فيزياء شابتر ٣ من ٧٥-٩٦ من الكتاب

Almost all forms of technology have concerns about temperature and heat transfer. The concern may be direct, as in refrigeration, or indirect, as in the thermal expansion of highways.

Temperature

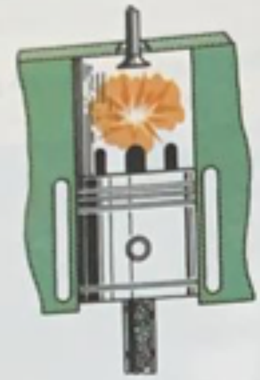


FIGURE 3.1
Force on a piston produced by hot expanding gas

Basically, **temperature** is a measure of the hotness or coldness of an object. Temperature could be measured in a simple way by using your hand to sense the hotness or coldness of an object. However, the range of temperatures that your hand can withstand is too small, and your hand is not precise enough to measure temperature adequately. Therefore, other methods are used for measuring temperature.

A property of matter that we use to find temperature is the change in volume of a liquid or a solid as its temperature changes. The liquid in glass thermometers is an example. This type of thermometer (Figure 3.2) consists of a hollow glass bulb and a hollow glass tube joined together. A small amount of liquid such as alcohol is placed in the bulb. The air is removed from the tube. When the liquid is heated, it expands and rises up the glass tube. The height to which the liquid rises indicates the temperature.

We will study the four temperature scales shown in Figure 3.3. The common metric temperature scale is the **Celsius scale** with freezing point 0°C and boiling point 100°C. To write a temperature, we write the number followed by the degree symbol (°) followed by the capital letter of the scale used. Temperatures below zero on a scale are written as negative numbers. Thus, 20° below zero on the Celsius scale is written as −20°C.

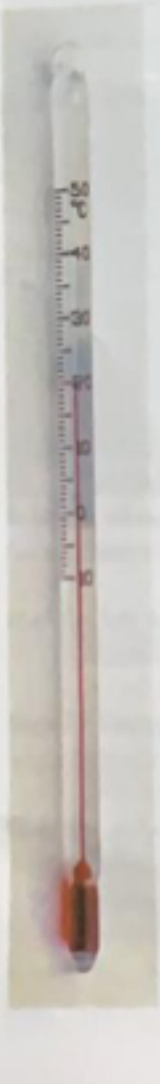


FIGURE 3.2
Common thermometer
Dave King © Dorling Kindersley

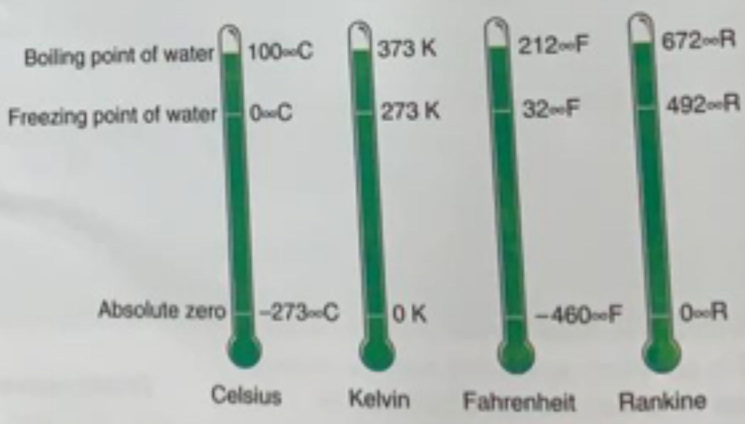


FIGURE 3.3
Four basic temperature scales

EXAMPLE 3.1

The human body average temperature is 98.6°F. What is it in degrees Celsius?

Data:

$$T_F = 98.6°F$$
$$T_C = ?$$

Basic Equation:

$$T_C = \frac{5}{9}(T_F - 32°)$$

Working Equation: Same

Substitution:

$$T_C = \frac{5}{9}(98.6° - 32°)$$
$$= \frac{5}{9}(66.6°)$$
$$= 37.0°\text{C}$$

Anders Celsius (1701–1744), astronomer, was born in Sweden. He devised the centigrade scale of temperature in 1742. The Celsius scale (formerly the centigrade scale) is named after him.

Gabriel Daniel Fahrenheit (1686–1736), physicist, was born in Poland. He invented the alcohol thermometer in 1709 and the mercury thermometer in 1714.

Sometimes it is necessary to use the *absolute temperature scales*, which are the Kelvin scale and the Rankine scale. These are called absolute scales because 0 on either scale refers to the lowest limit of temperature, called *absolute zero*.

The **Kelvin scale** is the metric absolute temperature scale on which absolute zero is 0 K and is closely related to the Celsius scale. The relationship is*

$$T_K = T_C + 273$$

The **Rankine scale** is the U.S. absolute temperature scale on which absolute zero is 0°R and is closely related to the Fahrenheit scale. The relationship is

$$T_R = T_F + 460°$$

Lord Kelvin (Sir William Thomson) (1824–1907), mathematician and physicist, was born in Belfast, Ireland. He helped develop the law of conservation of energy and the absolute temperature scale (now named the Kelvin scale), did fundamental research in thermodynamics, presented the dynamic theory of heat, developed theorems for the mathematical analysis of electricity and magnetism, and designed several kinds of electrometers.

EXAMPLE 3.2

Change 18°C to Kelvin.

Data:

$$T_C = 18°\text{C}$$
$$T_K = ?$$

Basic Equation:

$$T_K = T_C + 273$$

Working Equation: Same

Substitution:

$$T_K = 18 + 273$$
$$= 291\ \text{K}$$

William Rankine (1820–1872), engineer and scientist, was born in Scotland. He is noted for his work on the steam engine, machinery, shipbuilding, applied mechanics, the new science of thermodynamics, and the theories of elasticity and of waves.

EXAMPLE 3.3

Change 535°R to degrees Fahrenheit.

Data:

$$T_R = 535°\text{R}$$
$$T_F = ?$$

*The degree symbol (°) is not used when writing a temperature on the Kelvin scale.

Basic Equation: $T_R = T_F + 46\bar{0}°$

Working Equation: $T_F = T_R - 46\bar{0}°$

Substitution:

$$T_F = 535° - 46\bar{0}°$$
$$= 75°F$$

Heat

FIGURE 3.4

Friction causes a rise in temperature of the drill and plate.

When a hole is drilled in a metal block (Figure 3.4), it becomes very hot. As the drill does mechanical work on the metal, the temperature of the metal increases. How can we explain this? Note the difference between the metal at low temperatures and at high temperatures. At high temperatures, the atoms in the metal vibrate more rapidly than at low temperatures. Their velocity is higher at high temperatures, and thus their kinetic energy ($E_k = \frac{1}{2}mv^2$) is greater. To raise the temperature of a material, we must speed up the atoms; that is, we must add energy to them. **Heat** is a form of internal kinetic and potential energy contained in an object associated with the motion of its atoms or molecules and may be transferred from an object at a higher temperature to one at a lower temperature.

Since heat is a form of energy, we could measure it in joules or ft lb, which are energy units. However, before it was known that heat is a form of energy, special units for heat were developed, which are still in use. These units are the calorie and the kilocalorie in the metric system and the Btu (British thermal unit) in the U.S. system. The **kilocalorie** (kcal) is the amount of heat necessary to raise the temperature of 1 kg of water 1°C. ***Note:*** The precise definition is based on the amount of heat needed to raise the temperature of 1 kg of water from 14.5°C to 15.5°C; however, the variation for each 1°C change in temperature is so minimal that it can be ignored for all practical purposes.

The following are some examples in which heat is converted into useful work:

1. ***In our bodies.*** When food is oxidized, heat energy is produced, which can be converted into muscular energy, which in turn can be turned into work. Experiments have shown that only about 25% of the heat energy from our food is converted into muscular energy. That is, our bodies are about 25% efficient.
2. ***By burning gases.*** When a gas is burned, the gas expands and builds up a tremendous pressure that may convert heat to work by exerting a force to move a piston in an engine or turn the blades of a turbine. Since the burning of the fuel occurs within the cylinder or turbine, such engines are called *internal combustion engines.*
3. ***By steam.*** Heat from burning oil, coal, or wood may be used to generate steam. When water changes to steam under normal atmospheric pressure, it expands about 1700 times. When confined to a boiler, the pressure exerts a force against the piston in a steam engine or against the blades of a steam turbine. Since the fuel burns outside the engine, most steam engines or steam turbines are *external combustion engines.*

Technically, what is the difference between temperature and heat? *Temperature* is a measure of the hotness or coldness of an object. *Heat* is the total thermal energy (kinetic and potential) that can be transferred from an object at a higher temperature to one at a lower temperature. There are two basic ways of changing the temperature of an object:

1. By doing work *on* the object, such as the work done by the drill on the metal block in Figure 3.4.
2. By supplying energy *to* the object, such as mechanical, chemical, or electrical energy.

EXAMPLE 3.4

Find the amount of work (in J) that is equivalent to 4850 cal of heat.

$$4850\ \cancel{\text{cal}} \times \frac{4.19\ \text{J}}{1\ \cancel{\text{cal}}} = 20{,}300\ \text{J} \quad \text{or} \quad 20.3\ \text{kJ}$$

EXAMPLE 3.5

How much work must a person do to offset eating a 775-calorie breakfast?

First, note that one food calorie equals one kilocalorie.

$$775\ \cancel{\text{kcal}} \times \frac{4190\ \text{J}}{1\ \cancel{\text{kcal}}} = 3.25 \times 10^{6}\ \text{J} \quad \text{or} \quad 3.25\ \text{MJ}$$

EXAMPLE 3.6

A given coal gives off 7150 kcal/kg of heat when burned. How many joules of work result from burning one metric ton, assuming that 35.0% of the heat is lost?

First, note that one metric ton equals 1000 kg.

$$7150\ \frac{\cancel{\text{kcal}}}{\cancel{\text{kg}}} \times \frac{4190\ \text{J}}{\cancel{\text{kcal}}} \times 1000\ \cancel{\text{kg}} \times 0.350 = 1.05 \times 10^{10}\ \text{J}$$

Specific Heat

If we placed a piece of steel and a pan of water in the direct summer sunlight, we would find that the water becomes only slightly warmer whereas the steel gets quite hot. Why should one get so much hotter than the other? If equal masses of steel and water were placed over the same flame for 1 min, the temperature of the steel would increase almost 10 times more than that of the water. The water has a greater capacity to absorb heat.

The specific heat of a substance is a measure of its capacity to absorb or give off heat per degree change in temperature. This property of water to absorb or give off large amounts of heat makes it an effective substance for transferring heat in industrial processes.

The **specific heat** of a substance is the amount of heat necessary to change the temperature of 1 kg of it 1°C (1 lb of it 1°F in the U.S. system). By formula,

$$c = \frac{Q}{m\Delta T} \ \text{(metric)} \qquad c = \frac{Q}{w\Delta T} \ \text{(U.S)}$$

To find the amount of heat added or taken away from a substance to produce a certain temperature change, we use

$$Q = cm\Delta T \quad \text{(metric)} \qquad Q = cw\Delta T \quad \text{(U.S.)}$$

where c = specific heat
Q = heat
m = mass
w = weight
ΔT = change in temperature

A list of specific heats is given in Table 15 of Appendix C.

Try This Activity

Cool Floors

A dramatic example of heat conduction is often experienced on cold winter mornings. While standing with your bare feet on a cold tile floor, note how quickly heat is transferred from your feet to the tile. Then, stand in a doorway with one bare foot on tile and one bare foot on wood and note the difference in the rate at which heat is transferred. What are the general characteristics that determine the heat capacity for your floors? Why are mats commonly placed on bathroom floors?

EXAMPLE 3.7

How many kilocalories of heat must be added to 10.0 kg of steel to raise its temperature $15\bar{0}$°C?

Data:

$$m = 10.0 \text{ kg}$$
$$\Delta T = 15\bar{0}\text{°C}$$
$$c = 0.115 \text{ kcal/kg°C} \quad \text{(from Table 15 of Appendix C)}$$
$$Q = ?$$

Basic Equation:

$$Q = cm\Delta T$$

Working Equation: Same

Substitution:

$$Q = \left(0.115 \frac{\text{kcal}}{\cancel{\text{kg}}\,\cancel{\text{°C}}}\right)(10.0\ \cancel{\text{kg}})(15\bar{0}\ \cancel{\text{°C}})$$
$$= 173 \text{ kcal}$$

EXAMPLE 3.8

How many joules of heat must be absorbed to cool 5.00 kg of water from 75.0°C to 10.0°C?

Data:

$$m = 5.00 \text{ kg}$$
$$\Delta T = 75.0\text{°C} - 10.0\text{°C} = 65.0\text{°C}$$
$$c = 4190 \text{ J/kg°C} \quad \text{(from Table 15 of Appendix C)}$$
$$Q = ?$$

Basic Equation:

$$Q = cm\Delta T$$

Working Equation: Same

Substitution:

$$Q = \left(4190 \frac{\text{J}}{\cancel{\text{kg}}\cancel{^\circ\text{C}}}\right)(5.00\ \cancel{\text{kg}})(65.0\cancel{^\circ\text{C}})$$

$$= 1.36 \times 10^6\ \text{J} \quad \text{or} \quad 1.36\ \text{MJ}$$

Change of Phase

Many industries are concerned with a change of phase in the materials they use. In foundries the principal activity is to change solid metals to liquid, pour the liquid metal into molds, and allow it to become solid again (Figure 3.5). **Change of phase** (sometimes called *change of state*) is a change in a substance from one form of matter (solid, liquid, or gas) to another.

FIGURE 3.5

Molten iron at about 2900°F is poured from a bucket into an open mold by a person in protective clothes and gloves.

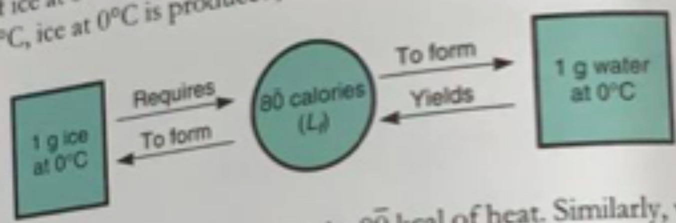
Katie Froster © Dorling Kindersley, Courtesy of the Ironbridge Gorge Museum, Telford Shropshire

FUSION

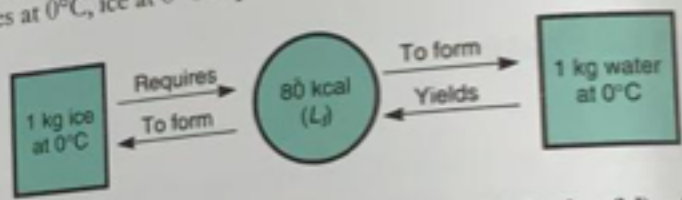
The change of phase from solid to liquid is called **melting** or **fusion**. The change from liquid to solid is called **freezing** or **solidification**. Most solids have a crystalline structure and a definite melting point at any given pressure. Melting and solidification of these substances occur at the same temperature. For example, water at 0°C (32°F) changes to ice and ice changes to water at the same temperature. There is no temperature change during change of phase. Ice at 0°C changes to water at 0°C. Only a few substances, such as butter and glass, have no particular melting temperature but change phase gradually.

Although there is no temperature change during a change of phase, *there is a transfer of heat.* A melting solid *absorbs* heat and a solidifying liquid *gives off* heat.

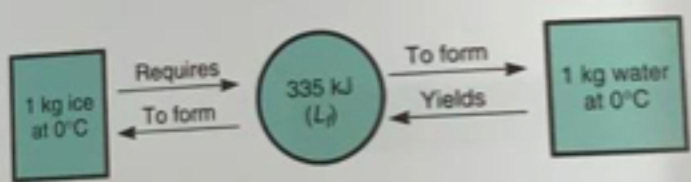
When 1 g of ice at 0°C melts, it absorbs $8\bar{0}$ cal of heat. Similarly, when 1 g of water freezes at 0°C, ice at 0°C is produced, and $8\bar{0}$ cal of heat is released.



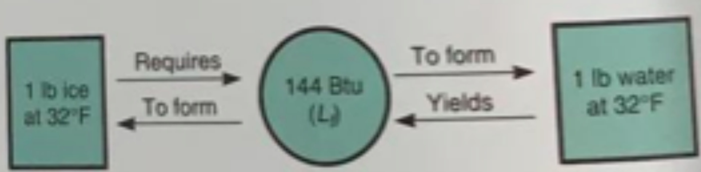
When 1 kg of ice at 0°C melts, it absorbs $8\bar{0}$ kcal of heat. Similarly, when 1 kg of water freezes at 0°C, ice at 0°C is produced and $8\bar{0}$ kcal of heat is released.



Or when 1 kg of ice at 0°C melts, it absorbs 335 kilojoules (kJ) of heat. Then, when 1 kg of water freezes at 0°C, ice at 0°C is produced and 335 kJ of heat is released.



When 1 lb of ice at 32°F melts, it absorbs 144 Btu of heat. Similarly, when 1 lb of water freezes at 32°F, ice at 32°F is produced and 144 Btu of heat is released.



The amount of heat required to melt 1 g or 1 kg or 1 lb of a liquid is called its **heat of fusion,** designated L_f.

$$L_f = \frac{Q}{m} \quad \text{(metric)} \qquad L_f = \frac{Q}{w} \quad \text{(U.S.)}$$

where L_f = heat of fusion (see Table 15 in Appendix C)
Q = quantity of heat
m = mass of substance (metric system)
w = weight of substance (U.S. system)

EXAMPLE 3.9

If 1340 kJ of heat is required to melt 4.00 kg of ice at 0°C into water at 0°C, what is the heat of fusion of water?

Data:

$Q = 1340 \text{ kJ}$
$m = 4.00 \text{ kg}$
$L_f = ?$

Basic Equation:

$$L_f = \frac{Q}{m}$$

Working Equation: Same

Substitution:

$$L_f = \frac{1340 \text{ kJ}}{4.00 \text{ kg}}$$
$$= 335 \text{ kJ/kg}$$

heat of fusion (water) = $8\overline{0}$ cal/g, or $8\overline{0}$ kcal/kg, or 335 kJ/kg, or 144 Btu/lb

A very interesting (and delicious) change-of-phase activity is to make homemade ice cream. A sealed container with a mixture of milk, egg, vanilla, and sugar is submerged in a mixture of rock salt and crushed ice. The salt causes the ice to rapidly melt, which requires heat, while the ice changes phase from solid to liquid. Most of this heat is transferred from the ice cream mixture, which hardens into ice cream.

VAPORIZATION

The change of phase from a liquid to a gas or vapor is called **vaporization.** A pot of boiling water (Figure 3.6) vividly shows this change of phase as the steam evaporates and leaves the liquid. Note that vaporization requires that heat be supplied; in this case heat is required to boil the water. The reverse process (change from a gas to a liquid) is called **condensation**. As steam condenses in radiators (Figure 3.7), large amounts of heat are released.

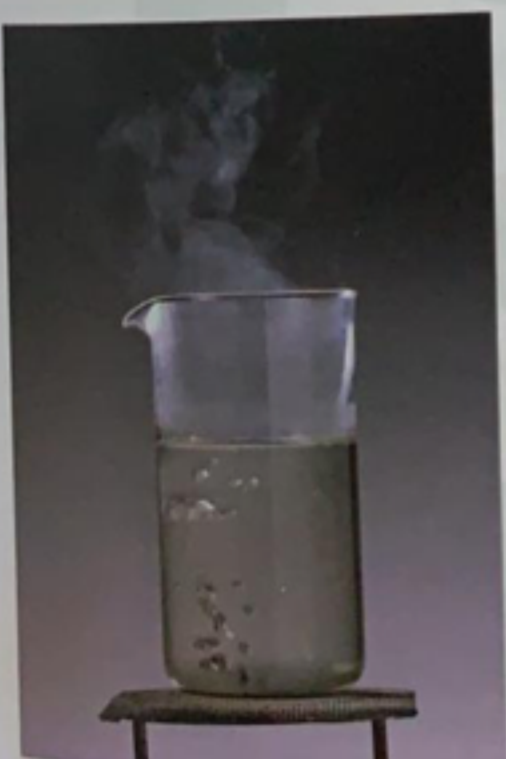


FIGURE 3.6

Heat supplied to boiling water changes liquid water into steam—the gas form of water.
© Dorling Kindersley

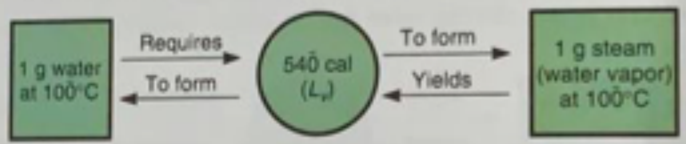
FIGURE 3.7

A large amount of heat is released by condensation of steam in a radiator.

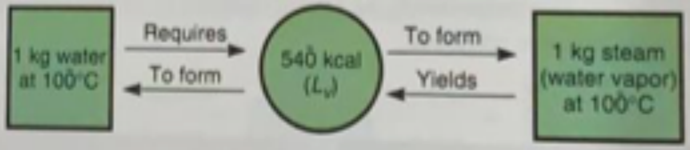
At the point of condensation, the vapor becomes *saturated*; that is, the vapor cannot hold any more moisture. For example, water vapor is always present in some amount in the earth's atmosphere. The weather term **relative humidity** is the ratio of the actual amount of vapor in the atmosphere to the amount of vapor required to reach 100% of saturation at the existing temperature. As the air temperature decreases without change in pressure or vapor content, the relative humidity increases until it reaches 100% at saturation. The temperature at which saturation is reached is called the **dew point**. Once saturation is reached and the temperature continues to decrease, condensation occurs in the form of dew, fog, mist, clouds, and rain or other forms of precipitation.

While a liquid is boiling, the temperature of the liquid does not change. However, there is a transfer of heat. A liquid being vaporized (boiled) *absorbs* heat. As a vapor condenses, heat is given off.

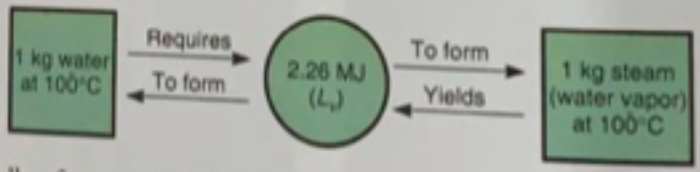
The amount of heat required to vaporize 1 g or 1 kg or 1 lb of a liquid is called its **heat of vaporization,** designated L_v. So when 1 g of water at $10\bar{0}$°C changes to steam at $10\bar{0}$°C, it absorbs $54\bar{0}$ cal; when 1 g of steam at $10\bar{0}$°C condenses to water at $10\bar{0}$°C, $54\bar{0}$ cal of heat is given off. The tremendous amount of heat released accounts for the potential for far more serious burns from steam than from hot water.



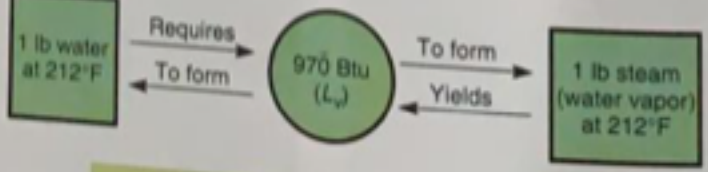
When 1 kg of water at $10\bar{0}$°C changes to steam at $10\bar{0}$°C, it absorbs $54\bar{0}$ kcal of heat. Similarly, when 1 kg of steam at $10\bar{0}$°C condenses to water at $10\bar{0}$°C, $54\bar{0}$ kcal of heat is given off.



Or when 1 kg of water at $10\bar{0}$°C changes to steam at $10\bar{0}$°C, it absorbs 2.26 MJ (2.26×10^6 J) of heat. Then, when 1 kg of steam at $10\bar{0}$°C condenses to water at $10\bar{0}$°C, 2.26 MJ of heat is given off.



When 1 lb of water at 212°F changes to steam at 212°F, $97\bar{0}$ Btu of heat is absorbed; when 1 lb of steam at 212°F condenses to water at 212°F, $97\bar{0}$ Btu of heat is given off.



$$L_v = \frac{Q}{m} \quad \text{(metric)} \qquad L_v = \frac{Q}{w} \quad \text{(U.S.)}$$

where L_v = heat of vaporization (see Table 15 in Appendix C)
Q = quantity of heat
m = mass of substance (metric system)
w = weight of substance (U.S. system)

EXAMPLE 3.10

If 135,000 cal of heat is required to vaporize $25\bar{0}$ g of water at $10\bar{0}$°C, what is the heat of vaporization of water?

Data:

$$Q = 135{,}000 \text{ cal}$$
$$m = 25\bar{0} \text{ g}$$
$$L_v = ?$$

Basic Equation:

$$L_v = \frac{Q}{m}$$

Working Equation: Same

Substitution:

$$L_v = \frac{135{,}000 \text{ cal}}{25\bar{0} \text{ g}}$$
$$= 54\bar{0} \text{ cal/g}$$

heat of vaporization (water) = $54\bar{0}$ cal/g, or $54\bar{0}$ kcal/kg, or 2.26 MJ/kg, or $97\bar{0}$ Btu/lb

EXAMPLE 3.11

If 15.8 MJ of heat is required to vaporize 18.5 kg of ethyl alcohol at 78.5°C (its boiling point), what is the heat of vaporization of ethyl alcohol?

Data:

$$Q = 15.8 \text{ MJ}$$
$$m = 18.5 \text{ kg}$$
$$L_v = ?$$

Basic Equation:

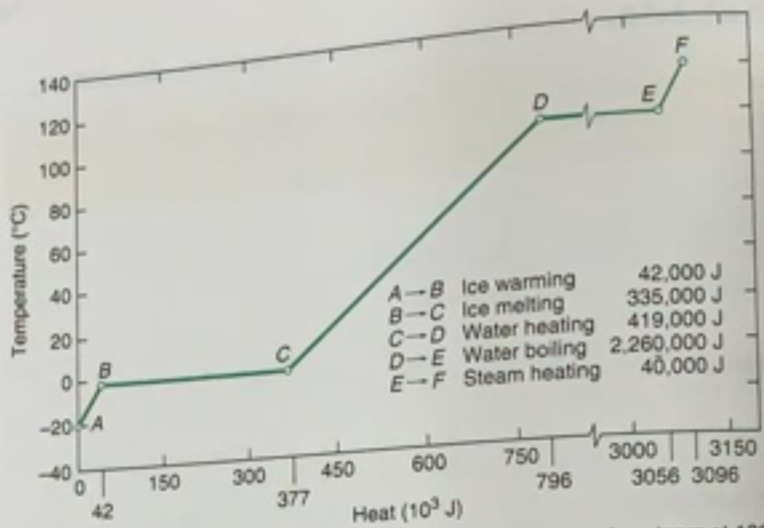
$$L_v = \frac{Q}{m}$$

Working Equation: Same

Substitution:

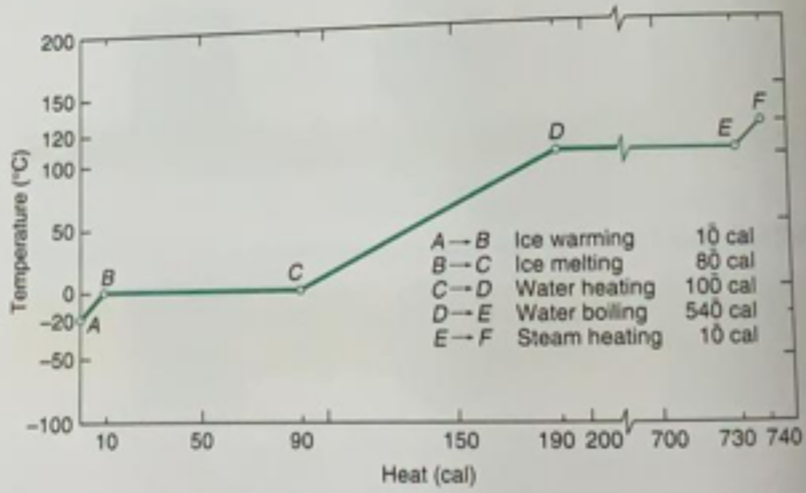
$$L_v = \frac{15.8 \text{ MJ}}{18.5 \text{ kg}}$$
$$= 0.854 \text{ MJ/kg or } 854 \text{ kJ/kg or } 8.54 \times 10^5 \text{ J/kg}$$

Figures 3.8 through 3.10 show the heat gained by one unit of ice at a temperature below its melting point as it warms to its melting point, changes to water, warms to its boiling point, changes to steam, and then is heated above its boiling point in joules, Btu, and calories. Note that during each change of phase there is no temperature change. Recall the basic shape of these graphs because we will use it to find the amount of heat gained or lost when a quantity of material goes through one or both changes of phase. Refer to Figure 3.11 to do such problems. See Table 15 of Appendix C for heat constants of some common substances.



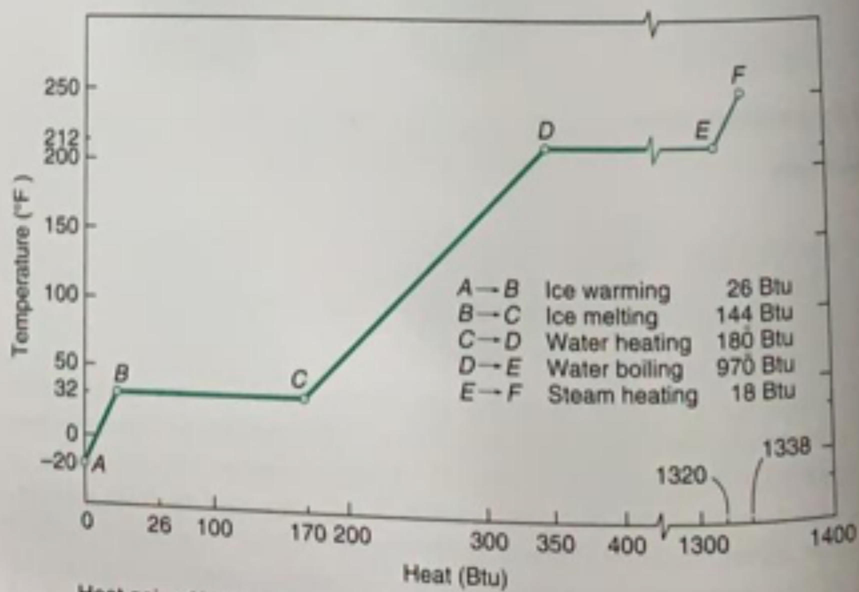
Heat gained by one kilogram of ice at −20°C as it is converted to steam at 120°C

FIGURE 3.8



Heat gained by one gram of ice at −20°C as it is converted to steam at 120°C

FIGURE 3.9



Heat gained by one pound of ice at −20°F as it is converted to steam at 250°F

FIGURE 3.10

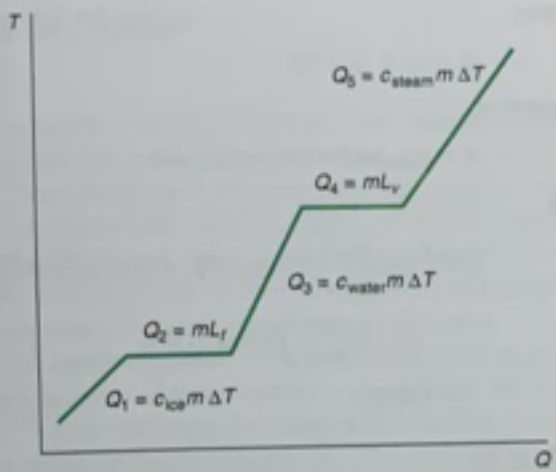


FIGURE 3.11

Graph of heat transfer during change of phase

EXAMPLE 3.12

How many Btu of heat are released when 4.00 lb of steam at 222°F is cooled to water at 82°F?

To find the amount of heat released when steam at a temperature above its vaporization point is cooled to water below its boiling point, we need to consider three amounts (see Figure 3.12):

$Q_5 = c_{steam} w \Delta T$ (amount of heat released as the steam changes temperature from 222°F to 212°F)

$Q_4 = wL_v$ (amount of heat released as the steam changes to water)

$Q_3 = c_{water} w \Delta T$ (amount of heat released as the water changes temperature from 212°F to 82°F)

So the total amount of heat released is

$$Q = Q_5 + Q_4 + Q_3$$

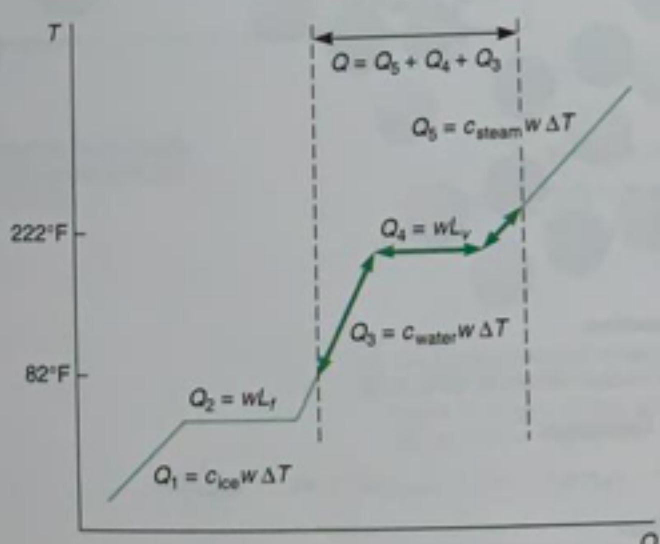


FIGURE 3.12

Data:

$$w = 4.00 \text{ lb}$$
$$T_i \text{ of steam} = 222°\text{F}$$
$$T_f \text{ of water} = 82°\text{F}$$
$$Q = ?$$

Basic Equation:

$$Q = Q_5 + Q_4 + Q_3$$

Working Equation:

$$Q = c_{steam} w \Delta T + wL_v + c_{water} w \Delta T$$

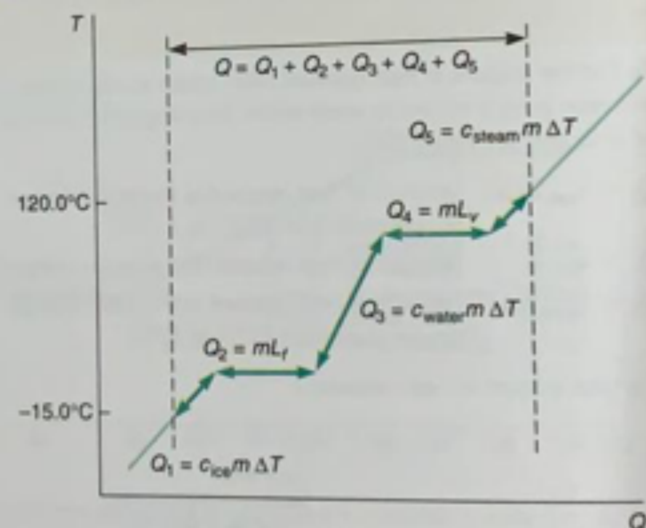
Substitution:

$$Q = \left(0.48 \frac{\text{Btu}}{\text{lb °F}}\right)(4.00 \text{ lb})(1\bar{0}\text{°F}) + (4.00 \text{ lb})\left(97\bar{0} \frac{\text{Btu}}{\text{lb}}\right)$$
$$+ \left(1.00 \frac{\text{Btu}}{\text{lb °F}}\right)(4.00 \text{ lb})(13\bar{0}\text{°F})$$
$$= 4420 \text{ Btu}$$

EXAMPLE 3.13

How many joules of heat are needed to change 3.50 kg of ice at -15.0°C to steam at 120.0°C?

Sketch:



Data:

$$m = 3.50 \text{ kg}$$
$$T_i \text{ of ice} = -15.0\text{°C}$$
$$T_f \text{ of steam} = 120.0\text{°C}$$
$$Q = ?$$

Basic Equation:

$$Q = Q_1 + Q_2 + Q_3 + Q_4 + Q_5$$

Working Equation:

$$Q = c_{ice} m \Delta T + mL_f + c_{water} m \Delta T + mL_v + c_{steam} m \Delta T$$

Substitution:

$$Q = \left(2100 \frac{\text{J}}{\text{kg °C}}\right)(3.50 \text{ kg})(15.0\text{°C}) + (3.50 \text{ kg})\left(335 \frac{\text{kJ}}{\text{kg}}\right) \times \frac{10^3 \text{ J}}{1 \text{ kJ}} \text{ (Change to joules)}$$
$$+ \left(4190 \frac{\text{J}}{\text{kg °C}}\right)(3.50 \text{ kg})(100.0\text{°C}) + (3.50 \text{ kg})\left(2.26 \frac{\text{MJ}}{\text{kg}}\right) \times \frac{10^6 \text{ J}}{1 \text{ MJ}}$$
$$+ \left(2\bar{0}00 \frac{\text{J}}{\text{kg °C}}\right)(3.50 \text{ kg})(20.0\text{°C})$$
$$= 1.080 \times 10^7 \text{ J} \quad \text{or} \quad 10.80 \text{ MJ}$$

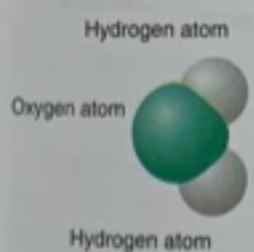
Properties of Matter

What are the building blocks of matter? First, **matter** is anything that occupies space and has mass. Suppose that we take a cube of sugar and divide it into two pieces. Then we divide a resulting piece into another two pieces. Can we continue this process indefinitely and get smaller and smaller particles of sugar each time? No, at some point we will arrive at the building blocks of sugar.

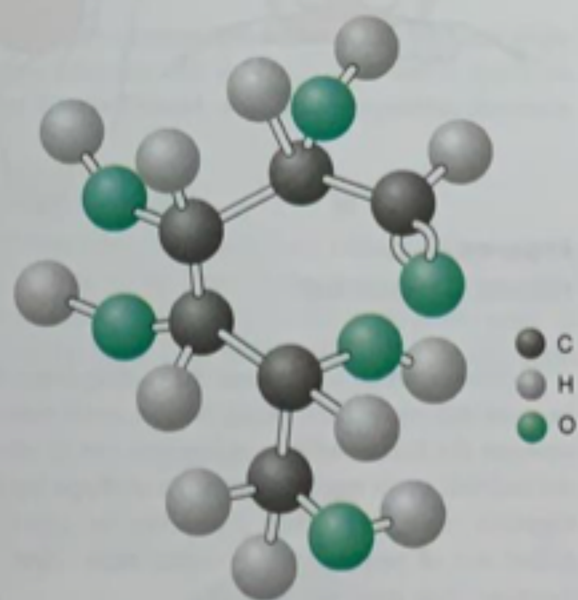
An **element** is a substance that cannot be separated into simpler substances. A **compound** is a substance containing two or more elements.

A **molecule** is the smallest particle of an element that can exist in a free state and still retain the characteristics of that element or compound. Most simple molecules are about 3×10^{-10} m in diameter. An **atom** is the smallest particle of an element that can exist in a stable or independent state. The molecules of elements consist of one atom or two or more similar atoms; the molecules of compounds consist of two or more different atoms.

What do we get if we divide the sugar molecule? The resulting particles are carbon, hydrogen, and oxygen atoms. Models of water and sugar molecules are shown in Figure 3.13. Not all atoms are the same size. The hydrogen atom is the smallest, with diameter 6×10^{-11} m and mass 1.67×10^{-27} kg. Uranium is one of the heaviest atoms, 3.96×10^{-25} kg.



(a) The water molecule is composed of two hydrogen atoms and one oxygen atom (H_2O).



(b) The sugar (glucose) molecule is composed of six carbon atoms, twelve hydrogen atoms, and six oxygen atoms ($C_6H_{12}O_6$).

FIGURE 3.13

The molecules of a gas are not fixed in relation to each other and move rapidly in all directions, colliding with each other [Figure 3.14(c)]. They are much farther apart than molecules in a liquid, and they are extremely far apart when compared to the distance between molecules in solids. The movement of the molecules is limited only by the container. Therefore, a gas takes the shape of its container. Because the molecules are far apart, a gas can easily be compressed, and it has the same volume as its container.

(a) Solid molecules vibrate in fixed positions. (b) Liquid molecules flow over each other. (c) Gas molecules move rapidly in all directions and collide.

FIGURE 3.14

ELASTICITY

An object becomes deformed when outside forces change its shape or size. **Elasticity** is a measure of a deformed object's ability to return to its original size and shape once the outside forces are removed. When the solid is being deformed, sometimes the molecules attract each other and sometimes they repel each other. For instance, try to pull a rubber ball apart (Figure 3.15). You will notice that the ball stretches out of shape.

(a) (b) (c)

FIGURE 3.15
Elasticity in a rubber ball

However, when you release the pulling force, the ball returns to its original shape because the molecules, being farther apart than normal, attract each other. If you squeeze the ball, it will again become out of shape. Now release the pressure, and the ball will again return to its original shape because the molecules, being too close together, repel each other. Therefore, we can see that when molecules are slightly pulled out of position, they attract each other. When they are pressed too close together, they repel each other.

Most solids have the property of elasticity; however, some are only slightly elastic. For example, wood and Styrofoam are two solids whose elasticity is small.

Not every elastic object returns to its original shape after being deformed. If too large a deforming force is applied, an object may become deformed permanently. Take a spring [Figure 3.16(a)] and pull it apart by a moderate amount [Figure 3.16(b)]. When you let it go, it should return to its original shape. Next, pull the spring apart as far as you can [Figure 3.16(c)]. When you let it go this time, it will probably not return to its original shape. The **elastic limit** of a solid is the point beyond which a deformed object cannot return to its original shape. The spring's molecules were pulled far enough apart that they slid past one another beyond the point at which the original molecular forces could return the spring to its original shape. If the applied force is great enough, the spring breaks apart [Figure 3.16(d)].

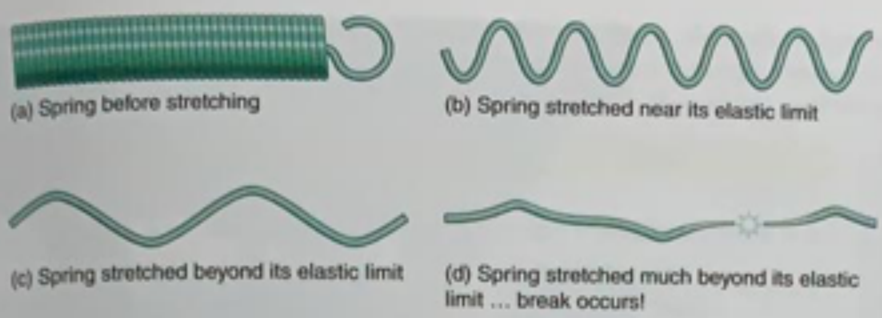


FIGURE 3.16

Stress is the ratio of the outside applied force, which tends to cause a distortion, to the area over which the force acts. In other words,

$$\text{stress} = \frac{\text{applied force}}{\text{area over which the force acts}}$$

or

$$S = \frac{F}{A}$$

where S = stress, usually in N/m^2 (Pa) or lb/in^2 (psi)
F = force applied, N or lb, perpendicular to the surface to which it is applied
A = area, m^2 or in^2

Since the SI metric unit for force is the newton (N) and the unit for area is the square metre (m^2), the corresponding pressure unit is N/m^2. This unit is given the special name *pascal* (Pa), named after **Blaise Pascal**, who made important discoveries in science and mathematics.

$$1\ N/m^2 = 1\ Pa$$

Blaise Pascal (1623–1662), *mathematician, physicist, and theologian, was born in France. He invented the calculating machine in 1647 and later the barometer, the hydraulic press, and the syringe. He also formulated the modern theory of probability.*

Imagine a brick weighing 12.0 N first lying on its side on a table and then standing on one end (Figure 3.17). The weight of the brick is the same no matter what its position, so the total force (the weight of the brick) on the table is the same in both cases. However, the position of the brick does make a difference in the stress

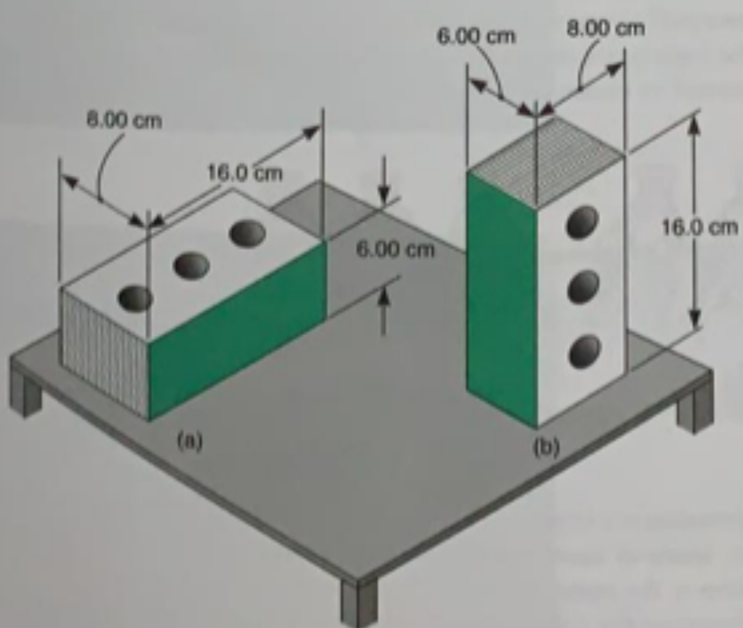


FIGURE 3.17

The weight of the brick is constant, but the stress on the table in part (b) is greater.

exerted on the table. In which case is the stress greater? When standing on end, the brick exerts a greater stress on the table because the area of contact on the end is *smaller* than on the side. Using $S = F/A$, find the stress in each case:

Case 1	Case 2
$F = 12.0\text{ N}$	$F = 12.0\text{ N}$
$A = 8.00\text{ cm} \times 16.0\text{ cm} = 128\text{ cm}^2$	$A = 6.00\text{ cm} \times 8.00\text{ cm} = 48.0\text{ cm}^2$
$S = \frac{F}{A} = \frac{12.0\text{ N}}{128\text{ cm}^2} \times \left(\frac{100\text{ cm}}{1\text{ m}}\right)^2$	$S = \frac{F}{A} = \frac{12.0\text{ N}}{48.0\text{ cm}^2} \times \left(\frac{100\text{ cm}}{1\text{ m}}\right)^2$
$= 938\text{ N/m}^2 = 938\text{ Pa}$	$= 25\bar{0}0\text{ N/m}^2 = 25\bar{0}0\text{ Pa}$

This shows that when the same force is applied to a smaller area, the stress is greater. From the discussion so far, would you rather someone step on your foot with a flat-heel shoe or with a pointed-heel shoe? (See Figure 3.18.)

FIGURE 3.18

The stress exerted by the heel in part (b) is greater because the weight rests on a smaller area.

Five basic types of stresses are as follows.

Tension is a stress caused by two forces acting directly opposite each other. This stress tends to cause objects to become longer and thinner. An example of such a stress is that on the rope in a tug-of-war (Figure 3.19). The rope has one team's force pulling one way and another team's force pulling in the opposite direction. If the rope is not strong enough to withstand the tension, it could ultimately stretch beyond its elastic limit and break.

FIGURE 3.19

The rope in a tug-of-war competition is in constant tension.
Pearson Education, Inc.

Compression is a stress caused by two forces acting directly toward each other. This stress tends to cause objects to become shorter and thicker. An example of compression is the stress present in a supporting column (Figure 3.20). A load is pushing down on the column, while the ground is applying a force pushing up on the column. As a result, the pillar compresses.

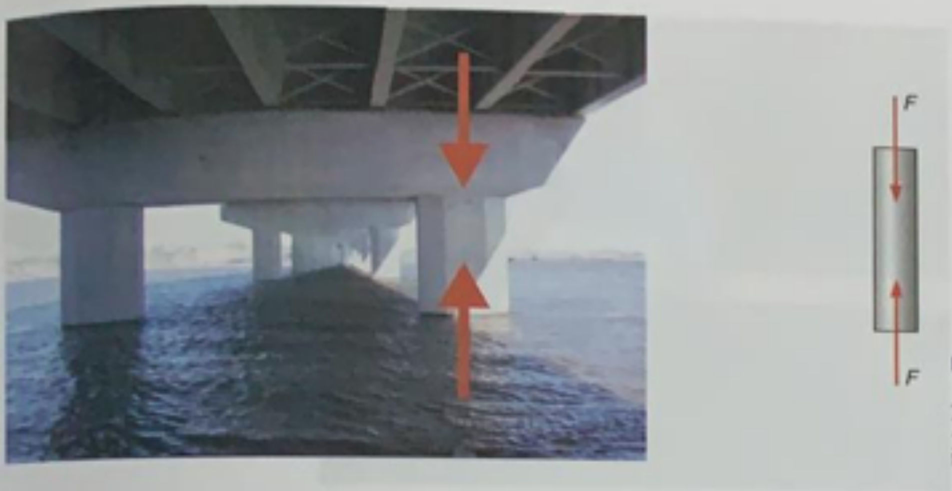


FIGURE 3.20
A column under the New Clark Bridge crossing the Mississippi River is in compression.

Shearing is a stress caused by two forces applied in parallel, opposite directions. In Figure 3.21, the table pushing the book to the left counteracts the force of the hand pushing the book to the right. The normally rectangular shape of the book is altered. Scissors use shearing to cut paper.

Torsion is a stress related to a twisting motion. Torsion occurs when two torques act in opposite directions. This type of stress severely compromises the strength of most materials. An example of torsion is the stress on a bolt or a screw as it is being tightened (Figure 3.22).

FIGURE 3.21
A book being pushed in this way is undergoing shear.

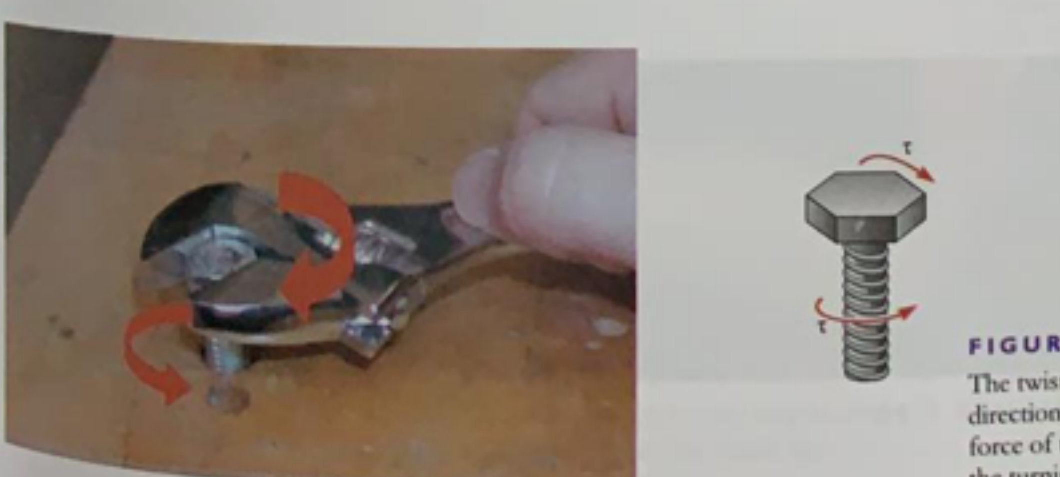


FIGURE 3.22
The twisting of the bolt in one direction is counteracted by the force of the wood resisting the turning motion.

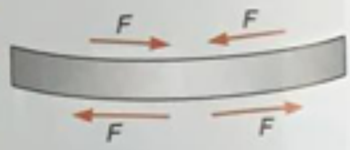


FIGURE 3.23
A beam that is bending

Bending consists of both tension and compression stresses. It occurs when a force is placed on an object and this causes it to sag. An example of bending is caused by a person sitting on a board (Figure 3.23). The top section of the board is being pushed together, in compression, while the bottom section of the board is being pulled apart, in tension.

Whenever a stress is applied to an object, the object is changed minutely, at least. If you stand on a steel beam, it bends—at least slightly. **Strain** is the deformation of an object due to an applied force. That is, strain is the relative amount of deformation of a body that is under stress. Or strain is *change in length per unit of length*, change in volume per unit of volume, and so on. Strain is a direct and necessary consequence of stress.

Try this activity

Stresses

Foam is a flexible material that can easily demonstrate the various types of stresses on solid materials. Using a permanent marker, draw lines at 1.0-in. intervals along the top and bottom sides of a rectangular piece of foam (Figure 3.24). Using Figures 3.19–3.23 as a guide, apply the appropriate forces to the foam to simulate the five types of stress. Observe how the stresses affect the spacing of the drawn lines. Describe how the strength of building materials such as concrete, wood, and steel is affected when the materials are subjected to the five types of stress.

FIGURE 3.24

EXAMPLE 3.14

A steel column in a building has a cross-sectional area of $25\bar{0}0 \text{ cm}^2$ and supports a weight of 1.50×10^5 N. Find the stress on the column.

Data:

$$A = 25\bar{0}0 \text{ cm}^2 \times \left(\frac{1 \text{ m}}{100 \text{ cm}}\right)^2 = 0.250 \text{ m}^2$$

$$F = 1.50 \times 10^5 \text{ N}$$

$$S = ?$$

Basic Equation:

$$S = \frac{F}{A}$$

Working Equation: Same

Substitution:

$$\begin{aligned} S &= \frac{1.50 \times 10^5 \text{ N}}{0.250 \text{ m}^2} \\ &= 6.00 \times 10^5 \text{ N/m}^2 \\ &= 6.00 \times 10^5 \text{ Pa} \quad \text{or} \quad 6\bar{0}0 \text{ kPa} \end{aligned}$$

HOOKE'S LAW

One of the most basic principles related to the elasticity of solids is **Hooke's law**, named after **Robert Hooke**.

Or stated another way: Stress is directly proportional to strain as long as the elastic limit has not been exceeded. (See Figure 3.25.) In equation form,

$$\frac{F}{\Delta l} = k$$

where F = applied force
Δl = change in length
k = elastic constant

Note: Δ (the Greek letter delta) is often used in mathematics and science to mean "change in."

Robert Hooke (1635–1703), chemist and physicist, was born in England. He formulated the law governing elasticity (Hooke's law), invented the balance spring for watches, worked with and made important observations with the telescope and the microscope, and formulated the theory of planetary movement.

Hooke's Law
The ratio of the force applied to an object to its change in length (resulting in its being stretched or compressed by the applied force) is constant as long as the elastic limit has not been exceeded.

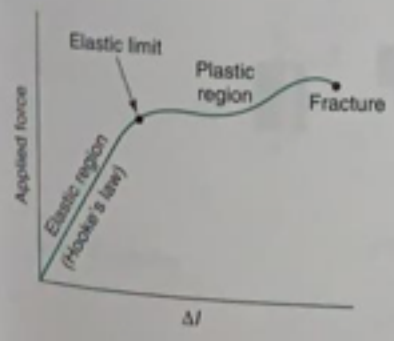


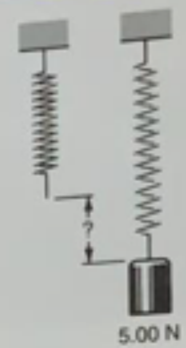
FIGURE 3.25

Graph of Hooke's law showing behavior within and beyond the elastic limit

EXAMPLE 3.15

A force of 5.00 N is applied to a spring whose elastic constant is 0.250 N/cm. Find its change in length.

Sketch:



Data:

$$F = 5.00 \text{ N}$$
$$k = 0.250 \text{ N/cm}$$
$$\Delta l = ?$$

Basic Equation:

$$\frac{F}{\Delta l} = k$$

Working Equation:

$$\Delta l = \frac{F}{k}$$

Substitution:

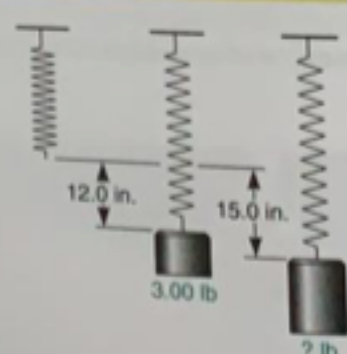
$$\Delta l = \frac{5.00 \text{ N}}{0.250 \text{ N/cm}}$$
$$= 20.0 \text{ cm}$$

$$\boxed{\frac{\text{N}}{\text{N/cm}} = \text{N} \div \frac{\text{N}}{\text{cm}} = \cancel{\text{N}} \cdot \frac{\text{cm}}{\cancel{\text{N}}} = \text{cm}}$$

EXAMPLE 3.16

A force of 3.00 lb stretches a spring 12.0 in. What force is required to stretch the spring 15.0 in.?

Sketch:



Data:

$$F_1 = 3.00 \text{ lb}$$
$$l_1 = 12.0 \text{ in.}$$
$$l_2 = 15.0 \text{ in.}$$
$$F_2 = ?$$

Basic Equation:

$$\frac{F}{\Delta l} = k$$

Working Equations:

$$\frac{F}{\Delta l} = k \quad \text{and} \quad F = k(\Delta l)$$

Substitution: There are two substitutions, one to find k and one to find the second force F_2:

$$\frac{3.00 \text{ lb}}{12.0 \text{ in.}} = k$$
$$0.250 \text{ lb/in.} = k$$

$$F_2 = (0.250 \text{ lb/in.})(15.0 \text{ in.})$$
$$= 3.75 \text{ lb}$$

EXAMPLE 3.17

A support column is compressed 3.46×10^{-4} m under a weight of 6.42×10^5 N. How much is the column compressed under a weight of 5.80×10^6 N?

First find k:

Data:

$$F_2 = 6.42 \times 10^5 \text{ N}$$
$$\Delta l_2 = 3.46 \times 10^{-4} \text{ m}$$
$$k = ?$$

Basic Equation:

$$\frac{F_2}{\Delta l_2} = k$$

Working Equation: Same

Substitution:

$$k = \frac{6.42 \times 10^5 \text{ N}}{3.46 \times 10^{-4} \text{ m}}$$
$$= 1.86 \times 10^9 \text{ N/m}$$

Then:

Data:

$$k = 1.86 \times 10^9 \text{ N/m}$$
$$F_1 = 5.80 \times 10^6 \text{ N}$$
$$\Delta l_1 = ?$$

Basic Equation:

$$\frac{F_1}{\Delta l_1} = k$$

Working Equation:

$$\Delta l_1 = \frac{F_1}{k}$$

Substitution:

$$\Delta l_1 = \frac{5.80 \times 10^6\ \text{N}}{1.86 \times 10^9\ \text{N/m}}$$

$$= 3.12 \times 10^{-3}\ \text{m} \quad \text{or} \quad 3.12\ \text{mm}$$

Properties of Liquids

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Density

Density is a property of all three states of matter. **Mass density,** D_m, is defined as mass per unit volume. **Weight density,** D_w, is defined as weight per unit volume, or

$$D_m = \frac{m}{V} \qquad D_w = \frac{F_w}{V}$$

where D_m = mass density, m = mass, V = volume; D_w = weight density, F_w = weight, V = volume

Although mass density and weight density can be expressed in both the metric system and the U.S. system, mass density is usually given in the metric units kg/m^3 and weight density is usually given in the U.S. units lb/ft^3 (Table 3.1).

The mass density of water is $10\bar{0}0$ kg/m^3; that is, 1 cubic metre of water has a mass of $10\bar{0}0$ kg. The weight density of water is 62.4 lb/ft^3; that is, 1 cubic foot of water weighs 62.4 lb.

In nearly all forms of matter, the density usually decreases as the temperature increases and increases as the temperature decreases. Water does not follow the usual pattern of increasing density at lower temperatures; ice is actually less dense than liquid water.

Note: Conversion factors must often be used to obtain the desired units.

TABLE 3.1

Densities for Various Substances

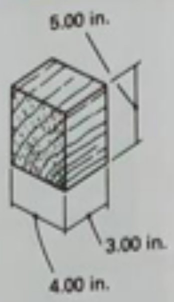
Substance	Mass Density (kg/m^3)	Weight Density (lb/ft^3)
Solids		
Aluminum	2,700	169
Brass	8,700	540
Concrete	2,300	140
Copper	8,890	555
Cork	240	15
Ice	917	57
Iron	7,800	490
Lead	11,300	708
Wood, white pine	420	26
Liquids		
Alcohol	790	49.4
Gasoline	680	42.0
Mercury	13,600	846
Oil	870	54.2
Seawater	1,025	64.0
Water	$1{,}\bar{0}00$	62.4
Gases*	At 0°C and 1 atm pressure	At 32°F and 1 atm pressure
Air	1.29	0.081
Ammonia	0.760	0.047
Carbon dioxide	1.96	0.123
Carbon monoxide	1.25	0.078
Helium	0.178	0.011
Hydrogen	0.0899	0.0056
Nitrogen	1.25	0.078
Oxygen	1.43	0.089
Propane	2.02	0.126

*The density of a gas is found by pumping the gas into a container, measuring its volume and mass or weight, and then using the appropriate density formula.

EXAMPLE 3.18

Find the weight density of a block of wood 3.00 in. × 4.00 in. × 5.00 in. with weight 0.700 lb.

Sketch:



Data:

$$\begin{aligned} l &= 4.00 \text{ in.} \\ w &= 3.00 \text{ in.} \\ h &= 5.00 \text{ in.} \\ F_w &= 0.700 \text{ lb} \\ D_w &= ? \end{aligned}$$

Basic Equations:

$$V = lwh \quad \text{and} \quad D_w = \frac{F_w}{V}$$

Working Equations: Same

Substitutions:

$$\begin{aligned} V &= (4.00 \text{ in.})(3.00 \text{ in.})(5.00 \text{ in.}) \\ &= 60.0 \text{ in}^3 \end{aligned}$$

$$\begin{aligned} D_w &= \frac{0.700 \text{ lb}}{60.0 \text{ in}^3} \\ &= 0.0117 \frac{\text{lb}}{\cancel{\text{in}^3}} \times \left(\frac{12 \cancel{\text{in.}}}{1 \text{ ft}}\right)^3 \\ &= 20.2 \text{ lb/ft}^3 \end{aligned}$$

EXAMPLE 3.19

Find the mass density of a ball bearing with mass 22.0 g and radius 0.875 cm.

Data:

$$\begin{aligned} r &= 0.875 \text{ cm} \\ m &= 22.0 \text{ g} \\ D_m &= ? \end{aligned}$$

Basic Equations:

$$V = \tfrac{4}{3}\pi r^3 \quad \text{and} \quad D_m = \frac{m}{V}$$

Working Equations: Same

Substitutions:

$$V = \tfrac{4}{3}\pi(0.875\text{ cm})^3$$
$$= 2.81\text{ cm}^3$$

$$D_m = \frac{22.0\text{ g}}{2.81\text{ cm}^3}$$
$$= 7.83\text{ g/cm}^3$$
$$= 7.83\frac{\cancel{\text{g}}}{\cancel{\text{cm}^3}} \times \left(\frac{100\cancel{\text{ cm}}}{1\text{ m}}\right)^3 \times \frac{1\text{ kg}}{10^3\cancel{\text{ g}}} = 7830\text{ kg/m}^3$$

EXAMPLE 3.20

Find the weight density of a gallon of water weighing 8.34 lb.

Data:

$$F_w = 8.34\text{ lb}$$
$$V = 1\text{ gal} = 231\text{ in}^3$$
$$D_w = ?$$

Basic Equation:

$$D_w = \frac{F_w}{V}$$

Working Equation: Same

Substitution:

$$D_w = \frac{8.34\text{ lb}}{231\text{ in}^3}$$
$$= 0.0361\frac{\text{lb}}{\cancel{\text{in}^3}} \times \left(\frac{12\cancel{\text{ in.}}}{1\text{ ft}}\right)^3$$
$$= 62.4\text{ lb/ft}^3$$

EXAMPLE 3.21

Find the weight density of a can of oil (1 quart) weighing 1.90 lb.

Data:

$$V = 1\text{ qt} = \tfrac{1}{4}\text{ gal} = \tfrac{1}{4}(231\text{ in}^3) = 57.8\text{ in}^3$$
$$F_w = 1.90\text{ lb}$$
$$D_w = ?$$

Basic Equation:

$$D_w = \frac{F_w}{V}$$

Working Equation: Same

Substitution:

$$D_w = \frac{1.90\text{ lb}}{57.8\text{ in}^3}$$
$$= 0.0329\frac{\text{lb}}{\cancel{\text{in}^3}} \times \left(\frac{12\cancel{\text{ in.}}}{1\text{ ft}}\right)^3$$
$$= 56.9\text{ lb/ft}^3$$

EXAMPLE 3.22

A quantity of gasoline weighs 5.50 lb with weight density 42.0 lb/ft^3. Find its volume.

Data:

$$D_w = 42.0\ \text{lb/ft}^3$$
$$F_w = 5.50\ \text{lb}$$
$$V = ?$$

Basic Equation:

$$D_w = \frac{F_w}{V}$$

Working Equation:

$$V = \frac{F_w}{D_w}$$

Substitution:

$$V = \frac{5.50\ \cancel{\text{lb}}}{42.0\ \cancel{\text{lb}}/\text{ft}^3}$$
$$= 0.131\ \text{ft}^3$$

Specific He
Find Q for each
1. Steel, w =
2. Copper, m
3. Water, w
4. Water, m
5. Ice, m =
6. Steam, w
7. Aluminu
8. Brass, m
9. Steel, m
10. Aluminu
11. Water, m
12. Lead, m
13. How m
per to r
14. How m
num wh
15. How m
copper
16. How m
freezer
from 8
17. How
peratu
18. How
of ste
19. How

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3. Protons and neutrons compose the nucleus. (The common form of the hydrogen atom, which has no neutron, is the only exception.) Protons are about 1800 times more massive than electrons, but they carry an amount of positive charge equal to the negative charge of electrons. Neutrons have slightly more mass than protons and have no net charge.
4. Atoms usually have as many electrons as protons, so the atom has zero *net* charge.

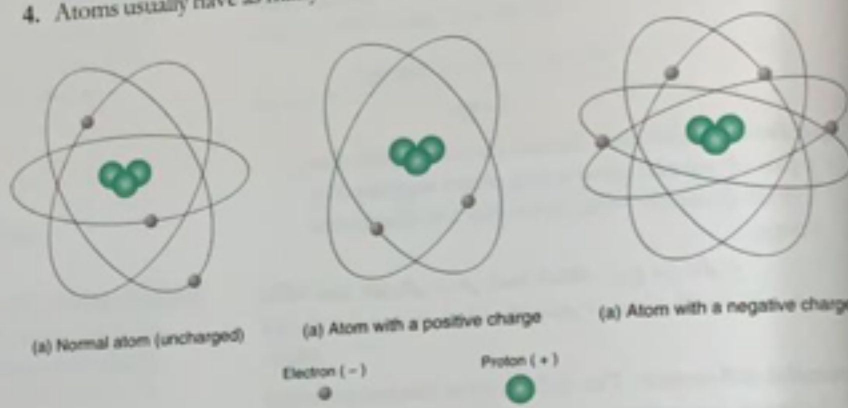


FIGURE 4.1

CHECK POINT

If you scuff electrons onto your feet while walking across a rug, are you negatively or positively charged?

Check Your Answer

You have more electrons after you scuff your feet, so you are negatively charged (and the rug is positively charged).

Coulomb's Law

The force between two point charges q_1 and q_2 is directly proportional to the product of their magnitudes and inversely proportional to the square of the distance separating them, r.

We use a *proportionality constant* k in writing Coulomb's law as an equation to take into account the air or other medium between the charges. Written in equation form, **Coulomb's law** becomes

$$F = \frac{kq_1q_2}{r^2}$$

where
F = force of attraction or repulsion (in newtons)
$k = 9.00 \times 10^9\ \text{N m}^2/\text{C}^2$ (k was found by experiment)
q_1, q_2 = electric charges (in coulombs)
r = distance between the charges (in metres)

The force between the charges is a vector quantity that acts on each charge.

An electric field has both magnitude (strength) and direction. The magnitude of the field at any point is simply the force per unit of charge. If a body with charge q experiences a force F at some point in space, then the electric field E at that point is

$$E = \frac{F}{q}$$

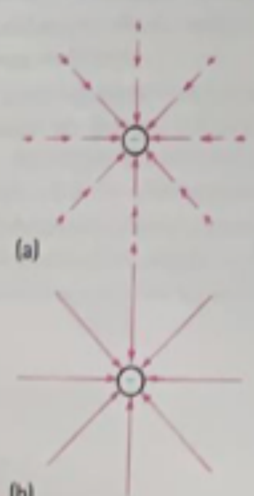


FIGURE 4.2
Electric-field representations about a negative charge. (a) A vector representation. (b) A lines-of-force representation.

EXAMPLE 4.1

Two charges, each with magnitude $+6.50\ \mu C$, are separated by a distance of 0.200 cm. Find the force of repulsion between them.

Data:

$$q_1 = q_2 = +6.50\ \mu C = +6.50 \times 10^{-6}\ C$$
$$r = 0.200\ cm = 0.00200\ m = 2.00 \times 10^{-3}\ m$$
$$k = 9.00 \times 10^{9}\ N\ m^2/C^2$$
$$F = ?$$

Basic Equation:

$$F = \frac{kq_1q_2}{r^2}$$

Working Equation: Same

Substitution:

$$F = \frac{(9.00 \times 10^{9}\ N\ m^2/C^2)(6.50 \times 10^{-6}\ C)(6.50 \times 10^{-6}\ C)}{(2.00 \times 10^{-3}\ m)^2}$$
$$= 9.51 \times 10^{4}\ N$$

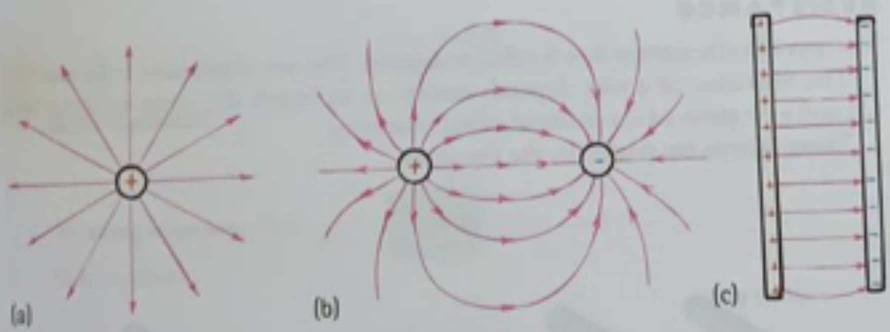


FIGURE 4.3

Some electric-field configurations. (a) Lines of force emanating from a single positively charged particle. (b) Lines of force for a pair of equal but oppositely charged particles. Note that the lines emanate from the positive particle and terminate on the negative particle. (c) Uniform lines of force between two oppositely charged parallel plates.

Electric Potential

The concept of electric potential energy per unit charge has a special name, **electric potential:**

$$\text{Electric potential} = \frac{\text{electric potential energy}}{\text{charge}}$$

The unit of measurement for electric potential is the volt, so electric potential is often called *voltage*. A potential of 1 volt (V) equals 1 joule (J) of energy per 1 coulomb (C) of charge.

$$1\ \text{volt} = 1\ \frac{\text{joule}}{\text{coulomb}}$$

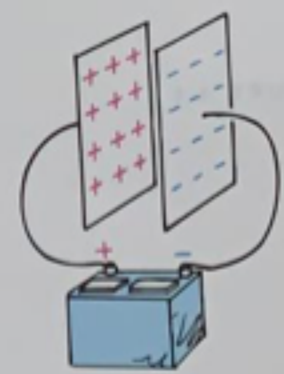
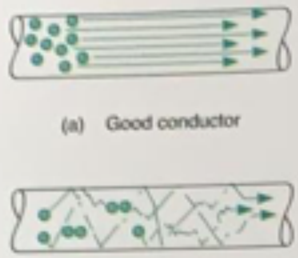


FIGURE 4.4

A capacitor consisting of two closely spaced parallel metal plates. When connected to a battery, the plates acquire equal and opposite charges. The voltage between the plates then matches the electric potential difference between the battery terminals.

THE CONDUCTOR

A conductor carries or transfers the electric charge to the load. A **conductor** (Figure 4.5) is a material (such as copper) through which an electric charge is readily transferred. Such materials have large numbers of free electrons (electrons that are free to move throughout the conductor).



(a) Good conductor

(b) Poor conductor

FIGURE 4.5

CURRENT

The flow of electrons through a conductor is called **current**. We define a unit for the rate of flow of charge as follows:

$$1 \text{ ampere (A)} = \frac{1 \text{ coulomb (C)}}{1 \text{ second (s)}}$$

VOLTAGE

The *potential difference* between two points in an electric field is the work done per unit of charge as the charge is moved between two points. That is,

$$\text{potential difference} = \frac{\text{work}}{\text{charge}}$$

In *sources*, the raising of the potential energy of electrons that results in a potential difference across a source is called **emf** (E). In *circuits*, the lowering of the potential difference across a load is called **voltage drop**.

The *volt* (V), named after **Allessandro Volta**, is the unit of both emf and voltage drop. We define the volt as the potential difference between two points if 1 J of work is produced or used in moving 1 C of charge from one point to another:

$$1 \text{ volt (V)} = \frac{1 \text{ joule (J)}}{1 \text{ coulomb (C)}}$$

RESISTANCE

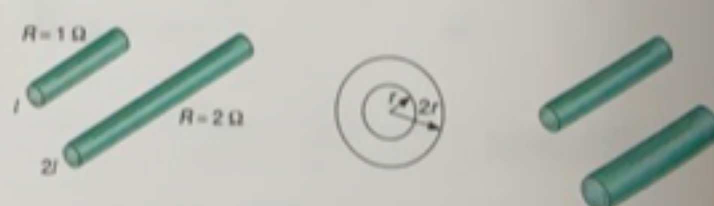
The opposition to current flow is called **resistance**. The unit of resistance is the *ohm* (Ω).

The resistance of a wire depends mainly on its length (L), cross-sectional area (A) and a property of the material called resistivity.

These factors are related by the equation

$$R = \frac{\rho l}{A}$$

FIGURE 4.6



(a) Resistance varies directly with length.

(b) Doubling the radius more than doubles the cross-sectional area.

EXAMPLE 4.2

Find the resistance of a copper wire 20.0 m long with cross-sectional area of 6.56×10^{-3} cm² at 20°C. The resistivity of copper at 20°C is 1.72×10^{-6} Ω cm.

Data:

$$l = 20.0 \text{ m} = 2.00 \times 10^3 \text{ cm}$$
$$A = 6.56 \times 10^{-3} \text{ cm}^2$$
$$\rho = 1.72 \times 10^{-6} \ \Omega \text{ cm}$$
$$R = ?$$

Basic Equation:

$$R = \frac{\rho l}{A}$$

Working Equation: Same

Substitution:

$$R = \frac{(1.72 \times 10^{-6}\ \Omega\ \cancel{cm})(2.00 \times 10^{3}\ \cancel{cm})}{6.56 \times 10^{-3}\ \cancel{cm^2}}$$
$$= 0.524\ \Omega$$

Ohm's Law

Ohm's law

$$I = \frac{V}{R}$$

where I = current through the resistance
V = voltage drop across the resistance
R = resistance

Ohm's law can also be written

$$I = \frac{E}{R}$$

where E = emf of the source of electrical energy

EXAMPLE 4.3

A heating element on an electric range operating on 240 V has a resistance of 30.0 Ω. What current does it draw?

Data:

$$E = 240\ \text{V}$$
$$R = 30.0\ \Omega$$
$$I = ?$$

Basic Equation:

$$I = \frac{E}{R}$$

Working Equation: Same

Substitution:

$$I = \frac{240\ \text{V}}{30.0\ \Omega}$$
$$= 8.0\ \text{V}/\Omega$$
$$= 8.0\ \text{A}$$

$$\boxed{\frac{\text{V}}{\Omega} = \text{A}}$$

Electric Power

The rate of consuming energy is called **power**. The unit of power is the watt. One *watt* (W) is the power generated by a current of 1 A flowing because of a potential difference of 1 V. A volt is a joule/coulomb (J/C); an ampere is a coulomb/second (C/s). Their product is

$$\text{VA} = \frac{\text{J}}{\text{C}} \cdot \frac{\text{C}}{\text{s}} = \frac{\text{J}}{\text{s}}$$

Thus, 1 W = 1 J/s.
Hence, power is

$$P = VI$$

where P = power (watts)
V = voltage drop
I = current

This equation applies to components of dc circuits and to whole dc circuits as well as to ac circuits with resistance only.

Recalling Ohm's law, $I = V/R$, we find two other equations for power: Given

$$P = VI$$

substitute for V using $V = IR$ to obtain

$$P = (IR)I = I^2R$$

$$P = I^2R$$

Note from the following unit analysis that amps squared times ohms gives watts:

$$\boxed{\mathrm{A}^2\,\Omega = \mathrm{A}^2 \cdot \frac{\mathrm{V}}{\mathrm{A}} = \mathrm{AV} = \frac{\mathrm{C}}{\mathrm{s}} \cdot \frac{\mathrm{J}}{\mathrm{C}} = \frac{\mathrm{J}}{\mathrm{s}} = \mathrm{W}}$$

Also, given

$$P = I^2R$$

substitute

$$I = \frac{V}{R}$$

to get

$$P = \left(\frac{V}{R}\right)^2 R = \frac{V^2}{R^2} \cdot R$$

$$P = \frac{V^2}{R}$$

EXAMPLE 4.4

A soldering iron draws 7.50 A in a 115-V circuit. What is its wattage rating?

Data:

$$I = 7.50\ \mathrm{A}$$
$$V = 115\ \mathrm{V}$$
$$P = ?$$

Basic Equation:

$$P = VI$$

Working Equation: Same

Substitution:

$$P = (115\ \mathrm{V})(7.50\ \mathrm{A})$$
$$= 863\ \mathrm{W}$$

Therefore, a soldering iron drawing 7.50 A in a 115-V circuit has a rating of 863 W.

EXAMPLE 4.5

A hand drill draws 4.00 A and has a resistance of 14.6 Ω. What power does it use?

Data:

$$I = 4.00\ \mathrm{A}$$
$$R = 14.6\ \Omega$$
$$P = ?$$

Basic Equation:

$$P = I^2R$$

Working Equation: Same

Substitution:

$$\begin{aligned} P &= (4.00\ \text{A})^2(14.6\ \Omega) \\ &= 234\ \text{W} \end{aligned}$$

Thus, a drill that draws 4.00 A with a resistance of 14.6 Ω has a rating of 234 W.

Since the watt is a relatively small unit, the kilowatt $(1\ \text{kW} = 1000\ \text{W})$ is commonly used in industry.

Although we speak of "paying our power bill," what power companies actually sell is **energy** in a form of work delivered to an electric component or appliance. Energy is sold in kilowatt-hours (kWh). The amount of energy consumed is equal to the power used times the time it is used. Therefore,

$$\text{energy} = \text{power} \times \text{time}$$

or

$$\begin{aligned} \text{energy (in kWh)} &= (VI)t \\ \text{number of kWh} &= VIt \end{aligned}$$

when V is in volts, I is in amperes, and t is time in hours. Note that electric energy can be expressed in other units (joules), but kilowatt-hours is commonly used. This equation is useful in finding the cost of electric energy. Cost is measured in cents per kilowatt-hour. The cost of operating an electric device may be found as follows:

$$\begin{aligned} \text{cost} &= \text{energy} \times \text{cost per unit energy} \\ \text{cost} &= (\text{kWh})\left(\frac{\text{cents}}{\text{kWh}}\right) \end{aligned}$$

$$\boxed{\text{cost (in cents)} = \text{power (in W)} \times \text{hours} \times \underbrace{\frac{1\ \text{kW}}{1000\ \text{W}}}_{\text{conversion factor}} \times \frac{\text{cents}}{\text{kWh}}}$$

EXAMPLE 4.6

An iron is rated at 550 W. How much would it cost to operate it for 2.50 h at \$0.08/kWh?

Data:

$$\begin{aligned} P &= 550\ \text{W} \\ t &= 2.50\ \text{h} \\ \text{rate} &= \$0.08/\text{kWh} \\ \text{cost} &= ? \end{aligned}$$

Basic Equation:

$$\text{cost} = Pt\left(\frac{\text{kW}}{1000\ \text{W}}\right)\left(\frac{\text{cents}}{\text{kWh}}\right)$$

Working Equation: Same

Substitution:

$$\text{cost} = (550\ \text{W})(2.50\ \text{h})\left(\frac{\text{kW}}{1000\ \text{W}}\right)\left(\frac{\$0.08}{\text{kWh}}\right)$$
$$= \$0.11$$

Remember that the source of electrons in a circuit is the conducting circuit material itself. You may be able to buy an empty water hose, but you cannot buy an "empty" wire. If you plug in an appliance, *energy* flows from the outlet to the appliance, not electrons. Energy is carried by the electric field and causes motion in the electrons already in the appliance. The power company sells the energy; the appliance supplies the electrons.

Electric Circuits

Most circuits have more than one device that receives electric energy. These devices are commonly connected in a circuit in one of two ways, *series* or *parallel*.

SERIES CIRCUITS

An electric circuit with only one path for the current to flow (Figure 4.7) is called a **series circuit**. The current in a series circuit is the same throughout. That is, the current flows out of one resistance and into the next resistance. Therefore, the total current is the same as the current flowing through each resistance in the circuit.

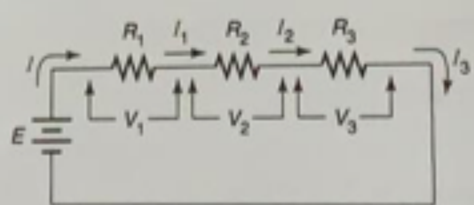


FIGURE 4.7
Series circuit.

$$\textit{SERIES}$$
$$I = I_1 = I_2 = I_3 = \cdots$$

where I = total current
I_1 = current through R_1
I_2 = current through R_2
I_3 = current through R_3

In a series circuit, the emf of the source equals the sum of the separate voltage drops in the circuit (Figure 4.7):

$$\textit{SERIES}$$
$$E = V_1 + V_2 + V_3 + \cdots$$

where E = emf of the source
V_1 = voltage drop across R_1
V_2 = voltage drop across R_2
V_3 = voltage drop across R_3

The resistance of the conducting wires is very small and will be neglected here. The total resistance of a series circuit equals the sum of all the resistances in the circuit:

SERIES

$$R = R_1 + R_2 + R_3 + \cdots$$

where R = total or equivalent resistance of the circuit
R_1 = resistance of first load
R_2 = resistance of second load
R_3 = resistance of third load

The **equivalent resistance** is the single resistance that can replace a series and/or parallel combination of resistances in a circuit and provide the same current flow and voltage drop. The equivalent resistance of a series combination is larger than the resistance of any one of the resistances in series.

EXAMPLE 4.7

Find the total resistance of the circuit shown in Figure 4.8.

Data:

$$R_1 = 7.00\ \Omega$$
$$R_2 = 9.00\ \Omega$$
$$R_3 = 21.0\ \Omega$$
$$R = ?$$

Basic Equation:

$$R = R_1 + R_2 + R_3$$

Working Equation: Same

Substitution:

$$R = 7.00\ \Omega + 9.00\ \Omega + 21.0\ \Omega = 37.0\ \Omega$$

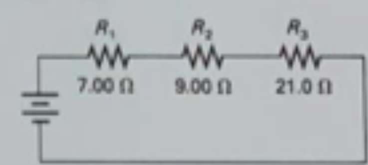


FIGURE 4.8

EXAMPLE 4.8

Find the current in the circuit shown in Figure 4.9.

Data:

$$R_1 = 5.00\ \Omega$$
$$R_2 = 13.0\ \Omega$$
$$R_3 = 12.0\ \Omega$$
$$R_4 = 96.0\ \Omega$$
$$E = 90.0\ \text{V}$$
$$I = ?$$

Basic Equations:

$$R = R_1 + R_2 + R_3 + R_4 \quad \text{and} \quad I = \frac{E}{R}$$

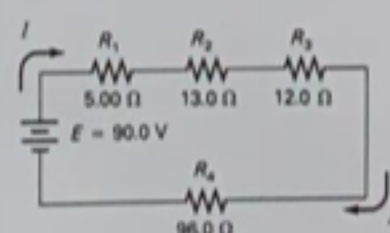


FIGURE 4.9

Working Equations: Same

Substitutions:

$$R = 5.00\ \Omega + 13.0\ \Omega + 12.0\ \Omega + 96.0\ \Omega$$
$$= 126.0\ \Omega$$

$$I = \frac{90.0\ \text{V}}{126.0\ \Omega}$$
$$= 0.714\ \text{A}$$

EXAMPLE 4.9

Find the value of R_3 in the circuit shown in Figure 4.10.

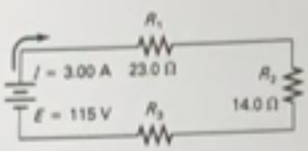


FIGURE 4.10

Data:

$$I = 3.00\ \text{A}$$
$$E = 115\ \text{V}$$
$$R_1 = 23.0\ \Omega$$
$$R_2 = 14.0\ \Omega$$
$$R_3 = ?$$

Basic Equations:

$$I = \frac{E}{R} \quad \text{and} \quad R = R_1 + R_2 + R_3$$

Working Equations:

$$R = \frac{E}{I} \quad \text{and} \quad R_3 = R - R_1 - R_2$$

Substitutions:

$$R = \frac{115\ \text{V}}{3.00\ \text{A}}$$
$$= 38.3\ \Omega$$

$$R_3 = 38.3\ \Omega - 23.0\ \Omega - 14.0\ \Omega$$
$$= 1.3\ \Omega$$

EXAMPLE 4.10

Find the voltage drop across R_3 in Example 4.9.

Data:

$$I = I_3 = 3.00\ \text{A}$$
$$R_3 = 1.3\ \Omega$$
$$V_3 = ?$$

Basic Equation:

$$I_3 = \frac{V_3}{R_3}$$

Working Equation:

$$V_3 = I_3 R_3$$

Substitution:

$$V_3 = (3.00\ \text{A})(1.3\ \Omega)$$
$$= 3.9\ \text{V}$$

PARALLEL CIRCUITS

An electric circuit with more than one path for the current to flow (Figure 4.11) is called a **parallel circuit**. All resistances connected in parallel have their ends connected to two common points (nodes) in the circuit (points *A* and *B* in Figure 4.11).

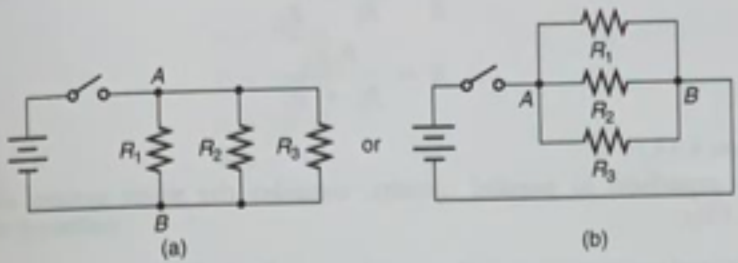


FIGURE 4.11
Different ways to represent a parallel circuit

The current in a parallel circuit is divided among the branches of the circuit (Figure 4.12). How it is divided depends on the resistance of each branch. The paths with the least resistance allow the largest currents to flow. Since the current divides, the current from the source equals the sum of the currents through each of the branches:

PARALLEL
$$I = I_1 + I_2 + I_3 + \cdots$$

where I = total current in the circuit
I_1 = current through R_1
I_2 = current through R_2
I_3 = current through R_3

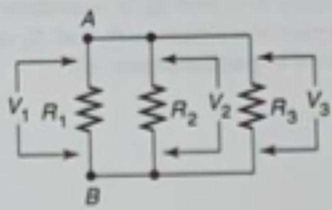


FIGURE 4.12
$I = I_1 + I_2 + I_3$.

Since the ends of all resistances in parallel are connected to the same common points (nodes) in the circuit, the voltage across each resistance is the same (Figure 4.12):

PARALLEL
$$V_1 = V_2 = V_3 = \cdots$$

The emf of the source is the same as the voltage drop across each resistance in the circuit if there are no other (series) elements in the circuit (Figure 4.13):

PARALLEL WITH VOLTAGE SOURCE
$$E = V_1 = V_2 = V_3 = \cdots$$

where E = emf of the source
V_1 = voltage drop across R_1
V_2 = voltage drop across R_2
V_3 = voltage drop across R_3

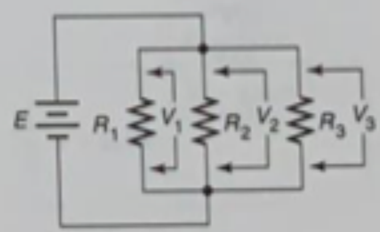


FIGURE 4.13
$E = V_1 = V_2 = V_3$.

Therefore, several different loads requiring the same voltage are connected in parallel.

The single resistance that would result in the same current flow and voltage drop as the combination of resistances is called the *equivalent resistance*. The equivalent resistance of a parallel circuit is less than the resistance of any single branch of the circuit. To find the equivalent resistance, use the formula

PARALLEL
$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \cdots$$

where R = equivalent resistance
R_1 = resistance of R_1
R_2 = resistance of R_2
R_3 = resistance of R_3

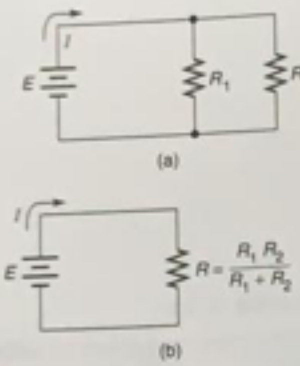


FIGURE 4.14

Resistor R in part (b) is equivalent to the pair of resistances R_1 and R_2 connected in parallel in part (a).

If the parallel combination of resistances is replaced by a single resistance with the resistance R, the same current flows in the circuit. In the case where there are only two resistances in parallel, then

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$$

$$R = \frac{R_1 R_2}{R_1 + R_2}$$

(See Figure 4.14.)

For comparison to parallel circuits, consider the water system shown in Figure 4.15(a).

1. The total amount of water flowing through $R_1 + R_2 + R_3$ equals the amount flowing through A or B.
2. The water flowing past point A divides into the three branches R_1, R_2, and R_3.
3. The larger pipes have *less* opposition to water flow than do the smaller pipes. Because R_1 has a larger cross-sectional area than R_2 or R_3, it has less opposition to the flow of water and therefore carries more water than R_2 or R_3.

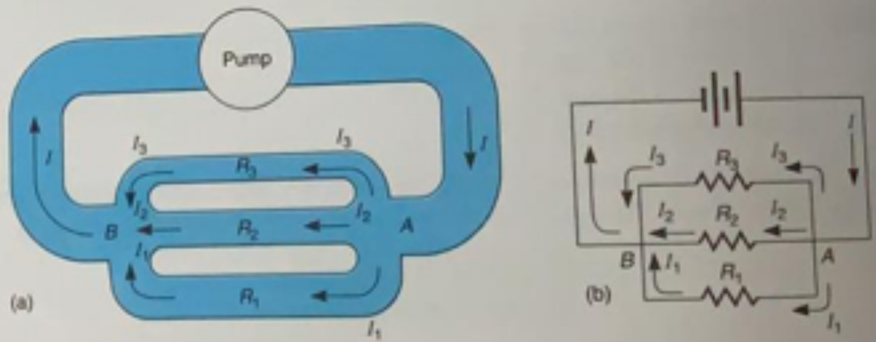


FIGURE 4.15

A water system may be compared to a parallel electric circuit.

Similarly, in a parallel electric circuit as in Figure 4.15(b):

1. The total amount of current flowing through $R_1 + R_2 + R_3$ equals the amount flowing through A or B.
2. The current flowing past point A divides into the three branches R_1, R_2, and R_3.
3. The smaller resistances have *less* opposition to current flow and therefore carry larger currents.

Try This Activity

Parallel Bulbs

Attach a D-cell battery to a small 2.5-V or 3.5-V light bulb and observe the brightness of the light. Attach a second light bulb in parallel with the first. After adding a third bulb in parallel with the others, note the brightness of the bulbs. Why, when using the same battery, wires, and bulbs does the brightness of the bulbs differ from the bulbs in the series circuit?

EXAMPLE 4.11

Find the equivalent resistance of the circuit shown in Figure 4.16.

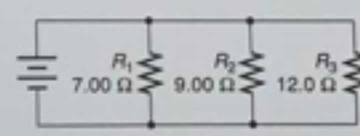


FIGURE 4.16

Data:

$$R_1 = 7.00\ \Omega$$
$$R_2 = 9.00\ \Omega$$
$$R_3 = 12.0\ \Omega$$
$$R = ?$$

Basic Equation:

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

Working Equation:
When using this formula, you should solve for the reciprocal of the unknown, then substitute.

Substitution:

$$\frac{1}{R} = \frac{1}{7.00\ \Omega} + \frac{1}{9.00\ \Omega} + \frac{1}{12.0\ \Omega}$$
$$R = 2.96\ \Omega$$

EXAMPLE 4.12

Find the total current in the circuit shown in Figure 4.17.

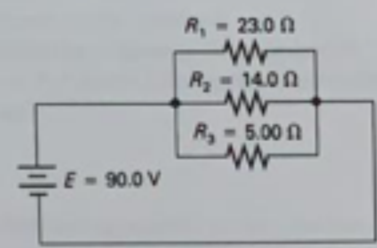


FIGURE 4.17

Data:

$$R_1 = 23.0\ \Omega$$
$$R_2 = 14.0\ \Omega$$
$$R_3 = 5.00\ \Omega$$
$$E = 90.0\ \text{V}$$
$$I = ?$$

First, find the equivalent resistance, R. Second, find the total current, I. To find R:

Basic Equation:

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

Working Equation: Same

Substitution:

$$\frac{1}{R} = \frac{1}{23.0\ \Omega} + \frac{1}{14.0\ \Omega} + \frac{1}{5.00\ \Omega}$$

Using a calculator sequence as in Example 4.11, we find

$$R = 3.18\ \Omega$$

To find I:

Basic Equation:

$$I = \frac{E}{R}$$

Working Equation: Same

Substitution:

$$\begin{aligned} I &= \frac{90.0\ \text{V}}{3.18\ \Omega} \\ &= 28.3\ \text{A} \end{aligned}$$

EXAMPLE 4.13

Find the current through R_2 in Figure 4.17 from Example 4.12.

Data:

$$\begin{aligned} R_2 &= 14.0\ \Omega \\ E &= 90.0\ \text{V} = V_2 \\ I_2 &= ? \end{aligned}$$

Basic Equation:

$$I_2 = \frac{V_2}{R_2}$$

Working Equation: Same

Substitution:

$$\begin{aligned} I_2 &= \frac{90.0\ \text{V}}{14.0\ \Omega} \\ &= 6.43\ \text{A} \end{aligned}$$

EXAMPLE 4.14

Find the equivalent resistance and the value of R_3 in the circuit shown in Figure 4.18.

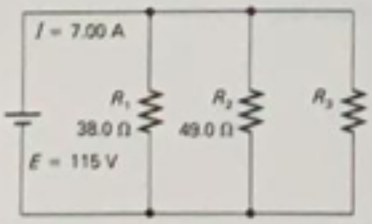


FIGURE 4.18

Data:

$$\begin{aligned} E &= 115\ \text{V} \\ I &= 7.00\ \text{A} \\ R_1 &= 38.0\ \Omega \\ R_2 &= 49.0\ \Omega \\ R_3 &= ? \end{aligned}$$

First find R:

Basic Equation:

$$I = \frac{E}{R}$$

Working Equation:

$$R = \frac{E}{I}$$

Substitution:

$$R = \frac{115\ \text{V}}{7.00\ \text{A}}$$
$$= 16.4\ \Omega$$

To find R_3:

Basic Equation:

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

Working Equation:

$$\frac{1}{R_3} = \frac{1}{R} - \frac{1}{R_1} - \frac{1}{R_2}$$

Substitution:

$$\frac{1}{R_3} = \frac{1}{16.4\ \Omega} - \frac{1}{38.0\ \Omega} - \frac{1}{49.0\ \Omega}$$
$$R_3 = 70.2\ \Omega$$

REVIEW QUESTIONS

Electric Charges

1. What part of an atom is *positively* charged and what part is *negatively* charged?
2. How does the charge of one electron compare to that of another electron? How does it compare with the charge of a proton?
3. What is normally the net charge of an atom?

Coulomb's Law

4. How does one *coulomb* of charge compare with the charge of a *single* electron?
5. How is Coulomb's law similar to Newton's law of gravitation? How is it different?

Conductors and Insulators

6. Why are metals good conductors both of heat and of electricity?
7. Why are materials such as glass and rubber good insulators?
8. How does a *semiconductor* differ from a *conductor* or an *insulator*?
9. What is a transistor composed of, and what are some of its functions?

Electric Potential

10. How much energy is given to each coulomb of charge that flows through a 1.5-V battery?
11. A balloon may easily be charged to several thousand volts. Does that mean it has several thousand joules of energy? Explain.

Ohm's Law

12. If the voltage impressed across a circuit is held constant while the resistance doubles, what change occurs in the current?
13. If the resistance of a circuit remains constant while the voltage across the circuit decreases to half its former value, what change occurs in the current?
14. How does wetness affect the resistance of your body?
15. What is the function of the round third prong in a modern household electric plug?

Electric Power

16. What is the relationship among electric power, current, and voltage?
17. Which of these is a unit of power and which is a unit of energy—a watt, a kilowatt, a kilowatt-hour?

Electric Circuits

18. In a circuit of two lamps in series, if the current through one lamp is 1 A, what is the current through the other lamp? Defend your answer.
19. If a voltage of 6 V is impressed across the circuit in the preceding question and the voltage across the first lamp is 2 V, what is the voltage across the second lamp? Defend your answer.
20. In a circuit of two lamps in parallel, if there is a voltage of 6 V across one lamp, what is the voltage across the other lamp?
21. How does the sum of the currents through the branches of a simple parallel circuit compare with the current that flows through the voltage source?
22. What is the function of fuses or circuit breakers in a circuit?

HOMEWORK

Coulomb's Law

1. Two identical charges, each -8.00×10^{-5} C, are separated by a distance of 25.0 cm. What is the force of repulsion?
2. The force of repulsion between two identical positive charges is 0.800 N when the charges are 0.100 m apart. Find the value of each charge.
3. A charge of $+3.0 \times 10^{-6}$ C exerts a force of 940 N on a charge of $+6.0 \times 10^{-6}$ C. How far apart are the charges?
4. A charge of -3.0×10^{-8} C exerts a force of 0.045 N on a charge of $+5.0 \times 10^{-7}$ C. How far apart are the charges?
5. When a -9.0-μC charge is placed 0.12 cm from a charge q in a vacuum, the force between the two charges is 850 N. What is the value of q?
6. How far apart are two identical charges of $+6.00\ \mu$C if the force between them is 25.0 N?
7. Three charges are located along the x-axis. Charge A $(+3.00\ \mu\text{C})$ is located at the origin. Charge B $(+5.50\ \mu\text{C})$ is located at $x = +0.400$ m. Charge C $(-4.60\ \mu\text{C})$ is located at $x = +0.750$ m. (a) Find the total force (and direction) on charge B. (b) Find the total force (and direction) on charge A. (c) Find the total force (and direction) on charge C.
8. An electric field has a positive test charge of 4.00×10^{-5} C placed on it. The force on it is 0.600 N. What is the magnitude of the electric field at the test charge location?
9. What is the field magnitude of an electric field in which a negative charge of 2.00×10^{-8} C experiences a force of 0.0600 N?
10. An electric field exerts a force of 2.50×10^{-4} N on a positive test charge of 5.00×10^{-4} C. Find the magnitude of the field at the charge location.
11. An electric field exerts a force of 3.00×10^{-4} N on a positive test charge of 7.50×10^{-4} C. Find the magnitude of the field at the charge location.
12. An electric field of magnitude 0.450 N/C exerts a force of 8.00×10^{-4} N on a test charge placed in the field. What is the magnitude of the test charge?
13. An electric field of magnitude 0.370 N/C exerts a force of 6.20×10^{-4} N on a test charge placed in the field. What is the magnitude of the test charge?
14. What force is exerted on a test charge of 3.86×10^{-5} C if it is placed in an electric field of magnitude 1.75×10^{4} N/C?
15. What force is exerted on a test charge of 4.00×10^{-5} C if it is placed in an electric field of magnitude 3.00×10^{6} N/C?

Resistance

1. Find the resistance of 78.0 m of No. 20 aluminum wire at 20°C. ($\rho = 2.83 \times 10^{-6}\ \Omega$ cm, $A = 2.07 \times 10^{-2}$ cm^2.)
2. Find the resistance of 315 ft of No. 24 copper wire with resistance 0.0262 Ω/ft.
3. Find the resistance per foot of No. 22 copper wire if $58\bar{0}$ ft has a resistance of 9.57 Ω.
4. At 77°F, $10\bar{0}$ ft of No. 18 copper wire has a resistance of 0.651 Ω. Find the resistance of $50\bar{0}$ ft of this wire.
5. Find the resistance of 475 m of No. 20 copper wire at 20°C. ($\rho = 1.72 \times 10^{-6}\ \Omega$ cm, $A = 2.07 \times 10^{-2}$ cm^2.)
6. Find the resistance of $10\bar{0}$ m of No. 20 copper wire at 20°C. ($\rho = 1.72 \times 10^{-6}\ \Omega$ cm, $A = 2.07 \times 10^{-2}$ cm^2.)
7. Find the resistance of 50.0 m of No. 20 aluminum wire at 20°C. ($\rho = 2.83 \times 10^{-6}\ \Omega$ cm, $A = 2.07 \times 10^{-2}$ cm^2.)
8. Find the length of copper wire with resistance 0.0262 Ω/ft and total resistance 3.00 Ω.
9. Find the cross-sectional area of copper wire at 20°C that is 60.0 m long and has resistivity $\rho = 1.72 \times 10^{-6}\ \Omega$ cm and resistance 0.788 Ω.
10. Find the length of a copper wire with resistance 0.0262 Ω/ft and total resistance 5.62 Ω.

Ohm's Law

1. A heating element operates on 115 V. If it has a resistance of 24.0 Ω, what current does it draw?
2. A coffeepot operates on 12.0 V. If it draws 2.50 A, find its resistance.
3. An electric heater draws a maximum of 14.0 A. If its resistance is 15.7 Ω, on what voltage is it operating?
4. A heating coil operates on $22\bar{0}$ V. If it draws 15.0 A, find its resistance.
5. Find the resistance that draws 0.750 A on 115 V.
6. What current does a 75.0-Ω resistance draw on 115 V?
7. A heater operates on $22\bar{0}$ V. If it draws 12.5 A, what is its resistance?
8. What current does a 50.0-Ω resistance draw on 115 V?
9. What current does a 175-Ω resistance draw on $22\bar{0}$ V?
10. A heater draws 3.50 A on 115 V. What is its resistance?
11. (a) What current does a 150-Ω resistance draw on a $1\bar{0}$-V battery? (b) What voltage battery would produce 3 times the current in (a)? (c) What current would a 75-Ω resistor draw on the $1\bar{0}$-V battery?
12. A heater draws 4.25 A on 32.0 V. (a) What is the resistance of the heater? (b) What resistance heater would draw 8.50 A on 32.0 V?

Electric Power

1. What power is needed for a sander that draws 3.50 A and has a resistance of 6.70 Ω?
2. How many amperes will a 75.0-W lamp draw on a $11\bar{0}$-V line?
3. Find the resistance of the lamp in Problem 2.
4. A car has a 12.0-V battery. If the current through the starter is $21\bar{0}$ A, what electric energy (in joules) is delivered to the starter in 10.0 s?
5. An electric heater is used 5.00 h each day. (a) If it draws 15.0 A on a $12\bar{0}$-V line, how much power does it use? (b) In 30 days, how much energy in kWh does the heater use? (c) At \$0.11/kWh, what does it cost to operate the heater for 30 days?

Electrical Circuits

1. Three resistors of 2.00 Ω, 5.00 Ω, and 6.50 Ω are connected in series with a 24.0-V battery. Find the total resistance of the circuit.
2. Find the current in Question 1.
3. Find the equivalent resistance in the circuit shown in Figure 4.19.

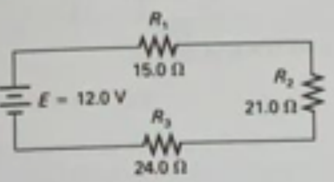


FIGURE 4.19

4. Find the current through R_2 in Question 3.
5. Find the current in the circuit shown in Figure 4.20.

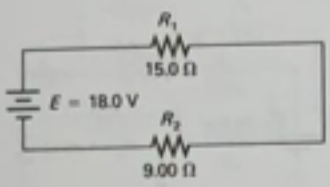


FIGURE 4.20

6. Find the voltage drop across R_1 in Question 5.
7. What emf is needed for the circuit shown in Figure 4.21?

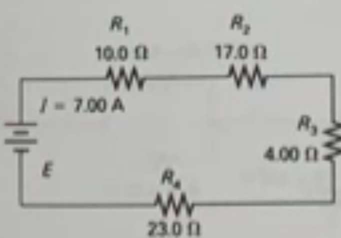


FIGURE 4.21

8. Find the voltage drop across R_3 in Question 7.
9. Find the equivalent resistance in the circuit shown in Figure 4.22.

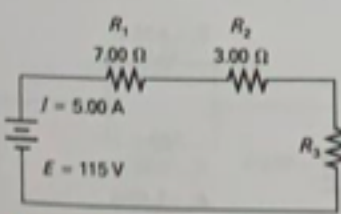


FIGURE 4.22

10. Find R_3 in the circuit in Question 9.
11. Find the values of R_1, R_2, and R_3 in Figure 4.23.

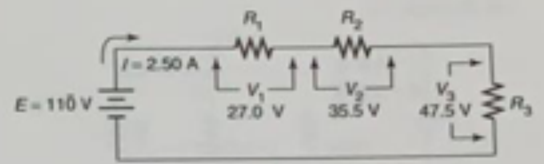


FIGURE 4.23

12. Find the values of V_1, R_2, and V_3 in Figure 4.24.

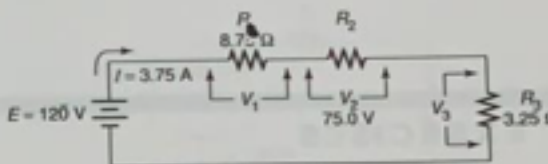


FIGURE 4.24

13. Find the values of R_1, V_2, and R_3 in Figure 4.25.

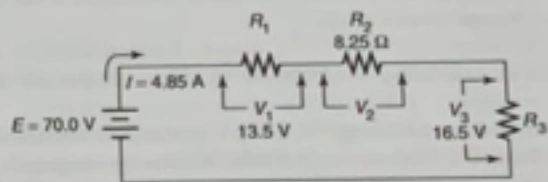


FIGURE 4.25

Parallel Circuits

1. (a) Find the equivalent resistance in the circuit shown in Figure 4.26. (b) What is the total current in the circuit? (c) What is the current through R_1? (d) What is the current through R_2?

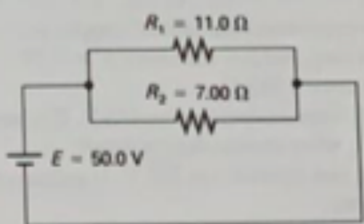


FIGURE 4.26

2. (a) Find I_2 (current through R_2) in the circuit shown in Figure 4.27. (b) Find I_3. (c) Find I_1. (d) Find the total current in the circuit. (e) Find the equivalent resistance in the circuit.

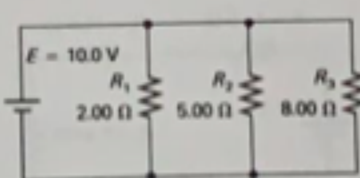


FIGURE 4.27

3. (a) Find the resistance of R_3 in the circuit in Figure 4.28. (b) What is the current through R_1? (c) What is the current through R_3?

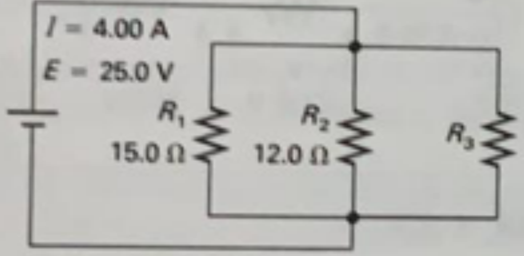


FIGURE 4.28

4. (a) What is the equivalent resistance in the circuit shown in Figure 4.29? (b) What emf is required for the circuit? (c) What is the voltage drop across each resistance? (d) What is the current through each resistance?

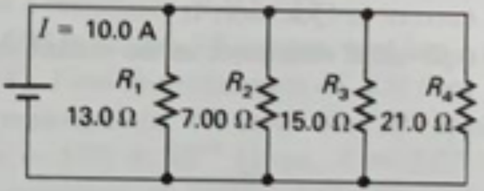


FIGURE 4.29

25. Find th

26. Find t

فيزياء شابتر ٥ من١٢٦-١٣٥ من الكتاب

The nature of light may still be somewhat of a mystery. However, its characteristics have been the subject of intensive study for hundreds of years. Light may be transmitted, reflected, or absorbed by a medium.

Anyone wearing glasses can appreciate the refraction of light as it bends upon passing from one medium to another. The index of refraction is a tool that the scientist uses to describe the ability of certain substances to bend light as it passes through them.

Nature of Light

Light may be defined as radiant energy that can be seen by the human eye. A new theory for the nature of light emerged as physicists began to consider light as an oscillating disturbance of an electric field and a corresponding magnetic field. It was discovered that an **electromagnetic wave** consists of two perpendicular transverse waves with one component of the wave being a vibrating electric field and the other being a corresponding vibrating magnetic field; the electromagnetic wave moves in a direction perpendicular to both electric and magnetic field components as shown in Figure 5.1. All such waves travel at the same speed in a vacuum (3.00×10^8) but differ in their frequencies and wavelengths. Note that as the frequency increases to the right in Figure 5.2, the wavelength decreases. Electromagnetic waves differ from other transverse and longitudinal waves in that they do not need a medium such as air, water, or a solid through which to travel. As a result, radio waves, visible light, gamma rays, and X rays travel through space at the same speed of light. Electromagnetic waves are produced by accelerating electric charges, which create an electric field that in turn creates a corresponding magnetic field.

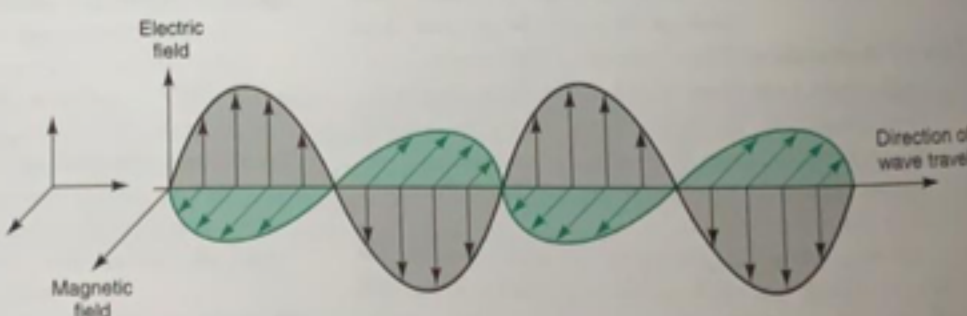


FIGURE 5.1

The electric and magnetic field components of an electromagnetic wave are perpendicular to each other as well as to the direction of travel of the electromagetic wave.

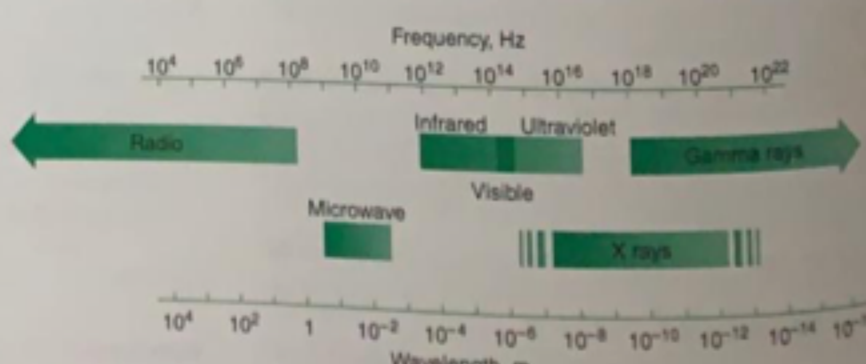


FIGURE 5.2

Electromagnetic spectrum.

The Speed of Light

One of the most important measured quantities in physics is the **speed of light,** the speed at which light and other forms of electromagnetic radiation travel. The speed of light, is now defined as 299,792,458 m/s. This is usually rounded to 3.00×10^8 m/s.

The distance travelled by any form of electromagnetic radiation can be found by substituting the speed of light c into the equation $s = vt$ as follows:

$$s = ct$$

where t = time
c = speed of light, 3.00×10^8 m/s
s = distance

EXAMPLE 5.1

Find the distance (in mi) traveled by an X ray in 0.100 s.

Data:

$$c = 186{,}000 \text{ mi/s}$$
$$t = 0.100 \text{ s}$$
$$s = ?$$

Basic Equation:

$$s = ct$$

Working Equation: Same

Substitution:

$$\begin{aligned} s &= (186{,}000 \text{ mi/s})(0.100 \text{ s}) \\ &= 18{,}600 \text{ mi} \end{aligned}$$

Very large distances, such as those between stars, cannot be conveniently expressed in common distance units. Astronomers therefore use the unit light-year to measure such distances. A **light-year** is the distance travelled by light in one earth year, so 1 light-year equals 9.45×10^{15} m.

Light as a Wave

Light and the other forms of electromagnetic radiation are composed of oscillations in the electric and magnetic fields that exist in space. These oscillations are set up by the rapid movement of charged particles such as electrons in radio antennas and electrons in a hot object such as a light bulb filament. A wave is characterized by its **wavelength,** the distance between two successive corresponding points on the wave (Figure 5.3). This distance is denoted by the Greek lowercase letter lambda, λ. The wavelength of visible light ranges from about 4.0×10^{-7} m to 7.6×10^{-7} m. The human eye perceives light in the visible spectrum as one or more colors depending upon the frequency or wavelength of the light hitting the retina of the eye. The longest visible wavelengths ($\lambda = {\sim}7.5 \times 10^{-7}$ m), which are also the lowest frequencies, are perceived as red. The shortest visible wavelengths ($\lambda = \sim 4.0 \times 10^{-7}$ m), which are the highest frequencies, are perceived as blue. The wavelengths of other electromagnetic radiations are given in Figure 5.2.

FIGURE 5.3

The wavelength of a repeating wave is the distance between two successive corresponding points.

Another characteristic of waves is the frequency, f. **Frequency** is the number of vibrations or cycles per second of a wave. Frequency can be measured by counting the number of wavelengths that pass a stationary point in 1 s. The measurement unit of frequency (cycles/s) is named the hertz (Hz). ($1 \text{ Hz} = 1$ cycle per second $= 1/\text{s}$.) Since a "cycle" has no units, it does not appear in the hertz unit.

The following basic relationship exists for all electromagnetic waves:

$$c = \lambda f$$

where f = frequency
λ = wavelength
c = speed of light

EXAMPLE 5.2

Find the frequency of a light wave with a wavelength of 5.00×10^{-7} m.

Data:

$$\lambda = 5.00 \times 10^{-7} \text{ m}$$
$$c = 3.00 \times 10^{8} \text{ m/s}$$
$$f = ?$$

Basic Equation:

$$c = \lambda f$$

Working Equation:

$$f = \frac{c}{\lambda}$$

Substitution:

$$f = \frac{3.00 \times 10^{8} \text{ m/s}}{5.00 \times 10^{-7} \text{ m}}$$
$$= 6.00 \times 10^{14} \text{ Hz} \quad \text{(or cycles/s)}$$

Reflection

Reflection is the turning back of all or a part of a beam of light as it strikes a surface. Unlike sound, light does not require a medium to travel through and may be transmitted through empty space. When light does strike a medium, the light may be reflected, absorbed, transmitted, or undergo a combination of the three. Mirrors show how light may be reflected. Any dark cloth shows how light may be absorbed. Window glass illustrates how light may be transmitted through a medium.

In studying reflection we observe what happens when light is turned back from a surface. The beam of a flashlight directed at a mirror shows several things about reflection. First, upon striking the surface of the glass, some of the light is reflected in all directions. This is called *scattering.* If there were no scattering, no light would reach our eyes and we would be unable to observe the beam at all. However, only a very small part of the beam of light is scattered. Rough or uneven surfaces produce more scattering than do smooth ones. This scattering of light by uneven surfaces is called **diffusion.** Diffused lighting has many applications at home and in industry where bright glare is not desirable.

Nearly complete reflection (with very little scattering) is called **regular** (or **specular**) reflection. **Regular reflection** occurs when parallel or nearly parallel rays of light (such as sunlight and spotlight beams) remain parallel after being reflected from a surface (Figure 5.4). Note that the incoming rays are referred to as incident rays.

A flashlight beam on a mirror in a darkened room also shows something else about light striking a regular reflecting surface: The reflected rays of light leave the surface at the same angle at which the incident (incoming) rays strike the surface (Figure 5.5). Expressed another way, the angles measured from the normal (the perpendicular) to the reflecting surface are equal. These angles are shown in Figure 5.6.

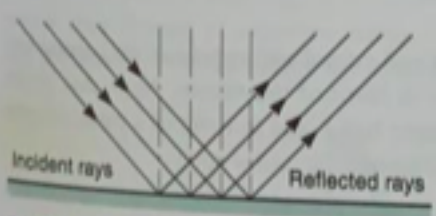


FIGURE 5.4

Regular reflection (reflected rays are parallel).

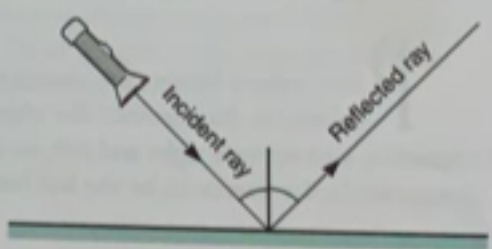


FIGURE 5.5

On a regular surface, the reflected rays leave at the same angle as the incident rays.

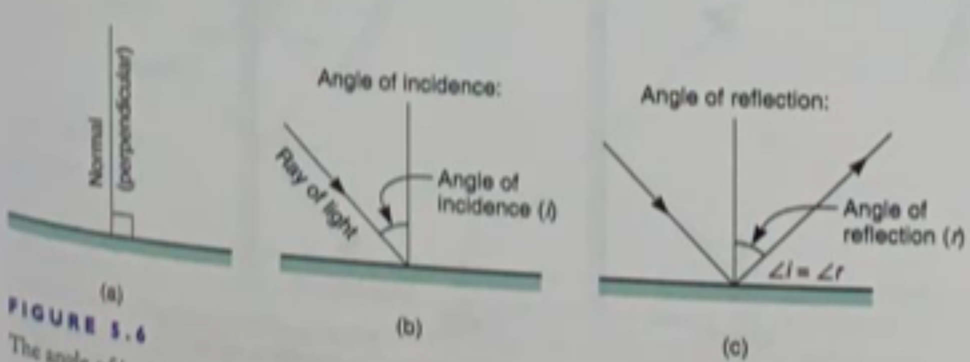


FIGURE 5.6

The angle of incidence is equal to the angle of reflection.

This behavior of light rays is defined by the following **First Law of Reflection:**

First Law of Reflection

The angle of incidence, i, is equal to the angle of reflection, r; that is,

$$\angle i = \angle r$$

Further observation of the light beam readily shows the following **Second Law of Reflection:**

Second Law of Reflection

The incident ray, the reflected ray, and the normal (perpendicular) to the surface all lie in the same plane.

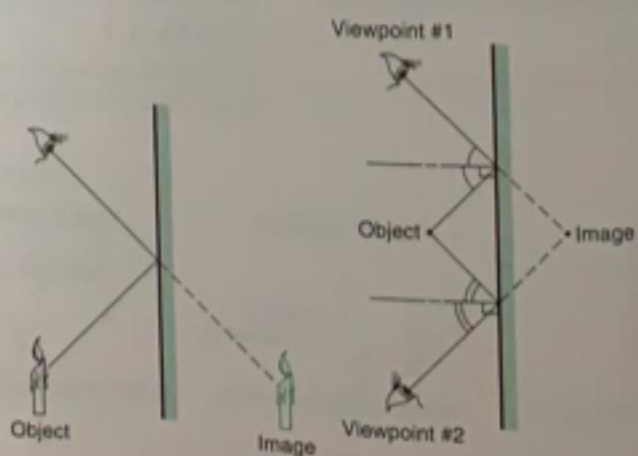
These laws of reflection apply not only to light, but to all kinds of waves.

We consider next how images are formed by plane, concave, and convex mirrors. Images formed by mirrors may be **real images** (images formed by rays of light) or **virtual images** (images that only appear to the eye to be formed by rays of light).

Real images made by a single mirror are always inverted (upside down) and may be larger than, smaller than, or the same size as the object. They can be shown on a screen. Virtual images are always erect and may be larger than, smaller than, or the same size as the object. They cannot be shown on a screen.

Images Formed by Plane Mirrors

Plane mirror images are always erect and virtual and appear as far behind the mirror as the distance the object is in front of the mirror. Note that plane mirrors also reverse right and left, so the right hand held in front of a plane mirror appears in the mirror to be the left hand (Figure 5.7).



(a) Plane mirror image

(b) Location of an image in a plane mirror

FIGURE 5.7

Images Formed by Concave Mirrors

Find a shiny tablespoon and look at your image in it (Figure 5.8). Now turn it over and look again. The images are very different; one is erect and the other, inverted (upside down). As we shall see, the kind of image produced depends on the location of the object with respect to the mirror.

FIGURE 5.8

Reflected images as seen on opposite sides of a large spoon.
Photo courtesy of Visuals Unlimited.

Figure 5.9(a) shows a spherical mirror with the key terms identified. The center of curvature, C, is the center of the sphere that forms a part of the spherical mirror. The vertex, V, is the center of the mirror (sometimes called its optical center). The principal axis is the line CV drawn through the center of curvature and the vertex. The *principal focus*, F, is the point on the principal axis through which all rays parallel to the principal axis converge in a concave mirror as shown in Figure 5.9(b) or from which they diverge in a convex mirror. The **focal length** is the distance between the principal focus of a mirror (or lens) and its vertex.

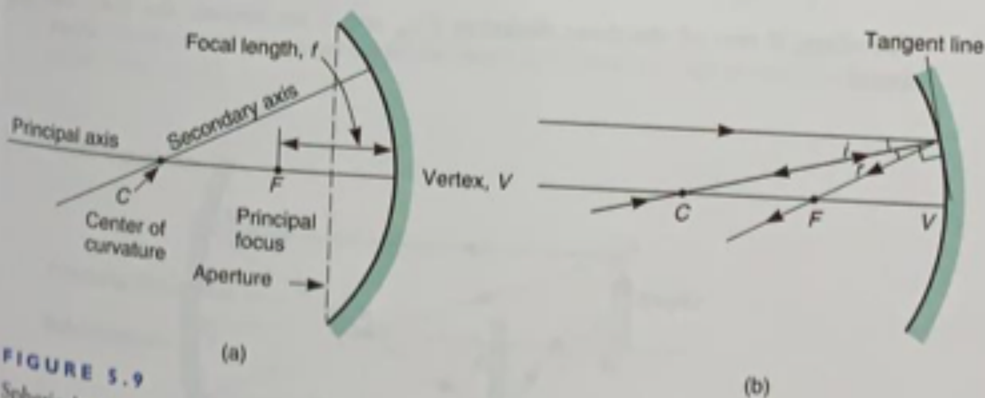


FIGURE 5.9

Spherical mirror.

An object placed outside the focal point, so that the object distance is greater than the (positive) focal length, produces a real and inverted image. If the object is placed inside the focal point of a concave mirror, the resulting image is *virtual*, *erect*, and *larger* than the object. When object is placed at the focal point, no image will be formed because the rays of light will be reflected parallel to the principal axis.

Images Formed by Convex Mirrors

By looking into the back side of our tablespoon in Figure 5.8, we see an erect, virtual, smaller image. Use the mirror diagram shown in Figure 5.10 to see how such an image is formed.

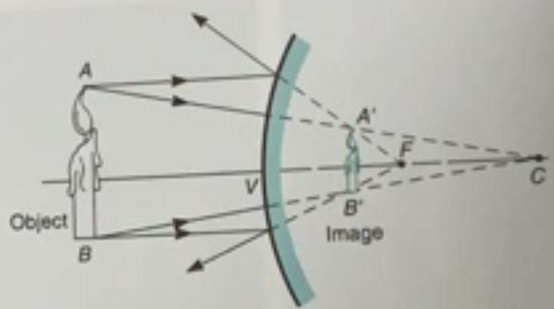


FIGURE 5.10
Formation of images in convex mirrors.

The Mirror Formula

The focal length, the distance from the object to the mirror, and the distance from the image to the lens are all related (Figure 5.11). This relationship can be expressed as the *mirror formula*:

$$\frac{1}{f} = \frac{1}{s_o} + \frac{1}{s_i}$$

where f = focal length of mirror
s_o = distance of object from mirror
s_i = distance of image from mirror

Therefore, if two of the three distances f, s_o, and s_i are known, the third can be found.

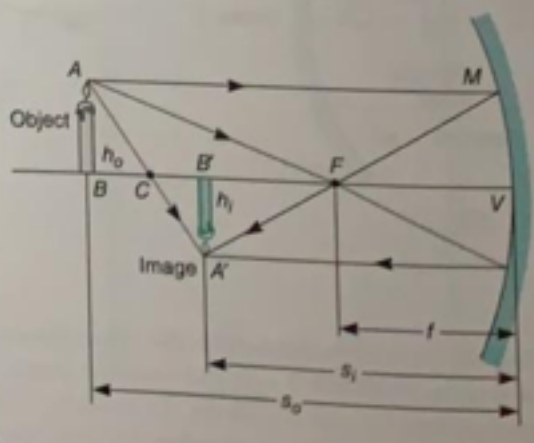


FIGURE 5.11
The mirror formula is expressed in terms of f, s_o, and s_i.

A second formula shows the magnification of the mirror and how the height of the object and the height of the image depend on the object distance and the image distance:

$$M = \frac{h_i}{h_o} = \frac{-s_i}{s_o}$$

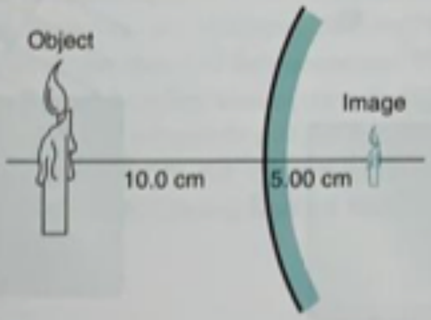
where M = magnification
h_i = image height
h_o = object height
s_i = image distance
s_o = object distance

In using *both* of the preceding formulas for concave and convex mirrors, remember that the distance to a virtual image is always negative; similarly, the focal length of a convex mirror is also negative. An inverted image has a negative magnification and an erect image has a positive magnification.

EXAMPLE 5.3

An object 10.0 cm in front of a convex mirror forms an image 5.00 cm behind the mirror. What is the focal length of the mirror?

Sketch:



Data:

$s_o = 10.0\text{ cm}$
$s_i = -5.00\text{ cm}$

Note: The image is virtual (appears behind the mirror) so si is given a (−) sign to show this. [Won't *f* also be (−)?]

$f = ?$

Basic Equation:

$$\frac{1}{f} = \frac{1}{s_o} + \frac{1}{s_i}$$

Working Equation: Same

Substitution:

$$\frac{1}{f} = \frac{1}{10.0\text{ cm}} + \frac{1}{-5.00\text{ cm}} = \frac{1}{10.0\text{ cm}} - \frac{1}{5.00\text{ cm}}$$

$$f = -10.0\text{ cm}$$

Remember that f and s_i may be negative only when forming virtual images and/or using convex mirrors.

Check yourself
What evidence can you cite to support the claim that the frequency of light does not change upon reflection?

فيزياء شابتر ٦ من ١٤٨-١٥٩ من الكتاب

عمر النصف الإشعاعي: عمر النصف الإشعاعي لمادة إشعاعية هو الوقت اللازم لانحلال نصف الذرات الإشعاعية.

Carbon Dating: Scientist can find how long ago a plant or animal died by measuring the ratio of carbon-14 to carbon-12 in the remains.

التاريخ بالكربون: يستطيع العلماء بموجبه معرفة الفترة التي عاشها نبات أو حيوان عن طريق قياس نسبة الكربون 14 إلى الكربون 12 في البقايا.

Radioactive Tracers: Scientists can analyze biological or mechanical processes using small amounts of radioactive isotopes as tracers.

مقتفي الأثر الإشعاعي: يمكن للعلماء تحليل العمليات البيولوجية أو الميكانيكية باستخدام كميات صغيرة من النظائر الإشعاعية كعناصر اقتفاء.

Environmental radioactivity: Is produced by the decay of unstable nuclides that is found in the environment. Example of radioactive isotopes present due to natural processes is radon (^{222}Rn), uranium-238 (^{238}U), thorium-232 (^{232}Th) and potassium-40 (^{40}K).

النشاط الإشعاعي البيئي: ينتج عن طريق انحلال النويدات غير المستقرة الموجودة في البيئة. مثال على النظائر الإشعاعية الموجودة بسبب العمليات الطبيعية هو الرادون (^{222}Rn)، واليورانيوم 238 (^{238}U) والثوريوم 232 (^{232}Th) والبوتاسيوم 40 (^{40}K).

Food irradiation: A process intended to preserve food for longer time and/or improve its quality.

تشعيع الغذاء: هو عملية الغرض منها حفظ الطعام لفترة أطول و/أو تحسين جودته.

Radiation Safety: Protective measure and actions to avoid/minimize the risk from radiation. Whenever possible, exposure to radiation should be avoided.

الأمان الإشعاعي: هو ضوابط وإجراءات وقائية لتجنب/ التقليل من خطر الإشعاع. يجب عدم التعرض للإشعاع قدر الإمكان.

Nuclear medicine: Is the use of radioactive sources in medical diagnosis or treatment.

الطب النووي: هو استخدام المصادر الإشعاعية لغرض التشخيص أو العلاج الطبي.

Radiology: Use of x-ray in medicine.

طب الأشعة: هو استخدام الأشعة السينية في الطب.

Radiation

Radiation is energy in the form of waves or moving particles that emitted by an atom it changes from a higher energy state to a lower energy state. Radiation can be classified into two categories: *ionizing radiation and non-ionizing radiation,* depending on its effect on the atom. Ionizing radiation can be classified as:

i. directly ionizing which is caused by charged particles and
ii. indirectly ionizing which is caused by uncharged particles (as a result of transfer of energy via momentum).

The international symbol used for hazard from radiation or radioactive material is shown in Figure 6.1.

Non-ionizing radiation: changes occur in bound electronic states of the atom. Affected electron stays with its original atom either by changing bound atomic orbital levels or by changing its spin state.

FIGURE 6.1
Trefoil is the hazard symbol for radiation

Bohr Model of the Atom

In 1913, Bohr applied the quantum theory of Planck and Einstein to the nuclear atom of Rutherford and formulated the well-known planetary model of the atom.[1] Bohr reasoned that electrons occupy "stationary" states (of fixed energy, not fixed position) at different distances from the nucleus and that the electrons can make "quantum jumps" from one energy state to another.

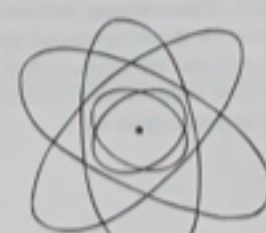


FIGURE 6.2
The Bohr model of the atom. Although this model is very oversimplified, it is still useful in understanding light emission.

[1] This model, like most models, has major defects because the electrons do not revolve in planes as planets do. The model was revised; "orbits" became "shells" and "clouds." We use *orbit* because it was, and still is, commonly used. Electrons are not just bodies, like planets, but rather behave like waves concentrated in certain parts of the atom.

FIGURE 6.3

According to classical theory, an electron accelerating around its orbit should continuously emit radiation. This loss of energy should cause it to spiral rapidly into the nucleus. But this does not happen.

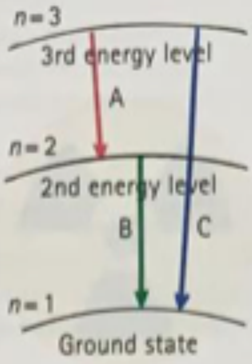


FIGURE 6.4

Three of many energy levels in an atom. An electron jumping from the third level to the second level (red A), and one jumping from the second level to the ground state (green B). The sum of the energies (and the frequencies) for these two jumps equals the energy (and the frequency) of the single jump from the third level to the ground state (blue C).

He reasoned that light is emitted when such a quantum jump occurs (from a higher to a lower energy state). Furthermore, Bohr realized that the frequency of emitted radiation is determined by $E = hf$ (actually, $f = E/h$), where E is the difference in the atom's energy when the electron is in the different orbits. This was an important breakthrough, because he said that the emitted photon's frequency is not the classic frequency at which an electron is vibrating but, instead, is determined by the energy *differences* in the atom. From there, Bohr could advance to the next step and determine the energies of the individual orbits.

Bohr's planetary model of the atom begged a major question. Accelerated electrons, according to Maxwell's theory, radiate energy in the form of electromagnetic waves. So an electron accelerating around a nucleus should radiate energy continuously. This radiating away of energy should cause the electron to spiral into the nucleus (Figure 6.3). Bohr boldly deviated from classical physics by stating that the electron doesn't radiate light while it accelerates around the nucleus in a single orbit, but that radiation of light occurs only when the electron makes a transition from a higher energy level to a lower energy level. As we now know, the atom emits a photon whose energy is equal to the *difference* in energy between the two energy levels, $E = hf$. The frequency of the emitted photon, its color, depends on the size of the jump. So the quantization of light energy neatly corresponds to the quantization of electron energy.

Bohr's views, as outlandish as they seemed at the time, explained the regularities found in atomic spectra. Bohr's explanation of the Ritz combination principle is shown in Figure 6.4. If an electron is raised to the third energy level, it can return to its initial level either by a single jump from the third to the first level or by a double jump, first to the second level and then to the first level. These two return paths will produce three spectral lines. Note that the sum of the energy jumps along paths A and B is equal to the single energy jump along path C. Since frequency is proportional to energy, the frequencies of light emitted along paths A and B when added equal the frequency of light emitted when the transition is along path C. Now we can see why the sum of two frequencies in the spectrum is equal to a third frequency in the spectrum.

Bohr was able to account for X-rays in heavier elements, showing that they are emitted when electrons jump from outer to innermost orbits. He predicted X-ray frequencies that were later experimentally confirmed. Bohr was also able to calculate the "ionization energy" of a hydrogen atom—the energy needed to knock the electron out of the atom completely. This also was verified by experiment.

Using measured frequencies of X-rays as well as visible, infrared, and ultraviolet light, scientists could map energy levels of all the atomic elements. Bohr's model had electrons orbiting in neat circles (or ellipses) arranged in groups or shells. This model of the atom accounted for the general chemical properties of the elements. It also predicted a missing element, which led to the discovery of hafnium.

Bohr solved the mystery of atomic spectra while providing an extremely useful model of the atom. He was quick to stress that his model was to be interpreted as a crude beginning, and the picture of electrons whirling about the nucleus like planets about the Sun was not to be taken literally (to which popularizers of science paid no heed). His sharply defined orbits were conceptual representations of an atom whose later description involved waves—quantum mechanics. His ideas of quantum jumps and frequencies being proportional to energy differences remain part of today's modern theory.

EXAMPLE 6.1

Match between Group I and Group II:

Group I	Group II
1. Atoms	A. Particles which orbit the nucleus of an atom.
2. Protons	B. Particles without an electric charge found in the nucleus of atoms.
3. Neutrons	C. Material with atoms which all have the same number of protons.
4. Electrons	D. Positively charged particles found in the nucleus of an atom.
5. Element	E. Basic building blocks of matter.

X-rays and Radioactivity

Deeper probing into the atom began in 1895 when the German physicist Wilhelm Roentgen discovered **X-rays**—rays of an unknown nature. Roentgen discovered these "new kind of rays" produced by a beam of "cathode rays" (later found to be electrons) striking the glass surface of a gas-discharge tube. He found that X-rays could pass through solid materials, could ionize the air, showed no refraction in glass, and were undeflected by magnetic fields. Today we know that X-rays are high-frequency electromagnetic waves, usually emitted by the de-excitation of the innermost orbital electrons of atoms. Whereas the electron current in a fluorescent lamp excites the outer electrons of atoms and produces ultraviolet and visible photons, a more energetic beam of electrons striking a solid surface excites the innermost electrons and produces higher-frequency photons of X-radiation.

X-ray photons have high energy and can penetrate many layers of atoms before being absorbed or scattered. X-rays do this when they pass through your soft tissue to produce an image of the bones inside your body (Figure 6.5). In a modern X-ray tube, the target of the electron beam is a metal plate rather than the glass wall of the tube.

In early 1896, a few months after Roentgen announced his discovery of X-rays, the French physicist Antoine Henri Becquerel stumbled upon a new kind of penetrating radiation. Becquerel was studying fluorescence and phosphorescence created by both light and the newly discovered X-rays, and one evening happened to leave a wrapped photographic plate in a drawer next to some crystals that contained

fyi

Now we'll burrow beneath the electrons and go deeper into the atom—to the atomic nucleus—where available energies dwarf those available to electrons. This is nuclear physics, a topic of great public interest—and public fear—not unlike the fear of electricity more than a century ago. With safeguards and well-informed consumers, society has determined that the benefits of electricity outweigh its risks. Likewise today with nuclear technology's risks versus its benefits.

Radioactivity has been around since Earth's beginning.

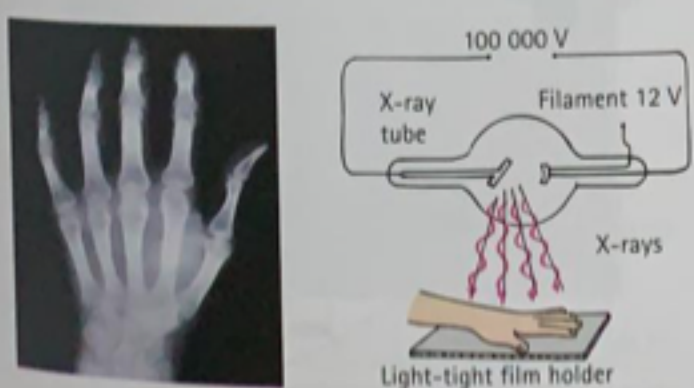


FIGURE 6.5
X-rays emitted by excited metallic atoms in the electrode penetrate flesh more readily than bone and produce an image on the film.

uranium. The next day he discovered to his surprise that the photographic plate had been darkened, apparently by spontaneous radiation from the uranium. He went on to show that this new radiation differed from X-rays in that it could ionize air and could be deflected by electric and magnetic fields.

It was soon discovered that similar rays are emitted by other elements, such as thorium, actinium, and two new elements discovered by Marie and Pierre Curie—polonium and radium. The emission of these rays was evidence of much more drastic changes in the atom than atomic excitation. These rays, as it turned out, were the result not of changes in the electron energy states of the atom but of changes occurring within the central atomic core—the nucleus. This process is **radioactivity,** which, because it involves the decay of the atomic nucleus, is often called *radioactive decay.*

Light is emitted by energy-level transitions in atoms; gamma rays are emitted by similar energy transitions within the atomic nucleus.

A common misconception is that radioactivity is something new in the environment, but it has been around far longer than the human race. It is as much a part of our environment as the Sun and the rain. It has always been in the soil we walk on and in the air we breathe, and it is what warms the interior of Earth and makes it molten. In fact, radioactive decay in Earth's interior is what heats the water that spurts from a geyser or wells up from a natural hot spring. Even the helium in a child's balloon is nothing more than the product of radioactive decay. Radioactivity is as natural as sunshine and rain.

Half-life

Half-life (or $t_{1/2}$) is defined as **the time taken for the activity of the sample to halve.** Note that the half-life remains the same throughout the life of the sample.

As the activity of a sample is proportional to the number of radioactive nuclides present it is also possible to say that the half-life is **the time taken for half of the radioactive nuclides in a sample to decay.**

It is possible to show from this graph that the gradient is equal to −1 called the decay constant. As you can see from the graph, the steeper the gradient the more quickly the substance will decay and hence a shorter half-life.

$$t_{1/2} \propto \frac{1}{\cdot} \quad \text{In fact} \quad t_{1/2} = \frac{0.693}{\cdot}$$

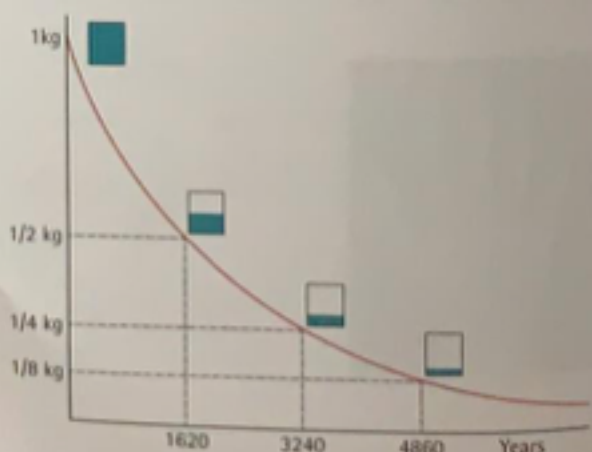


FIGURE 6.6
The graph shows the decay (red curve) of Ra-226 radionuclide. The x-axis presents the time elapsed and the y-axis presents the amount of activity remains. Half of the activity is reached at time of 1620 years; therefore we say this is the half-time of Ra-226.

Alpha, Beta, and Gamma Rays

More than 99.9% of the atoms in our everyday environment are stable. The nuclei in those atoms will be unlikely to change over the lifetime of the universe. But some kinds of atoms are unstable. All elements having an atomic number greater than 82 (lead) are radioactive. These elements, and others, emit three distinct types of radiation, named by the first three letters of the Greek alphabet, α, β, γ—*alpha, beta,* and *gamma.*

Alpha rays have a positive electrical charge, **beta rays** have a negative electrical charge, and **gamma rays** have no charge at all (Figure 6.7). The three rays can be separated by placing a magnetic field across their paths (Figure 6.8). Further investigation has shown that an alpha ray is a stream of helium nuclei, and a beta ray is a stream of electrons. Hence, we often call these *alpha particles* and *beta particles.* A gamma ray is electromagnetic radiation (a stream of photons) whose frequency is even higher than that of X-rays. Whereas X-rays originate in the electron cloud outside the atomic nucleus, alpha, beta, and gamma rays originate in the nucleus. Gamma photons provide information about nuclear structure, much as visible and X-ray photons provide information about atomic electron structure.

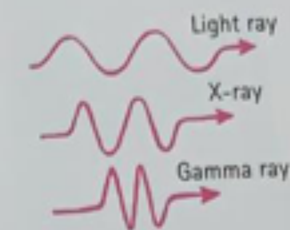


FIGURE 6.7

A gamma ray is part of the electromagnetic spectrum. It is simply electromagnetic radiation that is much higher in frequency and energy than light and X-rays.

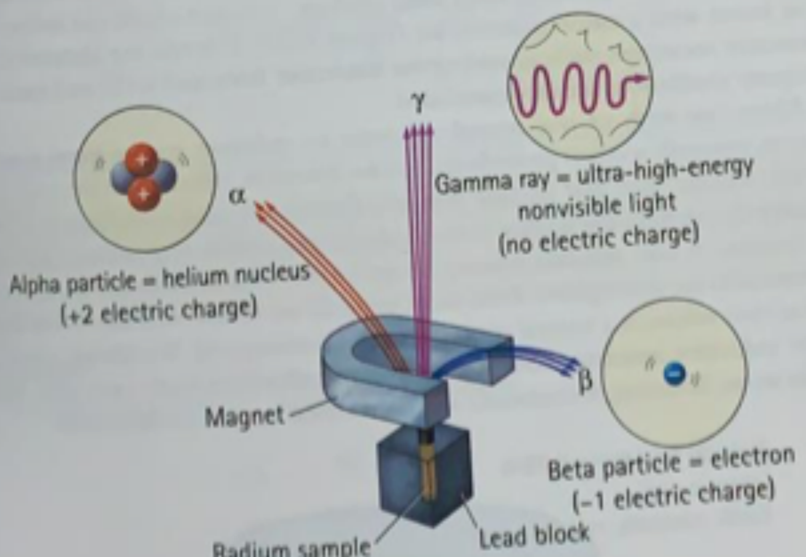


FIGURE 6.8

In a magnetic field, alpha rays bend one way, beta rays bend the other way, and gamma rays don't bend at all. The combined beam comes from a radioactive source placed at the bottom of a hole drilled in a lead block.

FIGURE 6.9

The shelf life of fresh strawberries and other perishables is markedly increased when the food is subjected to gamma rays from a radioactive source. The strawberries on the right were treated with gamma radiation, which kills the microorganisms that normally lead to spoilage. The food is only a receiver of radiation and is in no way transformed into an emitter of radiation, as can be confirmed with a radiation detector.

Carbon-14 Dating is a useful example of the concept of half-life in practice. Carbon-14 is a radioactive isotope of carbon with a half-life of 5730 years.

All living matter takes in carbon-14 during its lifetime as it naturally occurs in nature. Upon death this uptake ceases, and levels of carbon-14 decay. It is possible to compare the activity of a living sample of material with an ancient specimen (of the same mass) and estimate the age. For example if a specimen has half the activity of a living sample of equal mass it is around 5730 years old i.e. 1 half-life. If the activity were quarter it would be $2 \times 5730 = 11460$ years old i.e. 2 half-life's and so on.

Environmental Radiation

Common rock and minerals in our environment contain significant quantities of radioactive isotopes because most of them contain trace amounts of uranium. As a matter of fact, people who live in brick, concrete, or stone buildings are exposed to greater amounts of radiation than people who live in wooden buildings.

The leading source of naturally occurring radiation is radon-222, an inert gas arising from uranium deposits. Radon is a heavy gas that tends to accumulate in basements after it seeps up through cracks in the floor. Levels of radon vary from region to region, depending upon local geology. You can check the radon level in your home with a radon detector kit (Figure 6.10). If levels are abnormally high, corrective measures, such as sealing the basement floor and walls and maintaining adequate ventilation, are recommended.

About one-sixth of our annual exposure to radiation comes from nonnatural sources, primarily medical procedures. Smoke detectors, fallout from long-ago nuclear testing, and the coal and nuclear power industries are also contributors. The coal industry far outranks the nuclear power industry as a source of radiation. Globally, the combustion of coal annually releases about 13,000 tons of radioactive thorium and uranium into the atmosphere. Both these minerals are found naturally in coal deposits so that their release is a natural consequence of burning coal. Worldwide, the nuclear power industries generate about 10,000 tons of radioactive waste each year. Most all of this waste, however, is contained and *not* released into the environment.

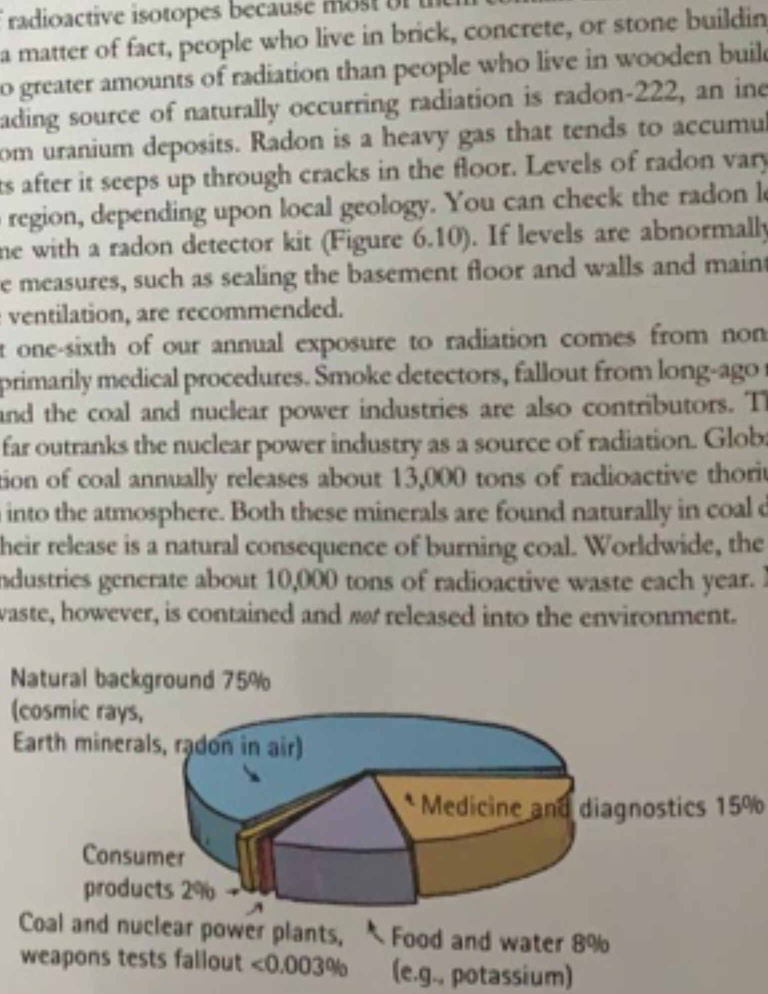


FIGURE 6.10

Origins of radiation exposure for an average individual in the United States.

UNITS OF RADIATION

Radiation dosage is commonly measured in *rads* (*r*adiation *a*bsorbed *d*ose), a unit of absorbed energy. One **rad** is equal to 0.01 joule of radiant energy absorbed per kilogram of tissue.

The capacity for nuclear radiation to cause damage is not just a function of its level of energy, however. Some forms of radiation are more harmful than others. For example, suppose you have two arrows, one with a pointed tip and one with a suction cup at its tip. Shoot both arrows at an apple at the same speed and both have the same kinetic energy. The one with the pointed tip, however, will invariably do more damage to the apple than the one with the suction cup. Similarly, some forms of radiation cause greater harm than other forms even when we receive the same number of rads from both forms.

The unit of measure for radiation dosage based on potential damage is the **rem** (*r*oentgen *e*quivalent *m*an).[2] In calculating the dosage in rems, we multiply the number of rads by a factor that corresponds to different health effects of different types of radiation determined by clinical studies. For example, 1 rad of alpha particles has the same biological effect as 10 rads of beta particles.[3] We call both of these dosages 10 rems.

Particle	Radiation Dosage		Factor		Health Effect
alpha	1 rad	×	10	=	10 rems
beta	10 rad	×	1	=	10 rems

FIGURE 6.11

A commercially available radon test kit for the home.

EXAMPLE 6.2

A sample of radium contains 6.64×10^{23} atoms. It emits alpha particles and has a half-life of 1620 years. How many atoms are left after 100 years?

Solution

Use equation 7.4, substitute $N_0 = 6.64 \times 10^{23}$ atoms; $t = 100$ year, then

$$N = 6.64 \times 10^{23} e^{-\frac{0.693 \times 100}{1620}}$$

$$N = 6.36 \times 10^{23} \text{ atoms}$$

EXAMPLE 6.3

A sample of wood from an old boat is found to contain 25% the number of carbon 14 nuclides as an equivalent piece from a modern sample. If the half-life of carbon 14 is taken to be 5730 years how old is the old wood?

Solution

Use equation 7.4, substitute $\frac{N}{N_0} = 25\% = 0.25$, this implies

$$0.25 = e^{-\frac{0.693}{5730} \cdot t}$$

$$\ln 0.25 = \frac{-0.693}{5730 \cdot t}$$

$$(\ln 0.25 = -1.3863)$$

Therefore, $t = 1.3863 \times \frac{5730}{0.693} = 11460$ years

CHECK POINT

Which is more harmful, being exposed to 1 rad of alpha particles or 1 rad of beta particles?

Check Your Answer

Alpha particles: Multiply these quantities of radiation by the appropriate factor to get the dosages in rems. Alpha: 1 rad × 10 = 10 rems; beta: 1 rad × 1 = 1 rem. The factors show us that, physiologically speaking, alpha particles are 10 times more damaging than beta particles.

[2] This unit is named for Wilhelm Roentgen, the discoverer of X-rays.

[3] This is true even though beta particles have more penetrating power, as previously discussed.

DOSE OF RADIATION AND ITS UNITS

Absorbed dose is a basic dose quantity which represents the average energy imparted to matter per unit mass (E/m) by ionizing radiation. The SI unit is joules per kilogram and its special name is called gray (Gy). Radiation risk (defined as *probability* of cancer induction) is calculated based on the type of radiation and the sensitivity of the irradiated tissues, which requires the use of weighting factors. The dose unit for health effects is given in Sievert (Sv).

Lethal doses of radiation begin at 500 rems. A person has about a 50% chance of surviving a dose of this magnitude delivered to the whole body over a short period of time. During radiation therapy, a patient may receive localized doses in excess of 200 rems each day for a period of weeks (Figure 6.12).

FIGURE 6.12
Nuclear radiation is focused on harmful tissue, such as a cancerous tumor, to selectively kill or shrink the tissue in a technique known as *radiation therapy*. This application of nuclear radiation has saved millions of lives—a clear-cut example of the benefits of nuclear technology. The inset shows the internationally used symbol indicating an area where radioactive material is being handled or produced.

All the radiation we receive from natural sources and from diagnostic medical procedures is only a fraction of 1 rem per year. For convenience, the smaller unit *millirem* is used, where 1 millirem (mrem) is 1/1000th of a rem. The average person in the United States is exposed to about 360 mrem a year, as Table 6.1 indicates. About 80% of this radiation comes from natural sources, such as cosmic rays and Earth itself. A typical chest X-ray exposes a person to 5 to 30 mrem (0.005 to 0.030 rem), less than one ten-thousandth of the lethal dose. Interestingly, the human body is a significant source of natural radiation, primarily from the potassium we ingest. Our bodies contain about 200 grams of potassium. Of this quantity, about 20 milligrams is the radioactive isotope potassium-40, which is a gamma-ray emitter. Between every heartbeat about 60,000 potassium-40 isotopes in the average human body undergo spontaneous radioactive decay. Radiation is indeed everywhere.

TABLE 6.1
Annual Radiation Exposure

Source	Typical Dose (mrem) Received Annually
Natural Origin	
Cosmic radiation	26
Ground	33
Air (radon-222)	198
Human tissues (K-40; Ra-226)	35
Human Origin	
Medical procedures	
Diagnostic X-rays	40
Nuclear diagnostics	15
Consumer products	8
Weapons-test fallout	1
Commercial fossil-fuel power plants	<1
Commercial nuclear power plants	<<1

When radiation encounters the intricately structured molecules in the watery, ion-rich brine that makes up our cells, the radiation can create chaos on the atomic scale. Some molecules are broken, and this change alters other molecules, which can be harmful to life processes.

Cells are able to repair most kinds of molecular damage caused by radiation if the radiation is not too severe. A cell can survive an otherwise lethal dose of radiation if the dose is spread over a long period of time to allow intervals for healing. When radiation is sufficient to kill cells, the dead cells can be replaced by new ones (except for most nerve cells, which are irreplaceable). Sometimes a radiated cell will survive with a damaged DNA molecule. New cells arising from the damaged cell retain the altered genetic information, producing a *mutation*. Usually the effects of a mutation are insignificant, but occasionally the mutation results in cells that do not function as well as unaffected ones, sometimes leading to a cancer. If the damaged DNA is in an individual's reproductive cells, the genetic code of the individual's offspring may retain the mutation.

FIGURE 6.13

The film badge worn by this scientist contains audible alerts for both radiation surge and accumulated exposure. Information from the individualized badge is periodically downloaded to a database for analysis and storage.

RADIOACTIVE TRACERS

In scientific laboratories radioactive samples of all the elements have been made. This is accomplished by bombardment with neutrons or other particles. Radioactive materials are extremely useful in scientific research and industry. To check the action of a fertilizer, for example, researchers combine a small amount of radioactive material with the fertilizer and then apply the combination to a few plants. The amount of radioactive fertilizer taken up by the plants can be easily measured with radiation detectors. From such measurements, scientists can inform farmers of the proper amount of fertilizer to use. Radioactive isotopes used to trace such pathways are called *tracers*.

ASSESSMENT QUESTIONS (MCQs)

1. Which of the following do electric or magnetic fields not deflect?
   (a) alpha particles
   (b) beta particles
   (c) gamma rays
   (d) Magnetic and electric fields deflect alpha particles, beta particles, and gamma rays.
2. Which of these is the most penetrating in common materials?
   (a) alpha particles
   (b) beta particles
   (c) gamma rays
   (d) all are equally penetrating
3. Uranium-235, uranium-238, and uranium-239 are different
   (a) elements.
   (b) ions.
   (c) isotopes.
   (d) nucleons.
4. The half-life of carbon-14 is about 5730 years. Which of the following statements about the amount of carbon present in your bones is accurate?
   (a) The present amount of carbon in your bones will reduce to zero when you die.
   (b) The present amount of carbon in your bones will reduce to zero in about 5730 years.
   (c) The present amount of carbon in your bones will reduce to zero in 11,460 years.
   (d) The present amount of carbon in your bones will never reach zero, as the amount of carbon will continue to decrease by half of the amount remaining.
5. Carbon-14 is a radioactive isotope of carbon that is primarily produced by cosmic radiation in the
   (a) atmosphere.
   (b) food we eat.
   (c) interior of Earth.
   (d) fallout of nuclear bomb tests.
6. Most of the radiation in Earth's biosphere
   (a) is the result of military activities.
   (b) originates from nuclear power plants.
   (c) occurs as natural background radiation.
   (d) is in the form of cosmic rays.
7. Gamma radiation
   (a) is high-energy charge particle
   (b) is low-energy charge particle
   (c) is high-energy photons
   (d) can be stopped with a sheet of paper
8. X-rays can be produce by
   (a) Interaction between protons
   (b) Acceleration of electrons
   (c) Decay of neutrons
   (d) Amplification of light

9. In food irradiation
   (a) the food becomes radioactive
   (b) the food quality can be improved
   (c) no change can be observed in food
   (d) electrons and gamma rays cannot be used
10. In industry many applications of radiation is available today, example of these:
    (a) Moisture density, gauges and well logging
    (b) Nuclear medicine, radiotherapy and diagnostic radiology
    (c) Hydrology, radon and uranium analysis
    (d) Research reactors, neutron generators and x-ray fluorescence.
11. The electromagnetic spectrum range from low to high energies. The highest energy of the electromagnetic spectrum among the following is the
    (a) Infra red waves.
    (b) Ultra-violet.
    (c) x-rays.
    (d) Gamma rays
12. Natural radioactivity can be found in
    (a) homes.
    (b) offices.
    (c) interior of Earth.
    (d) All of the above.
13. Which of these is a beam of electrons with high speed?
    (a) Alpha ray
    (b) Beta ray
    (c) Gamma rays
    (d) All are different forms of helium
14. Which of the following is not a radioactive element
    (a) Uranium
    (b) Radon
    (c) Nickel
    (d) Polonium
15. The unit of radiation dose for health is
    (a) Newton
    (b) Rem
    (c) Joule
    (d) watt
16. Cobalt isotope (^{60}Co) has a half-life of 5 years. This means the amount of that isotope remaining at the end of 5 years will be
    (a) zero.
    (b) $\frac{1}{2}$.
    (c) $\frac{1}{3}$.
    (d) the same.
17. When an element ejects an alpha particle, the atomic number of the resulting element
    (a) reduces by 1.
    (b) increases by 1.
    (c) reduces by 2.
    (d) increases by 2.
18. The following isotope is commonly used for dating
    (a) Cobalt-60.
    (b) Carbon-14.
    (c) Cesium-30.
    (d) None of the above.
19. Any atom that emits an alpha or beta particles
    (a) Always becomes an atom of a different element
    (b) Always remain the same atom.
    (c) Always becomes isotope of the same element.
    (d) Always change its density.
20. Atoms can transmute into completely different atoms in
    (a) Nature.
    (b) Advanced laboratories.
    (c) Normal laboratories
    (d) All the above

REVIEW QUESTIONS

Wave–Particle Duality

1. Why do photographs in a book or magazine look grainy when magnified?
2. Does light behave primarily as a wave or as a particle when it interacts with the crystals of matter in photographic film?

Double-Slit Experiment

3. Does light travel from one place to another in a wavelike or a particle-like way?
4. Does light interact with a detector in a wavelike or a particle-like way?
5. When does light behave as a wave? When does it behave as a particle?

Particles as Waves: Electron Diffraction

6. What evidence can you cite for the wave nature of particles?
7. When electrons are diffracted through a double slit, do they hit the screen in a wavelike way or in a particle-like way? Is the pattern of hits wavelike or particle-like?

Discovery of the Atomic Nucleus

8. Why do most alpha particles fired through a piece of gold foil emerge almost undeflected, and why do others bounce backward?
9. What did Rutherford discover about the atomic nucleus?

Discovery of the Electron

10. What did Benjamin Franklin postulate about electricity?
11. What is a cathode ray?
12. What property of a cathode ray is indicated when a magnet is brought near the tube?
13. What did J. J. Thomson discover about the cathode ray?
14. What did Robert Millikan discover about the electron?

Atomic Spectra: Clues to Atomic Structure

15. What did Johann Jakob Balmer discover about the spectrum of hydrogen?
16. What did Johannes Rydberg and Walter Ritz discover about atomic spectra?

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will be

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Bohr Model of the Atom

17. What relationship between electron orbits and light emission did Bohr postulate?
18. According to Niels Bohr, can a single electron in one excited state give off more than one photon when it jumps to a lower energy state?
19. What is the relationship between the energy differences of orbits in an atom and the light emitted by the atom?

Explanation of Quantized Energy Levels: Electron Waves

20. How does treating the electron as a wave rather than as a particle solve the riddle of why electron orbits are discrete?
21. According to the simple de Broglie model, how many wavelengths are there in an electron wave in the first orbit? In the second orbit? In the *n*th orbit?
22. How can we explain why electrons don't spiral into the attracting nucleus?

Quantum Mechanics

23. What does the wave function ψ represent?
24. Distinguish between a *wave function* and a *probability density function*.
25. How does the probability cloud of the electron in a hydrogen atom relate to the orbit described by Niels Bohr?

Correspondence Principle

26. Exactly what is it that "corresponds" in the correspondence principle?
27. Would Schrödinger's equation be valid if applied to the solar system? Would it be useful?

X-Rays and Radioactivity

28. What did the physicist Roentgen discover about a cathode-ray beam striking a glass surface?
29. What is the similarity between a beam of X-rays and a beam of light? What is the principal difference between the two?
30. What did the physicist Becquerel discover about uranium?
31. What two elements did Pierre and Marie Curie discover?

Alpha, Beta, and Gamma Rays

32. Why are gamma rays not deflected in a magnetic field?
33. What is the origin of a beam of gamma rays? A beam of X-rays?

Environmental Radiation

34. Distinguish between a *rad* and a *rem*.
35. Do humans receive more radiation from artificial or from natural sources of radiation?
36. Is the human body radioactive? Explain.
37. What kinds of cells are in most danger when they are irradiated?
38. What is a radioactive tracer?

EXERCISES

مصطلحات الكتاب

شابتر ٣

Summary of Terms

Absolute Zero: The lowest possible temperature.
الصفر المطلق: هو أقل درجة حرارة ممكنة.

Btu (British thermal unit): The amount of heat (energy) necessary to raise the temperature of 1 lb of water 1°F.
الوحدة الحرارية البريطانية: هي كمية الحرارة (الطاقة) اللازمة لرفع درجة حرارة 1 رطل من الماء 1 درجة فهرنهايت.

Calorie: The amount of heat necessary to raise the temperature of 1 g of water 1°C.
الكالوري (السعرة الحرارية): هو كمية الحرارة اللازمة لرفع درجة حرارة 1 غرام من الماء 1 درجة مئوية.

Celsius Scale: The metric temperature scale on which ice melts at 0° and water boils at 100°.
المقياس المئوي: هو مقياس الحرارة المتري حيث يذوب الثلج عند 0 درجة مئوية ويغلي الماء عند 100 درجة مئوية.

Change of Phase: (sometimes called *change of state*) A change in a substance from one form of matter (solid, liquid, or gas) to another.
تغير الطور: (يسمى أحياناً *تغير الحالة*). وهو تحول المادة من شكل إلى آخر (صلب، سائل أو غاز).

Condensation: The change of phase from gas or vapor to a liquid.
التكاثف: هو عملية تحول المادة من غاز أو بخار إلى سائل.

Evaporation: The process by which high-energy molecules of a liquid continually leave its surface.
التبخر: هو العملية التي تنفصل خلالها جزيئات السائل عالية الطاقة باستمرار عن سطحها.

Fahrenheit Scale: The U.S. temperature scale on which ice melts at 32° and water boils at 212°.
مقياس فهرنهايت: هو مقياس الحرارة الأمريكي حيث يذوب الثلج عند 32 درجة مئوية ويغلي الماء عند 212 درجة مئوية.

Freezing: The change of phase from liquid to solid. Also called *solidification*.
التجمد: هو عملية تحول المادة من الحالة السائلة إلى الحالة الصلبة. ويُطلق عليها أيضاً *التصلب*.

Fusion: The change of phase from solid to liquid. Also called *melting*.
الانصهار: هو عملية تحول المادة من الحالة الصلبة إلى السائلة. ويُطلق عليها أيضاً *انصهار*.

Heat: A form of internal kinetic and potential energy contained in an object associated with the motion of its atoms or molecules and which may be transferred from an object at a higher temperature to one at a lower temperature.
الحرارة: هي شكل من الطاقة الحركية والكامنة الموجودة في جسم ما، وتكون مصاحبة لحركة ذراته أو جزيئاته، ويمكن نقلها من جسم أعلى في درجة الحرارة إلى آخر أقل في درجة الحرارة.

Heat of Fusion: The heat required to melt 1 g or 1 kg or 1 lb of a liquid.
حرارة الانصهار: هي الحرارة اللازمة لانصهار 1 غرام أو 1 كيلو غرام أو 1 رطل من السائل.

Heat of Vaporization: The amount of heat required to vaporize 1 g or 1 kg or 1 lb of a liquid.
حرارة التبخر: هي كمية الحرارة اللازمة لتبخير 1 غرام أو 1 كيلو غرام أو 1 رطل من السائل.

Kelvin Scale: The metric absolute temperature scale on which absolute zero is 0 K and the units are the same as on the Celsius scale.
مقياس كلفن: هو مقياس الحرارة المطلق حيث تكون درجة الصفر المطلق هي 0 كلفن والوحدات هي نفسها في المقياس المئوي.

Kilocalorie: The amount of heat necessary to raise the temperature of 1 kg of water 1°C.
الكيلو كالوري: هي كمية الحرارة اللازمة لرفع درجة حرارة 1 كيلو غرام من الماء 1 درجة مئوية.

Mechanical Equivalent of Heat: The relationship between heat and mechanical work.
التكافؤ الميكانيكي للحرارة: هو العلاقة بين الحرارة والشغل الميكانيكي.

Melting: The change of phase from solid to liquid. Also called *fusion*.
الذوبان: هو عملية تحول المادة من الحالة الصلبة إلى السائلة. ويُطلق عليها أيضاً *الانصهار*.

Method of Mixtures: When two substances at different temperatures are mixed together, heat flows from the warmer body to the cooler body until they reach the same temperature. Part of the heat lost by the warmer body is transferred to the cooler body and to surrounding objects. If the two substances are well insulated from surrounding objects, the heat lost by the warmer body is equal to the heat gained by the cooler body.
طريقة المزج: عند مزج مادتين بدرجتي حرارة مختلفتين، تتدفق الحرارة من الجسم الأكثر سخونة إلى الجسم الأبرد حتى يصبحا بنفس درجة الحرارة. ينتقل جزء من الحرارة المفقودة من الجسم الأسخن إلى الجسم الأبرد وإلى الأجسام المحيطة. في حالة العزل الجيد للمادتين عن الأجسام المحيطة، فإن الحرارة المفقودة من الجسم الأسخن تساوي الحرارة التي يكتسبها الجسم الأبرد.

Specific Heat: The amount of heat necessary to change the temperature of 1 kg of a substance by 1°C in the metric system or 1 lb of a substance by 1°F in the U.S. system.
الحرارة النوعية: هي كمية الحرارة اللازمة لتغيير درجة حرارة 1 كيلو غرام من المادة 1 درجة مئوية في النظام المتري أو 1 رطل من المادة 1 درجة فهرنهايت في النظام الأمريكي.

Temperature: A measure of the hotness or coldness of an object.
درجة الحرارة: هي مقياس لمدى سخونة أو برودة جسم ما.

Thermal Conductivity: The ability of a material to transfer heat by conduction.
الموصلية الحرارية: هي قدرة المادة على نقل الحرارة بالتوصيل.

Vaporization: The change of phase from liquid to a gas or vapor.
التبخر: هو عملية تحول المادة من الحالة السائلة إلى غاز أو بخار.

Volatility: A measure of a liquid's ability to vaporize. The more volatile the liquid, the greater is its rate of evaporation.
قابلية التطاير: هو مقياس قدرة السائل على التبخر. كلما زادت قابلية تطاير السائل، زاد معدل تبخره.

4 Electricity

شابتر ٤

The major goals of this chapter are to enable you to:

1. Describe the nature of electric charges.
2. Distinguish conduction and induction.
3. Use Coulomb's law to find the force between charges.
4. Describe the characteristics of electricity.
5. Use Ohm's law to solve electric flow problems.
6. Use electrical symbols to describe circuits.
7. Find current, voltage, and resistance in simple circuits.
8. Describe the nature of cells and batteries.
9. Analyze circuits with cells in series and parallel.
10. Find electric power.

Keywords:

Electric charge; Electricity; electric force; potential; electric field Conduction; Electrical circuits; Electrical power

Summary of Terms

Electricity: General term for electrical phenomena, much like gravity has to do with gravitational phenomena, or sociology with social phenomena.
الكهرباء: مُصطلح عام لظواهر كهربائية، تشبه إلى حد بعيد الجاذبية والتي لها ظواهر جاذبة للأشياء، أو علم الاجتماع وارتباطه بالظواهر الاجتماعية.

Electrostatics: The study of electric charges at rest (not *in motion*, as in electric currents).
الشحنات الكهربائية: هي علم دراسة الشحنة الكهربائية في وضع السكون(وليس في وضع الحركة, كما هو في التيارات الكهربائية).

Coulomb's law: The relationship between electrical force, charge, and distance:

$$F = k\frac{q_1q_2}{d^2}$$

If the charges are alike in sign, the force is repulsive; if the charges are unlike, the force is attractive.
قانون كولوم: يعطي العلاقة بين القوة الكهربائية، ومقدار هذه الشحنة الكهربائية والمسافة بينهما:

$$F = k\frac{q_1q_2}{d^2}$$

فإذا كانت هذه الشحنات الكهربائية متماثلة في الإشارة، تكون القوة متنافرة؛ أما إذا كانت الشحنات غير متماثلة، تكون القوة جاذبة.

Coulomb: The SI unit of electrical charge. One coulomb (symbol C) is equal to the total charge of 6.25×10^{18} electrons.
الكولوم: هو نظام الوحدات الدولي للشحنة الكهربائية. حيث إن وحدة كولوم واحدة (الرمز C) تساوي إجمالي شحنة تبلغ 6.25×10^{18} إلكترون.

Conductor: Any material having free charged particles that easily flow through it when an electric force acts on them.
مُوَصِّل: أي مادة تحمل جُسيمات طليقة مشحونة تتدفق بسهولة عبرها عندما تعمل عليها قوة كهربائية.

Electric potential energy: The energy a charged object possesses by virtue of its location in an electric field.
طاقة الجهد الكهربائي: هي الطاقة التي يمتلكها جسم مشحون بمقتضى موقعه في مجال كهربائي.

شابتر ٤

Electric potential: The electric potential energy per unit of charge, measured in volts, and often called *voltage*:

$$\text{Voltage} = \frac{\text{electric potential energy}}{\text{charge}}$$

الجهد الكهربائي: طاقة الجهد الكهربائي لكل وحدة شحنة، ويتم قياسه بالفولت، وغالبًا ما يُطلق عليها بالفولطية:

$$\text{الفولطية} = \frac{\text{electric potential energy}}{\text{charge}}$$

Capacitor: An electrical device—in its simplest form, a pair of parallel conducting plates separated by a small distance—that stores electric charge and energy.

مُكثّف: جهاز كهربائي— في أبسط أشكاله، زوج من الألواح الموصلة المتوازية يفصلهما مسافة صغيرة—يُخزّن الشحنة الكهربائية والطاقة.

Potential difference: The difference in electric potential between two points, measured in volts. When two points of different electric potential are connected by a conductor, charge flows so long as a potential difference exists.
(Synonymous with *voltage difference*.)

فرق الجهد (الكهربائي): الفرق في الجهد الكهربائي بين نقطتين، يتم قياسهما بالفولت. فعند توصيل نقطتين ذاتا جهد كهربائي مختلف عن طريق موصل، تتدفق الشحنة طالما يوجد جهد كهربائي.
(وهو مرادف فرق الفولطية (الجهدا الكهربائي).)

Electric current: The flow of electric charge that transports energy from one place to another. Measured in amperes, where 1 A is the flow of 6.25×10^{18} electrons per second, or 1 coulomb per second.

تيار كهربائي: عملية تدفق الشحنة الكهربائية التي تنقل الطاقة من مكان لآخر. ويتم قياسه بالأمبير، حيث إن 1 أمبير يعني تدفق 6.25×10^{18} إلكترون في الثانية، أو 1 كولوم في الثانية.

Electrical resistance: The property of a material that resists electric current. Measured in ohms (Ω).

مقاومة كهربائية: هي خاصية لمادة تقاوم التيار الكهربائي. ويتم قياسها بوحدة الأوم (Ω).

Ohm's law: The statement that the current in a circuit varies in direct proportion to the potential difference or voltage across the circuit and inversely with the circuit's resistance.

$$\text{Current} = \frac{\textit{voltage}}{\textit{resistance}}$$

A potential difference of 1 V across a resistance of 1 Ω produces a current of 1 A.

قانون أوم: هو المبدأ الأساسي القائل بأن التيار في دائرة يتغير تناسبًا طرديًا مع الجهد الكهربائي أو الفولطية عبر الدائرة وعكسيًا مع مقاومة الدائرة.

$$\text{التيار} = \frac{\textit{voltage}}{\textit{resistance}}$$

جهد كهربائي يبلغ 1 فولت يمر عبر مقاومة تبلغ 1Ω ينتج تيار يبلغ 1 أمبير.

Electric power: The rate of energy transfer, or the rate of doing work; the amount of energy per unit time, which electrically can be measured by the product of current and voltage.

Power = current × voltage

Electric power is measured in watts (or kilowatts), where
$1 W = 1 A \times 1 V = 1 J/s.$

القدرة الكهربائية: هو معدل نقل الطاقة، أو معدل بذل شغل؛ مقدار الطاقة لكل وحدة من الزمن، والتي يمكن قياسها كهربائيًا من خلال التيار أو الفولطية.

القدرة = التيار × الفولطية

يتم قياس القدرة الكهربائية بالواط (أو الكيلو واط)، حيث
$1 W = 1 A \times 1 V = 1 J/s.$

Series circuit: An electric circuit in which electrical devices are connected along a single wire such that the same electric current exists in all of them.

دائرة مُسلسلة (كهربائية): دائرة كهربائيةيتم توصيل الأجهزة الكهربائية بها عبر سلك مفرد بحيث يكون هناك نفس التيار الكهربائي في جميع هذه الأجهزة.

Parallel circuit: An electric circuit in which electrical devices are connected in such a way that the same voltage acts across each one, and any single one completes the circuit independently of all the others.

دائرة متوازية: دائرة كهربائية يتم توصيل الأجهزة الكهربائية بها بطريقة بحيث تعمل نفس الفولطية عبر كل منها، وأي جهاز واحد يكمل الدائرة بصورة مُستقلة عن جميع الأجهزة الأخرى.

Electric Charges

To understand **electricity**, we need to know more about the structure of matter. Recall some important facts about atoms:

1. Every atom is composed of a positively charged *nucleus* surrounded by negatively charged electrons.
2. The electrons of all atoms are identical. Each has the same quantity of negative charge and the same mass.

5 Light and Optics

شابتر ٥

The major goals of this chapter are to enable you to:

1. Describe the nature of light.
2. Solve problems involving the speed of light.
3. Describe the laws of reflection.
4. Locate and describe images formed by plane, convex, and concave mirrors.
5. Apply the mirror formula to image formation.
6. Describe the law of refraction.
7. Describe total internal reflection.
8. Locate and describe images formed by converging and diverging lenses.
9. Describe how the colors of the visible spectrum are formed through dispersion of light.
10. Describe color as a property of light and how it is related to its frequency or its wavelength.

Keywords:

Aberration; Color; Concave Mirror; Converging Lens; Convex Mirror; Critical Angle; Diffusion; Dispersion; Diverging Lens; Electromagnetic Wave; First Law of Reflection; Focal Length; Frequency; Index of Refraction; Law of Refraction; Light; Light-Year; Optical Density- Plane Mirror; Rainbow; Real Image; Reflection; Refraction; Regular Reflection; Second Law of Reflection; Snell's Law; Speed of Light; Total Internal Reflection; Transparent; Virtual Image; Visible Spectrum; Wavelength

Summary of Terms

Aberration: Distortion in an image produced by a lens, which to some degree is present in all optical systems

الزيغ عبارة عن تشوه: في صورة تنتجها عدسة والتي تكون إلى حد ما موجودة في جميع النظم البصرية.

Color: A property of the light that reaches our eyes and is determined by its wavelength or its frequency.

اللون: هو إحدى خصائص الضوء الذي تراه العين ويتم تحديدها بواسطة طول الموجة والتردد الخاصين بها.

Concave Mirror: A mirror with a surface that curves away from an observer.

المرآة المقعرة: هي مرآة ينحني أو يتقوس سطحها بعيداً عن المشاهد.

Converging Lens: A lens that bends the light passing through it to some point beyond the lens. Converging lenses are thicker in the center.

العدسة المجمعة: هي عدسة تكسر الضوء الذي يمر عبرها إلى نقطة ما بعد العدسة. العدسة المجمعة أسمك عند المركز.

Convex Mirror: A mirror with a surface that curves inward toward an observer.

المرآة المحدبة: هي مرآة ينحني أو يتقوس سطحها للداخل نحو المشاهد.

Critical Angle: The smallest angle of incidence at which all light striking a surface is totally internally reflected.

الزاوية الحرجة: هي أصغر زاوية سقوط يتم عندها الانعكاس الداخلي التام لكل الضوء الساقط على السطح.

Diffusion: Scattering of light by an uneven surface.

الانتشار: هو تشتت الضوء نتيجة سطح غير منتظم.

Dispersion: The spreading of white light into the full spectrum.

التشتت: هو انتشار الضوء الأبيض إلى الطيف الكامل.

Diverging Lens: A lens that bends the light passing through it so as to spread the light. Diverging lenses are thicker at the edges than at the center.

العدسة المفرقة: هي عدسة تكسر الضوء الذي يمر عبرها، وبهذا فإنها تعمل على تفريق الضوء. العدسة المفرقة أسمك عند الحواف مقارنة بالمركز.

شابتر ٥

Electromagnetic Wave: A wave consisting of two perpendicular transverse waves with one component of the wave being a vibrating electric field and the other component being a corresponding vibrating magnetic field; the electromagnetic wave moves in a direction perpendicular to both electric and magnetic field components.

الموجات الكهرومغناطيسية: هي موجة تتكون من نوعين من الأمواج المستعرضة المتعامدة، حيث أن المكون الأول للموجة هو مجال كهربائي متذبذب، أما المكون الثاني فهو مجال مغناطيسي متذبذب متوافق. تتحرك الموجة الكهرومغناطيسية باتجاه متعامد على مكونات المجالين الكهربائي والمغناطيسي.

First Law of Reflection: The angle of incidence equals the angle of reflection.

القانون الأول للانعكاس: ينص على أن زاوية السقوط تساوي زاوية الانعكاس.

Focal Length: The distance between the principal focus of a mirror or lens and its vertex.

البعد البؤري: هو المسافة بين البؤرة الرئيسية للمرآة أو العدسة ومركزها البصري.

Frequency: The number of complete vibrations or cycles per second of a wave.

التردد: هو عدد الاهتزازات أو الدورات الكاملة في كل ثانية من الموجة.

Index of Refraction: A measure of the optical density of a material. Equal to the ratio of the speed of light in a vacuum to the speed of light in the material.

معامل الانكسار: هو مقياس الكثافة البصرية لمادة ما. يعادل النسبة بين سرعة الضوء في الفراغ وسرعته في المادة.

Law of Refraction: When a beam of light passes at an angle from a medium of lower optical density to a denser medium, the light is bent toward the normal. When a beam passes from a medium of greater optical density to one less dense, the light is bent away from the normal.

قانون الانكسار: عندما يمر شعاع ضوئي بزاوية عبر وسط أقل كثافة بصرية (شفاف) إلى وسط أكبر كثافة، يغير الشعاع مساره نحو المتعامد. عندما يمر شعاع من وسط أكبر كثافة بصرية إلى آخر أقل كثافة، ينكسر الضوء بعيداً عن المتعامد.

Light: Radiant energy that can be seen by the human eye.

الضوء: هو الطاقة الإشعاعية التي يمكن رؤيتها بالعين البشرية.

Light-Year: The distance that light travels in one earth year: 9.45×10^{15} m.

السنة الضوئية: هي المسافة التي يقطعها الضوء في سنة أرضية واحدة: 9.45×10^{15} م.

Optical Density: A property of a transparent material that is a measure of the speed of light through the given material.

الكثافة البصرية: هي إحدى خصائص المادة الشفافة، وهي مقياس سرعة الضوء عبر مادة معينة.

Plane Mirror: A mirror with a flat surface.

المرآة المستوية: هي مرآة ذات سطح مستو.

Rainbow: A spectrum of light formed when sunlight strikes raindrops, refracts into them, reflects within them, and then refracts out of them.

قوس قزح: هو طيف من الضوء ناتج عن انكسار وتحلل ضوء أشعة الشمس عند سقوطه على قطرات المطر.

Real Image: An image formed by rays of light.

الصورة الحقيقية: هي الصورة التي تتكون من تجمع أشعة الضوء.

Reflection: The turning or turning back of all or part of a beam of light as it strikes a surface.

الانعكاس: هو انعطاف أو ارتداد كل أو جزء من شعاع الضوء عند سقوطه على سطح ما.

Refraction: The bending of light as it passes at an angle from one medium to another of different optical density.

الانكسار: هو انكسار الضوء أثناء مروره بزاوية من وسط إلى آخر مختلفين في الكثافة البصرية.

Regular Reflection: Reflection of light with very little scattering.

الانعكاس المنتظم: هو انعكاس الضوء مع نسبة تشتت قليلة جداً.

Second Law of Reflection: The incident ray, the reflected ray, and the normal (perpendicular) to the reflecting surface all lie in the same plane.

القانون الثاني للانعكاس: ينص على أن الشعاع الساقط والشعاع المنعكس والعمود المقام على السطح العاكس من نقطة السقوط يحتويهم مستوى واحد عمودي على السطح العاكس.

Snell's Law: The index of refraction equals the sine of the angle of incidence divided by the sine of the angle of refraction.

قانون سنل: ينص على أن معامل الانكسار يساوي جيب زاوية السقوط مقسم على جيب زاوية الانعكاس.

Speed of Light: The speed at which light and other forms of electromagnetic radiation travel. Equal to 3.00×10^{8} m/s in a vacuum.

سرعة الضوء: هي السرعة التي ينتقل عندها الضوء والأشكال الأخرى من الإشعاع الكهرومغناطيسي. تساوي 3.00×10^{8} م/ث في الفراغ.

Total Internal Reflection: A condition such that light striking a surface does not pass through the surface but is completely reflected inside it.

الانعكاس الداخلي الكلي: هو الحالة التي يسقط فيها ضوء على سطح ما ولا ينفذ عبره ولكن ينعكس تماماً داخله.

Transparent: Allowing almost all light to pass through so that objects or images can be seen clearly.

شفاف: هو السماح لكل الضوء تقريباً بالمرور بحيث يمكن رؤية الأجسام أو الصور بوضوح.

Virtual Image: An image that only appears to the eye to be formed by rays of light.

الصورة التقديرية: هي صورة تظهر للعين كأنها تشكلت بفعل أشعة الضوء.

Visible Spectrum: The colors resulting from the dispersion of white light through a glass prism: red, orange, yellow, green, blue, and violet.

الطيف المرئي: هو ألوان ناتجة عن تشتت الضوء الأبيض عبر منشور زجاجي: الأحمر والبرتقالي والأصفر والأخضر والأزرق والبنفسجي.

Wavelength: The distance between two successive corresponding points on a wave.

طول الموجة: هو المسافة التي تفصل بين نقطتين متتاليتين على موجة ما.

6 Modern Physics

شابتر ٦

The major goals of this chapter are to enable you to:

1. Describe the development of the current model of the atom.
2. Describe the structure and properties of the atomic nucleus.
3. Analyze problems of radioactive decay.
4. Describe nuclear fission and fusion.
5. Describe principles of detection and measurement of radioactivity.

Keywords:

Ionizing Radiation; Non-ionizing radiation; Strong force; Nucleon; Radioactive Decay; Alpha particle (helium nuclei); Beta rays (electrons or positron); Radioactive Isotopes; Radioactive half-life; Gray (Gy) and Sievert (Sv); Rad and Rem; Carbon Dating; Radioactive Tracers; Environmental radioactivity; Food irradiation; Radiation Safety; Nuclear medicine; Radiology

Summary of Terms

Ionizing Radiation: It is energy in the form of waves or moving particles that emitted by an atom when it changes from a higher energy state to a lower energy state.

الإشعاع المؤين: هو طاقة في شكل موجات أو جزيئات متحركة تُطلقها ذرات معينة عندما تتغير من حالة طاقة أعلى إلى حالة طاقة أقل.

Non-ionizing radiation: Changes occur in bound electronic states of the atom.

الإشعاع غير المؤين: هو طاقة محدودة تكفي للتحرك حول الذرات داخل الجزيئات أو تسبب لهم اهتزازاً وتذبذباً.

Strong force: Is attractive nuclear force that bound nucleons together.

قوة التماسك القوي: هي قوة التماسك النووي التي تربط النيوكليونات معاً.

Nucleon: Is proton and/or neutron.

النيوكليون: هو بروتون و/أو نيترون.

Radioactive Decay: The atoms of radioactive elements emit three distinct types of radiation called *alpha particles*, *beta particles*, and *gamma rays*.

الاضمحلال الإشعاعي: هو ذرات العناصر الإشعاعية الصادرة عن ثلاثة أنواع مميزة من الإشعاع تسمى جزيئات ألفا وجزيئات بيتا وأشعة جاما.

Alpha particle (helium nuclei): Ejected by certain radioactive elements.

جسيمات ألفا (نوى الهيليوم): تصدر عن عناصر إشعاعية معينة.

Beta rays (electrons or positron): Emitted during decay of radioactive nuclide.

أشعة بيتا (إلكترون أو بوزترون): تصدر أثناء انحلال النويدة الإشعاعية.

Gamma rays: High-energy electromagnetic radiation.

أشعة جاما: إشعاع كهرومغناطيسي عالي الطاقة.

Radioactive Isotopes: Isotopes of an element are chemically identical but differ in the number of neutrons.

النظير المشع: هو نظائر أحد العناصر المتشابهة كيميائياً ولكن تختلف في عدد النيترونات.

Gray (Gy) and Sievert (Sv): SI units of radiation absorbed dose and equivalent (effective dose).

غراي (Gy) وسيفرت (Sv): هي وحدات النظام الدولي لجرعة الإشعاع الممتص والمكافئ (الجرعة المؤثرة).

Rad and Rem: Other units of radiation absorbed dose and equivalent (effective dose).

راد ورم: هي وحدات أخرى لجرعة الإشعاع الممتص والمكافئ (الجرعة المؤثرة).

Radioactive half-life: Radioactive half-life of a radioactive material is the time needed for half of the radioactive atoms to decay.

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شابتر ٦

عمر النصف الإشعاعي: عمر النصف الإشعاعي لمادة إشعاعية هو الوقت اللازم لانحلال نصف الذرات الإشعاعية.

Carbon Dating: Scientist can find how long ago a plant or animal died by measuring the ratio of carbon-14 to carbon-12 in the remains.

التأريخ بالكربون: يستطيع العلماء بموجبه معرفة الفترة التي مات فيها نبات أو حيوان عن طريق قياس نسبة الكربون 14 إلى الكربون 12 في البقايا.

Radioactive Tracers: Scientists can analyze biological or mechanical processes using small amounts of radioactive isotopes as tracers.

مقتفي الأثر الإشعاعي: يمكن للعلماء تحليل العمليات البيولوجية أو الميكانيكية باستخدام كميات صغيرة من النظائر الإشعاعية كعناصر اقتفاء.

Environmental radioactivity: Is produced by the decay of unstable nuclides that is found in the environment. Example of radioactive isotopes present due to natural processes is radon (^{222}Rn), uranium-238 (^{238}U), thorium-232 (^{232}Th) and potassium-40 (^{40}K).

النشاط الإشعاعي البيئي: ينتج عن طريق انحلال النويدات غير المستقرة الموجودة في البيئة. مثال على النظائر الإشعاعية الموجودة بسبب العمليات الطبيعية هو الرادون (^{222}Rn)، واليورانيوم 238 (^{238}U) والثوريوم 232 (^{232}Th) والبوتاسيوم 40 (^{40}K).

Food irradiation: A process intended to preserve food for longer time and/or improve its quality.

تشعيع الغذاء: هو عملية الغرض منها حفظ الطعام لفترة أطول و/أو تحسين جودته.

Radiation Safety: Protective measure and actions to avoid/minimize the risk from radiation. Whenever possible, exposure to radiation should be avoided.

الأمان الإشعاعي: هو ضوابط وإجراءات وقائية لتجنب/ التقليل من خطر الإشعاع. يجب عدم التعرض للإشعاع قدر الإمكان.

Nuclear medicine: Is the use of radioactive sources in medical diagnosis or treatment.

الطب النووي: هو استخدام المصادر الإشعاعية لغرض التشخيص أو العلاج الطبي.

Radiology: Use of x-ray in medicine.

طب الأشعة: هو استخدام الأشعة السينية في الطب.