

AP Chemistry – Chemical Equilibrium (Kotz)

Homework Answers 1, 5, 7, 9, 16, 18, 21, 23, 25, 28, 33, 39, 41, 51, 55

$$16.1 \quad (a) \quad K = \frac{[\text{H}_2\text{O}]^2[\text{O}_2]}{[\text{H}_2\text{O}_2]^2} \quad K_p = \frac{P_{\text{H}_2\text{O}}^2 P_{\text{O}_2}}{P_{\text{H}_2\text{O}_2}^2}$$

$$(b) \quad K = \frac{[\text{CO}_2]}{[\text{CO}][\text{O}_2]^{1/2}} \quad K_p = \frac{P_{\text{CO}_2}}{P_{\text{CO}} P_{\text{O}_2}^{1/2}}$$

$$(c) \quad K = \frac{[\text{CO}]^2}{[\text{CO}_2]} \quad K_p = \frac{P_{\text{CO}}^2}{P_{\text{CO}_2}}$$

$$(d) \quad K = \frac{[\text{CO}_2]}{[\text{CO}]} \quad K_p = \frac{P_{\text{CO}_2}}{P_{\text{CO}}}$$

$$16.5 \quad Q = \frac{[\text{SO}_3]^2}{[\text{SO}_2]^2[\text{O}_2]} = \frac{(6.9 \times 10^{-3})^2}{(5.0 \times 10^{-3})^2(1.9 \times 10^{-3})} = 1.0 \times 10^3$$

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

$$16.7 \quad K = \frac{[\text{PCl}_3][\text{Cl}_2]}{[\text{PCl}_5]} = \frac{(1.3 \times 10^{-2})(3.9 \times 10^{-3})}{4.2 \times 10^{-5}} = 1.2$$

$$16.9 \quad [\text{CO}] = \frac{0.10 \text{ mol}}{2.0 \text{ L}} = 0.050 \text{ mol/L} \quad [\text{CO}_2] = \frac{0.20 \text{ mol}}{2.0 \text{ L}} = 0.10 \text{ mol/L}$$

$$(a) \quad K = \frac{[\text{CO}]^2}{[\text{CO}_2]} = \frac{(0.050)^2}{0.10} = 0.025$$

(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.

$$16.16 \quad [\text{N}_2\text{O}_4] = \frac{15.6 \text{ g}}{5.00 \text{ L}} \cdot \frac{1 \text{ mol N}_2\text{O}_4}{92.01 \text{ g}} = 0.0339 \text{ M}$$

|  | N <sub>2</sub> O <sub>4</sub>                       | Æ | 2 NO <sub>2</sub> |
|--|---|---|-------------------|
| <i>Initial (M)</i>                                   | 0.0339  |   | 0                 |
| <i>Change (M)</i>                                    | -x  |   | +2x               |
| <i>Equilibrium (M)</i>                               | 0.0339 - x  |   | 2x                |
| $K = \frac{[\text{NO}_2]^2}{[\text{N}_2\text{O}_4]}$ | $= 5.88 \times 10^{-3} = \frac{(2x)^2}{0.0339 - x}$ |   |                   |

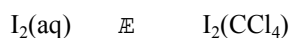
$$0 = 4x^2 - (5.88 \times 10^{-3})(0.0339 - x)$$

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

(a) Amount of NO<sub>2</sub> present at equilibrium =  $2x = 2(0.00636 \text{ mol/L})(5.00 \text{ L}) = 0.0636 \text{ moles NO}_2$

$$(b) \quad \% \text{ N}_2\text{O}_4 \text{ dissociated} = \frac{0.00636 \text{ M}}{0.0339 \text{ M}} \cdot 100\% = 18.8\%$$

$$16.18 \quad [\text{I}_2(\text{aq})] = \frac{0.0340 \text{ g}}{0.1000 \text{ L}} \cdot \frac{1 \text{ mol I}_2}{253.8 \text{ g}} = 0.00134 \text{ M}$$



|                        |             |    |
|------------------------|-------------|----|
| <i>Initial</i> (M)     | 0.00134     | 0  |
| <i>Change</i> (M)      | -x          | +x |
| <i>Equilibrium</i> (M) | 0.00134 - x | x  |

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

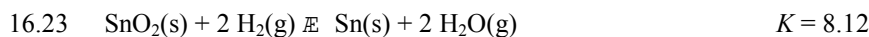
$$x = 0.00132$$

$$[\text{I}_2(\text{aq})] = 0.00134 - x = 2 \times 10^{-5} \text{ M}$$

$$\text{amount of I}_2 \text{ remaining in water} = (2 \times 10^{-5} \text{ mol/L})(0.1000 \text{ L})(253.8 \text{ g/mol}) = 4 \times 10^{-4} \text{ g I}_2$$

16.21 The second equation has been reversed and multiplied by 2

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



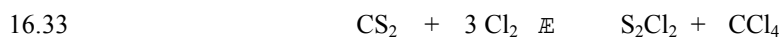
16.25 (a) Adding more  $\text{N}_2\text{O}_3(\text{g})$  will shift the equilibrium to the right

(b) Adding more  $\text{NO}_2(\text{g})$  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  $\text{NH}_4\text{HS}$ , a solid, will have no effect on the equilibrium. Adding  $\text{NH}_3(\text{g})$ , a product, will shift the equilibrium to the left. Removing  $\text{H}_2\text{S}$ , a product, will shift the reaction to the right, increasing the  $\text{NH}_3$  pressure.



$$K = \frac{[\text{CCl}_4][\text{S}_2\text{Cl}_2]}{[\text{CS}_2][\text{Cl}_2]^3} = \frac{(0.90)(0.90)}{(0.3)(0.9)^3} = 4$$

16.39 (a) no change

(b) shifts left

(c) no change

(d) shifts right

(e) shifts right

16.41 Adding  $\text{Cl}_2$ , a product, will shift the equilibrium to the left.

$$[\text{PCl}_5] = \frac{3.120 \text{ g}}{1.00 \text{ L}} \cdot \frac{1 \text{ mol PCl}_5}{208.24 \text{ g}} = 0.0150 \text{ M} \quad [\text{PCl}_3] = \frac{3.845 \text{ g}}{1.00 \text{ L}} \cdot \frac{1 \text{ mol PCl}_3}{137.33 \text{ g}} = 0.0280 \text{ M}$$

$$[\text{Cl}_2] = \frac{1.787 \text{ g}}{1.00 \text{ L}} \cdot \frac{1 \text{ mol Cl}_2}{70.905 \text{ g}} = 0.0252 \text{ M} \quad [\text{Cl}_2](\text{added}) = \frac{1.418 \text{ g}}{1.00 \text{ L}} \cdot \frac{1 \text{ mol Cl}_2}{70.905 \text{ g}} = 0.0200 \text{ M}$$

$$K = \frac{[\text{PCl}_3][\text{Cl}_2]}{[\text{PCl}_5]} = \frac{(0.0280)(0.0252)}{0.0150} = 0.0471$$

|  | $\text{PCl}_5$ | $\text{PCl}_3$ | $\text{Cl}_2$   |
|--|----------------|----------------|-----------------|
| <i>Initial (M)</i>                           | 0.0150         | 0.0280         | 0.0252          |
| Concentration on adding $\text{Cl}_2$ (M)    | 0.0150         | 0.0280         | 0.0252 + 0.0200 |
| <i>Change to reestablish equilibrium (M)</i> | +x             | -x             | -x              |
| <i>Equilibrium (M)</i>                       | 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  $0.00485$

$$[\text{PCl}_5] = 0.0150 + x = 0.0199 \text{ M}$$

$$[\text{PCl}_3] = 0.0280 - x = 0.0232 \text{ M}$$

$$[\text{Cl}_2] = 0.0452 - x = 0.0404 \text{ M}$$

16.51 (a)  $P_{\text{total}} = 1.50 \text{ atm} = P_{\text{NO}_2} + P_{\text{N}_2\text{O}_4}$        $P_{\text{N}_2\text{O}_4} = 1.50 - P_{\text{NO}_2}$

$$K_p = 0.148 = \frac{P_{\text{NO}_2}^2}{1.50 - P_{\text{NO}_2}}$$

Solve using the quadratic equation.

$$P_{\text{NO}_2} = 0.403 \text{ atm}$$

$$P_{\text{N}_2\text{O}_4} = 1.50 - P_{\text{NO}_2} = 1.10 \text{ atm}$$

$$P_{\text{N}_2\text{O}_4}(\text{initial}) = 1.10 \text{ atm} + (0.403 \text{ atm}) \left( \frac{1 \text{ mol N}_2\text{O}_4}{2 \text{ mol NO}_2} \right) = 1.30 \text{ atm}$$

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

$$(b) K_p = \frac{P_{\text{NO}_2}^2}{P_{\text{N}_2\text{O}_4}} = 0.148 = \frac{P_{\text{NO}_2}^2}{1.00 - P_{\text{NO}_2}}$$

Solve using the quadratic equation.  $P_{\text{NO}_2} = 0.318 \text{ atm}$        $P_{\text{N}_2\text{O}_4} = 1.00 - P_{\text{NO}_2} = 0.682 \text{ atm}$

$$P_{\text{N}_2\text{O}_4}(\text{initial}) = 0.682 \text{ atm} + (0.318 \text{ atm}) \left( \frac{1 \text{ mol N}_2\text{O}_4}{2 \text{ mol NO}_2} \right) = 0.841 \text{ atm}$$

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

If pressure decreases, the equilibrium will shift to the right, increasing the fraction of  $\text{N}_2\text{O}_4$  dissociated.

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

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

$$P_{\text{CO}} = 0.0010 \text{ atm}$$