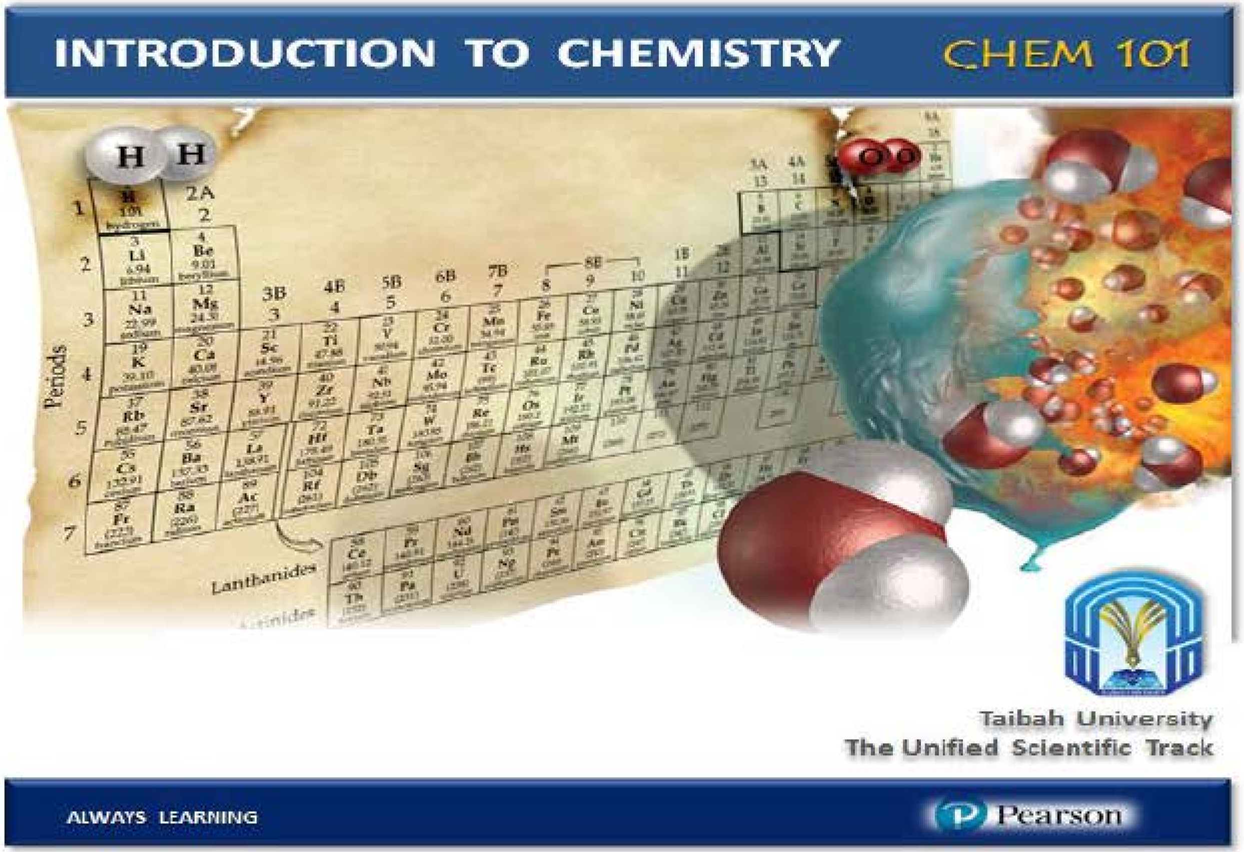


Lecture Presentation

Chapter 4

Stoichiometry, Solution Concentration and Chemical Reactions

- **Reaction Stoichiometry.**
- **Limiting Reagents, theoretical yield and percent Yield.**
- **Concentration of Solutions: The Molarity and Dilution.**
- **Types of Aqueous Solutions and Solubility**

Chapter 4: Chemical Bonding and Chemical Reactions

Reaction Stoichiometry

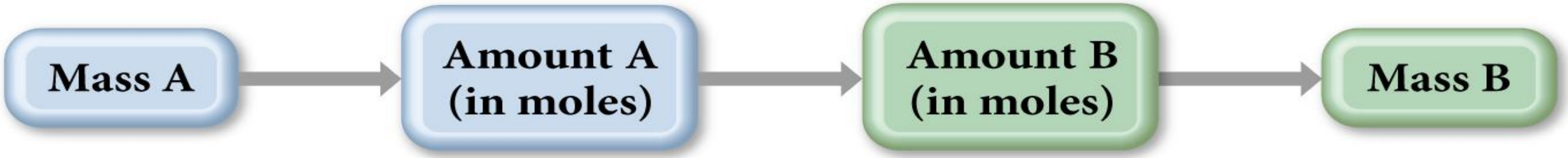
Two important questions:

1- How much <u>product</u> will be formed from specific amount of reactants?

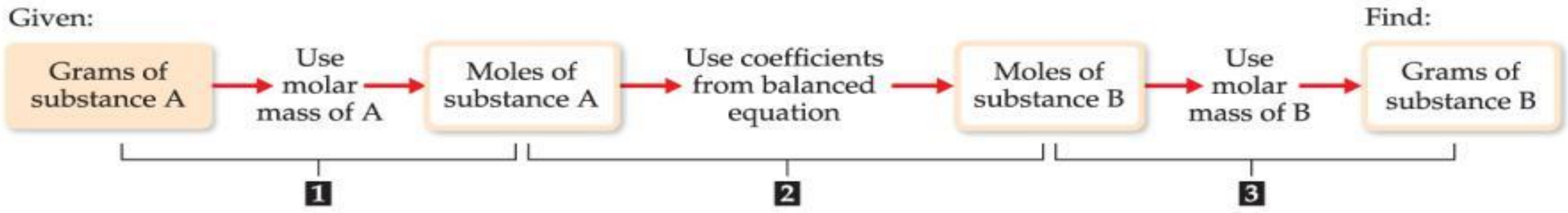
e.g. 8.0g reactant→ ? Product

2- How much <u>starting</u> reactants must be used to obtain a specific amount of product?

e.g. ? reactant → 7.0 g product



Reaction Stoichiometry



1. Write balanced chemical equation
2. Convert quantities of known substances into moles
3. Use coefficients in balanced equation to calculate the number of moles of the sought quantity
4. Convert moles of sought quantity into desired units

Reaction Stoichiometry

Example:

If 856g of $C_6H_{12}O_6$ is consumed by a person over a certain period, what is the mass of CO_2 produced?

$C_6H_{12}O_6(s) + 6\ O_2(g) \rightarrow 6\ CO_2(g) + 6\ H_2O(l)$

1- Write balanced chemical equation:

$C_6H_{12}O_6(s) + 6\ O_2(g) \rightarrow 6\ CO_2(g) + 6\ H_2O(l)$ ⇨ **Balanced!**

2- Convert quantities of known substances into moles:

convert grams of $C_6H_{12}O_6 \longrightarrow$ moles of $C_6H_{12}O_6$

$$n(C_6H_{12}O_6) = \frac{m(C_6H_{12}O_6)}{M(C_6H_{12}O_6)}$$

$$= \frac{856\text{g}}{180.2\text{g/mol}} = 4.750\ \text{mol}$$

Reaction Stoichiometry

Example:

If 856g of $C_6H_{12}O_6$ is consumed by a person over a certain period, what is the mass of CO_2 produced?

$$C_6H_{12}O_6(s) + 6\ O_2(g) \rightarrow 6\ CO_2(g) + 6\ H_2O(l)$$

3- Use coefficients in balanced equation to calculate the number of moles of the sought quantity → mole ratio (from the balanced equation):

1 mole $C_6H_{12}O_6$ → 6 mole CO_2

4.754 mole $C_6H_{12}O_6$ → ? mole CO_2

$$n(CO_2) = \frac{6\,\text{mol}\ x 4.754\,\text{mol}}{1\,\text{mol}} = 28.50\,\text{mol}$$

Chapter 4: Chemical Bonding and Chemical Reactions

Reaction Stoichiometry

Example:

If 856g of $C_6H_{12}O_6$ is consumed by a person over a certain period, what is the mass of CO_2 produced?

$$C_6H_{12}O_6(s) + 6\ O_2(g) \rightarrow 6\ CO_2(g) + 6\ H_2O(l)$$

4-Convert moles of sought quantity into desired units:

convert the moles of CO_2 → grams of CO_2

$$n(CO_2) = \frac{m(CO_2)}{M(CO_2)} \Rightarrow m = nxM$$

$$m(CO_2) = 28.50\ \text{mol}\ x 44.01\ \text{g/mol} = 1.25x10^3\ g$$

Summary: grams of $C_6H_{12}O_6$ → moles of $C_6H_{12}O_6$ → moles of CO_2 → grams of CO_2

Reaction Stoichiometry

Example:

How many grams of Li are needed to produce 9.89g of H_2?

$$2Li(s) + 2H_2O(l) \rightarrow 2LiOH(aq) + H_2(g)$$

Strategy:

grams of H_2 → moles of H_2 → moles of Li→ grams of Li

Solution:

1- Write balanced chemical equation:

$$2Li(s) + 2H_2O(l) \rightarrow 2LiOH(aq) + H_2(g)$$

2- convert grams of H_2 to moles of H_2

$$n(H_2) = \frac{m(H_2)}{M(H_2)}$$

$$= \frac{9.89\text{g}}{2.016\text{g/mol}} = 4.920\text{ mol}$$

Reaction Stoichiometry

Example:

How many grams of Li are needed to produce 9.89g of H_2?

$$2Li(s) + 2H_2O(l) \rightarrow 2LiOH(aq) + H_2(g)$$

Strategy:

grams of H_2 → moles of H_2 → moles of Li→ grams of Li

Solution:

3- Mole ratio (from the balanced equation) → Moles of Li

2 mole of Li → 1 mole H_2

?mole of Li → 4.927 mole H_2

$$\rightarrow n(Li) = \frac{2\ \text{mol}\ x 4.927\ \text{mol}}{1\ \text{mol}} = 9.854\ \text{mol}$$

4- Convert the moles of Li → grams of Li

$$n = \frac{m}{M} \Rightarrow m = nxM$$

$$m(Li) = 9.854\ \text{mol}\ x 6.941\ \text{g/mol} = 68.1g$$

Reaction Stoichiometry

Example:

Consider the combustion of carbon monoxide (CO) in oxygen gas:

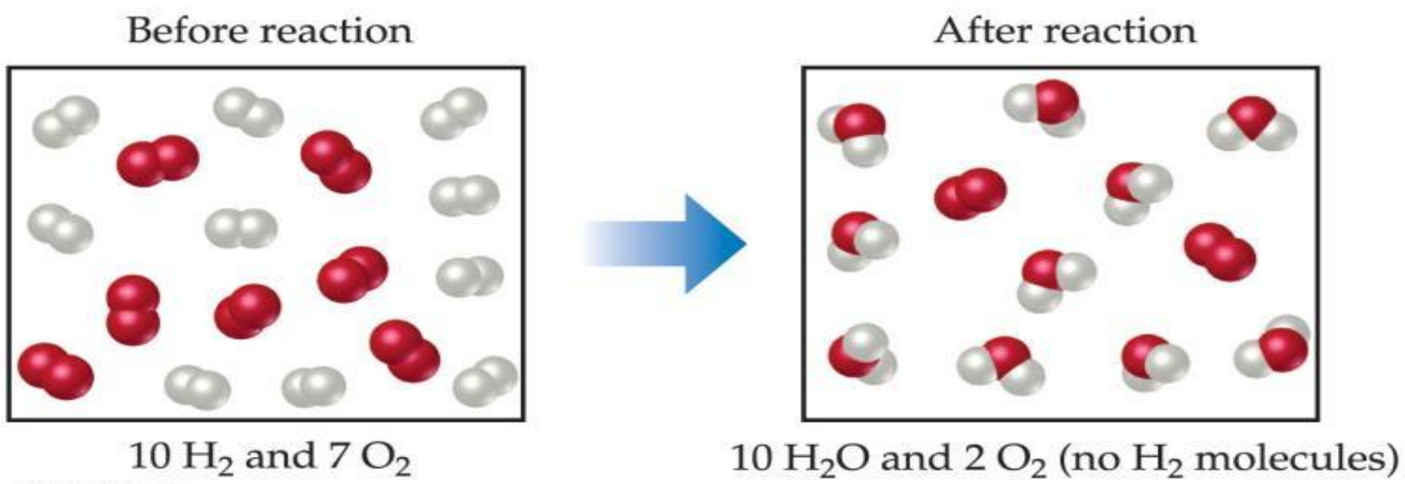
$$2CO(g) + O_2(g) \longrightarrow 2CO_2(g)$$

Starting with 3.60 moles of CO, calculate the number of moles of CO_2 produced if there is enough oxygen gas to react with all of the CO.

A. 7.20 mol
B. 44.0 mol
C. 3.60 mol
D. 1.80 mol

4.2 Limitting reactant (limiting Reagent):

The limiting reactant (الكاشف المحدد) is the reactant present in the smallest stoichiometric amount. In other words, it's the reactant you'll run out of first (in this case, the H_2).



In the example above, the O_2 would be the **excess reagent (الكاشف الفائض)**.

4.2 Limitting reactant (limiting Reagent):

The theoretical yield: is the amount of product that can be made in a chemical reaction based on the amount of limiting reactant.

The actual yield: is the amount of product actually produced by a chemical reaction.

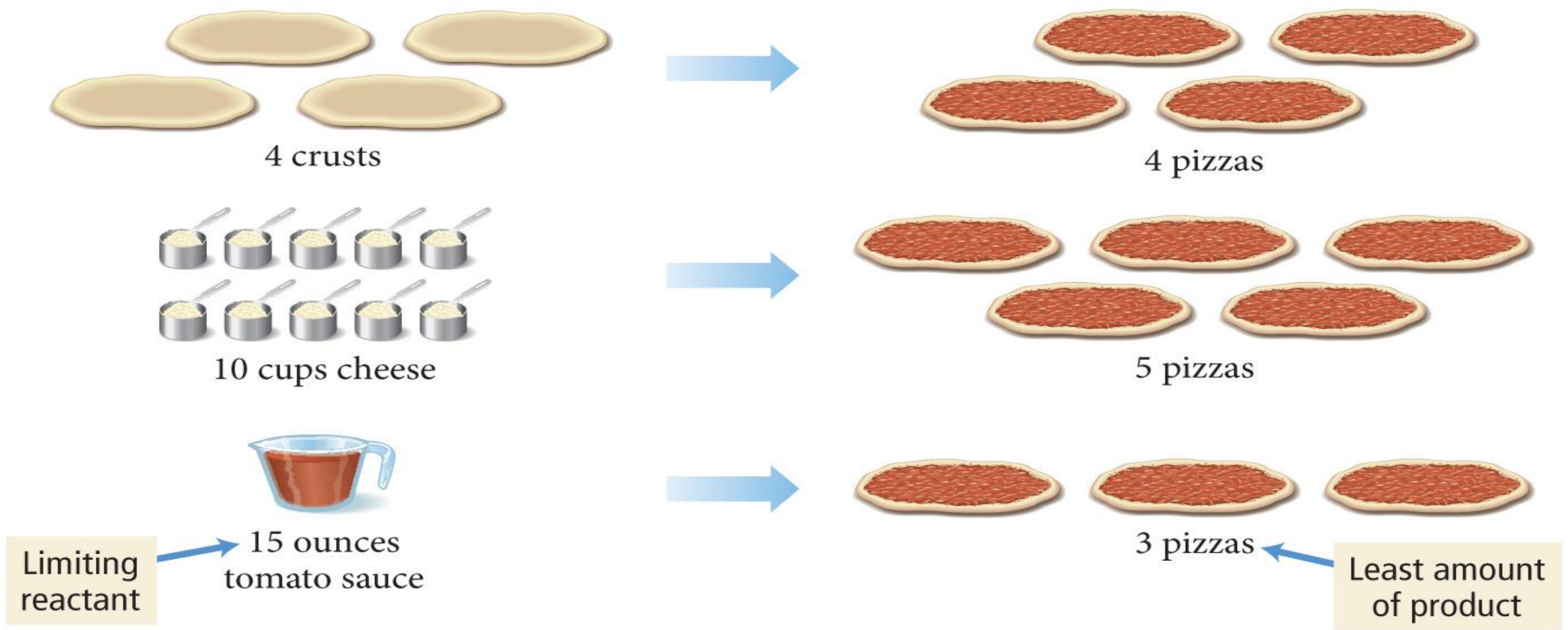
$$\% \text{ yield} = \frac{\textbf{\textit{Actual yield}}}{\textbf{\textit{Theoretical yield}}} \times 100$$

4.2 Limitting reactant (limiting Reagent):

Assume we use the following pizza recipe:

1 curst + 5 ounces tomato sauce + 2 cups cheese → 1 pizza

Suppose that we have 4 crust, 10 cups of cheese, and 15 ounces of tomato sauce. How many pizza can we make?



Chapter 4: Chemical Bonding and Chemical Reactions

4.2 Limitting reactant (limiting Reagent):

The maximum number of pizzas we can make In chemical reactions, we call this the **theoretical yield**

Assume that while making pizzas, we burn a pizza, drop one on the floor, or other uncontrollable events happen so that we only make **two pizzas.**

The actual amount of product made in a chemical reaction is called the **actual yield.**

We can determine the efficiency of making pizzas by calculating the percentage of the maximum number of pizzas we actually make.

In chemical reactions, we call this the **percent yield**.

Actual yield

$$\% \text{ yield} = \frac{2 \text{ pizzas}}{3 \text{ pizzas}} \times 100\% = 67\%$$

Theoretical yield

4.2 Limitting reactant (limiting Reagent):

Example 3.54 x10^7g of $TiCl_4$ are reacted with 1.13x 10^7g of Mg. Calculate the theoretical yield of Ti in grams ?

$$TiCl_4(g) + 2Mg(l) \rightarrow Ti(s) + 2MgCl_2(l)$$

grams of $TiCl_4$ → moles of $TiCl_4$ → moles of Ti

$$n(TiCl_4) = \frac{m}{M} = \frac{3.54x10^7\,g}{189.7\,g/mol} = 1.87x10^5\,mol$$

Mole ratio:

1 mole $TiCl_4$ → 1 mole Ti

1.97 x10^5 mole → ?n Ti

n(Ti) =1.87 x10^5 mol

How to Identify the Limiting Reactant

كيف يتم تحديد الكاشف المحدد

١-حساب عدد المولات للمواد المتفاعلة وذلك بقسمة الوزن بالجرام على الكتلة المولارية

٢- تقسم عدد مولات كل مادة متفاعلة على عدد مولاتها الموجودة في المعادلة.

٣- المادة اللي تكون ناتجها أقل هي الكاشف المحدد.

٤-حساب كمية المادة الناتجة بناء على الكاشف المحدد

٥- يستخدم الكاشف المحدد لحساب كمية المادة الناتجة المطلوبة تبعا للمعادلة الموزونة

4.2 Limitting reactant (limiting Reagent):

Example 3.54 x10^7g of $TiCl_4$ are reacted with 1.13x 10^7g of Mg. Calculate the theoretical yield of Ti in grams ?

$$TiCl_4(g) + 2Mg(l) \rightarrow Ti(s) + 2MgCl_2(l)$$

grams of Mg → moles of Mg → moles of Ti

$$n(Mg) = \frac{m}{M} = \frac{1.13x10^7\,g}{24.31g/mol} = 4.64x10^6\,mol$$

Mole ratio:

2 mole Mg → 1 mole Ti

4.64 x10^6 mole → ?n Ti

$$n(Ti) = \frac{4.64x10^6}{2} = 2.32x10^5\,mol$$

n(Ti) is the less number of moles (limiting reagent) = 1.87 x10^5 mol

Moles of Ti → grams of Ti

mass of Ti = theoretical yield of Ti = m =nM

$$m(Ti) = nM$$
$$= 1.87x10^5\,molx47.88g/mol = 8.95x10^6\,g$$

4.2 Limitting reactant (limiting Reagent):

Example: Nitrogen dioxide NO_2 can be synthesized by the reaction:

$$N_2(g) + 2\ O_2(g) \rightarrow 2\ NO_2(g)$$

Starting with 46.3 g N_2 and 92.0 g O_2, find the theoretical yield of NO_2 in grams.

*grams of $\mathbf{N_2}$ → moles of $\mathbf{N_2}$ → moles of $\mathbf{NO_2}$

$$n(N_2) = \frac{m}{M} = \frac{46.3\,\text{g}}{28g/mol} = 1.65mol$$

Mole ratio:

1 mole $\mathbf{N_2}$ → 2 mole $\mathbf{NO_2}$

1.65 mole → ?n $\mathbf{NO_2}$

~~n($\mathbf{NO_2}$) =3.307 mol~~

*grams of $\mathbf{O_2}$→ moles of $\mathbf{O_2}$ → moles of $\mathbf{NO_2}$

$$n(O_2) = \frac{m}{M} = \frac{92g}{32g/mol} = 2.87mol$$

Mole ratio:

2 mole $\mathbf{O_2}$ → 2 mole $\mathbf{NO_2}$

2.87 mole → ?n $\mathbf{NO_2}$

n($\mathbf{NO_2}$)=**2.87 mol**

---

n($\mathbf{NO_2}$) is limiting reagent = **2.87** mol

Moles of $\mathbf{NO_2}$ → grams of $\mathbf{NO_2}$

mass of $\mathbf{NO_2}$ = theoretical yield of $\mathbf{NO_2}$ = m =nM

$$m(\text{NO2}i) = nM$$
$$= 2.87molx46g/mol = 132.02g$$

4.3 Concentration of solutions (Molarity and Dilution)

The *solution* (المحلول)is a homogenous mixture of 2 or more substances

The *solute* (المذاب) is(are) the substance(s) present in the smaller amount(s)

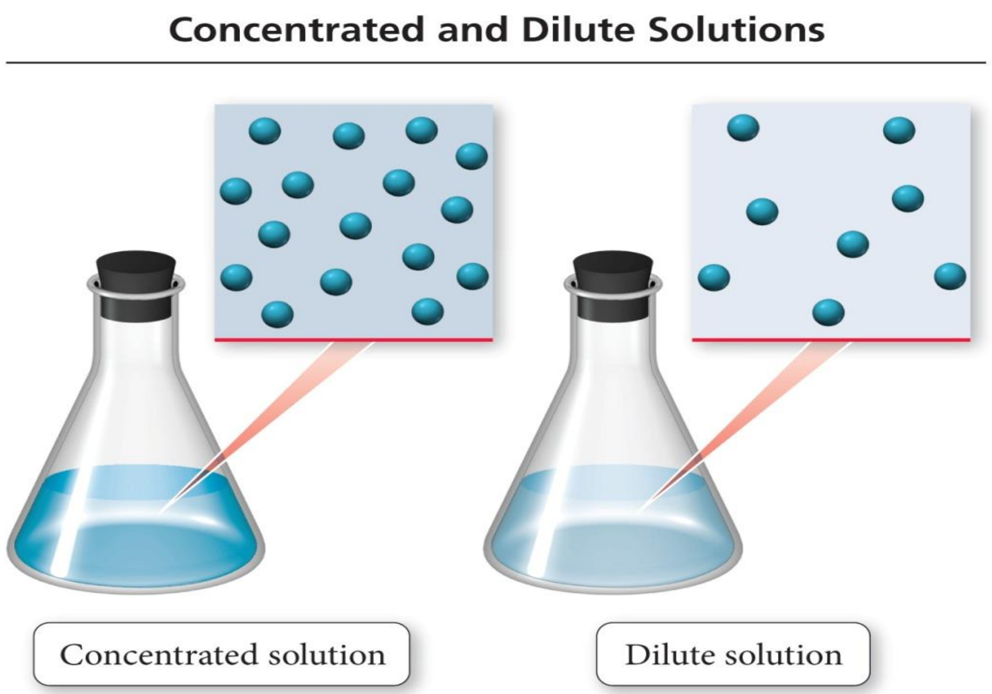
The *solvent* *(المذيب)* is the substance present in the larger amount and the majority component of a solution.

Solution	Solvent	Solute
Soft drink (*l*)	H_2O	Sugar, CO_2

4.3 Concentration of solutions (Molarity and Dilution)

- Solutions are often described quantitatively, as **dilute** or **concentrated**.

- **Concentrated solutions** have a large amount of solute compared to solvent.
- **Dilute solutions** have a small amount of solute compared to solvent.



4.3 Concentration of solutions (Molarity and Dilution)

- A common way to express solution concentration is **molarity (*M*)**.
  - Molarity is the amount of solute (in moles) divided by the volume of solution (in liters).

$$\text{Molarity (M)} = \frac{\text{amount of solute (in mol)}}{\text{volume of solution (in L)}}$$

$$n \text{ (amount of solute)} = M \text{ (molarity)} \times V \text{ (L)}$$

$$\frac{m(g)}{M_{wt}(g/mol)} = M\ (molarity) \times V\ (L)$$

$$\text{m (g)} = \text{M}_{\text{wt}}\text{(g/mol)} \times M\ (molarity) \times V\ (L)$$

4.3 Concentration of solutions (Molarity and Dilution)

Example

1-What is the molarity of an 85 ml ethanol C_2H_5OH solution containing 1.77g of ethanol?

Molar mass C_2H_5OH

M = 46.068 g/mol OR M.wt = 46.068 g/mol

m (g) = M.wt × M × *V (L)*

1.77 g = (46.068 g/mol)× M × (85 ml/1000L)

M = 0.452 M

4.3 Concentration of solutions (Molarity and Dilution)

Example

2-What is the volume (in ml) of 0.315M NaOH solution contains 6.22g of NaOH?

Molar mass NaOH= 40 g/mol

m (g) = M.wt × M × *V (L)*

$$6.22\ g = (40\ g/mol) \times (0.315\ M) \times V$$

$$V = 0.4937\ L$$

$$V = (0.4937 \times 1000) = 493.7\ mL \approx 494\ mL$$

4.3 Concentration of solutions (Molarity and Dilution)

3-What mass of KI is required to make 500 mL of a 2.80 *M* KI solution?

$$m\ (g) = M.wt \times M \times V\ (L)$$

M.wt of KI = 39.10 + 126.9

= 166 g

m = (166 g/mol)× 2.80 (M)× (500 ml/1000 L)

m = 232.4 g

4.3 Concentration of solutions (Molarity and Dilution)

- Often, solutions are stored as concentrated **stock solutions.**
- To make solutions of lower concentrations from these stock solutions, more solvent is added.
  - The amount of solute doesn't change, just the volume of solution:

moles solute in solution 1 = moles solute in solution 2

- The concentrations and volumes of the stock and new solutions are inversely proportional:

$$M_1 \cdot V_1 = M_2 \cdot V_2$$

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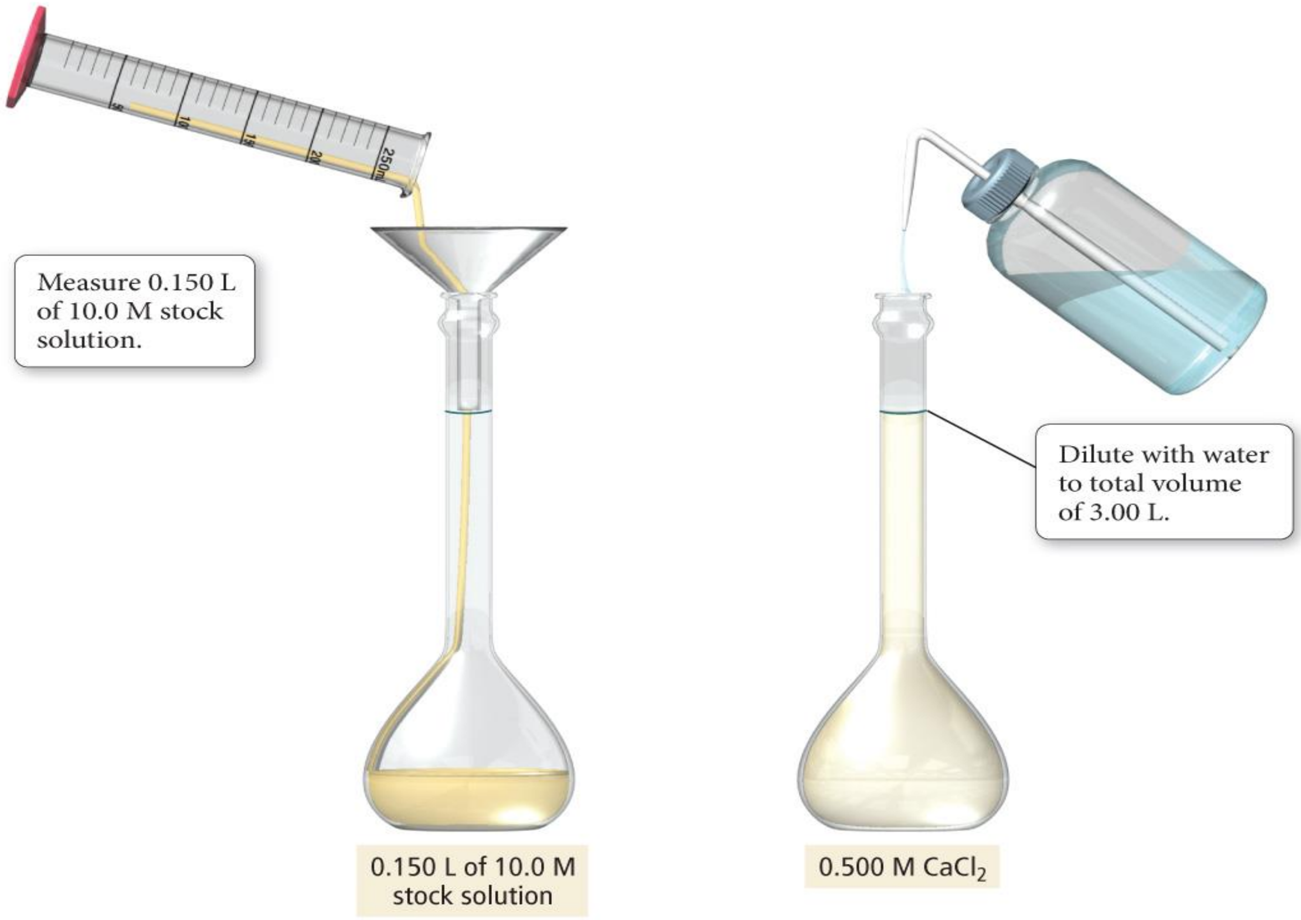
4.3 Concentration of solutions (Molarity and Dilution)

Diluting a Solution



$$M_1V_1 = M_2V_2$$

$$\frac{10.0\ \text{mol}}{\cancel{\text{L}}} \times 0.150\ \cancel{\text{L}} = \frac{0.500\ \text{mol}}{\cancel{\text{L}}} \times 3.00\ \cancel{\text{L}}$$

$$1.50\ \text{mol} = 1.50\ \text{mol}$$

4.3 Concentration of solutions (Molarity and Dilution)

Example:

1-How would you prepare 60.0 mL of 0.200 *M* HNO_3 from a stock solution of 4.00 *M* HNO_3?

$$M_iV_i = M_fV_f$$

$M_1 = 4.00$ $M_2 = 0.200$ $V_2 = 0.06$ L $V_1 = ?$ L

$$V_1 = \frac{M_2V_2}{M_1} = \frac{0.200 \times 0.06}{4.00} = 0.003 \text{ L} = 3 \text{ mL}$$

The units of V_1 & V_2 must be the same (ml or L)

3 mL of acid + 57 mL of water = 60 mL of solution

4.3 Concentration of solutions (Molarity and Dilution)

Example:

2-How many mL of 5.0 *M* $K_2Cr_2O_7$ solution must be diluted to prepare 250 mL of 0.10 *M* solution?

$V_1 = ?$ $\quad M_1 = 5.0M$ $\quad V_2 = 250$ mL $\quad M_2 = 0.10M$

$M_1 = M_2V_2 / V_1$

$V_1 = 250$ ml ×0.1M /5ml **= 5 ml**

4.3 Concentration of solutions (Molarity and Dilution)

Example:

3- If 10.0 mL of a 10.0 *M* stock solution of NaOH is diluted to 250 mL, what is the concentration of the resulting solution?

$M_2 = ?$ $V_1 = 10.0\text{ mL}$ $M_1 = 10.0M$ $V_2 = 250\text{ mL}$

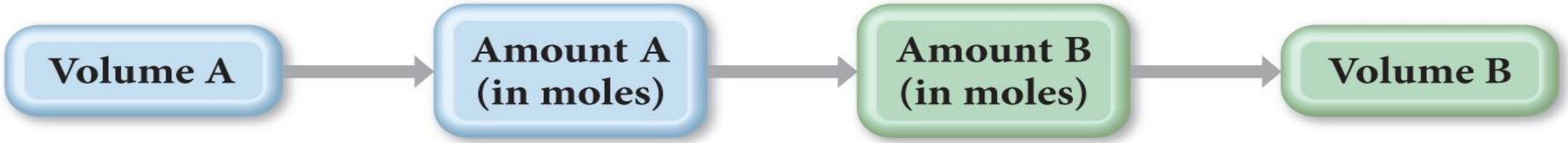
$$M_1 = M_2V_2/V_1$$

M_1 = 10ml ×10M /250ml = **0.4 *M***

4.3 Concentration of solutions (Molarity and Dilution)

since molarity relates the moles of solute to the liters of solution

it can be used to convert between amount of reactants and/or products in a chemical reaction



4.3 Concentration of solutions (Molarity and Dilution)

Example:

What volume of 0.150 M KCl is required to completely react with 0.150 L of 0.175 M $Pb(NO_3)_2$:

$$2\ KCl(aq) + Pb(NO_3)_2(aq) \rightarrow PbCl_2(s) + 2\ KNO_3(aq)$$

4.3 Concentration of solutions (Molarity and Dilution)

Example:

What volume of 0.150 M KCl is required to completely react with 0.150 L of 0.175 M $Pb(NO_3)_2$:

$$2\ KCl(aq) + Pb(NO_3)_2(aq) \rightarrow PbCl_2(s) + 2\ KNO_3(aq)$$

litter of $Pb(NO_3)_2$ → moles of $Pb(NO_3)_2$ → moles of KCl → litter of $Pb(NO_3)_2$

1- find mole of $Pb(NO_3)_2$

$$n(Pb(NO_3)_2) = MxV = 0.175Mx0.150L$$
$$n(Pb(NO_3)_2) = 0.026mol$$

2-find mole of KCl (Mole ratio):

1 mole $Pb(NO_3)_2$ → 1 mole KCl

0.026 mole → ? mole KCl

n(KCl) =0.052mol

3- find volume of KCl

$$n(Pb(NO_3)_2) = MxV$$
$$V(Pb(NO_3)_2) = \frac{n}{M} = \frac{0.052mol}{0.175mol/L} = 0.34L$$

4.4. Types of Aqueous Solutions and Solubility

- Consider two familiar aqueous solutions: salt water and sugar water.
  - Salt water is a homogeneous mixture of NaCl and H_2O.
  - Sugar water is a homogeneous mixture of $C_{12}H_{22}O_{11}$ and H_2O.
- As you stir either of these two substances into the water, it seems to disappear.

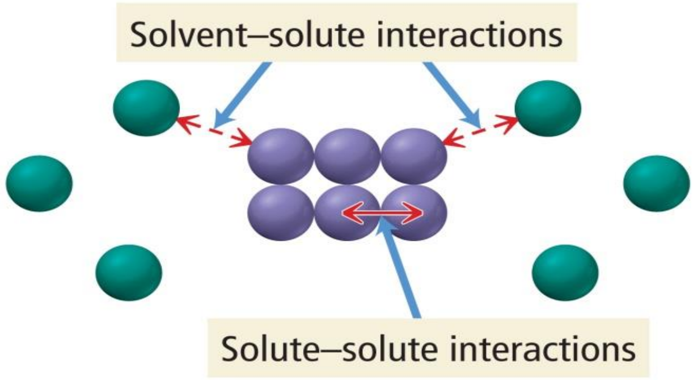
How do solids such as salt and sugar dissolve in water?

4.4. Types of Aqueous Solutions and Solubility

WHAT HAPPENS WHEN A SOLUTE DISSOLVES?

- There are attractive forces between the solute particles holding them together.
- There are also attractive forces between the solvent molecules.
- When we mix the solute with the solvent, there are attractive forces between the solute particles and the solvent molecules.
- If the attractions between solute and solvent are **strong** enough, the solute will **dissolve**.

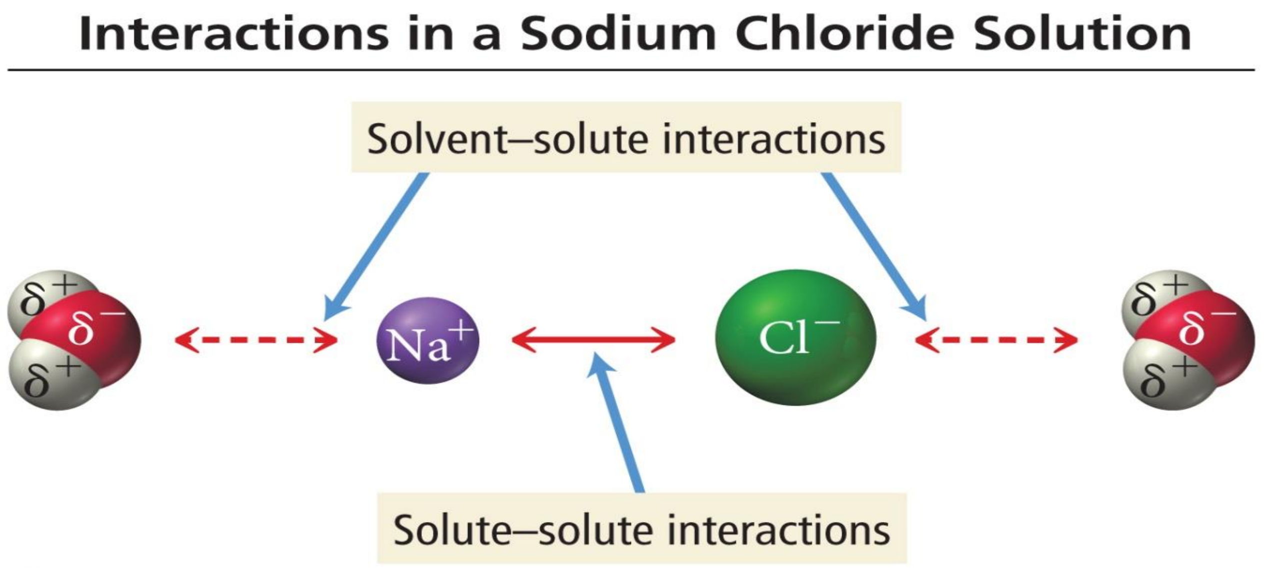
Solute and Solvent Interactions



4.4. Types of Aqueous Solutions and Solubility

Solute And Solvent Interactions In A Sodium Chloride Solution

- When sodium chloride is put into water, the attraction of Na^+ and Cl^- ions to water molecules competes.
- with the attraction among the oppositely charged ions themselves.

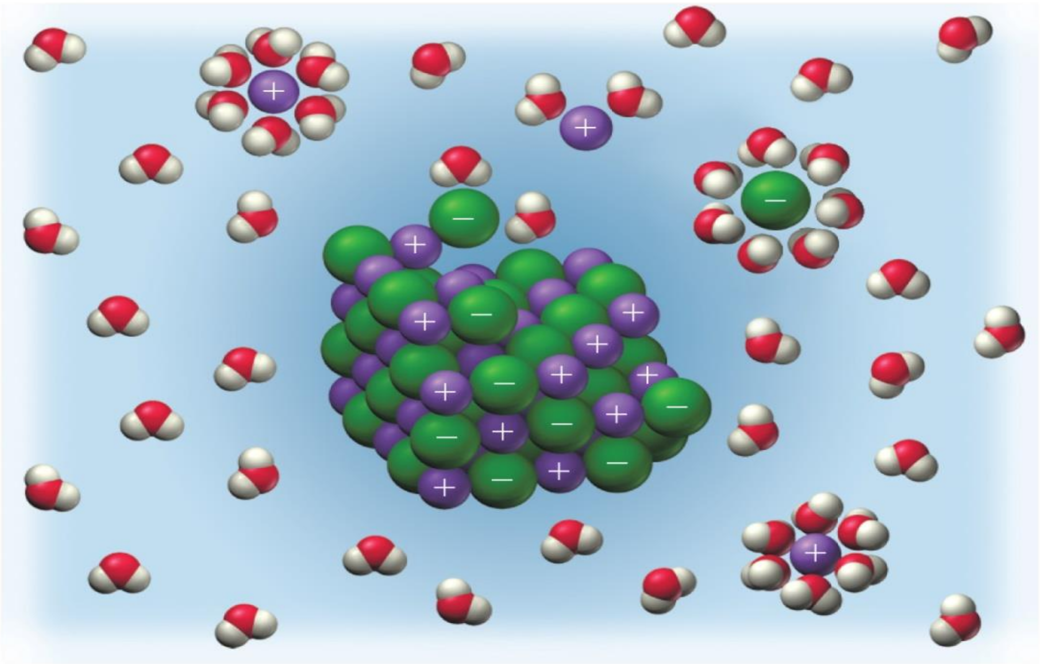


4.4. Types of Aqueous Solutions and Solubility

SODIUM CHLORIDE DISSOLVING IN WATER

- Each ion is attracted to the surrounding water molecules and pulled off and away from the crystal.
- When it enters the solution, the ion is surrounded by water molecules, insulating it from other ions.
- The result is a solution with free moving charged particles able to conduct electricity.

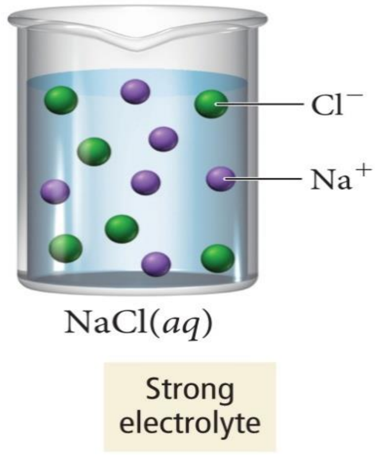
Dissolution of an Ionic Compound

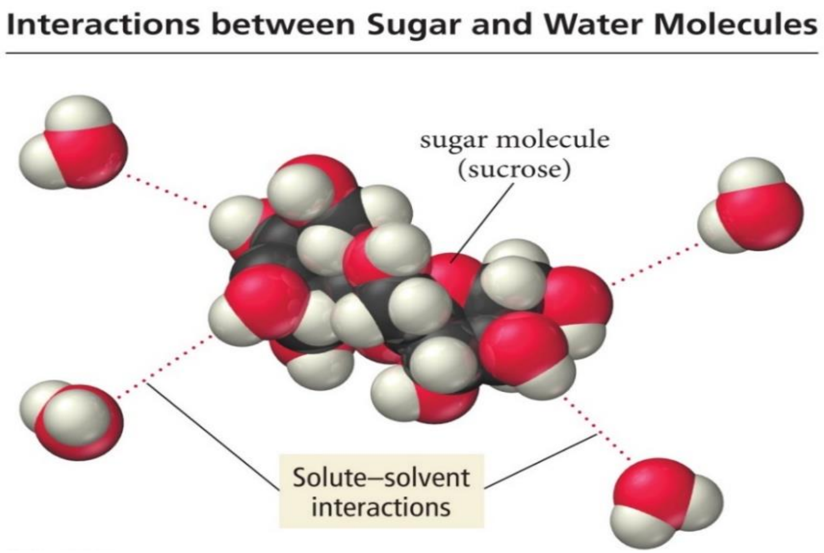


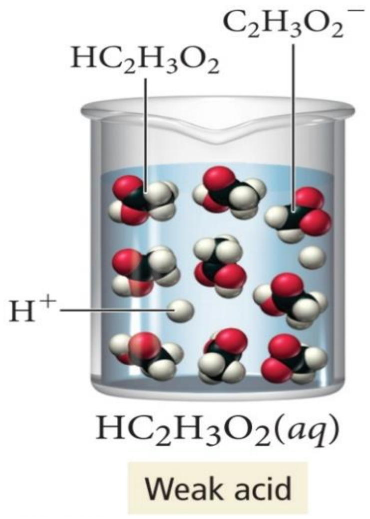
4.4. Types of Aqueous Solutions and Solubility

Electrolyte And Nonelectrolyte Solutions

- Ionic substances such as sodium chloride that completely dissociate into ions when they dissolve in water are **strong electrolytes.**
- In contrast to sodium chloride, sugar is a molecular compound.
- Most molecular compounds (except for acids), dissolve in water as intact molecules.





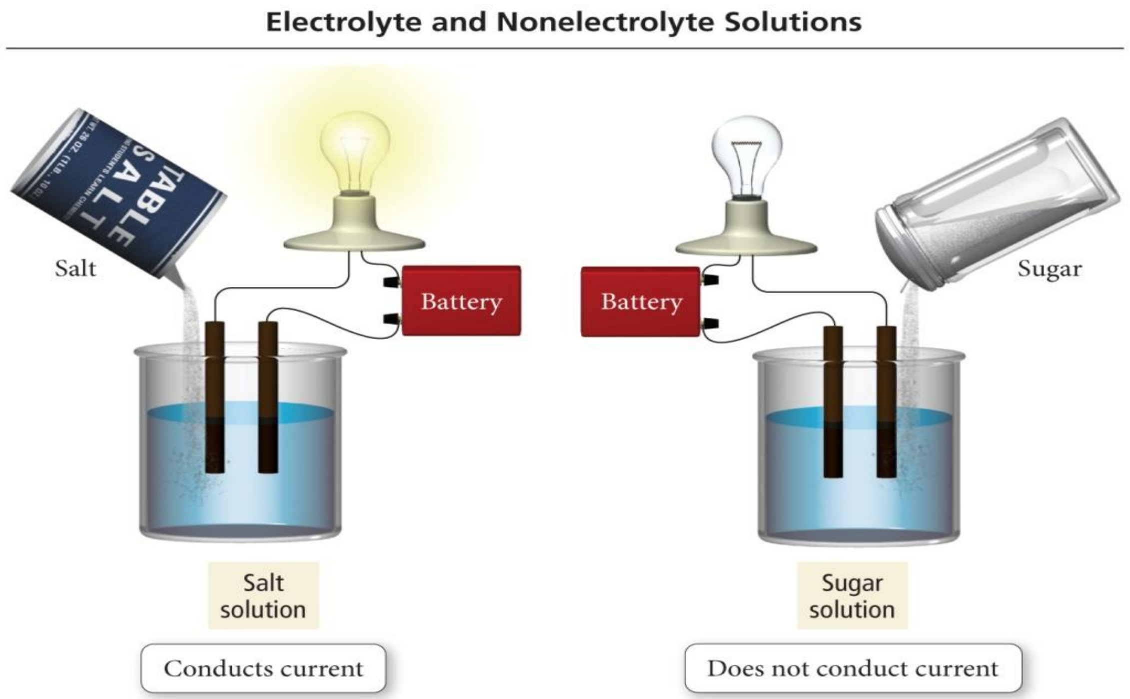


Chapter 4: Chemical Bonding and Chemical Reactions

4.4. Types of Aqueous Solutions and Solubility

Electrolyte And Nonelectrolyte Solutions

- Materials that dissolve in water to form a solution that will conduct electricity are called **electrolytes.**
- Materials that dissolve in water to form a solution that will not conduct electricity are called **nonelectrolytes.**



- A solution of salt (an electrolyte) conducts electrical current. A solution of sugar (a nonelectrolyte) does not.

4.4. Types of Aqueous Solutions and Solubility

- Acids are molecular compounds that **ionize** when they dissolve in water.
  - The molecules are pulled apart by their attraction for the water.
  - When acids ionize, they form H^+ cations and also anions.
- The percentage of molecules that ionize varies from one acid to another.
- Acids that ionize virtually 100% are called **strong acids.**

$$HCl(aq) \rightarrow H^+(aq) + Cl^-(aq)$$

- Acids that only ionize a small percentage are called **weak acids.**

$$HF(aq) \Leftrightarrow H^+(aq) + F^-(aq)$$

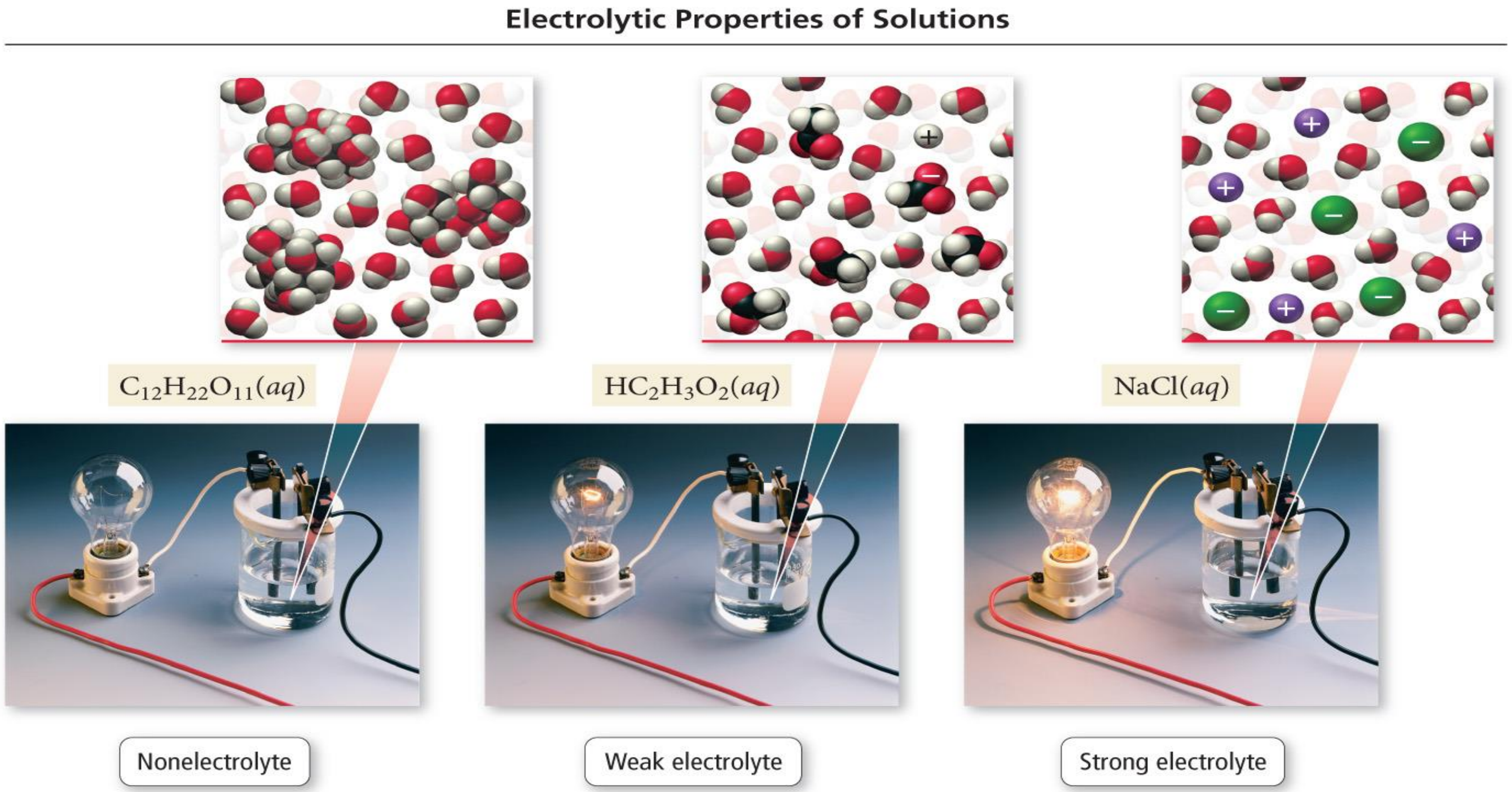
4.4. Types of Aqueous Solutions and Solubility

- **Strong electrolytes** are materials that dissolve completely as ions.
  - Ionic compounds and strong acids
  - Solutions conduct electricity well
- **Weak electrolytes** are materials that dissolve mostly as molecules, but partially as ions.
  - Weak acids
  - Solutions conduct electricity, but not well
- When compounds containing a polyatomic ion dissolve, the polyatomic ion stays together.

$$HC_2H_3O_2(aq) \Leftrightarrow H^+(aq) + C_2H_3O_2^-(aq)$$

4.4. Types of Aqueous Solutions and Solubility

Classes Of Dissolved Materials



4.4. Types of Aqueous Solutions and Solubility

1-Which of the following is considered a strong electrolyte?

A) NH_4NO_3

B) $C_{12}H_{22}O_{12}$

C) $PbCl_2$

D) $HC_2H_3O_2$

2-Which of the following is not a strong electrolyte?

A) CaS

B) $LiSO_4$

C) NH_4OH

D) $CH_3CH_2CH_3$

4.4. Types of Aqueous Solutions and Solubility

1-Which of the following is considered a strong electrolyte?

A) NH_4NO_3

B) $C_{12}H_{22}O_{12}$

C) $PbCl_2$

D) $HC_2H_3O_2$

2-Which of the following is not a strong electrolyte?

A) CaS

B) $LiSO_4$

C) NH_4OH

D) $CH_3CH_2CH_3$

4.7. Acid–Base Reactions

1- Acid–base Reactions

Arrhenius Definitions:

- **Base: Substance that produces OH^- ions in aqueous solution.**

$$NaOH(aq) \longrightarrow Na^+(aq) + OH^-(aq)$$

- **Acid: Substance that produces H^+ ions in aqueous solution.**

$$HCl(aq) \longrightarrow H^+(aq) + Cl^-(aq)$$

  – Some acids—called **polyprotic acids**
    - These acids contain **more** than one ionizable proton and release them sequentially.
    - **Example**, sulfuric acid, H_2SO_4 is a **diprotic acid**.

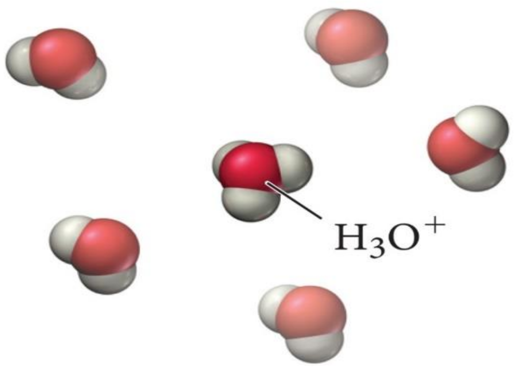
$$H_2SO_4\ aq) \longrightarrow H^+(aq) + HSO_4^-\ (aq)$$

$$HSO_4^-\ aq) \leftrightarrow H^+(aq) + SO_4^{2-}\ (aq)$$

4.7. Acid–Base and Gas-Evolution Reactions

1- Acid–base Reactions

- The H from the acid molecule is donated to a water molecule to form **hydronium ion, H_3O^+.**
- In the reaction of an **acid with a base**, the H^+ from the acid combines with the OH^- from the base to make **water**.
- The cation from the base combines with the anion from the acid to make the **salt**.



$$HCl(aq) + NaOH(aq) \longrightarrow H_2O(l) + NaCl(aq)$$

Acid	Base	Water	Salt

4.7. Acid–Base and Gas-Evolution Reactions

1- Acid–base Reactions

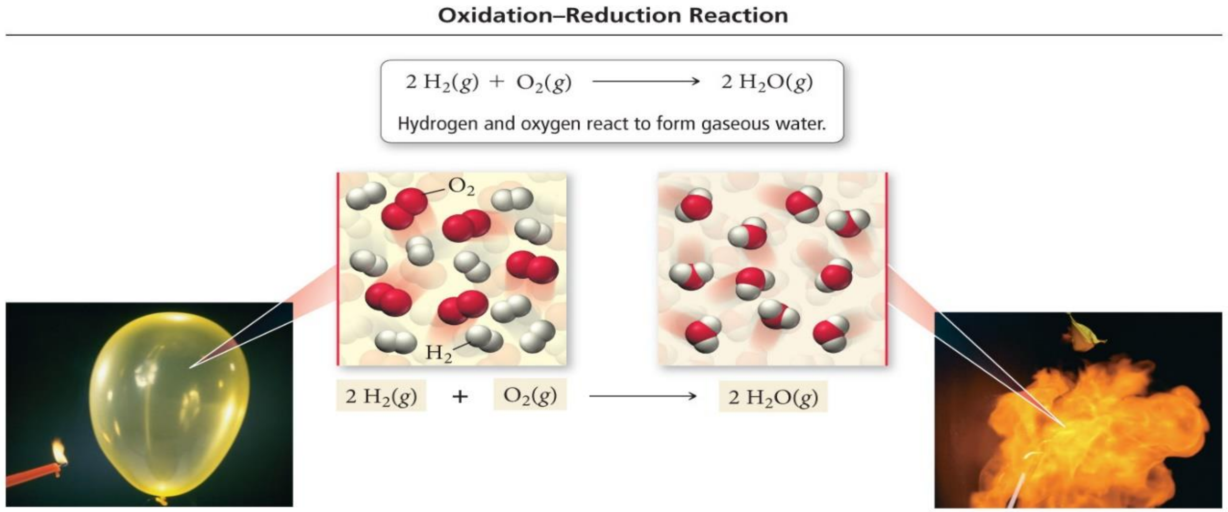
TABLE 4.2 Some Common Acids and Bases

Name of Acid	Formula	Name of Base	Formula
Hydrochloric acid	HCl	Sodium hydroxide	$NaOH$
Hydrobromic acid	HBr	Lithium hydroxide	$LiOH$
Hydroiodic acid	HI	Potassium hydroxide	KOH
Nitric acid	HNO_3	Calcium hydroxide	$Ca(OH)_2$
Sulfuric acid	H_2SO_4	Barium hydroxide	$Ba(OH)_2$
Perchloric acid	$HClO_4$	Ammonia*	NH_3 (weak base)
Acetic acid	$HC_2H_3O_2$ (weak acid)		
Hydrofluoric acid	HF (weak acid)		

*Ammonia does not contain OH^-, but it produces OH^- in a reaction with water that occurs only to a small extent: $NH_3(aq) + H_2O(l) \rightleftharpoons NH_4^+(aq) + OH^-(aq)$.

4.8. Oxidation–Reduction Reactions

- The reactions in which electrons are **transferred** from one reactant to the other are called **oxidation-reduction reactions**. **(redox reactions)**
  - Many redox reactions involve the reaction of a substance with oxygen.
  - Example:



$4\ Fe(s) + 3\ O_2(g) \rightarrow 2\ Fe_2O_3(s)$ (rusting)

$2\ H_2(g) + O_2(g) \rightarrow 2\ H_2O(g)$

4.8. Oxidation–Reduction Reactions

- Consider the following reactions:

$$4\ Na(s) + O_2(g) \rightarrow 2\ Na_2O(s)$$

$$2\ Na(s) + Cl_2(g) \rightarrow 2\ NaCl(s)$$

- The reactions involve a metal reacting with a nonmetal.
- In addition, both reactions involve the conversion of free elements into ions.

$$4\ Na(s) + O_2(g) \rightarrow 2\ Na^+{}_2O^{2-}\ (s)$$

$$2\ Na(s) + Cl_2(g) \rightarrow 2\ Na^+Cl^-(s)$$

4.8. Oxidation–Reduction Reactions

- The transfer of electrons does not need to be a *complete* transfer (as occurs in the formation of an ionic compound) for the reaction to qualify as oxidation–reduction.
  - For example, consider the reaction between hydrogen gas and chlorine gas:

    $H_2(g) + Cl_2(g) \longrightarrow 2\ HCl(g)$
- When hydrogen bonds to chlorine, the electrons are unevenly shared, resulting in
  - an increase of electron density (reduction) for chlorine
  - a decrease in electron density (oxidation) for hydrogen.

4.8. Oxidation–Reduction Reactions

- To convert a free element into an ion, the atoms must gain or lose electrons.
- Reactions where electrons are transferred from one atom to another are redox reactions.
- Atoms that **lose** electrons are being **oxidized (اكسدة)**
- while atoms that **gain** electrons are being **reduced (أختزال)**

$$2\ Na(s) + Cl_2(g) \rightarrow 2\ Na^+Cl^-(s)$$

$$Na \rightarrow Na^+ + 1\ e^-$$ (**oxidation**)

$$Cl_2 + 2\ e^- \rightarrow 2\ Cl^-$$ (**reduction**)

Oxidation States

- For reactions that are not metal + nonmetal, or do not involve O_2, we need a method for determining **how the electrons are transferred?**
- Chemists assign a number to each element in a reaction called an **oxidation state** that allows them to determine the electron flow in the reaction.
  - Even though they look like them, **oxidation states are not ion charges!**
    - Oxidation states are imaginary charges assigned based on a set of rules.
    - Ion charges are real, measurable charges.

Chapter 4: Chemical Bonding and Chemical Reactions

Oxidation States

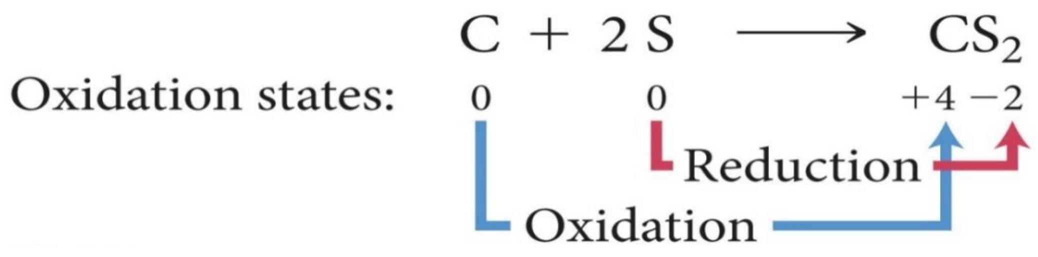
Rules for Assigning Oxidation States	Examples	
(These rules are hierarchical. If any two rules conflict, follow the rule that is higher on the list.)		
1. The oxidation state of an atom in a free element is 0.	Cu 0 ox state	Cl_2 0 ox state
2. The oxidation state of a monoatomic ion is equal to its charge.	Ca^{2+} +2 ox state	Cl^- −1 ox state
3. The sum of the oxidation states of all atoms in:		
• A neutral molecule or formula unit is 0.	H_2O 2(H ox state) + 1(O ox state) = 0	
• An ion is equal to the charge of the ion.	NO_3^- 1(N ox state) + 3(O ox state) = −1	
4. In their compounds, metals have positive oxidation states.		
• Group 1A metals *always* have an oxidation state of +1.	NaCl +1 ox state	
• Group 2A metals *always* have an oxidation state of +2.	CaF_2 +2 ox state	
5. In their compounds, nonmetals are assigned oxidation states according to the table that lists oxidation states of nonmetals in the margin. Entries at the top of the table take precedence over entries at the bottom of the table.		

4.8. Oxidation–Reduction Reactions

Nonmetal	Oxidation State	Example
Fluorine	−1	MgF_2 −1 ox state
Hydrogen	+1	H_2O +1 ox state
Oxygen	−2	CO_2 −2 ox state
Group 7A	−1	CCl_4 −1 ox state
Group 6A	−2	H_2S −2 ox state
Group 5A	−3	NH_3 −3 ox state

Identifying Redox Reactions

- Oxidation: An increase in oxidation state
- Reduction: A decrease in oxidation state



- Carbon changes from an oxidation state of 0 to an oxidation state of +4.
  - Carbon **loses** electrons and is **oxidized**.
- Sulfur changes from an oxidation state of 0 to an oxidation state of –2.
  - Sulfur **gains** electrons and is **reduced**.

Identifying Redox Reactions

- Oxidation and reduction must occur simultaneously.
  - If an atom loses electrons another atom must take them.
- The reactant that reduces an element in another reactant is called the **reducing agent.**
  - The reducing agent contains the element that is oxidized.
- The reactant that oxidizes an element in another reactant is called the **oxidizing agent.**
  - The oxidizing agent contains the element that is reduced.
  - **Example:**

$$2\ Na(s) + Cl_2(g) \rightarrow 2\ Na^+Cl^-(s)$$

Na is oxidized, while Cl is reduced.

Na is the reducing agent, and Cl_2 is the oxidizing agent.