CHAPTER 13

Chemical Kinetics

MULTIPLE CHOICE QUESTIONS

1. The units of "reaction rate" are
   A. \( \text{L mol}^{-1} \text{s}^{-1} \)
   B. \( \text{L}^2 \text{mol}^{-2} \text{s}^{-1} \)
   C. \( \text{s}^{-1} \)
   D. \( \text{s}^{-2} \)
   E. \( \text{mol L}^{-1} \text{s}^{-1} \)
   Answer: E

2. For the reaction \( \text{BrO}_3^- + 5\text{Br}^- + 6\text{H}^+ \rightarrow 3\text{Br}_2 + 3\text{H}_2\text{O} \) at a particular time,
   \( -\Delta [\text{BrO}_3^-]/\Delta t = 1.5 \times 10^{-2} \text{ M/s} \). What is \( -\Delta [\text{Br}^-]/\Delta t \) at the same instant?
   A. 13 M/s     B. 7.5 \times 10^{-2} M/s     C. 1.5 \times 10^{-2} M/s     D. 3.0 \times 10^{-3} M/s     E. 330 M/s
   Answer: B

3. For the following reaction,
   \( \Delta P(\text{C}_6\text{H}_{14})/\Delta t \) was found to be \( -6.2 \times 10^{-3} \text{ atm/s} \).
   \( \text{C}_6\text{H}_{14}(g) \rightarrow \text{C}_6\text{H}_6(g) + 4\text{H}_2(g) \)
   Determine \( \Delta P(\text{H}_2)/\Delta t \) for this reaction at the same time.
   A. 6.2 \times 10^{-3} \text{ atm/s}     B. 1.6 \times 10^{-3} \text{ atm/s}     C. 2.5 \times 10^{-2} \text{ atm/s}
   D. -1.6 \times 10^{-3} \text{ atm/s}     E. -2.5 \times 10^{-2} \text{ atm/s}
   Answer: C

4. For the reaction \( \text{C}_6\text{H}_{14}(g) \rightarrow \text{C}_6\text{H}_6(g) + 4\text{H}_2(g) \), \( \Delta P(\text{H}_2)/\Delta t \) was found to be \( 2.5 \times 10^{-2} \text{ atm/s} \), where \( \Delta P(\text{H}_2) \) is the change in pressure of hydrogen. Determine \( \Delta P(\text{C}_6\text{H}_{14})/\Delta t \) for this reaction at the same time.
   A. 2.5 \times 10^{-2} \text{ atm/s}     B. -6.2 \times 10^{-3} \text{ atm/s}     C. -2.5 \times 10^{-2} \text{ atm/s}
   D. 0.10 atm/s     E. 6.2 \times 10^{-3} \text{ atm/s}
   Answer: B

5. For the hypothetical reaction \( A + 3\text{B} \rightarrow 2\text{C} \), the rate of appearance of \( \text{C} \) given by
   \( (\Delta [\text{C}]/\Delta t) \) may also be expressed as
   A. \( \Delta [\text{C}]/\Delta t = \Delta [\text{A}]/\Delta t \)
   B. \( \Delta [\text{C}]/\Delta t = -(3/2) \Delta [\text{B}]/\Delta t \)
   C. \( \Delta [\text{C}]/\Delta t = -(2/3) \Delta [\text{B}]/\Delta t \)
   D. \( \Delta [\text{C}]/\Delta t = -(1/2) \Delta [\text{A}]/\Delta t \)
   Answer: C

6. For the overall chemical reaction shown below, which one of the following statements can be rightly assumed?
2H₂S(g) + O₂(g) → 2S(s) + 2H₂O(l)

A. The reaction is third-order overall.
B. The reaction is second-order overall.
C. The rate law is, rate = k[H₂S]²[O₂].
D. The rate law is, rate = k[H₂S][O₂].
E. The rate law cannot be determined from the information given.
Answer: E

7. The reaction A + 2B → products has been found to have the rate law, rate = k[A][B]². While holding the concentration of A constant, the concentration of B is increased from x to 3x. Predict by what factor the rate of reaction increases.
A. 3      B. 6      C. 9      D. 27      E. 30
Answer: C

8. For the hypothetical reaction A + 3B → 2C, the rate should be expressed as
   A. rate = ∆[A]/∆t
   B. rate = −∆[C]/∆t
   C. rate = −3 (∆[B]/∆t)
   D. rate = (1/2) (∆[C]/∆t)
   E. rate = (1/3) (∆[B]/∆t)
Answer: D

9. The reaction A + 2B → products has the rate law, rate = k[A][B]³. If the concentration of B is doubled while that of A is unchanged, by what factor will the rate of reaction increase?
A. 2      B. 4      C. 6      D. 8      E. 9
Answer: D

10. The reaction A + 2B → products was found to have the rate law, rate = k[A][B]². Predict by what factor the rate of reaction will increase when the concentration of A is doubled and the concentration of B is also doubled.
A. 2      B. 4      C. 6      D. 8      E. 9      Answer: D

11. The reaction A + 2B → products was found to follow the rate law: rate = k[A]²[B]. Predict by what factor the rate of reaction will increase when the concentration of A is doubled, the concentration of B is tripled, and the temperature remains constant.
A. 5      B. 6      C. 12      D. 18      E. None of these.
Answer: C
12. Appropriate units for a first-order rate constant are

A. M/s     B. 1/M·s     C. 1/s     D. 1/M²·s

Answer:  C

13. It takes 42.0 min for the concentration of a reactant in a first-order reaction to drop from 0.45 M to 0.32 M at 25°C. How long will it take for the reaction to be 90% complete?

A. 13.0 min            B. 86.0 min            C. 137 min          D. 222 min            E. 284 min

Answer:  E

14. Nitric oxide gas (NO) reacts with chlorine gas according to the equation

NO + ½Cl₂ → NOCl.

The following initial rates of reaction have been measured for the given reagent concentrations.

<table>
<thead>
<tr>
<th>Expt. #</th>
<th>Rate (M/hr)</th>
<th>NO (M)</th>
<th>Cl₂ (M)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.19</td>
<td>0.50</td>
<td>0.50</td>
</tr>
<tr>
<td>2</td>
<td>4.79</td>
<td>1.00</td>
<td>0.50</td>
</tr>
<tr>
<td>3</td>
<td>9.59</td>
<td>1.00</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Which of the following is the rate law (rate equation) for this reaction?

A. rate = k[NO]     B. rate = k[NO][Cl₂]¹/₂
C. rate = k[NO][Cl₂]     D. rate = k[NO]²[Cl₂]
E. rate = k[NO]²[Cl₂]²

Answer:  D

15. Use the following data to determine the rate law for the reaction

2NO + H₂ → N₂O + H₂O.

<table>
<thead>
<tr>
<th>Expt. #</th>
<th>[NO]₀</th>
<th>[H₂]₀</th>
<th>Initial rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.0210.065</td>
<td>1.46</td>
<td>1.46 M/min</td>
</tr>
<tr>
<td>2</td>
<td>0.0210.260</td>
<td>1.46</td>
<td>1.46 M/min</td>
</tr>
<tr>
<td>3</td>
<td>0.0420.065</td>
<td>5.84</td>
<td>5.84 M/min</td>
</tr>
</tbody>
</table>
A. rate = k[NO]  
B. rate = k[NO]^2  
C. rate = k[NO][H_2]  
D. rate = k[NO]^2[H_2]  
E. rate = k[NO]^2[H_2]^2

Answer: B

16. The data below were determined for the reaction \( S_2O_8^{2-} + 3I^- (aq) \rightarrow 2SO_4^{2-} + I_3^- \).

<table>
<thead>
<tr>
<th>Expt. #</th>
<th>([S_2O_8^{2-}])</th>
<th>([I^-])</th>
<th>Initial Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.038</td>
<td>0.060</td>
<td>1.4 \times 10^{-5} M/s</td>
</tr>
<tr>
<td>2</td>
<td>0.076</td>
<td>0.060</td>
<td>2.8 \times 10^{-5} M/s</td>
</tr>
<tr>
<td>3</td>
<td>0.076</td>
<td>0.030</td>
<td>1.4 \times 10^{-5} M/s</td>
</tr>
</tbody>
</table>

The rate law for this reaction must be:

A. rate = k[S_2O_8^{2-}][I^-]^3  
B. rate = k[S_2O_8^{2-}]  
C. rate = k[S_2O_8^{2-}]^2[I^-]^2  
D. rate = k[I^-]  
E. rate = k[S_2O_8^{2-}][I^-]

Answer: E

17. At 25°C the rate constant for the first-order decomposition of a pesticide solution is 6.40 \times 10^{-3} \text{ min}^{-1}. If the starting concentration of pesticide is 0.0314 M, what concentration will remain after 62.0 min at 25°C?

A. 1.14 \times 10^{-1} M  
B. 47.4 M  
C. -8.72 M  
D. 2.11 \times 10^{-2} M  
E. 2.68 \times 10^{-2} M

Answer: D

18. A certain first-order reaction \( A \rightarrow B \) is 25% complete in 42 min at 25°C. What is the half-life of the reaction?

A. 21 min  
B. 42 min  
C. 84 min  
D. 120 min  
E. 101 min

Answer: E

19. The following initial rate data apply to the reaction \( F_2(g) + 2Cl_2O(g) \rightarrow 2FCIO_2(g) + Cl_2(g) \).

<table>
<thead>
<tr>
<th>Expt. #</th>
<th>([F_2]) (M)</th>
<th>([Cl_2O]) (M)</th>
<th>Initial rate (M/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.05</td>
<td>0.010</td>
<td>5.0 \times 10^{-4}</td>
</tr>
<tr>
<td>2</td>
<td>0.05</td>
<td>0.040</td>
<td>2.0 \times 10^{-3}</td>
</tr>
</tbody>
</table>
Which of the following is the rate law (rate equation) for this reaction?

A. rate = k[F₂][Cl₂O]²
B. rate = k[F₂][Cl₂O]
C. rate = k[F₂][Cl₂O]
D. rate = k[F₂][Cl₂O]²
E. rate = k[F₂][Cl₂O]²

Answer: C

20. Nitric oxide reacts with chlorine to form nitrosyl chloride, NOCl. Use the following data to determine the rate equation for the reaction.

\[
\text{NO} + \frac{1}{2}\text{Cl}_2 \rightarrow \text{NOCl}
\]

<table>
<thead>
<tr>
<th>Expt. #</th>
<th>[NO]</th>
<th>[Cl₂]</th>
<th>Initial Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.22</td>
<td>0.065</td>
<td>0.96 M/min</td>
</tr>
<tr>
<td>2</td>
<td>0.66</td>
<td>0.065</td>
<td>8.6 M/min</td>
</tr>
<tr>
<td>3</td>
<td>0.44</td>
<td>0.032</td>
<td>1.9 M/min</td>
</tr>
</tbody>
</table>

A. rate = k[NO]
B. rate = k[NO][Cl₂]¹/₂
C. rate = k[NO][Cl₂]
D. rate = k[NO]²[Cl₂]
E. rate = k[NO]²[Cl₂]²

Answer: D

21. A first-order reaction has a rate constant of \(3.00 \times 10^{-3}\) s\(^{-1}\). The time required for the reaction to be 75.0% complete is

A. 95.8 s  B. 462 s  C. 231 s  D. 201 s  E. 41.7 s

Answer: B

22. A certain first-order reaction \(A \rightarrow B\) is 25% complete in 42 min at 25°C. What is its rate constant?

A. \(6.8 \times 10^{-3}\) min\(^{-1}\)  B. \(8.3 \times 10^{-3}\) min\(^{-1}\)  C. \(3.3 \times 10^{-2}\) min\(^{-1}\)
D. \(-3.3 \times 10^{-2}\) min\(^{-1}\)  E. 11 min\(^{-1}\)

Answer: A
23. Ammonium ion (NH$_4^+$) reacts with nitrite ion (NO$_2^-$) to yield nitrogen gas and liquid water. The following initial rates of reaction have been measured for the given reactant concentrations.

<table>
<thead>
<tr>
<th>Expt. #</th>
<th>[NH$_4^+$]</th>
<th>[NO$_2^-$]</th>
<th>Initial rate (M/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.010</td>
<td>0.020</td>
<td>0.020</td>
</tr>
<tr>
<td>2</td>
<td>0.015</td>
<td>0.020</td>
<td>0.030</td>
</tr>
<tr>
<td>3</td>
<td>0.030</td>
<td>0.010</td>
<td>0.015</td>
</tr>
</tbody>
</table>

Which of the following is the rate law (rate equation) for this reaction?

A. $\text{rate} = k \ [\text{NH}_4^+] \ [\text{NO}_2^-]^4$
B. $\text{rate} = k \ [\text{NH}_4^+] \ [\text{NO}_2^-]$
C. $\text{rate} = k \ [\text{NH}_4^+] \ [\text{NO}_2^-]^2$
D. $\text{rate} = k \ [\text{NH}_4^+]^2 \ [\text{NO}_2^-]$  
E. $\text{rate} = k \ [\text{NH}_4^+]^{1/2} \ [\text{NO}_2^-]^{1/4}$

Answer: C

24. Appropriate units for a second-order rate constant are

A. M/s  
B. 1/M·s  
C. 1/s  
D. 1/M$^2$·s

Answer: B

25. The isomerization of cyclopropane to form propene

\[
\begin{align*}
\text{H}_2\text{C} & \quad \text{CH}_2 \\
\text{\textbackslash} & \quad / \\
\text{\textbackslash} & \quad \rightarrow \quad \text{CH}_3 - \text{CH} = \text{CH}_2 \\
\text{CH}_2 &
\end{align*}
\]

is a first-order reaction. At 760 K, 15% of a sample of cyclopropane changes to propene in 6.8 min. What is the half-life of cyclopropane at 760 K?

A. $3.4 \times 10^{-2}$ min  
B. 2.5 min  
C. 23 min  
D. 29 min  
E. 230 min

Answer: D

26. The isomerization of cyclopropane to form propene

\[
\begin{align*}
\text{H}_2\text{C} & \quad \text{CH}_2 \\
\text{\textbackslash} & \quad / \\
\text{\textbackslash} & \quad \rightarrow \quad \text{CH}_3 - \text{CH} = \text{CH}_2 \\
\text{CH}_2 &
\end{align*}
\]
is a first-order reaction. At 760 K, 85% of a sample of cyclopropane changes to propene in 79.0 min. Determine the rate constant for this reaction at 760 K.

A. $3.66 \times 10^{-2}$ min$^{-1}$  
B. $1.04 \times 10^{-2}$ min$^{-1}$  
C. 2.42 min$^{-1}$  
D. $2.06 \times 10^{-3}$ min$^{-1}$  
E. $2.40 \times 10^{-2}$ min$^{-1}$

Answer: E

27. The isomerization of cyclopropane to propene follows first-order kinetics. At 700 K, the rate constant for this reaction is $6.2 \times 10^{-4}$ min$^{-1}$. How many minutes are required for 10.0% of a sample of cyclopropane to isomerize to propene?

\[
\begin{align*}
CH_2 \xrightarrow{H_2C} \text{CH}_2 \\
\text{CH}_2 \\
\text{\ /} \\
\rightarrow \text{CH}_3 \text{CH} = \text{CH}_2
\end{align*}
\]

A. 16,100 min  
B. 170 min  
C. 3,710 min  
D. $1.43 \times 10^{-3}$ min  
E. 1,120 min

Answer: B

28. At 700 K, the rate constant for the following reaction is $6.2 \times 10^{-4}$ min$^{-1}$. How many minutes are required for 20% of a sample of cyclopropane to isomerize to propene?

\[
\begin{align*}
C_3H_6 \text{ (cyclopropane)} \rightarrow C_3H_6 \text{ (propene)}
\end{align*}
\]

A. 1,120 min  
B. 360 min  
C. 3710 min  
D. $1.4 \times 10^{-4}$ min  
E. 280 min

Answer: B

29. A first-order reaction has a rate constant of $7.5 \times 10^{-3}$/s. The time required for the reaction to be 60% complete is

A. $3.8 \times 10^{-3}$ s  
B. $6.9 \times 10^{-3}$ s  
C. 68 s  
D. 120 s  
E. 130 s

Answer: D
30. At 25°C, the second-order reaction \( \text{NOCl}(g) \rightarrow \text{NO}(g) + 1/2\text{Cl}_2(g) \) is 50% complete after 5.82 hours when the initial concentration of NOCl is 4.46 mol/L. How long will it take for the reaction to be 75% complete?

A. 8.22 hr  B. 11.6 hr  C. 15.5 hr  D. 17.5 hr  E. 23.0 hr

Answer:  D

31. For the reaction \( \text{X} + \text{Y} \rightarrow \text{Z} \), the reaction rate is found to depend only upon the concentration of X. A plot of \( 1/\text{X} \) verses time gives a straight line.

What is the rate law for this reaction?

A. rate = k [X]  B. rate = k [X]^2  C. rate = k [X][Y]  D. rate = k [X]^2[Y]

Answer:  B

32. The reaction \( 2\text{NO}_2(g) \rightarrow 2\text{NO}(g) + \text{O}_2(g) \) is suspected to be second order in \( \text{NO}_2 \). Which of the following kinetic plots would be the most useful to confirm whether or not the reaction is second order?

A. a plot of [\( \text{NO}_2 \)]^{-1} vs. t  B. a plot of \( \ln [\text{NO}_2] \) vs. t  C. a plot of [\( \text{NO}_2 \)] vs. t  D. a plot of \( \ln [\text{NO}_2]^{-1} \) vs. t  E. a plot of [\( \text{NO}_2 \)]^2 vs. t

Answer:  A

33. The thermal decomposition of acetaldehyde, \( \text{CH}_3\text{CHO} \rightarrow \text{CH}_4 + \text{CO} \), is a second-order reaction. The following data were obtained at 518°C.

<table>
<thead>
<tr>
<th>time, s</th>
<th>Pressure ( \text{CH}_3\text{CHO} ), mmHg</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>364</td>
</tr>
</tbody>
</table>
Calculate the rate constant for the decomposition of acetaldehyde from the above data.

A. $2.2 \times 10^{-3}$/s  
B. 0.70 mmHg/s  
C. $2.2 \times 10^{-3}$/mmHg·s  
D. $6.7 \times 10^{-6}$/mmHg·s  
E. $5.2 \times 10^{-5}$/mmHg·s  

Answer: D

34. The thermal decomposition of acetaldehyde, $\text{CH}_3\text{CHO} \rightarrow \text{CH}_4 + \text{CO}$, is a second-order reaction. The following data were obtained at 518°C.

<table>
<thead>
<tr>
<th>Time, s</th>
<th>Pressure $\text{CH}_3\text{CHO}$, mmHg</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>364</td>
</tr>
<tr>
<td>42</td>
<td>330</td>
</tr>
<tr>
<td>105</td>
<td>290</td>
</tr>
<tr>
<td>720</td>
<td>132</td>
</tr>
</tbody>
</table>

Based on the data given, what is the half-life for the disappearance of acetaldehyde?

A. $1.5 \times 10^5$ s  
B. 410 s  
C. $5.4 \times 10^7$ s  
D. 520 s  
E. 305 s  

Answer: B

35. For the chemical reaction $A \rightarrow B + C$, a plot of $[A]$ versus time is found to give a straight line with a negative slope. What is the order of reaction with respect to $A$?

A. zeroth  
B. first  
C. second  
D. third  
E. Such a plot cannot reveal the order of the reaction.

Answer: A

36. For the chemical reaction $A \rightarrow C$, a plot of $1/[A]$ versus time was found to give a straight line with a positive slope. What is the order of reaction?

A. zeroth  
B. first  
C. second  
D. Such a plot cannot reveal the order of the reaction.
37. The graphs below all refer to the same reaction. What is the order of this reaction?

A. zeroth order       B. first order       C. second order       D. Unable to predict

Answer: A

38. For what order reaction does the half-life get longer as the initial concentration increases?

A. zeroth order
B. first order
C. second order
D. none of them because half-life is always independent of the initial concentration

Answer: A

39. For a second order reaction, the half-life is equal to

A. \( t_{1/2} = 0.693/k \)  B. \( t_{1/2} = k/0.693 \)  C. \( t_{1/2} = 1/[A]_o \)  D. \( t_{1/2} = k \)  E. \( t_{1/2} = [A]_o/2k \)

Answer: C

40. Which one of the following changes would alter the rate constant (k) for the reaction

\[ 2A + B \rightarrow \text{products} \]

A. increasing the concentration of A
B. increasing the concentration of B
C. increasing the temperature
D. measuring k again after the reaction has run for a while

Answer: C

41. The Arrhenius equation is \( k = A e^{-(E_a/RT)} \). The slope of a plot of ln k vs. 1/T is equal to
A. −k       B. k       C. E_a       D. −E_a/R       E. A

Answer: D

42. What is the slope of an Arrhenius plot for the following reaction?

\[ 2 \text{NOCl} \rightarrow 2 \text{NO} + \text{Cl}_2 \]

<table>
<thead>
<tr>
<th>Temperature (K)</th>
<th>k (L/mol·s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>400</td>
<td>6.6 \times 10^{-4}</td>
</tr>
<tr>
<td>500</td>
<td>2.9 \times 10^{-1}</td>
</tr>
<tr>
<td>600</td>
<td>16.3</td>
</tr>
</tbody>
</table>

A. 8.18 \times 10^{-2} K       B. 5.06 \times 10^{-2} K       C. −1.22 \times 10^{4} K
D. −1.96 \times 10^{4} K       E. not enough information to calculate the slope

Answer: C

43. The activation energy for the reaction \( \text{CH}_3\text{CO} \rightarrow \text{CH}_3 + \text{CO} \) is 71 kJ/mol. How many times greater is the rate constant for this reaction at 170°C than at 150°C?

A. 0.40       B. 1.1      C. 2.5      D. 4.0      E. 5.0

Answer: C

44. If \( E_a \) for a certain biological reaction is 50 kJ/mol, by what factor (how many times will the rate of this reaction increase when body temperature increases from 37°C (normal) to 40°C (fever))?

A. 1.15     B. 1.20      C. 2.0 \times 10^5     D.1.0002      E. 2.0

Answer: B

45. The activation energy for the following reaction is 60 kJ/mol.

\[ \text{Sn}^{2+} + 2 \text{Co}^{3+} \rightarrow \text{Sn}^{3+} + 2 \text{Co}^{2+} \]

By what factor (how many times) will the rate constant increase when the temperature is raised from 10°C to 28°C?

A. 1.002       B. 4.6      C. 5.6      D. 2.8      E. 696

Answer: B

46. The isomerization of cyclopropane follows first order kinetics. The rate constant at 700 K is \( 6.20 \times 10^{-4} \) min\(^{-1}\), and the half-life at 760 K is 29.0 min. Calculate the activation energy for this reaction.
47. The isomerization of methyl isocyanide, \( \text{CH}_3\text{NC} \rightarrow \text{CH}_3\text{CN} \), follows first-order kinetics. The half-lives were found to be 161 min at 199°C and 12.5 min at 230°C. Calculate the activation energy for this reaction.

A. \( 6.17 \times 10^{-3} \text{ kJ/mol} \)  
B. 31.4 kJ/mol  
C. 78.2 kJ/mol  
D. 124 kJ/mol  
E. 163 kJ/mol

Answer: E

48. Calculate the activation energy, in kJ/mol, for the redox reaction 
\( \text{Sn}^{2+} + 2\text{Co}^{3+} \rightarrow \text{Sn}^{4+} + 2\text{Co}^{2+} \).

Data:  \begin{array}{c|c}
\text{Temp (°C)} & \text{k (1/M·s)} \\
2 & 3.12 \times 10^3 \\
27 & 27.0 \times 10^3 \\
\end{array}

A. 59.2  
B. 0.477  
C. 5.37  
D. 163 kJ  
E. 48.1 kJ

Answer: A
49. The reaction $C_4H_{10} \rightarrow C_2H_6 + C_2H_4$ has an activation energy ($E_a$) of 350 kJ/mol, and the $E_a$ of the reverse reaction is 260 kJ/mol. Estimate $\Delta H$, in kJ/mol, for the reaction as written above.

A. $-90$ kJ/mol          B. $+90$ kJ/mol      C. 350 kJ/mol      D. $-610$ kJ/mol
E. $+610$ kJ/mol

Answer: B

50. The activation energy for the following first-order reaction is 102 kJ/mol.

$$N_2O_5(g) \rightarrow 2NO_2(g) + (1/2)O_2(g)$$

The value of the rate constant ($k$) is $1.35 \times 10^{-4}$ s$^{-1}$ at 35°C. What is the value of $k$ at 0°C?

A. $8.2 \times 10^{-7}$ s$^{-1}$          B. $1.9 \times 10^{-5}$ s$^{-1}$      C. $4.2 \times 10^{-5}$ s$^{-1}$      D. $2.2 \times 10^{-2}$ s$^{-1}$
E. none of these

Answer: A

51. Given that $E_a$ for a certain biological reaction is 48 kJ/mol and that the rate constant is $2.5 \times 10^{-2}$ s$^{-1}$ at 15°C, what is the rate constant at 37°C?

A. $2.7 \times 10^{-2}$ s$^{-1}$          B. $2.5 \times 10^{-1}$ s$^{-1}$      C. $1.0 \times 10^{-1}$ s$^{-1}$      D. $6.0 \times 10^{-3}$ s$^{-1}$     E. 1.1 s$^{-1}$

Answer: C

52. The activation energy for the reaction $O + O_3 \rightarrow 2O_2$ is 25 kJ/mol, and the enthalpy change is $\Delta H = -388$ kJ/mol. What is the activation energy for the decomposition of $O_2$ by the reverse reaction?

A. 413 kJ          B. 388 kJ      C. 363 kJ      D. 50 kJ      E. 25 kJ

Answer: A

53. For the chemical reaction system described by the diagram below, which statement is true?
A. The forward reaction is endothermic.
B. The activation energy for the forward reaction is greater than the activation energy for the reverse reaction.
C. At equilibrium, the activation energy for the forward reaction is equal to the activation energy for the reverse reaction.
D. The activation energy for the reverse reaction is greater than the activation energy for the forward reaction.
E. The reverse reaction is exothermic.

Answer: D

54. An increase in the temperature of the reactants causes an increase in the rate of reaction. The best explanation for this behavior is that as the temperature increases,

A. the concentration of reactants increases.
B. the activation energy decreases.
C. the collision frequency increases.
D. the fraction of collisions with total kinetic energy $> E_a$ increases.
E. the activation energy increases.

Answer: D

55. For the chemical reaction system described by the diagram below, which statement is true?
If the $E_a$ for the forward reaction is 25 kJ/mol and the enthalpy of reaction is $-95$ kJ/mol, what is $E_a$ for the reverse reaction?

A. 120 kJ/mol  B. 70 kJ/mol  C. 95 kJ/mol  D. 25 kJ/mol  E. $-70$ kJ/mol

Answer: A

56. According to the collision theory, all collisions do not lead to reaction. Which choice gives both reasons why not all collisions between reactant molecules lead to reaction?

1. The total energy of two colliding molecules is less than some minimum amount of energy.
2. Molecules cannot react with each other unless a catalyst is present.
3. Molecules that are improperly oriented during collision will not react.

A. 1 and 2  B. 1 and 3  C. 1 and 4  D. 2 and 3  E. 3 and 4

Answer: B
57. When the concentrations of reactant molecules are increased, the rate of reaction increases. The best explanation for this phenomenon is that as the reactant concentration increases,

A. the average kinetic energy of molecules increases.
B. the frequency of molecular collisions increases.
C. the rate constant increases.
D. the activation energy increases.
E. the order of reaction increases.

Answer: B

58. A reaction mechanism usually is

A. the same as the balanced chemical equation.
B. restricted to only one possible explanation.
C. obvious if the reaction order is known.
D. difficult, if not impossible, to prove.
E. obvious if the activation energy is known.

Answer: D

59. The rate law for the reaction \( H_2O_2 + 2H^- + 2I^- \rightarrow I_2 + 2H_2O \) is \( rate = k[H_2O_2][I^-] \). The following mechanism has been suggested.

\[
\begin{align*}
H_2O_2 + I^- & \rightarrow HOI + OH^- \quad \text{slow} \\
OH^- + H^- & \rightarrow H_2O \quad \text{fast} \\
HOI + H^- + I^- & \rightarrow I_2 + H_2O \quad \text{fast}
\end{align*}
\]

Identify all intermediates included in this mechanism.

A. \( H^- \) and \( I^- \)
B. \( H^- \) and \( HOI \)
C. \( HOI \) and \( OH^- \)
D. \( H^- \) only
E. \( H_2O \) and \( OH^- \)

Answer: C

60. The following reaction in aqueous solution was found to be first order in [OH\(^-\)], first order in [C\(_2\)H\(_5\)Br], and inverse first order in Br\(^-\).

\[ C_2H_5Br + OH^- \rightarrow C_2H_5OH + Br^- \]

Which one of the following mechanisms is consistent with the observed reaction order?
A. \[ \text{C}_2\text{H}_5\text{Br} \overset{\text{fast}}{\rightleftharpoons} \text{C}_2\text{H}_5^+ + \text{Br}^- \]
\[ \text{C}_2\text{H}_5^+ + \text{OH}^- \rightarrow \text{C}_2\text{H}_5\text{OH} \quad \text{slow} \]

B. \[ \text{C}_2\text{H}_5\text{Br} + \text{H}_2\text{O} \rightarrow \text{C}_2\text{H}_5\text{OH} + \text{H}^+ + \text{Br}^- \quad \text{slow} \]
\[ \text{H}^+ + \text{OH}^- \rightarrow \text{H}_2\text{O} \quad \text{fast} \]

C. \[ \text{C}_2\text{H}_5\text{Br} \overset{\text{slow}}{\rightarrow} \text{C}_2\text{H}_5^+ + \text{Br}^- \]
\[ \text{C}_2\text{H}_5^+ + \text{OH}^- \rightarrow \text{C}_2\text{H}_5\text{OH} \quad \text{fast} \]

D. \[ \text{C}_2\text{H}_5\text{Br} \overset{\text{slow}}{\rightarrow} \text{C}_2\text{H}_5^+ + \text{Br}^- \]
\[ \text{OH}^- + \text{Br}^- \rightarrow \text{HOBr} \quad \text{fast} \]
\[ \text{HOBr} + \text{C}_2\text{H}_5^+ \rightarrow \text{C}_2\text{H}_5\text{OH} + \text{Br}^- \quad \text{fast} \]

Answer: A

61. The rate law for the reaction \( 2\text{NO}_2 + \text{O}_3 \rightarrow \text{N}_2\text{O}_5 + \text{O}_2 \) is \( \text{rate} = k[\text{NO}_2][\text{O}_3] \). Which one of the following mechanisms is consistent with this rate law?

A. \( \text{NO}_2 + \text{NO}_2 \rightarrow \text{N}_2\text{O}_4 \quad \text{(fast)} \)
B. \( \text{NO}_2 + \text{O}_3 \rightarrow \text{NO}_5 \quad \text{(fast)} \)
C. \( \text{NO}_2 + \text{O}_3 \rightarrow \text{NO}_3 + \text{O}_2 \quad \text{(slow)} \)
D. \( \text{NO}_2 + \text{NO}_2 \rightarrow \text{N}_2\text{O}_2 + \text{O}_2 \quad \text{(slow)} \)

Answer: C

62. For the reaction \( \text{X}_2 + \text{Y} + \text{Z} \rightarrow \text{XY} + \text{XZ} \), it is found that the rate equation is \( \text{rate} = k [\text{X}_2][\text{Y}] \). Why does the concentration of \( \text{Z} \) have no effect on the rate?

A. The concentration of \( \text{Z} \) is very small and the others are very large.
B. \( \text{Z} \) must react in a step after the rate determining step.
C. \( \text{Z} \) is an intermediate.
D. The fraction of molecules of \( \text{Z} \) that have very high energies is zero.
E. The activation energy for \( \text{Z} \) to react is very high.

Answer: B

63. The gas phase reaction of nitrogen dioxide and carbon monoxide was found by experiment to be second-order with respect to \( \text{NO}_2 \), and zeroth-order with respect to \( \text{CO} \) below 25°C.

\[ \text{NO}_2 + \text{CO} \rightarrow \text{NO} + \text{CO}_2 \]
Which one of the following mechanisms is consistent with the observed reaction order?

A. \( \text{NO}_2 + 2\text{CO} \stackrel{\text{fast}}{\longrightarrow} \text{N} + 2\text{CO}_2 \)  
   \( \text{N} + \text{NO}_2 \rightarrow 2\text{NO} \)  
   \( \text{slow} \)

B. \( \text{NO}_2 + 2\text{CO} \rightarrow \text{N} + 2\text{CO}_2 \)  
   \( \text{N} + \text{NO}_2 \rightarrow 2\text{NO} \)  
   \( \text{fast} \)

C. \( \text{NO}_2 + \text{NO}_2 \rightarrow \text{NO}_3 + \text{NO} \)  
   \( \text{NO}_3 + \text{CO} \rightarrow \text{NO}_2 + \text{CO}_2 \)  
   \( \text{fast} \)

D. \( \text{NO}_2 + \text{NO}_2 \rightarrow \text{NO}_3 + \text{NO} \)  
   \( \text{NO}_3 + \text{CO} \rightarrow \text{NO}_2 + \text{CO}_2 \)  
   \( \text{slow} \)

Answer: D

64. Which of the following statements is false?

A. A catalyst increases the rate of the forward reaction, but does not alter the reverse rate.
B. A catalyst alters the mechanism of reaction.
C. A catalyst alters the activation energy.
D. A catalyst may be altered in the reaction, but is always regenerated.
E. A catalyst increases the rate of reaction, but is not consumed.

Answer: A

65. Complete the following statement: A catalyst

A. increases the activation energy.
B. alters the reaction mechanism.
C. increases the average kinetic energy of the reactants.
D. increases the concentration of reactants.
E. increases the collision frequency of reactant molecules.

Answer: B
66. With respect to the figure below, which choice correctly identifies all the numbered positions?

- A. catalyst intermediate activated complex product
- B. reactants activated complex intermediate product
- C. reactants activated complex catalyst product
- D. reactants intermediate activated complex product
- E. reactants intermediate activated complex catalyst

Answer: D

67. The activation energy of a certain uncatalyzed reaction is 64 kJ/mol. In the presence of a catalyst, the $E_a$ is 55 kJ/mol. How many times faster is the catalyzed than the uncatalyzed reaction at 400°C? Assume that the frequency factor remains the same.

- A. 5.0 times
- B. 1.16 times
- C. 15 times
- D. 2.0 times
- E. 0.2 times

Answer: A
68. Nitrous oxide (N₂O) decomposes at 600°C according to the balanced equation
   \[ 2\text{N}_2\text{O}(g) \rightarrow 2\text{N}_2(g) + \text{O}_2(g) \]

   A reaction mechanism involving three steps is shown below. Identify all of the
   catalysts in the following mechanism.
   
   \[
   \begin{align*}
   \text{Cl}_2(g) & \rightarrow 2\text{Cl}(g) \\
   \text{N}_2\text{O}(g) + \text{Cl}(g) & \rightarrow \text{N}_2(g) + \text{ClO}(g) \quad \text{(occurs twice)} \\
   \text{ClO}(g) + \text{ClO}(g) & \rightarrow \text{Cl}_2(g) + \text{O}_2(g)
   \end{align*}
   \]

   A. Cl    B. Cl₂    C. ClO    D. N₂O    E. ClO and Cl
   
   Answer: B

69. Peroxodisulfate ion can oxidize iodide ions to iodine according to the balanced
   equation
   \[ \text{S}_2\text{O}_8^{2-} + 2\text{I}^- \rightarrow 2\text{SO}_4^{2-} + \text{I}_2. \]

   The reaction is catalyzed by certain chemical species. Identify the catalyst in the
   following mechanism:
   
   \[
   \begin{align*}
   \text{step 1:} & \quad \text{Fe}^{3+} + 2\text{I}^- \rightarrow \text{Fe}^{2+} + \text{I}_2 \\
   \text{step 2:} & \quad \text{S}_2\text{O}_8^{2-} + \text{Fe}^{2+} \rightarrow 2\text{SO}_4^{2-} + \text{Fe}^{3+}
   \end{align*}
   \]

   A. Fe³⁺    B. I⁻    C. S₂O₈²⁻    D. Fe²⁺    E. SO₄²⁻
   
   Answer: A

70. In which of the forms listed below would 0.5 g aluminum react the fastest with
gaseous chlorine at 25°C?
   
   A. 0.5 g aluminum in one piece
   B. 0.5 g aluminum divided into 10 pieces
   C. 0.5 g aluminum divided into 100 pieces
   D. 0.5 g aluminum divided into 1,000 pieces
   E. All the choices will react at the same rate since the temperature is the
   same.
   
   Answer: D
71. For the reaction whose rate law is rate = k[X], a plot of which of the following is a straight line?

A. [X] versus time
B. log [X] versus time
C. 1/[X] versus time
D. [X] versus 1/time
E. log [X] versus 1/time

Answer: B

72. For the reaction represented below, the experimental rate law is given by rate = k [(CH₃)₃CCl].

\[
(CH_3)_3CCl(aq) + OH^- \rightarrow (CH_3)_3COH(aq) + Cl^-
\]

If some solid sodium hydroxide were added to a solution in which [(CH₃)₃CCl] = 0.01 M and [NaOH] = 0.10 M, which of the following would be true? (Assume the temperature and volume remain constant.)

A. Both the reaction rate and k would increase.
B. Both the reaction rate and k would decrease.
C. Both the reaction rate and k would remain the same.
D. The reaction rate would increase but k would remain the same.
E. The reaction rate would decrease but k would remain the same.

Answer: C

73. At a particular temperature the first-order gas-phase reaction 2N₂O₅ → 2N₂O₄ + O₂ has a half-life for the disappearance of dinitrogen pentoxide of 3240 s. If 1.00 atm of N₂O₅ is introduced into an evacuated 5.00 L flask, what will be the total pressure of the gases in the flask after 1.50 hours?

A. 0.685 atm  B. 1.00 atm  C. 0.315 atm  D. 1.68 atm  E. 1.34 atm

Answer: E

74. At a particular temperature the first-order gas-phase reaction N₂O₅ → 2NO₂ + (1/2)O₂ has a half-life for the disappearance of dinitrogen pentoxide of 5130 s. Suppose 0.450 atm of N₂O₅ is introduced into an evacuated 2.00 L flask. What will be the total gas pressure inside the flask after 3.00 hours?

A. 0.969 atm  B. 0.105 atm  C. 0.795 atm  D. 1.14 atm  E. 0.864 atm

Answer: A
75. When acetaldehyde at a pressure of 364 mmHg is introduced into an evacuated 500.
mL flask at 518°C, the half-life for the second-order decomposition process,
$\text{CH}_3\text{CHO} \rightarrow \text{CH}_4 + \text{CO}$, is 410. s. What will be the total pressure in the flask after
1.00 hour?

A. 327 mmHg  B. 654 mmHg  C. 37 mmHg
D. 691 mmHg  E. 728 mmHg

Answer: D
Difficulty: H