Chapter 12
Solutions

Solutions

- A ***solution*** is a homogeneous mixture.
- A solution is composed of a ***solute*** dissolved in a ***solvent***.
  - When two liquids make a solution, the solute is the lesser quantity, and the solvent is the greater quantity.
- Solutions can exist in all three physical states

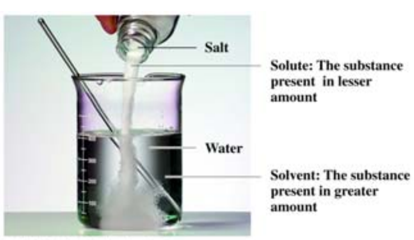
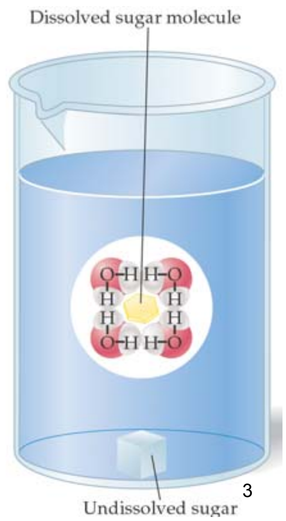


Table 11.1 Some Examples of Solutions

Type	Example	Solute	Solvent
Gas Solutions			
Gas in a gas	Air	Oxygen (gas)	Nitrogen (gas)
Liquid Solutions			
Gas in a liquid	Soda water	Carbon dioxide (gas)	Water (liquid)
	Household ammonia	Ammonia (gas)	Water (liquid)
Liquid in a liquid	Vinegar	Acetic acid (liquid)	Water (liquid)
Solid in a liquid	Seawater	Sodium chloride (solid)	Water (liquid)
	Tincture of iodine	Iodine (solid)	Alcohol
(liquid)			
Solid Solutions			
Liquid in a solid	Dental amalgam	Mercury (liquid)	Silver (solid)
Solid in a solid	Brass	Zinc (solid)	Copper (solid)
	Steel	Carbon (solid)	Iron (solid)

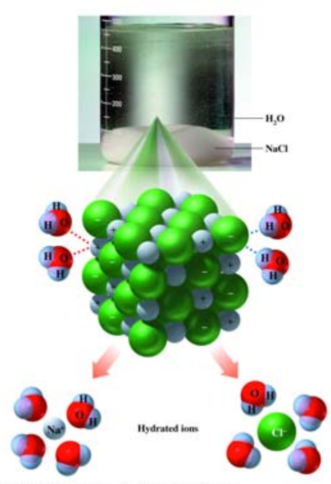
Formation of Solutions

- When a soluble crystal is placed into a solvent, it begins to dissolve.
- When a sugar crystal is placed in water, the water molecules attack the crystal and begin pulling part of it away and into solution.
- The sugar molecules are held within a cluster of water molecules called a ***solvent cage***.



Dissolving of Ionic Compounds

- In an ionic compound, the water molecules pull **individual ions** off of the crystal.
- When a sodium chloride crystal is placed in water, the water molecules attack the edge of the crystal.
- The **anions** (Cl^-) are surrounded by the positively charged **hydrogens** on water.
- The **cations** (Na^+) are surrounded by the negatively charged **oxygen** on water.
- This process is called ***hydration***, which diminished the attraction of the Na^+ for the Cl^-

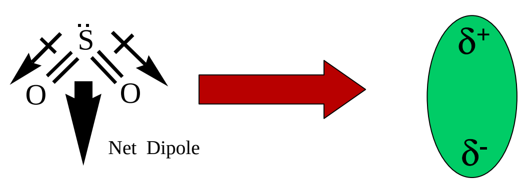


Why does matter dissolve? Intermolecular Forces

- An ***intermolecular force*** is an attraction between *molecules*
  - *Intra*molecular bonds occur between atoms within a molecule.
- Intermolecular forces are **much weaker** than intramolecular bonds
- There are three intermolecular forces:
  - Dipole forces
  - Hydrogen bonds
  - Dispersion forces

Dipole Forces

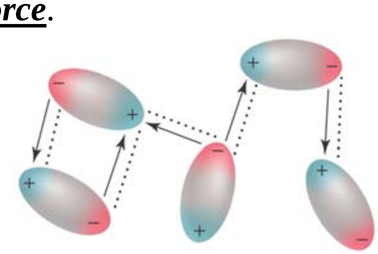
- Polar molecules have a permanent dipole.



- The oppositely charged ends of polar molecules are attracted to each other, this is the ***dipole force***.

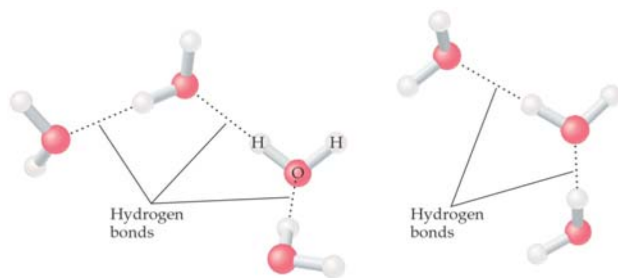
•The strength of a dipole force is typically 10% of a covalent bond's strength.

•Ionic molecules are considered to be "super polar"!



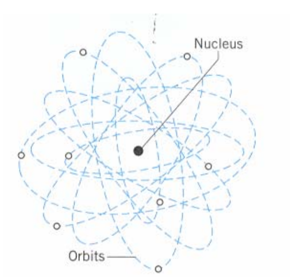
Hydrogen Bonds

- ***Hydrogen bonds*** are a special type of dipole attraction.
- Hydrogen bonds are present when a molecule has an **N-H, O-H, or F-H bond**.
- Hydrogen bonds are especially important in water and living organisms.
- These intermolecular forces are the **strongest** of the three!

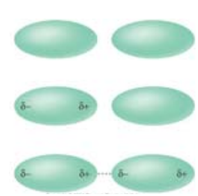


Dispersion Forces

- Dispersion forces, or London forces, are the result of the formation of a ***temporary dipole***.



- In a molecule, electrons are constantly orbiting the nucleus and a region may become temporarily electron poor and slightly positive while another region becomes slightly negative.



- This creates a temporary dipole and two molecules with temporary dipoles are attracted to each other.

Dispersion Forces

- Dispersion forces are the **weakest** intermolecular force.
- Dispersion forces are present in all molecules, but they are most influential among **non-polar** molecules.
- The strength of the dispersion forces in a molecule is related to the number of electrons in the molecule:
  - The more electrons in a molecule, the stronger the dispersion forces.

How to Determine What Type of Intermolecular Forces are Present

When trying to determine what type of intermolecular forces are involved in the attraction between two molecules ask yourself the following questions:

1) **Is there any potential for Hydrogen bonding between the two molecules?**
   - In other words, look for O-H, N-H, or F-H groups
2) **Is one or both of the molecules polar?**
   - If both, then usually dipole-dipole interactions
   - If one is polar and the other is nonpolar, then should be dipole-induced dipole interaction
3) **If both molecules are nonpolar, look and see if one molecule is charged.**
   - If yes, then should be an induced dipole interaction
   - If no, then dispersion forces (or London forces) interaction

Polar & Nonpolar Solvents

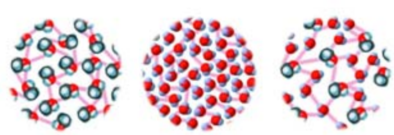
- A liquid composed of polar molecules is a ***polar solvent***.
  - Water and ethanol are polar solvents.
- A liquid composed of nonpolar molecules is a ***nonpolar solvent***.
  - Hexane is a non-polar solvent

Polar Solvents	Nonpolar Solvents
water, H_2O	hexane, C_6H_{14}
methanol, CH_3OH	heptane, C_7H_{16}
ethanol, C_2H_5OH	toluene, C_7H_8
acetone, C_3H_6O	carbon tetrachloride, CCl_4
methyl ethyl ketone, C_4H_8O	chloroform, $CHCl_3$
formic acid, $HCHO_2$	methylene chloride, CH_2Cl_2
acetic acid, $HC_2H_3O_2$	ethyl ether, $C_4H_{10}O$*

*The general rule that oxygen-containing solvents are polar has some exceptions. For example, ethyl ether contains oxygen and is a nonpolar solvent.

Like Dissolves Like

- Polar solvents (and Ionic solvents) dissolve in one another.
- Nonpolar solvents dissolve in one another.
- This it the ***like dissolves like rule***.
  - Methanol dissolves in water but hexane does not dissolve in water.
  - Hexane dissolves in toluene, but water does not dissolve in toluene.



Methanol (CH_3OH) solute   Water solvent   Methanol–water solution with H-bonding

WHY??

Solubility

- The **solubility** of a compound is used to describe the maximum amount of solute that can dissolve in a given amount of solvent.
- Many factors affect a solute's solubility:
  - Type of solute
  - Type of solvent
  - Temperature
  - Pressure (for solutions with gases)
- There are three terms we use to describe solubility:

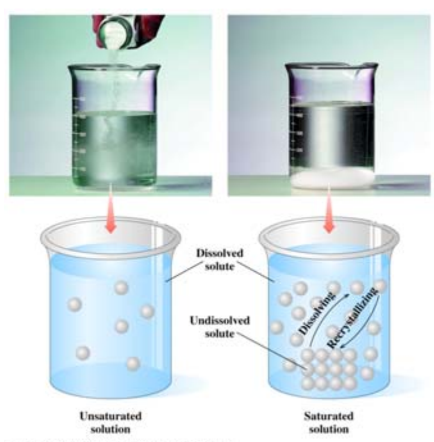
Saturated

Unsaturated

Supersaturated

Saturation of Solutions

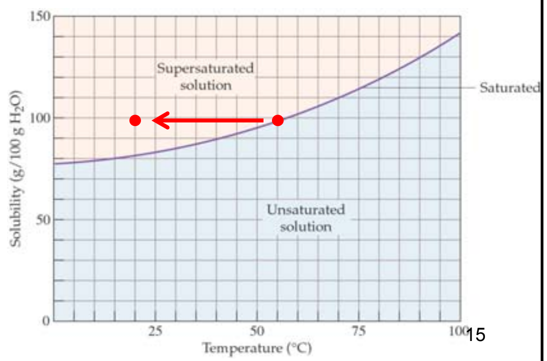
- A solution containing **exactly** the maximum amount of solute at a given temperature is a ***saturated solution***.
- A solution that contains **less** than the maximum amount of solute is an ***unsaturated solution***.
- Under certain conditions, it is possible to exceed the maximum solubility of a compound. A solution with **greater than** the maximum amount of solute is a ***supersaturated solution***.



$$\text{Solid solute} \underset{\text{crystallizes}}{\overset{\text{dissolves}}{\rightleftarrows}} \text{Saturate Solution}$$

Supersaturated Solutions

- At 55°C, the solubility of $NaC_2H_3O_2$ is 100 g per 100 g water.
- If a saturated solution at 55°C is cooled very carefully to 20°C, the solution is *supersaturated*.
- Supersaturated solutions are unstable.
- The excess solute can readily be precipitated.

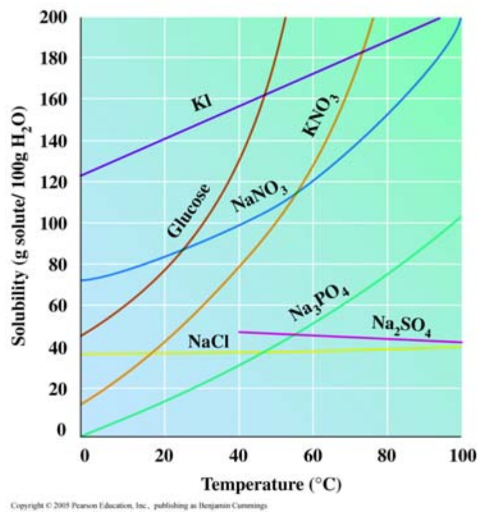


Rate of Dissolving

- There are three ways we can **<u>speed up</u>** the rate of dissolving for a solid compound.
- <u>Heating the solution</u>:
  - This increases the kinetic energy of the solvent and the solute is attacked faster by the solvent molecules.
- <u>Stirring the solution</u>:
  - This increases the interaction between solvent and solute molecules.
- <u>Grinding the solid solute</u>:
  - There is more surface area for the solvent to attack.

Solubility and Temperature

- *<u>For most solids</u>*, solubilities increase as the temperature increases.
- *<u>For most gases</u>*, solubility in a liquid solution decreases as the temperature increases.



WHY?!

Concentration of Solutions

- The ***concentration*** of a solution tells us how much solute is dissolved in a given quantity of solution.
- We often hear imprecise terms such as a "dilute solution" or a "concentrated solution".
- Three precise ways to express the concentration of a solution:

Mass/mass percent (m/m%)

Volume/volume percent (V/V%)

Molarity (M)

Percent Concentration

- Percent concentration can be in units of mass or volume
- These concentrations compare the amount (g or L) of solute to the amount of solvent (g or L).
- The ***mass/mass percent*** (***m/m %***) concentration is the mass of solute dissolved in 100 g of solution.
- The ***volume/volume percent*** (***V/V %***) concentration is the volume of solute dissolved in 100 mL of solution.

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

$$\frac{\text{g solute}}{\text{g solute + g solvent}} \times 100\% = \text{m/m \%}$$

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

$$\frac{\text{mL solute}}{\text{mL solute + mL solvent}} \times 100\% = \text{v/v \%}$$

Working Percent Concentration Problems

- When working these types of problems you MUST first identify the parts of your solution.
- Make a list of the solute, solvent and solution with any numerical values as given in the problem.
- This will make your preparation of any conversion factors much easier!

For Example:

A student prepares a 102.3 g of a solution of 5.62 g of $MgCl_2$ dissolved in water.

Identify the solute, solvent and solution

Calculating Mass/Mass Percent

- A student prepares a solution from 5.00 g NaCl dissolved in 97.0 g of water. What is the concentration in m/m %?

	Cmpd	Mass	Moles
Solute	NaCl	5.00	NA
Solvent	Water	97.0	NA
Solution	Solution	????	NA

Calculating Vol/Vol Percent

- A student prepares a solution from 25.0 mL acetic acid dissolved in 236.0 mL g of water. What is the concentration in V/V %?

	Cmpd	Volume	Moles
Solute	Acetic Acid	25.0	NA
Solvent	Water	236.0	NA
Solution	Solution	????	NA

Percent Concentration Unit Factors

- We can write two unit factors based on the percentage concentrations of solutions
- The percentage tells us "parts of solute PER 100 parts solution"
- The units can be in mass or volume

4.90% (m/m) NaCl Solution

$$\frac{4.90 \text{ g NaCl}}{100 \text{ g solution}} \quad \textbf{OR} \quad \frac{100 \text{ g solution}}{4.90 \text{ g NaCl}}$$

6.93% (v/v) Acetic Acid Solution

$$\frac{6.93 \text{ mL AA}}{100 \text{ mL solution}} \quad \textbf{OR} \quad \frac{100 \text{ mL solution}}{6.93 \text{ mL AA}}$$

Mass Percent Calculation

- What mass of a 5.00 m/m% solution of sucrose contains 25.0 grams of sucrose?
  - **Step 1:** Determine what you have: 5.00 % (m/m) sucrose solution and 25.0 g sucrose
  - **Step 2:** Determine what you want: ??? g solution
  - **Step 3:** Write out your plan to convert from grams of sucrose to grams of solution
  - **Step 4:** Select conversion factor(s): Use the % (m/m) to write your conversion factors

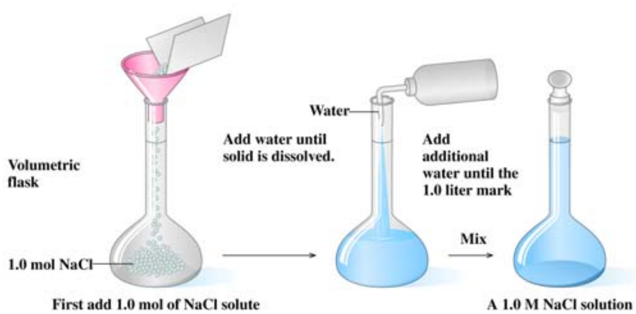
Volume Percent Calculation

- What volume of a 15.0% (V/V) solution of ethanol contains 31.0 mL of ethanol?
  - **Step 1:** Determine what you have: 15.0 % (v/v) ethanol solution and 31.0 mL ethanol
  - **Step 2:** Determine what you want: ??? mL solution
  - **Step 3:** Write out your plan to convert from mL of ethanol to mL of solution
  - **Step 4:** Select conversion factor(s): Use the % (v/v) to write your conversion factors

Molar Concentration

- The molar concentration, or ***molarity*** (M), is the number of moles of solute per liter of solution, is expressed as moles/liter.

$$M = \frac{\text{moles of solute}}{\text{liters of solution}}$$



Calculating Molarity

- What is the molarity of a solution containing 18.0 g of NaOH in 0.100 L of solution?
  - **Step 1:** Determine what you have: 18.0 g NaOH and 0.100 L solution
  - **Step 2:** Determine what you want: Molarity of the solution (mol/L)
  - **Step 3:** Write out a plan to convert from grams and L to Molarity
    - Check your units.
  - **Step 4:** Use the Molarity formula to divide moles of NaOH by the volume of solution (0.100 L).

Molarity Unit Factors

- Volumes of solutions are also used in stoichiometry calculations, similar to volumes of gases.
- When you have a volume of a solution, you can use the molarity of that solution to prepare conversion factors:
- For example, we can write unit factors based on the concentration 4.50 *M* NaOH:

$$\frac{4.50 \text{ mol NaOH}}{1 \text{ L solution}} \qquad \frac{1 \text{ L solution}}{4.50 \text{ mol NaOH}}$$

Molar Concentration Problem

- How many grams of $K_2Cr_2O_7$ are in 250.0 mL of 0.100 *M* $K_2Cr_2O_7$?
  - **Step 1:** Determine what you have: 250.0 mL of a 0.100 *M* $K_2Cr_2O_7$ solution
  - **Step 2:** Determine what you want: ??? g $K_2Cr_2O_7$
  - **Step 3**: Write a plan to convert from mL of a $K_2Cr_2O_7$ solution to grams of $K_2Cr_2O_7$.
  - **Step 4:** Select conversion factor(s) that allow you to perform your plan

Molar Concentration Problem

- What volume of 12.0 *M* HCl contains 7.30 g of HCl solute (MM = 36.46 g/mol)?
  - **Step 1:** Determine what you have: 12.0 M HCl and 7.30 g HCl
  - **Step 2:** Determine what you want: ??? L HCl Solution
  - **Step 3**: Write a plan to convert from g of HCl to L of HCl Solution.
  - **Step 4:** Select conversion factor(s) that allow you to perform your plan:

Dilution of a Solution

- Rather than prepare a solution by dissolving a solid in water, we can prepare a solution by diluting a more concentrated solution.
- When performing a dilution, the amount of solute does not change, only the amount of solvent.

$$M_1 \bullet V_1 = M_2 \bullet V_2$$

  - M_1 and V_1 are the initial molarity and volume and M_2 and V_2 are the new molarity and volume

Dilution Problem

- What volume of 6.0 *M* NaOH needs to be diluted to prepare 5.00 L if 0.10 *M* NaOH?
  - **Step 1:** Determine your unknown (V_1)
  - **Step 2:** Identify M_1, V_1 and M_2
  - **Step 3:** Plug these values into the dilution equation and solve for V_1

Solution Stoichiometry

- In a molarity-mass stoichiometry problem, we will convert an amount (volume) of reactant or product solution with a *given molarity* to an *unknown mass* of reactant or product.
- There are three steps:
  - **Step 1:** Convert the given volume of solution to moles using the molarity (mol/L) as a unit factor.
  - **Step 2:** Convert the moles of given to moles of the unknown using the coefficients in the balanced equation.
  - **Step 3:** Convert the moles of unknown to grams using the molar mass as a unit factor.

Volume of A ⇄ (Molarity of A) **Moles of A** ⇄ (Mole Ratio) **Moles of B** ⇄ (Molar Mass of B) **Grams of B**

Solution Stoichiometry Problem

- What mass of silver bromide is produced from the reaction of 37.5 mL of 0.100 *M* aluminum bromide with excess silver nitrate solution?

$$AlBr_3(aq) + 3\ AgNO_3(aq) \rightarrow 3\ AgBr(s) + Al(NO_3)_3(aq)$$

  - **Step 1:** Determine what you have: 37.5 mL of 0.100 M $AlBr_3$ solution
  - **Step 2:** Determine what you want: ??? g AgBr
  - **Step 3**: Write a plan to convert from mL of $AlBr_3$ to grams of AgBr.
  - **Step 4:** Select conversion factor(s) that allow you to perform your plan:

Summary of Stoichiometry Problems