19 REACTION RATES AND EQUILIBRIUM

PLANNING GUIDE

SECTION	STUDENT ACTIVITIES/FEATURES	TEACHER'S RESOURCE PACKAGE
19.1 Rates of Reaction **Objectives** ▸ Explain what is meant by the rate of a chemical reaction ▸ Using collision theory, explain how the rate of a chemical reaction is influenced by the reaction conditions	**Discover It!** *Temperature and Reaction Rates*, p. 532 **Link to Auto Shop** *Auto Body Repair*, p. 538	**Review Module** (Chapters 17–20) ▸ Section Review 19.1 ▸ Practice Problems ▸ Quizzes **Laboratory Manual** ▸ Experiment 34: *Factors Affecting Reaction Rates* ▸ Experiment 35: *A Clock Reaction* **Laboratory Practical** 19-1 **Small-Scale Chemistry Lab Manual,** Experiment 24: *Factors Affecting the Rate of a Chemical Reaction*
19.2 Reversible Reactions and Equilibrium **Objectives** ▸ Predict changes in the equilibrium position due to changes in concentration, temperature, and pressure ▸ Write the equilibrium-constant expression for a reaction and calculate its value from experimental data	**Sample Problems** 19-1 through 19-4	**Review Module** ▸ Section Review 19.2 ▸ Practice Problems ▸ Quizzes **Laboratory Manual,** Experiment 36: *Disturbing Equilibrium* **Small-Scale Chemistry Lab Manual,** Experiment 25: *Le Châtelier's Principle and Chemical Equilibrium*
19.3 Determining Whether a Reaction Will Occur **Objectives** ▸ Define entropy and free energy, and characterize reactions as spontaneous or nonspontaneous ▸ Describe how heat change and entropy change determine the spontaneity of a reaction	**Mini Lab** *Does Steel Burn?* p. 556 **Small-Scale Lab** *Enthalpy and Entropy*, p. 557	**Review Module** ▸ Section Review 19.3 ▸ Practice Problems ▸ Interpreting Graphics 19-1 ▸ Quizzes **Laboratory Recordsheets** 19-1 and 19-2
19.4 Calculating Entropy and Free Energy **Objectives** ▸ Calculate the standard entropy changes that accompany chemical and physical processes ▸ Calculate the free-energy changes that accompany chemical and physical processes	**CHEMath** *Balancing Equations*, p. 559 **Link to Geology** *Weathering of Rocks*, p. 562 **Sample Problems** 19-5 through 19-8	**Review Module** ▸ Section Review 19.4 ▸ Practice Problems ▸ Interpreting Graphics 19-2 ▸ Quizzes
19.5 The Progress of Chemical Reactions **Objectives** ▸ Interpret experimental rate data to deduce the rate laws for simple chemical reactions ▸ Given an energy diagram for a reaction, analyze the mechanism for the reaction	**Sample Problem** 19-9 **Chemistry Serving . . . the Consumer** *Don't Let Good Food Go Bad*, p. 570 **Chemistry in Careers** *FDA Inspector*, p. 570	**Review Module** ▸ Section Review 19.5 ▸ Practice Problems ▸ Vocabulary Review 19 ▸ Chapter 19 Tests and Quizzes **Solutions Manual for Chapter Reviews** **Graphing Calculator Problems**

PLANNING GUIDE continued

TECHNOLOGY RESOURCES

Internet Connections
Within this chapter, you will see the chemSURF logo. If you and your students have access to the Internet, the following URL address will provide various Internet connections that are related to topics and features presented in this chapter.

http://www.chemsurf.com

You can also find relevant chapter material at **The Chemistry Place address: http://www.chemplace.com**

CD-ROMs

Chem ASAP! CD-ROM
- Chapter 19

ResourcePro CD-ROM
- Chapter 19

Assessment Resources CD-ROM

Videodiscs and Videotapes

Chemistry Alive! Videodisc
- Grain Elevator Explosion
- Oscillating Clock

Small-Scale Lab Video and Videodisc
- #19: Equilibrium and Kinetics

Overhead Transparencies
- #63: Collision Theory
- #64: Activation Energy and Catalysts
- #65: Reversible Reactions and Equilibrium
- #66: Entropy
- #67: Heat, Entropy, and Free Energy

ASSESSMENT

Student Edition
- Section Reviews 19.1–19.5
- Chapter 19 Review, pp. 571–574
- Alternative Assessment, p. 575

Teacher's Resource Package
Review Module (Chap. 17–20)
- Vocabulary Review
- Chapter 19 Test A and Test B
- Chapter 19 Quizzes

Technology
Chem ASAP! CD-ROM
- Assessment 19.1–19.5

Assessment Resources CD-ROM
- Chapter 19 Tests

PLANNING FOR ACTIVITIES

STUDENT EDITION

Discover It! p. 532
- masking tape
- plastic cups
- hot and cold tap water
- ice
- thermometers
- effervescent antacid tablets
- clocks or watches with second hand
- graph paper
- pens or pencils

Mini Lab p. 556
- steel wool pads
- tissue paper
- tongs
- Bunsen burners
- heat-resistant pads
- pencils
- paper

Small-Scale Lab, p. 557
- alcohol thermometers
- 1-oz plastic cups
- $NaCl(s)$, $NH_4Cl(s)$, $CaCl_2(s)$
- plastic spoons
- crushed ice
- water

TEACHER'S EDITION

Teacher Demo, p. 536
- 5 mL of ethanoic acid
- 5 mL of isoamyl alcohol
- two test tubes
- granules of anhydrous calcium sulfate
- concentrated sulfuric acid
- boiling water bath

Teacher Demo, p. 537
- cornstarch
- water glass
- match
- Bunsen burner
- spatula
- goggles
- Plexiglas shield

Teacher Demo, p. 541
- sulfuric acid
- two test tubes
- anhydrous calcium sulfate

Teacher Demo, p. 544
- fume hood
- small amount (3 g or less) of copper turnings
- test tube
- 10 mL of $6M$ nitric acid
- one-hole stopper fitted with a glass delivery tube and rubber hose
- two Pyrex test tubes
- stoppers
- ice bath
- warm water bath

Teacher Demo, p. 552
- block of ice
- beaker
- water
- heat source

Teacher Demo, p. 562
- $0.1M$ solution of $KMnO_4$ in $0.1M$ HCl
- 1000-mL beaker
- thermometer
- graduated cylinder
- 20 mL of 30% H_2O_2
- watch glass
- glowing splint

Name ______________________ Class ____________ Date ____________

19.1 RATES OF REACTION
SECTION REVIEW

Objectives

- Explain what is meant by the rate of a chemical reaction
- Using collision theory, explain how the rate of a chemical reaction is influenced by the reaction conditions

Key Terms

- rates
- collision theory
- activation energy
- activated complex
- transition state
- catalyst
- inhibitor

Part A Completion

Use this completion exercise to check your understanding of the concepts and terms that are introduced in this section. Each blank can be completed with a term, short phrase, or number.

__1__ measure the speed of any change that occurs within a time interval. Collision theory states that particles __2__ when they collide, provided that they have enough __3__.

The rate at which a chemical reaction occurs is determined by an __4__ energy barrier. The activation energy is the __5__ energy that reactants must have to go to __6__. The higher the activation energy barrier, the __7__ the reaction. Chemists help reactants overcome the activation barrier in a number of ways. Two effective methods are to increase the __8__ at which the reaction is done or use a __9__. Rates of reaction can also be increased by __10__ the concentration of reactants.

1. ____________
2. ____________
3. ____________
4. ____________
5. ____________
6. ____________
7. ____________
8. ____________
9. ____________
10. ____________

Part B True-False

Classify each of these statements as always true, AT; sometimes true, ST; or never true, NT.

________ 11. An increase in temperature will generally increase the rate of a reaction.

________ 12. A catalyst is considered as a reactant in a chemical reaction.

______ **13.** The speed of a reaction can be increased by increasing reactant concentration or decreasing particle size.

______ **14.** An enzyme is a biological catalyst.

Part C Matching

Match each description in Column B to the correct term in Column A.

	Column A	Column B
______	**15.** rate	**a.** synonym for an activated complex
______	**16.** collision theory	**b.** speed of a change that occurs over time
______	**17.** activation energy	**c.** substance that interferes with the action of a catalyst
______	**18.** transition state	**d.** Particles can react to form products when they collide, provided they have enough kinetic energy.
______	**19.** catalyst	**e.** substance that increases the rate of a reaction without being used up
______	**20.** inhibitor	**f.** minimum energy particles must have in order to react

Part D Questions and Problems

Answer the following question and solve the following problem in the space provided.

21. An ice machine can produce 120 kg of ice in 24 hours. Express the rate of ice production in kg/hr.

22. Which of the following will increase the rate of a reaction?

a. increase particle size

b. increase temperature

c. decrease concentration

d. add a catalyst

Name ______________________ Class ____________ Date ____________

19.2 REVERSIBLE REACTIONS AND EQUILIBRIUM

SECTION REVIEW

Objectives

- Predict changes in the equilibrium position due to changes in concentration, temperature, and pressure
- Write the equilibrium-constant expression for a reaction and calculate its value from experimental data

Key Terms

- reversible reactions
- chemical equilibrium
- equilibrium position
- Le Châtelier's principle
- equilibrium constant (K_{eq})

Key Equation

- $K_{eq} = \frac{[C]^c \times [D]^d}{[A]^a \times [B]^b}$

  When $aA + bB \rightleftharpoons cC + dD$

Part A Completion

Use this completion exercise to check your understanding of the concepts and terms that are introduced in this section. Each blank can be completed with a term, short phrase, or number.

In principle, all reactions are __1__. That is, reactants go to __2__ in the __3__ direction and products go to __4__ in the __5__ direction.

The point at which the rate of conversion of __6__ to __7__ and vice versa is equal is the position of __8__. The __9__ of a reversible reaction, K_{eq}, is useful for determining the position of equilibrium. It is essentially a measure of the __10__ of products to reactants at equilibrium. The direction of change in the position of equilibrium may be predicted by applying __11__ principle.

1. ______________
2. ______________
3. ______________
4. ______________
5. ______________
6. ______________
7. ______________
8. ______________
9. ______________
10. ______________
11. ______________

Name ______________________ Class ____________ Date ____________

Part B True-False

Classify each of these statements as always true, AT; sometimes true, ST; or never true, NT.

________ **12.** The concentrations of reactants and products in a system at dynamic equilibrium are always changing.

________ **13.** A change in the pressure on a system can cause a shift in the equilibrium position.

________ **14.** For a chemical equilibrium to be established, the chemical reaction must be irreversible.

________ **15.** The K_{eq} for a certain reaction was 2×10^{-7}. For this reaction at equilibrium, the concentration of the reactants is greater than the concentration of the products.

Part C Matching

Match each description in Column B to the correct term in Column A.

Column A	Column B
________ **16.** reversible reactions	**a.** state of balance in which forward and reverse reactions take place at the same rate
________ **17.** chemical equilibrium	**b.** measurement of the amount of solute that is dissolved in a given quantity of solvent
________ **18.** equilibrium position	**c.** relative concentrations of reactants and products of a reaction that has reached equilibrium
________ **19.** Le Châtelier's principle	**d.** When stress is applied to a system at equilibrium, the system changes to relieve the stress.
________ **20.** equilibrium constant	**e.** reaction in which conversion of reactants to products and products to reactants occur simultaneously
________ **21.** concentration	**f.** ratio of product concentrations to reactant concentrations with each raised to a power given by the number of moles of the substance in the balanced equation

Part D Questions and Problems

Solve the following problem in the space provided. Show your work.

22. $$2SO_3(g) \rightarrow 2SO_2(g) + O_2(g)$$

Calculate K_{eq} for this reaction if the equilibrium concentrations are:
$[SO_2] = 0.42M$, $[O_2] = 0.21M$, $[SO_3] = 0.072M$

Name ____________________ Class __________ Date __________

19.3 DETERMINING WHETHER A REACTION WILL OCCUR

SECTION REVIEW

Objectives

- Define entropy and free energy, and characterize reactions as spontaneous or nonspontaneous
- Describe how heat change and entropy change determine the spontaneity of a reaction

Key Terms

- free energy
- spontaneous reactions
- nonspontaneous reactions
- entropy
- law of disorder

Part A Completion

Use this completion exercise to check your understanding of the concepts and terms that are introduced in this section. Each blank can be completed with a term, short phrase, or number.

Reactions that actually occur as written are called __1__ reactions. Equations for other reactions may be written, but the reactions are __2__. All spontaneous reactions release __3__ that becomes available to do __4__. This energy is called __5__.

It is the natural tendency for all things to go to lower __6__ and toward __7__ disorder. In addition to the change in heat content, __8__ is a factor that determines whether a reaction will be spontaneous.

Entropy is a measure of the __9__ of a system. The __10__ states that processes move in the direction of __11__ disorder.

1. ____________________
2. ____________________
3. ____________________
4. ____________________
5. ____________________
6. ____________________
7. ____________________
8. ____________________
9. ____________________
10. ____________________
11. ____________________

Part B True-False

Classify each of these statements as always true, AT; sometimes true, ST; or never true, NT.

________ 12 An exothermic reaction is a spontaneous reaction.

Name ______________________ Class ____________ Date ____________

________ 13. When a sandwich is eaten and digested, its entropy increases.

________ 14. Some spontaneous reactions appear to be nonspontaneous because their rate of reaction is slow.

________ 15. Spontaneous reactions release free energy.

________ 16. Entropy will increase in a spontaneous reaction.

Part C Matching

Match each description in Column B to the correct term in Column A.

Column A	Column B
________ 17. free energy	a. measure of the disorder of a system
________ 18. spontaneous reactions	b. energy in a reaction that is available to do work
________ 19. nonspontaneous reactions	c. It is the natural tendency of systems to move in the direction of maximum disorder.
________ 20. entropy	d. reactions that do not give products under the specified conditions
________ 21. law of disorder	e. reactions that favor formation of products under the specified conditions

Part D Questions and Problems

Complete the following question and solve the following problem in the space provided.

22. In each of the following pairs, choose the system with the higher entropy.
    a. a heap of loose stamps or stamps in an album ____________
    b. ice cubes in their tray or ice cubes in a bucket ____________
    c. 10 mL of water at 100 °C or 10 mL of steam at 100 °C ____________
    d. the people watching the parade or a parade ____________
23. Which combination of factors will always give a spontaneous reaction?
    a. heat absorbed, entropy increases
    b. heat released, entropy increases
    c. heat released, entropy decreases
    d. heat absorbed, entropy decreases
24. Which combination described in question 23 will never give a spontaneous reaction?

Name ______________________ Class ______________ Date ______________

19.4 CALCULATING ENTROPY AND FREE ENERGY

SECTION REVIEW

Objectives

- Calculate the standard entropy changes that accompany chemical and physical processes
- Calculate the free-energy changes that accompany chemical and physical processes

Key Terms

- standard entropy (S^0)
- Gibbs free-energy change (ΔG)

Key Equations

- $\Delta S^0 = S^0(\text{products}) - S^0(\text{reactants})$
- $\Delta G = \Delta H - T\Delta S$
- $\Delta G^0 = \Delta G_f^0(\text{products}) - \Delta G_f^0(\text{reactants})$

Part A Completion

Use this completion exercise to check your understanding of the concepts and terms that are introduced in this section. Each blank can be completed with a term, short phrase, or number.

S is the symbol for ___1___, which is a qualitative measure of disorder. The ___2___ of a substance is designated as S^0 at 25 °C and 101.3 kPa.

The standard entropy change in a reaction can be calculated by subtracting S^0 of the ___3___ from S^0 of the ___4___.

Energy from a reaction that is available to do work is called the ___5___, or ΔG. This quantity can be calculated when the entropy change and ___6___ change are known.

ΔG for a reaction can also be calculated using free energy of ___7___. Thus ΔG^0 can be obtained by subtracting ΔG_f^0 of the ___8___ from ΔG_f^0 of the ___9___.

1. ______________
2. ______________
3. ______________
4. ______________
5. ______________
6. ______________
7. ______________
8. ______________
9. ______________

Name ______________________ Class ____________ Date ____________

Part B True-False

Classify each of these statements as always true, AT; sometimes true, ST; or never true, NT.

_______ **10.** Spontaneous processes provide energy for work.

_______ **11.** A reaction with a negative ΔH is spontaneous.

_______ **12.** Substances have negative entropies below 0 °C.

_______ **13.** The higher the temperature, the more likely a reaction will be spontaneous.

Part C Matching

Match each description in Column B to the correct term in Column A.

Column A	Column B
_______ **14.** standard entropy	**a.** the amount of heat a substance has at a given temperature and pressure
_______ **15.** Gibbs free-energy change	**b.** maximum amount of energy that can be coupled to another process to do work
_______ **16.** enthalpy	**c.** a reaction known to give the products as written in a balanced equation at the specified conditions
_______ **17.** spontaneous reaction	**d.** entropy of a substance in its stable state at 25 °C and 1 atm

Part D Questions and Problems

Complete the following question and solve the following problem in the space provided.

18. Using the information found in Table 19.2 of your text, calculate the change in entropy for the following reaction.

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

19. The reaction $A + 2B \rightarrow 3C$ has a ΔH^0 of -163 kJ/mol and a ΔS^0 of -0.51 kJ/(K × mol) at 25 °C. Is this reaction spontaneous?

Name ______________________________ Class ______________ Date ____________

19.5 THE PROGRESS OF CHEMICAL REACTIONS
SECTION REVIEW

Objectives

- Interpret experimental rate data to deduce the rate laws for simple chemical reactions
- Given an energy diagram for a reaction, analyze the mechanism for the reaction

Key Terms

- rate law
- specific rate constant
- first-order reaction
- elementary reaction
- reaction mechanism
- intermediate

Part A Completion

Use this completion exercise to check your understanding of the concepts and terms that are introduced in this section. Each blank can be completed with a term, short phrase, or number.

The __1__ of a reaction is dependent in part on the __2__ of the reactants. An equation that relates reaction rate to reactant concentration is called a __3__. In a rate law equation, *K* is known as the __4__.

The power to which a reaction concentration is raised is called the __5__ of the reaction. A reaction whose rate is proportional to the concentration of one reactant is called a __6__ reaction. A reaction that is first order for each of two reactants is __7__ overall. The actual kinetic order of a reaction is determined by __8__.

A single step reaction is called an __9__. A series of elementary reactions combine to form the __10__ of a complex reaction.

1. ____________________
3. ____________________
4. ____________________
5. ____________________
6. ____________________
7. ____________________
8. ____________________
9. ____________________
10. ____________________

Name ______________________ Class ____________ Date ____________

Part B True-False

Classify each of these statements as always true, AT; sometimes true, ST; or never true, NT.

________ **11.** The rate order of a reaction can be determined from the balanced equation.

________ **12.** There is at least one intermediate product in a chemical reaction.

________ **13.** There is at least one activated complex in a chemical reaction.

________ **14.** An elementary reaction is a one-step reaction.

Part C Matching

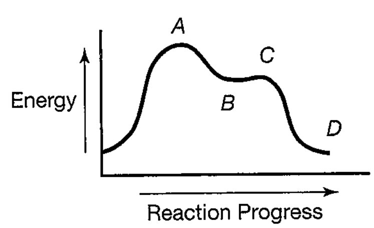
Match each description in Column B to the correct term in Column A.

Column A	Column B
________ **15.** rate law	**a.** a single-step reaction
________ **16.** specific rate constant	**b.** reaction in which the rate is directly proportional to the concentration of one reactant
________ **17.** first-order reaction	**c.** a product of a reaction that becomes a reactant in another reaction
________ **18.** elementary reaction	**d.** expression relating the rate of a reaction to the concentration of the reactants
________ **19.** reaction mechanism	**e.** series of elementary reactions that take place during a complex reaction
________ **20.** intermediate product	**f.** proportionality constant relating the concentrations of reactants to the reaction rate

Part D Questions and Problems

Complete the following question and solve the following problem in the space provided.

21. Below is the reaction progress curve for a complex reaction. Describe the reaction represented by the curve (number of steps and the significance of points *A*, *B*, *C*, and *D*).



____

____

____

____

Name ______________________ Class ______________ Date ____________

19 REACTION RATES AND EQUILIBRIUM

PRACTICE PROBLEMS

In your notebook, solve the following problems.

SECTION 19.1 RATES OF REACTION

1. List three ways that reaction rates can generally be increased.
2. Ethyl acetate ($C_4H_8O_2$) reacts with a solution of sodium hydroxide (NaOH) in water to form sodium acetate ($C_2H_3O_2Na$) and ethyl alcohol (C_2H_6O). Suppose at 25 °C two moles of ethyl acetate react completely in four hours. How would you express the rate of reaction?
3. How would the following actions likely change the rate of the reaction in problem 2?
   a. the temperature is lowered to 4 °C.
   b. the concentration of sodium hydroxide in water is increased.
4. Ethyl acetate and water are not miscible; thus, the reaction in problem 2 only occurs at the interface of the two liquids. What would be the effect on the reaction rate of adding a solvent to make the reaction homogeneous?

SECTION 19.2 REVERSIBLE REACTIONS AND EQUILIBRIUM

1. Write the expression for the equilibrium constant for this reaction:
   $$2N_2O_5(g) \rightleftharpoons 4NO_2(g) + O_2(g)$$
2. Calculate the equilibrium constant for the reaction in problem 1 if the equilibrium concentrations are $[N_2O_5] = 0.50$ mol/L, $[NO_2] = 0.80$ mol/L, $[O_2] = 0.20$ mol/L.
3. How would the equilibrium position for the equation in problem 1 be affected by
   a. an addition of O_2 to the reaction vessel?
   b. a decrease in the pressure?
4. The equilibrium constant for the reaction of nitrogen dioxide to form dinitrogen tetroxide is 5.6.
   $$2NO_2\,(g) \rightleftharpoons N_2O_4\,(g)$$
   In a one-liter container, the amount of N_2O_4, at equilibrium, is 0.66 mol. What is the equilibrium concentration of NO_2?
5. Write the equilibrium constant expression for each of the following reactions.
   a. $4NO(g) + 2O_2(g) \rightleftharpoons 2N_2O_4\,(g)$
   b. $2NO(g) + Br_2(g) \rightleftharpoons 2NOBr(g)$
   c. $CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g)$
   d. $SO_2(g) + NO_2(g) \rightleftharpoons SO_3(g) + NO(g)$
6. What effect would an increase in pressure have on the equilibrium position of each reaction in problem 5?

7. Which value of K_{eq} indicates most favorably for product formation, $K_{eq} = 1 \times 10^{12}$, $K_{eq} = 1.5$, or $K_{eq} = 5.6 \times 10^{-4}$?

8. Hydrogen sulfide gas decomposes into its elements and establishes an equilibrium at 1400 °C.

$$2H_2S(g) \rightleftharpoons 2H_2(g) + S_2(g)$$

A liter of this gas mixture contains 0.18 mol H_2S, 0.014 mol H_2, and 0.035 mol S_2. Calculate the equilibrium constant, K_{eq}, for this reaction.

SECTION 19.3 DETERMINING WHETHER A REACTION WILL OCCUR

1. When gently warmed, the element iodine will sublime:

$$I_2(s) \rightarrow I_2(g)$$

Is this process accompanied by an increase or decrease in entropy?

2. Is there an increase or decrease in entropy when air is cooled and liquefied (changed from a gas to a liquid)?

3. Is the degree of disorder increasing or decreasing in these reactions?

   a. $H_2(g) + Br_2(l) \rightarrow 2HBr(g)$

   b. $CuSO_4 \cdot 5H_2O(s) \rightarrow CuSO_4(s) + 5H_2O(g)$

   c. $2XeO_3(s) \rightarrow 2Xe(g) + 3O_2(g)$

4. Classify each of these systems as always spontaneous (A), never spontaneous (N), or depends on the relative magnitude of the heat and entropy changes (D).

   a. entropy decreases, heat is released

   b. entropy decreases, heat is absorbed

   c. entropy increases, heat is absorbed

   d. entropy increases, heat is released

SECTION 19.4 CALCULATING ENTROPY AND FREE ENERGY

For problems 1–4, calculate the standard entropy change associated with each reaction. Refer to table 19.2 in your textbook.

1. $2H_2O_2(l) \rightarrow 2H_2O(l) + O_2(g)$

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

3. $I_2(g) \rightarrow I_2(s)$

4. $2CO(g) + O_2(g) \rightarrow 2CO_2(g)$

5. A reaction is endothermic (positive ΔH) and has a positive entropy. Would this reaction more likely be spontaneous at high or low temperatures? Explain.

6. A reaction has a ΔS of -122 J/(K × mol) and a ΔH of -78 kJ/mol. Is this reaction spontaneous at 285 °C?

7. Calculate the standard free energy change for the reaction between iron(III) oxide and carbon (graphite). Refer to Table 19.4 in your textbook.

$$2Fe_2O_3(s) + 3C(s) \rightarrow 4Fe(s) + 3CO_2(g)$$

8. Calculate the ΔG^0 of each of these reactions. Indicate whether each reaction is spontaneous or nonspontaneous at 25°C. Refer to Table 19.4 in your textbook.
   a. $4NH_3(g) + 5O_2(g) \rightarrow 4NO(g) + 6H_2O(l)$
   b. $2SO_2(g) + O_2(g) \rightarrow 2SO_3(g)$
   c. $CO(g) + 3H_2(g) \rightarrow CH_4(g) + H_2O(g)$

SECTION 19.5 THE PROGRESS OF CHEMICAL REACTIONS

1. A first order reaction has an initial reaction rate of 2.4 mol/(L × s). What is the rate when one-eighth the starting materials remain?
2. It has been experimentally determined that the rate law for the reaction between mercury(II) chloride and sodium oxalate is third-order overall and first-order with respect to $HgCl_2$. Write the rate law for this equation.

$$2HgCl_2 + Na_2C_2O_4 \rightarrow 2NaCl + 2CO_2 + Hg_2Cl_2$$

3. A certain combination reaction gave the following data. What is the rate law for this reaction?

$$J + K \rightarrow M$$

Initial concentration (mol/L)		Initial rate (mol/L × s)
[J]	[K]	Reaction of J
0.30	0.50	0.080
0.60	0.50	0.160
0.60	0.25	0.080

4. Iodide ion catalyzes the decomposition of hydrogen peroxide. The reaction is first-order in H_2O_2. What is the value of the rate constant, *k*, if the initial rate is 0.00842 mol/(L × s)?
   The initial concentration of H_2O_2 is 0.500 mol/L.

$$2H_2O_2 \rightarrow 2H_2O + O_2$$

5. A proposed reaction mechanism has two intermediates. How many elementary reactions are there in this mechanism?
6. The reaction A + B → C is first order in A and B, second order overall. Complete the following table:

Initial concentration (mol/L)		Initial rate (mol/L × s)
[A]	[B]	
0.50	0.50	0.020
0.50		0.040
0.25	1.0	

7. The condensation of acetic acid ($C_2H_4O_2$) with methanol (CH_4O) to form methyl acetate ($C_3H_6O_2$) and water is catalyzed by HCl

$$C_2H_4O_2 + CH_4O \overset{HCl}{\rightleftharpoons} C_3H_8O_3 \overset{HCl}{\rightleftharpoons} C_3H_6O_2 + H_2O$$

   a. How many elementary reactions are there in this condensation?
   b. Write the formula for the reaction intermediate(s).
   c. Write the rate law for this condensation

Name ____________________ Class __________ Date __________

19 INTERPRETING GRAPHICS

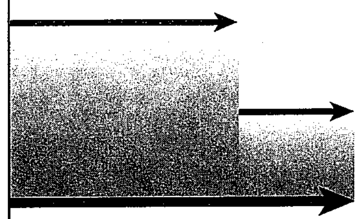
USE WITH SECTIONS 19.3 AND 19.4

A

Heat released (favorable)

Entropy increase (favorable)

Reaction spontaneous

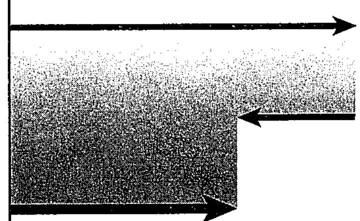


B

Entropy increase (favorable)

Heat absorbed (unfavorable)

Reaction spontaneous

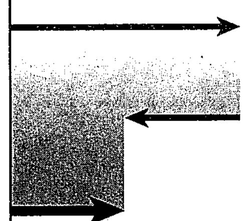


C

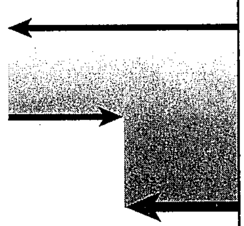
Heat released (favorable)

Entropy decrease (unfavorable)

Reaction spontaneous



D

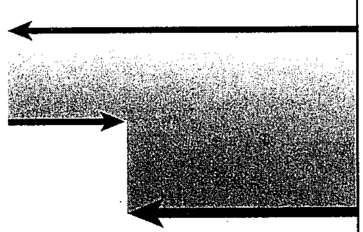


Heat absorbed (unfavorable)

Entropy increase (favorable)

Reaction nonspontaneous

E

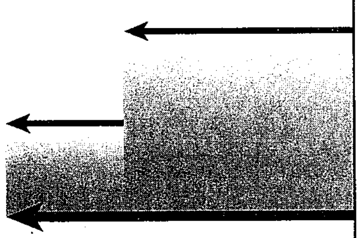


Entropy decrease (unfavorable)

Heat released (favorable)

Reaction nonspontaneous

F



Heat absorbed (unfavorable)

Entropy decrease (unfavorable)

Reaction nonspontaneous

Name ______________________ Class ____________ Date ____________

The lettered diagrams on the previous page are from Figure 19.20 in your textbook. Use them to answer the following questions.

1. For each example, state whether ΔG is positive or negative.

   a. ____________________

   b. ____________________

   c. ____________________

   d. ____________________

   e ____________________

   f. ____________________

2. For each example; state whether ΔH is positive or negative.

   a. ____________________

   b. ____________________

   c. ____________________

   d. ____________________

   e ____________________

   f. ____________________

3. For Example B, is $|T\Delta S|$ greater or less than $|\Delta G|$?

   ____

4. For Example D, is $|T\Delta S|$ greater or less than $|\Delta G|$?

   ____

5. Which example would provide the most energy for work?

   ____

6. Could Example D be made to be spontaneous by an increase in temperature?

   ____

Name ______________________ Class ______________ Date ______________

19 VOCABULARY REVIEW

Match the correct vocabulary term to each numbered statement. Write the letter of the correct term on the line provided.

Column A	Column B
________ **1.** the disorder of a system	**a.** activation energy
________ **2.** a substance that interferes with the action of a catalyst	**b.** catalyst
________ **3.** reactions that favor the formation of products at the specified conditions	**c.** chemical equilibrium
________ **4.** the minimum energy colliding particles must have in order to react	**d.** free energy
________ **5.** a substance that increases the rate of a reaction without being used up in the reaction	**e.** entropy
________ **6.** the arrangement of atoms at the peak of the activation-energy barrier	**f.** activated complex
________ **7.** a reaction in which the rate is directly proportional to the concentration of one of the reactants	**g.** inhibitor
________ **8.** energy that is available to do work	**h.** equilibrium constant
________ **9.** when the forward and reverse reactions are taking place at the same rate	**i.** spontaneous reactions
________ **10.** the ratio of product concentrations to reactant concentrations, with each concentration raised to a power given by the number of moles of that substance in the balanced equation	**j.** first-order reaction

Name ________________ Class ________ Date ________

19 REACTION RATES AND EQUILIBRIUM

Quiz for CHAPTER 19

Write the letter of the best answer in the blank.

______ **1.** At chemical equilibrium, the rates of the forward reaction and reverse reactions are: *19.2*

a. equal to 0. **c.** at a maximum.
b. equal to each other. **d.** at a minimum.

______ **2.** A catalyst works by: *19.1*

a. changing the pressure of the system.
b. changing the temperature of the reactants.
c. shifting the equilibrium position toward the products.
d. lowering the activation energy barrier.

______ **3.** The rate of a chemical reaction normally: *19.1*

a. increases as reactant concentration increases.
b. is slowed down by a catalyst.
c. decreases as temperature increases.
d. decreases as reactant concentration increases.

______ **4.** Activation energy is: *19.1*

a. heat released or absorbed in a reaction.
b. the minimum energy colliding particles must have in order to react.
c. the energy given off when reactants collide.
d. generally very high for a reaction that takes place rapidly.

______ **5.** Spontaneous reactions: *19.3*

a. are always exothermic.
b. always take place at a rapid rate.
c. always result in increased disorder of the system.
d. naturally favor the formation of products.

______ **6.** On a cold day, water vapor condenses to form frost. This represents an: *19.3*

a. entropy increase and enthalpy increase.
b. entropy increase and enthalpy decrease.
c. entropy decrease and enthalpy increase.
d. entropy decrease and enthalpy decrease.

Classify each of these statements as always true, AT; sometimes true, ST; or never true, NT.

______ **7.** The value of K_{eq} for a spontaneous reaction is much less than 1. *19.3*

______ **8.** The standard entropy, S^0, of a liquid or solid is the entropy at 25° C and 101.3 kPa. *19.4*

______ **9.** The Gibbs free energy for a spontaneous process is negative. *19.4*

______ **10.** In a first-order reaction involving several reactants, the reaction rate is directly proportional to the concentration of each of the reactants. *19.5*

Name ______________________ Class ____________ Date ____________

19 REACTION RATES AND EQUILIBRIUM

CHAPTER TEST A

A. Matching

Match each description in Column B with the correct term in Column A. Write the letter of the correct definition in the space provided.

Column A	Column B
______ 1. activated complex	a. the number of particles that react in a given time to form products
______ 2. reaction rate	b. energy available to do work
______ 3. Le Châtelier's principle	c. favoring the formation of products
______ 4. spontaneous	d. the minimum energy colliding particles must have in order to react
______ 5. elementary reaction	e. when the forward and reverse reactions take place at the same rate
______ 6. chemical equilibrium	f. a substance that interferes with the action of a catalyst
______ 7. entropy	g. reactants are converted to products in a single step
______ 8. activation energy	h. the measure of disorder
______ 9. inhibitor	i. the arrangement of atoms at the peak of the activation energy barrier
______ 10. free energy	j. If a stress is applied to a system in dynamic equilibrium, the system changes to relieve the stress.

B. Multiple Choice

Write the letter of the best answer in the blank.

______ 11. In which of the following physical states does a given substance have the highest entropy?
a. solid
b. gas
c. liquid
d. all of the above

______ 12. A reaction that requires free energy:
a. must be endothermic.
b. is nonspontaneous.
c. must correspond to a decrease in entropy.
d. is spontaneous.

Name ______________________ Class ____________ Date ____________

_______ **13.** The two factors that determine whether a reaction is spontaneous or nonspontaneous are:
- **a.** entropy and disorder.
- **b.** entropy and enthalpy change.
- **c.** electron configuration and energy change.
- **d.** energy and the heat of reaction.

_______ **14.** In which of these systems is the entropy decreasing?
- **a.** air escaping from a tire
- **b.** snow melting
- **c.** salt dissolving in water
- **d.** a gas condensing to a liquid

_______ **15.** All spontaneous processes:
- **a.** are exothermic.
- **b.** are endothermic
- **c.** involve an increase in entropy.
- **d.** release free energy.

_______ **16.** If a catalyst is used in a reaction:
- **a.** the energy of activation increases.
- **b.** the reaction rate does not change.
- **c.** the reaction rate increases.
- **d.** the equilibrium shifts.

_______ **17.** Which of the following affects the rate of a chemical reaction?
- **a.** the presence of a catalyst
- **b.** the temperature
- **c.** the concentration of reactants
- **d.** all of the above

_______ **18.** What is the expression for K_{eq} for this reaction?

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

- **a.** $K_{eq} = \frac{[2H_2O]}{[H_2] \times [O_2]}$
- **b.** $K_{eq} = \frac{[H_2]^2 \times [O_2]}{[H_2O]^2}$
- **c.** $K_{eq} = \frac{[2H_2] \times [O_2]}{[2H_2O]}$
- **d.** $K_{eq} = \frac{[H_2O]^2}{[H_2]^2 \times [O_2]}$

_______ **19.** In an equilibrium reaction with a K_{eq} of 1×10^8
- **a.** reactants are favored.
- **b.** reaction is nonspontaneous.
- **c.** products are favored.
- **d.** reaction is exothermic.

_______ **20.** What is the effect of adding more CO_2 to the following equilibrium reaction?

$$CO_2 + H_2O \rightleftharpoons H_2CO_3$$

- **a.** More H_2CO_3 is produced.
- **b.** More H_2O is produced.
- **c.** The equilibrium is pushed in the direction of reactants.
- **d.** no change

_______ **21.** Doing which of the following generally increases the entropy of a substance?
- **a.** freezing it
- **b.** dissolving it in water
- **c.** condensing it
- **d.** all of the above

_______ **22.** The K_{eq} of a reaction is 4×10^{-7}. At equilibrium:
- **a.** the reactants are favored.
- **b.** the products are favored.
- **c.** the reactants and products are present in equal amounts.
- **d.** the rate of the reverse reaction is much greater than the rate of the forward reaction.

_______ 23. Two opposing reactions ($A + B \rightleftharpoons C + D$) occurring simultaneously at the same rate is an example of:
a. reversibility.
b. chemical equilibrium.
c. neither a nor b
d. both a and b

C. Problems

Solve the following problems in the space provided. Show your work.

24. Calculate the value of K_{eq} for this reaction at equilibrium.

$$2NOCl(g) \rightleftharpoons 2NO(g) + Cl_2(g)$$

An analysis of the equilibrium mixture in a 1-L flask gives the following results: NOCl, 0.30 mol; NO, 1.2 mol; Cl_2, 0.60 mol.

25. Carbon monoxide and hydrogen are combined in the commercial preparation of methyl alcohol.

$$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g)$$

At a certain set of conditions, the equilibrium mixture contains 0.020 mol/L of CO, 0.60 mol/L of H_2, and the equilibrium constant is 2.2×10^2 L^2/mol^2. What is the concentration of CH_3OH in the equilibrium mixture?

26. Predict the changes in the equilibrium position for this reaction when the following changes are made:

$$2A(g) + B(g) \rightleftharpoons 4C(g) + \text{heat}$$

a. decrease the concentration of C;
b. add more heat;
c. increase the concentration of A;
d. increase the pressure.

In each case, state whether the change causes a shift that favors the formation of reactants or of products.

a. ______________________________

b. ______________________________

c. ______________________________

d. ______________________________

Name ______________________ Class ____________ Date ____________

D. Essay

Write a short essay for the following.

27. Characterize spontaneous and nonspontaneous reactions. Then explain why a spontaneous reaction may appear to be nonspontaneous.

E. Additional Problems

Solve the following problems in the space provided. Show your work.

28. The rate law for the following reaction is: Rate = $k[A]^a \times [B]^b$.

$$aA + bB \rightarrow cC + dD$$

From the data in the following chart, find the kinetic order of the reaction with respect to A and B, as well as the overall order.

Initial concentration of A (mol/L)	Initial concentration of B (mol/L)	Initial Rate [mol/(L × s)]
0.50	0.05	2×10^{-3}
0.10	0.05	4×10^{-3}
0.20	0.05	8×10^{-3}
0.01	0.05	1×10^{-3}
0.01	0.10	8×10^{-3}
0.01	0.20	64×10^{-3}

29. The following reaction has an H^0 of 53 kJ/mol and a S^0 of 0.070 kJ/(K × mol) at 25 °C.

$$2A + B \rightarrow 2C$$

Is this reaction spontaneous? (Calculate ΔG.)

Name ______________________ Class ______________ Date ______________

30. What is the standard change in entropy for the following reaction when all reactants are in the specified states?

$$2H_2O(l) + O_2(g) \rightarrow 2H_2O_2(l)$$

Standard entropies S^0 in J/(K × mol):
$H_2O(l) = 69.94$, $H_2O_2(l) = 92.0$, $O_2(g) = 205.0$

Name ________________________ Class ______________ Date ______________

19 REACTION RATES AND EQUILIBRIUM
CHAPTER TEST B

A. Matching

Match each term in Column B with the correct description in Column A. Write the letter of the correct term in the blank provided.

	Column A	Column B
______	1. when the forward and reverse reactions are taking place at the same rate	a. Le Châtelier's principle
______	2. Things move in the direction of maximum disorder or randomness.	b. activated complex
______	3. the minimum energy colliding particles must have in order to react	c. entropy
______	4. the ratio of product concentrations to reactant concentrations, with each concentration raised to a power given by the number of moles of that substance in the balanced equation	d. collision theory
______	5. a substance that increases the rate of a reaction without being used up itself in the reaction	e. free energy
______	6. the disorder of a system	f. catalyst
______	7. Atoms, ions, and molecules can form a chemical bond between them when they collide, provided the particles have enough kinetic energy.	g. law of disorder
______	8. energy that is available to do work	h. activation energy
______	9. the arrangement of atoms at the peak of the activation energy barrier	i. equilibrium constant
______	10. If a stress is applied to a system in a dynamic equilibrium, the system changes to relieve the stress.	j. chemical equilibrium

B. Multiple Choice

Choose the best answer and write its letter in the blank.

______ 11. According to the collision theory, in order for a chemical reaction to occur, the reactant atoms must:
- **a.** make contact with each other.
- **b.** have a minimum level of kinetic energy.
- **c.** form an activated complex.
- **d.** all of these

_______ **12.** In general, increasing temperature causes the rate of most chemical reactions to:

a. increase.
b. decrease.
c. remain the same.
d. vary unpredictably.

_______ **13.** Which of the following is true concerning the impact of increasing temperature on reaction rates?

a. The number of collisions between reactant atoms is increased.
b. The energy of each reactant atom is increased.
c. The percentage of collisions with sufficient energy to cross the activation energy barrier is increased.
d. all of these

_______ **14.** What would decrease the rate of most chemical reactions?

a. increasing the concentration of reactant atoms
b. increase the size of the reactant particles
c. adding an appropriate catalyst
d. all of these

_______ **15.** Catalysts alter the rate of a chemical reaction by:

a. increasing the number of collisions between reactant atoms.
b. increasing the kinetic energy of each reactant atom.
c. lowering the activation energy barrier.
d. being consumed in the reaction.

_______ **16.** Which of the following is true concerning a reaction that has reached chemical equilibrium?

a. The forward reaction is occurring faster than the reverse reaction.
b. The reverse reaction is occurring faster than the forward reaction.
c. The forward reaction is occurring as fast as the reverse reaction.
d. The mass of products is equal to the mass of reactants.

_______ **17.** Given the following system at equilibrium:

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

what would be the effect of removing $NH_3(g)$ as it is formed?

a. The equilibrium would shift to the left.
b. More $N_2(g)$ would be produced.
c. More $H_2(g)$ would be produced.
d. The equilibrium would shift to the right.

_______ **18.** Given the following system at equilibrium:

$$H_2O(l) + \text{heat} \rightleftharpoons H_2O(g)$$

how would a decrease in temperature affect the system?

a. The equilibrium would shift to the right.
b. More $H_2O(l)$ would be produced.
c. More $H_2O(g)$ would be produced.
d. The levels of reactants and products would remain the same.

_______ **19.** Which of the following would increase the yield of $CO(g)$ in the following equilibrium system?

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

a. decreasing temperature
b. increasing pressure
c. adding $H_2(g)$
d. adding $H_2O(g)$

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________ 20. Spontaneous reactions:
- **a.** favor the formation of products.
- **b.** give substantial amounts of reactants at equilibrium.
- **c.** absorb free energy.
- **d.** have high reaction rates.

________ 21. Which of the following has the greatest entropy?
- **a.** ice
- **b.** water
- **c.** steam
- **d.** cannot be predicted

________ 22. The type of reaction most likely to be spontaneous is one in which:
- **a.** both heat content and entropy are decreased.
- **b.** heat content is decreased, while entropy is increased.
- **c.** both heat content and entropy are increased.
- **d.** heat content is increased, while entropy is decreased.

________ 23. The expression for K_{eq} for the following reaction is:

$$H_2(g) + Cl_2(g) \rightleftharpoons 2HCl(g)$$

- **a.** $K_{eq} = \dfrac{[H_2] \times [Cl_2]}{[2HCl]}$
- **b.** $K_{eq} = \dfrac{[2HCl]}{[H_2] \times [Cl_2]}$
- **c.** $K_{eq} = \dfrac{[HCl]^2}{[H_2] \times [Cl_2]}$
- **d.** $K_{eq} = \dfrac{[H_2] \times [Cl_2]}{[HCl]^2}$

________ 24. If the equilibrium concentrations for the system in question 24 are as follows, find the value of K_{eq}:

$[H_2] = 0.450$ mol/L, $[Cl_2] = 0.450$ mol/L, $[HCl] = 6.25$ mol/L
- **a.** 1.62×10^{-2}
- **b.** 193
- **c.** 5.18×10^{-3}
- **d.** 61.7

C. Problems

Solve the following problems in the space provided. Show your work.

25. Given the following system at equilibrium:

$$4HCl(g) + O_2(g) \rightleftharpoons 2H_2O(g) + 2Cl_2(g) + \text{heat}$$

determine the effect of each of the following changes on the equilibrium position of the system (shifts right or left) and on the amount of $Cl_2(g)$ that would result (increases or decreases):

	Equilibrium Position	Amount of $Cl_2(g)$
a. increasing temperature		
b. decreasing pressure		
c. adding $O_2(g)$		
d. removing $H_2O(g)$		
e. increasing pressure		
f. adding $H_2O(g)$		

26. At equilibrium, the concentrations of the components of the reaction in problem 25 are as follows:

$[HCl] = 1.2 \times 10^{-3}$ mol/L, $[O_2] = 3.8 \times 10^{-4}$ mol/L,
$[H_2O] = 5.8 \times 10^{-2}$ mol/L, and $[Cl_2] = 5.8 \times 10^{-2}$ mol/L

Determine the value of K_{eq} for this system.

27. Calculate the standard entropy change, ΔS^0, that occurs in the following reaction at 25 °C and 101.3 kPa.

$$4NH_3(g) + 7O_2(g) \rightarrow 4NO_2(g) + 6H_2O(g)$$

Standard entropies S^0 (J/K $\times$ mol):
S^0 for $NH_3(g) = 192.5$
S^0 for $O_2(g) = 205.0$
S^0 for $NO_2(g) = 240.5$
S^0 for $H_2O(g) = 188.7$

D. Essay

Write short essays for the following.

28. Explain how and why an equilibrium system reacts to each of the following stresses:

a. the addition of more reactant

____

____

____

____

b. an increase in temperature

____

____

____

____

c. an increase in pressure (for a gaseous system with an unequal number of molecules)

____

____

____

Name ______________________ Class ____________ Date ____________

E. Additional Problems

Solve the following problems in the space provided. Show your work.

29. Given:

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \text{ with } K_{eq} = 6.59 \times 10^{-3} \text{ at } 450\ °C$$

If $[NH_3] = 1.23 \times 10^{-4}$ mol/L and $[H_2] = 2.75 \times 10^{-6}$ mol/L at equilibrium, what is the concentration of N_2 at equilibrium?

30. Determine whether the following reaction is spontaneous by using the ΔG_f^0 for the reactants and products.

$$CH_4(g) + 2O_2(g) \rightleftharpoons CO_2(g) + 2H_2O(l)$$

ΔG_f^0 for $CH_4(g) = -50.79$ kJ/mol
ΔG_f^0 for $O_2(g) = 0.00$ kJ/mol
ΔG_f^0 for $CO_2(g) = -394.4$ kJ/mol
ΔG_f^0 for $H_2O(l) = -237.2$ kJ/mol

31. Based on the values given below, calculate ΔG^0 and determine whether the reaction is spontaneous.

$$\Delta H^0 = -85.2 \text{ kJ/mol},\ T = 127\ °C,\ \Delta S^0 = 0.125 \text{ kJ/K} \times \text{mol}$$

19 REACTION RATES AND EQUILIBRIUM
PLANNING GUIDE

SECTION	STUDENT ACTIVITIES/FEATURES	TEACHER'S RESOURCE PACKAGE
19.1 Rates of Reaction **Objectives** ▸ Explain what is meant by the rate of a chemical reaction ▸ Using collision theory, explain how the rate of a chemical reaction is influenced by the reaction conditions	**Discover It!** *Temperature and Reaction Rates,* p. 532 **Link to Auto Shop** *Auto Body Repair,* p. 538	**Review Module** (Chapters 17–20) ▸ Section Review 19.1 ▸ Practice Problems ▸ Quizzes **Laboratory Manual** ▸ Experiment 34: *Factors Affecting Reaction Rates* ▸ Experiment 35: *A Clock Reaction* **Laboratory Practical** 19-1 **Small-Scale Chemistry Lab Manual,** Experiment 24: *Factors Affecting the Rate of a Chemical Reaction*
19.2 Reversible Reactions and Equilibrium **Objectives** ▸ Predict changes in the equilibrium position due to changes in concentration, temperature, and pressure ▸ Write the equilibrium-constant expression for a reaction and calculate its value from experimental data	**Sample Problems** 19-1 through 19-4	**Review Module** ▸ Section Review 19.2 ▸ Practice Problems ▸ Quizzes **Laboratory Manual,** Experiment 36: *Disturbing Equilibrium* **Small-Scale Chemistry Lab Manual,** Experiment 25: *Le Châtelier's Principle and Chemical Equilibrium*
19.3 Determining Whether a Reaction Will Occur **Objectives** ▸ Define entropy and free energy, and characterize reactions as spontaneous or nonspontaneous ▸ Describe how heat change and entropy change determine the spontaneity of a reaction	**Mini Lab** *Does Steel Burn?* p. 556 **Small-Scale Lab** *Enthalpy and Entropy,* p. 557	**Review Module** ▸ Section Review 19.3 ▸ Practice Problems ▸ Interpreting Graphics 19-1 ▸ Quizzes **Laboratory Recordsheets** 19-1 and 19-2
19.4 Calculating Entropy and Free Energy **Objectives** ▸ Calculate the standard entropy changes that accompany chemical and physical processes ▸ Calculate the free-energy changes that accompany chemical and physical processes	**CHEMath** *Balancing Equations,* p. 559 **Link to Geology** *Weathering of Rocks,* p. 562 **Sample Problems** 19-5 through 19-8	**Review Module** ▸ Section Review 19.4 ▸ Practice Problems ▸ Interpreting Graphics 19-2 ▸ Quizzes
19.5 The Progress of Chemical Reactions **Objectives** ▸ Interpret experimental rate data to deduce the rate laws for simple chemical reactions ▸ Given an energy diagram for a reaction, analyze the mechanism for the reaction	**Sample Problem** 19-9 **Chemistry Serving . . . the Consumer** *Don't Let Good Food Go Bad,* p. 570 **Chemistry in Careers** *FDA Inspector,* p. 570	**Review Module** ▸ Section Review 19.5 ▸ Practice Problems ▸ Vocabulary Review 19 ▸ Chapter 19 Tests and Quizzes **Solutions Manual for Chapter Reviews** **Graphing Calculator Problems**

TECHNOLOGY RESOURCES

Internet Connections
Within this chapter, you will see the chemSURF logo. If you and your students have access to the Internet, the following URL address will provide various Internet connections that are related to topics and features presented in this chapter.

http://www.chemsurf.com

You can also find relevant chapter material at **The Chemistry Place address: http://www.chemplace.com**

CD-ROMs

Chem ASAP! CD-ROM
- Chapter 19

ResourcePro CD-ROM
- Chapter 19

Assessment Resources CD-ROM

Videodiscs and Videotapes

Chemistry Alive! Videodisc
- Grain Elevator Explosion
- Oscillating Clock

Small-Scale Lab Video and Videodisc
- #19: Equilibrium and Kinetics

Overhead Transparencies
- #63: Collision Theory
- #64: Activation Energy and Catalysts
- #65: Reversible Reactions and Equilibrium
- #66: Entropy
- #67: Heat, Entropy, and Free Energy

ASSESSMENT

Student Edition
- Section Reviews 19.1–19.5
- Chapter 19 Review, pp. 571–574
- Alternative Assessment, p. 575

Teacher's Resource Package
Review Module (Chap. 17–20)
- Vocabulary Review
- Chapter 19 Test A and Test B
- Chapter 19 Quizzes

Technology
Chem ASAP! CD-ROM
- Assessment 19.1–19.5

Assessment Resources CD-ROM
- Chapter 19 Tests

PLANNING FOR ACTIVITIES

STUDENT EDITION

Discover It! p. 532
- masking tape
- plastic cups
- hot and cold tap water
- ice
- thermometers
- effervescent antacid tablets
- clocks or watches with second hand
- graph paper
- pens or pencils

Mini Lab p. 556
- steel wool pads
- tissue paper
- tongs
- Bunsen burners
- heat-resistant pads
- pencils
- paper

Small-Scale Lab, p. 557
- alcohol thermometers
- 1-oz plastic cups
- $NaCl(s)$, $NH_4Cl(s)$, $CaCl_2(s)$
- plastic spoons
- crushed ice
- water

TEACHER'S EDITION

Teacher Demo, p. 536
- 5 mL of ethanoic acid
- 5 mL of isoamyl alcohol
- two test tubes
- granules of anhydrous calcium sulfate
- concentrated sulfuric acid
- boiling water bath

Teacher Demo, p. 537
- cornstarch
- water glass
- match
- Bunsen burner
- spatula
- goggles
- Plexiglas shield

Teacher Demo, p. 541
- sulfuric acid
- two test tubes
- anhydrous calcium sulfate

Teacher Demo, p. 544
- fume hood
- small amount (3 g or less) of copper turnings
- test tube
- 10 mL of $6M$ nitric acid
- one-hole stopper fitted with a glass delivery tube and rubber hose
- two Pyrex test tubes
- stoppers
- ice bath
- warm water bath

Teacher Demo, p. 552
- block of ice
- beaker
- water
- heat source

Teacher Demo, p. 562
- $0.1M$ solution of $KMnO_4$ in $0.1M$ HCl
- 1000-mL beaker
- thermometer
- graduated cylinder
- 20 mL of 30% H_2O_2
- watch glass
- glowing splint

Name ______________________ Class ____________ Date ____________

19.1 RATES OF REACTION

SECTION REVIEW

Objectives

- Explain what is meant by the rate of a chemical reaction
- Using collision theory, explain how the rate of a chemical reaction is influenced by the reaction conditions

Key Terms

- rates
- collision theory
- activation energy
- activated complex
- transition state
- catalyst
- inhibitor

Part A Completion

Use this completion exercise to check your understanding of the concepts and terms that are introduced in this section. Each blank can be completed with a term, short phrase, or number.

__1__ measure the speed of any change that occurs within	1. ______________
a time interval. Collision theory states that particles __2__ when	2. ______________
they collide, provided that they have enough __3__.	3. ______________
The rate at which a chemical reaction occurs is determined	4. ______________
by an __4__ energy barrier. The activation energy is the __5__	5. ______________
energy that reactants must have to go to __6__. The higher the	6. ______________
activation energy barrier, the __7__ the reaction. Chemists help	7. ______________
reactants overcome the activation barrier in a number of ways.	8. ______________
Two effective methods are to increase the __8__ at which the	9. ______________
reaction is done or use a __9__. Rates of reaction can also be	10. ______________
increased by __10__ the concentration of reactants.	

Part B True-False

Classify each of these statements as always true, AT; sometimes true, ST; or never true, NT.

________ 11. An increase in temperature will generally increase the rate of a reaction.

________ 12. A catalyst is considered as a reactant in a chemical reaction.

________ **13.** The speed of a reaction can be increased by increasing reactant concentration or decreasing particle size.

________ **14.** An enzyme is a biological catalyst.

Part C Matching

Match each description in Column B to the correct term in Column A.

Column A	Column B
________ **15.** rate	**a.** synonym for an activated complex
________ **16.** collision theory	**b.** speed of a change that occurs over time
________ **17.** activation energy	**c.** substance that interferes with the action of a catalyst
________ **18.** transition state	**d.** Particles can react to form products when they collide, provided they have enough kinetic energy.
________ **19.** catalyst	**e.** substance that increases the rate of a reaction without being used up
________ **20.** inhibitor	**f.** minimum energy particles must have in order to react

Part D Questions and Problems

Answer the following question and solve the following problem in the space provided.

21. An ice machine can produce 120 kg of ice in 24 hours. Express the rate of ice production in kg/hr.

22. Which of the following will increase the rate of a reaction?

a. increase particle size

b. increase temperature

c. decrease concentration

d. add a catalyst

Name ______________________ Class ______________ Date ____________

19.2 REVERSIBLE REACTIONS AND EQUILIBRIUM

SECTION REVIEW

Objectives

- Predict changes in the equilibrium position due to changes in concentration, temperature, and pressure
- Write the equilibrium-constant expression for a reaction and calculate its value from experimental data

Key Terms

- reversible reactions
- chemical equilibrium
- equilibrium position
- Le Châtelier's principle
- equilibrium constant (K_{eq})

Key Equation

- $K_{eq} = \frac{[C]^c \times [D]^d}{[A]^a \times [B]^b}$

  When $aA + bB \rightleftharpoons cC + dD$

Part A Completion

Use this completion exercise to check your understanding of the concepts and terms that are introduced in this section. Each blank can be completed with a term, short phrase, or number.

In principle, all reactions are __1__. That is, reactants go to __2__ in the __3__ direction and products go to __4__ in the __5__ direction.

The point at which the rate of conversion of __6__ to __7__ and vice versa is equal is the position of __8__. The __9__ of a reversible reaction, K_{eq}, is useful for determining the position of equilibrium. It is essentially a measure of the __10__ of products to reactants at equilibrium. The direction of change in the position of equilibrium may be predicted by applying __11__ principle.

1. ____________________
2. ____________________
3. ____________________
4. ____________________
5. ____________________
6. ____________________
7. ____________________
8. ____________________
9. ____________________
10. ____________________
11. ____________________

Name ________________________ Class ____________ Date ____________

Part B True-False

Classify each of these statements as always true, AT; sometimes true, ST; or never true, NT.

_______ **12.** The concentrations of reactants and products in a system at dynamic equilibrium are always changing.

_______ **13.** A change in the pressure on a system can cause a shift in the equilibrium position.

_______ **14.** For a chemical equilibrium to be established, the chemical reaction must be irreversible.

_______ **15.** The K_{eq} for a certain reaction was 2×10^{-7}. For this reaction at equilibrium, the concentration of the reactants is greater than the concentration of the products.

Part C Matching

Match each description in Column B to the correct term in Column A.

Column A	Column B
_______ **16.** reversible reactions	**a.** state of balance in which forward and reverse reactions take place at the same rate
_______ **17.** chemical equilibrium	**b.** measurement of the amount of solute that is dissolved in a given quantity of solvent
_______ **18.** equilibrium position	**c.** relative concentrations of reactants and products of a reaction that has reached equilibrium
_______ **19.** Le Châtelier's principle	**d.** When stress is applied to a system at equilibrium, the system changes to relieve the stress.
_______ **20.** equilibrium constant	**e.** reaction in which conversion of reactants to products and products to reactants occur simultaneously
_______ **21.** concentration	**f.** ratio of product concentrations to reactant concentrations with each raised to a power given by the number of moles of the substance in the balanced equation

Part D Questions and Problems

Solve the following problem in the space provided. Show your work.

22. $$2SO_3(g) \rightarrow 2SO_2(g) + O_2(g)$$

Calculate K_{eq} for this reaction if the equilibrium concentrations are:
$[SO_2] = 0.42M$, $[O_2] = 0.21M$, $[SO_3] = 0.072M$

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19.3 DETERMINING WHETHER A REACTION WILL OCCUR

SECTION REVIEW

Objectives

- Define entropy and free energy, and characterize reactions as spontaneous or nonspontaneous
- Describe how heat change and entropy change determine the spontaneity of a reaction

Key Terms

- free energy
- spontaneous reactions
- nonspontaneous reactions
- entropy
- law of disorder

Part A Completion

Use this completion exercise to check your understanding of the concepts and terms that are introduced in this section. Each blank can be completed with a term, short phrase, or number.

Reactions that actually occur as written are called __1__ reactions. Equations for other reactions may be written, but the reactions are __2__. All spontaneous reactions release __3__ that becomes available to do __4__. This energy is called __5__.

It is the natural tendency for all things to go to lower __6__ and toward __7__ disorder. In addition to the change in heat content, __8__ is a factor that determines whether a reaction will be spontaneous.

Entropy is a measure of the __9__ of a system. The __10__ states that processes move in the direction of __11__ disorder.

1. ____________
2. ____________
3. ____________
4. ____________
5. ____________
6. ____________
7. ____________
8. ____________
9. ____________
10. ____________
11. ____________

Part B True-False

Classify each of these statements as always true, AT; sometimes true, ST; or never true, NT.

________ 12 An exothermic reaction is a spontaneous reaction.

_______ 13. When a sandwich is eaten and digested, its entropy increases.

_______ 14. Some spontaneous reactions appear to be nonspontaneous because their rate of reaction is slow.

_______ 15. Spontaneous reactions release free energy.

_______ 16. Entropy will increase in a spontaneous reaction.

Part C Matching

Match each description in Column B to the correct term in Column A.

Column A	Column B
_______ 17. free energy	a. measure of the disorder of a system
_______ 18. spontaneous reactions	b. energy in a reaction that is available to do work
_______ 19. nonspontaneous reactions	c. It is the natural tendency of systems to move in the direction of maximum disorder.
_______ 20. entropy	d. reactions that do not give products under the specified conditions
_______ 21. law of disorder	e. reactions that favor formation of products under the specified conditions

Part D Questions and Problems

Complete the following question and solve the following problem in the space provided.

22. In each of the following pairs, choose the system with the higher entropy.

    a. a heap of loose stamps or stamps in an album ______________

    b. ice cubes in their tray or ice cubes in a bucket ______________

    c. 10 mL of water at 100 °C or 10 mL of steam at 100 °C ______________

    d. the people watching the parade or a parade ______________

23. Which combination of factors will always give a spontaneous reaction?

    a. heat absorbed, entropy increases

    b. heat released, entropy increases

    c. heat released, entropy decreases

    d. heat absorbed, entropy decreases

24. Which combination described in question 23 will never give a spontaneous reaction?

Name ______________________ Class ______________ Date ______________

19.4 CALCULATING ENTROPY AND FREE ENERGY
SECTION REVIEW

Objectives

- Calculate the standard entropy changes that accompany chemical and physical processes
- Calculate the free-energy changes that accompany chemical and physical processes

Key Terms

- standard entropy (S^0)
- Gibbs free-energy change (ΔG)

Key Equations

- $\Delta S^0 = S^0(\text{products}) - S^0(\text{reactants})$
- $\Delta G = \Delta H - T\Delta S$
- $\Delta G^0 = \Delta G_f^0(\text{products}) - \Delta G_f^0(\text{reactants})$

Part A Completion

Use this completion exercise to check your understanding of the concepts and terms that are introduced in this section. Each blank can be completed with a term, short phrase, or number.

S is the symbol for __1__, which is a qualitative measure of disorder. The __2__ of a substance is designated as S^0 at 25 °C and 101.3 kPa.

The standard entropy change in a reaction can be calculated by subtracting S^0 of the __3__ from S^0 of the __4__.

Energy from a reaction that is available to do work is called the __5__, or ΔG. This quantity can be calculated when the entropy change and __6__ change are known.

ΔG for a reaction can also be calculated using free energy of __7__. Thus ΔG^0 can be obtained by subtracting ΔG_f^0 of the __8__ from ΔG_f^0 of the __9__.

1. ______________
2. ______________
3. ______________
4. ______________
5. ______________
6. ______________
7. ______________
8. ______________
9. ______________

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Part B True-False

Classify each of these statements as always true, AT; sometimes true, ST; or never true, NT.

________ **10.** Spontaneous processes provide energy for work.

________ **11.** A reaction with a negative ΔH is spontaneous.

________ **12.** Substances have negative entropies below 0 °C.

________ **13.** The higher the temperature, the more likely a reaction will be spontaneous.

Part C Matching

Match each description in Column B to the correct term in Column A.

Column A	Column B
________ **14.** standard entropy	**a.** the amount of heat a substance has at a given temperature and pressure
________ **15.** Gibbs free-energy change	**b.** maximum amount of energy that can be coupled to another process to do work
________ **16.** enthalpy	**c.** a reaction known to give the products as written in a balanced equation at the specified conditions
________ **17.** spontaneous reaction	**d.** entropy of a substance in its stable state at 25 °C and 1 atm

Part D Questions and Problems

Complete the following question and solve the following problem in the space provided.

18. Using the information found in Table 19.2 of your text, calculate the change in entropy for the following reaction.

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

19. The reaction $A + 2B \rightarrow 3C$ has a ΔH^0 of -163 kJ/mol and a ΔS^0 of -0.51 kJ/(K × mol) at 25 °C. Is this reaction spontaneous?

Name ________________ Class ________ Date ________

19.5 THE PROGRESS OF CHEMICAL REACTIONS
SECTION REVIEW

Objectives

- Interpret experimental rate data to deduce the rate laws for simple chemical reactions
- Given an energy diagram for a reaction, analyze the mechanism for the reaction

Key Terms

- rate law
- specific rate constant
- first-order reaction
- elementary reaction
- reaction mechanism
- intermediate

Part A Completion

Use this completion exercise to check your understanding of the concepts and terms that are introduced in this section. Each blank can be completed with a term, short phrase, or number.

The ___1___ of a reaction is dependent in part on the ___2___ of the reactants. An equation that relates reaction rate to reactant concentration is called a ___3___. In a rate law equation, K is known as the ___4___.

The power to which a reaction concentration is raised is called the ___5___ of the reaction. A reaction whose rate is proportional to the concentration of one reactant is called a ___6___ reaction. A reaction that is first order for each of two reactants is ___7___ overall. The actual kinetic order of a reaction is determined by ___8___.

A single step reaction is called an ___9___. A series of elementary reactions combine to form the ___10___ of a complex reaction.

1. ________________
3. ________________
4. ________________
5. ________________
6. ________________
7. ________________
8. ________________
9. ________________
10. ________________

Name ______________________ Class ____________ Date ____________

Part B True-False

Classify each of these statements as always true, AT; sometimes true, ST; or never true, NT.

________ **11.** The rate order of a reaction can be determined from the balanced equation.

________ **12.** There is at least one intermediate product in a chemical reaction.

________ **13.** There is at least one activated complex in a chemical reaction.

________ **14.** An elementary reaction is a one-step reaction.

Part C Matching

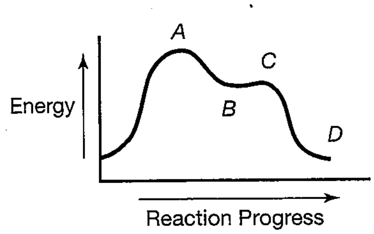
Match each description in Column B to the correct term in Column A.

	Column A	Column B
________	**15.** rate law	**a.** a single-step reaction
________	**16.** specific rate constant	**b.** reaction in which the rate is directly proportional to the concentration of one reactant
________	**17.** first-order reaction	**c.** a product of a reaction that becomes a reactant in another reaction
________	**18.** elementary reaction	**d.** expression relating the rate of a reaction to the concentration of the reactants
________	**19.** reaction mechanism	**e.** series of elementary reactions that take place during a complex reaction
________	**20.** intermediate product	**f.** proportionality constant relating the concentrations of reactants to the reaction rate

Part D Questions and Problems

Complete the following question and solve the following problem in the space provided.

21. Below is the reaction progress curve for a complex reaction. Describe the reaction represented by the curve (number of steps and the significance of points *A*, *B*, *C*, and *D*).



____

____

____

____

Name ______________________ Class ____________ Date ____________

19 REACTION RATES AND EQUILIBRIUM
PRACTICE PROBLEMS

In your notebook, solve the following problems.

SECTION 19.1 RATES OF REACTION

1. List three ways that reaction rates can generally be increased.
2. Ethyl acetate ($C_4H_8O_2$) reacts with a solution of sodium hydroxide (NaOH) in water to form sodium acetate ($C_2H_3O_2Na$) and ethyl alcohol (C_2H_6O). Suppose at 25 °C two moles of ethyl acetate react completely in four hours. How would you express the rate of reaction?
3. How would the following actions likely change the rate of the reaction in problem 2?
   a. the temperature is lowered to 4 °C.
   b. the concentration of sodium hydroxide in water is increased.
4. Ethyl acetate and water are not miscible; thus, the reaction in problem 2 only occurs at the interface of the two liquids. What would be the effect on the reaction rate of adding a solvent to make the reaction homogeneous?

SECTION 19.2 REVERSIBLE REACTIONS AND EQUILIBRIUM

1. Write the expression for the equilibrium constant for this reaction:
$$2N_2O_5(g) \rightleftharpoons 4NO_2(g) + O_2(g)$$
2. Calculate the equilibrium constant for the reaction in problem 1 if the equilibrium concentrations are $[N_2O_5] = 0.50$ mol/L, $[NO_2] = 0.80$ mol/L, $[O_2] = 0.20$ mol/L.
3. How would the equilibrium position for the equation in problem 1 be affected by
   a. an addition of O_2 to the reaction vessel?
   b. a decrease in the pressure?
4. The equilibrium constant for the reaction of nitrogen dioxide to form dinitrogen tetroxide is 5.6.
$$2NO_2\,(g) \rightleftharpoons N_2O_4\,(g)$$
In a one-liter container, the amount of N_2O_4, at equilibrium, is 0.66 mol. What is the equilibrium concentration of NO_2?
5. Write the equilibrium constant expression for each of the following reactions.
   a. $4NO(g) + 2O_2(g) \rightleftharpoons 2N_2O_4\,(g)$
   b. $2NO(g) + Br_2(g) \rightleftharpoons 2NOBr(g)$
   c. $CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g)$
   d. $SO_2(g) + NO_2(g) \rightleftharpoons SO_3(g) + NO(g)$
6. What effect would an increase in pressure have on the equilibrium position of each reaction in problem 5?

7. Which value of K_{eq} indicates most favorably for product formation, $K_{eq} = 1 \times 10^{12}$, $K_{eq} = 1.5$, or $K_{eq} = 5.6 \times 10^{-4}$?

8. Hydrogen sulfide gas decomposes into its elements and establishes an equilibrium at 1400 °C.

$$2H_2S(g) \rightleftharpoons 2H_2(g) + S_2(g)$$

A liter of this gas mixture contains 0.18 mol H_2S, 0.014 mol H_2, and 0.035 mol S_2. Calculate the equilibrium constant, K_{eq}, for this reaction.

SECTION 19.3 DETERMINING WHETHER A REACTION WILL OCCUR

1. When gently warmed, the element iodine will sublime:

$$I_2(s) \rightarrow I_2(g)$$

Is this process accompanied by an increase or decrease in entropy?

2. Is there an increase or decrease in entropy when air is cooled and liquefied (changed from a gas to a liquid)?

3. Is the degree of disorder increasing or decreasing in these reactions?

a. $H_2(g) + Br_2(l) \rightarrow 2HBr(g)$

b. $CuSO_4 \cdot 5H_2O(s) \rightarrow CuSO_4(s) + 5H_2O(g)$

c. $2XeO_3(s) \rightarrow 2Xe(g) + 3O_2(g)$

4. Classify each of these systems as always spontaneous (A), never spontaneous (N), or depends on the relative magnitude of the heat and entropy changes (D).

a. entropy decreases, heat is released

b. entropy decreases, heat is absorbed

c. entropy increases, heat is absorbed

d. entropy increases, heat is released

SECTION 19.4 CALCULATING ENTROPY AND FREE ENERGY

For problems 1–4, calculate the standard entropy change associated with each reaction. Refer to table 19.2 in your textbook.

1. $2H_2O_2(l) \rightarrow 2H_2O(l) + O_2(g)$

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

3. $I_2(g) \rightarrow I_2(s)$

4. $2CO(g) + O_2(g) \rightarrow 2CO_2(g)$

5. A reaction is endothermic (positive ΔH) and has a positive entropy. Would this reaction more likely be spontaneous at high or low temperatures? Explain.

6. A reaction has a ΔS of -122 J/(K × mol) and a ΔH of -78 kJ/mol. Is this reaction spontaneous at 285 °C?

7. Calculate the standard free energy change for the reaction between iron(III) oxide and carbon (graphite). Refer to Table 19.4 in your textbook.

$$2Fe_2O_3(s) + 3C(s) \rightarrow 4Fe(s) + 3CO_2(g)$$

8. Calculate the ΔG^0 of each of these reactions. Indicate whether each reaction is spontaneous or nonspontaneous at 25°C. Refer to Table 19.4 in your textbook.
   a. $4NH_3(g) + 5O_2(g) \rightarrow 4NO(g) + 6H_2O(l)$
   b. $2SO_2(g) + O_2(g) \rightarrow 2SO_3(g)$
   c. $CO(g) + 3H_2(g) \rightarrow CH_4(g) + H_2O(g)$

SECTION 19.5 THE PROGRESS OF CHEMICAL REACTIONS

1. A first order reaction has an initial reaction rate of 2.4 mol/(L × s). What is the rate when one-eighth the starting materials remain?
2. It has been experimentally determined that the rate law for the reaction between mercury(II) chloride and sodium oxalate is third-order overall and first-order with respect to $HgCl_2$. Write the rate law for this equation.

$$2HgCl_2 + Na_2C_2O_4 \rightarrow 2NaCl + 2CO_2 + Hg_2Cl_2$$

3. A certain combination reaction gave the following data. What is the rate law for this reaction?

$$J + K \rightarrow M$$

Initial concentration (mol/L)		Initial rate (mol/L × s)
[J]	[K]	Reaction of J
0.30	0.50	0.080
0.60	0.50	0.160
0.60	0.25	0.080

4. Iodide ion catalyzes the decomposition of hydrogen peroxide. The reaction is first-order in H_2O_2. What is the value of the rate constant, *k*, if the initial rate is 0.00842 mol/(L × s)?
   The initial concentration of H_2O_2 is 0.500 mol/L.

$$2H_2O_2 \rightarrow 2H_2O + O_2$$

5. A proposed reaction mechanism has two intermediates. How many elementary reactions are there in this mechanism?
6. The reaction A + B → C is first order in A and B, second order overall. Complete the following table:

Initial concentration (mol/L)		Initial rate (mol/L × s)
[A]	[B]	
0.50	0.50	0.020
0.50		0.040
0.25	1.0	

7. The condensation of acetic acid ($C_2H_4O_2$) with methanol (CH_4O) to form methyl acetate ($C_3H_6O_2$) and water is catalyzed by HCl

$$C_2H_4O_2 + CH_4O \overset{HCl}{\rightleftharpoons} C_3H_8O_3 \overset{HCl}{\rightleftharpoons} C_3H_6O_2 + H_2O$$

   a. How many elementary reactions are there in this condensation?
   b. Write the formula for the reaction intermediate(s).
   c. Write the rate law for this condensation

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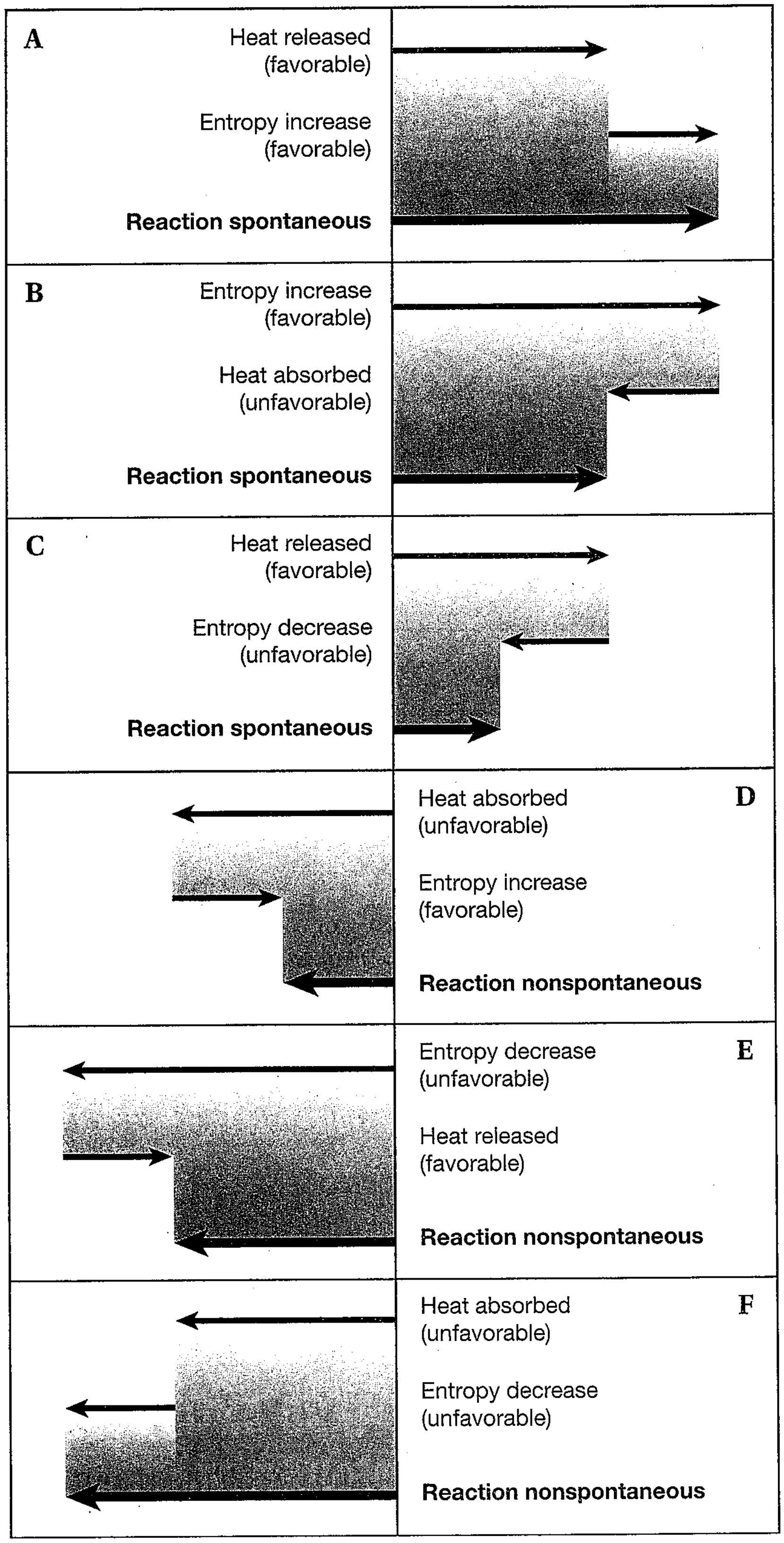
19 INTERPRETING GRAPHICS

USE WITH SECTIONS 19.3 AND 19.4



Name ______________________ Class ____________ Date ____________

The lettered diagrams on the previous page are from Figure 19.20 in your textbook. Use them to answer the following questions.

1. For each example, state whether ΔG is positive or negative.

   a. ____________

   b. ____________

   c. ____________

   d. ____________

   e ____________

   f. ____________

2. For each example; state whether ΔH is positive or negative.

   a. ____________

   b. ____________

   c. ____________

   d. ____________

   e ____________

   f. ____________

3. For Example B, is $|T\Delta S|$ greater or less than $|\Delta G|$?

   ____

4. For Example D, is $|T\Delta S|$ greater or less than $|\Delta G|$?

   ____

5. Which example would provide the most energy for work?

   ____

6. Could Example D be made to be spontaneous by an increase in temperature?

   ____

Name ______________________ Class ____________ Date ____________

19 VOCABULARY REVIEW

Match the correct vocabulary term to each numbered statement. Write the letter of the correct term on the line provided.

Column A	Column B
______ **1.** the disorder of a system	**a.** activation energy
______ **2.** a substance that interferes with the action of a catalyst	**b.** catalyst
______ **3.** reactions that favor the formation of products at the specified conditions	**c.** chemical equilibrium
______ **4.** the minimum energy colliding particles must have in order to react	**d.** free energy
______ **5.** a substance that increases the rate of a reaction without being used up in the reaction	**e.** entropy
______ **6.** the arrangement of atoms at the peak of the activation-energy barrier	**f.** activated complex
______ **7.** a reaction in which the rate is directly proportional to the concentration of one of the reactants	**g.** inhibitor
______ **8.** energy that is available to do work	**h.** equilibrium constant
______ **9.** when the forward and reverse reactions are taking place at the same rate	**i.** spontaneous reactions
______ **10.** the ratio of product concentrations to reactant concentrations, with each concentration raised to a power given by the number of moles of that substance in the balanced equation	**j.** first-order reaction

Name ____________________ Class ____________ Date ____________

19 REACTION RATES AND EQUILIBRIUM

Quiz for CHAPTER 19

Write the letter of the best answer in the blank.

______ **1.** At chemical equilibrium, the rates of the forward reaction and reverse reactions are: *19.2*
- **a.** equal to 0.
- **b.** equal to each other.
- **c.** at a maximum.
- **d.** at a minimum.

______ **2.** A catalyst works by: *19.1*
- **a.** changing the pressure of the system.
- **b.** changing the temperature of the reactants.
- **c.** shifting the equilibrium position toward the products.
- **d.** lowering the activation energy barrier.

______ **3.** The rate of a chemical reaction normally: *19.1*
- **a.** increases as reactant concentration increases.
- **b.** is slowed down by a catalyst.
- **c.** decreases as temperature increases.
- **d.** decreases as reactant concentration increases.

______ **4.** Activation energy is: *19.1*
- **a.** heat released or absorbed in a reaction.
- **b.** the minimum energy colliding particles must have in order to react.
- **c.** the energy given off when reactants collide.
- **d.** generally very high for a reaction that takes place rapidly.

______ **5.** Spontaneous reactions: *19.3*
- **a.** are always exothermic.
- **b.** always take place at a rapid rate.
- **c.** always result in increased disorder of the system.
- **d.** naturally favor the formation of products.

______ **6.** On a cold day, water vapor condenses to form frost. This represents an: *19.3*
- **a.** entropy increase and enthalpy increase.
- **b.** entropy increase and enthalpy decrease.
- **c.** entropy decrease and enthalpy increase.
- **d.** entropy decrease and enthalpy decrease.

Classify each of these statements as always true, AT; sometimes true, ST; or never true, NT.

______ **7.** The value of K_{eq} for a spontaneous reaction is much less than 1. *19.3*

______ **8.** The standard entropy, S^0, of a liquid or solid is the entropy at 25° C and 101.3 kPa. *19.4*

______ **9.** The Gibbs free energy for a spontaneous process is negative. *19.4*

______ **10.** In a first-order reaction involving several reactants, the reaction rate is directly proportional to the concentration of each of the reactants. *19.5*

Name ______________________ Class ____________ Date ____________

19 REACTION RATES AND EQUILIBRIUM

CHAPTER TEST A

A. Matching

Match each description in Column B with the correct term in Column A. Write the letter of the correct definition in the space provided.

Column A	Column B
______ 1. activated complex	a. the number of particles that react in a given time to form products
______ 2. reaction rate	b. energy available to do work
______ 3. Le Châtelier's principle	c. favoring the formation of products
______ 4. spontaneous	d. the minimum energy colliding particles must have in order to react
______ 5. elementary reaction	e. when the forward and reverse reactions take place at the same rate
______ 6. chemical equilibrium	f. a substance that interferes with the action of a catalyst
______ 7. entropy	g. reactants are converted to products in a single step
______ 8. activation energy	h. the measure of disorder
______ 9. inhibitor	i. the arrangement of atoms at the peak of the activation energy barrier
______ 10. free energy	j. If a stress is applied to a system in dynamic equilibrium, the system changes to relieve the stress.

B. Multiple Choice

Write the letter of the best answer in the blank.

______ 11. In which of the following physical states does a given substance have the highest entropy?
- a. solid
- b. gas
- c. liquid
- d. all of the above

______ 12. A reaction that requires free energy:
- a. must be endothermic.
- b. is nonspontaneous.
- c. must correspond to a decrease in entropy.
- d. is spontaneous.

Name ______________________ Class __________ Date __________

_______ 13. The two factors that determine whether a reaction is spontaneous or nonspontaneous are:

a. entropy and disorder.
b. entropy and enthalpy change.
c. electron configuration and energy change.
d. energy and the heat of reaction.

_______ 14. In which of these systems is the entropy decreasing?

a. air escaping from a tire
b. snow melting
c. salt dissolving in water
d. a gas condensing to a liquid

_______ 15. All spontaneous processes:

a. are exothermic.
b. are endothermic
c. involve an increase in entropy.
d. release free energy.

_______ 16. If a catalyst is used in a reaction:

a. the energy of activation increases.
b. the reaction rate does not change.
c. the reaction rate increases.
d. the equilibrium shifts.

_______ 17. Which of the following affects the rate of a chemical reaction?

a. the presence of a catalyst
b. the temperature
c. the concentration of reactants
d. all of the above

_______ 18. What is the expression for K_{eq} for this reaction?

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

a. $K_{eq} = \dfrac{[2H_2O]}{[H_2] \times [O_2]}$

b. $K_{eq} = \dfrac{[H_2]^2 \times [O_2]}{[H_2O]^2}$

c. $K_{eq} = \dfrac{[2H_2] \times [O_2]}{[2H_2O]}$

d. $K_{eq} = \dfrac{[H_2O]^2}{[H_2]^2 \times [O_2]}$

_______ 19. In an equilibrium reaction with a K_{eq} of 1×10^8

a. reactants are favored.
b. reaction is nonspontaneous.
c. products are favored.
d. reaction is exothermic.

_______ 20. What is the effect of adding more CO_2 to the following equilibrium reaction?

$$CO_2 + H_2O \rightleftharpoons H_2CO_3$$

a. More H_2CO_3 is produced.
b. More H_2O is produced.
c. The equilibrium is pushed in the direction of reactants.
d. no change

_______ 21. Doing which of the following generally increases the entropy of a substance?

a. freezing it
b. dissolving it in water
c. condensing it
d. all of the above

_______ 22. The K_{eq} of a reaction is 4×10^{-7}. At equilibrium:

a. the reactants are favored.
b. the products are favored.
c. the reactants and products are present in equal amounts.
d. the rate of the reverse reaction is much greater than the rate of the forward reaction.

______ **23.** Two opposing reactions ($A + B \rightleftharpoons C + D$) occurring simultaneously at the same rate is an example of:

a. reversibility.
b. chemical equilibrium.
c. neither a nor b
d. both a and b

C. Problems

Solve the following problems in the space provided. Show your work.

24. Calculate the value of K_{eq} for this reaction at equilibrium.

$$2NOCl(g) \rightleftharpoons 2NO(g) + Cl_2(g)$$

An analysis of the equilibrium mixture in a 1-L flask gives the following results: NOCl, 0.30 mol; NO, 1.2 mol; Cl_2, 0.60 mol.

25. Carbon monoxide and hydrogen are combined in the commercial preparation of methyl alcohol.

$$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g)$$

At a certain set of conditions, the equilibrium mixture contains 0.020 mol/L of CO, 0.60 mol/L of H_2, and the equilibrium constant is $2.2 \times 10^2\ L^2/mol^2$. What is the concentration of CH_3OH in the equilibrium mixture?

26. Predict the changes in the equilibrium position for this reaction when the following changes are made:

$$2A(g) + B(g) \rightleftharpoons 4C(g) + \text{heat}$$

a. decrease the concentration of C;
b. add more heat;
c. increase the concentration of A;
d. increase the pressure.

In each case, state whether the change causes a shift that favors the formation of reactants or of products.

a. ______________________________

b. ______________________________

c. ______________________________

d. ______________________________

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D. Essay

Write a short essay for the following.

27. Characterize spontaneous and nonspontaneous reactions. Then explain why a spontaneous reaction may appear to be nonspontaneous.

E. Additional Problems

Solve the following problems in the space provided. Show your work.

28. The rate law for the following reaction is: Rate = $k[A]^a \times [B]^b$.

$$aA + bB \rightarrow cC + dD$$

From the data in the following chart, find the kinetic order of the reaction with respect to A and B, as well as the overall order.

Initial concentration of A (mol/L)	Initial concentration of B (mol/L)	Initial Rate [mol/(L × s)]
0.50	0.05	2×10^{-3}
0.10	0.05	4×10^{-3}
0.20	0.05	8×10^{-3}
0.01	0.05	1×10^{-3}
0.01	0.10	8×10^{-3}
0.01	0.20	64×10^{-3}

29. The following reaction has an H^0 of 53 kJ/mol and a S^0 of 0.070 kJ/(K × mol) at 25 °C.

$$2A + B \rightarrow 2C$$

Is this reaction spontaneous? (Calculate ΔG.)

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30. What is the standard change in entropy for the following reaction when all reactants are in the specified states?

$$2H_2O(l) + O_2(g) \rightarrow 2H_2O_2(l)$$

Standard entropies S^0 in J/(K × mol):
$H_2O(l) = 69.94$, $H_2O_2(l) = 92.0$, $O_2(g) = 205.0$

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19 REACTION RATES AND EQUILIBRIUM

CHAPTER TEST B

A. Matching

Match each term in Column B with the correct description in Column A. Write the letter of the correct term in the blank provided.

	Column A	Column B
______	1. when the forward and reverse reactions are taking place at the same rate	a. Le Châtelier's principle
______	2. Things move in the direction of maximum disorder or randomness.	b. activated complex
______	3. the minimum energy colliding particles must have in order to react	c. entropy
______	4. the ratio of product concentrations to reactant concentrations, with each concentration raised to a power given by the number of moles of that substance in the balanced equation	d. collision theory
______	5. a substance that increases the rate of a reaction without being used up itself in the reaction	e. free energy
______	6. the disorder of a system	f. catalyst
______	7. Atoms, ions, and molecules can form a chemical bond between them when they collide, provided the particles have enough kinetic energy.	g. law of disorder
______	8. energy that is available to do work	h. activation energy
______	9. the arrangement of atoms at the peak of the activation energy barrier	i. equilibrium constant
______	10. If a stress is applied to a system in a dynamic equilibrium, the system changes to relieve the stress.	j. chemical equilibrium

B. Multiple Choice

Choose the best answer and write its letter in the blank.

______ 11. According to the collision theory, in order for a chemical reaction to occur, the reactant atoms must:
- a. make contact with each other.
- b. have a minimum level of kinetic energy.
- c. form an activated complex.
- d. all of these

________ **12.** In general, increasing temperature causes the rate of most chemical reactions to:
a. increase.
b. decrease.
c. remain the same.
d. vary unpredictably.

________ **13.** Which of the following is true concerning the impact of increasing temperature on reaction rates?
a. The number of collisions between reactant atoms is increased.
b. The energy of each reactant atom is increased.
c. The percentage of collisions with sufficient energy to cross the activation energy barrier is increased.
d. all of these

________ **14.** What would decrease the rate of most chemical reactions?
a. increasing the concentration of reactant atoms
b. increase the size of the reactant particles
c. adding an appropriate catalyst
d. all of these

________ **15.** Catalysts alter the rate of a chemical reaction by:
a. increasing the number of collisions between reactant atoms.
b. increasing the kinetic energy of each reactant atom.
c. lowering the activation energy barrier.
d. being consumed in the reaction.

________ **16.** Which of the following is true concerning a reaction that has reached chemical equilibrium?
a. The forward reaction is occurring faster than the reverse reaction.
b. The reverse reaction is occurring faster than the forward reaction.
c. The forward reaction is occurring as fast as the reverse reaction.
d. The mass of products is equal to the mass of reactants.

________ **17.** Given the following system at equilibrium:

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

what would be the effect of removing $NH_3(g)$ as it is formed?
a. The equilibrium would shift to the left.
b. More $N_2(g)$ would be produced.
c. More $H_2(g)$ would be produced.
d. The equilibrium would shift to the right.

________ **18.** Given the following system at equilibrium:

$$H_2O(l) + \text{heat} \rightleftharpoons H_2O(g)$$

how would a decrease in temperature affect the system?
a. The equilibrium would shift to the right.
b. More $H_2O(l)$ would be produced.
c. More $H_2O(g)$ would be produced.
d. The levels of reactants and products would remain the same.

________ **19.** Which of the following would increase the yield of CO(g) in the following equilibrium system?

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

a. decreasing temperature
b. increasing pressure
c. adding $H_2(g)$
d. adding $H_2O(g)$

______ **20.** Spontaneous reactions:
a. favor the formation of products.
b. give substantial amounts of reactants at equilibrium.
c. absorb free energy.
d. have high reaction rates.

______ **21.** Which of the following has the greatest entropy?
a. ice
b. water
c. steam
d. cannot be predicted

______ **22.** The type of reaction most likely to be spontaneous is one in which:
a. both heat content and entropy are decreased.
b. heat content is decreased, while entropy is increased.
c. both heat content and entropy are increased.
d. heat content is increased, while entropy is decreased.

______ **23.** The expression for K_{eq} for the following reaction is:

$$H_2(g) + Cl_2(g) \rightleftharpoons 2HCl(g)$$

a. $K_{eq} = \frac{[H_2] \times [Cl_2]}{[2HCl]}$
b. $K_{eq} = \frac{[2HCl]}{[H_2] \times [Cl_2]}$
c. $K_{eq} = \frac{[HCl]^2}{[H_2] \times [Cl_2]}$
d. $K_{eq} = \frac{[H_2] \times [Cl_2]}{[HCl]^2}$

______ **24.** If the equilibrium concentrations for the system in question 24 are as follows, find the value of K_{eq}:

$[H_2] = 0.450$ mol/L, $[Cl_2] = 0.450$ mol/L, $[HCl] = 6.25$ mol/L

a. 1.62×10^{-2}
b. 193
c. 5.18×10^{-3}
d. 61.7

C. Problems

Solve the following problems in the space provided. Show your work.

25. Given the following system at equilibrium:

$$4HCl(g) + O_2(g) \rightleftharpoons 2H_2O(g) + 2Cl_2(g) + \text{heat}$$

determine the effect of each of the following changes on the equilibrium position of the system (shifts right or left) and on the amount of $Cl_2(g)$ that would result (increases or decreases):

	Equilibrium Position	Amount of $Cl_2(g)$
a. increasing temperature		
b. decreasing pressure		
c. adding $O_2(g)$		
d. removing $H_2O(g)$		
e. increasing pressure		
f. adding $H_2O(g)$		

26. At equilibrium, the concentrations of the components of the reaction in problem 25 are as follows:

$[HCl] = 1.2 \times 10^{-3}$ mol/L, $[O_2] = 3.8 \times 10^{-4}$ mol/L,
$[H_2O] = 5.8 \times 10^{-2}$ mol/L, and $[Cl_2] = 5.8 \times 10^{-2}$ mol/L

Determine the value of K_{eq} for this system.

27. Calculate the standard entropy change, ΔS^0, that occurs in the following reaction at 25 °C and 101.3 kPa.

$$4NH_3(g) + 7O_2(g) \rightarrow 4NO_2(g) + 6H_2O(g)$$

Standard entropies S^0 ($J/K \times mol$):
S^0 for $NH_3(g) = 192.5$
S^0 for $O_2(g) = 205.0$
S^0 for $NO_2(g) = 240.5$
S^0 for $H_2O(g) = 188.7$

D. Essay

Write short essays for the following.

28. Explain how and why an equilibrium system reacts to each of the following stresses:

a. the addition of more reactant

____

____

____

____

b. an increase in temperature

____

____

____

____

c. an increase in pressure (for a gaseous system with an unequal number of molecules)

____

____

____

Name ______________________ Class ______________ Date ______________

E. Additional Problems

Solve the following problems in the space provided. Show your work.

29. Given:

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \text{ with } K_{eq} = 6.59 \times 10^{-3} \text{ at } 450\ °C$$

If $[NH_3] = 1.23 \times 10^{-4}$ mol/L and $[H_2] = 2.75 \times 10^{-6}$ mol/L at equilibrium, what is the concentration of N_2 at equilibrium?

30. Determine whether the following reaction is spontaneous by using the ΔG_f^0 for the reactants and products.

$$CH_4(g) + 2O_2(g) \rightleftharpoons CO_2(g) + 2H_2O(l)$$

ΔG_f^0 for $CH_4(g) = -50.79$ kJ/mol
ΔG_f^0 for $O_2(g) = 0.00$ kJ/mol
ΔG_f^0 for $CO_2(g) = -394.4$ kJ/mol
ΔG_f^0 for $H_2O(l) = -237.2$ kJ/mol

31. Based on the values given below, calculate ΔG^0 and determine whether the reaction is spontaneous.

$$\Delta H^0 = -85.2 \text{ kJ/mol}, T = 127\ °C, \Delta S^0 = 0.125 \text{ kJ/K} \times \text{mol}$$