Chapter 13 Equilibrium

Chapter 14 Acid-Base

Tied together

Equilibrium

Chemical Species

$$aA + bB \rightleftharpoons cC + dD$$

Coefficients

$$\text{Reaction Quotient} = Q = \frac{[C]^c [D]^d}{[A]^a [B]^b}$$

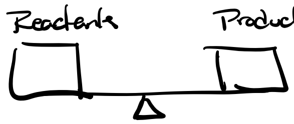
A measurement of the progress of the reaction.

$[\ ]$ = moles/Liter

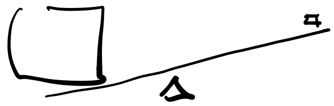
$[A]$ = Concentration of A $\underline{M}$ or moles/L

$$3H_2 + N_2 \rightleftharpoons 2NH_3$$

$$Q = \frac{[NH_3]^2}{[H_2]^3 [N_2]^1} = \text{number}$$

$Q = 1$ 

Products = Reactants

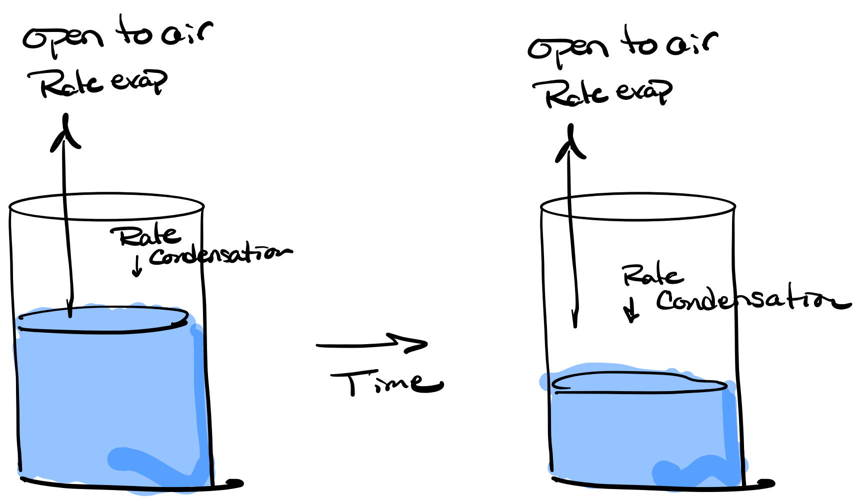
$Q = < 1$  Reactants > Products

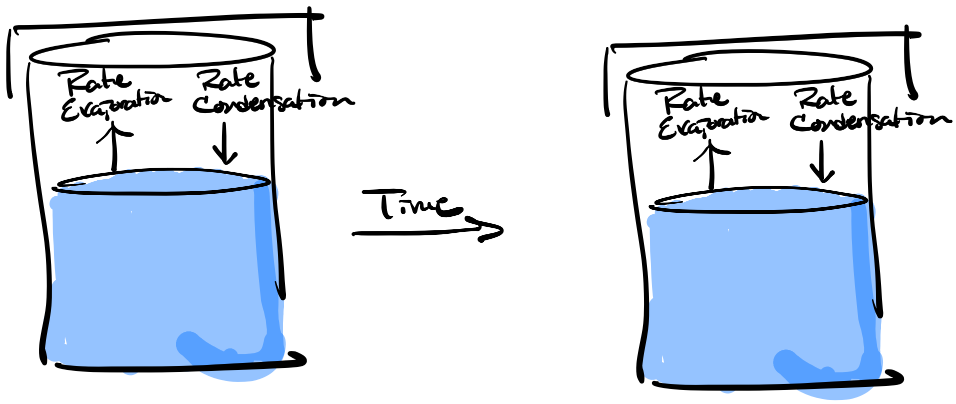
$Q = > 1$  Reactants < Products

Dynamic Equilibrium

Rate Forward = Rate Reverse

Not in equilibrium ⇒ Rates forward ≠ Rate Reverse





No Change in Volume

$H_2O_{(g)} \rightleftharpoons H_2O_{(l)}$

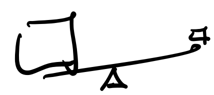
at Same Rate

$$H_2O_{(l)} \underset{\text{Rate Condensation}}{\overset{\text{Rate Evaporation}}{\rightleftharpoons}} H_2O_{(g)}$$

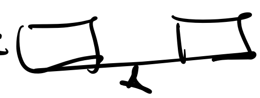
Dynamic Equilibrium

Out of Eq	Dynamic Eq	out of Eq
$Rate_f > Rate_R$	$Rate_f = Rate_R$	$Rate_f < Rate_R$
$aA + bB \rightarrow cC + dD$	$aA + bB \rightleftharpoons cC + dD$	$aA + bB \leftarrow cC + dD$
$Q = \frac{[C]^c[D]^d}{[A]^a[B]^b}$	$Q_{Dyn\,Eq} = \boxed{K = \frac{[C]^c[D]^d}{[A]^a[B]^b}}$	$Q = \frac{[C]^c[D]^d}{[A]^a[B]^b}$
Conceptual but not useful	Extremely Useful	Conceptual but not useful

At equilibrium every reaction has an $\underset{R_R}{\overset{R_f}{\rightleftharpoons}}$ individual equilibrium state.

Some favor the reactants at Eq. 

Some favor the products at Eq. 

Some sit in the middle at Eq 

K (the eq Const.) tells us where the reaction sits when at Eq.

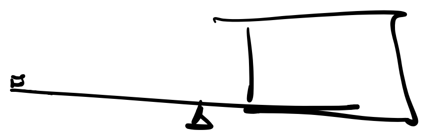
K value is a measure of how much progress a reaction has made at Eq. & it is a Constant

$$HCl_{(g)} + H_2O_{(l)} \rightleftharpoons H_3O^+_{(aq)} + Cl^-$$

Has a $\underbrace{K = 1\times10^{7}}_{\text{is a constant}}$ at 25°C

$1\times10^{7} >> 1$

$$K = \frac{[Cl^-][H_3O^+]}{[HCl][H_2O]} = 1\times10^{7} = \frac{[Cl^-][H_3O^+]^{\text{Products}}}{[HCl][H_2O]_{\text{Reactants}}}$$



$$HCl + H_2O \underset{R_R}{\overset{R_f}{\rightleftharpoons}} H_3O^+ + Cl^-$$

equal

# moles	0.0001	0.0001	0.9	0.9

Stressing the Equilibrium

$\Rightarrow$ To Change the conc. of a reactant or product at Eq. (Add or Subtract)

$\Rightarrow$ what happens?

Add HCl

$\downarrow$

made more products

$$HCl + H_2O \rightleftharpoons H_3O^+ + Cl^-$$

At Equilibrium

Initially at $K = \frac{[H_3O^+]_{eq}[Cl^-]_{eq}}{[HCl]_{eq}[H_2O]_{eq}} = 1\times10^7$

$\downarrow$ Add more HCl

Forward Reaction Increases to Reestablish K

$$Q = \frac{\uparrow[H_3O^+][Cl^-]\uparrow}{\downarrow[HCl]\downarrow[H_2O]} < 1\times10^7$$

$\downarrow$

$$K = \frac{[H_3O^+][Cl^-]}{[HCl][H_2O]} = 1\times10^7$$

Lê Chatliers Principle

when a reaction at equilibrium is Stressed it will move to regain equilibrium

Add A

moves towards making more products

$$aA + bB \rightleftharpoons cC + dD$$

Add D

moves to make more Reactants

$$aA + bB \rightleftharpoons cC + dD$$

moves to make More D

Remove D

$$aA + bB \rightleftharpoons cC + dD$$

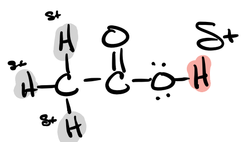
Acid / Base

Defined Acid & Base in Chapter 7

Acid = H^+ donor

Base = H^+ accepter

Acid	Base
HCl	OH^-
HBr	PO_4^{3-}
$HC_2H_3O_2$	SO_4^{2-}
H_3PO_4	$C_2H_3O_2^-$
H_2SO_4	NH_3



Acidic H on left

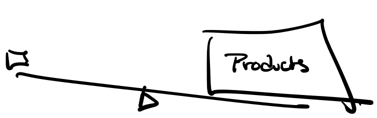
Strong Acid

Dissociates Completely

	k
HCl	1×10^7
HNO_3	$1\times10^{1.3}$
H_2SO_4	1×10^9

> 1

$$H\text{-}Acid + H_2O \rightleftharpoons H_3O^+ + Acid^-$$



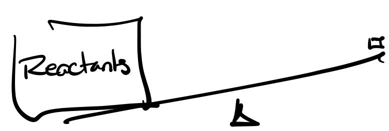
Weak Acid

Dissociates only a little

	k
$HC_2H_3O_2$	1.8×10^{-5}
H_2CO_3	4.3×10^{-7}

< 1

$$H\text{-}Acid + H_2O \rightleftharpoons H_3O^+ + Acid^-$$



H_2O can be an acid or a base
= amphoteric

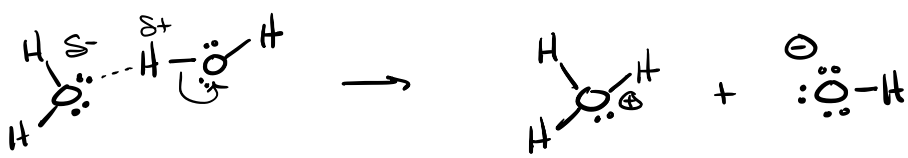
$H^+ + H_2O \longrightarrow H_3O^+$

acceptor
base

$B^- + H_2O \longrightarrow B{-}H + OH^-$

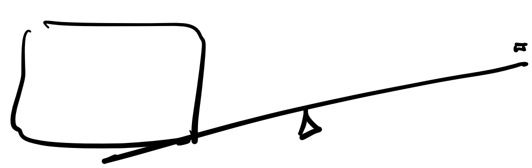
donor
Acid

$$H_2O_{(l)} + H_2O_{(l)} \longrightarrow H_3O^+_{(aq)} + OH^-_{(aq)}$$



$$k = \frac{[H_3O^+][OH^-]}{[H_2O]^2} = 1\times10^{-14} <<< 1$$

$$2H_2O_{(l)} \rightleftharpoons H_3O^+_{(aq)} + OH^-_{(aq)}$$



$$[H_2O]^2 \times K = \frac{[H_3O^+][OH^-]}{[H_2O]^2} \times [H_2O]^2$$

$$K[H_2O]^2 = \underbrace{K_w}_{\text{equilibrium Constant of water}} = [H_3O^+][OH^-] = 1\times10^{-14}$$

at 25°C

$$[H_3O^+] = [OH^-]$$

$$[H_3O^+]^2 = 1\times10^{-14}$$

$$[H_3O^+] = \sqrt{1\times10^{-14}} = (1\times10^{-14})^{\frac{1}{2}}$$

$$= 1\times10^{-14\times\frac{1}{2}} = 1\times10^{-7}$$

Pure H_2O

$$[H_3O^+] = [OH^-] = \underbrace{1\times10^{-7}}_{\text{Really Small \& hard to work with}} \text{ moles/L}$$

New function $p = -\log$

$$p(x) = -\log x$$

p = power function (a log function)

pH = power of hydrogen

$$pH = -\log [H^+] \text{ or } -\log [H_3O^+]$$

in pure H_2O $[H_3O^+] = 1 \times 10^{-7}$ moles/L

$$pH \text{ of pure } H_2O = -\log [H_3O^+]$$

$$= -\log (1 \times 10^{-7})$$

$$= (10^{?} = 1 \times 10^{-7}) \times -1$$

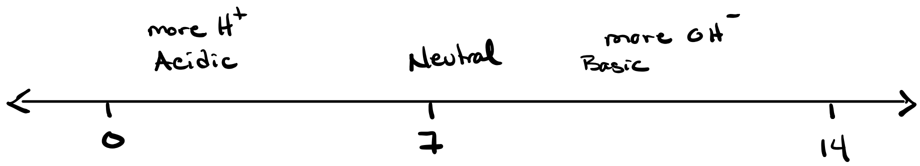
$$= (-7) \times -1$$

$$pH = 7$$

$\log x = ?$

$10^{?} = x$

pH scale



$-\log[H_3O^+] = pH$ $\quad K_w = [H_3O^+][OH^-] = 1\times10^{-14}$

Acidic	3	$[1\times10^{-3}][1\times10^{-11}]$		
more H_3O^+	4	$\uparrow[1\times10^{-4}][1\times10^{-10}] =$	1×10^{-14}	
	5	$\uparrow[1\times10^{-5}][1\times10^{-9}]\downarrow =$	1×10^{-14}	
	6	$\uparrow[1\times10^{-6}][1\times10^{-8}]\downarrow =$	1×10^{-14}	$\frac{1\times10^{-14}}{1\times10^{-6}} = 1\times10^{-8}$
Neutral $\rightarrow$	7 $\leftarrow$	$[1\times10^{-7}][1\times10^{-7}] =$	1×10^{-14}	
more OH^-	8	$\downarrow[1\times10^{-8}][1\times10^{-6}]\uparrow =$	1×10^{-14}	
Basic	9	$[1\times10^{-9}][1\times10^{-5}]\uparrow$		
	10	$[1\times10^{-10}][1\times10^{-4}]$		

Ex

What is the pH of a solution with a $[H_3O^+]$ of 3.26×10^{-4} moles/L ?

3

$$pH = -\log[H_3O^+]$$

$$= -\log[3.26\times10^{-4}]$$

3

$$= \log(3.26\ E\ (\pm)\ 4)\ \text{enter} \times -1$$

mantissa power on x10

$$pH = 3.48678239993$$

$$\boxed{pH = 3.487}$$

Sig figs are carried in the decimal part

Ex what is the $[H_3O^+]$ of a solution with a pH of 10.72 ?

$$\left.\begin{aligned} pH &= -\log[H_3O^+] \\ 10^{-pH} &= [H_3O^+] \end{aligned}\right\} \text{Inverse functions}$$

2 SF   2 SF

$$[H_3O^+] = 10^{-pH} = 10^{-10.72} = 1.905460 \times 10^{-11}$$

$$\boxed{[H_3O^+] = 1.9 \times 10^{-11} \text{ moles/L}}$$

pH	$[H_3O^+]$
$\overset{4}{1.3246}$	$10^{-1.3246} = 0.047358724 = \overset{4\text{ SF}}{0.04736}$
$\overset{2}{10.13}$	$10^{-10.13} = 7.413102 \times 10^{-11} = \overset{2}{7.4} \times 10^{-11}$
$\overset{2}{7.02}$	$10^{-7.02} = 9.549925860 \times 10^{-8} = \overset{2}{9.5} \times 10^{-8}$
$\overset{1}{5.1}$	

What is the pH of a solution with a $[OH^-] = 6.24 \times 10^{-6}$ moles/L ?

3

$$pH = -\log[H_3O^+] \quad ???$$

?

$$[H_3O^+][OH^-] = 1 \times 10^{-14}$$

$$[H_3O^+] = \frac{1 \times 10^{-14}}{[OH^-]}$$

Exact

3 SF

$$[H_3O^+] = \frac{1 \times 10^{-14}}{6.24 \times 10^{-6}} = 1.602564 \times 10^{-9}$$

3

3 SF

$$pH = -\log[H_3O^+] = -\log 1.602564 \times 10^{-9}$$

$$pH = 8.795184589$$

$$\boxed{pH = 8.795 \quad \text{3 SF}}$$

$$p = -\log \qquad p(x) = -\log x$$

Equilibrium Constant

$$
\begin{tikzcd}
K_w = & {[H_3O^+]} \arrow[d, shift right, "-\log"'] & \times & {[OH^-]} \arrow[d, shift right, "-\log"'] & = & 1 \times 10^{-14} \arrow[d, "-\log"] \\
& pH \arrow[u, shift right, "10^{-pH}"'] & + & pOH \arrow[u, shift right, "10^{-pOH}"'] & = & 14
\end{tikzcd}
$$

Always at 25°C

$$\log(AB) = \log A + \log B$$

What is the pH of a solution with a $[OH^-] = 6.24 \times 10^{-6}$ moles/L ?

3

$$
\begin{tikzcd}
{[H_3O^+]} \arrow[d, shift right, "-\log"'] & \times & {[OH^-]} \arrow[d, shift right, "-\log"'] & = & 1 \times 10^{-14} \arrow[d, "-\log"] \\
pH \arrow[u, shift right, "10^{-pH}"'] & + & pOH \arrow[u, shift right, "10^{-pOH}"'] & = & 14
\end{tikzcd}
$$

Rout A

6.24×10^{-6}

Route B

?

$[OH^-] = 6.24 \times 10^{-6}$ 3

$pOH = -\log 6.24 \times 10^{-6}$

$pOH = 5.204815410$

$pH + pOH = 14$

$pH = 14 - pOH$

$= 14 - 5.204815410$

$pH = 8.795|189589$

$$\boxed{pH = 8.795}$$

pH Road Map

$$\begin{tikzcd}
{[H_3O^+]} \arrow[d, shift right, "-\log"'] & \times & {[OH^-]} \arrow[d, shift right, "-\log"'] & = & 1\times10^{-14} \arrow[d, "-\log"] \\
pH \arrow[u, shift right, "10^{-pH}"'] & + & pOH \arrow[u, shift right, "10^{-pOH}"'] & = & 14
\end{tikzcd}$$

sig figs whole #

sig fig decimal only