15.3 Heterogeneous Aqueous Systems

Connecting to Your World It wiggles and jiggles. It comes in many colors and flavors. When you pop it in your mouth, it dissolves. It is gelatin, one of the most popular desserts in the United States. In fact, more than a million packages of gelatin are purchased or eaten every day. Gelatin has even traveled into space. In 1996, American astronaut Shannon Lucid shared a gelatin dessert with her Russian crewmates. Gelatin is a heterogeneous mixture called a colloid. In this section, you will learn more about the characteristics of colloids and a related mixture called a suspension.

Guide for Reading

Key Concepts

- What is the difference between a suspension and a solution?
- What distinguishes a colloid from a suspension and a solution?

Vocabulary

suspension
colloid
Tyndall effect
Brownian motion
emulsion

Reading Strategy

Previewing Before you read, rewrite the headings of this section as questions. As you read, write answers to your questions.

Suspensions

So far in this chapter, you have learned about homogeneous mixtures that are formed when compounds such as inorganic acids, bases, and ionic salts mix with water. These mixtures are classified as solutions. In contrast, heterogeneous mixtures are not solutions.

If you shake a piece of clay with water, the clay breaks into fine particles. The water becomes cloudy because the clay particles are suspended in the water. But if you stop shaking, the particles begin to settle out. A **suspension** is a mixture from which particles settle out upon standing. **A suspension differs from a solution because the particles of a suspension are much larger and do not stay suspended indefinitely.** The particles in a typical suspension have an average diameter greater than 1000 nm. By contrast, the particle size in a solution is usually about 1 nm. The larger size of suspended particles means that gravity plays a larger role in causing them to settle out of the mixture. Cooks use suspensions of flour or cornstarch in water to thicken sauces and gravies. These mixtures must be shaken or stirred immediately before use because the suspended particles quickly settle out.

Suspensions are heterogeneous because at least two substances can be clearly identified. In the example of clay particles mixed with water, you can clearly see the dispersed phase (clay) in the dispersion medium (water). Figure 15.14 shows that if muddy water is filtered, the filter traps the suspended clay particles and clear water passes through.

Figure 15.14 A suspension is a heterogeneous mixture. Suspended particles can be removed by filtration. **Comparing and Contrasting** ***How does the filtration of a suspension compare with the filtration of a solution?***

Section Resources

Print

- **Guided Reading and Study Workbook,** Section 15.3
- **Core Teaching Resources,** Section 15.3 Review
- **Transparencies,** T166–T168
- **Small-Scale Chemistry Laboratory Manual,** Lab 24

Technology

- **Interactive Textbook with ChemASAP,** Assessment 15.3
- **Go Online,** Section 15.3

15.3

1 FOCUS

Objectives

15.3.1 Distinguish between a suspension and a solution.

15.3.2 Identify the distinguishing characteristic of a colloid.

Guide for Reading

Build Vocabulary L2

Venn Diagram Have students make a Venn diagram using the following vocabulary terms: *solution, suspension, colloid, Tyndall effect, Brownian motion.*

Reading Strategy L2

Predict Before students begin to read this chapter, have them preview the section and predict how the properties of suspensions and colloids differ from those of solutions. Then, as they read, have them correct any misconceptions they may have.

2 INSTRUCT

Connecting to Your World

Have students study the photograph and read the text. Comment that gelatin is referred to as a heterogeneous mixture called a colloid. Ask, **What does that tell you about the composition of gelatin?** *(Its composition is not uniform throughout.)* **If a colloid such as gelatin differs from a solution with respect to the size of its particles, would you expect a colloid to have smaller or larger particles than a solution?** *(larger)*

Answers to...

Figure 15.14 When a solution is filtered, nothing is removed. When a suspension is filtered, suspended particles are removed.

Suspensions

Discuss L1

Refer students to the Career feature on wastewater treatment. Explain that sedimentation and filtration play important roles in the treatment process. First, large particles are removed from the water in large settling tanks by sedimentation. Lime and alum are added to help coagulate the particles. Filtration through sandy loams (diatomaceous earth) then removes the suspended matter and may absorb colloidal material as well.

Colloids

Word *Origins* L2

Egg white, jellies, and other sols and gels often have a gluelike appearance.

Use Visuals L1

Table 15.3 Display Table 15.3 on an overhead projector. Explain that colloids are characterized by the physical state of the *dispersed phase* and of the *continuous phase*—also called *dispersion medium*. Ask, **What is the dispersion medium in fog?** *(air)* **What is dispersed in fog?** *(water droplets)* Help students understand this two-part system by comparing it to a solution, which, instead of a dispersed phase and a dispersion medium, consists of a solute and a solvent.

Discuss L2

Point out that the main difference between solutions, suspensions, and colloids is particle size. Solution particles are typically less than 1 nm in diameter. Colloid particles are between 1 nm and 1000 nm in diameter. Suspension particles are typically larger than 1000 nm. Smaller particles are less susceptible to the effects of gravity and are influenced more by the effects of Brownian movement. The collisions of molecules with extremely small colloidal particles are sufficiently energetic to move colloidal particles in a random fashion that prevents their settling to the bottom.

Word *Origins*

Colloid comes from the Greek word *kolla* meaning "glue." The word *colloid* is based on the glue-like appearance of many colloids and was coined by the English scientist Thomas Graham in 1861. **As you read, identify examples of colloids that meet Graham's original definition.**

Colloids

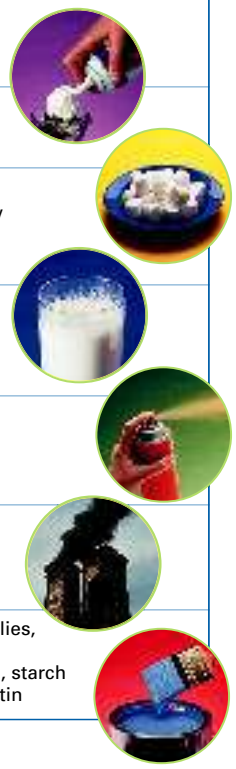
You read in *Connecting to Your World* that gelatin is a type of mixture called a colloid. A **colloid** is a heterogeneous mixture containing particles that range in size from 1 nm to 1000 nm. The particles are spread throughout the dispersion medium, which can be a solid, liquid, or gas. The first substances to be identified as colloids were glues. Other colloids include such mixtures as gelatin, paint, aerosol sprays, and smoke. Table 15.3 lists some common colloidal systems and gives examples of familiar colloids.

How do the properties of colloids differ from those of suspensions and solutions? Like suspensions, many colloids are cloudy or milky in appearance when they are concentrated. Like solutions, colloids may look clear or almost clear when they are dilute. The important difference between colloids and solutions and suspensions is in the size of the particles. **Colloids have particles smaller than those in suspensions and larger than those in solutions.** These intermediate-sized particles cannot be retained by filter paper as are the larger particles of a suspension, and they do not settle out with time. Colloids can be distinguished by the Tyndall effect and by the observation of Brownian motion. They are also subject to coagulation or clumping together, and they can be emulsified or made stable.

Table 15.3

Some Colloidal Systems

System		Type	Example
Dispersed phase	**Dispersion medium**		
gas	liquid	foam	whipped cream
gas	solid	foam	marshmallow
liquid	liquid	emulsion	milk, mayonnaise
liquid	gas	aerosol	fog, aerosols
solid	gas	smoke	dust in air
solid	liquid	sols and gels	egg white, jellies, paint, blood, colloidal gold, starch in water, gelatin



Differentiated Instruction

English Learners L2

Have students use a dictionary to look up the various uses of the word *disperse* or *dispersion*. Ask students to explain how the seeds of a plant being dispersed by the wind are related to the dispersed phase and dispersion medium of a colloid.

Figure 15.15 The path of light is visible only when the light is scattered by particles. a Fog or mist is a colloid and thus exhibits the Tyndall effect. b Particles in colloids and suspensions reflect or scatter light in all directions. Solutions do not scatter light.

The Tyndall Effect Ordinarily you can't see a beam of sunlight unless the light passes through particles of water (mist) or dust in the air. These particles scatter the sunlight. Similarly, a beam of light is visible as it passes through a colloid. The scattering of visible light by colloidal particles is called the **Tyndall effect.** Suspensions also exhibit the Tyndall effect, but solutions do not. The particles in solutions are too small to scatter light. Figure 15.15 shows how the Tyndall effect can differentiate solutions from colloids and suspensions.

Brownian Motion Flashes of light, or scintillations, are seen when colloids are studied under a microscope. Colloids scintillate because the particles reflecting and scattering the light move erratically. The chaotic movement of colloidal particles, which was first observed by the Scottish botanist Robert Brown (1773–1858), is called **Brownian motion.** Brownian motion is caused by collisions of the molecules of the dispersion medium with the small, dispersed colloidal particles. These collisions help prevent the colloidal particles from settling.

Coagulation Colloidal particles also tend to stay suspended because they become charged by adsorbing ions from the dispersing medium onto their surface. Some colloidal particles become positively charged by absorbing positively charged ions. Other colloidal particles become negatively charged by absorbing negatively charged ions. All the colloidal particles in a particular colloidal system will have the same charge, although the colloidal system is neutral. The repulsion between the like-charged particles prevents the particles from forming heavier aggregates that would have a greater tendency to settle out. Thus, a colloidal system can be destroyed or coagulated by the addition of ions having a charge opposite to that of the colloidal particles. The added ions neutralize the charged colloidal particles. The particles can clump together to form heavier aggregates and precipitate from the dispersion.

Go Online NSTA SCILINKS
For: Links on Brownian Motion
Visit: www.SciLinks.org
Web Code: cdn-1153

Checkpoint ***What is Brownian motion?***

Facts and Figures

Paint

Students may be interested in knowing why paint must be stirred before it is used. Explain that latex paint is a complex mixture of binders, pigments, and drying agents. Some ingredients are water-soluble; others are present as dispersed particles. For uniform color and composition, the paint must be stirred well before being used.

Go Online NSTA SCILINKS
Download a worksheet on **Brownian Motion** for students to complete, and find additional teacher support from NSTA SciLinks.

Relate L2

Many foods and other familiar products are colloids or suspensions. Bring to class examples of these products. For example, compare orange juice to orange soda. Ask students to apply the criteria they have learned to determine the proper classification for these items. *(The soda is a solution; the presence or absence of pulp affects the classification of the juice.)* Milk is a colloid of protein and fat. The curdling of milk occurs when bacteria produce enough lactic acid to cause dispersed protein and fat particles to coagulate into larger particles, which separate from the rest of the mixture. This process is comparable to the clotting of blood.

TEACHER Demo

Motion of Colloidal Particles L1

Purpose Students observe the Tyndall effect.

Materials whole milk, water, beaker, stirring rod, projector or laser pointer

Procedure Add a small amount of whole milk to some water in a beaker, and stir to mix. In a darkened room, shine a light from a projector or a laser pointer through the beaker.

Expected Outcome When viewed from the side, the path of the light beam is observed. This is the Tyndall effect. Students also can observe Brownian motion of airborne dust particles in the light beam. **CAUTION:** *If a laser pointer is used, warn students not to look directly at it.*

Relate L2

Ask, **Why it is usually recommended that drivers use low beams when driving under foggy conditions at night?** *(Fog is a colloid that produces the Tyndall effect. Bright lights produce a higher degree of light scattering in all directions, including straight back into the driver's eyes.)*

Answers to...

Checkpoint the random movement of colloidal particles caused by the collision of molecules of the dispersion medium with the small, dispersed colloidal particles

3 ASSESS

Evaluate Understanding L2

Ask, **In what way are colloids similar to solutions?** *(In both, dispersed particles are small enough to pass through standard filter paper and to withstand the pull of gravity.)* **In what way are colloids similar to suspensions?** *(Both types of mixtures produce the Tyndall effect.)*

Reteach L1

On the board, draw the relative sizes of solute, colloid, and suspension particles by making an analogy to golf balls, baseballs, and basketballs. Ask students which "particles" would get caught in a sieve a bit smaller than a basketball hoop and which would pass through? Remind students that solution particles are typically less than 1 nm in diameter, whereas colloid particles are ten to one thousand times larger and those of suspensions exceed the largest colloid particles.

Elements Handbook

Students' paragraphs should mention that electrolytes are excreted from the body in urine and sweat and can be restored by drinking water, juices, or sports drinks.

Interactive Textbook

If your class subscribes to the Interactive Textbook, use it to review key concepts in Section 15.3.

with ChemASAP

Figure 15.16 The addition of an egg yolk to a mixture of oil and vinegar produces mayonnaise, a stable emulsion.

Emulsions An **emulsion** is a colloidal dispersion of a liquid in a liquid. An emulsifying agent is essential for the formation of an emulsion and for maintaining the emulsion's stability. For example, oils and greases are not soluble in water. However, they readily form a colloidal dispersion if soap or detergent is added to the water. Soaps and detergents are emulsifying agents. One end of a large soap or detergent molecule is polar and is attracted to water molecules. The other end of the soap or detergent molecule is nonpolar and is soluble in oil or grease. Soaps and other emulsifying agents thus allow the formation of colloidal dispersions between liquids that do not ordinarily mix. Figure 15.16 shows a familiar example of an emulsion—mayonnaise. Mayonnaise is a heterogeneous mixture of oil and vinegar. Such a mixture would quickly separate without the presence of egg yolk, which is the emulsifying agent. Other foods such as milk, margarine, and butter are also emulsions. Cosmetics, shampoos, and lotions are formulated with emulsifiers to maintain consistent quality. Table 15.4 summarizes the properties of solutions, colloids, and suspensions.

Table 15.4

Properties of Solutions, Colloids, and Suspensions

	System		
Property	**Solution**	**Colloid**	**Suspension**
Particle type	ions, atoms, small molecules	large molecules or particles	large particles or aggregates
Particle size	0.1–1 nm	1–1000 nm	1000 nm and larger
Effect of light	no scattering	exhibits Tyndall effect	exhibits Tyndall effect
Effect of gravity	stable, does not separate	stable, does not separate	unstable, sediment forms
Filtration	particles not retained on filter	particles not retained on filter	particles retained on filter
Uniformity	homogeneous	heterogeneous	heterogeneous

15.3 Section Assessment

16. Key Concept How does a suspension differ from a solution?
17. Key Concept What distinguishes a colloid from a suspension and a solution?
18. How can you determine through observation that a mixture is a suspension?
19. Could you separate a colloid by filtering? Explain.
20. How can the Tyndall effect be used to distinguish between a colloid and a solution?
21. What causes Brownian motion? Can the presence of Brownian motion distinguish between a solution and a colloid? Explain.

Elements Handbook

Electrolytes Go to page R8 in the Elements Handbook and read about the importance of electrolytes in the body. Write a paragraph explaining why the concentration of these ions may decline and how they can be restored.

Interactive Textbook

Assessment 15.3 Test yourself on the concepts in Section 15.3.

with ChemASAP

Section 15.3 Assessment

16. The particles of a suspension are much larger and do not stay suspended indefinitely.
17. Colloids have particles smaller than those in suspensions and larger than those in solutions.
18. The particles in a suspension will settle out over time.
19. Particles in a colloid such as gelatin are smaller than the holes in filter paper and cannot be removed by filtering.
20. A beam of light is visible as it passes through a colloid; a beam of light is invisible as it passes through a solution.
21. Brownian motion is caused by collisions of the molecules of the dispersion medium with the small, dispersed colloidal particles. Flashes of light, or scintillations, are seen when colloids are studied under a microscope. Colloids scintillate because the particles reflecting and scattering the light move erratically. The particles in a solution are too small to be seen under a microscope and do not cause scintillations.

Water Worth Drinking

When you turn on a faucet, you probably don't think about the substances other than water that may end up in your glass. To ensure the safety of the water you drink, the Environmental Protection Agency (EPA) has established drinking water standards that state and local governments must follow. These standards set upper limits on potentially harmful substances that could be present in water. The standards are based on studies of how these substances affect human health. **Inferring** ***What might happen if water were not treated to kill bacteria and other pathogens?***

1 **Laboratory analysis** identifies natural or synthetic compounds that may be harmful when present in drinking water. Standards are set for these substances in parts per million (ppm) or parts per billion (ppb).

2 If periodic **water samples** indicate too high a level of coliform bacteria, disinfectants such as chlorine must be added to destroy these and other potentially dangerous microorganisms.

3 When water must be **treated with chlorine,** frequent tests ensure that levels of this disinfectant do not fall below 0.5 ppm.

Local water providers test their public water supplies regularly to monitor levels of minerals, chlorine, and microorganisms such as bacteria.

Facts and Figures

Parts per million

Parts per million, or ppm, is a unit of concentration. It is commonly used when measuring levels of pollutants in air and water. One ppm is 1 part in 1,000,000. A solution whose concentration is 1 ppm contains 1 g of solute for each million (10^6) grams of solution. Because the density of water is 1 g/mL, 1 kg of a dilute aqueous solution will have a volume very close to 1 L. Thus, 1 ppm also corresponds to 1 mg of solute per liter of solution. The maximum allowable concentration of arsenic is 0.01 ppm or 0.01mg of arsenic per liter of water.

Water Worth Drinking

Purpose

This feature builds on the discussion of water in the liquid state in section 15.1 and on some of the substances and materials that might be dissolved or suspended in the water.

Background

- 1999 marked the 25th year of public health protection under the Safe Drinking Water Act. The Act, passed in 1974 and amended in 1986 and 1996, gives the Environmental Protection Agency (EPA) the authority to set drinking water standards. Drinking water standards apply to public water systems, i. e., systems that provide water for human consumption through at least 15 service connections, or regularly serve at least 25 individuals. Public water systems include municipal water companies, homeowner associations, schools, businesses, campgrounds and shopping malls.
- Standards for safety are constantly being examined by the EPA and may change as new data become available. For example, the standard for arsenic was recently changed from 50 ppb to 10 ppb.
- Coliform bacteria are part of the normal bacterial flora of the intestinal tract of humans and other animals. *E. coli* is the best known of these bacteria, but there are many other species. The presence of coliform bacteria in the water supply is a strong indication of contamination by human or animal wastes. Microbes in these wastes can cause diarrhea, cramps, nausea, headaches, or other symptoms.
- *Cryptosporidium* is a parasite that enters lakes and rivers through sewage and animal waste. It causes cryptosporidiosis, a mild gastrointestinal disease. However, the disease can be severe or fatal for people with severely weakened immune systems.

Answers to...

Inferring A serious epidemic of typhoid, cholera, or other pathogen-caused disease might occur.