

## Unit 6 – Water and Its Properties

### 15.1 Water and Its Properties

#### I. Liquid Water

##### A. Surface Tension

###### 1. Surface Tension

- A force that tends to pull adjacent parts of a liquid's surface together, thereby decreasing surface area to the smallest possible size
- Hydrogen bonding in water creates stronger than normal surface tension

###### 2. Capillary Action

- The attraction of the surface of a liquid to the surface of a solid

##### B. Vapor Pressure

- Water has a very low vapor pressure due to the strong hydrogen bonding on the surface

#### II. Water in the Solid State

##### A. Density

- Water is one of only a few substances that is less dense as a solid than as a liquid

##### B. High melting point

- No other substance with such small molar mass has so high freezing/melting point

#### III. Summary of Water's Important Properties

Bond Type	Polar	Density of ice (0 °C)	0.917 g/cm <sup>3</sup>
Bond angle	105°	Density of water (0 °C)	0.999 g/cm <sup>3</sup>
Normal Boiling point	100 °	Point of maximum density	3.98 °C
Normal Melting Point	0 °C	Molar heat of fusion	6.009 kJ/mole
		Molar heat of vaporization	40.79 kJ/mole

### 13.2 The Nature of Liquids

#### I. A Model for Liquids

##### A. Liquids are Fluids

- Substances that can flow and therefore take the shape of their container

##### B. Liquids have Relatively High Density

- 10% less dense than solids (average)
  - Water is an exception
- 1000x more dense than gases

##### C. Liquids are Relatively Incompressible

- The volume of liquids doesn't change appreciably when pressure is applied

##### D. Liquids have the Ability to Diffuse

- Liquids diffuse and mix with other liquids
- Rate of diffusion increases with temperature (↑ average Kinetic Energy)

##### E. Evaporation and Boiling

###### 1. Evaporation

- Molecules with sufficient kinetic energy escape as vapor from the surface of the liquid

###### 2. Vapor Pressure

- A measure of the force exerted by a vapor above its liquid

###### 3. Boiling

- The change of a liquid to bubbles of vapor that appear throughout the liquid
- The normal boiling point is the temperature at which a substance boils at 101.3 kPa
- The boiling point of a substance decreases as the atmospheric pressure decreases

##### F. Formation of Solids

###### 1. Freezing (or Solidification)

- The physical change of a liquid to a solid by removal of heat

### 13.4 Changes of State

#### I. Boiling and Condensation

##### A. Boiling

1. The conversion of a liquid to a vapor within the liquid as well as at its surface. It occurs when the equilibrium vapor pressure of the liquid equals the atmospheric pressure

##### B. Boiling Point

1. The temperature at which the equilibrium vapor pressure of the liquid equals the atmospheric pressure
  - a. Water boils at 100 °C at 1 atm pressure
  - b. Water boils above 100 °C at higher pressures
  - c. Water boils below 100 °C at lower pressures

##### C. Condensation

1. The conversion of a gas to a liquid by the removal of energy

#### II. Freezing and Melting

##### A. Freezing Point

1. The temperature at which the solid and liquid are in equilibrium at 1 atm
2. For pure crystalline solids, the melting point and freezing point are the same
3. Temperature remains constant during a phase change

##### B. Sublimation and Deposition

1. Sublimation is the change of state from a solid directly to a gas
  - a. Dry ice  $\rightarrow$  Gaseous  $\text{CO}_2$
2. Deposition is the change of state from a gas directly to a solid

#### III. Phase Diagrams

##### A. Phase Diagram

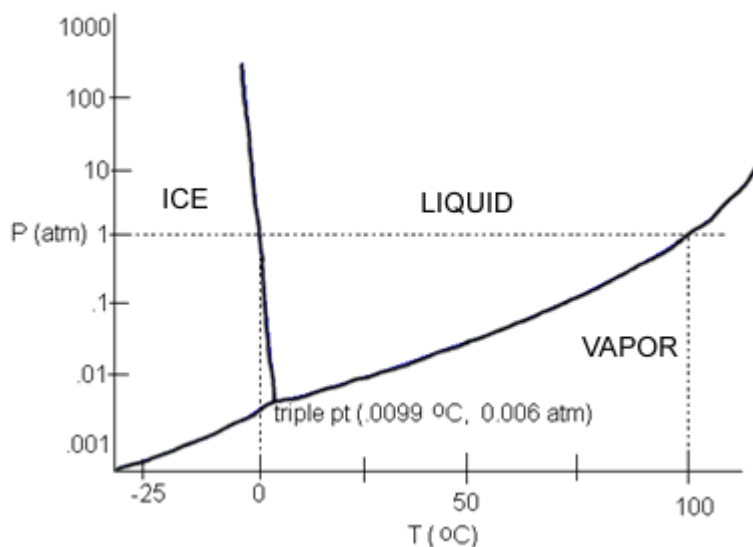
1. A graph of pressure versus temperature that shows the conditions under which the phases of a substance exist (notice that pressure is on a logarithmic scale)

##### B. Triple Point

1. The temperature and pressure conditions at which the solid, liquid, and vapor of the substance can coexist at equilibrium

##### C. Critical Temperature

1. The temperature at above which the substance cannot exist in the liquid state, regardless of pressure
  - a. For water, the critical temperature is 373.99 °C



##### D. Critical Pressure

1. The lowest pressure at which the substance can exist as a liquid at the critical temperature
  - a. For water, the critical pressure is 217.75 atm

##### E. Critical Point

1. The point on the graph describing simultaneously the critical temperature and the critical pressure  
P = 217.75 atm      Temperature = 373.99 °C

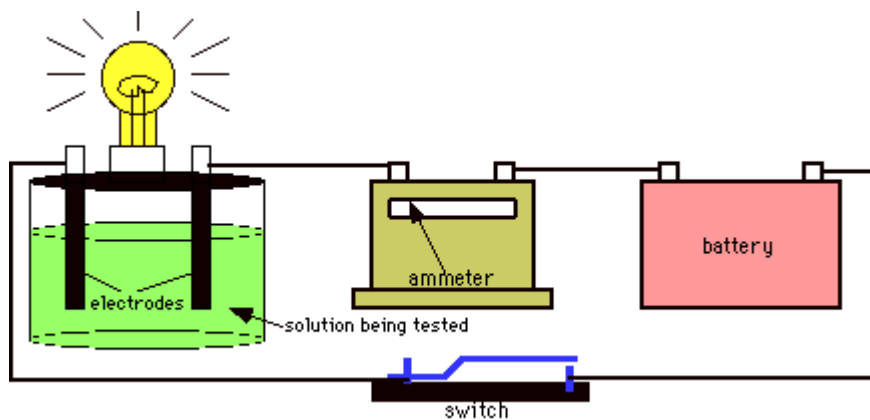
## 15.2 Homogeneous Aqueous Systems

### I. Solutions

- A. Soluble
  - 1. Capable of being dissolved
- B. Solution
  - 1. A homogeneous mixture of two or more substances in a single phase
- C. Solvent
  - 1. The dissolving medium in a solution
- D. Solute
  - 1. The dissolved substance in a solution
- E. Types of solutions
  - 1. Gaseous mixtures
    - a. Air is a solution
  - 2. Solid solutions
    - a. Metal alloys
  - 3. Liquid solutions
    - a. Liquid dissolved in a liquid (alcohol in water)
    - b. Solid dissolved in a liquid (salt water)

### II. Solutes: Electrolytes vs. Nonelectrolytes

- A. Electrolyte
  - 1. A substance that dissolves in water to give a solution that conducts electric current
  - 2. Solutions of acids, bases and salts are electrolytes
- B. Nonelectrolyte
  - 1. A substance that dissolves in water to give a solution that does not conduct an electric current
- C. Measuring Conductivity



- 1. Good conductors
  - a. Lamp glows brightly, ammeter registers a substantial current
- 2. Moderate conductors
  - a. Lamp is dull, ammeter registers a small current
- 3. Nonconductors
  - a. Lamp does not glow, ammeter may not register a current at all

### 15.3 Heterogeneous Aqueous Systems

- I. Suspensions
  - A. A mixture from which particles settle out upon standing
- II. Colloids
  - A. Colloidal Dispersions (Colloids)
    - 1. Tiny particles suspended in some medium
    - 2. Particles range in size from 1 to 1000 nm.
  - B. Tyndall Effect
    - 1. Scattering of light by particles
      - a. Light passes through a solution
      - b. Light is scattered in a colloid

Types of Colloids			
Examples	Dispersing Medium	Dispersed Substance	Colloid Type
Fog, aerosol sprays	Gas	Liquid	Aerosol
Smoke, airborne bacteria	Gas	Solid	Aerosol
Whipped cream, soap suds	Liquid	Gas	Foam
Milk, mayonnaise	Liquid	Liquid	Emulsion
Paint, clays, gelatin	Liquid	Solid	Sol
Marshmallow, polystyrene foam	Solid	Gas	Solid foam
Butter, cheese	Solid	Liquid	Solid emulsion
Ruby glass	Solid	Solid	Solid sol

### 16.1 Properties of Solutions

- I. Factors Affecting the Rate of Dissolution
  - A. Increasing the Surface Area of the Solute (Particle size)
    - 1. Finely divided substances dissolve more rapidly
  - B. Agitating a Solution
    - 1. Stirring or shaking brings solvent into contact with more solute particles
    - 2. Added energy temporarily increases solubility
  - C. Heating
    - 1. Heating always increasing the rate of dissolution of solids in liquids
- II. Solubility
  - A. Solution Equilibrium
    - 1. The physical state in which the opposing processes of dissolution and crystallization of a solute occur at equal rates
  - B. Saturation Levels
    - 1. Saturated solution
      - a. A solution that contains the maximum amount of dissolved solute
    - 2. Unsaturated solutions
      - a. A solution that contains less solute than a saturated solution under the existing conditions
    - 3. Supersaturated Solutions
      - a. A solution that contains more dissolved solute than a saturated solution contains under the same conditions
  - C. Solubility Values
    - 1. The solubility of a substance is the amount of that substance required to form a saturated solution with a specific amount of solvent at a specified temperature
    - 2. The rate at which a substance dissolves does not alter the substances solubility

### III. Factors Affecting Solubility

#### A. "Like dissolves like"

1. Polar substances dissolve in polar solvents
2. Nonpolar substances dissolve in nonpolar solvents

#### B. Dissolving Ionic Compounds in Aqueous Solutions

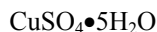
1. Electropositive hydrogen of the water molecule is attracted to negatively charged ions
2. Electronegative oxygen of the water molecule is attracted to positively charged ions

#### 3. Hydration

1. The solution process with water as the solvent

#### 4. Hydrates

1. Ionic substances that incorporate water molecules into their structure during the recrystallization process



- a. the "•" means that the water is loosely attached

#### C. Nonpolar Solvents

1. Polar and ionic compounds are not soluble in nonpolar solvents
2. Fats, oils and many petroleum products are soluble in nonpolar solvents
3. Nonpolar solvents include  $\text{CCl}_4$  and toluene (methyl benzene),  $\text{C}_6\text{H}_5\text{CH}_3$

#### D. Liquid Solutes and Solvents

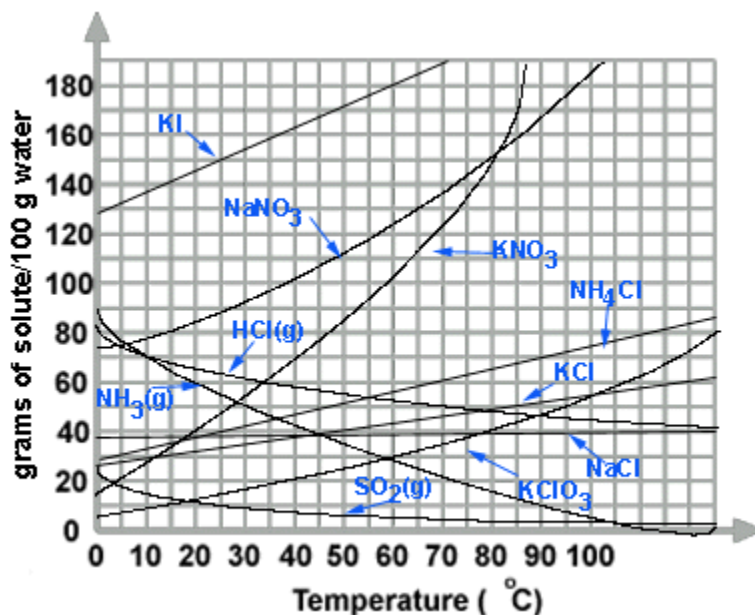
1. Immiscible - Liquid solutes and solvents that are not soluble in each other
  - a. Oil and water
2. Miscible - Liquids that dissolve freely in one another in any proportion
  - a. Benzene and carbon tetrachloride (both nonpolar)
  - b. Water and ethanol (both polar)

#### E. Effects of Pressure on Solubility

1. Pressure has no real effect on the solubilities of liquids and solids in liquid solvents
2. Increasing pressure increases the solubility of gases in liquids

#### F. Effects of Temperature on Solubility

1. Solubility of solids (generally) increases with temperature
2. Solubility of gases decreases with temperature



## 16.2 Concentration of Solutions

Concentration - A measure of the amount of solute in a given amount of solvent or solution

**Grams per liter** represent the mass of solute divided by the volume of solution, in liters. This measure of concentration is most often used when discussing the solubility of a solid in solution.

**Molarity** describes the concentration of a solution in moles of solute divided by liters of solution. Masses of solute must first be converted to moles using the molar mass of the solute. This is the most widely used unit for concentration when preparing solutions in chemistry and biology. The units of molarity, mol/L, are usually represented by a scripted capital "*M*".

**Parts per million (ppm)**, is a ratio of parts of solute to one million parts of solution, and is usually applied to very dilute solutions. It is often found in reports of concentration of water contaminants. To calculate parts per million, divide the mass of the solute by the total mass of the solution. This number is then multiplied by  $10^6$  and expressed as parts per million (ppm). In dilute water solutions, we can assume that 1 mL of water-based solution has a mass of 1 gram, so 1 liter of solution has a mass of 1000 grams.

**Percent composition** is the ratio of one part of solute to one hundred parts of solution and is expressed as a percent. Determine the mass of solute and solution and then divide the mass of the solute by the total mass of the solution. This number is then multiplied by 100 and expressed as a percent. In dilute water solutions, we can assume that 1 mL of water-based solution has a mass of 1 gram, so 1 liter of solution has a mass of 1000 grams.

## 16.3 Colligative Properties of Solutions

Colligative Properties: Properties that depend on the concentration of solute particles but not on their identity

### I. Vapor Pressure Lowering

#### A. Volatility

1. Nonvolatile substances
  - a. Substances that have little or no tendency to become a gas under existing conditions
2. Volatile substances
  - a. Substances with a definite tendency to become gases under existing conditions

#### B. Effect of Solutes on Vapor-Pressure

1. Any nonvolatile solute will lower the vapor pressure of a solution, having two noticeable effects
  - a. Raising the boiling point of the solution
  - b. Lowering the freezing point of the solution

### II. Freezing-Point Depression

#### A. Molal Freezing-Point Constant for Water

1. The freezing-point depression of the solvent in a 1-molal solution of a nonvolatile, nonelectrolyte solute
2.  $K_f = -1.86 \text{ }^\circ\text{C/m}$

#### B. Freezing-Point Depression

1. The difference between the freezing points of the pure solvent and a solution of a nonelectrolyte in that solvent

$$\Delta t_f = K_f m$$

#### C. Molal Boiling-Point Constant for Water

1. The boiling point elevation of the solvent in a 1-molal solution of a nonvolatile, nonelectrolyte solute
2.  $K_b = 0.51 \text{ }^\circ\text{C/m}$

#### D. Boiling-Point Elevation

1. The difference between the boiling points of the pure solvent and a solution of a nonelectrolyte in that solvent

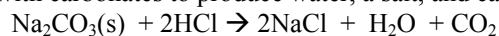
$$\Delta t_b = K_b m$$

## 19.1 Acid-Base Theories

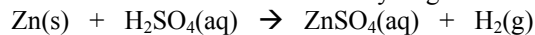
### I. Acids

#### A. Properties of Acids

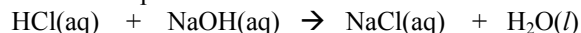
1. Aqueous solutions have a sour taste
2. Acids change the color of acid-base indicators
3. Acids react with carbonates to produce water, a salt, and carbon dioxide



4. Some acids react with active metals to release hydrogen



5. Acids react with bases to produce salts and water



6. Acids conduct electric current

#### B. Strength of Acids

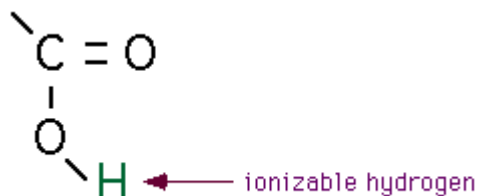
1. Strong acids ionize completely in solution
2. Weak acids ionize only slightly and are weak electrolytes

<i>Strong acids</i>	<i>Weak acids</i>
$\text{H}_2\text{SO}_4$	$\text{H}_3\text{PO}_4$
$\text{HClO}_4$	$\text{HF}$
$\text{HCl}$	$\text{HC}_2\text{H}_3\text{O}_2$
$\text{HNO}_3$	$\text{H}_2\text{CO}_3$
$\text{HBr}$	$\text{H}_2\text{S}$
$\text{HI}$	$\text{HCN}$

#### C. Organic Acids

1. Covalent molecular substances containing a carboxyl group
  - a. (-COOH)
2. Weak acids (only slightly ionize)
3. Examples

- a. Butyric acid - in rancid butter
- b. Lactic acid - in sour milk
- c. Citric acid - in citrus fruit
- d. Acetic acid - in vinegar



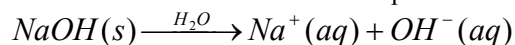
### II. Bases

#### A. Properties of Bases

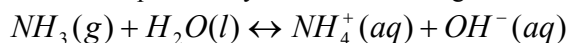
1. Aqueous solutions of bases have a bitter taste
2. Bases change the color of acid-base indicators
3. Dilute aqueous solutions of bases feel slippery
4. Bases react with acids to produce salts and water
5. Bases conduct electric current

#### B. Aqueous Solutions of Bases

1. Ionic bases dissociate to some extent when placed in water



2. Basic solutions are referred to as "alkaline"
3. Molecular bases produce hydroxide ions through a reaction with water



#### C. Strength of Bases

1. Strength of ionic bases is linked to solubility
  - a. High solubility = strong base
  - b. Low solubility = weak base
2. Molecular bases tend to be weak regardless of solubility

III. Arrhenius Acids and Bases

A. Acids

1. Acids are hydrogen-containing compounds that ionize in solution to produce  $H^+$  ions

B. Bases

1. Bases are compounds that produce  $OH^-$  ions in solution

IV. Bronsted-Lowry Acids and Bases

A. Acids

1. Acids are proton ( $H^+$  ion) donors in solution

B. Bases

1. Bases are proton acceptors in solution