1. A 29.0 g sample of NaOH is dissolved in water, and the solution is diluted to give a final volume of 1.60 L. The molarity of the final solution is
   A) 18.1 M.
   B) 0.453 M.
   C) 0.725 M.
   D) 0.0552 M.
   E) 0.862 M.

2. What is the molarity of hydrochloric acid in a solution containing 88.5 g of HCl in 215 mL of solution?
   A) 0.412 M
   B) 0.00243 M
   C) 2.43 M
   D) 412 M
   E) 11.3 M

3. What volume of 0.745 M Na₂CO₃ (106 g/mol) solution contains 50.3 g of Na₂CO₃?
   A) 0.354 L
   B) 7.16 x 10⁻³ L
   C) 0.637 L
   D) 3.97 x 10⁻³ L
   E) 1.57 L

4. How many moles of KOH are present in 25.4 mL of 0.965 M KOH?
   A) 2.63 x 10⁻² mol
   B) 26.3 mol
   C) 2.45 x 10⁻² mol
   D) 24.5 mol
   E) 0.965 mol

5. To dilute 1.00 L of a 0.600 M to 0.100 M, the final volume must be
   A) 60 L.
   B) 0.7 L.
   C) 1/6 the original volume.
   D) More information is needed to answer this question.
   E) 6 times the original volume.

\[ \text{M} \cdot V = \text{M'} \cdot V' \]
\[ (0.600 M)(1.00 L) = (0.100 M) \cdot V' \]
\[ V' = \frac{(0.600 \, M)}{(0.100 \, M)} \cdot L = 6 \, L \]
6. A dilute solution is prepared by transferring 45.00 mL of a 0.5616 M stock solution to a 400.0 mL volumetric flask and diluting to mark. What is the molarity of this dilute solution?

A) 0.06318 M  
B) 0.1264 M  
C) 0.04992 M  
D) 0.01580 M  
E) 0.2808 M

7. The reaction of H2SO4 with NaOH is represented by the equation

\[ \text{H}_2\text{SO}_4(aq) + 2\text{NaOH}(aq) \rightarrow \text{Na}_2\text{SO}_4(aq) + 2\text{H}_2\text{O}(l) \]

What volume of 0.587 M H2SO4 is required to neutralize 12.7 mL of 0.302 M NaOH?

A) 3.27 mL  
B) 1.70 mL  
C) 6.53 mL  
D) 12.7 mL  
E) 24.7 mL

8. In a volumetric analysis experiment, an acidic aqueous solution of methanol (CH3OH) is titrated with a solution of potassium dichromate (K2Cr2O7) according to the following balanced chemical equation:

\[ 2\text{K}_2\text{Cr}_2\text{O}_7(aq) + 8\text{H}_2\text{SO}_4(aq) + 3\text{CH}_3\text{OH}(aq) \rightarrow 2\text{Cr}_2(\text{SO}_4)_3(aq) + 11\text{H}_2\text{O}(l) + 3\text{HCOOH}(aq) + 2\text{K}_2\text{SO}_4(aq) \]

What volume of 0.00389 M K2Cr2O7 is required to titrate 1.77 g of CH3OH dissolved in 20.0 mL of solution?

A) 21.3 mL  
B) 683 mL  
C) 9.47 mL  
D) 20.0 mL  
E) 303 mL

9. An impure sample of benzoic acid (C6H5COOH, 122.12 g/mol) is titrated with 0.8067 M NaOH. A 5.109-g sample requires 36.97 mL of titrant to reach the endpoint. What is the percent by mass of benzoic acid in the sample?

\[ \text{C}_6\text{H}_5\text{COOH}(aq) + \text{NaOH}(aq) \rightarrow \text{NaC}_6\text{H}_5\text{COO}(aq) + \text{H}_2\text{O}(l) \]

A) 0.02442 %  
B) 2.982 %  
C) 100.0 %  
D) 24.42 %  
E) 71.29 %
\[ \text{Reaction:} \quad 2 \text{K}_2\text{Cr}_2\text{O}_7 + 3 \text{CH}_3\text{OH} \rightarrow \text{Products} \]

[7.11] 0.00389 M \[1.77 \text{ g in 20 mL solution}\]

\[3 \text{ (mols K}_2\text{Cr}_2\text{O}_7) = 2 \text{ (mols CH}_3\text{OH)}\]

\[3 \text{ (M \cdot V)} = 2 \left( \frac{1.77}{52 \text{ g mol}^{-1}} \right)\]

\[\text{mol} \quad \frac{ \text{c} \text{ (mol)}}{2} = 2 \text{ (mol)}\]

\[3 \times 0.00389 \text{ mol} \times 2 \left( \frac{1.77}{32 \text{ g mol}^{-1}} \right)\]

\[V = \left[ \frac{2 \left( \frac{1.77}{32} \right)}{3 \times 0.00389} \right] \text{ liters} = 2.48 \text{ L}\]
5.109g Impure Sample | 0.8067 M (36.97 ml)

m: 1:1 molar ratio → moles NaOH used = moles H\text{Benz} Neutralized

\[
\text{moles NaOH} = \text{molarity} \times \text{volume} = (0.8067 \text{M}) \times (0.03667 \text{L}) \\
= 0.0298 \text{ mole NaOH used} \\
= 0.0298 \text{ mole H\text{Benz} Neutralized}
\]

Given H\text{Benz} Neutralized = 0.0298 mole (12.12% yield)

\[
\text{3.642 g H\text{Benz} in Sample}
\]

% H\text{Benz} in Impure Sample = \[
\frac{3.642}{5.109} \times 100\% \\
= 71.29\% \text{ yield}
\]
10. For the hypothetical reaction $A + 2B \rightarrow 2C + D$, the initial rate of disappearance of $A$ is $2.0 \times 10^{-2}$ mol/(L $\cdot$ s). What is the initial rate of disappearance of $B$?
   A) $8.0 \times 10^{-2}$ mol/(L $\cdot$ s)  
   B) $4.0 \times 10^{-2}$ mol/(L $\cdot$ s)  
   C) $1.4 \times 10^{-1}$ mol/(L $\cdot$ s)  
   D) $4.0 \times 10^{-1}$ mol/(L $\cdot$ s)  
   E) $1.4 \times 10^{-2}$ mol/(L $\cdot$ s)

11. For a certain first-order reaction with the general form $aA \rightarrow$ products, the rate is $0.32$ M/s$^{-1}$ when the concentration of the reactant is $0.29$ M. What is the rate constant for this reaction?
   A) $0.26$ s$^{-1}$  
   B) $1.1$ s$^{-1}$  
   C) $0.32$ s$^{-1}$  
   D) $3.1$ s$^{-1}$  
   E) $3.8$ s$^{-1}$

12. Ozone reacts with nitrogen dioxide to produce oxygen and dinitrogen pentoxide according to the following chemical equation:
   $O_3(g) + 2NO_2(g) \rightarrow O_2(g) + N_2O_5(g)$

   The rate law for this reaction is $\text{Rate} = k[O_3][NO_2]$. If concentration is measured in moles per liter and time is measured in seconds, what are the units of $k$?
   A) L $\cdot$ mol$^{-1}$ $\cdot$ s  
   B) L$^2$ $\cdot$ mol$^{-2}$ $\cdot$ s$^{-1}$  
   C) L $\cdot$ mol$^{-1}$ $\cdot$ s$^{-1}$  
   D) mol $\cdot$ L$^{-1}$ $\cdot$ s$^{-1}$  
   E) mol$^2$ $\cdot$ L$^{-2}$ $\cdot$ s$^{-1}$

13. If a reaction is first-order with respect to a particular reactant, when the concentration of that reactant is increased by a factor of 2, the reaction rate will
   A) increase by a factor of 2.  
   B) remain constant.  
   C) decrease by a factor of $\frac{1}{2}$.  
   D) decrease by a factor of $\frac{1}{8}$.  
   E) increase by a factor of 4.
14. The rate law for the reaction between chlorine and nitric oxide,
\[ 2\text{NO}(g) + \text{Cl}_2(g) \rightarrow 2\text{NOCl}(g) \]
is \( \text{Rate} = k[\text{NO}]^2[\text{Cl}_2] \). Which of the following changes will not alter the initial rate of the reaction?
A) increasing the concentration of NOCl 
B) decreasing the volume of the reaction system 
C) running the reaction in a solvent rather than in the gas phase 
D) increasing the volume of the reaction system 
E) increasing the concentration of chlorine gas

15. A chemical reaction that is first-order in X is observed to have a rate constant of \(2.20 \times 10^{-2}\) s\(^{-1}\). If the initial concentration of X is 1.0 M, what is the concentration of X after 186 s?
A) 0.20 M 
B) 0.017 M 
C) 64 M 
D) 0.59 M 
E) 0.98 M

16. The nuclide \(^{188}\text{W}\) decays by a first-order process with a rate constant of \(1.0 \times 10^{-2}\) d\(^{-1}\). How long will it take for 91% of the initial amount of \(^{188}\text{W}\) to be consumed?
A) 4.1 d 
B) 220 d 
C) 9.4 d 
D) 240 d 
E) 110 d

17. A first-order chemical reaction is observed to have a rate constant of 25 min\(^{-1}\). What is the corresponding half-life for the reaction?
A) 1.7 s 
B) 1.7 min 
C) 36 min 
D) 2.4 s 
E) 35.8 s

18. What would happen if the kinetic energy of the reactants were not enough to provide the needed activation energy?
A) The rate of the reaction would tend to increase. 
B) The reactants would continue to exist in their present form 
C) The activated complex would be converted into products. 
D) The products would be produced at a lower energy state. 
E) The products would form at an unstable energy state.
19. For the formation of 1 mol of nitrosyl chloride at a given temperature, $\Delta H = -44$ kJ.

$$\text{NO(g)} + \frac{1}{2} \text{Cl}_2(g) \rightarrow \text{NOCl(g)}$$

The activation energy for this reaction is 59 kJ/mol. What is the activation energy for the reverse reaction?
A) 59 kJ/mol
B) 15 kJ/mol
C) 103 kJ/mol
D) $-44$ kJ/mol
E) $-103$ kJ/mol

20. The rate constant for a first-order reaction is $1.6 \times 10^{-2}$ s$^{-1}$ at 668 K and $5.1 \times 10^{-2}$ s$^{-1}$ at 916 K. What is the activation energy? ($R = 8.31$ J/(mol $\cdot$ K))
A) 11 kJ/mol
B) 14 kJ/mol
C) 23 kJ/mol
D) 2900 kJ/mol
E) 24 kJ/mol

21. The Ostwald process converts ammonia (NH$_3$) to nitric oxide (NO) by reaction with oxygen in the presence of a catalyst at high temperatures. In a test of the process a reaction vessel is initially charged with 3.90 mol NH$_3$(g) and 4.90 mol O$_2$(g), sealed, and heated at a fixed high temperature. When equilibrium is established the reaction mixture is analyzed and found to contain 2.90 mol NO(g). What is the quantity of NH$_3$(g) in the equilibrium reaction mixture?

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

A) 1.00 mol NH$_3$(g)
B) 6.80 mol NH$_3$(g)
C) 3.90 mol NH$_3$(g)
D) 1.28 mol NH$_3$(g)
E) 2.00 mol NH$_3$(g)

22. For the reaction Br$_2$(g) + Cl$_2$(g) $\rightleftharpoons$ 2BrCl(g), at equilibrium, it is found that the concentrations of Br$_2$, Cl$_2$, and BrCl are 0.398 M, 0.351 M, and $2.05 \times 10^{-3}$ M, respectively. What is the value of $K_c$?
A) $3.01 \times 10^{-5}$
B) $1.20 \times 10^{-4}$
C) $1.47 \times 10^{-2}$
D) $6.81 \times 10^1$
E) $3.32 \times 10^4$
23. For which of the following reactions are the numerical values of $K_p$ and $K_c$ the same?

1. $2\text{SO}_2(\text{g}) + \text{O}_2(\text{g}) \rightleftharpoons 2\text{SO}_3(\text{g})$
   - $K_p = K_c$ if $\Delta n (\text{g}) = 0$
2. $\text{N}_2(\text{g}) + \text{O}_2(\text{g}) \rightleftharpoons 2\text{NO}(\text{g})$
   - Yes
3. $\text{H}_2(\text{g}) + \text{I}_2(\text{g}) \rightleftharpoons 2\text{HI}(\text{g})$
   - Yes

A) 1 only
B) 2 only
C) 1 and 2
D) 2 and 3
E) 1, 2, and 3

24. At 298 K, the value of $K_c$ for the reaction $\text{H}_2(\text{g}) + \text{Br}_2(\text{g}) \rightleftharpoons 2\text{HBr}(\text{g})$ is $2.0 \times 10^{19}$. What is $K_c$ for $\text{HBr}(\text{g}) \rightleftharpoons \frac{1}{2}\text{H}_2(\text{g}) + \frac{1}{2}\text{Br}_2(\text{g})$?

A) $4.0 \times 10^{-38}$
B) $5.0 \times 10^{-20}$
C) $1.0 \times 10^{19}$
D) $2.0 \times 10^{19}$
E) $2.2 \times 10^{-10}$

25. Given the equilibrium constants for the following reactions:

4. $\text{Cu}_2(\text{s}) + \text{O}_2(\text{g}) \rightleftharpoons 2\text{Cu}_2\text{O}(\text{s}); K_1$
5. $\text{CuO}(\text{s}) \rightleftharpoons \text{Cu}_2\text{O}(\text{s}) + \frac{1}{2}\text{O}_2(\text{g}); K_2$

What is $K$ for the system $2\text{Cu}(\text{s}) + \text{O}_2(\text{g}) \rightleftharpoons 2\text{CuO}(\text{s})$

equivalent to?

A) $(K_2)^2/(K_1)$
B) $K_1 \times K_2$
C) $(K_1)(K_2)^{1/2}$
D) $(K_2)^{1/2}/(K_1)$
E) $(K_1)^{1/2}/(K_2)$
26. What is the $K_c$ equilibrium-constant expression for the following equilibrium?

$$S_8(s) + 24F_2(g) \rightleftharpoons 8SF_6(g)$$

A) $\frac{[SF_6]}{[S_8][F_2]}$
B) $\frac{[S_8][F_2]}{[SF_6]^{24}}$
C) $\frac{[F_2]^{24}}{[SF_6]^{24}}$
D) $\frac{[S_8][F_2]^{24}}{[SF_6]^{24}}$
E) $\frac{[SF_6]^{24}}{[F_2]^{24}}$

27. For which of the following values of the equilibrium constant does the reaction mixture contain mostly reactants?

A) $10^0$
B) $10^1$
C) $10^{-9}$
D) $10^{-1}$
E) $10^9$

28. Consider the following equilibrium:

$$C_2H_6(g) + C_5H_{12}(g) \rightleftharpoons CH_4(g) + C_6H_{14}(g); K_p = 9.57 \text{ at } 500 \text{ K}$$

Suppose 47.2 g each of CH$_4$, C$_2$H$_6$, C$_5$H$_{12}$, and C$_6$H$_{14}$ are placed in a 25.0-L reaction vessel at 500 K. Which of the following statements is correct?

A) Because $Q_c < K_c$, more products will be formed.
B) Because $Q_c = 1$, the system is at equilibrium.
C) Because $Q_c = 1$, more products will be formed.
D) Because $Q_c = 1$, more reactants will be formed.
E) Because $Q_c > K_c$, more reactants will be formed.

\[ \frac{\text{mol} \cdot \text{atm}}{\text{L}} \text{ at } \text{V} = \text{P} \Rightarrow K_p = 9.57 = K_c \]
\( \text{C}_2\text{H}_6 + \text{C}_5\text{H}_{12} \rightarrow \text{CH}_4 + \text{C}_6\text{H}_{14} \)  ;  \( K_P = K_C = 9.57 \)

\[ K_P = \frac{k_c}{b/c} \sum d V_m (R) = \sum d V_m (P) \]

\[
\begin{align*}
\text{C}_2\text{H}_6 & : \left( \frac{47.2 \text{ mmol}}{72 \text{ mmol}} \right) \left( \frac{1}{252} \right) = 0.0629 \\
\text{C}_5\text{H}_{12} & : \left( \frac{47.2 \text{ mmol}}{72 \text{ mmol}} \right) \left( \frac{1}{252} \right) = 0.0262 \\
\text{CH}_4 & : \left( \frac{47.2 \text{ mmol}}{72 \text{ mmol}} \right) \left( \frac{1}{252} \right) = 0.1180 \\
\text{C}_6\text{H}_{14} & : \left( \frac{47.2 \text{ mmol}}{72 \text{ mmol}} \right) \left( \frac{1}{252} \right) = 0.0220
\end{align*}
\]

\[
\Phi_c = \frac{(0.1180)(0.220)}{(0.0629)(0.262)} = 1.57
\]

\[
K_C = 9.57 > \Phi_c = 1.58
\]

Red Shifts Right → More Product Formed
29) Given:

\[ \text{C}_2 \text{H}_2 + 3 \text{Cl}_2 \rightarrow \text{CCl}_4 + 5 \text{Cl}_2 \]

\[ \text{C}_2 \text{H}_2: \quad 0.050 \text{m} \quad 0.25 \text{m} \quad 0.15 \text{m} \quad 0.35 \text{m} \]

\[ \text{Cl}_2: \quad 0.150 \text{m} \quad 0.21 \text{m} \quad 0.25 \text{m} \quad 0.34 \text{m} \]

\[ K_c = \frac{[\text{CCl}_4][\text{Cl}_2]^5}{[\text{C}_2 \text{H}_2][\text{Cl}_2]^3} = \frac{(0.15)(0.35)}{(0.05)(0.25)^3} = 67.2 \]

\[ \phi_c = \frac{[\text{CCl}_4][\text{Cl}_2]^5}{[\text{C}_2 \text{H}_2][\text{Cl}_2]^3} = \frac{(0.29)(0.34)}{(0.15)(0.21)^3} = 71.0 \]

\[ K_c = 67.2 < \phi_c = 71.0 \]

Run Shift Left
\[ H_2 + I_2 \rightleftharpoons 2HI; \quad K_c = 49 \]

\[ \begin{array}{c|cc}
C_i & 0.42\text{M} & 0.42\text{M} & \text{M} \\
\hline
C & -x & -x & 2x
\end{array} \]

\[ K_c = \frac{[HI]^2}{[H_2][I_2]} = \frac{(2x)^2}{(0.42-x)^2} = 49 \]

\[ \sqrt{(\frac{2x}{0.42-x})^2} = 7 = \frac{2x}{0.42-x} \]

\[ 2x = 7(0.42-x) = 2.94 - 7x \]

\[ 9x = 2.94 \Rightarrow x = \frac{2.94}{9} = 0.327\text{M} \]

\[ [HI]_{\text{eq}} = 2x = 2(0.327\text{M}) = 0.654\text{M} @ \text{eqv!} \]

\[ \approx 0.65\text{M} \]
33. Which of the following equilibria would be affected by volume changes at constant temperature?
   A) \( \text{HCl}(aq) + \text{NaOH}(aq) \rightleftharpoons \text{H}_2\text{O}(l) + \text{NaCl}(aq) \)
   B) \( \text{C}_2\text{H}_4(g) + \text{H}_2(g) \rightleftharpoons \text{C}_2\text{H}_6(g) \)
   C) \( 2\text{HCl}(g) \rightleftharpoons \text{H}_2(g) + \text{Cl}_2(g) \)
   D) \( \text{SO}_3(g) + \text{NO}(g) \rightleftharpoons \text{NO}_2(g) + \text{SO}_2(g) \)
   E) \( 2\text{HF}(g) \rightleftharpoons \text{H}_2(g) + \text{F}_2(g) \)

34. For the endothermic reaction \( 2\text{CO}_2(g) + \text{N}_2(g) \rightleftharpoons 2\text{NO}(g) + 2\text{CO}(g) \), the conditions that favor maximum conversion of the reactants to products are
   A) high temperature and low pressure.
   B) high temperature, pressure being unimportant.
   C) low temperature and low pressure.
   D) low temperature and high pressure.
   E) high temperature and high pressure.

35. How many grams of lithium nitrate, \( \text{LiNO}_3 \) (68.9 g/mol), are required to prepare 342.6 mL of a 0.783 \( \text{M} \) \( \text{LiNO}_3 \) solution?
   A) 0.00389 g
   B) 18.5 g
   C) 0.0541 g
   D) 30.1 g
   E) 0.00653 g

36. What volume of 0.76 M sodium bromide, \( \text{NaBr} \), contains \( 8.8 \times 10^{-4} \) mol of bromide ions?
   A) 0.58 mL
   B) 0.67 L
   C) 1.2 mL
   D) 0.86 L
   E) 0.67 mL

37. What volume of 2.52 M HCl is required to prepare 176.5 mL of 0.449 M HCl?
   A) \( 9.91 \times 10^2 \) mL
   B) \( 1.56 \times 10^2 \) mL
   C) 31.4 mL
   D) 0.0318 mL
   E) 2.00 \( \times 10^2 \) mL
38. The concentration of Pb\(^{2+}\) in a sample of wastewater is to be determined by using gravimetric analysis. To a 100.0-mL sample of the wastewater is added an excess of sodium carbonate, forming the insoluble lead (II) carbonate (267.2092 g/mol) according to the balanced equation given below. The solid lead (II) carbonate is dried, and its mass is measured to be 0.4078 g. What was the concentration of Pb\(^{2+}\) in the original wastewater sample?

\[
Pb^{2+}(aq) + Na_{2}CO_{3}(aq) \rightarrow PbCO_{3}(s) + 2Na^{+}(aq)
\]

A) 0.01526 M  
B) 0.001526 M  
C) 1.090 M  
D) 0.004078 M  
E) 65.52 M  

39. A 50.00-mL sample of a weak acid is titrated with 0.0955 M NaOH. At the endpoint, it is found that 32.56 mL of titrant was used. What was the concentration of the weak acid?

A) 0.0622 M  
B) 3.14 M  
C) 0.0955 M  
D) 5.87 \times 10^{-5} M  
E) 0.147 M

40. Nitrosyl chloride is produced from the reaction of nitrogen monoxide and chlorine:

\[
2NO(g) + Cl_{2}(g) \rightarrow 2NOCl(g)
\]

The following initial rates at a given temperature were obtained for the concentrations listed below.

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Initial Rate (mol\cdot L^{-1}\cdot h^{-1})</th>
<th>[NO] (_{0}) (mol\cdot L^{-1})</th>
<th>Cl(<em>{2}) (</em>{0}) (mol\cdot L^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3x [ 2.21 ]</td>
<td>0.25 [ 3x ]</td>
<td>0.25 [ 3x ]</td>
</tr>
<tr>
<td>2</td>
<td>19.89 [ 9x ]</td>
<td>0.75 [ 9x ]</td>
<td>0.75 [ 9x ]</td>
</tr>
<tr>
<td>3</td>
<td>6.63 [ 3x ]</td>
<td>0.25 [ 3x ]</td>
<td>0.75 [ 3x ]</td>
</tr>
</tbody>
</table>

From the data, what is the experimental rate law?

A) Rate = \( k[Cl_{2}] \)  
B) Rate = \( k[NO] \)  
C) Rate = \( k[NO][Cl_{2}]^{2} \)  
D) Rate = \( k[NO]^{2}[Cl_{2}] \)  
E) Rate = \( k[NO][Cl_{2}]^{1/2} \)

41. The radioactive nuclide \(^{63}\)Ni decays by a first-order process via the emission of a beta particle. The \(^{63}\)Ni nuclide has a half-life of 100 years. How long will it take for 71\% of \(^{63}\)Ni to decay?

A) 49.4 years  
B) 21.5 years  
C) 0.858 years  
D) 179 years  
E) 77.6 years
Sample = 100 mL waste water

\[ \text{Pb}^{2+} + \text{Na}_2\text{CO}_3 \rightarrow \text{PbCO}_3(s) + 2\text{Na}^+ \]

(Solution) + (Excess) \Rightarrow 0.4078 g \text{ PbCO}_3

\[
\frac{0.4078}{267.2092} \text{ mL of PbCO}_3
\]

= 0.001526 mL \text{ PbCO}_3

for 0.001526 mL \text{ PbCO}_3 \rightarrow 0.001526 mL \text{ Pb}^{2+} + 0.001526 mL \text{ CO}_3^{2-}

\[
\text{Pb}^{2+} = \frac{(0.001526 \text{ mL})}{(100 \text{ mL})} = 0.01526 M \text{ (Pb}^{2+})
\]
42. Which of the following changes will affect the activation energy of a reaction?

1. Increasing or decreasing the reaction temperature. **NO**
2. Adding a catalyst. **YES**
3. Increasing or decreasing the reactant concentrations. **NO**

A) 1 only  
B) 2 only  
C) 3 only  
D) 1 and 2  
E) 2 and 3

---

43. The potential-energy diagram below describes the hypothetical reaction $A + B \rightarrow C + D$. Assuming the $y$-axis label refers to the enthalpy $(H)$ per mol, which of the following statements concerning this reaction coordinate is/are correct?

1. The forward reaction is exothermic. **YES**
2. The forward reaction rate is proportional to the change in enthalpy $(\Delta H)$ of the forward reaction. **NO**
3. $E_a$ (forward) $- E_a$ (reverse) is equal to the change in enthalpy $(\Delta H)$ of the forward reaction. **YES**

![Potential-energy diagram](image)

---

A) 1 only  
B) 2 only  
C) 3 only  
D) 1 and 3  
E) 1, 2, and 3
44. For the following reaction producing 1 mol of oxygen gas at a particular temperature, $\Delta H = -200$ kJ.

$$\text{NO}(g) + \text{O}_3(g) \rightarrow \text{NO}_2(g) + \text{O}_2(g)$$

The activation energy is 11 kJ!mol. What is the activation energy for the reverse reaction?
A) 11 kJ!mol
B) 200 kJ!mol
C) 222 kJ!mol
D) 188 kJ!mol
E) 211 kJ!mol

45. For the first-order reaction

$$\frac{1}{2} \text{N}_2\text{O}_4(g) \rightarrow \text{NO}_2(g); \Delta H = 28.6 \text{ kJ}$$

the rate constant is $k = 9.29 \times 10^4 \text{ s}^{-1}$ at $-20^\circ\text{C}$, and the activation energy is 53.7 kJ!mol. What is the rate constant at $21^\circ\text{C}$?
A) $1.08 \times 10^5 \text{ s}^{-1}$
B) $9.29 \times 10^4 \text{ s}^{-1}$
C) $1.74 \times 10^5 \text{ s}^{-1}$
D) $3.27 \times 10^6 \text{ s}^{-1}$
E) $4.94 \times 10^4 \text{ s}^{-1}$

46. Consider the following equilibrium:

$$\text{C}_2\text{H}_6(g) + \text{C}_3\text{H}_{12}(g) \rightleftharpoons \text{CH}_4(g) + \text{C}_6\text{H}_{14}(g); K_p = 9.57 \text{ at } 500 \text{ K}$$

Suppose 57.5 g each of CH$_4$, C$_2$H$_6$, C$_3$H$_{12}$, and C$_6$H$_{14}$ are placed in a 10.0-L reaction vessel at 500 K. What is the value of $Q_p$?
A) 1.00
B) 0.104
C) 1.57
D) 0.637
E) 9.57

47. The reaction quotient for a system is $3.4 \times 10^3$. If the equilibrium constant for the system is $1.5 \times 10^{-4}$, what will happen as the reaction mixture approaches equilibrium?
A) The equilibrium constant will increase until it equals the reaction quotient.
B) There will be a net gain in both product(s) and reactant(s).
C) There will be a net gain in product(s).
D) There will be a net gain in reactant(s).
E) The equilibrium constant will decrease until it equals the reaction quotient.

$$k_c = 1.5 \times 10^{-4} < Q_c = 3.4 \times 10^3$$

Run Shifts Left $\rightarrow$ Net Gain in Reactants
\[ \text{(57.5 g each)} \quad \frac{16}{2} \quad \text{(82)} \]
\[ \text{C}_2\text{H}_6 + \text{H}_2 \quad \text{\rightleftharpoons} \quad \text{C}_2\text{H}_4 + \text{H}_2\text{O} \]

\[ k_p = 9.57 = k_c \quad \text{b/c} \quad \sum v_C = \sum v_A \]

\[ p_t = p_c = \frac{(\text{C}_2\text{H}_6)(\text{H}_2)}{(\text{C}_2\text{H}_4)(\text{H}_2\text{O})} \]

\[ [\text{CH}_4] = \frac{(57.5 \text{ g})}{(16 \text{ mole})} (102)^{-1} = 0.3534 \text{ M} \]

\[ [\text{C}_2\text{H}_4] = \frac{(57.5 \text{ g})}{(26 \text{ mole})} (102)^{-1} = 0.6669 \text{ M} \]

\[ [\text{C}_2\text{H}_6] = \frac{(57.5 \text{ g})}{(30 \text{ mole})} (102)^{-1} = 0.1917 \text{ M} \]

\[ [\text{C}_3\text{H}_2\text{O}] = \frac{(57.5 \text{ g})}{(72 \text{ mole})} (102)^{-1} = 0.0799 \text{ M} \]

\[ p_t = p_c = \frac{(0.3534)(0.0669)}{(0.1917)(0.0799)} = 1.57 \]
48. For the reaction $2\text{HI}(g) \rightleftharpoons \text{H}_2(g) + \text{I}_2(g)$, $K_c = 0.290$ at 400 K. If the initial concentrations of HI, H$_2$, and I$_2$ are all $1.50 \times 10^{-3}$ M at 400 K, which one of the following statements is correct?
A) The concentrations of HI and I$_2$ will increase as the system is approaching equilibrium.
B) The concentrations of H$_2$ and I$_2$ will increase as the system is approaching equilibrium.
C) The system is at equilibrium.
D) The concentrations of H$_2$ and HI will decrease as the system is approaching equilibrium.
E) The concentration of HI will increase as the system is approaching equilibrium.

49. For the equilibrium $\text{PCl}_5(g) \rightleftharpoons \text{PCl}_3(g) + \text{Cl}_2(g)$, $K_c = 4.0$ at 228°C. If pure PCl$_5$ is placed in a 1.00-L container and allowed to come to equilibrium, and the equilibrium concentration of PCl$_3(g)$ is 0.26 M, what is the equilibrium concentration of PCl$_5$?
A) 0.13 M
B) 0.37 M
C) 0.26 M
D) 1.0 M
E) 0.017 M

50. Sulfur dioxide combines with O$_2$ in the presence of a catalyst as represented by the equation

$$2\text{SO}_2(g) + \text{O}_2(g) \rightleftharpoons 2\text{SO}_3(g)$$

Suppose 0.10 mol of SO$_2$ and 0.10 mol of O$_2$ are added to a 1-L vessel. At equilibrium, which of the following conditions must be true?
A) $[\text{O}_2] = 2[\text{SO}_3]$
B) $[\text{SO}_2] = [\text{O}_2]$
C) $[\text{SO}_2] > [\text{O}_2]$
D) $[\text{SO}_2] < [\text{O}_2]$
E) $[\text{SO}_2] = [\text{O}_2] = [\text{SO}_3]$
\[2HI \rightleftharpoons H_2 + I_2; \quad k_c = 0.290\]

\[C_i: \quad 0.0015 \text{ M} \quad 0.0015 \text{ M} \quad 0.0015 \text{ M}\]

\[Q_c = \frac{(H_2)(I_2)}{(H_2)} = \frac{(0.0015)^2}{(0.0015)} = 1\]

\[k_c = 0.290 < Q_c = 1.000\]

The reaction will shift left \(\Rightarrow [HI]\) increases.
\[ \text{PCl}_3 \rightleftharpoons \text{PCl}_2 + \text{Cl}_2 \]  
\[ k_3 = 4.0 \]

\[ C_i \quad [\text{PCl}_3]_0 \]

\[ AC \quad -x \quad +x \quad +x \]

\[ 0.26 \quad m \quad x \quad -x \]

\[ k_3 = \frac{[\text{PCl}_3][\text{Cl}_2]}{[\text{PCl}_5]} = \frac{(x)(x)}{0.26} = 4 \]

\[ \frac{x^2}{0.26} = 4 \Rightarrow x = \sqrt{4(0.26)} \]

\[ = 1.04 \approx 1.0 \text{mM} \]
\[ \text{Starting with equal amounts of } \text{SO}_2 \text{ and O}_2 \text{, allowing the reaction to proceed as shown in the above ICE table, SO}_2 \text{ concentration will decrease by } 2x \text{ faster than O}_2 \text{. Consequently, at equilibrium, } \left[ \text{SO}_2 \right] < \left[ \text{O}_2 \right]. \]