Aqueous Solutions and Net Ionic Equations

- Reactions that occur in water are said to take place in aqueous solution
  - ✓ Solution: Homogeneous mixture of two or more substances
    - Solvent: The major component of the solution
    - Solutes: The minor components of the solution

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Solutions, Solvents, and Solutes

- Concentration is a key piece of information for solutions
  - ✓ Solutions are concentrated if many solute particles are present
  - ✓ Solutions are dilute if few solute particles are present

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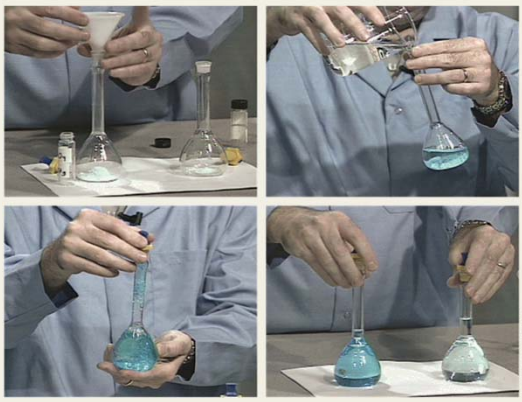
Solution preparation

Solution preparation

- Solid $CuSO_4$, the solute, is transferred to a flask
- Water, the solvent, is added
- The flask is shaken to speed the dissolution process
- Two $CuSO_4$ solutions of different concentrations are shown
  - Solution on the left is more concentrated, as seen from its darker color



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(Q.4)

For most concentrated solutions, which is present in greater amounts?

- Solute
- Solvent
- Both are roughly equal

Answer: Solute

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- Compounds can be characterized by their solubility
  - Soluble compounds dissolve readily in water
  - Insoluble compounds do not dissolve readily in water
- Solubility can be predicted using solubility rules

Solubility guidelines

Solubility guidelines for soluble salts

Usually Soluble	Exceptions
Group 1 cations (Li^+, Na^+, K^+, Rb^+, Cs^+), ammonium (NH_4^+)	No common exceptions
Nitrates (NO_3^-), nitrites (NO_2^-)	Moderately soluble: $AgNO_2$
Chlorides, bromides, iodides (Cl^-, Br^-, I^-)	Insoluble: AgCl, Hg_2Cl_2, $PbCl_2$, AgBr, Hg_2Br_2, $PbBr_2$, AgI, Hg_2I_2, and PbI_2
Fluorides (F^-)	Insoluble: MgF_2, CaF_2, SrF_2, BaF_2, PbF_2
Sulfates (SO_4^{2-})	Insoluble: $BaSO_4$, $PbSO_4$, $HgSO_4$ Moderately soluble: $CaSO_4$, $SrSO_4$, Ag_2SO_4
Chlorates (ClO_3^-), perchlorates (ClO_4^-)	No common exceptions
Acetates (CH_3COO^-)	Moderately soluble: $AgCH_3COO$

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Solubility guidelines

Solubility guidelines for insoluble salts

Usually Insoluble	Exceptions
Phosphates (PO_4^{3-})	Soluble: $(NH_4)_3PO_4$, Na_3PO_4, K_3PO_4
Carbonates (CO_3^{2-})	Soluble: $(NH_4)_2CO_3$, Na_2CO_3, K_2CO_3
Hydroxides (OH^-)	Soluble: LiOH, NaOH, KOH, $Ba(OH)_2$ Moderately soluble: $Ca(OH)_2$, $Sr(OH)_2$
Sulfides (S^{2-})	Soluble: $(NH_4)_2S$, Na_2S, K_2S, MgS, CaS

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Example Problem 3.2

- Which of the following compounds would you predict are soluble in water at room temperature?
  - $KClO_3$
  - $CaCO_3$
  - $BaSO_4$
  - $KMnO_4$

Answer: $KClO_3$ and $KMnO_4$ are soluble

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Electrolytes and nonelectrolytes

- Electrolytes are soluble compounds that conduct electricity when dissolved in water
  - ✓ Weak electrolytes dissociate partially into ions in solution
  - ✓ Strong electrolytes dissociate completely into ions in solution
- Nonelectrolytes are substances whose solutions do not conduct electricity

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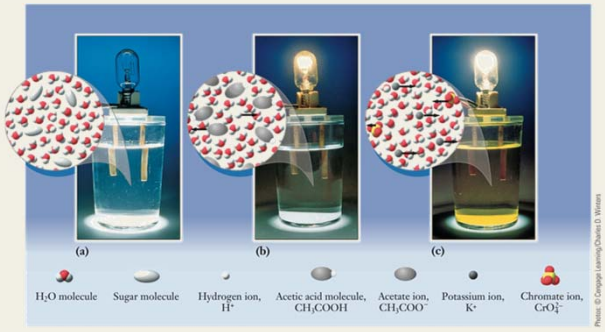

- Sugar, a nonelectrolyte, does not conduct electricity when dissolved in water
- Acetic acid, a weak electrolyte, weakly conducts electricity when dissolved in water
- Potassium chromate, a strong electrolyte, strongly conducts electricity when dissolved in water

Chemical Equations for Aqueous Reactions

- When a covalently bonded material dissolves in water and the molecules remain intact, they do not conduct electricity
  - These compounds are nonelectrolytes

$$C_6H_{12}O_6\,(s) \longrightarrow C_6H_{12}O_6\,(aq)$$

  - The water molecules are not shown clearly, although their presence is indicated by the "(aq)" labels on the product side

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Chemical Equations for Aqueous Reactions

- Dissociation reaction occurs when ionic solids dissolve in water and break into their constituent ions
  - These compounds conduct electricity and are electrolytes

$$NaCl\,(s) \longrightarrow Na^+\,(aq) + Cl^-\,(aq)$$

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Chemical Equations for Aqueous Reactions

- Aqueous chemical reactions can be written as a molecular equation, which shows the complete formula for each compound

$$HNO_3(aq) + NH_3(g) \longrightarrow NH_4NO_3(aq)$$

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Chemical Equations for Aqueous Reactions

- Dissociation of reactants and products is emphasized by writing a total ionic equation

$$H^+(aq) + NO_3^-(aq) + NH_3(g) \longrightarrow NH_4^+(aq) + NO_3^-(aq)$$

  - Note: HNO_3 is a strong acid and thus dissociates completely, whereas NH_3 does not dissociate

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Chemical Equations for Aqueous Reactions

- Spectator ions are ions not involved in the chemical reaction
- When spectator ions are removed, the result is a net ionic equation
  - Total ionic equation

$$H^+(aq) + \cancel{NO_3^-(aq)} + NH_3(g) \longrightarrow NH_4^+(aq) + \cancel{NO_3^-(aq)}$$

  - Net ionic equation

$$H^+(aq) + NH_3(g) \longrightarrow NH_4^+(aq)$$

$$\text{Spectator ion} = NO_3^-$$

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(Q.5)

When HCl reacts with ammonia, what is/are the spectator ion or ions?

- H^+
- Cl^-
- NH_4^+
- There are no spectator ions

Answer: Cl^-

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(Q.6)

What is left out when a net ionic equation is written?

- The physical states of the chemicals
- Any precipitate that forms
- Spectator ions
- Any gases or precipitates that form

Answer: Spectator ions

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Acid–Base Reactions

- According to Arrhenius definition for acids and bases,
- Acids are substances that dissolve in water to produce H^+ or H_3O^+ ions
  - Examples: HCl, HNO_3, H_3PO_4, HCN
- Bases are substances that dissolve in water to produce OH^- ions
  - Examples: NaOH, $Ca(OH)_2$, NH_3

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Acid–Base Reactions

- Strong acids and bases completely dissociate in water

$$HCl(g) + H_2O(\ell) \longrightarrow H_3O^+(aq) + Cl^-(aq)$$

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

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Acid–Base Reactions

All common strong acids and bases

Strong Acids		Strong Bases	
HCl	Hydrochloric acid	LiOH	Lithium hydroxide
HNO_3	Nitric acid	NaOH	Sodium hydroxide
H_2SO_4	Sulfuric acid	KOH	Potassium hydroxide
$HClO_4$	Perchloric acid	$Ca(OH)_2$	Calcium hydroxide
HBr	Hydrobromic acid	$Ba(OH)_2$	Barium hydroxide
HI	Hydroiodic acid	$Sr(OH)_2$	Strontium hydroxide

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Acid–Base Reactions

- Weak acids and bases partially dissociate (partial ionization) in water
  - Notice the two-way arrow, which emphasizes that the reaction does not proceed completely from left to right

$$CH_3COOH(aq) + H_2O(\ell) \rightleftharpoons H_3O^+(aq) + CH_3COO^-(aq)$$

$$NH_3(aq) + H_2O(\ell) \rightleftharpoons NH_4^+(aq) + OH^-(aq)$$

Many other weak bases are amines

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Acid–Base Reactions

- *Some* common weak acids and bases

Weak Acids		Weak Bases	
H_3PO_4	Phosphoric acid	NH_3	Ammonia
HF	Hydrofluoric acid	CH_3NH_2	Methylamine
CH_3COOH	Acetic acid		
HCN	Hydrocyanic acid		

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Acid–Base Reactions

- Mixing an acid and a base leads to a reaction known as neutralization, in which the resulting solution is neither acidic nor basic
  - Net ionic equation for neutralization of strong acid and strong base

$$H_3O^+(aq) + OH^-(aq) \longrightarrow 2H_2O(\ell)$$

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(Q.7)

What other property is true about a strong acid?

- Concentrated solution
- Strong electrolyte
- Strong salt

Answer: Strong electrolyte

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(Q.8)

What are the products of a neutralization reaction?

- Water
- Salt
- Both water and salt
- Water and a precipitate

Answer: Both water and salt

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Example Problem 3.3

When aqueous solutions of acetic acid and potassium hydroxide are combined, a neutralization reaction will occur

Write the following equations:

- Molecular
- Total ionic
- Net ionic

Answer:

1. $\mathrm{CH_3COOH + KOH \rightarrow H_2O + KCH_3COO}$
2. $\mathrm{CH_3COOH(aq) + K^+(aq) + OH^-(aq) \rightarrow H_2O(\ell) + K^+(aq) + CH_3COO^-(aq)}$
3. $\mathrm{CH_3COOH(aq) + OH^-(aq) \rightarrow H_2O(\ell) + CH_3COO^-(aq)}$

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