Questions

1. Consider the following equilibrium reaction.
   \[ \text{Cl}_2(g) + \text{SO}_2(g) \rightleftharpoons \text{SO}_2\text{Cl}_2(g) \quad \Delta H^\circ = -84.5 \text{ kJ} \]
   In a 1.00 dm\(^3\) closed container, at 375 \(^\circ\)C, 8.60 \times 10^{-3} \text{ mol of SO}_2 and 8.60 \times 10^{-3} \text{ mol of Cl}_2 were introduced. At equilibrium, 7.65 \times 10^{-4} \text{ mol of SO}_2\text{Cl}_2 was formed.
   a) Deduce the equilibrium constant expression \( K_c \) for the reaction. \[ \text{[1]} \]
   b) Determine the value of the equilibrium constant \( K_c \). \[ \text{[3]} \]
   c) If the temperature of the reaction is changed to 300 \(^\circ\)C, predict, stating a reason in each case, whether the equilibrium concentration of \( \text{SO}_2\text{Cl}_2 \) and the value of \( K_c \) will increase or decrease. \[ \text{[3]} \]
   d) If the volume of the container is changed to 1.50 dm\(^3\), predict, stating a reason in each case, how this will affect the equilibrium concentration of \( \text{SO}_2\text{Cl}_2 \) and the value of \( K_c \). \[ \text{[3]} \]
   e) Suggest, stating a reason, how the addition of a catalyst at constant pressure and temperature will affect the equilibrium concentration of \( \text{SO}_2\text{Cl}_2 \). \[ \text{[2]} \]

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2. When a mixture of 0.100 mol NO, 0.051 mol \( \text{H}_2 \) and 0.100 mol \( \text{H}_2\text{O} \) were placed in a 1.0 dm\(^3\) flask at 300 K, the following equilibrium was established.
   \[ 2\text{NO}(g) + 2\text{H}_2(g) \rightleftharpoons \text{N}_2(g) + 2\text{H}_2\text{O}(g) \]
   At equilibrium, the concentration of NO was found to be 0.062 mol dm\(^{-3}\). Determine the equilibrium constant, \( K_c \) of the reaction at this temperature.

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3. 0.50 mol of \( \text{I}_2(g) \) and 0.50 mol of \( \text{Br}_2(g) \) are placed in a closed flask. The following equilibrium is established.
   \[ \text{I}_2(g) + \text{Br}_2(g) \rightleftharpoons 2\text{IBr}(g) \]
   The equilibrium mixture contains 0.80 mol of \( \text{IBr}(g) \). What is the value of \( K_c \)?

4. a) The production of ammonia is an important industrial process.
   \[ \text{N}_2(g) + 3\text{H}_2(g) \rightleftharpoons 2\text{NH}_3(g) \]
   i) Using the average bond enthalpy values in Table 10 of the *Data Booklet*, determine the standard enthalpy change for this reaction. \[ \text{[3]} \]
   ii) The standard entropy values, \( S \), at 298 K for \( \text{N}_2(g), \text{H}_2(g) \) and \( \text{NH}_3(g) \) are 193, 131 and 192 JK\(^{-1}\) mol\(^{-1}\) respectively. Calculate \( \Delta S^\circ \) for the reaction and with reference to the equation above, explain the sign of \( \Delta S^\circ \). \[ \text{[4]} \]
   iii) Calculate \( \Delta G^\circ \) for the reaction at 298 K. \[ \text{[1]} \]
   iv) Describe and explain the effect of increasing temperature on the spontaneity of the reaction. \[ \text{[2]} \]
   b) The reaction used in the production of ammonia is an equilibrium reaction. Outline the characteristics of a system at equilibrium. \[ \text{[2]} \]
   c) Deduce the equilibrium constant expression, \( K_c \) for the production of ammonia. \[ \text{[1]} \]
   d) i) 0.20 mol of \( \text{N}_2(g) \) and 0.20 mol of \( \text{H}_2(g) \) were allowed to reach equilibrium in a 1 dm\(^3\) closed container. At equilibrium the concentration of \( \text{NH}_3(g) \) was 0.060 mol dm\(^{-3}\). Determine the equilibrium concentrations of \( \text{N}_2(g) \) and \( \text{H}_2(g) \) and calculate the value of \( K_c \). \[ \text{[3]} \]
   ii) Predict and explain how increasing the temperature will affect the value of \( K_c \). \[ \text{[2]} \]

**IB, May 2010**
Topic 17 – Equilibrium (AHL)

End of topic questions (page 394)

1. a) \( K_c = \frac{[SO_2 Cl_2]}{[Cl2][SO2]} \)
   b) 12.5;
   c) value of \( K_c \) increases; \([SO_2 Cl_2]\) increases; decrease in temperature favours (forward) reaction which is exothermic;
   d) no effect on the value of \( K_c \) as it depends only on temperature; \([SO_2 Cl_2]\) decreases; increase in volume favours the reverse reaction which has more gaseous moles;
   e) no effect; catalyst increases the rate of forward and reverse reactions (equally)/catalyst decreases activation energies (equally);

2. \( 2NO \ (g) + 2H_2 \ (g) \leftrightarrow N_2 \ (g) + 2H_2 O(g) \)

<table>
<thead>
<tr>
<th>( \text{Initial (mol dm}^{-3})</th>
<th>( \text{NO (g)} )</th>
<th>( \text{H}_2 \ (g) )</th>
<th>( \text{N}_2 \ (g) )</th>
<th>( \text{H}_2O \ (g) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \text{Change (mol dm}^{-3})</td>
<td>(-0.038)</td>
<td>(-0.038)</td>
<td>(+0.019)</td>
<td>(+0.038)</td>
</tr>
<tr>
<td>( \text{Equilibrium (mol dm}^{-3})</td>
<td>(0.062)</td>
<td>(0.013)</td>
<td>(0.019)</td>
<td>(0.138)</td>
</tr>
</tbody>
</table>

\([H_2] \) at equilibrium = 0.013 mol dm\(^{-3}\)

\([N_2] \) at equilibrium = 0.019 mol dm\(^{-3}\)

\([H_2O] \) at equilibrium = 0.138 mol dm\(^{-3}\)

\( K_c = \frac{[N_2][H_2O]^2}{[NO]^2[H_2]^2} = \frac{(0.019)(0.138)^2}{(0.062)^2(0.013)^2} = 5.6 \times 10^2 \)