Section 1- Concepts and Definitions
(50 % of the total for this Exam, 5 points each)

1. Fill in the blank.

The Four Laws of Thermodynamics, not necessarily in order are:

The ________________ of the isolated system increases for a spontaneous process.

The total ________________ of the universe is constant.

The ________________ of a perfectly ordered crystal at 0 K is 0.

If A is in ________________ with B, and B is in ________________ with C, then C is also in ________________ with A.

2. Which of the following produces a DECREASE in entropy of the system? *Hint: the system is shown in italic.*
   a. Producing H₂ and O₂ gases during photocatalytic decomposition of water by TiO₂ catalyst.
   b. Condensation of water on the surface of a glass of iced tea on a hot summer day.
   c. Boiling water in a pot on the stove to make spaghetti.
   d. Dissolving sugar in a cup of coffee.
   e. Allowing the liquid propane in a gas grill to escape from the tank.

3. Which of the following is (are) an intensive property (es)?
   a. temperature
   b. mass
   c. chemical composition
   d. pressure
   e. entropy
   f. none of the above
4. A vapor and a liquid of the same substance can coexist (there could be multiple correct answers):
   a. only above the critical pressure
   b. only below the critical volume
   c. only above the critical temperature
   d. below the critical temperature
   e. none of the above

5. **When the pressure of an ideal gas** is reduced by factor of 3 and the absolute temperature is increased by factor of 3, its volume is:
   a. constant
   b. increased 3-fold
   c. decreased 3-fold
   d. increased 9-fold
   e. decreased 9-fold
   f. none of the above

6. **The graph on the left** shows a Boltzmann distribution of states at 298 K. Complete the graph on the right to make it consistent with the Third law of thermodynamics at temperature of zero degrees Kelvin.
7. **For a particular chemical reaction, both $\Delta H^\circ$ and $\Delta S^\circ$ are positive.** Which of the following statements about the spontaneity of the reaction under standard conditions is (are) **TRUE**?  
   a. The reaction will be spontaneous only if $\Delta A^\circ$ is negative.  
   b. The reaction will be spontaneous only if the magnitude of $\Delta H^\circ$ is large enough to overcome the unfavorable entropy change.  
   c. The reaction will be spontaneous only if the magnitude of $\Delta S^\circ$ is large enough to overcome the unfavorable enthalpy change.  
   d. The reaction will be spontaneous regardless of the magnitudes of $\Delta H^\circ$ and $\Delta S^\circ$.  
   e. The reaction cannot be spontaneous.  
   f. The reaction will be spontaneous only if $\Delta G^\circ$ is positive.  
   g. None of the above.

8. **On the figure below, label the isobar and isotherm:**

![Diagram of pressure, temperature, and volume axes with isobar and isotherm labels](image)
9. Provide at least four thermodynamic properties that are the state functions and do form the exact differentials.

10. In the figure below, \( G \) is shown as a function of which variable?
Section 2- Problems (50 % of the total for this exam, 10 points each)

1. Calculate the change in the molar Gibbs energy of nitrogen when its pressure is increased isothermally from 1.0 atm to 10.0 atm at 200 K.

2. The fusion (melting) point of a substance is the temperature at which the equilibrium is achieved between its liquid and solid phases.

\[ C_6H_6 (s) \leftrightarrow C_6H_6 (l) \]

Calculate the melting point (fusion temperature) point of benzene, if \( \Delta f^\circ H = 10.59 \) kJ/mol and \( \Delta f^\circ S = 38.00 \) J K\(^{-1}\) mol\(^{-1}\) for this process.
3. **For the following reaction** and thermodynamic data in the Table below,

\[
4 \text{ HCl (g)} + \text{ O}_2 (g) \rightleftharpoons 2 \text{ Cl}_2 (g) + 2 \text{ H}_2\text{O (l)}
\]

<table>
<thead>
<tr>
<th>Compound</th>
<th>( \Delta_h^\circ ), kJ mol(^{-1})</th>
<th>( S_m^\circ ), J mol(^{-1}) K(^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>HCl (g)</td>
<td>-92.31</td>
<td>186.91</td>
</tr>
<tr>
<td>O(_2) (g)</td>
<td></td>
<td>205.138</td>
</tr>
<tr>
<td>Cl(_2) (g)</td>
<td></td>
<td>223.07</td>
</tr>
<tr>
<td>H(_2)O (l)</td>
<td></td>
<td>-285.83</td>
</tr>
</tbody>
</table>

calculate (in kJ) the standard Gibbs energy \( \Delta_G^\circ \) of the reaction above at 298 K.

4. Five moles of Ne gas is expanded isothermally from a volume of 100 L to 1000 L at 700 K. **Calculate** (a) work \( w \), (b) heat \( q \), (c) change of internal energy \( \Delta U \), (d) change of enthalpy \( \Delta H \).
5. **Show** how to derive the Maxwell relation for Gibbs energy.