Chemistry 12 – Dynamic Equilibrium
Learning Goal B5
Equilibrium Calculations: Problem Set E

Solve each problem and show all of your work.

1. At equilibrium, a 5.0L flask contains:
0.75 mol of PCl_5 0.50 mol of H_2O 7.50 mol of HCl 5.00 mol of $POCl_3$
Calculate the K_{eq} for the reaction:
$$PCl_{5\,(s)} + H_2O_{(g)} \rightleftharpoons 2HCl_{(g)} + POCl_{3\,(g)}$$

$$K_{eq} = \frac{[HCl]^2[POCl_3]}{[H_2O]}$$

$$= \frac{\left(\frac{7.50\,mol}{5.0\,L}\right)^2\left(\frac{5.00\,mol}{5.0\,L}\right)}{\left(\frac{0.50\,mol}{5.0\,L}\right)} = \boxed{23}$$

or 22. rounding rules (Round to even)

2. $K_{eq} = 798$ for the reaction at a particular temperature: $2\,SO_{2\,(g)} + O_{2\,(g)} \rightleftharpoons 2\,SO_{3\,(g)}$.

In a particular mixture at equilibrium, $[SO_2] = 4.20$ M and $[SO_3] = 11.0$ M. Calculate the equilibrium $[O_2]$ in this mixture.

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

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

$$= \frac{(11.0)^2}{(4.20)^2(798)}$$

$$= \boxed{8.60 \times 10^{-3}}$$

3. Consider the following equilibrium:

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

When 0.600 moles of SO_2 and 0.600 moles of O_2 are placed into a 1.00 L container and allowed to reach equilibrium, the equilibrium $[SO_3]$ is to be 0.250 M. Calculate K_{eq}.

	$2SO_2$	O_2	$2SO_3$
R	$2SO_2$ +	O_2 ⇌	$2SO_3$
I	0.600	0.600	0
C	$-2x$	$-x$	$+2x$
E	$0.600-2x$ $= 0.600-2(0.125)$ $= 0.350$ M	$0.600-x$ $= 0.600-0.125$ $= 0.475$ M	$2x$ $= 0.250$ M

$2x = 0.250$ M

$x = \frac{0.250 \text{ M}}{2}$

$x = 0.125$ M

$$K_{eq} = \frac{[SO_3]^2}{[SO_2]^2[O_2]} = \frac{(0.250)^2}{(0.350)^2(0.475)} = \boxed{1.07}$$

4. Consider the following equilibrium:

$$2\ NO_{2\ (g)} \rightleftharpoons N_2O_{4\ (g)}$$

2.00 moles of NO_2 are placed in a 1.00 L flask and allowed to react. After equilibrium is established, 1.80 moles of NO_2 are present. Calculate K_{eq}.

R	$2NO_2$ ⇌	N_2O_4
I	2.00 M	0
C	$-2x$	$+x$
E	$2.00-2x$ $= 1.80$	x $= 0.100$

$2.00 - 2x = 1.80$

$x = 0.100$

$$K_{eq} = \frac{[N_2O_4]}{[NO_2]^2} = \frac{(0.100)}{(1.80)^2} = \boxed{0.0309}$$

5. Consider the chemical system below:

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

4.00 moles of SO_2 and 5.00 moles O_2 are placed in a 2.00 L container at 200°C and allowed to reach equilibrium. If the equilibrium $[O_2]$ is 2.00 M, calculate the value of K_{eq}.

R	$2SO_2$	$+ O_2$	$\rightleftharpoons 2SO_3$
I	2.00 M	2.50 M	0
C	−2x	−x	+2x
E	2.00−2x = 2.00−1.0 = 1.0	2.50−x = 2.00	2x = 1.0

$2.50 - x = 2.00$

$x = 0.50$

$$K_{eq} = \frac{[SO_3]^2}{[SO_2]^2[O_2]} = \frac{(1.0)^2}{(1.0)^2(2.00)} = \boxed{0.50}$$

6. If the initial $[H_2]$ = 0.200 M, $[I_2]$ = 0.200 M and K_{eq} = 55.6 (at 250°C) calculate the equilibrium concentrations of all molecules in the following chemical system.

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

R	H_2	$+ I_2$	$\rightleftharpoons 2HI$
I	0.200	0.200	0
C	−x	−x	+2x
E	0.200−x	0.200−x	2x

$[H_2] = [I_2] = 0.200 - x = 0.200 - 0.158 = 0.042\ M$

$[HI] = 2(0.158) = 0.316\ M$

$$K_{eq} = \frac{[HI]^2}{[H_2][I_2]} = 55.6$$

$$\sqrt{\frac{(2x)^2}{(0.200-x)^2}} = \sqrt{55.6}$$

$2x = \sqrt{55.6}\,(0.200 - x)$

$2x + 7.456x = 1.4913$

$x = 0.158$

7. 1.60 moles CO and 1.60 moles H_2O are placed in a 2.00 L container at 690 °C

$$CO_{(g)} + H_2O_{(g)} \rightleftharpoons CO_{2\,(g)} + H_{2\,(g)} \qquad K_{eq} = 10.0$$

Calculate all equilibrium concentrations.

R	CO	$+ H_2O$	$\rightleftharpoons CO_2$	$+ H_2$
I	0.800	0.800	0	0
C	−x	−x	+x	+x
E	0.800−x	0.800−x	x	x

$[CO_2] = [H_2] = 0.607\ M$

$[CO] = [H_2O] = 0.800 - 0.607 = 0.192\ M$

$$K_{eq} = \frac{[CO_2][H_2]}{[CO][H_2O]} = 10.0$$

$$K_{eq} = \frac{(x)(x)}{(0.800-x)(0.800-x)} = 10.0$$

$$\sqrt{\frac{x^2}{(0.800-x)^2}} = \sqrt{10.0}$$

$x = 2.5298 - 3.162x$

$$\frac{4.162x}{4.162} = \frac{2.5298}{4.162}$$

$x = 0.607\ M$

8. $SO_{3\,(g)} + NO_{(g)} \rightleftharpoons NO_{2\,(g)} + SO_{2\,(g)}$; $K_{eq} = 0.800$ at 100°C.

If 4.00 moles of each reactant are placed in a 2.00L container, calculate all equilibrium concentrations at 100°C for the chemical system shown above.

R	SO_3 +	NO ⇌	NO_2 +	SO_2
I	2.00 M	2.00 M	0	0
C	−x	−x	+x	+x
E	2.00 − x	2.00 − x	x	x

$= 2.00 - 0.944$ $= 0.944 M$

$= 1.06\ M$

$[SO_3] = [NO] = 1.06\ M$
$[NO_2] = [SO_2] = 0.944 M$

$$K_{eq} = \frac{[NO_2][SO_2]}{[SO_3][NO]} = 0.800$$

$$\frac{(x)(x)}{(2.00-x)(2.00-x)} = 0.800$$

$$\sqrt{\frac{x^2}{(2.00-x)^2}} = \sqrt{0.800}$$

$$x = \sqrt{0.800}\,(2.00-x)$$

$$x = 1.7889 - 0.8944x$$

$$\frac{1.8944x}{1.8944} = \frac{1.7889}{1.8944}$$

$$x = 0.944\ M$$

*9. Consider the following equilibrium system:

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

Two sets of equilibrium data are listed for the same temperature.

Container 1	2.00 L	0.12 moles NO_2	0.16 moles N_2O_4
Container 2	5.00 L	0.26 moles NO_2	? moles N_2O_4

Determine the number of moles N_2O_4 in the second container.

$$K_{eq} = \frac{[N_2O_4]}{[NO_2]^2} = \frac{(0.16\,mol/2.00L)}{(0.12\,mol/2.00L)^2}$$

Data from container 1

$$= 22$$

Same temperature
∴ same K_{eq} value

$$22 = \frac{(x\,mol/5.00L)}{(0.26\,mol/5.00L)^2}$$

$$22 = \frac{(x\,mol/5.00L)}{2.704\times10^{-3}\,M}$$

$$0.0595M = x\,mol/5.00L$$

0.30 mol = mol N_2O_4