ELECTRIC CIRCUITS

Seventh Edition

DAVID A. BELL

Lambton College of Applied Arts and Technology
Sarnia, Ontario, Canada

OXFORD
UNIVERSITY PRESS

OXFORD
UNIVERSITY PRESS

YMCA Library Building, Jai Singh Road, New Delhi 110001

Oxford University Press is a department of the University of Oxford.
It furthers the University's objective of excellence in research, scholarship,
and education by publishing worldwide in

Oxford New York
Auckland Cape Town Dar es Salaam Hong Kong Karachi
Kuala Lumpur Madrid Melbourne Mexico City Nairobi
New Delhi Shanghai Taipei Toronto

With offices in
Argentina Austria Brazil Chile Czech Republic France Greece
Guatemala Hungary Italy Japan Poland Portugal Singapore
South Korea Switzerland Thailand Turkey Ukraine Vietnam

Original seventh edition published by and © Oxford Univerity Press,
70 Wynford Drive, Don Mills, Ontario, Canada.

Previous editions published by Prentice-Hall, Inc.

This adapted edition first published in 2009
by Oxford University Press India

ISBN-13: 978-0-19-569428-4
ISBN-10: 0-19-569428-7

Typeset in Palatino Roman
by Archetype, New Delhi 110063
Printed in India by Ram Book Binding House, New Delhi 110020
and published by Oxford University Press
YMCA Library Building, Jai Singh Road, New Delhi 110001

CONTENTS

CHAPTER 1

Basics of Electricity

Objectives

You will be able to:

1. Explain electrification by friction and the concept of positive and negative electricity.
2. State the fundamental law of electrification by friction.
3. Describe the planetary atom and sketch a diagram to represent an atom and its component parts.
4. Describe what happens when an electric current flows.
5. Define a conductor, an insulator, and a resistance.
6. Explain potential difference and its relationship to current and resistance.
7. Sketch the basic construction of a voltage cell and discuss its operation.
8. Sketch the graphic symbols used to represent basic circuit components and draw simple circuit diagrams.
9. Explain conventional current direction and electron flow.
10. Explain the difference between direct current (dc) and alternating current (ac).
11. Discuss how electric shock occurs, and describe some of the situations in which electricity can be hazardous to humans.

INTRODUCTION

Human knowledge of electricity began with the study of the phenomenon known to experimenters as *electrification by friction*. The early concept of an electric fluid being transferred from one body to another is now understood as a motion of electrons that have become detached from their atoms. A flow of electrons constitutes an electric current, and the pressure that produces the electron flow is a potential difference between two bodies or between two terminals. A potential difference is produced by an excess of electrons on one body and/or a deficiency of electrons on the other. In the simplest source of electricity the excess and deficiency of electrons are the result of chemical action. When an electric current flows, heat is generated by the electron motion. In certain circumstances, light may also be produced—hence the electric lamp. The various components and interconnections of an electrical system comprise an electric circuit, and a circuit diagram is a graphic representation of an electric circuit. Because electricity can be dangerous, it is important to use it carefully and to take immediate action when someone suffers an electric shock.

1-1 ELECTRIFICATION BY FRICTION

The study of electricity began with investigations of *electrification by friction.* The ancient Greeks knew that when amber was rubbed with wool it could attract lightweight particles of other material, such as feathers or lint. The Greek word *elektron,* which means amber, is the origin of the word *electricity.*

Early in the seventeenth century it was discovered that amber was not the only material that had this property. Glass rubbed with silk and ebonite rubbed with fur were both found capable of attracting small particles of other materials. It was also discovered that when two silk-rubbed glass rods were brought close together they were repelled from each other [see Figure 1-1(a)]. Also, when a silk-rubbed glass rod and a fur-rubbed ebonite rod were brought close together there was a force of attraction between them [Figure 1-1(b)].

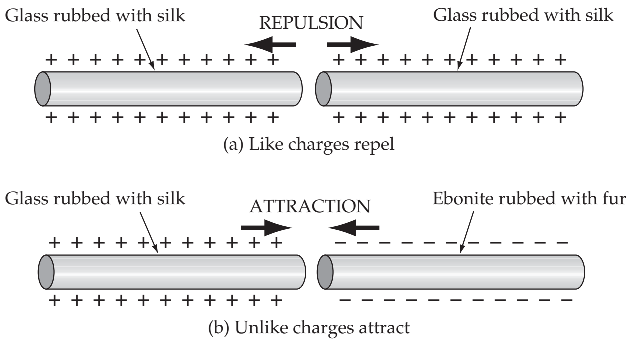


Figure 1-1 Glass and ebonite rods can be used to demonstrate electrification by friction. A silk-rubbed glass rod becomes positively charged. A fur-rubbed ebonite rod acquires a negative charge.

From these results it was concluded that there were two types of electricity and that materials *charged* with the same type of electricity repelled each other, while those charged with different types of electricity attracted each other. This conclusion produced a fundamental law:

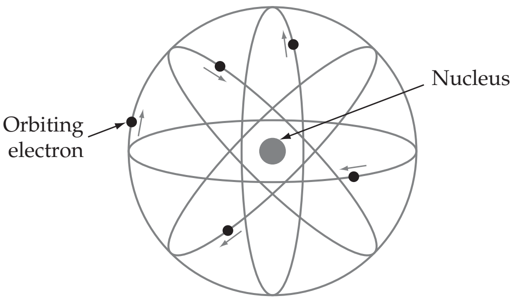
Like charges repel; unlike charges attract.

Around the middle of the eighteenth century, Benjamin Franklin[1] suggested that when glass was rubbed with silk, some kind of *electric fluid* passed from the silk to the glass and that this gave the glass an increased

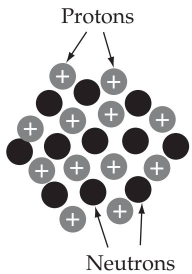
[1]American statesman and scientist (1706–1790).

amount of electric fluid, or *positive charge.* Conversely, when ebonite was rubbed with fur, the electric fluid passed from the ebonite to the fur, he argued. Thus, the ebonite acquired a reduced amount of electricity, or *negative charge.*

The modern explanation of electrification by friction utilizes our present day understanding that the atom consists of a central *nucleus* surrounded by orbiting *electrons*. The diagram in Figure 1-2(a) illustrates the concept of the *planetary atom*. The electrons have a negative charge, and relative to the nucleus they are extremely small particles. The nucleus [Figure 1-2(b)] is largely a cluster of two types of particles, *protons* and *neutrons*, each of which has a mass approximately *1800 times the mass of the electron*. Neutrons have no charge at all, and protons have a positive charge equal in magnitude to the negative charge on an electron. Consequently, the nucleus is positively charged. The three basic particles—*proton, neutron,* and *electron*—are similar from one atom to another. Differences between atoms are due to differing numbers and arrangements of the three particles. Different materials are made up of different types of atoms or combinations of several types of atoms.



(a) Nucleus with orbiting electrons



(b) The nucleus is largely a cluster of protons and neutrons

Figure 1-2 An atom consists of a central nucleus surrounded by orbiting electrons. The electrons have a negative charge and the protons in the nucleus have a positive charge.

It has been found that electrons can occupy only certain orbital rings, or *shells*, at fixed distances from the nucleus and that each shell can contain only a certain number of electrons. The outer shell is named the *valence shell*, and the electrons that occupy it are referred to as *valence electrons*. The valence electrons largely determine the electrical (and chemical) characteristics of an atom.

Because the protons and orbital electrons of an atom are equal in number and equal and opposite in charge, they neutralize each other electrically. So, each atom is normally electrically neutral; it exhibits neither a positive nor a negative charge. If an atom loses an electron it loses some negative charge, and so it exhibits a positive charge. In this case the atom is referred to as a *positive ion*. Similarly, an atom that gains an additional electron becomes negatively charged and is then termed a *negative ion*.

Benjamin Franklin's electric fluid can now be looked upon as being composed of electrons passing from one material to another. The material that loses electrons becomes positively charged as the result of the loss of negative charges. The material that gains electrons becomes negatively charged. So, glass rubbed with silk acquires its positive charge by losing some electrons to the silk, and ebonite rubbed with fur becomes negatively charged by gaining electrons from the fur.

1-2 VOLTAGE, CURRENT, AND RESISTANCE

When two oppositely charged bodies make contact, electrons flow from the negatively charged body to the positively charged body. This means that electrons move from a location with an excess of electrons to one with a deficiency of electrons. Electrons will also flow from a negatively charged body to an uncharged body or to one with a lower negative charge.

The movement of electrons constitutes a flow of electric current.

The flow of charge carriers (i.e., electrons) also occurs if the two charged bodies are connected by a piece of metallic material (Figure 1-3). The flow does not occur when nonmetallic material is employed.

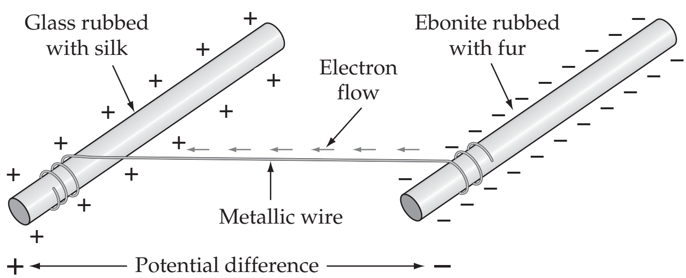


Figure 1-3 A potential difference (PD) exists between a negatively charged body and a positively charged body. When connected by a metallic wire, electrons flow from the negatively charged body to the positively charged body.

Materials that readily allow electrons to pass through them are termed conductors.

Materials that do not permit electron flow are known as insulators.

Because some materials are better conductors than others, it can be said that ***they offer lower* resistance *to the flow of electric current.*** Conductors obviously have much lower resistance than insulators. Electric current is measured in *amperes,* or *amps* (symbol A), and resistance is measured in *ohms* (symbol Ω—Greek letter omega).

The ability of two oppositely charged bodies to produce a flow of electricity between them may be thought of as a *potential* for the production of electric current. A positively charged body is said to have a *positive potential*, and a plus sign (+) is used to identify this potential on all diagrams. Similarly, a negatively charged body is described as having a *negative potential,* and a minus sign (−) is used for its identification. Two oppositely charged bodies are said to have a *potential difference* (PD) between them (see Figure 1-3). It is also possible for a potential difference to exist between two similarly charged bodies if one is charged to a higher potential than the other. Potential difference is measured in *volts* (symbol V), and the term *voltage* is commonly applied for potential difference. Another, more descriptive term for potential difference is *electromotive force* (emf).

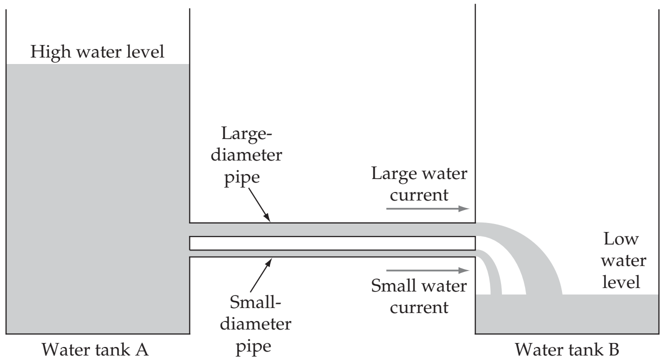
> **Electromotive force is an electrical pressure that tends to cause current to flow when a suitable conducting path is provided.**

Figure 1-4 compares the basic electrical quantities to the quantities in a water system. Water tank A in Figure 1-4(a) has a larger quantity of liquid than tank B. So, at the level of the connecting pipes, there is a pressure causing water to flow from tank A to tank B. Similarly, in Figure 1-4(b) body A has a larger quantity of electrons than body B. Consequently, there is an electrical pressure (electromotive force) causing a current of electrons to flow along the conductors from A to B. The large-diameter water pipe passes a greater water current than the small-diameter pipe, and the conductor with the large cross-sectional area passes a greater electrical current than the conductor with the small cross-sectional area. The large-diameter conductor offers less *resistance* to current flow than the small-diameter conductor.
Summarizing:

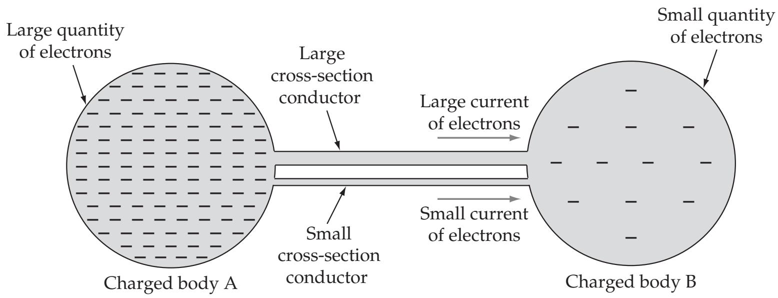
> **Voltage (emf, potential difference) is an electrical pressure that produces current flow (a movement of electrons) through a conductor. Resistance is opposition to current flow.**

1-3 BASIC SOURCE OF ELECTRICITY

The simplest modern source of electricity is a *zinc-carbon voltage cell*. As illustrated in Figure 1-5, the cell consists basically of a zinc can containing certain chemicals and having a centrally located carbon rod (see Chapter 10).



(a) Water pressure causes a current of water to flow between two tanks. The large-diameter pipe passes a larger current of water than the small-diameter pipe.



(b) Electrical pressure (potential difference) causes a current of electrons to flow. The large cross-section conductor passes a greater electrical current than the small cross-section conductor. The large cross-section conductor has a *lower resistance* than the small cross-section conductor.

Figure 1-4 Comparison of water system and electrical system. In both systems a pressure difference causes a current to flow along a suitable path.

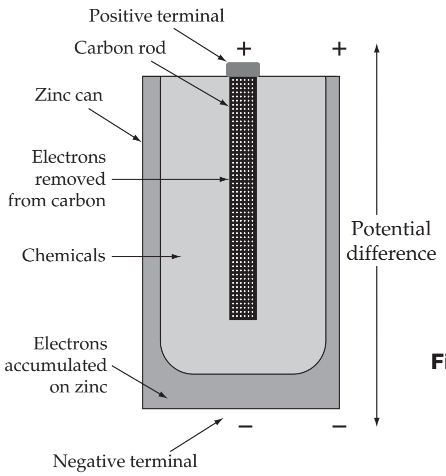
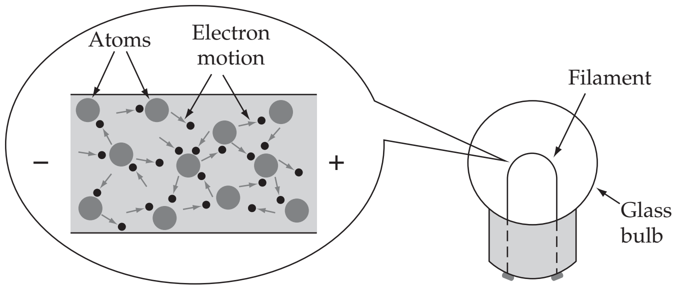


Figure 1-5 Cross-section of a zinc-carbon cell. Chemical action transfers electrons from the carbon to the zinc. The carbon rod is the positive terminal of the cell and the zinc can is the negative terminal.

Chemical action removes electrons from the carbon and causes them to accumulate on the zinc. Because the carbon has lost (negatively charged) electrons, it is positively charged. Also, the electron accumulation on the zinc makes the zinc negatively charged. The carbon rod is the *positive terminal* of the cell and the zinc can is the *negative terminal*. The outside of the zinc can is usually insulated and the bottom is left uncovered for connection purposes. A potential difference, or voltage, exists between the cell positive and negative terminals. When the terminals are connected via a suitable conducting path, electrons flow from the negative terminal to the positive.

1-4 ELECTRIC LAMP

Figure 1-6(a) illustrates the movement of electrons in a conductor when a potential difference is applied across the ends of the conductor. The electrons are repelled from the negative terminal and attracted toward the positive terminal. However, the atoms within the conductor impede the motion of the electrons, so that they cannot simply accelerate from the negative end to the positive end. Instead, each electron bounces about from one atom to another and merely drifts toward the positive end. Each time the electron strikes an atom, it dissipates energy in the form of heat. When a great many electrons are involved in a flow of current, the heat dissipation can be considerable. A simple electric lamp consists of a thin tungsten wire, or *filament*, contained in a glass bulb from which the air has been evacuated [see Figure 1-6(b)]. When a current of electrons is passed through the filament, many electron-atom collisions occur, and the resulting heat makes the filament glow white hot, so that it emits light.



(a) Electron motion within the lamp filament (b) Electric lamp

Figure 1-6 When a current of electrons flows in the filament of an electric lamp a great many electron-atom collisions occur. These collisions produce sufficient heat to cause the filament to glow.

1-5 ELECTRIC CIRCUIT

The flashlight circuit shown in Figure 1-7 is made up of a voltage cell, a switch, an electric lamp (or bulb), and connecting conductors. The voltage cell and lamp have already been discussed. In this case, the conductors are the spring at the bottom of the voltage cell, the metal tube that contains the cell, and the metal reflector which is connected to one terminal of the lamp. The switch is simply a thin sliding metal strip that can make or break contact between the tube/container and the reflector.

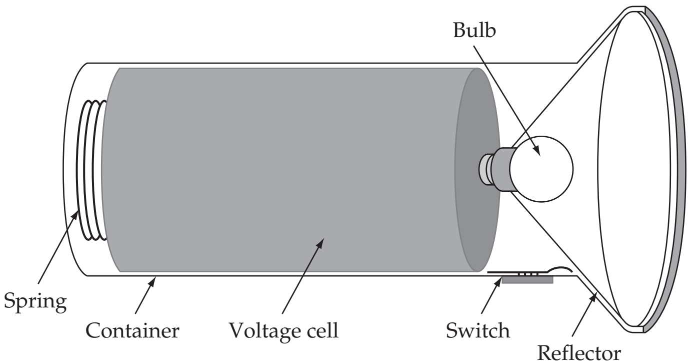
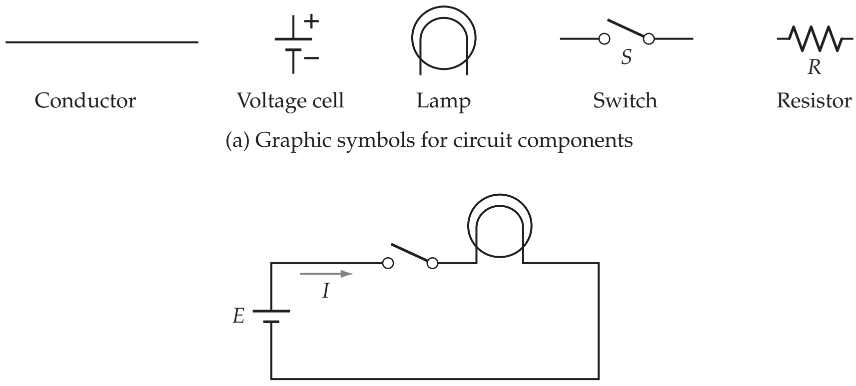


Figure 1-7 A flashlight consists of a battery, a light bulb, a switch, and connecting conductors.

Recall from Section 1-2 that a potential difference (voltage or emf) is an electrical pressure that causes current to flow when a suitable conducting path is provided. When the flashlight switch is open, the conducting path is interrupted so that no current flows. When the switch is closed, the potential difference between the terminals of the voltage cell causes a current of electrons to flow from the negative terminal through the conductors, the lamp filament, and the switch to the positive terminal of the cell.

The circuit in Figure 1-7 can be represented by a *circuit diagram* consisting of lines and graphic symbols. Figure 1-8(a) shows that a conductor is depicted by a straight line, and that the graphic symbol for a voltage cell is a long bar and a short bar side by side. The long bar represents the positive terminal and the short bar is the negative terminal. Lamp and switch symbols are also shown, and a *resistor* circuit symbol is illustrated. As will be explained later, a resistor is a component constructed to have a particular resistance value. Other circuit symbols are given in Appendix 1.

Figure 1-8(b) shows the complete diagram for the flashlight circuit in Figure 1-7. As illustrated on the diagram, the letter E is used to represent voltage (sometimes V is used instead of E), the letter I represents current, and R is used for resistance.



(a) Graphic symbols for circuit components

(b) Flashlight circuit

Figure 1-8 An electric circuit can be represented by a circuit diagram that uses graphic symbols for each component. The letter symbols *E*, *I*, and *R* identify voltage, current, and resistance respectively.

1-6 CURRENT DIRECTION

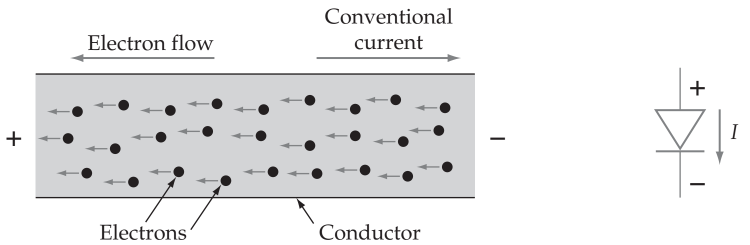
Early electrical researchers believed that a positive charge identified an increased quantity of electricity, and that a negative charge showed a reduced quantity. Consequently, they assumed that current flowed from positive to negative. This is a convention that remains in use today, even though current flow has long been accepted as a movement of electrons from negative to positive [see Figure 1-9(a)].

Current flow from positive to negative is known as the conventional current direction.

Electron flow from negative to positive is termed the direction of electron flow.

It is important to understand and to be able to think in terms of both conventional current direction and electron flow. Electron flow is used to explain how electronic devices operate, but *the graphic symbol for every electronic device employs an arrowhead that points in the direction of conventional current*. Figure 1-9(b) shows the symbol for the simplest electronic device; a *diode*. A diode is a one-way device; current flow occurs only when the polarity of the applied voltage is such that the arrowhead points from positive to negative. When the voltage is reversed (arrowhead pointing from negative to positive) current cannot flow. So, the arrowhead indicates the direction of *conventional current* flow.

Electronic component and equipment manufacturers normally use conventional current direction when they indicate current on a circuit diagram. Conventional current direction is employed throughout this book.



(a) Electron flow and conventional current direction

(b) Graphic symbols for electronic devices use arrowheads that point in the conventional current direction

Figure 1-9 Electric current is a movement of electrons from negative to positive. Conventional current direction assumes current flow from positive to negative. All graphic symbols for electronic devices have arrowheads that indicate conventional current direction.

It should be noted that some books use the direction of electron motion as current direction.

1-7 DIRECT CURRENT AND ALTERNATING CURRENT

Current that flows continuously in one direction is termed *direct current* (abbreviated to dc). This is the kind of current supplied by a voltage cell. Because the voltage at the terminals of a voltage cell remains substantially constant, the current in a circuit supplied by the voltage cell also remains constant. A voltage cell can be described as a *direct voltage source*. Figure 1-10(a) shows the graph of direct current (I) plotted versus time (t); obviously, the current remains constant. The graphic symbol for a direct voltage source is also shown, and this is the voltage cell symbol already discussed.

Alternating current (abbreviated to ac) is current that flows first in one direction for a time (usually a fraction of a second), and then reverses to flow in the opposite direction for a similar time. This is illustrated in Figure 1-10(b), where a graph of alternating current (i) is plotted versus time (t). Note that the current level increases from zero to a peak (positive or negative) value, decreases to zero again, and then increases once more in the opposite direction. This cycle repeats over and over again. The circuit symbol for an alternating voltage source is also illustrated.

1-8 ELECTRIC SHOCK

Electricity can kill, and so it is very important to treat electrical supplies and equipment with great care. The greatest domestic danger exists in bathrooms and kitchens, because of the presence of water and water taps. Water pipes are connected to other pipes that are buried in the ground, so they provide an

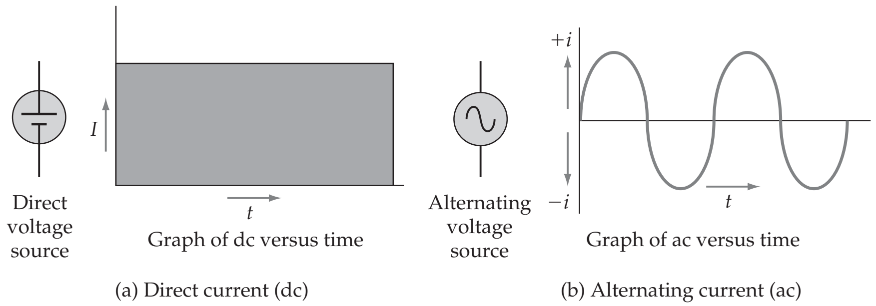


Figure 1-10 A graph of direct current (dc) plotted versus time shows that the current remains constant. A graph of alternating current (ac) versus time shows that the current repeatedly reverses, alternately flowing in one direction and then in the other.

electrical connection to ground. Normally, there is a high potential difference between at least one of the electric supply conductors and ground. Consequently, when a person holds a faulty appliance in one hand and a grounded water tap in the other, a path is provided for current to flow from the conductor to ground via the person. In this case the individual can experience a severe electric shock and may find it impossible to open either hand!

A similar danger exists when someone is using a portable appliance, such as an electric drill, if, for example, the supply cable is worn or has temporary taped splices. While holding the appliance in one hand and pulling the cable, the other hand might close around a bare wire. Here again it may be impossible to open either hand as the electricity flows through the body. An even more lethal situation exists when someone taking a bath reaches for an electrical appliance. The person's body is grounded via the water, and if the appliance is faulty *death is virtually inevitable*.

In a case of electric shock, it is most important to immediately get the victim away from the source of the shock. To avoid endangering a rescuer, the electricity supply must be switched off or disconnected before the victim is touched. Medical help should be summoned, and the victim should be made comfortable and kept calm. If the victim has stopped breathing, artificial respiration should be commenced and continued until medical help arrives. If the victim's heart has stopped beating, external heart compression should be applied by a trained individual.

Summary of Important Terms

- ***Potential difference*** (PD), ***voltage,*** and ***electromotive force*** (emf) are all names for the electrical pressure that tends to cause current flow.

- ***Electrical current*** is a movement of electrons from a negative potential to a positive potential.
- ***Electrical resistance*** is opposition to current flow.
- ***Conventional current direction*** is from positive to negative.
- ***Electron flow*** is electron movement from negative to positive.
- ***Direct current*** (dc) is current that constantly flows in a single direction.
- ***Alternating current*** (ac) is current that alternately flows in one direction and then in the opposite direction.

Review Questions

Section 1-1

1-1 Explain what is meant by electrification by friction. Also define positive and negative electricity as related to electrification by friction.

1-2 State the fundamental law that originated from the study of electrification by friction. Briefly explain the law.

1-3 Draw a diagram of the planetary atom. Identify the three basic particles that constitute an atom and define their relative quantities of charge and mass.

1-4 Define a valence electron and discuss the effect on an atom when it loses an electron and the effect when it gains an electron.

Section 1-2

1-5 Describe what occurs when an electric current flows between two charged bodies. Briefly define: conductor, insulator, resistance.

1-6 Explain what constitutes a potential difference and how it is related to electric current.

Section 1-3

1-7 Sketch the basic construction of a voltage cell and explain how it produces positive and negative terminals.

Section 1-4

1-8 Explain how electric current can produce light and briefly describe an electric lamp.

Section 1-5

1-9 Sketch a diagram for an electric circuit consisting of a voltage cell, a lamp, and a switch. Briefly explain the operation of the circuit.

1-10 Refer to the circuit symbols in Appendix 1. Sketch an electric circuit consisting of a generator, a switch, a resistor, and a lamp.

Section 1-6

1-11 Explain the difference between conventional current direction and direction of electron flow. Sketch the circuit diagram of a lamp supplied from a voltage cell, and identify the directions of conventional current flow and electron flow.

1-12 Sketch the circuit symbol for a diode showing the polarity of applied voltage for current flow. Show the direction of conventional current flow and the direction of electron movement.

Section 1-7

1-13 Define direct current, alternating current, emf, potential difference, and voltage.

1-14 Draw graphs to show the difference between direct current and alternating current. Briefly explain.

Section 1-8

1-15 Describe some of the most dangerous situations in which a person can suffer an electric shock. List the emergency actions that should be taken to aid a victim of electric shock.