to separate charges depends on the voltage developed and the amount of charge moved.

$$W = QV$$

where *W* is energy in joules (*J*), *Q* is charge in coulombs (C), and *V* is the resulting voltage in volts (V)

Example 2 If it takes 35 J of energy to move a charge of 5 C from one point to another, what is the voltage between the two points?

$$V = \frac{W}{Q} = \frac{35}{5} = 7V$$

H.W 2: The voltage between two points is 19 V. How much energy is required to move 67 $\times 10^{18}$ electrons from one point to the other? (Ans= 204J)

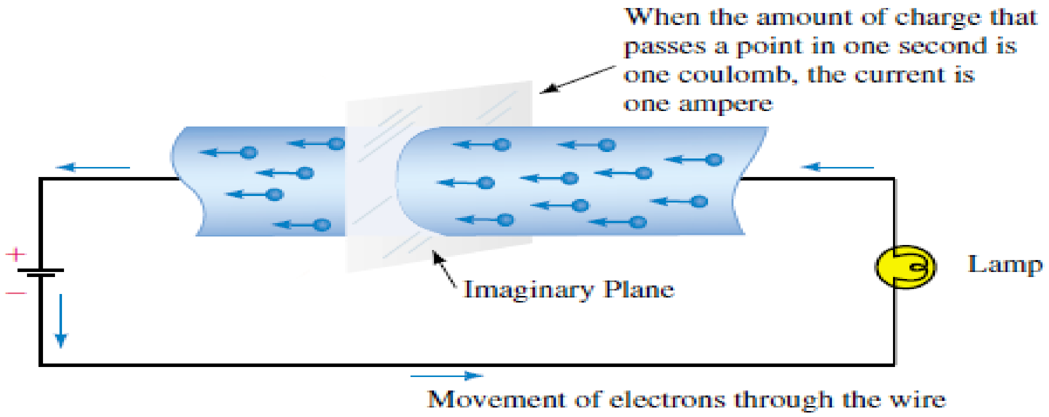
H.W 3 The potential difference between two points is 140 mV. If 280 mJ of work are required to move a charge *Q* from one point to the other, what is *Q?* (Ans= 2mC)

1.5 Current

The battery is the source of electrical energy that moves charges around the circuit. This movement of charges called an electric current. The more electrons per second that pass through the circuit, the greater is the current. Thus, current is the *rate of flow* (or *rate of movement*) of charge.

$$I = \frac{Q}{t} \qquad \text{[Amperes, A]}$$

where *Q* is the charge (in coulombs) and *t* is the time interval (in seconds)



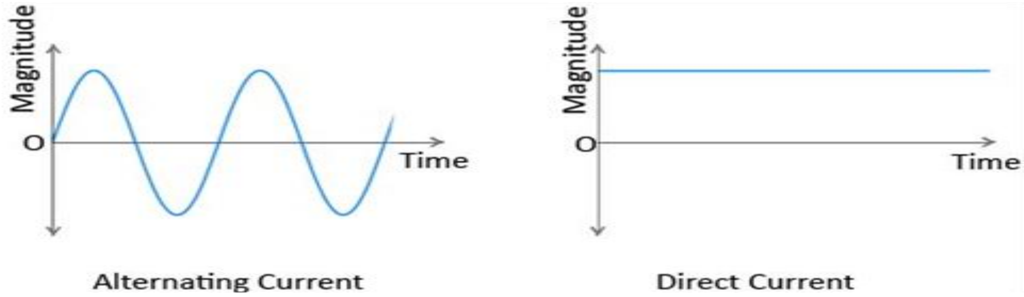
Example 3: If 840 coulombs of charge pass through the imaginary plane of the above Figure during a time interval of 2 minutes, what is the current?

$$I = \frac{Q}{t} = \frac{840}{2*60} = 7A$$

H.W 4: Between t =1 ms and t =14 ms, 8 μC of charge pass through a wire. What is the current? (*Ans.* 0.615 mA)

1.6 Direct current (DC) vs Alternating current (AC)

Direct current (DC) is the flow of electric charge in only one direction. Direct current is produced by batteries, solar cells and DC generators. **Alternating current** (AC) is the flow of electric charge that periodically reverses direction. The most common ac source is the commercial AC power system that supplies energy to your home.

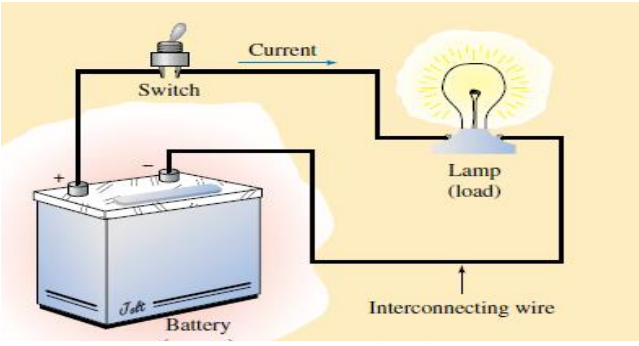


Exercises

1. Body A has a negative charge of 0.2 μC and body B has a charge of 0.37 μC (positive). If 87 x10^{12} electrons are transferred from A to B, what are the charges in coulombs on A and on B after the transfer? (Ans. Q_A = +13.74 μC and Q_B = -13.57 μC)

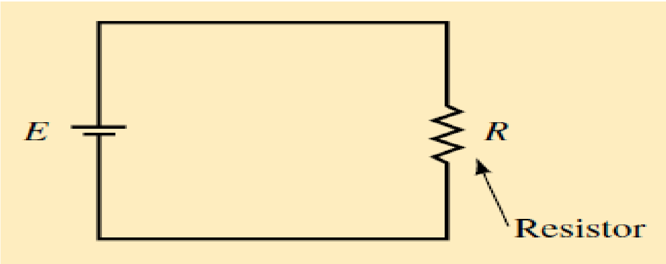
2. If 12.48 x10^{20} electrons pass a certain point in a circuit in 2.5 s, what is the current in amperes? (Ans. I=80A)

3. For the following circuit, assume a 12-V battery. The switch is closed for a short interval, then opened. If I =6 A and the battery expends 230 040 J moving charge through the circuit, how long was the switch closed? (Ans. t = 3195 s)



1.7 Resistance

The flow of charge through any material encounters an opposing force similar in many respects to mechanical friction. This opposition due to the collision between electrons and between electrons and other atoms in the material, which converts electrical energy into heat, is called the **resistance** of the material. Circuit components (called **resistors R**) are specifically designed to possess resistance and are used in almost all electronic and electrical circuits. The unit of measurement of resistance is the ohm (Ω).



1.7.1 Resistance of Conductors

The resistance of a material is dependent upon several factors:

- Type of material
- Length of the conductor
- Cross-sectional area
- Temperature

The factors governing the resistance of a conductor at a given temperature may be summarized mathematically as follows:

$$R = \frac{\rho l}{A} \qquad [\text{ohms, } \Omega]$$

where

ρ : resistivity, in ohm-meters (Ω -m)
l : length, in meters (m)
A : cross-sectional area, in square meters (m^2).

Greek letter rho (ρ) is the constant of proportionality and is called the **resistivity** of the material. Resistivity is a physical property of a material where good conductors of electricity have a low value of resistivity and good insulators have a high value of resistivity. Table 3–1 lists the resistivities of various materials at a temperature of 20°C.

TABLE 3–1 Resistivity of Materials, ρ

Material	Resistivity, ρ, at 20°C (Ω-m)
Silver	1.645×10^{-8}
Copper	1.723×10^{-8}
Gold	2.443×10^{-8}
Aluminum	2.825×10^{-8}
Tungsten	5.485×10^{-8}
Iron	12.30×10^{-8}
Lead	22×10^{-8}
Mercury	95.8×10^{-8}
Nichrome	99.72×10^{-8}
Carbon	3500×10^{-8}
Germanium	20–2300*
Silicon	≅500*
Wood	10^{8}–10^{14}
Glass	10^{10}–10^{14}
Mica	10^{11}–10^{15}
Hard rubber	10^{13}–10^{16}
Amber	5×10^{14}
Sulphur	1×10^{15}
Teflon	1×10^{16}

1.7.2 Conductance

Conductance (G) is reciprocal of resistance where it measures of how well the material will conduct electricity

$$G = \frac{1}{\rho}.\frac{A}{l} = \frac{\sigma A}{l} \qquad \text{(mho)}$$

Where σ is conductivity or specific conductance of a conductor (*mho/m*) and G is conductance (mho).

Example 4: Determine the resistance of 75 meters of a solid copper wire having a diameter of 1.63 mm (resistivity of copper is $1.723\ x10^{-8}$).

$$A = \frac{\pi d^2}{4} = \frac{\pi(1.63x10^{-3})^2}{4} = 2.09x10^{-6}m^2$$

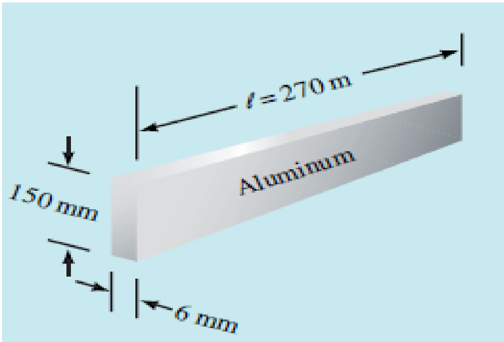
$$R = \frac{\rho l}{A} = \frac{(1.723\ x10^{-8})(75)}{2.09x10^{-6}} = 0.619\Omega$$

H.W 5: Find the resistance of a 100-m long tungsten wire which has a circular cross-section with a diameter of 0.1 mm (resistivity of tungsten is $5.485x10^{-8}$). Ans. 698Ω

Example 5: Determine the resistance between the ends of aluminum bus bar at a temperature of 20°C. (Resistivity of tungsten is $2.825x10^{-8}$)

$$A = (150x10^{-3}x6x10^{-3}) = 9x10^{-4}m^2$$

$$R = \frac{\rho l}{A} = \frac{(2.825\ x10^{-8})(270)}{9x10^{-4}} = 8.48\ m\Omega$$



1.7.3 Temperature Effects

The resistance of a conductor will not be constant at all temperatures. For most conducting materials, the increase in the temperature translates into a relatively linear increase in resistance.

The rate at which the resistance of a material changes with a variation in temperature is called the **temperature coefficient** of the material (α). To determine the resistance, R_2 of a conductor at a temperature, T_2

$$R_2 = R_1 [\ 1 + \alpha_1 (T_2 - T_1)]$$

where

α : temperature coefficient is measured in $(°C)^{-1}$, R_1 : is the resistance in ohms at a temperature, T_1 and R_2 : is the resistance in ohms at a temperature, T_2

Example 5: A coil of copper wire has a resistance of 10 at 20°C. If the temperature coefficient of resistance of copper at 20°C is 0.004/°C determine the resistance of the coil when the temperature rises to 100°C

$R_2 = R_{20} [\ 1 + \alpha_{20} (T_2 - 20)]$

$= 10 [\ 1 + 0.004 (100 - 20)] = 13.2\ \Omega$

Example 6: The resistance of a coil of aluminum wire at 18°C is 200 Ω. The temperature of the wire is increased and the resistance rises to 240 Ω. If the temperature coefficient of resistance of aluminum is 0.0039/°C at 18°C determine the temperature to which the coil has risen.

$R_2 = R_{18}[1 + \alpha_{18}(T_2 - 18)]$

$240 = 200[1 + 0.0039(T_2 - 18)]$

$T_2 = 69.28\ ^oC$

H.W 6: A coil of aluminium wire has a resistance of 50 Ω when its temperature is 0°C. Determine its resistance at 100°C if the temperature coefficient of resistance of aluminium at 0°C is 0.0038/°C. [69Ω]

H.W 7: A copper cable has a resistance of 30 Ω at a temperature of 50°C. Determine its resistance at 0°C. Take the temperature coefficient of resistance of copper at 0°C as 0.0043/°C. [24.69 Ω]

Exercises:

1. Given two lengths of wire having identical dimensions. If one wire is made of copper and the other is made of iron, which wire will have the greater resistance? How much greater will the resistance be? (Ans. $R_{iron} = 7\ R_{copper}$)
2. Given two pieces of copper wire which have the same cross-sectional area, determine the relative resistance of the one which is twice as long as the other. (Ans. $R_{long} = 2\ R_{short}$)
3. Given two pieces of copper wire which have the same length, determine the relative resistance of the one which has twice the diameter of the other. (Ans. $R_{wide} = 0.25\ R_{thin}$)
4. A 2500-m section of alloy wire has a resistance of 32Ω. If the wire has a diameter of 1.5 mm, determine the resistivity of the material in ohm-meters. Is this alloy a better conductor than copper?