AP Chemistry – Chemical Equilibrium (Kotz)
Homework Answers 1, 5, 7, 9, 16, 18, 21, 23, 25, 28, 33, 39, 41, 51, 55

16.1 (a) $K = \dfrac{[H_2O]^2[O_2]}{[H_2O_2]^2}$ $\qquad K_p = \dfrac{P^2_{H_2O}P_{O_2}}{P^2_{H_2O_2}}$

(b) $K = \dfrac{[CO_2]}{[CO][O_2]^{1/2}}$ $\qquad K_p = \dfrac{P_{CO_2}}{P_{CO}P^{1/2}_{O_2}}$

(c) $K = \dfrac{[CO]^2}{[CO_2]}$ $\qquad K_p = \dfrac{P^2_{CO}}{P_{CO_2}}$

(d) $K = \dfrac{[CO_2]}{[CO]}$ $\qquad K_p = \dfrac{P_{CO_2}}{P_{CO}}$

16.5 $Q = \dfrac{[SO_3]^2}{[SO_2]^2[O_2]} = \dfrac{(6.9 \times 10^{-3})^2}{(5.0 \times 10^{-3})^2(1.9 \times 10^{-3})} = 1.0 \times 10^3$

$Q > K$ The reaction is not at equilibrium. The reaction will proceed to the left, to form more reactants.

16.7 $K = \dfrac{[PCl_3][Cl_2]}{[PCl_5]} = \dfrac{(1.3 \times 10^{-2})(3.9 \times 10^{-3})}{4.2 \times 10^{-5}} = 1.2$

16.9 $[CO] = \dfrac{0.10 \text{ mol}}{2.0 \text{ L}} = 0.050 \text{ mol/L}$ $\qquad [CO_2] = \dfrac{0.20 \text{ mol}}{2.0 \text{ L}} = 0.10 \text{ mol/L}$

(a) $K = \dfrac{[CO]^2}{[CO_2]} = \dfrac{(0.050)^2}{0.10} = 0.025$

(b) Only the amount of C has changed, and solids do not appear in equilibrium constant expressions.

$K = 0.025$

(c) The value of K is independent of the quantity of solid present.

16.16 $[N_2O_4] = \dfrac{15.6 \text{ g}}{5.00 \text{ L}} \cdot \dfrac{1 \text{ mol } N_2O_4}{92.01 \text{ g}} = 0.0339 \text{ M}$

	N_2O_4	Æ	$2\ NO_2$
Initial (M)	0.0339		0
Change (M)	$-x$		$+2x$
Equilibrium (M)	$0.0339 - x$		$2x$

$K = \dfrac{[NO_2]^2}{[N_2O_4]} = 5.88 \times 10^{-3} = \dfrac{(2x)^2}{0.0339 - x}$

$0 = 4x^2 - (5.88 \times 10^{-3})(0.0339 - x)$

Solve using the quadratic equation. $x = 0.00636$ and -0.00783

(a) Amount of NO_2 present at equilibrium = $2x = 2(0.00636 \text{ mol/L})(5.00 \text{ L}) = 0.0636$ moles NO_2

(b) % N_2O_4 dissociated = $\dfrac{0.00636 \text{ M}}{0.0339 \text{ M}} \cdot 100\% = 18.8\%$

16.18 $[I_2(aq)] = \dfrac{0.0340 \text{ g}}{0.1000 \text{ L}} \cdot \dfrac{1 \text{ mol } I_2}{253.8 \text{ g}} = 0.00134 \text{ M}$

$I_2(aq)$ Æ $I_2(CCl_4)$

Initial (M)	0.00134	0
Change (M)	$-x$	$+x$
Equilibrium (M)	$0.00134 - x$	x

$$K = 85.0 = \frac{x}{0.00134 - x}$$

$x = 0.00132$

$[I_2(aq)] = 0.00134 - x = 2 \times 10^{-5}$ M

amount of I_2 remaining in water = $(2 \times 10^{-5}$ mol/L)(0.1000 L)(253.8 g/mol) = 4×10^{-4} g I_2

16.21 The second equation has been reversed and multiplied by 2

(e) $K_2 = 1/K_1^2$

16.23

$SnO_2(s) + 2\ H_2(g) \rightleftharpoons Sn(s) + 2\ H_2O(g)$	$K = 8.12$
$2\ H_2O(g) + 2\ CO(g) \rightleftharpoons 2\ H_2(g) + 2\ CO_2(g)$	$K = 1/(0.771)^2$
$SnO_2(s) + 2\ CO(g) \rightleftharpoons Sn(s) + 2\ CO_2(g)$	$K_{net} = (8.12)/(0.771)^2 = 13.7$

16.25 (a) Adding more $N_2O_3(g)$ will shift the equilibrium to the right

(b) Adding more $NO_2(g)$ will shift the equilibrium to the left

(c) Increasing the volume of the reaction flask will shift the equilibrium to the right

(d) Lowering the temperature will shift the equilibrium to the left

16.28 When the temperature is raised, the reaction adjusts to the added heat by consuming reactants and forming more products. The equilibrium shifts to the right. Adding NH_4HS, a solid, will have no effect on the equilibrium. Adding $NH_3(g)$, a product, will shift the equilibrium to the left. Removing H_2S, a product, will shift the reaction to the right, increasing the NH_3 pressure.

16.33

	CS_2	+ $3\ Cl_2$ $\rightleftharpoons$	S_2Cl_2	+ CCl_4
Initial (M)	1.2	3.6	0	0
Change (M)	–0.90	–3(0.90)	+0.90	+0.90
Equilibrium (M)	0.3	0.9	0.90	0.90

$$K = \frac{[CCl_4][S_2Cl_2]}{[CS_2][Cl_2]^3} = \frac{(0.90)(0.90)}{(0.3)(0.9)^3} = 4$$

16.39 (a) no change

(b) shifts left

(c) no change

(d) shifts right

(e) shifts right

16.41 Adding Cl_2, a product, will shift the equilibrium to the left.

$$[PCl_5] = \frac{3.120\text{ g}}{1.00\text{ L}} \cdot \frac{1\text{ mol }PCl_5}{208.24\text{ g}} = 0.0150\text{ M} \quad [PCl_3] = \frac{3.845\text{ g}}{1.00\text{ L}} \cdot \frac{1\text{ mol }PCl_3}{137.33\text{ g}} = 0.0280\text{ M}$$

$$[Cl_2] = \frac{1.787\text{ g}}{1.00\text{ L}} \cdot \frac{1\text{ mol }Cl_2}{70.905\text{ g}} = 0.0252\text{ M} \qquad [Cl_2](\text{added}) = \frac{1.418\text{ g}}{1.00\text{ L}} \cdot \frac{1\text{ mol }Cl_2}{70.905\text{ g}} = 0.0200\text{ M}$$

$$K = \frac{[PCl_3][Cl_2]}{[PCl_5]} = \frac{(0.0280)(0.0252)}{0.0150} = 0.0471$$

	PCl_5 $\rightleftharpoons$	PCl_3 +	Cl_2
Initial (M)	0.0150	0.0280	0.0252
Concentration on adding Cl_2 (M)	0.0150	0.0280	0.0252 + 0.0200
Change to reestablish equilibrium (M)	$+x$	$-x$	$-x$
Equilibrium (M)	$0.0150 + x$	$0.0280 - x$	$0.0452 - x$

$$K = 0.0471 = \frac{(0.0280 - x)(0.0452 - x)}{0.0150 + x}$$

$$0 = x^2 - 0.1203x + 0.00559$$

Solve using the quadratic equation. $x = 0.115$ and 0.00485

$[PCl_5] = 0.0150 + x = 0.0199$ M

$[PCl_3] = 0.0280 - x = 0.0232$ M

$[Cl_2] = 0.0452 - x = 0.0404$ M

16.51 (a) $P_{total} = 1.50\text{ atm} = P_{NO_2} + P_{N_2O_4}$ $\qquad P_{N_2O_4} = 1.50 - P_{NO_2}$

$$K_p = 0.148 = \frac{P_{NO_2}^{\ 2}}{1.50 - P_{NO_2}}$$

Solve using the quadratic equation.

$P_{NO_2} = 0.403$ atm

$P_{N_2O_4} = 1.50 - P_{NO_2} = 1.10$ atm

$$P_{N_2O_4}(\text{initial}) = 1.10\text{ atm} + (0.403\text{ atm})\left(\frac{1\text{ mol }N_2O_4}{2\text{ mol }NO_2}\right) = 1.30\text{ atm}$$

$$\text{fraction dissociated} = \frac{1.30\text{ atm} - 1.10\text{ atm}}{1.30\text{ atm}} = 0.15$$

(b) $$K_p = \frac{P_{NO_2}^{\ 2}}{P_{N_2O_4}} = 0.148 = \frac{P_{NO_2}^{\ 2}}{1.00 - P_{NO_2}}$$

Solve using the quadratic equation. $P_{NO_2} = 0.318$ atm $\qquad P_{N_2O_4} = 1.00 - P_{NO_2} = 0.682$ atm

$$P_{N_2O_4}(\text{initial}) = 0.682\text{ atm} + (0.318\text{ atm})\left(\frac{1\text{ mol }N_2O_4}{2\text{ mol }NO_2}\right) = 0.841\text{ atm}$$

$$\text{fraction dissociated} = \frac{0.841\text{ atm} - 0.682\text{ atm}}{0.841\text{ atm}} = 0.189$$

If pressure decreases, the equilibrium will shift to the right, increasing the fraction of N_2O_4 dissociated.

16.55 $K = \frac{[\text{HbCO}]P_{O_2}}{[\text{HbO}_2]P_{CO}}$

$$2.0 \times 10^2 = (1)\frac{0.20 \text{ atm}}{P_{CO}}$$

$P_{CO} = 0.0010$ atm