Cellular and Molecular Biochemistry [FHS1104]

Water, pH and Buffer

Lecture {2}

MBCHB/BDS
1ST YEAR SEM.-1
2026

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Quick review

- ✓ **Define Biochemistry?**
- ✓ **What Does Biochemistry Study?**
- ✓ **What is the major objective of Biochemistry ?**
- ✓ **Classify biomolecules and give examples for each class.**
- ✓ **Why Biochemistry is important ?**
- ✓ **Explain the relationship between Biochemistry and Medicine**

{Lecture 2 Outline}

- Physiological functions of water
- Water imbalance
- Properties of water
  - The pH
- The importance of pH
  - What is the buffer and what are its mechanisms?
  - Biological buffers system
  - Acid-base disorders(imbalance)

Water:

It is the most abundant biomolecule in living organisms making up to **60 - 70%** of the total body weight of human .

- 40-55% in intracellular fluids (ICF)
- 20% in extra cellular fluids (ECF)
- Blood =Plasma (55%) + 45% blood cells
- Plasma (90% water) + (10%) Proteins, electrolytes, nutrients ... etc.

What is the physiological importance of water?

The physiological importance of water:

1.It is the medium for all biochemical reactions (the enzyme catalyzed the metabolic reactions).

2. transport of nutrients and other biomolecules

3. It serves as a reactant in –and as a product of- for many metabolic reactions (Hydrolysis &Condensation).

4. Water act as principal end product of oxidative metabolism of foods (ETC)

Biological importance of water:

5.Regulation of body temperature (sweating & evaporation which removes heat from the body).

6. Regulation of osmatic pressure (OP is prevents the movement of water across a semipermeable membrane due to osmosis, so water maintains osmatic balance by regulating the concentration of solutes in body fluids and prevent cellular shrinking **and** swelling.

Water imbalance :

- Water depletion may result from decreased intake (e.g., coma) or increased loss (e.g. severe sweating; renal loss in diabetes mellitus; diarrhea).
- Excess body water include increased intake (e.g. excessive administration of intravenous fluids) and decreased excretion (e.g. severe renal failure).

Water imbalance :

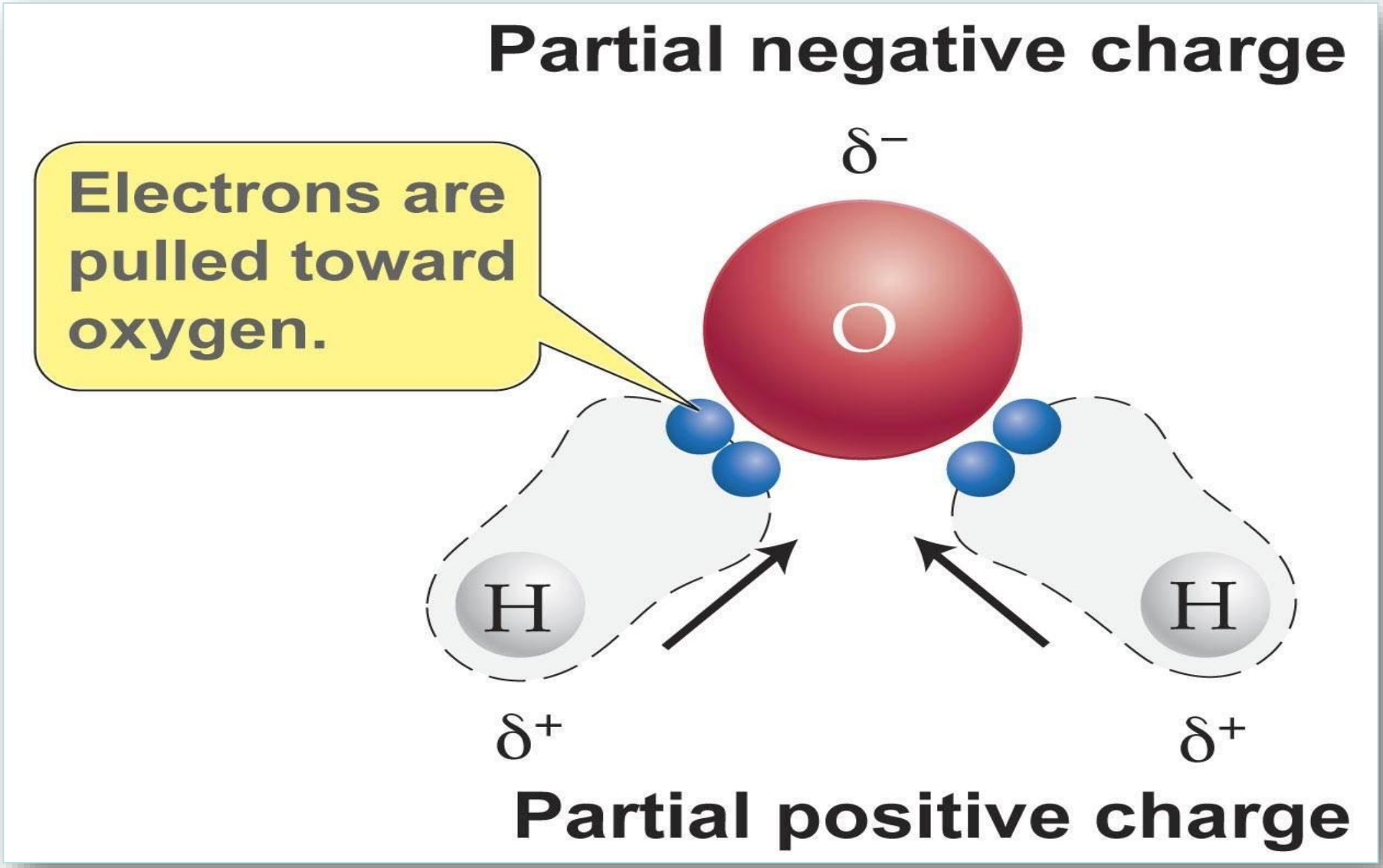
Water imbalance resulting :

- Water Loss Causes ; excessive sweating , vomiting, diarrhea and insufficient water intake

  ⟹ dehydration

- Water excess (overhydration) Causes ; due to Renal Disease ⟹ edema

Structure of water:



Properties of water:

Biophysical chemistry: is study of physical properties of biological.

Physical and chemical properties of water:

1. Bent shape

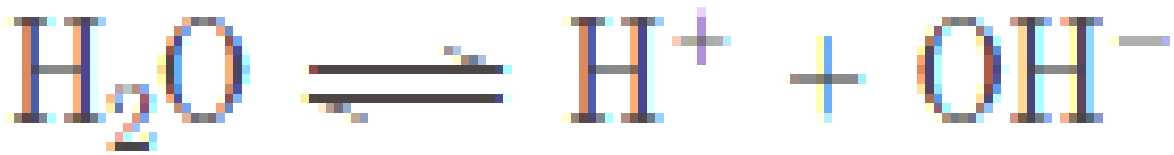
2. Water is a dipolar molecule

3. Partial charges on O and H atoms favor formation of weak bonds called hydrogen bonds

4. Water act as excellent solvent

Ionization of Water

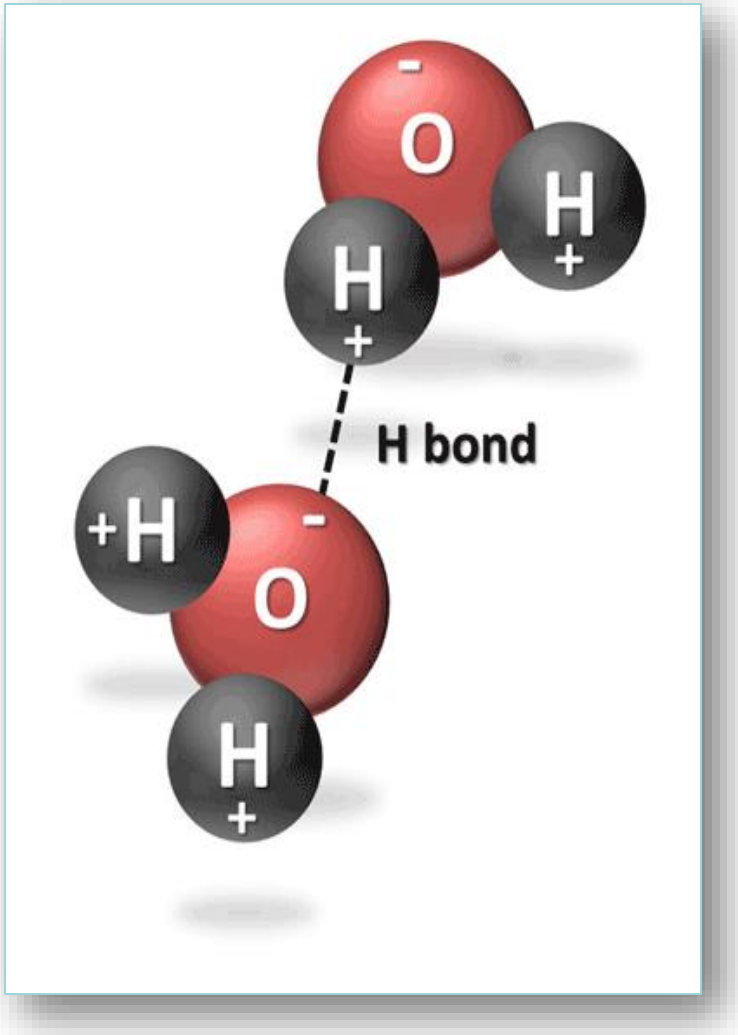
5. Water molecules have a slight tendency to undergo reversible **ionization** to yield a **hydrogen ion** (a proton) and a **hydroxide ion**, giving the equilibrium



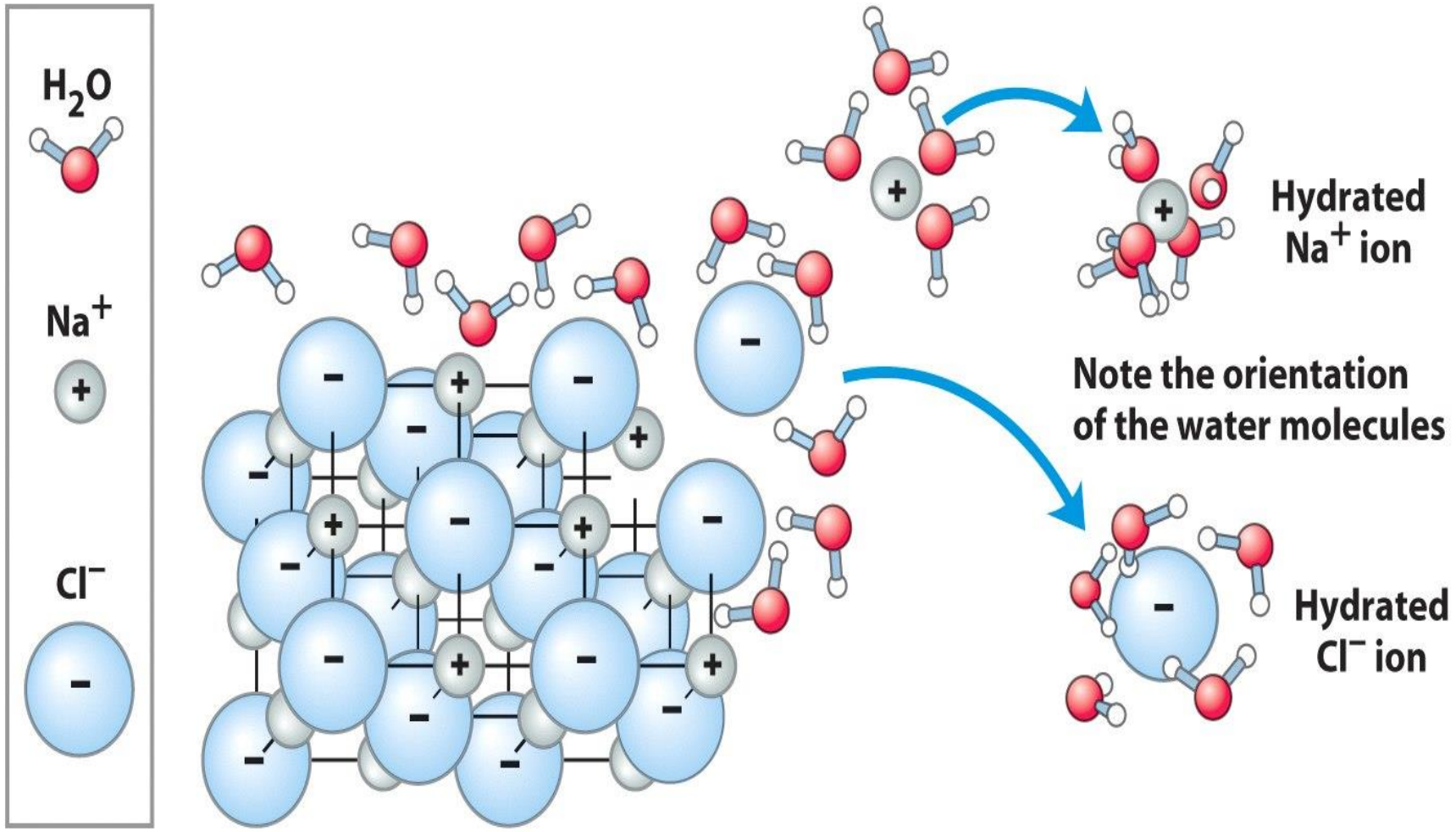
Structure of water:

What is dipolar ? and what is hydrogen bond?

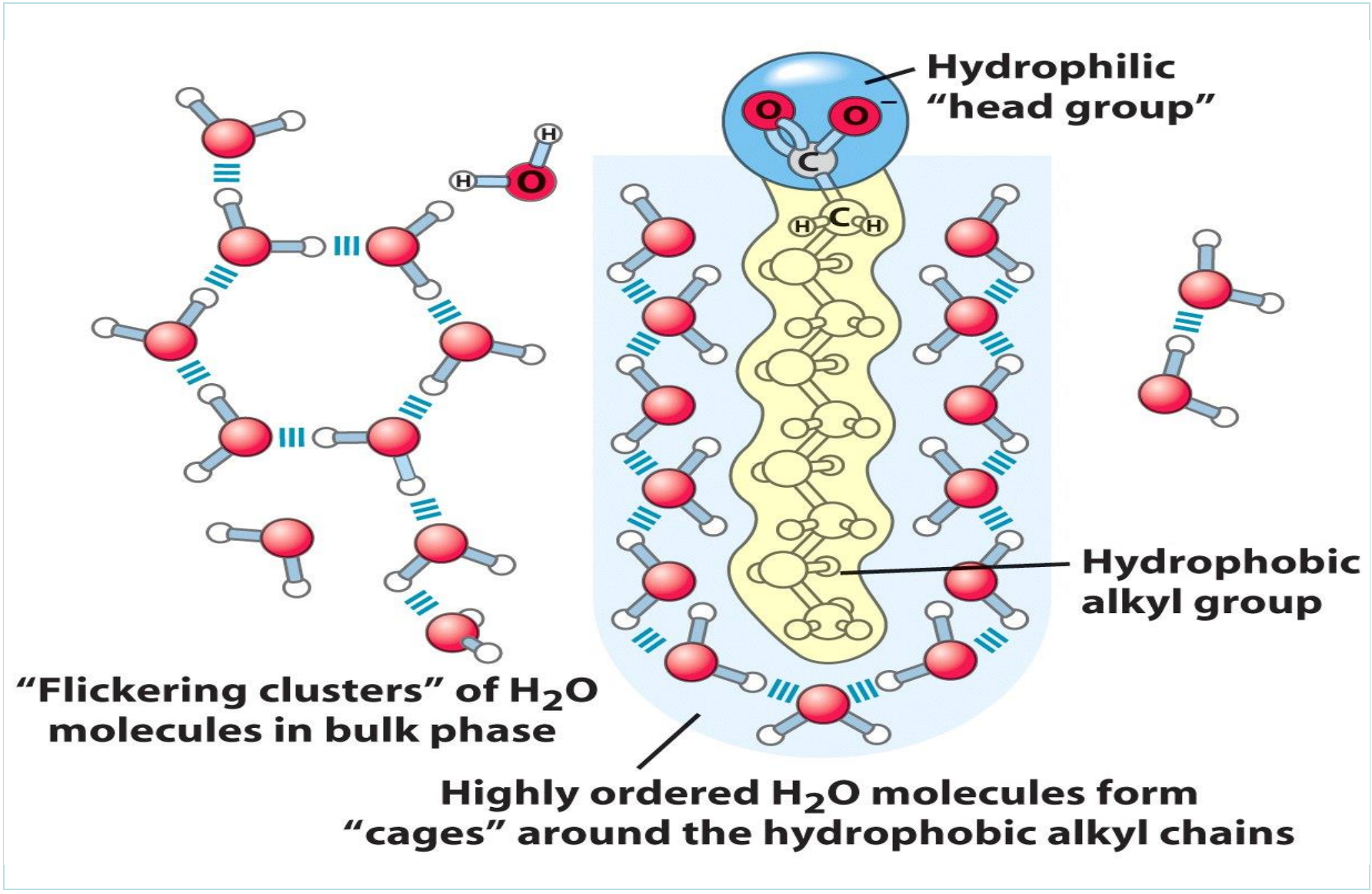
- Each molecule can act either as a donor or an acceptor of proton and making **H bonds.** **(Hydrogen (H) bond** is a special type of non-covalent bond).



6. Water interacts with charged molecules



7. Water **does not** interact with nonpolar molecules



Properties of water:

Water has physical and chemical properties which make it ideal solvent.

Physical properties:

It is liquid at room temp.

Low Freezing (melting) point

High boiling point

Acid and Base

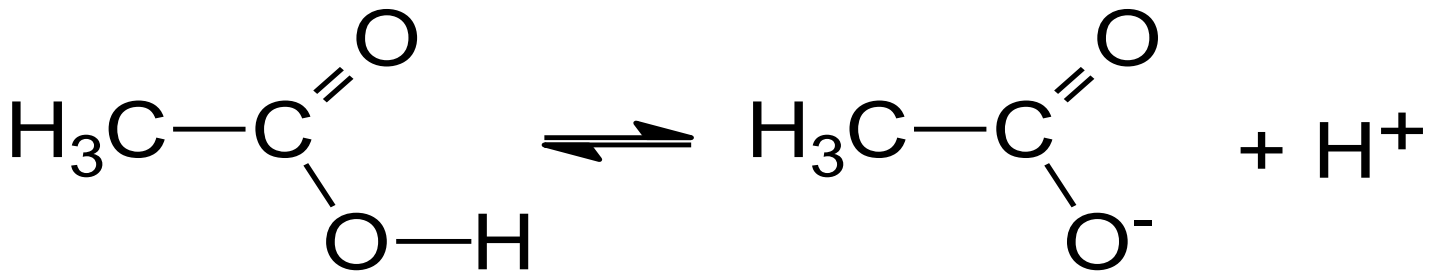
Acid and Base

In general, **acids** are defined as substances that can donate hydrogen ions (**protons**), while **bases** are compounds that accept **protons**.

- Strong acids fully dissociate in water:

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

- Weak acids partially dissociate in water

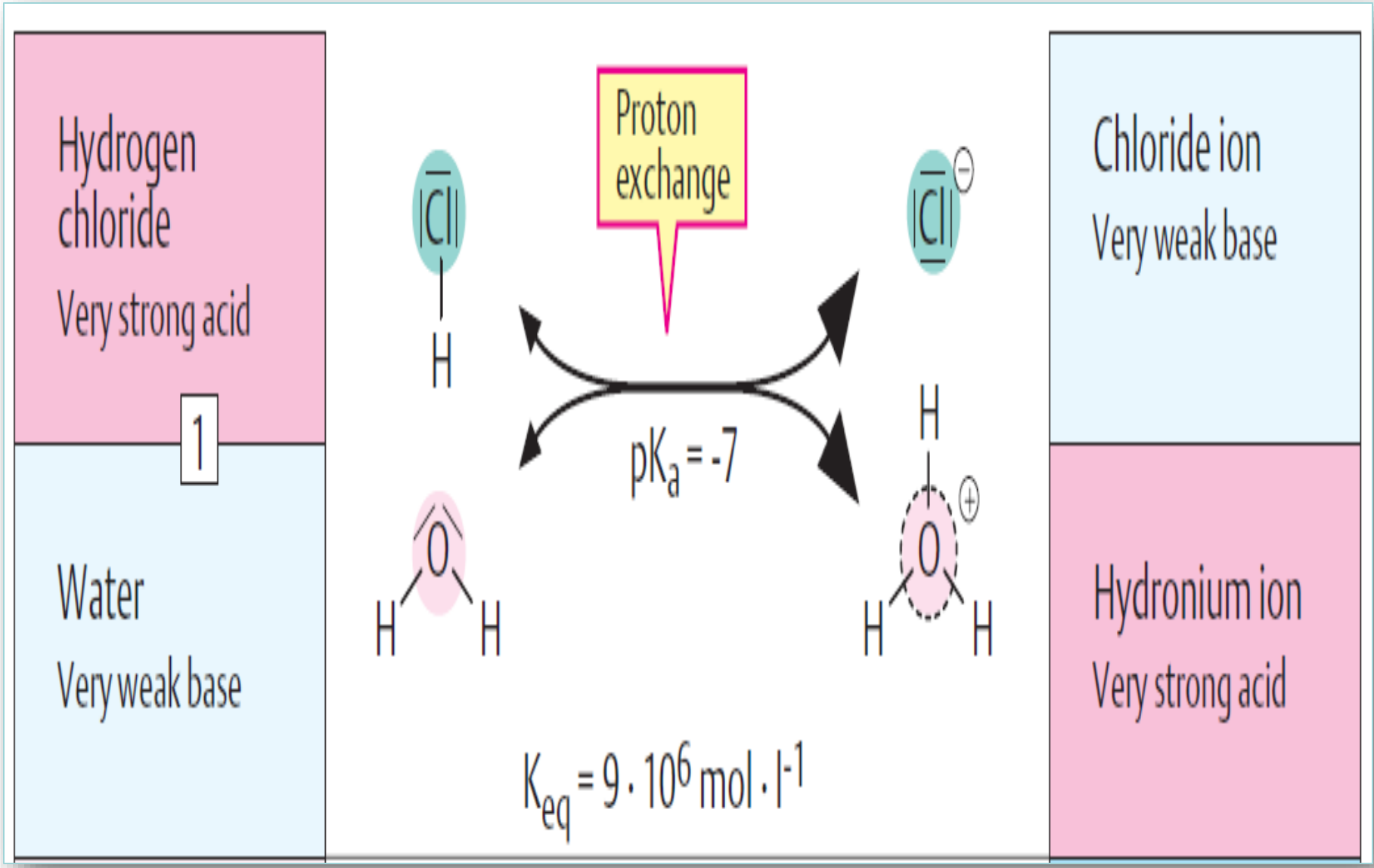


Acid and Base

For example, when **hydrogen chloride (HCl)** is in **aqueous** solution, it donates **protons** to the solvent

This results in the formation of chloride ions **(Cl^-)** and protonated water molecules (**hydronium** ions, **H_3O^+**, usually simply referred to as **H^+**).

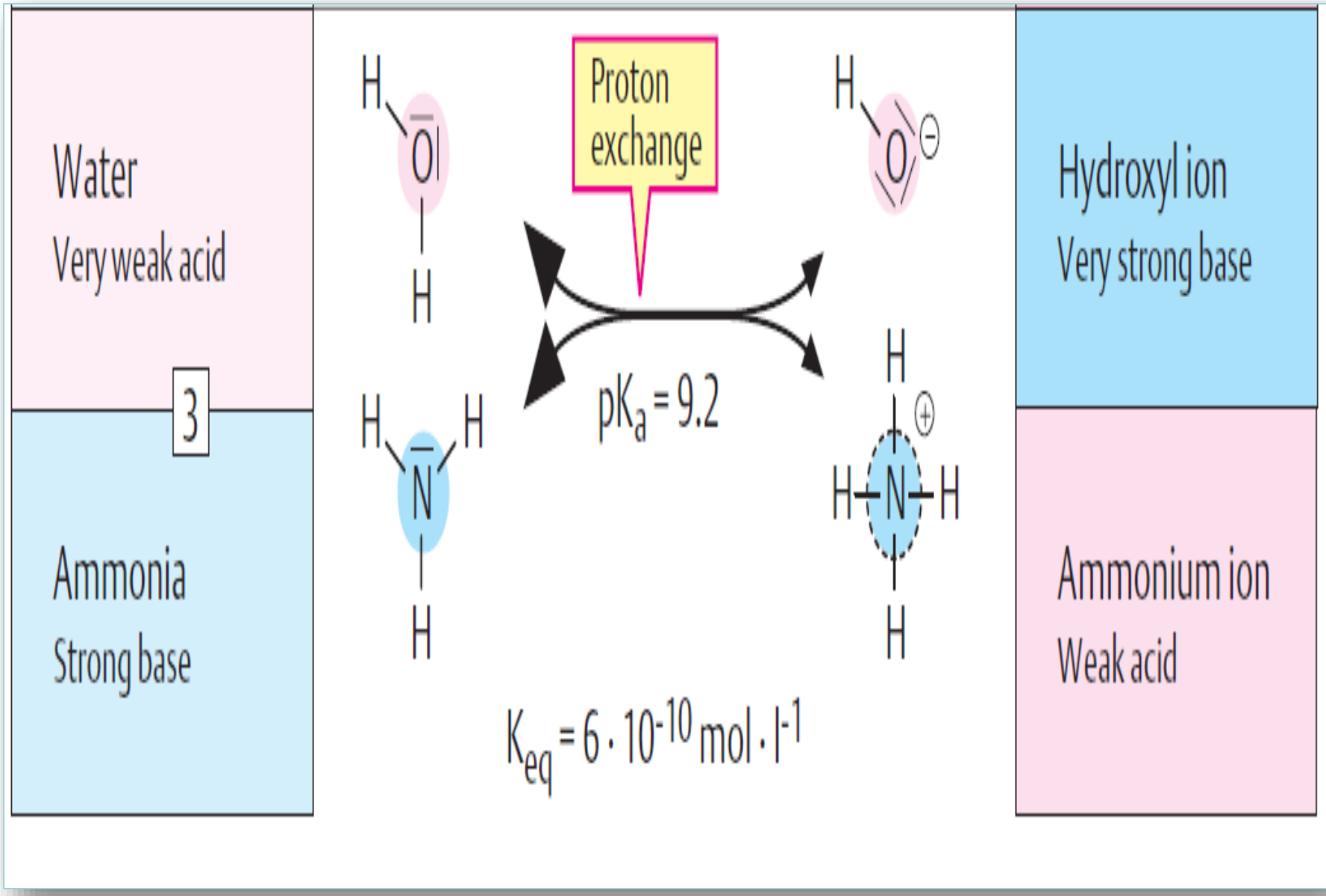
Acid and Base (water act as base)



Acid and Base

Bases such as **ammonia (NH_3)** take over **protons** from **water** molecules. As a result, **hydroxyl ions (OH^-)** and positively charged **ammonium ions (NH_4^+)** formed.

Acid and Base (water act as acid)



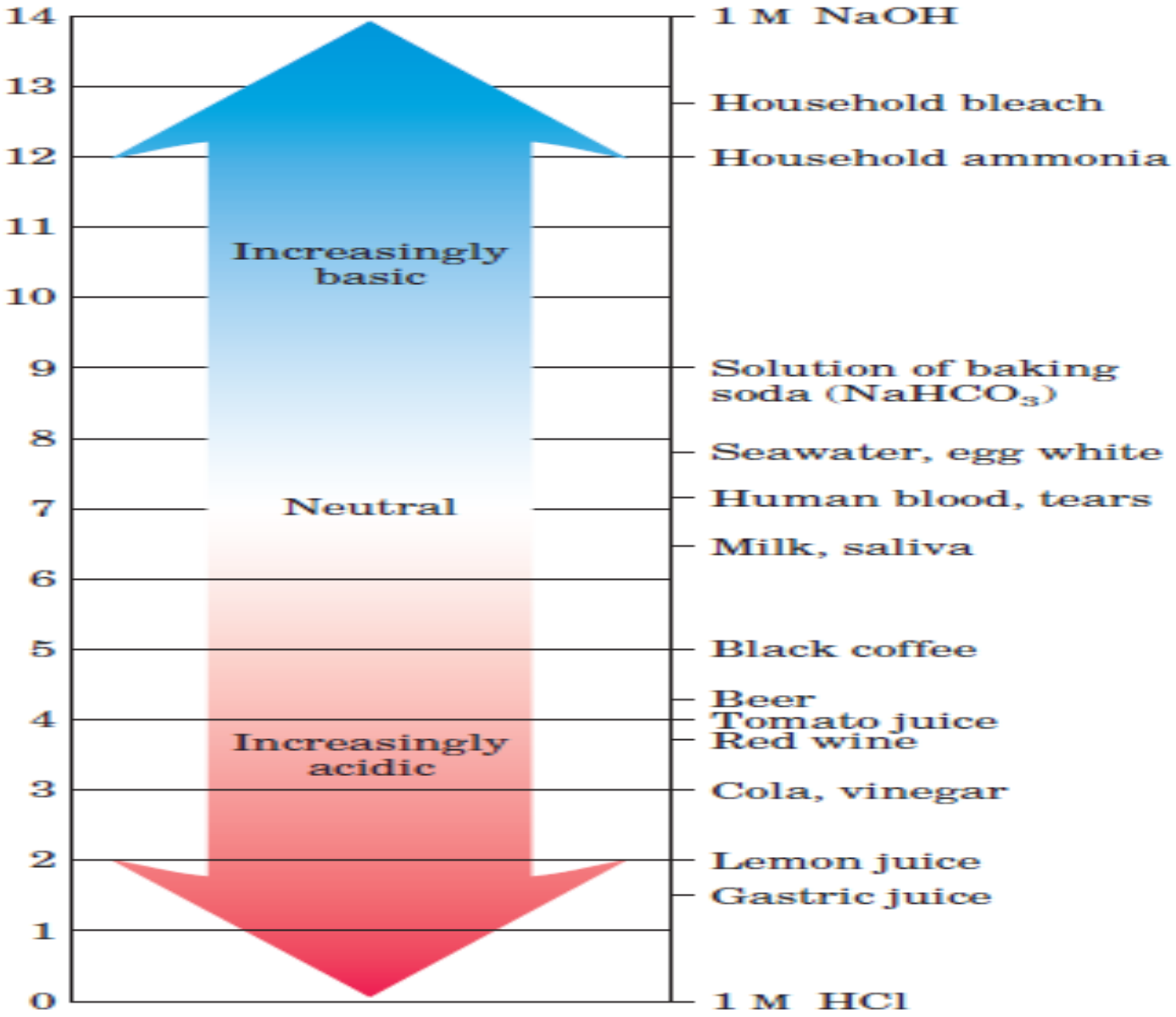
What is the pH

The pH Scale Designates the H Concentrations

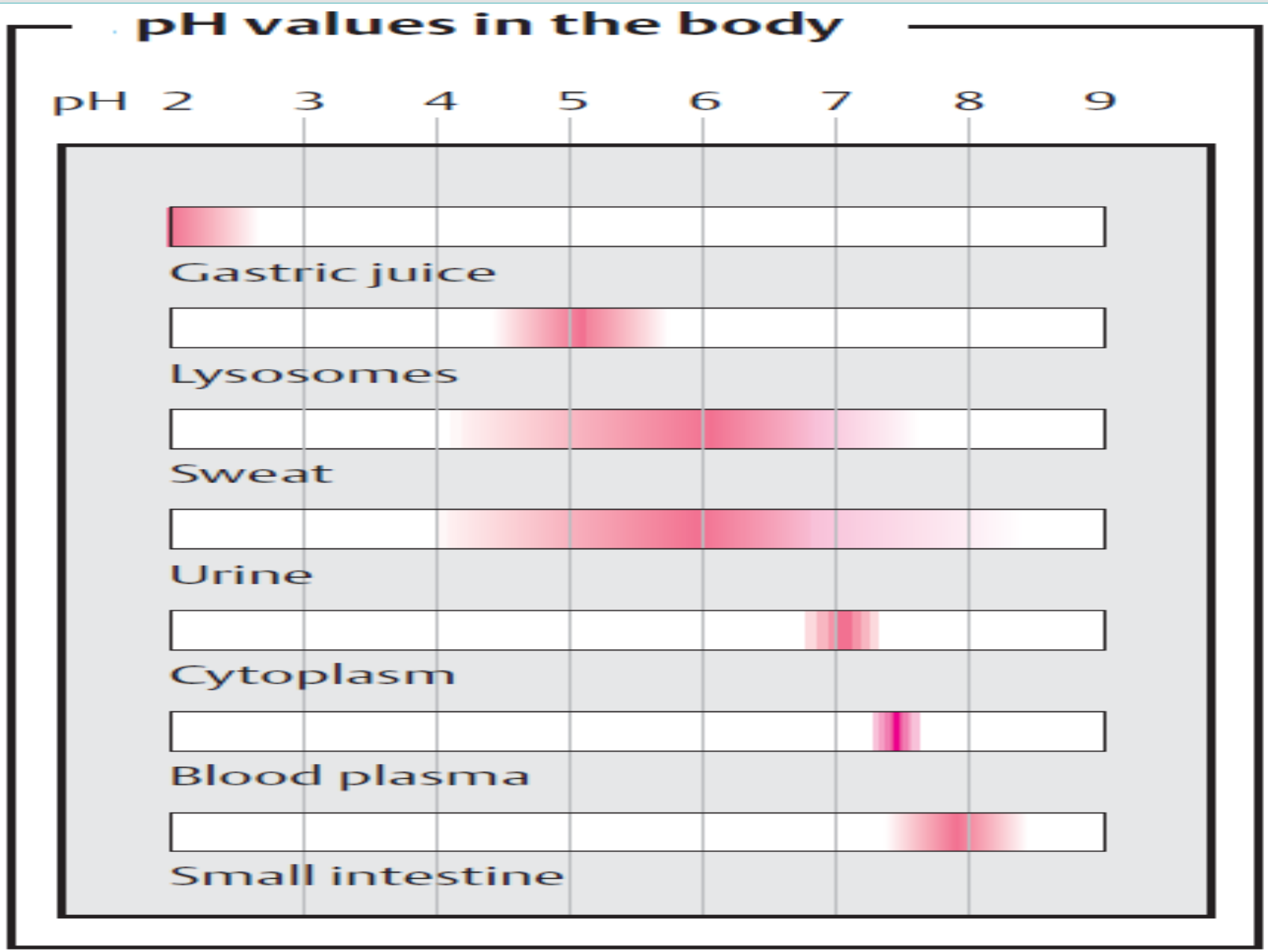
pH is the **negative logarithm of hydrogen ion concentration.**

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

The pH Scale


14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
Increasingly basic
Neutral
Increasingly acidic
1 M NaOH
Household bleach
Household ammonia
Solution of baking soda ($NaHCO_3$)
Seawater, egg white
Human blood, tears
Milk, saliva
Black coffee
Beer
Tomato juice
Red wine
Cola, vinegar
Lemon juice
Gastric juice
1 M HCl

Human body pH



The importance of pH

- provides the optimal pH for the enzyme which catalyzed all biochemical reactions
- affects chemical reactions , biological processes and function of many substances.

How the human body regulates and maintains the pH?

What is a buffer?

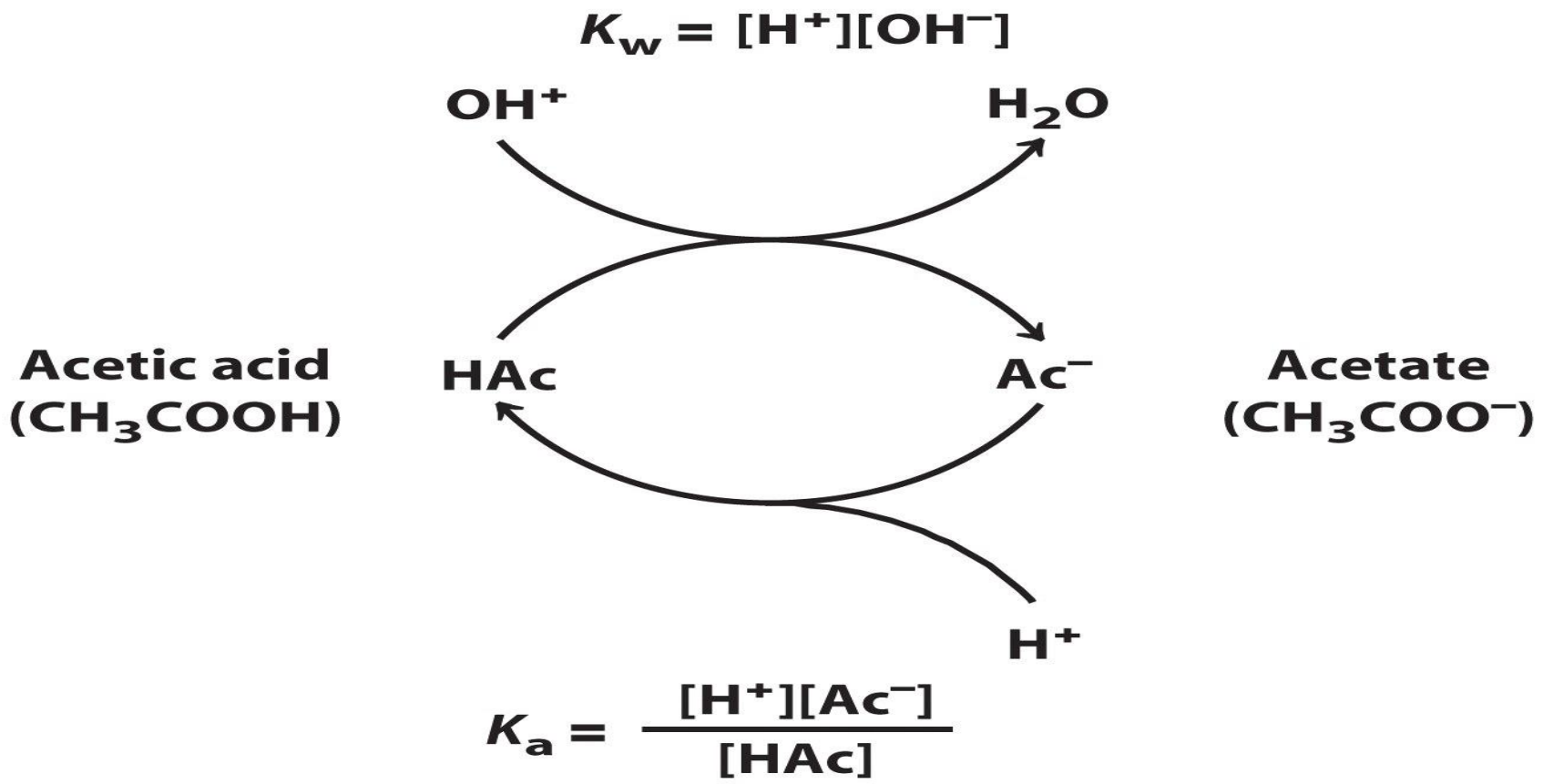
A buffer is a solution that resist change in pH

A buffer is a molecule that tends to either bind or release hydrogen ions in order to maintain a particular pH.

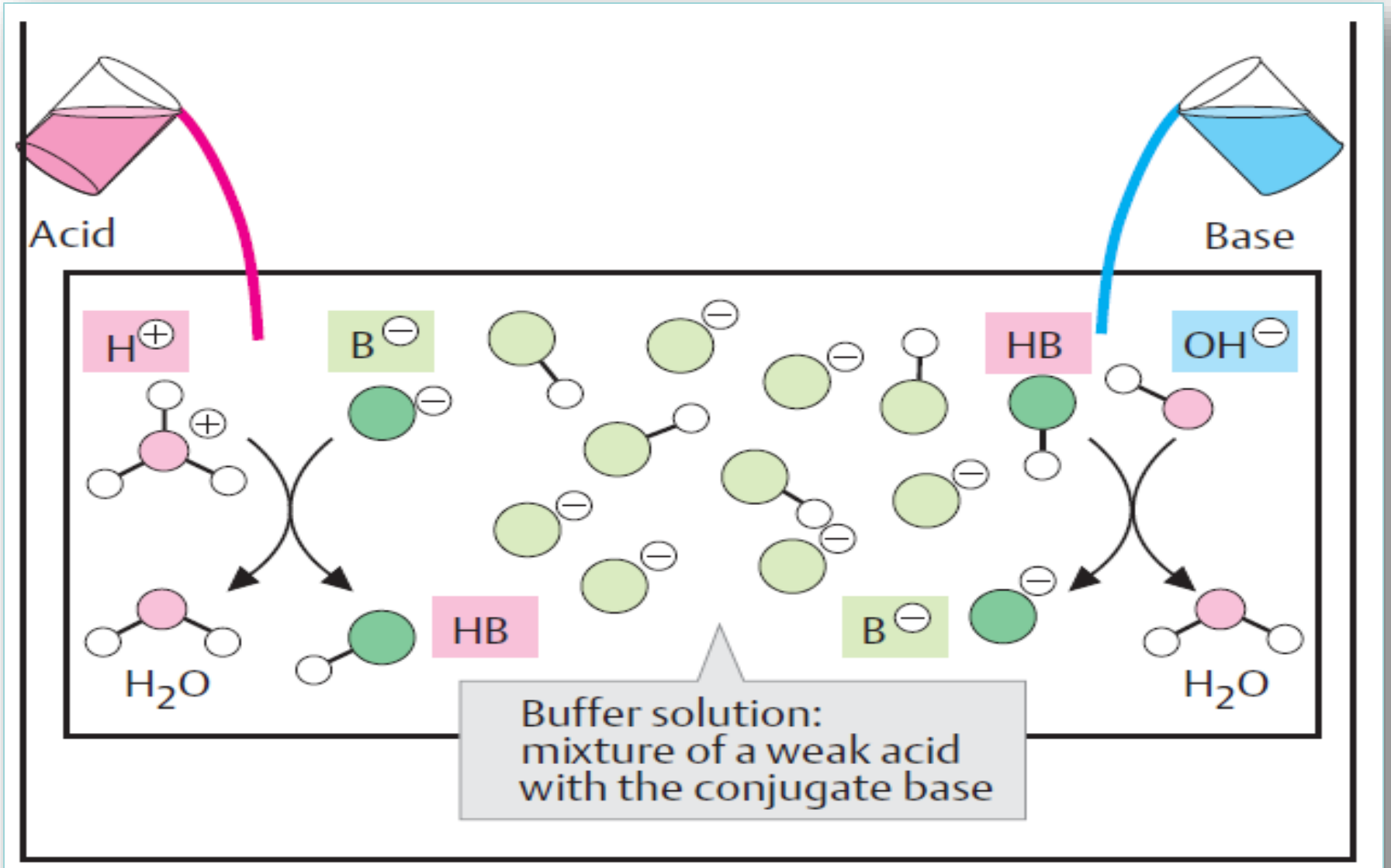
Good buffers are made up of a weak acids and their conjugate bases.

Buffer:

A mixture of a weak acid and its conjugate base



buffer


Acid
Base
H⊕
B⊖
HB
OH⊖
H2O
HB
B⊖
H2O
Buffer solution:
mixture of a weak acid
with the conjugate base

Buffers How they work (mechanism)?

a buffer can either accept or donate hydrogen ions, depending on the solution they are in. Since the buffers will accept hydrogen ions in acids and donate hydrogen ions in bases, (accept or donate hydrogen ions).

Buffers in Human body (Biological buffers):

There are three important buffer systems in our bodies:

1. bicarbonate buffer system

2. phosphate buffer system

3. protein buffer system

Buffers in Human body (Biological buffers)

1. Bicarbonate Buffer System.

The two components of this buffer system are carbonic acid (H_2CO_3), a weak acid, and sodium bicarbonate ($NaHCO_3$), a weak base. Each of these molecules participates in a specific type of reaction.

$$H_2CO_3 \rightleftharpoons HCO_3^- + H^+ \rightleftharpoons CO_3^- + 2H^+$$

Buffer How they work (mechanism)?

- If a potential pH change is created by a strong acid, the following reaction takes place:

$HCl + NaHCO_3 \rightarrow NaCl + H_2CO_3$

(strong acid) (weak acid)

The strong acid has reacted with the sodium bicarbonate to produce a salt (NaCl) that has no effect on pH and a weak acid that has little effect on pH.

- If a potential pH change is created by a strong base, the following reaction takes place:

$NaOH + H_2CO_3 \rightarrow H_2O + NaHCO_3$

(strong base) (weak base)

Biological buffers

The strong base has reacted with the carbonic acid to produce water, which has no effect on pH and a weak base that has little effect on pH.

The bicarbonate buffer system is important in both the blood and tissue fluid.

During normal metabolism, these fluids tend to become more acidic, so more sodium bicarbonate than carbonic acid is needed.

Biological buffers:

2. Phosphate Buffer System

The two components of this buffer system are sodium dihydrogen phosphate (NaH_2PO_4), a weak acid, and sodium monohydrogen phosphate (Na_2HPO_4), a weak base.

If a potential pH change is created by a strong acid, the following reaction takes place:

$$HCl + Na_2HPO_4 \rightarrow NaCl + NaH_2PO_4$$

(strong acid) (weak acid)

Biological buffers:

The strong base has reacted with the sodium dihydrogen phosphate to form water, which has no effect on pH and a weak base that has little effect on pH.

Biological buffers:

The strong acid has reacted with the sodium monohydrogen phosphate to produce a salt that has no effect on pH and a weak acid that has little effect on pH.

If a potential pH change is created by a strong base, the following reaction takes place:

$$NaOH + NaH_2PO_4 \rightarrow H_2O + Na_2HPO_4$$

(strong base) (weak base)

Biological buffers:

3. Protein Buffer System.

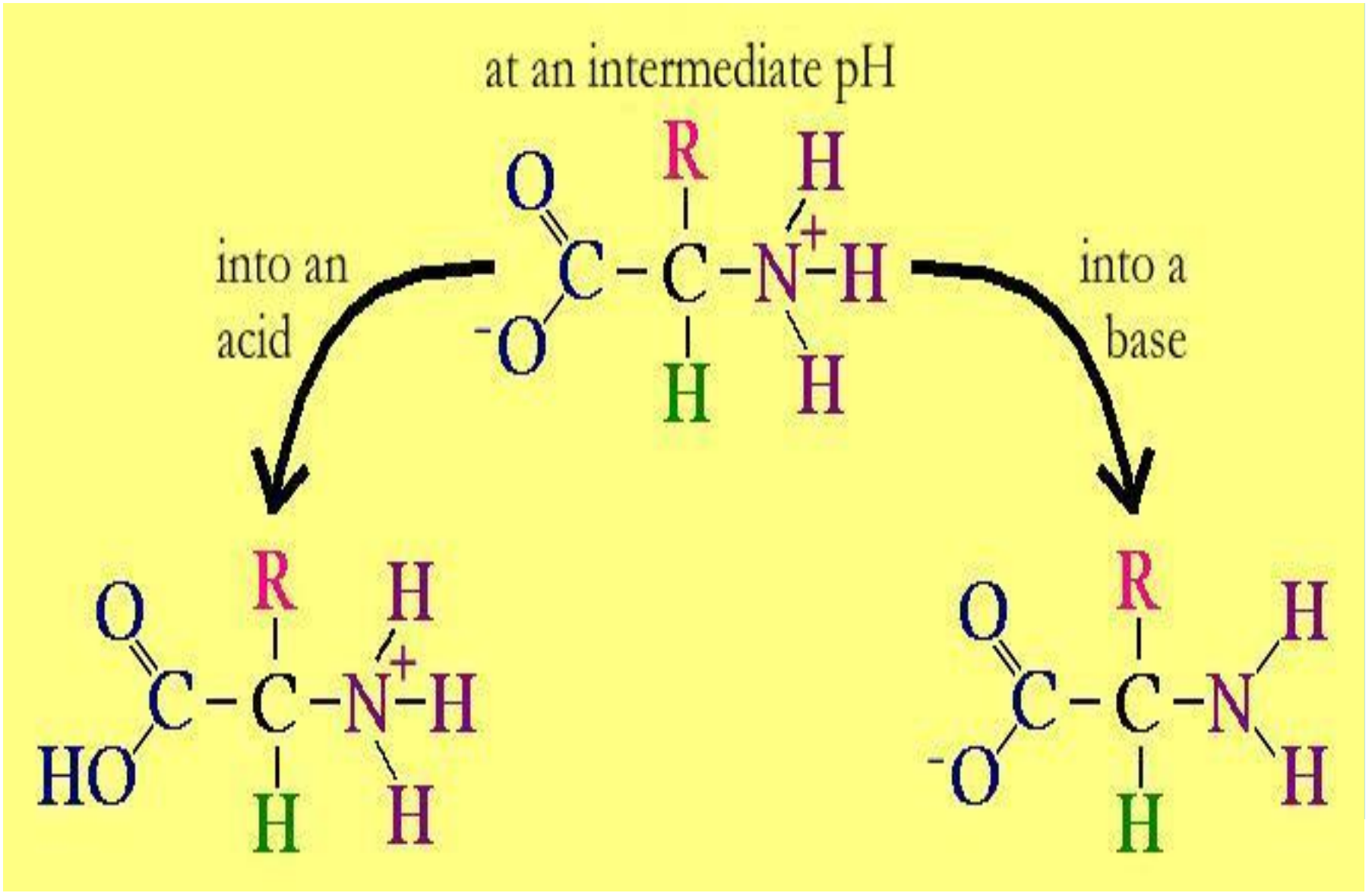
The amino acids that make up proteins each have a **carboxyl group (COOH) and an amine (or amino) group (NH2) and may act as either acids or bases.**

The carboxyl group may act as an acid because it can donate a hydrogen ion (H) to the fluid.

Biological buffers

The amine group may act as a base because it can pick up an excess hydrogen ion from the fluid.

Overview of amino acids providing buffering functions



Buffers in Human body

- **Carbonic acid Bicarbonate Buffer system:**
  - **ISF (interstitial fluid), ECF (Blood plasma)**
- **Phosphate buffer System:**
  - **ICF,** (intracellular fluid) and in the fluids of the kidneys **Urine.**
- **Proteins:**
  - **ICF, Blood (Plasma Proteins)**. Hemoglobin inside red blood cells RBCs.

Acid-base disorders(imbalance):

Acidosis (blood pH < 7.35) diabetic ketoacidosis and lactic acidosis.

Alkalosis (blood pH > 7.45) vomiting of acidic gastric contents.

Acid-base disorders(imbalance):

- Blood pH < 7.2 --> pathological condition = acidosis
- Blood PH < 6.8 --> death
- Blood pH > 7.6 --> pathological condition = alkalosis
- Blood pH > 8.6 --> death

NB: the body needs blood pH to stay within a very narrow range (7.35-7.45) Enzyme ,heart ,muscle the brain and other organs depend on this balance.

References:

1-lipincotts biochemistry 8th edition 2022

2. Harpers 25th , 27th and 32nd edition 2023

3- Lehninger principles biochemistry 8th edition 2021

4- Medical biochemistry 6th edition 2023

5- Mark Basic Medical biochemistry 6th edition 2023

6- Stryer biochemistry


Thank You