Name: ____________________ Date: ____________________

Unit Test **50 marks total**

CHEMICAL EQUILIBRIUM

I. Multiple Choice

15 marks

1. Reactions that can proceed in both the forward and reverse directions are said to be:
   A. complete
   B. reversible
   C. balanced
   D. kinetically oriented

2. A state of chemical equilibrium exists when
   A. one or more of the products is a gas or aqueous.
   B. products of a reaction combine to form reactants.
   C. concentration of reactants and products are equal.
   D. forward and reverse reactions are occurring at the same rate.

3. For the reaction $H_{2(g)} + ½\ O_{2(g)} \rightleftharpoons H_2O_{(g)}$

   ΔG is found to be 0. This means that:
   A. the products are favored in this reaction.
   B. the reactants are favored in this reaction.
   C. the system is at equilibrium.
   D. the reaction is neither exothermic nor endothermic.

4. Which one of the following will change the value of the equilibrium constant, K_{eq}:
   A. changes in temperature.
   B. changes in the concentration of reactants.
   C. presence of a catalyst.
   D. changes in pressure.

5. For the reaction $2A_{(g)} + 3\ B_{2(g)} \rightleftharpoons 2\ AB_{3(g)}$

   an increase in pressure would
   A. shift the reaction to form more products.
   B. shift the reaction to form more reactants.
   C. increase the value of the equilibrium constant, K_{eq}
   D. not affect equilibrium.

6. For an exothermic forward reaction the addition of heat to the reaction can be expected to:
   A. shift the reaction to favor more products.
   B. shift the reaction to favor more reactants.
   C. speed up the rates of reactions but not affect the equilibrium.
   D. have no effect on either the rates of reaction or the equilibrium.

7. Consider the following system at equilibrium:

   $$2\ NO_{(g)} \rightleftharpoons N_2O_{4(g)} + \text{energy}$$

   This equilibrium can be shifted to the left (towards the reactants) by:
   A. adding a catalyst
   B. increasing volume
   C. removing N_2O_4
   D. decreasing the temperature

8. For the reaction

$$mA_{(g)} + nB_{(g)} \rightleftharpoons pC_{(g)} + qD_{(g)}$$

the equilibrium constant expression would be written as:

A. $\frac{[C \times D]^{pq}}{[A \times B]^{mn}}$

B. $\frac{[C]^p[D]^q}{[A]^m[B]^n}$

C. $\frac{[A]^m[B]^n}{[C]^p[D]^q}$

D. $\frac{p[C]+q[D]}{m[A]+n[B]}$

9. Assume that the following reaction has reached equilibrium in a closed container, and that it is desired to obtain a greater yield of $SO_{3(g)}$ by shifting the equilibrium to the right. This may be accomplished by making which of the following changes?

$$S_{8(s)} + 12\ O_{2(g)} \rightleftharpoons 8\ SO_{3(g)} + 95.1\ \text{kcal}$$

A. Increase the pressure by compressing the mixture into a smaller volume.
B. Add a catalyst without changing the temperature or pressure.
C. Increase the temperature without changing the pressure.
D. Remove oxygen gas from the system.

10. The square bracket symbols [ ] around a substance are used to indicate:

A. concentration, usually expressed in moles per litre.
B. a substance involved in a chemical reaction, as opposed to a physical change.
C. a system that has reached equilibrium.
D. rate of conversion into reactants or products, whichever is appropriate.

11. Consider the following reaction:
$N_{2(g)} + O_{2(g)} \rightleftharpoons 2\ NO_{(g)}$

$$K_{eq} = \frac{[NO]^2}{[N_2][O_2]}$$

Doubling the pressure on this system will:

A. double the value of K_{eq}.
B. decrease the value of K to zero.
C. not affect the value of K.
D. decrease the rate at which equilibrium is reached.

12. Consider the following system at equilibrium:

$N_{2(g)} + O_{2(g)} \rightleftharpoons 2\ NO_{(g)}$ $\Delta H = -43$ kcal

Which of the following changes will be certain to increase the concentration of the product NO?

I. Increase the temperature.
II. Decrease the temperature.
III. Decrease the pressure.
IV. Increase the oxygen or nitrogen concentration.
V. Introduce a catalyst.

A. I and IV only.
B. II and IV only.
C. II and V only.
D. III and II only.

13. Consider the following system at equilibrium:

$$CO_{2(g)} + H_{2(g)} \rightleftharpoons CO_{(g)} + H_2O_{(g)}$$

When the equilibrium was established at 900°C, the following concentrations were found to exist:

$[CO] = 0.186$ M $[CO_2] = 0.314$ M
$[H_2O] = 0.686$ M $[H_2] = 0.314$ M

The equilibrium constant for this reaction at 900°C is:

A. 0.775
B. 0.271
C. 1.29
D. 3.69

14. Consider the following equilibrium reaction in which the chromate ion, $CrO_4^{2-}{}_{(aq)}$ is converted into the dichromate ion, $Cr_2O_7^{2-}{}_{(aq)}$:

$2\ CrO_4^{2-}{}_{(aq)} + 2\ H_3O^+{}_{(aq)} \rightleftharpoons Cr_2O_7^{2-}{}_{(aq)} + 3\ H_2O_{(l)}$
yellow *orange*

Which of the following is **TRUE** about the above equation:

A. When CrO_4^{2-} ions are removed (by precipitation with Ba^{2+} ions), the concentration of $Cr_2O_7^{2-}$ ion is increased.
B. At equilibrium, the concentration of the dichromate ions is increasing.
C. The addition of a strong base (which removes H_3O^+) changes the color of the solution from orange to yellow.
D. The addition of a catalyst will increase the equilibrium concentration of $Cr_2O_7^{2-}$.

15. In the Haber Process for producing ammonia, described by the equation

$N_{2(g)} + 3\ H_{2(g)} \rightleftharpoons 2\ NH_{3(g)} + 92.4\ kJ$

a student claims that the yield of ammonia in the reactor at equilibrium can be increased by

I. adding more N_2 gas to the reactor.
II. cooling the reactor.
III. increasing the pressure by reducing the total volume.
IV. adding some more hydrogen gas.

Which combination of changes is most likely to produce the largest yield of NH_3?

A. Using all of the student's suggestions.
B. Using only suggestions I and III.
C. Using only suggestions III and IV.
D. Using only suggestions I and II.

II. Short Answer **35 *marks***

1. Write the equilibrium constant expression for the following equilibrium. Be sure to pay attention to the physical state.
3

a. $3\ O_{2(g)} \rightleftharpoons 2\ O_{3(g)}$ K_{eq} = ______________________________

b. $2\ NO_{(g)} + Cl_{2(g)} \rightleftharpoons 2\ NOCl_{(g)}$ K_{eq} = ______________________________

c. $CaCO_{3(s)} \rightleftharpoons CaO_{(s)} + CO_{2(g)}$ K_{eq} = ______________________________

2. For systems involving gases, the equilibrium constant is often determined by using partial pressure instead of concentration. Given the following reaction at equilibrium at the partial pressures of the participants,

$H_{2(g)} + I_{2(g)} \rightleftharpoons 2\ HI_{(g)}$ Partial Pressures: $P_{HI} = 4 \times 10^{-3}$ atm

$P_{H2} = 7.5 \times 10^{-3}$ atm

$P_{I2} = 4.3 \times 10^{-5}$ atm

a. Calculate K_{eq} for this reaction, carried out at a constant temperature. Begin by writing the equilibrium constant expression for the reaction. Show your work. **3**

b. Are the reactants (H_2 and I_2) or products (HI) favored at equilibrium at this temperature? **2**

How do you know?

3. For the equilibrium system at a certain temperature, described by the equation

$PCl_{3(g)} + Cl_{2(g)} \rightleftharpoons PCl_{5(g)}$

$K_{eq} = 60$ $[PCl_3] = 0.2$ M $[Cl_2] = 0.1$ M

a. Calculate the equilibrium concentration of PCl_5. **3**

b. Are reactants or products favored at equilibrium for this system? **1**

4. Each of the following systems has come to equilibrium. The systems are then subjected to the changes indicated.

Tell how the concentrations of the following substances will change as a result of the stress – will their concentrations **increase**, **decrease**, or undergo **no change** when the indicated change is made: **5**

a. $Cu^{2+}_{(aq)} + 4\ NH_{3(g)} \rightleftharpoons Cu(NH_3)_4{}^{2+}_{(aq)}$ More Cu^{2+} is added

$[NH_3]$ will ______________________________

$[Cu(NH_3)_4{}^{2+}]$ will ______________________________

b. $CO_{(g)} + \frac{1}{2}\ O_{2(g)} \rightleftharpoons CO_{2(g)}$ + energy   The system is put on ice

[CO] will ______________________________

$[O_2]$ will ______________________________

$[CO_2]$ will ______________________________

5. For the reaction $PBr_{3(g)} + Br_{2(g)} \rightleftharpoons PBr_{5(g)}$ + heat **3**

How will the reaction shift (**forward**; **reverse**; **no change**) if:

a. the pressure is increased ______________________________

b. concentration of Br_2 is decreased ______________________________

c. temperature is increased ______________________________

6. The following system is allowed to reach equilibrium:

$$CO_{(g)} + 2\ H_{2(g)} \rightleftharpoons CH_3OH_{(g)}$$

At a given temperature, K_{eq} for the reaction = 12, and the following concentrations are noted:

[CO] = 0.02 M $[H_2]$ = 0.35 M $[CH_3OH]$ = ???

Calculate the concentration of CH_3OH at equilibrium. Begin by writing the equilibrium constant expression.

3

7. Consider the following system at equilibrium:

$$2\ NaOH_{(aq)} + CaCO_{3\ (aq)} \rightleftharpoons Na_2CO_{3\ (aq)} + Ca(OH)_{2\ (s)} + \text{energy}$$

a. Write the equilibrium constant expression for this reaction. Read the equation carefully. **1**

b. Predict the effect of increasing the concentration of NaOH to the system: **4**

Select the appropriate answer in each case

The reaction will shift to the (right / left) ______________________________

$[CaCO_3]$ will (increase / decrease / no change) ______________________________

$[Na_2CO_3]$ will (increase / decrease / no change) ______________________________

The value of K_{eq} will (increase / decrease / not change) ______________________________

c. What will happen to the system if the temperature of the system is increased and the volume is kept constant? **4**

The reaction will shift to the (right / left) ______________________________

$[CaCO_3]$ will (increase / decrease / no change) ______________________________

$[Na_2CO_3]$ will (increase / decrease / no change) ______________________________

The value of K_{eq} will (increase / decrease / no change) ______________________________

8. A flask is filled with some $HI_{(g)}$ and allowed to reach equilibrium.

$$2\ HI_{(g)} \rightleftharpoons H_{2(g)} + I_{2(g)} \qquad K_{eq} = 0.25$$

At equilibrium the concentration of [HI] = 0.80 M. What is the concentration of H_2 at equilibrium?

[Hint: you will also be finding $[I_2]$ – consider how $[H_2]$ and $[I_2]$ compare to each other] **3**