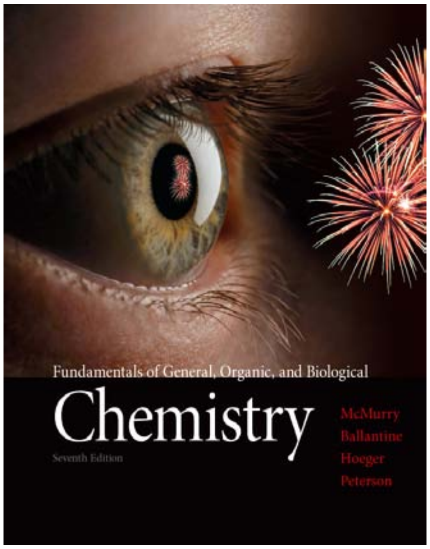
Chapter 9 Lecture



Fundamentals of General, Organic, and Biological Chemistry

7th Edition

McMurry, Ballantine, Hoeger, Peterson

Chapter Nine

Solutions

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ALWAYS LEARNING PEARSON

Outline

9.1 Mixtures and Solutions
9.2 The Solution Process
9.3 Solid Hydrates
9.4 Solubility
9.5 The Effect of Temperature on Solubility
9.6 The Effect of Pressure on Solubility: Henry's Law
9.7 Units of Concentration
9.8 Dilution
9.9 Ions in Solution: Electrolytes
9.10 Electrolytes in Body Fluids: Equivalents and Milliequivalents
9.11 Properties of Solutions
9.12 Osmosis and Osmotic Pressure
9.13 Dialysis

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Goals

1. **What are solutions, and what factors affect solubility?**

   Be able to define the different kinds of mixtures and explain the influence on solubility of solvent and solute structure, temperature, and pressure.

2. **How is the concentration of a solution expressed?**

   Be able to define, use, and convert between the most common ways of expressing solution concentrations.

3. **How are dilutions carried out?**

   Be able to calculate the concentration of a solution prepared by dilution and explain how to make a desired dilution.

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Goals, *Continued*

4. **What is an electrolyte?**

   Be able to recognize strong and weak electrolytes and nonelectrolytes, and express electrolyte concentrations.

5. **How do solutions differ from pure solvents in their behavior?**

   Be able to explain vapor-pressure lowering, boiling-point elevation, and freezing-point depression for solutions.

6. **What is osmosis?**

   Be able to describe osmosis and some of its applications.

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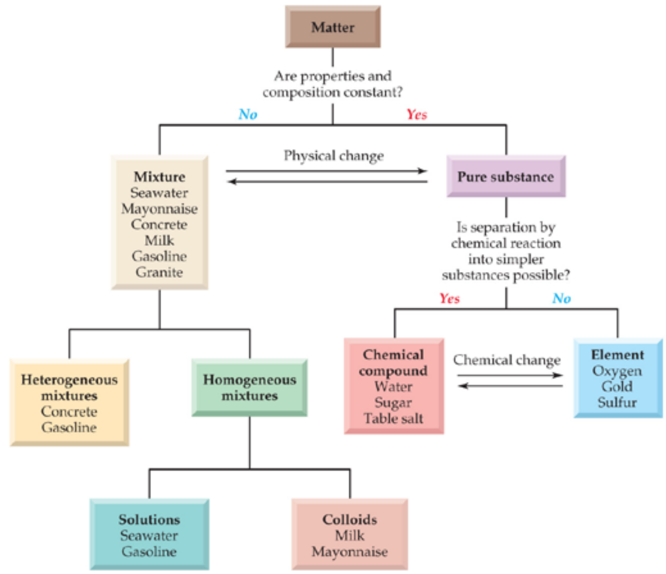
9.1 Mixtures and Solutions



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9.1 Mixtures and Solutions

- **Heterogeneous mixtures** are those in which the mixing is not uniform and have regions of different composition.
- **Homogeneous mixtures** are those in which the mixing *is* uniform and have the same composition throughout.
  – **Solutions** are homogeneous mixtures that contain particles the size of a typical ion or small molecule.
  – **Colloids** are homogeneous mixtures that contain particles ranging in diameter from 2 to 500 nm.

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9.1 Mixtures and Solutions

TABLE 9.1 Some Characteristics of Solutions, Colloids, and Heterogeneous Mixtures

Type of Mixture	Particle Size	Examples	Characteristics
Solution	<2.0 nm	Air, seawater, gasoline, wine	Transparent to light; does not separate on standing; nonfilterable
Colloid	2.0–500 nm	Butter, milk, fog, pearl	Often murky or opaque to light; does not separate on standing; nonfilterable
Heterogeneous	>500 nm	Blood, paint, aerosol sprays	Murky or opaque to light; separates on standing; filterable

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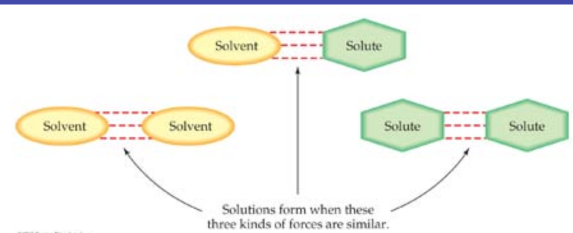
9.2 The Solution Process



- "Like dissolves like."
  - Polar solvents dissolve polar and ionic solutes.
  - Nonpolar solvents dissolve nonpolar solutes.
- "Oil and water don't mix."
  - The intermolecular forces between water molecules are so strong that after an oil–water mixture is shaken, the water layer re-forms, squeezing out the oil molecules.

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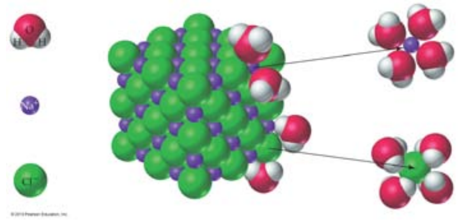
9.2 The Solution Process



- Positively charged Na^+ ions are attracted to the negatively polarized oxygen of water; negatively charged ions are attracted to the positively polarized hydrogens.
- The forces of attraction between an ion and water molecules pull the ion away from the crystal.
- Once in solution, the water molecules form a loose shell around the ions, stabilizing them by electrical attraction, a phenomenon called **solvation** or *hydration*.

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9.2 The Solution Process

- The dissolution of a solute in a solvent is a physical change since the solution components retain their chemical identities.
- The dissolution of a substance in a solvent has an *enthalpy* change associated with it.
- Some substances dissolve exothermically, releasing heat; other substances dissolve endothermically, absorbing heat and cooling the resultant solution.

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9.3 Solid Hydrates

- Some ionic compounds attract water strongly enough to hold onto water molecules even when crystalline, forming *solid hydrates*.
- In the formula of a hydrate, $CaSO_4$• ½ H_2O for example, the dot between the compound and the water indicates that there is one water for every two units of the ionic compound.
- Ionic compounds that attract water so strongly that they pull water vapor from humid air to become hydrated are called **hygroscopic.**

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9.4 Solubility

- **Miscible:** Mutually soluble in all proportions.
  - Ethyl alcohol will continue to dissolve in water no matter how much is added.
  - Most substances reach a solubility limit beyond which no more will dissolve in solution.
- **Saturated solution:** Contains the maximum amount of dissolved solute at equilibrium.
  - A maximum of 35.8 g of NaCl will dissolve in 100 mL of water at 20 °C. Any amount above this limit simply sinks to the bottom of the container and sits there.

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9.4 Solubility

- A saturated solution is in a state of dynamic equilibrium:

$$\text{Solid solute} \underset{\text{Crystallize}}{\overset{\text{Dissolve}}{\rightleftharpoons}} \text{Solution}$$

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- **Solubility:** The maximum amount of a substance that will dissolve in a given amount of solvent at a specified temperature.
  - Only 9.6 g of sodium hydrogen carbonate will dissolve in 100 mL of water at 20 °C, for instance, but 204 g of sucrose will dissolve under the same conditions.

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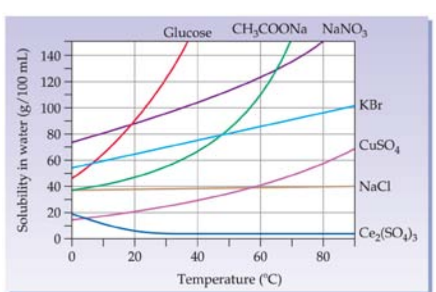
9.5 The Effect of Temperature on Solubility

- Temperature often has a dramatic effect on solubility, but is usually unpredictable.
- Most solids become more soluble as temperature rises, while the solubility of gases decreases.



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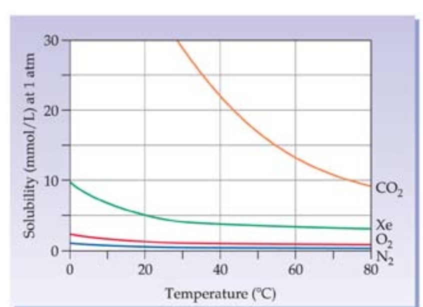

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9.5 The Effect of Temperature on Solubility

- Solids that are more soluble at high temperature than at low temperature can form **supersaturated solutions**.
- These are unstable and will precipitate dramatically when disturbed.

- Addition of heat decreases the solubility of most gases. As water temperature increases, the concentration of oxygen in the water decreases, killing fish that cannot tolerate low oxygen levels.

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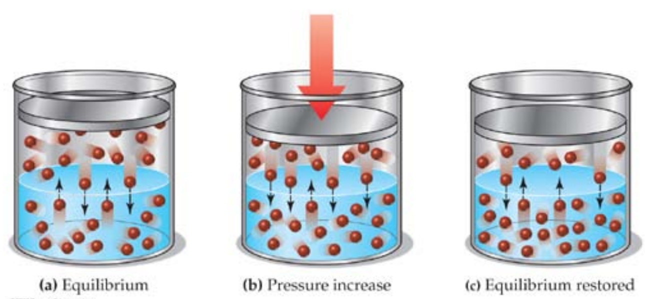
9.6 The Effect of Pressure on Solubility: Henry's Law

- Pressure has a strong effect on the solubility of a gas.



- **Henry's law:** The solubility of a gas is directly proportional to the partial pressure of the gas if the temperature is constant.

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9.6 The Effect of Pressure on Solubility: Henry's Law

- Henry's law can be explained using Le Châtelier's principle.

[Pressure increases ⟶]

$$\text{Gas} + \text{Solvent} \rightleftarrows \text{Solution}$$

  - When the system is stressed by increasing the pressure of the gas, more gas molecules go into solution to relieve that increase.
  - When the pressure of the gas is decreased, more gas molecules come out of solution to relieve the decrease.

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9.6 The Effect of Pressure on Solubility: Henry's Law

$$P_{gas} = C / k$$

- Partial pressure can be used to express the concentration of a gas in solution.
- If the partial pressure of a gas over a solution changes while the temperature is constant, the new solubility of the gas can be found easily:

$$\frac{C_1}{P_1} = \frac{C_2}{P_2}$$

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9.6 The Effect of Pressure on Solubility: Henry's Law

Breathing and Oxygen Transport

- When we breathe, oxygen diffuses through the alveolar sacs of the lungs and into arterial blood, which transports it to all body tissues.
- Only about 3% of the oxygen in blood is dissolved; the rest is bound to *hemoglobin* molecules, which can bind up to four O_2 molecules each.
- The delivery of oxygen depends on the concentration of O_2 in the various tissues, as measured by partial pressure and expressed as percent saturation.
- In the lungs, the partial pressure of oxygen is 100 mmHg, and the saturation is 97.5%, meaning that each hemoglobin is carrying close to its maximum of four O_2 molecules. When the partial pressure drops to 26 mmHg the saturation drops to 50%.
- When large amounts of oxygen are needed, oxygen is released from hemoglobin. Increasing the supply of oxygen to the blood (by breathing harder and faster) supplies the additional O_2 needed.
- At high altitudes, less oxygen is available. The body responds by producing erythropoietin (EPO), a hormone that stimulates the bone marrow to produce more red blood cells and hemoglobin molecules.

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9.7 Units of Concentration

TABLE 9.5 Some Units for Expressing Concentration

Concentration Measure	Solute Measure	Solution Measure
Percent		
Mass/mass percent, (m/m)%	Mass (g)	Mass (g)
Volume/volume percent, (v/v)%	Volume*	Volume*
Mass/volume percent, (m/v)%	Mass (g)	Volume (mL)
Parts per million, ppm	Parts*	10^6 parts*
Parts per billion, ppb	Parts*	10^9 parts*
Molarity, M	Moles	Volume (L)

*Any units can be used as long as they are the same for both solute and solution.

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9.7 Units of Concentration

- **Percent Concentrations**
  - For solid solutions, concentrations are typically expressed as **mass/mass percent concentration, (m/m)%**:

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

  - For liquid solutions, concentrations are expressed as **volume/volume percent concentration, (v/v)%.**

$$(v/v)\%\ \text{concentration} = \frac{\text{volume of solute (mL)}}{\text{volume of solution (mL)}} \times 100\%$$

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9.7 Units of Concentration

- **Percent Concentrations**
  - A third method is to give the number of grams of solute as a percentage of the number of milliliters. This is **mass/volume percent concentration, (m/v)%**:

$$(m/v)\%\ \text{concentration} = \frac{\text{Mass of solute (g)}}{\text{Volume of solution (mL)}} \times 100\%$$

  - The appropriate amount of solute is weighed and placed in a *volumetric flask*. Enough solvent is then added to dissolve the solute. Additional solvent is then added to reach final volume.

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9.7 Units of Concentration

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

- When concentrations are very small, as often occurs in dealing with trace amounts of pollutants or contaminants, it is more convenient to use **parts per million (ppm)** or **parts per billion (ppb)**. The "parts" can be in any unit of either mass or volume as long as the units of both solute and solvent are the same:

$$\text{ppm} = \frac{\text{Mass of solute (g)}}{\text{Mass of solution (g)}} \times 10^6 \text{ or } \frac{\text{Volume of solute (mL)}}{\text{Volume of solution (mL)}} \times 10^6$$

$$\text{ppb} = \frac{\text{Mass of solute (g)}}{\text{Mass of solution (g)}} \times 10^9 \text{ or } \frac{\text{Volume of solute (mL)}}{\text{Volume of solution (mL)}} \times 10^9$$

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9.7 Units of Concentration

Mole/Volume Concentration: Molarity

- The most generally useful means of expressing concentration in the laboratory is **molarity (M)**, the number of moles of solute dissolved per liter of solution.

$$\text{Molarity (M)} = \frac{\text{Moles of solute}}{\text{Liters of solution}}$$

- Note that a solution of a given molarity is prepared by dissolving the solute in enough solvent to give a *final* solution volume of 1.00 L, not by dissolving it in an *initial* volume of 1.00 L.
- Molarity can be used as a conversion factor to relate the volume of a solution to the moles of solute it contains.

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9.8 Dilution

- Many solutions are stored in high concentrations and then prepared for use by *dilution*.
- The amount of *solute* remains constant; only the *volume* is changed by adding more solvent.
- Because the number of moles remains constant, we can set up the following equation:

$$M_c V_c = M_d V_d$$

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9.8 Dilution

- This equation can be rewritten to solve for the concentration of the solution after dilution:

$$M_d = M_c \times \frac{V_c}{V_d}$$

- **Dilution factor** is the ratio of the initial and final solution volumes V_c / V_d.
- The dilution equation can be generalized to other concentration units: $C_c V_c = C_d V_d$.

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9.9 Ions in Solution: Electrolytes

- Ionic compounds in aqueous solution can conduct electricity.
- Conduction occurs because negatively charged Cl^- anions migrate through the solution toward the positive terminal of the power source, whereas cations migrate toward the negative terminal.

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9.9 Ions in Solution: Electrolytes

- **Strong electrolytes** are substances that ionize completely when dissolved in water.
- **Weak electrolytes** are substances that are only partly ionized in water.
- **Nonelectrolytes** are substances that do not produce ions when dissolved in water.

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9.10 Electrolytes in Body Fluids

- Blood and other body fluids contain many different anions and cations.
- To discuss such mixtures, we use a new term—*equivalents* of ions.
  - **Equivalent (Eq):** For ions, the amount equal to 1 mol of charge.
  - **Gram-equivalent (g-Eq):** For ions, the molar mass of the ion divided by the ionic charge.

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9.10 Electrolytes in Body Fluids

- Clinical chemists use *milliequivalents* of ions rather than equivalents.
  - The normal concentration of Na^+ in blood is 0.14 Eq/L, or 140 mEq/L.

TABLE 9.6 Concentrations of Major Electrolytes in Blood Plasma

Cation	Concentration (mEq/L)
Na^+	136–145
Ca^{2+}	4.5–6.0
K^+	3.6–5.0
Mg^{2+}	3
Anion	**Concentration (mEq/L)**
Cl^-	98–106
HCO_3^-	25–29
SO_4^{2-} and HPO_4^{2-}	2

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9.10 Electrolytes in Body Fluids

Electrolytes, Fluid Replacement, and Sports Drinks

- Significant changes in electrolyte levels can be potentially life-threatening if not addressed quickly.
- Cholera can result in dehydration and very low sodium levels in the body (hyponatremia). Restoration of electrolytes can be accomplished by oral rehydration therapy (ORT).
- Plain water works well to replace sweat lost during short bouts of activity, but a carbohydrate–electrolyte beverage is superior for longer activity.
- Nutritional research has shown that a serious sports drink should meet the following criteria:
  - Should contain 6–8% of soluble complex carbohydrates (about 15 g per 8 oz serving.
  - Should contain electrolytes to replenish those lost in sweat.
  - Should be noncarbonated and should not contain caffeine.
  - Should taste good so the athlete will want to drink it.
  - Some sports drinks also contain vitamin A (as beta-carotene), vitamin C (ascorbic acid), selenium, and glutamine, which appears to lessen lactic acid buildup.

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9.11 Properties of Solutions

- **Colligative property:** A property of a solution that depends only on the number of dissolved particles, not on their identity.
  - Vapor pressure is lower for a solution than for a pure solvent.
  - Boiling point is higher for a solution than for a pure solvent.
  - Freezing point is lower for a solution than for a pure solvent.
  - Osmosis occurs when a solution is separated from a pure solvent by a semipermeable membrane.

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9.11 Properties of Solutions

Vapor Pressure Lowering in Solutions

- Vapor pressure depends on the equilibrium between molecules entering and leaving the liquid surface.
- If some solvent molecules are replaced by solute particles, the rate of evaporation decreases.
- The vapor pressure of a solution is lower than that of the pure solvent.
- The *identity* of the solute particles is irrelevant; only their concentration matters.

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9.11 Properties of Solutions

Boiling Point Elevation in Solutions

- The boiling point of the solution is higher than that of the pure solvent.
- The solution must be heated to a higher temperature for its vapor pressure to reach atmospheric pressure.
- Each mole of solute particles raises the boiling point of 1 kg of water by 0.51 °C.
- 1 mol of glucose raises the temperature by 0.51 °C, 1 mol of NaCl by 1.02 °C. NaCl dissociates into two particles.

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9.11 Properties of Solutions

Freezing-Point Depression of Solutions

– The freezing point of a solution is lower than that of the pure solvent.

– Solute molecules are dispersed between solvent molecules, making it more difficult for solvent molecules to organize into ordered crystals.

– For each mole of nonvolatile solute particles, the freezing point of 1 kg of water is lowered by 1.86 °C.

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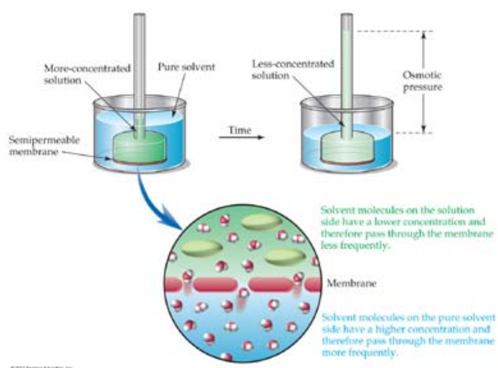
9.12 Osmosis and Osmotic Pressure

- **Osmosis:** The passage of a solvent through a semipermeable membrane separating two solutions of different concentration.



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9.12 Osmosis and Osmotic Pressure

- As the liquid in the tube rises, its weight creates a pressure that pushes solvent back through the membrane until the rates of forward and reverse passage become equal and the liquid level stops rising.
- **Osmotic pressure** is the amount of external pressure that must be applied to a solution to prevent the net movement of solvent molecules across a semipermeable membrane.

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9.12 Osmosis and Osmotic Pressure

$$\pi = \left(\frac{n}{V}\right)RT$$

- The osmotic pressure of a 0.15 M NaCl solution at 25 °C is 7.3 atm.
- Osmotic pressure depends only on the concentration of solute particles.
- **Osmolarity (osmol)** is the sum of the molarities of all dissolved particles in a solution.

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9.12 Osmosis and Osmotic Pressure

- Osmosis is particularly important in living organisms because the membranes around cells are semipermeable.
  - **Isotonic:** Having the same osmolarity
  - **Hypotonic:** Having an osmolarity *less than* the surrounding blood plasma or cells.
  - **Hypertonic:** Having an osmolarity *greater than* the surrounding blood plasma or cells.

(a) (b) (c)

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9.13 Dialysis

- The pores in a *dialysis* membrane allow both solvent molecules and small solute particles to pass through.
- *Hemodialysis* is used to cleanse the blood of patients whose kidneys malfunction.
  - Blood is diverted from the body and pumped through a long cellophane dialysis tube suspended in an isotonic solution.
  - Small waste materials such as urea pass through the dialysis membrane and are washed away.

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9.13 Dialysis

- Protein molecules do not cross semipermeable membranes and thus play an essential role in determining the osmolarity of body fluids.
- The pressure of blood inside the capillary tends to push water out of the plasma (filtration).
- The osmotic pressure of colloidal protein molecules tends to draw water into the plasma (reabsorption).

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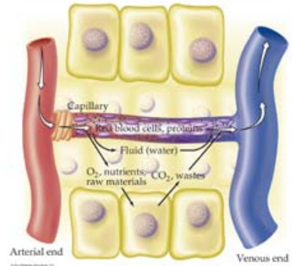
9.13 Dialysis

- At the arterial end of a capillary, filtration is favored.
- At the venous end, where blood pressure is lower, reabsorption is favored, and waste products from metabolism enter the bloodstream.



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9.13 Dialysis

Timed-Release Medications

- The widespread use of timed-release medication dates from the introduction of Contac decongestant in 1961: Tiny beads of medicine were encapsulated by coating them with varying thicknesses of a slow-dissolving polymer.
- Beads with a thinner coat dissolve and release their medicine more rapidly; those with a thicker coat dissolve more slowly.
- The enteric coating is a polymeric material formulated so that it is stable in acid but reacts and is destroyed when it passes into the more basic environment of the intestines.
- Dermal patches have been developed to deliver drugs directly by diffusion through the skin.
- One device for timed release of medication through the skin uses the osmotic effect to force a drug from its reservoir. The device is divided into two compartments, one containing medication and the other containing a hygroscopic material covered by a semipermeable membrane. As moisture from the air diffuses through the membrane, the buildup of osmotic pressure squeezes the medication out of the other compartment through tiny holes.

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Chapter Summary

1. What are solutions, and what factors affect solubility?

- Mixtures are classified as either *heterogeneous*, if the mixing is nonuniform, or *homogeneous*, if the mixing is uniform.
- *Solutions* are homogeneous mixtures that contain particles the size of ions and molecules, whereas larger particles (2.0–500 nm diameter) are present in *colloids*.
- The maximum amount of one substance (the *solute*) that can be dissolved in another (the *solvent*) is called the substance's *solubility*. Substances tend to be mutually soluble when their intermolecular forces are similar.
- The solubility in water of a solid often increases with temperature, but the solubility of a gas decreases with temperature. Pressure significantly affects gas solubilities, which are directly proportional to their partial pressure over the solution.

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Chapter Summary, *Continued*

2. How is the concentration of a solution expressed?

- The concentration of a solution can be expressed in several ways, including molarity, weight/weight percent composition, weight/volume percent composition, and parts per million.
- Osmolarity is used to express the total concentration of dissolved particles (ions and molecules).
- Molarity, which expresses concentration as the number of moles of solute per liter of solution, is the most useful method when calculating quantities of reactants or products for reactions in aqueous solution.

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Chapter Summary, *Continued*

3. How are dilutions carried out?

- A dilution is carried out by adding more solvent to an existing solution. Only the amount of solvent changes; the amount of solute remains the same.
- Thus, the molarity times the volume of the dilute solution is equal to the molarity times the volume of the concentrated solution: $M_cV_c = M_dV_d$.

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Chapter Summary, *Continued*

4. What is an electrolyte?

- Substances that form ions when dissolved in water and whose water solutions conduct an electric current are called *electrolytes*.
- Substances that ionize completely in water are *strong electrolytes*, those that ionize partially are *weak electrolytes*, and those that do not ionize are *nonelectrolytes*.
- Body fluids contain small amounts of many different electrolytes, whose concentrations are expressed as moles of ionic charge, or equivalents, per liter.

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Chapter Summary, *Continued*

5. How do solutions differ from pure solvents in their behavior?

- In comparing a solution to a pure solvent, the solution has a lower vapor pressure at a given temperature, a higher boiling point, and a lower melting point.
- Called *colligative properties*, these effects depend only on the number of dissolved particles, not on their chemical identity.

6. What is osmosis?

- *Osmosis* occurs when solutions of different concentration are separated by a semipermeable membrane that allows solvent molecules to pass but blocks the passage of solute ions and molecules.
- Solvent flows from the more dilute side to the more concentrated side until sufficient *osmotic pressure* builds up and stops the flow. An effect similar to osmosis occurs when membranes of larger pore size are used. In *dialysis*, the membrane allows the passage of solvent and small dissolved molecules but prevents passage of proteins and larger particles.

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