

Chapter 8

Acid-Base Imbalances

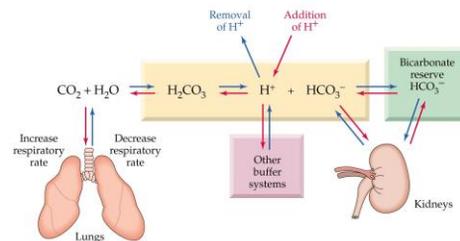
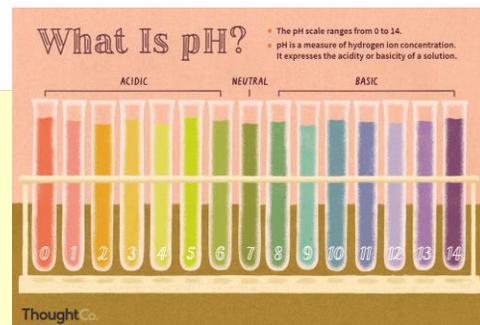
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Overview

- Alterations in pH disrupt body functioning, especially protein structure and function
- pH must be maintained in a narrow range
 - Blood pH 7.35–7.45
- *Buffer systems* help prevent large changes in pH by:
 - Donating H⁺ when solution is too basic
 - Absorbing H⁺ when solution is too acidic



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Acids and Bases

Acid

- → Donate H⁺ ions

Acidic solution

- → H⁺ predominate

Base

- → Accepts H⁺ ions in solution

Basic solution

- → Basic ions (OH⁻) predominate

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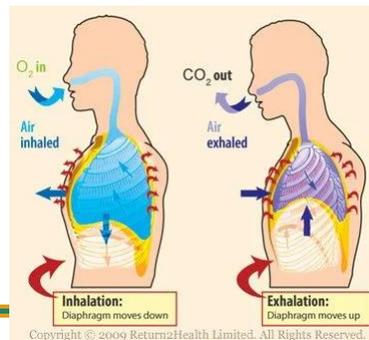
Volatile and Fixed Acids

Volatile Acid

- CO₂ combines with water forming the volatile acid, carbonic acid (H₂CO₃)
 - Enzyme: carbonic anhydrase in RBCs
- H₂CO₃ dissociates into CO₂ and water
- CO₂ exhaled by the lungs

Non-volatile (fixed) acids

- Not converted to CO₂
- Ketones, lactic acid, etc.



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pH and Metabolic Acids and Bases

- pH: negative logarithm of H⁺ concentration
 - Lower pH value: more acidic
 - Higher pH value: more basic
- Metabolic acids (examples)
 - CO₂ (volatile)
 - Ketones
 - Lactic acid
- Metabolic bases (example)
 - Metabolism of negatively charged amino acids

Three Major Buffer Systems

- Protein
 - Largest buffering system in the body
- Phosphate
 - Regulate intracellular pH
- Carbonic acid-bicarbonate buffering
 - Involves carbon dioxide, carbonic acid, hydrogen ions, bicarbonate
 - Lungs and kidneys utilize this system to help maintain blood pH

Carbonic Acid-Bicarbonate System



- **Carbon dioxide combines with water forming carbonic acid**
 - $\text{CO}_2 + \text{H}_2\text{O} \leftrightarrow \text{H}_2\text{CO}_3$
 - Carbonic anhydrase: enzyme in erythrocytes
- **Carbonic acid dissociates into bicarbonate and hydrogen ion**
 - $\text{H}_2\text{CO}_3 \leftrightarrow \text{HCO}_3^- + \text{H}^+$
 - HCO_3^- is a WEAK BASE
 - H^+ is a STRONG ACID

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Carbonic Acid-Bicarbonate System (continued)



- **Equation goes in both directions**
- **When CO_2 is elevated:** Equation moves toward the RIGHT
 - More $\text{HCO}_3^- + \text{H}^+$ are formed
- **When H^+ ions are elevated:** Equation moves toward the LEFT
 - H^+ ions are converted to CO_2

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Renal and Respiratory Compensation

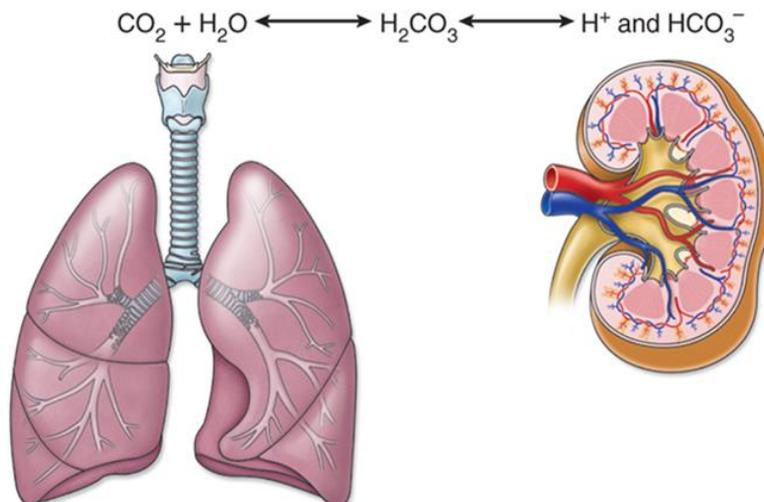
- **Lungs** and **kidneys** help regulate blood pH
- Use **carbonic acid-bicarbonate buffering system**
- Process known as “**COMPENSATION**”
- **Lungs**
 - Respond within minutes
 - Response can not be maintained indefinitely
- **Kidneys**
 - Hours to days to compensate
 - Response maintained for longer

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Lung and Kidney Compensation



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Respiratory Compensation



- Compensate by *adjusting VENTILATION* to alter CO₂ LEVELS
- **pH too ACIDIC: increase ventilation**
 - CO₂ exhaled and equations moves toward LEFT
 - H⁺ ion concentration falls, raising pH
- **pH too BASIC: decrease ventilation**
 - CO₂ retained and equation moves toward RIGHT
 - H⁺ ion level elevated, lowering pH

Respiratory Compensation (continued)

- Ventilation, CO₂, and pH are related
- Normal range for PCO₂ (partial pressure of carbon dioxide) is **35–45** mm Hg
- Chemoreceptors in brain monitor H⁺ ion levels
 - Send signal to medullary center to adjust ventilation as needed
 - Acidosis: increase ventilation
 - Alkalosis: decrease ventilation

Renal Compensation



- *Adjust* amount of HCO_3^- and H^+ *excreted* and *retained*
- pH too acidic
 - Retain HCO_3^-
 - Excrete H^+
- pH too basic
 - Retain H^+
 - Excrete HCO_3^-

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Arterial Blood Gases (ABGs)

- Blood pH: 7.35 to 7.45
- PCO_2 : 35 to 45 mm Hg
- HCO_3^- : 22 to 26 mEq/L
- PO_2 : 90 to 100 mm Hg
- SaO_2 (saturation of hemoglobin with oxygen): 95% to 100%



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Acid-Base Disorders

- **Acidosis** (acidemia): blood pH less than 7.35
- **Alkalosis** (alkalemia): blood pH greater than 7.45
- **Origin of Disturbance**
 - **Respiratory**
 - Abnormality in carbon dioxide
 - pH and CO₂ levels will be moving in OPPOSITE directions
 - **Metabolic**
 - Cause is not related to pulmonary system and carbon dioxide levels
 - pH and CO₂ levels will be moving in SAME direction

Acid-Base Disorders (continued_1)

- **Respiratory acidosis**
 - Elevated carbon dioxide
- **Respiratory alkalosis**
 - Reduced carbon dioxide
- **Metabolic acidosis**
 - Elevated acid other than carbon dioxide (i.e., ketones)

Acid-Base Disorders (continued_2)

- **Metabolic alkalosis**
 - Excess base or loss of H⁺ ions

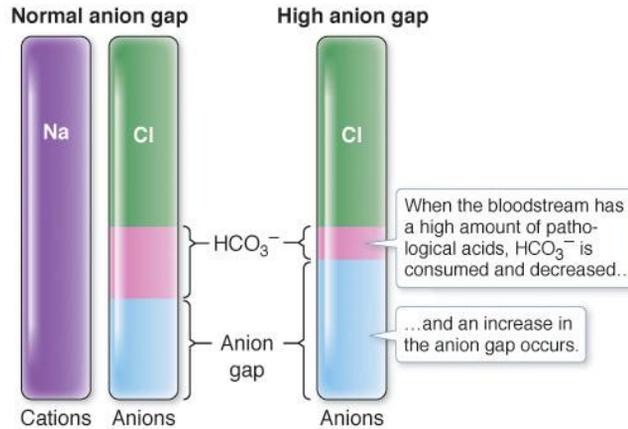
- **How do we assess?**
 - → ABGs
 - → Vital signs, history, physical examination

Anion Gap

- The **anion gap** is a measurement of the **difference or gap** between the **negatively charged and positively charged electrolytes.**
- If the **anion gap** is either **too high or too low**, it may be a **sign of a disorder** in your lungs, kidneys, or other organ systems.

- Measured cations minus measured anions
 - (Na⁺ and K⁺) - (Cl⁻ and HCO₃⁻)
- Anion gap
 - *Unmeasured anions* (i.e., the difference between the measured cations and anions)
- **Normal range:** 8 to 16 mEq/L
 - Laboratory reference ranges may vary
- *Deviations in anion gap can help to differentiate forms of metabolic acidosis*

Anion Gap (continued_1)



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Anion Gap (continued_2)

- **Increased anion gap**
 - Large amounts of unmeasured acids enter bloodstream
 - *Example:* ketones in diabetic ketoacidosis
 - Bicarbonate levels fall as bicarbonate ions (measured anions) buffer the acid
- **Normal anion gap**
 - Some forms of metabolic acidosis, such as GI loss of bicarbonate, do not have elevated anion gap

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Anion Gap (continued_3)

Elevated

- Lactic acidosis
- Ketoacidosis
- Renal failure
- Aspirin overdose
- Ingestion of methanol or glycol

Normal

- GI loss of bicarbonate
- Increased renal bicarbonate loss
- Hypoaldosteronism
- Ingestion of ammonium chloride

pH and Electrolytes

- Changes in pH affect ion movement
 - K⁺
 - Ca⁺⁺
- Changes in ion concentration can also affect pH
- Some of the signs and symptoms associated with pH imbalances are due to electrolyte disturbances

Relationship Between pH and Potassium

- Acidosis (especially metabolic)
 - H^+ shifts into cells and K^+ shifts out of cells leading to hyperkalemia
- Alkalosis
 - K^+ ions shift into the cells from plasma leading to hypokalemia
- Hyperkalemia
 - H^+ shifts out of cells leading to acidosis
- Hypokalemia
 - H^+ shifts into cells leading to alkalosis

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Relationship Between pH and Calcium

- H^+ and Ca^{++} compete for binding to albumin
- Acidosis
 - Increased free Ca^{++} (fewer binding sites on albumin for Ca^{++} due to H^+ binding)
 - Hypercalcemia
- Alkalosis
 - Increased binding of Ca^{++} to albumin (less competition with H^+)
 - Hypocalcemia

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Acid-Base Disturbances

- Respiratory acidosis
- Respiratory alkalosis
- Metabolic acidosis
- Metabolic alkalosis

Respiratory Acidosis

- pH less than 7.35
- CO₂ greater than 45 mm Hg
- Lungs unable to remove sufficient CO₂
- Moves equation to the right
$$\text{CO}_2 + \text{H}_2\text{O} \leftrightarrow \text{H}_2\text{CO}_3 \leftrightarrow \text{HCO}_3^- + \text{H}^+$$
- **Compensation**
 - Kidneys retain bicarbonate and excrete hydrogen ions

Respiratory Acidosis (continued)

- **Signs and Symptoms:**
 - Restless, headache, rapid breathing
 - Can develop confusion, “carbon dioxide narcosis”
- **Possible causes:**
 - Obstructive lung disease may be present
 - Respiratory centers may become insensitive to chronically high CO₂
- **Treatment**
 - Improve gas exchange

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Respiratory Alkalosis

- pH greater than 7.45
 - PCO₂ less than 35 mm Hg
 - **Possible causes:**
 - Hyperventilation (Often due to anxiety)
 - Moves equation to the left
- $$\text{CO}_2 + \text{H}_2\text{O} \leftrightarrow \text{H}_2\text{CO}_3 \leftrightarrow \text{HCO}_3^- + \text{H}^+$$

➤ Hypocalcemia and hypokalemia may develop

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Respiratory Alkalosis (continued)

- **Signs and Symptoms:**
 - Tingling of extremities, tetany, dizziness
 - If patient hypoxic → cyanosis may be present
- **Compensation**
 - Kidney reabsorb H^+ , excrete HCO_3^-
- **Treatment**
 - Slow respiration
 - Breathing into paper bag

Metabolic Acidosis

- pH less than 7.35 with normal to low CO_2
 - **Causes:**
 - Excess acid: diabetic ketoacidosis, for example
 - Bicarbonate loss: GI disorders
- May present with normal or elevated anion gap
- Hyperkalemia and hypercalcemia may develop

Metabolic Acidosis (continued)

- **Signs and Symptoms:**
 - Increased respirations, tachycardia, hypotension, confusion
- **Compensations**
 - **Lungs:** increase ventilation (Kussmaul's breathing)
 - **Kidneys:** excrete H⁺, reabsorb HCO₃⁻
- **Treatment**
 - Correct underlying cause

Metabolic Alkalosis

- pH greater than 7.45, with normal or high CO₂
- **Causes**
 - Excessive loss of acids, unrelated to CO₂
 - Kidneys and GI tract loss
 - Increase in bicarbonate levels

➤ Hypocalcemia and hypokalemia may develop

Metabolic Alkalosis (continued)

- **Signs and Symptoms**
 - Confusion, dizziness, weakness, diarrhea
- **Compensation**
 - **Lungs:** decrease ventilation to increase CO_2
 - **Kidneys:** excrete HCO_3^- and retain H^+
- **Treatment**
 - Electrolyte and fluid replacement

Mixed Disorders

- More than one type of acid-base disturbance may be present at the same time
- Analysis of **ABG values**, **anion gap**, and **patient presentation (s/s)** are critical for correct diagnosis

ABG tic tac toe

Tic Tac Toe Method for Arterial Blood Gas Interpretation:

<https://www.youtube.com/watch?v=URCS4t9aM5o>

Partially Compensated vs Fully Compensated Uncompensated ABGs Interpretation

<https://www.youtube.com/watch?v=3neNB0w1P9M>

Goals of ABG Analysis

With the given lab values, we need to determine if the interpretation is:

1. ACIDOSIS
ALKALOSIS
2. METABOLIC
RESPIRATORY
3. FULLY COMPENSATED
PARTIALLY COMPENSATED
UNCOMPENSATED

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