Assignment 3 – Equilibrium (Calculations)

1. Consider the following equilibrium:

$$2NO_{(g)} + O_{2(g)} \rightleftarrows 2NO_{2(g)} \qquad K_{eq} = 6.45 \times 10^5$$

a) Write the K_{eq} expression. **(1 mark)**

$K_{eq} = \dfrac{[NO_2]^2}{[NO]^2[O_2]}$

b) Explain why the $[NO_2]$ is greater than the $[NO]$ at equilibrium when the $[O_2]$ is 1.0 mol/L. **(1 mark)**

The value of K_{eq} is larger than 1, so the equilibrium favors the products. ∴ $[NO_2]$ is larger than the $[NO]$ at equilibrium.

2. Consider the following equilibrium system:

$$C_{(s)} + 2H_{2(g)} \rightleftarrows CH_{4(g)} \qquad K_{eq} = 8.1 \times 10^8 \text{ at } 25^\circ C$$

A student places 4.5 mol of carbon, 3.6×10^{-3} mol of hydrogen and 5.1 mol of methane in a 1.0 L flask. The student predicts that the $[CH_4]$ increases as equilibrium is established. Do you agree? Explain your answer using appropriate calculations. **(3 marks)**

$K_{eq} = \dfrac{[CH_4]}{[H_2]^2} = 8.1 \times 10^8$ $\qquad K_t = \dfrac{(5.1M)}{(3.6 \times 10^{-3})^2} = 3.9 \times 10^5$

$K_t < K_{eq}$ ∴ rxn will shift to the right ⇌ $[CH_4]$ will increase.

3. Consider the following:

$$H_{2(g)} + F_{2(g)} \rightleftarrows 2HF_{(g)} \qquad K_{eq} = 1.00 \times 10^2$$

A 1.00 L flask is initially filled with 2.00 mol H_2 and 2.00 mol F_2. Calculate the $[H_2]$ at equilibrium. **(4 marks)**

	H_2	+	F_2	⇌	$2HF$
I	2.00		2.00		—
C	−x		−x		+2x
E	2.00−x		2.00−x		2x

$K_{eq} = \dfrac{[HF]^2}{[H_2][F_2]} = 1.00 \times 10^2$

$\sqrt{1.00 \times 10^2} = \sqrt{\dfrac{(2x)^2}{(2.00-x)^2}}$ $\qquad x = 1.67$

∴ $[H_2]_{eq} = 2.00 - x = 0.33\ M$

4. At high temperature, 0.500 mol HBr was placed in a 1.00 L container where it decomposed to give the equilibrium:

$$2HBr_{(g)} \rightleftarrows H_{2(g)} + Br_{2(g)}$$

At equilibrium, the $[Br_2]$ is 0.0855 mol/L. What is the value of the equilibrium constant? **(3 marks)**

	$2HBr$	⇌	H_2	+	Br_2
I	0.500M		—		—
C	−0.171M		+0.0855M		+0.0855M
E	0.329M		0.0855M		0.0855M

$K_{eq} = \dfrac{[H_2][Br_2]}{[HBr]^2}$

$= \dfrac{(0.0855)^2}{(0.329)^2}$

$= 0.0675$

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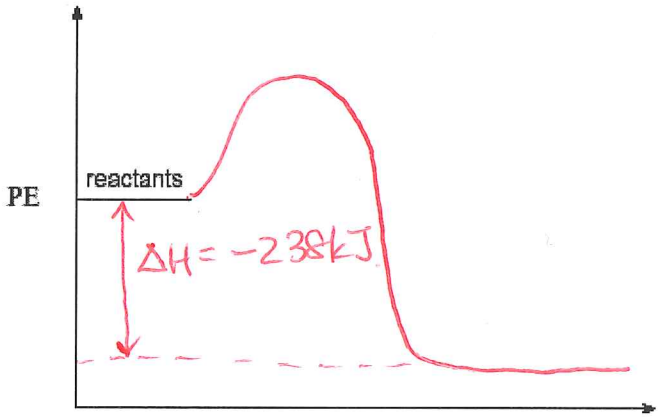
5. Consider the following equilibrium:

$$CS_{2(g)} + 3Cl_{2(g)} \rightleftarrows CCl_{4(g)} + S_2Cl_{2(g)} \qquad \Delta H = -238 \text{ kJ}$$

a) Sketch a potential energy diagram for the reaction above and label ΔH. **(2 marks)**



b) Some CS_2 is added and equilibrium is then reestablished. State the direction of the equilibrium shift and the resulting change in $[Cl_2]$. **(1 mark)**

Rxn will shift to the right (product side) and $[Cl_2]$ will decrease.

c) The temperature is decreased and equilibrium is then reestablished. What will the effect be on the value of K_{eq}? **(1 mark)**

Rxn will shift to the right ∴ Keq will increase.

6. Consider the following equilibrium:

$$H_{2(g)} + I_{2(g)} \rightleftarrows 2HI_{(g)} \qquad K_{eq} = 64$$

$H_2 + I_2 \rightleftarrows 2HI$

I X X 0

C −0.0800 −0.0800 +0.160

E x−0.0800 x−0.0800 0.160

$K_{eq} = \frac{[HI]^2}{[H_2][I_2]} = 64$

$\sqrt{64} = \sqrt{\frac{(0.160)^2}{(x-0.0800)^2}}$

Equal moles of H_2 and I_2 are placed in a 1.00 L container. At equilibrium, the $[HI] = 0.160$ mol/L. Calculate the initial $[H_2]$. **(3 marks)**

$x = 0.10$

$[H_2]_i = x = 0.10\,M$

7. Consider the following equilibrium:

$$H_{2(g)} + S_{(s)} \rightleftarrows H_2S_{(g)} \qquad K_{eq} = 6.8 \times 10^{-2}$$

A 1.0 L container is initially filled with 0.050 mol H_2 and 0.050 mol S. The container is heated to 90°C and equilibrium is established. What is the equilibrium $[H_2S]$? **(3 marks)**

$H_2 + S_2 \rightleftharpoons H_2S$

I 0.050M — +x

C −x — x

E 0.050−x — x

$K_{eq} = \frac{[H_2S]}{[H_2]}$

$6.8 \times 10^{-2} = \frac{x}{0.050 - x}$

$x = 0.0032$

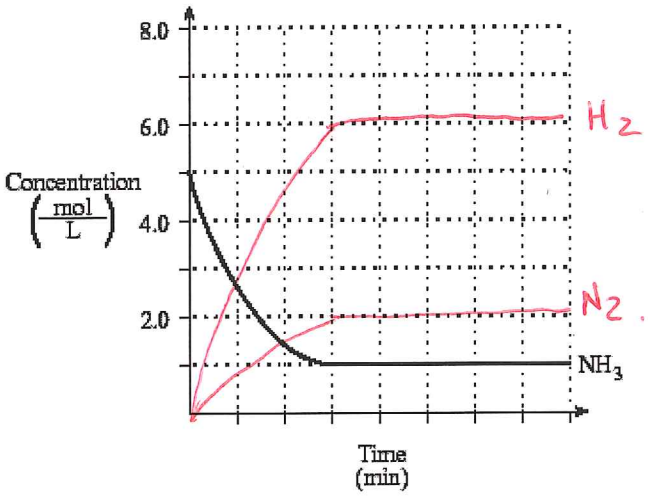
∴ $[H_2S]_{eq} = x = 0.0032\,M$

Assignment 3 – Equilibrium (Calculations)

8. Consider the following equilibrium system:

$$N_{2(g)} + 3H_{2(g)} \rightleftarrows 2NH_{3(g)} + \text{energy}$$

A 1.00 L container is filled with 5.0 mol NH_3 and the system proceeds to equilibrium as indicated by the graph.



a) Draw and label the graph for N_2 and H_2. **(2 marks)**

b) Calculate the K_{eq} for $N_{2(g)} + 3H_{2(g)} \rightleftarrows 2NH_{3(g)}$. **(2 marks)**

$$K_{eq} = \frac{[NH_3]^2}{[N_2][H_2]^3} = \frac{(1.0)^2}{(2.0)(6.0)^3} = 2.3 \times 10^{-3}$$

9. Consider the following equilibrium:

$$2CO_{2(g)} \rightleftarrows 2CO_{(g)} + O_{2(g)}$$

Initially, a 1.0 L container is filled with 0.050 mol of CO_2. At equilibrium, the $[CO_2]$ is 0.030 mol/L. Calculate the value of K_{eq}. **(3 marks)**

	$2CO_2$	$\rightleftharpoons$	$2CO$	$+$	O_2
I	0.050		—		—
C	−0.020		+0.020		+0.010
E	0.030		0.020		0.010

$$K_{eq} = \frac{[CO]^2[O_2]}{[CO_2]^2} = \frac{(0.020)^2(0.010)}{(0.030)^2} = 0.0044$$

10. Consider the following equilibrium:

$$2CH_{4(g)} \rightleftarrows C_2H_{2(g)} + 3H_{2(g)}$$

A 0.180 mol sample of CH_4 is added to an empty 1.00 L container. At equilibrium, the $[C_2H_2]$ is 0.0800 mol/L. Calculate the equilibrium constant. **(4 marks)**

	$2CH_4$	$\rightleftharpoons$	C_2H_2	$+$	$3H_2$
I	0.180		—		—
C	−0.160		+0.0800		+0.240
E	0.020		0.0800		0.240

$$K_{eq} = \frac{[C_2H_2][H_2]^3}{[CH_4]^2} = \frac{(0.0800)(0.240)^3}{(0.020)^2} = 2.8$$

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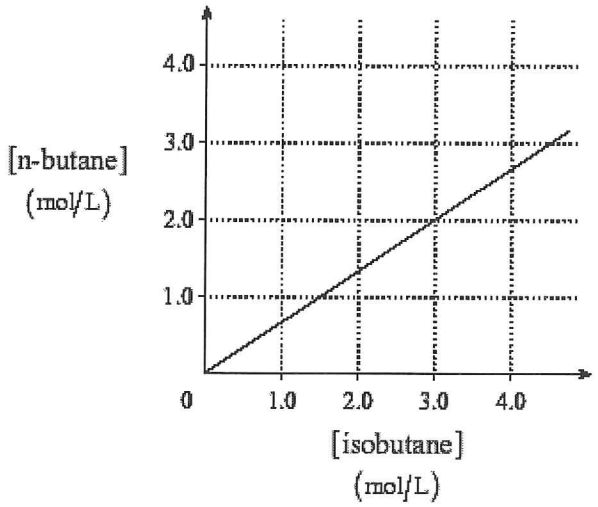
11. Consider the graph below representing the following equilibrium:

$$CH_3CH_2CH_2CH_{3(g)} \rightleftarrows CH_3CH(CH_3)_{2(g)}$$

n-butane isobutane

Data for the graph was obtained from various equilibrium mixtures.



Calculate the value of K_{eq} for the equilibrium. **(2 marks)**

$K_{eq} = \frac{[CH_3CH(CH_3)_2]}{[CH_3CH_2CH_2CH_3]} = \frac{3.0M}{2.0M} = 1.5$

12. Consider the following equilibrium:

$$N_{2(g)} + 3H_{2(g)} \rightleftarrows 2NH_{3(g)} \qquad K_{eq} = 626 \text{ at } 200°C$$

At equilibrium, $[N_2]$ is 1.06 mol/L and $[H_2]$ is 0.456 mol/L. Calculate $[NH_3]$ in the equilibrium mixture. **(2 marks)**

$K_{eq} = \frac{[NH_3]^2}{[N_2][H_2]^3}$

$626 = \frac{[NH_3]^2}{(1.06)(0.456)^3}$

$[NH_3] = 7.93M$

13. Consider the following equilibrium system:

$$C_{(s)} + H_2O_{(g)} \rightleftarrows CO_{(g)} + H_{2(g)} \qquad K_{eq} = 0.80$$

In an experiment, a student places 0.10 mol of C, 0.15 mol of H_2O, 0.25 mol of CO, and 0.20 mol of H_2 into a 1.0 L flask. The student predicts that the [CO] will decrease as equilibrium becomes established. **(3 marks)**

a) Would you agree or disagree with the student? Disagree with the student

b) Justify your answer, including appropriate calculations.

$K_{eq} = \frac{[H_2][CO]}{[H_2O]} = 0.80$

$K_t = \frac{(0.20)(0.25)}{(0.15)} = 0.33$

$K_t < K_{eq}$

∴ rxn shifts to the right and [products] will increase.

[CO] increases

14. Consider the following equilibrium system:

$$PCl_{3(g)} + Cl_{2(g)} \rightleftarrows PCl_{5(g)}$$

At 250°C, 0.40 mol of PCl_3 and 0.60 mol of Cl_2 are placed into a 1.0 litre container. At equilibrium, the $[PCl_5] = 0.11$ mol/L. Calculate the value of K_{eq}. **(3 marks)**

	PCl_3	+ Cl_2	⇌ PCl_5
I	0.40	0.60	
C	−0.11	−0.11	+0.11
E	0.29	0.49	0.11

$$K_{eq} = \frac{[PCl_5]}{[PCl_3][Cl_2]} = \frac{(0.11)}{(0.29)(0.49)}$$

$$= 0.77$$

15. Consider the following equilibrium:

$$H_{2(g)} + I_{2(g)} \rightleftarrows 2HI_{(g)} \qquad K_{eq} = 1.2 \times 10^{-2}$$

A 2.0 L flask is filled with 0.10 mol HI. Calculate the concentration of H_2 at equilibrium. **(3 marks)**

$$[HI]_i = \frac{0.10 \text{ mol}}{2.0 \text{ L}} = 0.050 \text{ M}$$

	H_2	+ I_2	⇌ 2HI
I	—	—	0.050 M
C	+x	+x	−2x
E	x	x	0.050 − 2x

$$K_{eq} = \frac{[HI]^2}{[H_2][I_2]}$$

$$\sqrt{1.2 \times 10^{-2}} = \sqrt{\frac{(0.050 - 2x)^2}{x^2}}$$

$$0.11 = \frac{(0.050 - 2x)}{x}$$

$$x = 0.024$$

$$[H_2]_{eq} = x = 0.024 \text{ M}$$