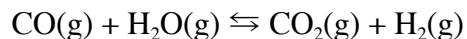


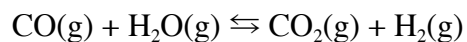
**Chemical Equilibrium:**

Chemical Reactions reach a state of dynamic equilibrium in which the rates of the forward and reverse reactions are equal and there is no net change in composition.

**Le Chatelier's Principle**

When a system at equilibrium is subjected to a stress, the equilibrium will shift to relieve the stress.

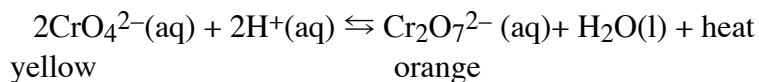
Consider:



Which direction does the equilibrium shift if we:

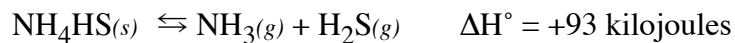
- a) Add CO
- b) Add water
- c) Add carbon dioxide
- d) Remove Hydrogen gas
- e) Remove CO

Now consider



Which direction does the equilibrium shift if we:

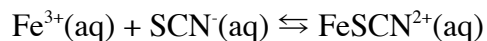
- a)  $\text{K}_2\text{CrO}_4$  is added
- b)  $\text{K}_2\text{Cr}_2\text{O}_7$  is added
- c) HCl is added
- d) It is placed in an ice bath.
- e) What color will predominate if we remove water?



The equilibrium above is established by placing solid  $\text{NH}_4\text{HS}$  in an evacuated container at  $25^\circ\text{C}$ . At equilibrium, some solid  $\text{NH}_4\text{HS}$  remains in the container. Predict each of the following.

- a) The effect on the equilibrium partial pressure of  $\text{NH}_3$  gas when additional solid  $\text{NH}_4\text{HS}$  is introduced into the container
- b) The effect on the equilibrium partial pressure of  $\text{NH}_3$  gas when additional solid  $\text{H}_2\text{S}$  is introduced into the container
- c) The effect on the mass of solid  $\text{NH}_4\text{HS}$  present when the volume of the container is decreased
- d) The effect on the mass of solid  $\text{NH}_4\text{HS}$  present when the temperature is increased.

In this unit you did a lab that dealt with the following equilibrium:

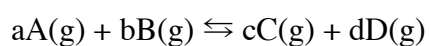


Fill in the following table based upon what you observed during the lab.

Solution Added	What two ions are in this solution?	Will it get darker or lighter?	How will the $[\text{FeSCN}^{2+}]$ Change?
Potassium carbonate			
Calcium thiocyanate			
Sodium bromide			
Potassium hydroxide			
Potassium nitrate			
Iron (III) bromide			
Ammonium bromide			

What is an equilibrium constant?

How do you write an equilibrium constant?



Who is included in an equilibrium constant?

Why not solids and pure liquids? What is the physical difference?

What are the special cases of the equilibrium constant?

$K_c$

$K_p$

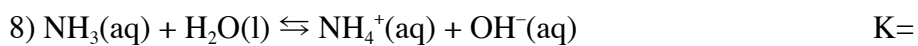
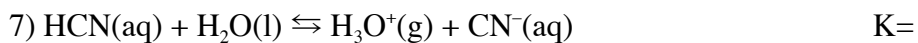
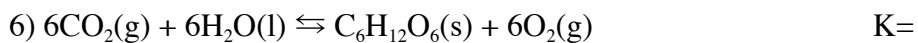
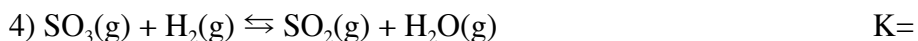
$K_a$

$K_b$

$K_w$

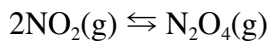
$K_{sp}$

Write the equilibrium constant expression for the following reactions:



**How do you calculate an equilibrium constant?**

Calculate the equilibrium constants for the following reactions:



K=

Experiment	[NO <sub>2</sub> ]	[N <sub>2</sub> O <sub>4</sub> ]
1.	0.052	0.595
2.	0.024	0.127
3.	0.068	1.02

Show work here

Show answers here

K<sub>1</sub>=

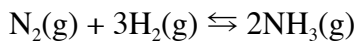
=

K<sub>2</sub>=

=

K<sub>3</sub>=

=



K=

Experiment	[N <sub>2</sub> ]	[H <sub>2</sub> ]	[NH <sub>3</sub> ]
1.	0.921	0.763	0.157
2.	0.399	1.197	0.203
3.	2.59	2.77	1.82

Show work here

Show answers here

K<sub>1</sub>=

=

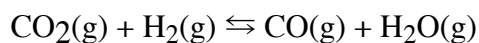
K<sub>2</sub>=

=

K<sub>3</sub>=

=

This equation:



describes a reaction that was carried out at 900 Celsius with the following results:

Partial Pressure(atm) at equilibrium

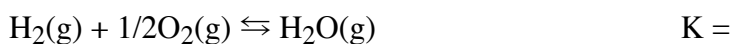
Trial	CO	H <sub>2</sub> O	CO <sub>2</sub>	H <sub>2</sub>
1	0.352	0.352	0.648	0.148
2	0.266	0.266	0.234	0.234
3	0.186	0.686	0.314	0.314

a) Write the equilibrium expression for this reaction

b) Verify that the constant for this expression is constant by calculating the value for all three trials.

### **Manipulating the equilibrium constant**

For the following reaction:



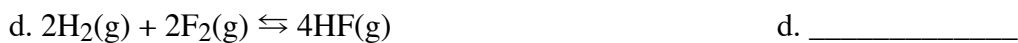
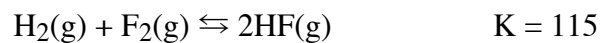
Write the following reactions and their equilibrium constants:

Reverse Reaction

Twice the forward reaction

Half the forward reaction

Give numerical values for K in the following situations dealing with:



### **K<sub>p</sub> versus K<sub>c</sub>**

Let's think about how we measure the concentration using the ideal gas law.

Now apply this to the idea of equilibrium constants:

### **The Reaction Quotient**

**Solving Equilibrium Problems**

Steps to solving an equilibrium problem.

1)

2)

3)

4)

5)

6)

7)

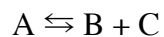
**The Quadratic Equation.**

For an equation of the form:

$$ax^2+bx+c=0$$

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

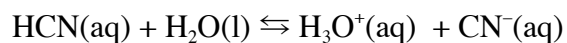
1. For the reaction:



the equilibrium constant is  $3.0 \times 10^{-6}$ . What is the concentration of B at equilibrium if A was originally 0.10 M?

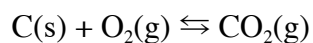


2. The K for the reaction of HCN is  $6.3 \times 10^{-10}$  for the following reaction:



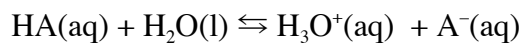
What is the concentration of cyanide ion at equilibrium if you start with 0.100 M HCN?

3. An equilibrium mixture contains oxygen gas at 2.9 atm and carbon dioxide at 2.6 atm.

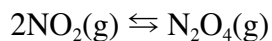


Calculate  $K_p$  and  $K_c$  at for this system at 289 Kelvin.

4 . If a 0.10 M solution of an acid HA has an  $\text{H}_3\text{O}^+$  concentration of  $4.0 \times 10^{-4}$  what is the equilibrium constant  $K_a$  for the reaction?

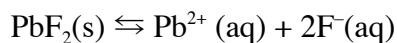


5. For the equilibrium system:



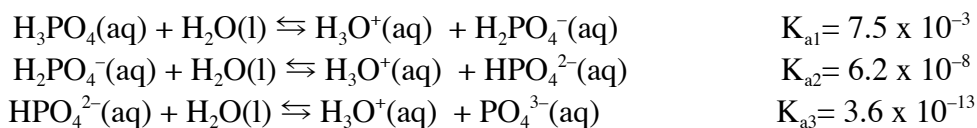
the equilibrium constant is 170 at room temperature. Assume a 1.00 liter container contains 0.005 moles of nitrogen dioxide and 0.005 moles of dinitrogen tetraoxide. Is this system at equilibrium? Which direction will it shift to reach equilibrium?

6. The K for the following reaction is  $1.9 \times 10^{-3}$ .

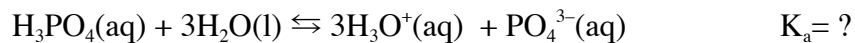


What is the concentration of lead ion at equilibrium?

7. Phosphoric acid undergoes three reactions in succession:



What is K for the overall reaction:



From the 2000 Exam



When heated, hydrogen sulfide gas decomposes according to the equation above. A 3.40 g sample of  $\text{H}_2\text{S}(\text{g})$  is introduced into an evacuated rigid 1.25 L container. The sealed container is heated to 483 K and  $3.72 \times 10^{-2}$  mole of  $\text{S}_2(\text{g})$  is present at equilibrium.

(a) Write the expression for the equilibrium constant,  $K_c$ , for the decomposition reaction represented above.

(b) Calculate the equilibrium concentration, in mole per L, of the following gases in the container at 483 K.

(i)  $\text{H}_2(\text{g})$

(ii)  $\text{H}_2\text{S}(\text{g})$

(c) Calculate the value of the equilibrium constant,  $K_c$ , for the decomposition reaction at 483 K.

(d) Calculate the partial pressure of  $\text{S}_2(\text{g})$  in the container at equilibrium at 483 K.

(e) For the reaction  $\text{H}_2(\text{g}) + 1/2\text{S}_2(\text{g}) \rightleftharpoons \text{H}_2\text{S}(\text{g})$  at 483 K, calculate the value of the equilibrium constant  $K_c$ .

From the 1992 Exam



Solid sodium hydrogen carbonate,  $\text{NaHCO}_3$ , decomposes on heating according to the equation above.

- (a) A sample of 100. grams of solid  $\text{NaHCO}_3$  was placed in a previously evacuated rigid 5.00-liter container and heated to  $160^\circ\text{C}$ . Some of the original solid remained and the total pressure in the container was 7.76 atmospheres when equilibrium was reached. Calculate the number of moles of  $\text{H}_2\text{O}_{(g)}$  present at equilibrium.
- (b) How many grams of the original solid remain in the container under the conditions described in (a)?
- (c) Write the equilibrium expression for the equilibrium constant,  $K_p$ , and calculate its value for the reaction under the conditions in (a).
- (d) If 110. grams of solid  $\text{NaHCO}_3$  had been placed in the 5.00-liter container and heated to  $160^\circ\text{C}$ , what would the total pressure have been at equilibrium? Explain.