Name ______________________
Period ___ Date ___/___/___

16 • Chemical Equilibrium

STUDY QUESTIONS & PROBLEMS

1. Write the expressions for the equilibrium constant K_c for the following reactions:
   a. $4\ NH_3(g) + 7\ O_2(g) \rightleftharpoons 4\ NO_2(g) + 6\ H_2O(l)$
   b. $HCN\ (aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + CN^-(aq)$
   c. $PCl_5(g) + \rightleftharpoons PCl_3(g) + Cl_2(g)$
   d. $CaCO_3(s) \rightleftharpoons CaO(s) + CO_2(g)$
   e. $3\ O_2(g) \rightleftharpoons 2\ O_3(g)$
   f. $2\ H_2O(l) \rightleftharpoons H_3O^+(aq) + OH^-(aq)$
   g. $3\ Zn(s) + 2\ Fe^{3+}(aq) \rightleftharpoons 2\ Fe(s) + 3\ Zn^{2+}(aq)$

2. Write the equilibrium constant expressions for the following reactions. How are they related to one another?
   a. $2\ N_2O(g) + 3\ O_2(g) \rightleftharpoons 4\ NO_2(g)$
   b. $N_2O(g) + {}^3/_2\ O_2(g) \rightleftharpoons 2\ NO_2(g)$
   c. $4\ NO_2(g) \rightleftharpoons 2\ N_2O(g) + 3\ O_2(g)$

3. Calculate the value of the equilibrium constant for the following system, given the data shown:

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

   Concentrations at equilibrium:

$[H_2]$	=	1.5 mol Liter^{-1}
$[CO_2]$	=	2.5 mol Liter^{-1}
$[H_2O]$	=	0.5 mol Liter^{-1}
$[CO]$	=	3.0 mol Liter^{-1}

4. Chlorine molecules will dissociate at high temperatures into chlorine atoms. At 3000°C, for example, K_c for the equilibrium shown is 0.55. If the partial pressure of chlorine molecules is 1.5 atm, calculate the partial pressure of the chlorine atoms: $Cl_2(g) \rightleftharpoons 2\ Cl(g)$

5. Suppose that 0.50 moles of hydrogen gas, 0.50 moles of iodine gas, and 0.75 moles of hydrogen iodide gas are introduced into a 2.0 Liter vessel and the system is allowed to reach equilibrium.

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

   Calculate the concentrations of all three substances at equilibrium. At the temperature of the experiment, K_c equals 2.0×10^{-2}.

6. If the mechanism of a chemical equilibrium consists of two reversible elementary steps, each with its own equilibrium constant K_{c1} and K_{c2}, what expression relates the equilibrium constant Kc for the overall equilibrium to the two constants K_{c1} and K_{c2}?

7. When 2.0 mol of carbon disulfide and 4.0 mol of chlorine are placed in a 1.0 Liter flask, the following equilibrium system results. At equilibrium, the flask is found to contain 0.30 mol of carbon tetrachloride. What quantities of the other components are present in this equilibrium mixture?

$$CS_2(g) + 3\ Cl_2(g) \rightleftharpoons S_2Cl_2(g) + CCl_4(g)$$

8. 3.0 moles each of carbon monoxide, hydrogen, and carbon are placed in a 2.0 Liter vessel and allowed to come to equilibrium according to the equation: $CO(g) + H_2(g) \rightleftharpoons C(s) + H_2O(g)$
If the equilibrium constant at the temperature of the experiment is 4.0, what is the equilibrium concentration of water vapor?

9. Nitrosyl chloride NOCl decomposes to nitric oxide and chlorine when heated:
$$2\ NOCl(g) \rightleftharpoons 2\ NO(g) + Cl_2(g)$$
At 600K, the equilibrium constant K_p is 0.060. In a vessel at 600K, there is a mixture of all three gases. The partial pressure of NOCl is 675 torr, the partial pressure of NO is 43 torr and the partial pressure of chlorine is 23 torr.
   a. What is the value of the reaction quotient?
   b. Is the mixture at equilibrium?
   c. In which direction will the system move to reach equilibrium?
   d. When the system reaches equilibrium, what will be the partial pressures of the components in the system?

10. Sulfuryl chloride decomposes at high temperatures to produce sulfur dioxide and chlorine gases:
$$SO_2Cl_2(g) \rightleftharpoons SO_2(g) + Cl_2(g)$$
At 375°C, the equilibrium constant K_c is 0.045. If there are 2.0 grams of sulfuryl chloride, 0.17 gram of sulfur dioxide, and 0.19 gram of chlorine present in a 1.0 Liter flask,
   a. What is the value of the reaction quotient?
   b. Is the system at equilibrium?
   c. In which direction will the system move to reach equilibrium?

11. Ammonium chloride is placed inside a closed vessel where it comes into equilibrium at 400°C according to the equation shown. Only these three substances are present inside the vessel. If K_p for the system at 400°C is 0.640, what is the pressure inside the vessel?
$$NH_4Cl(s) \rightleftharpoons NH_3(g) + HCl(g)$$

12. Bromine and chlorine react to produce bromine monochloride according to the equation. $K_c = 36.0$ under the conditions of the experiment. $Br_2(g) + Cl_2(g) \rightleftharpoons 2\ BrCl(g)$
If 0.180 moles of bromine gas and 0.180 moles of chlorine gas are introduced into a 3.0 Liter flask and allowed to come to equilibrium, what is the equilibrium concentration of the bromine monochloride? How much BrCl is produced?

13. When ammonia is dissolved in water, the following equilibrium is established. If the equilibrium constant is 1.8×10^{-5}, calculate the hydroxide ion concentration in the solution if 0.100 mol of ammonia is dissolved in sufficient water to make 500 mL of solution.
$$NH_3(aq) + H_2O(l) \rightleftharpoons NH_4^+(aq) + OH^-(aq)$$

14. The following reaction is exothermic:
$$Ti(s) + 2\ Cl_2(g) \rightleftharpoons TiCl_4(g)$$
List all the ways the yield of the product $TiCl_4$ could be increased.

Review

Name: **Period:** **Seat#:**

STATION 1 • MASS ACTION EXPRESSIONS

Write the mass action expression for the equilibrium: $Fe_3O_4(s) + 4\ H_2(g) \rightleftharpoons 3\ Fe(s) + 4\ H_2O(g)$

Write the mass action expression for the equilibrium: $Ca(OH)_2(s) \rightleftharpoons Ca^{2+}(aq) + 2\ OH^-(aq)$

The equilibrium constant, $K_c = 7.9 \times 10^{-6}$, is this equilibrium system reactant or product-favored. __________

Chemical Equilibrium

STATION 2 • MANIPULATING K

Given:

$H_2O(l) \rightleftharpoons H^+(aq) + OH^-(aq)$ $K_c = 1 \times 10^{-14}$

$HCN(aq) \rightleftharpoons H^+(aq) + CN^-(aq)$ $K_c = 4.0 \times 10^{-10}$

Calculate K_c for this reaction:

$HCN(aq) + OH^-(aq) \rightleftharpoons H_2O(l) + CN^-(aq)$ $K_c = ???$

This reaction is ___________________-favored.

Chemical Equilibrium

S T A T I O N 3 • K_p & K_c

Consider the equilibrium: $2NO(g) + O_2(g) \rightleftharpoons 2NO_2(g)$.

At 100°C, the equilibrium concentrations for this system are:
[NO] = 0.52 M; [O_2] = 0.24 M; [NO_2] = 0.18 M

Write the expression for K_c and calculate its value at this temperature?

What is Δn for this system? _____

Write the expression for K_p and calculate its value at this temperature.

Chemical Equilibrium

S T A T I O N 4 • L E C H Â T E L I E R ' S P R I N C I P L E

Consider the gaseous equilibrium: $2CCl_4(g) + O_2(g) \rightleftharpoons 2COCl_2(g) + 2Cl_2(g)$ $\Delta H = +35$ kJ
Predict the effect each change would have on the concentrations of the each substance.

Add CCl_4	____	____	____	____
Remove Cl_2	____	____	____	____
Add $COCl_2$	____	____	____	____
Increase temperature	____	____	____	____
Reduce container volume	____	____	____	____
Add a catalyst	____	____	____	____
Remove O_2	____	____	____	____
Add He to increase pressure	____	____	____	____

A different equilibrium shifts toward the reactants when the temperature is increased. From this observation, you know that the reaction is ________________________ (exothermic / endothermic).

Chemical Equilibrium

STATION 5 • ICE BOX PROBLEM

Consider the equilibrium: $2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$

If 0.200 mol $SO_3(g)$ is placed a 0.500 Liter container, it is found that 0.050 mole of $O_2(g)$ is in the container at equilibrium. Fill in the ICE box and determine the K_c for this reaction.

	SO_2	O_2	SO_3
Initial			
Change			
Equilibrium			

Chemical Equilibrium

STATION 6 • ANOTHER ICE BOX PROBLEM

At 985°C, the equilibrium constant, K_c, for the reaction, $H_2(g) + CO_2(g) \rightleftarrows H_2O(g) + CO(g)$, is 1.63.

If 2.00 moles each of $H_2(g)$ and $CO_2(g)$ are placed in a 1.00-Liter container and allowed to come to equilibrium, determine the equilibrium concentrations of the four chemicals.

	H_2	CO_2	H_2O	CO
Initial				
Change				
Equilibrium				

Chemical Equilibrium

STATION 7 • TEST QUOTIENT, Q

Consider the equilibrium: $2NO(g) + O_2(g) \rightleftharpoons 2NO_2(g)$. $K_c = 0.499$

The system is set up with the following concentrations:
[NO] = 0.50 M; $[O_2]$ = 0.25 M; $[NO_2]$ = 0.25 M

This reaction will ____________________ (shift right, shift left, remain unchanged).

Justify your prediction.

Chemical Equilibrium

STATION 8 • NChO PROBLEMS

33. Mercury(II) oxide, HgO, is decomposed upon heating according to this equation.

$$2HgO(s) \rightleftharpoons 2Hg(l) + O_2(g)$$

What is the equilibrium expression for this process?

(A) $K = \frac{[Hg]^2[O_2]}{[HgO]^2}$ **(B)** $K = \frac{[Hg][O_2]}{[HgO]}$

(C) $K = [Hg][O_2]$ **(D)** $K = [O_2]$

34. Consider this reaction.

$$2NO(g) + Cl_2(g) \rightleftharpoons 2NOCl(g) \qquad \Delta H = -78.38 \text{ kJ}$$

What conditions of temperature and pressure will produce the highest yield of NOCl at equilibrium?

	T	*P*
(A)	high	high
(B)	high	low
(C)	low	high
(D)	low	low

Questions **32** and **33** should both be answered with reference to this system.

$$H_2(g) + I_2(s) \rightleftharpoons 2HI(g) \qquad \Delta H = +51.8 \text{ kJ}$$

32. Which would increase the equilibrium quantity of HI(g)? Assume the system has reached equilibrium with all three components present.

I. increasing pressure **II.** increasing temperature

(A) **I** only **(B)** **II** only

(C) Both **I** and **II** **(D)** Neither **I** nor **II**

33. What is the equilibrium constant expression for this system?

(A) $K = \frac{[HI]^2}{[H_2][I_2]}$ **(B)** $K = \frac{[H_2][I_2]}{[HI]^2}$

(C) $K = \frac{2[HI]}{[H_2][I_2]}$ **(D)** $K = \frac{[HI]^2}{[H_2]}$

Chemical Equilibrium – Not assessed. Challenge Problem

STATION 9 • PREDICTING REACTIONS

A solution of hydrochloric acid is added to a solution of potassium nitrite.

(i) Balanced equation:

(ii) What are the oxidation states of the N atom before and after the reaction?

____

____

Answers to Study Questions and Problems

1\. a. $K = \dfrac{[NO_2]^4}{[NH_3]^4[O_2]^7}$ $H_2O(l)$ is a liquid and therefore not included

b. $K = \dfrac{[H_3O^+][CN^-]}{[HCN]}$ $H_2O(l)$ is the solvent and is not included.

c. $K = \dfrac{[PCl_3][Cl_2]}{[PCl_5]}$

d. $K = [CO_2]$ $CaCO_3(s)$ and $CaO(s)$ are not included.

e. $K = \dfrac{[O_3]^2}{[O_2]^3}$

f. $K = [H_3O^+][OH^-]$ $H_2O(l)$ is the solvent and is not included.

g. $K = \dfrac{[Zn^{2+}]^3}{[Fe^{3+}]^2}$ $Zn(s)$ and $Fe(s)$ are not included.

2.

a. $2N_2O(g) + 3O_2(g) \rightleftharpoons 4NO_2(g)$ $K_1 = \dfrac{[NO_2]^4}{[N_2O]^2[O_2]^3}$

b. $N_2O(g) + 3/2\,O_2(g) \rightleftharpoons 2NO_2(g)$ $K_2 = \dfrac{[NO_2]^2}{[N_2O][O_2]^{3/2}}$

c. $4NO_2(g) \rightleftharpoons 2N_2O(g) + 3O_2(g)$ $K_3 = \dfrac{[N_2O]^2[O_2]^3}{[NO_2]^4}$

$K_1 = (K_2)^2$ and $K_1 = (K_3)^{-1}$ and $K_2 = (K_3)^{-1/2}$

3. $K = \dfrac{[H_2O][CO]}{[H_2][CO_2]} = (0.5 \times 3.0)/(1.5 \times 2.5) = 0.40$

4. $Cl_2(g) \rightleftharpoons 2Cl(g)$ $K_c = \dfrac{[Cl]^2}{[Cl_2]}$ and $K_p = \dfrac{P^2_{Cl}}{P_{Cl_2}}$

$K_p = K_c(RT)^{\Delta n} = 0.55 \times 0.08206 \times 3273K = 1.48 \times 10^2 = \dfrac{P^2_{Cl}}{P_{Cl_2}}$

and therefore $P_{Cl} = 14.9$ atm

$\Delta n = 1$
an increase of one mole of gas

5.

		$H_2(g)$ +	$I_2(g)$ $\rightleftharpoons$	$2HI(g)$
I	Initial	0.25	0.25	0.375
C	Change	+x	+x	−2x
E	Equilibrium	0.25+x	0.25+x	0.375−2x

Remember always to use concentrations (or partial pressures).
Convert amounts given in moles to concentrations by dividing by the volume.

Remember that the change is always in the stoichiometric ratio.

$$K = \frac{[HI]^2}{[H_2][I_2]} = \frac{(0.375-2x)^2}{(0.25+x)(0.25+x)} = 2.0 \times 10^{-2}$$

$(0.375-2x) = (0.25+x) \times 0.1414$ so $x = 0.159$

the equilibrium concentrations are:

$[H_2] = 0.41$ moles liter^{-1}

$[I_2] = 0.41$ moles liter^{-1}

$[HI] = 0.058$ moles liter^{-1}

If you don't know which way the system will move, just choose a direction arbitrarily, then see if x turns out to be negative or positive.

Look out for the opportunity to take the square root of both sides–it avoids the quadratic.

6. The equilibrium constant for the combination of two successive equilibria is the product of the equilibrium constants for the two steps.

$K_c = K_{c1} \times K_{c2}$

Don't make problems like these more complicated than they have to be; there's no need for any algebra in this problem.

If 0.30 moles of CCl_4 are formed, then the changes in the other concentrations can be calculated directly from the stoichiometry.

7.

		$CS_2(g)$ +	$3Cl_2(g)$ $\rightleftharpoons$	$S_2Cl_2(g)$ +	$CCl_4(g)$
I	Initial	2.0	4.0	0.0	0.0
C	Change	−0.30	−0.90	+0.30	+0.30
E	Equilibrium	1.7	3.1	0.30	0.30

Remember always to use concentrations (or partial pressures).
Convert amounts given in moles to concentrations by dividing by the volume.

8.

		$CO(g)$ +	$H_2(g)$ $\rightleftharpoons$	$C(s)$ +	$H_2O(g)$
I	Initial	1.5	1.5	3.0	0.0
C	Change	−x	−x	+x	+x
E	Equilibrium	1.5−x	1.5−x	3.0+x	x

Note that C(s) is not included in the equilibrium expression! However, it is sometimes useful to include the quantities in the table—just in case there's any likelihood of all the solid being used up.

$$K = \frac{[H_2O]}{[CO][H_2]} = \frac{(x)}{(1.5-x)(1.5-x)} = 4.0,$$ therefore x = 1.0 which is the equilibrium concentration of water

9. $2NOCl(g) \rightleftharpoons 2NO(g) + Cl_2(g)$

a. $Q_p = \dfrac{P_{NO}^2 \times P_{Cl_2}}{P_{NOCl}^2} = (43^2 \times 23)/\,675^2 = 0.093$

b. No, Q_p is greater than K_p; ie. there is too much product present.

c. The system will move to the left.

		$2NOCl(g)$ $\rightleftharpoons$	$2NO(g)$ +	$Cl_2(g)$
I	Initial	675	43	23
C	Change	+2x	−2x	−x
E	Equilibrium	675+2x	43−2x	23−x

Solving higher order equations like this for x using algebra is not especially easy. An iterative method using a good calculator or a spreadsheet is highly recommended. Using a spreadsheet for example, enter the expression for K in a cell, referencing another cell for x. Then put values for x in that cell until the expression yields a value of 0.060. You should be able to narrow the value for x to a sufficient number of sig. fig. in 5 or 6 tries.

d. $K_p = \dfrac{P_{NO}^2 \times P_{Cl_2}}{P_{NOCl}^2} = (43-2x)^2(23-x)/(675+2x)^2 = 0.060$

x = 2.90 so the partial pressure of NOCl at equilibrium = 681 torr
and the partial pressure of NO = 37 torr
and the partial pressure of Cl_2 = 20 torr

10. $SO_2Cl_2(g) \rightleftharpoons SO_2(g) + Cl_2(g)$

Must convert to moles and then to moles/liter.

SO_2Cl_2	2.0 grams	MM = 134.97 g mol−1	Moles = 0.0148
SO_2	0.17 gram	MM = 64.064 g mol−1	Moles = 0.0027
Cl_2	0.19 gram	MM = 70.91 g mol−1	Moles = 0.0027

a. $Qp = (0.0027)^2/0.0148 = 4.93 \times 10^{-4}$.

b. No, the system is not at equilibrium. Q_p does not equal K_p.

c. Q_p is too small, the reaction will move toward product.

11. $NH_4Cl(s) \rightleftharpoons NH_3(g) + HCl(g)$

The expression for K_p is:

$K_p = P_{NH_3} \times P_{HCl} = 0.640$

Since the partial pressures of ammonia and hydrogen chloride must be equal to one another, each must equal 0.80 atm.

The total pressure is the sum of the partial pressures, so the total pressure = 1.60 atm.

The amount of NH_3 present must equal the amount of HCl present since one cannot be made without the other. Therefore their partial pressures are equal.

12.

		$Br_2(g)$ +	$Cl_2(g)$ ⇌	$2BrCl(g)$
I	Initial	0.060	0.060	0.0
C	Change	−x	−x	+2x
E	Equilibrium	0.060−x	0.060−x	+2x

Remember to change amounts to concentrations.

$$K = \frac{[BrCl]^2}{[Br_2][Cl_2]} = \frac{(2x)^2}{(0.060-x)(0.060-x)} = 36.0$$

Take the square root of both sides.

x = 0.045

So the concentration of BrCl produced = 2x = 0.090 mol L^{-1}.

Quantity produced = 0.090 mol L^{-1} × 3 L = 0.27 mol = 31 grams.

Don't assume x is the desired answer to the problem! In this case the required quantity is the concentration of BrCl (which is 2x) and the total amount of BrCl (which is the volume of 3 liters × this concentration).

13.

		NH_3 +	H_2O ⇌	NH_4^+ +	OH^-
I	Initial	0.200		0.0	0.0
C	Change	−x		+x	+x
E	Equilibrium	0.200−x		+x	+x

Remember to convert amounts into concentrations—it's easy to forget.

$$K = \frac{[NH_4^+][OH^-]}{[NH_3]} = \frac{x^2}{(0.200-x)} = 1.8 \times 10^{-5}$$

Can assume that 0.200−x is near enough to 0.200.

$x = 1.90 \times 10^{-3}$ M —this is the concentration of hydroxide ion.

14. $Ti(s) + 2Cl_2(g) \rightleftharpoons TiCl_4(g) + \text{heat}$

The yield of the product $TiCl_4$ is increased by moving the system to the right:

a. remove heat; cool the system down.

b. remove $TiCl_4(g)$.

c. add chlorine gas $Cl_2(g)$.

d. increase the pressure (or decrease the volume).

Note that:

adding more Ti(s) has no effect.
adding a catalyst has no effect.

South Pasadena • AP Chemistry

Name KEY
Period ___ Date ___/___/___

16 • Chemical Equilibrium

STATION 1 • MASS ACTION EXPRESSIONS

Write the mass action expression for the equilibrium: $Fe_3O_4(s) + 4\ H_2(g) \rightleftharpoons 3\ Fe(s) + 4\ H_2O(g)$

$$K_c = \frac{[H_2O]^4}{[H_2]^4}$$

Write the mass action expression for the equilibrium: $Ca(OH)_2(s) \rightleftharpoons Ca^{2+}(aq) + 2\ OH^-(aq)$

$$K_c = [Ca^{2+}][OH^-]^2$$

The equilibrium constant, $K_c = 7.9 \times 10^{-6}$, is this equilibrium system reactant or product-favored. REACTANT-FAVORED

$K_c << 1$ $\frac{[\text{PRODUCTS}]}{[\text{REACTANTS}]}$

16 • Chemical Equilibrium

STATION 2 • MANIPULATING K

Given:

① $H_2O(l) \rightleftharpoons H^+(aq) + OH^-(aq)$ FLIP $\quad K_c = 1 \times 10^{-14}$ INVERSE $\frac{1}{1\times10^{-14}}$

② $HCN(aq) \rightleftharpoons H^+(aq) + CN^-(aq)$ $\quad K_c = 4.0 \times 10^{-10}$

Calculate K_c for this reaction:

$HCN(aq) + OH^-(aq) \rightleftharpoons H_2O(l) + CN^-(aq)$ $\quad K_c = ???$

①' $\cancel{H^+} + OH^- \rightleftharpoons H_2O_{(l)}$ $\quad K_1' = \frac{1}{1\times10^{-14}}$

② $HCN \rightleftharpoons \cancel{H^+} + CN^-$ $\quad K_2 = 4.0 \times 10^{-10}$

$HCN + OH^- \rightleftharpoons H_2O_{(l)} + CN^-$

$$K_c = K_1' \times K_2 = \frac{4.0\times10^{-10}}{1.0\times10^{-14}} = \boxed{4.0\times10^{4}}$$

$K_c >> 1$

This reaction is PRODUCT -favored.

16 • Chemical Equilibrium

STATION 3 • K_p & K_c

Consider the equilibrium: $2NO(g) + O_2(g) \rightleftharpoons 2NO_2(g)$.

At 100°C, the equilibrium concentrations for this system are:
$[NO] = 0.52$ M; $[O_2] = 0.24$ M; $[NO_2] = 0.18$ M

Write the expression for K_c and calculate its value at this temperature?

$$K_c = \frac{[NO_2]^2}{[NO]^2[O_2]} = \frac{(.18)^2}{(.52)^2(.24)} = .49926 \approx \boxed{.50\ M^{-1}}$$

What is Δn for this system? $\underline{-1}$ $2 - 3 = -1$ (moles of product gas) − (moles of reactant gas)

Write the expression for K_p and calculate its value at this temperature.

$$K_p = \frac{(P_{NO_2})^2}{(P_{NO})^2(P_{O_2})} = K_c(RT)^{\Delta n} = (.50)(.0821 \times 373K)^{-1}$$
$$= \boxed{0.016}\ atm^{-1}$$

16 • Chemical Equilibrium

STATION 4 • LE CHÂTELIER'S PRINCIPLE

Consider the gaseous equilibrium: Heat + $2CCl_4(g) + O_2(g) \rightleftharpoons 2COCl_2(g) + 2Cl_2(g)$ $\Delta H = +35$ kJ
Predict the effect each change would have on the concentrations of the each substance.

3 mol gas ⇌ 4 mol gas

Add CCl_4	↑	↓	→	↑	↑
Remove Cl_2	↓	↓	→	↑	↓
Add $COCl_2$	↑	↑	←	↑	↓
Increase temperature	↓	↓	→	↑	↑
Reduce container volume	↑	↑	←	↓	↓
Add a catalyst	—	—		—	—
Remove O_2	↑	↓	←	↓	↓
Add He to increase pressure	—	—		—	—

A different equilibrium shifts toward the reactants ← when the temperature Heat is increased. From this observation, you know that the reaction is EXOTHERMIC (exothermic / endothermic).

16 • Chemical Equilibrium

STATION 5 • ICE BOX PROBLEM

Consider the equilibrium: $2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$

If 0.200 mol $SO_3(g)$ is placed a 0.500 Liter container, it is found that 0.050 mole of $O_2(g)$ is in the container at equilibrium. Fill in the ICE box and determine the K_c for this reaction.

	2 SO_2	O_2	2 SO_3
Initial	0 M	0 M	$\frac{.200\text{ mol}}{.500\text{ L}} = .400$ M
Change	+.200 M	+.100 M	−.200 M
Equilibrium	.200 M	$\frac{.050\text{ mol}}{.500\text{ L}} = .100$ M	.200 M

$$K_c = \frac{[SO_3]^2}{[SO_2]^2[O_2]} = \frac{(.200)^2}{(.200)^2(.100)} = \boxed{10.0}$$

16 • Chemical Equilibrium

STATION 6 • ANOTHER ICE BOX PROBLEM

At 985°C, the equilibrium constant for the reaction, $H_2(g) + CO_2(g) \rightleftarrows H_2O(g) + CO(g)$, is 1.63.

If 2.00 moles each of $H_2(g)$ and $CO_2(g)$ are placed in a 1.00-Liter container and allowed to come to equilibrium, determine the equilibrium concentrations of the four chemicals.

	H_2	CO_2	H_2O	CO
Initial	2.00 M	2.00 M	0 M	0 M
Change	−x	−x	+x	+x
Equilibrium	2.00 − x	2.00 − x	x	x
Answers	.880 M	.880 M	1.12 M	1.12 M

$$K_c = \frac{[H_2O][CO]}{[H_2][CO_2]} = 1.63 = \frac{x^2}{(.200-x)^2}$$

SQUARE ROOT BOTH SIDES

$$\sqrt{1.63} = 1.2767 = \frac{x}{2.00-x}$$

$$x = (1.2767)(2.00-x)$$

$$x = 2.55 - 1.2767x$$

$$\frac{2.2767x}{2.2767} = \frac{2.55}{2.2767}$$

$$x = 1.12\text{ M}$$

16 • Chemical Equilibrium

STATION 7 • TEST QUOTIENT, Q

Consider the equilibrium: $2NO(g) + O_2(g) \rightleftharpoons 2NO_2(g)$. $K_c = 0.499$

The system is set up with the following concentrations:

$[NO] = 0.50\ \underline{M}$; $[O_2] = 0.25\ \underline{M}$; $[NO_2] = 0.25\ \underline{M}$

This reaction will SHIFT LEFT (shift right, shift left, remain unchanged).

Justify your prediction.

$$Q = \frac{[NO_2]^2}{[NO]^2[O_2]} = \frac{(.25\ \underline{M})^2}{(.50\underline{M})^2(.25\ \underline{M})} = 1.0$$

$Q > K_c$ TOO MANY PRODUCTS $\frac{[PRODUCTS]}{[REACTANTS]}$

SHIFT TOWARD REACTANTS TO REACH EQUILIBRIUM.

16 • Chemical Equilibrium

STATION 8 • NChO PROBLEMS

33. Mercury(II) oxide, HgO, is decomposed upon heating according to this equation.

$$2HgO(s) \rightleftharpoons 2Hg(l) + O_2(g)$$

What is the equilibrium expression for this process?

(A) $K = \frac{[Hg]^2[O_2]}{[HgO]^2}$ **(B)** $K = \frac{[Hg][O_2]}{[HgO]}$

(C) $K = [Hg][O_2]$ **(D)** $\boxed{K = [O_2]}$

34. Consider this reaction.

$$2NO(g) + Cl_2(g) \rightleftharpoons 2NOCl(g) + HEAT \quad \Delta H = -78.38\ \text{kJ}$$

What conditions of temperature and pressure will produce the highest yield of NOCl at equilibrium? means "SHIFT RIGHT"

	T	*P*
~~(A)~~	~~high~~	high
~~(B)~~	~~high~~	low
(C)	low	high
(D)	low	low

3 moles gas ⇌ 2 moles gas

HIGH P

Questions **32** and **33** should both be answered with reference to this system. 1 mole gas ⇌ 2 mole gas

$$\text{Heat} + H_2(g) + I_2(s) \rightleftharpoons 2HI(g) \quad \Delta H = +51.8\ \text{kJ}$$

SHIFT

32. Which would increase the equilibrium quantity of $HI(g)$? Assume the system has reached equilibrium with all three components present.

I. increasing pressure **II.** increasing temperature

(A) I only **(B)** II only

(C) Both I and II **(D)** Neither I nor II

33. What is the equilibrium constant expression for this system?

(A) $K = \frac{[HI]^2}{[H_2][I_2]}$ **(B)** $K = \frac{[H_2][I_2]}{[HI]^2}$

(C) $K = \frac{2[HI]}{[H_2][I_2]}$ **(D)** $\boxed{K = \frac{[HI]^2}{[H_2]}}$

STATION 9 • PREDICTING REACTIONS

$2HCl + 2KNO_2 \rightarrow 2KCl + \cancel{2HNO_2}$ $NO_2 + NO + H_2O$

A solution of hydrochloric acid is added to a solution of potassium nitrite.

(i) Balanced equation:

$2H^+ + 2NO_2^- \rightarrow NO + NO_2 + H_2O$

(ii) What are the oxidation states of the N atom before and after the reaction?

O = −2 in most of its compounds

NO_2^-	NO	NO_2
N = +3	N = +2	N = +4

Note: Begin with: $HCl + KNO_2 \rightarrow KCl + HNO_2$
Recognize that HNO_2 decomposes into two gases (NO & NO_2)
To show the correct decomposition, you need 2 moles of HNO_2

$$2\,HNO_2 \rightarrow NO(g) + NO_2(g) + H_2O(l)$$

Molecular Equation:

$$2\,HCl + 2KNO_2 \rightarrow 2\,KCl + NO + NO_2 + H_2O$$

Ionic Equation:

$$2H^+ + 2\,Cl^- + 2\,K^+ + 2\,NO_2^- \rightarrow 2\,K^+ + 2\,Cl^- + NO + NO_2 + H_2O$$

Net Equation is shown above.