Introduction to Biochemistry

Biochemistry

Is it Biology or Chemistry

بيوكمستري تخصصان

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لا أحل النشر والتصوير

Biochemistry

It is sort of in between, quite literally, in term of size

Biochemistry

In the great panoply of sciences, biochemistry sits in the middle.

Biochemistry

Chemistry

If we go smaller, we get into small molecules made of just a few atoms, which is chemistry,

If instead, we go much bigger, we are looking no longer at individual molecules, but entire cells or parts of and cell.
That is biology

Biology

Biochemistry

Chemistry

Big

Science panoply

Small

Biology

Biochemistry

Chemistry

Right in between is biochemistry

Big

Science panoply

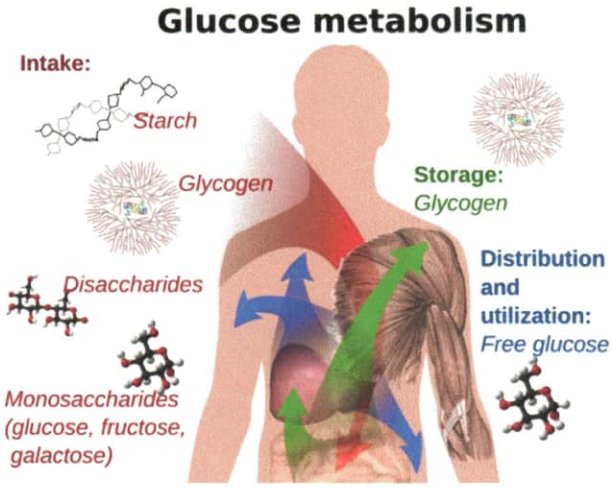
Small

Biochemistry →

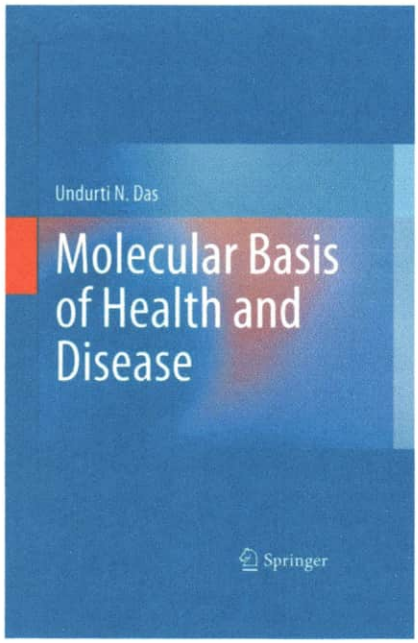
- Protein
- DNA
- Lipids
- Carbohydrates
- Enzymes
- And other biomolecules ☺

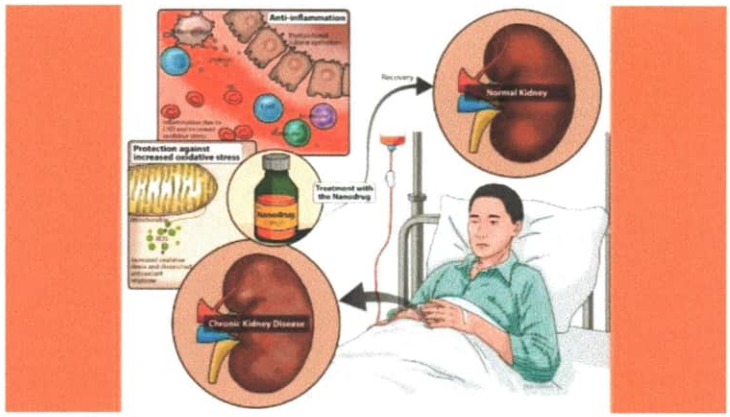
Biochemistry is indeed the domain of large biomolecules like proteins, DNA, and other essential components of life, and understanding these molecules is absolutely critical.

Anything that has to do with nutrition, medicine, or general health is rooted in biochemistry.



Nutrition is intrinsically linked to metabolism—the complex chemical process by which your body converts the food you eat into energy and essential molecules needed for growth, repair, and maintenance.





Your health is intricately governed by biochemistry, as all diseases and bodily functions are rooted in molecular processes.

Objectives

1. To define biochemistry.
2. To understand why biochemistry is important.
3. To Know Nutrition, dietary components and metabolic fuels.
4. Define the types of chemical bonds.
5. Know what kinds of molecules are studied in biochemistry.

WHAT IS BIOCHEMISTRY?

- Biochemistry is the study of the chemistry of biological organisms. It bridges biology and chemistry by studying how complex chemical reactions and structures give rise to life and life's processes.

دراسة التفاعلات الكيميائية المعقدة
التي تقوم بالكميات الحيوية

Why biochemistry is important?

- **Understanding the biochemical changes in the body and their physiological effects is crucial.** Biochemical changes are key to studying the pathology of any disease, allowing for interpreting these changes. This understanding also aids in analysing various biochemical tests conducted in laboratories.

Pathology

- Biochemistry is the **only field that explains the function and role of vitamins**.

Vitamins

- Biochemistry **examines the process of hormone formation** in the human body, which **aids in understanding various disorders resulting from hormonal imbalances**.

Hormones

Why biochemistry is important?

- It can **assist in deciding the appropriate dosage of medication** to prescribe or administer to patients.

dose

- **Understanding the caloric content of various components** in food is also beneficial

Calorie

Why biochemistry is important?

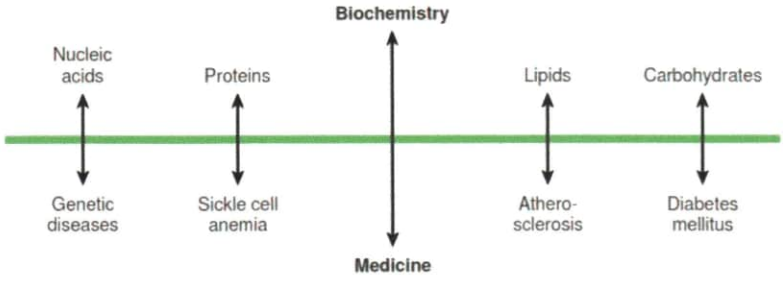


FIGURE 1–1 Examples of the two-way street connecting biochemistry and medicine. Knowledge of the biochemical molecules shown in the top part of the diagram has clarified our understanding of the diseases shown on the bottom half—and conversely, analyses of the diseases shown below have cast light on many areas of biochemistry. Note that sickle cell anemia is a genetic disease and that both atherosclerosis and diabetes mellitus have genetic components.

Nutrition, Dietary components and Metabolic Fuels:

- **Nutrition**: is the sum of the processes involved in taking food, its digestion, absorption, metabolism and their impact on health.
- **Nutrients**: chemical substances in food that perform a specific function(s) in the body. They include carbohydrates, lipids, proteins, vitamins, minerals, and water.

Nutrition, Dietary components and Metabolic Fuels

What are the energy-producing nutrients?

Nutrients are categorised into:

- **Macronutrients**: they include carbohydrates, lipids, and proteins. They are required in grams, and they are energy-producing nutrients.
- **Micronutrients**: they include vitamins and minerals and are required in milligrams or micrograms.

g	carb lipids Proteins
mg Mg	vitamins Minerals

What do we study in biochemistry?

1. Water, buffer and acid base-balance
2. Carbohydrates
3. Lipids
4. Amino acids and Proteins
5. Enzymes
6. Vitamins
7. Hormones
8. Nucleic acids
9. Metabolism and bioenergetics
10. Minerals

Water

Without water, life ceases to exist as it is the medium in which all biochemical reactions occur

الوسط الذي يحدث فيه تفاعلات بيوكيميائية

Objectives

1. To define water.
2. To understand the importance of water.
3. To understand the general function of water in the body.
4. Define the types of chemical bonds.
5. Know what kinds of molecules are studied in biochemistry.

Water

What is the definition of water?

- It is one of the most plentiful and essential of compounds.
- Transparent, odorless, tasteless liquid, a compound of hydrogen and oxygen, H 2 O, freezing at 32°F or 0°C and boiling at 212°F or 100°C.

Freezing Boiling

Water

لـ الأحياء الحية مكونة من الماء

- **Why are living things mostly made of water?**

Living things are mostly made up of water for many reasons:

1. Molecules of water play a role in the chemical reactions of living organisms.
2. Water is made up of hydrogen and oxygen (H_2O), essential to most organisms' life.

- **Up to 60-70% of the human adult body is water.**

Water

What are the roles or functions of water in the body?

1. Flushing waste from the body.
2. Regulating body temperature.
3. Transportation of nutrients.
4. It is necessary for digestion.

- **No wonder it is considered "essential!" Plain water is the best choice for hydrating the body.**

Interaction with water influence the structure of biomolecules

- The covalent bond is the strongest force that holds molecules together (Table).

- Noncovalent forces, while of lesser magnitude, predominate in stabilizing the folding of the polypeptides and other macromolecules into the complex three-dimensional conformations essential to their functional competence as well as the association of biomolecules into multicomponent complexes.

Bond Type	Energy (kcal/mol)	Bond Type	Energy (kcal/mol)
O—O	34	O=O	96
S—S	51	C—H	99
C—N	70	C=S	108
S—H	81	O—H	110
C—C	82	C=C	147
C—O	84	C=N	147
N—H	94	C=O	164

non cov. forces

Folding of PP + other Macromol. into → 3D Conform.

↓

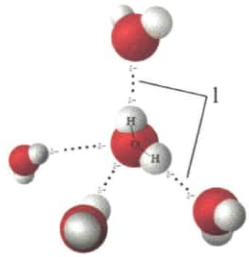
Functional Competencies

Water molecules form hydrogen bonds

- Hydrogen bonding is a critical feature of water that profoundly influences its physical and chemical properties, making it essential for biological systems.

- **Formation of hydrogen bonds**

1. Hydrogen bonds occur between a partially positive hydrogen atom (attached to oxygen or nitrogen) and an unshared electron pair on another electronegative atom. N-O-F
2. Water molecules can form up to four hydrogen bonds (two as donors and two as acceptors).



Water molecules form hydrogen bonds

1. Hydrogen bonds in water are **weak and transient**, with a half-life of a few picoseconds, allowing flexibility in molecular interactions.
2. Breaking a hydrogen bond requires, much less energy than breaking covalent bonds.
3. Water dissolves many organic biomolecules **by interacting with functional groups** (e.g., aldehydes, ketones, alcohols, carboxylic acids, amines).
4. Biomolecules can act as hydrogen bond donors or acceptors, facilitating dissolution and biochemical interactions.

- **Biological Importance**

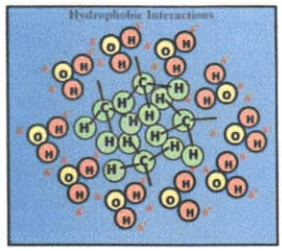
1. Stabilizes the structures of proteins and DNA.
2. Supports enzymatic reactions and biochemical processes.
3. Enables nutrient transport and waste removal in biological systems.

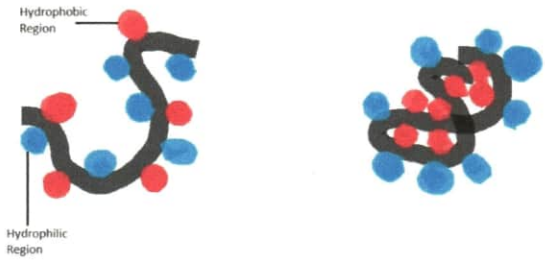
In water, biomolecules fold to position hydrophobic groups within their interior

Hydrophobic Interactions

Hydrophobic interaction refers to the tendency of nonpolar compounds to self-associate in an aqueous environment. Self-association minimises energetically unfavourable interactions between nonpolar groups and water.

يهرب من الماء ويتجمع بنفسها





In water, biomolecules fold to position hydrophobic groups within their interior

Hydrophilic and hydrophobic effects drive folding, stability, and self-assembly, while water's role as a solvent facilitates biochemical reactions and molecular interactions essential for life.

Examples of interaction of Biomolecules with Water

1. **Hydrophilic Interactions:**
   Polar and charged regions interact with water via hydrogen bonds or ionic interactions (e.g., DNA phosphate backbone).
2. **Hydrophobic Interactions**:
   Nonpolar regions avoid water, driving protein folding and lipid bilayer formation.
3. **Protein Structure:**
   Hydrophobic cores and hydrophilic exteriors are shaped by water interaction, stabilizing 3D structures.
4. **DNA/RNA Stabilization:**
   Water forms hydrogen bonds with the phosphate backbone and base pairs, maintaining structure.

P ب

H_2O —(makes H-bonds with)→ P & BP

Electrostatic interactions and water

1. ionic.
2. dipole - dipole
3. van der waals (london dispersion)

- Electrostatic interactions come in various forms, from strong ionic bonds to weak van der Waals forces. **These interactions are critical in biological and chemical systems**, affecting molecular recognition, structural stability, and dynamic processes such as enzymatic catalysis and membrane transport.

- **Water profoundly influences electrostatic interactions by reducing their strength through its polarity and high dielectric constant.** It stabilizes ions and polar groups, facilitates dissolution, and ensures the proper structure and function of biomolecules. These properties make water necessary in biological systems, where electrostatic interactions play a critical role.

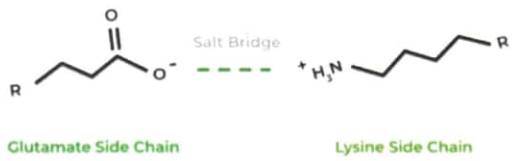
خواص الماء: Polarity, High dielectric constant → water influences electrostatic interactions by stabilizing ions - polar grps - .....

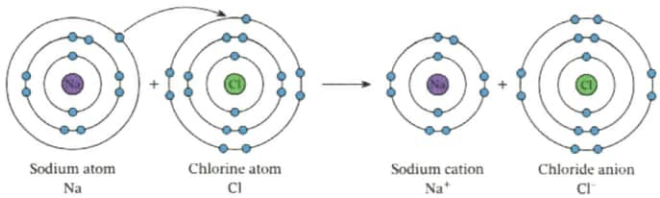
Electrostatic interactions

- **Ionic bond**

An ionic bond is a type of chemical bond that **forms through the electrostatic attraction between oppositely charged** groups (NH_3^+ and COO^-) or ions (Na^+ and Cl^-). It occurs when one atom donates an electron to another, resulting in a positively charged ion (cation) and a negatively charged ion (anion).

= transfer of e -





Electrostatic interactions

Biological Importance of Ionic Bonds

1. **Salt Bridges in Proteins**:
   Ionic bonds between charged amino acid side chains (e.g., lysine and glutamate) stabilize protein structure.

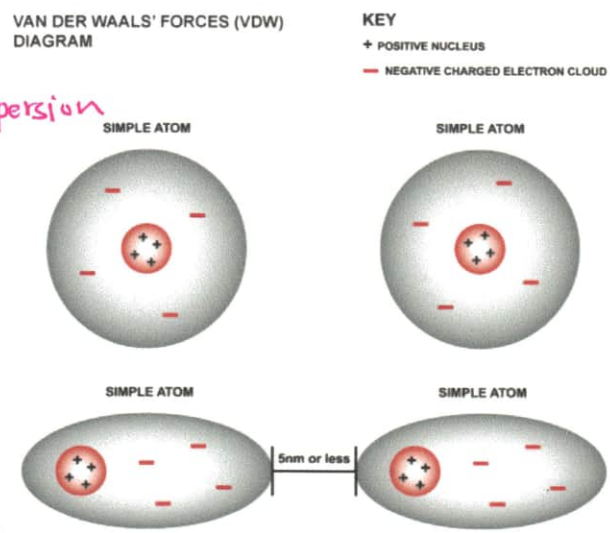
2. **Electrolytes**:
   Ionic compounds like sodium chloride (NaCl) dissociate in water, producing ions essential for maintaining cellular osmotic balance and electrical activity.

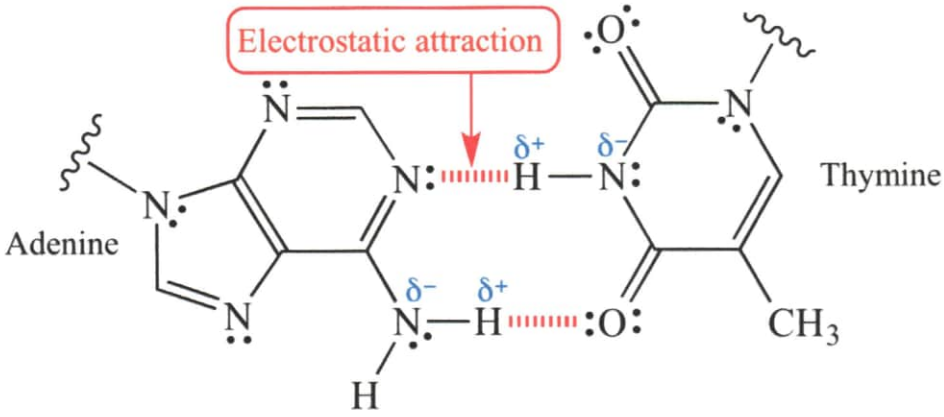
Electrostatic interactions

- **Van der Waals Forces** = London dispersion

Van der Waals forces are **weak, transient electrostatic forces** that arise due to the **momentary distribution of electrons around atoms or molecules.**

or Temporary





Electrostatic attraction (shown in red) between the δ+ and δ- ends of a polar covalent N-H bond allow for hydrogen bonding and base pairing within the DNA double helix.

Water in hydrolysis and condensation Reactions

Definitions

1. **Hydrolysis** is a chemical reaction in which water is used to **break** a covalent bond in a molecule, splitting it into smaller components.
2. **Condensation** is a chemical reaction in which two molecules **combine** to form a larger molecule, with the loss of a small molecule, typically water.

Comparison of Hydrolysis and Condensation

Feature	Hydrolysis	Condensation
Definition	Breaks bonds using water	Forms bonds and releases water
Type of Reaction	Catabolic (breakdown)	Anabolic (synthesis)
Water Role	H_2O Consumed	H_2O Produced
Energy	Often releases energy	Often requires energy
Examples	Digestion of macromolecules, ATP breakdown	Synthesis of proteins, DNA, lipids

both by enzymes

Water in hydrolysis and condensation reactions

Enzymes help water molecules break down various molecules into smaller components, a process known as hydrolysis.

Carbohydrates, fats and proteins can be split (hydrolysed) in this way:

- Large carbohydrates like starch can be split to form smaller carbohydrates like glucose. Carb. → glucose
- Fats or lipids can be split into glycerol and other molecules, including fatty acids. Fats → FA + Glycerol
- Proteins can be split into building blocks (amino acids). Proteins → aa

Condensation can be considered a building process in which two or more molecules are combined to make one molecule by removing water with the help of enzymes.

Buffering and acid-base balance

Water tends to dissociate

Dissociation Process:

- Water (H_2O) dissociates into hydrogen ions (H^+) and hydroxide ions (OH^-):

$$H_2O \leftrightarrow H^+ + OH^-$$

- The equilibrium constant (K_w) is 1.0×10^{-14} at 25°C.

Neutral pH:

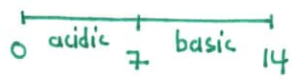
- In pure water, $[H^+]=[OH^-]=1.0\times10^{-7}$, producing a neutral pH of 7.

Understanding pH:

- pH Definition:

$$pH = -\log [H]$$

- A lower pH means higher H^+ concentration (acidic).
- A higher pH means lower H^+ concentration (basic/alkaline).
- The pH scale ranges from 0 to 14: **Acidic:** pH < 7, **Neutral:** pH = 7, **Basic:** pH > 7.



The role of water dissociation in regulating body pH

- Water dissociation is the process by which water molecules split into hydrogen (H^+) and hydroxide (OH^-) ions, **providing the foundation for the pH scale and acid-base chemistry**.

- This self-ionization enables water to act as both an acid and a base, making it essential for maintaining physiological pH (7.35–7.45) through buffering systems like bicarbonate, respiratory regulation, and renal mechanisms, which collectively ensure the stability required for vital biological functions.

Acid-base balance

The human body is a complex system composed of various levels and subsystems.

- Acids and bases are essential chemical compounds crucial for all biochemical processes.
- Biochemical reactions in the body are highly sensitive to changes in pH.
- Acid-base homeostasis is critical for:
    1. Cellular viability
    2. Enzymatic activity
    3. Protein structure and conformation
    4. Central nervous system (CNS) functions
- Changes in cellular and extracellular acid-base balance can modify these critical functions.
- To achieve acid-base balance, there must be a balance between the intake or production of hydrogen ions and net removal of hydrogen ions from the body. The various mechanisms that contribute to the regulation of hydrogen ion concentration

Acids, Bases and buffers

An acid is defined as a substance that **releases protons** or hydrogen ions (H^+), e.g. hydrochloric acid (HCl), carbonic acid (H_2CO_3).

$$HCl \longrightarrow H^+ + Cl^-$$

$$H_2CO_3 \longrightarrow H^+ + HCO_3^-$$

A base is a substance that **accepts protons** or hydrogen ions, e.g. bicarbonate ion (HCO_3^-) and (HPO_4^-).

$$HCO_3^- + H^+ \longrightarrow H_2CO_3$$

$$HPO_4^{--} + H^+ \longrightarrow H_2PO_4^-$$

Proteins in the body also function as bases, because some of the amino acids accept hydrogen ions, e.g. **hemoglobin** in red blood cells and plasma protein, mainly **albumin** is the most important of the body's bases

Acids, Bases and buffers

- **Buffer** is a solution of weak acid and its corresponding salt, **which resists a change in pH** when a small amount of acid or base is added. **The components of a Buffer are a mix of :**
    1. **Weak Acid**: Donates H^+ ions when the pH increases (neutralizes added bases). Example: Carbonic acid (H_2CO_3).
    2. **Conjugate Base**: Accepts H^+ ions when the pH decreases (neutralizes added acids). Example: Bicarbonate (HCO_3^-).

- **Example: Carbonic Acid-Bicarbonate Buffer System**
    - This system is critical in maintaining blood pH around 7.4.
    - The reaction is:

      $H_2CO_3 \rightleftharpoons H^+ + HCO_3^-$ (Excess H^+ ions combine with HCO_3^- to form H_2CO_3, reducing acidity).

      $H_2CO_3 + OH^- \rightarrow HCO_3^- + H_2O$ (Excess OH^- ions react with H_2CO_3 to form HCO_3^- and water, reducing alkalinity).

Normal pH of the body fluids

بسبب الـ CO_2 الناتج من الأنسجة

- The normal pH of arterial blood is 7.4, whereas venous blood and interstitial fluids are about 7.35 because of the extra amounts of carbon dioxide (CO_2) released from tissues to form H_2CO_3 in these fluids. **Thus, the pH of blood is maintained within a constant level of 7.34 to 7.45.**

Regulation of blood pH

The body uses three main mechanisms to regulate blood pH:

1. Buffer mechanism: First line of defense.
2. Respiratory mechanism: Second line of defense.
3. Renal mechanism: Third line of defense.

Buffer mechanism

1. Buffers of extracellular fluid present in plasma
    i. Bicarbonate buffer ($NaHCO_3/H_2CO_3$).
    ii. Phosphate buffer (Na_2HPO_4/NaH_2PO_4).
    iii. Protein buffer (Na protein/H protein).
2. Buffers of intracellular fluid present in RBCs
    i. Bicarbonate buffer ($KHCO_3/H_2CO_3$).
    ii. Phosphate buffer (K_2HPO_4/KH_2PO_4).
    iii. Hemoglobin buffer (KHb/HHb), ($KHbO_2/HHbO_2$).

Acid-base disorders

- Acid-base disorders result from a variety of pathological conditions. If the pH is higher than the normal range, then it is termed alkalemia, and if it is lower than the normal range, it is called acidemia. The conditions are called alkalosis and acidosis, respectively (Table).
- There are two reasons for the pH abnormalities in blood, which are metabolic or respiratory causes.
    1. Metabolic causes are responsible for metabolic acidosis and metabolic alkalosis.
    2. The respiratory causes are responsible for respiratory acidosis and respiratory alkalosis.

Condition	Type	Primary Cause	Mechanism	Examples of Causes
Acidosis	Metabolic Acidosis	Excess production of acids or loss of bicarbonate	Decreased HCO3-, leading to lower pH.	Diabetic ketoacidosis, lactic acidosis, renal failure, diarrhea (loss of bicarbonate).
Acidosis	Respiratory Acidosis	Hypoventilation or reduced gas exchange	Increased CO2, leading to higher H2CO3 and H+.	Chronic obstructive pulmonary disease (COPD), asthma, respiratory depression (e.g., drugs).
Alkalosis	Metabolic Alkalosis	Loss of acids or excessive bicarbonate	Increased HCO3-, leading to higher pH.	Vomiting (loss of gastric acid), overuse of antacids, diuretics causing loss of H+.
Alkalosis	Respiratory Alkalosis	Hyperventilation	Decreased CO2, leading to lower H2CO3 and H+.	Anxiety, pain, high-altitude breathing, fever.

السعة الشرح