A.P. Chemistry Practice Test - Ch. 13: Equilibrium

Name________________________________ CALVIN

MULTIPLE CHOICE. Choose the one alternative that best completes the statement or answers the question.

1) At equilibrium, __________.
   A) the rates of the forward and reverse reactions are equal
   B) the rate constants of the forward and reverse reactions are equal
   C) all chemical reactions have ceased
   D) the value of the equilibrium constant is 1
   E) the limiting reagent has been consumed

2) Which one of the following will change the value of an equilibrium constant?
   A) adding other substances that do not react with any of the species involved in the equilibrium
   B) varying the initial concentrations of reactants
   C) changing temperature
   D) varying the initial concentrations of products
   E) changing the volume of the reaction vessel

3) The value of K_{eq} for the following reaction is 0.25:

$$SO_2\ (g) + NO_2\ (g) \rightleftharpoons SO_3\ (g) + NO\ (g)$$

Doubled so K^2

The value of K_{eq} at the same temperature for the reaction below is __________.

$$2SO_2\ (g) + 2NO_2\ (g) \rightleftharpoons 2SO_3\ (g) + 2NO\ (g)$$

A) 0.062 B) 16 C) 0.25 D) 0.50 E) 0.12

4) The value of K_{eq} for the equilibrium

$$H_2\ (g) + I_2\ (g) \rightleftharpoons 2\ HI\ (g)$$

Reversed and cut in half so $\left(\frac{1}{K}\right)^{1/2}$

is 794 at 25°C. At this temperature, what is the value of K_{eq} for the equilibrium below?

$$HI\ (g) \rightleftharpoons 1/2\ H_2\ (g) + 1/2\ I_2\ (g)$$

A) 0.035 B) 0.0013 C) 28 D) 397 E) 1588

5) The K_{eq} for the equilibrium below is 7.52×10^{-2} at 480°C.

$$2Cl_2\ (g) + 2H2O\ (g) \rightleftharpoons 4HCl\ (g) + O_2\ (g)$$

cut in ½

What is the value of K_{eq} at this temperature for the following reaction?

$K' = K^{1/2}$

$$Cl_2\ (g) + H_2O\ (g) \rightleftharpoons 2HCl\ (g) + \frac{1}{2}O_2\ (g)$$

A) 0.150 B) 0.274 C) 0.0376 D) 5.66×10^{-3} E) 0.0752

6) At 1000 K, the equilibrium constant for the reaction

$$2NO\ (g) + Br_2\ (g) \rightleftharpoons 2NOBr\ (g)$$

Reversed

is $K_p = 0.013$. Calculate K_p for the reverse reaction,

$K' = \frac{1}{K}$

$$2NOBr\ (g) \rightleftharpoons 2NO\ (g) + Br_2\ (g).$$

A) 0.99 B) 1.1 C) 0.013 D) 1.6×10^{-4} E) 77

7) The expression for K_{eq} for the reaction below is ________.

$$4CuO\ (s) + CH_4\ (g) \rightleftharpoons CO_2\ (g) + 4Cu\ (s) + 2H_2O\ (g)$$

A) $\frac{P_{CO_2} P_{H_2O}{}^2}{P_{CH_4}}$

B) $\frac{P_{CH_4}}{P_{H_2O}{}^2 P_{CO_2}}$

C) $\frac{[Cu]\, P_{CO_2} P_{H_2O}{}^2}{[CuO]^4 P_{CH_4}}$

D) $\frac{P_{CH_4}}{P_{CO_2} P_{H_2}{}^2}$

E) $\frac{P_{CO_2} P_{H_2O}{}^2}{P_{CuO}}$

8) Acetic acid is a weak acid that dissociates into the acetate ion and a proton in aqueous solution:

$$HC_2H_3O_2\ (aq) \rightleftharpoons C_2H_3O_2G\ (aq) + H^+\ (aq)$$

At equilibrium at 25°C a 0.100 M solution of acetic acid has the following concentrations: [HC2H3O2] = 0.0990 M, [C2H3O2G] = 1.33×10^{-3} M, and [H+] = 1.33×10^{-3} M. The equilibrium constant, K_{eq}, for the ionization of acetic acid at 25°C is ________.

A) 5.71×10^4 B) 1.79×10^{-5} C) 1.75×10^{-7} D) 5.71×10^6 E) 0.100

$$K = \frac{[H^+][C_2H_3O_2]}{[HC_2H_3O_2]} = \frac{(1.33\times10^{-3})(1.33\times10^{-3})}{(0.0990)} = 1.79\times10^{-5}$$

9) At 200°C, the equilibrium constant for the reaction below is 2.40×10^3.

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

A closed vessel is charged with 36.1 atm of NO. At equilibrium, the partial pressure of O_2 is __________ atm.

A) 35.7 B) 18.1 C) 1.50×10^{-2} D) 6.00 E) 294

10) How is the reaction quotient used to determine whether a system is at equilibrium?

A) The reaction is at equilibrium when $Q < K_{eq}$.

B) The reaction is at equilibrium when $Q > K_{eq}$.

C) At equilibrium, the reaction quotient is undefined.

D) The reaction quotient must be satisfied for equilibrium to be achieved.

E) The reaction is at equilibrium when $Q = K_{eq}$.

	CO	+ H_2O	$\rightleftharpoons CO_2$	+ H_2
I	0.35	0.40	0	0
C	−0.16	−0.16	+0.16	+0.16
E	0.19	0.24	0.16	0.16

$K_{eq} = \frac{(0.16)^2}{(0.19)(0.24)} = 0.56$

11) In the coal-gasification process, carbon monoxide is converted to carbon dioxide via the following reaction:

$$CO\ (g) + H_2O\ (g) \rightleftharpoons CO_2\ (g) + H_2\ (g)$$

In an experiment, 0.35 mol of CO and 0.40 mol of H_2O were placed in a 1.00-L reaction vessel. At equilibrium, there were 0.19 mol of CO remaining. K_{eq} at the temperature of the experiment is __________.

A) 0.75 B) 1.0 C) 5.47 D) 1.78 E) 0.56

	$2NOBr$	$\rightleftharpoons 2NO$	+ Br_2
I	0.64	0	0
C	−0.18	+0.18	+0.09
E	0.46	0.18	0.09

12) Nitrosyl bromide decomposes according to the following equation.

$$2NOBr\ (g) \rightleftharpoons 2NO\ (g) + Br_2\ (g)$$

A sample of NOBr (0.64 mol) was placed in a 1.00-L flask containing no NO or Br_2. At equilibrium the flask contained 0.46 mol of NOBr. How many moles of NO and Br_2, respectively, are in the flask at equilibrium?

A) 0.46, 0.23 B) 0.18, 0.090 C) 0.46, 0.46 D) 0.18, 0.360 E) 0.18, 0.18

13) In which of the following reactions would increasing pressure at constant temperature not change the concentrations of reactants and products, based on Le Châtelier's principle?

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

B) $2N_2\ (g) + O_2\ (g) \rightleftharpoons 2N_2O\ (g)$

C) $N_2\ (g) + 2O_2\ (g) \rightleftharpoons 2NO_2\ (g)$

D) $N_2O_4\ (g) \rightleftharpoons 2NO_2\ (g)$

E) $N_2\ (g) + O_2\ (g) \rightleftharpoons 2NO\ (g)$

	$2NO$	$\rightleftharpoons N_2$	+ O_2
I	36.1	0	0
C	−2x	+x	+x
E	36.1−2x	x	x

$K = 2400 = \frac{x^2}{(36.1-2x)^2}$

$2400 = \left(\frac{x}{36.1-2x}\right)^2$

$\sqrt{2400} = \frac{x}{36.1-2x}$

$49.0 = \frac{x}{36.1-2x}$

$x = (49.0)(36.1-2x)$

$x = 1768.53 - 97.98x$

$98.98x = 1768.53$

$x = 17.9$

$x = P_{O_2} = 17.9$

14) Consider the following reaction at equilibrium:

$$2CO_2\ (g) \rightleftharpoons 2CO\ (g) + O_2\ (g) \qquad \Delta H° = -514\ kJ$$

Le Châtelier's principle predicts that adding O_2 (g) to the reaction container will __________.

A) decrease the partial pressure of CO_2 (g) at equilibrium
B) decrease the value of the equilibrium constant
C) increase the partial pressure of CO_2 (g) at equilibrium
D) increase the value of the equilibrium constant
E) increase the partial pressure of CO (g) at equilibrium

Shifts LEFT

15) Consider the following reaction at equilibrium:

$$2CO_2\ (g) \rightleftharpoons 2CO\ (g) + O_2\ (g) \text{ + heat} \qquad \Delta H° = -514\ kJ$$

Le Châtelier's principle predicts that an increase in temperature will __________.

A) increase the partial pressure of O_2 (g)
B) decrease the value of the equilibrium constant
C) increase the partial pressure of CO
D) decrease the partial pressure of CO_2 (g)
E) increase the value of the equilibrium constant

Shifts LEFT

16) Consider the following reaction at equilibrium.

$$2CO_2\ (g) \rightleftharpoons 2CO\ (g) + O_2\ (g) \text{ + heat} \qquad \Delta H° = -514\ kJ$$

Le Châtelier's principle predicts that the equilibrium partial pressure of CO (g) can be maximized by carrying out the reaction __________.

A) at high temperature and high pressure
B) at high temperature and low pressure
C) at low temperature and low pressure
D) at low temperature and high pressure
E) in the presence of solid carbon

low temp ⇝ shifts right
low P ⇝ shifts right

17) The effect of a catalyst on an equilibrium is to __________.

A) increase the rate at which equilibrium is achieved without changing the composition of the equilibrium mixture
B) increase the rate of the forward reaction only
C) shift the equilibrium to the right
D) increase the equilibrium constant so that products are favored
E) slow the reverse reaction only

18) The following equilibrium is readily established:

$SO_2Cl_2 (g) \rightarrow SO_2 (g) + Cl_2 (g)$

$K = \frac{[SO_2][Cl_2]}{[SO_2Cl_2]} = \frac{(0.0287)(0.0287)}{(0.0106)} = 0.0777$

At equilibrium at 373 K, a 1.00–L reaction vessel contains 0.0106 mol of SO_2Cl_2 and 0.0287 mol each of SO_2 and Cl_2. What is K_{eq} for the reaction at 373 K?

A) 12.8 B) 2.72 C) 0.0781 D) 2.39 E) 0.418

19) Dinitrogentetraoxide partially decomposes according to the following equilibrium:

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

A 1.000–L flask is charged with 3.00×10^{-2} mol of N_2O_4. At equilibrium, 2.36×10^{-2} mol of N_2O_4 remains. K_{eq} for this reaction is __________.

A) 0.723
B) 1.92×10^{-4}
C) 6.93×10^{-3}
D) 0.391
E) 0.212

	$N_2O_4 \rightleftharpoons$	$2 NO_2$
I	0.0300	0
C	−0.0064	+0.0128
E	0.0236	0.0128

$K = \frac{(0.0128)^2}{(0.0236)} = 6.94 \times 10^{-3}$

20) The K_{eq} for the reation below is 1.49 × 108 at 100°C:

$CO (g) + Cl_2 (g) \rightarrow COCl_2 (g)$

$1.49 \times 10^8 = \frac{(x)}{(8.60 \times 10^{-4})^2}$ $x = 1.10 \times 10^2$ atm

In an equilibrium mixture of the three gases, $P_{CO} = P_{Cl_2} = 8.60 \times 10^{-4}$ atm. The partial pressure of the product, phosgene ($COCl_2$), is __________ atm.

A) 2.01×10^{14} B) 1.72×10^{11} C) 1.28×10^5 D) 4.96×10^{-15} E) 1.10×10^2

21) Phosphorous trichloride and phosphorous pentachloride equilibrate in the presence of molecular chlorine according to the reaction:

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

$PV = nRT$

$P = \frac{(0.990 \text{ mol})(0.0821 \frac{L \cdot atm}{mol \cdot K})(500 K)}{1.000 L} = 40.6$ atm

* See Next page *

K_{eq} = 2.01 at 500 K. A 1.000–L reaction vessel is charged with 0.990 mol of PCl_5 and allowed to equilibrate at this temperature. The equilibrium partial pressure of PCl_3 is __________ atm.

A) 0.702 B) 4.25 C) 4.50 D) 36.4 E) 0.496

22) Phosphorous trichloride and phosphorous pentachloride equilibrate in the presence of molecular chlorine according to the reaction:

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

K_{eq} = 2.01 at 500 K. A 1.000–L reaction vessel is charged with 0.300 mol of PCl_5 and allowed to equilibrate at this temperature. The equilibrium partial pressure of PCl_5 is __________ atm.

A) 10.1 B) 0.386 C) 2.24 D) 2.48 E) 0.211

21) $PV = nRT$

$$P = \frac{(0.990\ \text{mol})(0.0821\ \frac{L\cdot atm}{mol\cdot K})(500\ K)}{(1.000\ L)} = 40.6\ \text{atm}$$

	PCl_3 +	Cl_2 ⇌	PCl_5
I	0	0	40.6 atm
C	+x	+x	−x
E	x	x	40.6−x

$$K_p = 2.01 = \frac{(40.6-x)}{x^2}$$

$$2.01x^2 = 40.6 - x$$

$$2.01x^2 + x = 40.6$$

$$2.01x^2 + x - 40.6 = 0$$

$a = 2.01$
$b = 1$
$c = -40.6$

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

$$= \frac{-1 \pm \sqrt{1^2 - (4)(2.01)(-40.6)}}{(2)(2.01)}$$

$$= \frac{-1 \pm \sqrt{1 + 326.4}}{4.02} = \frac{-1 + 18.09}{4.02} = \boxed{4.25\ \text{atm}} = P_{Cl_2}$$

22)

$$PCl_3 + Cl_2 \rightleftharpoons PCl_5$$

$$P = \frac{nRT}{V} = \frac{(0.300)(0.0821)(500)}{(1.00)}$$

$= 12.3\,atm$

	PCl_3	Cl_2	PCl_5
I	0	0	12.3
C	+x	+x	−x
E	x	x	12.3−x

$$K_p = 2.01 = \frac{12.3 - x}{x^2}$$

$$2.01x^2 + x - 12.3 = 0$$

$$x = \frac{-1 \pm \sqrt{1 - (4)(2.01)(-12.3)}}{(2)(2.01)}$$

$$x = \frac{-1 + 10}{4.02} = \frac{9}{4.02} = 2.24$$

$P_{Cl_5} = 12.3 - 2.24 = \boxed{10.1\,atm}$

Question 1

$$N_2(g) + 3\,H_2(g) \rightleftarrows 2\,NH_3(g)$$

1. For the reaction represented above, the value of the equilibrium constant, K_p, is 3.1×10^{-4} at 700. K.

(a) Write the expression for the equilibrium constant, K_p, for the reaction.

$K_p = \dfrac{p^2_{NH_3}}{p_{N_2} \times p^3_{H_2}}$	1 point for pressure expression 1 point for correct substitution

(b) Assume that the initial partial pressures of the gases are as follows:

$p_{N_2} = 0.411$ atm, $p_{H_2} = 0.903$ atm, and $p_{NH_3} = 0.224$ atm.

(i) Calculate the value of the reaction quotient, Q, at these initial conditions.

$Q = \dfrac{p^2_{NH_3}}{p_{N_2} \times p^3_{H_2}} = \dfrac{(0.224)^2}{(0.411)(0.903)^3}$ $Q = 0.166$	1 point for calculation of Q with correct mass action expression Note: must be consistent with part (a)

(ii) Predict the direction in which the reaction will proceed at 700. K if the initial partial pressures are those given above. Justify your answer.

Since $Q > K_p$, the numerator must decrease and the denominator must increase, so the reaction must proceed from right to left to establish equilibrium.	1 point for direction or for stating that $Q > K_p$ 1 point for explanation

(c) Calculate the value of the equilibrium constant, K_c, given that the value of K_p for the reaction at 700. K is 3.1×10^{-4}.

$K_p = K_c(RT)^{\Delta n}$ $\Delta n = 2 - 4 = -2$	1 point for calculating Δn
$K_p = K_c(RT)^{-2}$ $3.1 \times 10^{-4} = K_c(0.0821 \dfrac{\text{L atm}}{\text{mol K}} \times 700\text{ K})^{-2}$ $3.1 \times 10^{-4} = K_c(57.5)^{-2}$ $3.1 \times 10^{-4} = K_c(3.0 \times 10^{-4})$ $1.0 = K_c$	1 point for correct substitution and value of K_c

Question 1 (cont'd.)

(d) The value of K_p for the reaction represented below is 8.3×10^{-3} at 700. K.

$$NH_3(g) + H_2S(g) \rightleftarrows NH_4HS(g)$$

Calculate the value of K_p at 700. K for each of the reactions represented below.

(i) $NH_4HS(g) \rightleftarrows NH_3(g) + H_2S(g)$

$K_p = \dfrac{1}{8.3 \times 10^{-3}} = 1.2 \times 10^2$	1 point for the calculation of K_p

(ii) $2\,H_2S(g) + N_2(g) + 3\,H_2(g) \rightleftarrows 2\,NH_4HS(g)$

$2 \times [NH_3(g) + H_2S(g) \rightleftarrows NH_4HS(g)]$ $\quad K_p = (8.3 \times 10^{-3})^2$ $N_2(g) + 3\,H_2(g) \rightleftarrows 2\,NH_3(g)$ $\quad K_p = 3.1 \times 10^{-4}$	1 point for squaring K_p for NH_4HS or for multiplying K_p's
$2\,H_2S(g) + N_2(g) + 3\,H_2(g) \rightleftarrows 2\,NH_4HS(g)$ $K_p = (8.3 \times 10^{-3})^2\,(3.1 \times 10^{-4}) = 2.1 \times 10^{-8}$	1 point for correct K_p