Sawa University

Biochemistry I

Biochemistry at Water PH, Acid-base Balance

Sawa University | جامعـــــــة ســـــــــاوة الاهلية

College of health and medical techniques | كليـــــــة التقنيـــات الصحيـة والطبيـة

Department of Medical Laboratories | قسم تقنيات المختبرات الطبية

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الجانب النظري محاضرة رقم 4

Lecture No. 4 Theoretical

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Topics

- **Biochemistry at Water PH, acid-base balance :**
  - **Subtopics:**
    - **Acid-Base Balance**
    - **Importance of Acid-Base Balance**
    - **Regulation of Acid-Base Balance**
    - **Acidosis and Alkalosis**
      - **Respiratory Acidosis**
      - **Metabolic Acidosis**
      - **Respiratory Alkalosis**
      - **Metabolic Alkalosis**

Acid-Base Homeostasis in the Body

❑ Acid-Base Balance

- **Acids**: Acids dissociate to **release hydrogen ions (H^+)**, also known as **protons or** is **a proton donor.**

- **Alkalis**: An **alkali** dissociates to **release hydroxyl ions (OH^-) or** is **a proton acceptor**.

- While **alkalis** can neutralize **acids**, **acidosis (increased acidity)** is more common than **alkalosis (decreased acidity)** because the body's metabolism tends to generate

Strong vs. Weak Acids:

– **Strong acids:** Completely dissociate in aqueous solution, releasing a large number of **H^+**. For example, hydrochloric acid **(HCl)**.

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

– **Weak acids:** Only partially dissociate, producing fewer **H^+**. For example carbonic acid (**H_2CO_3**).

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

- **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 to it. By buffering mechanism, a **strong acid** (or **base**) is replaced by a weaker one.

$$\underset{\text{(strong acid)}}{H^+Cl^-} + \underset{\text{(buffer)}}{NaHCO_3} \leftrightarrow \underset{\text{(weak acid)}}{H_2CO_3} + \underset{\text{(neutral salt)}}{NaCl}$$

❑ Importance of Acid-Base Balance

— **Acid-base balance** is crucial for maintaining normal physiological functions, particularly in controlling **hydrogen ion ($H^{\pm}$) concentration**. The normal extracellular fluid **pH** is around **7.4**, and any imbalance can lead to conditions like acidosis (**increased acidity**) or alkalosis (**decreased acidity**).

❑ Carbon Dioxide (CO_2) Formation

- **Aerobic metabolism**: Converts **carbon**, **hydrogen**, and **oxygen** from **organic compounds** into **carbon dioxide** (**CO_2**) and **water**. **CO_2** plays a key role in **the body's acid-base buffering system.**

- **CO_2 as a Buffer Component**: When dissolved in blood, **CO_2** reacts with water to form **carbonic acid** (**H_2CO_3**), which dissociates into **H^+** and **bicarbonate** (**HCO_3^-**). This process is central to regulating $CO_2 + H_2O \leftrightarrow H_2CO_3 \leftrightarrow H^+ + HCO_3^-$

❑ Metabolic Sources of Acids

- During metabolic processes, two types of **acids** are produced:

1) non-volatile acids: **Fixed acids are non-gaseous acids** such as:
   - **Phosphoric** and **sulfuric acids** are produced from the **sulfur** and **phosphorus** of **proteins** and **lipoproteins**.
   - **Organic acids** such as **pyruvic acid, lactic acid, keto acids** and **uric acid.**
2) Volatile acids: **CO_2 excretion via the lung,** the physiologically important volatile acid is **carbonic acid (H_2CO_3).**

Metabolic Sources of Bases

- **The catabolism** of a few food materials produces bases. For example:
  - **Citrate salts** of fruit juices may produce **bicarbonate salt**.
  - **Deamination** of amino acids produces **ammonia (NH_3).**

Regulation of Acid-Base Balance (Regulation of Blood pH)

To maintain the blood **pH** at **7.35 –7.45, there are three primary systems** that regulate the **hydrogen ion concentration** in the body fluids. These are:

1) **Buffer mechanism:** First line of defense. Chemical buffering by intracellular and extracellular buffers.
2) **The respiratory mechanism:** Second line of defense. Control of **pCO_2** by normal respiratory function.
3) **Renal mechanism:** Third line of defense. Control of **HCO_3^-** concentration and acid excretion by the kidney

- Some of most critical ions in body fluids are **H^+** (**hydrogen**) and **OH^-** (**hydroxyl**) ions. The concentrations of these two ions affect the **acidity** or **alkalinity** of body fluids. **Acidity/alkalinity** is measured on **pH** scale

– **pH** of 7 is **neutral**
– **pH** < 7: more **H^+**, fewer **OH^-** **acidic.**
– **pH** > 7: fewer **H^+**, more **OH^-** **basic.**

1. **Buffer mechanism:**

- **Buffer Systems and their Role in Acid-base Balance**

– **The buffer systems** of **the blood**, **tissue fluids** and **cells**; immediately combine with **acid** or **base** to prevent excessive changes in **hydrogen ion ($H^{\pm}$) concentration**.

- **Blood Buffers**

– Various buffer systems present in human body are given below

a) **HCO_3^{-}/H_2CO_3**: Most important in **plasma**, **glomerular filtrate** & **RBCs**.

$$CO_2 + H_2O \leftrightarrow H_2CO_3 \leftrightarrow H^+ + HCO_3^-$$

b) **HPO_4^{-2}/H_2PO^{-4}**: Most important in **urine**.

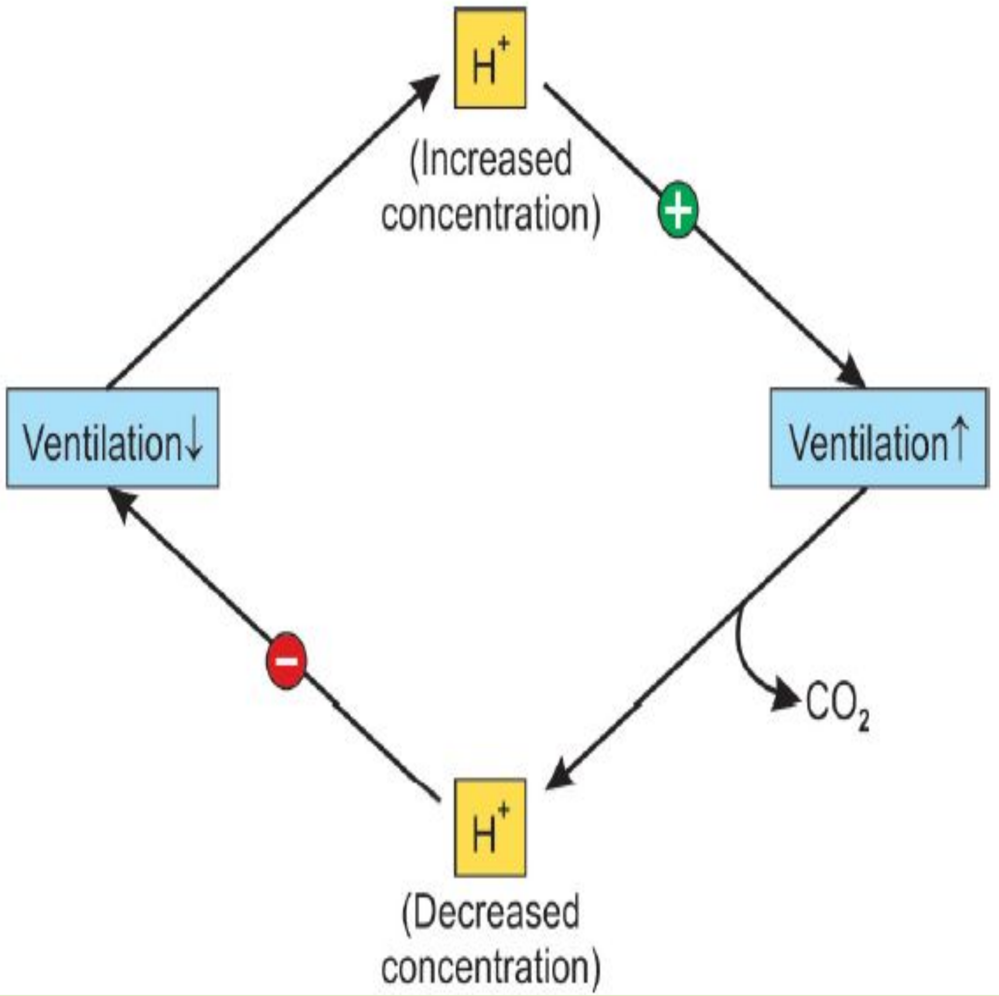
c) **Plasma Proteins** as buffers: **the imidazole ring of histidene** acts as buffer. It is important in **plasma**.

d) **Hb** as buffer: important in **RBCs**.

2) Respiratory Mechanism in Acid-base Balance

– **Respiratory Function**: The respiratory system is able to compensate for changes in the **acid/base balance** by **increasing or decreasing the ventilatory rate**. This would result in an increase or decrease of **pCO_2** in the blood, thus changing the bicarbonate

– **Respiratory Mechanism:** The respiratory system acts as a feedback controller of $\mathbf{H^+}$ concentration. Increased $\mathbf{H^+}$ concentration stimulates respiratory center and **alveolar ventilation**. This decreases the concentration of **CO_2** in extracellular fluid and reduces $\mathbf{H^+}$ concentration back to normal. Conversely, decreased $\mathbf{H^+}$ concentration below normal depresses respiratory center and alveolar ventilation and $\mathbf{H^+}$ concentration increases back to normal.



3) Renal Mechanism in Acid-base Balance

- <u>**Renal mechanism**</u> is **the third line** of defense in **acid-base balance**.
- **Renal mechanisms** exert long-term **acid-base control**.
- **The renal mechanism** is the most complex and effective.
- <u>**Renal compensation**</u> occurs by three main mechanisms:-

1) **Bicarbonate ions** <u>**reabsorption**</u> in **proximal tubules**.
2) **Bicarbonate ions** <u>**regeneration**</u> in **distal tubules**.
3) **A normal diet** produces more **acid** than **alkaline** waste products.

- The **pH** of the initial **glomerular filtrate** is approximately **7.4**, the same as that of the **plasma**.
- The **pH** of the urine may vary from **4.5** to **8.0** corresponding to the case of **acidosis** or **alkalosis**. In **acidosis**, the excretion of **acids** is increased and the **base** is conserved, in **alkalosis**, the opposite occurs. This ability to excrete variable amounts of **acid** or **base** makes **the kidney**, the final defense mechanism against change in body **pH**.

❑ Acidosis and Alkalosis

— **Acid-base balance** depends on the ***ratio*** HCO_3^-/H_2CO_3 which is constant at ***20:1*** at physiological **pH**. Any alteration produced in the ratio between **carbonic acid** **(H_2CO_3)** and **bicarbonate** **(HCO_3^-)** results in an **acid-base imbalance** and leads to **acidosis** or **alkalosis.**

- ***Acidosis*** may be defined as an abnormal condition caused by the accumulation of excess **acid** in the body or by the loss of **alkali** from the body.
- ***Alkalosis*** is an abnormal condition caused by the accumulation of excess **alkali** in the body or by the loss of **acid** from the body.

❑ Acid-Base Balance Disturbances

There are several classifications of acid-base balance disturbances:

— **Respiratory Alkalosis**

— **Respiratory Acidosis**

— **Metabolic Alkalosis**

— **Metabolic Acidosis**

1. Acidosis

- **Acidosis- a decline in blood pH ↓**
  - **Respiratory acidosis:** due to an increase in **carbonic acid ↑. (Accumulation of excess acids(**
  - **Metabolic acidosis:** due to a decrease in **bicarbonate ↓. (Excessive loss of bases)**

❖ Respiratory Acidosis

– It results from an increase in the concentration of **carbonic acid** (**H_2CO_3**) in plasma (**Acidosis** is caused by an accumulation of **CO_2**), lowering the **pH** of the blood to less than **7.35**. An increase in the concentration of **H_2CO_3** is due to a decrease in **alveolar ventilation (hypoventilation)**, and that leads to the retention of **CO_2**. Any condition that results in **hypoventilation** can cause respiratory acidosis. These conditions include:

1. **Obstruction to respiration**: This may occur in **pneumonia**, **emphysema**, **asthma**, etc.
2. **Depression of respiration**: Administration of respiratory depressant **toxic drugs**, e.g. **morphine** depresses the respiratory center.
3. **Neuromuscular diseases** and **chest abnormalities**.

✔ Compensatory mechanisms: **Increase in renal reabsorption of bicarbonate**.

❖ Metabolic Acidosis

– A fall in blood **pH** due to decreased plasma **bicarbonate** levels is called **metabolic acidosis**.

- Decrease in **bicarbonate** levels may be due to:
  - **Increased production of acids**. In uncontrolled **diabetes mellitus** and **starvation**, **acetoacetic acid** and **β-hydroxybutyric acid** are excessively produced. These acids are buffered by utilizing the base component (i.e. HCO_3^-) of the **bicarbonate** buffer. Consequently, the concentration of **bicarbonate ions** falls, and results in **metabolic acidosis** (**ketoacidosis**).
  - Excessive loss of **bicarbonate** occurs through **the urine** in cases of **renal tubular dysfunction** and through the **gastrointestinal tract** during **severe diarrhea**

✔ Compensatory mechanisms

– **Metabolic acidosis is compensated by:**

1. Increasing rate of respiration (**hyperventilation**) to wash out CO_2 (hence H_2CO_3) faster. Consequently, the ratio $HCO_3^- : H_2CO_3$ is elevated.
2. Increasing excretion of H^+ ions as NH_4^+ ions.
3. Increasing elimination of acid ($H_2PO_4^-$) in the urine.

1. Alkalosis

- **Alkalosis - a rise in blood pH ↑**
  - **Respiratory alkalosis:** due to a decrease in **carbonic acid ↓.** (Excessive loss of acids)
  - **Metabolic alkalosis:** due to an increase in **bicarbonate ↑.** (Accumulation of excess bases(

❖ Respiratory Alkalosis

- **Respiratory alkalosis** is defined as a **pH** greater than **7.45** with a **pCO_2** less than 35 mmHg.
- **Respiratory alkalosis** appears if the removal of **CO_2** is greater than its production by tissues.
- Any condition that causes **hyperventilation** can result in **respiratory alkalosis**. These conditions include:

1. Increased metabolic demands, such as **high fever, sepsis,** and **pregnancy**.
2. Lack of oxygen, **hypoxia.**
3. Excessive artificial respiration.
4. Pulmonary diseases.

✔ Compensatory mechanism: **glomerular filtration of bicarbonate ion**, **lowering of bicarbonate regeneration**, because the fall in **pCO_2** slows the carbonic anhydrase mechanism in renal tubules. The compensatory fall in [HCO_3^-] tends to correct **pH**.

❖ Metabolic Alkalosis

– A rise in blood **pH** due to rise in the **bicarbonate** levels of plasma is called **metabolic alkalosis**. This is seen in the following conditions:

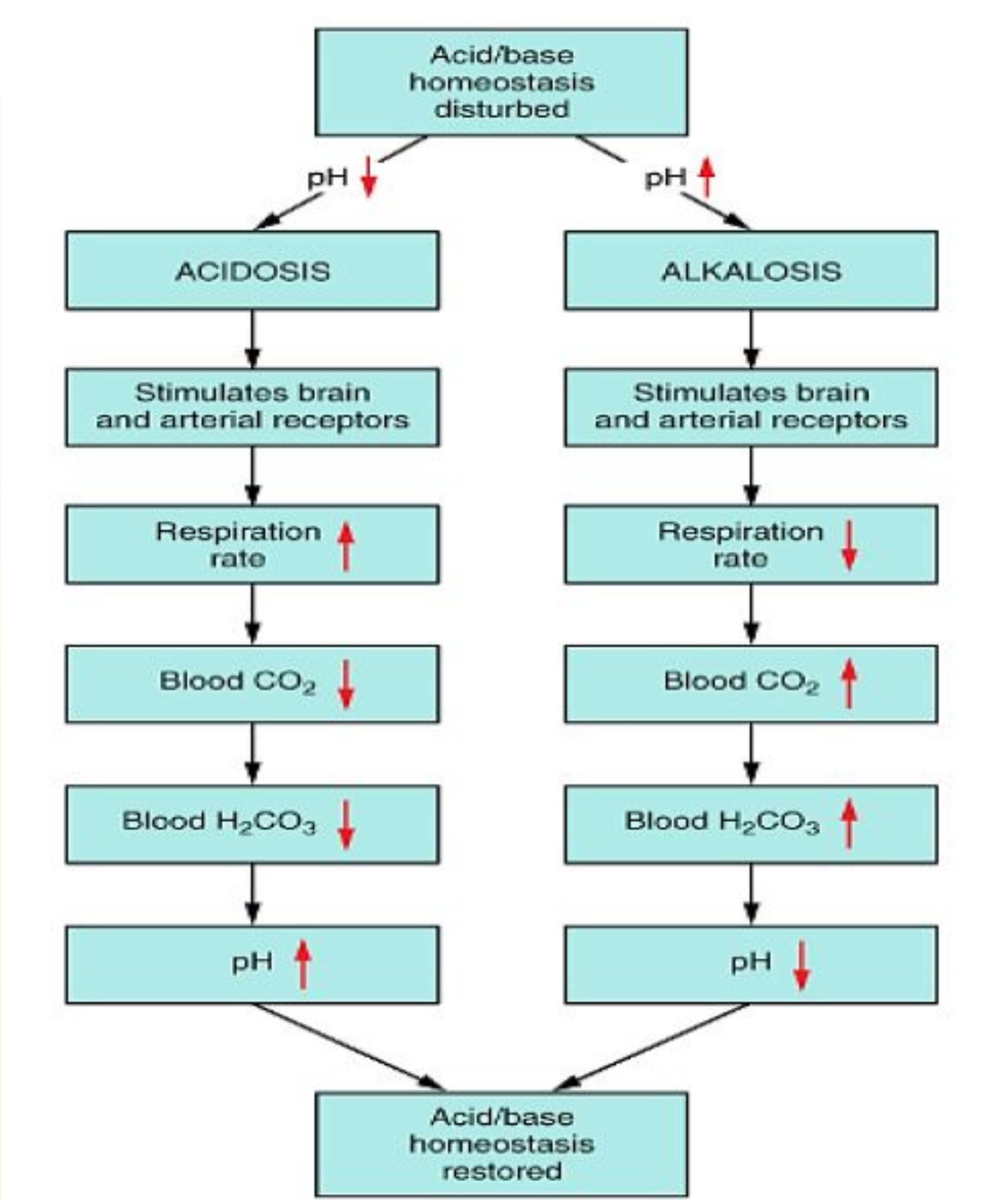
- Loss of gastric juice along with $\mathbf{H^+}$ ions in prolonged and severe vomiting.
- Therapeutic administration of large dose of alkali (as in peptic ulcer) or chronic intake of excess antacids.

✔ Compensatory mechanisms

1. Increased excretion of alkali (HCO_3^-) by the kidney.

2. Diminished formation of ammonia.

3. Respiration is depressed to conserve CO_2.


Acid/base homeostasis disturbed
pH
pH
ACIDOSIS
ALKALOSIS
Stimulates brain and arterial receptors
Stimulates brain and arterial receptors
Respiration rate
Respiration rate
Blood CO_2
Blood CO_2
Blood H_2CO_3
Blood H_2CO_3
pH
pH
Acid/base homeostasis restored

Any questions?

Thank You