CHEM1612 Worksheet 4 – 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. $K_c\,(A) = \dfrac{[N_2O_4(g)]}{[NO_2(g)]^2}$ $K_c\,(B) = \dfrac{[N_2O_4(g)]^{1/2}}{[NO_2(g)]}$

   $K_c\,(C) = \dfrac{[NO_2(g)]^2}{[N_2O_4(g)]}$ $K_c\,(D) = \dfrac{[NO_2(g)]}{[N_2O_4(g)]^{1/2}}$

2. (a) $K_c\,(B) = \sqrt{K_c\,(A)}$ (b) $K_c\,(A) = 1 / K_c\,(C)$
3. $K_c\,(A) = 0.078$, $K_c\,(B) = 0.280$, $K_c\,(C) = 12.8$.

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) $Q_c = 0.0500$

   (b) $Q_c = 0.200$.
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.

Model 3: Equilibrium calculations

Model 2 gives you the tools to predict the direction in which a reaction will move if it is not at equilibrium. The concentrations that will be obtained when equilibrium is finally reached can be calculated using an ICE table: **i**nitial-**c**hange-**e**quilibrium.

Consider the starting mixture in Q1 of Model 2: $[NO_2(g)] = 2.00$ M and $[N_2O_4(g)] = 0.20$ M. These are the **i**nitial concentrations and are written in the first row of the *reaction table* below. You know from Model 2 that this reaction will shift so that some $NO_2(g)$ reacts to make $N_2O_4(g)$. We do not know *how much* will react but we *can* calculate it:

	$2NO_2(g)$	$\rightleftharpoons$	$N_2O_4(g)$
initial	2.00		0.20
change	$-2x$		$+x$
equilibrium	$2.00 - 2x$		$0.20 + x$

Critical thinking questions

1. See above.
2. Complete the third row of the table.
3. $K_c\,(A) = \dfrac{[N_2O_4(g)]}{[NO_2(g)]^2} = \dfrac{(0.20+x)}{(2.00-2x)^2}$
4. $x = 0.070$ M so $[NO_2(g)] = 1.86$ M and $[N_2O_4(g)] = 0.27$ M

   (The second root is non-physical as it leads to a negative concentration for NO_2.

Marks 4

The CO(g) in water gas can be reacted further with $H_2O(g)$ in the so-called "water-gas shift" reaction:

$$CO(g) + H_2O(g) \rightleftharpoons CO_2(g) + H_2(g)$$

At 900 K, K_c = 1.56 for this reaction. A sample of water gas flowing over coal at 900 K contains a 1:1 mole ratio of CO(g) and $H_2(g)$, as well as 0.250 mol L^{-1} $H_2O(g)$. This sample is placed in a sealed container at 900 K and allowed to come to equilibrium, at which point it contains 0.070 mol L^{-1} $CO_2(g)$. What was the initial concentration of CO(g) and $H_2(g)$ in the sample?

The reaction table is

	CO(g)	$H_2O(g)$	$\rightleftharpoons$	$CO_2(g)$	$H_2(g)$
initial	x	0.250		0	x
change	-0.070	-0.070		+0.070	+0.070
equilibrium	x – 0.070	0.250 – 0.070		0.070	x + 0.070

The equilibrium constant in terms of concentrations, K_c, is:

$$K_c = \frac{[CO_2(g)][H_2(g)]}{[H_2O(g)][CO(g)]} = \frac{(0.070)(x + 0.070)}{(0.180)(x - 0.070)} = 1.56$$

$$x = [CO(g)]_{initial} = [H_2(g)]_{initial} = 0.12 \text{ mol L}^{-1}$$

[CO] = $[H_2]$ = **0.12 mol L^{-1}**

If the walls of the container are chilled to below 100 ºC, what will be the effect on the concentration of $CO_2(g)$?

At temperatures below 100 °C, the water vapour will condense to form $H_2O(l)$. Following Le Chatelier's principle, the equilibrium will shift to the left as $[H_2O(g)]$ is reduced by this process and so $[CO_2(g)]$ will decrease.

Marks
5

- At 700 °C, hydrogen and iodine react according to the following equation.

$$H_2(g) + I_2(g) \rightleftharpoons 2HI(g) \qquad K_c = 49.0$$

Hydrogen also reacts with sulfur at 700 °C:

$$2H_2(g) + S_2(g) \rightleftharpoons 2H_2S(g) \qquad K_c = 1.075 \times 10^8$$

Determine K_c for the following overall equilibrium reaction at 700 °C.

$$2I_2(g) + 2H_2S(g) \rightleftharpoons S_2(g) + 4HI(g)$$

The overall reaction corresponds to the twice the first reaction combined with the reverse of the second reaction:

$2H_2(g) + 2I_2(g) \rightleftharpoons 4HI(g)$	$K_c(1) = (49.0)^2$
$2H_2S(g) \rightleftharpoons 2H_2(g) + S_2(g)$	$K_c(2) = 1/(1.075 \times 10^8)$
$2I_2(g) + 2H_2S(g) \rightleftharpoons S_2(g) + 4HI(g)$	$K_c(3) = K_c(1) \times K_c(2)$

The 1st reaction is doubled so the original equilibrium constant is squared.

The 2nd reaction is reversed so the reciprocal of the equilibrium constant is used.

The two reactions are then combined and the overall equilibrium constant is then the product:

$$K_c(3) = K_c(1) \times K_c(2) = (49.0)^2 \times (1/(1.075 \times 10^8)) = 2.23 \times 10^{-5}$$

K_c = **2.23×10^{-5}**

If 0.250 mol of HI(g) is introduced into a 2.00 L flask at 700 °C, what will be the concentration of $I_2(g)$ at equilibrium?

The initial concentration of HI(g) is 0.250 / 2.00 mol L^{-1} = 0.125 mol L^{-1}.

	$H_2(g)$	$I_2(g)$	$\rightleftharpoons$	$2HI(g)$
Initial	**0**	**0**		**0.125**
Change	$+x$	$+x$		$-2x$
Equilibrium	x	x		$0.125 - 2x$

Thus,

$$K_c = \frac{[HI]^2}{[H_2][I_2]} = \frac{(0.125-2x)^2}{(x)(x)} = \frac{(0.125-2x)^2}{x^2} = 49.0 \text{ (from 2008-N-5)}$$

$$(49.0)^{1/2} = \frac{(0.125-2x)}{x}$$

Rearranging gives $x = [I_2(g)] = 0.0139$ M.

Answer: **0.0139 M**

If 0.274 g of H_2S were now introduced into the same flask, what would be the concentration of $S_2(g)$ at equilibrium?

The molar mass of H_2S is (2 × 1.008 (H) + 32.06 (S)) = 34.08 g mol^{-1}. Hence, 0.274 g of H_2S corresponds to:

number of moles = mass / molar mass
= (0.274 g) / (34.08 g mol^{-1}) = 8.04 × 10^{-3} mol

The initial concentration of H_2S is thus 8.04 × 10^{-3} mol / 2.00 M = 4.02 × 10^{-3} M.

From above, [I_2(g)] = 0.0139 M and [HI(g)] = (0.125 – 2 × 0.0139) M = 0.0972 M.

Using the overall equilibrium reaction derived in 2008-N-5:

	$2I_2(g)$	$2H_2S(g)$	$\rightleftharpoons$	$S_2(g)$	$4HI(g)$
Initial	**0.0139**	**0.00402**		**0**	**0.0972**
Change	**-2x**	**-2x**		**+x**	**+2x**
Equilibrium	**0.0139 - 2x**	**0.00402 – 2x**		**x**	**0.0972 + 4x**

Thus,

$$K_c = \frac{[S_2][HI]^4}{[I_2]^2[I_2]^2} = \frac{(x)(0.0972+4x)^4}{(0.0139-2x)^2(0.00402-2x)^2}$$

$$\sim \frac{(x)(0.0972)^4}{(0.0139)^2(0.00402)^2} = 2.23 \times 10^{-5} \text{ (from 2008-N-5)}$$

where the small x approximation has been used as K_c is so small. This gives:

x = [S_2(g)] = 7.82 × 10^{-10} M

Answer: **7.82 × 10^{-10} M**

Key to success: practice further by completing this week's tutorial homework

Key to even greater success: practice even further by completing this week's suggested exam questions