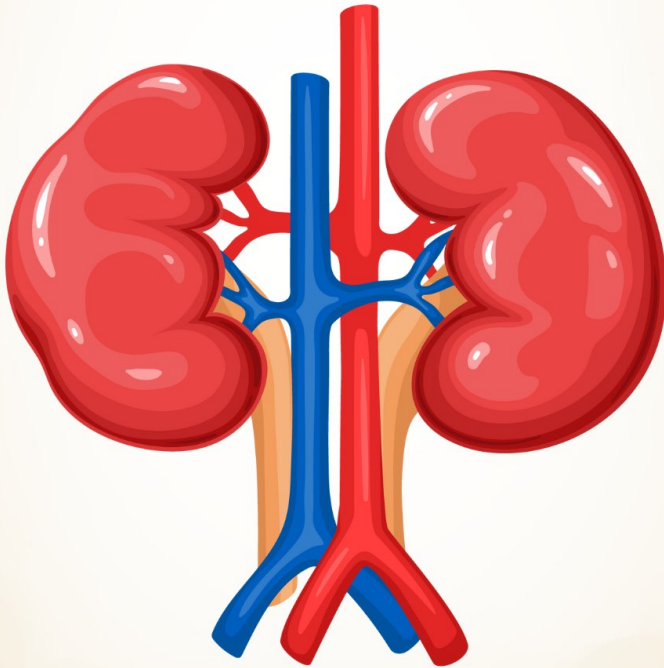




Internal Medicine



Topic : Acid Base Balance Notes
Done by : Johainah Taha

Acid-Base Balance

Basics and Terminology

pH

- pH represents the “potential of Hydrogen” and determines the acidity or alkalinity of a solution.
- It is mathematically defined as:
$$\text{pH} = -\log[\text{H}^+]$$

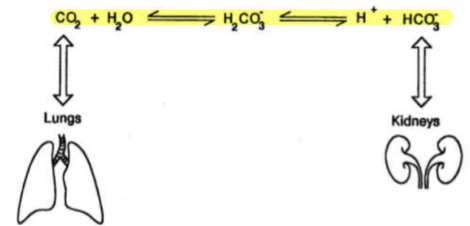
- Blood pH normally ranges between 7.35 - 7.45.
- Changes in pH impact enzymatic function, oxygen delivery, and cellular metabolism.

Henderson-Hasselbalch Equation

- This equation describes the relationship between CO_2 , HCO_3^- (bicarbonate), and pH:

$$\text{pH} = \text{pK}_a + \log \left(\frac{[\text{HCO}_3^-]}{0.03 \times \text{PaCO}_2} \right) \quad \text{pH} = \text{HCO}_3^- / \text{CO}_2 \text{ of } \text{H}^+ = 24 \times \text{CO}_2 / \text{HCO}_3^-$$

- The equation explains how bicarbonate (HCO_3^-) acts as a buffer in acid-base balance.



Key Terminology

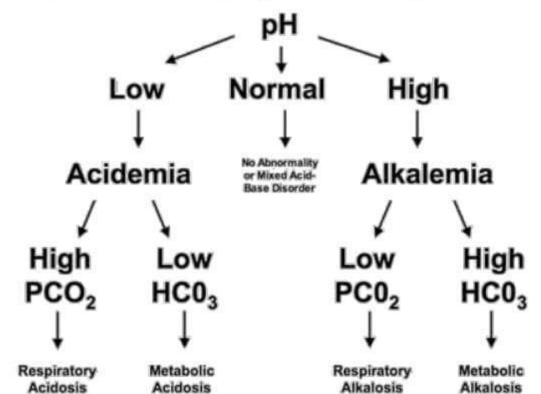
Term	Definition
Acid	A substance that donates H⁺ ions (protons).
Base	A substance that accepts H⁺ ions .
Acidosis	A process that increases H ⁺ concentration.
Alkalosis	A process that decreases H ⁺ concentration.
Acidemia	Blood pH < 7.35 (actual state of acidity).
Alkalemia	Blood pH > 7.45 (actual state of alkalinity).

Acid-Base Regulation

Maintaining a normal extracellular pH (7.35-7.45) is critical for physiological function. This is achieved through three main regulatory systems:

	Mechanism	Function	Response Time
①	Chemical Buffers	Immediate neutralization of pH changes.	Seconds
②	Respiratory System	Controls CO_2 elimination via ventilation.	Minutes
③	Renal System	Regulates H^+ and HCO_3^- excretion/reabsorption.	Hours to Days

Figure 1: Identifying the Primary Process



1. Chemical Buffer Systems

- **Bicarbonate Buffer** ($\text{HCO}_3^-/\text{H}_2\text{CO}_3$): The most important buffer in extracellular fluid.
- **Protein Buffer** (Hemoglobin, Albumin): Acts in intracellular fluid & plasma.
- **Phosphate Buffer** ($\text{HPO}_4^{2-}/\text{H}_2\text{PO}_4^-$): Effective in intracellular & renal tubules.

2. Respiratory Regulation

- **Lungs** control CO_2 levels, affecting pH.
- **Hyperventilation** $\downarrow \text{CO}_2 \rightarrow \uparrow \text{pH}$ (Alkalosis)
- **Hypoventilation** $\uparrow \text{CO}_2 \rightarrow \downarrow \text{pH}$ (Acidosis)

3. Renal Regulation

- **Kidneys** excrete H^+ and reabsorb HCO_3^- to maintain pH balance.
- They also excrete NH_4^+ (ammonium) and titratable acids for further pH control.

Respiratory Acid-Base Disorders

Respiratory Acidosis ($\downarrow \text{pH}$, $\uparrow \text{PaCO}_2$)

Caused by hypoventilation (low respiratory rate).

* A case of COPD

Causes	Examples
CNS Depression	Stroke, head trauma, narcotics overdose.
Increased Intracranial Pressure (ICP)	Brain injury, hemorrhage.
Neuromuscular Disorders	Guillain-Barré Syndrome (GBS), Myasthenia Gravis (MG).
Obstructive Lung Disease	COPD, obstructive sleep apnea (OSA), airway obstruction, pneumonia, Asthma

Respiratory Alkalosis ($\uparrow \text{pH}$, $\downarrow \text{PaCO}_2$)

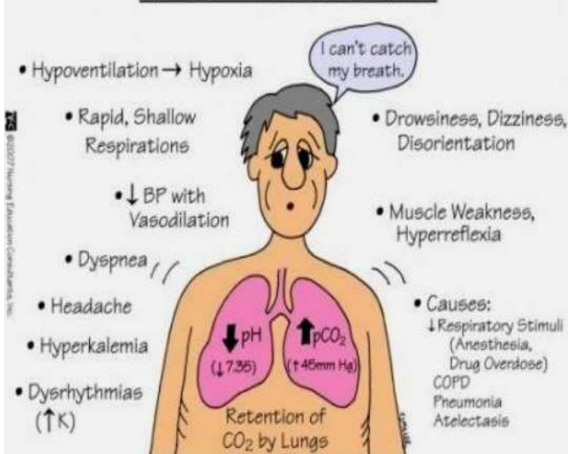
Caused by hyperventilation (high respiratory rate).

* A case of Panic Attack

Causes	Examples
CNS Hyperactivity	Pain, fever, anxiety, CNS trauma, stroke, CVA
Hypoxia (Increased Demand)	Anemia, hyperthyroidism.
Hypoxemia (Impaired Oxygenation)	Pneumonia, pulmonary embolism (PE), pulmonary edema.
Systemic Disorders	Liver disease, pregnancy.

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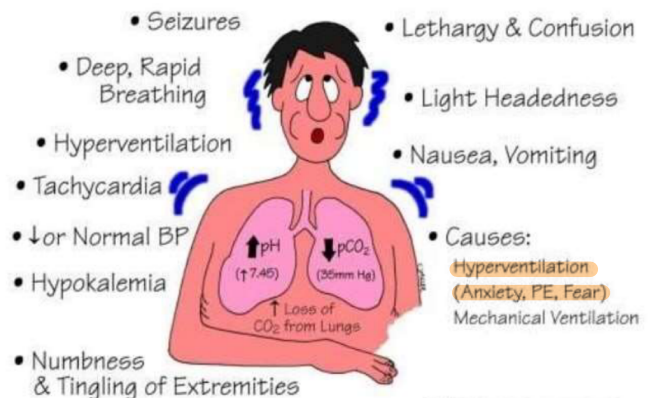
RESPIRATORY ACIDOSIS



* Treatment:

1. improve ventilation $\rightarrow$ BiPAP $\rightarrow$ O_2 , but cautiously in COPD.
2. Naloxone (opioid reverse)

RESPIRATORY ALKALOSIS



* Treatment:

1. Breathing into a bag (rebreathing CO_2)
2. IV bicarbonate.

Metabolic Acidosis ($\downarrow$ pH, $\downarrow$ HCO_3^-) * A case of DKA with Kussmaul breathing.

Two Types:

1. High Anion Gap Metabolic Acidosis (AGMA): Due to excess unmeasured anions.
2. Normal Anion Gap Metabolic Acidosis (NAGMA): Due to loss of bicarbonate (HCO_3^-).



$$\underbrace{\text{unmeasured cation}} \ominus \underbrace{\text{unmeasured Anion}} = \text{Na}^+ - \text{Cl} - \text{HCO}_3^-$$

Anion Gap

Anion Gap (AG) Calculation:

$$\text{AG} = \text{Na} - (\text{Cl} + \text{HCO}_3^-)$$

• Normal AG: 8-12 mEq/L

• AGMA: $\text{AG} > 12 \text{ mEq/L}$ → increasing in Acids

• NAGMA: $\text{AG} \leq 12 \text{ mEq/L}$ → Loss of HCO_3^-

G	Glycols (ethylene and propylene)
O	5-Oxoproline (pyroglutamic acid) chronic paracetamol use, EtOH, poor nutrition, vegetarian diet, renal failure, infection, flucloxacillin/dicloxacillin/netilmicin, Vigabatrin
L	Lactate (Shock, Sepsis, Ischemia)
D	D-lactic acid Associated with short bowel syndrome
M	Methanol and other toxins (ethanol, Aldehyde)
A	Aspirin, salicylates
R	Renal failure (uremia)
K	Ketoacidosis (Diabetic, Alcoholic, Starvation)

Gastrointestinal losses of HCO_3^-

Diarrhea

Enteric fistula
Pancreatic fistula

Ureteral diversions

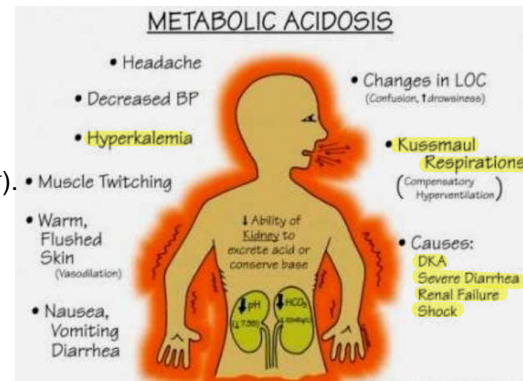
Uretero-sigmoidostomy
Ileal bladder
Ileal ureter

Renal tubular acidosis

Proximal
Distal
Buffer deficiency (phosphate, ammonia)

Medications

Carbonic anhydrase inhibitors (i.e., acetazolamide)
Amphotericin B



Urine Anion Gap (UAG)

$$\text{UAG} = (\text{Na} + \text{K}) - \text{Cl}$$

• Used to differentiate renal vs. gastrointestinal causes of metabolic acidosis.

Treatment

DKA → IV Fluid + Insulin + K^+

Lactic Acid → Shock + Hypoxia treatment.

Toxins → Antidote or dialysis

$$\text{Na} + \text{K} - \text{Cl}$$

Surrogate for Urine NH_4^+

!
 NH_4^+ is excreted with Cl^- as counter-ion
Hence increasingly negative AG implies $\uparrow$ ammonium

NEGATIVE when distal acidification is intact

- All GI disturbances
- Proximal RTA

POSITIVE when urinary NH_4^+ excretion impaired

- Distal RTA
- Type 4 RTA (nb $\uparrow$ K)
- Renal failure

Unreliable: Polyuria, $\text{UNa} < 20$

!
 Reduced distal Na^+ delivery will reduce urine acidification (and make urine more alkaline)

Metabolic Alkalosis ($\uparrow$ pH, $\uparrow$ HCO_3^-) ** A Case of Vomiting*

Phases of Metabolic Alkalosis

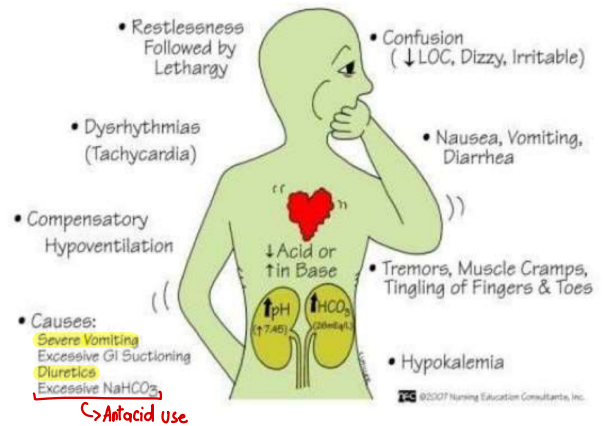
or diuretics

1. Generation: **Loss of acid** (e.g., vomiting) or gain of HCO_3^- .
2. Maintenance: Kidney fails to excrete excess HCO_3^- due to volume depletion, hypokalemia, or chloride depletion.

Causes	Examples
Exogenous (HCO_3^- Load)	Milk-alkali syndrome.
Volume Contraction (Hypochloremia, Hypokalemia)	Vomiting, chloride-losing diarrhea.
Renal Causes	Diuretics, Bartter & Gitelman Syndromes.
ECF Expansion (Mineralocorticoid Excess)	Primary hyperaldosteronism, Liddle syndrome.

Treatment:
Iv fluids ($\text{NaCl} + \text{K}^+$)

METABOLIC ALKALOSIS



7-Step Clinical Approach to Acid-Base Disorders

1. Assess Validity of blood gas.
2. Determine Acidemia or Alkalemia.
3. Identify the Primary Disorder (Metabolic or Respiratory).
4. Check for Compensation (Winter's formula for metabolic acidosis).
5. Calculate the Anion Gap (AG).
6. Use Delta/Delta ($\Delta\text{AG}/\Delta\text{HCO}_3^-$) to assess mixed disorders.
7. Correlate with Clinical Presentation.

Step-by-Step Approach to Acid-Base Disorders

Step 1: Look at the pH → Acidosis or Alkalosis?

- $\text{pH} < 7.35 \rightarrow \text{Acidosis}$
- $\text{pH} > 7.45 \rightarrow \text{Alkalosis}$
- $\text{pH } 7.35\text{--}7.45 \rightarrow \text{Normal}$ (but check if compensation is happening)

In our case:

$\text{pH} = 7.52$ (Alkalosis)

Step 2: Identify if the primary problem is Respiratory or Metabolic

- If PCO_2 follows the pH → Respiratory disorder
- If HCO_3^- follows the pH → Metabolic disorder
- Since PCO_2 is low and pH is high, this suggests respiratory alkalosis (because low PCO_2 means excessive CO_2 loss, which causes alkalosis).
- The low HCO_3^- means there is some compensation by the kidneys (they are trying to bring the pH back to normal by excreting bicarbonate).

In our case:

$\text{PCO}_2 = 26$ (Low, meaning less acid is present)

$\text{HCO}_3^- = 21$ (Low, but slightly)

Step 3: Check If the Compensation is Appropriate (Acute vs. Chronic)

- If it's a respiratory problem, check if HCO_3^- has changed in the same direction as PCO_2 .
- If it's a metabolic problem, check if PCO_2 has changed in the same direction as HCO_3^- .

💡 If there is a change in the compensating value, compensation is happening!

💡 If the compensating value is still normal, there is no compensation!

To check if this is acute or chronic respiratory alkalosis, we use:

$$\text{Expected HCO}_3^- = 24 - \left(\frac{\Delta \text{PCO}_2}{2} \right) \quad (\text{for acute cases})$$

Since normal PCO_2 is 40 mmHg:

$$\Delta \text{PCO}_2 = 40 - 26 = 14$$

$$\text{Expected HCO}_3^- = 24 - \left(\frac{14}{2} \right) = 24 - 7 = 17$$

- If HCO_3^- is close to 17 → Acute Respiratory Alkalosis
- If HCO_3^- is higher (like 21) → Chronic Respiratory Alkalosis

Since our patient's $\text{HCO}_3^- = 21$, this is chronic respiratory alkalosis, meaning the kidneys have had time to compensate.

• $\text{pH} = 7.52$	$\text{PCO}_2 = 26 \text{ mm Hg}$
• $\text{PO}_2 = 105 \text{ mm Hg}$	$\text{HCO}_3^- = 21 \text{ m mol / L}$
• $\text{BE} = -3$	$\text{SaO}_2 = 99\%$
• $\text{Na}^+ = 138 \text{ m mol / L}$	$\text{K}^+ = 3.8 \text{ m mol / L}$
• $\text{Cl}^- = 104 \text{ m mol / L}$	Anion Gap = 13

Step 4: Check for Additional Metabolic Problems (Anion Gap Calculation)

We check for metabolic problems using the Anion Gap (AG):

$$AG = \text{Na}^+ - (\text{Cl}^- + \text{HCO}_3^-)$$

$$AG = 138 - (104 + 21) = 13$$

- Normal AG = 8–12, so 13 is slightly high but not significantly.
- Since the anion gap is normal, there is no primary metabolic acidosis.

Step 5: Look at Possible Causes

What conditions can cause chronic respiratory alkalosis?

- Chronic hyperventilation (anxiety, high altitude, pregnancy, chronic pain)
- Lung disease (interstitial lung disease, pulmonary embolism)
- Liver failure (increased respiratory drive)

Since PO_2 is normal (105 mmHg), hypoxia is unlikely, so this could be anxiety or chronic hyperventilation.

Step 6: Write a Final Answer in Exams

Final Answer: **Chronic Respiratory Alkalosis** due to chronic hyperventilation (likely anxiety or lung disease).

- Primary Disorder: Respiratory Alkalosis (low PCO_2 , high pH).
- Compensation: Renal excretion of bicarbonate (HCO_3^- is lower than normal but not severely low).
- Anion Gap: Normal (no metabolic acidosis).
- Most Likely Cause: Chronic hyperventilation (anxiety, lung disease, or pregnancy).

- pH = 7.52
- $\text{PO}_2 = 105 \text{ mm Hg}$
- BE = - 3
- $\text{Na}^+ = 138 \text{ m mol / L}$
- $\text{Cl}^- = 104 \text{ m mol / L}$
- $\text{PCO}_2 = 26 \text{ mm Hg}$
- $\text{HCO}_3 = 21 \text{ m mol / L}$
- $\text{SaO}_2 = 99\%$
- $\text{K}^+ = 3.8 \text{ m mol / L}$
- Anion Gap = 13

- pH = 7.3
- $\text{PO}_2 = 60 \text{ mm Hg}$
- BE = + 2
- $\text{Na}^+ = 140 \text{ m mol / L}$
- $\text{Cl}^- = 100 \text{ m mol / L}$
- $\text{PCO}_2 = 60 \text{ mm Hg}$
- $\text{HCO}_3 = 26 \text{ m mol / L}$
- $\text{SaO}_2 = 89 \%$
- $\text{K}^+ = 4 \text{ m mol / L}$

- pH = 7.32
- $\text{PO}_2 = 62 \text{ mm Hg}$
- BE = + 8
- $\text{Na}^+ = 136 \text{ m mol / L}$
- $\text{Cl}^- = 96 \text{ m mol / L}$
- $\text{PCO}_2 = 70 \text{ mm Hg}$
- $\text{HCO}_3 = 32 \text{ m mol / L}$
- $\text{SaO}_2 = 90 \%$
- $\text{K}^+ = 3.5 \text{ m mol / L}$

- pH = 7.44
- $\text{PO}_2 = 100 \text{ mm Hg}$
- BE = - 5
- $\text{Na}^+ = 137 \text{ m mol / L}$
- $\text{Cl}^- = 108 \text{ m mol / L}$
- $\text{PCO}_2 = 29 \text{ mm Hg}$
- $\text{HCO}_3 = 19 \text{ m mol / L}$
- $\text{SaO}_2 = 98 \%$
- $\text{K}^+ = 3.7 \text{ m mol / L}$

- pH : 7.36
- PCO_2 : 34 mm Hg
- PO_2 : 100 mm Hg
- HCO_3 : 16mmol/L
- BE : -8
- Sats : 98%
- Na^+ : 140mmol/L
- K^+ : 3.5mmol/L
- Cl^- : 98mmol/L
- Anion Gap : 26

- pH : 7.40
- PCO_2 : 28 mm Hg
- PO_2 : 60 mm Hg
- HCO_3 : 15mmol/L
- BE : -9mmol/L
- Sats : 90%
- Na^+ : 140mmol/L
- K^+ : 3.5mmol/L
- Cl^- : 98mmol/L
- Anion Gap : 27

- pH : 7.55
- PCO_2 : 30 mm Hg
- PO_2 : 104 mm Hg
- HCO_3 : 29mmol/L
- BE : +5
- Sats : 99%
- Na^+ : 135mmol/L
- K^+ : 3.5mmol/L
- Cl^- : 95mmol/L
- Anion Gap: 11

- pH = 7.50
- PO_2 = 75 mm Hg
- BE = + 16
- Na^+ = 132 m mol / L
- Cl^- = 88 m mol / L
- PCO_2 = 50 mm Hg
- HCO_3 = 40 mmol / L
- SaO_2 = 95 %
- K^+ = 3.1 m mol / L
- Anion Gap = 4

- pH = 7.30
- PO_2 = 80 mm Hg
- BE = - 14
- Na^+ = 139 m mol / L
- Cl^- = 100 m mol / L
- PCO_2 = 30 mm Hg
- HCO_3 = 10 mmol / L
- SaO_2 = 95 %
- K^+ = 4.1 m mol / L
- Anion Gap = 29