Chapter 9. Chemical Reactions

Introduction to Inorganic Chemistry
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Online Tests on Following days
March 24, 2017: Test 1 (Chapters 1-3)
April 10, 2017 : Test 2 (Chapters 4-5)
May 1, 2017: Test 3 (Chapters 6,7 &8)
May 12, 2017 : Test 4 (Chapters 9, 10 &11)
May 15, 2017: Make Up Exam: Chapters 1-11)

.

Chapter 9

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Section 9.1

Types of Chemical Reactions

Chemical Reaction

- Process in which at least one new substance is produced as a result of chemical change.
- Major types of chemical reactions
  - Combination
  - Decomposition
  - Displacement (single)
  - Exchange (double)
  - Combustion

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Section 9.2

Redox and Nonredox Reactions

- Oxidation-Reduction (Redox) Reaction
  - A chemical reaction in which there is a transfer of electrons from one reactant to another reactant.
- Nonoxidation-Reduction (Nonredox) Reaction
  - A chemical reaction in which there is no transfer of electrons from one reactant to another reactant.

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Section 9.1

Types of Chemical Reactions

Combination Reaction

- A chemical reaction in which a single product is produced from two (or more) reactants.

$$X + Y \rightarrow XY \text{ (redox)}$$

$$2H_2 + O_2 \rightarrow 2H_2O$$

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Section 9.1

Types of Chemical Reactions

Decomposition Reaction

- A chemical reaction in which a single reactant is converted into two (or more) simpler substances (elements or compounds).

$$XY \rightarrow X + Y \text{ (redox)}$$

$$2H_2O \rightarrow 2H_2 + O_2$$

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Section 9.1

Types of Chemical Reactions

Displacement Reaction

- A chemical reaction in which an atom or molecule displaces an atom or group of atoms from a compound.

$$X + YZ \rightarrow Y + XZ \text{ (redox)}$$

$$Zn + 2HCl \rightarrow ZnCl_2 + H_2$$

Section 9.1

Types of Chemical Reactions

Exchange Reaction (double displacement)

- A chemical reaction in which two substances exchange parts with another and form two different substances.

$$AX + BY \rightarrow AY + BX \text{ (non-redox)}$$

$$Na_2SO_4(aq) + Pb(NO_3)_2(aq) \rightarrow 2NaNO_3(aq) + PbSO_4(s)$$

Section 9.1

Types of Chemical Reactions

Combustion Reaction

- A chemical reaction between a substance and oxygen (usually from air) that proceeds with the evolution of heat and light (usually from a flame).

$$C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O \text{ (redox)}$$

Section 9.1

Types of Chemical Reactions

Concept Check

Classify each of the following chemical reactions as a combination, decomposition, displacement, exchange, or combustion reaction.

a) $Mg(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + H_2(g)$

b) $HCl(g) + NH_3(g) \rightarrow NH_4Cl(s)$

c) $4NH_3 + 5O_2 \rightarrow 4NO + 6H_2O$

Section 9.1

Types of Chemical Reactions

Concept Check

Classify each of the following chemical reactions as a combination, decomposition, displacement, exchange, or combustion reaction.

a) $Mg(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + H_2(g)$

displacement

b) $HCl(g) + NH_3(g) \rightarrow NH_4Cl(s)$

combination

c) $4NH_3 + 5O_2 \rightarrow 4NO + 6H_2O$

combustion

Section 9.2

Redox and Nonredox Reactions

Oxidation Number (Oxidation State)of an Element

- A number that represents the charge that an atom appears to have when the electrons in each covalent/ionic bond it is participating in are assigned to the more electronegative of the two atoms involved in the bond.

E.g. NaCl made up of Na^+ and Cl^-

H_2O has $\overset{1+}{H}\text{-}\overset{2-}{O}\text{-}\overset{1+}{H}$

Section 9.2

Redox and Nonredox Reactions

Rules for Assigning Oxidation Numbers

1. Oxidation # of an element in its elemental state = 0.
2. Oxidation # of a monatomic ion = charge on ion.
3. Group 1A = +1; Group IIA = +2.
4. Hydrogen = +1 in covalent compounds.
5. Oxygen = –2 in covalent compounds (except in peroxides where it = –1).
6. In binary molecular compounds, the more electronegative element is assigned a negative oxidation # equal to its charge in binary ionic compounds. $H^{1+}\ O^{2-}\ H^{1+}$
7. Sum of oxidation states = 0 in compounds;
8. Sum of oxidation states of an ion = charge of the ion.

Section 9.2

Redox and Nonredox Reactions

Exercise

Find the oxidation numbers for each of the elements in each of the following compounds:

- $K_2Cr_2O_7$
- CO_3^{2-}
- MnO_2
- PCl_5
- SF_4

Section 9.2

Redox and Nonredox Reactions

Exercise

Find the oxidation numbers for each of the elements in each of the following compounds:

- $K_2Cr_2O_7$ — K = +1; Cr = +6; O = –2
- CO_3^{2-} — C = +4; O = –2
- MnO_2 — Mn = +4; O = –2
- PCl_5 — P = +5; Cl = –1
- SF_4 — S = +4; F = –1

Section 9.2

Redox and Nonredox Reactions

- To determine whether a reaction is a redox reaction or a nonredox reaction, look for changes in the oxidation # of elements involved in the reaction.
- Changes in oxidation # mean a transfer of electrons = redox reaction.

Section 9.2

Redox and Nonredox Reactions

Reaction Between Calcium Metal and Chlorine Gas

$$Ca + Cl_2 \rightarrow CaCl_2$$

0 0 +2 –1

Section 9.3

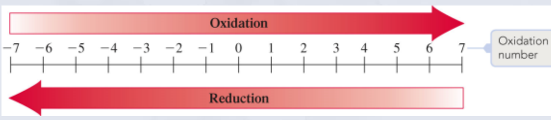
Terminology Associated with Redox Processes

Redox Characteristics

- In a redox reaction, one reactant undergoes oxidation, and another reactant undergoes reduction.
- Oxidation – a reactant loses one or more electrons; reducing agent.
- Reduction – a reactant gains one or more electrons; oxidizing agent.

Section 9.3

Terminology Associated with Redox Processes



Section 9.3

Terminology Associated with Redox Processes

Table 9.1 Summary of Redox Terminology in Terms of Electron Transfer

Term	Electron Transfer
oxidation	loss of electron(s)
reduction	gain of electron(s)
oxidizing agent (substance reduced)	electron(s) gained
reducing agent (substance oxidized)	electron(s) lost

Section 9.3

Terminology Associated with Redox Processes

Concept Check

Which of the following are oxidation-reduction reactions? Identify the oxidizing agent and the reducing agent.

a) $Zn(s) + 2HCl(aq) \rightarrow ZnCl_2(aq) + H_2(g)$
b) $Cr_2O_7^{2-}(aq) + 2OH^-(aq) \rightarrow 2CrO_4^{2-}(aq) + H_2O(l)$
c) $2CuCl(aq) \rightarrow CuCl_2(aq) + Cu(s)$

Section 9.3

Terminology Associated with Redox Processes

Concept Check

Which of the following are oxidation-reduction reactions? Identify the oxidizing agent and the reducing agent.

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c) $2CuCl(aq) \rightarrow CuCl_2(aq) + Cu(s)$

a) Zn – reducing agent; HCl – oxidizing agent
c) CuCl acts as the reducing and oxidizing agent.

Section 9.4

Collision Theory and Chemical Reactions

Collision Theory

- Molecular Collisions
- Activation Energy
- Collision Orientation

Section 9.4

Collision Theory and Chemical Reactions

Molecular Collisions

- The reactant molecules, ions, or atoms must come in contact (collide) with one another in order for any chemical change to occur.

Section 9.4

Collision Theory and Chemical Reactions

Activation Energy

- Minimum combined kinetic energy that colliding reactant particles must possess in order for their collision to result in a chemical reaction.

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Section 9.4

Collision Theory and Chemical Reactions

Collision Orientation

- Reaction rates are sometimes very slow because reactant molecules must be orientated in a certain way in order for collisions to lead successfully to products.

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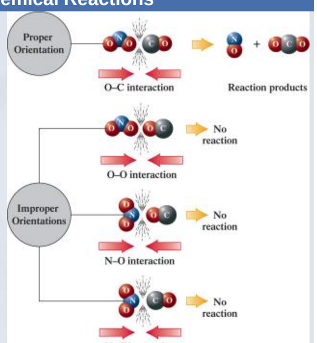
Section 9.4

Collision Theory and Chemical Reactions

Reaction of NO_2 and CO to Produce NO and CO_2



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Section 9.5

Exothermic and Endothermic Chemical Reactions

Exothermic Reaction

- A chemical reaction in which energy is released as the reaction occurs.
- Energy is a "product" of the chemical reaction.
  - Example – burning of a fuel

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Section 9.5

Exothermic and Endothermic Chemical Reactions

Exothermic Reaction

- Occurs when the energy required to break bonds in the reactants is less than the energy released by bond formation in the products.

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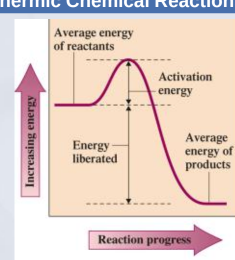
Section 9.5

Exothermic and Endothermic Chemical Reactions

Exothermic Reaction



Exothermic reaction

In an exothermic reaction, the average energy of the reactants is higher than that of the products, indicating that energy has been released in the reaction

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Section 9.5

Exothermic and Endothermic Chemical Reactions

Endothermic Reaction

- A chemical reaction in which a continuous input of energy is needed for the reaction to occur.
- Energy is a “reactant” of the chemical reaction.
  - Example – photosynthesis in plants

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Section 9.5

Exothermic and Endothermic Chemical Reactions

Endothermic Reaction

- Occurs when the energy required to break bonds in the reactants is more than the energy released by bond formation in the products.
- Additional energy must be supplied from external sources as the reaction proceeds.

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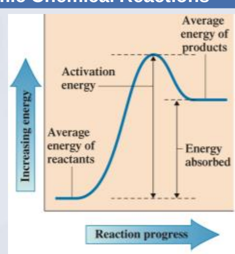
Section 9.5

Exothermic and Endothermic Chemical Reactions

Endothermic Reaction



Endothermic reaction

b In an endothermic reaction, the average energy of the reactants is less than that of the products, indicating that energy has been absorbed in the reaction

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Section 9.6

Factors That Influence Chemical Reaction Rates

Chemical Reaction Rate

- The rate at which reactants are consumed or products produced in a given time period in a chemical reaction.

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Section 9.6

Factors That Influence Chemical Reaction Rates

Four Factors That Affect Reaction Rate

1. Physical nature of the reactants
2. Reactant concentrations
3. Reaction temperature
4. Presence of catalysts

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Section 9.6

Factors That Influence Chemical Reaction Rates

Physical Nature of Reactants

- Includes the physical state of each reactant (s, l, or g) and the particle size.
- When reactants are all the same physical state, reaction rate is generally faster between liquid-state reactants than between solid-state reactants and is fastest between gaseous-state reactants.

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Section 9.6

Factors That Influence Chemical Reaction Rates

Physical Nature of Reactants

- For reactants in the solid state, reaction rate increases as subdivision of the solid increases.
- When the particle size of a solid is extremely small, reaction rates can be so fast than an explosion results.

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Section 9.6

Factors That Influence Chemical Reaction Rates

Reactant Concentrations

- An increase in the concentration of a reactant causes an increase in the rate of the reaction.
- There are more molecules of that reactant present in the reaction mixture; thus collisions between this reactant and other reactant particles are more likely.

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Section 9.6

Factors That Influence Chemical Reaction Rates

Reaction Temperature

- Reaction rate increases as the temperature of the reactants increases.
- The increased molecular speed causes more collisions to take place in a given time.

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Section 9.6

Factors That Influence Chemical Reaction Rates

Presence of Catalysts

- Catalyst – a substance that increases a chemical reaction rate without being consumed in the chemical reaction.
- Increases reaction rates by providing alternative reaction pathways that have lower activation energies than the original, uncatalyzed pathway.
- Enzymes are the catalysts in the human body.

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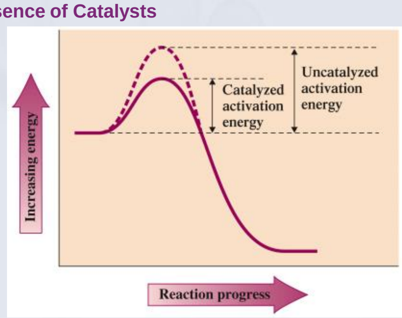
Section 9.6

Factors That Influence Chemical Reaction Rates

Presence of Catalysts



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Section 9.7

Chemical Equilibrium

Chemical Equilibrium

- The state in which forward and reverse chemical reactions occur simultaneously at the same rate.
- The concentrations of reactants and products no longer change (but do not have to be equal).
- On the molecular level, there is frantic activity. Equilibrium is not static, but is a highly dynamic situation.

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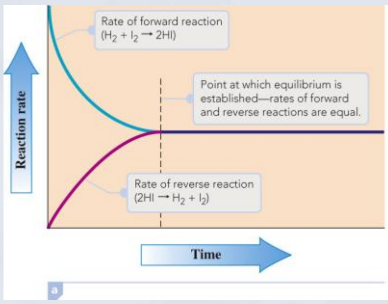
Section 9.7

Chemical Equilibrium

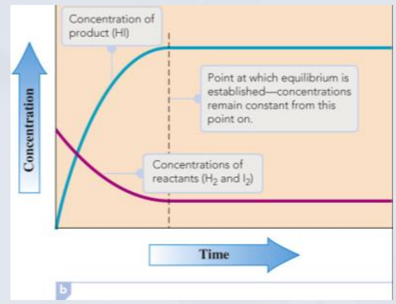
$H_2 + I_2 \rightleftharpoons 2HI$



Section 9.7

Chemical Equilibrium

$H_2 + I_2$ □ 2HI



Section 9.7

Chemical Equilibrium

Reversible Reaction

- A chemical reaction in which the conversion of reactants to products (the forward reaction) and the conversion of products to reactants (the reverse reaction) occur at the same time.
- All reactions are reversible (can go in either direction) under right conditions.

Section 9.7

Chemical Equilibrium

Concept Check

Consider an equilibrium mixture in a closed vessel reacting according to the equation:

$$H_2O(g) + CO(g) \rightleftharpoons H_2(g) + CO_2(g)$$

You add more $H_2O(g)$ to the flask. How does the concentration of each chemical compare to its original concentration after equilibrium is reestablished? Justify your answer. Remove H_2O $CO(g)$ is decreased $H_2(g) + CO_2(g)$ are increased

Section 9.7

Chemical Equilibrium

Concept Check

Consider an equilibrium mixture in a closed vessel reacting according to the equation:

$$H_2O(g) + CO(g) \rightleftharpoons H_2(g) + CO_2(g)$$

You add more H_2 to the flask. How does the concentration of each chemical compare to its original concentration after equilibrium is reestablished? Justify your answer. Remove $H_2(g)$ $CO(g)$ is increased $H_2(g) + CO_2(g)$ are decreased.

Section 9.8

Equilibrium Constants

Equilibrium Constant

- A numerical value that characterizes the relationship between the concentrations of reactants and products in a system at chemical equilibrium.

Section 9.8

Equilibrium Constants

$$wA + xB \rightleftharpoons yC + zD$$

$$K_{eq} = \frac{[C]^y [D]^z}{[A]^w [B]^x}$$

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Section 9.8

Equilibrium Constants

Conclusions About the Equilibrium Expression

- Square brackets refer to molar concentrations.
- Product concentrations are always placed in the numerator.
- Reactant concentrations are always placed in the denominator.
- The coefficients in the balanced chemical equation determine the powers to which the concentrations are raised.
- K_{eq} is used to denote an equilibrium constant.

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Section 9.8

Equilibrium Constants

Conclusions About the Equilibrium Expression

- Only concentrations of gases and substances in solution are written in an equilibrium expression.
- The concentrations of pure liquids and pure solids, which are constants, are never included in an equilibrium expression.

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Section 9.8

Equilibrium Constants

Temperature Dependence

- K_{eq} always has the same value at a given temperature regardless of the amounts of reactants or products that are present initially.
- If the temperature changes, the value of K_{eq} also changes.
- For reactions where the forward reaction is exothermic, K_{eq} decreases with increasing T.
- For reactions where the forward reaction is endothermic, K_{eq} increases with increasing T.

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Section 9.9

Altering Equilibrium Conditions: Le Châtelier's Principle

Le Châtelier's Principle

- If a stress is applied to a system in equilibrium, the system will readjust in the direction that best reduces the stress imposed on the system.
- If more products have been produced as a result of the disruption, the equilibrium is said to have shifted to the *right*.
- When disruption causes more reactants to form, the equilibrium has shifted to the *left*.

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Section 9.8

Equilibrium Constants

Reaction Completeness

- If K_{eq} is large, the equilibrium system contains more products than reactants.
- If K_{eq} is small, the equilibrium system contains more reactants than products.

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Section 9.8
Equilibrium Constants

Equilibrium Position

- Qualitative indication of the relative amounts of reactants and products present when a chemical reaction reaches equilibrium.

Section 9.8
Equilibrium Constants

K_{eq} and the Extent to Which a Chemical Reaction Has Taken Place

Table 9.2 Equilibrium Constant Values and the Extent to Which a Chemical Reaction Has Taken Place

Value of K_{eq}	Relative Amounts of Products and Reactants	Description of Equilibrium Position
very large (10^{30})	essentially all products	far to the right
large (10^{10})	more products than reactants	to the right
near unity (between 10^{3} and 10^{-3})	significant amounts of both reactants and products	neither to the right nor to the left
small (10^{-10})	more reactants than products	to the left
very small (10^{-30})	essentially all reactants	far to the left

Section 9.8
Equilibrium Constants

Le Châtelier's Principle

- If a stress (a change) is applied to a system in equilibrium, the system will readjust in the direction that best reduces the stress imposed on the system.
- If more products have been produced as a result of the disruption, the equilibrium is said to have shifted to the *right*.
- When disruption causes more reactants to form, the equilibrium has shifted to the *left*.

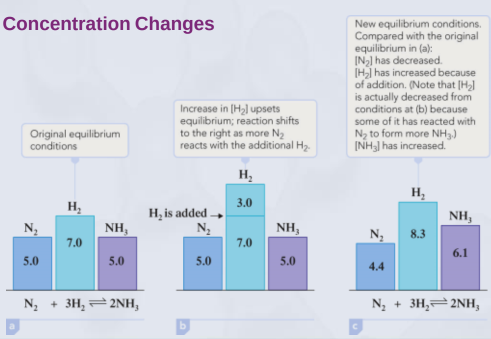
Section 9.9
Altering Equilibrium Conditions: Le Châtelier's Principle

Effects of Changes on the System

1. Concentration Changes: The system will shift away from the added component. If a component is removed, the opposite effect occurs.

Section 9.9
Altering Equilibrium Conditions: Le Châtelier's Principle

Concentration Changes



Section 9.9
Altering Equilibrium Conditions: Le Châtelier's Principle

Effects of Changes on the System

2. Temperature: K_{eq} will change depending upon the temperature (endothermic – heat is a reactant; exothermic – energy is a product).

Endothermic:

$$wA + xB + \text{Heat} \rightleftharpoons yC + zD$$

Endothermic:

$$wA + xB \rightleftharpoons yC + z + \text{Heat}$$

Section 9.9

Altering Equilibrium Conditions: Le Châtelier's Principle

Exothermic reaction

$$[\text{Blue}] \rightleftharpoons [\text{Red}] + \text{Heat}$$

Effect of Temperature Change on an Equilibrium Mixture

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Section 9.9

Altering Equilibrium Conditions: Le Châtelier's Principle

Effects of Changes on the System

3. Pressure:
   a) The system will shift away from the added gaseous component. If a component is removed, the opposite effect occurs.
   b) Addition of inert gas does not affect the equilibrium position.
   c) Decreasing the volume shifts the equilibrium toward the side with fewer moles of gas.

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Section 9.9

Altering Equilibrium Conditions: Le Châtelier's Principle

Effects of Changes on the System

4. Addition of Catalysts: Do not change the position of an equilibrium; although equilibrium is established more quickly.

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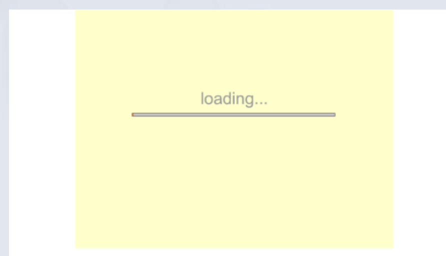
Section 9.9

Altering Equilibrium Conditions: Le Châtelier's Principle



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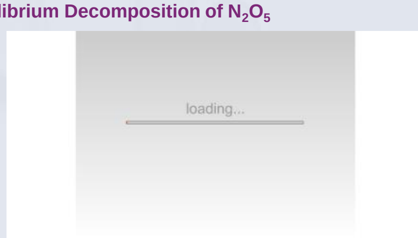
Section 9.9

Altering Equilibrium Conditions: Le Châtelier's Principle

Equilibrium Decomposition of N_2O_5



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