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AP Chemistry

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Equilibrium Worksheet #5

Ref: Mr. Dick Powell, Chemistry Teacher, Arlington, Texas, Personal Communication, July 2003.

1. The following results were collected for two experiments involving the reaction at 600°C between gaseous sulfur dioxide and oxygen to form gaseous sulfur trioxide:

$$2\ SO_{2\,(g)} + O_{2\,(g)} \leftrightarrows 2\ SO_{3\,(g)}$$

Experiment 1		Experiment 2	
Initial	Equilibrium	Initial	Equilibrium
$[SO_2]_0 = 2.00$ M	$[SO_2] = 1.50$ M	$[SO_2]_0 = 0.500$ M	$[SO_2] = 0.590$ M
$[O_2]_0 = 1.50$ M	$[O_2] = 1.25$ M	$[O_2]_0 = 0$ M	$[O_2] = 0.045$ M
$[SO_3]_0 = 3.00$ M	$[SO_3] = 3.50$ M	$[SO_3]_0 = 0.350$ M	$[SO_3] = 0.260$ M

$$K = \frac{[SO_3]^2}{[SO_2]^2[O_2]}$$

initial conc.

Equilib conc

Show the equilibrium constant (K) is approximately the same in both cases.

K = 4.36
K = 4.32

EXPERIMENT #1

$$K = \frac{[3.50]^2}{[1.50]^2[1.25]} = 4.36$$

EXPERIMENT #2

$$K = \frac{[.260]^2}{[.590]^2[.045]} = 4.32$$

2. The reaction for the formation of nitrosyl chloride was studied at 25°C.

$$2NO_{(g)} + Cl_{2\,(g)} \leftrightarrows 2\ NOCl_{(g)}$$

The pressures at equilibrium were found to be:
$P_{NOCl} = 1.2$ atm $P_{NO} = 5.0 \times 10^{-2}$ atm $P_{Cl_2} = 3.0 \times 10^{-1}$ atm

Calculate the value of **K** for this reaction at 25°C. **1920**

we can treat pressures just like molarity values

$$K = \frac{[NOCl]^2}{[NO]^2[Cl_2]}$$

$$K = \frac{[1.2]^2}{[5.0 \times 10^{-2}]^2[3.0 \times 10^{-1}]} = 1920$$

3. For the synthesis of ammonia at 500°C, the equilibrium constant is 6.0×10^{-2}. Predict the direction in which the system will shift to reach equilibrium in each of the following cases:

K

$$N_{2\,(g)} + 3\,H_{2\,(g)} \leftrightarrows 2\,NH_{3\,(g)}$$

must compare K with Q to determine initial direction

a) $[NH_3]_0 = 1.0 \times 10^{-3}$ M; $[N_2]_0 = 1.0 \times 10^{-5}$ M; $[H_2]_0 = 2.0 \times 10^{-3}$ M; **(left)**

$$Q = \frac{[1.0 \times 10^{-3}]^2}{[1.0 \times 10^{-5}][2.0 \times 10^{-3}]^3} = 1.25 \times 10^7$$

$\boxed{K < Q \text{ shifts left}}$

b) $[NH_3]_0 = 2.00 \times 10^{-4}$ M; $[N_2]_0 = 1.5 \times 10^{-5}$ M; $[H_2]_0 = 3.54 \times 10^{-1}$ M; **(no shift)**

$$Q = \frac{[2.00 \times 10^{-4}]^2}{[1.5 \times 10^{-5}][3.54 \times 10^{-1}]^3} = 6.0 \times 10^{-2}$$

$\boxed{K = Q \text{ so already @ equilibrium}}$

c) $[NH_3]_0 = 1.0 \times 10^{-4}$ M; $[N_2]_0 = 5.0$ M; $[H_2]_0 = 1.0 \times 10^{-2}$ M; **(right)**

$$Q = \frac{[1.0 \times 10^{-4}]^2}{[5.0][1.0 \times 10^{-2}]^3} = 2.0 \times 10^{-3}$$

$\boxed{K > Q \text{ so system shifts to the right}}$

4. Dinitrogen tetroxide in its liquid state was used as one of the fuels on the lunar lander for the NASA Apollo missions. In the gas phase, it decomposes to gaseous nitrogen dioxide:

$$\mathbf{N_2O_{4\,(g)} \leftrightarrows 2\,NO_{2\,(g)}}$$

Consider an experiment in which gaseous N_2O_4 was placed in a flask and allowed to reach equilibrium at a temperature where K = 0.133 . At equilibrium, the pressure of N_2O_4 was found to be 2.71 atm. Calculate the equilibrium pressure of $NO_{2\,(g)}$.

0.600 atm

$$K = \frac{[NO_2]^2}{[N_2O_4]} = .133$$

$$.133 = \frac{[NO_2]^2}{2.71}$$

$$\boxed{[NO_2] = .600 \text{ atm}}$$

5. At a certain temperature, a 1.00-L flask initially contained 0.298 moles of $PCl_{3\,(g)}$ and 8.7×10^{-3} moles of $PCl_{5\,(g)}$. After the system had reached equilibrium, 2.00×10^{-3} moles of $Cl_{2\,(g)}$ was found in the flask. Gaseous PCl_5 decomposes according to the reaction:

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

Calculate the equilibrium concentrations of all species and the value of K.

$x = 2.00 \times 10^{-3}$ M

PCl_5	$\rightleftarrows$ PCl_3	+ Cl_2
8.7×10^{-3} M	.298 M	0
$-x$	$+x$	$+x$
$8.7 \times 10^{-3} - x$	$.298 + x$	x

$[Cl_2] = 2 \times 10^{-3}$ M
$[PCl_3] = .3$ M
$[PCl_5] = 6.7 \times 10^{-3}$ M
$K = 8.96 \times 10^{-2}$

$$K = \frac{[.298 + 2.00 \times 10^{-3}][2.00 \times 10^{-3}]}{[8.7 \times 10^{-3} - 2.00 \times 10^{-3}]} = \boxed{8.96 \times 10^{-2}}$$

6. Carbon monoxide reacts with steam to produce carbon dioxide and hydrogen. At 700 Kelvin the K value is determined to be 5.10. Calculate the concentrations of all species if one mole of each component (reactants and products) is mixed inside a 1.0-L flask.

H_2O is a gas @ this temp

$CO_{(g)}$	+ $H_2O_{(g)}$	$\leftrightarrows$ $CO_{2\,(g)}$	+ $H_{2\,(g)}$
1.0 M	1.0 M	1.0 M	1.0 M
$-x$	$-x$	$+x$	$+x$
$1.0 - x$	$1.0 - x$	$1.0 + x$	$1.0 + x$

$[CO] = 0.614$ M
$[H_2O] = 0.614$ M
$[CO_2] = 1.386$ M
$[H_2] = 1.386$ M

Must calculate Q to determine which direction system shifts to reach equilibrium

$$Q = \frac{[1.0][1.0]}{[1.0][1.0]} = 1$$

K > Q

$$5.10 = \frac{[1+x][1+x]}{[1-x][1-x]}$$

$\boxed{x = .387}$

7. The reaction for the formation of gaseous hydrogen fluoride from H_2 and F_2 has an equilibrium constant of 115 at a certain temperature. In a particular experiment, 3.0 moles of each component was added to a 1.5-L flask. Calculate the equilibrium concentrations of all species.

$\frac{3.0}{1.5} = 2.0$ M

$H_{2\,(g)}$	+ $F_{2\,(g)}$	$\leftrightarrows$ $2\,HF_{(g)}$
2.0 M	2.0 M	2.0 M
$-x$	$-x$	$+2x$
$2.0 - x$	$2.0 - x$	$2.0 + 2x$

K = 115

$$Q = \frac{[2.0]^2}{[2.0][2.0]} = 1.0$$

K > Q

$[HF] = 5.06$ M
$[H_2] = 0.47$ M
$[F_2] = 0.47$ M

$$115 = \frac{[2.0 + 2x]^2}{[2.0 - x][2.0 - x]}$$

$\boxed{x = 1.53}$

8. Gaseous HI is prepared from hydrogen gas and iodine vapor at a temperature where the equilibrium constant is 1.00×10^{2}. Suppose 5.0×10^{-1} atm of HI, 1.0×10^{-2} atm of H_2, and 5.0×10^{-3} atm of I_2 are mixed inside a 5.0-L flask. Calculate the equilibrium pressure of all species.

$$H_{2\,(g)} + I_{2\,(g)} \leftrightarrows 2\,HI_{(g)}$$

H_2	I_2	$2HI$
.010	.0050	.50
+x	+x	−2x
.010+x	.0050+x	.50−2x

$Q = \dfrac{[.50]^2}{[.010][.0050]} = 5000$

$$1.00 \times 10^{2} = \frac{[.50-2x]^2}{[.010+x][.0050+x]}$$

HI = 4.29×10^{-1} atm
$H_2 = 4.55 \times 10^{-2}$ atm
$I_2 = 4.05 \times 10^{-2}$ atm

Solver guess: .001

X = .0355

9. Gaseous phosphorus pentachloride decomposes to gaseous phosphorus trichloride and chlorine at a temperature where $K = 1.0 \times 10^{-3}$. Suppose 2.0 moles of PCl_5 in a 2.0-L vessel is allowed to come to equilibrium. Calculate the equilibrium concentrations of all species.

$$PCl_5 \leftrightarrows PCl_3 + Cl_2$$

$K = 1.0 \times 10^{-3}$

PCl_5	PCl_3	Cl_2
1.0 M	0	0
−x	+x	+x
1.0−x	x	x

$[PCl_5] = 0.97$ M
$[PCl_3] = 3.11 \times 10^{-2}$ M
$[Cl_2] = 3.11 \times 10^{-2}$ M

$$1.0 \times 10^{-3} = \frac{[x][x]}{[1.0-x]}$$

$X = 3.11 \times 10^{-2}$

10. Arsenic can be extracted from its ores by first reacting the ore with oxygen (called Roasting) to from solid As_4O_6, which is then reduced using carbon:

$$As_4O_6\,(s) + 6\,C\,(s) \leftrightarrows As_4\,(g) + 6\,CO\,(g)$$

Predict the direction of the shift in the equilibrium position in response to each of the following changes in conditions:

(a) Addition of CO — **Shifts left**

(b) Addition or removal of C or As_4O_6 — since solids — **No effect**

(c) Removal of gaseous arsenic (As_4) — **Shifts right**

11. Consider the following chemical reaction:

$$H_2\,(g) \quad + \quad F_2\,(g) \quad \leftrightarrows \quad 2\,HF\,(g) \qquad\qquad K = 1.0 \times 10^2$$

In an experiment, 2.0 moles of H_2 and 2.0 moles of F_2 are introduced into a 1.0-Liter flask. Calculate the concentration of all species at equilibrium.

H_2	+	F_2	$\rightleftarrows$	$2\ HF$
2 M		2 M		0
$-x$		$-x$		$+2x$
$2-x$		$2-x$		$2x$

$$1.0 \times 10^2 = \frac{[2x]^2}{[2-x][2-x]}$$

$\boxed{x = 1.67}$

$[H_2] = 0.33$ M
$[F_2] = 0.33$ M
$[HF] = 3.3$ M

12. Consider the following reaction:

$$N_2O_4\,(g) \leftrightarrow 2\,NO_2\,(g) \qquad\qquad K = 0.25$$

What are the equilibrium partial pressures of N_2O_4 and NO_2 if the system begins with 0.05 atm of pressure of pure NO_2?

N_2O_4	$\rightleftarrows$	$2\ NO_2$
0		.05
$+x$		$-2x$
x		$.05-2x$

$$K = .25 = \frac{[.05-2x]^2}{[x]}$$

Solver Guess .01

$\boxed{x = 5.9 \times 10^{-3}}$

$N_2O_4 = 5.9 \times 10^{-3}$ atm
$NO_2 = 3.8 \times 10^{-2}$ atm