THERMODYNAMICS

True or False?
1. _____ A process in which the system absorbs heat from its surroundings is called endothermic.
2. _____ The process described by the thermochemical equation below is exothermic.
   \[ \text{H}_2(g) + \text{I}_2(g) \rightarrow 2\text{HI}(g) + \text{heat} \]
3. _____ The process described by the thermochemical equation below has a positive $\Delta H$.
   \[ \text{H}_2(g) + \text{I}_2(g) \rightarrow 2\text{HI}(g) + \text{heat} \]
4. _____ A reaction that is exothermic must be spontaneous.
5. _____ A reaction that is spontaneous is known as endergonic.

Fill in the Blank
6. Hess’s Law is true because ______________ is a state function.
7. For a change that takes place at constant pressure, the heat change for the system is known as the change in ____________.
8. Given that a reaction is spontaneous, and it goes to a decreased state of disorder, will it be exothermic or endothermic, or can you not tell without calculations? ______________
9. If a reaction is endothermic, but also spontaneous, what must the sign of $\Delta S$ be? ___________
10. If a reaction is exothermic and it goes to an increased state of disorder, will it be spontaneous or non-spontaneous? ________________ What is the sign of $\Delta G$? __________
11. A) In the laboratory you are performing an experiment and you note that heat is given off. What is the sign for the change in enthalpy of this reaction? ______________
    B) Is the potential energy of the reactants lesser or greater than the potential energy of the products? ______________
    C) You note that the reaction is spontaneous. Just from this information, can you determine the sign of the change in entropy, and if so, what is it? ______________
12. Predict the sign of the change in entropy for the condensation of steam to liquid water. ___________
13. Predict the sign of the change in entropy for the sublimation of a solid to a gas. ___________
14. When we have a system at equilibrium, we know that $\Delta G$ is equal to __________.
15. When ammonium chloride dissolves in water, the mixture becomes cool. For this change, which is of a larger magnitude, $T \Delta S$ or $\Delta H$? __________
16. For the reaction $2 \text{H}_2(g) + \text{O}_2(g) \rightarrow 2 \text{H}_2\text{O}(l)$, which is more disordered, the products or reactants? ______________
17. What are the units for entropy? ______________

D2-1
18. On the basis of ∆G, decide if the reaction is spontaneous or non-spontaneous.
   A. 2 H₂O₂(aq) → O₂(g) + 2 H₂O(l)  ΔG = -211 kJ/mol  ________________
   B. HCOOH(l) → CO₂(g) + H₂(g)  ΔG = 119 kJ/mol  ________________

Short Answer & Multiple Choice
Write the reaction for the standard molar enthalpy of formation for hydrogen iodide gas.

1. Arrange the following in order of increasing entropy:
   Hg(l), Hg(s), C₆H₆(l), CH₃OH(g)
   • a. Hg(s), CH₃OH(g), C₆H₆(l), Hg(l)
   • b. CH₃OH(g), Hg(s), Hg(l), C₆H₆(l)
   • c. Hg(l), Hg(s), C₆H₆(l), CH₃OH(g)
   • d. Hg(s), Hg(l), C₆H₆(l), CH₃OH(g)
   • e. Hg(s), Hg(l), CH₃OH(g), C₆H₆(l)

2. The heat of fusion of acetic acid is 11.5 kJ/mol. Its melting point is 16.6°C. The change in entropy for the melting of acetic acid in J/mol·K is
   • a. -11.5
   • b. 11.5
   • c. 15.1
   • d. 39.7
   • e. 694

3. In which one of the following processes would one expect ∆S to have a value closest to zero?
   • a. H₂(g) + F₂(g) --> 2HF(g)
   • b. C₂H₄(g) + HBr(g) --> C₂H₅Br(g)
   • c. CO(g) + 1/2 O₂(g) --> CO₂(g)
   • d. 2NO(g) + O₂(g) --> 2NO₂(g)
   • e. CH₃C(O)H(g) + 5/2 O₂(g) --> 2CO₂(g) + 2H₂O(g)
4. For each of the following sets of conditions, predict the conditions of spontaneity by placing a mark in the appropriate box.

<table>
<thead>
<tr>
<th>ΔH &gt; 0</th>
<th>ΔS &gt; 0</th>
<th>Always Spontaneous</th>
<th>Only at Low Temp.</th>
<th>Only at High Temp.</th>
<th>Never Spontaneous</th>
</tr>
</thead>
<tbody>
<tr>
<td>ΔH &gt; 0</td>
<td>ΔS &lt; 0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ΔH &lt; 0</td>
<td>ΔS &gt; 0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ΔH &lt; 0</td>
<td>ΔS &lt; 0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

5. Calculate ΔG (in kJ/mol) for the following reaction at 25°C using the data in the table to the right.

\[ 2 \text{NO}_2(g) \rightarrow \text{N}_2\text{O}_4(g) \]

<table>
<thead>
<tr>
<th></th>
<th>ΔH°f</th>
<th>S°</th>
</tr>
</thead>
<tbody>
<tr>
<td>NO₂(g)</td>
<td>33.18</td>
<td>240.06</td>
</tr>
<tr>
<td>N₂O₄(g)</td>
<td>11.10</td>
<td>304.29</td>
</tr>
</tbody>
</table>

6. Is the previous reaction driven by enthalpy or entropy change?

7. A student wishes to determine the heat capacity of a coffee-cup calorimeter. After she mixes 100.0g of water at 58.5°C with 105.0g of water already in the calorimeter at 22.8°C, the final temperature of the water is 39.7°C. The specific heat of water is 4.184 J/g °C.

Calculate the heat capacity of the calorimeter, C’, in J/°C.

Remember that \( q_{\text{system}} = -q_{\text{surroundings}} \)

We will treat the water added to the calorimeter as the system and the calorimeter and the water in it as the surroundings.

This can therefore be re-written as:

\[-(m)(c)(\Delta T)_{\text{water added to calorimeter}} = [(m)(c)(\Delta T)]_{\text{water in calorimeter}} + C'\Delta T \] (calorimeter)

Note: This is how the calorimeter constant for this week’s experiment was calculated!
8. \( \text{CS}_2(g) + 4 \text{H}_2(g) \rightarrow \text{CH}_4(g) + 2 \text{H}_2\text{S}(g) \) at 298 K and 1 atm

A. Calculate \( \Delta H_{\text{Rxn}}^{\circ} \) for the above reaction, using the \( \Delta H_{f}^{\circ} \) values in your references.

B. Is this reaction exothermic or endothermic? __________________

C. Will it favor spontaneity based on enthalpy? __________________

D. What would you predict the sign of \( \Delta S_{\text{Rxn}}^{\circ} \) to be. Give your reasoning.

E. Calculate the \( \Delta S_{\text{Rxn}}^{\circ} \) using the \( S^{\circ} \) values in your references.

F. Did your result match your prediction? ______

G. Calculate \( \Delta G_{\text{Rxn}}^{\circ} \) using the Gibbs Free Energy equation.

H. Calculate \( \Delta G_{\text{Rxn}}^{\circ} \) using the \( \Delta G_{f}^{\circ} \) values in your references.

I. Is the reaction spontaneous at this temp? Give your reasoning.

J. Is the reaction spontaneous at all temps? If not, calculate the temperature at which it switches to being non-spontaneous.