other, (2) The colliding reactants must possess a certain minimum of energy, and (3) In some cases, colliding reactants must be oriented in a specific way if reaction is to occur (Section 9.4).

Exothermic and endothermic chemical reactions. An exothermic chemical reaction releases energy as the reaction occurs. An endothermic chemical reaction requires an input of energy as the reaction occurs (Section 9.5).

Chemical reaction rates. A chemical reaction rate is the speed at which reactants are converted to products. Four factors affect the rates of all reactions: (1) the physical nature of the reactants, (2) reactant concentrations, (3) reaction temperature, and (4) the presence of catalysts (Section 9.6).

Chemical equilibrium. Chemical equilibrium is the state wherein the rate of the forward reaction is equal to the rate of the reverse reaction. Equilibrium is indicated in chemical equations by writing half-headed arrows pointing in both directions between reactants and products (Section 9.7).

Equilibrium constant. The equilibrium constant relates the concentrations of reactants and products at equilibrium. The value of an equilibrium constant is obtained by writing an equilibrium constant expression and then numerically evaluating it. Equilibrium constant expressions can be obtained from the balanced chemical equations for reactions (Section 9.8).

Equilibrium position. The relative amounts of reactants and products present in a system at equilibrium define the equilibrium position. The equilibrium position is toward the right when a large amount of product is present and is toward the left when a large amount of reactant is present (Section 9.8).

Le Châtelier's principle. Le Châtelier's principle states that when a stress (change of conditions) is applied to a system in equilibrium, the system will readjust (change the equilibrium position) in the direction that best reduces the stress imposed on it. Stresses that change an equilibrium position include (1) changes in amount of reactants and/or products, (2) changes in temperature, and (3) changes in pressure (Section 9.9).

KEY REACTIONS AND EQUATIONS

1. Combination reaction (Section 9.1)

$$X + Y \longrightarrow XY$$

2. Decomposition reaction (Section 9.1)

$$XY \longrightarrow X + Y$$

3. Single-replacement reaction (Section 9.1)

$$X + YZ \longrightarrow Y + XZ$$

4. Double-replacement reaction (Section 9.1)

$$AX + BY \longrightarrow AY + BX$$

5. Equilibrium constant expression equation for a general reaction (Section 9.8)

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

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

EXERCISES *and* PROBLEMS

The members of each pair of problems in this section test similar material.

Types of Chemical Reactions (Section 9.1)

9.1 What is the general chemical equation for each of the following types of chemical reactions?
a. Single-replacement reaction b. Combination reaction

9.2 What is the general chemical equation for each of the following types of chemical reactions?
a. Double-replacement reaction b. Decomposition reaction

9.3 Classify each of the following reactions as a combination, decomposition, single-replacement, double-replacement, or combustion reaction.
a. $3CuSO_4 + 2Al \rightarrow Al_2(SO_4)_3 + 3Cu$
b. $K_2CO_3 \rightarrow K_2O + CO_2$
c. $2AgNO_3 + K_2SO_4 \rightarrow Ag_2SO_4 + 2KNO_3$
d. $2P + 3H_2 \rightarrow 2PH_3$

9.4 Classify each of the following reactions as a combination, decomposition, single-replacement, double-replacement, or combustion reaction.
a. $2NaHCO_3 \rightarrow Na_2CO_3 + CO_2 + H_2O$
b. $2Ag_2CO_3 \rightarrow 4Ag + 2CO_2 + O_2$
c. $2C_2H_6 + 7O_2 \rightarrow 4CO_2 + 6H_2O$
d. $Mg + 2HCl \rightarrow MgCl_2 + H_2$

9.5 Indicate to which of the following types of reactions each of the statements listed applies: *combination, decomposition, single-replacement, double-replacement,* and *combustion.* More than one answer is possible for a given statement.
a. An element may be a reactant.
b. An element may be a product.
c. A compound may be a reactant.
d. A compound may be a product.

9.6 Indicate to which of the following types of reactions each of the statements listed applies: *combination, decomposition, single-replacement, double-replacement,* and *combustion.* More than one answer is possible for a given statement.
a. Two reactants are required.
b. Only one reactant is present.
c. Two products are present.
d. Only one product is present.

Redox and Nonredox Chemical Reactions (Section 9.2)

9.7 Determine the oxidation number of each of the following.
a. Ba in Ba^{2+} b. S in SO_3
c. F in F_2 d. P in PO_4^{3-}

9.8 Determine the oxidation number of each of the following.
a. Al in Al^{3+} b. N in NO_2
c. O in O_3 d. S in SO_4^{2-}

9.9 Determine the oxidation number of Cr in each of the following chromium-containing species.
a. Cr_2O_3 b. CrO_2
c. CrO_3 d. Na_2CrO_4
e. $BaCrO_4$ f. $BaCr_2O_7$
g. $Na_2Cr_2O_7$ h. CrF_5

9.10 Determine the oxidation number of Cl in each of the following chlorine-containing species.
a. $BeCl_2$ b. $Ba(ClO)_2$
c. ClF_4^+ d. Cl_2O_7
e. NCl_3 f. $AlCl_4^-$
g. ClF h. ClO^-

9.11 What is the oxidation number of each element in each of the following substances?
a. PF_3 b. NaOH
c. Na_2SO_4 d. CO_3^{2-}

9.12 What is the oxidation number of each element in each of the following substances?
a. H_2S b. H_2
c. N^{3-} d. MnO_4^-

9.13 Classify each of the following reactions as a redox reaction or a nonredox reaction.
a. $2Cu + O_2 \rightarrow 2CuO$
b. $K_2O + H_2O \rightarrow 2KOH$
c. $2KClO_3 \rightarrow 2KCl + 3O_2$
d. $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$

9.14 Classify each of the following reactions as a redox reaction or a nonredox reaction.
a. $2NO + O_2 \rightarrow 2NO_2$
b. $CO_2 + H_2O \rightarrow H_2CO_3$
c. $Zn + 2AgNO_3 \rightarrow Zn(NO_3)_2 + 2Ag$
d. $HNO_3 + NaOH \rightarrow NaNO_3 + H_2O$

Terminology Associated with Redox Processes (Section 9.3)

9.15 Identify which substance is oxidized and which substance is reduced in each of the following redox reactions.
a. $N_2 + 3H_2 \rightarrow 2NH_3$
b. $Cl_2 + 2KI \rightarrow 2KCl + I_2$
c. $Sb_2O_3 + 3Fe \rightarrow 2Sb + 3FeO$
d. $3H_2SO_3 + 2HNO_3 \rightarrow 2NO + H_2O + 3H_2SO_4$

9.16 Identify which substance is oxidized and which substance is reduced in each of the following redox reactions.
a. $2Al + 3Cl_2 \rightarrow 2AlCl_3$
b. $Zn + CuCl_2 \rightarrow ZnCl_2 + Cu$
c. $2NiS + 3O_2 \rightarrow 2NiO + 2SO_2$
d. $3H_2S + 2HNO_3 \rightarrow 3S + 2NO + 4H_2O$

9.17 Identify which substance is the oxidizing agent and which substance is the reducing agent in each of the redox reactions of Problem 9.15.

9.18 Identify which substance is the oxidizing agent and which substance is the reducing agent in each of the redox reactions of Problem 9.16.

Collision Theory and Chemical Reactions (Section 9.4)

9.19 What are the three central concepts associated with collision theory?

9.20 Why are most chemical reactions carried out either in liquid solution or in the gaseous phase?

9.21 What two factors determine whether a collision between two reactant molecules will result in a reaction?

9.22 What happens to the reactants in an ineffective molecular collision?

Exothermic and Endothermic Chemical Reactions (Section 9.5)

9.23 Which of the following reactions are endothermic, and which are exothermic?
a. $C_2H_4 + 3O_2 \rightarrow 2CO_2 + 2H_2O + \text{heat}$
b. $N_2 + 2O_2 + \text{heat} \rightarrow 2NO_2$
c. $2H_2O + \text{heat} \rightarrow 2H_2 + O_2$
d. $2KClO_3 \rightarrow 2KCl + 3O_2 + \text{heat}$

9.24 Which of the following reactions are endothermic, and which are exothermic?
a. $CaCO_3 + \text{heat} \rightarrow CaO + CO_2$
b. $N_2 + 3H_2 \rightarrow 2NH_3 + \text{heat}$
c. $CO + 3H_2 + \text{heat} \rightarrow CH_4 + H_2O$
d. $2N_2 + 6H_2O + \text{heat} \rightarrow 4NH_3 + 3O_2$

9.25 In a certain chemical reaction, the average energy of the products is 35 kcal lower than the average energy of the reactants.
a. Is the chemical reaction exothermic or endothermic?
b. Is energy released or absorbed in the chemical reaction?

9.26 Indicate whether each of the following is a characteristic of an endothermic or an exothermic chemical reaction.
a. There is more energy stored in product molecule bonds than in reactant molecule bonds.
b. The energy required to break bonds in the reactants is less than the energy released by bond formation in the products.

9.27 Sketch an energy diagram graph representing an exothermic reaction, and label the following.
a. Average energy of reactants
b. Average energy of products
c. Activation energy
d. Amount of energy liberated during the reaction

9.28 Sketch an energy diagram graph representing an endothermic reaction, and label the following.
a. Average energy of reactants
b. Average energy of products
c. Activation energy
d. Amount of energy absorbed during the reaction

Factors That Influence Chemical Reaction Rates (Section 9.6)

9.29 Using collision theory, indicate why each of the following factors influences the rate of a reaction.
a. Temperature of reactants
b. Presence of a catalyst

9.30 Using collision theory, indicate why each of the following factors influences the rate of a reaction.
a. Physical nature of reactants
b. Reactant concentrations

9.31 Substances burn more rapidly in pure oxygen than in air. Explain why.

9.32 Milk will sour in a couple of days when left at room temperature, yet it can remain unspoiled for 2 weeks when refrigerated. Explain why.

9.33 Will each of the changes listed increase or decrease the rate of the following chemical reaction?

$$2CO + O_2 \longrightarrow 2CO_2$$

a. Adding some O_2 to the reaction mixture
b. Lowering the temperature of the reaction mixture
c. Adding a catalyst to the reaction mixture
d. Removing some CO from the reaction mixture

9.34 Will each of the changes listed increase or decrease the rate of the following chemical reaction?

$$N_2 + 3H_2 \longrightarrow 2NH_3$$

a. Adding some N_2 to the reaction mixture
b. Raising the temperature of the reaction mixture
c. Removing a catalyst present in the reaction mixture
d. Removing some H_2 from the reaction mixture

9.35 Draw an energy diagram graph for an exothermic reaction where no catalyst is present. Then draw an energy diagram graph for the same reaction when a catalyst is present. Indicate the similarities and differences between the two diagrams.

9.36 Draw an energy diagram graph for an endothermic reaction where no catalyst is present. Then draw an energy diagram graph for the same reaction when a catalyst is present. Indicate the similarities and differences between the two diagrams.

9.37 The characteristics of four reactions, each of which involves only two reactants, are given.

Reaction	Activation Energy	Temperature	Concentration of Reactants
1	low	low	1 mole/L of each
2	high	low	1 mole/L of each
3	low	high	1 mole/L of each
4	low	low	1 mole/L of first reactant and 4 moles/L of second reactant

For each of the following pairs of the preceding reactions, compare the reaction rates when the two reactants are first mixed by indicating which reaction is faster.

a. 1 and 2 b. 1 and 3 c. 1 and 4 d. 2 and 3

9.38 The characteristics of four reactions, each of which involves only two reactants, are given.

Reaction	Activation Energy	Temperature	Concentration of Reactants
1	high	low	1 mole/L of each
2	high	high	1 mole/L of each
3	low	low	1 mole/L of first reactant and 4 moles/L of second reactant
4	low	low	4 moles/L of each

For each of the following pairs of the preceding reactions, compare the reaction rates when the two reactants are first mixed by indicating which reaction is faster.

a. 1 and 2 b. 1 and 3
c. 1 and 4 d. 3 and 4

Chemical Equilibrium (Section 9.7)

9.39 What condition must be met in order for a system to be in a state of chemical equilibrium?

9.40 What relationship exists between the rates of the forward and reverse reactions for a system in a state of chemical equilibrium?

9.41 Consider the following equilibrium system.

$$N_2(g) + O_2(g) \rightleftharpoons 2NO(g)$$

a. Write the chemical equation for the forward reaction.
b. Write the chemical equation for the reverse reaction.

9.42 Consider the following equilibrium system.

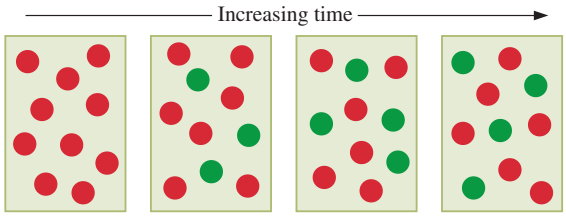
$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$$

a. Write the chemical equation for the forward reaction.
b. Write the chemical equation for the reverse reaction.

9.43 Sketch a graph showing how the concentrations of the reactants and products of a typical reversible chemical reaction vary with time.

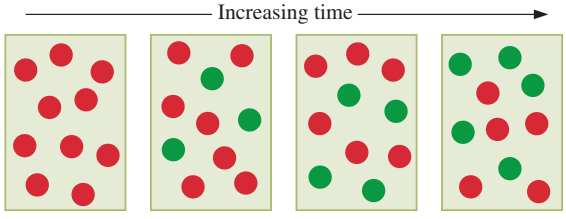
9.44 Sketch a graph showing how the rates of the forward and reverse reactions for a typical reversible chemical reaction vary with time.

9.45 The following series of diagrams represent the reaction $X \rightleftharpoons Y$ followed over a period of time. The X molecules are red and the Y molecules are green.



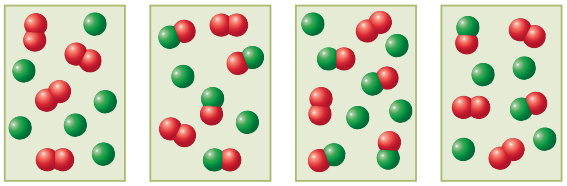
At the end of the time period depicted, has the reaction system reached equilibrium? Justify your answer with a one-sentence explanation.

9.46 The following series of diagrams represent the reaction $X \rightleftharpoons Y$ followed over a period of time. The X molecules are red and the Y molecules are green.



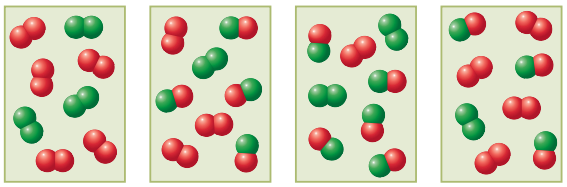
At the end of the time period depicted, has the reaction system reached equilibrium? Justify your answer with a one-sentence explanation.

9.47 For the reaction $A_2 + 2B \rightarrow 2AB$, diagram I depicts an initial reaction mixture, where A_2 molecules are red and B atoms are green. Which of the diagrams II through IV is a possible equilibrium state for the reaction system? There may be more than one correct answer.



I II III IV

9.48 For the reaction $A_2 + B_2 \rightarrow 2AB$, diagram I depicts an initial reaction mixture, where A_2 molecules are red and B_2 molecules are green. Which of the diagrams II through IV is a possible equilibrium state for the reaction system? There may be more than one correct answer.



I II III IV

Equilibrium Constants (Section 9.8)

9.49 Write equilibrium constant expressions for the following reactions.

a. $N_2O_4(g) \rightleftharpoons 2NO_2(g)$
b. $COCl_2(g) \rightleftharpoons CO(g) + Cl_2(g)$
c. $CS_2(g) + 4H_2(g) \rightleftharpoons CH_4(g) + 2H_2S(g)$
d. $2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$

9.50 Write equilibrium constant expressions for the following reactions.

a. $3O_2(g) \rightleftharpoons 2O_3(g)$
b. $2NOCl(g) \rightleftharpoons 2NO(g) + Cl_2(g)$
c. $4NH_3(g) + 5O_2(g) \rightleftharpoons 4NO(g) + 6H_2O(g)$
d. $CO(g) + H_2O(g) \rightleftharpoons CO_2(g) + H_2(g)$

9.51 Write equilibrium constant expressions for the following reactions.

a. $H_2SO_4(l) \rightleftharpoons SO_3(g) + H_2O(l)$
b. $2Ag(s) + Cl_2(g) \rightleftharpoons 2AgCl(s)$
c. $BaCl_2(aq) + Na_2SO_4(aq) \rightleftharpoons 2NaCl(aq) + BaSO_4(s)$
d. $2Na_2O(s) \rightleftharpoons 4Na(l) + O_2(g)$

9.52 Write equilibrium constant expressions for the following reactions.

a. $2KClO_3(s) \rightleftharpoons 2KCl(s) + 3O_2(g)$
b. $PCl_5(s) \rightleftharpoons PCl_3(l) + Cl_2(g)$
c. $AgNO_3(aq) + NaCl(aq) \rightleftharpoons AgCl(s) + NaNO_3(aq)$
d. $2FeBr_3(s) \rightleftharpoons 2FeBr_2(s) + Br_2(g)$

9.53 Calculate the value of the equilibrium constant for the reaction

$$N_2O_4(g) \rightleftharpoons 2NO_2(g)$$

if the concentrations of the species at equilibrium are $[N_2O_4] = 0.213$ and $[NO_2] = 0.0032$.

9.54 Calculate the value of the equilibrium constant for the reaction

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

if the concentrations of the species at equilibrium are $[N_2] = 0.0013$, $[O_2] = 0.0024$, and $[NO_2] = 0.00065$.

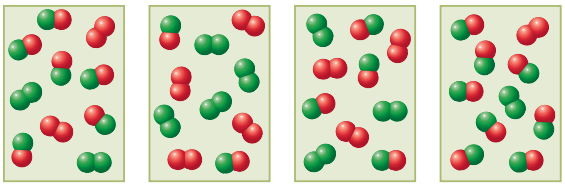
9.55 Use the given K_{eq} value and the terminology in Table 9.2 to describe the relative amounts of reactants and products present in each of the following equilibrium situations.

a. $H_2(g) + Br_2(g) \rightleftharpoons 2HBr(g)$ $K_{eq}\,(25°C) = 2.0 \times 10^{9}$
b. $2HCl(g) \rightleftharpoons H_2(g) + Cl_2(g)$ $K_{eq}\,(25°C) = 3.2 \times 10^{-34}$
c. $SO_2(g) + NO_2(g) \rightleftharpoons NO(g) + SO_3(g)$ $K_{eq}\,(460°C) = 85.0$
d. $COCl_2(g) \rightleftharpoons CO(g) + Cl_2(g)$ $K_{eq}\,(395°C) = 0.046$

9.56 Use the given K_{eq} value and the terminology in Table 9.2 to describe the relative amounts of reactants and products present in each of the following equilibrium situations.

a. $2NO(g) \rightleftharpoons N_2(g) + O_2(g)$ $K_{eq}\,(25°C) = 1 \times 10^{30}$
b. $N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$ $K_{eq}\,(25°C) = 1 \times 10^{9}$
c. $PCl_5(g) \rightleftharpoons PCl_3(g) + Cl_2(g)$ $K_{eq}\,(127°C) = 1 \times 10^{-2}$
d. $2Na_2O(s) \rightleftharpoons 4Na(l) + O_2(g)$ $K_{eq}\,(427°C) = 1 \times 10^{-25}$

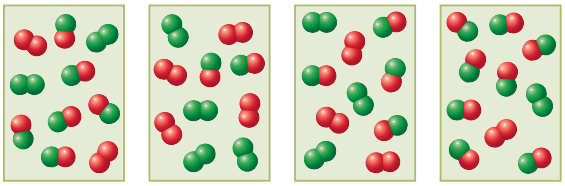
9.57 The following four diagrams represent gaseous equilibrium mixtures for the reaction $A_2 + B_2 \rightarrow 2AB$ at four different temperatures. For which of the diagrams is the numerical value of the equilibrium constant the largest? (A atoms are red and B atoms are green in the various diagrams.)



I II III IV

9.58 Based on the diagrams, chemical reaction, and reaction conditions depicted in Problem 9.57, for which of the diagrams is the numerical value of the equilibrium constant the smallest?

9.59 The following four diagrams represent gaseous reaction mixtures for the chemical reaction $A_2 + B_2 \rightarrow 2AB$. If the numerical value of the equilibrium constant for the reaction is 64, which of the diagrams represents the equilibrium mixture? (A atoms are red and B atoms are green in the various diagrams.)



I II III IV

9.60 Based on the diagrams, chemical reaction, and reaction conditions depicted in Problem 9.59, which of the diagrams represents the equilibrium mixture if the numerical value of the equilibrium constant is 9.0?

Le Châtelier's Principle (Section 9.9)

9.61 For the reaction

$$2Cl_2(g) + 2H_2O(g) \rightleftharpoons 4HCl(g) + O_2(g)$$

determine in what direction the equilibrium will be shifted by each of the following changes.

a. Increase in Cl_2 concentration
b. Increase in O_2 concentration
c. Decrease in H_2O concentration
d. Decrease in HCl concentration

9.62 For the reaction

$$2Cl_2(g) + 2H_2O(g) \rightleftharpoons 4HCl(g) + O_2(g)$$

determine in what direction the equilibrium will be shifted by each of the following changes.

a. Increase in H_2O concentration
b. Increase in HCl concentration
c. Decrease in O_2 concentration
d. Decrease in Cl_2 concentration

9.63 For the reaction

$$C_6H_6(g) + 3H_2(g) \rightleftharpoons C_6H_{12}(g) + \text{heat}$$

determine in what direction the equilibrium will be shifted by each of the following changes.
a. Increasing the concentration of C_6H_{12}
b. Decreasing the concentration of C_6H_6
c. Increasing the temperature
d. Decreasing the pressure by increasing the volume of the container

9.64 For the reaction

$$C_6H_6(g) + 3H_2(g) \rightleftharpoons C_6H_{12}(g) + \text{heat}$$

determine in what direction the equilibrium will be shifted by each of the following changes.
a. Decreasing the concentration of H_2
b. Increasing the concentration of C_6H_6
c. Decreasing the temperature
d. Increasing the pressure by decreasing the volume of the container

9.65 Consider the following chemical system at equilibrium.

$$CO(g) + H_2O(g) + \text{heat} \rightleftharpoons CO_2(g) + H_2(g)$$

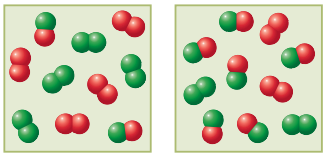
For each of the following adjustments of conditions, indicate the effect (shifts left, shifts right, or no effect) on the position of equilibrium.
a. Refrigerating the equilibrium mixture
b. Adding a catalyst to the equilibrium mixture
c. Adding CO to the equilibrium mixture
d. Increasing the size of the reaction container

9.66 Consider the following chemical system at equilibrium.

$$CO(g) + H_2O(g) + \text{heat} \rightleftharpoons CO_2(g) + H_2(g)$$

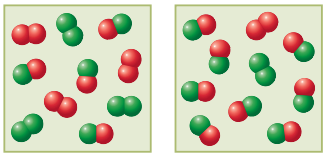
For each of the following adjustments of conditions, indicate the effect (shifts left, shifts right, or no effect) on the position of equilibrium.
a. Heating the equilibrium mixture
b. Increasing the pressure on the equilibrium mixture by adding a nonreactive gas
c. Adding H_2 to the equilibrium mixture
d. Decreasing the size of the reaction container

9.67 The following two diagrams represent the composition of an equilibrium mixture for the reaction $A_2 + B_2 \longrightarrow 2AB$ at two different temperatures. Based on the diagrams, is the chemical reaction endothermic or exothermic? Explain your answer using Le Châtelier's principle. (A atoms are red and B atoms are green in the diagrams.)



$T = 150°C$ $T = 200°C$

9.68 The following two diagrams represent the composition of an equilibrium mixture for the reaction $A_2 + B_2 \longrightarrow 2AB$ at two different temperatures. Based on the diagrams, is the chemical reaction endothermic or exothermic? Explain your answer using Le Châtelier's principle. (A atoms are red and B atoms are green in the diagrams.)



$T = 250°C$ $T = 400°C$

ADDITIONAL PROBLEMS

9.69 Characterize each of the following reactions using one selection from the choices *redox* and *nonredox* combined with one selection from the choices *combination, decomposition, single-replacement, double-replacement,* and *combustion.*
a. $Zn + Cu(NO_3)_2 \rightarrow Zn(NO_3)_2 + Cu$
b. $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$
c. $2CuO \rightarrow 2Cu + O_2$
d. $NaCl + AgNO_3 \rightarrow AgCl + NaNO_3$

9.70 Classify each of the following reactions as (1) a redox reaction, (2) a nonredox reaction, or (3) "can't classify" because of insufficient information.
a. A combination reaction in which one reactant is an element and the other is a compound
b. A decomposition reaction in which the products are all elements
c. A decomposition reaction in which one of the products is an element
d. A single-replacement reaction in which both of the reactants are compounds

9.71 In each of the following statements, choose the word in parentheses that best completes the statement.
a. The process of reduction is associated with the (loss, gain) of electrons.
b. The oxidizing agent in a redox reaction is the substance that undergoes (oxidation, reduction).
c. Reduction always results in an (increase, decrease) in the oxidation number of an element.
d. A reducing agent in a redox reaction is the substance that contains the element that undergoes an (increase, decrease) in oxidation number.

9.72 Indicate whether each of the following substances loses or gains electrons in a redox reaction.
a. The oxidizing agent
b. The reducing agent
c. The substance undergoing oxidation
d. The substance undergoing reduction

9.73 Indicate whether each of the following substances undergoes an increase in oxidation number or a decrease in oxidation number in a redox reaction.
a. The oxidizing agent
b. The reducing agent
c. The substance undergoing oxidation
d. The substance undergoing reduction

9.74 Which of the following changes would affect the *value* of a system's equilibrium constant?
a. Removal of a reactant or product from an equilibrium mixture
b. Decrease in the system's total pressure
c. Increase in the system's temperature
d. Addition of a catalyst to the equilibrium mixture

9.75 Write a balanced chemical equation for the totally gaseous equilibrium system that would lead to the following expression for the equilibrium constant.

$$K_{eq} = \frac{[CH_4][H_2S]^2}{[CS_2][H_2]^4}$$

9.76 For which of the following reactions is product formation favored by high temperature?
a. $N_2(g) + 2O_2(g) + \text{heat} \rightleftharpoons 2NO_2(g)$
b. $2N_2(g) + 6H_2O(g) + \text{heat} \rightleftharpoons 4NH_3(g) + 3O_2(g)$
c. $C_2H_4(g) + 3O_2(g) \rightleftharpoons 2CO_2(g) + 2H_2O(g) + \text{heat}$
d. $2KClO_3(s) + \text{heat} \rightleftharpoons 2KCl(s) + 3O_2(g)$

9.77 Predict the direction in which each of the following equilibria will shift if the pressure within the system is increased by reducing volume, using the choices *left, right,* and *no effect.*
a. $H_2(g) + C_2N_2(g) \rightleftharpoons 2HCN(g)$
b. $CO(g) + Br_2(g) \rightleftharpoons COBr_2(g)$
c. $CS_2(g) + 4H_2(g) \rightleftharpoons CH_4(g) + 2H_2S(g)$
d. $Ni(s) + 4CO(g) \rightleftharpoons Ni(CO)_4(g)$

Multiple-Choice Practice Test

9.78 Which of the following general equations is a representation of a single-replacement reaction?
a. $X + Y \rightarrow XY$
b. $XY \rightarrow X + Y$
c. $X + YZ \rightarrow Y + XZ$
d. $AX + BY \rightarrow AY + BX$

9.79 In which of the following compounds does Cl have an oxidation number of +5?
a. KCl b. $KClO_2$ c. $KClO_3$ d. HClO

9.80 Which substance is oxidized in the following redox reaction?

$$2H_2S + O_2 \rightarrow 2H_2O + 2S$$

a. H_2S b. O_2 c. H_2O d. S

9.81 In a redox reaction, which of the following is true for the substance that is reduced?
a. It is also the reducing agent.
b. It always gains electrons.
c. It never contains oxygen.
d. It must contain hydrogen.

9.82 For a collision between molecules to result in reaction, the molecules must possess a certain minimum energy and also undergo which of the following?
a. Exchange electrons
b. Interact with a catalyst
c. Have a favorable orientation relative to each other when they collide
d. Have the same activation energy

9.83 Increasing the temperature at which a chemical reaction occurs will also do which of the following?
a. Increase the activation energy
b. Cause more reactant collisions to take place in a given time
c. Increase the energy of the system, thus decreasing the reaction rate
d. Decrease the energy of the system, thus increasing the reaction rate

9.84 Which of the following conditions characterizes a system in a state of chemical equilibrium?
a. The concentrations of reactants and products are equal.
b. The rate of the forward reaction has dropped to zero.
c. Reactants are being consumed at the same rate at which products are converted to reactants.
d. Reactant molecules no longer react with each other.

9.85 In writing an equilibrium constant expression, which of the following is *incorrect*?
a. Concentrations are always expressed in molarity units.
b. Product concentrations are always placed in the numerator of the expression.
c. Reactant concentrations are always placed in the denominator of the expression.
d. Concentrations of pure solids and pure liquids are always placed in the denominator of the expression.

9.86 According to Le Châtelier's principle, which of these effects will occur if NH_3 is *removed* from an equilibrium mixture governed by the following chemical equation?

$$N_2(g) + 3H_2(g) \rightarrow 2NH_3(g) + \text{heat}$$

a. Concentration of N_2 will increase.
b. Heat will be generated.
c. Concentration of H_2 will remain the same.
d. Concentration of N_2 will decrease and that of H_2 will increase.

9.87 Which of these changes will cause the equilibrium position to shift to the left for the following chemical reaction?

$$4NH_3(g) + 3O_2(g) \rightarrow 2N_2(g) + 6H_2O(g) + \text{heat}$$

a. Adding more NH_3
b. Decreasing the temperature
c. Adding a catalyst
d. Increasing the pressure by decreasing the volume