MED439
KING SAUD UNIVERSITY

Physiology Team 439

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PHYSIOLOGY

BASICS OF ACID-BASE

Objectives

- What are acids and bases?
- What is meant by a weak/strong acid or base?
- What is the normal pH of body fluids?
- Why is it important to keep body pH within certain limits?
- What are the body's defense mechanisms against changes in blood pH: body buffers, the lungs and the kidney.
- Understand the role of the kidney in regulating pH of the body fluids.
- Acid-base disturbances.
- To explain the role of Henderson-Hasselbalch equation in acid-base regulation

Black: in male AND female slides
Red : important
Pink: in female slides only
Blue: in male slides only
Green: Notes
Gray: extra information

Editing file

Acids

01

Acids are molecules that **donate, release H^+ ions** into solutions
$HCl \rightarrow H^+ + Cl^-$ in H_2O solutions

Strong Acids dissociate **all** their H^+ when dissolved in H_2O, **releasing a large amount of H+** (e.g. hydrochloric acid HCl)

02

Weak acids dissociate **partially** when dissolved in H_2O , **releasing small amounts of H^+** (e.g. carbonic acid H_2CO_3)

Body solutions are mainly weak acids to avoid sharp changes in pH

03

Normal $[H^+]$ = 0.00004 mEq/L (40 nEq/L) if $[Na^+]$ = 145 mEq/L

04

05

Protons (H^+) are highly reactive chemical species that combine easily with negative charged ions and bases.

Precise H^+ control is vital because almost all enzymes are influenced by it

A hydrogen ion is a single free proton released from a hydrogen atom. Molecules containing hydrogen atoms that can release hydrogen ions in solutions are referred to as acids. An example is hydrochloric acid (HCl), which ionizes in water to form hydrogen ions (H^+) and chloride ions (Cl^-). Likewise, carbonic acid (H_2CO_3) ionizes in water to form H^+ and bicarbonate ions (HCO_3 –).

06

Bases

01

Bases are molecules that **accept H^+ ions** into solutions
(e.g. Bicarbonate ions HCO_3-)
(e.g. Hydrogen phosphate $HPO4^{-2}$).
(They carries a -ve charge so it can easily attract Hydrogen which is positive charge)

$HCO^{3-} + H^+ \rightarrow H_2CO_3$ in H_2O solutions

02

03

Alkali is a molecule formed by one of the alkaline metals (Na, K, Li) with a highly basic ion (OH^-)

Alkali also can be defined as a base that dissolves in water.

Strong bases dissociate easily in H_2O and quickly bind to H^+
Weak bases accept H^+ more slowly

04

Acid-Base balance

Acid-base balance is concerned with the precise regulation of free (unbound) hydrogen ion (H^+) concentration in body fluids.
Especially in ECF (interstitial + plasma) , because it's the fluid where cells swim inside:"internal environment"

Slight deviations in [H^+] have **profound effects** on enzyme and protein activity and thus the body's metabolic activity in general.
Because of many functions in the body are controlled by enzymes > enzymes get affected by acid conc.

Changes in [H^+] affects K^+ levels in the body.

Why is the Body's [H+] Constantly Changing?

A number of processes can alter H^+ concentration in the body , such as:

◇ Generation of acids & bases from stored fat, amino acid, glycogen and protein metabolism.

Catabolism of amino acid release bases and acids "**non-**volatile acid like CO2". There are many types of Non volatile acid will be released such as sulfuric acid.
Non volatile acids cannot be excreted by the lungs -> therefore acid will accumulate.

◇ Metabolism of ingested food.

Our ingested food can contain **acids and bases**, they may affect pH, H+ ion concentration. The end product of Metabolism of glucose = CO_2 + H_2O
CO_2 is a potential volatile acid (اسيد متطاير) because it can be **combined with water** in the **presence of carbonic acid** and give us -> **H+ ions and bicarbonate**

◇ GI secretions. (As a physiological conditions the **stomach secrete acid (Hcl)** and we need this acid to digest proteins. and the opposite in the **intestine is secret base**)

Whenever hydrogen is secreted into the lumen of the stomach, bicarbonate is excreted into the circulation that surrounds the lumen so the blood becomes alkaline.
The opposite thing happens in the Intestine. Because secretion of intestine is actually alkaline. So hydrogen ions are excreted into the circulation.
So as a final result the blood that will exist the GI system **it will be Neutral** (PH in balance neither acid nor base)
In other word: the blood circulating around the stomach Is alkaline due to secretion of bicarbonate in blood after the secretion of H+ in the lumen of stomach.
Then this blood when it goes to intestine it becomes balanced after adding hydrogen in the circulation because of the alkaline secretion of intestine.
This is a physiological condition happens in our body that ends with "balance blood". it becomes problematic "imbalance" in:
1. Vomiting —> body Loss HCl (Acid), the blood becomes more alkaline.
2. Diarrhea —> body loss bicarbonate (Base), the blood becomes more acidic.

◇ Changes in CO_2 production. (CO_2 is potentially volatile Acid)

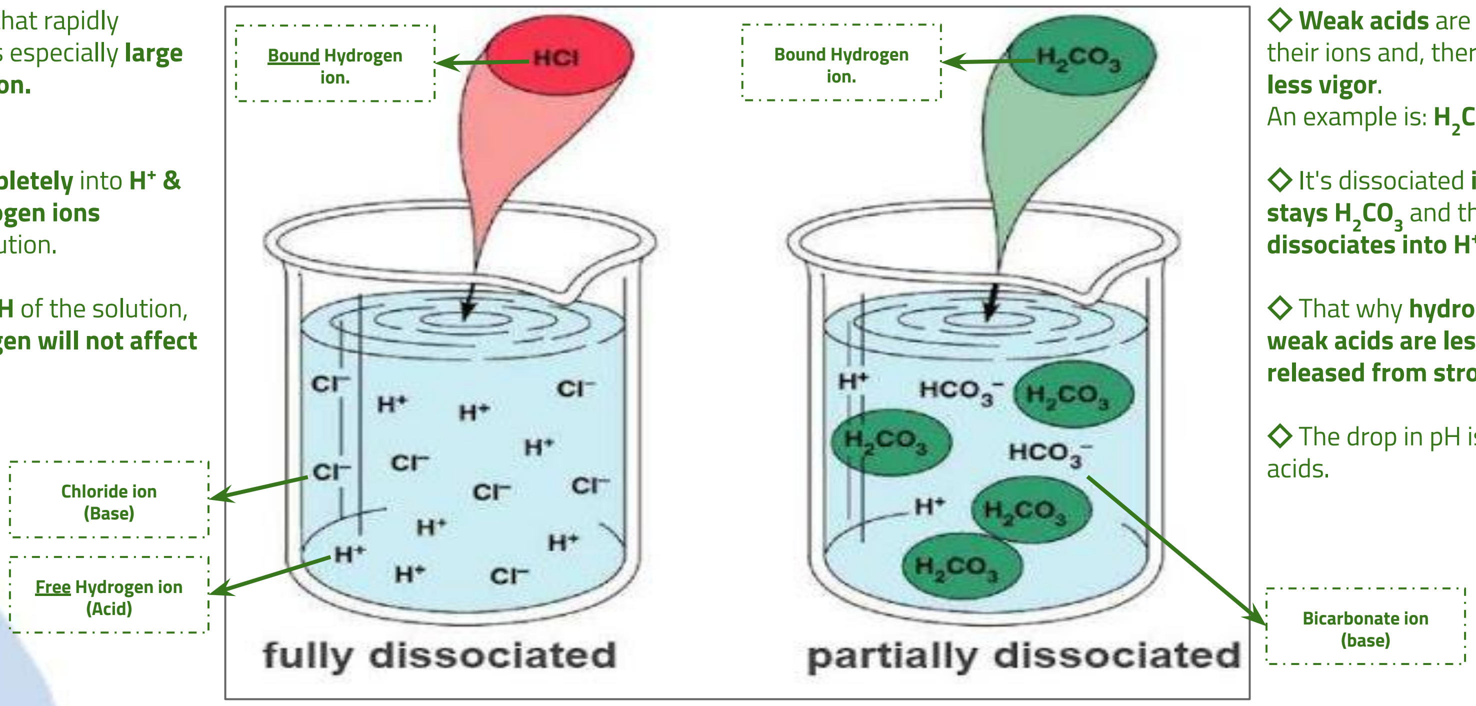
1. Whenever metabolism increase —> Production of CO_2 will increase. **(Proportional with Metabolism)**
2. Whenever Ventilation get inhibited —> Production of CO_2 will Increase . and this will lead to Acidosis. **(Inversely with Ventilation)**

Difference between strong & weak acid

◇ **A strong acid** is one that rapidly dissociates and releases especially **large amounts of H^+ in solution.**
An example is: **HCl.**

◇ They **dissociate completely** into **H^+ & Cl^-** leading to **high hydrogen ions** concentration in the solution.

◇ **Free H^+ effects the pH** of the solution, while the **bound Hydrogen will not affect the pH** of solution.



◇ **Weak acids** are **less likely to dissociate** their ions and, therefore, **release H^+ with less vigor**.
An example is: **H_2CO_3**.

◇ It's dissociated **incompletely**. **Part of it stays H_2CO_3** and the **other part dissociates into H^+ & HCO_3^-**

◇ That why **hydrogen ion released from weak acids are less than hydrogen ions released from strong acids.**

◇ The drop in pH is much **less than** strong acids.

Henderson-Hasselbalch Equation

Means the base that derivatives from the weak acid (H_2CO_3) which is **HCO_3-**

$AH \rightarrow A^- + H^+$

Acid → Conjugate base + H^+

Concentration of products depends on two:
1-The concentration of WEAK acid "AH"
Multiply
2-Dissociation constant (K) ثابت التفكك
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The extent to which a given acid dissociates in solution is constant. Also known as the **Dissociation constant (K).**

The ratio of dissociated to undissociated forms of the acid is constant and shows the strength of an acid.

$$K = \frac{[H^+][A^-]}{[AH]}$$

Carbonic acid "weak acid"

$$H_2CO_3 \leftrightharpoons HCO_3- + H^+ \longrightarrow K = \frac{[H^+][HCO_3^-]}{[H_2CO_3]}$$

Male slides only

- Relates pH to the ratio of the concentration of conjugate base and acid.
- pH = pK x log (base / acid)

$$H_2CO_3 \leftrightharpoons HCO_3- + H^+ \longrightarrow K = \frac{[H^+][HCO_3^-]}{[H_2CO_3]}$$

$$H^+ = \frac{[K'][HCO_3^-]}{[H_2CO_3]}$$

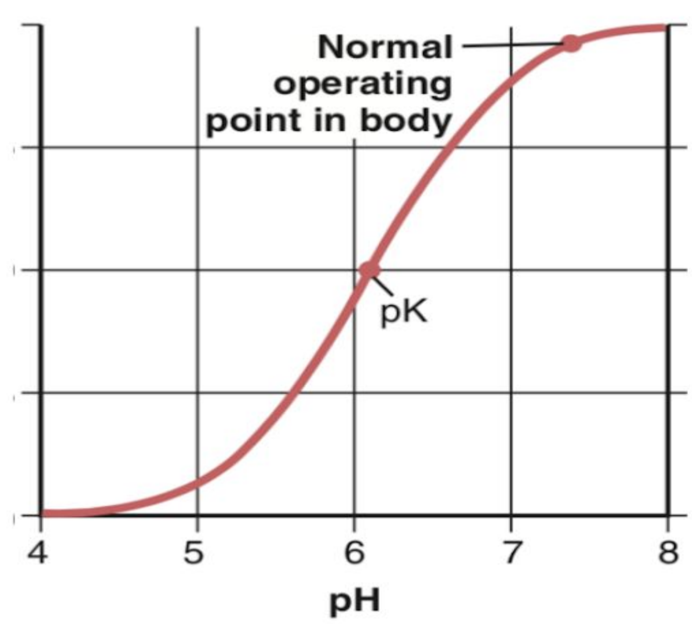
$$H^+ = \frac{[K][0.03][CO_2]}{[HCO_3-]}$$

$$-\log H^+ = -\log K \times -\log \frac{[0.03][CO_2]}{[HCO_3-]}$$

$$pH = pK \times \log \frac{[HCO_3-]}{[CO_2]}$$

pK Dissociation Constant

- pK (also a log) is where concentration of both components of the buffer are equal.
- Remember to maintain plasma pH at 7.4, there needs to be much more HCO_3- than H_2CO_3
- pH = pK x base/acid
- pH = pK x 50/50
- pH = pK



pH & H^+ ion concentration

01

H^+ ion concentrations are expressed as pH.
pH= - Log $[H^+]$
OR =log (1/ [H^+])
(this means when H+ increases —> the PH will Decrease)

02

pH is the log of the reciprocal of the H^+ ion concentration.

	$[H^+]$(mEq/L)	pH
Extracellular fluid	-	-
Arterial blood	4.0×10^{-5}	7.4
Venous blood	4.5×10^{-5}	7.35
IF	4.5×10^{-5}	7.35
Intracellular fluid	1×10^{-3} to 4×10^{-5}	6.0 - 7.4
Urine	3×10^{-2} to 1×10^{-5}	4.5 - 8.0
Gastric HCL	160	0.8

03

If the **$[H^+]$ decrease** → **pH** will **increase** (more alkaline)
If the $[H^+]$ **increase** → pH will **decrease** (more acidic)

04

pH levels range inside body fluids based on its function.

05

One point change in pH results in a **ten fold** change in H^+ ion concentration.

06

Activities of all enzyme systems in the body is influenced by hydrogen ions.

07

The **normal pH** of the ECF is **7.35 - 7.45** (the average=7.4)
Death is most likely if **pH >8** or **<6.8**

08

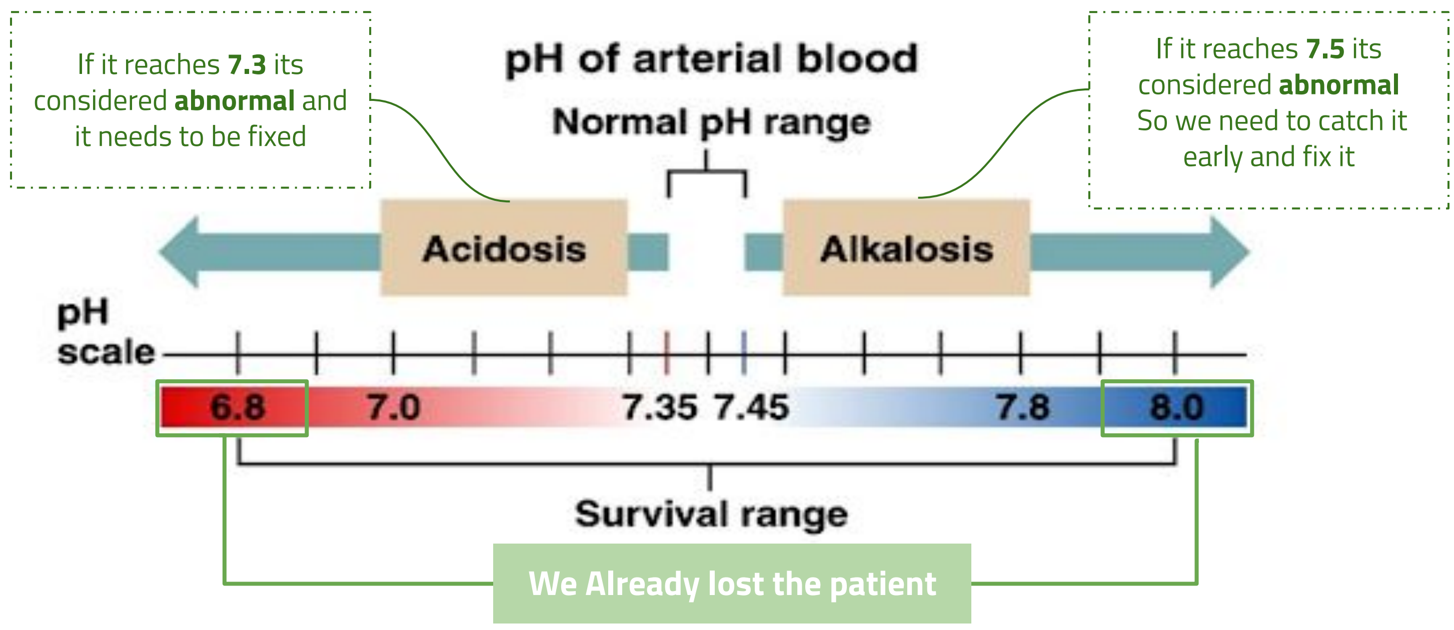
Because **H ion concentration in blood is so low** that it is expressed in negative log to the base 10 of H ion concentration.

09

H^+ ions are deadly because they can affect cell function by altering the charge of functional proteins including enzymes

10

H ions are very reactive cations and bind to protein anions strongly if they are in high amounts and impair their activity



Acid production by the body

1

Generally, the body produces **acids more than bases** and they're of two types as by products of:
- Metabolism of dietary proteins.
-Anaerobic metabolism of carbs and fat.

2

1. Volatile: in aerobic metabolism (CO_2). $CO_2 + H_2O \rightarrow H_2CO_3 \rightarrow H^+ + HCO_3^-$

(formation catalyzed by carbonic anhydrase)

3

Produces 12,500 mmol or 300 L of CO_2/day.
Normal daily diet yields 80 meq/day. Mostly excreted by the lung(volatile)

2 & 3 Volatile

4

2. Non-volatile: generated by the incomplete metabolism of carbohydrates, lipids & proteins

5

Incomplete Carbohydrate and Fat Metabolism Produces Nonvolatile Acids:

4,5,6 & 7 Non-Volatile

6

Eg. strenuous exercise, hemorrhagic or cardiogenic shock, uncontrolled diabetes mellitus, starvation, and alcoholism

7

Daily acid load is 50-100 mEq/day (0.8 mEq/kg/d). E.g. phosphoric acid, lactic acid, Butyric acid,keto acid produced by the metabolism of fat, sulfuric acid produced by metabolism of sulfur-containing amino acids). Mostly excreted by the kidneys (non-volatile)
In normal/ average condition there is 1ml mole (1mEq) of acid is added **per kg per day**
70mEq/kg/d of acid THIS IS LETHAL! because as we know the normal hydrogen conc. is 0.00004mEq/kg/d
So, the body has to have a <u>protective mechanism</u> to protect the body against this high amount of acid.

Lactic acid: produced by anaerobic metabolism of glucose and carbs

Female slides only

The body's defense against changes in H^+

◇ There are **3** main systems:

1. **Body fluid buffers:** Works within **seconds** buffers found in **ECF and ICF**, but it has limitation like it **cannot** get rid of the hydrogen in the body, The only way to get rid of hydrogen is either through the lungs or kidneys.

2. **Lungs:** Works within **minutes**, also with limitations. (cause there are non-volatile acids cannot excrete by the lungs, so the lung is effective **only if the acids is volatile**)

3. **Kidneys:** Works within **hours-days**. It is the most **powerful** of the three. It's the **only one that can rid of non-volatile acids (fixed acids)** by excreting them in the urine.

Summary

- **What are acids & bases?**
- **Acids** are molecules that donate, release, H^+ ions into solutions $HCl \rightarrow H^+ + Cl^-$ in H_2O solutions. **Bases** are molecules that accept H^+ ions into solutions e.g. HCO_3 (Bicarbonate ions), $HPO4^{-2}$ (Hydrogen phosphate)

- **What is meant by a weak/strong acid or base?**
- **Strong Acids** dissociate all their H^+ when dissolved in H_2O e.g. HCl (hydrochloric acid)
  Weak acids dissociate partially when dissolved in H_2O (e.g. H_2CO_3) (carbonic acid)
  Strong bases dissociate easily in H_2O and quickly bind to H^+
  Weak bases accept H^+ more slowly

- **What is the normal pH of body fluids?**
- The pH of normal body fluids is **7.35 - 7.45**

- **Why is it important to keep body pH within certain limits?**
- H^+ ions are deadly because they can affect cell function by altering the charge of functional proteins including enzymes. Also H ions are very reactive cations and bind to protein anions strongly if they are in high amounts and impair their activity.

- **What are the body's defense mechanisms against changes in blood pH?**
- There are 3 main systems:

1. **Body fluid buffers:** Works within seconds
2. **Lungs:** Works within minutes
3. **Kidneys:** Works within hours-days. It is the most powerful of the 3.

- **What is the role of the kidney in regulating the pH of body fluids?**
- Daily acid load is 50-100 mEq/day (0.8 mEq/kg/d). E.g. phosphoric acid, lactic acid, Butyric acid, sulfuric acid). They are mostly excreted by the kidneys.

- **What causes acid base disturbance?**
- Changes in CO_2 production, Metabolism of ingested food, GI secretions & Generation of acids & bases from metabolism of stored fat & glycogen.

- **Explain the role of Henderson-Hasselbalch equation in acid-base regulation?**
- Relates pH to the ratio of the concentration of conjugate base and acid.

$$pH = pK \times \log (base / acid)$$

MCQ & SAQ

Q1: Which of the following substances can accept a H^+

A. HCO_3^-
B. H_2CO_3
C. HCL
D. H_2CO_4

Q2: How long does it take body fluid buffers to react to a change in H^+

A. Days
B. Hours
C. Minutes
D. Seconds

Q3: Cellular metabolism produces

A. Proteins
B. CO_2
C. Lipids
D. O_2

Q4: Which of the following is a strong base

A. HCL
B. NaOH
C. HCO_3
D. H_2CO_3

Q5: The normal body pH is between

A. 7.05 - 7.15
B. 7.25 - 7.35
C. 7.35 - 7.45
D. 7.50 - 7.65

Q6: Weak acids dissociate .... when dissolved in H_2O

A. Partially
B. Completely
C. Vigorously
D. None of the above

answer key:
1: A
2: D
3: B
4: B
5: C
6: A

1- What is a strong acid and give an example?

2- What is the dissociation constant?

3- What are the 3 main systems that defend the body against a change in H^+ ?

4- What are the mechanisms of acid production in the body?

A1: Strong Acids dissociate all their H^+ when dissolved in H_2O (e.g. HCl) (hydrochloric acid)

A2: The extent to which a given acid dissociates in solution is constant. Also known as the Dissociation constant (K).

A3: **Body fluid buffers:** Works within seconds , **Lungs:** Works within minutes , **Kidneys:** Works within hours-days. It is the most powerful of the

A4: 1. Volatile: in aerobic metabolism , 2. Non-volatile: generated by the incomplete metabolism of carbohydrates, lipids & proteins

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