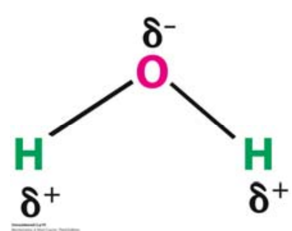
Water and Weak Bonds

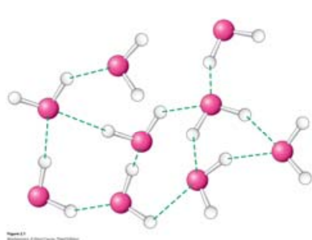
Stryer Short Course

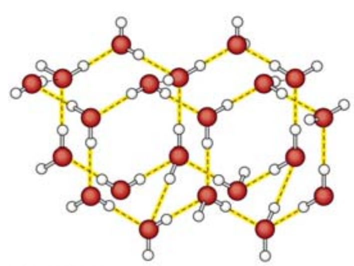
Chapter 2

Water

- Polarity
- Medium for Brownian motion
- Solvent

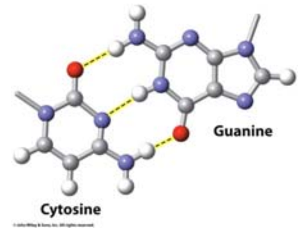


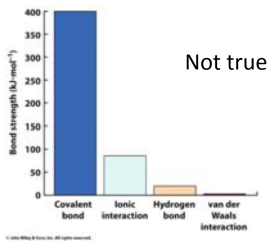




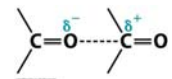
Intermolecular Forces

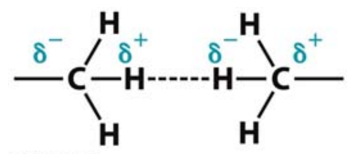
- Electrostatic: Ionic
  - Permanent dipole
- H-bonding
- Van der Walls





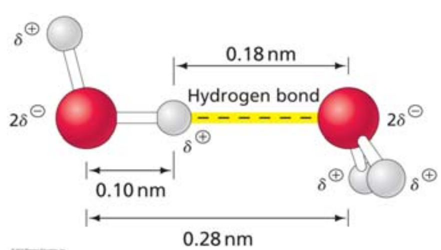
Not true categories…

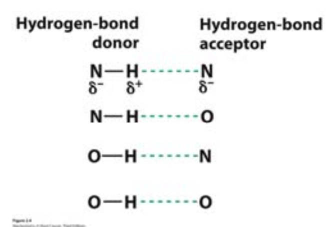




H-bonding

- 1/10 the strength of some covalent bonds
- Donor/acceptor
- ~2.3 H-bonds/ water molecule





Transient Interactions

- Intermediate strength of H-bonds key to function
- Changes in structure, association

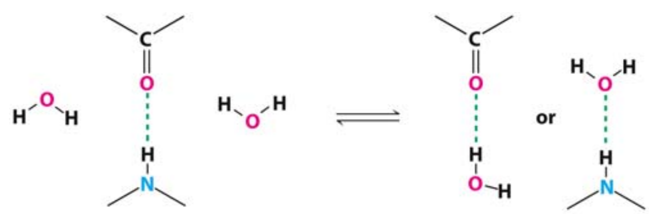


Figure 2.5
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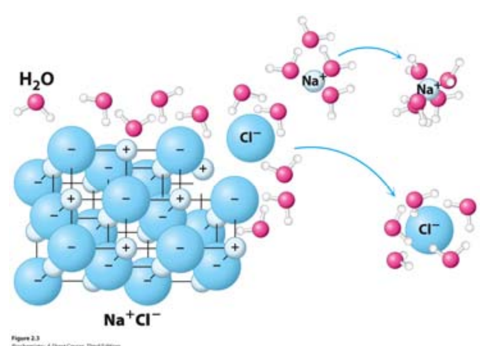
Solvation Of Ions

- Dielectric constant
- Solvation shell
- Solvent/solute



Hydrophobic Effect

- Exclusion of nonpolar substances from aqueous solution
- $\Delta G = \Delta H - T\Delta S$
- Cage-like structure of water minimized upon aggregation
- Powerful structural determination

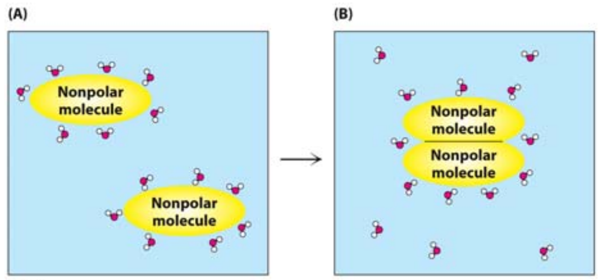


Figure 2.9
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Structure of Biomolecules

- Increased order in protein
- Decreased order overall
- How?

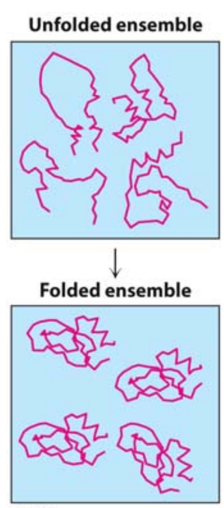

Figure 2.10
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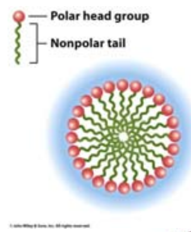
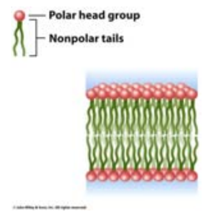
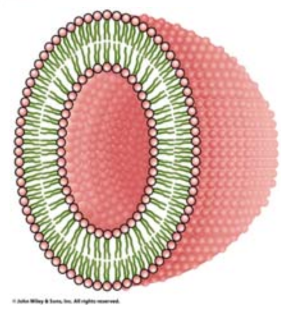
Amphipathic Compounds

- Structures determined by hydrophobic effect
  - Micelles
  - Bilayer
  - Vesicle

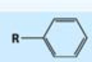
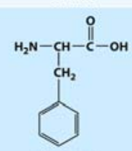






Functional Groups

Table 2.1 Some key functional groups in biochemistry

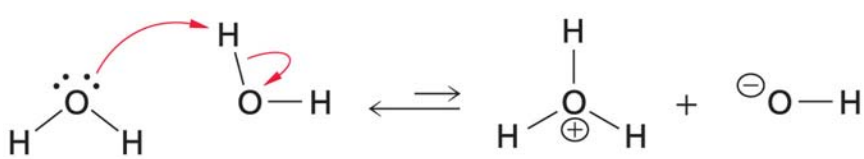
Functional group	Class of compounds	Structural formula	Example
Hydrophobic	Hydrocarbon chains (aliphatic)	$R-CH_3$	$H_2N-CH(CH_3)-C(=O)-OH$ Alanine
	Aromatic (hydrocarbons in a ring structure with multiple double bonds)		 Phenylalanine
Hydroxyl	Alcohol	$R-OH$	H_3C-CH_2-OH Ethanol
Aldehyde	Aldehydes	$R-C(=O)-H$	$H_3C-C(=O)-H$ Acetaldehyde
Keto	Ketones	$R-C(=O)-R$	$H_3C-C(=O)-CH_3$ Acetone

Functional Groups

Table 2.1 Some key functional groups in biochemistry

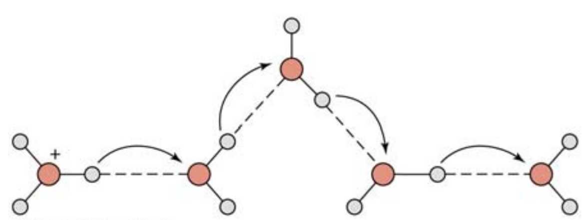
Functional group	Class of compounds	Structural formula	Example
Carboxyl	Carboxylic acid	R—C(=O)—OH	H_3C—C(=O)—OH Acetic acid
Amino	Amines	R—NH_2	H_2N—CH(CH_3)—C(=O)—OH Alanine
Phosphate	Organic phosphates	R—O—P(=O)(O^-)—O^-	HO—C(=O)—HC(OH)—H_2C—O—P(=O)(O^-)—O^- 3-Phosphoglyceric acid
Sulfhydryl	Thiols	R—SH	H_2N—CH(CH_2—SH)—C(=O)—OH Cysteine

Autoionization of Water



$$H_2O + H_2O \rightleftharpoons H_3O^{\oplus} + OH^{\ominus}$$

Proton jumping:
faster than
diffusion limit



K_w, The Ion Product of Water

$$H_2O \rightleftharpoons H^{\oplus} + OH^{\ominus}$$

$$K_{eq} = \frac{[H^{\oplus}][OH^{\ominus}]}{H_2O} \qquad K_{eq}[H_2O] = [H^{\oplus}][OH^{\ominus}]$$

$$(1.8 \times 10^{-16}\ M)(55.5\ M) = 1.0 \times 10^{-14}\ M^2 = [H^{\oplus}][OH^{\ominus}]$$

$$K_w = [H^{\oplus}][OH^{\ominus}] = 1.0 \times 10^{-14}\ M^2$$

Reciprocal Relationship

Table 2.3 Relation of $[H^{\oplus}]$ and $[OH^{\ominus}]$ to pH

pH	$[H^{\oplus}]$ (M)	$[OH^{\ominus}]$ (M)
0	1	10^{-14}
1	10^{-1}	10^{-13}
2	10^{-2}	10^{-12}
3	10^{-3}	10^{-11}
4	10^{-4}	10^{-10}
5	10^{-5}	10^{-9}
6	10^{-6}	10^{-8}
7	10^{-7}	10^{-7}
8	10^{-8}	10^{-6}
9	10^{-9}	10^{-5}
10	10^{-10}	10^{-4}
11	10^{-11}	10^{-3}
12	10^{-12}	10^{-2}
13	10^{-13}	10^{-1}
14	10^{-14}	1

pH of Neutral Water

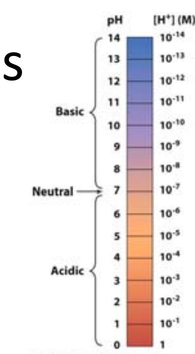
$$K_w = [H^{\oplus}][OH^{\ominus}] = 1.0 \times 10^{-14}\ M^2$$

$$K_w = [H^{\oplus}]^2 = 1.0 \times 10^{-14}\ M^2$$

$$[H^{\oplus}] = 1.0 \times 10^{-7}\ M$$

$$pH = -\log[H^{\oplus}] = \log\frac{1}{[H^{\oplus}]}$$

pH of Solutions



- If acid is added to water, the concentration of hydronium increases and pH decreases
- If base is added to water, the concentration of hydronium decreases (ion product of water) and the pH increases
- Addition of MORE acid vs. addition of a STRONGER acid

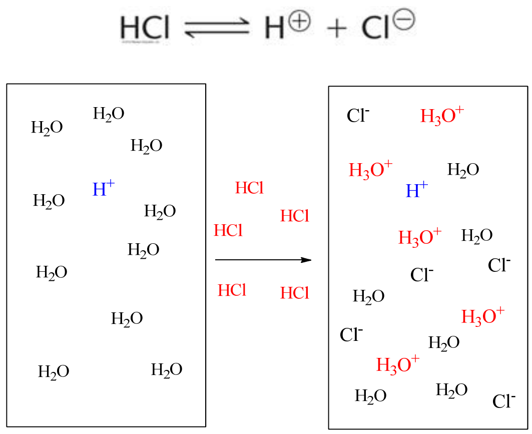
[TABLE 2-3]

pH Values of Some Biological Fluids

Fluid	pH
Pancreatic juice	7.8–8.0
Blood	7.4
Saliva	6.4–7.0
Urine	5.0–8.0
Gastric juice	1.5–3.0

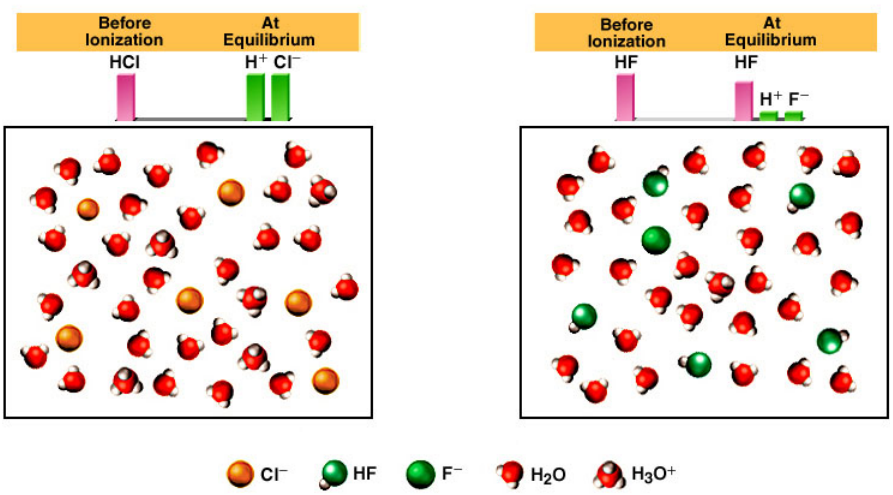
Strong Acid

- Complete dissociation
- What is the pH of a 0.01 M HCl solution?
- You add a drop of HCl to make a 1 x 10^{-8} M solution. What is the pH?
- What is your assumption?



Weak Acids

Strong **Weak**



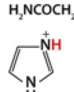
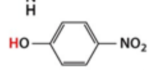
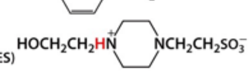
Weak Acid Dissociation Constants

- Weak acids have low [pdts], therefore low K_a
- Low K_a = high pK_a
- Weaker acids have __________ K_a values and __________ pK_as

$$\underset{\substack{\text{Acetic acid}\\\text{(weak acid)}}}{CH_3COOH} \overset{K_a}{\rightleftharpoons} H^{\oplus} + \underset{\substack{\text{Acetate anion}\\\text{(conjugate base)}}}{CH_3COO^{\ominus}}$$

$$K_a = \frac{[H^{\oplus}][CH_3COO^{\ominus}]}{[CH_3COOH]}$$

TABLE 2.4 pK Values of Some Acids

Name	Formula[a]	pK
Trifluoroacetic acid	CF_3COOH	0.18
Phosphoric acid	H_3PO_4	2.15[b]
Formic acid	HCOOH	3.75
Succinic acid	$HOOCCH_2CH_2COOH$	4.21[b]
Acetic acid	CH_3COOH	4.76
Succinate	$HOOCCH_2CH_2COO^-$	5.64[c]
Thiophenol	C_6H_5SH	6.60
Phosphate	$H_2PO_4^-$	6.82[c]
N-(2-acetamido)-2-amino-ethanesulfonic acid (ACES)	$H_2NCOCH_2\overset{+}{N}H_2CH_2CH_2SO_3^-$	6.90
Imidazole		7.00
p-Nitrophenol		7.24
N-2-hydroxyethylpiperazine-N′-2-ethanesulfonic acid (HEPES)		7.55
Glycinamide	$^+H_3NCH_2CONH_2$	8.20
Tris(hydroxymethyl)-aminomethane (Tris)	$(HOCH_2)_3C\overset{+}{N}H_3$	8.30
Boric acid	H_3BO_3	9.24
Ammonium ion	NH_4^+ 9.25	
Phenol	C_6H_5OH	9.90
Methylammonium ion	$CH_3NH_3^+$	10.60
Phosphate	HPO_4^{2-}	12.38[d]

[a]The acidic hydrogen is highlighted in red; [b]pK_1; [c]pK_2; [d]pK_3.

Henderson-Hasselbalch

$$HA \rightleftharpoons H^{\oplus} + A^{\ominus} \qquad \log K_a = \log \frac{[H^{\oplus}][A^{\ominus}]}{[HA]}$$

$$\log K_a = \log[H^{\oplus}] + \log \frac{[A^{\ominus}]}{[HA]}$$

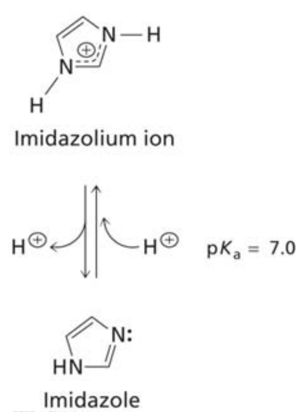
$$-\log[H^{\oplus}] = -\log K_a + \log \frac{[A^{\ominus}]}{[HA]}$$

$$pH = pK_a + \log \frac{[A^{\ominus}]}{[HA]}$$

Proton Acceptor

Proton Donor

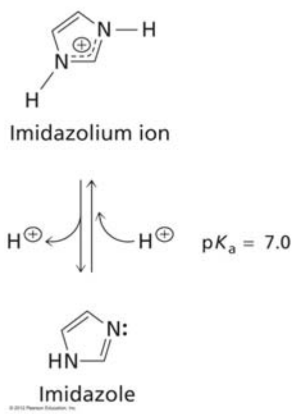
Qualitative Understanding



$$pH = pK_a + \log \frac{[A^{\ominus}]}{[HA]}$$

- Relationship of
  - Solution pH
  - Strength of acid
  - Ratio of CB to CA
- Solve quantitatively, but understand qualitatively

Quantitative Understanding



$$pH = pK_a + \log\frac{[A^{\ominus}]}{[HA]}$$

- What percent of molecules in an imidazole buffer are protonated at pH 7.2?

Understand Figures

Be able to explain what is happening as you trace the line from left to right in this figure.

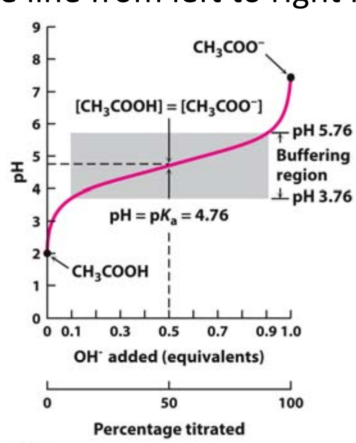


Figure 2.12
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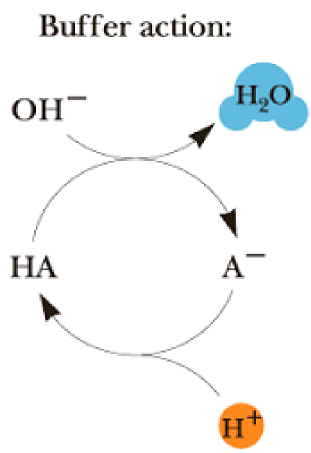
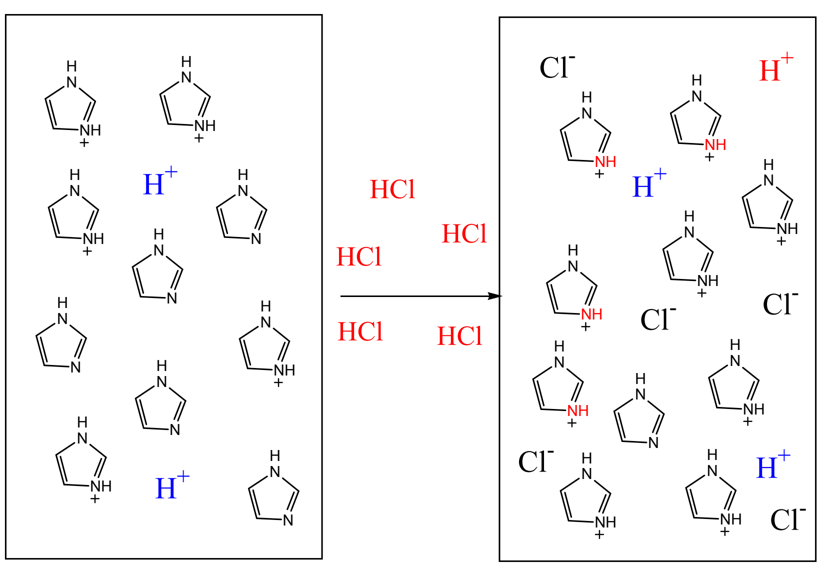
$$pH = pK_a + \log\frac{[A^{\ominus}]}{[HA]}$$

Key Tool in biochemistry: Buffer

Buffers





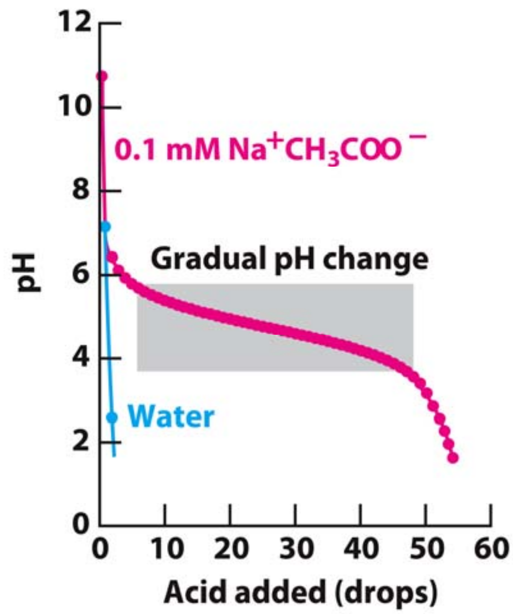


Figure 2.13
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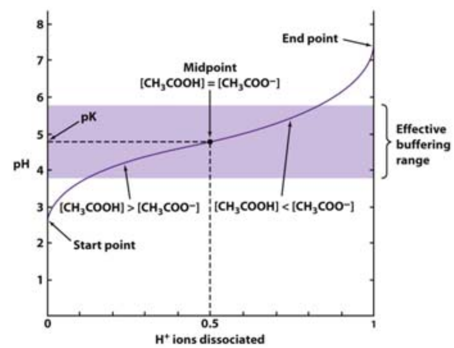
Buffer Capacity

- Depends on pKa of CA/CB mix
- Depends on concentration of CA/CB



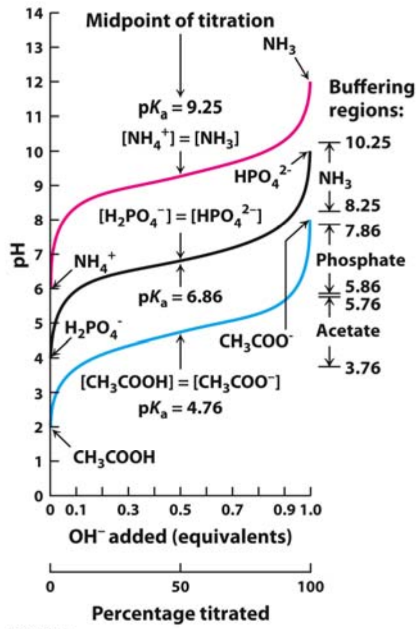


Figure 2.14
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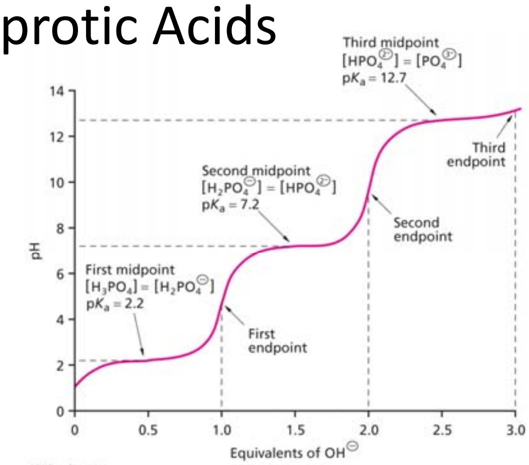
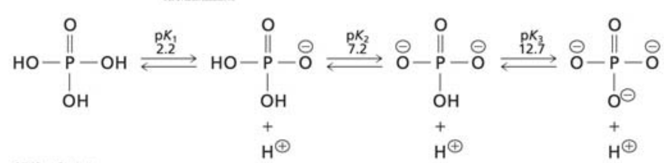
Polyprotic Acids

- Must be able to match the pKa with the appropriate proton
- Assumptions are legitimate if the pKa values are more than ~3 units from each other





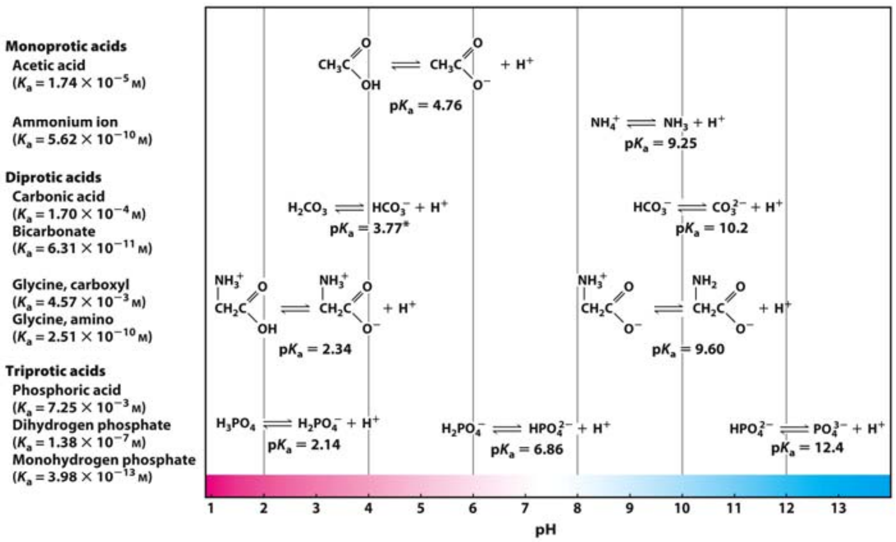


Figure 2.11
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- What is/are the major ionization state(s) for succinic acid at pH 3.2, 4.2, 5.2, and 6.2?

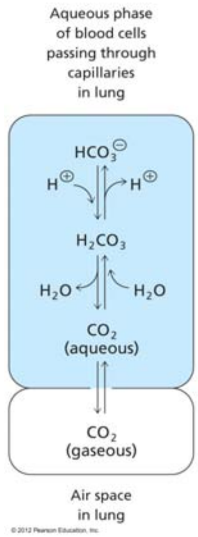
[TABLE 2.4] pK Values of Some Acids

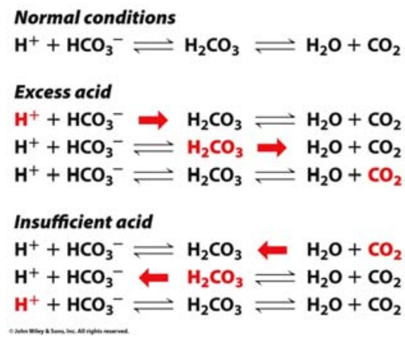
Name	Formula [a]	pK
Trifluoroacetic acid	CF_3COOH	0.18
Phosphoric acid	H_3PO_4	2.15[b]
Formic acid	HCOOH	3.75
Succinic acid	$HOOCCH_2CH_2COOH$	4.21[b]
Acetic acid	CH_3COOH	4.76
Succinate	$HOOCCH_2CH_2COO^-$	5.64[c]
Thiophenol	C_6H_5SH	6.60
Phosphate	$H_2PO_4^-$	6.82[c]
N-(2-acetamido)-2-aminoethanesulfonic acid (ACES)	$H_2NCOCH_2\overset{+}{N}H_2CH_2CH_2SO_3^-$	6.90

$$pH = pK_a + \log\frac{[A^{\ominus}]}{[HA]}$$

Blood Buffer

- Physiological pH 7.4
- Closed vs. Open systems
- Acidosis





Kidney Function

- Kidneys fight acidosis caused by common metabolic processes
- Reclaims excreted bicarbonate by excreting acid
- Forms new bicarb by CO_2 producing metabolism