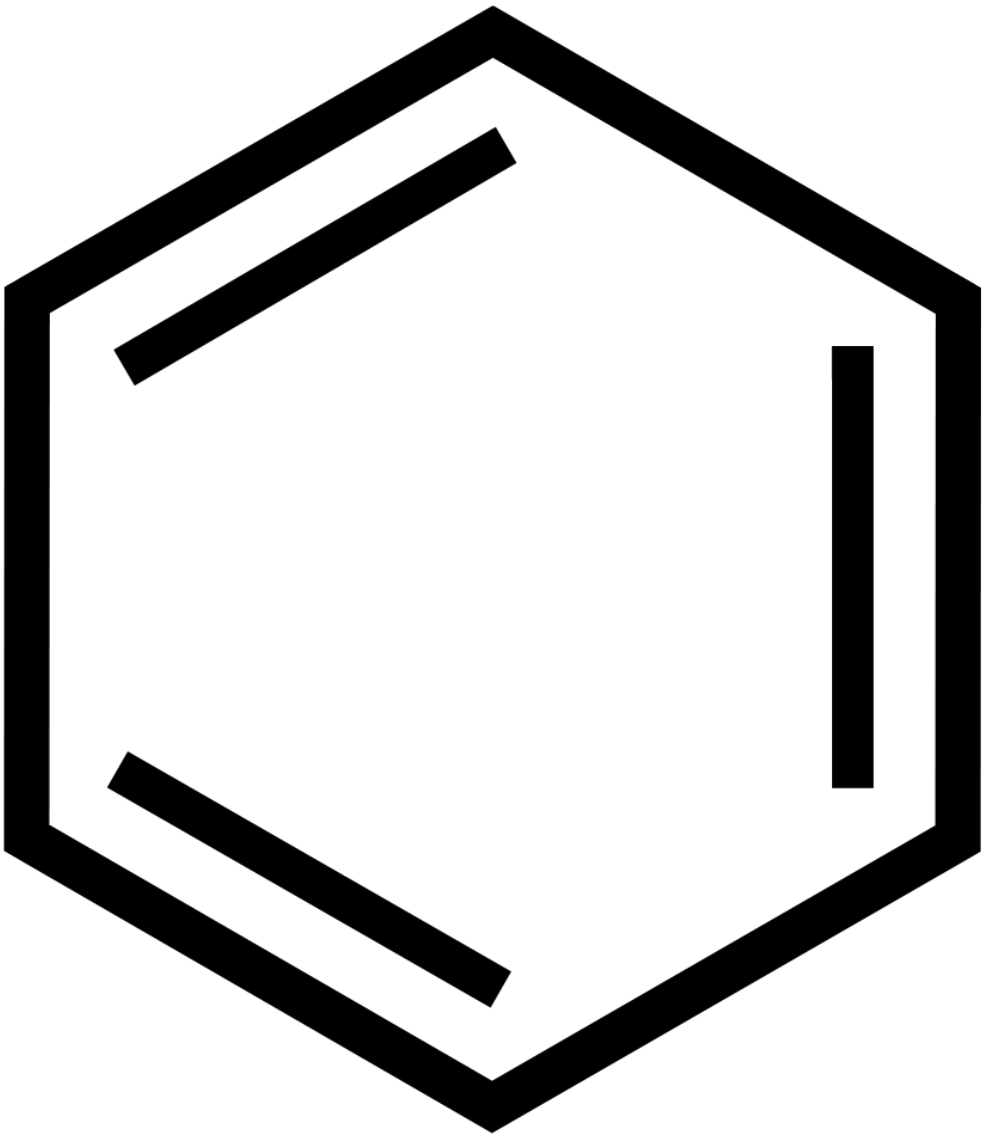

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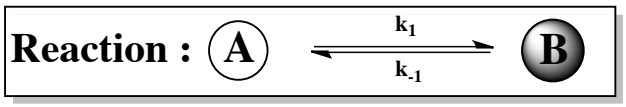
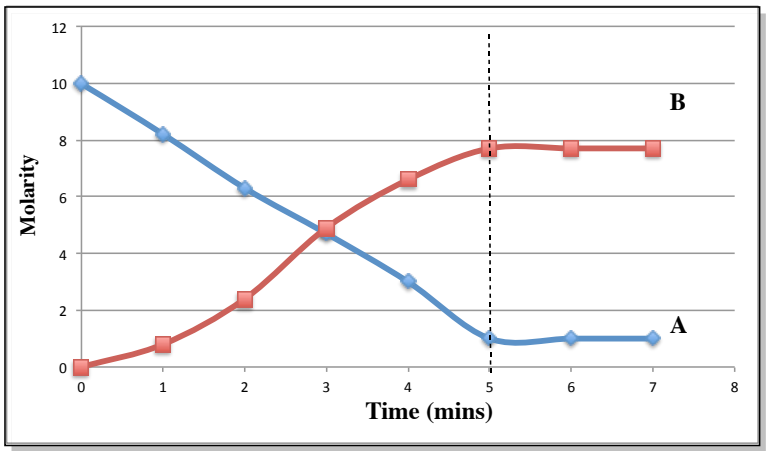
CONCEPT: THE EQUILIBRIUM STATE

Most chemical reactions do not go to ***completion***.

- _____ do not completely convert into _____ and reactant concentrations do not go down to _____.
- Instead, these reactions reach a state of ***chemical equilibrium***, in which the reaction moves in the forward and reverse direction.

These reactions are also called _____ reactions and are represented by using a double arrow.





PRACTICE: Which one of the following statements does not describe the equilibrium state?

a. While at equilibrium, a dynamic process is still occurring.

b. The concentration of the reactants is equal to the concentration of the products.

c. The concentration of the reactants and products reach a constant level.

d. At equilibrium, the net concentration of all species is not changing.

e. All are true.

CONCEPT: THE EQUILIBRIUM CONSTANT

The equilibrium constant, K, is a number equal to the ratio of _____ to _____ at a given temperature.

- Its magnitude tells us how far to the left or to the right our chemical equation lies at a particular temperature.
- If K is greater than 1 then _____ are favored over _____ and _____ direction is favored.
- If K is less than 1 then _____ are favored over _____ and _____ direction is favored.

K =

The equilibrium constant, K, takes into account all states of matter except: _____ and _____.

EXAMPLE: Write the equilibrium expression for the following reaction.

a) $2\ N_2O_5\ (aq) \rightleftharpoons 4\ NO_2\ (aq) + O_2\ (aq)$

b) $2\ PbO\ (s) + O_2\ (g) \rightleftharpoons 2\ PbO_2\ (s)$

c) $I_2\ (s) + 3\ XeF_2\ (s) \rightleftharpoons 2\ IF_3\ (s) + 3\ Xe\ (g)$

PRACTICE: State which is greater in amount: reactants or products, based on the given equilibrium constant, K.

a) $N_2\ (g) + O_2\ (g) \rightleftharpoons 2\ NO\ (g)$ $\quad K = 1.0 \times 10^{20}$

b) $2\ CO\ (g) + O_2 \rightleftharpoons 2\ CO_2\ (g)$ $\quad K = 2.2 \times 10^{-22}$

c) $2\ BrCl\ (g) \rightleftharpoons Br_2\ (g) + Cl_2\ (g)$ $\quad K = 1$

PRACTICE: THE EQUILIBRIUM CONSTANT (CALCULATIONS)

PRACTICE 1: The decomposition of nitrogen monoxide can be achieved under high temperatures to create the products of nitrogen and oxygen gas.

$$6 \quad NO\,(aq) \rightleftharpoons 3\,N_2\,(aq) + 3\,O_2\,(aq)$$

a) What is the equilibrium equation for the reaction above?

b) Write the equilibrium expression for the reverse reaction.

PRACTICE 2: The equilibrium constant, K, for the $2\,NO\,(g) + O_2\,(g) \rightleftharpoons 2\,NO_2\,(g)$ is 6.9×10^{2}. What is the [NO] in an equilibrium mixture of gaseous NO, O_2 and NO_2 at 500 K that contains 1.5×10^{-2} M O_2 and 4.3×10^{-3} M NO_2?

CONCEPT: TYPES OF EQUILIBRIUM CONSTANTS

When dealing with gases, we use the equilibrium constant, _____, which uses the partial pressure unit of _____.

When dealing with aqueous solutes, we use the equilibrium constant, _____, which uses the concentration unit of _____.

To relate K_P to K_C we use the formula:

EXAMPLE: For the following reaction, 2 A (s) + 3 B (g) $\rightleftharpoons$ 2 C (g), $K_c = 4.9 \times 10^{-9}$ at 25 ^oC. Which of the following statements is true?

a) The reaction is favored in the forward direction.
b) The concentration of the products is greater than the concentration of the reactants.
c) The reaction is favored in the reverse direction.
d) The value of K_p will be larger than the value of K_c.

PRACTICE: Methane (CH_4) reacts with hydrogen sulfide to yield hydrogen gas and carbon disulfide, a solvent used in the manufacturing rayon and cellophane. What is the value of K_C at 1000 K if the partial pressures in an equilibrium mixture at 1000 K are 0.20 atm methane, 0.15 atm hydrogen sulfide, 0.30 atm carbon disulfide and 0.10 atm hydrogen gas?

$$CH_4\ (g) + 2\ H_2S\ (g) \rightleftharpoons 4\ H_2\ (g) + CS_2\ (g)$$

PRACTICE: TYPES OF EQUILIBRIUM CONSTANTS (CALCULATIONS)

PRACTICE 1: In which of the given reactions is K_p greater than, less than and equal to K_c?

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

b) $P_4\,(s) + 5\,O_2\,(g) \rightleftharpoons P_4O_{10}\,(s)$

c) $4\,NH_3\,(g) + 3\,O_2\,(g) \rightleftharpoons 2\,N_2\,(g) + 6\,H_2O\,(g)$

PRACTICE 2: Given the hypothetical reaction $2\,A\,(s) + ?\,B\,(g) \rightleftharpoons 3\,C\,(g)$, Kp = 0.0105 and Kc = 0.45 at 250 degrees Celsius. What is the value of the coefficient of B?

CONCEPT: HESS'S LAW….KIND OF

We learned to find the total enthalpy change of a reaction by taking into account each individual reaction step, now we will do it all over again but in finding the rate constant, K.

EXAMPLE 1: The equilibrium constant K for the reaction

$$CO_2\,(g) \rightleftharpoons CO\,(g) + \frac{1}{2}\,O_2\,(g)$$

is 6.83×10^{-12} at 1000 K. Calculate K for the reaction

$$4\,CO\,(g) + 2\,O_2\,(g) \rightleftharpoons 4\,CO_2\,(g)$$

EXAMPLE 2: Calculate the rate constant, Kc, for the reaction below:

$$H\,(g) + Br\,(g) \longrightarrow HBr\,(g)$$

Use the following information to calculate Kc.

$$H_2\,(g) \longrightarrow 2\,H\,(g) \qquad Kc = 11.8$$

$$Br_2\,(g) \longrightarrow 2\,Br\,(g) \qquad Kc = 1.15 \times 10^{-5}$$

$$H_2\,(g) + Br_2\,(g) \longrightarrow 2\,HBr\,(g) \qquad Kc = 2.78 \times 10^{3}$$

PRACTICE: HESS'S LAW….KIND OF (CALCULATIONS)

EXAMPLE 1: The value for K_p is 0.39 for the following reaction:

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

What is the value of K_p for the reaction of $\frac{1}{3}\ N_2O_4\ (g) \rightleftharpoons \frac{2}{3}\ NO_2\ (g)$ at the same temperature?

EXAMPLE 2: Calculate the rate constant, Kc, for the reaction below:

$$CH_4\ (g) + 2\ O_2\ (g) \longrightarrow CO_2\ (g) + 2\ H_2O\ (l) \qquad Kc = ?$$

Use the following information to calculate Kc for the combustion of methane

$$CH_4\ (g) + O_2\ (g) \longrightarrow CH_2O\ (g) + H_2O\ (g) \qquad Kc = 1.12 \times 10^{-3}$$

$$CH_2O\ (g) + O_2\ (g) \longrightarrow CO_2\ (g) + H_2O\ (g) \qquad Kc = 4.32 \times 10^{2}$$

$$H_2O\ (l) \longrightarrow H_2O\ (g) \qquad Kc = 6.12 \times 10^{-4}$$

CONCEPT: CALCULATING EQUILIBRIUM CONCENTRATIONS

Sometimes you will be asked to calculate concentrations at equilibrium after being given initial concentrations. To do this we use our favorite friend the _____ Chart.

EXAMPLE 1: We have a solution where $Ag(CN)_2^-$(g), CN^- (g), and Ag^+ (g) have an equilibrium constant, K, equal to 1.8×10^{-19}. If the equilibrium concentrations of $Ag(CN)_2^-$ and CN^- are 0.030 and 0.10 respectively, what is the equilibrium concentration of Ag^+?

$$Ag(CN)_2^- (g) \rightleftharpoons 2\ CN^- (g) + Ag^+ (g)$$

EXAMPLE 2: We place 2.5 mol of CO and 2.5 mol of CO_3 in a 10.0 L flask and let the system come to equilibrium. What will be the final concentration of CO_2?

$$CO (g) + CO_3 (g) \rightleftharpoons 2\ CO_2 (g) \qquad K = 0.47$$

PRACTICE: For the reaction: $N_2 (g) + 2\ O_2 (g) \rightleftharpoons 2\ NO_2 (g)$, $K_C = 8.3 \times 10^{-10}$ at 25°C. What is the concentration of N_2 gas at equilibrium when the concentration of NO_2 is twice the concentration of O_2 gas?

PRACTICE: CALCULATING EQUILIBRIUM CONCENTRATIONS (CALCULATIONS 1)

EXAMPLE 1: When 0.600 atm of NO_2 was allowed to come to equilibrium the total pressure was 0.875 atm. Calculate the K_p of the reaction.

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

EXAMPLE 2: An important reaction in the formation of acid rain is,

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

Initially, 0.023 M SO_2 and 0.015 M O_2 are mixed and allowed to react in an evacuated flask at 340 ^{o}C. When an equilibrium is established the equilibrium amount of SO_3 was found to be 0.00199 M. Calculate the equilibrium constant, K_c, for the reaction at 340 ^{o}C.

PRACTICE: CALCULATING EQUILIBRIUM CONCENTRATIONS (CALCULATIONS 2)

EXAMPLE: If K_c is 32.7 at 300°C for following reaction:

$$H_2\,(g) + Br_2\,(g) \rightleftharpoons 2\,HBr\,(g)$$

What is the concentration of H_2 at equilibrium if a 20.0 L flask contains 5.0 mol HBr initially?

PRACTICE: At a given temperature the gas phase reaction: $N_2\,(g) + O_2\,(g) \rightleftharpoons 2\,NO\,(g)$ has an equilibrium constant of 4.00×10^{-15}. What will be the concentration of NO at equilibrium if 2.00 moles of nitrogen and 6.00 moles oxygen are allowed to come to equilibrium in a 2.0 L flask.

CONCEPT: THE EQULIBRIUM CONSTANT AND THERMODYNAMICS

Earlier you learned that _____ studied the rate at which our reactants changed into products.

In this Chapter you will learn that _____ deals with the direction that a chemical reaction at equilibrium will shift.

_____ Principle states that once a system that is at equilibrium is disturbed it will do whatever it can to get back to equilibrium.

EXAMPLE: For the following endothermic reaction $K_c = 6.73 \times 10^{3}$. Predict in which direction the reaction will proceed.

$$4\ NH_3\ (g)\ +\ 3\ O_2\ (g) \rightleftharpoons 2\ N_2\ (g)\ +\ 6\ H_2O\ (g)$$

a) Addition of a catalyst

b) Decreasing the volume

c) Removing H_2O (g)

d) Increasing the Temperature

e) Addition of NH_3 (g)

f) Decreasing the pressure

g) Removing H_2O (l)

h) Addition of a precipitate

i) The addition of an inert gas at constant volume.

PRACTICE: THE EQULIBRIUM CONSTANT AND THERMODYNAMICS (CALCULATIONS 1)

PRACTICE 1: Consider the reaction below:

$$CH_4\,(g) + F_2\,(g) \rightleftharpoons CF_4\,(g) + HF\,(g) \quad \Delta H = +38.1\ KJ/mol$$

The following changes will shift the equilibrium to the **left** except one. Which one would not cause a shift to the **left**?

a) Add some CF_4.

b) Remove some F_2.

c) Decrease the Temperature.

d) Decrease the container volume.

e) Increase the partial pressure of HF.

PRACTICE 2: The following data was collected for the following reaction at equilibrium.

$$2\,A\,(g) + 3\,B\,(g) \rightleftharpoons C\,(g)$$

At $25^{o}C$, K is 5.2×10^{-4} and at $50^{o}C$ K is 1.7×10^{-7}. Which of the following statements is true?

a) The reaction is exothermic.

b) The reaction is endothermic.

c) The enthalpy change, ΔH, is equal to zero.

d) Not enough information is given.

PRACTICE: THE EQULIBRIUM CONSTANT AND THERMODYNAMICS (CALCULATIONS 2)

PRACTICE 1: Which direction will the following reaction (in a 10.0 L flask) proceed if a catalyst is added to the system?

$$CaCO_3\,(s) \rightleftharpoons CaO\,(s) + CO_2\,(g) \qquad K_p = 3.2 \times 10^{-28}$$

a) To the right.

b) To the left.

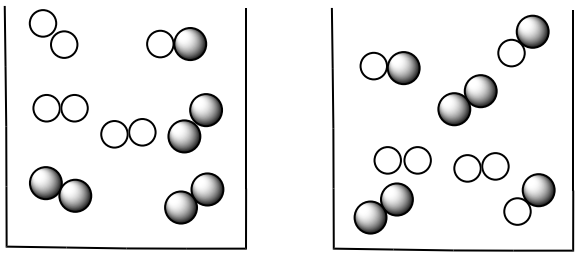
c) The equilibrium position will not change but the rate will increase.

d) The equilibrium position will not change but the concentrations of everything will increase.

PRACTICE 2: Consider the following gas reaction of A_2 (● shaded spheres) and B_2 (○ unshaded spheres)

$$A_2\,(g) + B_2\,(g) \rightleftharpoons 2\,AB\,(g)$$

Which container proceeds more to completion?



A **B**

CONCEPT: THE REACTION QUOTIENT

We've learned thus far that any given chemical reaction at equilibrium has an equilibrium constant, K, associated with it.

Now, we take a look at a new variable, _____, which is called the reaction quotient.

- It is used to determine if our chemical reaction is at equilibrium.
- If the reaction quotient is _____ the equilibrium constant K then our reaction is at equilibrium.

EXAMPLE: For the reaction: $2\ H_2S\ (g) \rightleftharpoons 2\ H_2\ g) + S_2\ (g)$, the equilibrium constant is 1.60×10^{-2} at 400 K. If the reaction quotient is 4.18×10^{-4} which of the following statements is/are **not** true?

a) The pressure of S_2 increase

b) The pressure of H_2 will decrease

c) The equilibrium constant will not change.

d) The pressure of H_2S will decrease

PRACTICE: THE REACTION QUOTIENT (CALCULATIONS)

EXAMPLE 1: For the following reaction:

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

K_{eq} = 25. At a particular time, the following concentrations are measured for the given compounds: $[H_2] = 2.25 \times 10^{-6}$ M, $[N_2] = 3.30\ 10^{-1}$ M and $[NH_3] = 1.50 \times 10^{-2}$ M. Which of the following statements is true?

a) The concentration of H_2 will increase.

b) The equilibrium constant will increase.

c) The concentration of NH_3 will increase.

d) The concentration of N_2 will decrease.

e) No change will occur.

EXAMPLE 2: For the reaction: $2\ CO_2\ (g) \rightleftharpoons 2\ CO\ g) + 2\ O_2\ (g)$, the equilibrium constant is 3.12×10^{-4} at 400 K, while the reaction quotient is 4.18×10^{-4}. If initially we have 0.20 atm CO_2, 0.30 atm CO and 0.15 atm O_2, which of the following statements is **not** true?

a) The pressure of CO_2 will be greater than 0.20 atm.

b) The pressure of CO will be less than 0.30 atm.

c) The pressure of O_2 will be greater than 0.15 atm.

d) The pressure of O_2 will be less than 0.15 atm.

e) The reaction will favor reactants.