CHEM1001 Worksheet 11 – Answers to Critical Thinking Questions

The worksheets are available in the tutorials and form an integral part of the learning outcomes and experience for this unit.

Model 1: The Equilibrium Constant

1. \[ K_c (A) = \frac{[N_2O_4(g)]}{[NO_2(g)]^2} \]
   \[ K_c (B) = \frac{[N_2O_4(g)]^{1/2}}{[NO_2(g)]} \]
   \[ K_c (C) = \frac{[NO_2(g)]^2}{[N_2O_4(g)]} \]
   \[ K_c (D) = \frac{[NO_2(g)]}{[N_2O_4(g)]^{1/2}} \]

2. (a) \[ K_c (B) = \sqrt{K_c (A)} \]  
   (b) \[ K_c (A) = 1/K_c (C) \]

3. \[ K_c (A) = 0.078, K_c (B) = 0.28, K_c (C) = 13. \] These values agree with the mathematical analysis in Q2.

Model 2: The Reaction Quotient

1. The reaction will shift to the right to decrease \([NO_2(g)]\).

2. The reaction will shift to the left to increase \([NO_2(g)]\).

3. (a) \[ [NO_2(g)] = 2.00 \text{ M and } [N_2O_4] = 0.20 \text{ M: } Q_c = 0.050 \]
   (b) \[ [NO_2(g)] = 1.00 \text{ M and } [N_2O_4] = 0.20 \text{ M: } Q_c = 0.20 \]

4. (a) If \( Q_c < K_c \), the reaction will shift to the right.
   (b) If \( Q_c > K_c \), the reaction will shift to the left.

\[ \text{Consider the following reaction at equilibrium.} \]
\[ \text{CH}_3\text{OH(g)} \rightleftharpoons \text{CO(g)} + 2\text{H}_2(g) \]
\[ K_c = 1.30 \times 10^{-2} \]

What is the concentration of \( \text{CO(g)} \) when \( [\text{CH}_3\text{OH(g)}] = 3.49 \times 10^{-1} \text{ M and } [\text{H}_2(g)] = 1.76 \times 10^{-1} \text{ M?} \)

The equilibrium constant for the reaction is given by \( K_{eq} = \frac{[\text{CO(g)}][\text{H}_2(g)]^2}{[\text{CH}_3\text{OH(g)}]} = 1.30 \times 10^{-2} \)

When \( [\text{CH}_3\text{OH(g)}] = 3.49 \times 10^{-1} \text{ M and } [\text{H}_2(g)] = 1.76 \times 10^{-1} \text{ M,} \)

\[ [\text{CO(g)}] = \frac{K_{eq}[\text{CH}_3\text{OH(g)}]}{[\text{H}_2(g)]^2} = \frac{(1.30 \times 10^{-2})(3.49 \times 10^{-1})}{(1.76 \times 10^{-1})^2} \text{ M} = 0.146 \text{ M} \]

Answer: 0.146 M
The value of the equilibrium constant, $K_c$, for the following reaction is 0.118.

$$2\text{CO}_2(\text{g}) + \text{N}_2(\text{g}) \rightleftharpoons 2\text{CO}(\text{g}) + 2\text{NO}(\text{g})$$

What is the equilibrium concentration of CO(g) if the equilibrium concentration of $[\text{CO}_2(\text{g})] = 0.492$ M, $[\text{N}_2(\text{g})] = 0.319$ M and $[\text{NO}(\text{g})] = 0.350$ M?

The equilibrium constant for the reaction is given by

$$K_{eq} = \frac{[\text{CO}(\text{g})]^2[\text{NO}(\text{g})]^2}{[\text{CO}_2(\text{g})]^2[\text{N}_2(\text{g})]} = 0.118$$

When $[\text{CO}_2(\text{g})] = 0.492$ M, $[\text{N}_2(\text{g})] = 0.319$ M and $[\text{NO}(\text{g})] = 0.350$ M,

$$[\text{CO}(\text{g})]^2 = \frac{K_{eq}[\text{CO}_2(\text{g})]^2[\text{N}_2(\text{g})]}{[\text{NO}(\text{g})]^2} = \frac{(0.118)(0.492)^2(0.319)}{(0.350)^2} \text{M}^2 = 0.0744 \text{M}^2$$

$$[\text{CO}(\text{g})] = 0.273 \text{M}$$

**Answer:** $0.273 \text{M}$

**Model 3: Equilibrium calculations**

1. As there was no O$_2$(g) or H$_2$(g) at the beginning (“initial”), the reaction had to proceed to the right. The amount of H$_2$O(g) had to decrease so the “change”

2. The ‘ICE’ table and calculation is shown below.

<table>
<thead>
<tr>
<th></th>
<th>N$_2$(g)</th>
<th>O$_2$(g)</th>
<th>$\Rightarrow$</th>
<th>2NO(g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>[I]</td>
<td>0.033</td>
<td>0.0081</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>[C]</td>
<td>-x</td>
<td>-x</td>
<td>+2x</td>
<td></td>
</tr>
<tr>
<td>[E]</td>
<td>0.033-</td>
<td>0.0081-</td>
<td>x</td>
<td></td>
</tr>
</tbody>
</table>

$$K_c = \frac{[\text{NO}(\text{g})]^2}{[\text{N}_2(\text{g})][\text{O}_2(\text{g})]} = \frac{4x^2}{(0.033 - x)(0.0081 - x)}$$

If $K_c$ is very small, $x$ will be very small and so $0.033 - x \approx 0$ and $0.0081 - x \approx 0$. Hence:

$$K_c = \frac{4x^2}{(0.033 \times 0.0081)}$$

$$x = \sqrt{(4.8 \times 10^{-31} \times 0.033 \times 0.0081/4)}$$

$$x = 5.7 \times 10^{-18}$$

$[\text{NO}(\text{g})]$ at equilibrium $= 2x = 1.1 \times 10^{-17}$ M.

3. $[\text{CO}] = [\text{H}_2\text{O}] = 0.0332$ M; $[\text{CO}_2] = [\text{H}_2] = 0.0668$ M

4. $[\text{CO}] = [\text{H}_2\text{O}] = 0.0530$ M; $[\text{CO}_2] = [\text{H}_2] = 0.107$ M

5. $K_c = 64$