PHYSIO

MODIFIED NO.12

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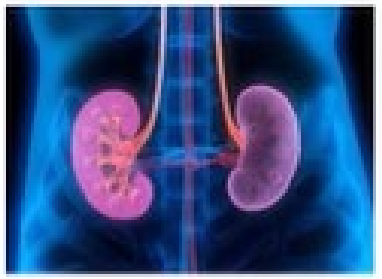

Acid Base-continued part II

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2025

Color code

- Slides
- Doctor
- Additional info
- Important

Topics will be discussed

Objectives

- Understand the mechanism of renal compensations for

Acid-Base Disorders.

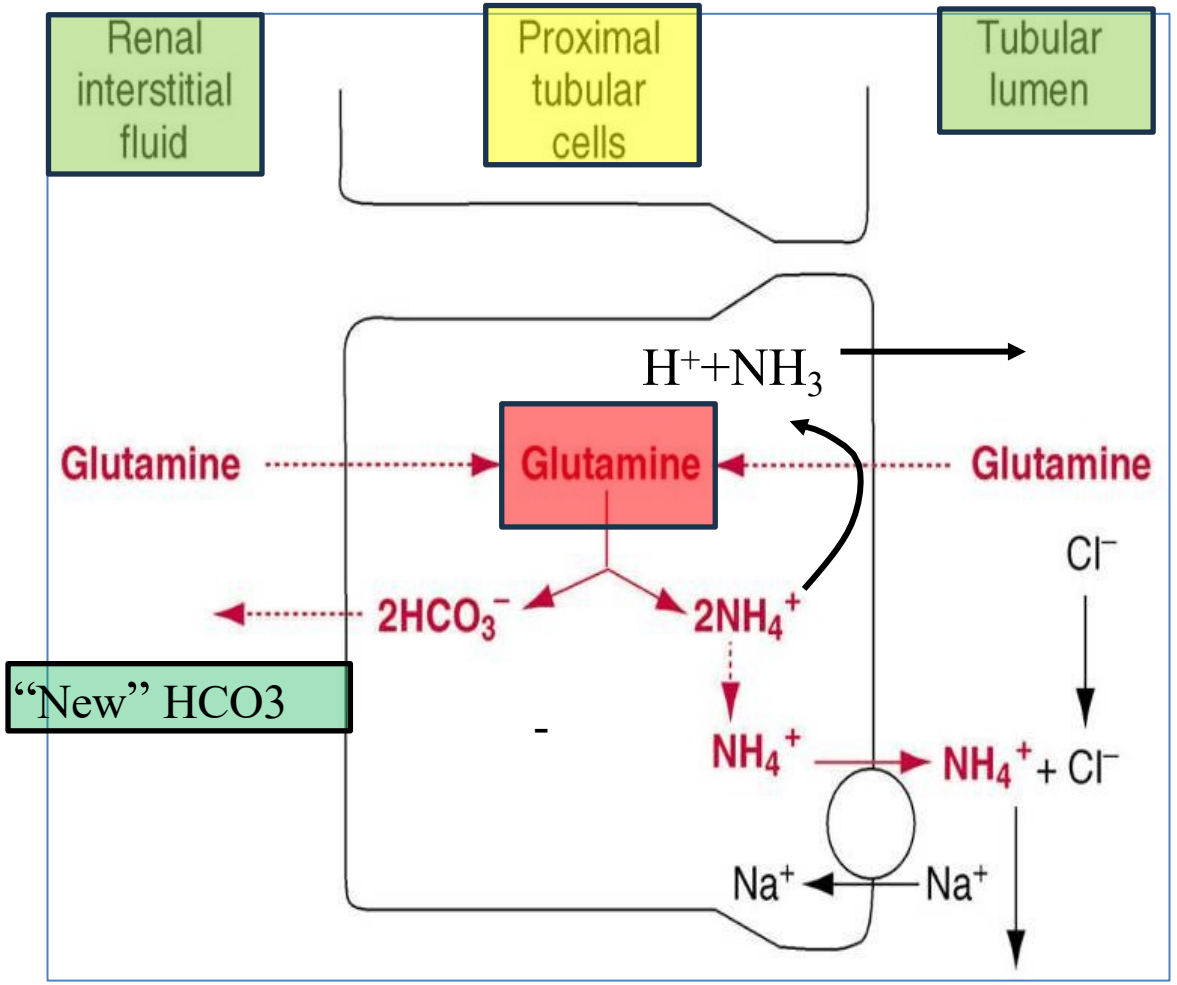
- To be able to determine the type of acid-base imbalance from given lab results and figure out the compensatory changes.
- To know how to use "Anion Gap" as a Diagnostic Tool for Metabolic Acidosis
- Identify main clinical conditions that are accompanied with acid-base imbalance

- Lets revise some concepts from modified 11:

- In acid-base physiology, bicarbonate (HCO_3^-) and hydrogen ions (H^+) interact closely in the renal tubules.
- HCO3 – and H+ normally "**titrate**" each other in the tubules. And The **secreted H^+ combines** with filtered HCO_3^- in the **lumen**, **neutralizing** it and allowing HCO_3^- to be reabsorbed.

- However, only a small amount of excess H^+ can be excreted directly in its free ionic form (H^+), because urine pH cannot drop below about 4.5.
- When there is more H^+ than can be excreted as free ions, it binds to other urinary buffers (such as phosphate NaHPO4- or ammonia NH3). These reactions result in the generation of new HCO_3^-, which is added to the blood.

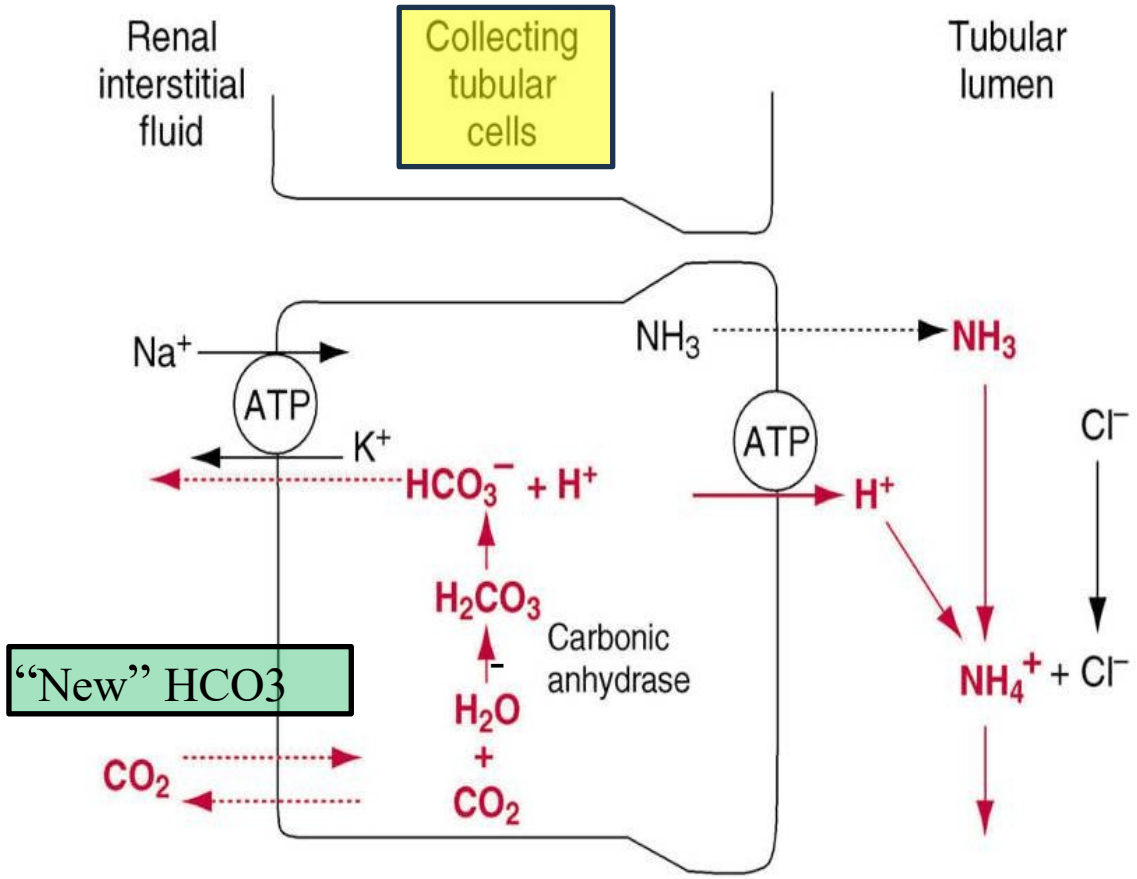
Production and secretion of NH_4^+ and HCO_3^- by proximal, thick loop of Henle, and distal tubules



In proximal tubules:

- Ammonium ion is synthesized from glutamine, which comes mainly from the metabolism of amino acids in the liver. The glutamine delivered to the kidneys is transported into the epithelial cells of the proximal tubules, thick ascending limb of the loop of Henle
- Once inside the cell, each molecule of glutamine is metabolized in a series of reactions to form bicarbonate and ammonium.
- The NH4+ is secreted into the tubular lumen by a counter- transport mechanism in exchange for sodium, which is reabsorbed.
- New HCO3− is transported across the basolateral membrane, along with the reabsorbed Na+, into the interstitial fluid
- In addition, H^+ can disassociated from ammonium ($NH4^+$) to form ammonia NH3, which would be secreted in tubular fluid. Which can be used as a buffer in tubular lumen by binding H+ there.

Buffering of hydrogen ion secretion by ammonia (NH_3) in the collecting tubules.



In the collecting tubules:

- The addition of NH4+ to the tubular fluid occurs through a different mechanism.
- NH3 acts as a buffer for H+ in the tubular lumen, and this NH3 is sourced either from capillaries or produced by tubular cells at the apical surface.
- In this process, H+ is secreted from the tubular membrane into the lumen, where it combines with NH3 to form NH4+, which is then excreted.
- The advantage of forming the ammonium ion (NH4+) is that H+ is buffered without the loss of HCO3-, leading to the formation of new HCO3-.
- In summary, H+ is titrated with NH3 without the loss of HCO3-, resulting in the formation of new HCO3-.
- Therefore, whenever an H+ secreted into the tubular lumen combines with a buffer other than HCO3-, the net effect is the addition of new HCO3- to the blood.

Quantification of Normal Renal Acid-Base Regulation

Total H^+ secretion
= 4320 mEq of H+ secreted (HCO3)+ 60 mEq of H+ non-volatile= 4380

Total H^+ secretion = 4380 mmol/day
= HCO_3^- reabsorption (4320 mmol/d)
+ titratable acid ($NaHPO_4^-$) (30 mmol/d)
+ NH_4^+ excretion (30 mmol/d)

Total H+ *Secretion* :

- **Green part :** H+ is secreted before HCO3-, and **the total amount that should be secreted** is 4320 mmol/day. **This matches the amount that needs to be reabsorbed for HCO3-**.

- **Blue part :** The goal is to conserve HCO3-.To achieve this, we need to eliminate **60 mEq** of H+ from non-volatile acids produced daily, as they cannot be excreted through respiration. We can **determine the amount of non-volatile acids by titrating the secreted H+ with other buffers like NaHPO4- and NH4+.**

1. **Titratable acid (NaHPO4-)= the concentration of base used in titrating the urine. check next slide for details**
2. **NH4+ Eexcretion = urine flow rate × [NH4+] in urine**

- The rest of the non-bicarbonate, non-NH4 + buffer excreted in the urine is measured by determining a value known as **titratable acid.** The amount of titratable acid in the urine is measured by titrating the urine with a strong base, such as NaOH, to a pH of 7.4, the pH of normal plasma and the pH of the glomerular filtrate.

- This titration reverses the events that occurred in the tubular lumen when the tubular fluid was titrated by secreted H+. Therefore, the number of milliequivalents of NaOH required to return the urinary pH to 7.4 equals the number of milliequivalents of H+ added to the tubular fluid that combined with phosphate and other organic buffers.
-
- **The titratable acid measurement does not include H+ in association with NH4+** because the pK of the ammonia - ammonium reaction is 9.2, and titration with NaOH to a pH of 7.4 does not remove the H+ from NH4+.

Quantification of Normal Renal Acid-Base Regulation

Net H+ excretion=

H+ excreted by buffers not bicarbonate(=new bicarb) - newH+ added to blood(=HCO3- excreted)

$$\text{Net } H^+ \text{ excretion} = 59 \text{ mmol/day}$$

$$= \text{titratable acid (30 mmol/d)} + NH_4^+ \text{ excretion (30 mmol/d)} - HCO_3^- \text{ excretion (1 mmol/d)(or new H to blood)}$$

Net H+ *Excretion* :

- The amount of H+ excreted by **buffers other than HCO3-** is equal to the amount of **new HCO3- produced.**
- To calculate Net H+ Excretion, we need to account for any **new H+ added to the blood**, which results from the **excretion of HCO3- in urine**. In this context, the new H+ added to the blood needs to **be subtracted**.

Net H+ excretion = titratable acid (NaHPO4 + NH4+)(60 mmol / day) – HCO3- excretion (1 mmol/day) = 59 mmol/day

Normal Renal Acid-Base Regulation

Net addition of HCO_3^- to body
(i.e. net loss of H^+)

Titratable acid = 30 mmol/day
+ NH_4^+ excretion = 30 mmol/day
- HCO_3^- excretion = 1 mmol/day
Total = 59 mmol/day

- the net addition of HCO3- (bicarbonate) to the body signifies a corresponding net loss of H+ (hydrogen ions) in the tubular fluid.
- To calculate the addition of HCO3-, use the following formula:

Addition of HCO3- = Titratable Acid (NaHPO4-)+ (NH4+) Excretion – (HCO3-) excretion

- If this calculated value is **positive**, it indicates a **loss of H+ from the body.**

Renal Compensation for Acidosis

Increased addition of HCO_3^- to body by kidneys
(increased H^+ loss by kidneys)

Titratable acid	= 35 mmol/day (small increase)
NH_4^+ excretion	= 165 mmol/day (**increased!!**)
HCO_3^- excretion	= 0 mmol /day (decreased)
Total	= 200 mmol/day

This can increase to as high as 500 mmol/day

- Increased HCO3- in the body means more H+ loss in urine
- **In chronic acidosis**, there is an increase in the production of NH4+, which further contributes to the excretion of H+ and the addition of new HCO3 – to the extracellular fluid

Renal Compensation for Alkalosis

Net loss of HCO_3^- from body
(i.e. decreased H^+ loss by kidneys)

Titratable acid = 0 mmol/day (decreased)
NH_4^+ excretion = 0 mmol/day (decreased)
HCO_3^- excretion = 80 mmol /day (**increased!!**)
Total = 80 mmol/day

- HCO_3 excretion can increase markedly in alkalosis

- In alkalosis, the tubular secretion of H+ is reduced to a level that is too **low** to achieve complete **HCO3 – reabsorption**, enabling the kidneys to increase HCO3– excretion.

To calculate Addition of HCO3-, formula:
Addition of HCO3- = Titratable acid (NaHPO4-) + (NH4+) secretion (0 mmol/day) – HCO3- excretion (80 mmol /day) = -80 mmol/day

- The **negative** value indicates that **H+ ions are added to the blood.**

- Titratable acid and ammonia are not excreted during alkalosis, which helps correct the alkalosis by lowering the pH.

Classification of Acid-Base Disorders from plasma pH, pCO_2, and HCO_3^-

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

$$pH = pK + \log \frac{HCO_3^-}{\alpha \; pCO_2}$$

Acidosis : pH < 7.4

- metabolic : ↓ HCO_3^-
- respiratory : ↑ pCO_2

Alkalosis : pH > 7.4

- metabolic : ↑ HCO_3^-
- respiratory : ↓ pCO_2

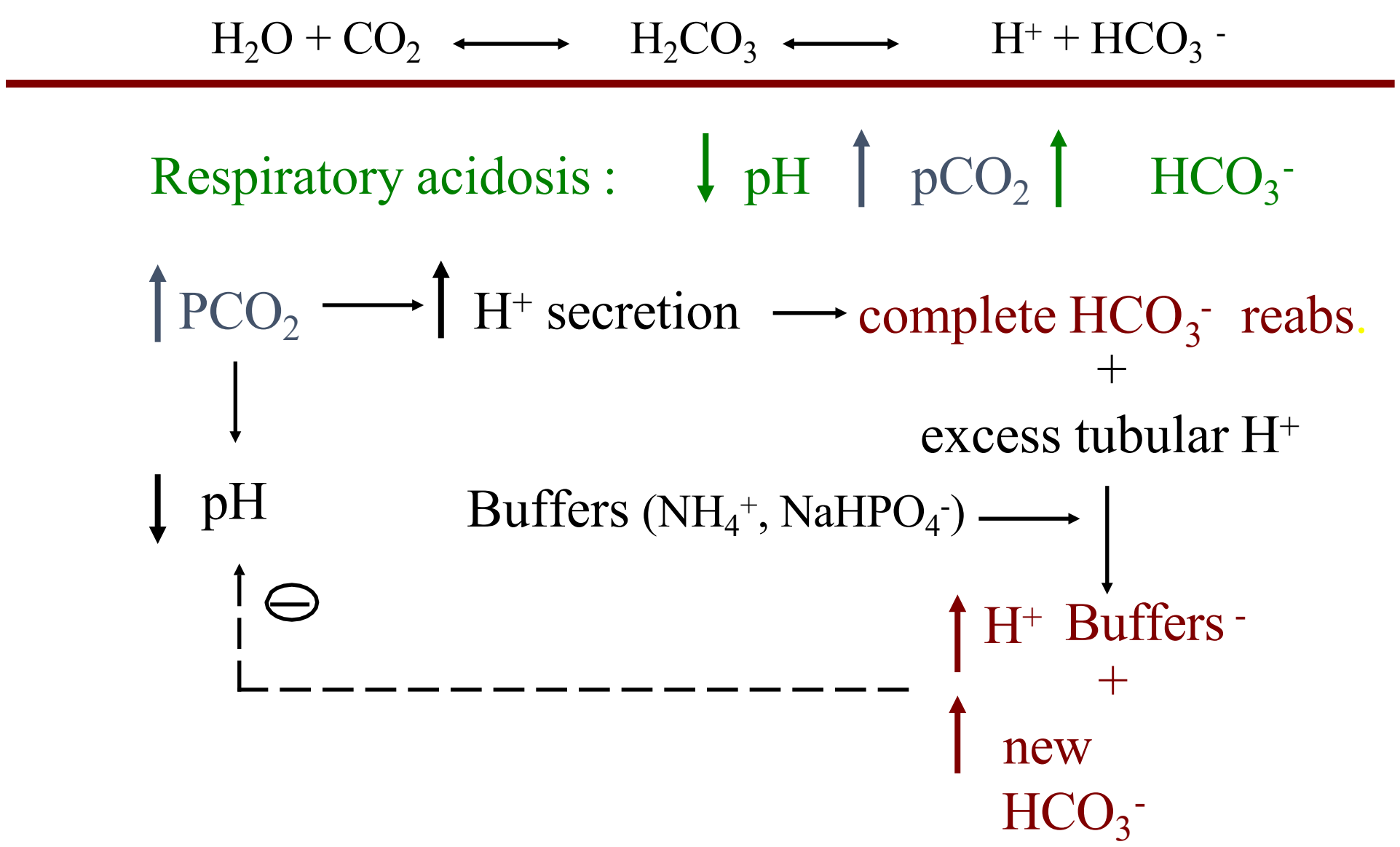
Clinical Perspective

Renal Compensations for Acid-Base Disorders

- Acidosis:
  - increased H^+ excretion
  - increased HCO_3^- reabsorption
  - production of new HCO_3^-
- Alkalosis:
  - decreased H^+ excretion
  - decreased HCO_3^- reabsorption
  - loss of HCO_3^- in urine

- To make it easier to remember: The body compensates by adjusting the other side of the acid-base equation in the same direction as the primary disturbance.
- For example, if pCO_2 is increased (respiratory acidosis), the kidneys compensate by increasing HCO_3^- reabsorption.
- If HCO_3^- is decreased (metabolic acidosis), the lungs compensate by decreasing pCO_2 through hyperventilation.

Renal Responses to Respiratory Acidosis



Renal Responses to Respiratory Acidosis

: Problem

: Body compensation

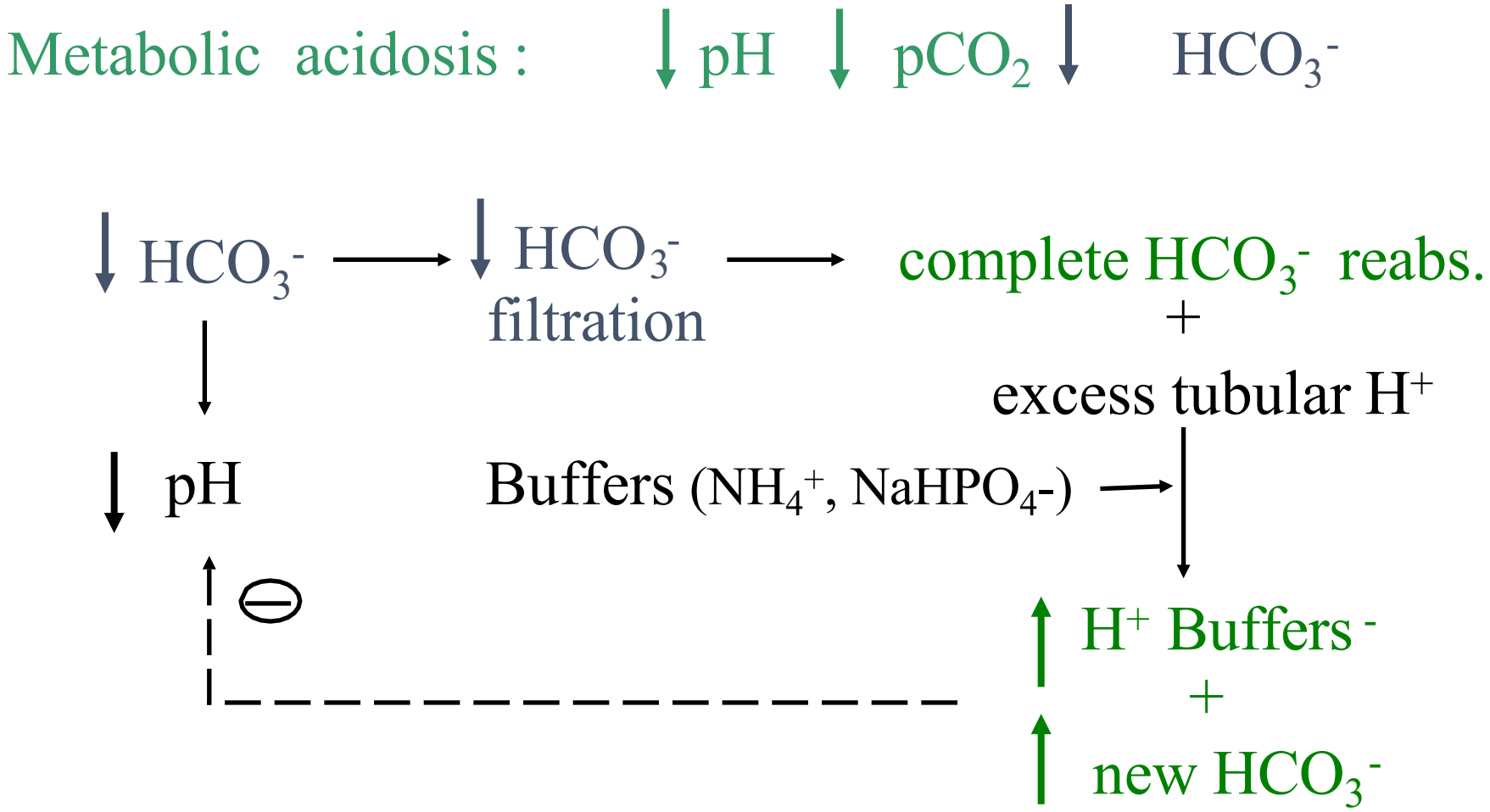
$$H_2O + CO_2 \uparrow \longleftrightarrow H_2CO_3 \longleftrightarrow H^+ + HCO_3^- \qquad pH = pK + \log \frac{HCO3^- \downarrow}{\alpha\, PCO_2 \uparrow}$$

- in respiratory acidosis, there is a reduction in pH due to increase in partial pressure of CO2, which cause an increase in extracellular fluid H+ concentration, which is the initial cause of the acidosis.
- The excess H+ in the tubular fluid is due mainly to the rise in extracellular fluid Pco2, which stimulates H+ secretion.

$$H_2O + CO_2 \longleftrightarrow H_2CO_3 \longleftrightarrow H^+ + HCO_3^- \uparrow \qquad pH = pK + \log \frac{HCO3^- \uparrow}{\alpha\, PCO_2}$$

- The compensatory response is to increase H+ secretion and complete reabsorption of bicarbonate (HCO3-), increase in plasma HCO3 −, caused by the addition of new HCO3 − to the extracellular fluid by the kidneys. the rise in HCO3 − helps offset the increase in Pco2, thereby returning the plasma pH toward normal.

Renal Responses to Metabolic Acidosis



Renal Responses to Metabolic Acidosis

: Problem

: Body compensation

$$H_2O + CO_2 \longleftrightarrow H_2CO_3 \longleftrightarrow H^+ + HCO_3^- \downarrow$$

$$pH = pK + \log \frac{HCO3^- \downarrow}{\alpha\, PCO_2}$$

- In metabolic acidosis, there is also a decrease in pH and a rise in the extracellular fluid H+ Concentration.
- However, in this case, the primary abnormality is a decrease in plasma HCO3 −.

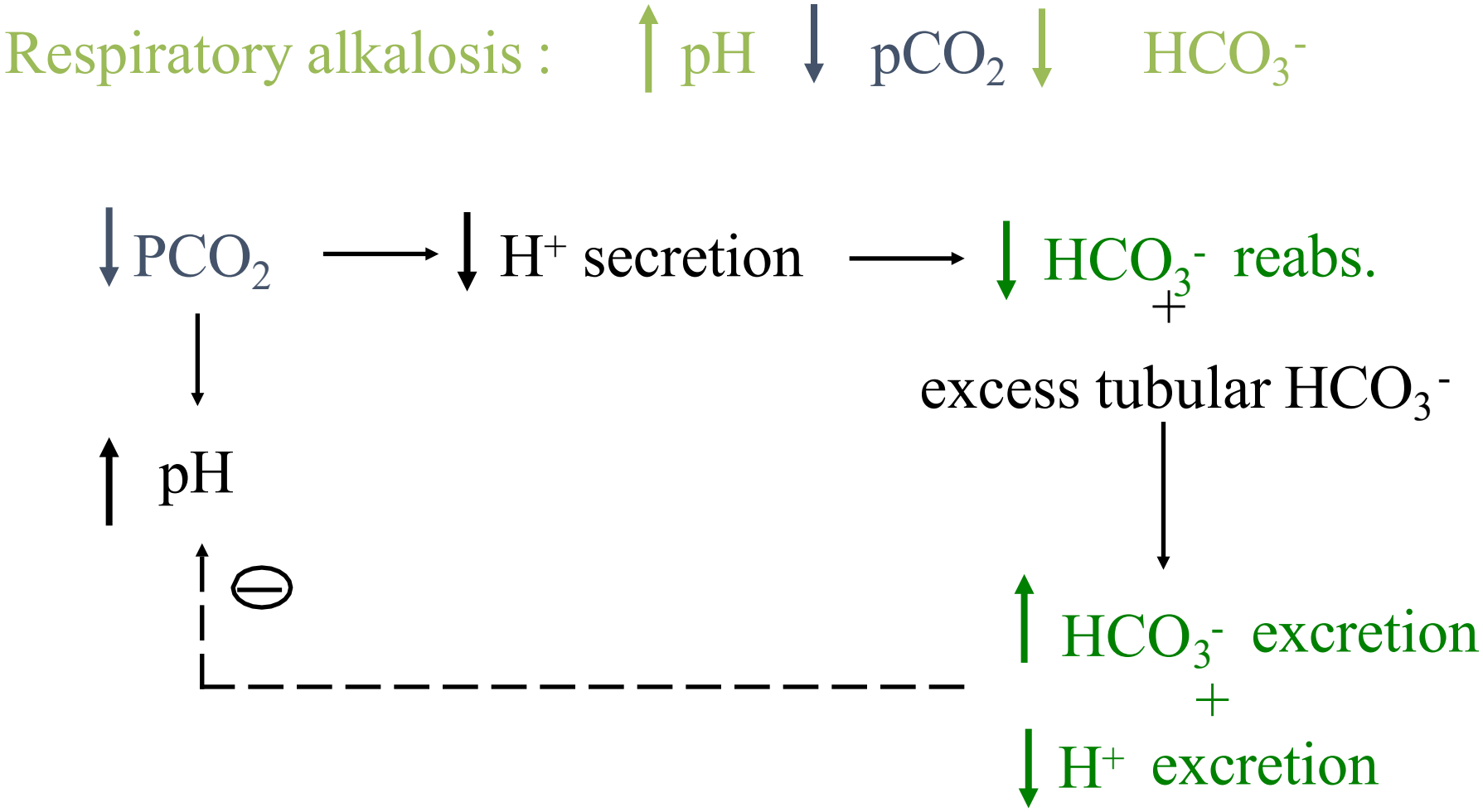
[H+ ions are buffered by bicarbonate ions. When the concentration of bicarbonate ions in the blood decreases, the kidneys are unable to buffer as much H+. This leads to an excess of H+ in the tubular fluid.]

$$H_2O + CO_2 \downarrow \longleftrightarrow H_2CO_3 \longleftrightarrow H^+ + HCO_3^-$$

$$pH = pK + \log \frac{HCO3^-}{\alpha\, PCO_2 \downarrow}$$

- The excess of H+ occurs in the tubular fluid, primarily because of decreased extracellular fluid concentration of HCO3 − and therefore decreased glomerular filtration of HCO3 −.
- The primary compensations include increased ventilation rate, which reduces Pco2, and renal compensation, which, by reducing the filtration of HCO3- , which eventually cause complete reabsorption HCO3- that helps minimize the initial fall in extracellular HCO3 − concentration.
- The excess H+ would be buffered by (NH4+ and NaHPO4-) and new HCO3 − is added to the extracellular fluid.

Renal Responses to Respiratory Alkalosis



Renal Responses to Respiratory Alkalosis

: Problem

: Body compensation

$$H_2O + CO_2 \downarrow \longleftrightarrow H_2CO_3 \longleftrightarrow H^+ + HCO_3^-$$

$$pH = pK + \log \frac{HCO3^-}{\alpha\, PCO_2 \downarrow}$$

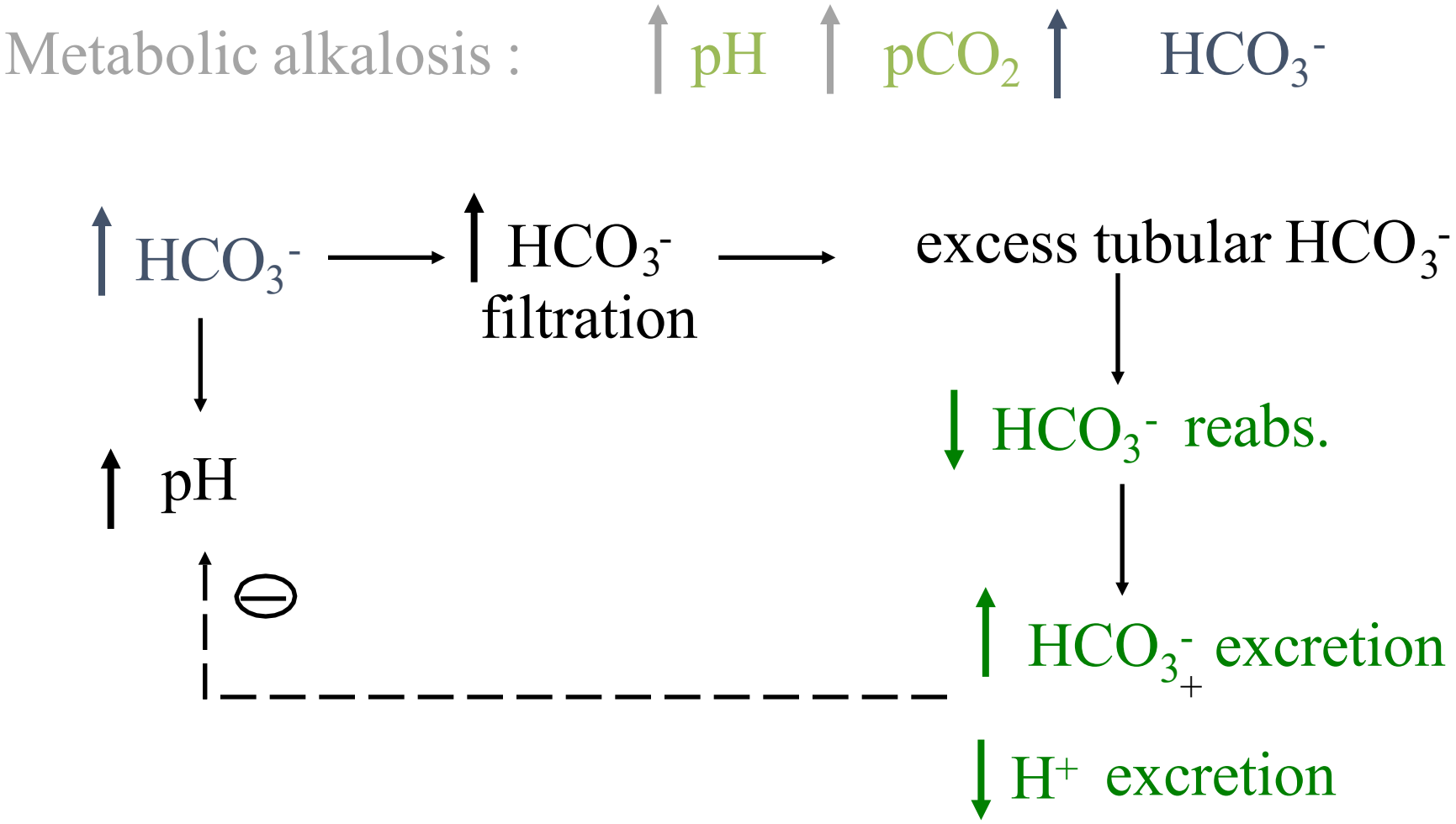
- In respiratory alkalosis, there is an increase in extracellular fluid pH and a decrease in H+ concentration. The cause of the alkalosis is decreased plasma PCO2, caused by hyperventilation.
- Reduction in PCO2 then leads to decreased renal tubular H+ secretion.
- Consequently, there is not enough H+ in the renal tubular fluid to react with all the **HCO3 –** that is filtered. therefore, the HCO3 – ,that cannot react with H+, is **not reabsorbed and is excreted in the urine.**

$$H_2O + CO_2 \longleftrightarrow H_2CO_3 \longleftrightarrow H^+ + HCO_3^- \downarrow$$

$$pH = pK + \log \frac{HCO3^- \downarrow}{\alpha\, PCO_2}$$

- the compensatory response to a primary reduction in PCO2 in respiratory alkalosis is a reduction in plasma HCO3 – concentration, caused by increased renal excretion of HCO3 –.
- In addition, the excess HCO3- in renal tubular fluid would cause addition of new H+ into the blood. This all will eventually decrease pH back to normal.

Renal Responses to Metabolic Alkalosis



Metabolic Alkalosis

- In **metabolic alkalosis**, as we discussed before, the cause is **elevated bicarbonate levels**. Therefore, the **pH is high due to increased bicarbonate, not because of low PCO_2**—as you can see here, the **PCO_2 is actually elevated**.

- The **filtration of bicarbonate increases** because its level in the blood is high, resulting in **higher bicarbonate concentration in the renal tubules**. In response, the **kidneys decrease the reabsorption of bicarbonate**, leading to **increased bicarbonate excretion**.

- **More bicarbonate excretion** means less is available to be **titrated with H^+**, which results in **reduced H^+ secretion**. As we know, the **reabsorption of bicarbonate is closely linked to H^+ secretion**, so a **decrease in medullary bicarbonate reabsorption** will also lead to **decreased H^+ secretion**.

Question

The following data were taken from a patient:

urine volume = 1.0 liter/day
urine HCO_3^- concentration = 2 mmol/liter
urine NH_4^+ concentration = 15 mmol/liter
urine titratable acid = 10 mmol/liter

- What is the daily net acid excretion in this patient ?
- What is the daily net rate of HCO_3^- addition to the extracellular fluids ?

Question

The following data were taken from a patient:

urine volume = 1.0 liter/day

urine HCO_3^- concentration = 2 mmol/liter

urine NH_4^+ concentration = 15 mmol/liter

urine titratable acid = 10 mmol/liter

net acid excretion = Titr. Acid + NH_4^+ excret - HCO_3^-

= (10 x 1) + (15 x 1) - (1 x 2)

= 23 mmol/day

net rate of HCO_3^- addition to body = 23 mmol/day

- **23 mmol/day** is the **net acid excretion**, and it also equals the **net rate of bicarbonate addition**; it is **not** the **total amount of reabsorbed bicarbonate**.
- **Net acid excretion = net bicarbonate addition = 23 mmol/day**

Classification of Acid-Base Disorders from plasma pH, pCO_2, and HCO_3^-

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

$$pH = pK + \log \frac{HCO_3^-}{\alpha\ pCO_2}$$

Acidosis : pH < 7.4

- metabolic: ↓ HCO_3^-
- respiratory: ↑ pCO_2

Alkalosis : pH > 7.4

- metabolic: ↑ HCO_3^-
- respiratory: ↓ pCO_2

Clinical Perspective

Classification of Acid-Base Disturbances

	Plasma			
Disturbance	pH	HCO_3^-	pCO_2	Compensation
metabolic acidosis	↓	↓	↓	↑ ventilation ↑ renal HCO_3 production
respiratory acidosis	↓	↑	↑	↑ renal HCO_3 production
metabolic alkalosis	↑	↑	↑	↓ ventilation ↑ renal HCO_3 excretion
respiratory alkalosis	↑	↓	↓	↑ renal HCO_3 excretion

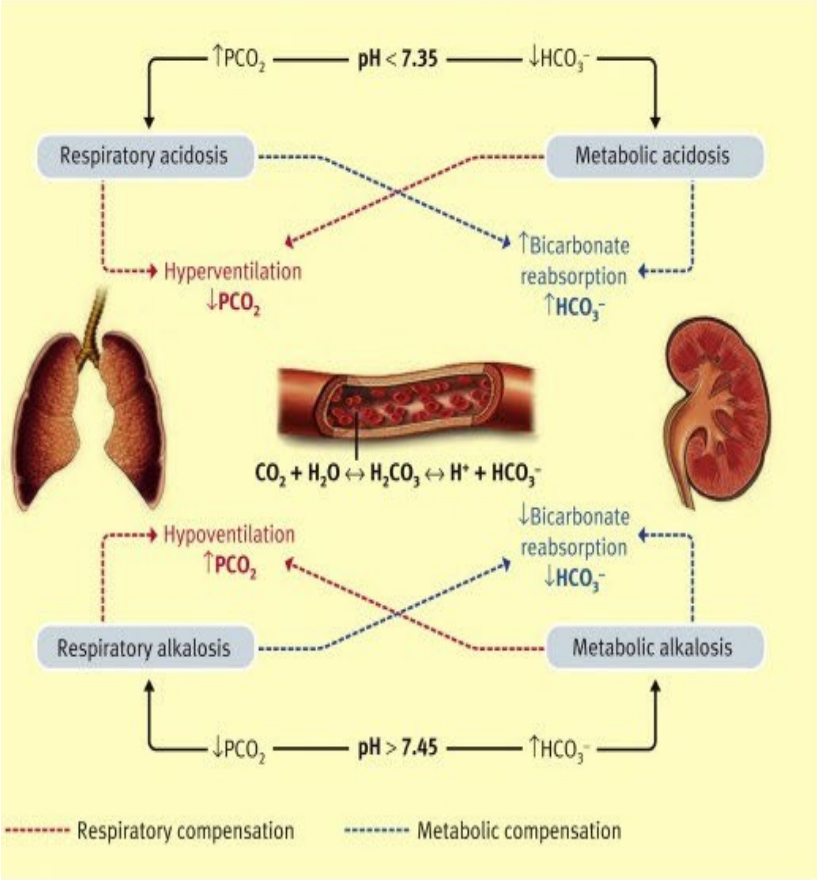
- In **metabolic acidosis**, the **primary cause is decreased HCO_3^-**. However, **PCO_2 is not the cause** of the acidosis; instead, it will be **lower than normal** due to **respiratory compensation**. This occurs through **increased ventilation** to reduce PCO_2. Additionally, there is **renal compensation** by **increasing HCO_3^- production** to **titrate more acids**.

- In **respiratory acidosis**, the **primary cause is elevated PCO_2**. If we look at HCO_3^-, we will find it **increased**, **not decreased**. This is due to **renal compensation**, which responds by **increasing HCO_3^- production**—that's why HCO_3^- is elevated in this condition.

- In **metabolic alkalosis**, the cause is **increased HCO_3^-**. You will find that **PCO_2 is also increased**, and the reason behind this is **compensation** by both the **respiratory system**—through **decreased ventilation**—and the **renal system**, which responds by **increasing HCO_3^- excretion**.

- In **respiratory alkalosis**, the cause is **decreased PCO_2**, and **HCO_3^- is also decreased**. This is due to **renal compensation**, where the kidneys respond by **increasing HCO_3^- excretion**.

- In this table, we have a **demonstration of acid-base balance** and how the **renal and respiratory systems** can **correct or compensate for imbalances**.



	pH	HCO_3^-	CO_2
Metabolic acidosis	↓	↓	Normal
Metabolic alkalosis	↑	↑	Normal
Metabolic acidosis with respiratory compensation	↓	↓	↓
Metabolic alkalosis with respiratory compensation	↑	↑	↑

Test	Normal	Decrease Value	Increase Value
pH	7.35-7.45	Acidosis	Alkalosis
PaCO2	35-45	Alkalosis	Acidosis
HCO3	22-26	Acidosis	Alkalosis
PaO2	80-100	Hypoxemia	O2 therapy
SaO2	95-100%	Hypoxemia	----------

- You can also see the **normal values of pH, PCO_2, and HCO_3^-**, which are **very important numbers to memorize** in order to answer questions about the **type of acidosis or alkalosis** or any **acid-base disturbance**.

Question

A plasma sample revealed the following values
in a patient: norm for PCO2 35-45, HCO3 22-26

pH = 7.12
$PCO_2 = 50$
$HCO_3^- = 18$

- Low PH --> Acidosis
- High PCO2 --> it could be respiratory.
- Low HCO3 --> it could be metabolic.

- In such cases we call it **Mixed Acidosis.**

diagnose this patient's acid-base status :
acidotic or alkalotic ? Acidotic
respiratory, metabolic, or both ? Both

Mixed acidosis: metabolic and respiratory acidosis

Mixed Acid-Base Disturbances

Two or more underlying causes of acid-base disorder.

pH= 7.60
pCO_2 = 30 mmHg
plasma HCO_3^- = 29 mmol/L

Another example shows Mixed Alkalosis

What is the diagnosis?

Mixed Alkalosis

- Metabolic alkalosis : increased HCO_3^-
- Respiratory alkalosis : decreased pCO_2

Question

A patient presents in the emergency room and the following data are obtained from the clinical labs:

plasma pH= 7.15, HCO_3^- = 8 mmol/L, pCO_2 = 24 mmHg

This patient is in a state of:

1. metabolic alkalosis with partial respiratory compensation
2. respiratory alkalosis with partial renal compensation
3. metabolic acidosis with partial respiratory compensation Because it didn't bring PH to normal
4. respiratory acidosis with partial renal compensation

Acid-Base Disturbances

- Metabolic Acidosis : ↓ HCO_3^- / pCO2 in plasma
  (↓ pH, ↓HCO_3^-)

Examples:

- aspirin poisoning (↑ H^+ intake)
- diabetes mellitus (↑H^+ production)
- diarrhea (HCO_3^- loss)
- renal tubular acidosis (↓ H^+ secretion, ↓ HCO_3^- reabs.)
- carbonic anhydrase inhibitors (↓ H^+ secretion)

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

$$\downarrow \; pH = pK + \log \frac{HCO_3^-}{\alpha \; pCO_2}$$

Clinical Perspective

Anion Gap as a Diagnostic Tool

In body fluids: total cations = total anions

Cations (mEq/L)		Anions (mEq/L)	
Na^+	(142)	Cl^-	(108)
		HCO_3^-	(24)
Unmeasured			
K^+	(4)	Proteins	(17)
Ca^{++}	(5)	Phosphate,	
Mg^{++}	(2)	Sulfate,	
		lactate, etc	(4)
Total	(153)		(153)

Clinical Perspective

Anion Gap as a Diagnostic Tool

In body fluids: total cations = total anions

$Na^+ = Cl^- + HCO_3^- +$ unmeasured anions

unmeasured anions = $Na^+ - Cl^- - HCO_3^-$ = anion gap

$= 142 - 108 - 24 = 10$ mEq/L

Normal anion gap = 8 - 16 mEq / L

- The **anion gap** is a **diagnostic tool** used in **acid-base disturbances**, particularly helpful for making a **differential diagnosis** in cases of **metabolic disorders**.

- Usually, we **don't measure all the cations and anions** in the blood. The **measured cation** is mainly **sodium (Na^+)**, and the **measured anions** are **chloride (Cl^-)** and **bicarbonate (HCO_3^-)**.

- Since the body maintains **electrical neutrality** (i.e., total cations = total anions), we can **roughly estimate** that:

$$[Na^+] = [Cl^-] + [HCO_3^-] + \text{unmeasured anions}$$

- These **unmeasured anions** are referred to as the **anion gap**. By rearranging the equation, we get:

$$\text{Anion Gap} = [Na^+] - [Cl^-] - [HCO_3^-]$$

Clinical Perspective

Anion Gap in Metabolic Acidosis

- loss of HCO_3^- = normal anion gap

  ⟷ anion gap = Na^+ - ↑Cl^- - ↓HCO_3^-

  hyperchloremic metabolic acidosis

- ↑ unmeasured anions = ↑ anion gap

  ↑anion gap = Na^+ – ⟷ Cl^- – ↓HCO_3^-

  normochloremic metabolic acidosis

  i.e. diabetic ketoacidosis, lactic acidosis, salicylic acid, etc.

How can we use the anion gap in metabolic acidosis?

- We know that the main cause of **metabolic acidosis** is the **loss of HCO_3^-**. However, if the acidosis is due to a **direct loss of bicarbonate**, the **anion gap remains normal**.

- If we apply the anion gap equation (**Anion Gap = $Na^+ - Cl^- - HCO_3^-$**), and **bicarbonate is low**, then to maintain electrical neutrality, **chloride will increase**. This condition is known as **hyperchloremic metabolic acidosis**.

- So, in cases of **metabolic acidosis with low bicarbonate and high chloride**, the **anion gap stays normal**, and we call this **hyperchloremic metabolic acidosis**. There are various **conditions and disturbances** associated with this pattern.

- On the other hand, if the **unmeasured anions (anion gap) are high**, this also indicates **metabolic acidosis** (since bicarbonate is still low), but in this case, **chloride remains normal**. This is referred to as **normochloremic metabolic acidosis** and is associated with conditions such as **diabetic ketoacidosis**, **lactic acidosis**, and **salicylate poisoning**, among others. These are all characterized by a **high anion gap** with **normal chloride** levels.

Clinical Perspective

Use of "Anion Gap" as a Diagnostic Tool for Metabolic Acidosis

Increased Anion Gap (normal Cl^-)

- diabetes mellitus (ketoacidosis)
- lactic acidosis
- aspirin (acetysalicylic acid) poisoning
- methanol poisoning
- starvation

Normal Anion Gap (increased Cl^-, hyperchloremia)

- diarrhea
- renal tubular acidosis
- Addison' disease
- carbonic anhydrase inhibitors

Question

Laboratory values for an uncontrolled diabetic patient include the following:

arterial pH = 7.25

Plasma HCO_3^- = 12

Plasma P_{CO_2} = 28

Plasma Cl^- = 102

Plasma Na^+ = 142

Metabolic Acidosis

Respiratory Compensation

What type of acid-base disorder does this patient have?

What is his anion gap ?

Anion gap = 142 - 102 -12 = 28

Question

Which of the following are the most likely causes of his acid-base disorder?

a. diarrhea

b. diabetes mellitus

c. Renal tubular acidosis

d. primary aldosteronism

Acid-Base Disturbances

- Respiratory Acidosis : ↓ HCO_3^- / pCO2 in plasma
  (↓pH, ↑pCO_2)

  - brain damage
  - pneumonia
  - emphysema
  - other lung disorders

Most of them are lung disorders

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

$$\downarrow \quad pH = pK + \log \frac{HCO_3^-}{\alpha \; pCO_2}$$

Acid-Base Disturbances

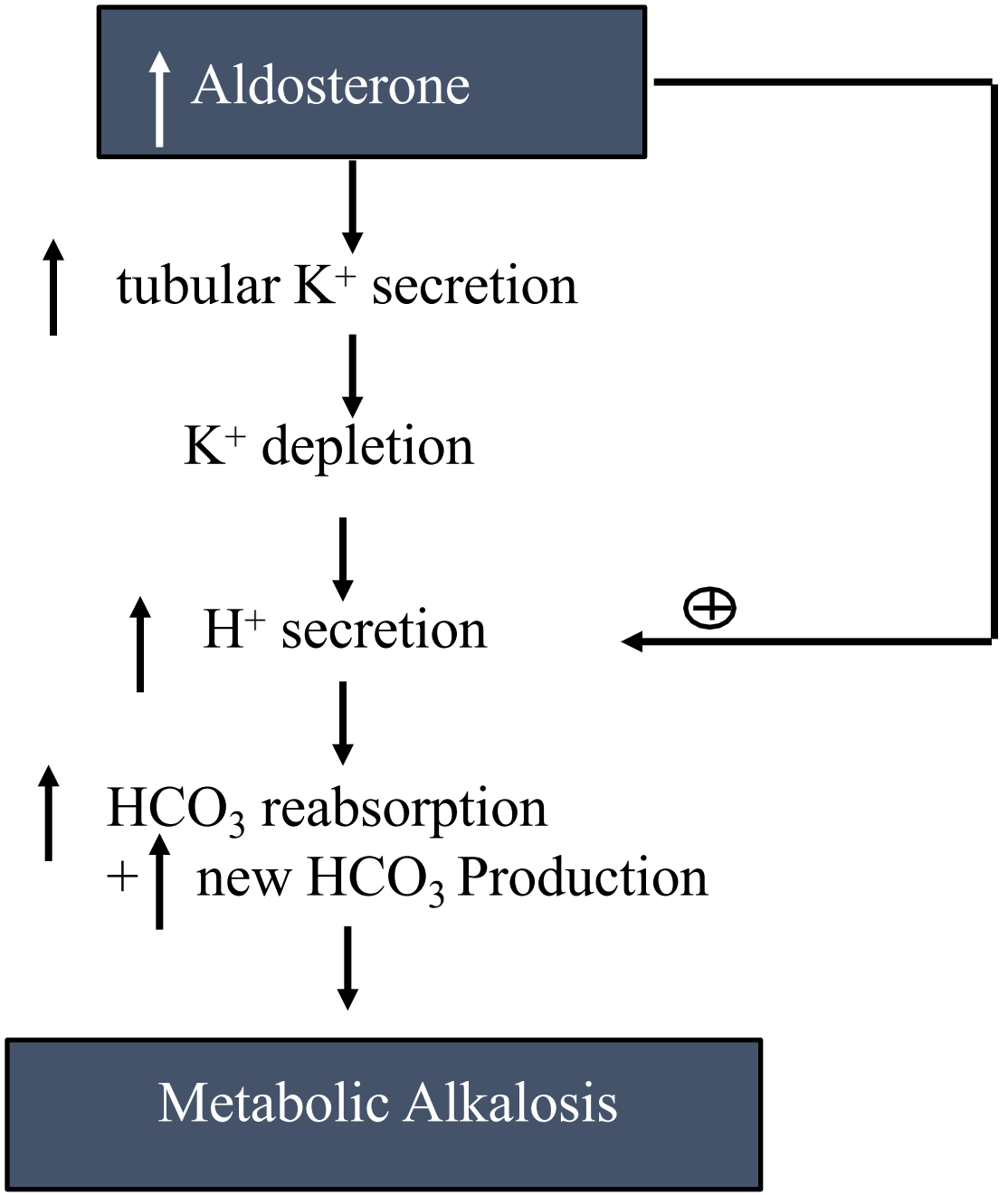
- Metabolic Alkalosis : ↑ HCO_3^- / pCO_2 in plasma
  ↑ (↑pH, HCO_3^-)

  - increased base intake (e.g. $NaHCO_3$)
  - vomiting gastric acid
  - mineralocorticoid excess **like aldosterone**
  - overuse of diuretics (except carbonic anhydrase Inhibitors, **because they cause acidosis**)

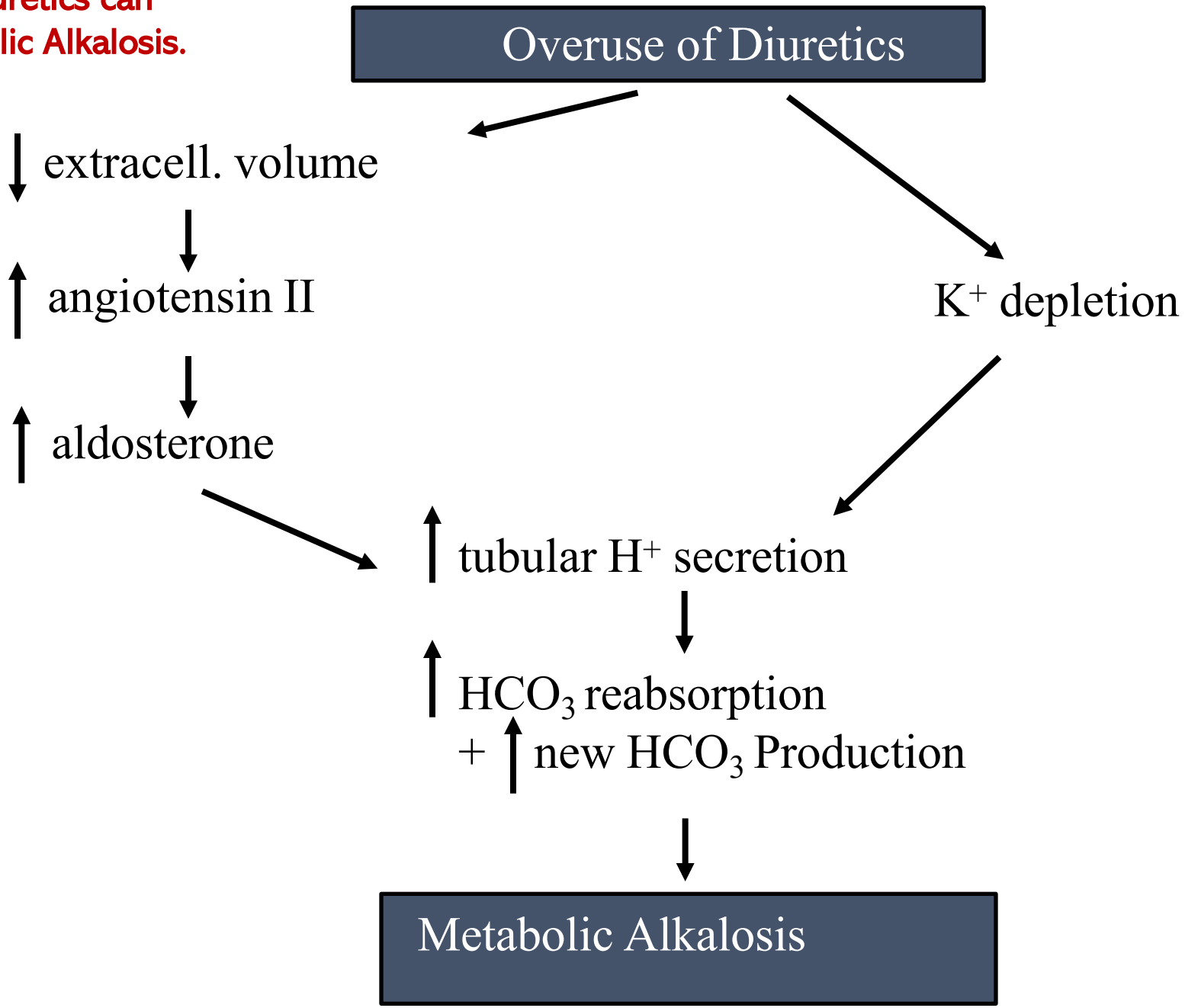
$$H_2O + CO_2 \longleftrightarrow H_2CO_3 \longleftrightarrow H^+ + HCO_3^-$$

$$\uparrow \quad pH = pK + \log \frac{HCO_3^-}{\alpha \; pCO_2}$$

This is how aldosterone can induce Metabolic Alkalosis.



This is how Diuretics can induce Metabolic Alkalosis.



Acid-Base Disturbances

- Respiratory Alkalosis : ↑ HCO_3^- / pCO2 in plasma
  (↑ pH, ↓ pCO_2)

Low PCO_2 is usually caused by hyperventilation, often triggered by hypoxia in the affected area.

- high altitude
- psychic (fear, pain, etc)

$$H_2O + CO_2 \longleftrightarrow H_2CO_3 \rightleftharpoons H^+ + HCO_3^-$$

$$\uparrow \quad pH = pK + \log \frac{HCO_3^-}{\alpha \; pCO_2}$$

Question

Laboratory values for a patient include the following:

arterial pH = 7.34
Plasma HCO_3^- = 15
Plasma P_{CO_2} = 29
Plasma Cl^- = 118
Plasma Na^+ = 142

Metabolic Acidosis
Respiratory Compensation

What type of acid-base disorder does this patient have?
What is his anion gap ?

Hyperchloremic

Anion gap = 142 - 118 - 15 = 9 (normal)

- We can see here that the **arterial pH is within the normal range**, while **plasma bicarbonate is very low** and **plasma PCO_2 is also low**. The low bicarbonate indicates that there is an underlying **metabolic acidosis**. However, **compensation occurs via the respiratory system** through **hyperventilation**, which leads to a **decrease in PCO_2**. This respiratory compensation helps bring the **pH back to normal**.

So in this case, we describe the condition as:
Metabolic Acidosis with Respiratory Compensation

Question

Which of the following are the most likely causes of his acid-base disorder?

a. diarrhea

b. diabetes mellitus

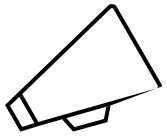
c. aspirin poisoning

d. primary aldosteronism

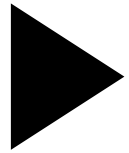
Question

Indicate the Acid -Base Disorders in Each of the Following Patients

pH	HCO_3^-	PCO_2	Acid-Base Disorder ?
7.34	15	29	Metabolic acidosis
7.49	35	48	Metabolic alkalosis
7.34	31	60	Respiratory acidosis
7.62	20	20	Respiratory alkalosis
7.09	15	50	Acidosis: respiratory + metabolic



Audio-Visual Aid



Links to recorded lectures

UGS physiology lecture 11 - YouTube

UGS physiology - lecture 12 - YouTube

Test your knowledge

Questions 89–93

Match each of the patients described in Questions 89–93 with the correct set of blood values in the following table (the same values may be used for more than one patient).

	pH	HCO_3^- (mEq/L)	P_{CO_2} (mm Hg)	Na^+ (mEq/L)	Cl^- (mEq/L)
A)	7.66	22	20	143	111
B)	7.28	30	65	142	102
C)	7.24	12	29	144	102
D)	7.29	14	30	143	117
E)	7.52	38	48	146	100
F)	7.07	14	50	144	102

89. A patient with severe diarrhea

90. A patient with primary aldosteronism

91. A patient with proximal renal tubular acidosis

92. A patient with diabetic ketoacidosis and emphysema

93. A patient treated chronically with a carbonic anhydrase inhibitor

89. D) Severe diarrhea would result in loss of HCO_3^- in the stool, thereby causing metabolic acidosis that is characterized by low plasma HCO_3^- and low pH. Respiratory compensation would reduce P_{CO_2}. The plasma anion gap would be normal, and the plasma chloride concentration would be elevated (hyperchloremic metabolic acidosis) in metabolic acidosis caused by HCO_3^- loss in the stool.
TMP13 pp. 421-426

90. E) Primary excessive secretion of aldosterone causes metabolic alkalosis due to increased secretion of hydrogen ions and HCO_3^- reabsorption by the intercalated cells of the collecting tubules. Therefore, the metabolic alkalosis would be associated with increases in plasma pH and HCO_3^-, with a compensatory reduction in respiration rate and increased P_{CO_2}. The plasma anion gap would be normal, with a slight reduction in plasma chloride concentration.
TMP13 pp. 424-426

91. D) Proximal tubular acidosis results from a defect of renal secretion of hydrogen ions, reabsorption of bicarbonate, or both. This defect leads to increased renal excretion of HCO_3^- and metabolic acidosis characterized by low plasma HCO_3^- concentration, low plasma pH, a compensatory increase in respiration rate and low P_{CO_2}, and a normal anion gap with an increased plasma chloride concentration.
TMP13 pp. 421-426

92. F) A patient with diabetic ketoacidosis and emphysema would be expected to have metabolic acidosis (due to excess ketoacids in the blood caused by diabetes), as well as increased plasma P_{CO_2} due to impaired pulmonary function. Therefore, the patient would be expected to have decreased plasma pH, decreased HCO_3^-, increased P_{CO_2}, and an increased anion gap (Na^+-Cl^--HCO_3^- > 10-12 mEq/L) due to the addition of ketoacids to the blood.
TMP13 pp. 422-426

93. D) Secretion of hydrogen ions and reabsorption of HCO_3^- depend critically on the presence of carbonic anhydrase in the renal tubules. After inhibition of carbonic anhydrase, renal tubular secretion of hydrogen ions and reabsorption of HCO_3^- would decrease, leading to increased renal excretion of HCO_3^-, reduced plasma HCO_3^- concentration, and metabolic acidosis. The metabolic acidosis, in turn, would stimulate the respiration rate, leading to decreased P_{CO_2}. The plasma anion gap would be within the normal range.
TMP13 pp. 416-417, 425-426

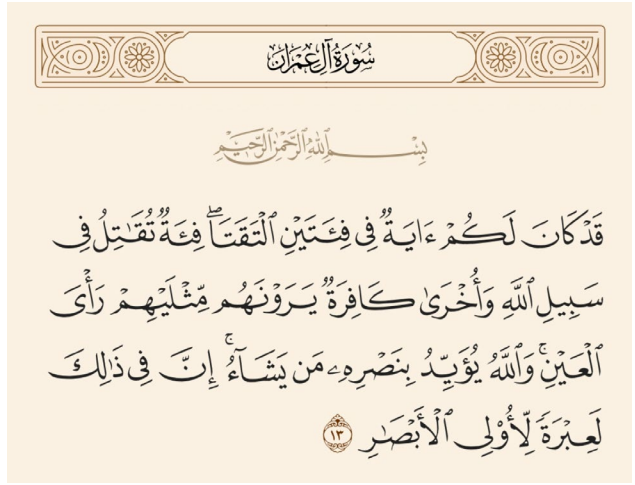
79. A patient reports that he is always thirsty, and his breath has an acetone smell. You suspect that he has diabetes mellitus, and that diagnosis is confirmed by a urine sample that tests positive for glucose and a blood sample that shows a fasting blood glucose concentration of 400 mg/dl. Compared with normal, you would expect to find which changes in his urine?

	Urine pH	NH_4^+ Excretion	Urine volume (ml/24 h)	Renal HCO_3^- Production
A)	↓	↓	↓	↓
B)	↓	↑	↓	↓
C)	↑	↓	↓	↓
D)	↓	↑	↑	↑
E)	↑	↑	↑	↑

79. D) The patient has classic symptoms of diabetes mellitus: increased thirst, breath smelling of acetone (due to increased acetoacetic acids in the blood), high fasting blood glucose concentration, and glucose in the urine. The acetoacetic acids in the blood cause metabolic acidosis that leads to a compensatory decrease in renal HCO_3^- excretion, decreased urine pH, and increased renal production of ammonium and HCO_3^-. The high level of blood glucose increases the filtered load of glucose, which exceeds the transport maximum for glucose, causing an osmotic diuresis (increased urine volume) due to the unreabsorbed glucose in the renal tubules acts as an osmotic diuretic.
TMP13 pp. 350-351, 422

Normal values

PH	**=7.35 -7.45**
Anion gap	**= 8 - 16**
PaCO2	**= 35 – 45**
HCO3-	**= 22 – 26**



قد كان لكم آية في فئتين التقتا فئة تقاتل في سبيل الله - تفسير السعدي

{ قد كان لكم آية }- أي: عبرة عظيمة { في فئتين التقتا } وهذا يوم بدر { فئة تقاتل في سبيل الله } وهم الرسول صلى الله عليه وسلم وأصحابه { وأخرى كافرة }- أي: كفار قريش الذين خرجوا من ديارهم بطرا وفخرا ورئاء الناس، ويصدون عن سبيل الله، فجمع الله بين الطائفتين في بدر، وكان المشركون أضعاف المؤمنين، فلهذا قال { يرونهم مثليهم رأي العين }- أي: يرى المؤمنون الكافرين يزيدون عليها زيادة كثيرة، تبلغ المضاعفة وتزيد عليها، وأكد هذا بقوله { رأي العين } فنصر الله المؤمنين وأيدهم بنصره فهزموهم، وقتلوا صناديدهم، وأسروا كثيرا منهم، وما ذاك إلا لأن الله ناصر من نصره، وخاذل من كفر به، ففي هذا عبرة لأولي الأبصار- أي: أصحاب البصائر النافذة والعقول الكاملة، على أن الطائفة المنصورة معها الحق، والأخرى مبطلة، وإلا فلو نظر الناظر إلى مجرد الأسباب الظاهرة والعدد والعدد لجزم بأن غلبة هذه الفئة القليلة لتلك الفئة الكثيرة من أنواع المحالات، ولكن وراء هذا السبب المشاهد بالأبصار سبب أعظم منه لا يدركه إلا أهل البصائر والإيمان بالله والتوكل على الله والثقة بكفايته، وهو نصره وإعزازه لعباده المؤمنين على أعدائه الكافرين.

VERSIONS	SLIDE #	BEFORE CORRECTION	AFTER CORRECTION
V1→ V2	41 12		Check the arrows in yellow Check the numbers in yellow
V2→V3			

امسح الرمز و شاركنا بأفكارك لتحسين أدائنا !!