(15) 1. Consider the combustion of ethanol, \( \text{C}_2\text{H}_5\text{OH} \), to produce carbon dioxide and water. Use the data in the table below to answer the following questions.

<table>
<thead>
<tr>
<th></th>
<th>( \Delta G^\circ ) (kJ mol(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \text{C}_2\text{H}_5\text{OH} ) (l)</td>
<td>-174.9</td>
</tr>
<tr>
<td>( \text{CO}_2 ) (g)</td>
<td>-394.4</td>
</tr>
<tr>
<td>( \text{H}_2\text{O} ) (l)</td>
<td>-237.2</td>
</tr>
<tr>
<td>( \text{O}_2 ) (g)</td>
<td>0</td>
</tr>
</tbody>
</table>

5. Write a balanced chemical equation for the reaction.

\[
\text{C}_2\text{H}_5\text{OH} + 3 \text{O}_2 \rightarrow 2\text{CO}_2 + 3\text{H}_2\text{O}
\]

5. Calculate \( \Delta G^\circ \) for the reaction.

\[
\Delta G^\circ_{\text{reaction}} = \Sigma v \Delta G^\circ_{\text{prod}} - \Sigma v \Delta G^\circ_{\text{react}}
\]

\[
= \left[ (2 \text{mol})(-394.4 \text{kJ/mol}) + (3 \text{mol})(-237.2 \text{kJ/mol}) \right] - \left[ (1 \text{mol})(-174.9 \text{kJ/mol}) \right]
\]

\[
= -1326 \text{kJ/mol}
\]

5. Is this reaction spontaneous at 25°C? Why or why not?

\[
\text{Spontaneous} - \text{the sign of } \Delta G \text{ is negative}
\]
II. Consider a 0.01 M solution of benzoic acid, HC$_7$H$_5$O$_2$, a food preservative. $K_a = 6.17 \times 10^{-5}$

1. Write the chemical equation for the reaction of benzoic acid with water and identify both conjugate acid-base pairs.

\[
\text{acid} & \quad \text{base} \\
HC_7H_5O_2 + H_2O & \rightleftharpoons H_3O^+ + C_7H_5O_2^- \\
\text{base} & \quad \text{acid}
\]

15 2. What is the equilibrium concentration of H$_3$O$^+$?

\[
\begin{align*}
K_a &= \frac{[H_3O^+][C_7H_5O_2^-]}{[HC_7H_5O_2]} \\
6.17 \times 10^{-5} &= \frac{x^2}{0.01} \\
x^2 &= 6.17 \times 10^{-7} \\
[H_3O^+] &= x = 7.85 \times 10^{-4} \text{ M}
\end{align*}
\]

5 3. What is the pH of this solution?

\[
\begin{align*}
\text{pH} &= -\log [H_3O^+] = -\log (7.85 \times 10^{-4}) \\
\text{pH} &= 3.1
\end{align*}
\]

III.

1. Fill in the following table for the processes indicated.

<table>
<thead>
<tr>
<th>Process</th>
<th>Sign of $\Delta S$</th>
<th>Is the process spontaneous?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Burning of octane, C$<em>8$H$</em>{18}$</td>
<td>$+$</td>
<td>yes</td>
</tr>
<tr>
<td>Collapse of a building</td>
<td>$+$</td>
<td>yes</td>
</tr>
<tr>
<td>Freezing of water at -10$^\circ$C</td>
<td>$-$</td>
<td>yes</td>
</tr>
</tbody>
</table>

2. How can a process be spontaneous if entropy is decreasing?

*If the total entropy (system + surroundings) is increasing, the process is spontaneous.*
IV. A possible reaction for the degradation of the pesticide DDT to a less harmful compound was simulated in the lab. The reaction was found to be first order, with $k = 4.0 \times 10^{-8} \text{ s}^{-1}$ at 25°C.

1. Write the rate expression (rate law) for this reaction.

$$\text{Rate} = k [\text{DDT}]$$

2. The rate of the process increases at higher temperature. Explain, based on your rate expression in part 1 above, why the rate increases at a higher temperature.

$$k \text{ increases at high temperature, so } -\frac{\Delta E}{RT}$$

3. A catalyst could increase the rate of the reaction. What is a catalyst? Explain, based on your rate expression in part 1, why the rate increases with a catalyst.

A catalyst is something that is present at both the beginning and end of the reaction that changes the rate of the reaction. A catalyst allows the reaction to proceed by a different mechanism with a lower $E_a$.

4. What is the half-life for this reaction in years?

For a first order process

$$t_{1/2} = \frac{0.693}{k}$$

$$t_{1/2} = \frac{0.693}{4.0 \times 10^{-8} \text{ s}^{-1}} = 1.73 \times 10^7 \text{ sec}$$

$$t_{1/2} = 1.73 \times 10^7 \text{ sec} \left( \frac{1 \text{ min}}{60 \text{ sec}} \right) \left( \frac{1 \text{ hr}}{60 \text{ min}} \right) \left( \frac{1 \text{ day}}{24 \text{ hr}} \right) \left( \frac{1 \text{ yr}}{365 \text{ days}} \right)$$

5. How long (in years) would it take for 1 g of DDT to degrade to 0.125 g?

1 $\rightarrow$ 0.125 is 3 half-lives

$$t_{1/2} = 0.55 \text{ years}$$

$$t_{1/2} = 0.55 \text{ yr} \text{ half-life} (3 \text{ half-lives}) = 1.65 \text{ years}$$