Unit A Chemical Change

Chapter 1: Aqueous Solutions

Practice, page 8

1. **a.** Protons are found in the nucleus and have a positive charge. They determine the identity of the atom—the number of protons equals the atomic number.

   b. Neutrons are found in the nucleus and have no charge—they are neutral. Neutrons add mass to the atom. The sum of the number of neutrons and the number of protons is the mass number.

   c. Electrons are found outside the nucleus in a region much larger than the nucleus itself. Electrons have a negative charge and play a significant role in chemical bonding.

2. **a.**

$$\begin{aligned}\text{mass number} &= \text{number of protons} + \text{number of neutrons}\\ &= 6 + 6\\ &= 12\end{aligned}$$

   The mass number is 12.

   b. This atom is carbon. Only carbon has 6 protons, which corresponds to its atomic number.

   c. This atom is neutral because it has 6 protons (positive charges) and 6 electrons (negative charges) that neutralize one another.

3. **a.**

$$\begin{aligned}\text{mass number} &= \text{number of protons} + \text{number of neutrons}\\ \text{number of protons} &= \text{mass number} - \text{number of neutrons}\\ &= 35 - 18\\ &= 17\end{aligned}$$

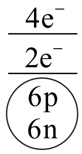
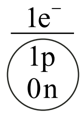
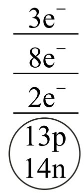
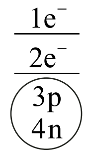
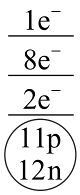
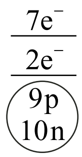
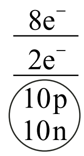
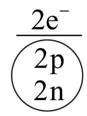
   This atom has 17 protons.

   b. This atom is chlorine because only chlorine has an atomic number of 17.

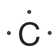
   c. This atom has a charge of 1– and is properly referred to as an ion. (You will study ions in more detail later in this lesson.) There is one more negative charge than there are positive charges, making the overall charge 1–.

4. Atoms have distinct properties that influence the properties of the matter they make up, much like the ingredients used in cooking all have distinct tastes or functions. Atomic properties are determined by the arrangement of the protons, neutrons, and electrons in the atoms.

Practice, page 9

5. a. 
b. 
c. 
d. 
e. 
f. 
g. 
h. 

Practice, page 10

6. a. 
b. 
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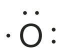
Practice, page 13

7. a.  An oxygen atom needs to gain two electrons.

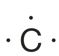
b.  A fluorine atom needs to gain one electron.

c.  A phosphorous atom needs to gain three electrons.

d.  A potassium atom needs to lose one electron.

e.  A calcium atom needs to lose two electrons.

f.  A lithium atom needs to lose one electron.

g.  A carbon atom needs to lose or gain four electrons, or it could share four electrons since it is a non-metallic element.

h.  A hydrogen atom needs to gain or lose one electron. It could also share one electron since it is a non-metallic element. Hydrogen has metallic properties as well.

i.  Neon will not gain, lose, or share electrons because it has a completely filled outer energy level.

8. The charge of each ion shown on the periodic table is consistent with the descriptions given in the answers to question 7. It appears that the process of gaining or losing electrons to obtain a full outer energy level results in the negative and positive charges associated with each ion.

1.1 Questions, page 14

Knowledge

1. **a.** An atom is the smallest part of an element that has all the properties of that element.

b. A proton is a positively charged, subatomic particle located in the nucleus of an atom. It has a mass of one atomic mass unit.

c. A neutron is a subatomic particle with no charge located in the nucleus of an atom. It has a mass of one atomic mass unit.

d. An electron is a negatively charged, subatomic particle located outside the nucleus of an atom. It has a mass much less than one atomic mass unit.

e. An element is a pure substance that cannot be broken down into simpler substances by chemical means.

f. The mass number is the total number of protons and neutrons in an atom.

g. The atomic number is the number of protons in the nucleus of an atom.

h. An energy level is a specific region surrounding the nucleus that is available for electrons. An energy level may contain electrons or it may be empty.

i. A Lewis dot diagram is a representation of an atom that shows only the valence (outermost) electrons of the atom.

j. A valence electron is an electron in the outermost energy level. Valence electrons are involved in chemical bonding.

k. An ion is a charged atom or group of atoms. Ions have an unequal number of protons and electrons.

l. An anion is a negatively charged ion.

m. A cation is a positively charged ion.

2.

Element	Atomic Number	Atomic Mass (g/mol)	Electron Configuration
chlorine, Cl	17	35.45	17 electrons spread over three energy levels (2,8,7) with 7 valence electrons
oxygen, O	8	16.00	8 electrons spread over two energy levels (2,6) with 6 valence electrons

3. A sodium atom is electrically neutral with eleven protons balancing eleven electrons. When a sodium atom loses one electron, it becomes a sodium ion with one less electron than it has protons. As a result, a sodium ion has a charge of 1+.

4. An oxygen atom has six valence electrons and, therefore, has the ability to accept two electrons to complete its outer energy level. When an oxygen atom accepts two electrons to become an oxide ion, the number of electrons is two greater than the number of protons, resulting in a charge of $2-$.

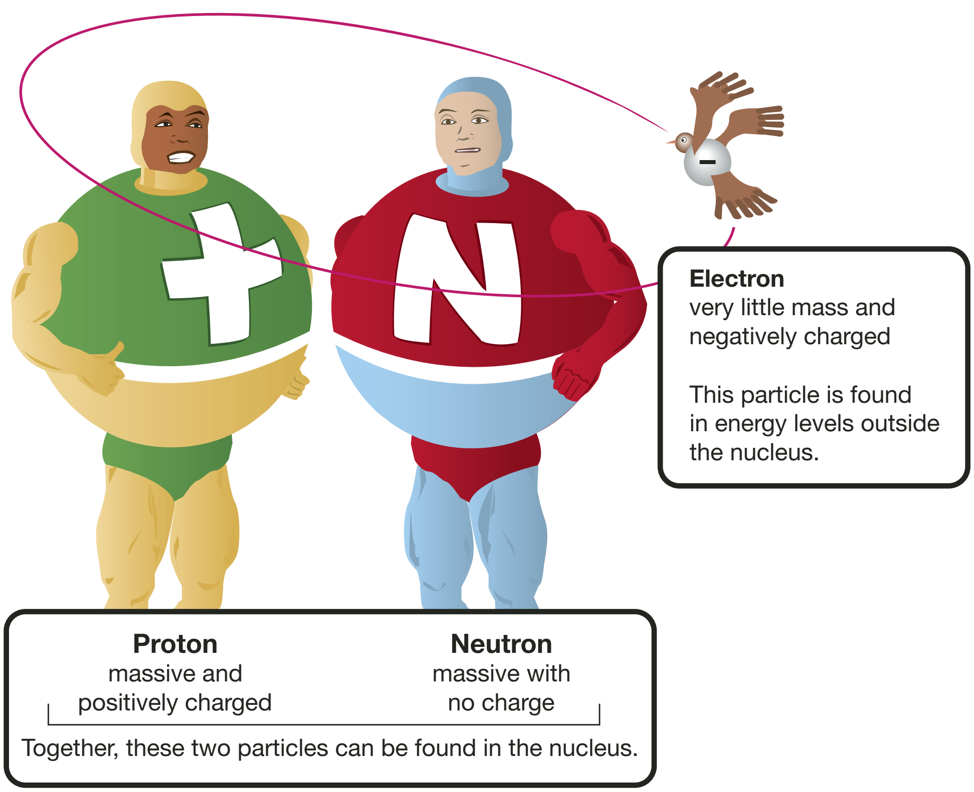
5. A magnesium atom has two valence electrons. Since metallic atoms tend to lose electrons, a magnesium atom will lose two electrons. This results in the magnesium ion having a charge of $2+$ because it has two less electrons than protons.

6. **ANIONS AND CATIONS**

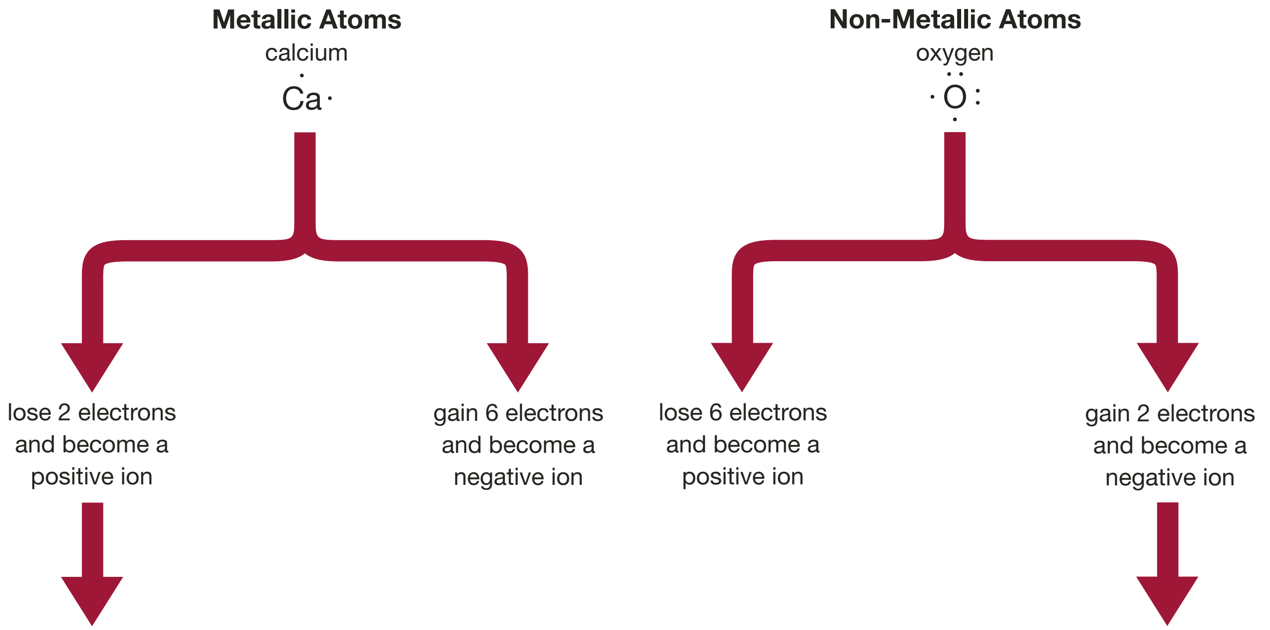
Similarities	Differences
• Both ions have unequal numbers of protons and electrons.	• Anions have a negative charge; cations have a positive charge. • Anions tend to be formed from non-metallic atoms; cations tend to be formed from metallic atoms.

Applying Concepts

7. In this cartoon of particles that comprise an atom, the proton and neutron are imagined to be like a team of superheroes. The electron is represented by a small circling bird.



8. The following is an example using calcium (a metallic atom) and oxygen (a non-metallic atom). It shows the processes involved in obtaining a full outer energy level.



It is easier to lose 2 electrons than it is to gain 6.

Trend: Metals have so few valence electrons that it is easier to lose few than to gain many.

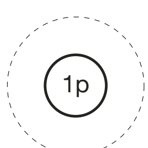
It is easier to gain 2 electrons than it is to lose 6.

Trend: Non-metals have so many valence electrons that it is easier to gain few than to lose many.

9. a. 

b. Chlorine is a very reactive element because it contains seven outer electrons. This means that chlorine is only one electron away from obtaining a complete outer shell of eight electrons. A chlorine atom aggressively seeks that other electron through a chemical reaction with another atom.

c. Chlorine is able to kill bacteria and viruses by bonding with and destroying the outer surfaces of these substances. Similar harmful reactions are possible with the outer surfaces of cells of the human body. So, it makes sense to carefully add the chlorine to the pool water through a pipe, from a special room, away from the swimmers.

10. a. 

b. A hydrogen atom consists of a single proton and an orbiting electron. When the electron is removed to create a hydrogen ion, all that is left is the nucleus containing the proton and an empty energy level. A substance that increases the concentration of hydrogen ions is therefore effectively adding protons to the solution.

Practice, page 17

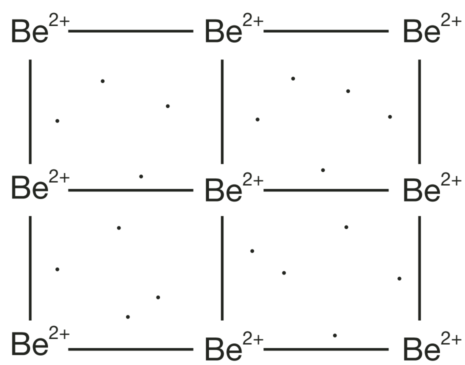
9. a. step 1: Draw the Lewis dot diagram of the atom.

$$\dot{\mathrm{Be}}\cdot$$

step 2: Determine how the atom can fill its outer energy level. A beryllium atom can obtain a full outer energy level by losing two electrons.

$$\dot{\mathrm{Be}}\cdot \longrightarrow \mathrm{Be}^{2+} + 2e^-$$

step 3: Make a bond with beryllium ions.

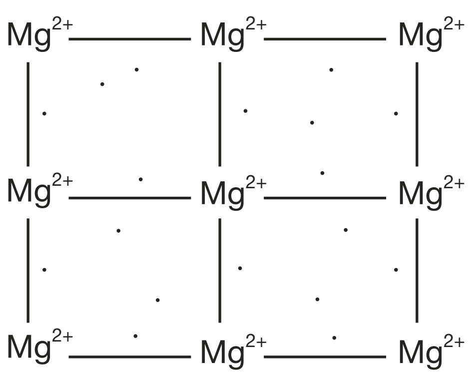


The beryllium ions remain together due to their mutual attraction of the free-moving electrons.

b. step 1: $\dot{\mathrm{Mg}}\cdot$

step 2: $\dot{\mathrm{Mg}}\cdot \longrightarrow \mathrm{Mg}^{2+} + 2e^-$

step 3:



The magnesium ions remain together due to their mutual attraction of the free-moving electrons.

Practice, page 18

10. a. step 1: Draw the Lewis dot diagram of each atom.

step 2: Determine how each atom can obtain a full outer energy level.

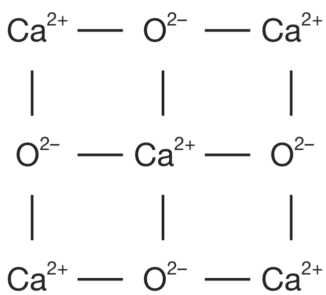
A calcium atom can obtain a full outer energy level by losing two electrons.

$$\dot{C}a\cdot \longrightarrow Ca^{2+} + 2e^{-}$$

An oxygen atom can obtain a full outer energy level by gaining two electrons.

$$\cdot\ddot{O}: + 2e^{-} \longrightarrow O^{2-}$$

step 3: Make a bond with positive and negative ions.

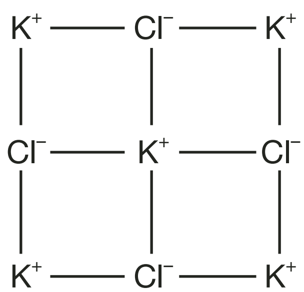


b. step 1:

step 2: $\dot{K} \longrightarrow K^{+} + 1e^{-}$

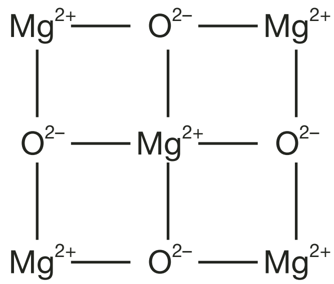
$$\cdot\ddot{Cl}: + 1e^{-} \longrightarrow Cl^{-}$$

step 3:

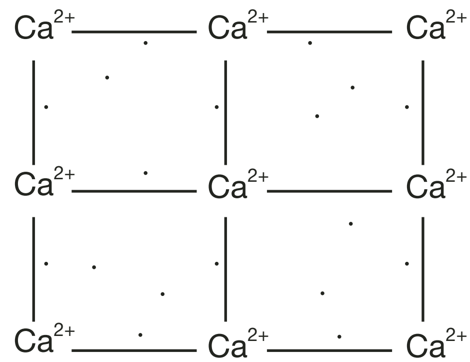


Practice, page 21

11. **a.** Magnesium oxide is an ionic crystal that forms ionic bonds.



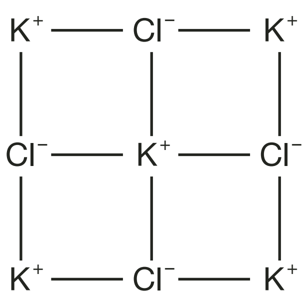
b. A sample of calcium is characterized by metallic bonds.



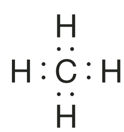
c. A water molecule contains covalent bonds.

Practice, page 23

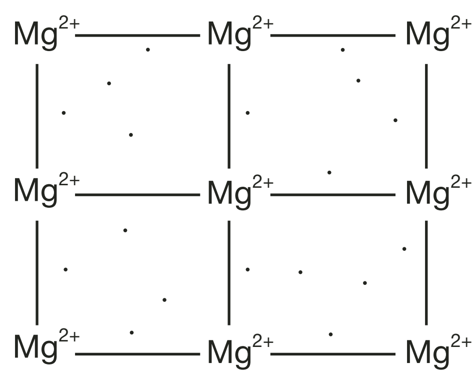
12. **a.** **Potassium Chloride**



Methane



Magnesium Metal



b. Covalent bonds involve the simultaneous sharing of electrons by two atoms. As a result, electrons in the system are held tightly by the atoms and are not free to move. Therefore, molecular compounds are not able to conduct an electric current. Since they are poor conductors, they make good insulators.

c. The movement of the ions within the ionic crystal forces similarly charged ions toward each other. The tendency of similarly charged particles is to repel. If further forces occur, the strength of the bonds within the crystal are reduced and the crystal can break.

d. Metals are good conductors of heat. This is due to the ability of the free electrons to move; thus, they can absorb thermal energy, which increases their motion. By moving throughout the metal crystal, they transfer some of their energy.

e. In this case, heat excites some of the electrons in the metal, enabling them to transfer to atoms of oxygen in the air surrounding the metal. The metal ions (cations) become immediately attracted to the anions of oxygen, producing the black coating.

1.2 Questions, page 23

Knowledge

1. **a.** A compound is a pure substance formed from the chemical bonding of atoms of two or more elements joined in fixed ratios.

b. Metals are a group of elements that are malleable, ductile, and lustrous. They are good conductors of electricity and heat. Metals tend to form positive ions when involved in chemical reactions.

c. An ionic compound is a pure substance formed from the chemical bonding of a metal and a non-metal.

d. An ionic bond is the simultaneous attraction between positive and negative ions, holding them together in solid crystals.

e. A covalent bond is the simultaneous attraction of two nuclei for a shared pair of electrons.

f. A molecule is a particle containing a fixed number of covalently bonded, non-metal atoms.

g. A molecular compound is a pure substance formed from the covalent bonding of non-metals.

2. **a.** A chlorine atom has a neutral charge. A chloride ion is a chlorine atom with one extra valence electron, resulting in a charge of 1−.

b. A sodium ion is a sodium atom with one less valence electron, resulting in a charge of 1+. A chloride ion is a chlorine atom with one extra valence electron, resulting in a charge of 1−.

c. An ionic bond involves a simultaneous attraction between two oppositely charged ions. A covalent bond involves the simultaneous attraction of two nuclei for a shared pair of electrons.

d. An ionic compound is formed by the mutual attraction between the ions of metals and the ions of non-metals. A molecular compound is formed by covalent bonds between non-metallic elements.

Applying Concepts

3. Using sketches allows you to better visualize electrons and other charged particles that influence the properties discussed.

4. Metals tend to have one, two, or three valence electrons. Metals tend to have a weaker attraction for valence electrons and, therefore, tend to lose electrons and form positively charged ions.

Non-metals tend to have five, six, or seven valence electrons. Non-metals tend to have a stronger attraction for valence electrons and, therefore, tend to gain electrons and form negatively charged ions.

5. Three metallic properties that result from the “free” electrons moving around the positive ions are

- excellent conduction of heat and electricity
- lustre or shiny appearance
- ductility and the ability of metals to bend

Practice, page 25

13. **ALCHEMY AND MODERN INDUSTRY**

Similarities	Differences
The goal of alchemists was to turn non-precious metals into gold. Similarly, modern industry's goals are broader in that it turns raw materials into finished products. Both groups are involved in developing methods to change matter.	Modern industry uses theoretical and practical evidence; alchemists used practical evidence, but their theoretical evidence did not include any knowledge about atoms or atomic structure.

14. Find a natural source containing the atoms you want for your material. These atoms most likely will be bonded in a way that is different from what you want. Break the current bonds between the atoms in the natural source to separate them. Then create new bonds with the atoms required to form your product.

15. The atoms you wish to use in the finished product may not be available in a pure or unbonded form. In order to use them, the bonds to other atoms must first be broken.

Practice, page 27

16. **a.** A solution is a homogeneous mixture of dissolved substances that contains a solute and a solvent. An example of a solution is maple syrup.

    b. A solute is the substance that dissolves in the solvent. Interactions between solvent and solute particles break bonds or associations between the particles of the solute. Sugar is one of the solutes in maple syrup.

    c. A solvent is a substance in the solution that breaks down bonds or associations between particles of the solute; it is the substance that does the dissolving and is in greater proportion in the mixture. Water is the solvent in maple syrup.

17. Solutions look as though they are only one substance because particles of the solute and solvent mix uniformly. Solute particles are surrounded by solvent particles or go into spaces in between solvent particles.

18. Both melting and dissolving involve the separation of particles of a solid. When melting, no solvent is present and the resulting substance is not a solution.

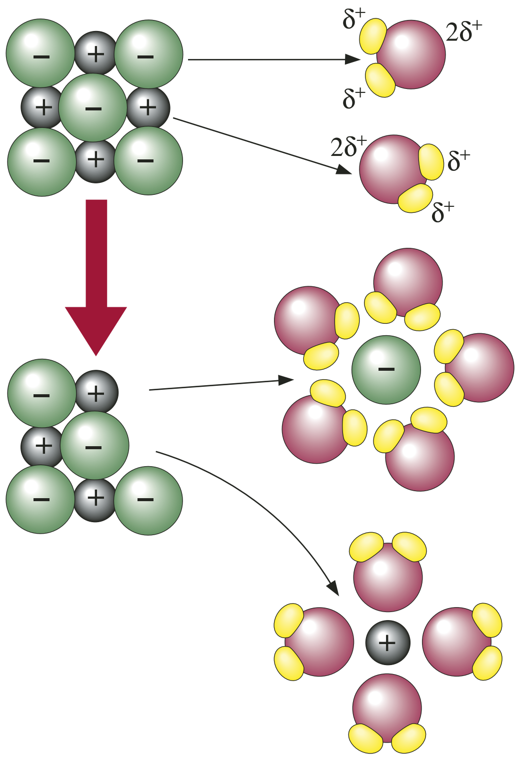
19. Water is an excellent medium for chemical change because it is able to dissolve many substances, breaking the bonds or associations between particles. Once these bonds or associations have been broken, particles are better able to form new combinations with other particles, in other words, undergo a chemical reaction.

20. The solvent was water, and the solutes were cobalt(II) nitrate and sodium carbonate.

Practice, page 30

21. The charged parts of water molecules can be attracted to other charged particles in the system. When enough water particles associate with a charged particle, the attractions between the particle and the water becomes stronger than the attraction to other particles in the solid crystal.

22.



23. The non-polar molecules in oil-based paints do not associate with polar water molecules and, therefore, do not dissolve.

Practice, page 31

24. **a.** This is an ionic compound having ions $K^{+}(aq)$ and $Br^{-}(aq)$. If this compound was added to water, it would be classified as an electrolyte.

b. This is an ionic compound having ions $Ag^{+}(aq)$ and $NO_3^{-}(aq)$. If this compound was added to water, it would be classified as an electrolyte.

c. This is an ionic compound having ions $Li^{+}(aq)$ and $PO_4^{3-}(aq)$. If this compound was added to water, it would be classified as an electrolyte.

d. This is a molecular compound and, therefore, does not form ions. If this compound was added to water, it would be classified as a non-electrolyte.

e. This is an ionic compound having ions $Al^{3+}(aq)$ and $SO_4^{2-}(aq)$. If this compound was added to water, it would be classified as an electrolyte.

f. This is an ionic compound having ions $Na^{+}(aq)$ and $S^{2-}(aq)$. If this compound was added to water, it would be classified as an electrolyte.

1.3 Questions, page 33

Knowledge

1. **a.** Solubility refers to the ability of a solute to dissolve in a solvent.
   b. Dissolving is the process of particles of a solute becoming distributed between the particles of a solvent.
   c. An aqueous solution is a solution in which water is the solvent.
   d. Dissociation is the separation of an ionic compound into individual ions in a solution.
   e. An electrolyte is a solute in a solution that conducts electricity.
   f. A non-electrolyte is a solute in a solution that does not conduct electricity.

2. When a solute dissolves in water, it forms associations with water molecules. These associations usually occur because of attractions between charges on both the water particles and on the particles of the solute.

3. Ionic compounds dissociate into individual ions when they dissolve. Molecules remain intact and do not dissociate when they dissolve.

Applying Concepts

4. Aqueous solutions can be used in foods (such as apple juice), in cleaning supplies, and in medicines (such as cough syrup).

5. Medication administered in a solid pill must first dissolve before the medicinal compounds can pass into the bloodstream. Medication administered intravenously is already in solution form.

6. Pure water is very rare to find. Because so many substances, namely ionic compounds, can dissolve in water, most of the water you encounter is an aqueous solution containing ions and, therefore, is an electrolyte. It follows that such a solution would conduct electricity and could become a hazard if a person was exposed to an electric current.

   Another consideration is that skin is not a good conductor of electricity when it is dry; but the conductivity of skin improves significantly when it becomes wet. Since many of the substances naturally found on the surface of the skin are electrolytes, skin becomes a much better conductor of electricity when it comes in contact with water.

Practice, page 35

25. Shipping costs are drastically reduced by transporting a concentrated form of the soft drink.

26. **a.** Since the dry, granular powder is the substance being dissolved by water to form a solution, the powder is considered to be the solute.

    b. $m_{\text{powder}} = 0.500$ kg and $V_{\text{solution}} = 189$ L

    Since the density of water is 1 kg/L, $m_{\text{solution}} = 189$ kg.

$$\begin{aligned}\text{shipping costs increase} &= \frac{m_{\text{solution}}}{m_{\text{powder}}}\\ &= \frac{189\ \cancel{\text{kg}}}{0.500\ \cancel{\text{kg}}}\\ &= 378\end{aligned}$$

    Shipping costs would approximately increase by a factor of 378.

c. Disadvantages of selling a dry powder where the gardener has to do the mixing include the following:

- The gardener has to be able to read the label and follow the instructions to obtain the proper concentration. If the concentration is too weak, the plants will not get the required nutrients. If the concentration is too strong, the plants can be harmed (chemically burned) by the highly concentrated solution.

- The dry powder likely contains chemicals that are poisonous and possibly explosive. This powder has to be stored properly in child-proof containers and in conditions that would not promote dangerous chemical reactions with other materials.

- The dry powder may be a greater hazard to the health of the gardener if proper procedures are not followed during the mixing process. Just as you follow proper procedures in the lab by using gloves, safety glasses, and a lab apron, the gardener would need to take the same precautions. If the dry powder is dusty, the additional precaution of a proper dust mask would be necessary to prevent the gardener from inhaling the concentrated chemicals in the dust.

Practice, page 38

27 . a. The pail with the solution that has a more intense blue colour is the one with the greater concentration. This means that even though the gardeners were attempting to create identical solutions, at least one error was made in preparing the solutions. Since solutions that are too dilute deny plants the nutrients they need and solutions that are too concentrated may harm plants, the gardeners should return to the instructions on the bag and locate the source of the error(s).

b. A coloured solution dispensed by a hose is useful because it reminds the gardener and others that the hose is dispensing fertilizer and not water. If the gardener was called away, and someone else started to use the hose thinking that it was water, the solution could be accidentally used to water animals, wash a vehicle, or fill a wading pool for small children. Fertilizers contain compounds that may be hazardous if not handled properly.

1.4 Questions, page 39

Knowledge

1. a. Concentration is the ratio of the quantity of solute to the quantity of solution.

b. A concentrated solution is a solution containing a high ratio of solute to solution.

c. A dilute solution is a solution containing a low ratio of solute to solution.

d. The qualitative properties of a solution are the basic attributes of a solution that can be observed with one or more of the five senses.

e. The collision-reaction theory states that chemical reactions occur due to the collision and rearrangement of particles.

2. Concentrated solutions demonstrate greater colour intensity, higher conductivity, and other physical characteristics compared to dilute solutions.

3. At higher concentrations, more reactant particles are present in the solution. An increased number of particles increases the probability of collisions occurring between reactant particles. With a greater number of collisions, there is a greater probability of forming new bonds and product(s).

Applying Concepts

4. Water will dilute the poison in the stomach and intestinal tract, hopefully decreasing the effect of the poison on cells or decreasing the speed of its absorption into the bloodstream.

5. Dilute solutions are often used in food products, such as vinegar and dilute juices for young children. Concentrated solutions are often used in household cleaning products and in industrial processes, such as bleaching wood pulp to make white paper.

6. Concentrated solutions often react more quickly and for greater periods of time than dilute solutions. This increases the potential hazard to the user and requires him or her to pay greater attention to proper safety procedures.

7. Concentrated solutions are often shipped for economic reasons to reduce the amount of solution that needs to be moved. They are then diluted to the required concentration once they reach their destination. The first step is appropriate warnings and information. Rail cars that transport concentrated substances contain labels on the outside of the car to serve as a notice of the contents. Secondly, trained individuals are used to load and unload these cars as well as deal with spills that might occur in the event of a derailment or collision. Trains transporting hazardous materials, which may include some concentrated solutions, may only be able to travel along certain routes and, thus, are forced to bypass cities or only travel at certain times of the day.

Practice, page 42

28. $V_{\text{solute}} = 30\text{ mL}$

$V_{\text{solution}} = 70\text{ mL}$

$(\%\ V/V) = ?$

$$\begin{aligned}(\%\ V/V) &= \frac{V_{\text{solute}}}{V_{\text{solution}}} \times 100\% \\ &= \frac{30\text{ mL}}{70\text{ mL}} \times 100\% \\ &= 43\%\end{aligned}$$

The percent by volume concentration of the antiseptic is 43%.

29. $(\%\ V/V) = 60\%$

$V_{\text{solution}} = 200\text{ mL}$

$V_{\text{solute}} = ?$

$$\begin{aligned}(\%\ V/V) &= \frac{V_{\text{solute}}}{V_{\text{solution}}} \times 100\% \\ V_{\text{solute}} &= \frac{(\%\ V/V)}{100\%} \times V_{\text{solution}} \\ &= \frac{60\%}{100\%} \times 200\text{ mL} \\ &= 120\text{ mL} \\ &= 1.2 \times 10^2\text{ mL}\end{aligned}$$

The volume of rubbing alcohol present is 1.2×10^2 mL.

30. $(\% \; V/V) = 25\%$

$V_{\text{solution}} = 250 \text{ mL}$

$V_{\text{solute}} = ?$

$$(\% \; V/V) = \frac{V_{\text{solute}}}{V_{\text{solution}}} \times 100\%$$

$$V_{\text{solute}} = \frac{(\% \; V/V)}{100\%} \times V_{\text{solution}}$$

$$= \frac{25\%}{100\%} \times 250 \text{ mL}$$

$$= 63 \text{ mL}$$

You purchased 63 mL of DEET.

Practice, page 44

31. **a.** $m_{\text{solute}} = 8.30 \times 10^{-3} \text{ g}$

$m_{\text{solution}} = 250 \text{ g}$

parts per million = ?

$$\text{parts per million} = \frac{m_{\text{solute}}}{m_{\text{solution}}} \times 10^6 \text{ ppm}$$

$$= \frac{8.30 \times 10^{-3} \text{ g}}{250 \text{ g}} \times 10^6 \text{ ppm}$$

$$= 33.2 \text{ ppm}$$

The concentration of the lead in the water is 33.2 ppm.

b. No, this water is not safe to drink because it exceeds the maximum allowable concentration of 0.010 ppm for lead in drinking water.

32. parts per million = 2.00 ppm

$m_{\text{solution}} = 227 \text{ g}$

$m_{\text{solute}} = ?$

$$\text{parts per million} = \frac{m_{\text{solute}}}{m_{\text{solution}}} \times 10^6 \text{ ppm}$$

$$m_{\text{solute}} = \frac{\text{parts per million}}{10^6 \text{ ppm}} \times m_{\text{solution}}$$

$$= \frac{2.00 \; \cancel{\text{ppm}}}{10^6 \; \cancel{\text{ppm}}} \times 227 \text{ g}$$

$$= 4.54 \times 10^{-4} \text{ g}$$

The mass of the PCBs in the fish is 4.54×10^{-4} g.

33. parts per million = 50.0 ppm

$m_{\text{solution}} = 250 \text{ g}$

$m_{\text{solute}} = ?$

$$\text{parts per million} = \frac{m_{\text{solute}}}{m_{\text{solution}}} \times 10^6 \text{ ppm}$$

$$m_{\text{solute}} = \frac{\text{parts per million}}{10^6 \text{ ppm}} \times m_{\text{solution}}$$

$$= \frac{50.0 \; \cancel{\text{ppm}}}{10^6 \; \cancel{\text{ppm}}} \times 250 \text{ g}$$

$$= 0.0125 \text{ g or } 1.25 \times 10^{-2} \text{ g}$$

You would ingest 1.25×10^{-2} g of arsenic.

Practice, page 46

34. **a.** $n = 0.435 \text{ mol}$

$$V = 200 \text{ mL} \times \frac{1 \text{ L}}{1000 \text{ mL}} = 0.200 \text{ L}$$

$C = ?$

$$C = \frac{n}{V} = \frac{0.435 \text{ mol}}{0.200 \text{ L}} = 2.18 \text{ mol/L}$$

The molar concentration of the sodium chloride solution is 2.18 mol/L.

b. $n = 0.674 \text{ mol}$

$$V = 800 \text{ mL} \times \frac{1 \text{ L}}{1000 \text{ mL}} = 0.800 \text{ L}$$

$C = ?$

$$C = \frac{n}{V} = \frac{0.674 \text{ mol}}{0.800 \text{ L}} = 0.843 \text{ mol/L}$$

The molar concentration of the sodium hydroxide solution is 0.843 mol/L.

35. **a.** $m = 30.0 \text{ g}$

$$M = 1(M \text{ of Na}) + 1(M \text{ of Cl}) = 22.99 \text{ g/mol} + 35.45 \text{ g/mol} = 58.44 \text{ g/mol}$$

$n = ?$

$$n = \frac{m}{M} = \frac{30.0 \text{ g}}{58.44 \text{ g/mol}} = 0.513\ 347\ 022\ 6 \text{ mol} = 0.513 \text{ mol}$$

There are 0.513 mol in 30.0 g of NaCl(s).

b. $n = 0.513\ 347\ 022\ 6 \text{ mol}$

$$V = 800 \text{ mL} \times \frac{1 \text{ L}}{1000 \text{ mL}} = 0.800 \text{ L}$$

$C = ?$

$$C = \frac{n}{V} = \frac{0.513\ 347\ 022\ 6 \text{ mol}}{0.800 \text{ L}} = 0.642 \text{ mol/L}$$

The molar concentration of the salt solution is 0.642 mol/L. **Note:** The unrounded value for the number of moles from the answer to question 35.a. was used here to get a more accurate calculation of molar concentration.

36. $m = 5.00 \text{ g}$, $V = 300 \text{ mL}$, $C = ?$

First, determine the number of moles of solute.

$m = 5.00 \text{ g}$

$$M = 1(M \text{ of Na}) + 1(M \text{ of O}) + 1(M \text{ of H}) = 22.99 \text{ g/mol} + 16.00 \text{ g/mol} + 1.01 \text{ g/mol} = 40.00 \text{ g/mol}$$

$n = ?$

$$n = \frac{m}{M} = \frac{5.00 \text{ g}}{40.00 \text{ g/mol}} = 0.125 \text{ mol}$$

The sample contains 0.125 mol of sodium hydroxide.

Next, determine the molar concentration.

$$n = 0.125 \text{ mol}$$
$$V = 300 \text{ mL} \times \frac{1 \text{ L}}{1000 \text{ mL}} = 0.300 \text{ L}$$
$$C = ?$$

$$C = \frac{n}{V} = \frac{0.125 \text{ mol}}{0.300 \text{ L}} = 0.417 \text{ mol/L}$$

The molar concentration of the NaOH solution is 0.417 mol/L.

Practice, pages 50 and 51

37. **a.** $V_f = 360 \text{ mL} + 640 \text{ mL} = 1000 \text{ mL}$

The total volume of the solution in the battery is 1000 mL.

b. $C_i = 17.8$ mol/L

$V_i = 360$ mL

$V_f = 1000$ mL

$C_f = ?$

$$C_iV_i = C_fV_f$$
$$C_f = \frac{C_iV_i}{V_f} = \frac{(17.8 \text{ mol/L})(360 \text{ mL})}{1000 \text{ mL}} = 6.41 \text{ mol/L}$$

The molar concentration of the solution in the battery is 6.41 mol/L.

c. $V_{solute} = 360$ mL

$V_{solution} = 1000$ mL

$(\% \ V/V) = ?$

$$(\% \ V/V) = \frac{V_{solute}}{V_{solution}} \times 100\% = \frac{360 \text{ mL}}{1000 \text{ mL}} \times 100\% = 36.0\%$$

The percent by volume concentration of the battery is 36.0%.

d. The scientists who are working on a new design for a battery would likely use molar concentration, since they would be keeping detailed records of the chemical reaction within the battery. A consumer reading a brochure would likely be more comfortable with the percent by volume concentration, since this is used on labels for other consumer products.

38. **a.** $V_f = 275$ L

$C_f = 4.25$ mol/L

$C_i = 17.8$ mol/L

$V_i = ?$

$$C_iV_i = C_fV_f$$
$$V_i = \frac{C_fV_f}{C_i} = \frac{(4.25 \text{ mol/L})(275 \text{ L})}{17.8 \text{ mol/L}} = 65.660\,112\,36 \text{ L} = 65.7 \text{ L}$$

The technician must measure 65.7 L of concentrated sulfuric acid.

b. The amount of water to be added can be determined by subtracting the volume of concentrated sulfuric acid from the final volume.

$$\begin{aligned} V_{\text{water}} &= V_{\text{f}} - V_{\text{i}} \\ &= 275\ \text{L} - 65.660\,112\,36\ \text{L} \\ &= 209\ \text{L} \end{aligned}$$

The technician needs to combine 209 L of water with the concentrated sulfuric acid.

39. **a.** $V_{\text{i}} = 2.50\ \text{L}$

$C_{\text{i}} = 10.0\ \text{mol/L}$

$C_{\text{f}} = 3.75\ \text{mol/L}$

$V_{\text{f}} = ?$

$V_{\text{added}} = ?$

$$\begin{aligned} C_{\text{i}}V_{\text{i}} &= C_{\text{f}}V_{\text{f}} \\ V_{\text{f}} &= \frac{C_{\text{i}}V_{\text{i}}}{C_{\text{f}}} \\ &= \frac{(10.0\ \cancel{\text{mol/L}})(2.50\ \text{L})}{3.75\ \cancel{\text{mol/L}}} \\ &= 6.6\overline{6}\ \text{L} \end{aligned}$$

To determine the volume of water to be added, subtract the initial volume from the final volume.

$$\begin{aligned} V_{\text{added}} &= V_{\text{f}} - V_{\text{i}} \\ &= 6.6\overline{6}\ \text{L} - 2.50\ \text{L} \\ &= 4.17\ \text{L} \end{aligned}$$

The technician must add 4.17 L of water to the concentrated solution.

b. $V_{\text{i}} = 655\ \text{mL}$

$C_{\text{i}} = 10.0\ \text{mol/L}$

$C_{\text{f}} = 11.0\ \text{mol/L}$

$V_{\text{f}} = ?$

$V_{\text{evaporated}} = ?$

$$\begin{aligned} C_{\text{i}}V_{\text{i}} &= C_{\text{f}}V_{\text{f}} \\ V_{\text{f}} &= \frac{C_{\text{i}}V_{\text{i}}}{C_{\text{f}}} \\ &= \frac{(10.0\ \cancel{\text{mol/L}})(655\ \text{mL})}{11.0\ \cancel{\text{mol/L}}} \\ &= 595.\overline{45}\ \text{mL} \end{aligned}$$

To determine the volume of water that must evaporate, subtract the final volume from the initial volume.

$$\begin{aligned} V_{\text{evaporated}} &= V_{\text{i}} - V_{\text{f}} \\ &= 655\ \text{mL} - 595.\overline{45}\ \text{mL} \\ &= 60\ \text{mL} \end{aligned}$$

The amount of water that must evaporate is 60 mL.

1.5 Questions, page 52

Knowledge

1. **a.** A mole is a specific amount of a substance that consists of 6.022×10^{23} particles.

   b. Molar concentration, or molarity, is the amount of solute, in moles, per litre of a solution.

   c. A conversion factor is a fraction used to convert one set of units into another.

   d. Molar mass is the mass of 1 mol of a substance.

   e. Parts per million concentration is a method of communicating very dilute concentrations, particularly those in the field of health and safety standards.

   f. Percent by volume concentration is a method of communicating the concentration involving a liquid solute completely dissolved into a total volume of solution. This method is often used to communicate concentration on consumer goods.

   g. A standard solution is a solution of a known concentration, prepared by dissolving a measured amount of solute into a specific volume of solvent.

   h. A volumetric flask is a device used to accurately measure a defined volume of liquid in the preparation of a standard solution.

   i. A pipette is a device used to measure a defined amount of a solution to be transferred to another container.

2. The concentration of a solution can affect its physical and chemical properties, including the intensity of colour and the speed of reactions it may be involved in.

3. Different methods are used in different situations to accurately convey information about the concentration of the solution. Most consumers are comfortable with a percentage; so, percent by volume is appropriate for consumer goods. Health and safety standards that relate to things like the concentration of toxins in drinking water usually involve very minute quantities. So, parts per million is appropriate in these applications. Technologists and scientists work with balanced chemical equations in instances when it is important to know the amounts of the substances reacting and the amount of the product produced. Molar concentration is the best method in these cases.

4. **a.** The concentration of a solution decreases as the amount of solvent increases because there are the same number of moles of solute in more volume of solution.

   b. The volume or amount of solution increases as more solvent is added.

   c. The number of moles in the solution remains unchanged. Adding more solvent only provides a greater volume to dissolve the particles of solute.

5. A solution with a known concentration is important in many situations. Given that many products purchased or used are solutions, differences in concentration can affect the performance of these products. Many chemical reactions depend on accurate concentrations in order for the reaction to completely convert all the reactants into the product.

Applying Concepts

6. a. Determine the number of moles of $KMnO_4$(s).

$$m = 7.00\text{ g}$$
$$\begin{aligned} M &= 1(M\text{ of K}) + 1(M\text{ of Mn}) + 4(M\text{ of O}) \\ &= (39.10\text{ g/mol}) + (54.94\text{ g/mol}) + 4(16.00\text{ g/mol}) \\ &= 158.04\text{ g/mol} \end{aligned}$$
$$n = ?$$

$$\begin{aligned} n &= \frac{m}{M} \\ &= \frac{7.00\text{ g}}{158.04\text{ g/mol}} \\ &= 0.044\ 292\ 584\ 2\text{ mol} \end{aligned}$$

Next, determine molar concentration.

$$n = 0.044\ 292\ 584\ 2\text{ mol}$$
$$\begin{aligned} V &= 30.0\ \cancel{\text{mL}} \times \frac{1\text{ L}}{1000\ \cancel{\text{mL}}} \\ &= 0.0300\text{ L} \end{aligned}$$
$$C = ?$$

$$\begin{aligned} C &= \frac{n}{V} \\ &= \frac{0.044\ 292\ 584\ 2\text{ mol}}{0.0300\text{ L}} \\ &= 1.476\ 419\ 472 \\ &= 1.48\text{ mol/L} \end{aligned}$$

The concentration of the solution is 1.48 mol/L.

b. $m_{\text{solute}} = 7.00\text{ g}$

$m_{\text{solvent}} = 30.0\text{ g}$

parts per million = ?

$$\begin{aligned} \text{parts per million} &= \frac{m_{\text{solute}}}{m_{\text{solvent}}} \times 10^6\text{ ppm} \\ &= \frac{7.00\ \cancel{\text{g}}}{30.0\ \cancel{\text{g}}} \times 10^6\text{ ppm} \\ &= 2.33 \times 10^5\text{ ppm} \end{aligned}$$

The resulting concentration is 2.33×10^5 ppm. This is not an appropriate way to communicate this concentration because parts per million is designed to describe very dilute concentrations.

c. $C_i = 1.476\ 419\ 472\text{ mol/L}$

$V_i = 30.0\text{ mL}$

$$\begin{aligned} V_f &= 30.0\text{ mL} + 250\text{ mL} \\ &= 280\text{ mL} \end{aligned}$$

$C_f = ?$

$$\begin{aligned} C_i V_i &= C_f V_f \\ C_f &= \frac{C_i V_i}{V_f} \\ &= \frac{(1.476\ 419\ 472\text{ mol/L})(30\ \cancel{\text{mL}})}{280\ \cancel{\text{mL}}} \\ &= 0.158\text{ mol/L} \end{aligned}$$

The final concentration is 0.158 mol/L.

d. $m_{\text{solute}} = 7.00\text{ g}$

$m_{\text{solvent}} = 4.00 \times 10^6\text{ g}$

parts per million = ?

$$\begin{aligned} \text{parts per million} &= \frac{m_{\text{solute}}}{m_{\text{solvent}}} \times 10^6\text{ ppm} \\ &= \frac{7.00\ \cancel{\text{g}}}{4.00 \times 10^6\ \cancel{\text{g}}} \times 10^6\text{ ppm} \\ &= 1.75\text{ ppm} \end{aligned}$$

The resulting concentration in the reservoir is 1.75 ppm. Yes, this is an appropriate way to describe this concentration because the solution is very dilute.

7. **a.**

$C_i = 5.00$ mol/L

$V_f = 2.00$ L

$C_f = 0.400$ mol/L

$V_i = ?$

$$C_iV_i = C_fV_f$$

$$V_i = \frac{C_fV_f}{C_i} = \frac{(0.400\ \cancel{\text{mol/L}})(2.00\ \text{L})}{5.00\ \cancel{\text{mol/L}}} = 0.160\ \text{L}$$

The technician needs 0.160 L of the disinfectant solution.

b.

$V_{solute} = 20.0$ mL

$V_{solution} = 20.0\ \text{mL} + 150\ \text{mL} = 170\ \text{mL}$

$(\%\ V/V) = ?$

$$(\%\ V/V) = \frac{V_{solute}}{V_{solution}} \times 100\% = \frac{20.0\ \cancel{\text{mL}}}{170\ \cancel{\text{mL}}} \times 100\% = 11.8\%$$

The percent by volume concentration is 11.8%.

c.

$V_i = 50.0$ mL

$C_i = 5.00$ mol/L

$V_f = 40.0$ mL

$C_f = ?$

$$C_iV_i = C_fV_f$$

$$C_f = \frac{C_iV_i}{V_f} = \frac{(5.00\ \text{mol/L})(50.0\ \cancel{\text{mL}})}{40.0\ \cancel{\text{mL}}} = 6.25\ \text{mol/L}$$

The new molar concentration of the solution is 6.25 mol/L.

8. Flowcharts will vary. A sample answer is given.

Making a Standard Solution of Copper(II) Sulfate

Calculate the number of moles of solute needed.

↓

Calculate the mass of solute needed.

↓

Use an analytical balance to measure the mass of solute.

↓

Add the solute to a beaker, and dissolve it with as little water as possible.

↓

Carefully transfer the contents of the beaker to a volumetric flask.

↓

Rinse the beaker, and add the rinse water to the volumetric flask.

↓

Add water to the volumetric flask until the meniscus is just below the mark on the flask.

↓

Carefully add water with an eyedropper or pipette until the bottom of the meniscus is aligned with the mark on the flask.

9. The photo of the bottled water shows the concentration of the fluoride ion in parts per million because there is only a trace amount of this substance. The photo of the volumetric flask uses moles per litre because this is the unit preferred by scientists and technicians to make standard solutions with volumetric glassware.

The photo of the sun block lists the concentration of the ingredients as percentages because this method communicates relatively large concentrations in a format that is easily understood by consumers.