1. Which substance has the greatest ideal van’t Hoff factor?
   A. AlPO₄             C. (NH₄)₂SO₄
   B. C₆H₁₄             D. Fe(C₂H₃O₂)₃

2. A solution is prepared at 25 °C from 25.0 g of lauric acid (nonvolatile, 200.3 g/mol) in 50.0 g of H₂O. What is the vapor pressure of the solution? The vapor pressure of pure water at 25 °C is 23.8 torr.
   A. 1.04 torr             C. 22.8 torr
   B. 1.08 torr             D. 24.9 torr

3. Calculate the freezing point of a solution prepared by dissolving 0.250 g CHCl₃ in 15.00 g CCl₄.
   Normal freezing point, CHCl₃ = −6.36 °C
   Normal freezing point, CCl₄ = −22.9 °C
   \( K_f (\text{CHCl}_3) = 4.70 \degree C/m \)
   \( K_f (\text{CCl}_4) = 29.9 \degree C/m \)
   A. 4.25 °C             C. −18.5 °C
   B. −1.81 °C            D. −27.1 °C
4. What is the molarity of a \( \text{Na}_2\text{SO}_4 \) solution with an osmotic pressure of 1.20 atm at 18.5 °C?

A. 0.0271 M  
B. 0.00223 M  
C. 0.0167 M  
D. 0.0693 M

5. Which aqueous solution has the highest boiling point? Assume ideal van’t Hoff factors.

A. 0.25 \( m \) \( \text{NaCl} \)  
B. 0.10 \( m \) \( \text{AlCl}_3 \)  
C. 0.20 \( m \) \( \text{CaBr}_2 \)  
D. 0.25 \( m \) glucose (non-electrolyte)

6. The rate of a reaction can be defined as

A. the change in mass over concentration.  
B. the change in concentration over time.  
C. the change in time over mass.  
D. the change in speed over time.

7. Nitrogen dioxide forms according to the reaction

\[
\text{N}_2\text{O}_4(g) \rightleftharpoons 2 \text{NO}_2(g)
\]

What is the rate of the reaction if the concentration of NO\(_2\) goes from zero to 0.500 M in 30 seconds?

A. \(8.3 \times 10^{-3}\) M/s  
B. \(1.6 \times 10^{-2}\) M/s  
C. \(3.2 \times 10^{-2}\) M/s  
D. 0.60 M/s
8. For the reaction

\[
4 \text{NH}_3(g) + 5 \text{O}_2(g) \rightarrow 4 \text{NO}(g) + 6 \text{H}_2\text{O}(g)
\]

the concentration of \( \text{NH}_3(g) \) dropped at a rate of 0.032 M/s during the first 10 seconds. What is the rate of change of \( \text{H}_2\text{O}(g) \) during this same time interval?

A. 0.050 M/s  
B. 0.026 M/s  
C. 0.048 M/s  
D. 0.036 M/s

9. Select the **false** statement concerning the following reaction and its corresponding rate law.

\[
2 \text{H}_2(g) + 2 \text{NO}(g) \rightarrow \text{N}_2(g) + 2 \text{H}_2\text{O}(g) \quad \text{rate} = k[\text{H}_2][\text{NO}]^2
\]

A. The reaction is second order in NO.  
B. The reaction is third order overall.  
C. Doubling the concentration of NO will quadruple the rate of the reaction.  
D. The given rate law must be incorrect; it must be second order in \( \text{H}_2 \).

10. What is the order of the reaction for the uncatalyzed decomposition of \( \text{N}_2\text{O}_4 \) given the following experimental data?

\[
\text{N}_2\text{O}_4(g) \rightleftharpoons 2 \text{NO}_2(g)
\]

<table>
<thead>
<tr>
<th>( \text{N}_2\text{O}_4(M) )</th>
<th>Initial rate (M/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.100</td>
<td>( 3.0 \times 10^{-2} )</td>
</tr>
<tr>
<td>0.300</td>
<td>( 9.1 \times 10^{-2} )</td>
</tr>
<tr>
<td>0.500</td>
<td>( 1.5 \times 10^{-1} )</td>
</tr>
</tbody>
</table>

A. 0  
B. 1  
C. 2  
D. 3
11. Which statement below best describes the graph of $[X]$ vs. time for a **first-order reaction** where $X \rightarrow$ products?

A. The rate of the reaction decreases over time as shown by Curve 1 because the concentration of reactant decreases.

B. The rate of the reaction is constant as shown by Curve 2 because the rate is independent of the concentration of the reactant.

C. The rate of the reaction decreases over time as shown by Curve 3 because the concentration of the reactant decreases.

D. The rate of the reaction is smallest at time zero.
12. For the reaction

\[ \text{SO}_2\text{Cl}_2 (g) \rightarrow \text{SO}_2 (g) + \text{Cl}_2 (g) \]

a plot of \( \ln[\text{SO}_2\text{Cl}_2] \) versus time yields a straight line with slope \( = -2.90 \times 10^{-4} \text{ s}^{-1} \).

If the initial concentration of \( \text{SO}_2\text{Cl}_2 \) is 0.150 M, what is the concentration at 20.0 minutes?

A. 0.145 M  
B. 0.0225 M  
C. 0.106 M  
D. 0.977 M

13. A plot of \( \frac{1}{[A]} \) versus time for a certain reaction produces a straight line with slope equal to 0.269 M\(^{-1}\)s\(^{-1} \). Which of the following is true?

A. The reaction is second order. The rate constant is 0.269 M\(^{-1}\)s\(^{-1} \).
B. The reaction is first order. The rate constant is 0.269 s\(^{-1} \).
C. The reaction is second order. The activation energy is 0.269 kJ/mol.
D. The reaction is first order. The activation energy is 0.269 kJ/mol.

14. What is the rate constant for the second-order decay of a substance whose initial concentration is 0.400 M with an initial half-life of 39 minutes?

A. \( 1.7 \text{ M}^{-1}\text{min}^{-1} \)  
B. \( 5.1 \times 10^{-3} \text{ M}^{-1}\text{min}^{-1} \)  
C. \( 1.9 \times 10^{-1} \text{ M}^{-1}\text{min}^{-1} \)  
D. \( 6.4 \times 10^{-2} \text{ M}^{-1}\text{min}^{-1} \)
15. A plot of $\ln k$ versus $(1/T)$ yields a straight line with a slope of $-1.35 \times 10^6$ K. What information can we calculate from the given slope?

A. frequency factor, $A$  
B. rate constant, $k$  
C. order of the reaction, $n$  
D. activation energy, $E_a$

16. Consider the reaction between nitrogen dioxide and carbon monoxide.

$$\text{NO}_2(g) + \text{CO}(g) \rightarrow \text{NO}(g) + \text{CO}_2(g)$$

The activation energy is 145 kJ/mol. At 622 °C, the rate constant is 567 M$^{-1}$s$^{-1}$. Determine the rate constant at 430 °C.

A. 2.77 M$^{-1}$s$^{-1}$  
B. $2.11 \times 10^{-3}$ M$^{-1}$s$^{-1}$  
C. $1.21 \times 10^5$ M$^{-1}$s$^{-1}$  
D. 321 M$^{-1}$s$^{-1}$

17. Identify the intermediate(s) in the proposed mechanism.

$$\text{HNO}_2 + \text{H}^+ \quad \Leftrightarrow \quad \text{H}_2\text{O} + \text{NO}^+ \quad \text{(fast)}$$

$$\text{NH}_4^+ \quad \Leftrightarrow \quad \text{NH}_3 + \text{H}^+ \quad \text{(fast)}$$

$$\text{NO}^+ + \text{NH}_3 \quad \rightarrow \quad \text{NH}_3\text{NO}^+ \quad \text{(slow)}$$

$$\text{NH}_3\text{NO}^+ \quad \rightarrow \quad \text{H}_2\text{O} + \text{H}^+ + \text{N}_2 \quad \text{(fast)}$$

A. NH$_3$NO$^+$ only  
B. NO$^+$ and H$^+$  
C. NH$_3$ only  
D. NO$^+$, NH$_3$ and NH$_3$NO$^+$
18. A proposed mechanism for the reaction $2\text{NO} + \text{Cl}_2 \rightleftharpoons 2\text{NOCl}$ is:

- **Step 1:** $\text{NO} + \text{Cl}_2 \rightleftharpoons \text{NOCl}_2$ (fast)
- **Step 2:** $\text{NOCl}_2 + \text{NO} \rightarrow 2\text{NOCl}$ (slow)

What is the rate law for the overall reaction?

- A. $\text{rate} = k[\text{NO}]^2[\text{Cl}_2]$  
- B. $\text{rate} = k[\text{NO}][\text{Cl}_2]$  
- C. $\text{rate} = k[\text{NOCl}_2][\text{NO}]^2$  
- D. $\text{rate} = k[\text{NOCl}]^2$

19. Which statement is **false** concerning a catalyst?

- A. A catalyst is a reactant in an elementary step of a mechanism but is not consumed in the overall reaction.
- B. An enzyme is a biological catalyst.
- C. A catalyst decreases the rate constant of a reaction.
- D. A catalyst lowers the activation energy of the overall reaction.

20. A _____ catalyst is in the _____ phase as the reactants and a/an _____ is a biological catalyst.

- A. homogeneous, same, heterogeneous  
- B. heterogeneous, same, enzyme  
- C. homogeneous, same, enzyme  
- D. heterogeneous, different, homogeneous

21. Which of the following statements is **false** about dynamic equilibrium?

- A. The concentration of reactants is equal to the concentration of products.
- B. Both the forward and the reverse reactions continue.
- C. The rate of the forward reaction is equal to the rate of the reverse reaction.
- D. The concentrations of reactants and products remain constant.
22. Consider the reaction:

\[ 2 \text{SO}_2(g) + \text{O}_2(g) \rightleftharpoons 2 \text{SO}_3(g) \quad K_p = 0.120 \text{ at a fixed temperature.} \]

The reaction chamber is charged with 1.0 atm SO₃. Select the true statement. [HINT: It is not necessary to solve explicitly for equilibrium pressures.]

A. At equilibrium, \(1/2 P(\text{SO}_3) = P(\text{O}_2)\).
B. At equilibrium, \(P(\text{SO}_2) = P(\text{SO}_3)\).
C. At equilibrium, \(P(\text{SO}_3) > P(\text{SO}_2)\).
D. At equilibrium, \(P(\text{SO}_2) = 2 P(\text{O}_2)\).

23. Given

\[ \text{NO}(g) + \frac{1}{2} \text{Br}_2(g) \rightleftharpoons \text{NOBr}(g) \quad K_1 = 5.3 \]

What is the equilibrium constant for the following reaction?

\[ 2 \text{NOBr}(g) \rightleftharpoons 2 \text{NO}(g) + \text{Br}_2(g) \quad K_2 = ? \]

A. \( K_2 = (K_1)^{-2} \)
B. \( K_2 = -2 \times K_1 \)
C. \( K_2 = \sqrt{K_1} \)
D. \( K_2 = 2 \div K_1 \)

24. What is the expression of \(K_c\) for the reaction below?

\[ \text{P}_4(s) + 6 \text{Cl}_2(g) \rightleftharpoons 4 \text{PCl}_3(l) \]

A. \( K_c = \frac{[\text{PCl}_3]^4}{[\text{P}_4][\text{Cl}_2]^6} \)
B. \( K_c = \frac{[\text{PCl}_3]^4}{[\text{P}_4]} \)
C. \( K_c = \frac{1}{[\text{Cl}_2]^6} \)
D. \( K_c = \frac{[\text{PCl}_3]^4}{[\text{Cl}_2]^6} \)
25. Consider the reaction

\[ A(g) \rightleftharpoons 2 \text{B}(g). \]

Initially 0.250 M of compound A is placed in the reaction chamber at 250 °C. At equilibrium, it is determined that the concentration of B is 0.110 M. Calculate \( K_c \) at this temperature.

A. 0.0877  
B. 0.0481  
C. 0.552  
D. 0.0621

26. Which statement is true?

A. For \( Q < K \), the concentrations of products will decrease to reach equilibrium.

B. For \( Q < K \), the concentrations of reactants will decrease while the concentrations of products will stay the same.

C. For \( Q > K \), the reaction will proceed to the left to reach equilibrium.

D. For \( Q > K \), the concentrations of reactants will increase while the concentrations of products will stay the same.
27. The equilibrium partial pressures of O$_2$ and SO$_2$ are 0.120 atm and 0.0245 atm, respectively, at 350 °C for the reaction

\[ \text{O}_2(\text{g}) + 2 \text{SO}_2(\text{g}) \leftrightharpoons 2 \text{SO}_3(\text{g}) \quad K_p = 5.60 \times 10^4 \text{ at } 350 \degree \text{C}. \]

What is the partial pressure of SO$_3(\text{g})$ at equilibrium?

A. 1.04 atm  
B. 15.8 atm  
C. 0.270 atm  
D. 2.01 atm

28. Consider the reaction

\[ 2 \text{H}_2\text{S} (\text{g}) \leftrightharpoons 2 \text{H}_2(\text{g}) + \text{S}_2(\text{g}) \quad K_p = 2.4 \times 10^{-4} \text{ at } 1073 \text{ K}. \]

If a reaction vessel initially contains only $1.20 \times 10^3$ torr H$_2$S, what is the equilibrium pressure of H$_2$?

A. 32.5 torr  
B. 620 torr  
C. 80.7 torr  
D. 149 torr
29. Which changes will cause the **amount of reactant** to increase?

\[ 2 \text{KClO}_3(s) \leftrightharpoons 2 \text{KCl}(s) + 3 \text{O}_2(g) \]

I. Removal of KCl
II. Addition of O₂
III. Removal of O₂

A. I only       C. II only
B. I and III    D. III only

30. Photosynthesis can be represented by

\[ 6 \text{CO}_2(g) + 6 \text{H}_2\text{O}(l) \leftrightharpoons \text{C}_6\text{H}_{12}\text{O}_6(s) + 6 \text{O}_2(g) \quad \Delta H^\circ = 2,801 \text{ kJ/mol} \]

Which change results in a shift in equilibrium towards products?

A. H₂O is added.       C. The pressure of CO₂ is increased.
B. C₆H₁₂O₆ is removed. D. The temperature is lowered.
Answer Key:

1. D
2. C
3. D
4. C
5. C
6. B
7. A
8. C
9. D
10. B
11. A
12. C
13. A
14. D
15. D
16. A
17. D
18. A
19. C
20. C
21. A
22. A
23. A
24. C
25. D
26. C
27. D
28. C
29. C
30. C