1. The compound RX$_3$ decomposes according to the equation

$$RX_3 \rightarrow R + R_2X_3 + 3X_2$$

In an experiment the following data were collected for the decomposition at 100°C. What is the average rate of reaction over the entire experiment?

<table>
<thead>
<tr>
<th>$t$(s)</th>
<th>[RX$_3$](mol L$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.85</td>
</tr>
<tr>
<td>2</td>
<td>0.67</td>
</tr>
<tr>
<td>6</td>
<td>0.41</td>
</tr>
<tr>
<td>8</td>
<td>0.33</td>
</tr>
<tr>
<td>12</td>
<td>0.20</td>
</tr>
<tr>
<td>14</td>
<td>0.16</td>
</tr>
</tbody>
</table>

a. 0.019 mol L$^{-1}$s$^{-1}$

b. 0.044 mol L$^{-1}$s$^{-1}$

c. 0.049 mol L$^{-1}$s$^{-1}$

d. 0.069 mol L$^{-1}$s$^{-1}$

2. Consider the following reaction

$$A(g) + 2B(g) \rightarrow C(g) + D(g)$$

If [C] is increasing at the rate of 4.0 mol L$^{-1}$s$^{-1}$, at what rate is [B] changing?

a. -0.40 mol L$^{-1}$s$^{-1}$

b. -2.0 mol L$^{-1}$s$^{-1}$

c. -4.0 mol L$^{-1}$s$^{-1}$

d. -8.0 mol L$^{-1}$s$^{-1}$

3. For the reaction

$$3A(g) + 2B(g) \rightarrow 2C(g) + 2D(g)$$

the following data were collected at constant temperature. Determine the correct rate law for this reaction.

<table>
<thead>
<tr>
<th>Trial</th>
<th>Initial [A] (mol/L)</th>
<th>Initial [B] (mol/L)</th>
<th>Initial Rate (mol/(L·min))</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.200</td>
<td>0.100</td>
<td>$6.00 \times 10^{-2}$</td>
</tr>
<tr>
<td>2</td>
<td>0.100</td>
<td>0.100</td>
<td>$1.50 \times 10^{-2}$</td>
</tr>
<tr>
<td>3</td>
<td>0.200</td>
<td>0.200</td>
<td>$1.20 \times 10^{-1}$</td>
</tr>
<tr>
<td>4</td>
<td>0.300</td>
<td>0.200</td>
<td>$2.70 \times 10^{-1}$</td>
</tr>
</tbody>
</table>

a. Rate = $k[A][B]^2$

b. Rate = $k[A]^2[B]$

c. Rate = $k[A]^1[B]^2$

d. Rate = $k[A]^{1.5}[B]$
4. For the reaction
\[ A(g) + 2B(g) \rightarrow 2C(g) + 2D(g) \]

the following data were collected at constant temperature. Determine the correct rate law for this reaction.

<table>
<thead>
<tr>
<th>Trial</th>
<th>Initial [A] (mol/L)</th>
<th>Initial [B] (mol/L)</th>
<th>Initial Rate (mol/(L·min))</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.125</td>
<td>0.200</td>
<td>7.25</td>
</tr>
<tr>
<td>2</td>
<td>0.375</td>
<td>0.200</td>
<td>21.75</td>
</tr>
<tr>
<td>3</td>
<td>0.250</td>
<td>0.400</td>
<td>14.50</td>
</tr>
<tr>
<td>4</td>
<td>0.375</td>
<td>0.400</td>
<td>21.75</td>
</tr>
</tbody>
</table>

a. Rate = \( k[A][B] \)
b. Rate = \( k[A]^2[B] \)
c. Rate = \( k[A][B]^2 \)
d. Rate = \( k[A] \)

5. When the reaction \( A \rightarrow B + C \) is studied, a plot of \( \ln[A] \) vs. time gives a straight line with a negative slope. The order of the reaction is:

a. zero
b. first
c. second
d. third

6. The reaction \( A \rightarrow B \) is first-order overall and first-order with respect to the reactant A. The result of doubling the initial concentration of A will be to

a. shorten the half-life of the reaction
b. increase the rate constant of the reaction
c. decrease the rate constant of the reaction
d. shorten the time taken to reach equilibrium
e. double the initial rate

7. Cyclopropane is converted to propene in a first-order process. The rate constant is \( 5.4 \times 10^{-2} \text{ hr}^{-1} \). If the initial concentration of cyclopropane is 0.150 \( M \), what will its concentration be after 22.0 hours?

a. 0.0457 \( M \)
b. 0.105 \( M \)
c. 0.127 \( M \)
d. 0.492 \( M \)
8. A first-order reaction has a half-life of 20.0 minutes. Starting with \( \text{1.00} \times \text{10}^{20} \) molecules of reactant at time \( t = 0 \), how many molecules remain unreacted after 100.0 minutes?

a. \( 3.13 \times \text{10}^{18} \)

b. \( 1.00 \times \text{10}^{4} \)

c. \( 2.00 \times \text{10}^{19} \)

d. \( 3.20 \times \text{10}^{16} \)

e. none of the above

9. The decomposition of dinitrogen pentaoxide has an activation energy of 102 kJ/mol and \( \Delta H_{\text{rxn}}^\circ = +55 \text{ kJ/mol} \). What is the activation energy for the reverse reaction?

a. 27 kJ/mol

b. 47 kJ/mol

c. 55 kJ/mol

d. 102 kJ/mol

10. The kinetics of the decomposition of dinitrogen pentaoxide is studied at 50°C and at 75°C. Which of the following statements concerning the studies is correct?

a. The rate at 75°C will be greater than the rate at 50°C because the activation energy will be lower at 75°C than at 50°C.

b. The rate at 75°C will be greater than the rate at 50°C because the number of molecules with enough energy to react increases with increasing temperature.

c. The rate at 75°C will be less than the rate at 50°C because the molecules at higher speeds do not interact as well as those at lower speeds.

d. The rate at 75°C will be greater than at 50°C because the concentration of a gas increases with increasing temperature.

11. Consider the following mechanism for the oxidation of bromide ions by hydrogen peroxide in aqueous acid solution.

\[
\begin{align*}
\text{H}^+ & + \text{H}_2\text{O}_2 & \rightarrow \text{H}_3\text{O}_2^+ \text{ (rapid equilibrium)} \\
\text{H}_3\text{O}_2^+ & + \text{Br}^- & \rightarrow \text{HOBr} + \text{H}_2\text{O} \text{ (slow)} \\
\text{HOBr} & + \text{H}^+ & + \text{Br}^- & \rightarrow \text{Br}_2 + \text{H}_2\text{O} \text{ (fast)}
\end{align*}
\]

What is the overall reaction equation for this process?

a. \( 2 \text{H}_2\text{O}_2^+ + 2\text{Br}^- \rightarrow \text{H}_2\text{O}_2 + \text{Br}_2 + 2\text{H}_2\text{O} \)

b. \( 2\text{H}^+ + 2\text{Br}^- + \text{H}_2\text{O}_2 \rightarrow \text{Br}_2 + 2\text{H}_2\text{O} \)

c. \( 2\text{H}^+ + \text{H}_2\text{O}_2 + \text{Br}^- + \text{HOBr} \rightarrow \text{H}_3\text{O}_2^+ + \text{Br}_2 + \text{H}_2\text{O} \)

d. \( \text{H}_3\text{O}_2^+ + \text{Br}^- + \text{H}^+ \rightarrow \text{Br}_2 + \text{H}_2\text{O} \)
12. Consider the following mechanism for the oxidation of bromide ions by hydrogen peroxide in aqueous acid solution.

\[
\begin{align*}
H^+ + H_2O_2 & \quad \rightarrow \quad H_3O_2^+ \text{ (rapid equilibrium)} \\
H_3O_2^+ + Br^- & \quad \rightarrow \quad HOBr + H_2O \text{ (slow)} \\
HOBr + H^+ + Br^- & \quad \rightarrow \quad Br_2 + H_2O \text{ (fast)}
\end{align*}
\]

Which of the following rate laws is consistent with the mechanism?

a. Rate = \( k [H_2O_2][H^+]^2[Br^-] \)

b. Rate = \( k [H_3O_2^+][Br^-] \)

c. Rate = \( k [H_2O_2][H^+]^2[Br^-] \)

d. Rate = \( k [HOBr][H^+][Br^-][H_2O_2] \)

13. Which of the following affects the activation energy of a reaction?

a. temperature of the reactants

b. concentrations of reactants

c. presence of a catalyst

d. surface area of reactants

14. When a catalyst is added to a reaction mixture, it

a. increases the rate of collisions between reactant molecules

b. provides reactant molecules with more energy

c. slows down the rate of the back reaction

d. provides a new pathway (mechanism) with a lower activation energy.

e. does none of the above

**TRUE-FALSE**

True = a    False = b

15. The rate law cannot be predicted from the stoichiometry of a reaction.

16. The half-life of a first-order reaction does not depend on the initial concentration of reactant.

17. The greater the energy of activation, \( E_a \), the faster will be the reaction.

18. An elementary reaction is a simple, one-step process.

19. The rate of a reaction is determined by the rate of the fastest step in the mechanism.

20. A transition state is a species (or state) corresponding to an energy maximum on a reaction energy diagram.
21. When a chemical system is at equilibrium,

a. the concentrations of the reactants are equal to the concentrations of the products.
b. the concentrations of the reactants and products have reached constant values.
c. the forward and reverse reactions have stopped.
d. the reaction quotient, $Q$, has reached a maximum.

22. Which of the following has an effect on the magnitude of the equilibrium constant?

a. activation energy of the forward reaction
b. concentrations of the reactants and products
c. presence of a catalyst
d. change in temperature

23. Write the mass-action expression, $Q_c$, for the following chemical reaction equation.

$$2C_6H_6(g) + 15O_2(g) \rightarrow 12CO_2(g) + 6H_2O(g)$$

a. $\frac{[CO_2][H_2O]}{[C_6H_6][O_2]}$

b. $\frac{[CO_2]^{12}[H_2O]^6}{[C_6H_6]^2[O_2]^{15}}$

c. $\frac{[C_6H_6][O_2]}{[CO_2][H_2O]}$

d. $\frac{[C_6H_6]^2[O_2]^{15}}{[CO]^{12}[H_2O]^6}$

24. Write the mass-action expression, $Q_c$, for the following chemical reaction.

$$2Cu^{2+}(aq) + 4I^-(aq) \rightarrow 2CuI(s) + I_2(aq)$$

a. $\frac{[CuI]^2[I_2]}{[Cu^{2+}]^2[I]^4}$

b. $\frac{[Cu^{2+}]^2[I]^4}{[CuI]^2[I_2]}$

c. $\frac{[I_2]}{[Cu^{2+}]^2[I]^4}$

d. $\frac{[Cu^{2+}]^2[I]^4}{[I_2]}$
25. Consider the reactions of cadmium with the thiosulfate anion.

\[
\begin{align*}
\text{Cd}^{2+}(aq) + \text{S}_2\text{O}_3^{2-}(aq) & \rightleftharpoons \text{Cd(S}_2\text{O}_3)^{(aq)} \quad K_1 = 8.3 \times 10^3 \\
\text{Cd(S}_2\text{O}_3)^{(aq)} + \text{S}_2\text{O}_3^{2-}(aq) & \rightleftharpoons \text{Cd(S}_2\text{O}_3)_2^{2-}(aq) \quad K_2 = 2.5 \times 10^2
\end{align*}
\]

What is the value for the equilibrium constant for the following reaction?

\[
\text{Cd}^{2+}(aq) + 2\text{S}_2\text{O}_3^{2-}(aq) \rightleftharpoons \text{Cd(S}_2\text{O}_3)_2^{2-}(aq)
\]

a. 33  
b. \(8.1 \times 10^3\)  
c. \(8.6 \times 10^3\)  
d. \(2.1 \times 10^6\)

26. The equilibrium constant, \(K_C\), for the decomposition of COBr₂

\[
\text{COBr}_2(g) \rightleftharpoons \text{CO}(g) + \text{Br}_2(g)
\]

is 0.190. What is \(K_C\) for the following reaction?

\[
2\text{CO}(g) + 2\text{Br}_2(g) \rightleftharpoons 2\text{COBr}_2(g)
\]

a. 0.0361  
b. 2.63  
c. 10.5  
d. 27.7

27. The equilibrium constant, \(K_P\), for the reaction

\[
\text{H}_2(g) + \text{I}_2(g) \rightleftharpoons 2\text{HI}(g)
\]

is 55.2 at 425°C. A rigid cylinder at that temperature contains 0.127 atm of hydrogen, 0.134 atm of iodine, and 1.055 atm of hydrogen iodide. Is the system at equilibrium?

a. Yes.  
b. No, the forward reaction must proceed to establish equilibrium.  
c. No, the reverse reaction must proceed to establish equilibrium.  
d. More data is needed to draw a conclusion.

28. Compounds A, B, and C react according to the following equation.

\[
3\text{A}(g) + 2\text{B}(g) \rightleftharpoons 2\text{C}(g)
\]

At 100°C a mixture of these gases at equilibrium showed that \([\text{A}] = 0.855 \, M\), \([\text{B}] = 1.23 \, M\), and \([\text{C}] = 1.75 \, M\). What is the value of \(K_C\) for this reaction?

a. 0.309  
b. 0.601  
c. 1.66  
d. 3.24
29. A mixture of 0.600 mol of bromine and 1.600 mol of iodine is placed into a rigid 1.000-L container at 350°C.

\[
\text{Br}_2(g) + \text{I}_2(g) \rightleftharpoons 2\text{IBr}(g)
\]

When the mixture has come to equilibrium, the concentration of iodine monobromide is 1.190 M. What is the equilibrium constant for this reaction at 350°C?

a. \(3.6 \times 10^{-3}\)

b. 1.5

c. 280

d. 330

30. At 25°C, the equilibrium constant \(K_c\) for the reaction

\[
2\text{A}(aq) \rightleftharpoons \text{B}(aq) + \text{C}(aq)
\]

is 65. If 2.50 mol of A is added to enough water to prepare 1.00 L of solution, what will the equilibrium concentration of A be?

a. 0.14 M

b. 0.28 M

c. 1.18 M

d. 2.4 M

31. The reaction system

\[
\text{POCl}_3(g) \rightleftharpoons \text{POCl}(g) + \text{Cl}_2(g)
\]

is at equilibrium. Which of the following statements describes the behavior of the system if more POCl is added to the container?

a. The forward reaction will proceed to establish equilibrium.

b. The reverse reaction will proceed to establish equilibrium.

c. The partial pressures of POCl\(_3\) and POCl will remain steady while the partial pressure of chlorine increases.

d. The partial pressure of chlorine remains steady while the partial pressures of POCl\(_3\) and POCl increase.
32. The reaction system

\[ CS_2(g) + 4H_2(g) \rightarrow CH_4(g) + 2H_2S(g) \]

is at equilibrium. Which of the following statements describes the behavior of the system if the partial pressure of carbon disulfide is reduced?

a. As equilibrium is reestablished, the partial pressure of carbon disulfide increases.
b. As equilibrium is reestablished, the partial pressure of hydrogen decreases.
c. As equilibrium is reestablished, the partial pressure of methane, CH₄, increases.
d. As equilibrium is reestablished, the partial pressures of hydrogen and hydrogen sulfide decrease.

33. Magnesium hydroxide is used in several antacid formulations. When it is added to water it dissociates into magnesium and hydroxide ions.

\[ Mg(OH)_2(s) \rightarrow Mg^{2+}(aq) + 2OH^-(aq) \]

The equilibrium constant at 25°C is \( 8.9 \times 10^{-12} \). One hundred grams of magnesium hydroxide is added to 1.00 L of water and equilibrium is established. What happens to the hydroxide ion concentration if 10 grams of Mg(OH)₂ are added to the mixture?

a. The hydroxide ion concentration will decrease.
b. The hydroxide ion concentration will increase.
c. The hydroxide ion concentration will be unchanged.
d. More information is needed to make a valid judgment.

34. At 450°C, tert-butyl alcohol decomposes into water and isobutene.

\[ (CH_3)_3COH(g) \rightarrow (CH_3)_2CCH_2(g) + H_2O(g) \]

A reaction vessel contains these compounds at equilibrium. What will happen if the volume of the container is reduced by 50% at constant temperature?

a. The forward reaction will proceed to reestablish equilibrium.
b. The reverse reaction will proceed to reestablish equilibrium.
c. No change occurs.
d. The equilibrium constant will increase.

35. A container was charged with hydrogen, nitrogen, and ammonia gases at 120°C and the system was allowed to reach equilibrium. What will happen if the volume of the container is increased at constant temperature?

\[ 3H_2(g) + N_2(g) \rightarrow 2NH_3(g) \]

a. There will be no effect.
b. More ammonia will be produced at the expense of hydrogen and nitrogen.
c. Hydrogen and nitrogen will be produced at the expense of ammonia.
d. The equilibrium constant will increase.
36. The reaction of nitric oxide to form dinitrogen oxide and nitrogen dioxide is exothermic.

\[ 3\text{NO}(g) \rightarrow \text{N}_2\text{O}(g) + \text{NO}_2(g) \text{ + heat} \]

What effect will be seen if the temperature of the system at equilibrium is raised by 25°C?

a. The moles of NO will increase.
b. The moles of NO will decrease.
c. The moles of NO\(_2\) will increase.
d. The moles of NO and N\(_2\)O will increase.

37. Hydrogen bromide will dissociate into hydrogen and bromine gases.

\[ 2\text{HBr}(g) \rightarrow \text{H}_2(g) + \text{Br}_2(g) \quad \Delta H^\circ_{\text{rxn}} = 68 \text{ kJ} \]

What effect will a temperature increase of 50°C have on this system at equilibrium?

a. The moles of hydrogen bromide will increase.
b. The moles of hydrogen will increase.
c. The moles of hydrogen bromide and bromine will increase.
d. There will be no effect on number of moles of any of the gases.

38. Ethane can be formed by reacting acetylene with hydrogen.

\[ \text{C}_2\text{H}_2(g) + 2\text{H}_2(g) \rightarrow \text{C}_2\text{H}_6(g) \quad \Delta H^\circ_{\text{rxn}} = -311 \text{ kJ} \]

Under which reaction conditions would you expect to have the greatest equilibrium yield of ethane?

a. high temperature, high pressure 
b. low temperature, high pressure 
c. high temperature, low pressure 
d. low temperature, low pressure

39. The following reaction is at equilibrium in a sealed container.

\[ \text{N}_2(g) + 3\text{H}_2(g) \rightarrow 2\text{NH}_3(g) \quad (\Delta H^\circ < 0) \]

Which, if any, of the following actions will increase the value of the equilibrium constant, \(K_c\)?

a. adding a catalyst 
b. adding more N\(_2\) 
c. increasing the pressure 
d. lowering the temperature 
e. raising the temperature