

Topic 24: Pulmonary Study Guide

RESPIRATORY ANATOMY

Organization of the Respiratory System

- The respiratory system consists of two major functional divisions:
 - (1) _____ **Zone** (nose → terminal bronchioles) and
 - (2) _____ **Zone** (respiratory bronchioles → alveoli).
- Conducting zone structures provide no gas exchange; their primary roles are: *air delivery, filtration, humidification, and adjustment to body temperature.*
- The respiratory zone contains thin-walled, highly vascularized alveoli, optimized for rapid diffusion of gases.
- The structural complexity of branching airways maximizes surface area while reducing resistance to airflow.

Conducting Zone Functions

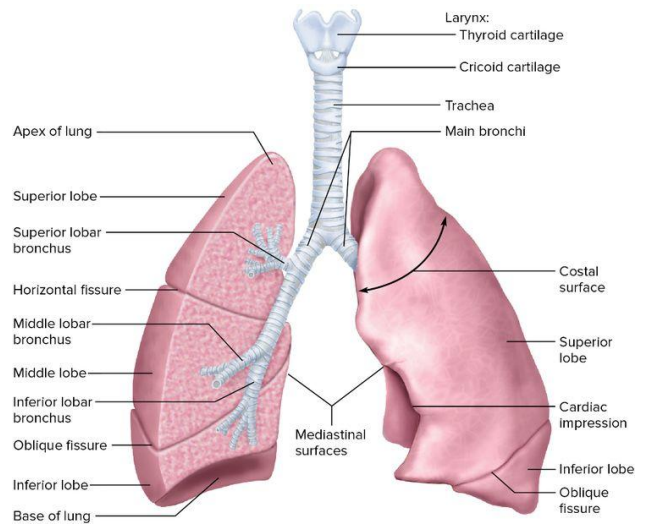
- Inspired air contains particulates, microorganisms, and temperature variation. The conducting zone modifies this air before it reaches delicate alveoli.
- Mucociliary _____ (use of mucus and cilia to push mucus upward from bronchi toward the throat) uses coordinated ciliary movement to sweep mucus upward toward the pharynx for swallowing. Goblet cells produce mucus to capture pathogens.
- Airflow resistance here is influenced by: *airway diameter, mucus production, and smooth muscle tone.*
 - 1) *Airway diameter (Poiseuille's law: decrease in radius -> increases resistance)*
 - 2) *Mucus production (excessive mucus can narrow airways)*
 - 3) *Smooth muscle tone (hyperreactive smooth muscles constricts aggressively during irritant exposure)*
- Cigarette smoke, pollutants, and chronic inflammation damage cilia → impaired mucociliary clearance → chronic bronchitis and repeated infections.

Nasal Cavity and Turbinates

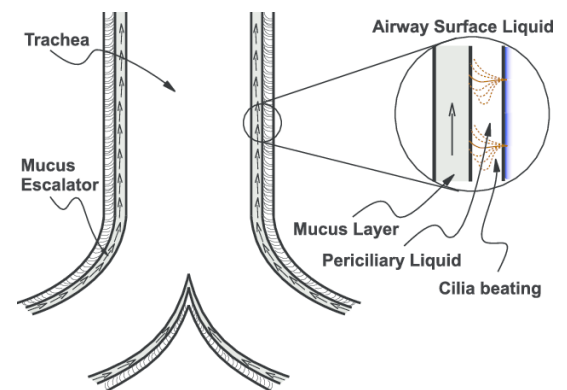
- The nasal _____ (conchae) create turbulent airflow, causing particles to collide with mucus-lined surfaces.
- Extensive capillary beds warm and humidify inspired air, preventing desiccation (drying out) of alveoli.
- Parasympathetic stimulation dilates mucosal vessels, increasing congestion. Sympathetic activation produces decongestion.
- *Overuse of topical nasal decongestants leads to rebound congestion (rhinitis medicamentosa).

Trachea and Bronchi

- The trachea contains _____-shaped hyaline cartilage rings supporting airway patency during inhalation and exhalation.



	Name of branches	Number of tubes in branch
Conducting zone	Trachea	1
	Bronchi	2
		4
		8
		16
Bronchioles	32	
Terminal bronchioles	6×10^4	
Respiratory zone	Respiratory bronchioles	5×10^5
	Alveolar ducts	
	Alveolar sacs	8×10^6



- As airways branch into bronchi and lobar bronchi, cartilage becomes discontinuous, and smooth muscle proportion increases.
- Airflow velocity decreases as cross-sectional area increases.
- β_2 -AR in the lungs: Bronchodilators (albuterol)(β_2 -agonists) _____ smooth muscle \rightarrow improved airflow in asthma.

Bronchioles and Transition to Respiratory Zone

- Beyond the terminal bronchioles, cartilage disappears \rightarrow airways now depend on surrounding lung tissue (parenchymal tethering) for patency.
- Smooth muscle dominates \rightarrow primary site of resistance modulation.
- Airway caliber responds to CO_2 levels in local alveoli — low ventilation triggers bronchiolar constriction.
- Clinical relevance: Asthma involves exaggerated smooth muscle _____, increasing airway resistance.

Respiratory Zone

- Begins at respiratory bronchioles, continues through alveolar ducts, ending at alveolar sacs.
- Each alveolus is wrapped in a dense pulmonary capillary network.
- The enormous number of alveoli (~300 million) provides 70–100 m² surface area — roughly the area of a tennis court.

Alveolar Structure and Cell Types

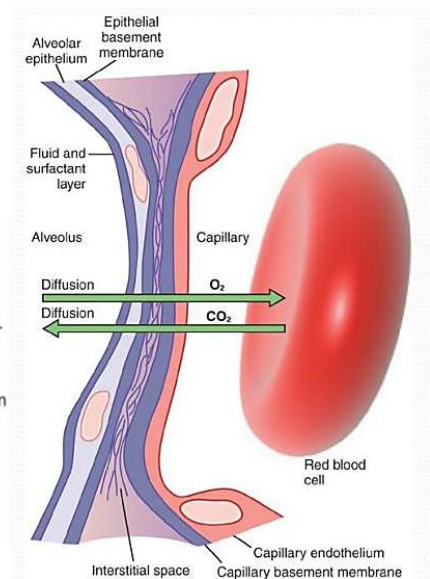
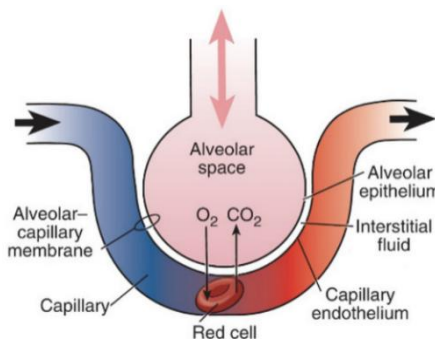
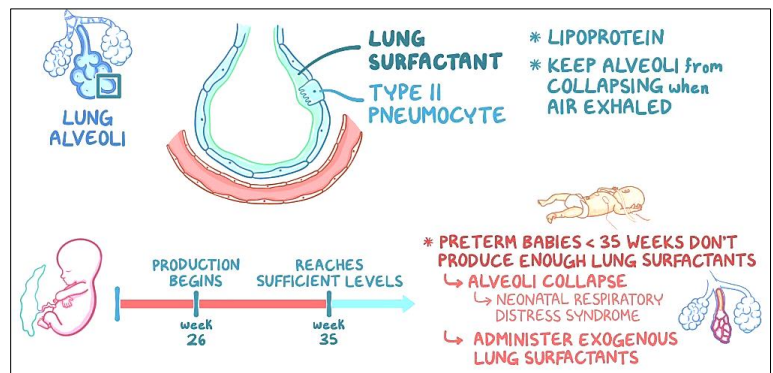
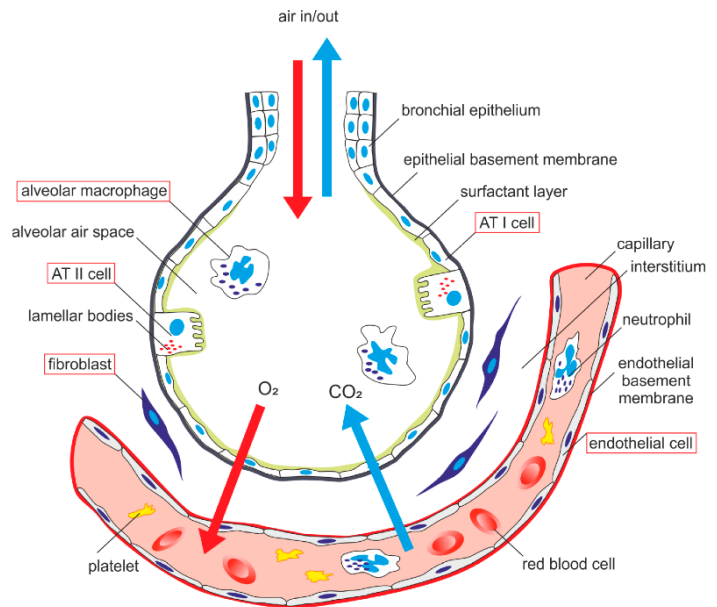
- Type I pneumocytes: Flat epithelial cells covering >90% of alveolar surface; primary site for gas exchange.
- Type II pneumocytes: Produce _____, a phospholipid compound that reduces surface tension.
- Alveolar macrophages: Remove debris and pathogens.

Surfactant

- Surfactant reduces the work of breathing by lowering surface tension and promoting alveolar stability.
- Without surfactant, small alveoli collapse into larger ones (_____ Law).
- Clinical: Premature infants lacking mature Type II cells develop neonatal respiratory distress syndrome (RDS) — treated with surfactant replacement therapy and positive-pressure ventilation.

Alveolar-Capillary Barrier

- Extremely _____ diffusion membrane: Type I cell + basement membrane + capillary endothelium.
- The barrier supports rapid diffusion of O_2 and CO_2 due to: (1) High surface area, Minimal diffusion distance, High perfusion. (2) Any thickening (edema, fibrosis) impairs gas exchange.



Steps of Inspiration

Active process — requires muscle contraction and energy.

1. Brain Sends Signal

- The medulla oblongata (respiratory center) sends impulses via the _____ nerve to the diaphragm.

2. Diaphragm Contracts & Moves Down

- It flattens from a dome shape → increases vertical dimension of thoracic cavity.

3. External Intercostal Muscles Contract

- Lift and pull ribs _____ and _____ → increases side-to-side and front-to-back chest dimensions.

4. Thoracic Cavity Volume Increases

- The space inside the chest becomes bigger.

5. Intrapulmonary (Alveolar) Pressure Drops

- Boyle's law: volume ↑ = pressure ↓
- Alveolar pressure drops from 760 → ~758 mmHg

6. Air Rushes Into Lungs

- Air always moves from higher pressure (outside) → lower pressure (inside lungs)
- This fills alveoli with fresh air.

7. Gas Exchange Begins

- Oxygen diffuses from alveoli → _____
- CO₂ diffuses from blood → alveoli

Steps of Expiration

Normal expiration is passive — no muscles contracting.

1. Nervous System Stops Stimulus

- The diaphragm and intercostals _____.

2. Diaphragm Moves Up

- Returns to dome shape → reduces vertical chest dimension.

3. Ribs Fall Down and In

- External intercostals _____ → chest wall recoils.

4. Thoracic Cavity Volume Decreases

- Space in the lungs becomes smaller.

5. Intrapulmonary Pressure Rises

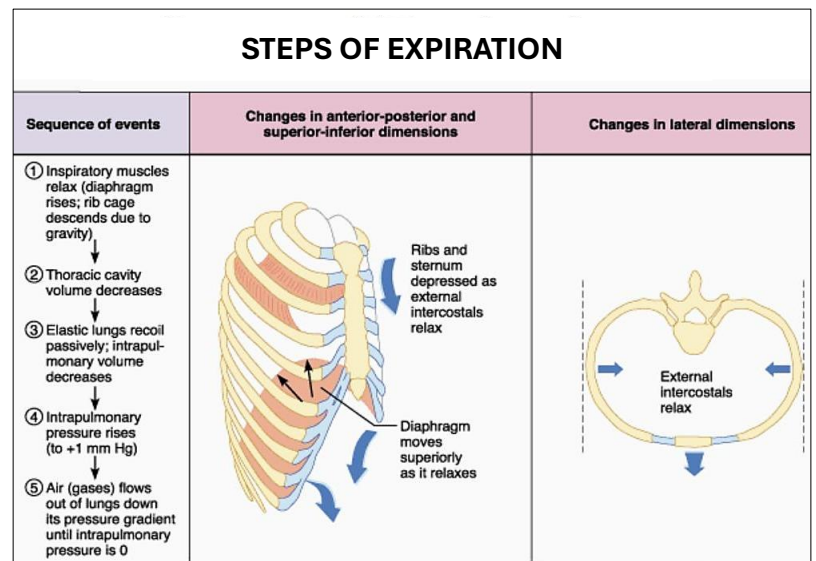
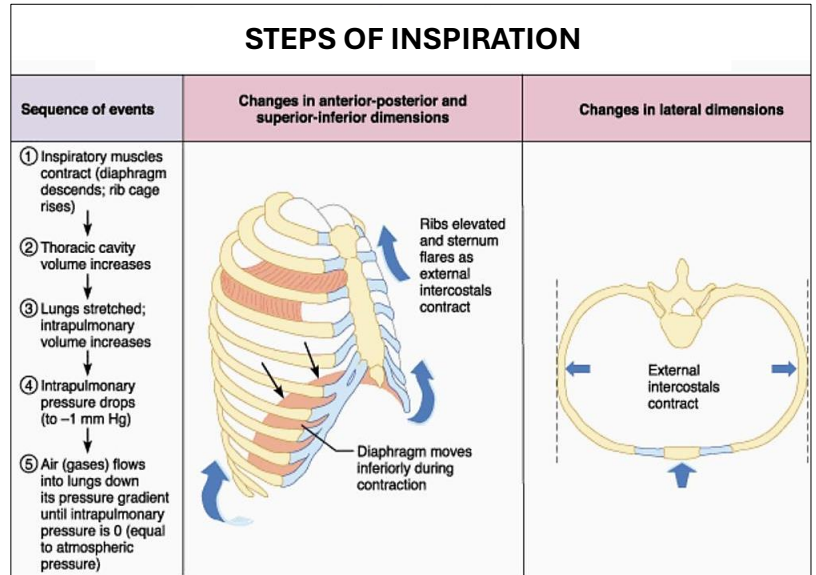
- As volume ↓, pressure ↑ above atmospheric: ~762 mmHg

6. Air Flows Out of Lungs

- Air moves from high pressure (lungs) → low pressure (outside)

7. Alveoli Remain Partially Open

- Thanks to residual volume and _____ preventing collapse.



Feature	Normal Inspiration	Normal Expiration
Energy	Requires ATP (active)	Passive at rest
Diaphragm	Contracts ↓	Relaxes ↑
Pressure	Decreases	Increases
Air Movement	In → lungs	Out → atmosphere

Feature	Forced Inhalation	Forced Exhalation
Process Type	Active	Active
Goal	Bring in more air than normal	Push out more air than normal
Primary Muscles	Diaphragm (contracts strongly), External intercostals, Sternocleidomastoid, Scalenes, Pectoralis minor	Internal intercostals, Abdominal muscles (rectus abdominis, transverse abdominis, obliques)
Chest Wall Movement	Ribs move up and out, thoracic cavity expands	Ribs pulled down and in, abdominal organs push diaphragm upward
Thoracic Volume	Increases greatly	Decreases significantly
Intrapulmonary Pressure	Drops well below atmospheric pressure	Rises above atmospheric pressure

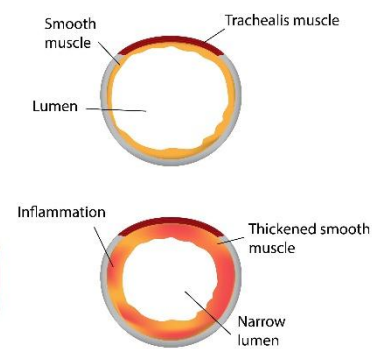
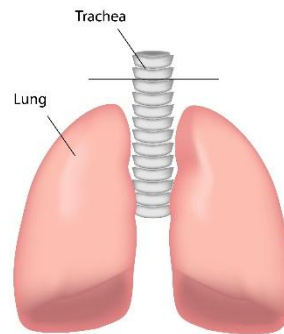
LUNG MECHANICS (VENTILATION) AND COPD

_____ refers to the mechanical movement of air into and out of the lungs. For air to move, a pressure gradient must exist—air always flows from an area of higher pressure to lower pressure. The respiratory system creates these gradients by changing thoracic volume via muscle contraction.

- Inspiration is an active process at rest:
 - The diaphragm contracts and descends, increasing thoracic cavity volume.
 - This expands the lungs, causing intrapulmonary (alveolar) pressure to drop below atmospheric pressure.
 - Air rushes in until alveolar pressure equilibrates with atmospheric pressure.
- Expiration during quiet breathing is passive:
 - The diaphragm relaxes.
 - Elastic elements of the lung recoil back to their resting state.
 - This reduces lung volume, increasing alveolar pressure above atmospheric pressure, pushing air out.
- Forced expiration (exercise, coughing, COPD) becomes active:
 - Internal intercostals and abdominal muscles contract.
 - Raises intrathoracic pressure and accelerates airflow out of the lungs.
- Patients with COPD rely heavily on accessory muscles due to loss of elastic recoil, making expiration labored.

COPD = Chronic Obstructive Pulmonary Disease

- COPD is a progressive, _____ lung condition characterized by airflow obstruction that makes it difficult to exhale fully. It is a major cause of morbidity and mortality worldwide.



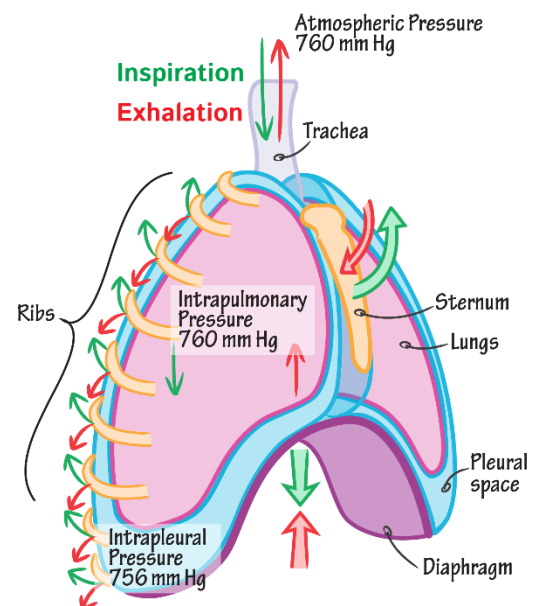
Healthy

COPD

- Chronic Airflow Limitations: Persistent obstruction due to airway narrowing and loss of elastic recoil. Air becomes trapped in the lungs → hyperinflation → difficulty breathing
- Pathophysiological Changes in COPD:
 - Loss of elastic fibers → decreased recoil → air trapping
 - Mucus production → obstructs airflow
 - Small airway inflammation → narrowing of bronchioles
 - Flattened diaphragm due to hyperinflation → inefficient breathing mechanics

Pressure Relationships

- Breathing mechanics depends on three key pressures:
- (1) Atmospheric Pressure (P_{atm})
 - ~760 mmHg at sea level (used as reference).
 - Does not change during normal breathing.
- (2) Alveolar Pressure = Intrapulmonary Pressure (PA)
 - Changes with ventilation:
 - Slightly negative during inspiration,
 - Slightly positive during expiration.
 - Determines airflow direction.
- (3) Intrapleural Pressure (Ppl)

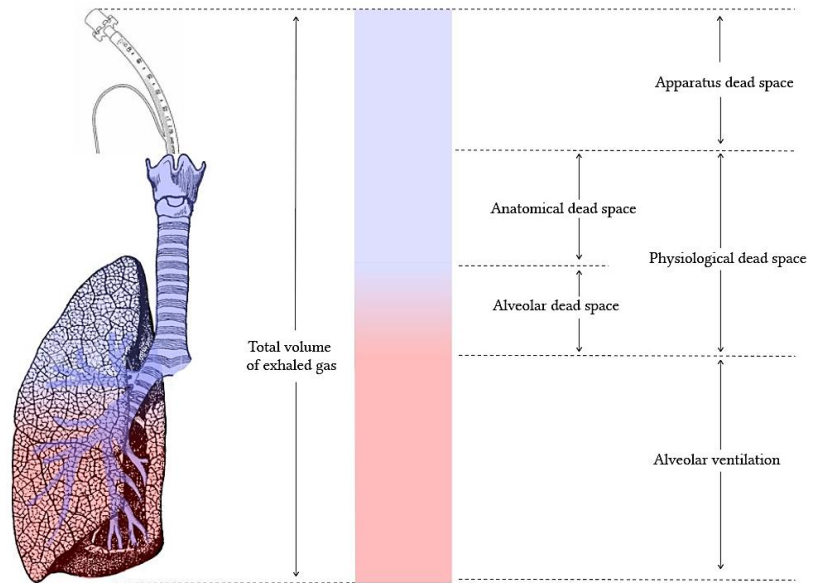


- Normally negative due to opposing forces of chest wall expansion and lung recoil.
- Prevents lung collapse.
- Becomes more negative during inspiration as thoracic volume increases.
- If intrapleural pressure becomes positive (e.g., pneumothorax), the lung collapses. A pneumothorax occurs when air enters the pleural space, usually due to trauma (stab wound, fractured rib) or spontaneously (ruptured bleb).

DEAD SPACE

Anatomical Dead Space

- The volume of the conducting zone (nose, trachea, bronchi, terminal bronchioles) that does not contain alveoli and therefore does not participate in gas exchange.
- Approximately 150 mL in an average adult—roughly 2 mL/kg of ideal body weight.
- This value remains relatively constant, regardless of depth of breathing.
- If tidal volume (TV) is small (e.g., shallow breaths), a large fraction of each breath remains in dead space → wasted ventilation.



Physiological Dead Space

- Represents *anatomical dead space* + *alveolar dead space*.
- Alveolar dead space occurs when alveoli are ventilated but not perfused.
- Classic cause: Pulmonary embolism (PE)—blood flow is interrupted, so ventilated alveoli receive no blood and cannot exchange gases.

Apparatus Dead Space

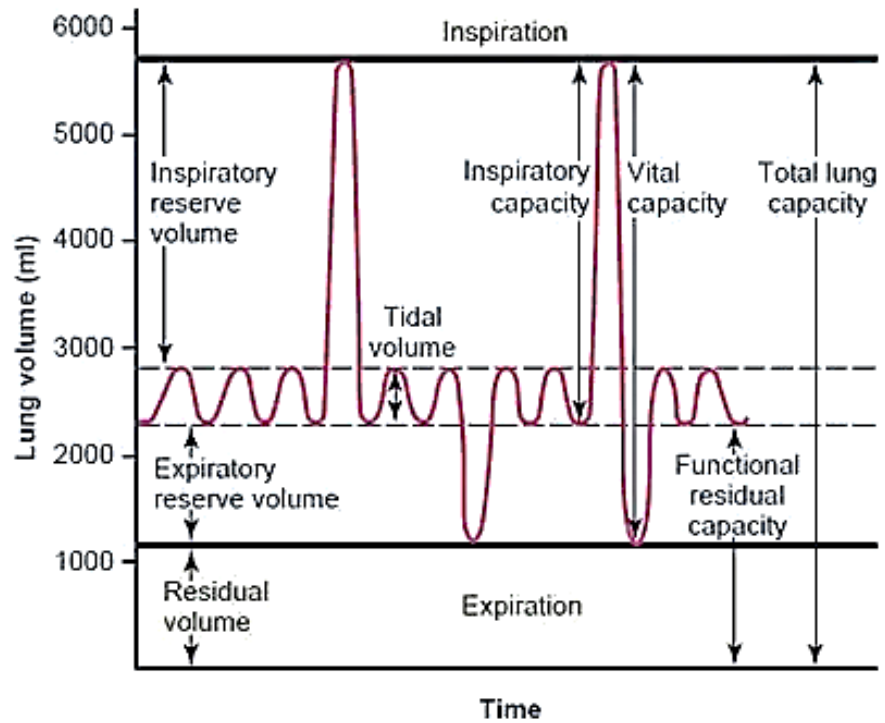
- Referring to the volume of breathing equipment (tubing, valves, masks, mouthpieces, snorkels, ventilator circuits, etc.) that does not participate in gas exchange and adds to the air a person must move with each breath without delivering it to the alveoli. Apparatus dead space increases the total physiological dead space, meaning more of each breath is wasted and does not reach the alveoli.

PULMONARY CIRCULATION and LUNG VOLUMES/ SPIOGRAM

Term	Definition	Normal Volume	Includes	What it Represents
Tidal Volume (TV)	Air moved in and out during normal, quiet breathing	~500 mL	—	Basic breathing at rest
Inspiratory Reserve Volume (IRV)	Extra air you can inhale after a normal tidal inhalation	~3000 mL	TV + IRV → part of IC	Maximum extra breath in
Expiratory Reserve Volume (ERV)	Extra air you can exhale after a normal tidal exhalation	~1100 mL	TV + ERV (part of FRC)	Maximum extra breath out
Residual Volume (RV)	Air left in lungs after maximum exhalation (you can never get this out)	~1200 mL	RV part of FRC, TLC	Keeps alveoli open; prevents lung collapse
Inspiratory Capacity (IC)	Total air you can inhale after a normal exhalation	TV + IRV	~3500 mL	Max inhalation from end-expiration
Functional Residual Capacity (FRC)	Air remaining in lungs after a normal exhalation	ERV + RV	~2300 mL	The lung's resting volume
Vital Capacity (VC)	Total air exhaled after a maximum inhalation	IRV + TV + ERV	~4600 mL	Maximum air you can move voluntarily
Total Lung Capacity (TLC)	Total volume of lungs after maximum inhalation	VC + RV	~5800–6000 mL	All air lungs can hold

Pulmonary Circulation Basics

- The pulmonary vasculature is a high-flow, low-pressure system:
 - Prevents damage to delicate alveolar membranes
 - Minimizes edema formation
- Blood flow distribution varies with gravity and patient position.
- Although both gases diffuse across the same membrane, their behavior differs dramatically:
- CO₂ is ~ _____ more diffusible than O₂
 - Due to greater solubility in blood and tissues
 - CO₂ easily crosses membranes even when pathologic changes exist
 - As a result, hypercapnia (high CO₂) generally occurs later in disease than hypoxemia
- O₂ is far more vulnerable to disruption
 - Oxygen diffusion relies heavily on maintaining a strong pressure gradient and thin membrane
 - Diseases that alter membrane thickness disproportionately impair O₂ transfer
- *A patient may be severely hypoxemic with normal CO₂ levels early in disease—O₂ fails first.

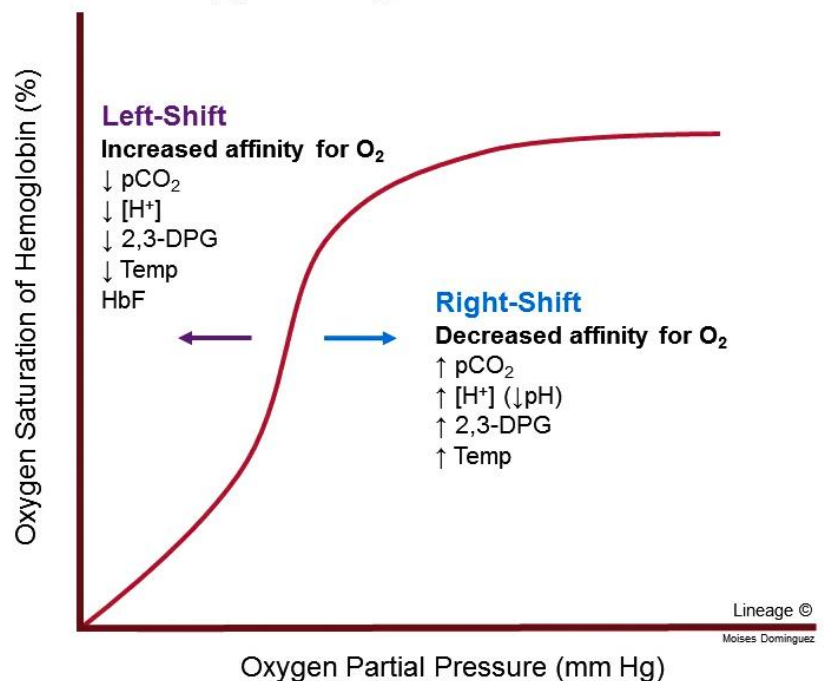


O₂ & CO₂ TRANSPORT

Hemoglobin and Oxygen

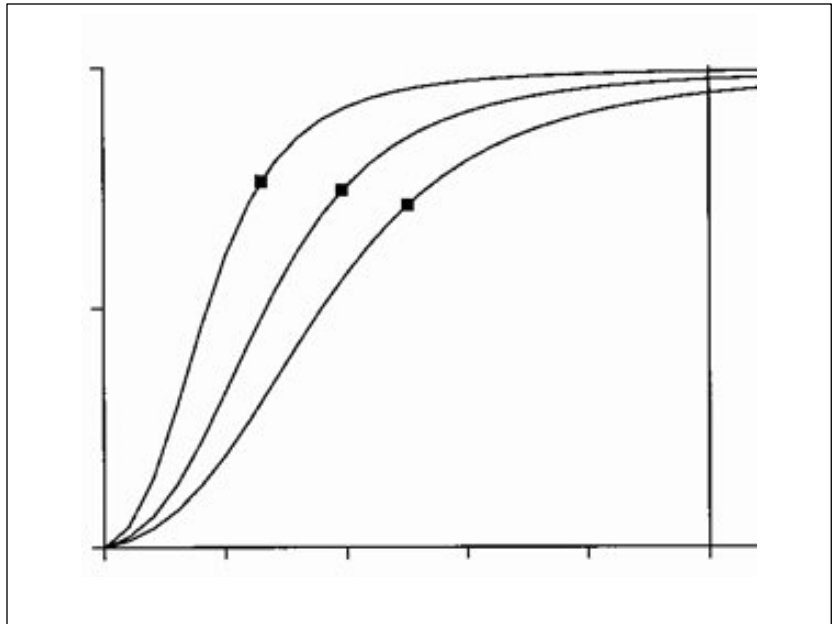
- Oxygen transport relies overwhelmingly on hemoglobin (Hb) inside red blood cells.
- Although oxygen dissolves in plasma, the dissolved fraction is tiny—only 0.3 mL O₂ per 100 mL blood at normal PaO₂.
- Human metabolism requires ~250 mL O₂/min, far exceeding what dissolved O₂ can supply.
- Hemoglobin provides reservoir capacity so oxygen can be carried, stored, and released in proportion to tissue demand.
- Each Hb molecule binds _____ O₂ molecules via iron atoms in heme groups—creating a reversible and regulated transport system.
- Clinical: Anemia reduces oxygen-carrying capacity without altering PaO₂ — meaning the blood appears “normally oxygenated” but cannot deliver adequate oxygen.

Oxygen-Hemoglobin Dissociation Curve



Oxyhemoglobin Curve

- Sigmoid shape reflects cooperative binding.
- P50 indicates affinity of hemoglobin for O₂. P50 = the partial pressure of oxygen (PO₂) at which hemoglobin is 50% saturated with oxygen.
- The curve relates PaO₂ (partial pressure of O₂ in blood) to % saturation of Hb.
- Its sigmoid shape reflects cooperative binding—binding of one O₂ molecule increases affinity for the next.
- Low P50 = high affinity (left shift)
 - Hypothermia, Hyperventilation, Carbon monoxide poisoning, fetal hemoglobin, anemia, high altitude
- High P50 = low affinity (right shift)
 - Exercise, fever, renal failure, sepsis, pregnancy, hyperthyroidism (Grave's Disease)
- Why this matters: Small shifts dramatically alter oxygen delivery, even if PaO₂ appears normal.

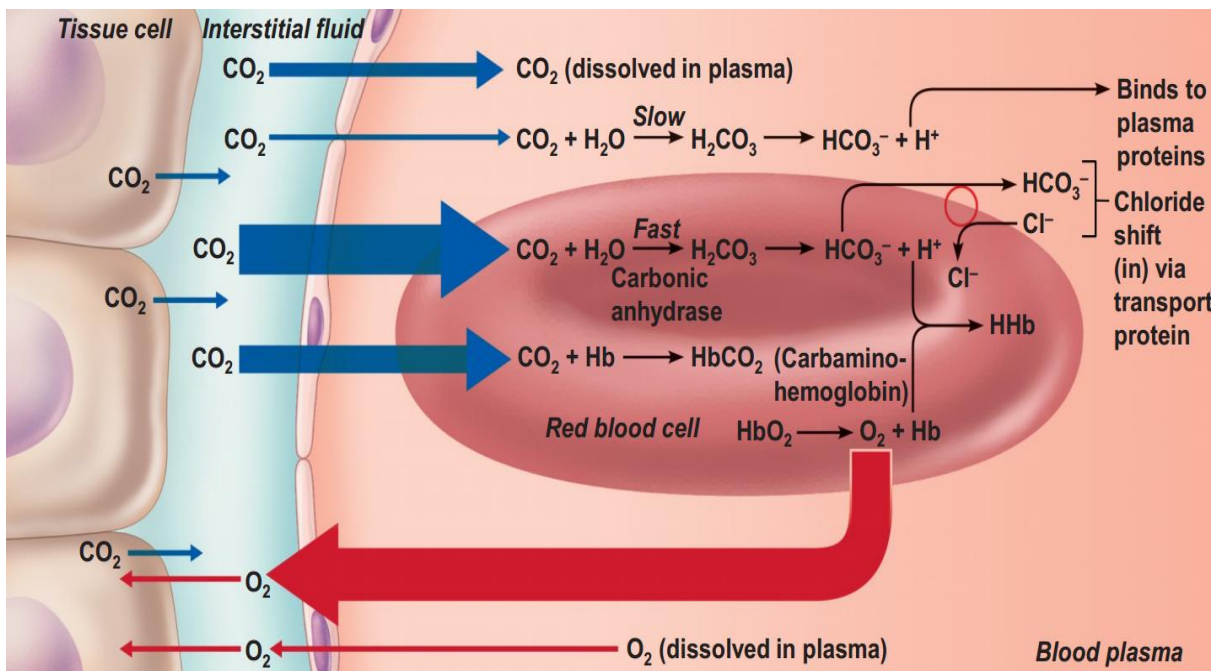


CO₂ Transport

- CO₂ is transported in three forms:

Form	Percentage	Mechanism
Dissolved	~5%	Directly dissolved in plasma
Carbamino compounds	~5%	Bound to hemoglobin proteins
Bicarbonate (HCO ₃ ⁻)	~90%	Converted by carbonic anhydrase

- The chloride shift maintains electroneutrality:
 - Bicarbonate exits the RBC into plasma
 - Chloride moves into the RBC
 - Supports continuous CO₂ transport during metabolism



NEURAL CONTROL OF BREATHING

Central Pattern Generator

- Located in the medulla and pons
- Generates the rhythmic drive for inspiration
- Projects to diaphragm via phrenic nerve (C3–C5)

Central Chemoreceptors

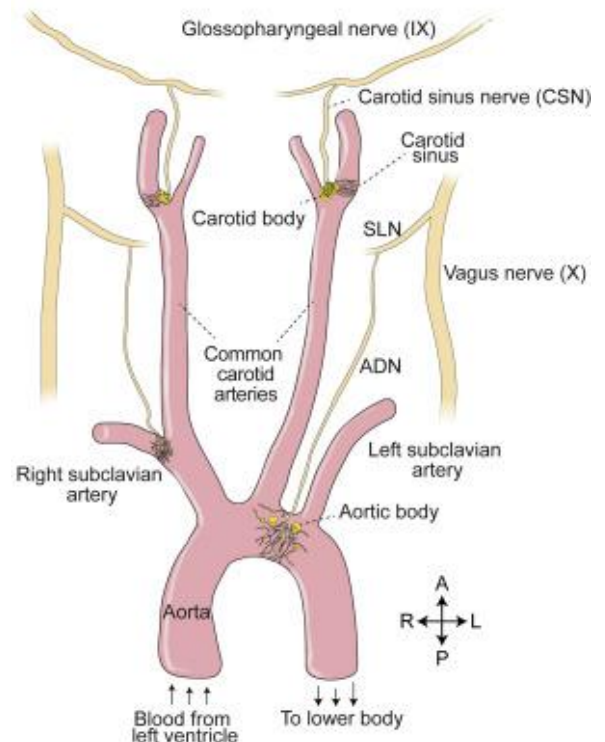
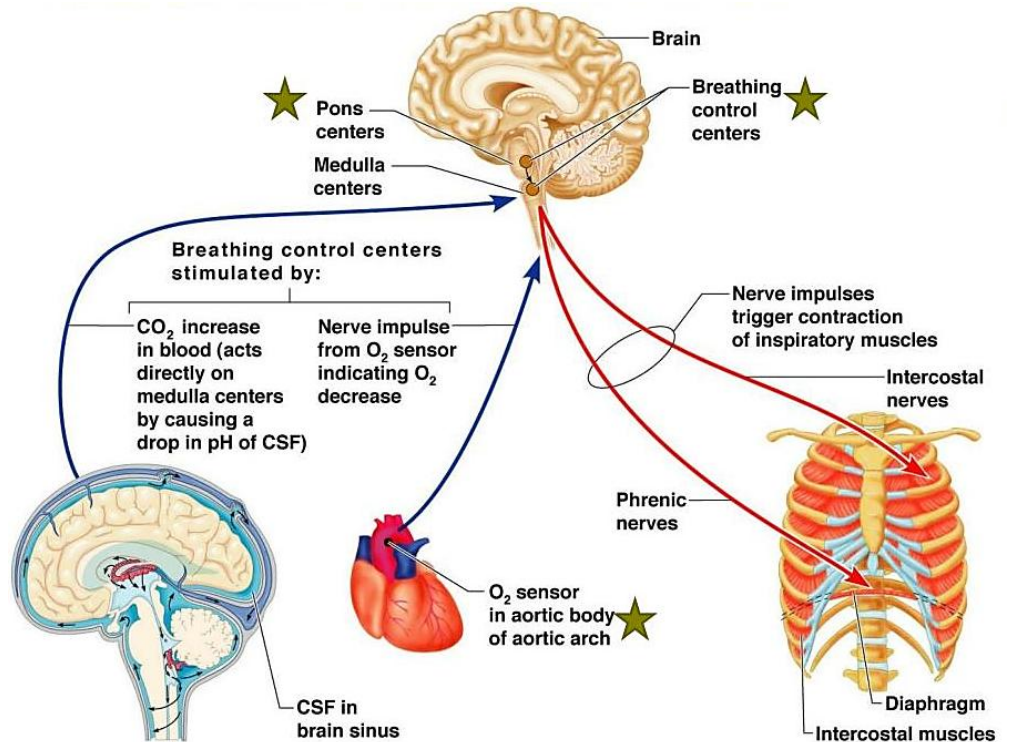
- Located near the medulla, bathing in CSF
- Respond primarily to H^+ generated from CO_2
- Most powerful driver of ventilation
- Do not respond directly to O_2

Peripheral Chemoreceptors

- Located in carotid and aortic bodies
- Respond to:
 - $\downarrow PaO_2$ (<60 mmHg)
 - $\uparrow PaCO_2$
 - $\downarrow pH$
- Activate ventilation when hypoxemia threatens oxygen delivery
- Important distinction: CO_2 drives ventilation under normal conditions; O_2 drives ventilation only in hypoxic states.

Abnormal Breathing Patterns

- Cheyne–Stokes: alternating apnea and hyperpnea. This pattern occurs when the brain's respiratory centers respond slowly to changes in blood gases, often seen in heart failure, stroke, or brain injury.
- Kussmaul: deep rapid breathing in acidosis. It is the body's attempt to blow off CO_2 to raise pH, commonly associated with diabetic ketoacidosis (DKA) and severe metabolic acidosis.
- Central apnea: absent respiratory drive. The brain temporarily stops sending signals to respiratory muscles, causing no effort to breathe, often linked to neurological disorders, opioid use, or sleep instability.
- Obstructive Sleep Apnea: airway collapse during sleep despite respiratory effort. The soft tissues of the throat relax and block the upper airway, causing repeated episodes of snoring, gasping, and brief awakenings, commonly associated with obesity, enlarged tonsils, or a thick neck.



Topic 24: Pulmonary Study Guide Questions (preppages)

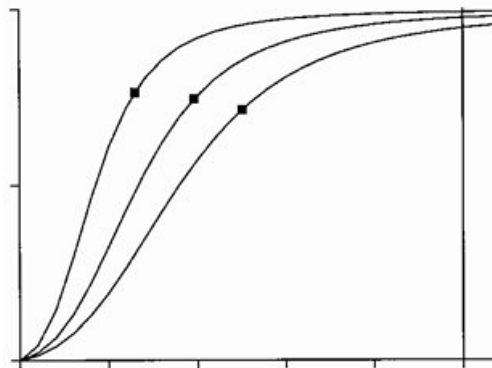
- Which of the following best describes the conducting zone of the respiratory system?
 - Site of gas exchange
 - Structures from nose to terminal bronchioles that warm, filter, and humidify air
 - Structures from respiratory bronchioles to alveoli
 - Only the nasal cavity and trachea
- Gas exchange occurs primarily in which part of the respiratory system?
 - Trachea
 - Nasal cavity
 - Respiratory bronchioles and alveoli
 - Larynx
- The mucociliary escalator's primary function is to:
 - Increase airway resistance
 - Push mucus and trapped particles toward the pharynx
 - Stimulate bronchodilation
 - Produce surfactant
- Cigarette smoking impairs mucociliary clearance primarily by:
 - Increasing surfactant production
 - Damaging Type I pneumocytes
 - Paralyzing and destroying cilia
 - Decreasing alveolar capillary networks
- Nasal turbinates function to:
 - Increase tidal volume
 - Create turbulent airflow for filtration and humidification
 - Reduce blood flow to nasal tissues
 - Enhance alveolar surface area
- The trachea remains patent during breathing due to:
 - Smooth muscle dominance
 - C-shaped hyaline cartilage rings
 - Alveolar recoil
 - Surfactant secretion
- β_2 -agonists such as albuterol improve airflow by:
 - Increasing mucus production
 - Destroying alveolar macrophages
 - Relaxing bronchial smooth muscle
 - Stimulating surfactant release
- The primary site of airway resistance modulation is located in the:
 - Trachea
 - Terminal bronchioles
 - Bronchioles lacking cartilage
 - Alveolar sacs
- Type II pneumocytes are responsible for producing:
 - Hemoglobin
 - Surfactant
 - Carbonic anhydrase
 - Pulmonary capillaries
- Without surfactant, alveoli collapse due to:
 - Boyle's Law
 - Laplace's Law
- During inspiration, intrapulmonary pressure:
 - Rises above atmospheric pressure
 - Drops below atmospheric pressure
 - Equals intrapleural pressure
 - Does not change
- Forced expiration requires activation of which muscles?
 - Diaphragm and scalenes
 - Internal intercostals and abdominal muscles
 - External intercostals only
 - Sternocleidomastoid and pectoralis minor
- Patients with COPD have difficulty exhaling because of:
 - Increased elastic recoil
 - Excess surfactant
 - Loss of elastic fibers causing air trapping
 - Increased alveolar surface area
- A pneumothorax causes lung collapse by:
 - Increasing mucous secretions
 - Making intrapleural pressure positive
 - Decreasing tidal volume
 - Increasing arterial oxygenation
- Anatomical dead space refers to air:
 - In alveoli that are ventilated but not perfused
 - In the conducting zone that does not participate in gas exchange
 - Trapped due to COPD
 - Remaining after forced expiration
- Most CO_2 in the blood is transported as:
 - Dissolved CO_2 in plasma
 - Carbaminohemoglobin
 - Bicarbonate ion (HCO_3^-)
 - Carbon monoxide
- Peripheral chemoreceptors are activated primarily when:
 - PaO_2 falls below 60 mmHg
 - PaCO_2 decreases
 - Surfactant levels increase
 - Mucus production stops
- Which breathing pattern is characterized by deep, rapid respirations due to metabolic acidosis?
 - Cheyne–Stokes
 - Kussmaul breathing
 - Central apnea
 - Obstructive apnea
- A rightward shift of the oxyhemoglobin curve (high P50) indicates:
 - Increased O_2 affinity
 - Decreased O_2 affinity and easier O_2 release to tissues
 - Carbon monoxide poisoning
 - Hypothermia

20. List the two locations where the peripheral chemoreceptors are located?

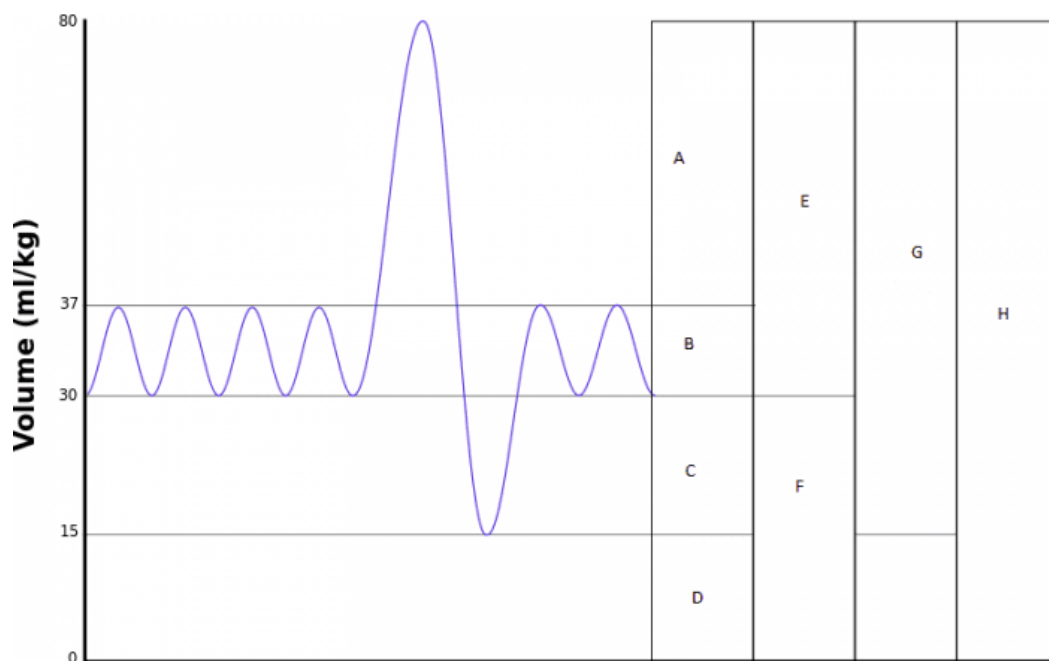
21. Explain the importance of the chloride shift in the blood?

- a. Explain if it maintains acid-base balance, does it transport CO₂? What is the role of carbonic anhydrase?

22. Explain the left and right shift of the oxygen hemoglobin dissociation curve? What happens when you increase and decrease pH, what happens when you increase or decrease temperature to the curve (indicate this by drawing $\uparrow\downarrow$ pH/temperature? List a disease state or condition that would shift the curve left or right?

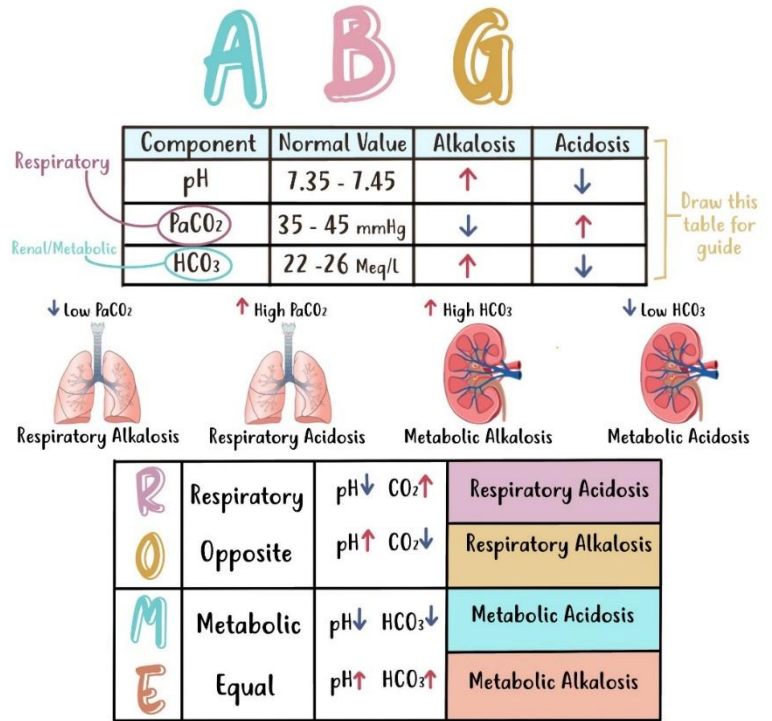


23. Identify the following lung parameters on this spirogram:



ACID-BASE BALANCE PHYSIOLOGY QUESTION

The body maintains a precise acid–base balance to ensure proper cellular function, mainly regulated by the lungs and kidneys. Arterial Blood Gas (ABG) analysis helps determine whether a patient’s blood is acidic or alkalotic by measuring pH, PaCO₂ (a marker of respiratory function), and HCO₃⁻ (a marker of metabolic/kidney function). The lungs control CO₂ levels by altering ventilation, while the kidneys regulate bicarbonate (HCO₃⁻) production and excretion. When an imbalance occurs, the organ system not primarily responsible attempts to compensate—for example, lungs adjust breathing to correct metabolic disturbances, and kidneys modify bicarbonate levels to compensate for respiratory issues. Importantly, compensation never fully corrects the pH beyond normal ranges. Different clinical conditions can cause each disturbance: respiratory acidosis results from hypoventilation (e.g., COPD), respiratory alkalosis from hyperventilation (e.g., anxiety), metabolic acidosis from bicarbonate loss (e.g., diarrhea), and metabolic alkalosis from excess bicarbonate or acid loss (e.g., vomiting).



1. In an ABG analysis, a primary increase in PaCO₂ indicates which type of disturbance?

- A) Metabolic acidosis B) Respiratory acidosis
C) Metabolic alkalosis D) Respiratory alkalosis

2. Which condition is most commonly associated with metabolic alkalosis?

- A) Diarrhea B) Renal failure C) Vomiting D) COPD

3. Which organ is primarily responsible for regulating bicarbonate (HCO₃⁻) levels in the blood?

- A) Lungs B) Kidneys C) Liver D) Brainstem

4. A patient presents with anxiety and is hyperventilating. Their ABG shows elevated pH and low PaCO₂. What is the most likely diagnosis?

- A) Respiratory acidosis B) Metabolic acidosis C) Respiratory alkalosis D) Metabolic alkalosis

NCLEX-LEVEL EXAMPLE QUESTION

5. A client with COPD presents with lethargy, headache, and confusion.

ABG results show: pH 7.30, PaCO₂ 58 mmHg, HCO₃⁻ 26 mEq/L. Which interpretation is correct?

- A) Respiratory alkalosis, uncompensated B) Respiratory acidosis, uncompensated
C) Metabolic acidosis, partially compensated D) Metabolic alkalosis, fully compensated

6. A nurse is caring for a patient who has been vomiting for the past three days.

Which ABG pattern does the nurse anticipate?

- A) ↓ pH, ↓ HCO₃⁻ B) ↑ pH, ↓ PaCO₂ C) ↑ pH, ↑ HCO₃⁻ D) ↓ pH, ↑ PaCO₂

7. Which finding indicates that compensation is occurring in respiratory acidosis?

- A) Elevated serum bicarbonate levels B) Decreased PaCO₂
C) Increased respiratory rate D) Decreased urinary output