Conductors and Insulators

Conductors

As was shown in Figure 741.1.2, the nucleus of the copper atom contains 29 protons. A neutral copper atom must therefore have 29 electrons distributed amongst its various shells. Shells *k, 1*, and *m* are filled to capacity with a total of 28 electrons, so there is only one electron in the *n* shell. The outermost shell of an atom, the *n* shell in this case, is called the **valence shell**, and the number of electrons it contains strongly influences the electrical properties of the element that the atom represents.

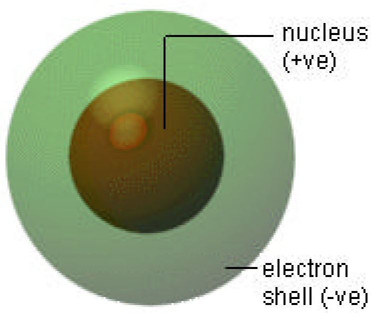


figure 741.2.1 Free electron
(click to activate)

Since electrons in the valence shell are the farthest removed from their nucleus, they experience the least force of attraction to the nucleus. Coupled with the fact that electrons in a nearly empty shell are easily dislodged from that shell, we find that the lone electron in the valence shell of copper can readily vacate that shell. When an electron breaks away from its 'parent' atom, it is called a **free electron**, since it is then free to wander randomly through the material.

An atom producing such a free electron acquires a net positive charge, because its total number of protons is then one greater than its total number of electrons. Such an atom is called a **positive ion**. To become free, an electron must acquire enough energy to overcome the force that binds it to its nucleus. In copper, there is enough heat energy at ordinary room temperatures to liberate a vast number of the weakly held valence electrons.

The presence of a large number of free electrons in copper, as in other metals, is what makes it a good **conductor** of electricity. As we shall presently learn, conduction is the transfer of electrical charge through a material, a process that is enhanced by the availability of large numbers of free electrons. In an isolated conductor having no electrical circuit connections (no battery connections, for example), the free electrons are continually subjected to random forces and move in all different directions as they come under the influence of other electrons and nuclei. Since there are, on average, as many electrons moving in any one direction as in any other, there is no long-term net transfer of charge from any one region of the conductor to any other.

Below is a table of several materials and the number of valence electrons:

Material	Electrons	Valence electrons
Lead	82	4
Aluminum	13	3
Copper	29	1
Silver	47	1

Table 741.2.1

Conductors in Industry

The best conductors (in order) are

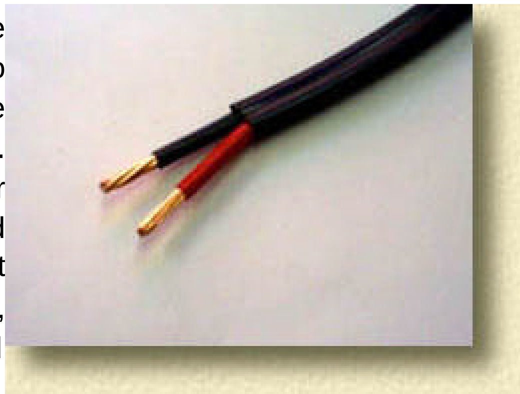
- Silver
- Copper
- Gold

Since copper is the least expensive, it is widely used in the electrical and electronic industries. A cubic centimeter of copper (about the size of a thimble) contains approximately 8.4×10^{22} free electrons at room temperature.

There are many factors, which influence the choice of conductor in a given application. The following list is just some of the attributes to consider: cost, availability, resistivity, machinability, weight, strength, flexibility and corrosion resistability.

figure 741.2.3 Various industrial cables

Insulators



Materials whose valence electrons are tightly held to their parent atoms produce relatively few free electrons. Such materials are poor conductors of electricity and are called **insulators**. Most materials, including plastics, ceramics, rubber, paper, and most liquids and gases, fall into that category. Of course, there are many practical uses for insulators in the electrical and electronic industries, including wire coatings, safety enclosures, and power-line insulators.

The criteria for selecting a given material are generally dependent upon the voltage rating of the cable, the flexibility requirements, the temperature to which the insulating material will be subjected, and the environment (chemicals etc). Some of the more common insulating materials follow.

- Polyvinyl chloride (PVC)
- Polycarbonate
- Rubber compounds
- Ceramics
- Glass
- Air
- Oil

Summary

- The **valence** shell is the outermost shell in an atom
- A free electron is one which has broken away from the valence shell of its parent ato
- A **positive ion** is produced when a parent atom loses an electron
- **Electrical conduction** is the flow of free electrical charge through a material
- A good **conductor** contains a large number of free electrons
- Metals are typically good conductors
- **Copper** is a commonly used conductor in the electrical and electronic industries
- **Insulators** are poor conductors of electricity
- **Insulator** produces few free electrons
- Some insulators are Polyvinyl chloride (PVC), Polycarbonate, Rubber compounds, Ceramics, Glass, Air, Oil

Electric Current

Electrical Charge

It is conventional to speak of the motion, or transfer, of electrical charge from one location to another with the understanding that it is actually charged *particles* that do the moving. In conductors, the transfer of charge occurs only as a result of the motion of electrons, and for that reason, electrons are often called **charge carriers**. The greater the number of electrons that move from one location to another, the greater the transfer of charge. For this course we will conform to convention, and refer to charge as if it were, by itself, a movable object.

The Coulomb

In the SI system, the unit of charge is the **Coulomb** (C). One coulomb of negative charge is the total charge carried by 6.242×10^{18} electrons. We can then find the total charge on one electron (the number of coulombs per electron) as follows:

$$1 \text{ coulomb} / [6.242 \times 10^{18}] \text{ electrons} = 1.6 \times 10^{-19} \text{ C/electron}$$

We should note that charge can be either positive or negative. One coulomb of positive charge is the total charge of 6.242×10^{18} positively charged atoms, each of which has lost one electron. The symbol *Q* is used to represent a quantity of charge. For example, it would be correct to write Q = 100 µC (Do not confuse the symbol *Q* for the quantity of charge with the symbol C for the units of charge).

Electrical Current

Electrical current exists in material when there is a net transfer of charge through the material, from one region to another. For example, if electrons are somehow injected into one end of a copper wire, travel through the wire, and emerge at the other end, we say that there is current in the wire. Current is measured in terms of the **rate** at which charge is transferred, that is, the amount of charge that moves past a point per unit time.

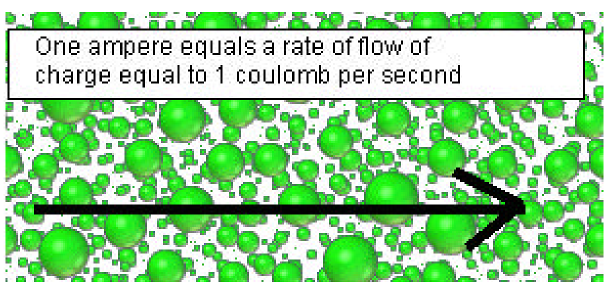


figure 741.4.1

The SI unit of current is the **Ampere** (**A**), named after the eighteenth-century French physicist André Ampère. One ampere equals a rate of flow of charge equal to 1 coulomb per second. Thus, 2 amperes of current exist when 2 coulombs of charge pass a point in 1 second (or when 4 coulombs pass in 2 seconds, etc.) The symbol for current is I, from the French word *intensite* (intensity). From the definition it follows that the general relationship between current, charge, and time is...

$$\boxed{\mathbf{I = Q / t}}$$

where *Q* is the number of coulombs of charge that pass a point in t seconds.

Strictly speaking, it is not correct to say that current *flows*, or *goes* from one point to another, since current is a *rate* of flow. We would not say, for example, that a rate (speed) of 45 km/h *goes* down the highway. However, it is a widely used practice to speak of current as flowing from one point to another (meaning that charge flows from one point to another), and we will follow that practice during this course.

Summary

- **Q** is the symbol for electrical charge, and may be positive or negative
- The unit for electrical charge is the Coulomb (symbol C)
- One Coulomb is the total charge of 6.242×10^{18} electrons
- **Electric current** is the **rate of transfer** of electrical charge through a material
- **I** is the symbol for electrical current
- The unit for current is the **Ampere** (symbol **A**)
- One Ampere equals a rate of flow of charge equal to one Coulomb per second (or I = Q/t)

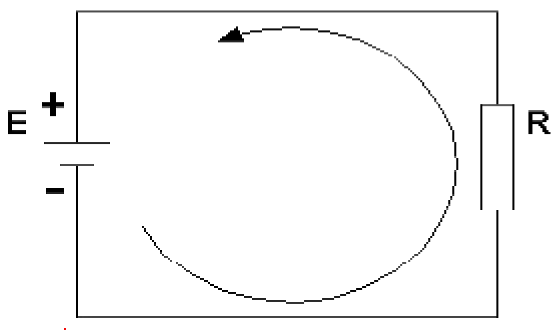
Conventional Current

Electric Circuits

Current will not flow in a conductor unless there is a complete path from the negative terminal of a voltage source to the positive terminal. In other words, there must be a destination that will accept electrons as well as a source of electrons. Figure 741.5.1(a) shows a diagram of a voltage source with a conductor, such as a copper wire, and resistance R, connected in a path between the positive and negative terminals. The resistance could represent the resistance of the wire itself or some other component connected in the path. Since there is a complete path, electrons will flow from the negative terminal of the source, through the conductor and resistance, and into the positive terminal of the source.

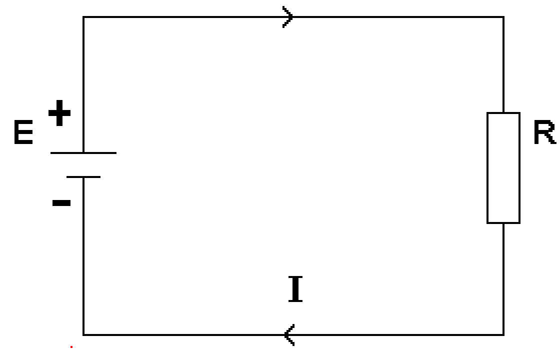
Electron Flow versus Conventional Current

This current, flowing from negative (-ve) to positive (+ve) , is often called **electron flow**. Early investigators of electrical phenomena, notably Benjamin Franklin, believed that current flow was caused by the motion of positive charge, rather than negative charge. As a consequence, much of the early theory and technical literature was based on the assumption that current flowed from positive to negative. That assumption, or rather that usage, has persisted to this day and is called **conventional current**, as shown beside it in Figure 741.5.1(b).



Direction of electron flow

figure 741.5.1 (a)



Conventional Current

figure 741.5.1 (b)

It is important to realize that none of the practical consequences nor any of the results of computations performed in the study of electricity and electronics are in any way affected by the direction of current flow that one assumes. On this course, as in most books, the direction of conventional current will always be assumed and will be used in all diagrams where current directions are shown. By definition, **conventional current** is that which has been adopted by the majority of practicing engineers, technologists, scientists, and technical writers.

Water System Analogy

Figure 741.5.2 shows how a voltage source with resistance connected between its terminals is analogous to a water flow system. The voltage produced by the source (eg. a battery) is like the pressure produced at the water pump. The greater the pressure, the greater the flow rate. The flow rate itself, say, in liters per minute, is like the electrical current in coulombs per second. The constriction in the pipe, which slows the flow rate, is like the resistance in the conductor.

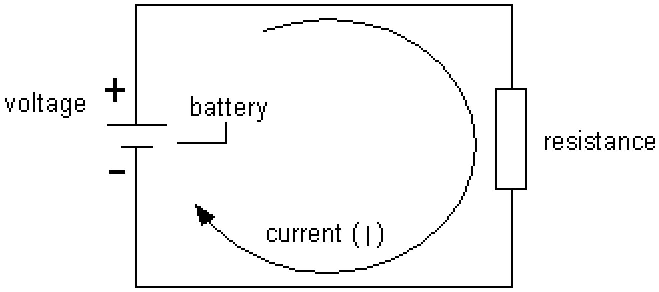


figure 741.5.2 (a)

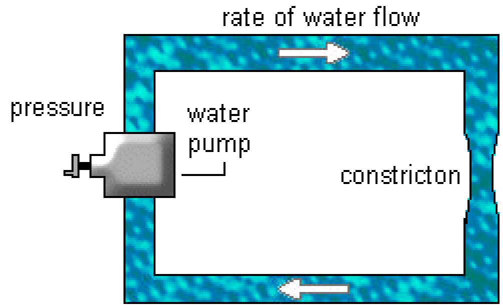


figure 741.5.2 (b*)*

Summary

- Current will not flow in a conductor unless there is a complete path from the negative terminal of a voltage source to the positive terminal
- Such a path is called an **electrical circuit**
- **Electron flow** is the physical flow of **electrons** from negative to positive
- **Conventional current** is the convention that electrical current (I) is measured in terms of a **hypothetical** 'flow' of positive charge from positive to negative
- A water flow system is a good analogy for an electrical circuit