1. The slowest of the following reactions is:

A. \( \text{Ag}^+_{(aq)} + \text{Cl}^-_{(aq)} \rightarrow \text{AgCl}_{(s)} \)
B. \( \text{H}^+_{(aq)} + \text{OH}^-_{(aq)} \rightarrow 2\text{H}_2\text{O}_{(l)} \)
C. \( 3\text{Ba}^{2+}_{(aq)} + 2\text{PO}_4^{3-}_{(aq)} \rightarrow \text{Ba}_3(\text{PO}_4)_2_{(aq)} \)
D. \( \text{Cu}_{(s)} + 2\text{Ag}^+_{(aq)} \rightarrow \text{Cu}^{2+}_{(aq)} + 2\text{Ag}_{(s)} \)

2. The rate of a chemical reaction is equal to the slope of the line with axes labelled

<table>
<thead>
<tr>
<th>x-axis</th>
<th>y-axis</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. time</td>
<td>rate</td>
</tr>
<tr>
<td>B. mass</td>
<td>time</td>
</tr>
<tr>
<td>C. volume of gas</td>
<td>time</td>
</tr>
<tr>
<td>D. time</td>
<td>concentration</td>
</tr>
</tbody>
</table>

3. Consider the following reaction: \( \text{CH}_4_{(g)} + 2\text{O}_2_{(g)} \rightarrow \text{CO}_2_{(g)} + 2\text{H}_2\text{O}_{(g)} + \text{heat} \)

The diagram that represents the relationship between rate and temperature is:

A. ![Diagram A](image)
B. ![Diagram B](image)
C. ![Diagram C](image)
D. ![Diagram D](image)

4. Which of the following describes the energy of colliding particles as reacting molecules approach each other?

<table>
<thead>
<tr>
<th>KE</th>
<th>PE</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. decreases</td>
<td>increases</td>
</tr>
<tr>
<td>B. increases</td>
<td>decreases</td>
</tr>
<tr>
<td>C. decreases</td>
<td>remains constant</td>
</tr>
<tr>
<td>D. remains constant</td>
<td>increases</td>
</tr>
</tbody>
</table>
5. The average kinetic energy per molecule can be increased by
   A. adding a catalyst  
   B. increasing pressure  
   C. increasing temperature  
   D. increasing reactant concentration

6. Consider the following reaction: \( C(s) + 2H_2(g) \rightleftharpoons CH_4(g) \) \( \Delta H = -74.8 \text{ kJ} \)
   Which of the following will cause an increase in the value of the Keq?
   A. increasing \([H_2]\)  
   B. decreasing the volume  
   C. finely powdering the \( C(s) \)  
   D. decreasing the temperature

7. Consider the following equilibrium: \( H_2(g) + I_2(g) \rightleftharpoons 2HI(g) \)
   At equilibrium \([H_2] = 0.00220 \text{ M}, [I_2] = 0.00220 \text{ M}, \) and \([HI] = 0.0156 \text{ M} \)
   The value of the Keq is
   A. \( 3.10 \times 10^{-4} \)  
   B. \( 1.99 \times 10^{-2} \)  
   C. \( 5.03 \times 10^{1} \)  
   D. \( 3.22 \times 10^{3} \)

8. Consider the rate diagram for the following reaction: \( 2HI(g) \rightleftharpoons H_2(g) + I_2(g) \)

   ![Rate diagram](image)

   Which of the following occurs at \( t_1 \)?
   A. addition of \( H_2 \)  
   B. addition of \( HI \)  
   C. addition of a catalyst  
   D. a decrease in volume

9. Chemical equilibrium is said to be dynamic because
   A. the reaction proceeds quickly  
   B. the mass of the reactants is decreasing  
   C. the macroscopic properties are constant  
   D. both forward and reverse rates are occurring
10. Which equation has the largest value of Keq?

A. \( \text{N}_2(g) + \text{O}_2(g) \rightleftharpoons 2\text{NO}(g) \quad \Delta H = 21 \text{ kJ} \)
B. \( \text{C}_2\text{H}_6(g) \rightleftharpoons 2\text{C}(s) + 3\text{H}_2(g) \quad \Delta H + 83 \text{ kJ} \)
C. \( \text{H}_2(g) + \frac{1}{2}\text{O}_2(g) \rightleftharpoons \text{H}_2\text{O}(g) \quad \Delta H = -240 \text{ kJ} \)
D. \( \text{Ca}(s) + 3\text{H}_2\text{O}(l) \rightleftharpoons \text{Ca(OH)}_2(aq) + \text{H}_2(g) \quad \Delta H = -240 \text{ kJ} \)

11. The value of the Keq can be changed by

A. adding a catalyst  
B. changing the temperature  
C. changing the reactant concentration  
D. changing the volume of the container

12. Consider the following equilibrium: \( \text{PCl}_3(g) + \text{Cl}_2(g) \rightleftharpoons \text{PCl}_5(g) \)
When 0.40 mole of \( \text{PCl}_3 \) and 0.40 mole of \( \text{Cl}_2 \) are placed in a 1.00 L container and allowed to reach equilibrium, 0.244 mole of \( \text{PCl}_5 \) are present. From this information, the value of the Keq is

A. 0.10  
B. 0.30  
C. 3.3  
D. 10

13. Consider the following equilibrium: \( \text{PCl}_3(g) + \text{Cl}_2(g) \rightleftharpoons \text{PCl}_5(g) \quad \text{Keq} = 2.30 \)
A 1.0 L container is filled with 0.05 mole \( \text{PCl}_5 \), 1.0 mole \( \text{PCl}_3 \), and 1.0 mole \( \text{Cl}_2 \). The system proceeds to the

A. left because the Trial Keq > Keq  
B. left because the Trial Keq < Keq  
C. right because the Trial Keq > Keq  
D. right because the Trial Keq < Keq

14. Given the following system: \( 2\text{CrO}_4^{2-}(aq) + 2\text{H}^+(aq) \rightleftharpoons \text{Cr}_2\text{O}_7^{2-}(aq) + \text{H}_2\text{O}(l) \)
Which of the following chemicals, when added to the above system at equilibrium, would result in a decrease in \([\text{Cr}_2\text{O}_7^{2-}])?\)

A. NaOH  
B. HNO_3  
C. Na_2CrO_4  
D. Na_2Cr_2O_7

15. What is the Keq expression for the following equilibrium?
\( 3\text{Fe}(s) + 4\text{H}_2\text{O}(g) \rightleftharpoons \text{Fe}_3\text{O}_4(s) + 4\text{H}_2(g) \)

A. \( \text{Keq} = [\text{H}_2]^4 \)  
B. \( \text{Keq} = \frac{[\text{H}_2]}{[\text{H}_2\text{O}]} \)  
C. \( \text{Keq} = \frac{[\text{H}_2]^4}{[\text{H}_2\text{O}]^4} \)  
D. \( \text{Keq} = \frac{[\text{Fe}_3\text{O}_4][\text{H}_2]^4}{[\text{Fe}][\text{H}_2\text{O}]^4} \)
16. Consider the following equilibrium: \(2O_3(g) \rightleftharpoons 3O_2(g)\) \(K_{eq} = 65\)

Initially 0.10 mole of \(O_3\) and 0.10 mole of \(O_2\) are placed in a 1.0 L container. Which of the following describes the changes in concentrations as the reaction proceeds towards equilibrium?

<table>
<thead>
<tr>
<th>([O_3])</th>
<th>([O_2])</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. decreases</td>
<td>decreases</td>
</tr>
<tr>
<td>B. decreases</td>
<td>increases</td>
</tr>
<tr>
<td>C. increases</td>
<td>decreases</td>
</tr>
<tr>
<td>D. increases</td>
<td>increases</td>
</tr>
</tbody>
</table>

17. Consider the following equilibrium: \(2CrO_4^{2-}(aq) + 2H^+(aq) \rightleftharpoons Cr_2O_7^{2-}(aq) + H_2O(l)\)

An unknown solution is added to an orange equilibrium system until the sample turns yellow. The solution could be

A. KNO\(_3\)  
B. NaOH  
C. NH\(_4\)NO\(_3\)  
D. CH\(_3\)COOH

18. Consider the following equilibrium:
\(CH_3COO^-(aq) \rightleftharpoons CH_3COOH(aq) + H^+(aq) + \text{heat}\)

A stress was applied at time \(t_1\) and the data plotted on the following graph:

The stress imposed at time \(t_1\) is the result of

A. the addition of HCl  
B. decreasing the temperature  
C. the addition of NaCH\(_3\)COO  
D. increasing the volume of the container
19. Consider the following potential energy diagram for an equilibrium system:

When the temperature of the system is increased, the equilibrium shifts to the

A. left and the Keq increases  
B. left and the Keq decreases  
C. right and the Keq increases  
D. right and the Keq decreases

20. Addition of a catalyst to an equilibrium system

A. increases the value of the Keq  
B. increases the yield of the product  
C. has no effect on the rates of the reaction  
D. increases the rates of formation of both reactants and products

21. Ammonia, NH₃, is produced by the following reaction:

\[ \text{N}_2(\text{g}) + 3\text{H}_2(\text{g}) \rightleftharpoons 2\text{NH}_3(\text{g}) + \text{energy} \]

Which of the following would result in the highest concentration of ammonia at equilibrium?

A. increasing the temperature and increasing the pressure  
B. decreasing the temperature and increasing the pressure  
C. increasing the temperature and decreasing the pressure  
D. decreasing the temperature and decreasing the pressure

22. Consider the following equilibrium:

\[ 2\text{NO}_2(\text{g}) \rightleftharpoons \text{N}_2\text{O}_4(\text{g}) \quad K_{\text{eq}} = 1.15 \]

The equilibrium concentration of NO₂ is 0.05mol/L. Calculate the equilibrium concentration of N₂O₄(g).

A. 0.22 mol/L  
B. 0.29 mol/L  
C. 0.43 mol/L  
D. 0.58 mol/L
23. Consider the following equilibrium:

\[ \text{H}_2(\text{g}) + \text{I}_2 \rightleftharpoons 2\text{HI}(\text{g}) \quad \text{K}_{\text{eq}} = 50.0 \]

What is the value \( \text{K}_{\text{eq}} \) for the reaction rewritten as:

\[ 2\text{HI}(\text{g}) \rightleftharpoons \text{H}_2(\text{g}) + \text{I}_2(\text{g}) \quad \text{K}_{\text{eq}} = ? \]

A. -50.0  
B. 0.0200  
C. 25.0  
D. 50.0

24. Consider the following equilibrium: \( 2\text{NOCl}(\text{g}) \rightleftharpoons 2\text{NO}(\text{g}) + \text{Cl}_2(\text{g}) \)

A flask is filled with NOCl, NO, and Cl\(_2\)(g). Initially there were a total of 5.0 moles of gases present. When equilibrium is reached, there are a total of 8.0 moles of gases present. Which of the following explains the observation?

A. The reaction shifted left because the Trial \text{K}_{\text{eq}} > \text{K}_{\text{eq}}  
B. The reaction shifted left because the Trial \text{K}_{\text{eq}} < \text{K}_{\text{eq}}  
C. The reaction shifted right because the Trial \text{K}_{\text{eq}} > \text{K}_{\text{eq}}  
D. The reaction shifted right because the Trial \text{K}_{\text{eq}} < \text{K}_{\text{eq}}

25. Consider the following equilibrium:

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

Which of the following will cause the equilibrium to shift to the left?

A. adding \text{H}_2\text{O}(\text{g})  
B. removing some \text{NO}(\text{g})  
C. increasing the volume  
D. decreasing the temperature

26. A catalyst is added to a system already at equilibrium. How are the forward and reverse reaction rates affected by the addition of the catalyst.

<table>
<thead>
<tr>
<th>Forward Rate</th>
<th>Reverse Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. increases</td>
<td>increases</td>
</tr>
<tr>
<td>B. increases</td>
<td>constant</td>
</tr>
<tr>
<td>C. constant</td>
<td>decreases</td>
</tr>
<tr>
<td>D. constant</td>
<td>constant</td>
</tr>
</tbody>
</table>

27. Consider the following equilibrium: \( 2\text{NOBr}(\text{g}) \rightleftharpoons 2\text{NO}(\text{g}) + \text{Br}_2(\text{g}) \) \( \text{K}_{\text{eq}} = 0.064 \)

At equilibrium, a 1.00 L flask contains 0.030 mole NOBr and 0.030 mole NO. How many moles of Br\(_2\) are present?

A. 0.0019  
B. 0.064  
C. 0.030  
D. 0.47
28. Which of the following does not apply to all chemical equilibrium systems?

A. They are closed.
B. The macroscopic properties are constant
C. Forward and reverse rates are equal
D. There are equal concentrations of reactants and products

29. The relationship between $E_a$ and reaction rate is best represented as

A.  
B.  
C.  
D.  

30. The relationship between $K_{eq}$ and temperature for an exothermic reaction is best represented as

A.  
B.  
C.  
D.  

31. The relationship between reaction rate and temperature is best represented by

A.  
B.  
C.  
D.  
32. The relationship between Ea and temperature is best represented by

A.  

B.  

C.  

D.  

32. Methanol, CH\textsubscript{3}OH, can be produced by the following:
\[ \text{CO}(g) + 2\text{H}_2(g) \rightleftharpoons \text{CH}_3\text{OH}(g) + \text{energy} \]
The conditions necessary to maximize the equilibrium yield of CH\textsubscript{3}OH are

A. low temperature and low pressure  
B. high temperature and low pressure  
C. low temperature and high pressure  
D. high temperature and high pressure

33. Consider the following equilibrium:  
\[ 2\text{NO}(g) + \text{O}_2(g) \rightleftharpoons 2\text{NO}_2(g) + \text{energy} \]
When the volume of the container is increased, the equilibrium shifts to the

A. left and the Keq decreases  
B. right and the Keq increases  
C. left and the Keq remains constant  
D. right and the Keq remains constant

34. Consider the following reaction:
\[ \text{C}_3\text{H}_8(g) + 5\text{O}_2(g) \rightarrow 3\text{CO}_2(g) + 4\text{H}_2\text{O}(g) \quad \Delta H = -2202 \text{ kJ} \]
Which of the following applies to the forward reaction?

<table>
<thead>
<tr>
<th>Entropy</th>
<th>Enthalpy</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. increases</td>
<td>increases</td>
</tr>
<tr>
<td>B. increases</td>
<td>decreases</td>
</tr>
<tr>
<td>C. decreases</td>
<td>increases</td>
</tr>
<tr>
<td>D. decreases</td>
<td>decreases</td>
</tr>
</tbody>
</table>
Subjective

1. Consider the following equilibrium:

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

More oxygen is added to the above equilibrium. After the system re-establishes equilibrium, identify the substance(s), if any, that have a net

a) increase in concentration

b) decrease in concentration

2. Given the following equilibrium:

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

Initially, 0.200 mole H\(_2\) and 0.200 mole I\(_2\) were placed into a 1.0 L container. At equilibrium, the [I\(_2\)] is 0.040 M. Calculate the Keq.

3. Consider the following equilibrium:

\[ 2\text{CrO}_4^{2-} + 2\text{H}^+ \rightleftharpoons \text{Cr}_2\text{O}_7^{2-} + \text{H}_2\text{O}(\text{l}) \]

When HCl is added, the solution turns orange. Explain why this colour change occurs.

4. Consider the following equilibrium system:

\[ \text{N}_2(\text{g}) + 3\text{H}_2(\text{g}) \rightleftharpoons 2\text{NH}_3(\text{g}) + \text{energy} \]

A 1.00 L container is filled with 7.0 mole NH\(_3\) and the system proceeds to equilibrium as indicated by the graph.
a) Draw and label the graph for $N_2$ and $H_2$. Fill in an ICE chart if you are not sure how to do this.

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

I
C
E

b) Calculate the $K_{eq}$ for the above reaction.

5. Consider the following equilibrium $2NO(g) + O_2(g) \rightleftharpoons 2NO_2(g)$ $K_{eq} = 1.5$

0.800 mole NO, 0.600 moles $O_2$, and 0.400 moles $NO_2$ are placed in a vessel that 2.0 L. Show by calculation that the reaction is not at equilibrium? What will happen to $[O_2]$ as equilibrium is approached?

6. Consider the following equilibrium:

$$SO_3(g) + NO(g) \rightleftharpoons NO_2(g) + SO_2(g)$$ $K_{eq} = 0.500$

Exactly 0.100 mole $SO_3$ and 0.100 mole $NO$ were placed in a 1.00 L flask and allowed to go to equilibrium. Calculate the equilibrium concentration of $SO_2$. 
1. The slowest of the following reactions is:
   A. \( \text{Ag}^+_{(aq)} + \text{Cl}^-_{(aq)} \rightarrow \text{AgCl}_{(s)} \)
   B. \( \text{H}^+_{(aq)} + \text{OH}^-_{(aq)} \rightarrow 2\text{H}_2\text{O}_{(l)} \)
   C. \( 3\text{Ba}^{2+}_{(aq)} + 2\text{PO}_4^{3-}_{(aq)} \rightarrow \text{Ba}_3(\text{PO}_4)_2_{(aq)} \)
   D. \( \text{Cu}_{(s)} + 2\text{Ag}^+_{(aq)} \rightarrow \text{Cu}^{2+}_{(aq)} + 2\text{Ag}_{(s)} \)

2. The rate of a chemical reaction is equal to the slope of the line with axes labelled
   x-axis                  y-axis
   A. time                rate
   B. mass                time
   C. volume of gas       time
   D. time                concentration

3. Consider the following reaction: \( \text{CH}_4_{(g)} + 2\text{O}_2_{(g)} \rightarrow \text{CO}_2_{(g)} + 2\text{H}_2\text{O}_{(g)} + \text{heat} \)
   The diagram that represents the relationship between rate and temperature is:

   A.  
     ![Diagram A](image)
   B.  
     ![Diagram B](image)
   C.  
     ![Diagram C](image)
   D.  
     ![Diagram D](image)

4. Which of the following describes the energy of colliding particles as reacting molecules approach each other?

   KE        PE
   A. decreases increases
   B. increases decreases
   C. decreases remains constant
5. The average kinetic energy per molecule can be increased by
   A. adding a catalyst
   B. increasing pressure
   C. **increasing temperature**
   D. increasing reactant concentration

6. Consider the following reaction: \( \text{C}(s) + 2\text{H}_2(g) \rightleftharpoons \text{CH}_4(g) \quad \Delta H = -74.8 \text{ kJ} \)
   Which of the following will cause an increase in the value of the Keq?
   A. increasing \([\text{H}_2]\)
   B. decreasing the volume
   C. finely powdering the \(\text{C}(s)\)
   D. **decreasing the temperature**

7. Consider the following equilibrium: \( \text{H}_2(g) + \text{I}_2(g) \rightleftharpoons 2\text{HI}(g) \)
   At equilibrium \([\text{H}_2] = 0.00220 \text{ M}, [\text{I}_2] = 0.00220 \text{ M}, \text{ and } [\text{HI}] = 0.0156 \text{ M} \)
   The value of the Keq is
   A. \(3.10 \times 10^{-4}\)
   B. \(1.99 \times 10^{-2}\)
   C. **5.03 \times 10^4**
   D. \(3.22 \times 10^3\)

8. Consider the rate diagram for the following reaction: \( 2\text{HI}(g) \rightleftharpoons \text{H}_2(g) + \text{I}_2(g) \)

   ![Rate Diagram]

   Which of the following occurs at \(t_1\)?
   A. addition of \(\text{H}_2\)
   B. **addition of \(\text{HI}\)**
   C. addition of a catalyst
   D. a decrease in volume

9. Chemical equilibrium is said to be dynamic because
A. the reaction proceeds quickly
B. the mass of the reactants is decreasing
C. the macroscopic properties are constant
D. both forward and reverse rates are occurring

10. Which equation has the largest value of Keq?

A. \( \text{N}_2(\text{g}) + \text{O}_2(\text{g}) \rightleftharpoons 2\text{NO}(\text{g}) \quad \Delta H = 21 \text{ kJ} \)
B. \( \text{C}_2\text{H}_6(\text{g}) \rightleftharpoons 2\text{C}(\text{s}) + 3\text{H}_2(\text{g}) \quad \Delta H = 83 \text{ kJ} \)
C. \( \text{H}_2(\text{g}) + 1/2\text{O}_2(\text{g}) \rightleftharpoons \text{H}_2\text{O}(\text{g}) \quad \Delta H = -240 \text{ kJ} \)
D. \( \text{Ca}(\text{s}) + 3\text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{Ca(OH)}_2(\text{aq}) + \text{H}_2(\text{g}) \quad \Delta H = -240 \text{ kJ} \)

11. The value of the Keq can be changed by

A. adding a catalyst
B. changing the temperature
C. changing the reactant concentration
D. changing the volume of the container

12. Consider the following equilibrium: \( \text{PCl}_3(\text{g}) + \text{Cl}_2(\text{g}) \rightleftharpoons \text{PCl}_5(\text{g}) \)
When 0.40 mole of \( \text{PCl}_3 \) and 0.40 mole of \( \text{Cl}_2 \) are placed in a 1.00 L container and allowed to reach equilibrium, 0.244 mole of \( \text{PCl}_5 \) are present. From this information, the value of the Keq is

A. 0.10
B. 0.30
C. 3.3
D. 10

13. Consider the following equilibrium: \( \text{PCl}_3(\text{g}) + \text{Cl}_2(\text{g}) \rightleftharpoons \text{PCl}_5(\text{g}) \quad \text{Keq} = 2.30 \)
A 1.0 L container is filled with 0.05 mole \( \text{PCl}_5 \), 1.0 mole \( \text{PCl}_3 \), and 1.0 mole \( \text{Cl}_2 \). The system proceeds to the

A. left because the Trial Keq > Keq
B. left because the Trial Keq < Keq
C. right because the Trial Keq > Keq
D. right because the Trial Keq < Keq

14. Given the following system: \( 2\text{CrO}_4^{2-}(\text{aq}) + 2\text{H}^+(\text{aq}) \rightleftharpoons \text{Cr}_2\text{O}_7^{2-}(\text{aq}) + \text{H}_2\text{O}(\text{l}) \)
Which of the following chemicals, when added to the above system at equilibrium, would result in a decrease in \([\text{Cr}_2\text{O}_7^{2-}]\)?

A. \text{NaOH}
B. \text{HNO}_3
15. What is the Keq expression for the following equilibrium?

\[ 3\text{Fe}_3\text{O}_4(s) + 4\text{H}_2\text{O}(g) \rightleftharpoons \text{Fe}_3\text{O}_4(s) + 4\text{H}_2(g) \]

A. \( \text{Keq} = [\text{H}_2]^4 \)
B. \( \text{Keq} = \frac{[\text{H}_2]}{[\text{H}_2\text{O}]} \)
C. \( \text{Keq} = \frac{[\text{H}_2]^4}{[\text{H}_2\text{O}]} \)
D. \( \text{Keq} = \frac{[\text{Fe}_3\text{O}_4][\text{H}_2]^4}{[\text{Fe}_3][\text{H}_2\text{O}]} \)

16. Consider the following equilibrium: \( 2\text{O}_3(g) \rightleftharpoons 3\text{O}_2(g) \) \( \text{Keq} = 65 \)

Initially 0.10 mole of \( \text{O}_3 \) and 0.10 mole of \( \text{O}_2 \) are placed in a 1.0 L container, Which of the following describes the changes in concentrations as the reaction proceeds towards equilibrium?

\[
\begin{array}{c|c}
\text{[O}_3\text{]} & \text{[O}_2\text{]} \\
\text{A. decreases} & \text{decreases} \\
\text{B. decreases} & \text{increases} \\
\text{C. increases} & \text{decreases} \\
\text{D. increases} & \text{increases} \\
\end{array}
\]

17. Consider the following equilibrium: \( 2\text{CrO}_4^{2-}(aq) + 2\text{H}^+(aq) \rightleftharpoons \text{Cr}_2\text{O}_7^{2-}(aq) + \text{H}_2\text{O}(l) \)

An unknown solution is added to an orange equilibrium system until the sample turns yellow. The solution could be

A. KNO\textsubscript{3}
B. NaOH
C. NH\textsubscript{4}NO\textsubscript{3}
D. CH\textsubscript{3}COOH

18. Consider the following equilibrium:

\( \text{CH}_3\text{COOH(aq)} \rightleftharpoons \text{CH}_3\text{COO}^-(aq) + \text{H}^+(aq) + \text{heat} \)

A stress was applied at time \( t_1 \) and the data plotted on the following graph:

The stress imposed at time \( t_1 \) is the result of

![Graph showing \([\text{H}^+]\) vs. time]
A. the addition of HCl
B. decreasing the temperature
C. the addition of NaCH₃COO
D. increasing the volume of the container

19. Consider the following potential energy diagram for an equilibrium system:

![Potential Energy Diagram]

Progress of the reaction

When the temperature of the system is increased, the equilibrium shifts to the

A. left and the Keq increases
B. left and the Keq decreases
C. right and the Keq increases
D. right and the Keq decreases

20. Addition of a catalyst to an equilibrium system

A. increases the value of the Keq
B. increases the yield of the product
C. has no effect on the rates of the reaction
D. increases the rates of formation of both reactants and products

21. Ammonia, NH₃, is produced by the following reaction:

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) + \text{energy}$$

Which of the following would result in the highest concentration of ammonia at equilibrium?

A. increasing the temperature and increasing the pressure
B. decreasing the temperature and increasing the pressure
C. increasing the temperature and decreasing the pressure
D. decreasing the temperature and decreasing the pressure

22. Consider the following equilibrium:

\[ 2\text{NO}_2(g) \rightleftharpoons \text{N}_2\text{O}_4(g) \quad K_{eq} = 1.15 \]

The equilibrium concentration of NO\(_2\) is 0.05 mol/L. Calculate the equilibrium concentration of N\(_2\)O\(_4\)(g).

A. 0.22 mol/L
B. 0.29 mol/L
C. 0.43 mol/L
D. 0.58 mol/L

23. Consider the following equilibrium:

\[ \text{H}_2(g) + \text{I}_2 \rightleftharpoons 2\text{HI}(g) \quad K_{eq} = 50.0 \]

What is the value \(K_{eq}\) for the reaction rewritten as:

\[ 2\text{HI}(g) \rightleftharpoons \text{H}_2(g) + \text{I}_2(g) \quad K_{eq} = ? \]

A. -50.0
B. 0.0200
C. 25.0
D. 50.0

24. Consider the following equilibrium: \(2\text{NOCl}(g) \rightleftharpoons 2\text{NO}(g) + \text{Cl}_2(g)\)

A flask is filled with NOCl, NO, and Cl\(_2\)(g). Initially there were a total of 5.0 moles of gases present. When equilibrium is reached, there are a total of 8.0 moles of gases present. Which of the following explains the observation?

A. The reaction shifted left because the Trial \(K_{eq}\) > \(K_{eq}\)
B. The reaction shifted left because the Trial \(K_{eq}\) < \(K_{eq}\)
C. The reaction shifted right because the Trial \(K_{eq}\) > \(K_{eq}\)

D. The reaction shifted right because the Trial \(K_{eq}\) < \(K_{eq}\)

25. Consider the following equilibrium:

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

Which of the following will cause the equilibrium to shift to the left?

A. adding \(\text{H}_2\text{O}(g)\)
B. removing some NO_{(g)}
C. increasing the volume
D. decreasing the temperature

26. A catalyst is added to a system already at equilibrium. How are the forward and reverse reaction rates affected by the addition of the catalyst.

<table>
<thead>
<tr>
<th>Forward Rate</th>
<th>Reverse Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. increases</td>
<td>increases</td>
</tr>
<tr>
<td>B. increases</td>
<td>constant</td>
</tr>
<tr>
<td>C. constant</td>
<td>decreases</td>
</tr>
<tr>
<td>D. constant</td>
<td>constant</td>
</tr>
</tbody>
</table>

27. Consider the following equilibrium: 2NOBr_{(g)} \rightleftharpoons 2NO_{(g)} + Br_2(g) \quad \text{Keq} = 0.064
At equilibrium, a 1.00 L flask contains 0.030 mole NOBr and 0.030 mole NO. How many moles of Br_2 are present?

A. 0.0019
B. 0.064
C. 0.030
D. 0.47

28. Which of the following does not apply to all chemical equilibrium systems?

A. They are closed.
B. The macroscopic properties are constant
C. Forward and reverse rates are equal
D. **There are equal concentrations of reactants and products**

29. The relationship between Ea and reaction rate is best represented as

A. ![Graph A]
B. ![Graph B]
C. ![Graph C]
D. ![Graph D]

30. The relationship between Keq and temperature for an exothermic reaction is best represented as

A. ![Graph A]
B. ![Graph B]
31. The relationship between reaction rate and temperature is best represented by

![Graph Options](A. B. C. D.)

32. The relationship between Ea and temperature is best represented by

![Graph Options](A. B. C. D.)

32. Methanol, CH$_3$OH, can be produced by the following:

\[ \text{CO}(g) + 2\text{H}_2(g) \rightleftharpoons \text{CH}_3\text{OH}(g) + \text{energy} \]

The conditions necessary to maximize the equilibrium yield of CH$_3$OH are

A. low temperature and low pressure
B. high temperature and low pressure
C. low temperature and high pressure
D. high temperature and high pressure

33. Consider the following equilibrium: \( \text{2NO}(g) + \text{O}_2(g) \rightleftharpoons \text{2NO}_2(g) + \text{energy} \)

When the volume of the container is increased, the equilibrium shifts to the

A. left and the Keq decreases
B. right and the Keq increases
C. left and the Keq remains constant
D. right and the Keq remains constant

34. Consider the following reaction:
\[
\text{C}_3\text{H}_8(g) + 5\text{O}_2(g) \rightarrow 3\text{CO}_2(g) + 4\text{H}_2\text{O}(g) \quad @H = -2202 \text{ kJ}
\]

Which of the following applies to the forward reaction?

A. Entropy increases and Enthalpy decreases
B. Entropy decreases and Enthalpy increases
C. Entropy decreases and Enthalpy decreases
D. Entropy increases and Enthalpy increases

Subjective

1. Consider the following equilibrium:
\[
\text{N}_2\text{H}_4(g) + 2\text{O}_2(g) \rightleftharpoons 2\text{NO}_2(g) + 2\text{H}_2\text{O}(g)
\]

More oxygen is added to the above equilibrium. After the system re-establishes equilibrium, identify the substance(s), if any, that have a net

a) increase in concentration \( \text{NO} \quad \text{H}_2\text{O} \quad \text{O}_2 \)
b) decrease in concentration \( \text{N}_2\text{H}_4 \)

2. Given the following equilibrium: \( \text{H}_2(g) + \text{I}_2(g) \rightleftharpoons 2\text{HI}(g) \)

Initially, 0.200 mole \( \text{H}_2 \) and 0.200 mole \( \text{I}_2 \) were placed into a 1.0 L container. At equilibrium, the \([\text{I}_2]\) is 0.040 M. Calculate the Keq.

\[
\begin{array}{ccc}
\text{H}_2(g) & + & \text{I}_2(g) & \rightleftharpoons & 2\text{HI}(g) \\
1 & 0.200 \text{ M} & 0.200 \text{ M} & \rightarrow & 0
\end{array}
\]
3. Consider the following equilibrium: \[ 2\text{CrO}_4^{2-}(aq) + 2\text{H}^+(aq) \rightleftharpoons \text{Cr}_2\text{O}_7^{2-}(aq) + \text{H}_2\text{O}(l) \]

When HCl is added, the solution turns orange. Explain why this colour change occurs.

**Adding HCl increases the [H\(^+\)] and shifts the system right turning orange.**

4. Consider the following equilibrium system:

\[ \text{N}_2(g) + 3\text{H}_2(g) \rightleftharpoons 2\text{NH}_3(g) + \text{energy} \]

A 1.00 L container is filled with 7.0 mole NH\(_3\) and the system proceeds to equilibrium as indicated by the graph.

\[ \begin{array}{c|c|c|c|c|c|c} \hline & \text{N}_2(g) & + & 3\text{H}_2(g) & \rightleftharpoons & 2\text{NH}_3(g) & \text{M} \\
\hline \text{I} & 0 & 0 & 7.0 & & & \\
\text{C} & 3.0 & 9.0 & 6.0 & & & \\
\hline \end{array} \]

\[ \text{Keq} = \frac{(0.320)^2}{(0.040)^2} = 64 \]

\[ \text{Keq} = \frac{(0.320)^2}{(0.040)^2} = 64 \]
b) Calculate the Keq for the above reaction.

\[
Keq = \frac{(1.0)^2}{(3.0)(9.0)^3} = 0.00046
\]

5. Consider the following equilibrium \(2\text{NO}_2(g) + \text{O}_2(g) \rightleftharpoons 2\text{NO}_2(g)\) \(\text{Keq} = 1.5\)

0.800 mole NO, 0.600 moles O\(_2\), and 0.400 moles NO\(_2\) are placed in a vessel that 2.0 L. Show by calculation that the reaction is not at equilibrium? What will happen to \([\text{O}_2]\) as equilibrium is approached?

Trial \(Keq = \frac{(0.200)^2}{(0.400)(0.300)} = 0.833 < Keq = 1.5\)

Not at equilibrium Shifts Right \([\text{O}_2]\) will decrease.

6. Consider the following equilibrium:

\[
\text{SO}_3(g) + \text{NO}_2(g) \rightleftharpoons \text{NO}_2(g) + \text{SO}_2(g) \quad \text{Keq} = 0.500
\]

Exactly 0.100 mole SO\(_3\) and 0.100 mole NO were placed in a 1.00 L flask and allowed to go to equilibrium. Calculate the equilibrium concentration of SO\(_2\).

\[
\begin{array}{cccccc}
\text{SO}_3(g) + & \text{NO}_2(g) & \rightleftharpoons & \text{NO}_2(g) + & \text{SO}_2(g) & \\
\text{I} & 0.100 & 0.100 & 0 & 0 & \\
\text{C} & \text{x} & \text{x} & \text{x} & \text{x} & \\
\text{E} & 0.100 - \text{x} & 0.100 - \text{x} & \text{x} & \text{x} & \\
\end{array}
\]

\[
\frac{x^2}{(0.100 - x)^2} = 0.500
\]

\[
\frac{x}{0.100 - x} = 0.7071
\]

\[1.7071x = 0.07071\]

\[x = 0.0414 \text{ M}\]

\[[\text{SO}_2] = 0.0414 \text{ M}\]