Week 4 Free energy

QUESTION 1

Which one of the following processes has a negative standard free energy change at 25°C?

A. \( \text{CO}_2(g) + 2 \text{H}_2\text{O}(l) \rightarrow \text{CH}_4(g) + 2 \text{O}_2(g) \)
B. \( 2 \text{Na}(s) + 2 \text{H}_2\text{O}(l) \rightarrow 2 \text{NaOH}(aq) + \text{H}_2(g) \)
C. \( 2 \text{H}_2\text{O}(l) \rightarrow 2 \text{H}_2(g) + \text{O}_2(g) \)
D. \( 2 \text{KCl}(s) \rightarrow 2 \text{K}(s) + \text{Cl}_2(g) \)
E. \( \text{AgCl}(s) \rightarrow \text{Ag}^+(aq) + \text{Cl}^-(aq) \)

QUESTION 2

Consider the following reaction occurring in an automobile engine. What are the signs of \( \Delta H \), \( \Delta S \), and \( \Delta G \) for this process?

\( 2 \text{C}_8\text{H}_{18}(l) + 25 \text{O}_2(g) \rightarrow 16 \text{CO}_2(g) + 18 \text{H}_2\text{O}(g) \)

<table>
<thead>
<tr>
<th>( \Delta H )</th>
<th>( \Delta S )</th>
<th>( \Delta G )</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>–</td>
<td>+</td>
</tr>
<tr>
<td>B.</td>
<td>+</td>
<td>–</td>
</tr>
<tr>
<td>C.</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>D.</td>
<td>–</td>
<td>+</td>
</tr>
<tr>
<td>E.</td>
<td>+</td>
<td>+</td>
</tr>
</tbody>
</table>

QUESTION 3

Consider the reaction (demonstrated in class) which occurs when a balloon filled with \( \text{H}_2(g) \) and \( \text{O}_2(g) \) is ignited. What would be the signs of \( \Delta H \), \( \Delta S \) and \( \Delta G \) for this reaction?

\( 2 \text{H}_2(g) + \text{O}_2(g) \rightarrow 2 \text{H}_2\text{O}(g) \)

<table>
<thead>
<tr>
<th>( \Delta H )</th>
<th>( \Delta S )</th>
<th>( \Delta G )</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>B.</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>C.</td>
<td>–</td>
<td>+</td>
</tr>
<tr>
<td>D.</td>
<td>+</td>
<td>–</td>
</tr>
<tr>
<td>E.</td>
<td>+</td>
<td>+</td>
</tr>
</tbody>
</table>

QUESTION 4

Consider the following reaction. What will be the signs of \( \Delta H \) and \( \Delta S \) if the reaction is ALWAYS spontaneous?

\( \text{A} + \text{B} \rightarrow \text{C} + \text{D} \)

<table>
<thead>
<tr>
<th>( \Delta H )</th>
<th>( \Delta S )</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>+</td>
</tr>
<tr>
<td>B.</td>
<td>–</td>
</tr>
<tr>
<td>C.</td>
<td>+</td>
</tr>
<tr>
<td>D.</td>
<td>–</td>
</tr>
</tbody>
</table>
QUESTION 5

Determine the value of $\Delta G^\circ$ for the following reaction taking place at 25°C.

$$2 \text{C}_2\text{H}_6(\text{g}) + 7 \text{O}_2(\text{g}) \rightarrow 4 \text{CO}_2(\text{g}) + 6 \text{H}_2\text{O}(\text{g})$$

<table>
<thead>
<tr>
<th>Substance</th>
<th>$\Delta G^\circ_f$ (kJ/mol)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C$_2$H$_6$(g)</td>
<td>-32.89</td>
</tr>
<tr>
<td>O$_2$(g)</td>
<td>0</td>
</tr>
<tr>
<td>CO$_2$(g)</td>
<td>-394.4</td>
</tr>
<tr>
<td>H$_2$O(g)</td>
<td>-228.57</td>
</tr>
</tbody>
</table>

A. $-3015 \text{ kJ mol}^{-1}$
B. $-2883 \text{ kJ mol}^{-1}$
C. $-2851 \text{ kJ mol}^{-1}$
D. $-590 \text{ kJ mol}^{-1}$
E. $-557 \text{ kJ mol}^{-1}$

QUESTION 6

Consider the following table of thermodynamic data. What is the value of $\Delta H^\circ$ at 25°C for the reaction shown below?

$$\text{N}_2\text{O}(\text{g}) + \text{NO}_2(\text{g}) \rightarrow 3 \text{NO}(\text{g})$$

<table>
<thead>
<tr>
<th>Substance</th>
<th>$\Delta G^\circ_f$ (kJ/mol)</th>
<th>$S^\ast$ (J/mol K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NO(g)</td>
<td>86.7</td>
<td>211</td>
</tr>
<tr>
<td>NO$_2$(g)</td>
<td>51.8</td>
<td>240</td>
</tr>
<tr>
<td>N$_2$O(g)</td>
<td>103.6</td>
<td>220</td>
</tr>
</tbody>
</table>

A. +156.2 kJ
B. +5.5 kJ
C. +53.2 kJ
D. +109.0 kJ
E. −142.9 kJ

QUESTION 7

The enthalpy $\Delta H$ and T$\Delta S$ for a reaction are shown on the plot below. If the dashed line corresponds to a temperature of 425 K, are the following statements true or false?

I. The reactants and products are at equilibrium at 425 K.
II. Above 425 K, the reaction will be spontaneous.
QUESTION 8
At 298 K, ΔH° = 88.3 kJ and ΔS° = 151.3 J K⁻¹ for the following reaction.

\[ \text{PbCO}_3(s) \rightarrow \text{PbO}(s) + \text{CO}_2(g) \]

a. What is ΔG° for this reaction at 298 K?

b. What is ΔG for this reaction at 1210 K?

QUESTION 9
Using the information given in the table below, determine ΔG°rxn for the following reactions. Under standard conditions, is the reaction spontaneous?

<table>
<thead>
<tr>
<th>ΔH°rxn (kJ)</th>
<th>ΔS°rxn (J K⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. 2 CH₃OH(g) + H₂(g) → C₂H₅(g) + 2 H₂O(g)</td>
<td>-165.9</td>
</tr>
<tr>
<td>b. 2 NH₃(g) → N₂H₄(g) + H₂(g)</td>
<td>+188.0</td>
</tr>
<tr>
<td>c. BaCO₃(s) → BaO(s) + CO₂(g)</td>
<td>+267.1</td>
</tr>
</tbody>
</table>

QUESTION 10
A student mixes two reagents together and nothing happens. He then adds a catalyst to the mixture and the reaction proceeds. What does this tell the student about ΔG?

A. Information does not give any information about ΔG.
B. The student knows that ΔG is positive and that the reaction is not spontaneous.
C. The student knows that ΔG is negative and that the reaction is spontaneous.
D. The student knows that ΔG is zero and that the reaction is at equilibrium.

QUESTION 11
A student mixes two reagents together and nothing happens. He then adds a catalyst to the mixture and the reaction proceeds. Which of the following statements about this are true?

A. The reaction does not proceed without a catalyst because the activation energy is too high.
B. The reaction does not proceed without a catalyst because it is not spontaneous.
C. The reaction does not proceed without a catalyst because it is at equilibrium.
D. There is not enough information to be able to tell why the reaction does not occur without a catalyst.

QUESTION 12
Which of the following statements is false?

A. A spontaneous reaction can be endothermic.
B. A spontaneous reaction can be very slow.
C. A catalyst can be used to speed up some spontaneous reactions.
D. For a system at equilibrium ΔGrxn is zero.
E. A spontaneous reaction must have a negative enthalpy change.

QUESTION 13
For the following reaction, ΔH° = 131.3 kJ mol⁻¹, and ΔS° = 133.6 J mol⁻¹ K⁻¹. Assuming ΔH and ΔS do not vary with temperature, at what temperature will the reaction become spontaneous?

\[ \text{C(s) + H}_2\text{O}(g) \rightarrow \text{CO(g) + H}_2(g) \]

A. -272°C
B. 1°C
C. 552°C
D. 710°C
E. 947°C
QUESTION 14

For the following reaction, \( \Delta G^\circ = -140.1 \text{ kJ}, \Delta H^\circ = -196.6 \text{ kJ}, \) and \( \Delta S^\circ = -189.6 \text{ J/K}. \) Assuming \( \Delta H \) and \( \Delta S \) do not vary with \( T \), at what temperature would the following reaction become non-spontaneous?

\[ 2 \text{SO}_2(\text{g}) + \text{O}_2(\text{g}) \rightarrow 2 \text{SO}_3(\text{g}) \]

A. The reaction would be spontaneous at all temperatures.
B. 1037°C
C. 739°C
D. 764°C
E. The reaction would be nonspontaneous at all temperatures.

QUESTION 15

The entropy of vaporization (\( \Delta S^\circ_{\text{vap}} \)) for benzene is 96.4 J/K-mol. The enthalpy of vaporization (\( \Delta H^\circ_{\text{vap}} \)) is 33.9 kJ/mol. What is the normal boiling point of benzene?

A. 2.8°C
B. 0.35°C
C. 100°C
D. 54°C
E. 79°C

QUESTION 16

Given the following thermodynamic data, calculate the magnitude of the equilibrium constant at 25°C for the following reaction.

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

<table>
<thead>
<tr>
<th>Substance</th>
<th>( \Delta G^\circ_f ) (kJ/mol)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HBr(g)</td>
<td>-53.22</td>
</tr>
<tr>
<td>Cl(_2)(g)</td>
<td>0</td>
</tr>
<tr>
<td>HCl(g)</td>
<td>-95.27</td>
</tr>
<tr>
<td>Br(_2)(g)</td>
<td>+3.14</td>
</tr>
</tbody>
</table>

A. \( 2.0 \times 10^{15} \)
B. \( 1.6 \times 10^{14} \)
C. \( 5.5 \times 10^{14} \)
D. \( 1.6 \times 10^{-14} \)
E. \( 5.5 \times 10^{-14} \)

QUESTION 17

What is the value of \( \Delta G^\circ \) for this reaction at 25°C if \( K_{\text{eq}} = 5.0 \times 10^8 \)?

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

A. +22 kJ/mole
B. +50 kJ/mole
C. -4.2 kJ/mole
D. -25 kJ/mole
E. -50 kJ/mole

QUESTION 18

Which one of the following statements is always true about the equilibrium constant for a reaction if \( \Delta G^\circ \) for the reaction is negative?

A. \( K = 0 \)
B. \( K = 1 \)
C. \( K > 1 \)
D. \( K < 1 \)
E. \( K < 0 \)
**QUESTION 19**

If $K_a$ is $1.8 \times 10^{-5}$ for the following reaction at 298K, what is the value of $\Delta G$ under the following set of conditions?

$[\mathrm{CH}_3\mathrm{COOH}] = 0.100 \text{ M}, [\mathrm{CH}_3\mathrm{COO}^-] = 0.100 \text{ M}, [\mathrm{H}^+] = 0.0200 \text{ M}$

$\mathrm{CH}_3\mathrm{COOH(aq)} \rightleftharpoons \mathrm{H}^+(aq) + \mathrm{CH}_3\mathrm{COO}^-(aq)$

A. −17.4 kJ/mole  
B. 27.1 kJ/mole  
C. 17.4 kJ/mole  
D. −27.1 kJ/mole  
E. 36.7 kJ/mole

**QUESTION 20**

For the following reactions, explain qualitatively what will happen to $\Delta G$, how the direction of the reaction will shift, and how the spontaneity will be affected when the partial pressure of $\mathrm{O}_2(g)$ increases.

a. $2 \mathrm{H}_2\mathrm{O}(l) \rightarrow 2 \mathrm{H}_2\mathrm{O}(l) + \mathrm{O}_2(g)$  
b. $2 \mathrm{Mg}(s) + \mathrm{O}_2(g) \rightarrow 2 \mathrm{MgO}(s)$  
c. $2 \mathrm{CO}(g) \rightarrow 2 \mathrm{CO}(g) + \mathrm{O}_2(g)$

**QUESTION 21**

Write the expression for the equilibrium constant for each of the following reactions. Use the thermodynamic data in the data tables to determine the value of the equilibrium constant at standard conditions.

a. $3 \mathrm{C}_2\mathrm{H}_2(g) \rightleftharpoons \mathrm{C}_6\mathrm{H}_6(l)$  
b. $\mathrm{BaSO}_4(s) \rightleftharpoons \mathrm{Ba}^{2+}(aq) + \mathrm{SO}_4^{2-}(aq)$  
c. $\mathrm{NH}_3(aq) + \mathrm{H}_2\mathrm{O}(l) \rightleftharpoons \mathrm{NH}_4^+(aq) + \mathrm{OH}^-(aq)$

**QUESTION 22**

For the following reaction, what is the value of $\Delta G$ when the concentration of $\mathrm{NO}_2(g)$ is 1.00 M, the concentration of $\mathrm{O}_2(g)$ is 0.50 M, and the concentration of $\mathrm{N}_2\mathrm{O}(g)$ is 0.50 M at 25°C? Use the thermodynamic data provided in the data table.

$2 \mathrm{N}_2\mathrm{O} (g) + 3 \mathrm{O}_2 (g) \rightarrow 4 \mathrm{NO}_2 (g)$

<table>
<thead>
<tr>
<th>Substance</th>
<th>$\Delta G^\circ$ (kJ mol$^{-1}$)</th>
<th>$\Delta H^\circ$ (kJ mol$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\mathrm{N}_2\mathrm{O}$</td>
<td>103.59</td>
<td></td>
</tr>
<tr>
<td>$\mathrm{NO}_2$</td>
<td>51.84</td>
<td></td>
</tr>
</tbody>
</table>

A. −7.82 kJ mol$^{-1}$  
B. +6.45 kJ mol$^{-1}$  
C. +10.21 kJ mol$^{-1}$  
D. −3.28 kJ mol$^{-1}$  
E. +8.77 kJ mol$^{-1}$

**QUESTION 23**

In the fermentation process, microorganisms convert sugar to alcohol according to the following reaction. Use the thermodynamic data below to determine the maximum amount of work that the microorganism can get out of this fermentation process.

$\mathrm{C}_6\mathrm{H}_12\mathrm{O}_6(s) = 2 \mathrm{C}_2\mathrm{H}_5\mathrm{OH}(l) + 2 \mathrm{CO}_2(g)$

<table>
<thead>
<tr>
<th>$\Delta G^\circ$ (kJ mol$^{-1}$)</th>
<th>$\Delta H^\circ$ (kJ mol$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>−910.4</td>
<td>−174.76</td>
</tr>
<tr>
<td>−394.4</td>
<td>−277.7</td>
</tr>
<tr>
<td>−393.5</td>
<td></td>
</tr>
</tbody>
</table>