7.10 Reaction Quotient and Le Chatelier's Principle
Worksheet Key

1) The equilibrium constant, K_c, is 9.8×10^5 for $H_2(g) + S(s) \rightleftharpoons H_2S(g)$.
   a. Find the reaction quotient, Q_c, if $[H_2] = 0.762\ M$ and $[H_2S] = 0.483\ M$.
   b. Has the process established equilibrium? If not, in which direction will it proceed? Justify your answer.

2) The equilibrium constant, K_c, is 4.7 for $H_2O(g) + CH_4(g) \rightleftharpoons 3\ H_2(g) + CO(g)$ at 1127°C.
   a. Find the reaction quotient, Q_c, when 0.20 mol $H_2O(g)$, 0.50 mol $CH_4(g)$, 1.7 mol $H_2(g)$, and 0.60 mol $CO(g)$ are placed in a rigid 2.5 L container at 1127°C.
   b. Has the process established equilibrium? If not, in which direction will it proceed? Justify your answer.

3) The equilibrium constant, K_p, is 0.140 for $ClF_3(g) \rightleftharpoons F_2(g) + ClF(g)$ at 427°C.
   a. Find the reaction quotient, Q_p, when the partial pressures are 0.632 atm for ClF_3, 0.025 atm for F_2, and 0.097 atm for ClF.
   b. Will the partial pressure of ClF_3 increase, decreases, or stay the same as the system approaches equilibrium? Justify your answer.

4) Suppose NaOH is added to the following system when it is at equilibrium.
$$NH_3(aq) + H_2O(l) \rightleftharpoons NH_4^+(aq) + OH^-(aq)$$
   a. In which direction will the reaction shift after the NaOH is added?
   b. Will this stress increase or decrease the value of the reaction quotient, Q? Justify your answer.
   c. Will the rate of the forward reaction exceed the rate of the reverse reaction before equilibrium is re-established? Justify your answer.
   d. When equilibrium is re-established will the rate of the forward reaction exceed the rate of the reverse reaction? Justify your answer.

5) Suppose additional $CO(g)$ is added to the following system when it is at equilibrium? $CO(g) + PbO(s) \rightleftharpoons CO_2(g) + Pb(s)$
   a. In which direction will the reaction shift after the CO is added?
   b. Will this stress increase or decrease the value of the reaction quotient, Q? Justify your answer.
   c. Will the rate of the forward reaction exceed the rate of the reverse reaction before equilibrium is re-established? Justify your answer.
   d. When equilibrium is re-established will Q be greater than, equal to, or less than K? Justify your answer.

6) Suppose SO_2 is removed from the following system when it is at equilibrium.

$$SO_2(g) + H_2O(l) \rightleftharpoons H_2SO_3(aq)$$

   a. In which direction will the reaction shift after the SO_2 is removed?
   b. Will the value of the reaction quotient, Q, change in response to this stress? Justify your answer.
   c. Will the value of the equilibrium constant, K_{eq}, change in response to this stress? Justify your answer.

7) Suppose the following system is in a state of equilibrium. If the pressure is then reduced, in which direction will the reaction shift?

$$Br_2(g) + 3\ F_2(g) \rightleftharpoons 2\ BrF_3(g)$$

8) In order to maximize the production of sulfur dioxide gas, a chemist suggested that they increase the pressure on the following system. Would this work? Justify your answer. $2\ PbS(g) + 3\ O_2(g) \rightleftharpoons 2\ PbO(s) + 2\ SO_2(g)$.

9) A chemical company was producing $Mo(CO)_5P(CH_3)_3$ through the following process.

$$Mo(CO)_5 + P(CH_3)_3 \rightleftharpoons Mo(CO)_5P(CH_3)_3$$

One of the chemists suggested that they should add $Mo(CO)_6$ to the system, as it would create the following reactions.

$$Mo(CO)_6 \rightleftharpoons Mo(CO)_5 + CO$$

Why would the chemist make this suggestion?

10) Suppose a system operating in accordance with the chemical equation below is in a state of equilibrium. Will the reaction shift if the pressure is reduced? If so, in which direction will it shift? $Cl_2(g) + 2\ I^-(aq) \rightleftharpoons 2\ Cl^-(aq) + I_2(s)$

11) Suppose a system operating in accordance with the chemical equation below is in a state of equilibrium. Will the reaction shift when the pressure acting on the system is increased? If so, in which direction will it shift?

$$Br_2(g) + H_2(g) \rightleftharpoons 2\ HBr(g)$$

12) Suppose a system operating in accordance with the chemical equation below is in a state of equilibrium at 25°C. In which direction will the reaction shift when the temperature is increased to 75°C ?

$$CO(g) + NO(g) \rightleftharpoons CO_2(g) + \tfrac{1}{2}\ N_2(g) \qquad \Delta H_{rxn} = -373\ kJ$$

13) Suppose a system operating in accordance with the chemical equation below is in a state of equilibrium. In which direction will the reaction shift when heat is added to the system? $2\ N_2O_5(s) \rightleftharpoons 4\ NO(g) + 3\ O_2(g)$ $\Delta H_{rxn} = +247.4\ kJ$

14) Will decreasing the temperature of the following equilibrium system cause the ratio of $[CO]/[CO_2]$ to increase, decrease, are remain the same? Justify your answer.

$$2\ CO(g) + O_2(g) \rightleftharpoons 2\ CO_2(g) \qquad \Delta H_{rxn} = -566.0\ kJ$$

15) $NO_2(g)$ is a reddish-brown color and $N_2O_4(g)$ is colorless. Suppose the two gases establish the following equilibrium.

$$NO_2(g) \rightleftharpoons N_2O_4(g) \qquad \Delta H^o = -57.2\ kJ$$

If the temperature increased from 25°C to 45°C, and the volume remained the same, what would happen to the overall color of the gaseous system? Justify your answer.

16) What is the only thing that one can do to reduce the value of the equilibrium constant, K_{eq}, for the following system?

$$2\ SO_2(g) + O_2(g) \rightleftharpoons 2\ SO_3(g) \qquad \Delta H_{rxn} = -198.4\ kJ$$

17) The value of K_{eq} for a certain reaction is 5.6 at 650 K and 1.2 at 125 K. Is the forward reaction endothermic or exothermic? Justify your answer.

18) Suppose a system is in a state of equilibrium in accordance with the chemical equation below. Will the reaction below shift if distilled water is added to the system? If so, in which direction will it shift?

$$CH_3COOH\ (aq) \rightleftharpoons CH_3COO^-\ (aq) + H^+\ (aq)$$

19) Gaseous HCl is added to a rigid vessel containing excess solid iodine at 25°C until the partial pressure of HCl reaches 1.47 atm. The following reaction brings the system to equilibrium.

$$2\ HCl(g) + I_2(s) \rightleftharpoons 2\ HI(g) + Cl_2(g) \qquad (K_p = 3.91 \times 10^{-33} \text{ at } 25\,^\circ C)$$

a. Find the equilibrium partial pressures of all species at 25°C.
b. The temperature of the system changed, and the equilibrium constant, K_p, became 8.39×10^{-27}. Find the new partial pressures of all the species at equilibrium.

20) The equilibrium constant, K_p, is 6.3×10^{-5} at 1500 K for the reaction represented below. A chemist mixed 55% $CH_3Cl(g)$ and 45% $HCl(g)$ by moles into a rigid container until the total pressure inside the container was 1.5 atm at 1500 K.

$$HCl(g) + CH_3Cl(g) \rightleftharpoons CH_4(g) + Cl_2(g)$$

a. Find the initial partial pressures of each gas.
b. Find the equilibrium partial pressures of each gas at 1500 K.
c. The temperature of the system changed, and the equilibrium constant, K_p, became 4.7×10^{-10}. Find the new partial pressures of all gaseous species at equilibrium.