Chapter 4
Reactions in Aqueous Solution

Properties of Aqueous Solutions

- Substances behave differently when they are placed in water, specifically ionic versus covalent compounds.
- One breaks apart in water, the other does not.
- Which one is more likely to be pulled apart by water molecules?
- Electrolytes are ionic and strong acid solutions (e.g., Gatorade™); Nonelectrolytes are covalent compounds (e.g., sugar); weak electrolytes are in between.

Electrolytes in Aqueous Solutions

- **Strong electrolyte**: substance that, when dissolved in water, results in a solution that can conduct electricity (NaCl) soluble ionic compounds, strong acids
- **Weak electrolyte**: substance that is a poor conductor of electricity when dissolved in water (CH₃COOH – vinegar) insoluble ionic compounds, weak acids
- **Nonelectrolyte**: substance that doesn’t conduct electricity when dissolved in water (CH₃OH – methanol), covalent compounds

Electrolytes in Aqueous Solutions

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<tr>
<th>Strong Electrolytes</th>
<th>Weak Electrolytes</th>
<th>Nonelectrolytes</th>
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<tbody>
<tr>
<td>HCl, HBr, HI</td>
<td>CH₃COOH</td>
<td>H₂O</td>
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<td>HNO₃</td>
<td>CH₃OH (methyl alcohol)</td>
<td>C₂H₅OH (ethyl alcohol)</td>
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<td>H₂SO₄</td>
<td>C₆H₁₂O₇ (fructose)</td>
<td>Most compounds of carbon (organic compounds)</td>
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<td>NaOH, KOH</td>
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<td>Other soluble ionic compounds</td>
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Properties of Aqueous Solutions

- Most reactions in general chemistry take place in an aqueous environment. What does that mean?
- **Terms:**
  - **Solution**: homogeneous mixture of two or more substances
  - **Solute**: substance present in smaller amount
  - **Solvent**: substance present in greater amount
  - **Aqueous solution**: solvent is water
Ways Reactions Occur

- Three general categories:
  - Precipitation: insoluble (solid) product is formed from aqueous solutions
  - Acid-base neutralization: acid and base react to form water and a salt (ionic compound)
  - Oxidation-Reduction: electrons are transferred between atoms in reaction
    - Combination
    - Decomposition
    - Single-replacement (metal or hydrogen)

Precipitation (Double-Replacement) Reactions

- Precipitation reactions always begin with two ionic compounds.
- Example: NaCl(aq) + AgNO₃(aq) → ?
- Draw these compounds in two separate aqueous environments. What are the possible products when they are combined?
- Write formulas of products (based on charges), predict phases (Solubility Rules on back of periodic table), and balance the equation.

Solubility Rules – on periodic table

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<th>Soluble Compounds</th>
<th>Exceptions</th>
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<tr>
<td>Compounds containing alkaline ions (Li⁺, Na⁺, K⁺, NH₄⁺), and amphoteric ions (OH⁻)</td>
<td>Halides of Ag⁺, Cu²⁺, and Pb²⁺.</td>
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<td>Nitrites (NO₂⁻), bistetrafluorosilicates (SiF₄²⁻), and dibromides (Br₂⁻)</td>
<td>Halides of Ag⁺, Cu²⁺, and Pb²⁺.</td>
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<td>Solubility Chart</td>
<td>Solubility Chart</td>
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If not covered by the rules, it is probably insoluble.

Solubility Rules

- Determine if the following ionic compounds will be soluble (aq) or insoluble (s) in water:
  - K₂CO₃
  - BaSO₄
  - PbI₂
  - NaClO₄
  - Ag₂S
  - (NH₄)₃PO₄
  - Cu(OH)₂

Solubility Rules Answers

- Determine if the following ionic compounds will be soluble (aq) or insoluble (s) in water:
  - K₂CO₃ soluble (aq)
  - BaSO₄ insoluble (s)
  - PbI₂ insoluble (s)
  - NaClO₄ soluble (aq)
  - Ag₂S insoluble (s)
  - (NH₄)₃PO₄ soluble (aq)
  - Cu(OH)₂ insoluble (s)

Molecular, Ionic, and Net Ionic Equations

- There are 3 ways to represent ppt reactions:
  - As whole compounds (molecular equation)
  - As ionic species (ionic equation) – more accurate
  - As participants in reaction (net ionic equation)
- Any aqueous ionic substance is written as a compound (e.g., AgNO₃), but this isn’t accurate. What does this look like in water? It is Ag⁺ and NO₃⁻ ions
- Solids, liquids, and gases remain as compounds.
Formation of Silver Chloride

- **Molecular equation:**
  \[ \text{NaCl}(aq) + \text{AgNO}_3(aq) \rightarrow \text{AgCl}(s) + \text{NaNO}_3(aq) \]

- **Ionic equation** (write separate ions for soluble (aq) compounds):
  \[ \text{Na}^+(aq) + \text{Cl}^-(aq) + \text{Ag}^+(aq) + \text{NO}_3^-(aq) \rightarrow \text{AgCl}(s) + \text{Na}^+(aq) + \text{NO}_3^-(aq) \]

- **Net ionic equation** (cancel any identical ion on both sides of the equation, called spectator ions): 
  \[ \text{Ag}^+(aq) + \text{Cl}^-(aq) \rightarrow \text{AgCl}(s) \]

- **Note:** s, l, and g stay together!!!!!

Chemistry humor, ha ha!

Precipitation Reactions

- Reaction of lead (II) nitrate and potassium iodide. What is the precipitate?
- Write the molecular, ionic, and net ionic equations.
- **Worked Ex. 4.2 – 4.5; Problems 4.4 – 4.8**

Acid-Base (Double-Replacement) Reactions

- **Acid:** substance that breaks apart in water to form \( H^+ \) (e.g., HCl, HNO_3, CH_3COOH, lemon, lime, vitamin C).
  \[ \text{HA}(aq) \rightarrow H^+(aq) + A^-(aq) \]

- **Base:** substance that breaks apart in water to form \( \text{OH}^- \) (e.g., NH_3, Drano™, Milk of Magnesia™)
  \[ \text{MOH}(aq) \rightarrow \text{M}^+(aq) + \text{OH}^-(aq) \]

Common Acids and Bases

- You need to KNOW these!!!

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<th>Strong acid</th>
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Acid-Base Reaction

\[ \text{Acid} + \text{Base} \rightarrow \text{H}_2\text{O} + \text{Salt} \]

Water is created from \( \text{H}^+ \) and \( \text{OH}^- \)

\[ 2\text{HCl(aq)} + \text{Mg(OH)}_2(\text{s}) \rightarrow 2\text{H}_2\text{O(l)} + \text{MgCl}_2(\text{aq}) \]

The salt is created from spectator ions

Group Work

- Determine the products of the reaction. Identify the phase of each compound, and balance the equation. Also write the ionic and net ionic equations.
- Molecular: \( \text{Na}_2\text{S} + \text{Cr(NO}_3)_3 \rightarrow \)
- Complete Ionic:
- Net Ionic:

Group Answers

- Molecular: \( 3\text{Na}_2\text{S(aq)} + 2\text{Cr(NO}_3)_3(\text{aq}) \rightarrow \text{Cr}_2\text{S}_3(\text{s}) + 6\text{NaNO}_3(\text{aq}) \)
- Complete Ionic: \( 6\text{Na}^+(\text{aq}) + 3\text{S}^2-(\text{aq}) + 2\text{Cr}^{3+}(\text{aq}) + 6\text{NO}_3^-(\text{aq}) \rightarrow \text{Cr}_2\text{S}_3(\text{s}) + 6\text{Na}^+(\text{aq}) + 6\text{NO}_3^-(\text{aq}) \)
- Net Ionic: \( 2\text{Cr}^{3+}(\text{aq}) + 3\text{S}^2-(\text{aq}) \rightarrow \text{Cr}_2\text{S}_3(\text{s}) \)

Complete/Balance These Equations

- Complete and balance these equations. Write ionic and net ionic equations, if applicable.
- \( \text{Na}_2\text{S(aq)} + \text{CuCl}_2(\text{aq}) \rightarrow \)
- \( \text{KNO}_3(\text{aq}) + \text{CaCl}_2(\text{aq}) \rightarrow \)
- \( \text{KOH(aq)} + \text{H}_2\text{SO}_4(\text{aq}) \rightarrow \)

Oxidation-Reduction Reactions

- Oxidation-Reduction (redox) reactions: electron-transfer reactions
- When iron rusts, it loses electrons to form a cation, oxygen gain electrons to form an anion: \( 4\text{Fe(s)} + 3\text{O}_2(g) \rightarrow 2\text{Fe}_3\text{O}_4(\text{s}) \)
- Use oxidation number rules to determine gain and loss of electrons.
- Oxidation numbers are assigned as if elements in compounds completely transferred electrons (like in ionic compounds).
Assigning Oxidation Numbers

1) An atom (or molecule) in its elemental state has an oxidation number of 0.
2) An atom in a monatomic ion (Na⁺, Cl⁻) has an oxidation number identical to its charge.
3a) Hydrogen has an oxidation number of +1, unless it is combined with a metal, in which case it has an oxidation number of -1.
3b) Oxygen usually has an oxidation number of -2. Oxygen in peroxides (O₂²⁻) has an oxidation number of -1.
3c) Halogens usually have an oxidation number of -1 (except when bonded to oxygen or in polyatomic ions).
4) The sum of oxidation numbers is 0 for a neutral compound and is equal to the net charge for a polyatomic ion.
(Example: NaCl = 0, SO₄²⁻ = -2)
4a) For binary ionic compounds, the position of the element in the periodic table may be useful:
   • Group IA: +1; Group IIA: +2; Group VIIA: -1; Group VIA: -2; Group VA: -3

Example

H₂SO₄
- H = +1; O = -2
- S is unknown, so leave this for last.
- The overall charge on this compound is 0.
- Use algebra to solve for S:
  2(+1) + 1(x) + 4(-2) = 0
- Solve for each element: MgCr₂O₇
- Worked Ex. 4.8; Problem 4.13

Assigning Oxidation Numbers

Determine values of the oxidation number of each element in these compounds or ions:
H₂O  SO₂  CCl₄  H₂O₂  Fe₃(PO₄)₂  MnO₄⁻  NaNO₃  KClO₄

Oxidation-Reduction Reactions

- Oxidized: atom, molecule, or ion becomes more positively charged
  • Loss of electrons is oxidation (LEO)
- Reduced: atom, molecule, or ion becomes less positively charged (reduced charge)
  • Gain of electrons is reduction (GER)
- Or: OIL RIG (oxidation is loss; reduction is gain)
Assigning Oxidation Numbers

- The substance oxidized causes the other substance to be reduced and is called the **reducing agent**.
- The substance reduced causes the other substance to be oxidized and is called the **oxidizing agent**.

\[
4 \text{Fe(s)} + 3 \text{O}_2(g) \rightarrow 2 \text{Fe}_2\text{O}_3(s)
\]

Worked Ex. 4.9; Problems 4.14, 4.15

Oxidation-Reduction Reactions

- Identify the element or ion oxidized/reduced. Also identify the oxidizing agent and the reducing agent.

\[
\text{Zn(s)} + 2\text{HCl(aq)} \rightarrow \text{ZnCl}_2(\text{aq}) + \text{H}_2(g)
\]

Group Work

- Identify the oxidation number of each element in the compounds or ions below:
  - \(\text{Ba(ClO}_3)_2\)
  - \(\text{SO}_4^{2-}\)
  
- For the reaction below, identify what has been oxidized and reduced; identify the oxidizing agent and the reducing agent.

\[
\text{Cu(s)} + 2\text{AgNO}_3(\text{aq}) \rightarrow 2\text{Ag(s)} + \text{Cu(NO}_3)_2(\text{aq})
\]

Group Answers

- Ba: +2
- Cl: +5
- O: -2

- Cu: oxidized
- Ag: reduced

Redox Reactions

- Combination (1 product)
  - \(\text{Na(s)} + \text{Cl}_2(g) \rightarrow \text{NaCl(s)}\)
- Decomposition (1 reactant) – usually give off gases
  - \(\text{CuCO}_3(s) \rightarrow \text{CuO} + \text{CO}_2(g)\)
- Single Replacement (or Displacement) (start and end with an element and a compound)
  - \(\text{Zn(s)} + \text{HCl(aq)} \rightarrow \text{ZnCl}_2(\text{aq}) + \text{H}_2(\text{g})\)
Combination Reactions
- Element + element → compound
  - H₂(g) + O₂(g) →
- Metal + nonmetal → ionic compound
  - Na(s) + Cl₂(g) →
- Nonmetal + nonmetal → covalent compound
  - C(s) + O₂(g) →
- Why are these redox reactions?

Decomposition Reactions
- Compound → 2 elements; element + compound; or 2 compounds
  - Oxides, peroxides
    - Give off O₂
  - Nitrates
    - Give off NO₂, NO₃⁻
  - Carbonates
    - Give off CO₂
  - Ammonium salts
    - Give off NH₃

Single-Displacement Reactions
- Element + compound → compound + element (The more metallic/active element in the compound is displaced.)
  - Metal Displacement
    - Zn(s) + Cu(NO₃)₂(aq) → Cu(s) + Zn(NO₃)₂(aq)
  - Hydrogen Displacement
    - Mg(s) + HCl(aq) → MgCl₂(aq) + H₂(g)

Single Displacement: Cu + AgNO₃
- The copper salt reduces Ag⁺ ions and becomes coated with silver.
- The solution turns blue as Cu²⁺ ions are formed.
Single Displacement: $\text{Fe} + \text{Cu(NO}_3\text{)}_2$

Activity Series

- The higher the metal on the activity series, the more active that metal.
- Translation: higher metals on the chart will form ions as products.

Predict whether a reaction occurs

- $\text{Na} + \text{H}_2\text{O}$
- $\text{Fe} + \text{H}_2\text{O}$
- $\text{Fe} + \text{Cr(NO}_3\text{)}_2$
- $\text{Ni} + \text{Pb}^{2+}$
- $\text{Ag} + \text{Mg}^{2+}$
- $\text{Zn} + \text{Co}^{2+}$

Worked Ex. 4.10; Problems 4.16, 4.17

Combustion Reactions

- Burning hydrocarbons
- $\text{C}_x\text{H}_y\text{O}_z + \text{O}_2(g) \rightarrow \text{CO}_2(g) + \text{H}_2\text{O}(g)$
- Methanol, $\text{CH}_3\text{OH}$
- $\text{CH}_3\text{OH}(l) + \text{O}_2(g) \rightarrow \text{CO}_2(g) + \text{H}_2\text{O}(g)$

Types of Reactions Summary

- Precipitation: use Solubility Rules ($\text{AB} + \text{CD} \rightarrow \text{AD} + \text{CB}$)
- Acid-Base Neutralization: acid + base $\rightarrow$ salt + water ($\text{AB} + \text{CD} \rightarrow \text{AD} + \text{H}_2\text{O}$)
- Combination: start with elements ($\text{A} + \text{B} \rightarrow \text{AB}$)
- Decomposition: often produces gas ($\text{AB} \rightarrow \text{A} + \text{B}$)
- Single Displacement: use Activity Series to predict if a reaction occurs ($\text{A} + \text{BC} \rightarrow \text{B} + \text{AC}$)
- Combustion:
  - Hydrocarbon + $\text{O}_2(g) \rightarrow \text{CO}_2(g) + \text{H}_2\text{O}(g)$

Classify (and balance) these rxns

1. $\text{Co(s)} + \text{AgNO}_3(aq) \rightarrow$
2. $\text{Fe(s)} + \text{HCl(aq)} \rightarrow$
3. $\text{Na}_2\text{CO}_3(s) \rightarrow$
4. $\text{Ca(s)} + \text{H}_2\text{O(l)} \rightarrow$
5. $\text{CaCO}_3(s) \rightarrow$
6. $\text{HClO}_4(aq) + \text{KOH (aq)} \rightarrow$
7. $\text{BaCl}_2(aq) + \text{Na}_2\text{SO}_4(aq) \rightarrow$
Classify (and balance) these rxns

8. HgO(s) \rightarrow
9. LiOH(aq) + H_2SO_4(aq) \rightarrow
10. Na_2CrO_4(aq) + Ni(NO_3)_2(aq) \rightarrow
11. Li(s) + O_2(g) \rightarrow
12. Mg(OH)_2(aq) + 2HCl(aq) \rightarrow
13. NH_3(g) + HCl(g) \rightarrow
14. NiCO_3(s) \rightarrow
15. Ca(s) + F_2(g) \rightarrow

Group Work

- Determine what type of reaction will happen for each set of reagents below.
- Predict products of the following reactions.
- Write correct phases for the products and balance each equation:
  - ___ Al (s) + ___ NaNO_3 (aq) \rightarrow ___ Na (s) + ___ O_2 (g) \rightarrow ___ Na_2SO_4 (aq) + ___ Pb(NO_3)_2 (aq) \rightarrow

Group Answers

- SR: Al (s) + NaNO_3 (aq) \rightarrow No reaction
- Combo: 4 Na (s) + O_2 (g) \rightarrow 2 Na_2O (s)
- DR/PPT: Na_2SO_4 (aq) + Pb(NO_3)_2 (aq) \rightarrow 2NaNO_3 (aq) + PbSO_4 (s)

The End

- Given reactants, be able to identify the reaction type, predict the products of reaction (with correct phases), and balance the equation – similar to the worksheet questions!