Chapter 15 “Water and Aqueous Systems”
The Water Molecule: a Review

• Water is a simple tri-atomic molecule, H₂O

• Each O-H bond is *highly polar*, because of the high electronegativity of the oxygen (N, O, F, and Cl have high values)

• bond angle of water = 105°

• due to the *bent shape*, the O-H bond polarities do not cancel. This means: *water is a polar molecule.*
The Water Molecule: a Review

δ is the lowercase Greek symbol delta

Thus, water has a partial negative end (Oxygen) and a partial positive end (Hydrogen), and it is called “polar” because of these areas of difference.
The Water Molecule

• Water’s **bent shape** and **ability to hydrogen bond** gives it many special properties!

• What was hydrogen bonding?

• Water molecules are attracted to one another by dipole interactions – p. 446

• This hydrogen bonding gives water:    a) its **high surface tension**, and           b) its **low vapor pressure**.
a) High Surface Tension?
• liquid water acts like it has a “skin”
  – glass of water bulges over the top
• Water forms round drops
  – spray water on greasy surface
• All because water hydrogen bonds.
• Fig. 15.4, p.447 – how does this insect walk on the water? (see next slide)
Due to the high Surface Tension of water!
Surface Tension

• One water molecule can hydrogen bond to another because of this electrostatic attraction.

• Also, hydrogen bonding occurs with many other molecules surrounding them on all sides.
Surface Tension

• A water molecule in the *middle* of a solution is pulled in *all directions*. 
Surface Tension

- **Not** true at the surface.
- They are pulled *down* and *to each side*, not upward since the water and air are not attracted to each other.
- This holds the molecules at the surface together tightly.
- This causes *surface tension*. 
Surface Tension

• Water drops are rounded, because all molecules on the edge are pulled to the middle, not outward to the air!

• A drop has the least amount of surface area for any given volume.
Surface Tension

- Glass has polar molecules.
- Glass can also hydrogen bond.
- This **attracts** the water molecules.
- Some of them are pulled up a cylinder wall.
Meniscus

A meniscus is the curved surface at the top of a column of liquid.

• Thus, water *curves up* along the sides of glass.
• This makes the *meniscus*, as in a graduated cylinder.
• However, *Plastics* are non-wetting; there is no attraction to water.
Meniscus

Water is attracted to the Glass, thus curves up the sides

Water not attracted to Plastic, but to other water molecules
Surface tension

• All liquids have surface tension
  – water is just higher than most others, due to the hydrogen bonding present

• How can we decrease surface tension?
  – Use a surfactant - surface active agent
  – Also called a “wetting agent”, like detergent or soap (makes water “wetter”)
  – Interferes with hydrogen bonding
b) Low vapor pressure?

- Hydrogen bonding also explains water’s unusually **low vapor pressure**.
  - It holds water molecules together, so they *do not escape (evaporate) easily, like gasoline or acetone does.*
  - This is a good thing, because lakes and oceans would evaporate very quickly due to their large surface area!
Ice

- Most liquids contract (get smaller) as they are cooled.
  - They get more dense.
- When they change to solid, they are more dense than the liquid.
- Solid metals sink in their own liquid metal.
  - But, ice *floats* in water.
- Why?
Ice

• Water becomes more dense as it cools, until it reaches about 4ºC.
  – Then it becomes less dense by starting to expand (Want your water pipes to freeze in the winter?)

• Because as the molecules slow down, they arrange themselves into **honeycomb-shaped crystals**.

• These are held together by hydrogen bonds. Fig. 15.5, p.449
Liquid = random shaped arrangement

Solid = honeycomb-shaped arrangement
Ice

- Is 10% lower in density than liquid water.
- Water *freezes from the top down*.
  - The layer of ice on a pond acts as an insulator for water below
- **Why** is ice less dense than liquid water?
  - The structure of ice is a regular *open framework of water molecules*, arranged like a honeycomb.
Ice

• A considerable amount of energy is required to return water in the solid state to the liquid (called melting)
  – The heat absorbed when 1 g of water changes from solid to liquid is 334 J.
  – This is the same amount of energy needed to raise the temperature of 1 g of liquid water from 0 °C to 80 °C!
Solvents and Solutes

- **Solution** - a *homogenous mixture*, that is mixed molecule by molecule; made of:

  1) **a Solvent** - the dissolving medium
  
  2) **a Solute** - the dissolved particles

- **Aqueous solution** - a solution with *water* as the solvent.

- Particle size is less than 1 nm; *cannot* be separated by filtration – Fig. 15.6, p.450
Parts of a Solution:

1. the **Solute**
   A solute is the *dissolved substance* in a solution.
   - **Salt** in salt water   **Sugar** in soda drinks
   - **Carbon dioxide** in soda drinks

2. the **Solvent**
   A solvent is the *dissolving medium* in a solution.
   - **Water** in salt water   **Water** in soda
Solutions

• Keep in mind that solutions do not have to contain water, but this is the type we are studying in this chapter = aqueous solutions

– Example: air and jewelry are also types of solutions.
There are a tremendous number of solutions we use in our daily lives!
Concentrated vs. Dilute

Lots of **solute**, but little solvent

Lots of **solvent**, but little solute
Aqueous Solutions

- Water **dissolves** ionic compounds and polar covalent molecules very well.
- The rule is: *“like dissolves like”*
- Polar dissolves polar.
- Nonpolar dissolves nonpolar.
- Oil is nonpolar.
  - Oil and water don’t mix.
- Salt is ionic- makes salt water.
The Solution Process

• Called “solvation”.

• Water 1) breaks the + and - charged pieces apart, and 2) surrounds them.

• Fig. 15.7, p. 451

• But, in some ionic compounds, the attraction between ions is greater than the attraction exerted by water
  – Barium sulfate and calcium carbonate do not dissolve in water!
How Ionic solids dissolve in water

These ions have been pulled away from the main crystal structure by water’s polarity.

These ions have been surrounded by water, and are now dissolved!
• Solids *will dissolve if* the attractive force of the water molecules is *stronger* than the attractive force of the crystal.
• If not, the solids are *insoluble*.
• Water doesn’t dissolve nonpolar molecules (like oil) because the water molecules can’t hold onto them.
• The water molecules hold onto other water molecules, and separate from the nonpolar molecules.
• Nonpolars? No repulsion between them
Electrolytes and Nonelectrolytes

• **Electrolytes** - compounds that *conduct an electric current in aqueous solution*, or in the *molten state*
  
  —all ionic compounds are electrolytes because they dissociate into ions (they are also called “salts”)

• barium sulfate - will conduct when molten, but is *insoluble* in water!
Electrolytes and Nonelectrolytes

- Do not conduct? = Nonelectrolytes.
  - Most are molecular materials, because they do not have ions.
- Not all electrolytes conduct to the same degree.
  - There are weak electrolytes, and strong electrolytes.
  - Depends on: the degree of ionization.
The ammeter measures the flow of electrons (current) through the circuit.

- If the ammeter measures a current and the bulb glows, then the solution conducts.
- If the ammeter fails to measure a current and the bulb does not glow, the solution is non-conducting.
Electrolytes and Nonelectrolytes

• Strong electrolytes exist as nearly 100% ions
• Weak electrolytes have only a fraction of the solute that exists as ions
• How do you know if it is strong or weak? Refer to the rules on the handout sheet.
Electrolyte Summary

• Substances that conduct electricity when dissolved in water, or molten.
• Must have charged particles that can move.
• Ionic compounds break into charged ions:
  \[ \text{NaCl} \rightarrow \text{Na}^{1+} \text{ and } \text{Cl}^{1-} \]
• These ions can conduct electricity.
• Nonelectrolytes do not conduct electricity when dissolved in water or molten
• Polar covalent molecules such as methanol (CH$_3$OH) don’t fall apart into ions when they dissolve.
• Weak electrolytes don’t fall completely apart into ions.
• Strong electrolytes do ionize completely.
Water of Hydration (or Water of Crystallization)

- Water molecules are chemically bonded to solid salt molecules (not in solution).
- These compounds have fixed amounts of water.
- The water can be driven off by heating:
  - \( \text{CuSO}_4 \cdot 5\text{H}_2\text{O} \) + heat \( \rightarrow \text{CuSO}_4 + 5\text{H}_2\text{O} \)
  - Called \textit{copper(II)sulfate pentahydrate}.
Hydrates

• Table 15.2, p.455 list some familiar hydrates

• Since heat can drive off the water, the forces holding the water are weak

• If a hydrate has a vapor pressure higher than that of water vapor in air, the hydrate will effloresce by losing the water of hydration
Hydrates

• Some hydrates that have a **low vapor pressure** remove water *from the air* to form **higher** hydrates—these are called **hygroscopic**
  – used as drying agents, or **dessicants**
  – packaged with products to absorb moisture
Finding the Percent of Water in a Hydrate

Calculate the percent by mass of water in washing soda, sodium carbonate decahydrate (Na₂CO₃·10H₂O).

1. **Analyze** List the known and the unknown.

   **Known**
   - Formula of hydrate = Na₂CO₃·10H₂O

   **Unknown**
   - percent H₂O = ? %

   To determine the percent by mass, determine the mass of 10 moles of water and the mass of one mole of the hydrated compound. Substitute these values into the following equation and solve.

   \[
   \text{Percent } H₂O = \frac{\text{mass of water}}{\text{mass of hydrate}} \times 100\%
   \]

2. **Calculate** Solve for the unknown.

   - mass of 10 H₂O = 180 g
   - mass of Na₂CO₃·10H₂O = 286.0 g

   \[
   \text{percent } H₂O = \frac{1.80 \times 10² \, g}{286.0 \, g} \times 100\% = 62.9\%
   \]
Hydrates

• Some compounds are so hygroscopic, they become wet when exposed to normally moist air - called deliquescent

—remove sufficient water to dissolve completely and form solutions: Fig. 15.13, page 457
Mixtures that are NOT Solutions:

1. **Suspensions**: Mixtures that slowly settle upon standing. Example: sand in water
   - Particles of a suspension are *greater* in diameter than 1000 nm.
   - *Can* be separated by filtering (p.459)

2. **Colloids**: Heterogeneous mixtures with particles *between* the size of suspensions and true solutions (1-1000 nm)
Mixtures that are NOT Solutions

• The colloid particles are the dispersed phase, and are spread throughout the dispersion medium.

• The first colloids were glues. Others include mixtures such as gelatin, paint, aerosol sprays, and smoke.

• Table 15.3, p.460 (next slide) lists some common colloidal systems and examples.
### Some Colloidal Systems

<table>
<thead>
<tr>
<th>System</th>
<th>Dispersed phase</th>
<th>Dispersion medium</th>
<th>Type</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>gas</td>
<td>liquid</td>
<td>foam</td>
<td>whipped cream</td>
</tr>
<tr>
<td></td>
<td>gas</td>
<td>solid</td>
<td>foam</td>
<td>marshmallow</td>
</tr>
<tr>
<td></td>
<td>liquid</td>
<td>liquid</td>
<td>emulsion</td>
<td>milk, mayonnaise</td>
</tr>
<tr>
<td></td>
<td>liquid</td>
<td>gas</td>
<td>aerosol</td>
<td>fog, aerosols</td>
</tr>
<tr>
<td></td>
<td>solid</td>
<td>gas</td>
<td>smoke</td>
<td>dust in air</td>
</tr>
<tr>
<td></td>
<td>solid</td>
<td>liquid</td>
<td>sols and gels</td>
<td>egg white, jellies, paint, blood, colloidal gold, starch in water, gelatin</td>
</tr>
</tbody>
</table>
Mixtures that are NOT Solutions

• Many colloids are *cloudy or milky* in appearance when concentrated, but almost clear when dilute
  – They *do not* settle out
  – They *can not* be filtered out

• Colloids exhibit the *Tyndall effect* - the scattering of visible light in all directions.
  – Suspensions also show Tyndall effect
Colloids and suspensions scatter light, making a beam visible, due to their large particle size.

Solutions do not scatter light, because of their small particle size.

You can see the light beam because the large particles reflect the light. Here you cannot see the light beam; particles are too small to reflect light.

Which glass contains a colloid? Should you drive in fog with your high beams on? Why?
Note that you can easily see the “sunbeams”, probably due to the presence of fog (a colloid) in the forest reflecting light.
Mixtures that are NOT Solutions

• Flashes of light are seen when colloids are studied under a microscope- light is reflecting- called Brownian motion to describe the chaotic movement of the particles. Observed by Robert Brown.

• Table 15.4, p.462 (next slide) will summarize the properties of solutions, colloids, and suspensions
<table>
<thead>
<tr>
<th>Property</th>
<th>Solution</th>
<th>Colloid</th>
<th>Suspension</th>
</tr>
</thead>
<tbody>
<tr>
<td>Particle type</td>
<td>ions, atoms, small molecules</td>
<td>large molecules or particles</td>
<td>large particles or aggregates</td>
</tr>
<tr>
<td>Particle size</td>
<td>0.1–1 nm</td>
<td>1–1000 nm</td>
<td>1000 nm and larger</td>
</tr>
<tr>
<td>Effect of light</td>
<td>no scattering</td>
<td>exhibits Tyndall effect</td>
<td>exhibits Tyndall effect</td>
</tr>
<tr>
<td>Effect of gravity</td>
<td>stable, does not separate</td>
<td>stable, does not separate</td>
<td>unstable, sediment forms</td>
</tr>
<tr>
<td>Filtration</td>
<td>particles not retained on filter</td>
<td>particles not retained on filter</td>
<td>particles retained on filter</td>
</tr>
<tr>
<td>Uniformity</td>
<td>homogeneous</td>
<td>borderline</td>
<td>heterogeneous</td>
</tr>
</tbody>
</table>
Mixtures that are NOT Solutions

- **Emulsions** - dispersions of a liquid in a liquid (2 immiscible liquids + an **emulsifier**)
  - an **emulsifying agent** is essential for maintaining stability; it has **one polar end**, and the **other end is nonpolar**
  - oil and water not soluble; but with soap or detergent added, they will be.

- Oil + vinegar in dressing – are they soluble?
  - What makes up Mayonnaise? (page 462)
  - What makes up Margarine?
Distillation equipment – Exp. #26

(Distillation works because of differences in boiling points)

Chemicals are heated, and those that boil first will escape as vapor.

The condenser has cool water that turns the vapors back into liquid.

The “distillate” is then collected as a liquid.

Run hose into sink

Connect hose to cold water tap

Cold water in

Cold water out

Thermometer