1. The Nobel prize in physics was just awarded for discoveries on graphene, a 2-dimensional form of carbon. Answer the following questions on two more well-known forms of carbon, graphite and diamond, using the data provided.

<table>
<thead>
<tr>
<th></th>
<th>(\Delta H^0_f)</th>
<th>(S^0_f)</th>
<th>(\Delta G^0_f)</th>
<th>Density (g/m(^3))</th>
</tr>
</thead>
<tbody>
<tr>
<td>C (s, graphite)</td>
<td>0 kJ/mol</td>
<td>5.740 J/K·mol</td>
<td>0 kJ/mol</td>
<td>2.25 x 10(^6)</td>
</tr>
<tr>
<td>C (s, diamond)</td>
<td>1.895 kJ/mol</td>
<td>2.377 J/K·mol</td>
<td>2.90 kJ/mol</td>
<td>3.51 x 10(^6)</td>
</tr>
</tbody>
</table>

C (s, graphite) \(\rightarrow\) C (s, diamond)

a) Is the conversion of graphite to diamond spontaneous at 1 atm and 25°C? Explain.

\[
\Delta G^0 = (2.90 - 0)kJ/mol
\]
\[
\Delta G > 0 \text{ so process is NOT spontaneous}
\]

b) Do you expect this reaction to become more or less spontaneous as \(T\) increases above 25 °C? Why? Sketch a plot of \(\Delta G\) vs \(T\) and use this sketch in your explanation.

\[
\Delta G^0 = \Delta H^0 - T\Delta S^0
\]
\[
\Delta S^0 = (2.377 - 5.740)J/K·mol < 0
\]
\[
\Delta H^0 = (1.895 - 0)kJ/mol
\]
\(\Delta G\) vs \(T\) is a line with slope = \(-\Delta S^0 > 0\)
Also positive y intercept (at 0 K – not drawn to scale)

Positive slope means positive \(\Delta G\) at 25 °C increases as \(T\) increases (arrow on plot), and process becomes even less spontaneous.

c) Suppose you want to produce diamonds from graphite. What is the minimum pressure (in atm) needed for this reaction to be spontaneous? Show your work.

Find \(P_2\) where \(\Delta G = 0\) (\(P_1 = 1\)atm):

\[
\frac{\Delta G(P_2) - \Delta G(P_1)}{\Delta V} = P_2 - P_1
\]

\[
P_2 = \frac{\Delta G(P_2) - \Delta G(P_1)}{\Delta V} + P_1 = \frac{0 - 2.90kJ/mol}{1\text{atm}} + 1\text{atm}
\]

\[
\Delta V = V_{\text{diamond}} - V_{\text{graphite}} = \frac{12g/mole}{3.51 \times 10^6 g/m^3} - \frac{12g/mole}{2.25 \times 10^6 g/m^3} = -1.92 \times 10^{-6} m^3/mole
\]

\[
P_2 = \frac{0 - 2.90kJ/mol}{-1.92 \times 10^{-6} m^3/mol} + 1\text{atm} = 1.51 \times 10^6 kJ/m^3 + 1\text{atm} = 1.51 \times 10^9 J/m^3 + 1\text{atm}
\]

\[
P_2 = 1.51 \times 10^9 N/m^3 + 1\text{atm} = (1.51 \times 10^9 Pa)\frac{1\text{atm}}{1.01 \times 10^5 Pa} + 1\text{atm} = 14,998\text{atm}
\]
2. One mole of liquid water at 100 °C is brought into contact with one mole of liquid water at 0 °C in an insulated container.

<table>
<thead>
<tr>
<th></th>
<th>$C_p$ (J K$^{-1}$mol$^{-1}$)</th>
<th>$C_p$ (J K$^{-1}$mol$^{-1}$)</th>
<th>$L_{\text{vaporization}}$ (J mol$^{-1}$)</th>
<th>$L_{\text{melting}}$ (J mol$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>water</td>
<td>75.2</td>
<td>36.9</td>
<td>40,680</td>
<td>5994</td>
</tr>
</tbody>
</table>

(a) Deduce whether each of the following thermodynamic quantities is greater than, equal to, or less than zero for the system described. State your reasoning (give a reason that does not require you to do a detailed calculation).

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Value</th>
<th>Reason</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta S_{\text{sys}}$</td>
<td>$&gt; 0$</td>
<td>Since process is spontaneous (heat flows from hot to cold water).</td>
</tr>
<tr>
<td>$\Delta S_{\text{surr}}$</td>
<td>$= 0$</td>
<td>Since $\Delta S = q/T$ &amp; insulated, no heat flow to surroundings;</td>
</tr>
<tr>
<td>$q$</td>
<td>$= 0$</td>
<td>Since insulated, no heat flow in or out of system.</td>
</tr>
<tr>
<td>$w$</td>
<td>$= 0$</td>
<td>Since $\Delta V = 0$ (T change in liquid water won’t change volume).</td>
</tr>
<tr>
<td>$\Delta E$</td>
<td>$= 0$</td>
<td>Since $\Delta E = q + w$</td>
</tr>
</tbody>
</table>

(b) Use whichever values are needed to calculate $\Delta S_{\text{sys}}$. Show your work.

Two equal halves of system start at 100°C and 0 °C, so final T = average = 50 °C = 323K.

Calculate $\Delta S_{\text{sys}} = C_p \ln \frac{T_f}{T_i}$ for both halves and sum them:

$\Delta S_{\text{sys}} = \Delta S_{\text{hot}} + \Delta S_{\text{cold}} = C_p \left( \ln \frac{323}{373} + \ln \frac{323}{273} \right)$

$\Delta S_{\text{sys}} = (1\text{ mol})(75.2 J K^{-1} \text{ mol}^{-1})(-0.144 + 0.168) = 1.8 J K^{-1}$

(or $\Delta S_{\text{sys}} = 2.3 J K^{-1}$ with round-off error: fine)