

# ACIDS & BASES



## Acids and Bases

Dr. Diala Abu-Hassan, DDS, PhD

[Dr.abuhassan@gmail.com](mailto:Dr.abuhassan@gmail.com)

Lecture 1

MD summer

# Required material and further reading

Required:

Handout

Text books:

Biochemistry. Campbell Chapter 2

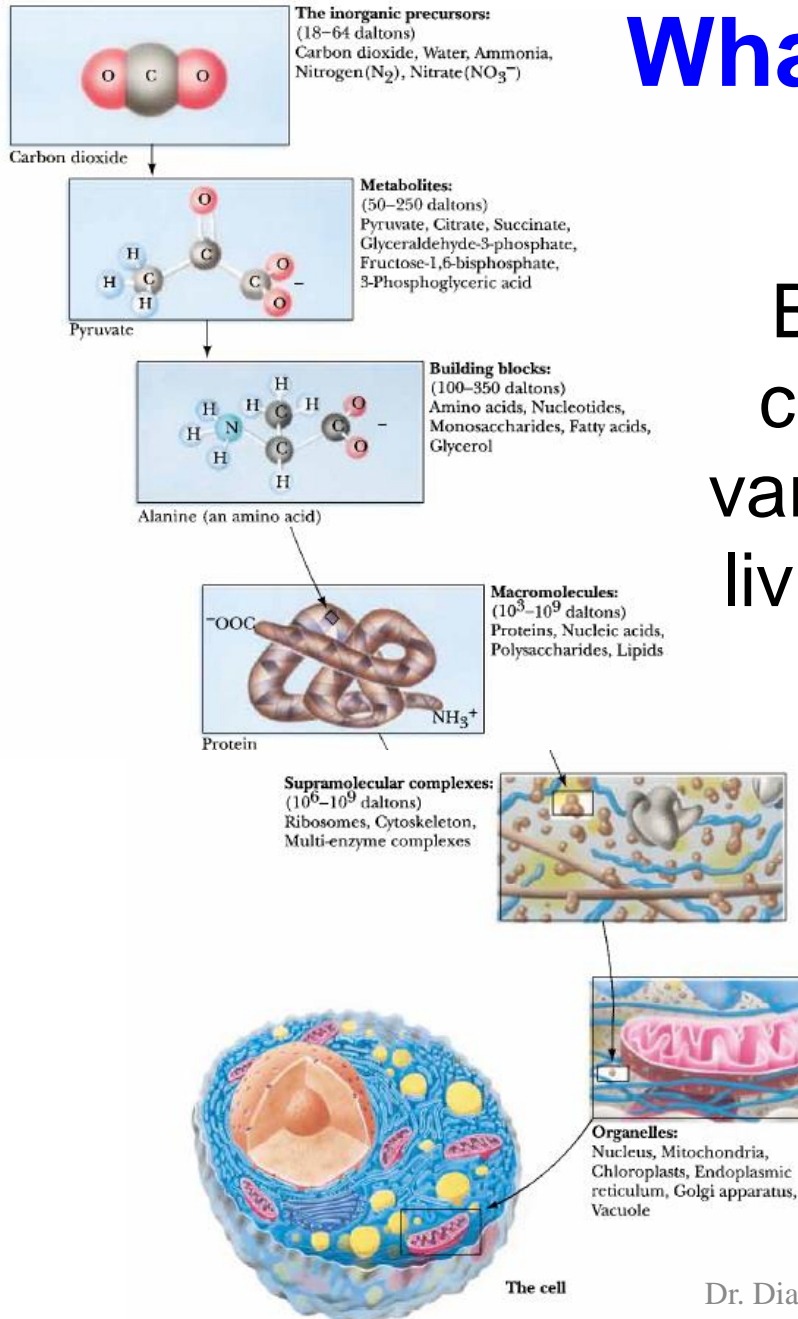
Fundamentals of General, Organic, and  
Biological Chemistry. McMurry. Chapter 10

softcopy will be sent

# Outline

- Introduction- The Science of Biochemistry
- Definitions of acids and bases
- Acid and base strength
- The dissociation constant
- Conjugate pair strength
- Water dissociation

# What is Biochemistry?



Biochemistry is the science concerned with studying the various molecules that occur in living cells and organisms and their chemical reactions.

# Why Biochemistry is important to Human Biology?

1. Biochemistry is an intrinsically beautiful and fascinating body of knowledge. “Lubert Stryer”

Because it unravels the details of the most fundamental processes in biological systems.

2. Biochemistry massively influences medicine and treatment development, ex. sickle-cell anemia, cystic fibrosis, hemophilia, etc.

3. By advances in biochemistry, researchers can tackle many questions in biology and medicine, ex. Biochemical changes in diseases, causes of diseases, lab tests..etc.

# **Benefits of studying biological systems at the molecular and biochemical level**

When we unravel the molecular and biochemical details of biological molecules:

1. Molecular and biochemical basis of diseases become clear.
2. Manipulate the biochemical processes and simulating them in vivo and in vitro.
3. Molecules of life can be prepared on the bench

# What makes biomolecules special?

Table 1.1 Functional Groups of Biochemical Importance				
Class of Compound	General Structure	Characteristic Functional Group	Name of Functional Group	Example
Alkenes	$RCH=CH_2$ $RCH=CHR$ $R_2C=CHR$ $R_2C=CR_2$	$C=C$	Double bond	$CH_2=CH_2$
Alcohols	$ROH$	$-OH$	Hydroxyl group	$CH_3CH_2OH$
Ethers	$ROR$	$-O-$	Ether group	$CH_3OCH_3$
Amines	$RNH_2$ $R_2NH$ $R_3N$	$-N<$	Amino group	$CH_3NH_2$
Thiols	$RSH$	$-SH$	Sulfhydryl group	$CH_3SH$
Aldehydes	$R-\overset{\overset{O}{\parallel}}{C}-H$	$-\overset{\overset{O}{\parallel}}{C}-$	Carbonyl group	$CH_3CHO$
Ketones	$R-\overset{\overset{O}{\parallel}}{C}-R$	$-\overset{\overset{O}{\parallel}}{C}-$	Carbonyl group	$CH_3COCH_3$
Carboxylic acids	$R-\overset{\overset{O}{\parallel}}{C}-OH$	$-\overset{\overset{O}{\parallel}}{C}-OH$	Carboxyl group	$CH_3COOH$
Esters	$R-\overset{\overset{O}{\parallel}}{C}-OR$	$-\overset{\overset{O}{\parallel}}{C}-OR$	Ester group	$CH_3COOCH_3$
Amides	$R-\overset{\overset{O}{\parallel}}{C}-NR_2$ $R-\overset{\overset{O}{\parallel}}{C}-NHR$ $R-\overset{\overset{O}{\parallel}}{C}-NH_2$	$-\overset{\overset{O}{\parallel}}{C}-N<$	Amide group	$CH_3CON(CH_3)_2$
Phosphoric acid esters	$R-O-\overset{\overset{O}{\parallel}}{P}(OH)_2$	$-O-\overset{\overset{O}{\parallel}}{P}(OH)_2$	Phosphoric ester group	$CH_3-O-\overset{\overset{O}{\parallel}}{P}(OH)_2$
Phosphoric acid anhydrides	$R-O-\overset{\overset{O}{\parallel}}{P}(OH)_2-O-\overset{\overset{O}{\parallel}}{P}(OH)_2$	$-\overset{\overset{O}{\parallel}}{P}(OH)_2-O-\overset{\overset{O}{\parallel}}{P}(OH)_2-$	Phosphoric anhydride group	$HO-\overset{\overset{O}{\parallel}}{P}(OH)_2-O-\overset{\overset{O}{\parallel}}{P}(OH)_2$

-The cellular apparatus of living organisms is made up of carbon compounds.

# Different Definitions of Acids and Bases

- Arrhenius
- Bronsted-Lowry
- Lewis

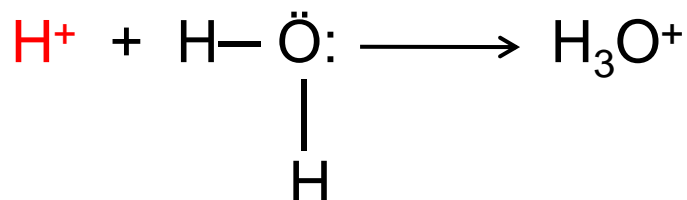
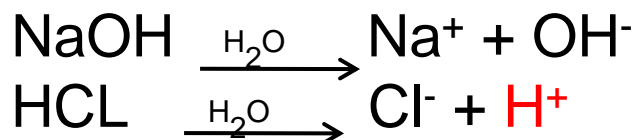


# Arrhenius Definition of Acids and Bases and Their Reactions

Arrhenius Acids and Bases Acids are

- Acids in  $\text{H}_2\text{O}$  are  $\text{H}^+$  donors
- Bases in  $\text{H}_2\text{O}$  are  $\text{OH}^-$  donors

Neutralization of acids and bases produces salt and water.



**Arrhenius  
1903**

**Nobel  
Prize**

Drawbacks:

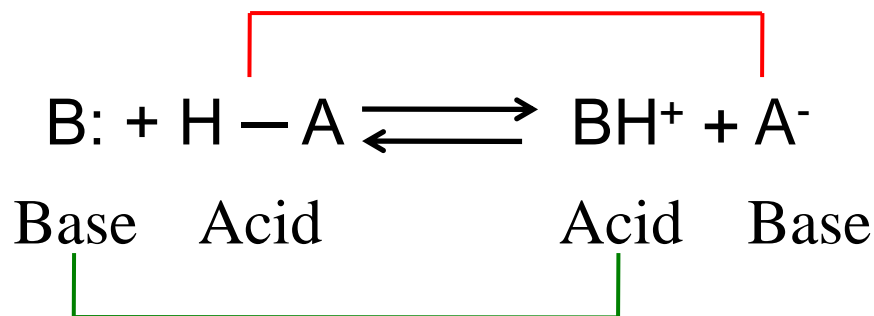
1. Reactions has to happen in aqueous solutions
2.  $\text{H}_3\text{O}^+$  is released but not  $\text{H}^+$

# Bronsted-Lowry Definition of Acids and Bases and Their Reactions

## Bronsted-Lowry Acids and Bases (1923)

- Acids donate  $H^+$
- Bases accept  $H^+$  (non-bonding pairs)

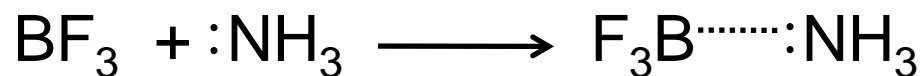
Conjugate acid-base pair



Conjugate acid-base pair

# Lewis Definition of Acids and Bases and Their Reactions

- Acids accept electrons
- Bases donate electrons (non-bonding pairs)



**Acid**      **base**

# Common Acids

- $\text{HCl}$ - hydrochloric- stomach acid
- $\text{H}_2\text{SO}_4$ - sulfuric acid - car batteries
- $\text{HNO}_3$  – nitric acid - explosives
- $\text{HC}_2\text{H}_3\text{O}_2$ - acetic acid - vinegar
- $\text{H}_2\text{CO}_3$ -carbonic acid – sodas
- $\text{H}_3\text{PO}_4$ - phosphoric acid -flavorings





# Common Bases

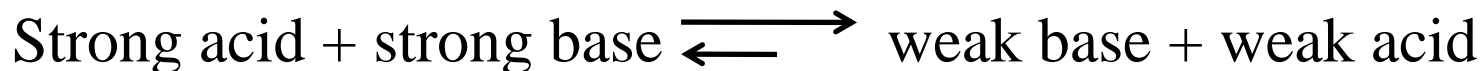
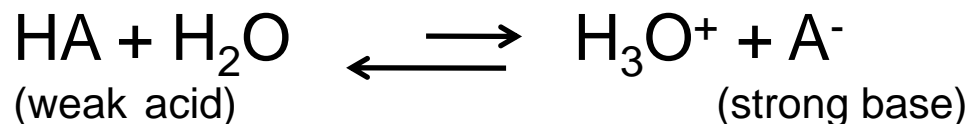
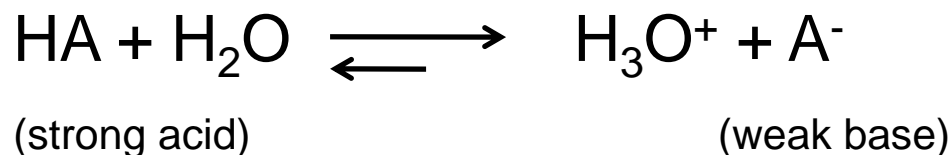
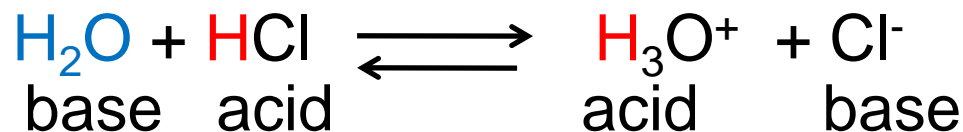
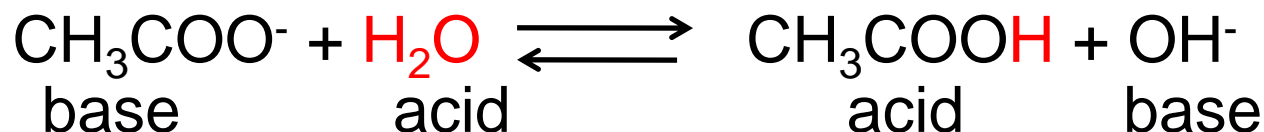
- $\text{NaOH}$ - sodium hydroxide (LYE) soaps, drain cleaner
- $\text{Mg}(\text{OH})_2$  - magnesium hydroxide-antacids
- $\text{Al}(\text{OH})_3$ -aluminum hydroxide-antacids, deodorants
- $\text{NH}_4\text{OH}$ -ammonium hydroxide- “ammonia”



Dr. Diala Abu-Hassan

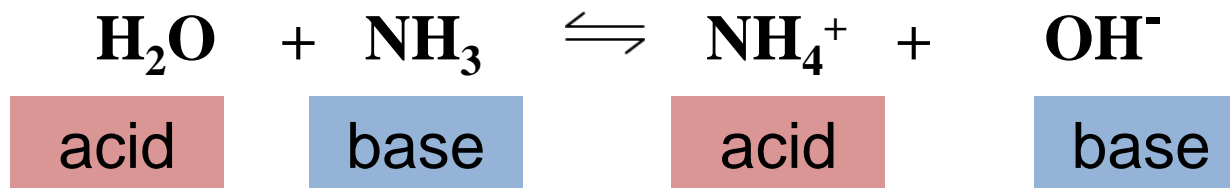


# Water as both an acid and a base

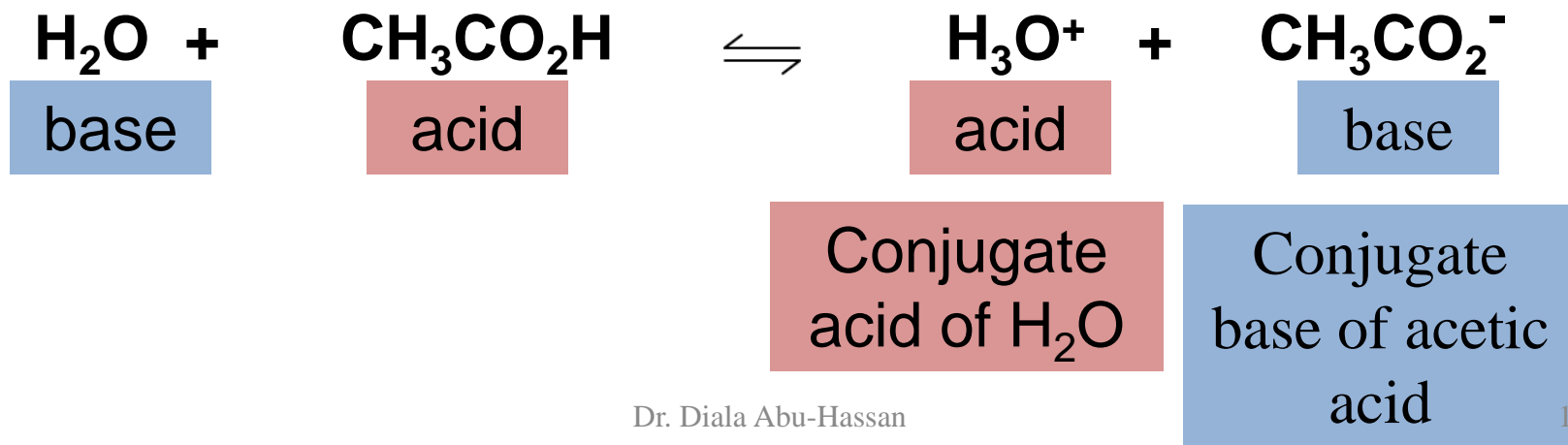


**Amphoterism** - an ion or molecule can act as an acid or base depending upon the reaction conditions

Water in  $\text{NH}_3$  serves as an acid



Water in acetic acid serves as a base



# Measuring concentrations

**Molarity:** the number of moles in a liter of solution

Unit: Mole/Liter = M

mM =  $10^{-3}$  M,  $\mu$ M =  $10^{-6}$  M

Symbol: [X]

Concentration =  $\frac{\text{Amount of solute}}{\text{Amount of solvent}}$

Dissolve 2 moles of glucose in 5 liters of H<sub>2</sub>O. what is the concentration?

[Glucose] =  $2/5 = 0.4$  M



# Acid and Base Strength

- Some acids can cause burns if come in contact with skin, other acids are safe. why?
- How easy can the acid produce proton

- Strong acid: gives up  $\text{H}^+$  easily (100% dissociated in water)

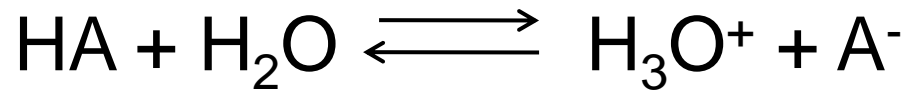


- Weak acid: gives up  $\text{H}^+$  with difficulty ( less than 100% dissociated)



# Acid dissociation constant, $K_a$

- The general ionization of an acid is as follows:



So the acid dissociation constant is as follows:

$$K_a = \frac{[\text{H}_3\text{O}^+][\text{A}^-]}{[\text{HA}][\text{H}_2\text{O}]}$$

$[\text{H}_2\text{O}] = 55.5 \text{ M}$  and is constant in all equations

$$K_a = \frac{[\text{H}_3\text{O}^+][\text{A}^-]}{[\text{HA}]}$$

# Acid dissociation constant

- The general ionization of an acid is as follows:



So the acid dissociation constant is as follows:

$$K_a = \frac{[\text{H}^+][\text{A}^-]}{[\text{HA}]}$$

There are many orders of magnitude spanned by  $K_a$  values, so  $\text{p}K_a$  is used instead:

$$\text{p}K_a = \log 1/K_a = -\log_{10} K_a$$

The larger the value of the  $\text{p}K_a$ , the smaller the extent of dissociation.

# The equilibrium constant, $K_a$



Acid

Conjugate  
base

$$K_a = \frac{[\text{H}^+][\text{A}^-]}{[\text{HA}]}$$

Larger  $K_a$  means:  
More dissociation  
Smaller  $\text{p}K_a$   
Stronger acid

Increase acid strength ↑

↓ Decrease acid strength

TABLE 8-2		Acidity Constants in Water at 25°C		
Acid	Formula	Conjugate Base	$K_a$	$pK_a$
Hydriodic	HI	$I^-$	$\approx 10^{11}$	$\approx -11$
Hydrobromic	HBr	$Br^-$	$\approx 10^9$	$\approx -9$
Perchloric	$HClO_4$	$ClO_4^-$	$\approx 10^7$	$\approx -7$
Hydrochloric	HCl	$Cl^-$	$\approx 10^7$	$\approx -7$
Chloric	$HClO_3$	$ClO_3^-$	$\approx 10^3$	$\approx -3$
Sulfuric (1)	$H_2SO_4$	$HSO_4^-$	$\approx 10^2$	$\approx -2$
Nitric	$HNO_3$	$NO_3^-$	$\approx 20$	$\approx -1.3$
Hydronium ion	$H_3O^+$	$H_2O$	1	0.0
Urea acidium ion	$(NH_2)CONH_3^+$	$(NH_2)_2CO$ (urea)	$6.6 \times 10^{-1}$	0.18
Iodic	$HIO_3$	$IO_3^-$	$1.6 \times 10^{-1}$	0.80
Oxalic (1)	$H_2C_2O_4$	$HC_2O_4^-$	$5.9 \times 10^{-2}$	1.23
Sulfurous (1)	$H_2SO_3$	$HSO_3^-$	$1.5 \times 10^{-2}$	1.82
Sulfuric (2)	$HSO_4^-$	$SO_4^{2-}$	$1.2 \times 10^{-2}$	1.92
Chlorous	$HClO_2$	$ClO_2^-$	$1.1 \times 10^{-2}$	1.96
Phosphoric (1)	$H_3PO_4$	$H_2PO_4^-$	$7.5 \times 10^{-3}$	2.12
Arsenic (1)	$H_3AsO_4$	$H_2AsO_4^-$	$5.0 \times 10^{-3}$	2.30
Chloroacetic	$ClCH_2COOH$	$ClCH_2COO^-$	$1.4 \times 10^{-3}$	2.85
Hydrofluoric	HF	$F^-$	$6.6 \times 10^{-4}$	3.18
Nitrous	$HNO_2$	$NO_2^-$	$4.6 \times 10^{-4}$	3.34
Formic	$HCOOH$	$HCOO^-$	$1.8 \times 10^{-4}$	3.74

# Acid dissociation constant

Acid Dissociation Constants and  $pK_a$  Values for Some Weak Electrolytes  
(at 25°C)

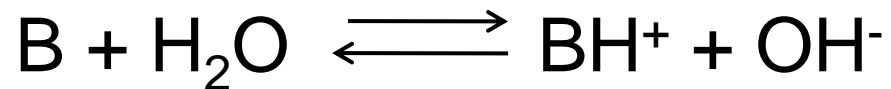
Acid	$K_a$ (M)	$pK_a$
HCOOH (formic acid)	$1.78 \times 10^{-4}$	3.75
CH <sub>3</sub> COOH (acetic acid)	$1.74 \times 10^{-5}$	4.76
CH <sub>3</sub> CH <sub>2</sub> COOH (propionic acid)	$1.35 \times 10^{-5}$	4.87
CH <sub>3</sub> CHOHCOOH (lactic acid)	$1.38 \times 10^{-4}$	3.86
HOOCCH <sub>2</sub> CH <sub>2</sub> COOH (succinic acid) $pK_1^*$	$6.16 \times 10^{-5}$	4.21
HOOCCH <sub>2</sub> CH <sub>2</sub> COO <sup>-</sup> (succinic acid) $pK_2$	$2.34 \times 10^{-6}$	5.63
H <sub>3</sub> PO <sub>4</sub> (phosphoric acid) $pK_1$	$7.08 \times 10^{-3}$	2.15
H <sub>2</sub> PO <sub>4</sub> <sup>-</sup> (phosphoric acid) $pK_2$	$6.31 \times 10^{-8}$	7.20
HPO <sub>4</sub> <sup>2-</sup> (phosphoric acid) $pK_3$	$3.98 \times 10^{-13}$	12.40
C <sub>3</sub> N <sub>2</sub> H <sub>5</sub> <sup>+</sup> (imidazole)	$1.02 \times 10^{-7}$	6.99
C <sub>6</sub> O <sub>2</sub> N <sub>3</sub> H <sub>11</sub> <sup>+</sup> (histidine-imidazole group) $pK_R^\dagger$	$9.12 \times 10^{-7}$	6.04
H <sub>2</sub> CO <sub>3</sub> (carbonic acid) $pK_1$	$1.70 \times 10^{-4}$	3.77
HCO <sub>3</sub> <sup>-</sup> (bicarbonate) $pK_2$	$5.75 \times 10^{-11}$	10.24
(HOCH <sub>2</sub> ) <sub>3</sub> CNH <sub>3</sub> <sup>+</sup> ( <i>tris</i> -hydroxymethyl aminomethane)	$8.32 \times 10^{-9}$	8.07
NH <sub>4</sub> <sup>+</sup> (ammonium)	$5.62 \times 10^{-10}$	9.25
CH <sub>3</sub> NH <sub>3</sub> <sup>+</sup> (methylammonium)	$2.46 \times 10^{-11}$	10.62

\*These  $pK$  values listed as  $pK_1$ ,  $pK_2$ , or  $pK_3$  are in actuality  $pK_a$  values for the respective dissociations. This simplification in notation is used throughout this book.

<sup>†</sup> $pK_R$  refers to the imidazole ionization of histidine.

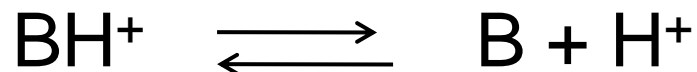
Data from *CRC Handbook of Biochemistry*, The Chemical Rubber Co., 1968.

# Base dissociation constant



$$K_b = \frac{[\text{BH}^+][\text{OH}^-]}{[\text{B}]}$$

Reverse the reaction:



$$K_a = \frac{[\text{B}][\text{H}^+]}{[\text{BH}^+]}$$

# Weak Bases

**TABLE 7.3** Values of  $K_b$  for Some Common Weak Bases

Name	Formula	Conjugate Acid	$K_b$
Ammonia	$\text{NH}_3$	$\text{NH}_4^+$	$1.8 \times 10^{-5}$
Methylamine	$\text{CH}_3\text{NH}_2$	$\text{CH}_3\text{NH}_3^+$	$4.38 \times 10^{-4}$
Ethylamine	$\text{C}_2\text{H}_5\text{NH}_2$	$\text{C}_2\text{H}_5\text{NH}_3^+$	$5.6 \times 10^{-4}$
Aniline	$\text{C}_6\text{H}_5\text{NH}_2$	$\text{C}_6\text{H}_5\text{NH}_3^+$	$3.8 \times 10^{-10}$
Pyridine	$\text{C}_5\text{H}_5\text{N}$	$\text{C}_5\text{H}_5\text{NH}^+$	$1.7 \times 10^{-9}$



# Strong Acids

- Dissociate readily
- $K_a$  is very large
- Examples: Hydrochloric, Nitric; Sulfuric



$$K_a = \frac{[\text{H}^+][\text{Cl}^-]}{[\text{HCl}]}$$

$$[\text{H}^+] = [\text{acid}]$$

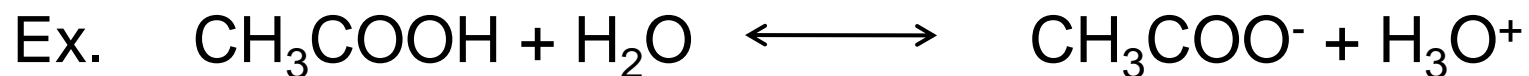
Ex. 1 M solution of HCl has a  $[\text{H}^+]$  of 1 M

1 mM HCl solution has a  $[\text{H}^+]$  of 1 mM

0.1 M  $\text{H}_2\text{SO}_4$  solution has a  $[\text{H}^+]$  of 0.2 M

# Weak Acids

- Dissociate slightly
- $K_a$  is smaller than strong acids
- Examples: Acetic, Boric, Nitrous, Phosphoric, Sulfurous



$$K_a = \frac{[\text{H}^+][\text{CH}_3\text{COO}^-]}{[\text{CH}_3\text{COOH}]}$$

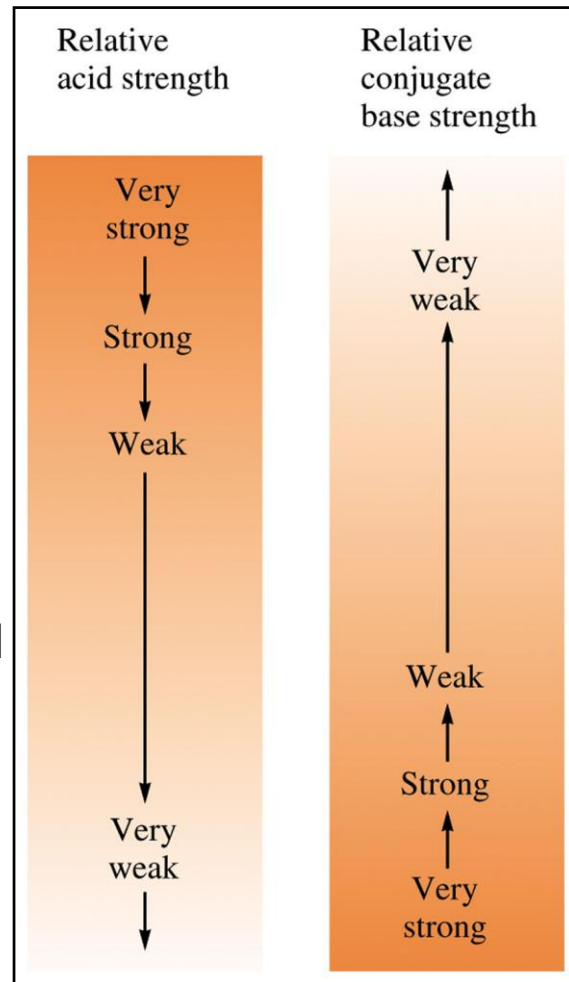
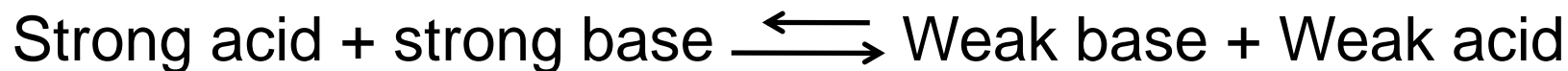
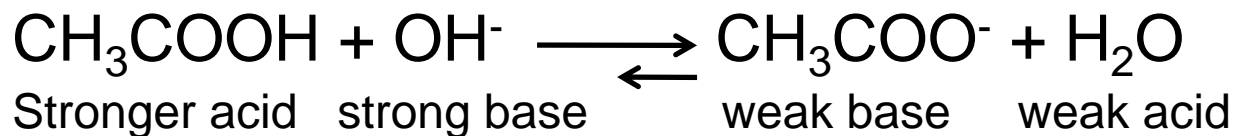
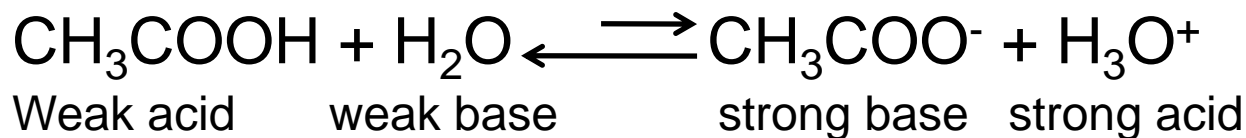
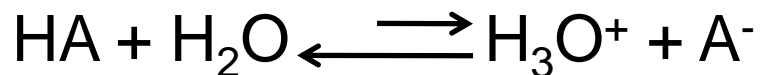
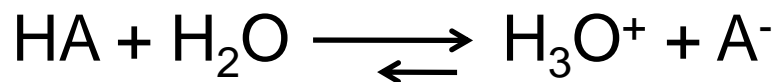
What is the  $\text{H}^+$  of a 0.1 M solution of acetic acid?

$$K_a = 1.74 \times 10^{-5}$$

$$1.74 \times 10^{-5} = x^2/0.1$$

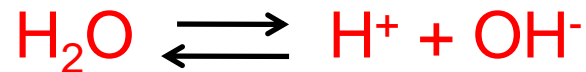
$$x^2 = 1.74 \times 10^{-6}, \text{ or } x = 1.32 \times 10^{-3} \text{ M}$$

# Conjugate pair strength



# Equilibrium constant and the pH of water

H<sub>2</sub>O dissociates to a slight extent to form hydrogen (H<sup>+</sup>) and hydroxyl (OH<sup>-</sup>) ions.



$$K_{\text{eq}} = \frac{[\text{H}^+][\text{OH}^-]}{[\text{H}_2\text{O}]}$$

$$K_{\text{eq}} = \frac{(10^{-7})(10^{-7})}{55.5} = 1.8 \times 10^{-16}$$

Because the concentration of H<sub>2</sub>O in pure water is essentially constant, a new constant,  $K_w$ , the ion product of water, can be written as

$$K_w = 55.5 K_{\text{eq}} = 10^{-14} = [\text{H}^+][\text{OH}^-]$$

[H<sup>+</sup>] of pure water is only 0.0000001 M

## Dissociation of water

- $K_w = [\text{H}^+] [\text{OH}^-] = 10^{-14}$

Example: A solution has an  $[\text{OH}^-] = 10^{-9} \text{ M}$

$$[\text{H}_3\text{O}^+] = 10^{-5} \text{ M}$$

# Problem solving

## Example:

What is the  $[H^+]$  of a 0.01 M NaOH solution?

$$K_w = [H^+] \times [OH^-] = [H^+] \times 10^{-2} = 10^{-14}$$

$$[H^+] = 10^{-12} \text{ M}$$

## Example:

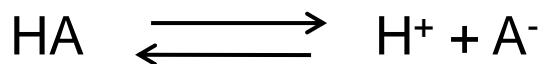
What is the  $[OH^-]$  of a 0.01 M HCl solution?

$$K_w = [H^+] \times [OH^-] = 10^{-2} \times [OH^-] = 10^{-14}$$

$$[OH^-] = 10^{-12} \text{ M}$$

Example:

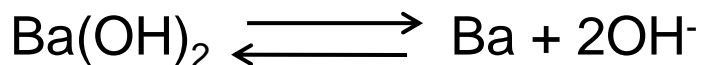
Find the  $K_a$  of a 0.04 M weak acid HA whose  $[H^+]$  is  $1 \times 10^{-4}$ ?



$$K_a = [\text{A}^-] [\text{H}^+] / [\text{HA}] = [\text{H}^+]^2 / [\text{HA}] = 10^{-4} \times 10^{-4} / 0.04 = 2.5 \times 10^{-7}$$

Example 2:

What is the  $[H^+]$  of a 0.05 M  $\text{Ba(OH)}_2$ ?

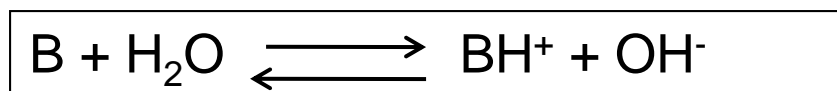


$$[\text{OH}^-] = 2 \times 0.05 = 0.10 \text{ M} = 1 \times 10^{-1}$$

$$[\text{H}^+] = 1 \times 10^{-13}$$

Example 4:

The  $[H^+]$  of a 0.03 M weak base solution is  $1 \times 10^{-10}$  M. Calculate  $pK_b$ ?



$$[OH^-] = 10^{-4}$$

$$K_b = (10^{-4} \times 10^{-4}) / 0.03 = 3.33 \times 10^{-7} \text{ M}$$

$$pK_b = -\log K_b = 6.48$$