1. Which is true, by definition, for a system that has reached a state of chemical equilibrium?

(A) The substance having the smaller volume has a tendency to form at the expense of the other substances.

(B) No further reaction occurs in either direction.

(C) The concentrations of reactants and products are necessarily equal.

(D) The opposing reactions have equal velocities.

(E) The total mass of the products is equal to the total mass of the reactants.

2. When $COCl_2$ is heated to 527 °C in a reaction vessel, the following equilibrium is attained:

$$COCl_{2(g)} \rightarrow CO_{(g)} + Cl_{2(g)}$$

If the equilibrium concentrations are found to be [CO] = 0.0456, $[Cl_2]$ = 0.0456 and $[COCl_2]$ = 0.449 M, what is the equilibrium constant?

3. Consider the reaction:

$H_{2(g)} + Cl_{2(g)} \rightarrow 2\ HCl_{(g)}$ $K_c = 1.7 \times 104$

Write the equilibrium expressions, Kc , and determine Kc for each of the following:

(a) $\frac{1}{2}\ H_{2(g)} + \frac{1}{2}\ Cl_{2(g)} \rightarrow HCl_{(g)}$

(b) $2\ HCl_{(g)} \rightarrow H_{2(g)} + Cl_{2(g)}$

(c) $HCl_{(g)} \rightarrow \frac{1}{2}\ H_{2(g)} + \frac{1}{2}\ Cl_{2(g)}$

4. Consider the reaction below along with the equilibrium constant given.

$N_2O_{4(g)} \rightarrow 2NO_{2(g)}$ Kc = 0.20

Suppose that $[N_2O_4]$ = 0.730 M at equilibrium. Calculate the concentration of $NO_2$ at equilibrium.

6. Consider the equilibrium:.

$N_{2(g)} + O_{2(g)} \rightarrow 2\ NO_{(g)}$ Kc = 0.050 at 2200°C

If 0.070 moles of NO were placed in a 1.0 L flask and allowed to reach equilibrium, what is the equilibrium concentration of each gas?

7. Consider the equilibrium:

H2(g) + I2(g) → 2 HI(g) Kc = 9.00

Hydrogen, iodine and HI were placed in a flask in order that the initial concentrations were [H2] = 2 M, [I2] = 4 M, and [HI] = 1.5 M. Determine if the system is at equilibrium. If not, which direction must it shift in order to attain equilibrium?

8. For which value for K will the equilibrium mixture consist almost entirely of reactants?

A. 1 x 10-12 B. 0.012 C. 1.5 D. 19 E. 3 x 107

9. Consider the reaction:

PCl5(g) → PCl3(g) + Cl2(g) Kc = 1.8 at 250oC

A 1.5 mol sample of PCl5 is injected into a 0.50-L reaction vessel. Calculate the concentration of each gas at equilibrium.

10. For the all-gas system:

2 X + Y → 3 Z K = 0.34

Starting with 0.90 M concentrations of X and Y, it was found that the equilibrium concentration of X was 0.60 M. What is [Z] at equilibrium?

11. Suppose 2.00 mol NO were placed in a 1.0 L flask at 2273 K. At equilibrium, 0.863 mol N2 and 0.863 mol O2 are present. What is Kc for the reaction at this temperature?

$N_2(g) + O_2(g) \rightarrow 2\ NO(g)$

12. At 70oC, Kc = 0.090 for the equilibrium given below. If at equilibrium, $N_2O_4$ = 3.22 M, what is the molar concentration of $NO_2$?

$N_2O_4(g) \rightarrow 2NO_2(g)$

13. The value of Kc for the equilibrium

$PCl_5(g) \rightarrow PCl_3(g) + Cl_2(g)$

is 0.042 at 250oC. If 0.20 mol $PCl_3$ 0.20 mol $Cl_2$ and 0.50 mol $PCl_5$ were mixed in a 5.0 L container, which direction, if either, will the reaction shift in order to establish equilibrium?

14. Consider the equilibrium: $H_2(g) + CO_2(g) \rightarrow H_2O(g) + CO(g)$

Predict the qualitative effect on the equilibrium concentration of each gas by an increase in the pressure of water.

15. For the system $A(g) \rightarrow B(g) + 2\ C(g)$, the Kc is 8.0 x 1016. Which of the following statements is possible?

A. The equilibrium [B] and [C] is much greater than [A].

B. Increasing the pressure will decrease Kc.

C. Adding A will increase Kc

D. Increasing the volume container will increase Kc

16. Which of the following would shift left if the container volume were decreased?

Shift right? Not shift?

(a) $N_2(g) + O_2(g) \rightarrow 2\ NO(g)$

(b) $2\ NO(g) + O_2(g) \rightarrow 2\ NO_2(g)$

(c) $2\ HI(g) \rightarrow H_2(g) + I_2(g)$

(d) $2\ HI(g) \rightarrow H_2(g) + I_2(s)$

17. Consider the reaction:

$C(s) + 2\ H_2(g) \rightarrow CH_4(g)$ DH = -75 kJ:

Which way will the equilibrium shift by:

(a) an increase in temperature

(b) an increase in the size of the reaction container's volume

(c) an increase in the pressure of hydrogen

(d) a decrease in the pressure of methane

(e) addition of more carbon

18. Consider the equilibrium:

$2\ NH_3(g) \rightarrow N_2(g) + 3\ H_2(g)$ DH = -92 kJ

The concentration of $NH_3$ may be increased by: (possibly more than one of the following!)

A. increasing the pressure in the container.

B. decreasing the pressure in the container

C. adding an inert gas such as argon

D. increasing the temperature

E. adding hydrogen

19. Which of the following will be affected by the addition of a catalyst::

(a) Kc (b) Kp (c) the rate constant

20. The only stress to an equilibrium resulting in a change to the value of the equilibrium constant is:

A. a change in temperature

B. a change in the pressure

C. an addition of a reactant

D. the addition of a catalyst

E. the removal of a product

21. Assume that the concentrations of $H_2$, $I_2$, and HI can be measured for the following reaction at any moment in time.

$H_2(g) + I_2(g) \rightleftharpoons 2\ HI(g)$ $K_c = 60$

For each of the following sets of concentrations, determine whether the reaction is at equilibrium. If it isn't, decide in which direction it must go to reach equilibrium.

(a) $(H_2) = (I_2) = (HI) = 0.010$ M

(b) $(HI) = 0.30$ M; $(H_2) = 0.01$ M; $(I_2) = 0.15$ M

(c) $(H_2) = (HI) = 0.10$ M; $(I_2) = 0.0010$ M

22. Phosphorus pentachloride decomposes to phosphorus trichloride and chlorine when heated.

$$PCl_5(g) \rightleftharpoons PCl_3(g) + Cl_2(g)$$

The equilibrium constant for this reaction is 0.030 at 250°C. Assuming that the initial concentration of $PCl_5$ is 0.100 moles per liter and there is no $PCl_3$ or $Cl_2$ in the system when we start, let's calculate the concentrations of $PCl_5$, $PCl_3$, and $Cl_2$ at equilibrium.

23. Calculate the increase in the $PCl_3$ and $Cl_2$ concentrations that occur as the following reaction comes to equilibrium if the concentration of $PCl_5$ decreases by 0.042 moles per liter.

$PCl_5(g) \rightleftharpoons PCl_3(g) + Cl_2(g)$

24. Assume the following initial concentrations: $(PCl_5) = 0.100$ M and $(Cl_2) = 0.020$ M. Calculate the equilibrium concentrations of $PCl_5$, $PCl_3$, and $Cl_2$ if the equilibrium constant for the decomposition of $PCl_5$ is 0.030.

25. Sulfur trioxide decomposes to give sulfur dioxide and oxygen with an equilibrium constant of $1.6 \times 10^{-10}$ at 300°C.

$2\ SO_3(g) \rightleftharpoons 2\ SO_2(g) + O_2(g)$

Let's calculate the equilibrium concentrations of the three components of this system if the initial concentration of $SO_3$ is 0.100 M.

26. Ammonia is made from nitrogen and hydrogen by the following reversible reaction.

$N_2(g) + 3\ H_2(g) \rightleftharpoons 2\ NH_3(g)$

Assume that the initial concentration of $N_2$ is 0.050 moles per liter and the initial concentration of $H_2$ is 0.100 moles per liter. Calculate the equilibrium concentrations of the three components of this reaction at 500°C if the equilibrium constant for the reaction at this temperature is 0.040.

27. Nitrogen oxide reacts with oxygen to form nitrogen dioxide.

$2\ NO(g) + O_2(g) \rightleftharpoons 2\ NO_2(g)$

The equilibrium constant for this reaction is $3 \times 10^6$ at 200°C. Assume initial concentrations of 0.100 M for NO and 0.050 M for $O_2$. Let's calculate the concentrations of the three components of this reaction at equilibrium