1. The gas-phase conversion reaction between the geometric isomers cis-2-butene and trans-2-butene is represented by the equation above. The value of the equilibrium constant, $K_{eq}$, for the reaction is 3.2 at 298 K and 1.0 atm.

(a) In a mixture of the isomers at equilibrium at 298 K and 1.0 atm, which is present at a higher concentration, cis-2-butene or trans-2-butene? Justify your answer.

The $K_{eq}$ is larger than one, this means that the concentration of the products will be higher than the reactants. If the $K$ value was less than one the concentration of reactants would be higher than the products.

(b) If 1.00 mol of pure cis-2-butene and 1.0 mol of pure trans-2-butene were introduced into an evacuated container at 298 K, in which direction (to the right or to the left) would the reaction proceed to establish equilibrium? Justify your answer.

The reaction quotient $Q$ would be equal to 1.0, this is less than $K$. This means that the concentration of the products is lower than it would be at equilibrium and therefore the reaction will shift to produce more products, using up reactants. So the shift would be to the right.

(c) Given that $K_{eq}$ for the reaction at 400 K has the value 1.3, predict whether the reaction is endothermic or exothermic. Justify your answer.

As the temperate increases the $K$ value has decreased. This means the equilibrium has shifted to have more reactants and less products. This would happen if the reaction was exothermic. In exothermic reactions the reverse reaction rate will increase faster than the forward reaction rate when the temperature is increased.
2. Ammonia hydrogen sulfide is a crystalline solid that decomposes as follows:

\[ \text{NH}_4\text{HS}_\text{(s)} \rightarrow \text{NH}_3\text{(g)} + \text{H}_2\text{S}_\text{(g)} \]

(a) Some solid NH\(_4\)HS is placed in an evacuated vessel at 25 °C. After equilibrium is attained, the total pressure inside the vessel is found to be 0.659 atmosphere. Some solid NH\(_4\)HS remains in the vessel at equilibrium. For this decomposition, write the expression for \(K_p\) and calculate its numerical value at 25 °C.

\[ K_p = P_{\text{NH}_3} \cdot P_{\text{H}_2\text{S}} \]

Remember that solids are not included in the equilibrium expression. We also know that the pressure of NH\(_3\) and H\(_2\)S must be equal because of the coefficients. So, \(P_{\text{NH}_3} = P_{\text{H}_2\text{S}}\).

The total pressure is the sum of the pressures for ammonia and hydrogen sulfide.

\[ P_{\text{NH}_3} + P_{\text{H}_2\text{S}} = 0.659 \text{ atm} \quad P_{\text{NH}_3} = P_{\text{H}_2\text{S}} = 0.330 \text{ atm} \]

(b) Some extra NH\(_3\) gas is injected into the vessel containing the sample described in part (a). When equilibrium is reestablished at 25 °C, the partial pressure of NH\(_3\) is twice the partial pressure of H\(_2\)S. Calculate the numerical value of the partial pressure of NH\(_3\) and the partial pressure of H\(_2\)S in the vessel after the NH\(_3\) has been added and equilibrium has been reestablished.

\[ P_{\text{NH}_3} = 2P_{\text{H}_2\text{S}} \]

\[ K_p = P_{\text{NH}_3} \cdot P_{\text{H}_2\text{S}} = 0.330 \cdot 0.330 = 0.109 \]

(c) In a different experiment, NH\(_3\) gas and H\(_2\)S gas are introduced into an empty 1.00-liter vessel at 25 °C. The initial partial pressure of each gas is 0.500 atmosphere. Calculate the number of moles of solid NH\(_4\)HS that is present when equilibrium is established.

We are given the initial values and an equilibrium constant and need to find the equilibrium values, this is an I.C.E. problem.

<table>
<thead>
<tr>
<th></th>
<th>NH(_4)HS</th>
<th>NH(_3)</th>
<th>H(_2)S</th>
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<tbody>
<tr>
<td>I</td>
<td>0.500</td>
<td></td>
<td>0.500</td>
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<tr>
<td>C</td>
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<tr>
<td>E</td>
<td>0.500-x</td>
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\[ K_p = 0.109 = P_{\text{NH}_3} \cdot P_{\text{H}_2\text{S}} \]

\[ 0.109 = (0.500-x) \cdot (0.500-x) \]

\[ x = 0.170 \]

So 0.170 atm of the products are used up to produce the solid.\[ PV=nRT \]

\[ 0.170 \text{ atm} \cdot 1.00 \text{ L} = n \cdot 0.0821 \cdot 298 \text{ K} \]

\[ n = 0.00694 \text{ moles NH}_4\text{HS formed} \]