Name ______________________ Class ______ Date ______

15 Water and Aqueous Systems

Big idea BONDING AND INTERACTIONS

15.1 Water and Its Properties

For students using the Foundation edition, assign problems 1–7, 9, 11, 12.

Essential Understanding The bonding between water molecules differs when water is in different states, giving it different properties.

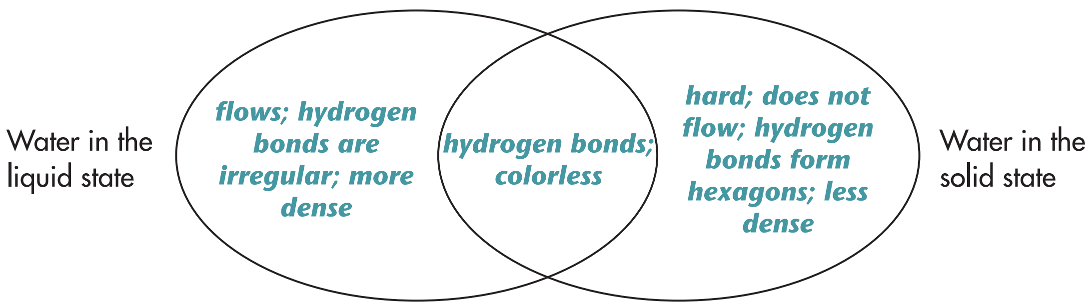
Reading Strategy

Compare and Contrast Organizing information in a table helps you compare and contrast several topics at one time. Compare water in the liquid state to water in the solid state. As you read, ask yourself, "How are they similar? How are they different?"

As you read Lesson 15.1, use the compare and contrast table below.

Attributes of water	Water in the liquid state	Water in the solid state
Physical properties	***liquid; flows; colorless***	***hard; does not flow; colorless***
How atoms bond	***hydrogen bonds are irregular***	***hydrogen bonds in hexagons***
Relative density	***more dense***	***less dense***

EXTENSION Make a Venn diagram of the information in the compare and contrast table.



Lesson Summary

Water in the Liquid State The polarity of water molecules causes its high surface temperature, low vapor pressure, and high boiling point.

- The O—H bonds in a water molecule are polar because oxygen is more electronegative than hydrogen.
- Hydrogen bonding between water molecules occurs because a hydrogen atom is weakly bonded to an unshared electron pair of another water molecule's oxygen atom.

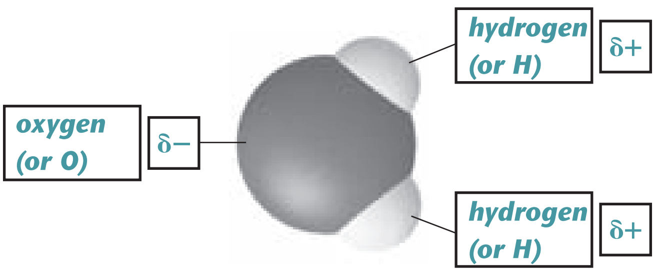
Water in the Solid State Hydrogen bonding gives ice unique properties.

- Hydrogen bonds hold water molecules in place in the solid phase, so ice is less dense than water.
- Because ice is less dense than liquid water, ice floats on liquid water.

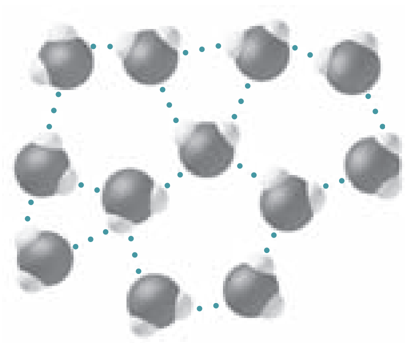
After reading Lesson 15.1, answer the following questions.

Water in the Liquid State

1. What unique substance is essential to all life on Earth? ***water***
2. Approximately what fraction of Earth's surface is covered in water? $\frac{3}{4}$
3. Circle the letter next to each sentence that is true concerning water molecules.
   a. Each O—H covalent bond in a water molecule is nonpolar.
   b. In a water molecule, the less electronegative hydrogen atoms acquire a partial positive charge and the oxygen atom acquires a partial negative charge.
   c. Because the water molecule has an H—O—H bond angle of 105°, the molecule as a whole is polar.
4. The diagram below depicts a water molecule. Complete the labels showing the locations of the hydrogen atoms, the oxygen atom, and the regions of positive and negative charge.



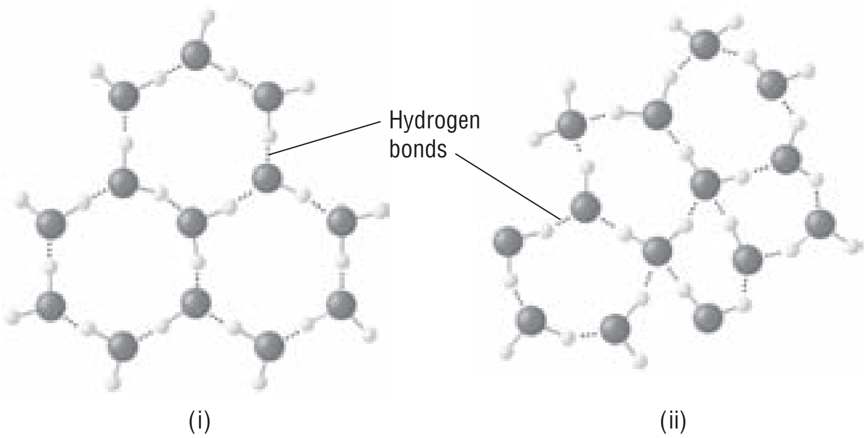
5. The diagram below depicts a collection of water molecules. Draw dotted lines showing where hydrogen bonding occurs.



6. Circle the letter next to each sentence that describes a result of the surface tension of water.
   a. In a full glass of water, the water surface seems to bulge over the rim of the glass.
   b. Water beads up into small, nearly spherical drops on a paper towel.
   c. Water forms nearly spherical drops at the end of an eyedropper.
   d. An insect called a water strider is able to "walk" on water.
7. Using Figure 15.4, explain why a water drop has surface tension.
   Because water molecules at the surface cannot form hydrogen bonds with air molecules, molecules on the surface are drawn into the body of liquid. The inward pull on the molecules is surface tension.
8. Do liquids that have higher surface tension produce drops that are flatter or more nearly spherical than liquids with lower surface tension?
   Liquids with higher surface tension produce drops that are more nearly spherical.
9. What is the name for an agent, such as a detergent, that has the ability to reduce surface tension? ***surfactant***

Water in the Solid State

10. What happens to the density of most substances as they cool and solidify?
    Density usually increases as a substance cools.
11. The diagrams below show hydrogen bonding between water molecules.



   a. Which diagram depicts ice? ***(i)***
   b. Which diagram depicts liquid water? ***(ii)***
   c. Why is ice less dense than liquid water? Refer to the diagrams to help you explain.
      Ice molecules are arranged in an open, rigid framework, as shown in diagram (i). When ice melts, the framework collapses, as shown in diagram (ii), and the molecules pack closer together.

Name ______________________ Class ______ Date ______

12. Look at Table 15.1. To four significant figures, list the density of

   a. liquid water at 4°C ***1.000 g/cm³***

   b. liquid water at 0°C ***0.9998 g/cm³***

   c. ice at 0°C ***0.9168 g/cm³***

13. What is unusual about the data in Question 12? Will ice float on liquid water?

The density of liquid water decreases from 4°C to 0°C, and ice at 0°C is less dense than liquid water at 0°C. Yes, ice will float on liquid water.

15.2 Homogeneous Aqueous Systems

For students using the Foundation edition, assign problems 1–26.

Essential Understanding Water forms aqueous solutions with other compounds, and usually those compounds are ionic or polar covalent.

Reading Strategy

Combination Notes Combination notes help you to convey ideas in words and pictures at the same time. Write *Solutions* at the top of the T. In the left column, write brief phrases about solutions and the solution process. In the right column, draw pictures that help you visualize these concepts.

As you read Lesson 15.2, use the T-chart below. As you read about solutions and solvation, write notes on the left side of the T and illustrate them with molecular diagrams on the right side.

Solutions

The dissolving medium is the solvent. Dissolved particles are solute.	***diagram showing solvent molecules and ions of the solute***
Solutes dissolve when charged solvent particles pull the ions away from the solid and into solution.	***diagram similar to the bottom half of Figure 15.8***
Ions in solution become surrounded by solvent molecules.	***diagram similar to the solvated ions shown in Figure 15.8***

EXTENSION Complete another T-chart that shows the differences in ionic concentration and movement for nonelectrolytes, weak electrolytes, and strong electrolytes.

Name ______________________________ Class ______ Date ______

Lesson Summary

Solutions A solution consists of a dissolving medium, called a solvent, and dissolved particles, called the solute.

- Ionic and polar covalent compounds form aqueous solutions most easily.
- During the process of solvation, charged ions of an ionic solid are surrounded by solvent molecules.

Electrolytes and Nonelectrolytes A compound is classified as an electrolyte or a nonelectrolyte based on how well it conducts an electric current when it is in solution or melted.

- An electrolyte conducts an electric current when it is dissolved in water or molten. All ionic compounds are electrolytes.
- A nonelectrolyte does not conduct an electric current when it is dissolved in water or molten. Many molecular compounds are nonelectrolytes.
- An electrolyte is a strong electrolyte if many ions exist in solution, and it is a weak electrolyte if it produces some, but not many, ions in solution.

Hydrates A hydrate is a compound that contains water molecules in its crystal structure.

- The water in a hydrate is called water of hydration.
- Water of hydration is not held tightly to the compound, so the water molecules can be easily lost and regained.

BUILD Math Skills

Calculating a Percent of a Hydrate A percent is a way of expressing the proportion you have of something compared to the total amount. The percent equation is

$$\% = \frac{\text{part}}{\text{whole}} \times 100$$

The term *hydrate* is used to describe a molecule or compound that contains water as part of its structure. The hydrate formula is written with the compound or molecule formula first, followed by a dot, then the number of water molecules present for every one unit of the compound. For example, the formula for calcium sulfate trihydrate is $CaSO_4 \cdot 3H_2O$. So, for every mole of calcium sulfate, there are 3 moles of water.

To find the percent of water by mass for any given hydrate, just follow these steps:

- Write out the formula for the hydrate.
- Calculate the mass of water and multiply it by the number of moles indicated in the hydrate formula.
- Calculate the mass of the compound.
- Add the mass of the compound to the mass of the water to get the total mass for the hydrate.
- Use the equation: $\% = \frac{\text{mass of water}}{\text{mass of hydrate}} \times 100\%$ to obtain percent of water by mass for the hydrate.

Name ______________________ Class ______ Date ______

Sample Problem Determine the percent by mass of the hydrate copper sulfate pentahydrate, $CuSO_4 \cdot 5H_2O$.

First, write out the hydrate formula.	$CuSO_4 \cdot 5H_2O$
Calculate the mass of water and multiply it by the number of moles indicated in the hydrate formula.	mass of H: 1.01 g × 2 = 2.02 g mass of O: 16 g mass of water: (2.02 + 16) × 5 = 90.1 g
Calculate the mass of the compound ($CuSO_4$)	mass of Cu: 63.55 g mass of S: 32.07 g mass of O: 16 g × 4 = 64 g mass of compound: 63.55 + 32.07 + 64 = 159.62 g
Add the mass of the compound to the mass of the water to get the total hydrate mass.	total hydrate mass: 90.1 + 159.62 = 249.72 g
Use the equation: $\frac{\text{mass of water}}{\text{mass of hydrate}} \times 100$ to get mass percent of water.	mass % of water: $\frac{90.1\text{ g}}{249.72\text{ g}} \times 100 =$ 0.3608 × 100 = 36.08%

Now it's your turn to practice finding the mass percent of water for a given hydrate. Remember to multiply the mass of water by the number of moles indicated in the hydrate formula.

1. Determine the mass percent of water for magnesium carbonate pentahydrate, $MgCO_3 \cdot 5H_2O$.

   51.66%

2. Determine the mass percent of water for gypsum or calcium sulfate dehydrate, $CaSO_4 \cdot 2H_2O$.

   20.93%

3. Determine the mass percent of water for lithium perchlorate trihydrate, $LiClO_4 \cdot 3H_2O$.

   33.69%

4. Determine the mass percent of water for cobalt (II) chloride hexahydrate, $CoCl_2 \cdot 6H_2O$.

   45.44%

Name ______________________ Class ______ Date ______

After reading Lesson 15.2, answer the following questions.

Solutions

5. Water samples containing dissolved substances are called ***aqueous solutions***.

Match each term to its description by writing its letter on the line next to the description.

c	6. dissolving medium	a. solution
b	7. dissolved particles	b. solute
a	8. homogeneous mixture of particles in a dissolving medium	c. solvent

9. Is the following sentence true or false? After sodium chloride dissolves in a container of water, the sodium chloride will eventually settle to the bottom of the container if the solution remains undisturbed at a constant temperature. ***false***

10. Circle the letter next to each sentence that is true about aqueous solutions.
    - **a.** Solute particles can be either ionic or molecular, and their average diameters are usually less than 1 nanometer.
    - **b.** When a solution is filtered, both solute and solvent will pass through the filter paper.
    - **c.** Ionic compounds and substances containing polar covalent molecules readily dissolve in water.
    - **d.** Nonpolar covalent molecules, such as those found in oil, grease, and gasoline, readily dissolve in water.

11. What happens when a solid crystal of sodium chloride is placed in water?

    Water molecules collide with the crystal and attract its Na^+ and Cl^- ions.

12. What process occurs when solute ions become surrounded by solvent molecules?
    solvation

13. Look at the model of solvation in Figure 15.8. If enough solvent is present, what will eventually happen to the ionic solid depicted at the bottom of the diagram?

    All of the ions will become surrounded by solvent molecules and the ionic solid will disappear into the solution.

14. When a compound cannot be solvated to any significant extent, it is called ***insoluble***.

Name ______________________ Class ______ Date ______

15. Circle the letter next to the one sentence that best explains why the ionic compounds barium sulfate ($BaSO_4$) and calcium carbonate ($CaCO_3$) are nearly insoluble in water.

a. The attractions between the ions in the crystals of these ionic compounds are weaker than the attractions between the ions and water molecules.

b. The attractions between the ions in the crystals of these ionic compounds are stronger than the attractions between the ions and water molecules.

c. There is no difference in the strength of the attractions between the ions in the crystals and the attractions between the ions and water molecules.

d. These ionic compounds are easily dissolved in water.

16. What saying sums up the observation that, as a rule, polar solvents dissolve ionic compounds and polar molecules, but nonpolar solvents dissolve nonpolar compounds?
"like dissolves like"

Electrolytes and Nonelectrolytes

17. What types of compounds can carry an electric current in the molten state or in aqueous solution? ***electrolytes***

18. Is the following sentence true or false? All ionic compounds are electrolytes.
true

19. Compounds that do not conduct an electric current in either aqueous solution or the molten state are called ***nonelectrolytes***.

Look at the light bulbs in Figure 15.10 to answer Questions 20, 21, and 22.

c 20. Which bulb, *a, b,* or *c*, indicates that the solution is nonconductive?

b 21. Which bulb, *a*, *b*, or *c*, indicates that the solution is weakly conductive?

a 22. Which bulb, *a*, *b*, or *c*, indicates that the solution is highly conductive?

Hydrates

23. Water in a crystal that is an integral part of the crystal structure is called ***water of hydration***.

24. A compound that contains water as an integral part of its crystal structure is called ***a hydrate***.

25. What does "$\cdot 5H_2O$" mean when included in a chemical formula?
The compound contains five water molecules per formula unit.

26. Circle the letter next to each sentence that is true about hydrated compounds. Use Figures 15.12 and 15.13 to help you.

a. Crystals of copper sulfate pentahydrate always contain five molecules of water for each copper and sulfate ion pair.

b. Heating blue crystals of copper sulfate pentahydrate above 100°C drives off the water of hydration, leaving a white anhydrous powder.

c. It is possible to regenerate copper sulfate pentahydrate by treating anhydrous copper sulfate with water.

d. Anhydrous cobalt(II) chloride is a good indicator for the presence of water because it changes from pink to blue when exposed to moisture.

27. If a hydrate has a vapor pressure greater than that of the water in the surrounding air, the hydrate will lose water to the air, or ***effloresce***.

28. Hygroscopic substances that remove water from the air are used as drying agents called ***dessicants***.

29. Look at Figure 15.15. What happens to dry sodium hydroxide pellets that are exposed to normally moist air? What kind of compound exhibits this behavior?

The sodium hydroxide pellets remove enough water from the air to dissolve completely and form a solution. Sodium hydroxide is an example of a deliquescent compound.

15.3 Heterogeneous Aqueous Systems

For students using the Foundation edition, assign problems 1–6.

Essential Understanding Particles larger than the particles in a solution form heterogeneous aqueous systems, such as suspensions and colloids.

Lesson Summary

Suspensions The particles in a suspension will eventually settle out if left undisturbed.

- The particles in a suspension can be removed by filtration.

Colloids The particles in a colloid cannot be separated by settling or filteration.

- Milk is an example of a colloid.
- Both the dispersed phase and the dispersion medium in a colloid can be any state of matter.
- Colloids exhibit both the Tyndall effect and Brownian motion.

Name ______________________ Class ______ Date ______

After reading Lesson 15.3, answer the following questions.

Suspensions

1. Is the following sentence true or false? Heterogeneous mixtures are not true solutions. ***true***

2. Heterogeneous mixtures in which particles settle out upon standing are called ***suspensions***.

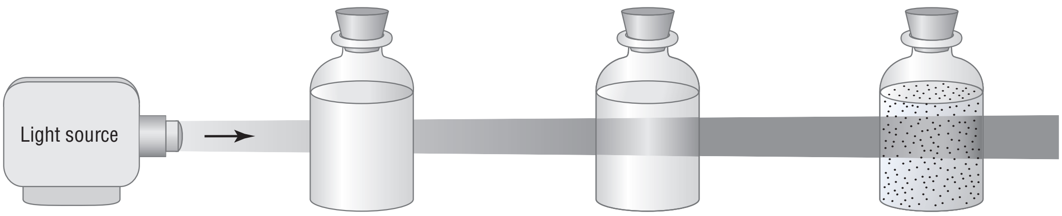
3. Is the following sentence true or false? When a suspension of clay particles in water is filtered, both clay and water will pass through the filter paper. ***false***

Colloids

4. Heterogeneous mixtures in which particles are of intermediate size between those of true solutions and suspensions are called ***colloids***.

5. The scattering of light in all directions by colloidal particles is known as the ***Tyndall effect***.

6. Identify each type of system shown in the figure below.



Solution ***Colloid*** ***Suspension***

Apply the Big idea

A student is examining three different aqueous systems.

a. From what you know about aqueous systems, explain how the student can decide which sample is a solution, which is a suspension, and which is a colloid.
Sample answer: Shine a light through the three systems. Light completely passes through the solution. You can see the beam in a colloid or a suspension. Then let the colloid and the suspension sit for a while. The particles in the suspension will settle out.

b. Sequence *solution, suspension*, and *colloid* according to how much the polarity of water molecules affects the particles in the system. Explain your answer.
The polarity of the water molecule affects smallest particles the most. It would have the greatest effect on particles in a solution and the least effect on particles in a suspension.

Name ______________________ Class ________ Date ________

15 Self-Check Activity

For Questions 1–8, complete each statement by writing the correct word or words. If you need help, you can go online.

15.1 Water and Its Properties

1. Many of the unique properties of water result from the ***hydrogen*** bonding between water molecules.

2. The unique properties of water include its low ***vapor pressure*** and its high surface tension and boiling point.

3. Both liquid water and solid water have hydrogen bonds, but in solid water, they form a(n) ***hexagonal*** arrangement.

15.2 Homogeneous Aqueous Systems

4. ***Ionic*** compounds and polar covalent compounds dissolve most readily in water.

5. Because all ionic compounds form ions, all ionic compounds are ***electrolytes***.

6. The water molecules in ***hydrates*** are easily gained or lost because they are held in place by weak bonds.

15.3 Heterogeneous Aqueous Systems

7. The particles in a(n) ***suspension*** are relatively large and will settle out over time.

8. ***Colloids*** contain particles smaller than those in suspensions but larger than those in solutions.

If You Have Trouble With...								
Question	1	2	3	4	5	6	7	8
See Page	489	490	492	494	496	498	504	505

Name ______________________ Class ______ Date ______

Review Key Equations

From the choices below, write in each box the term that correctly completes the equation.

mass of water   percent by mass H_2O mass of hydrate

$$\boxed{\textit{percent by mass } H_2O} = \frac{\boxed{\textit{mass of water}}}{\boxed{\textit{mass of hydrate}}} \times 100\%$$

EXTENSION **Choose a hydrate from Table 15.2 and find its percent by mass H_2O.**

Review Vocabulary

Answer the following questions.

1. Use the terms *weak electrolyte, electrolyte, nonelectrolyte,* and *strong electrolyte* to complete this diagram.

Greatest number of ions ← No ions

$\underbrace{\textit{strong electrolyte} \quad \textit{weak electrolyte}}_{\textit{electrolyte}}$ *nonelectrolyte*

2. Complete the following paragraph with vocabulary terms from Lesson 15.2.

Sheryl was working with a sample of $MgSO_4 \cdot 7H_2O$ in the lab. She knew the compound was a(n) ***hydrate*** because it contained water molecules in its formula. She placed the compound in a test tube and heated it, driving off the ***water of hydration***. The resulting compound was ***anhydrous***. Because this compound is now ***hygroscopic***, which means it absorbs water from its environment, it could be used as a(n) ***dessicant*** to remove water from other compounds.

3. Sequence the following terms according to the size of the particles they contain, from smallest to largest: *colloid, solution, suspension.*

solution, colloid, suspension