Worksheet – Entropy

Entropy, $S$, is a measure of how dispersed or spread out a system’s energy is among the available energy levels. The number of energy levels and how many are populated depend on a number of factors.

- As temperature is increased more of the excited state energy levels will be populated
  Increasing temperature always increases entropy
- In gaseous system, increasing volume will increase the number of trajectories (energy levels) available to molecules
  Increasing volume will increase entropy for gases
- Phase changes ($s \rightarrow l \rightarrow g$) result in an increase in the energy levels available to the molecules in a system
  $S_{\text{solids}} < S_{\text{liquids}} << S_{\text{gases}}$
- Change in the number of moles of gas means a large change in the entropy of the system
  $\Delta n > 0 \rightarrow \Delta S > 0$, $\Delta n < 0 \rightarrow \Delta S < 0$
- Molecules with more degrees of freedom have more energy levels
  Increasing molecular complexity $\rightarrow$ increasing $S$
- Larger atoms (more electrons) have more closely spaced energy levels
  Increasing atomic weight $\rightarrow$ increasing $S$

Shown below is the heating curve for water. It plots heat added to the system (x-axis) versus temperature (y-axis).

specific heat capacity ice = 2.09 J/g°C.
specific heat capacity water = 4.18 J/g°C
specific heat capacity steam = 2.00 J/g°C

$\Delta H_{\text{fusion}} = 6.02 \text{ kJ/mol}$
$\Delta H_{\text{vaporization}} = 40.7 \text{ kJ/mol}$

1. How much heat is given off when 10.00 g of H$_2$O goes from steam at 110°C to ice at -10°C?
2. Draw the diagram for the temperature (x-axis) versus entropy \((q_r/T)\) (y-axis) for water, going from -10°C to 110°C. Label the phases (s, l and g). Indicate which changes are \(\Delta H_{\text{fusion}}/T\) and \(\Delta H_{\text{vap}}/T\).

\[
\begin{array}{c}
\text{T (°C)}
\end{array}
\]

3. Decide whether the entropy change of each of these systems is positive, negative or impossible to determine without more information

a) \(2\text{H}_2\text{O}_2 (aq) \rightarrow 2\text{H}_2\text{O} (aq) + \text{O}_2 (g)\) + - ?

b) \(4 \text{Al} (s) + 3 \text{O}_2 (g) \rightarrow \text{Al}_2\text{O}_3 (s)\) + - ?

c) \(\text{NaCl} (s) + \text{H}_2\text{O}(l) \rightarrow \text{Na}^+(aq) + \text{Cl}^- (aq)\) + - ?

d) \(2 \text{HCl} (g) \rightarrow \text{H}_2 (g) + \text{Cl}_2 (g)\) + - ?

e) Increasing the pressure of gas at constant \(T\) + - ?

f) Cooling one mole of ideal gas + - ?

g) Expanding a gas into a vacuum + - ?

4. From each pair of substances below, choose the one with the higher molar \(S^\circ\), at 298 K

a) \(\text{Hg} (s), \text{Hg} (l)\) d) \(\text{C}_2\text{H}_6 (g), \text{C}_2\text{H}_4 (g)\)

b) \(\text{HI} (g), \text{HCl} (g)\) e) \(\text{H}_2 (1 \text{ atm}), \text{H}_2 (2 \text{ atm}), 1 \text{ mol at 298 K}\)

c) \(\text{NH}_3 (g), \text{Ne} (g)\) f) \(\text{NaCl(s)}, \text{NaCl} (aq)\)
5. Calculate $\Delta S_{\text{universe}}$ for the process $\text{H}_2\text{O} (\text{s}) \rightarrow \text{H}_2\text{O} (\text{l})$ given that $\Delta H_{\text{fusion}} = 6.02$ kJ/mol and $\Delta S_{\text{system}} = 22.1$ J/K mol. Remember that $\Delta S_{\text{surrounding}} = -\Delta H_{\text{system}} / T$.

   a) -20°C
   
   b) 0°C
   
   c) 20°C

6. Consider the following synthesis reaction:

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

   Decide which standard entropy ($S^o$) corresponds to which chemical species

<table>
<thead>
<tr>
<th>Species</th>
<th>$S^o$ (kJ/K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\text{N}_2 (\text{g})$</td>
<td>192.5</td>
</tr>
<tr>
<td>$\text{H}_2 (\text{g})$</td>
<td>191.5</td>
</tr>
<tr>
<td>$\text{NH}_3 (\text{g})$</td>
<td>130.6</td>
</tr>
</tbody>
</table>

   Calculate the $\Delta S_{\text{rxn}}$

   Does your answer make sense?

7. The melting of ice proceeds spontaneously at room T and 1 atm pressure. What is the sign of each of the following?

   a) q
   
   b) $\Delta E$
   
   c) $\Delta H$
   
   d) $\Delta S$

8. Which of the following statements is false?

   a) $\Delta S$ is negative when water condenses at 100°C
   
   b) $\Delta S_{\text{surroundings}}$ is positive when water condenses at 100°C
   
   c) $\Delta S_{\text{universe}}$ is equal to zero when water condenses at 99°C
   
   d) $\Delta S_{\text{universe}}$ increases when water condenses at 110°C