Q1
Consider the methane molecule, CH₄.

a) How many translational degrees of freedom does this molecule have? 3

b) How many rotational degrees of freedom does this molecule have? 3

c) How many vibrational degrees of freedom does this molecule have? 9

CH₄ is not linear therefore the degrees of freedom are: 3N-6, or 3(5)-6=9

Q2
Consider the two diagrams below showing the energies of each of four A particles and four B particles. The dotted lines represent the allowed energies of each particle. (There are four allowed energy levels for A and three allowed energy levels for B.)

<table>
<thead>
<tr>
<th>What is the total energy of system A?</th>
<th>15 units</th>
</tr>
</thead>
<tbody>
<tr>
<td>What is the total energy of system B?</td>
<td>16 units</td>
</tr>
<tr>
<td>In how many ways can the energy of system A be distributed?**</td>
<td>40 **</td>
</tr>
<tr>
<td>In how many ways can the energy of system B be distributed?**</td>
<td>19 **</td>
</tr>
<tr>
<td>Which system has the greater entropy?</td>
<td>A</td>
</tr>
</tbody>
</table>
**The diagram shows only one of several energy configurations that give the total energy for each of the systems. You will need to consider all of the configurations that give that energy, along with the weight of each configuration to answer these questions.**

(a) Add up the energy levels for each system.
   - For A: 6+6+3+0=15
   - For B: 0+4+4+8=16
(b) \[ W = \frac{N!}{\prod n!} \]
   - For System A, 15 can be made by 9330, 9600, or 6630. Then plug in N=4 and n=2, n=1, and n=1 for each combination.
(c) \[ W = \frac{N!}{\prod n!} = \left( \frac{4!}{2!1!1!} \right) (3) = 36 \]
(d) \[ W = \frac{N!}{\prod n!} = \left( \frac{4!}{2!2!} \right) + \left( \frac{4!}{2!1!1!} \right) = 18 \]

**Q3**

Determine the standard molar entropy of formation at 298K for each of the following (recall what a formation reaction is from our discussion of heats of formation):

<table>
<thead>
<tr>
<th>Substance</th>
<th>( \Delta S^\circ \text{ J/mol-K} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>H(_2)(g)</td>
<td>0</td>
</tr>
<tr>
<td>H(_2)O(g)</td>
<td>-44.4</td>
</tr>
<tr>
<td>NH(_3)(g)</td>
<td>-99.3</td>
</tr>
<tr>
<td>O(_3)(g)</td>
<td>-68.73</td>
</tr>
<tr>
<td>I(_2)(g)</td>
<td>144.46</td>
</tr>
</tbody>
</table>

Use \( \Delta G = \Delta H - T\Delta S \) and values in table from the book.
H₂: \( \Delta G^o_f = \Delta H^o_f = 0 \) so \( \Delta S^o_f = 0 \) J/molK

H₂O: \( \Delta S^o_f = \frac{\Delta H^o_f - \Delta G^o_f}{T} = \frac{-241820 + 228590}{298} = -44.4 \) J/molK

NH₃: \( \Delta S^o_f = \frac{\Delta H^o_f - \Delta G^o_f}{T} = \frac{-46600 + 16500}{298} = -101 \) J/molK

O₂: \( \Delta S^o_f = \frac{\Delta H^o_f - \Delta G^o_f}{T} = \frac{14300 - 163000}{298} = -67 \) J/molK

I₂: \( \Delta S^o_f = \frac{\Delta H^o_f - \Delta G^o_f}{T} = \frac{62400 - 19400}{298} = 144 \) J/molK

Q4

Indicate the sign of the entropy change for each of the following processes.

(a) increasing the temperature of a pot of water

\[ \Delta S > 0 \]

(b) condensing a gas

\[ \Delta S < 0 \]

(c) clearing a field and planting rows of corn

\[ \Delta S > 0 \]

(d) \( \text{NH}_4\text{NO}_3(s) \rightarrow \text{N}_2\text{O}(g) + 2 \text{H}_2\text{O}(g) \)

\[ \Delta S < 0 \]

Entropy increases if disorder increases. Therefore, increasing temperature and creating gas increases entropy. Creating order, by planting crops and condensing a gas decreases entropy.