CHAPTER 22

Electric Circuits

22.1 INTRODUCTION

Electrical energy is very important in our lives, as evidenced by the great inconvenience when it is not available — for instance, trying to cope without refrigeration when camping, or trying to cope without cooking appliances during electrical blackouts caused by industrial strikes or storm damage. The great explosion in technology in the twentieth century has been almost solely due to applications of electrical energy. The information age to which we belong would not be possible without methods of distributing large quantities of electrical energy for operating appliances or being able to store and transmit information across telephone, television and computer networks.

The electrical age began around 200 years ago when it was discovered how to store electrical energy and thus control it, rather than just deal with its electrostatic effects. The Italian scientists **Luigi Galvani** (1737–98) and Count **Alessandro Volta** (1745–1827) experimented with electrical effects in animal tissues, showing that the nervous system is electrically operated. Volta was able to produce the first example of an electric battery, which he called a 'pile', constructed from a series of pairs of dissimilar metal electrodes separated by moist cloth layers. Today we call this apparatus a voltaic battery or just a battery.

In this chapter we will examine the various effects of electric current, together with a model for its behaviour and the laws under which it flows in circuits. By the end of the chapter questions such as:

- what causes electric current to flow?
- what controls the direction of electric current flow?
- how is electric current measured?
- which is the more dangerous, voltage or current?
- how can we use electrical energy safely?
- how will electrical energy affect me in the future?

which you may have asked in the past, will be able to be answered satisfactorily.

Although electrical energy is widely used in modern society, it should never be treated lightly as it can become extremely dangerous when used inappropriately.

NEI Activity 22.1 ELECTRICITY AROUND THE HOME

1. Examine the following electrical devices found around the home and find the voltage marked on each: torch battery, car battery, calculator battery, watch battery.
2. Look at several light bulbs and determine the wattage rating marked on each.
3. Determine how many electric cable wires are coming into your house from the distribution pole in your street.

ELECTRIC CHARGES IN MOTION 22.2

In Chapter 21 we saw that an electric potential difference applied across a set of parallel plates causes an electric field with a resulting force acting on any electric charges within the field. In this chapter this idea will be taken further to define the nature of electric current in various types of conductors.

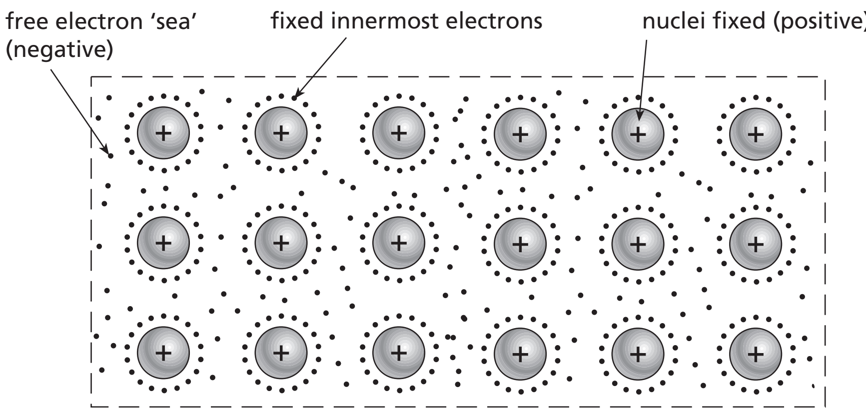

Figure 22.1
Metallic lattice. Positive nuclei in a sea of mobile electrons.

Generally metals are very good conductors of electric current. (Refer to Section 21.3.) This is because metal elements contain loosely bonded **valence electrons** in their outermost atomic electron shells. These are available for shared bonds with other nuclei. This atomic bonding pattern within blocks of metals creates a virtual 'sea of electrons' within the metal, allowing very easy motion of the electron particles under the influence of an applied electric field (Figure 22.1). The non-metal graphite is also a good conductor because of a similar pattern of loosely bound electrons within its solid crystalline lattice structure. Within metals it is therefore the negative electron particles that are free to move through a fixed nuclei lattice of positive charges.

Consider crystalline solids such as sodium chloride (common salt — NaCl). If this substance is dissolved in water, it dissociates into positive sodium **ions** (neutral atoms that have lost electrons) and negative chloride ions (neutral atoms that have gained electrons). Salt solution is referred to as an **electrolyte**. If an electric field is placed across this type of material, then charge movement of both positive and negative ions will occur. This is referred to as electrolyte conduction. A typical voltaic or electrolytic cell is shown in Figure 22.2, involving both electrolyte conduction and metallic conduction.

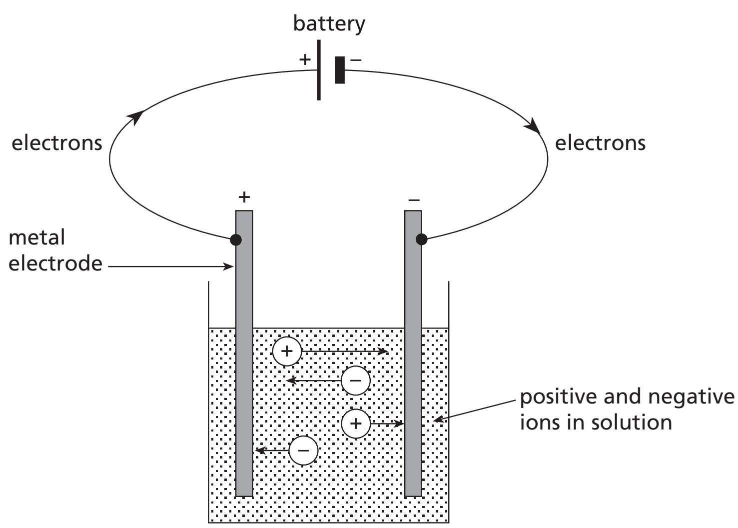

Figure 22.2
Electrolyte conduction.

Gaseous substances are normally insulators and will not conduct electricity due mainly to the wide spacing between nuclei and possible charge carriers. Gases can be made to conduct if the atoms are given enough energy by either heating or high voltage, or by irradiating with ultraviolet light or X-rays. Under these conditions the atoms of the gas are stripped of some of their electrons, the atoms become ionised, and charge motion due to both ions and free electrons can occur (Figure 22.3).

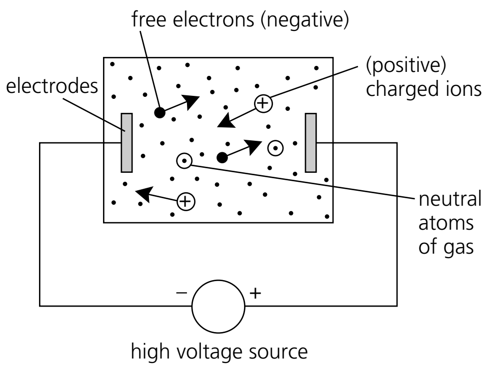

Figure 22.3
Gaseous conduction.

Let us return to conduction within typical metals. Consider a piece of copper conductor that has been drawn out into a fine wire owing to its very good **ductility**. The valence electrons within the metallic lattice are moving about at very high speed in random directions. If an external electric field is applied through the copper wire by means of a potential difference across its ends, then the free electrons will move under the influence of electric forces towards the higher potential. Remember, any one particular electron will experience a force $\boldsymbol{F} = q\boldsymbol{E}$ (Figure 22.4).

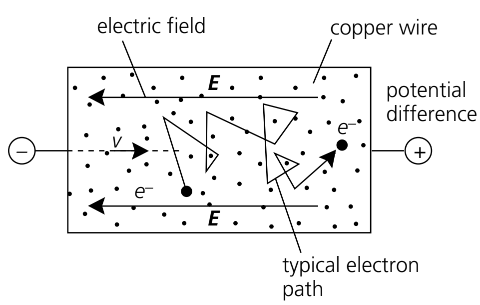

Figure 22.4
Drift velocity in metals.

Because the metallic lattice contains large numbers of nuclei, the electrons in motion undergo collisions that slow their progress. In general, the electrons drift at a particular terminal velocity characteristic of the conductor, which is known as the **electron drift velocity**, *v*. Typical metals have values for drift velocities of about 1×10^{-4} m s^{-1}. The flow of electric current along the wire occurs much more rapidly because an electrostatic repulsive pulse between neighbouring electrons occurs as soon as the electrons begin to move under the influence of the applied electric field. We would imagine an electron entering one end of the wire and, almost instantaneously, another electron being repelled from the opposite end of the wire. The actual electric current, *I*, flowing along the wire is the total number of electrons, *q*, passing any given point in the wire every second, *t*. If the rate of flow is constant then:

$$I = \frac{\text{charge}}{\text{time}} = \frac{q}{t}$$