Chemistry 106, Chapter 11 Exercises

Reaction Rate

1. Consider the combustion of ethane:

\[
\text{C}_2\text{H}_6(\text{g}) + 7\text{O}_2(\text{g}) \rightarrow 4\text{CO}_2(\text{g}) + 6\text{H}_2\text{O}(\text{g})
\]

If the ethane is burning at the rate of 0.20 M/s, at what rates are CO\(_2\) and H\(_2\)O being formed?

Ans. CO\(_2\), 0.8 M/s; H\(_2\)O, 1.2 M/s

2. For the reaction

\[
5\text{Br}^- (\text{aq}) + \text{BrO}_3^-(\text{aq}) + 6\text{H}^+ (\text{aq}) \rightarrow 3\text{Br}_2(\text{aq}) + 3\text{H}_2\text{O}
\]

it was found that at a particular instant bromine was being formed at the rate of 0.039 M/s. At that instant, at what rate is

a. water being formed? Ans. 0.039 M/s
b. bromide ion being oxidized? Ans. 0.065 M/s
c. H\(^+\) being consumed? Ans. 0.078 M/s

3. The order of a reaction with respect to some reagent is determined to be 0 order. Determine the effect on the rate if the concentration of that reactant is:

a. doubled
b. tripled.

4. The order of a reaction with respect to some reagent is determined to be 1st order. Determine the effect on the rate if the concentration of that reactant is:

a. doubled
b. tripled.

5. The order of a reaction with respect to some reagent is determined to be 2nd order. Determine the effect on the rate if the concentration of that reactant is:

a. doubled
b. tripled
c. quadrupled.

Answers for 3-5: 3 no affect for both, 4a. doubled, 4b. tripled, 5a. rate would be 4 times greater, 5b. 9 times, 5c. 16 times
### Rate Expressions

6. Complete the following table for the reaction below.

\[ 2R(g) + 3S(g) \rightarrow \text{products} \]

The reaction is first order with respect to \( R \) and second with respect to \( S \).

<table>
<thead>
<tr>
<th>[R]</th>
<th>[S]</th>
<th>( k ) L(^2)/(mol(^2) min)</th>
<th>Rate M/min</th>
</tr>
</thead>
<tbody>
<tr>
<td>a 0.200</td>
<td>0.200</td>
<td>1.49</td>
<td></td>
</tr>
<tr>
<td>b 0.633</td>
<td></td>
<td>0.42</td>
<td>0.833</td>
</tr>
<tr>
<td>c 0.100</td>
<td>0.298</td>
<td></td>
<td>0.162</td>
</tr>
<tr>
<td>d 0.0500</td>
<td>0.0911</td>
<td></td>
<td>0.00624</td>
</tr>
</tbody>
</table>

**Ans.** a. 0.0119 M/min  
  b. 4.9 L  
  c. 2.33 M  
  d. 15.0 L\(^2\)/(mol\(^2\) min)

7. Complete the following table for the following reaction. The reaction is 1st order in both \( X \) and \( Y \).

\[ 2X(g) + Y(g) \rightarrow \text{products} \]

<table>
<thead>
<tr>
<th>[X]</th>
<th>[Y]</th>
<th>( k ) L/(mol min)</th>
<th>Rate M/hr</th>
</tr>
</thead>
<tbody>
<tr>
<td>a 0.100</td>
<td>0.400</td>
<td>1.89</td>
<td></td>
</tr>
<tr>
<td>b 0.600</td>
<td></td>
<td>0.884</td>
<td>0.159</td>
</tr>
<tr>
<td>c 0.025</td>
<td>13.4</td>
<td></td>
<td>0.0479</td>
</tr>
<tr>
<td>d 0.592</td>
<td>0.233</td>
<td></td>
<td>0.00112</td>
</tr>
</tbody>
</table>

**Ans.** a. 0.0756 M/hr  
  b. 0.300 M  
  c. 0.143 M  
  d. 8.12 \times 10^{-3} L/(mol hr)

8. For the reaction

\[ A \rightarrow \text{products} \]

The following data were obtained.

<table>
<thead>
<tr>
<th>Rate (M/min)</th>
<th>0.0167</th>
<th>0.0107</th>
<th>0.00601</th>
<th>0.00267</th>
</tr>
</thead>
<tbody>
<tr>
<td>[A]</td>
<td>0.100</td>
<td>0.0800</td>
<td>0.0600</td>
<td>0.0400</td>
</tr>
</tbody>
</table>

a. Write the rate expression for the reaction.  *Ans. rate = k[A]\(^2\)  
b. Calculate \( k \) for the experiment.  *Ans. \( k = 1.67 \text{ L/ (mol min)} \)
9. For the reaction involving the decomposition of Y, the following data were obtained.

<table>
<thead>
<tr>
<th>Rate (M/min)</th>
<th>0.288</th>
<th>0.245</th>
<th>0.202</th>
<th>0.158</th>
</tr>
</thead>
<tbody>
<tr>
<td>[Y]</td>
<td>0.200</td>
<td>0.170</td>
<td>0.140</td>
<td>0.110</td>
</tr>
</tbody>
</table>

a. Write the rate expression for the reaction. Ans. rate = k[Y]
b. Calculate k for the experiment. Ans. k = 1.44 min⁻¹

10. For the reaction

\[ \text{S}_2\text{O}_8^{2-}(\text{aq}) + 3\text{I}^-(\text{aq}) \rightarrow 2\text{SO}_4^{2-}(\text{aq}) + 3\text{I}^-(\text{aq}) \]

the following data were obtained at a certain temperature.

<table>
<thead>
<tr>
<th>Expt.</th>
<th>[S₂O₈²⁻]</th>
<th>[I⁻]</th>
<th>Initial Rate M/min</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.0200</td>
<td>0.0155</td>
<td>1.15 x 10⁻⁴</td>
</tr>
<tr>
<td>2</td>
<td>0.0250</td>
<td>0.0200</td>
<td>1.85 x 10⁻⁴</td>
</tr>
<tr>
<td>3</td>
<td>0.0300</td>
<td>0.0200</td>
<td>2.22 x 10⁻⁴</td>
</tr>
<tr>
<td>4</td>
<td>0.0300</td>
<td>0.0275</td>
<td>3.06 x 10⁻⁴</td>
</tr>
</tbody>
</table>

a. Write the rate expression for the reaction. Ans. rate = k[S₂O₈²⁻][I⁻]
b. Calculate k. Ans. 0.371 L/(mol.min)
c. When [S₂O₈²⁻] = 0.105 M and [I⁻] = 0.0875 M, what is the rate of the reaction. Ans. 3.41 x 10⁻³ M/min

11. For the reaction

\[ \text{BF}_3(\text{g}) + \text{NH}_3(\text{g}) \rightarrow \text{BF}_3\text{NH}_3(\text{g}) \]

the following data were obtained at a certain temperature.

<table>
<thead>
<tr>
<th>Expt.</th>
<th>[BF₃]</th>
<th>[NH₃]</th>
<th>Initial Rate M/min</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.100</td>
<td>0.100</td>
<td>0.0341</td>
</tr>
<tr>
<td>2</td>
<td>0.200</td>
<td>0.233</td>
<td>0.159</td>
</tr>
<tr>
<td>3</td>
<td>0.200</td>
<td>0.0750</td>
<td>0.0512</td>
</tr>
<tr>
<td>4</td>
<td>0.300</td>
<td>0.100</td>
<td>0.102</td>
</tr>
</tbody>
</table>

a. Write the rate expression for the reaction. Ans. rate = k[BF₃][NH₃]
b. Calculate k. Ans. 3.41 L/(mol.min)
c. When [BF₃] = 0.553 M and [NH₃] = 0.300 M, what is the rate of the reaction. Ans. 0.566 M/min
12. Hydrogen bromide is a highly reactive and corrosive gas used mainly as a catalyst for organic reactions. It is produced by reacting hydrogen and bromine gases together.

\[ \text{H}_2(\text{g}) + \text{Br}_2(\text{g}) \rightarrow 2\text{HBr} \]

The rate is followed by measuring the intensity of the orange color of the bromine gas. The following data are obtained.

<table>
<thead>
<tr>
<th>Expt.</th>
<th>[H(_2)]</th>
<th>[Br(_2)]</th>
<th>Initial Rate M/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.100</td>
<td>0.100</td>
<td>4.74 \times 10^{-3}</td>
</tr>
<tr>
<td>2</td>
<td>0.100</td>
<td>0.200</td>
<td>6.71 \times 10^{-3}</td>
</tr>
<tr>
<td>3</td>
<td>0.250</td>
<td>0.200</td>
<td>1.68 \times 10^{-2}</td>
</tr>
</tbody>
</table>

a. Write the rate expression for the reaction. \( \text{Ans. rate} = k[H_2][Br_2]^{1/2} \)

b. Calculate \( k \). \( \text{Ans. 0.150 L}^{1/2}/(\text{mol}^{1/2}\text{s}) \)

c. When \([H_2] = 0.455 \text{ M}\) and \([Br_2] = 0.215 \text{ M}\), what is the rate of the reaction? \( \text{Ans. 0.0316 M/s} \)

13. For the reaction

\[ 6\text{I}^- (\text{aq}) + \text{BrO}_3^- (\text{aq}) + 6\text{H}^+ (\text{aq}) \rightarrow 3\text{I}_2 (\text{aq}) + \text{Br}^- (\text{aq}) + 3\text{H}_2\text{O} \]

the rate was followed by measuring the appearance of \( \text{I}_2 \). The following data were obtained.

<table>
<thead>
<tr>
<th>[I(^-)]</th>
<th>[BrO(_3)(^-)]</th>
<th>[H(^+)]</th>
<th>Initial Rate (M/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0020</td>
<td>0.0080</td>
<td>0.020</td>
<td>8.89 \times 10^{-5}</td>
</tr>
<tr>
<td>0.0040</td>
<td>0.0080</td>
<td>0.020</td>
<td>1.78 \times 10^{-4}</td>
</tr>
<tr>
<td>0.020</td>
<td>0.0160</td>
<td>0.020</td>
<td>1.78 \times 10^{-4}</td>
</tr>
<tr>
<td>0.0020</td>
<td>0.0080</td>
<td>0.040</td>
<td>3.56 \times 10^{-4}</td>
</tr>
<tr>
<td>0.0015</td>
<td>0.0040</td>
<td>0.030</td>
<td>7.51 \times 10^{-5}</td>
</tr>
</tbody>
</table>

a. Write the rate expression. \( \text{Ans. rate} = k[I^-][BrO_3^-][H^+]^2 \)

b. Find \( k \). \( \text{Ans. 1.4 x 10}^4 \text{ L}^3/(\text{mol}^3\text{s}) \)

c. What is \( [H^+] \) when the rate is \( 5.00 \times 10^{-4} \text{ M/s} \) and \([I^-] = 0.0075 \text{ M}\) and \([\text{BrO}_3^-] = 0.015 \text{ M}\)? \( \text{Ans. 1.8 x 10}^2 \text{ M} \)

14. In dilute acid, sucrose (C\(_{12}\)H\(_{22}\)O\(_{11}\)) decomposes to glucose and fructose. The following data were obtained for the decomposition of sucrose.

<table>
<thead>
<tr>
<th>Time (min)</th>
<th>[C(<em>{12})H(</em>{22})O(_{11})]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.368</td>
</tr>
<tr>
<td>20</td>
<td>0.333</td>
</tr>
<tr>
<td>60</td>
<td>0.287</td>
</tr>
<tr>
<td>120</td>
<td>0.235</td>
</tr>
<tr>
<td>160</td>
<td>0.208</td>
</tr>
</tbody>
</table>

Write the rate expression for the reaction. \( \text{Ans. rate} = k[C_{12}H_{22}O_{11}]^2 \)
15. Nitrosyl bromide (NOBr) decomposes to nitrogen monoxide and bromine. Use the following data to obtain a rate expression for this reaction.

<table>
<thead>
<tr>
<th>Time (s)</th>
<th>0</th>
<th>6</th>
<th>12</th>
<th>18</th>
<th>24</th>
</tr>
</thead>
<tbody>
<tr>
<td>[NOBr]</td>
<td>0.0286</td>
<td>0.0253</td>
<td>0.0229</td>
<td>0.0208</td>
<td>0.0190</td>
</tr>
</tbody>
</table>

Ans. rate = k[NOBr]^2

Reactant Concentration and Time Relationship for First Order Reactions

16. The first order rate constant for the decomposition of a certain hormone in water at 25°C is $3.42 \times 10^{-4}$ day$^{-1}$.
   a. If a 0.0200 M solution of the hormone is stored at 25°C for two months, what will its concentration be at the end of that period? Ans. 0.0196 M
   b. How long will it take for the concentration of the solution to drop from 0.0200 M to 0.00350 M? Ans. $5.09 \times 10^3$ days (~14 yrs)
   c. What is the half-life for this hormone? Ans. $2.03 \times 10^3$ days (5.5 yrs)

17. In the first order decomposition of acetone at 500°C,

CH$_3$-CO-CH$_3$(g) → products

it was found that the concentration was 0.0300 M after 200 min and 0.0200 M after 400 min.
   a. Find the rate constant. Ans. $2.03 \times 10^{-3}$ min$^{-1}$
   b. Find the half life. Ans. 342 min
   c. Find the initial concentration. Ans. 0.0450 M

18. The decomposition of dimethyl ether (CH$_3$OCH$_3$) to methane, carbon monoxide, and hydrogen gases it was found to be first order. At 500°C, a 150.0 mg sample of dimethyl ether is reduced to 43.2 mg after three quarters of an hour.
   a. Find the rate constant. Ans. 1.65/hr
   b. Find the half life at 500°C. Ans. 0.420 hr
   c. How long will it take to decompose 95% of the dimethyl ether? Ans. 1.8 hr

19. The first order rate constant for the decomposition of a certain drug at 25°C is 0.215 month$^{-1}$.
   a. If 10.0 g of the drug is stored at 25°C for one year, how many grams of the drug will remain at the end of the year? Ans. 0.758 g
   b. What is the half life of the drug? Ans. 3.22 months
   c. How long will it take to decompose 65% of the drug? Ans. 4.9 months

20. The decomposition of phosphine, PH$_3$, to P$_4$(g) and H$_2$(g) is first order. Its rate constant at a certain temperature is 1.1 min$^{-1}$.
   a. What is the half-life in seconds? Ans. 38 s
   b. What percentage of phosphine is decomposed after 1.25 min? Ans. 75%
   c. How long will it take to decompose one fifth of the phosphine? Ans. 0.20 min
21. The decomposition of ethane, C\(_2\)H\(_6\), is a first order reaction. It is found that it takes 212 s to decompose 0.00839 M C\(_2\)H\(_6\) to 0.00768 M.
   a. What is the rate constant for the reaction? \textit{Ans. }4.17 \times 10^{-4} \text{ s}^{-1}
   b. What is the rate of decomposition (in M/hr) when [C\(_2\)H\(_6\)] = 0.00422 M? \textit{Ans. }6.34 \times 10^{-3} \text{ M/hr}
   c. How long (in minutes) will it take to decompose C\(_2\)H\(_6\) so that 27 \% remains? \textit{Ans. }52 \text{ min}
   d. What percentage of C\(_2\)H\(_6\) is decomposed after 22 min? \textit{Ans. }42\%

22. Copper-64 is one of the metals used to study brain activity. Its decay constant is 0.0546 hr\(^{-1}\). If a solution containing 5.00 mg of Cu-64 is used, how many milligrams of Cu-64 remain after eight hours? \textit{Ans. }3.23 \text{ mg}

23. Iodine-131 is used to treat tumors in the thyroid. Its first order half-life is 8.1 days. If a patient is given a sample containing 5.00 mg of I-131, how long will it take for 25\% of the isotope to remain in her system? \textit{Ans. }16 \text{ days}

\textbf{Rate Expressions from Reaction Mechanisms}

24. Reaction: H\(_2\) + I\(_2\) \rightarrow 2HI

   Mechanism:
   \(I_2 \leftrightarrow 2I\) (fast)
   \(H_2 + I + I \rightarrow 2HI\) (slow)

   Determine the rate expression.
   \textit{Ans. }rate = k[H\(_2\)][I\(_2\)]

25. Reaction: 2H\(_2\) + 2NO \rightarrow N\(_2\) + 2H\(_2\)O

   Mechanism:
   2NO \leftrightarrow N\(_2\)O\(_2\) (fast)
   N\(_2\)O\(_2\) + H\(_2\) \rightarrow H\(_2\)O + N\(_2\)O (slow)
   N\(_2\)O + H\(_2\) \rightarrow N\(_2\) + H\(_2\)O (fast)

   Determine the rate expression.
   \textit{Ans. }rate = k[NO]^2[H\(_2\)]

26. Reaction: CO + NO\(_2\) \rightarrow CO\(_2\) + NO

   Mechanism:
   2NO\(_2\) \rightarrow 2NO + O\(_2\) (slow)
   O\(_2\) + 2CO \leftrightarrow 2CO\(_2\) (fast)

   Determine the rate expression.
   \textit{Ans. }rate = k[NO\(_2\)]^2
For the reaction below there are two possible mechanisms.

$$2\text{NO} + \text{O}_2 \rightarrow 2\text{NO}_2$$

**Mechanism a:**
- \(\text{NO} + \text{O}_2 \leftrightarrow \text{NO}_3\) (fast)
- \(\text{NO}_3 + \text{NO} \rightarrow 2\text{NO}_2\) (slow)

**Mechanism b:**
- \(\text{NO} + \text{NO} \leftrightarrow \text{N}_2\text{O}_2\) (fast)
- \(\text{N}_2\text{O}_2 + \text{O}_2 \rightarrow 2\text{NO}_2\) (slow)

Determine the rate expression for each.

*Ans. a. rate = k[NO]^{2}[O_2],  b. rate = k[NO]^{2}[O_2]*