Suspensions and colloids are two common types of mixtures whose properties are in many ways intermediate between those of true solutions and heterogeneous mixtures. A suspension is a heterogeneous mixture of particles with diameters of about 1 µm (1000 nm) that are distributed throughout a second phase. Common suspensions include paint, blood, and hot chocolate, which are solid particles in a liquid, and aerosol sprays, which are liquid particles in a gas. If the suspension is allowed to stand, the two phases will separate, which is why paints must be thoroughly stirred or shaken before use. A colloid is also a heterogeneous mixture, but the particles of a colloid are typically smaller than those of a suspension, generally in the range of 2 to about 500 nm in diameter. Colloids include fog and clouds (liquid particles in a gas), milk (solid particles in a liquid), and butter (solid particles in a solid). Other colloids are used industrially as catalysts. Unlike in a suspension, the particles in a colloid do not separate into two phases on standing. The only combination of substances that cannot produce a suspension or a colloid is a mixture of two gases because their particles are so small that they always form true solutions. The properties of suspensions, colloids, and solutions are summarized in Table 13.10.1.

Table 13.10.1: Properties of Liquid Solutions, Colloids, and Suspensions

<table>
<thead>
<tr>
<th>Type of Mixture</th>
<th>Approximate Size of Particles (nm)</th>
<th>Characteristic Properties</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>solution</td>
<td>&lt; 2</td>
<td>not filterable; does not separate on standing; does not scatter visible light</td>
<td>air, white wine, gasoline, salt water</td>
</tr>
<tr>
<td>colloid</td>
<td>2–500</td>
<td>scatters visible light; translucent or opaque; not filterable; does not separate on standing</td>
<td>smoke, fog, ink, milk, butter, cheese</td>
</tr>
<tr>
<td>suspension</td>
<td>500–1000</td>
<td>cloudy or opaque; filterable; separates on standing</td>
<td>muddy water, hot cocoa, blood, paint</td>
</tr>
</tbody>
</table>

Colloids and Suspensions

Colloids were first characterized in about 1860 by Thomas Graham, who also gave us Graham's law of diffusion and effusion. Although some substances, such as starch, gelatin, and glue, appear to dissolve in water to produce solutions, Graham found that they diffuse very slowly or not at all compared with solutions of substances such as salt and sugar. Graham coined the word colloid (from the Greek kólla, meaning "glue") to describe these substances, as well as the words sol and gel to describe certain types of colloids in which all of the solvent has been absorbed by the solid particles, thus preventing the mixture from flowing readily, as we see in Jell-O. Two other important types of colloids are aerosols, which are dispersions of solid or liquid particles in a gas, and emulsions, which are dispersions of one liquid in another liquid with which it is immiscible.

Colloids share many properties with solutions. For example, the particles in both are invisible without a powerful microscope, do not settle on standing, and pass through most filters. However, the particles in a colloid scatter a beam of visible light, a phenomenon known as the Tyndall effect. The effect is named after its discoverer, John Tyndall, an English physicist (1820–1893), whereas the particles of a solution do not. The Tyndall effect is responsible for the way the beams from automobile headlights are clearly visible from the side on a foggy night but cannot be seen from the side on a clear night. It is also responsible for the colored rays of light seen in many sunsets, where the sun’s light is scattered by water droplets and dust particles high in the atmosphere. An example of the Tyndall effect is shown in
Although colloids and suspensions can have particles similar in size, the two differ in stability: the particles of a colloid remain dispersed indefinitely unless the temperature or chemical composition of the dispersing medium is changed. The chemical explanation for the stability of colloids depends on whether the colloidal particles are hydrophilic or hydrophobic.

Most proteins, including those responsible for the properties of gelatin and glue, are hydrophilic because their exterior surface is largely covered with polar or charged groups. Starch, a long-branched polymer of glucose molecules, is also hydrophilic. A hydrophilic colloid particle interacts strongly with water, resulting in a shell of tightly bound water molecules that prevents the particles from aggregating when they collide. Heating such a colloid can cause aggregation because the particles collide with greater energy and disrupt the protective shell of solvent. Moreover, heat causes protein structures to unfold, exposing previously buried hydrophobic groups that can now interact with other hydrophobic groups and cause the particles to aggregate and precipitate from solution. When an egg is boiled, for example, the egg white, which is primarily a colloidal suspension of a protein called albumin, unfolds and exposes its hydrophobic groups, which aggregate and cause the albumin to precipitate as a white solid.

In some cases, a stable colloid can be transformed to an aggregated suspension by a minor chemical modification. Consider, for example, the behavior of hemoglobin, a major component of red blood cells. Hemoglobin molecules normally form a colloidal suspension inside red blood cells, which typically have a “donut” shape and are easily deformed, allowing them to squeeze through the capillaries to deliver oxygen to tissues. In a common inherited disease called sickle-cell anemia, one of the amino acids in hemoglobin that has a hydrophilic carboxylic acid side chain (glutamate) is replaced by another amino acid that has a hydrophobic side chain. Under some conditions, the abnormal hemoglobin molecules can aggregate to form long, rigid fibers that cause the red blood cells to deform, adopting a characteristic sickle shape that prevents them from passing through the capillaries. The reduction in blood flow results in severe cramps, swollen joints, and liver damage. Until recently, many patients with sickle-cell anemia died before the age of 30 from infection, blood clots, or heart or kidney failure, although individuals with the sickle-cell genetic trait are more resistant to malaria than are those with “normal” hemoglobin.
Figure \(\PageIndex{2}\): Sickle cell anemia. (CC2.0, Ed Uthman, Wikimedia Commons)

Figure \(\PageIndex{2}\): Formation of New Land by the Destabilization of a Colloid Suspension. This satellite photograph shows the Mississippi River delta from New Orleans (top) to the Gulf of Mexico (bottom). Where seawater mixes with freshwater from the Mississippi River, colloidal clay particles in the river water precipitate (tan area).

Aggregation and precipitation can also result when the outer, charged layer of a particle is neutralized by ions with the opposite charge. In inland waterways, clay particles, which have a charged surface, form a colloidal suspension. High salt concentrations in seawater neutralize the charge on the particles, causing them to precipitate and form land at the mouths of large rivers, as seen in the satellite view in Figure 13.10.3. Charge neutralization is also an important strategy for precipitating solid particles from gaseous colloids such as smoke, and it is widely used to reduce particulate emissions from power plants that burn fossil fuels.

Aerosols

Aerosols are very important in atmospheric chemistry and much atmospheric chemistry occurs in aerosols. In the next chapter we will study the rates of reactions, and from bimolecular collision theory realize that if two reactants react, they have to collide with each other. We will learn that the more concentrated they are, the higher the collision frequency. From Henry's law we know that many compounds will dissolve in water and so the concentration of many reactants is higher in aerosol than in the raw gas phase, meaning many reactions occur within these tiny airborne particles of water. Smog is fog that contains dangerous solutes like ozone, particulate matter, oxides of nitrogen, volatile organic compounds, and other unhealthy compounds.
Video \(\PageIndex{1}\): 3:50min video by the Center for Aerosol Impacts on Chemistry of the Environment describing soot (https://youtu.be/CT8Bapq6pro)

Today citizens can stream data on air quality to web services, and one such service is Purple Air. Purple air sensors primarily measure particulate matter, which is a major concern out west and their interactive map allows you to zoom in to geographic areas, and there are even two Purple Air sensors in the Little Rock area. The EPA runs Federal Monitoring stations that are much more accurate (and expensive) and their AirData Quality Monitors map allows you to pick specific gases the EPA is monitoring (you need to click the layers icon on their map and choose the monitors you wish to see), but there are monitors here in Little Rock providing data on toxins like Ozone, which is a serious health issue in this region.

Figure \(\PageIndex{3}\): Two Interactive Air Quality Maps. On the left is the Purple Air Map where citizens can stream data on particulate matter and on the right is the EPA Air Quality Data Map streamed from government sensors. Both maps are interactive, although on the EPA map you need to open up the layers option and choose the types of monitors you want to read (you can zoom down to Little Rock) (CC0, Bob Belford, captured Sep 11, 2022)
Emulsions

Emulsions are colloids formed by the dispersion of a hydrophobic liquid in water, thereby bringing two mutually insoluble liquids, such as oil and water, in close contact. Various agents have been developed to stabilize emulsions, the most successful being molecules that combine a relatively long hydrophobic “tail” with a hydrophilic “head”. Soaps are natural emulsifying agents and detergents are synthetic ones. Figure \(\PageIndex{4}\) shows the similarity in structure between the soap sodium stearate \([\text{NaCH}_3(\text{CH}_2)_{16}\text{CO}_2,]\) and detergent sodium dodecyl sulfate \([\text{NaCH}_3(\text{CH}_2)_{11}\text{OSO}_3],\) both of which are salts with a charge on one end (the head) and a long tailed (nonpolar) hydrocarbon chain on the other. The charged head is soluble in polar compounds like water while the long hydrophobic head is soluble in nonpolar compounds like fats and oils.

![Figure \(\PageIndex{4}\): The soap sodium stearate (left) and the detergent sodium lauryl sulfate (right) and Paste Caption here. (CC0, Bob Belford using MolView)](image)

When you wash your laundry, the hydrophobic tails of soaps and detergents interact with hydrophobic particles of dirt or
grease through dispersion forces, dissolving in the interior of the hydrophobic particle. The hydrophilic group is then exposed at the surface of the particle, which enables it to interact with water through ion–dipole forces and hydrogen bonding. This causes the particles of dirt or grease to disperse in the wash water and allows them to be removed by rinsing. Similar agents are used in the food industry to stabilize emulsions such as mayonnaise.

A related mechanism allows us to absorb and digest the fats in buttered popcorn and French fries. To solubilize the fats so that they can be absorbed, the gall bladder secretes a fluid called bile into the small intestine. Bile contains a variety of bile salts, detergent-like molecules that emulsify the fats.

**Micelles**

Detergents and soaps are surprisingly soluble in water in spite of their hydrophobic tails. The reason for their solubility is that they do not, in fact, form simple solutions. Instead, above a certain concentration they spontaneously form micelles, which are spherical or cylindrical aggregates that minimize contact between the hydrophobic tails and water. In a micelle, only the hydrophilic heads are in direct contact with water, and the hydrophobic tails are in the interior of the aggregate (part (a) in Figure 13.10.4).

![Micelle and Phospholipid Bilayer](image)

**Figure 13.10.4: Micelles and a Phospholipid Bilayer.** (a) Soaps and detergents, which contain a single hydrophobic tail on each molecule, form spherical micelles with the intertwined tails in the interior and the hydrophilic head groups on the exterior. (b) Phospholipids, which have two hydrophobic tails, tend to form extended double layers in which the hydrophobic tails are sandwiched between the hydrophilic head groups.

A large class of biological molecules called phospholipids consists of detergent-like molecules with a hydrophilic head and two hydrophobic tails, as can be seen in the molecule of phosphatidylcholine. The additional tail results in a cylindrical shape that prevents phospholipids from forming a spherical micelle. Consequently, phospholipids form bilayers, extended sheets consisting of a double layer of molecules. As shown in part (b) in Figure 13.10.4, the hydrophobic tails are in the center of the bilayer, where they are not in contact with water, and the hydrophilic heads are on the two surfaces, in contact with the surrounding aqueous solution.
A cell membrane is essentially a mixture of phospholipids that form a phospholipid bilayer. One definition of a cell is a collection of molecules surrounded by a phospholipid bilayer that is capable of reproducing itself. The simplest cells are bacteria, which consist of only a single compartment surrounded by a single membrane. Animal and plant cells are much more complex, however, and contain many different kinds of compartments, each surrounded by a membrane and able to carry out specialized tasks.

Summary

A suspension is a heterogeneous mixture of particles of one substance distributed throughout a second phase; the dispersed particles separate from the dispersing phase on standing. In contrast, the particles in a colloid are smaller and do not separate on standing. A colloid can be classified as a sol, a dispersion of solid particles in a liquid or solid; a gel, a semisolid sol in which all of the liquid phase has been absorbed by the solid particles; an aerosol, a dispersion of solid or liquid particles in a gas; or an emulsion, a dispersion of one liquid phase in another. A colloid can be distinguished from a true solution by its ability to scatter a beam of light, known as the Tyndall effect. Hydrophilic colloids contain an outer shell of groups that interact favorably with water, whereas hydrophobic colloids have an outer surface with little affinity for water. Emulsions are prepared by dispersing a hydrophobic liquid in water. In the absence of a dispersed hydrophobic liquid phase, solutions of detergents in water form organized spherical aggregates called micelles. Phospholipids are a class of detergent-like molecules that have two hydrophobic tails attached to a hydrophilic head. A bilayer is a two-dimensional sheet consisting of a double layer of phospholipid molecules arranged tail to tail with a hydrophobic interior and a hydrophilic exterior. Cells are collections of molecules that are surrounded by a phospholipid bilayer called a cell membrane and are able to reproduce themselves.
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