CHEMISTRY REVIEW

Chemical Components in The Cell-

Inorganic Components

Learning Objectives:

- ❖ Explain the importance of salts to the body homeostasis.
- ❖ Define the terms “acid” and “base”, and explain the concept of pH.
- ❖ Describe the pH of different body fluids.
- ❖ Describe the pathological changes in blood pH.
- ❖ Explain how food intake & stress can affect blood pH
- ❖ Describe the physiologic & chemical buffering systems of the blood.

Chemical Components in The Cell

- **Biochemistry:** is the study of the chemical composition and reactions of living matter.

- All chemicals in the body fall into one of two major classes: ***organic*** (have carbon) or ***inorganic*** (lack carbon) compounds.

- **Inorganic components**: Minerals, usually found as salts, acids and bases.

- **Organic components**: contain carbon. All organic compounds are covalently bonded molecules. Carbon, hydrogen, oxygen and nitrogen, combined to form carbohydrates, proteins, fats and nucleic acids.

- To be defined as an organic compound, ***Carbon is the central element. All compounds with carbon-carbon bonds are organic.***

- *If there is just one carbon atom, it needs to be covalently bonded with hydrogen atoms.*

- *1-carbon compound with oxygen (CO_2, carbonates and bicarbonates) are inorganic.*

Inorganic Chemistry in Body Fluids:

1- Salts-Ionic bonds: Salts crystallize out when dry, cations and anions alternately arranged in a lattice. In water, salts may dissociate into their component cations and anions.

- ❖ Water molecules align with appropriate polarity to facilitate the dissociation.
- ❖ Dissociated salts are electrolytes, i.e. ***they conduct an electrical current in water.***

A- Electrolyte cations: Sodium, potassium , calcium and magnesium cations are responsible for:

- *Providing ionic strength for protein stability* and for chemical reactions to occur.
- *Maintenance of osmotic pressure*, especially sodium.
- *Sensitivity & reactivity of nerves* (Na^+ and K^+) and *muscles* (Ca^{++} and Mg^{++}).
- Calcium and Magnesium are less soluble, and *confer hardness to skeleton*.
- *Miscellaneous functions*, e.g. Ca^{++} functions in blood clotting & communication.

- ❖ ***The balance between these 4 cations is crucial, and is often disrupted by dietary factors.***

Inorganic Chemistry in Body Fluids - Salts:

B- Anions: Chloride, sulfate, carbonate and phosphate are responsible for:

- ***Ionic strength*** and ***osmotic function***, especially chloride.
- ***Chemical buffering*** of body fluid pH, especially carbonate and phosphate.
- ***Electrical balance*** with cations, and ***reactivity of nerves and muscles***.
- Phosphate and sulfate are ***covalently bound into organic compounds***.

C- Other minerals: Many ***act as cofactors for enzymes:***

- e.g. zinc, manganese, copper, selenium, molybdenum.
- ***Magnesium is our most extensively used cofactor, involved in all ATP utilization***.
- ***Iron is essential in hemoglobin, for carrying oxygen***.

Inorganic Chemistry in Body Fluids study p41 - Acids:

2- Acids: are substances that releases hydrogen ions (H^+) in detectable amount.

❖ H^+ is essentially a naked proton, so acids are sometimes defined as ***"proton donors".***

❖ Strong acids ionize completely, liberating all of their protons, e.g. hydrochloric acid: $HCL \longrightarrow H^+ + Cl^-$

❖ Weak Acids ionize incompletely, liberating some protons, depending on the medium:

Acetic acid: $CH_3COOH \longrightarrow CH_3COO^- + H^+ + CH_3COOH$

Carbonic acid: $H_2CO_3 \longrightarrow H^+ + HCO_3^- + H_2CO_3$

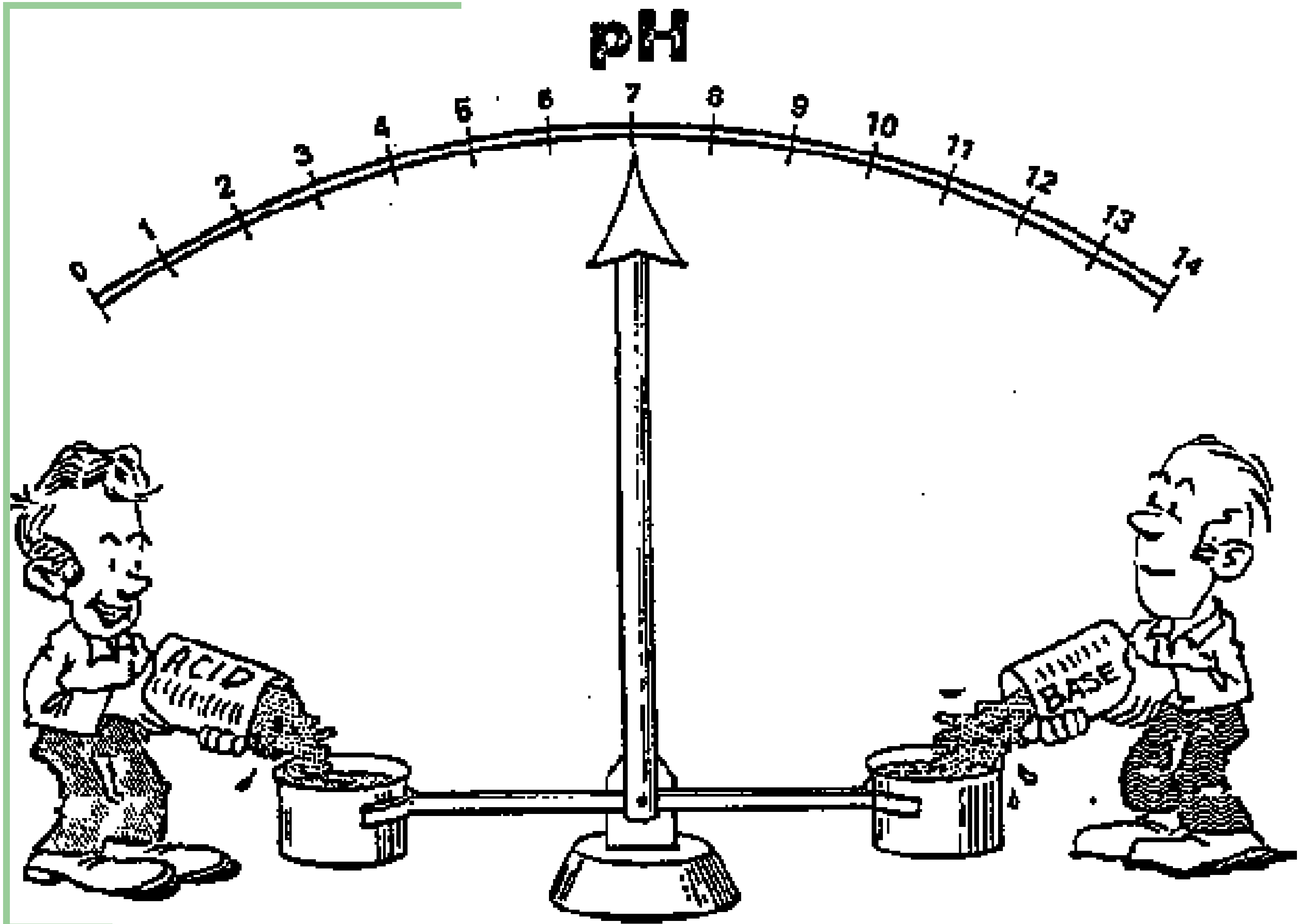
3- Bases: are ***proton (H^+) acceptors***. Hydroxides release hydroxyl ions (OH^-) and cations.

❖ OH^- are avid proton seekers. **Sodium hydroxide:** $NaOH \rightarrow Na^+ + OH^-$ This is a strong base, because it fully dissociates, and OH^- take protons from water.

Inorganic Chemistry in Body Fluids – Acid-Base Concentration:

- The more hydrogen ions in a solution, the more acidic the solution is. Conversely, the greater the concentration of hydroxyl ions (the lower the concentration of H^+), the more basic, or *alkaline the solution becomes. The relative concentration* of hydrogen ions in various body fluids is measured in concentration units called **pH units.**

- The pH scale is based on the concentration of hydrogen ions in a solution, expressed in terms of moles per liter, or molarity***. The pH scale runs from 0 to 14 and is logarithmic. In other words, each successive change of one pH unit represents atenfold change in hydrogen ion concentration.***


pH
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
ACID
BASE

Inorganic Chemistry in Body Fluids – Acid-Base Concentration:

- The pH of a solution is thus defined as the negative logarithm of the hydrogen ion concentration $[H^+]$ in moles per liter, or $-\log[H^+]$. (At a pH of 7 (at which $[H^+]$ is 10^{-7} *M), the solution is neutral—neither acidic nor basic. The number of hydrogen* ions exactly equals the number of hydroxyl ions (pH = pOH). Absolutely pure (distilled) water has a pH of 7.

- Solutions with a pH below 7 are acidic—the hydrogen ions outnumber the hydroxyl ions. The lower the pH, the more acidic the solution. A solution with a pH of 6 has ten times as many hydrogen ions as a solution with a pH of 7.

Inorganic Chemistry in Body Fluids – Acid-Base Concentration:

pH Scale (Acid-Base Concentration):

- ❖ Pure water dissociates into ions very slightly, giving H^+ concentration of 10^{-7} moles/liter:
  - ➢ It has a pH of 7, because 7 is the negative log of the proton concentration in moles.
  - ➢ The number of hydroxyl ions is equal to the number of protons. 0.0000001 moles.
- ❖ **Acid**: When acid is added, the number of protons increases. Acid taste sour.
  - ➢ Vinegar (acetic acid) at a pH of 3, contain 0.001 moles of H^+ per liter.
  - ➢ A change of 1 pH unit represents a 10-fold change in molarity of protons.
- ❖ **Base**: When a base is added, hydroxyl ions use up protons from the medium, causing the number of protons to decrease. Bases are caustic and feel slimy in water.
  - ➢ Pancreatic juice has only 10^{-13} moles of protons, giving a pH of 13

This figure shows the pH scale and pH values of representative Substances:

The pH scale is based on the number of hydrogen ions in solution. The actual concentrations of hydrogen ions, $[H^+]$, and hydroxyl ions, $[OH^-]$, in moles per liter are indicated for each pH value noted. At a pH of 7, $[H^+] = [OH^-]$ and the solution is neutral.

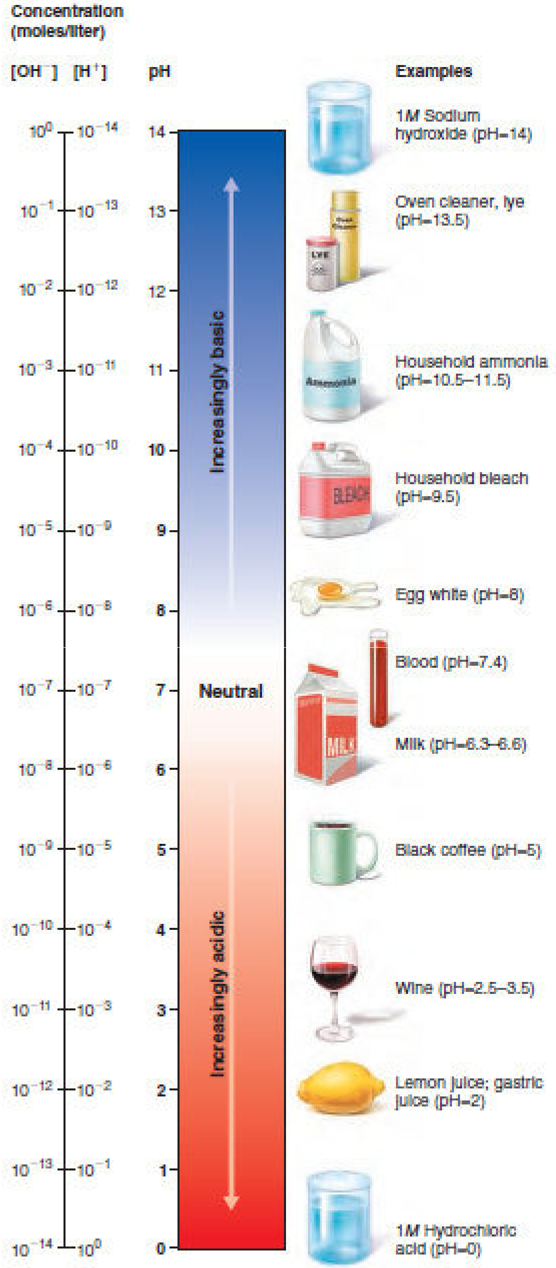


Table to show pH scale:

H^+ conc (Moles)	pH	Examples	Description
1	0	1 Molar HCL	Very acidic
0.1	1	Human gastric juice	
0.01	2	Lemon Juice	
0.001	3	Vinegar	Acidic
0.0001	4	Pineapple	
0.00001	5	Tomato juice	Slightly acidic
0.000001	6	Cow's milk	
0.0000001	7	Pure water, Cytoplasm	Neutral
	7.4	Blood, interstitial fluid	
0.00000001	8	Sea water	
0.000000001	9	Most soil water	Slightly alkaline
0.0000000001	10	Alkaline desert ponds	
0.00000000001	11		
0.000000000001	12	Limewater	Alkaline
10^{-13}	13	Pancreatic juice	Very alkaline
10^{-14}	14	1 Molar NaOH	

Neutralization Reactions:

- When acids and bases mix, they undergo an ***exchange reaction*** forming water and salt:

$$HCL + NaOH \longrightarrow H_2O + NaCl$$

ACID + BASE = SALT + WATER

Inorganic Chemistry in Body Fluids – pH of Body Fluids:

- **Blood and Interstitial fluid** have pH = 7.4. It varies from 7.35-7.45 . Venous blood is slightly more acidic, but in a healthy person it never goes below 7.35.

Pathological blood pH changes:

- **Acidosis** ***prevents blood from carrying O_2, kidneys can't excrete acidic wastes***. This occurs in Diabetes mellitus. CNS depressed, person goes into coma.

- **Alkalosis** ***causes hyperexcitation of CNS, with muscle spasms causing respiratory arrest***. Caused by prolonged vomiting or by taking alkaline drugs.

- **Cytoplasm** has a pH of 7.0; most enzymes have pH optimum of 6.5-7.5.

Inorganic Chemistry in Body Fluids – pH of Body Fluids:

- **Digestive tract** pH varies between enormous extremes:
  - **Saliva pH= 6.75-7.0**, but this varies depending what we have been eating, and also because it may be used for buffering the blood.
  - **Stomach pH=1-3** when stomach acid is secreted.
  - **Small intestine pH=13** as a result of pancreatic juice secretion.
  - **Large intestine & fecal pH are variable** depending on microbial growth:
    - ✓ ***The more dietary fiber you eat, the more acid it becomes***, so a pH of 5-6 seems healthy. Too little fiber causes purification, and too much causes too much acidity in feces.
- **Urine** pH=4.5-8.0, usually averaging about 6.0. Varies like saliva (depends on what we ate and what the need for blood buffering).

Blood Buffering:

- It is important to remember that healthy blood pH varies least of all body fluids. At 7.4, varying only half a pH unit each way.

1- How food intake & stress can affect blood pH: This is predicted by physically burning the food and measuring the pH of the ash. The physiologic significance of this is that ***cellular respiration causes all organic material to convert to CO_2 and H_2O***, just as if it were being physically burned. The inorganic material (minerals in the food) is left, and can influence body pH.:

A) Acid ash foods: are those foods which , after burning off all the organic materials, leave acidic inorganic salts behind. Foods such ***as meat and flour products do this and are eaten by most Americans***. The physiological buffering actions (described later) , causes most ***people eating these foods to have somewhat acidic urine and saliva.***

Blood Buffering:

B) Stress tends to ***place an acid load on body fluids, through increases in blood levels of lactic acid and uric acid.***

C) Alkaline ash foods are ***vegetables and most fruit***. Urine and saliva may be alkaline in vegetarians, and in ***people who have been vomiting***.

2- Physiologic buffering systems maintain homeostasis by taking differently charged out of the blood, depending on the needs of the body at the time.

A) Kidneys adjust blood pH by altering the amount of bicarbonate ions (HCO_3^-) or hydrogen ions being passed into the urine or retained in the blood.

B) Lungs also adjust blood pH by altering CO_2 expiration in relation to the amount of bicarbonate ions in the blood.

Blood Buffering:

3- Chemical buffering: Chemical buffers act by either combining with protons if the medium should become too acidic, or by releasing protons if it becomes too alkaline.

- Although there are other chemical blood buffers, the ***carbonic acid–bicarbonate system*** is a major one. Carbonic acid (H_2CO_3) dissociates reversibly, releasing bicarbonate ions ($HCO3^-$) and protons (H^+):

$$\underset{\text{(weak acid)}}{\underset{H^+ \text{ donor}}{H_2CO_3}} \underset{\text{Response to drop in pH}}{\overset{\text{Response to rise in pH}}{\rightleftharpoons}} \underset{\text{(weak base)}}{\underset{H^+ \text{ acceptor}}{HCO_3^-}} + \underset{\text{proton}}{H^+}$$

The chemical equilibrium between carbonic acid (a weak acid) and bicarbonate ion (a weak base) resists changes in blood pH by shifting to the right or left as H1 ions are added to or removed from the blood. As blood pH rises (becomes more alkaline due to the addition of a strong base), the equilibrium shifts to the right, forcing more carbonic acid to dissociate.

- Other buffers include **protein buffers** e.g. ***hemoglobin & serum albumin*** buffers in the blood and ***phosphate buffer*** in cells: $H_2PO_4^- \longleftrightarrow H^+ + HPO_4^=$