

Lecture Presentation

Chapter 8

Solution Chemistry

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Outline

- 8.1 Solutions Are Mixtures
- 8.2 Formation of Solutions
- 8.3 Chemical Equations for Solution Formation
- 8.4 Concentrations
- 8.5 Dilution
- 8.6 Osmosis and Diffusion
- 8.7 Transport across Cell Membranes

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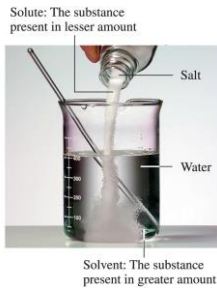
8.1 Solutions Are Mixtures

- A glass of iced tea represents a type of homogeneous mixture called a **solution**.
- A solution consists of at least one substance—the **solute**—evenly dispersed throughout a second substance—the **solvent**.
- The components in a solution do not react with each other: the sugar is still sugar.
- The solute is the substance present in the smaller amount, and the solvent is the substance present in the larger amount.

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8.1 Solutions Are Mixtures

- A glass of iced tea is translucent; if held up to a light, you can see through the liquid.
- Once the sugar is dissolved into the water, it will not undissolve over time.
- These properties provide a quick way to determine whether a substance is a solution.



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8.1 Solutions Are Mixtures

TABLE 8.1 Some Properties of Solutions

Particles are evenly distributed.
Components do not chemically react with each other.
Aqueous solutions are transparent.
Components do not separate upon standing.
Concentration can be changed.

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8.1 Solutions Are Mixtures

States of Solutes and Solvents

- Solutions can be homogeneous mixtures of gases.
 - Air is a homogeneous mixture of gases, so it is also a solution in which nitrogen is the solvent and oxygen and other gases are the solutes.
- Brass is a solution of solids in solids.
 - It is the solute metal zinc in the solvent metal copper.
- The solute and solvent can be solid, liquid, or gas.

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8.1 Solutions Are Mixtures

Colloids and Suspensions

- Homogenized milk is not a transparent liquid, so not a solution.
- Homogenized milk is a **colloid** (or colloidal mixture) because of the proteins and fat molecules that do not dissolve.
- By definition, the particles in a colloid must be between 1 and 1000 nanometers in diameter.
- Particles of this size remain suspended in solution, so a colloid does not separate over time.

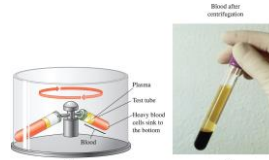


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8.1 Solutions Are Mixtures

Colloids and Suspensions

- Muddy water will separate upon standing. If the diameter of the particles in a mixture is greater than 1000 nanometers (1 micrometer), the mixture is a **suspension**.
- Blood is also a suspension. Blood cells are larger than 1 micrometer and will settle to the bottom of a test tube upon standing.
- Blood can be separated by centrifugation.



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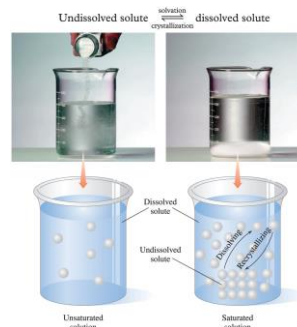
8.2 Formation of Solutions

Factors Affecting Solubility and Saturated Solutions

- If a solution does *not* contain the maximum amount of the solute that the solvent can hold, it is **unsaturated**.
- If a solution contains all the solute that can possibly dissolve, the solution is **saturated**.
- If more solute is added to a saturated solution, the additional solute would remain undissolved.
- A solution that is saturated reaches an **equilibrium** state between the dissolved solute and undissolved solute.
- The rate of dissolving solute and the rate of dissolved solute reforming crystals are the same. This can be represented in an equation where a double arrow or *equilibrium arrow* is used between the products and reactants in the chemical equation.

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8.2 Formation of Solutions



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8.2 Formation of Solutions

GOUT, KIDNEY STONES, AND SOLUBILITY

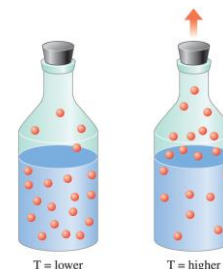
- Gout and kidney stones happen when compounds exceed their solubility limits in the body.
- In the case of gout, the solid compound is uric acid. In some individuals, the release of uric acid into the urine is reduced, causing a buildup in bodily fluids. Insoluble needlelike crystals form in cartilage and tendons at the joints, often in the ankles and feet.
- Kidney stones contain uric acid, calcium phosphate, or calcium oxalate. They form in the urinary tract, kidneys, ureter, or bladder when the compounds do not remain dissolved in the urine.
- Both gout and kidney stones can be treated through changes in diet and drug therapy.

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8.2 Formation of Solutions

Solubility and Temperature

- The solubility of most solids dissolved in water *increases* with temperature.
- Solubility can be manipulated by changing the temperature of a solution.
- The solubility of a gas dissolved in water *decreases* with a rise in temperature.

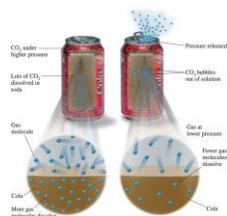


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8.2 Formation of Solutions

Solubility and Pressure—Henry's Law

- The relationship between gas solubility and pressure was summarized by the English chemist William Henry.
- Henry's law:** the solubility of a gas in a liquid is directly related to the pressure of that gas over the liquid.



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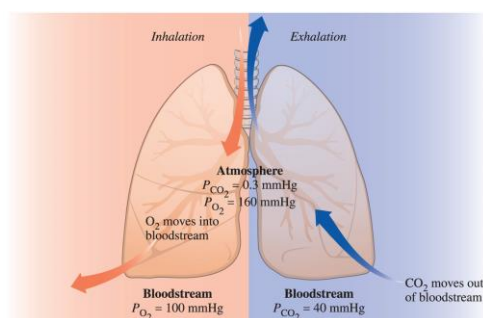
8.2 Formation of Solutions

Solubility and Pressure—Henry's Law

- The pressure exerted by carbon dioxide produced in the tissues or the pressure of oxygen inhaled at the lungs results in an exchange of gases.
- If the pressure of CO₂ is higher in the blood delivered back to the lungs (coming from the tissues) than the pressure of CO₂ found at the lungs, the gaseous CO₂ will pass out of the bloodstream into the lungs.
- Similarly, oxygen dissolves into the blood at the lungs because the pressure of oxygen in the air is higher, allowing it to dissolve in the bloodstream.
- This oxygenated blood then circulates throughout the body.

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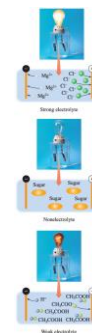
8.2 Formation of Solutions



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8.3 Chemical Equations for Solution Formation

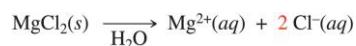
- Ionic compounds that dissolve in water are **strong electrolytes**.
- Covalent compounds do not **ionize** in solution, do not conduct electricity, and are **nonelectrolytes**.
- Some covalent compounds partially ionize in water. These are **weak electrolytes**.



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8.3 Chemical Equations for Solution Formation

Strong Electrolytes

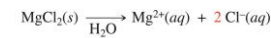


- The number of magnesium and chloride ions formed as products is the same as the number in the reactant.
- This was first stated by the French chemist Antoine Lavoisier (1743–1794) as the **law of conservation of matter**: Matter can neither be created nor destroyed.
- The coefficient 2 indicates that two chloride ions are produced for every MgCl₂ that dissociates.
- MgCl₂ has no net charge. One Mg²⁺ and two Cl⁻ sum to a total charge of zero: the charges are also balanced.

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8.3 Chemical Equations for Solution Formation

Strong Electrolytes



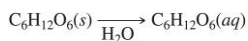
Charge in reactants = 0 Charge in products
2 + 2(-1) = 0

- The reaction arrow points in one direction, implying that the process occurs in only one direction.
- For ionic compounds, the reactants will usually be a solid that dissolves. In the products, the phases will always be aqueous.
- Substances, such as solvent, that are not involved in the balanced equation are often placed at the arrow to give information regarding the conditions of the reaction.

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8.3 Chemical Equations for Solution Formation

Nonelectrolytes



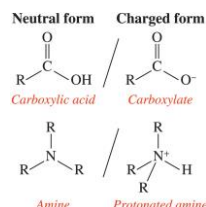
- Nonelectrolytes are polar compounds that dissolve in water but do not ionize in water.
- Covalent compounds do not dissociate.
- The only difference between the reactant and the product is the phase.
- We indicate this on the products side of the chemical equation by changing the phase of the solute molecules to aqueous.

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8.3 Chemical Equations for Solution Formation

Weak Electrolytes

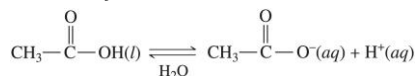
- There are two functional groups that contain a form with an ionic charge, the carboxylic acid/carboxylate group and the amine/protonated amine.
- Carboxylic acids and amines are weak electrolytes.



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8.3 Chemical Equations for Solution Formation

Weak Electrolytes



- As the number of H^+ and CH_3COO^- ions builds up in the solution, some will recombine to form CH_3COOH .
- Eventually, the rates of the forward and reverse reactions equalize, and an equilibrium exists. An equilibrium arrow is used in this chemical equation to indicate this.
- The number of atoms and the total charge on each side are balanced, so the equation is balanced.
- The phase of the weak electrolyte before hydration may be solid, liquid, or gas.

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8.3 Chemical Equations for Solution Formation

Ionic Solutions and Equivalents

- Blood and other bodily fluids contain many electrolytes as dissolved ions.
- The amount of a dissolved ion found in fluids can be expressed by the unit **equivalent (Eq)**. An equivalent relates the charge in a solution to the number of ions or the moles of ions present.
- One mole of Na^+ has one equivalent of charge because the charge on a sodium ion is plus 1. One mole of Ca^{2+} has two equivalents of charge because one mole of calcium contains two charges (or equivalents) per mole.
- The number of equivalents present per mole of an ion equals the charge on that ion.*

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8.3 Chemical Equations for Solution Formation

Electrolytes in Blood Plasma

- The amount of electrolytes present in bodily fluids and intravenous fluid replacements is represented as milliequivalents per liter of solution (mEq/L).
- Ionic solutions have a balance in the number of positive and negative charges present because they are formed by dissolving ionic compounds that have no net charge.
- Typical blood plasma has a total electrolyte concentration of 150 mEq/L: the total concentration of both positive and negative ions is 150 mEq/L.

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8.3 Chemical Equations for Solution Formation

TABLE 8.4 Electrolyte Concentrations in Intravenous Replacement Solutions

Solution	Electrolytes (mEq/L)	Use
Sodium chloride (0.90%)	Na^+ 154, Cl^- 154	Replacement of fluid loss
Potassium chloride with 5.0% dextrose	K^+ 40, Cl^- 40	Treatment of malnutrition (low potassium levels)
Ringer's solution	Na^+ 147, K^+ 4, Ca^{2+} 4, Cl^- 155	Replacement of fluids and electrolytes lost through dehydration
Maintenance solution with 5.0% dextrose	Na^+ 40, K^+ 35, Cl^- 40, lactate $^-$ 20, HPO_4^{2-} 15	Maintenance of fluid and electrolyte levels
Replacement solution (extracellular)	Na^+ 140, K^+ 10, Ca^{2+} 5, Mg^{2+} 3, Cl^- 103, acetate $^-$ 47, citrate $^{3-}$ 8	Replacement of electrolytes in extracellular fluids

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8.4 Concentrations

TABLE 8.3 Some Typical Concentrations of Electrolytes in Blood Plasma

Electrolyte (mEq/L)	Concentration
Cations	
Na ⁺	138
K ⁺	5
Mg ²⁺	3
Ca ²⁺	4
Total	150
Anions	
Cl ⁻	110
HCO ₃ ⁻	30
HPO ₄ ²⁻	4
Proteins	6
Total	150

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8.4 Concentrations

Millimoles per Liter (mmol/L) and Molarity (M)

- Sometimes the units for electrolytes are given in mmoles/L instead of mEq/L.
- The charge on an ion is the number of equivalents present in 1 mole.
- For an ion with a +1 charge, the units mEq/L and mmole/L are the same.
- A related unit is molarity (M), which is defined as

$$M = \frac{\text{mole solute}}{\text{L solution}}$$

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8.4 Concentrations

SOLVING A PROBLEM: CALCULATING MOLARITY

- **Step 1: Examine the problem.** Decide what information is given and what information is being sought.
- **Step 2: Find appropriate conversion factors.**
- **Step 3: Solve the problem.** Be sure that the units you don't want cancel and you are left with the units you need.

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8.4 Concentrations

Percent (%) Concentration

- There are three common concentration units that use percent: mass/volume percent, mass/mass percent, and volume/volume percent.

Percent Mass/Mass, % (m/m) or % (wt/wt)

- A % (m/m) solution is prepared by measuring solute and solvent on a balance and mixing.
- Mass of solute + mass of solvent = mass of solution.

$$\%(\text{m/m}) = \frac{\text{g solute}}{\text{g solution}} \times 100\%$$

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8.4 Concentrations

Relationship to Other Common Units

- The unit used for measurement of hemoglobin in the blood is g/dL, which is the same as % (m/v).
- A deciliter is equal to 100 mL, so g/dL is the same as g/100 mL.
- To measure molecules like glucose and cholesterol, milligrams per deciliter (mg/dL) are used.
- This unit is also mg% (milligram percent). The mg in front of the % symbol indicates that the definition is mg per 100 mL.

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8.4 Concentrations

Parts per Million (ppm) and Parts per Billion (ppb)

- Parts per million (ppm) and parts per billion (ppb) are convenient units for very dilute solutions.
- A penny is a ppm of \$10,000.
- In terms of volume, 1 drop of food coloring in an Olympic-sized swimming pool of water is about a part per billion.
- Ppm is sometimes referred to as 1 mg/L and ppb as 1 µg/L.
- Percent mass/volume (% m/v) is *parts per hundred*. Ppm and ppb can be determined by multiplying by a million or a billion, respectively.

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8.5 Dilution

- One way to prepare solutions of lower concentration is to dilute a solution of higher concentration by adding more solvent.



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8.5 Dilution

- When you add water to a can of orange juice, the amount of orange juice present does not change.
- The *amount of solute* stayed the same, but the *volume* of solution increased, so the *concentration* of the solution decreased.



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8.5 Dilution

- The following dilution equation represents this mathematically, where
 - C_{initial} represents the initial concentration,
 - C_{final} represents the final concentration,
 - V_{initial} represents the initial volume, and
 - V_{final} represents the final volume.
- If three of the variables are known, the fourth can be determined.

$$C_{\text{initial}} V_{\text{initial}} = C_{\text{final}} V_{\text{final}}$$

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8.5 Dilution

- The dilution equation works with any concentration unit where the amount of solution is expressed in volume units.
- The dilution equation is useful because many pharmaceuticals are prepared as concentrates and must be diluted.

Using the Dilution Equation

- Step 1: Establish the given information.
- Step 2: Arrange the dilution equation to solve for the unknown quantity.
- Step 3: Solve for the unknown quantity.

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8.6 Osmosis and Diffusion

Osmosis

- Our bodies are mostly water, composed of a set of specialized aqueous solutions.
- The solutions are separated by a semipermeable *cell membrane*, which allows some molecules to pass through but not others.
- Under normal physiological conditions, these are **isotonic solutions**, meaning that the concentration of dissolved solutes is the same on both sides of the membrane.

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8.6 Osmosis and Diffusion

Osmosis

- When a person drinks large quantities of water, it dilutes the blood, resulting in an imbalance between the concentration of solutes outside and inside the cells.
- The solution outside of the cells is **hypotonic**.
- Water will travel across the cell membrane in an attempt to equalize the concentrations.
- This passage of water is called **osmosis**.
- If too much water enters, the cells swell up and could even burst (a phenomenon called lysing).

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8.6 Osmosis and Diffusion

Osmosis

- As water flows through a semipermeable membrane, the water molecules in the more concentrated solution exert pressure on the membrane.
- This is **osmotic pressure**.
- The more concentrated the solution, the higher the osmotic pressure.
- Pure water has an osmotic pressure of zero.
- Applying pressure in opposition to the osmotic pressure will stop osmosis.

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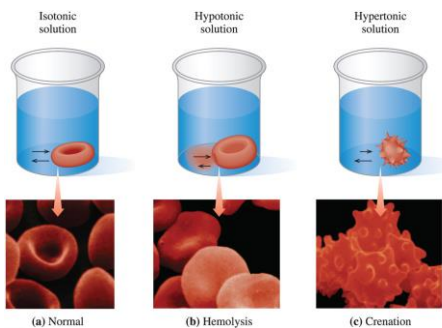
8.6 Osmosis and Diffusion

Osmosis

- The concentration of dissolved ions in sea water is about three times that of the blood.
- When sea water is consumed, it draws water out of the cells.
- If a person were to drink sea water, the concentration of solutes in the bloodstream would go up, resulting in a **hypertonic solution**.
- During dehydration, the cells shrivel in a process known as **crenation**.

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8.6 Osmosis and Diffusion



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8.6 Osmosis and Diffusion

- Intravenous (IV) solutions delivered into patients' bloodstreams are isotonic.
- They have solute concentrations equal to the solute concentrations inside of cells.
- Isotonic solutions minimize osmosis.
- Common isotonic IV solutions used in hospitals include 0.90% (m/v) NaCl (normal saline, NS) and a 5% (m/v) D-glucose (dextrose) solution commonly referred to as D5W ("Dextrose 5% in Water").
- These are called **physiological solutions**.

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8.6 Osmosis and Diffusion

Diffusion

- If a drop of green food coloring is put into a large beaker of water, the green dye molecules (solute) will mix with the water (solvent) and the resulting solution will have a uniform light green tinge to it.
- The two solutions spontaneously mix, and the green solute molecules *diffuse* into the water to form one dilute solution with a final green color intermediate between green food coloring from the dropper bottle and water.

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8.6 Osmosis and Diffusion

Dialysis

- **Diffusion** is the movement of molecules in a direction that equalizes concentration.
- The kidneys act to remove small waste molecules out of the blood through diffusion across membranes in the kidneys.
- Cells and larger molecules are reabsorbed into the bloodstream.
- Small molecules diffuse out of the blood (higher concentration) and move into urine (lower concentration) in a process called **dialysis**.

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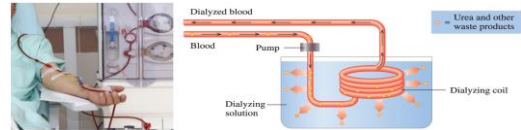
8.6 Osmosis and Diffusion

Dialysis

- A person whose kidneys are failing can undergo artificial dialysis—called hemodialysis—to cleanse the blood.
- In this process, blood is removed from the patient and passes through one side of a semipermeable membrane in contact on the opposite side with an isotonic dialyzing solution.
- Urea and small waste molecules diffuse out of the passing blood and into the dialyzing solution, and the dialyzed blood returns to the patient.

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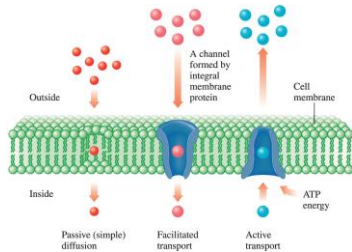
8.6 Osmosis and Diffusion



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8.7 Transport across Cell Membranes

- Ions, nonpolar molecules, and polar molecules move across cell membranes using diffusion, facilitated transport, and active transport.



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8.7 Transport across Cell Membranes

- Small molecules like water and the nonpolar molecules O_2 , N_2 , and CO_2 can diffuse directly through the cell membrane.
- Diffusion moves solutes to equalize the concentrations on either side of a membrane.
- This process does not require any additional energy so is also referred to as **passive diffusion**.
- Other nonpolar molecules like steroids can also passively diffuse through cell membranes.

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8.7 Transport across Cell Membranes

- To enable small molecules and ions to pass through the cell membrane, some proteins in the cell membrane have polar channels that open and close, allowing small polar molecules and ions to be transported across the cell membrane.
- These proteins are often integral membrane proteins, spanning the phospholipid bilayer.
- This **facilitated transport** does not require energy.
- Glucose transporter proteins are found in virtually all cell membranes and facilitate transport of glucose into the cell when blood glucose concentrations are high.

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8.7 Transport across Cell Membranes

- Transporting ions or small polar molecules across the cell membrane in a direction opposite to equalizing concentrations requires the assistance of a protein channel or pump.
- **Active transport** requires energy, usually in the form of the energy molecule adenosine triphosphate (ATP).
- One active transport pump, the K/H ATPase, controls the concentration of potassium and hydrogen ions in the stomach.
- Medications like Tagamet®, Zantac®, and Pepcid® block the production of stomach acid through these pumps.

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Chapter Eight Summary

8.1 Solutions Are Mixtures

- A solution forms when a solute dissolves in a solvent.
- In a solution, the particles of a solute are evenly distributed in the solvent.
- The solute and solvent may be solid, liquid, or gas.
- Solutions are transparent.
- Mixtures with particles suspended in a solution are colloids and are usually not transparent.
- Mixtures that contain particles that settle upon standing are suspensions.

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Chapter Eight Summary

8.2 Formation of Solutions

- An increase in temperature increases the solubility of most solids in water but decreases the solubility of gases in water.
- Henry's law discusses the relationship between pressure and gas solubility.
- Increasing the pressure above a solution with a dissolved gas in it increases the solubility of the gas.
- A solution that contains the maximum amount of dissolved solute is a saturated solution.
- A solution that is saturated reaches an equilibrium state between the dissolved solute and undissolved solid solute where the rate of dissolving and reforming crystals is the same.

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Chapter Eight Summary

8.3 Chemical Equations for Solution Formation

- Hydration equations can be written for solutes dissolving in solvents. The form of this equation depends on the ability of the solute to dissociate in solution.
- Substances that release ions when they dissolve in water are called electrolytes because the solution will conduct an electrical current.
- Strong electrolytes are ionic compounds that completely dissociate in water.
- Weak electrolytes only partially dissociate into ions.
- Nonelectrolytes are substances (usually covalent compounds) that dissolve in water but do not dissociate.
- The unit known as an equivalent expresses the amount of dissolved ion in fluids. The number of equivalents per mole of an ion equals the charge on that ion.

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Chapter Eight Summary

8.4 Concentration

- The concentration of a solution is the amount of solute dissolved in a certain amount of solution.
- Fluid replacement solutions are often expressed in units of mEq/L or in some cases mmol/L.
- Molarity is the moles of solute per liter of solution.
- Percent mass/volume expresses the ratio of the mass of solute (in g) to the volume of solution (in mL) multiplied by 100. This percent mass/volume is equivalent to the unit g/dL.
- Percent concentration is also expressed as mass/mass and volume/volume ratios.
- Parts per million and parts per billion describe very dilute solutions.

8.5 Dilution

- When a solution is diluted, the amount of solute stays the same while the volume of solution increases.
- The concentration of the solution decreases.

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Chapter Eight Summary

8.6 Osmosis and Diffusion

- In osmosis, solvent (water) passes through a semipermeable membrane from a solution of lower solute concentration to a solution of higher solute concentration.
- The osmotic pressure exerted on the membrane is directly related to the number of water molecules pushing against that membrane.
- Isotonic solutions have osmotic pressures equal to those of bodily fluids. Cells maintain their volume in an isotonic solution, but they swell and may burst in a hypotonic solution and shrivel in a hypertonic solution.
- In dialysis, water and small solute particles pass through a dialyzing membrane in a related process called diffusion while large particles like proteins are retained.

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Chapter Eight Summary

8.7 Transport across Cell Membranes

- The semipermeable membrane surrounding cells separates the cellular contents from the external fluids.
- Molecules can be transported across the cell membrane by passive diffusion, facilitated transport, or active transport depending on their concentration inside and outside the cell and their polarity.

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Chapter Eight Study Guide

- **8.1 Solutions Are Mixtures**
 - Distinguish solute and solvent.
 - Identify solutions, colloids, and suspensions.
- **8.2 Formation of Solutions**
 - Define saturated and dilute solutions.
 - Predict the effect of temperature on the solubility of a solute.
 - Predict the effect of pressure on the solubility of a gas in a liquid.

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Chapter Eight Study Guide

- **8.3 Chemical Equations for Solution Formation**
 - Write chemical equations for hydration of electrolytes, nonelectrolytes, and weak electrolytes.
 - Calculate the number of milliequivalents present for an ionic compound that fully dissociates in solution.
 - Convert from mEq to moles.
- **8.4 Concentrations**
 - Express concentration in molarity units.
 - Express concentration in percent units.
 - Express concentration in parts per million and parts per billion.

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Chapter Eight Study Guide

- **8.5 Dilution**
 - Calculate concentrations or determine volumes using the dilution equation.
- **8.6 Osmosis and Diffusion**
 - Predict the direction of osmosis or diffusion given the concentration on both sides of a semipermeable membrane.
- **8.7 Transport across Cell Membranes**
 - Characterize three forms of transport across a cell membrane.

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