Chemical Equilibrium – Theory Review

1. What are the empirical characteristics of a system at equilibrium?

2. Why is the theory of equilibrium called "dynamic"?

3. What three types of changes shift the position of a chemical equilibrium?

4. For each of the following chemical systems at equilibrium, use Le Châtelier's principle to predict the effect of the change imposed on the chemical system. Indicate the direction in which the equilibrium is expected to shift. Assume that the systems are closed and that they are initially at equilibrium.
   a) $H_2O(l)$ + energy ⇆ $H_2O(g)$ — The container is heated.
   b) $H_2O(l)$ ⇆ $H^+(aq)$ + $OH^-(aq)$ — A few crystals of NaOH(s) are added to the container.
   c) $CaCO_3(s)$ + energy ⇆ $CaO(s)$ + $CO_2(g)$ — Carbon dioxide is removed from the container.

5. The following equation represents part of the industrial production of nitric acid. Predict the direction of the equilibrium shift for each of the following changes.

   $$4\ NH_3(g) + 5\ O_2(g) \leftrightarrows 4\ NO(g) + 6\ H_2O(g) + \text{energy}$$

   a) Oxygen is added to the system.
   b) The temperature of the system is increased.
   c) Nitrogen monoxide is removed from the system.
   d) The pressure of the system is increased by decreasing the volume.

6. Does a catalyst affect a state of equilibrium? What does it do?

7. Chemical engineers use Le Châtelier's principle to predict shifts in chemical systems at equilibrium resulting from changes in the reaction conditions. Predict the changes necessary to maximize the yield of product in each of the following industrial chemical systems.
   a) the production of ethene (ethylene) — $C_2H_6(g)$ + energy ⇆ $C_2H_4(g)$ + $H_2(g)$
   b) the production of methanol — $CO(g)$ + 2 $H_2(g)$ ⇆ $CH_3OH(g)$ + energy

8. For the reaction: A + B ⇆ C, the activation energy of the forward reaction is 5 kJ and the total energy change is –20 kJ. What is the activation energy of the reverse reaction?

9. By means of a sketch, show that the activation energy of an endothermic reaction must be greater than or equal to the total energy change in the reaction. Does a similar relationship exist for exothermic reactions?

10. Draw a potential energy diagram for a reaction in which the heat of reaction is: ΔH = –80 kJ/mol; and the activation is 28 kJ/mol. Label both axes, the activation energy, heat of reaction, site of activated complex, reactants and products. Show on the diagram, using a dashed line, how a catalyst is effective in increasing the reaction rate.

11. Name the factors that influence the rate of a chemical reaction. How are the effects of these factors explained by the collision theory?

12. The following reaction is at equilibrium. Predict the effect (if any) that each of the following changes will have on (i) the equilibrium, and (ii) the reaction rate.

    $$N_2(g) + 3H_2(g) \leftrightarrows 2NH_3(g) \qquad \Delta H = -92\ kJ$$

    a) lowering the temperature
    b) adding hydrogen
    c) adding a catalyst
    d) decreasing the pressure
    e) removing nitrogen
    f) decreasing the volume