UNIT6-DAY1-LaB1230

Wednesday, February 06, 2013
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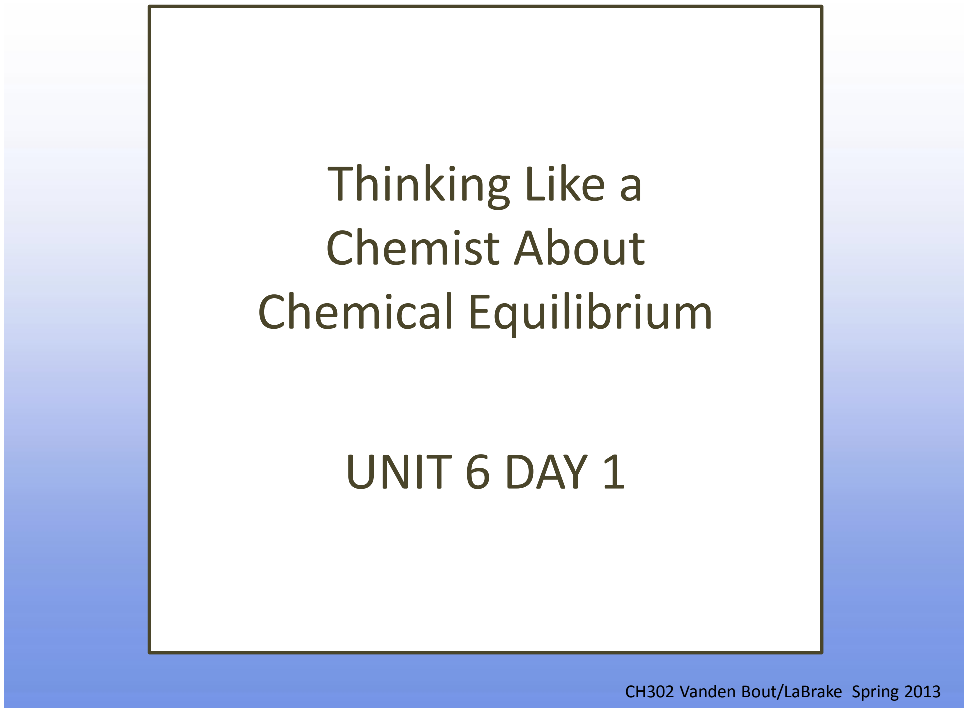
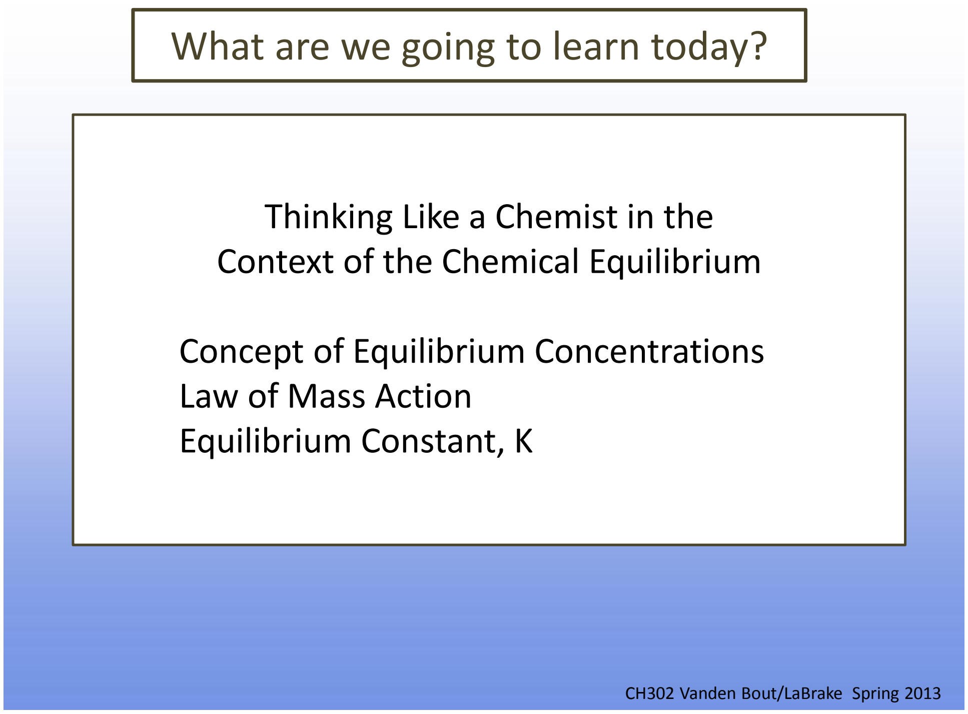


Thinking Like a Chemist About Chemical Equilibrium

UNIT 6 DAY 1

CH302 Vanden Bout/LaBrake Spring 2013



What are we going to learn today?

Thinking Like a Chemist in the Context of the Chemical Equilibrium

Concept of Equilibrium Concentrations
Law of Mass Action
Equilibrium Constant, K

CH302 Vanden Bout/LaBrake Spring 2013

IMPORTANT INFORMATION

HW4 due Tue 9 AM
LM13 Equilibrium Constant ← 1st then hmwk
LM14 K and ΔG

Exams Grades Posted by Saturday

POLLING CLICKER 1

Indicate the level of agreement that you have with the following question:

You have a certain amount of intelligence, and you can't really do much to change it.

A) Strongly Disagree
B) Disagree
C) Somewhat in between, depends
D ~~C)~~ Agree
E ~~D)~~ Strongly Agree

grow your brain!
Exercise it with mental work to increase intelligence

Y'ALL THINK ABOUT Chemical Equilibrium

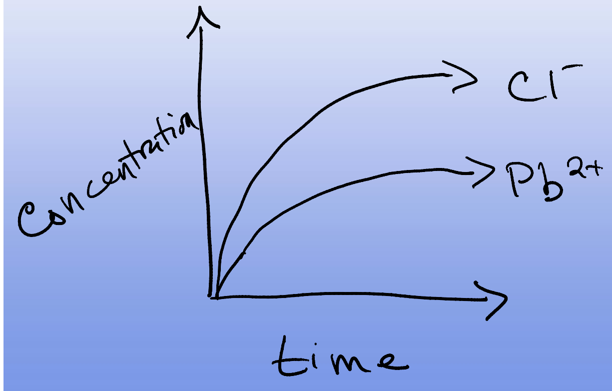
Consider graphically: $PbCl_2(s) \leftarrow\rightarrow Pb^{2+}(aq) + 2Cl^{-}(aq)$

Plot change in concentration with time → solids do not have concentrations

Consider graphically: $PbCl_2(s) \leftrightarrow Pb^{2+}(aq) + 2Cl^-(aq)$

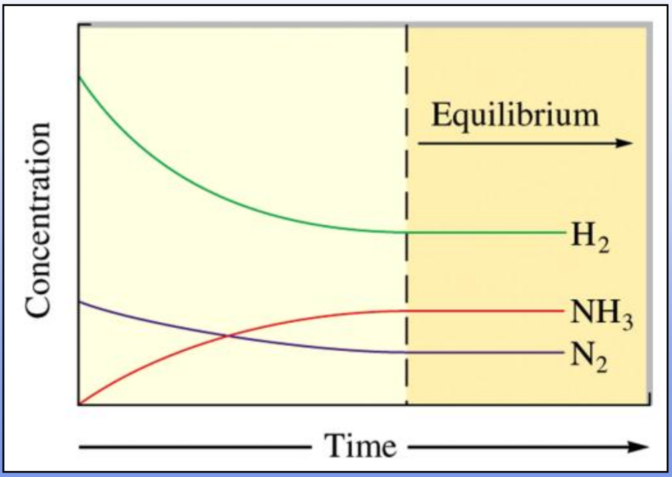
→solids do not have concentrations

Plot change in concentration with time



Y'ALL THINK ABOUT Chemical Equilibrium

Try to interpret what is going on in this graph.



POLL: CLICKER 2

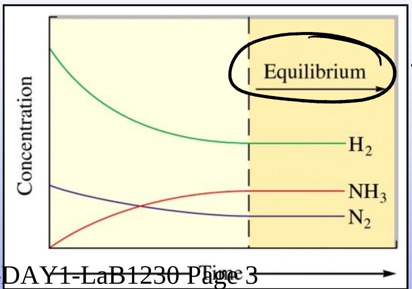
Try to interpret what is going on in this graph.

The chemical reaction is:

A) $N_2(g) + H_2(g) \leftrightarrow NH_3(g)$

B ~~A)~~ $N_2(g) + 3H_2(g) \rightarrow 2NH_3(g)$

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



The end is equilibrium

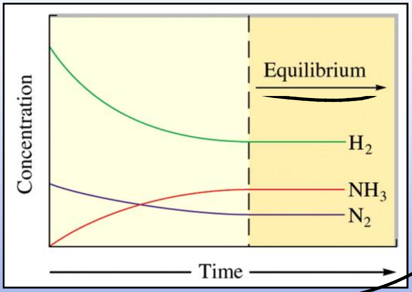
The chemical reaction is:

A) $N_2(g) + H_2(g) \leftrightarrow NH_3(g)$

B ~~A)~~ $N_2(g) + 3H_2(g) \rightarrow 2NH_3(g)$

C ~~A)~~ $N_2(g) + 3H_2(g) \boxed{\leftrightarrow} 2NH_3(g)$

D ~~A)~~ $2NH_3(g) \rightarrow N_2(g) + 3H_2(g)$



equilibrium

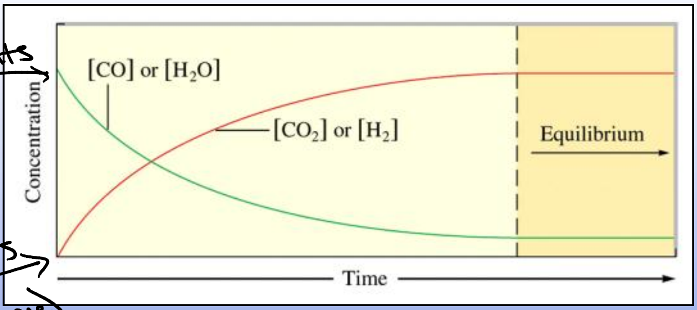
dynamic equilibrium

Y'ALL THINK ABOUT Chemical Equilibrium

What are reactants? Products? micro view?

Try to interpret what is going on in this graph.

reactants



products (start with none)

Draw a micro view of what is going on.
Reactants and products are all in gas phase.
Use different colored (shading) spheres to model the atoms of different elements.

CO CO H_2O
CO H_2O
H_2O

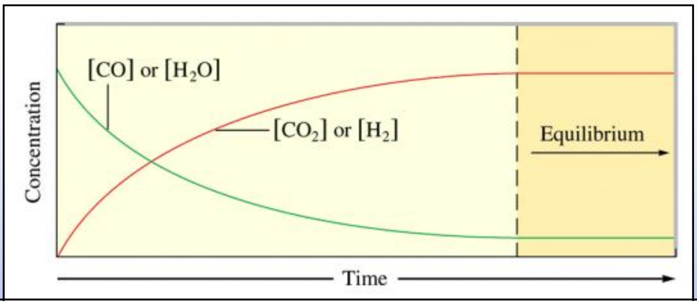
→

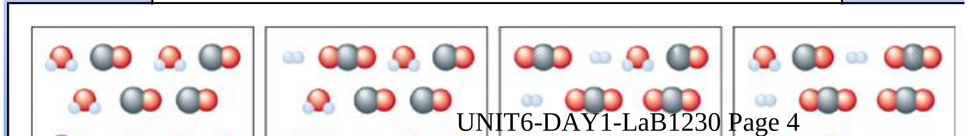
CO_2 H_2 CO
CO_2 H_2
CO_2 H_2 H_2O

still some reactants but less!

pretty version

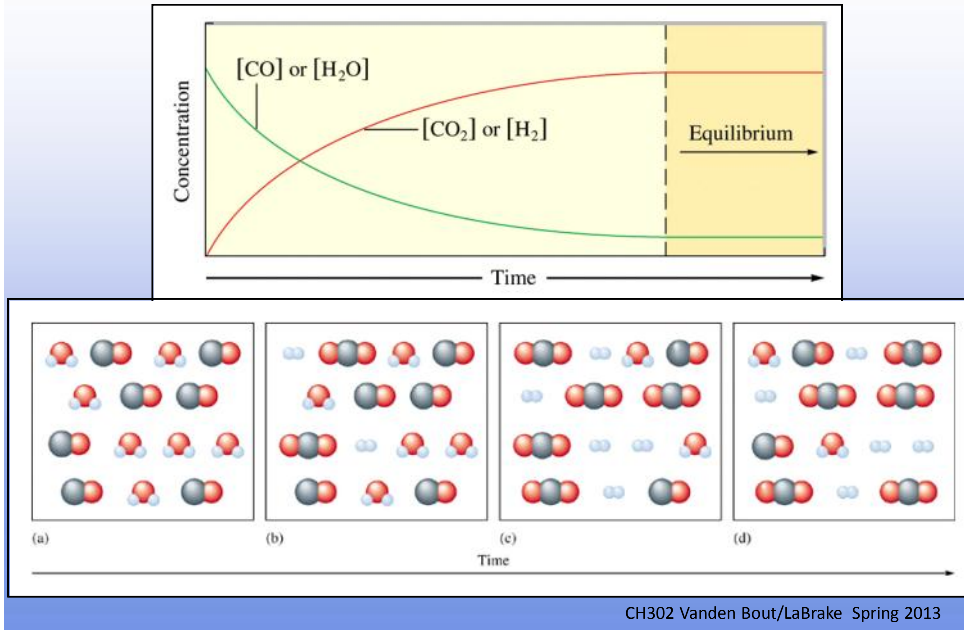
Y'ALL THINK ABOUT Chemical Equilibrium





pretty version

Y'ALL THINK ABOUT Chemical Equilibrium



LL: CLICKER 3

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

Imagine you start out with
10 mole of H_2 and 1 moles of N_2

At equilibrium you find you have 1 mole of NH_3
How many moles of H_2 are there at equilibrium?

A. 5 moles H_2
B. 7 moles H_2
[✓ C. 8.5 moles H_2]
D. 9.5 moles H_2

Given 1 mole NH_3, How much H_2 did we use?

$$\frac{1\ \text{mol}\ NH_3 \mid 3\ H_2\ \text{mol}}{\mid 2\ NH_3\ \text{mol}} = 1.5\ \text{mol}\ H_2$$

initial 10
−used 1.5
8.5

Keeping it straight (R)ICE diagram

$$R \quad 3H_2(g) + N_2(g) \longrightarrow 2NH_3(g)$$

~~Compound Initial Change Equilibrium~~

I 10 1 0

from question Know @ equil. 1 mol NH_3

So.

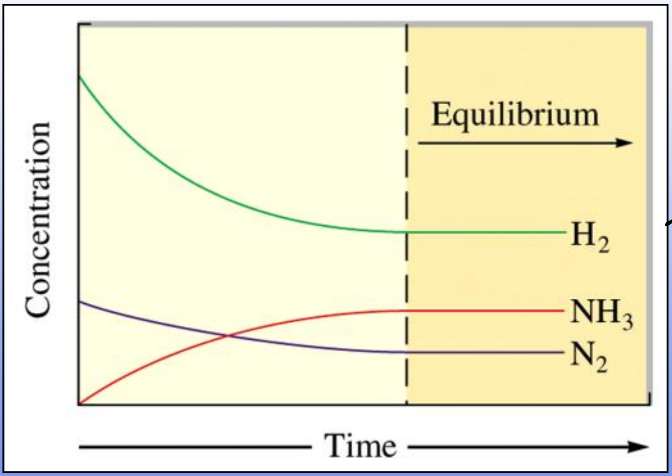
Compound	Initial	Change	Equilibrium
I	10	1	0
C	$-3x$	$-x$	$+2x$
E	$10-3x$	$1-x$	$2x$
	$10-3(0.5)$	$1-0.5$	$2(0.5)$
	8.5	0.5	1

So

$2x = 1$

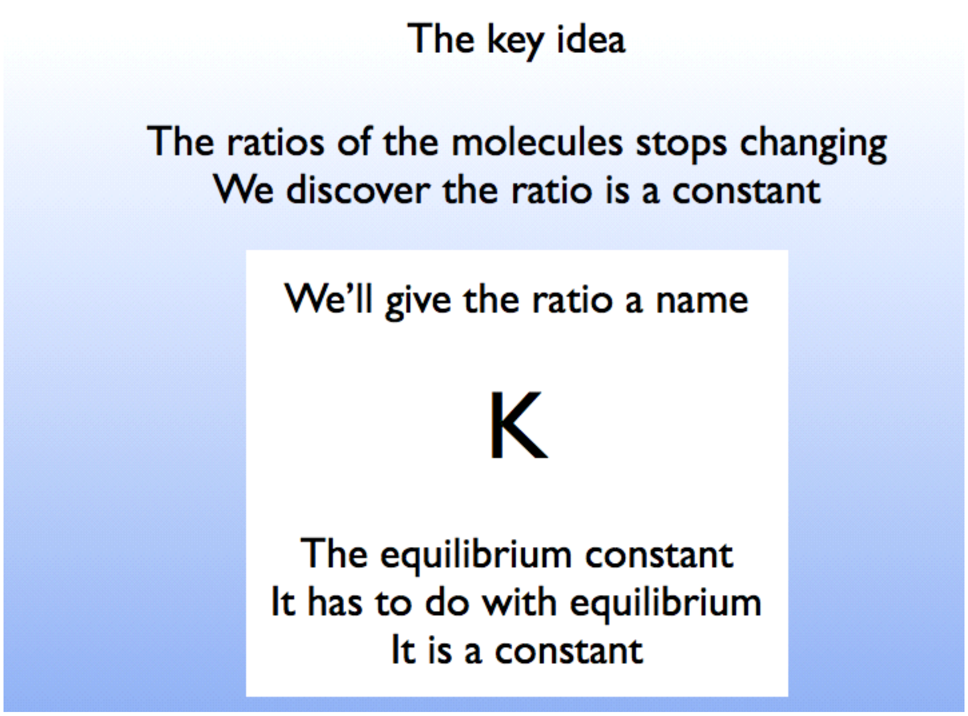
$x = 0.5$

Think about what is going on toward the end – can we quantify end?.



At equilibrium concentrations Do not change

straight



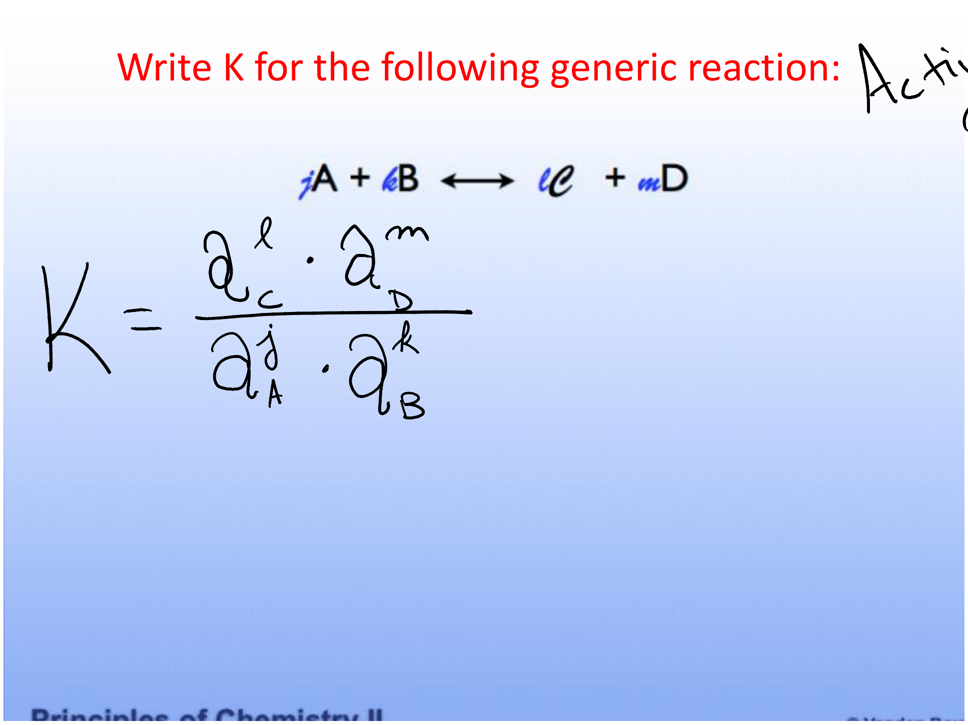
The key idea

The ratios of the molecules stops changing
We discover the ratio is a constant

We'll give the ratio a name

K

The equilibrium constant
It has to do with equilibrium
It is a constant



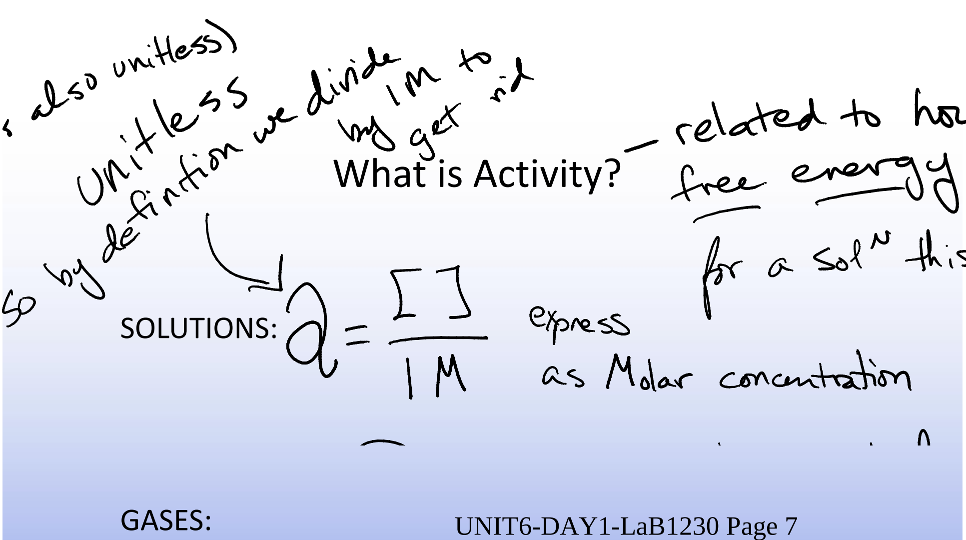
Write K for the following generic reaction: Activity

a
↑
fancy "A"

$$jA + kB \longleftrightarrow lC + mD$$

$$K = \frac{a_C^{l} \cdot a_D^{m}}{a_A^{j} \cdot a_B^{k}}$$

Principles of Chemistry II



(K is also unitless)

Unitless so by definition we divide by 1M to get rid

What is Activity? — related to how free energy is changing

for a solⁿ this is concentration

SOLUTIONS: $a = \frac{[\ ]}{1\,M}$ express as Molar concentration

GASES:

SOLUTIONS: ~ 1 M as Molar concentration

GASES: $a = \frac{P_{gas}}{1 atm}$ or $\frac{P_{gas}}{1 bar}$ ← partial pressure (not torr)

SOLID or LIQUID: $a = 1$ free energy doesn't change w/ solids or liquids → so activity is 1

Y'ALL THINK ABOUT Chemical Equilibrium

$PbCl_2(s) \leftrightarrow Pb^{2+}(aq) + 2Cl^-(aq)$

Write the equilibrium constant for this reaction:

$$K = \frac{a_{Pb^{2+}} \cdot a_{Cl^-}^2}{a_{PbCl_2}} = \frac{\frac{[Pb^{2+}]}{1M} \cdot \frac{[Cl^-]^2}{1M^2}}{1} = \text{simplify}$$

$$K_{sp} = [Pb^{2+}][Cl^-]^2$$

What is the expression for the equilibrium constant for this reaction?

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

A. $(P_{NH3})/(P_{N2})(P_{H2})$

B. $(P_{N2})(P_{H2})/(P_{NH3})$

[✓ C.] $(P_{NH3})^2/(P_{N2})(P_{H2})^3$

D. $(P_{N2})3(P_{H2})/2(P_{NH3})$

K depends on balanced eqn

B. $(P_{N2})(P_{H2})/(P_{NH3})$

[✓ C.] $(P_{NH3})^2/(P_{N2})(P_{H2})^3$

D. $(P_{N2})3(P_{H2})/2(P_{NH3})$

[illegible]

eqn

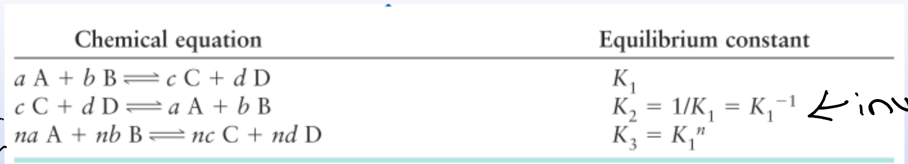
Law of Mass Action

at equilibrium
mass action = K

- The law of mass action: at equilibrium the composition of the reaction mixture can be expressed in terms of an equilibrium constant, K, which is expressed as the ratio of the concentrations at equilibrium of the products raised to the stoichiometric coefficient divided by the concentrations of the reactants at equilibrium raised to the power of the stoichiometric coefficients.

not at
equilibrium,
mass action = Q

THINK ABOUT K in Learning Module:



Chemical equation	Equilibrium constant
$a\,A + b\,B \rightleftharpoons c\,C + d\,D$	K_1
$c\,C + d\,D \rightleftharpoons a\,A + b\,B$	$K_2 = 1/K_1 = K_1^{-1}$
$na\,A + nb\,B \rightleftharpoons nc\,C + nd\,D$	$K_3 = K_1^{n}$

reverse

multiple

← inverse

Value of K depends on <u>exact</u> balanced eqn

ALL in Learning Module

K in terms of pressure, K_p

gases can use either...

- $N_2(g) + 3\,H_2(g)$ ←→ $2\,NH_3(g)$
- Express as K_c $= \dfrac{[NH_3]^2}{[N_2][H_2]^3}$

in sol$^{\underline{n}}$

- Express as K_p

$$K_p = \frac{P_{NH_3}^2}{P_{N_2}\,P_{H_3}^3}$$

↳ from free energy

K_c & K_p are different <u>values</u>

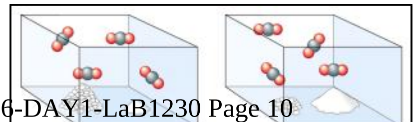
use ideal gas law to derive relationship & switch b/w K_c & K_p

$\boxed{\text{in LM}}$

<u>Homogenous</u> vs. $\boxed{\text{Heterogeneous}}$ Equilibria

What about water?

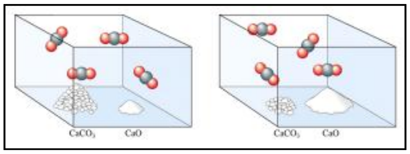
- Homogeneous – reactants and products are all in the <u>same</u> phase
- Heterogeneous – reactants and products are in <u>different</u> phases
- $N_2(g) + 3\,H_2(g)$ ←→ $2\,NH_3(g)$
- $CaCO_3(s)$ ←→ $CaO(s) + CO_2(g)$



- Homogeneous – reactants and products are all in the same phase
- Heterogeneous – reactants and products are in different phases

- $N_2(g) + 3\ H_2(g) \leftrightarrow 2\ NH_3(g)$
- $CaCO_3(s) \leftrightarrow CaO(s) + CO_2(g)$
- $Ca(OH)_2(s) \leftrightarrow Ca^{2+}(aq) + 2\ OH^-(aq)$

  Ksp
- $Ni(s) + 4CO(g) \leftrightarrow Ni(CO)_4(g)$



- Write the equilibrium constants for these reactions.

pure liquids
(like H_2O)
has an activity of 1

$$K = \frac{\text{products}}{\text{reactants}}$$

What does the value of K tell us?

- K > 1 more products than reactants
  "product favored" at equilibrium

- K < 1 more reactants than products
  at equilibrium
  "favors reactants"

Equilibrium does not depend on starting conditions

TABLE 6.1 Results of Three Experiments for the Reaction $N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$

all different

Experiment	Initial Concentrations	Equilibrium Concentrations	$K = \frac{[NH_3]^2}{[N_2][H_2]^3}$
I	$[N_2]_0 = 1.000\ M$ $[H_2]_0 = 1.000\ M$ $[NH_3]_0 = 0$	$[N_2] = 0.921\ M$ $[H_2] = 0.763\ M$ $[NH_3] = 0.157\ M$	$K = 6.02 \times 10^{-2}\ L^2/mol^2$
II	$[N_2]_0 = 0$ $[H_2]_0 = 0$ $[NH_3]_0 = 1.000\ M$	$[N_2] = 0.399\ M$ $[H_2] = 1.197\ M$ $[NH_3] = 0.203\ M$	$K = 6.02 \times 10^{-2}\ L^2/mol^2$
III	$[N_2]_0 = 2.00\ M$ $[H_2]_0 = 1.00\ M$ $[NH_3]_0 = 3.00\ M$	$[N_2] = 2.59\ M$ $[H_2] = 2.77\ M$ $[NH_3] = 1.82\ M$	$K = 6.02 \times 10^{-2}\ L^2/mol^2$

all same constant

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Each equilibrium has different concentrations, but the same value for Kc

Really Easy problems

At equilibrium you find
$[H_2]$ = .1 M, $[N_2]$ = 0.2 M, and $[NH_3]$ = .2M

1) Write K expression

$$K = ?\ \frac{[NH_3]^2}{[H_2]^3[N_2]} = \frac{(0.2)^2}{(0.1)^3(0.2)} = 200$$

Reaction	$3H_2(g) + N_2(g) \longleftrightarrow$	$2NH_3(g)$
Initial		
Change		
Equilibrium		

Fairly Easy problem

Brackets are for equilibrium concentratin

Given K = 200 and
$[H_2]$ = .2 M, $[N_2]$ = 0.4 M, and C_{NH3} = .1M
fill in the rest

Concentration initially

$[NH_3]^2$

Fairly Easy problem

Given K = 200 and
$[H_2]$ = .2 M, $[N_2]$ = 0.4 M, and C_{NH_3} = .1M
fill in the rest → Concentration initially (not at equilibrium)

$$K = 200 = \frac{[NH_3]^2}{(0.2)^3(0.4)}$$

$$[NH_3] = 0.8$$

$$0.1 + 2x = 0.8$$

$$x = 0.35$$

Reaction	$3H_2(g)$ +	$N_2(g)$ ⟷	$2NH_3(g)$
Initial	$\boxed{1.25}$	$\boxed{0.75}$	0.1
Change	$-3x$ (−1.05)	$-x$ (−0.35)	$+2x$ (+.7)
Equilibrium	0.2	0.4	$\boxed{0.8}$

Typical problem

Wolfram Alpha on hmwk or graphing calc.

Given K = 200 and
C_{H_2} = .2 M, N_2 = 0.2 M what are the concentrations at equilibrium

Reaction	$3H_2(g)$ +	$N_2(g)$ ⟷	$2NH_3(g)$
Initial	0.2	0.2	0
Change	$-3x$	$-x$	$+2x$
Equilibrium	$0.2-3x$	$0.2-x$	$2x$

$$K = \frac{[NH_3]^2}{[H_2]^3[N_2]}$$

$$200 = \frac{(2x)^2}{(0.2-3x)^3(0.2-x)}$$

Solve for x w/ scientific calc...

Know how to set this up

$\boxed{x = 0.045}$

$x = 0.211$

x = imaginary

POLL: CLICKER 4

For the following reaction what is the change value for H_2O?

$$2C_2H_6(g) + 7O_2(g) \longrightarrow 4CO_2(g) + 6H_2O(g)$$

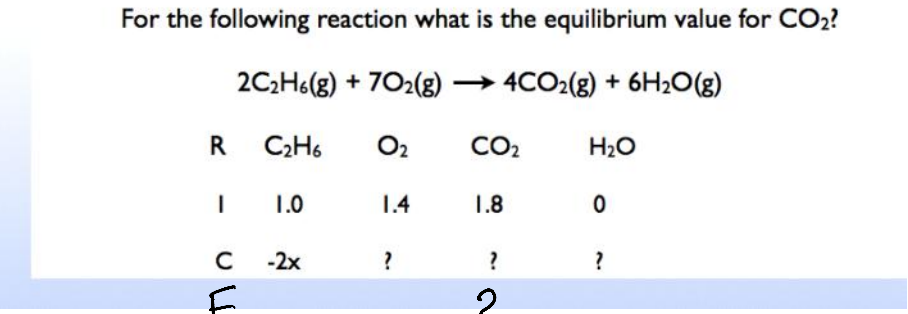
R	C_2H_6	O_2	CO_2	H_2O
I	1.0	1.4	1.8	0
C	-2x	?	?	?

A. - 2x
B. + 2x
C. + 3x
D. + 6x

C	-2x	?	?	?

A. - 2x
B. + 2x
C. + 3x
[✓ D. + 6x]

POLL: CLICKER 5



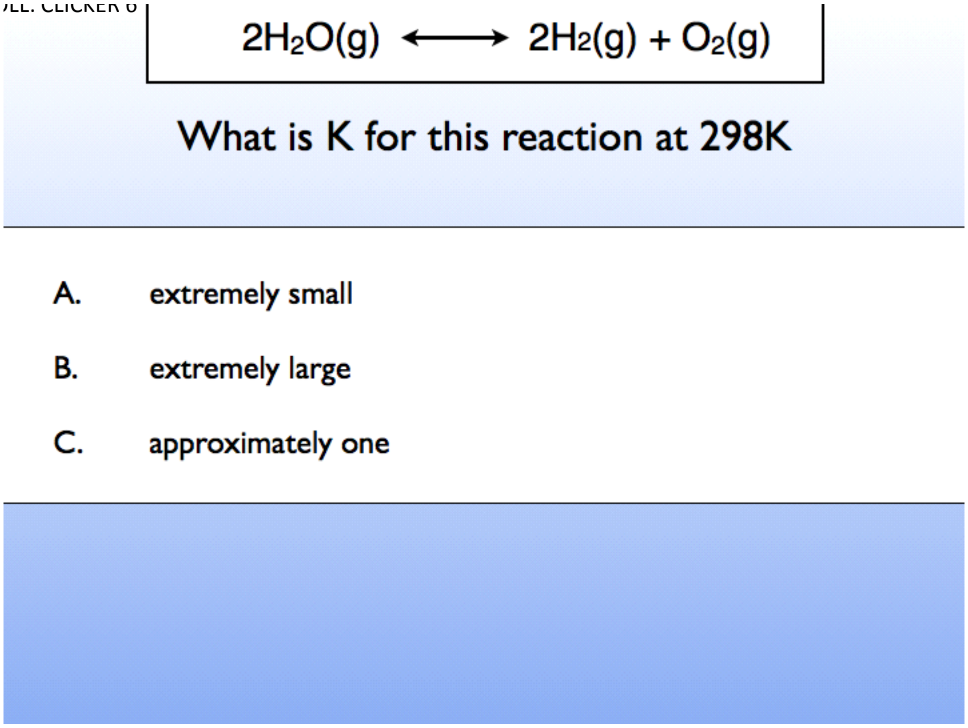
For the following reaction what is the equilibrium value for CO_2?

$$2C_2H_6(g) + 7O_2(g) \longrightarrow 4CO_2(g) + 6H_2O(g)$$

R	C_2H_6	O_2	CO_2	H_2O
I	1.0	1.4	1.8	0
C	-2x	?	?	?
E			?	

A. 1.8 – 2x
B. 1.8 + 2x
[✓ C. 1.8 + 4x]
D. 1.0 + 6x

LL. CLICKER 6



$$2H_2O(g) \longleftrightarrow 2H_2(g) + O_2(g)$$

What is K for this reaction at 298K

A. extremely small

B. extremely large

C. approximately one

Explanation Space

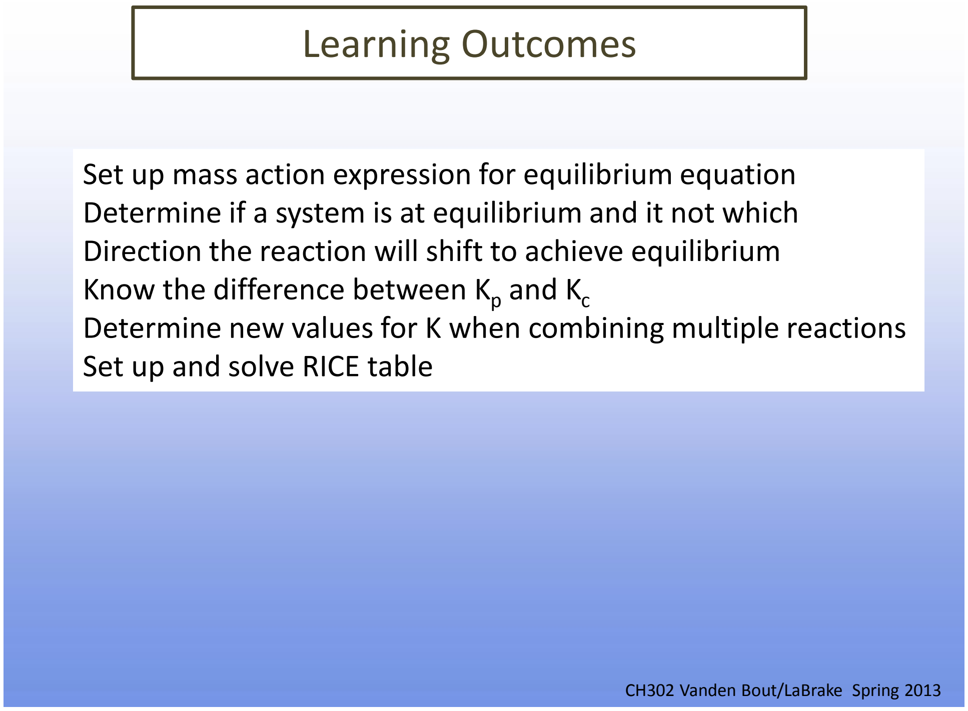
What did we learn today?

Reactions don't always go 100 % to products.

Law of Mass Action

Concept of the "Activity" of reactant or product.

Quantify the extent of reaction using equilibrium constant, K.



Learning Outcomes

Set up mass action expression for equilibrium equation
Determine if a system is at equilibrium and it not which
Direction the reaction will shift to achieve equilibrium
Know the difference between K_p and K_c
Determine new values for K when combining multiple reactions
Set up and solve RICE table