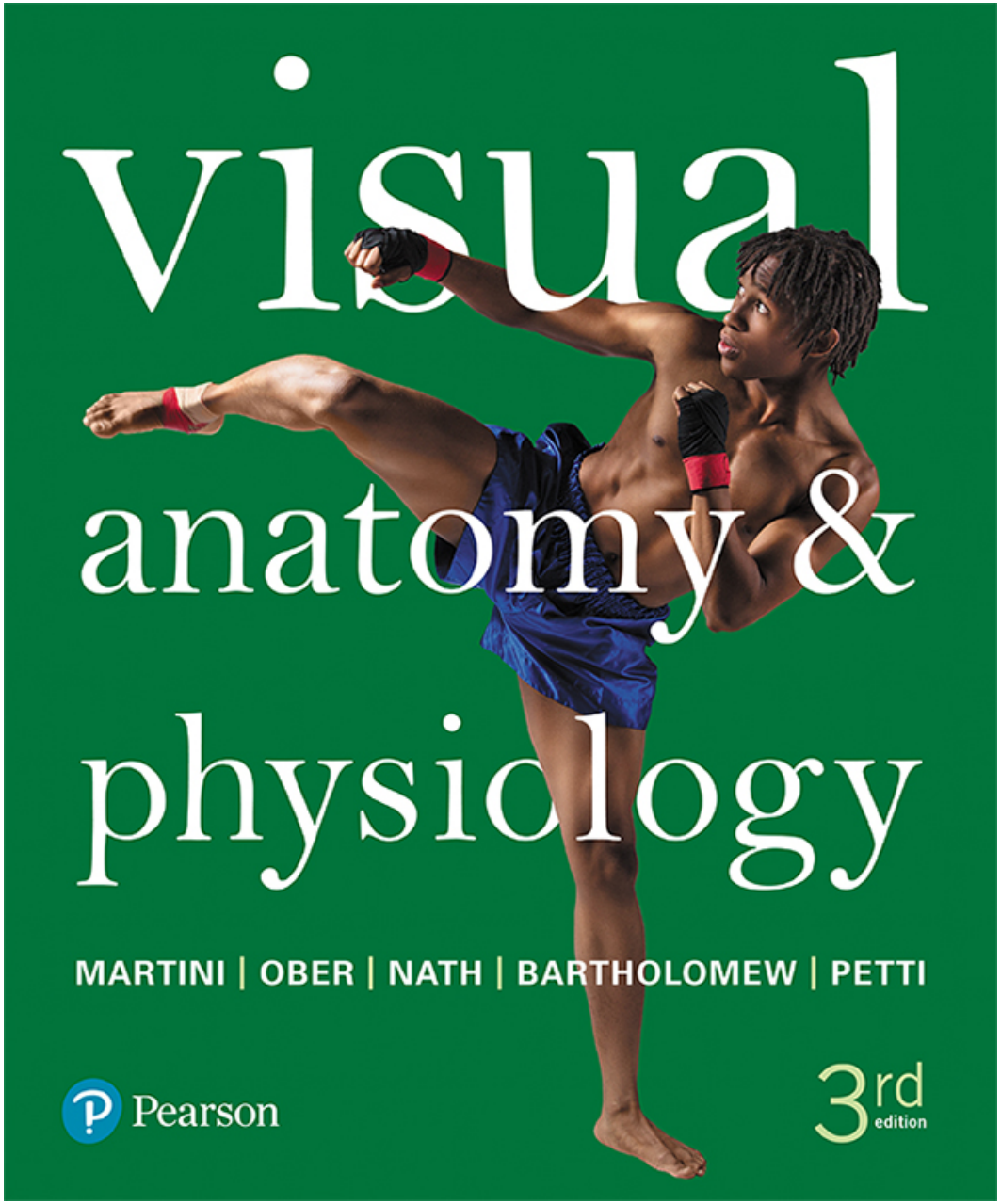


# 25

## *Fluid, Electrolyte, and Acid–Base Balance*

Lecture Presentation by
Lori Garrett

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# Section 1: Fluid and Electrolyte Balance

## Learning Outcomes

25.1 Name the body's fluid compartments, identify the solid components, and summarize their contents.

25.2 Explain what is meant by fluid balance, and discuss its importance for homeostasis.

25.3 Explain what is meant by mineral balance, and discuss its importance for homeostasis.

25.4 Summarize the relationship between sodium and water in maintaining fluid and electrolyte balance.

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# Section 1: Fluid and Electrolyte Balance

**Learning Outcomes** (continued)

25.5 **Clinical Module:** Explain factors that control potassium balance, and discuss hypokalemia and hyperkalemia.

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# Module 25.1: Body composition may be viewed in terms of solids and two fluid compartments

Water is distributed in **fluid compartments**

- Distinct environments, behaving separately, maintaining different ionic concentrations
- **Extracellular fluid** (**ECF**)
  - Interstitial fluid of peripheral tissues and plasma of circulating blood
  - Lymph, cerebrospinal fluid (CSF), synovial fluid, serous fluids, aqueous humor, perilymph, and endolymph
- **Intracellular fluid** (**ICF**)
  - Cytosol inside cells

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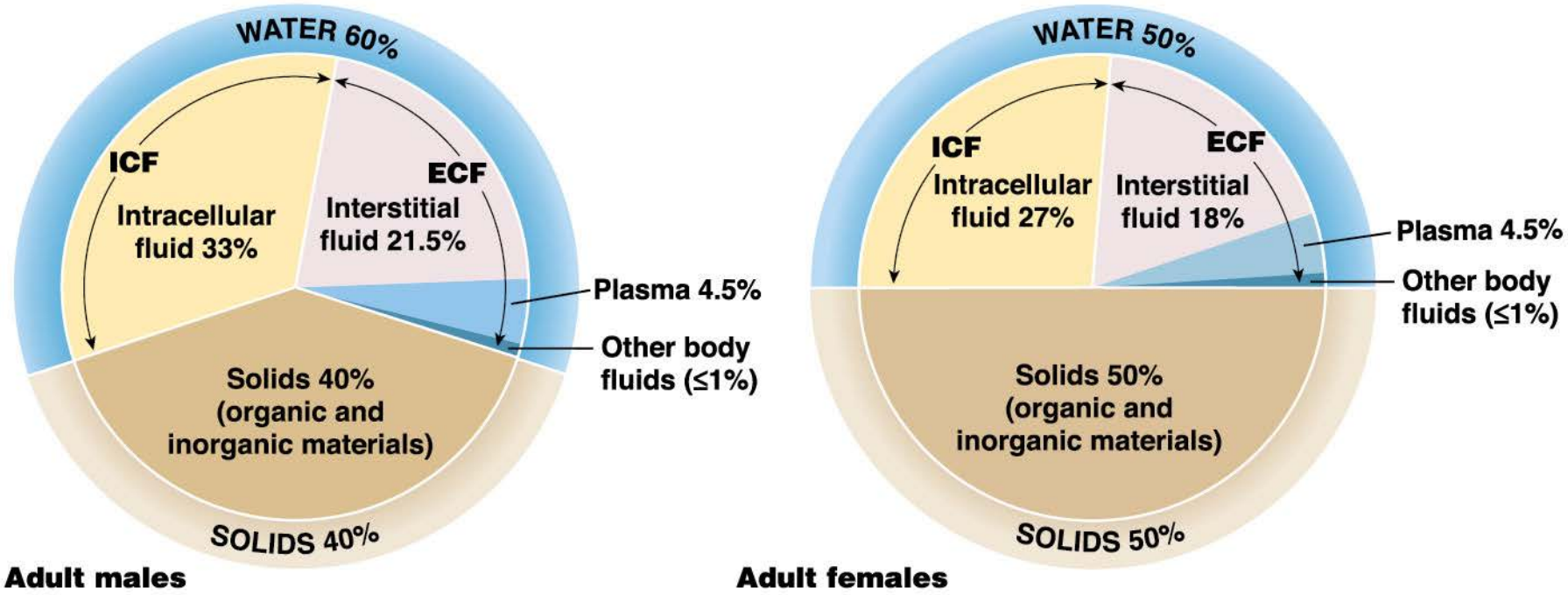
# Body composition

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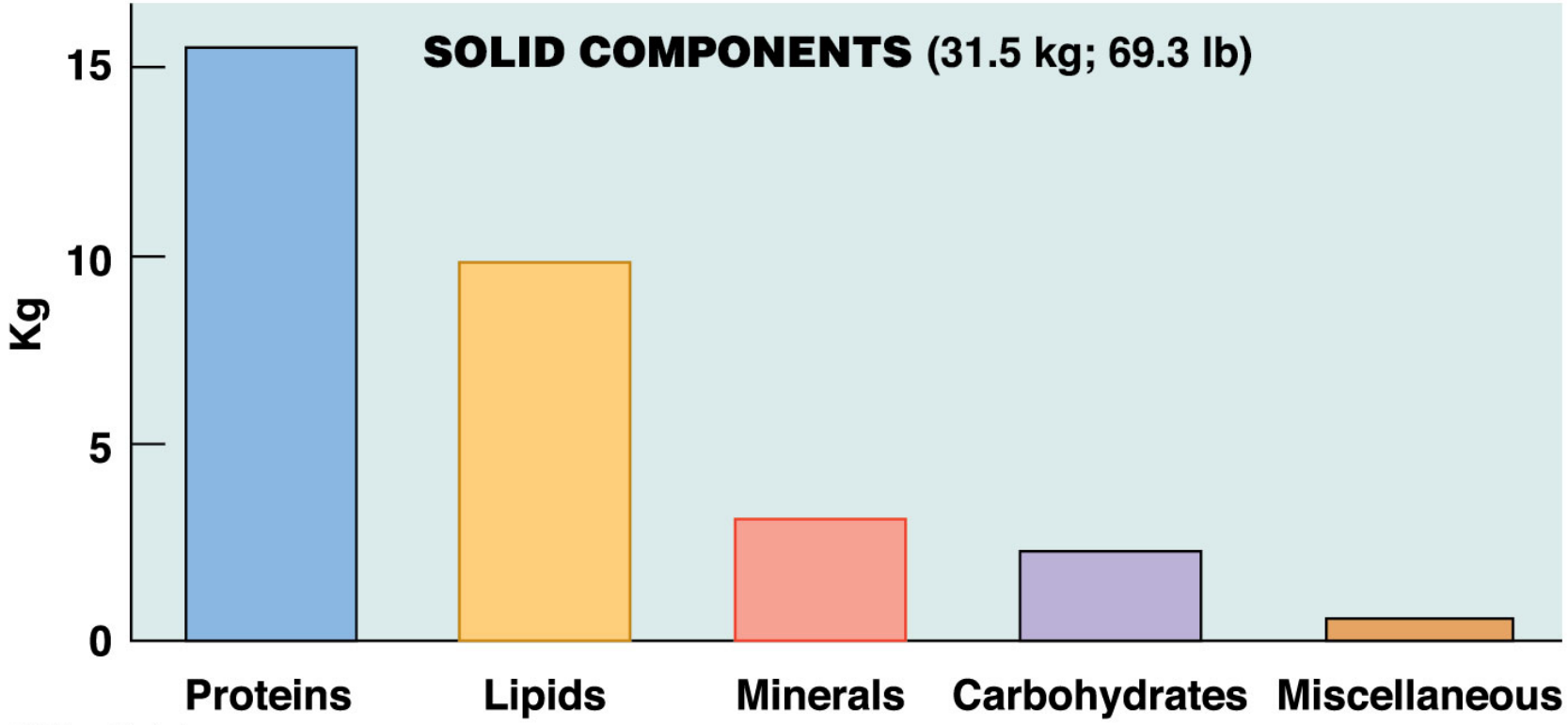
# Module 25.1: Body composition

## Solid components of the body

- Account for 40–50 percent body mass
  - Includes proteins, lipids, carbohydrates, minerals

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# Module 25.1: Review

A. Define *ECF* and *ICF*.
B. Describe the fluid compartments.
C. Which solid component makes up most of the body mass?

*Learning Outcome:* Name the body's fluid compartments, identify the solid components, and summarize their contents.

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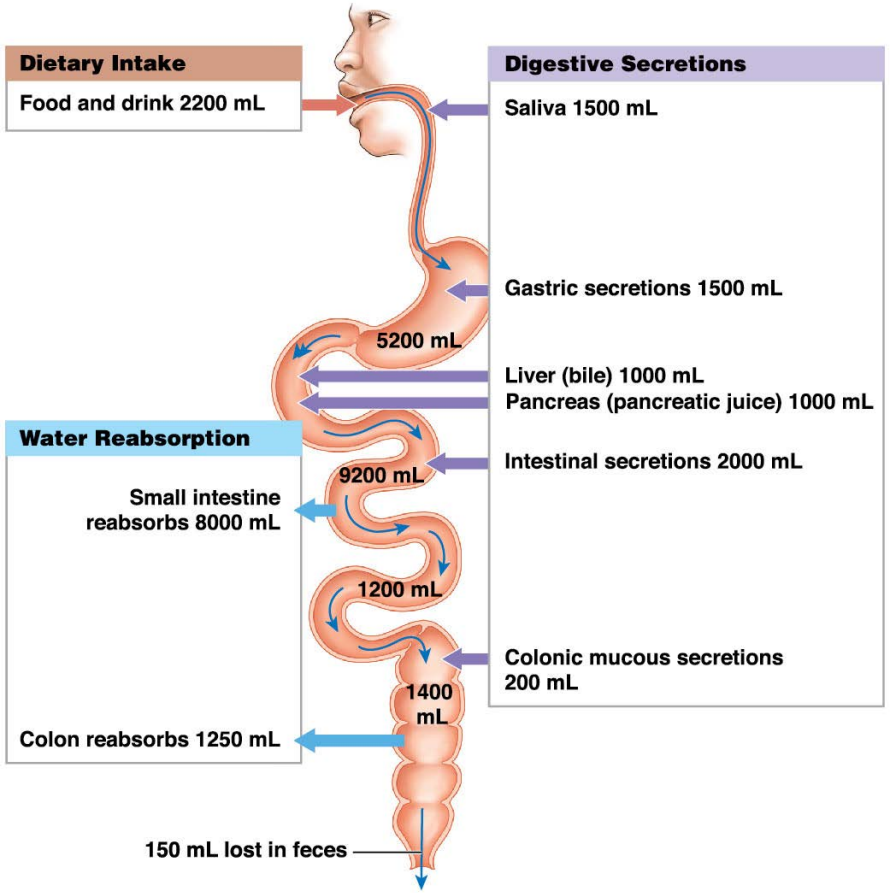
# Module 25.2: Fluid balance exists when water gain equals water loss

## Fluid balance

- When water content remains stable over time
- Water gained through:
  - Absorption along the digestive tract (primary method)
  - Metabolic processes

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# Module 25.2: Fluid balance

- Water lost through:
  - Urination (over 50 percent)
  - Other losses through feces and evaporation (at skin and lungs)
- Water moves by osmosis
  - Passive flow down osmotic gradients

**Fluid Balance**

| Source | Daily Input (mL) |
|---|---|
| Water content of food | 1000 |
| Water consumed as liquid | 1200 |
| Metabolic water produced during catabolism | 300 |
| **Total** | **2500** |
| **Method of Elimination** | **Daily Output (mL)** |
| Urination | 1200 |
| Evaporation at skin | 750 |
| Evaporation at lungs | 400 |
| Loss in feces | 150 |
| **Total** | **2500** |

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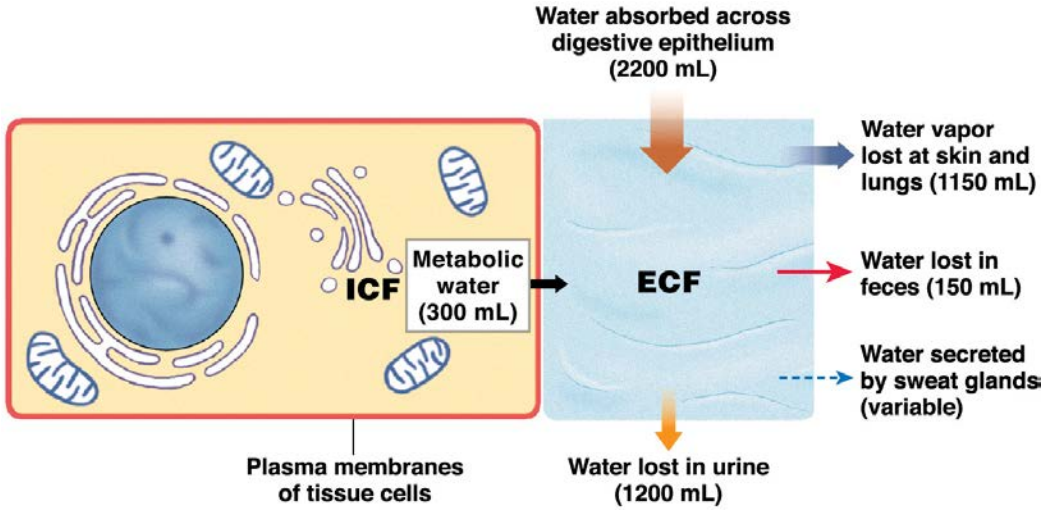
# Module 25.2: Fluid balance

## ICF and ECF compartment interactions

- Composition of compartments is very different
- At osmotic equilibrium
- **Fluid shift**
  - Rapid water movement between ECF and ICF in response to osmotic gradients
  - Equilibrium reached in minutes to hours

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# Module 25.2: Fluid balance

## Dehydration

- Develops when water losses outpace water gains
  - Water loss from ECF increases osmotic concentration in ECF
  - Water moves from ICF to ECF to reach osmotic equilibrium (both fluids now more concentrated)
  - If fluid imbalance continues, loss of water from ICF produces severe thirst, dryness, wrinkling of skin
  - Continued fluid loss causes drop in blood volume and blood pressure
    - May lead to circulatory shock

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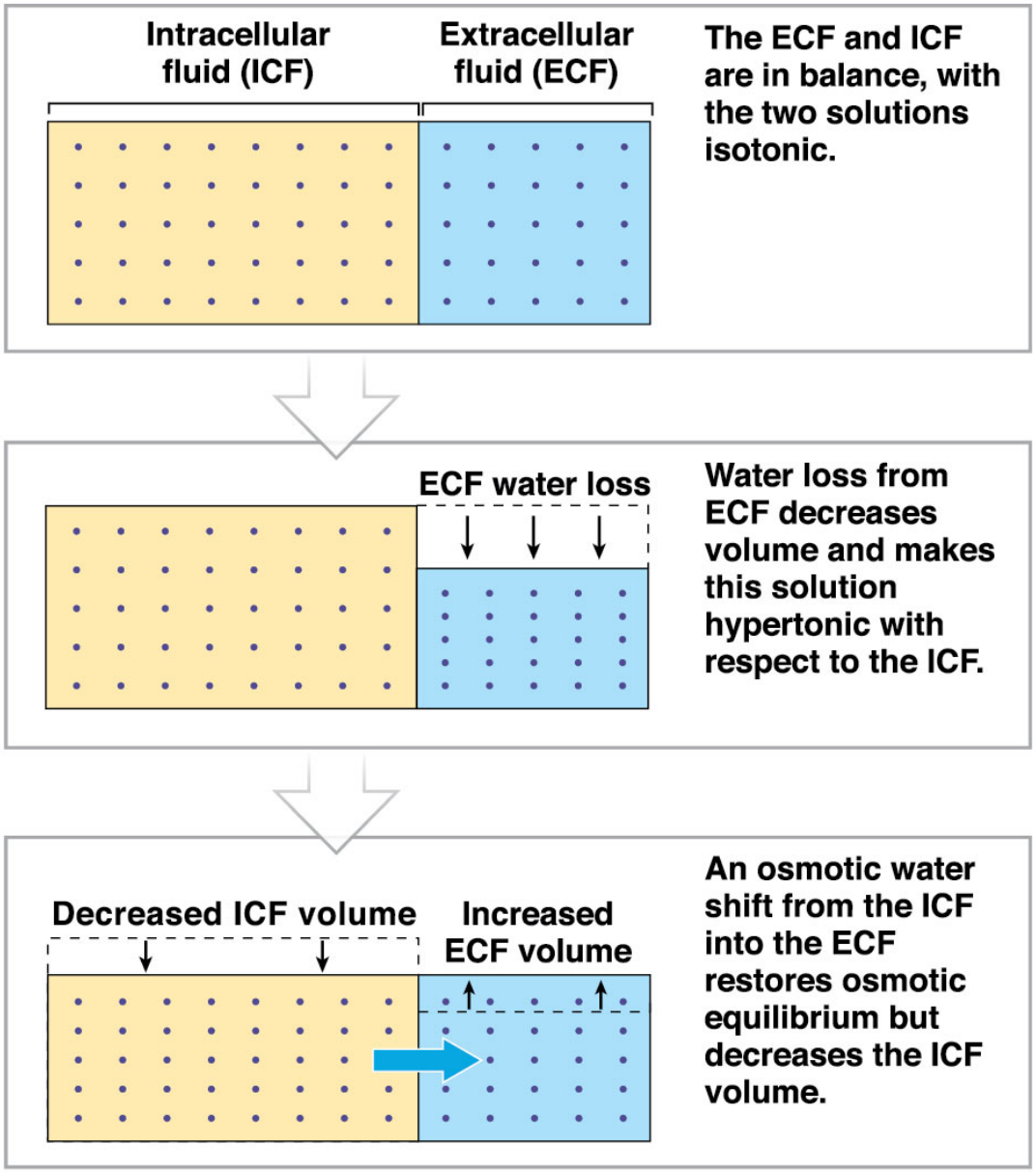
# Fluid balance

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# Module 25.2: Review

A. Identify routes of fluid loss from the body.
B. Describe a fluid shift.
C. Explain dehydration and its effect on the osmotic concentration of blood.

*Learning Outcome:* Explain what is meant by fluid balance, and discuss its importance for homeostasis.

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# Module 25.3: Mineral balance involves balancing electrolyte gain and loss

- **Mineral:** inorganic substance
- **Electrolyte:** ion released when mineral salts dissociate
- **Mineral balance**
  - When ion absorption and excretion are about the same
    - Absorption
      - Occurs across the lining of the small intestine and colon

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# Module 25.3: Mineral balance

## **Mineral balance** (continued)

- When ion absorption and excretion are about the same (continued)
  - Excretion
    - Occurs primarily at the kidneys
    - Variable loss at sweat glands
- Body maintains reserves of key minerals
- Daily intake needs to average amount lost each day for body to stay in balance

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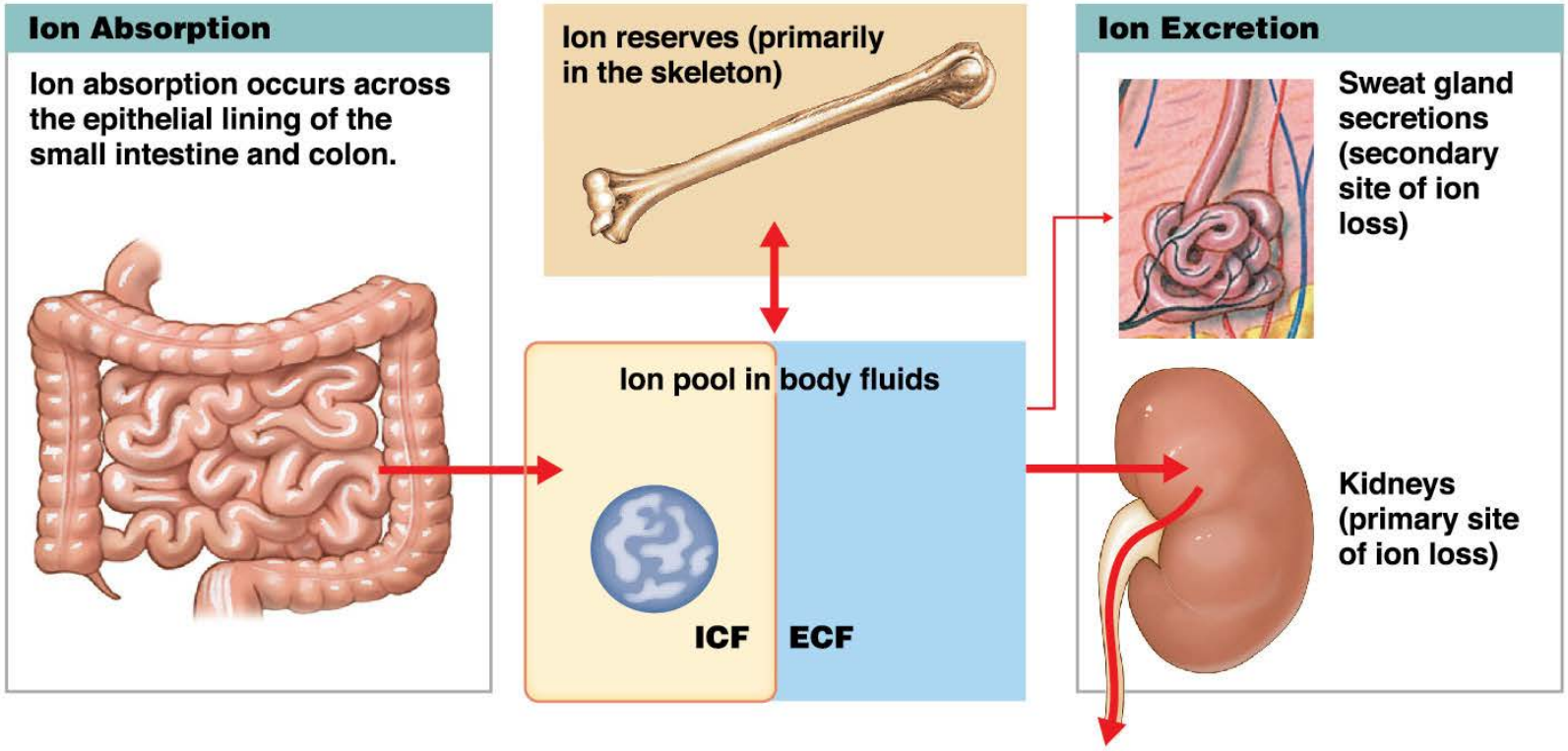
# Module 25.3: Mineral balance

- Absorption
  - Occurs across the epithelial lining of the small intestine and colon

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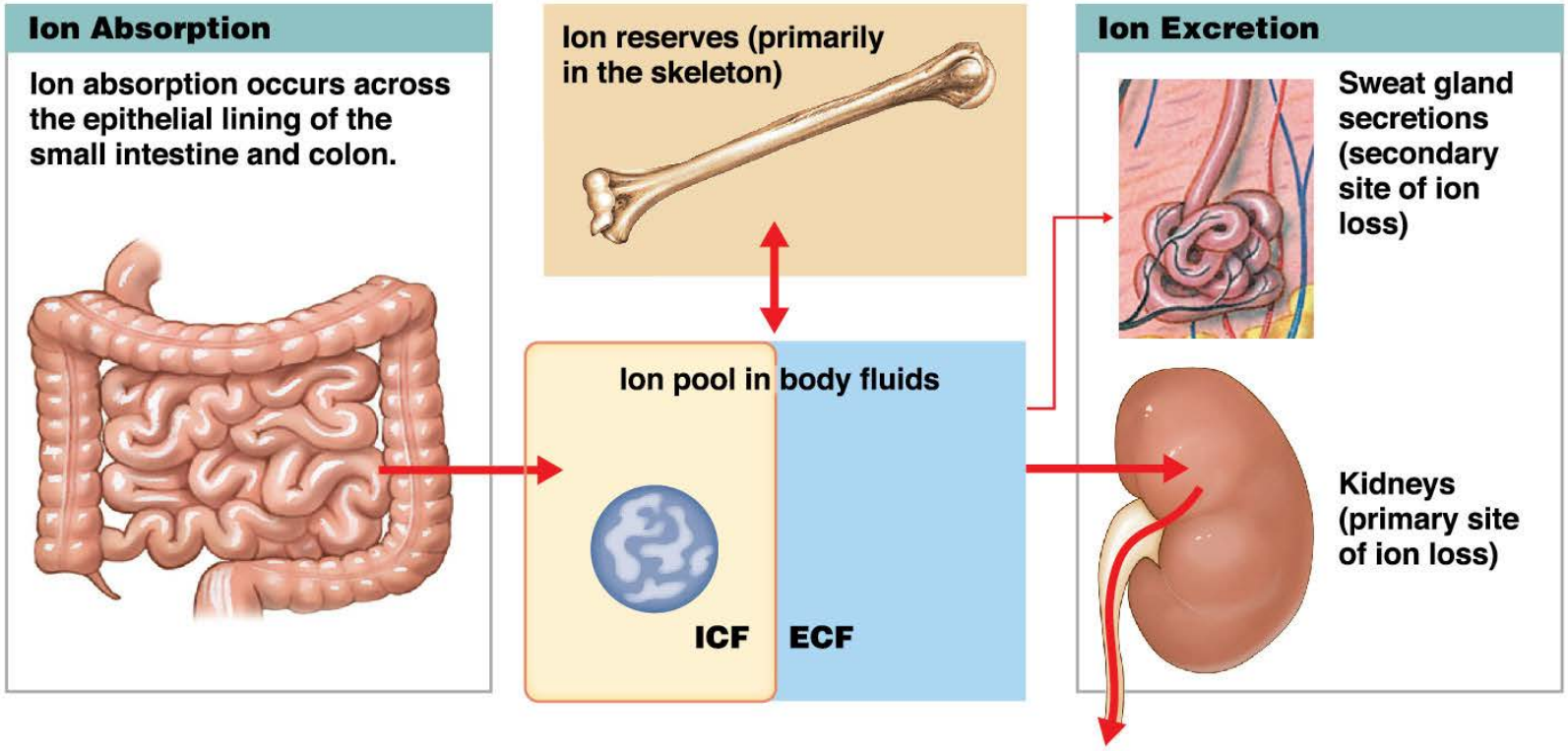
# Module 25.3: Mineral balance

- Excretion
  - Occurs primarily at the kidneys
  - Variable loss at sweat glands
- Ion reserves in skeleton

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# Dissociated salts are *electrolyte solutions*

**Movement of Electrolytes in Solution**

| Electrolyte | Mechanism |
|---|---|
| Sodium ($Na^+$) | Channel-mediated diffusion, cotransport, or active transport |
| Calcium ($Ca^{2+}$) | Active transport |
| Potassium ($K^+$) | Channel-mediated diffusion |
| Magnesium ($Mg^{2+}$) | Active transport |
| Iron ($Fe^{2+}$) | Active transport |
| Chloride ($Cl^-$) | Channel-mediated diffusion or carrier-mediated transport |
| Iodide ($I^-$) | Channel-mediated diffusion or carrier-mediated transport |
| Bicarbonate ($HCO_3^-$) | Channel-mediated diffusion or carrier-mediated transport |
| Nitrate ($NO_3^-$) | Channel-mediated diffusion or carrier-mediated transport |
| Phosphate ($PO_4^{3-}$) | Active transport |
| Sulfate ($SO_4^{2-}$) | Active transport |

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## Minerals and Mineral Reserves

| Mineral | Functions | Total Body Content (Adults) | Primary Route of Excretion | Recommended Dietary Allowance (RDA) (in mg) |
|---|---|---|---|---|
| ***Bulk Minerals*** | | | | |
| **Sodium (Na)** | Major cation in body fluids; essential for normal membrane function | 110 g, primarily in body fluids | Urine, sweat, feces | 1500 |
| **Potassium (K)** | Major cation in cytosol; essential for normal membrane function | 140 g, primarily in cytosol | Urine | 4700 |
| **Chloride (Cl)** | Major anion in body fluids; functions in forming HCl | 89 g, primarily in body fluids | Urine, sweat | 2300 |
| **Calcium (Ca)** | Essential for normal muscle and neuron function and normal bone structure | 1.36 kg, primarily in skeleton | Urine, feces | 1000–1200 |
| **Phosphorus (P)** | In high-energy compounds, nucleic acids, and bone matrix (as phosphate) | 744 g, primarily in skeleton | Urine, feces | 700 |
| **Magnesium (Mg)** | Cofactor of enzymes, required for normal membrane functions | 29 g (skeleton, 17 g; cytosol and body fluids, 12 g) | Urine | 310–400 |

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## Minerals and Mineral Reserves

| Mineral | Functions | Total Body Content (Adults) | Primary Route of Excretion | Recommended Dietary Allowance (RDA) (in mg) |
|---|---|---|---|---|
| ***Trace Minerals*** | | | | |
| **Iron (Fe)** | Component of hemoglobin, myoglobin, and cytochromes | 3.9 g (1.6 g stored as ferritin or hemosiderin) | Urine (traces) | 8–18 |
| **Zinc (Zn)** | Cofactor of enzyme systems, notably carbonic anhydrase | 2 g | Urine, hair (traces) | 8–11 |
| **Copper (Cu)** | Required as cofactor for hemoglobin synthesis | 127 mg | Urine, feces (traces) | 0.9 |
| **Manganese (Mn)** | Cofactor for some enzymes | 11 mg | Feces, urine (traces) | 1.8–2.3 |
| **Cobalt (Co)** | Cofactor for transaminations; mineral in vitamin $B_{12}$ (cobalamin) | 1.1 g | Feces, urine | 0.0001 |

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# Module 25.3: Review

A. Define *mineral balance*.
B. Identify the electrolytes absorbed by active transport.
C. Explain the significance of two important body minerals: sodium and calcium.

*Learning Outcome:* Explain what is meant by mineral balance, and discuss its importance for homeostasis.

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# Module 25.4: Water balance depends on sodium balance, and the two are regulated simultaneously

## Sodium balance

- When sodium gains = sodium losses
- Regulatory mechanisms change the ECF volume while keeping $Na^+$ concentration stable
  - When $Na^+$ gains exceed losses, ECF volume increases
  - When $Na^+$ losses exceed gains, ECF volume decreases
  - Primary hormone involved is ADH
- Small changes in ECF volume do not cause adverse physiological effects

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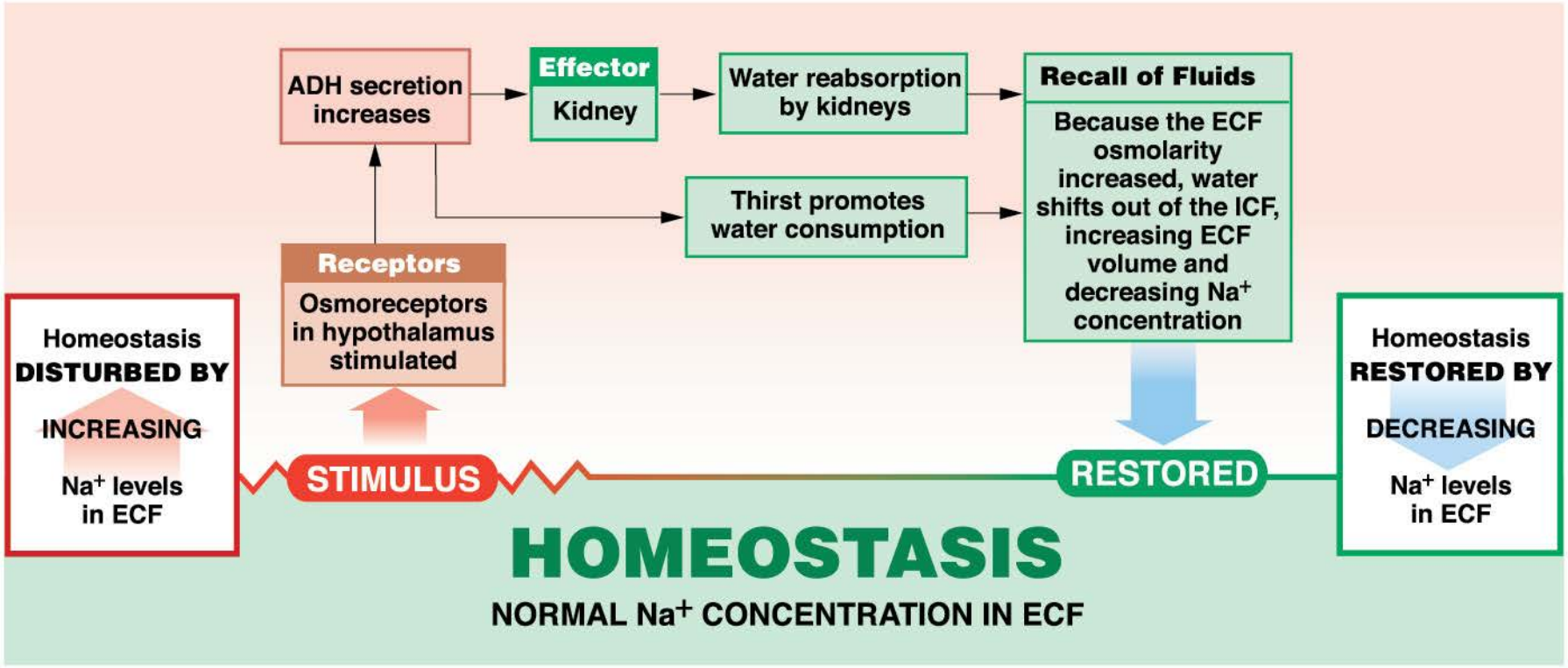
# Response to increasing sodium levels

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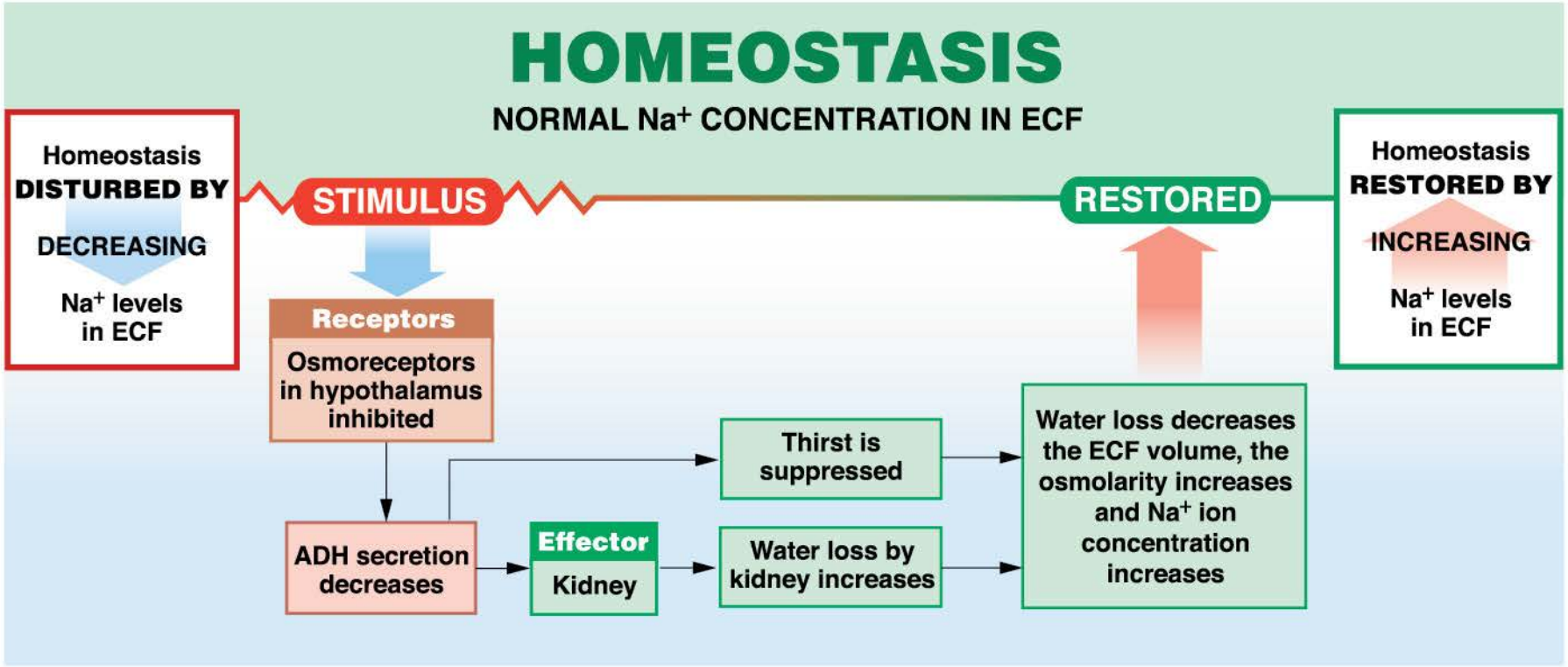
# Response to decreasing sodium levels

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# Module 25.4: Water and sodium balance

When changes in ECF volume are extreme, additional homeostatic mechanisms are utilized

- Increased ECF volume = increased blood volume and blood pressure
  - Mechanisms respond to lower blood volume and blood pressure
- Decreased ECF volume = decreased blood volume and blood pressure
  - Mechanisms respond to increase blood volume and pressure

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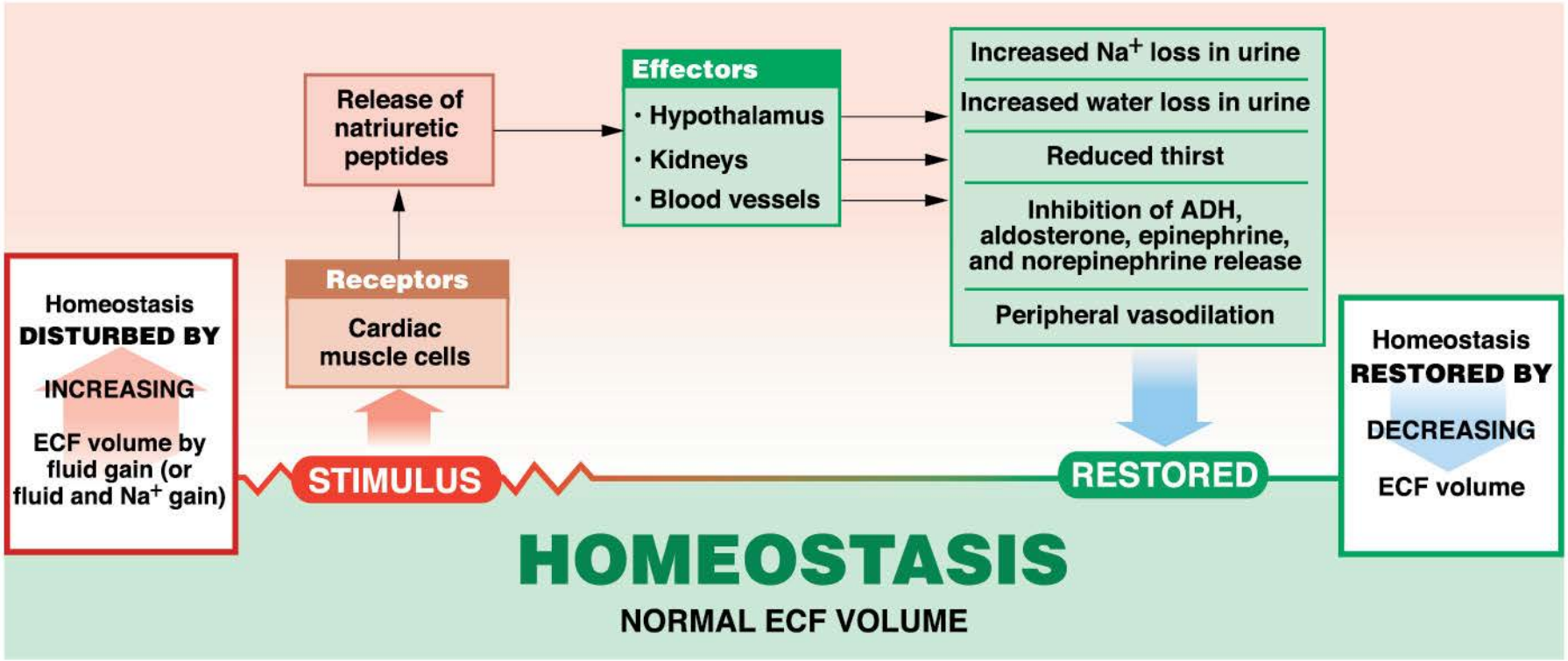
# Response to increasing ECF volume

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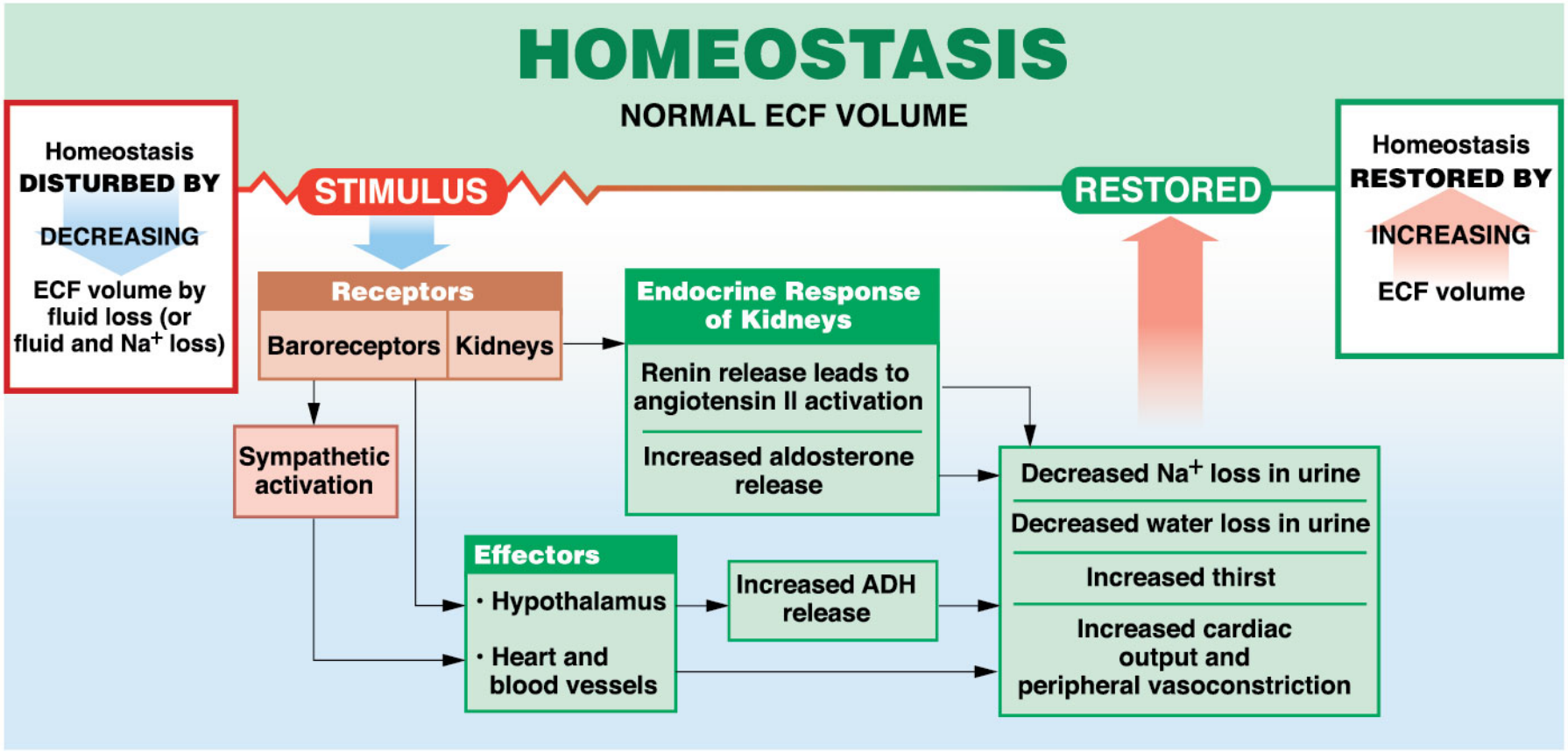
# Response to decreasing ECF volume

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# Module 25.4: Water and sodium balance

## Sodium imbalances

- Sustained sodium imbalances in ECF occur only with severe fluid balance problems
- Serious, potentially life-threatening conditions
  - **Hyponatremia** (*natrium*, sodium)
    - Low ECF $Na^+$ concentration (<136 mEq/L)
    - From overhydration or inadequate salt intake
  - **Hypernatremia**
    - High ECF $Na^+$ concentration (>145 mEq/L)
    - Dehydration is the most common cause

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# Module 25.4: Review

A. What effect does inhibition of osmoreceptors have on ADH secretion and thirst?
B. What effect does aldosterone have on sodium ion concentration in the ECF?

*Learning Outcome:* Summarize the relationship between sodium and water in maintaining fluid and electrolyte balance.

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# Module 25.5: Clinical Module: Disturbances of potassium balance are uncommon but extremely dangerous

## Potassium balance

- Key factors to maintaining balance include:
  1. Rate of $K^+$ entry across the digestive epithelium
     - ~100 mEq (1.9–5.8 g)/day
  2. Rate of $K^+$ loss into urine
- Potassium ion concentration is highest in ICF because of $Na^+/K^+$ exchange pump
  - ~135 mEq/L in ICF vs. ~5 mEq/L in ECF

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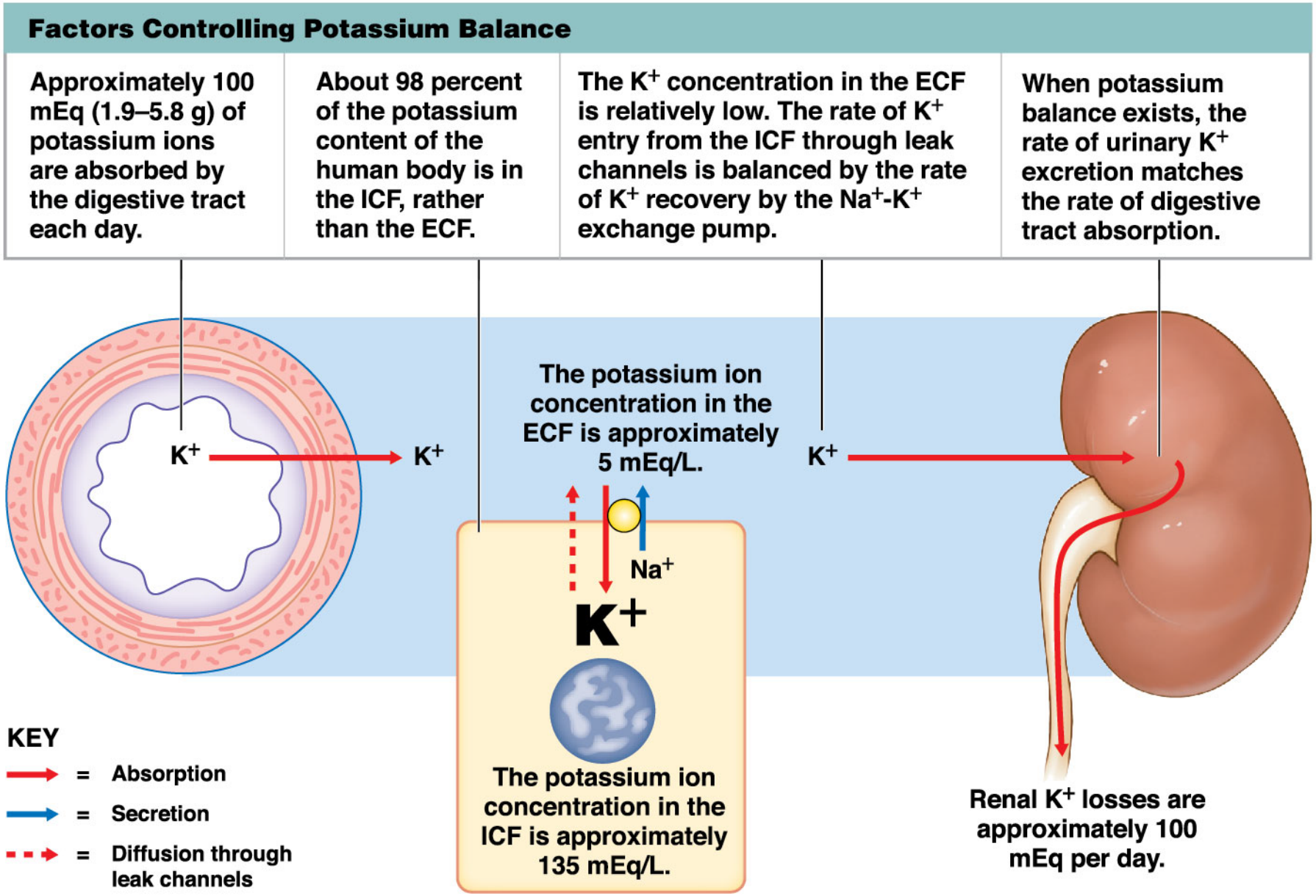
# Factors controlling potassium balance

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# Module 25.5: Disturbances of potassium balance

## **Potassium balance** (continued)

- Kidneys are the main factor determining $K^+$ concentration in ECF
  - Dietary intake of $K^+$ is relatively constant
- $K^+$ loss controlled by aldosterone's regulation of ion pump activities in the distal convoluted tubule (DCT) and collecting duct
  - $Na^+/K^+$ exchange pumps
    - Aldosterone stimulates $Na^+$ reabsorption and $K^+$ excretion
    - Low pH in ECF can cause $H^+$ to be substituted for $K^+$

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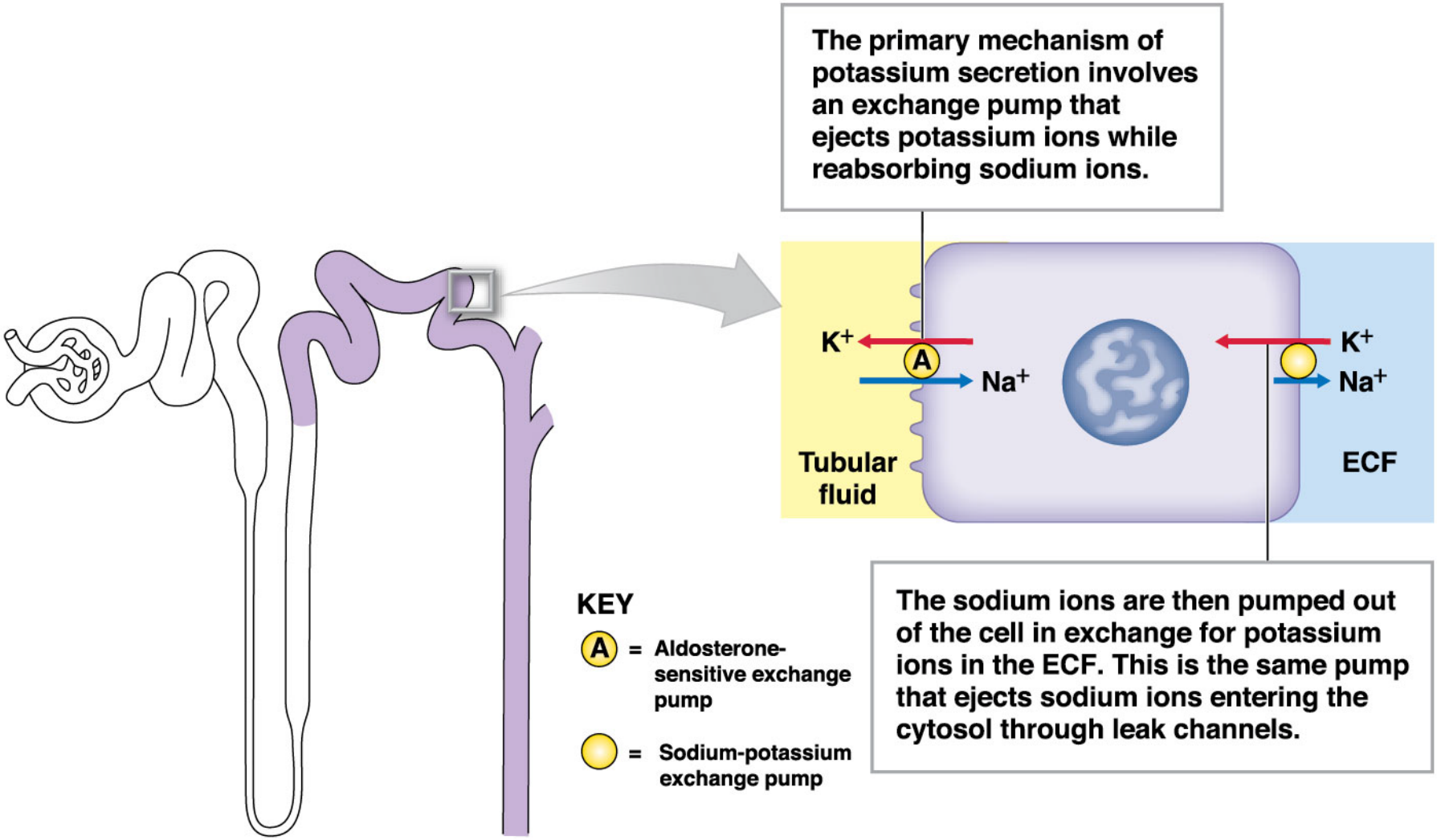
# Potassium excretion

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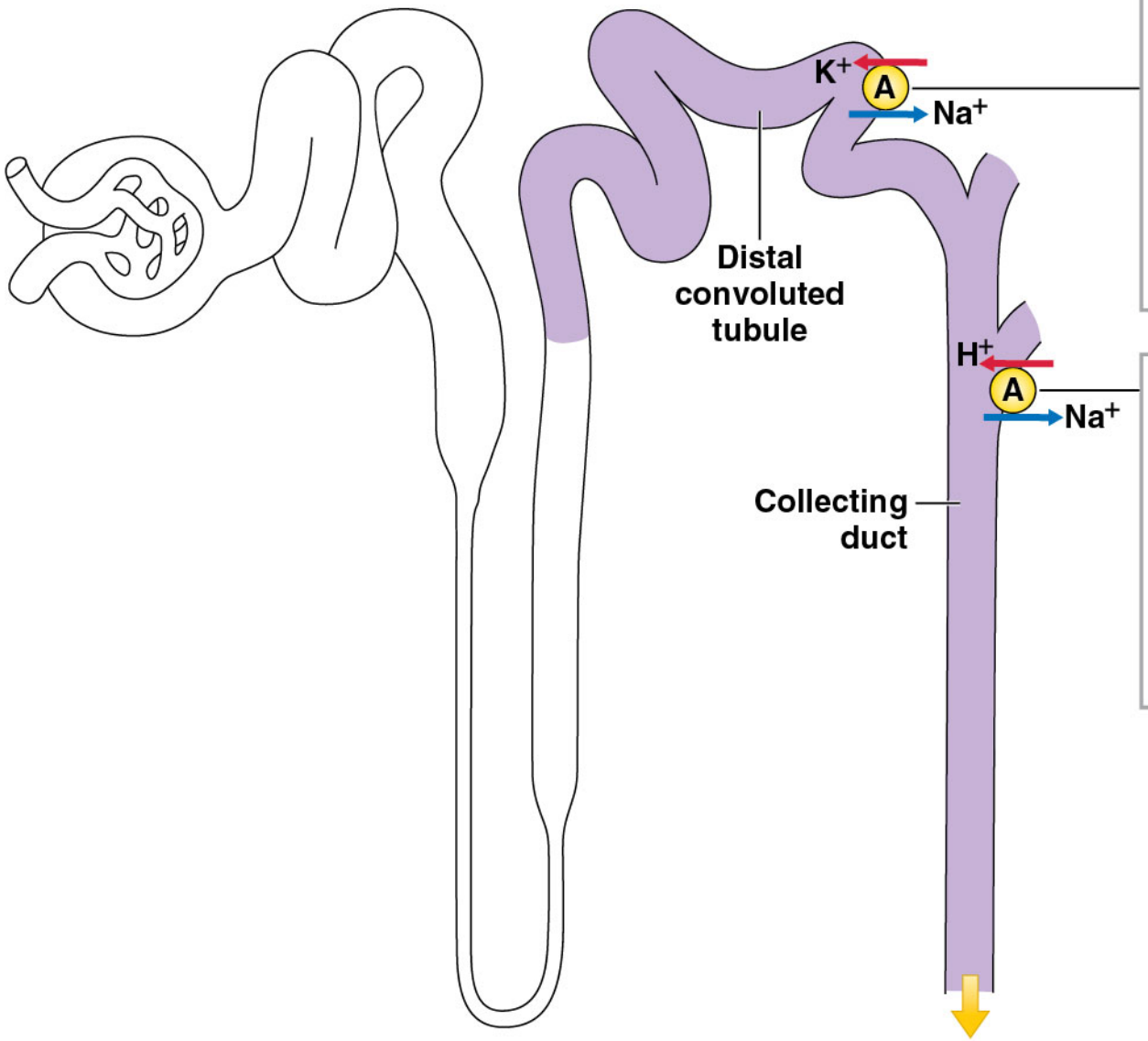
# Aldosterone and potassium




Under normal conditions, the aldosterone-sensitive pumps exchange $K^+$ in the ECF for $Na^+$ in the tubular fluid. The net result is increased blood sodium levels and increased $K^+$ loss in the urine.

When the pH decreases in the ECF and the concentration of hydrogen ions ($H^+$) is relatively high, the exchange pumps bind $H^+$ instead of $K^+$. This helps to stabilize the pH of the ECF, but at the cost of increasing $K^+$ levels in the ECF.

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# Module 25.5: Disturbances of potassium balance

**Hypokalemia** (*kalium*, potassium)

- Potassium levels below 2 mEq/L in plasma
  - Normal levels 3.5–5.0 mEq/L
- Can be caused by:
  - Diuretics
  - **Aldosteronism** (excessive aldosterone secretion)
- Symptoms
  - Muscular weakness, followed by paralysis
  - Potentially lethal when affecting heart
- Treatment
  - Increasing dietary intake of potassium

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# Module 25.5: Disturbances of potassium balance

## Hyperkalemia

- Potassium levels above 5 mEq/L in plasma
- Can be caused by:
  - Chronically low pH
  - Kidney failure
  - Drugs promoting diuresis by blocking $Na^+/K^+$ pumps
- Symptoms
  - Muscular spasm, including heart arrhythmias

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# Module 25.5: Disturbances of potassium balance

## **Hyperkalemia** (continued)

- Treatment
  - Diluting ECF with a solution low in $K^+$
  - Stimulating $K^+$ loss in urine with diuretics
  - Adjusting pH of the ECF
  - Restricting dietary $K^+$ intake
  - If caused by renal failure, dialysis may be required

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# Hypokalemia and hyperkalemia

When the blood concentration of potassium falls below 2 mEq/L, extensive muscular weakness develops, followed by eventual paralysis. This condition, called severe **hypokalemia** (*kalium*, potassium), is potentially lethal due to its effects on the heart.

Normal potassium levels in blood (3.5–5.0 mEq/L)

High $K^+$ concentrations in the blood produce an equally dangerous condition known as **hyperkalemia**. Severe hyperkalemia occurs when $K^+$ concentration exceeds 7 mEq/L, which results in cardiac arrhythmias.

| Factors Promoting Hypokalemia | |
|---|---|
| Several diuretics can produce hypokalemia by increasing the volume of urine produced. | The endocrine disorder called **aldosteronism**, characterized by excessive aldosterone secretion, results in hypokalemia by overstimulating sodium retention and potassium loss. |

| Factors Promoting Hyperkalemia | | |
|---|---|---|
| Chronically low blood pH promotes hyperkalemia by interfering with $K^+$ excretion by the kidneys. | Kidney failure due to damage or disease will prevent normal $K^+$ secretion and thereby produce hyperkalemia. | Several drugs promote urination by blocking $Na^+$ reabsorption by the kidneys. When sodium reabsorption slows down, so does potassium secretion, and hyperkalemia can result. |

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# Module 25.5: Review

A. Which organs are primarily responsible for regulating the potassium ion concentration in the ECF?
B. Identify factors that cause potassium excretion.
C. Define *hypokalemia* and *hyperkalemia*.

*Learning Outcome:* Explain factors that control potassium balance, and discuss hypokalemia and hyperkalemia.

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# Section 2: Acid-Base Balance

## Learning Outcomes

25.6 Describe the three categories of acids in the body.

25.7 Explain the role of buffer systems in maintaining acid-base balance and pH.

25.8 Explain the role of buffer systems in regulating the pH of the intracellular fluid and the extracellular fluid.

25.9 Describe the compensatory mechanisms involved in maintaining of acid-base balance.

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# Section 2: Acid-Base Balance

**Learning Outcomes** (continued)

25.10 **Clinical Module:** Describe respiratory acidosis and respiratory alkalosis.

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# Module 25.6: There are three categories of acids in the body

## Acid-base balance

- Body is in acid-base balance when $H^+$ production = $H^+$ loss and pH of body fluids are within normal limits

Buffer systems temporarily store $H^+$ and provide short-term pH stability

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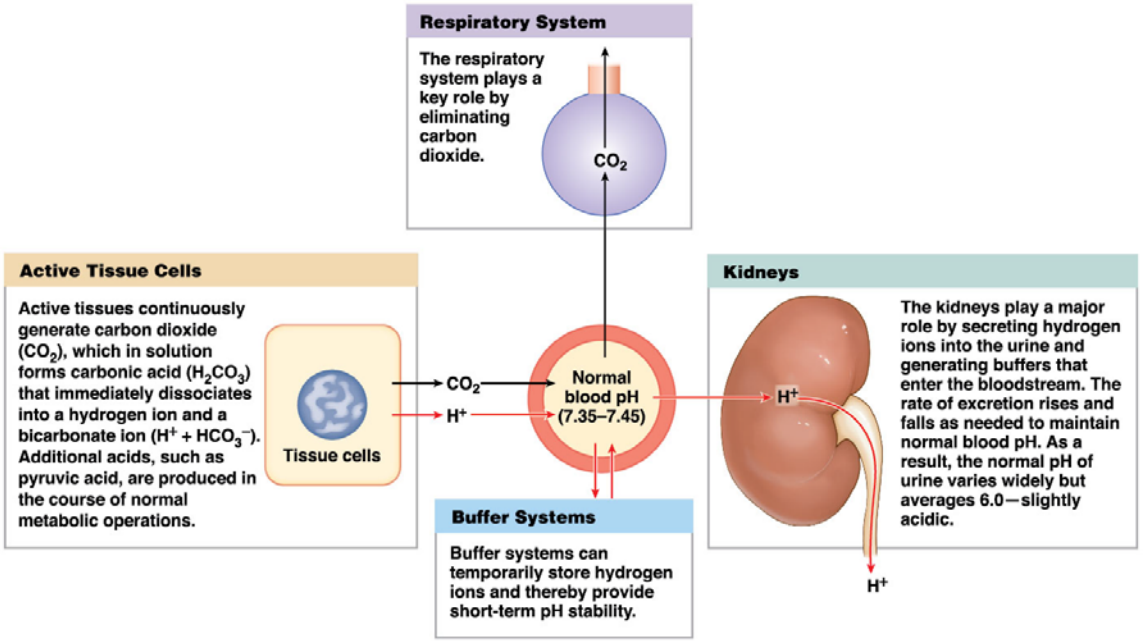
# Module 25.6: Acids

$H^+$ production

- $CO_2$ (to carbonic acid) from aerobic respiration
- Lactic acid from glycolysis
- Constant production by these processes creates primary challenge to acid-base homeostasis

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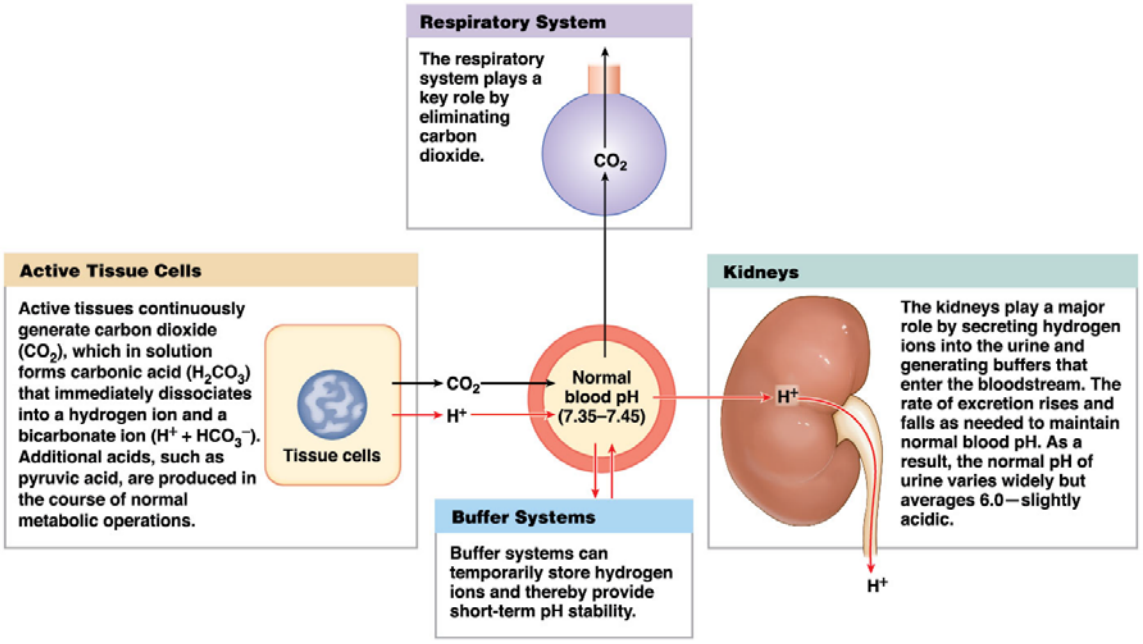
# Module 25.6: Acids

## $H^+$ loss

- Respiratory system eliminates $CO_2$
- $H^+$ excretion from kidneys
- Buffers temporarily store $H^+$
  - Storage removes $H^+$ from circulation, affecting pH

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# Module 25.6: Acids

## Classes of acids that threaten pH balance

- **Fixed acids**
  - Do not leave solution
    - Remain in body fluids until kidney excretion
  - *Examples:* sulfuric and phosphoric acid
    - Generated during catabolism of amino acids, phospholipids, and nucleic acids

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# Module 25.6: Acids

## Classes of acids that threaten pH balance (continued)

- **Metabolic acids**
  - Participants in or by-products of cellular metabolism
  - *Examples:* pyruvic acid, lactic acid, and ketones
  - Most are metabolized rapidly, so no significant accumulation
- **Volatile acids**
  - Can leave the body by entering the atmosphere at the lungs
  - *Example:* carbonic acid ($H_2CO_3$)

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# Module 25.6: Review

A. When is your body in acid-base balance?
B. What is the primary challenge to acid-base homeostasis?
C. Compare the three categories of acids.

*Learning Outcome:* Describe the three categories of acids in the body.

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# Module 25.7: Potentially dangerous disturbances in acid-base balance are opposed by buffer systems

Buffers in body fluids temporarily neutralize the acids produced by metabolic operations

**A Review of Important Terms Relating to Acid-Base Balance**

| | |
|---|---|
| **pH** | The negative exponent (negative logarithm) of the hydrogen ion concentration $[H^+]$ in a solution; pH is a measure of how acidic or basic a solution is |
| **Neutral** | A solution with a pH of 7; the solution contains equal numbers of hydrogen ions ($H^+$) and hydroxide ions ($OH^-$) |
| **Acidic** | A solution with a pH below 7; in this solution, hydrogen ions predominate |
| **Basic (alkaline)** | A solution with a pH above 7; in this solution, hydroxide ions predominate |
| **Acid** | A substance that dissociates to release hydrogen ions, decreasing pH |
| **Base** | A substance that dissociates to release hydroxide ions or to remove hydrogen ions, increasing pH |
| **Salt** | An ionic compound consisting of a cation other than a hydrogen ion and an anion other than a hydroxide ion |
| **Buffer** | A substance that tends to oppose changes in the pH of a solution by removing or replacing hydrogen ions; in body fluids, buffers maintain blood pH within normal limits (7.35–7.45) |

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# Module 25.7: pH and buffer systems

## pH

- Normal pH of the ECF is 7.35–7.45
- Extremely dangerous to go outside that range
- Changes in $H^+$ concentrations
  - Alter the stability of plasma membranes
  - Alter the structure of proteins
  - Change activities of enzymes
  - Have major effects on the nervous and cardiovascular systems
- pH below 6.8 or above 7.7 is quickly fatal

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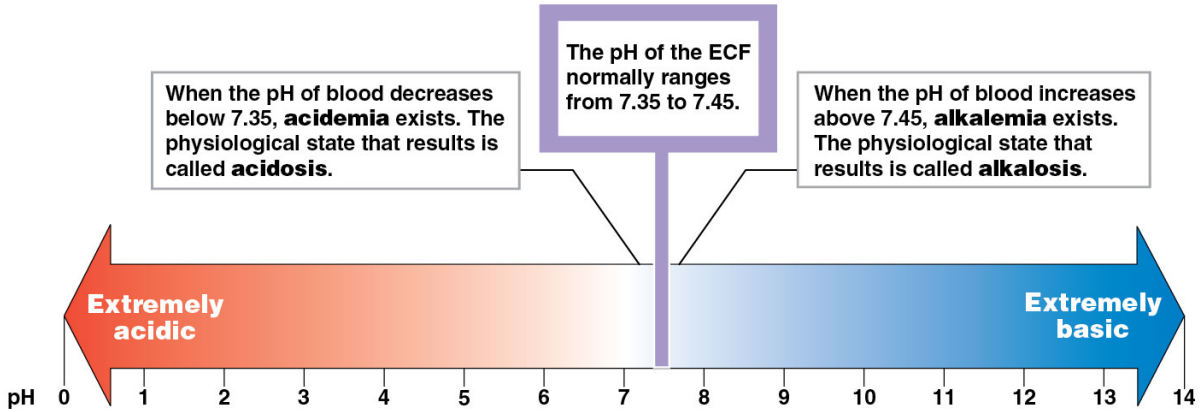
# Module 25.7: pH and buffer systems

## pH of the ECF

- **Acidosis** is a physiological condition
  - Caused by plasma pH < 7.35 (**acidemia**)
  - Severe acidosis (pH < 7.0) can be deadly because:
    - CNS function deteriorates, potentially causing coma
    - Cardiac contractions grow weak and irregular
    - Peripheral vasodilation causes BP drop, potentially leading to circulatory collapse

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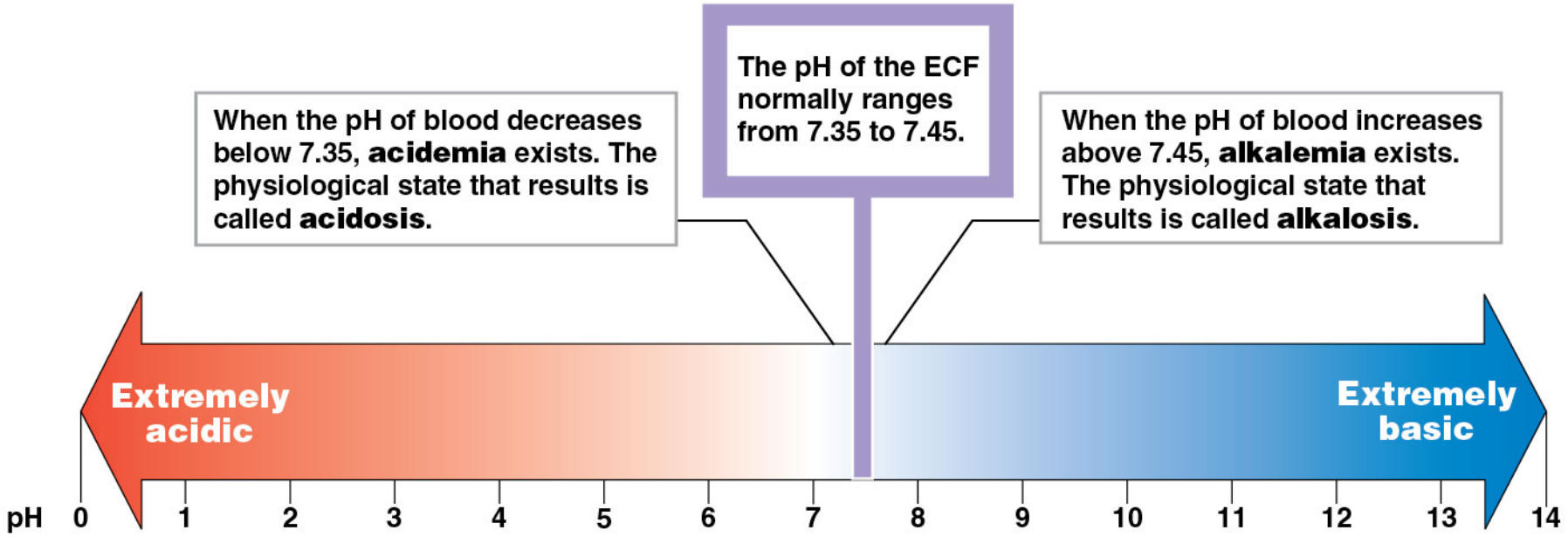
# Module 25.7: pH and buffer systems

## **pH of the ECF** (continued)

- **Alkalosis** is a physiological condition
  - Caused by plasma pH > 7.45 (**alkalemia**)
    - Can be dangerous but is relatively rare

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# Module 25.7: pH and buffer systems

## Carbon dioxide and pH

- Partial pressure of carbon dioxide ($P_{CO_2}$) is the most important factor affecting pH of body tissues
  - Carbon dioxide ($CO_2$) combines with water to form **carbonic acid** ($H_2CO_3$), which can dissociate into hydrogen ions ($H^+$) and bicarbonate ions ($HCO_3^-$)
    - Reversible reaction
- Inverse relationship between $P_{CO_2}$ and pH
  - Increase in $P_{CO_2}$ = decrease in pH
  - Decrease in $P_{CO_2}$ = increase in pH

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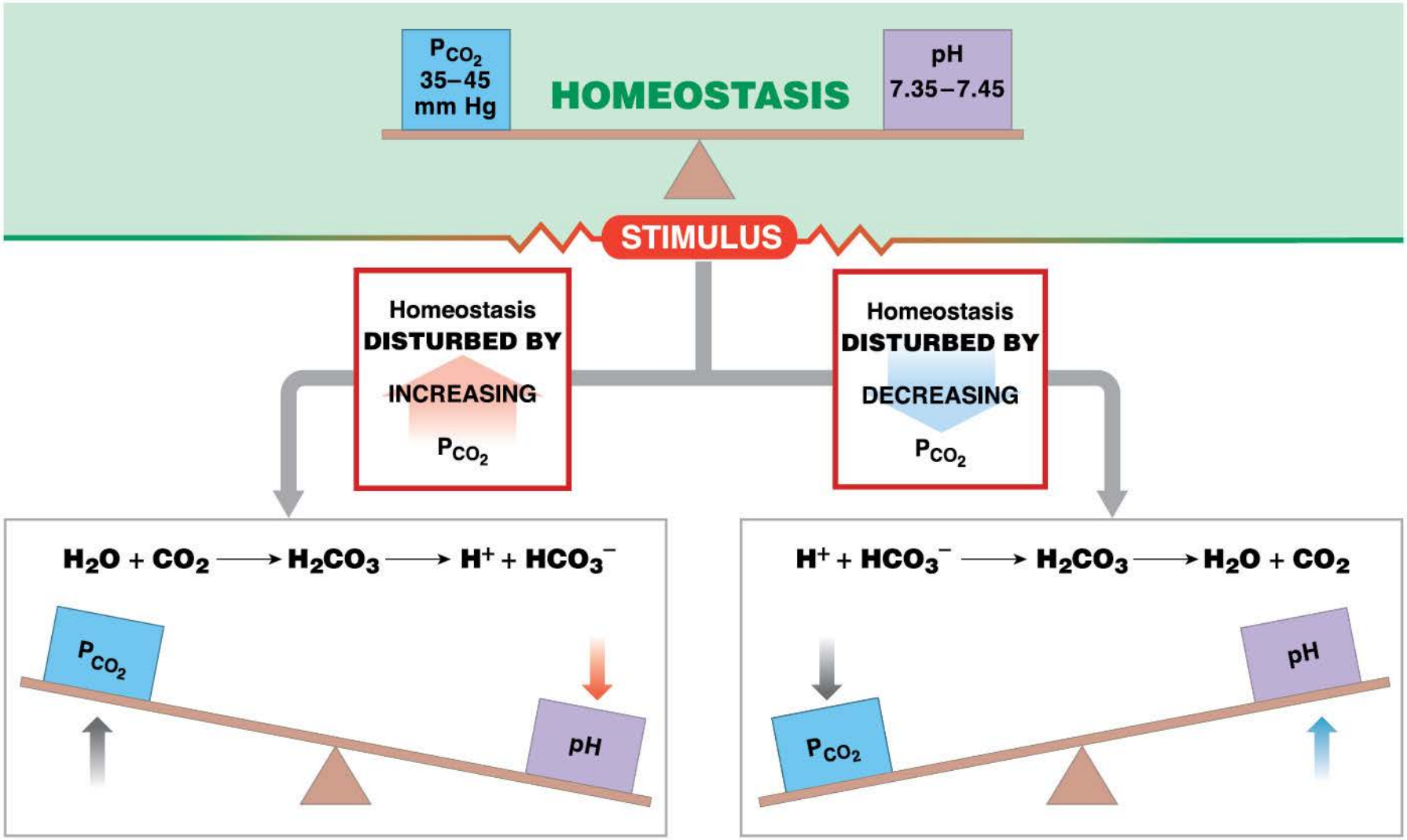
# Carbon dioxide and pH

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# Module 25.7: pH and buffer systems

## Buffer system in body fluids

- Generally consists of:
  - Weak acid (HY)
  - Anion released by its dissociation ($Y^-$)
    - Anion functions as a weak base

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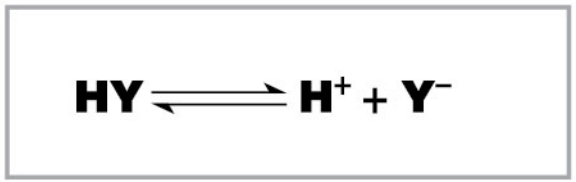
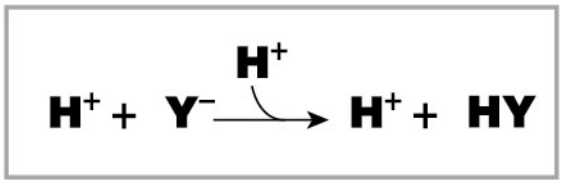
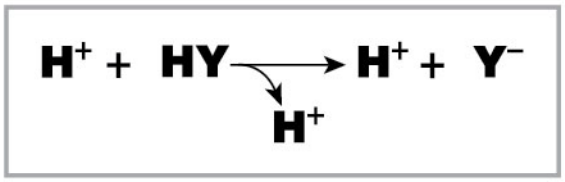
# Module 25.7: pH and buffer systems

## **Buffer system in body fluids** (continued)

- Weak acid and the anion are in equilibrium
- Adding $H^+$ ions disrupts equilibrium
  - Result is formation of more weak acid molecules (and fewer free $H^+$ ions)
- Removing $H^+$ ions also disrupts equilibrium
  - Results in more dissociation (and more free $H^+$ ions)
- These actions oppose changes to body fluid pH

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# Module 25.7: Review

A. Define *acidemia* and *alkalemia*.
B. What intermediate compound formed from water and carbon dioxide directly affects the pH of the ECF?
C. Summarize the relationship between $P_{CO_2}$ levels and pH.

*Learning Outcome:* Explain the role of buffer systems in maintaining acid-base balance and pH.

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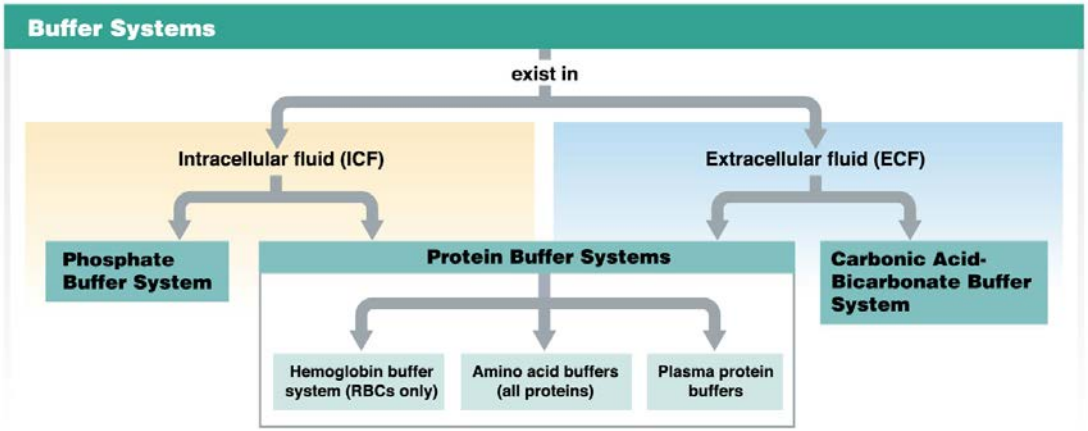
# Module 25.8: Buffer systems can delay, but not prevent, pH shifts in the ICF and ECF

## Three major body buffer systems

- All bind excess $H^+$ temporarily
  - $H^+$ ions are not eliminated
  - Utilize limited supply of buffer molecules

1. **Phosphate buffer system**
   - Buffers pH of ICF and urine
2. **Protein buffer systems**
3. **Carbonic acid–bicarbonate buffer system**

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# Module 25.8: Major buffer systems

## Protein buffer systems: Hemoglobin buffer system

- Only intracellular buffer system that can have an immediate effect on the pH of body fluids
- Red blood cells (RBCs) absorb carbon dioxide from the plasma
  - $CO_2$ is converted to carbonic acid
  - Carbonic acid dissociates, and hemoglobin proteins buffer (attach to) hydrogen ions
- In the lungs, the process is reversed, and $CO_2$ is released into the alveoli

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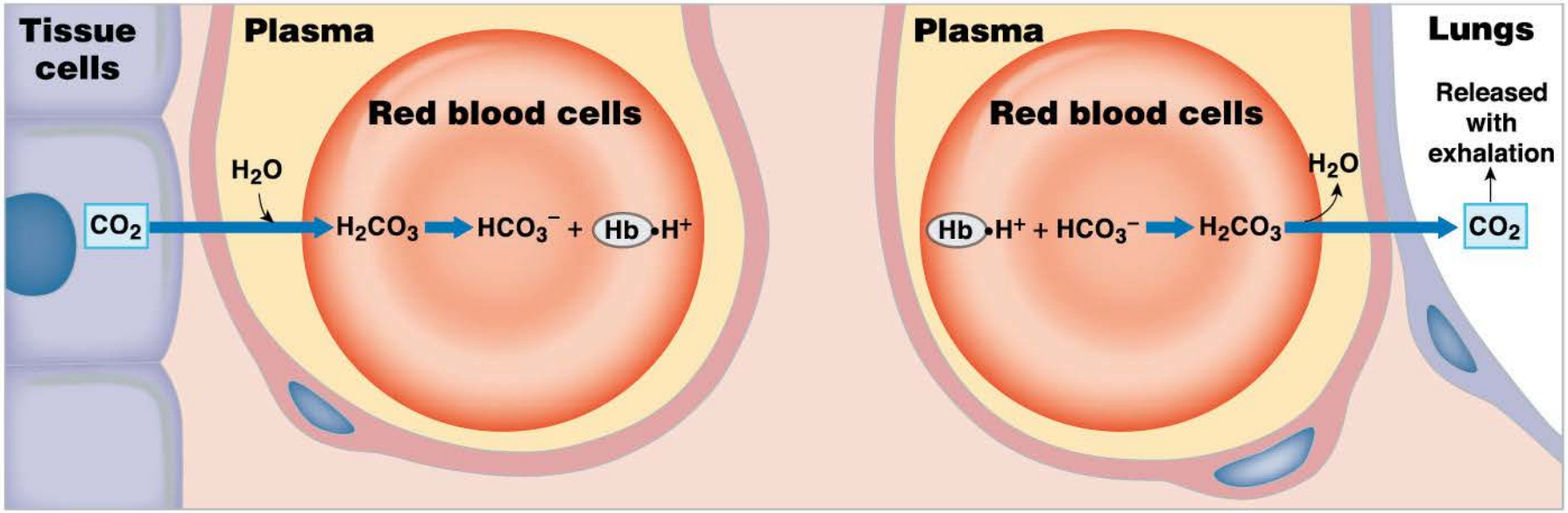
# Protein buffer systems: Hemoglobin buffer system

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# Module 25.8: Major buffer systems

## Protein buffer systems

- Contribute to regulation of pH in ECF and ICF
  - Usually by binding excess $H^+$ ions

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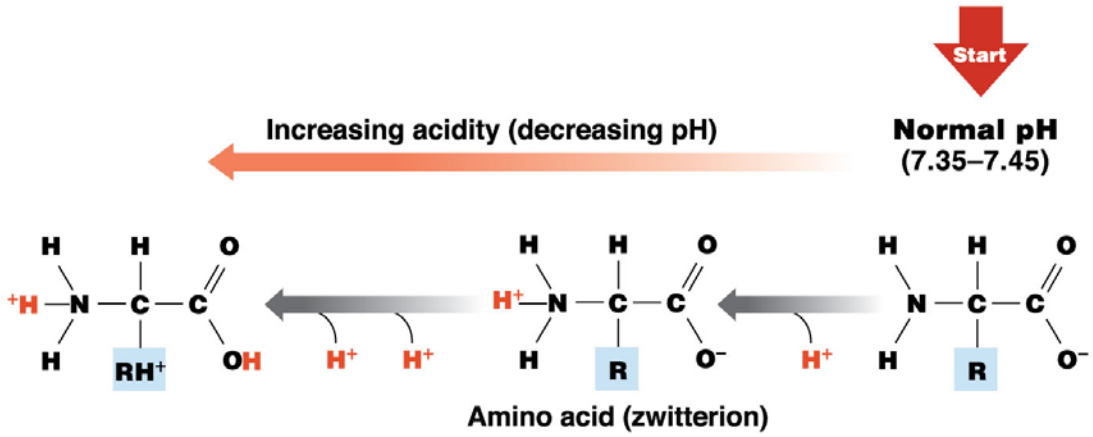
# Module 25.8: Major buffer systems

## **Protein buffer systems** (continued)

- **Amino acid buffers**
  - Excess $H^+$ ions bind to:
    - Carboxylate group ($COO^-$), forming carboxyl group (–COOH)
    - Amino group ($–NH_2$), forming an amino ion ($–NH_3^+$)
    - R-groups, forming $RH^+$
      - Provide most of the buffering capacity

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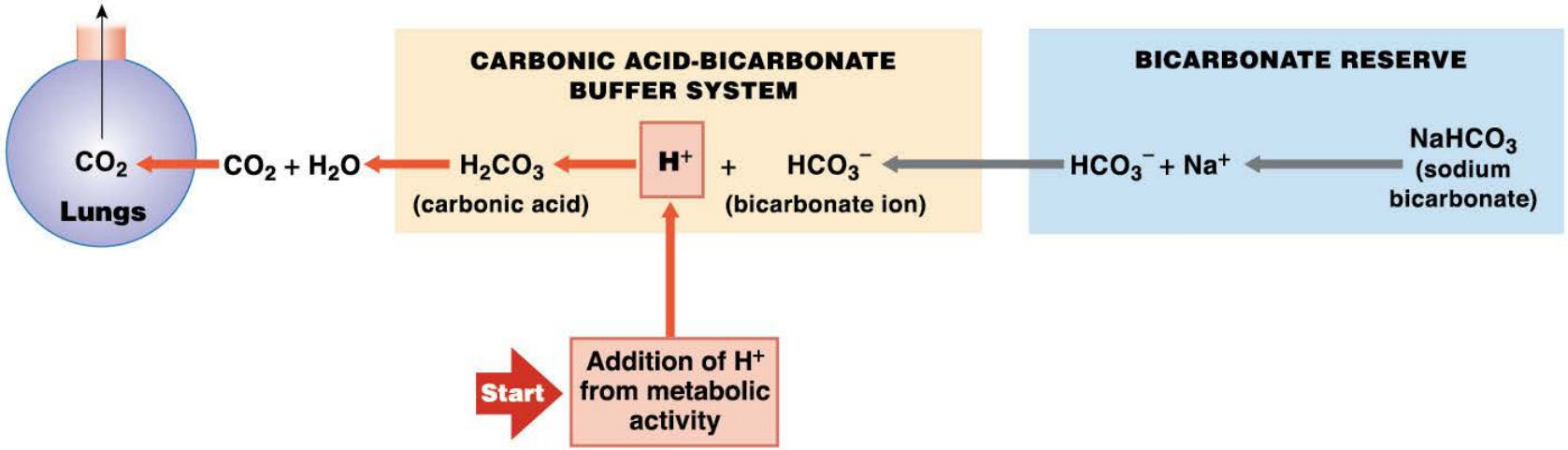
# Module 25.8: Major buffer systems

## Carbonic acid–bicarbonate buffer system

- Involves freely reversible reactions
- Protects against the effects of acids generated by metabolic activity
  - Takes released $H^+$ and generates carbonic acid by combining $H^+$ with bicarbonate ion ($HCO_3^-$)
    - Carbonic acid then dissociates into water and carbon dioxide

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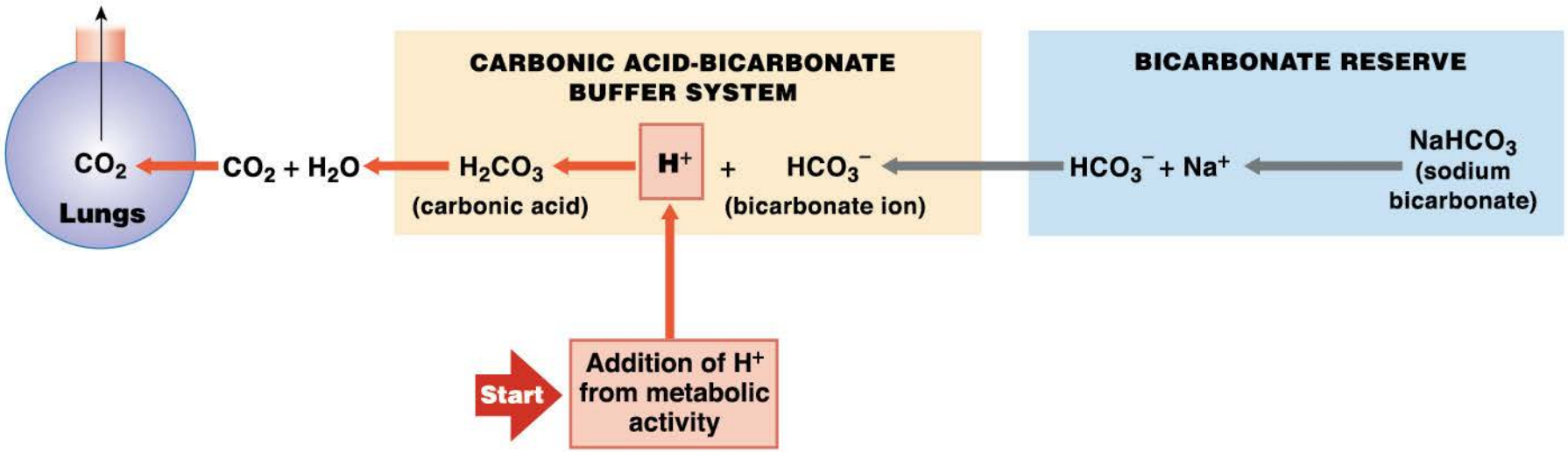
# Module 25.8: Major buffer systems

## Carbonic acid–bicarbonate buffer system (continued)

- **Bicarbonate reserve** is in the body fluid in the form of sodium bicarbonate ($NaHCO_3$)

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# Module 25.8: Major buffer systems

## Disorders

- **Metabolic acid-base disorders**
  - Result from the production or loss of excessive amounts of fixed or organic acids
  - Carbonic acid–bicarbonate buffer system protects against these disorders
- **Respiratory acid-base disorders**
  - Result from imbalance of $CO_2$ generation and elimination
  - Carbonic acid–bicarbonate buffer system cannot protect against respiratory disorders
  - Imbalances must be corrected by change in depth and rate of respiration

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# Module 25.8: Review

A. Identify the body's three major buffer systems.
B. Which fluids are buffered by the phosphate buffer system?
C. Describe the carbonic acid–bicarbonate buffer system.

*Learning Outcome:* Explain the role of buffer systems in regulating the pH of the intracellular fluid and the extracellular fluid.

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# Module 25.9: The homeostatic responses to metabolic acidosis and alkalosis involve respiratory and renal mechanisms as well as buffer systems

## Metabolic acidosis

- Develops when large numbers of $H^+$ are released by organic or fixed acids and pH decreases
- Responses to restore homeostasis
  - Respiratory response
    - Increasing respiratory rate, lowering $P_{CO_2}$ levels
    - Converting more carbonic acid to water

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# Module 25.9: Homeostatic responses to metabolic acidosis and alkalosis

## **Metabolic acidosis** (continued)

- Responses to restore homeostasis (continued)
  - Renal response: occurs in the proximal convoluted tublule (PCT), distal convoluted tubule (DCT), and collecting system
    - Secreting more $H^+$ ions into urine
    - Removing $CO_2$
    - Reabsorbing more bicarbonate to help replenish the bicarbonate reserve

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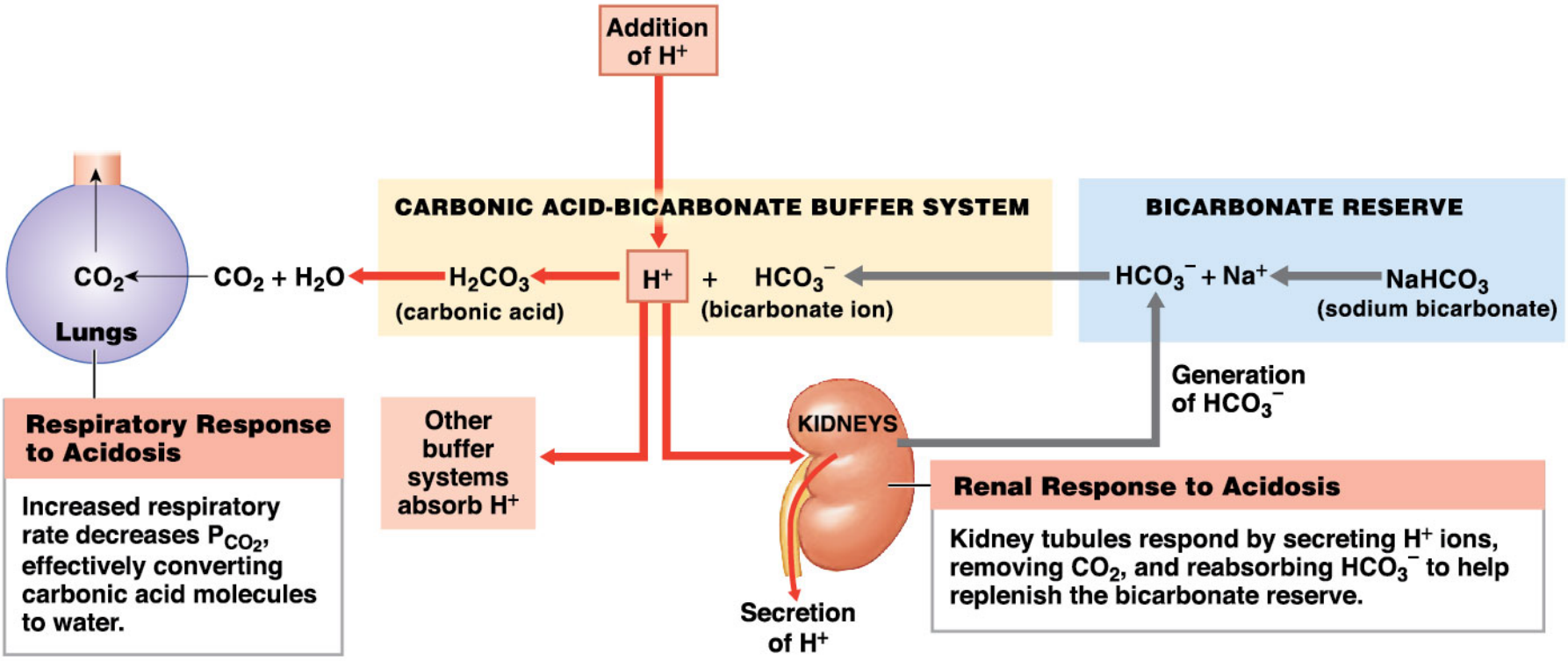
# Metabolic acidosis

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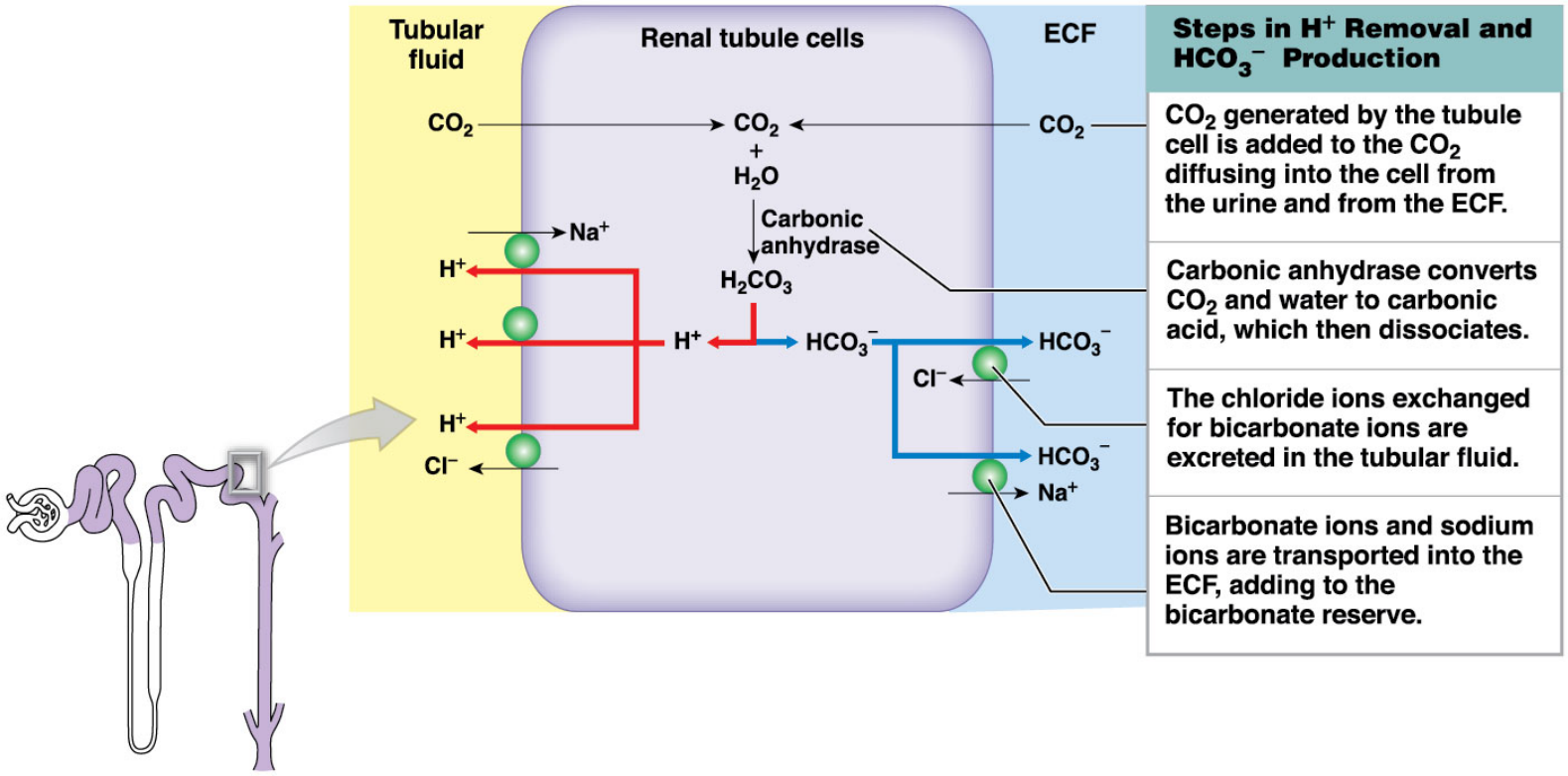
# Module 25.9: Homeostatic responses to metabolic acidosis and alkalosis

## **Metabolic acidosis** (continued)

- Renal tubule cells secrete $H^+$ into tubular fluid along PCT, DCT, and collecting system

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# Module 25.9: Homeostatic responses to metabolic acidosis and alkalosis

## Metabolic alkalosis

- Develops when large numbers of $H^+$ are removed from body fluids, raising pH

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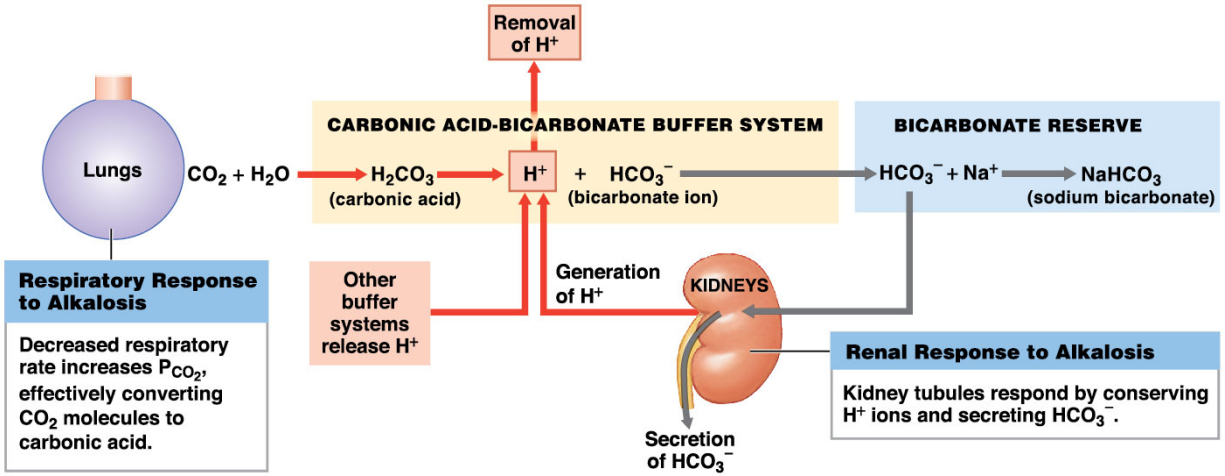
# Module 25.9: Homeostatic responses to metabolic acidosis and alkalosis

## **Metabolic alkalosis** (continued)

- Kidney responses
  - Rate of kidney $H^+$ secretion declines
  - Tubular cells do not reclaim bicarbonate
  - Collecting system transports bicarbonate into tubular fluid (urine) and releases acid (HCl) into the ECF

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# Module 25.9: Homeostatic responses to metabolic acidosis and alkalosis

## **Metabolic alkalosis** (continued)

- Responses to restore homeostasis
  - Respiratory response
    - Decreasing respiratory rate, which raises $P_{CO_2}$ levels
    - Converting more $CO_2$ to carbonic acid

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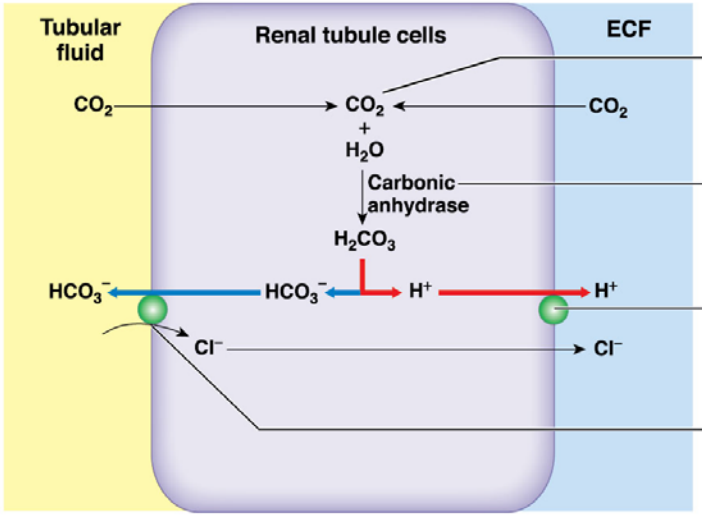
# Module 25.9: Homeostatic responses to metabolic acidosis and alkalosis

## **Metabolic alkalosis** (continued)

- Responses to restore homeostasis (continued)
  - Renal response (occurs in the PCT, DCT, and collecting system)
    - Conserving more $H^+$
      - Actively reabsorbed into the ECF
    - Excreting more bicarbonate (in exchange for chloride)




| Steps in $HCO_3^-$ Removal and $H^+$ Production |
| --- |
| $CO_2$ generated by the tubule cell is added to the $CO_2$ diffusing into the cell from the tubular fluid and from the ECF. |
| Carbonic anhydrase converts $CO_2$ and water to carbonic acid, which then dissociates. |
| The hydrogen ions are actively transported into the ECF, accompanied by the diffusion of chloride ions. |
| $HCO_3^-$ is pumped into the tubular fluid in exchange for chloride ions that will diffuse into the ECF. |

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# Module 25.9: Review

A. Describe metabolic acidosis.
B. Describe metabolic alkalosis.
C. If the kidneys are conserving $HCO_3^-$ and eliminating $H^+$ in acidic urine, which is occurring: metabolic alkalosis or metabolic acidosis?

*Learning Outcome:* Describe the compensatory mechanisms involved in maintaining acid-base balance.

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# Module 25.10: Respiratory acid-base disorders are the most common challenges to acid-base balance

## Respiratory acid-base disorders

- Result from an imbalance between the rate of $CO_2$ generation in body tissues and the rate of $CO_2$ elimination at the lungs
- Cannot be corrected by the carbonic acid–bicarbonate buffer system

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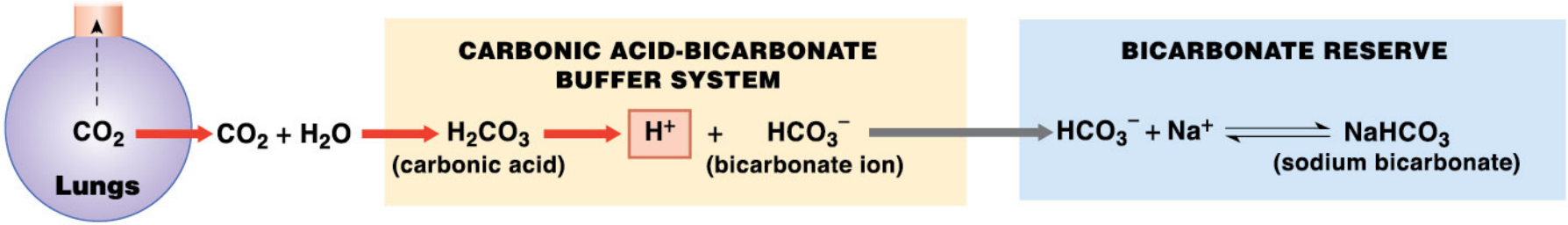
# Module 25.10: Respiratory acid-base disorders

## Respiratory acidosis

- Rate of $CO_2$ generation exceeds rate of $CO_2$ removal
  - Shifts carbonic acid–bicarbonate buffer system to the right, generating more carbonic acid and releasing more $H^+$ ions
    - $HCO_3^-$ goes into bicarbonate reserve
    - Excess $H^+$ must be "tied up" by other buffer systems or excreted by kidneys
  - Underlying problem cannot be corrected without an increase in the respiratory rate

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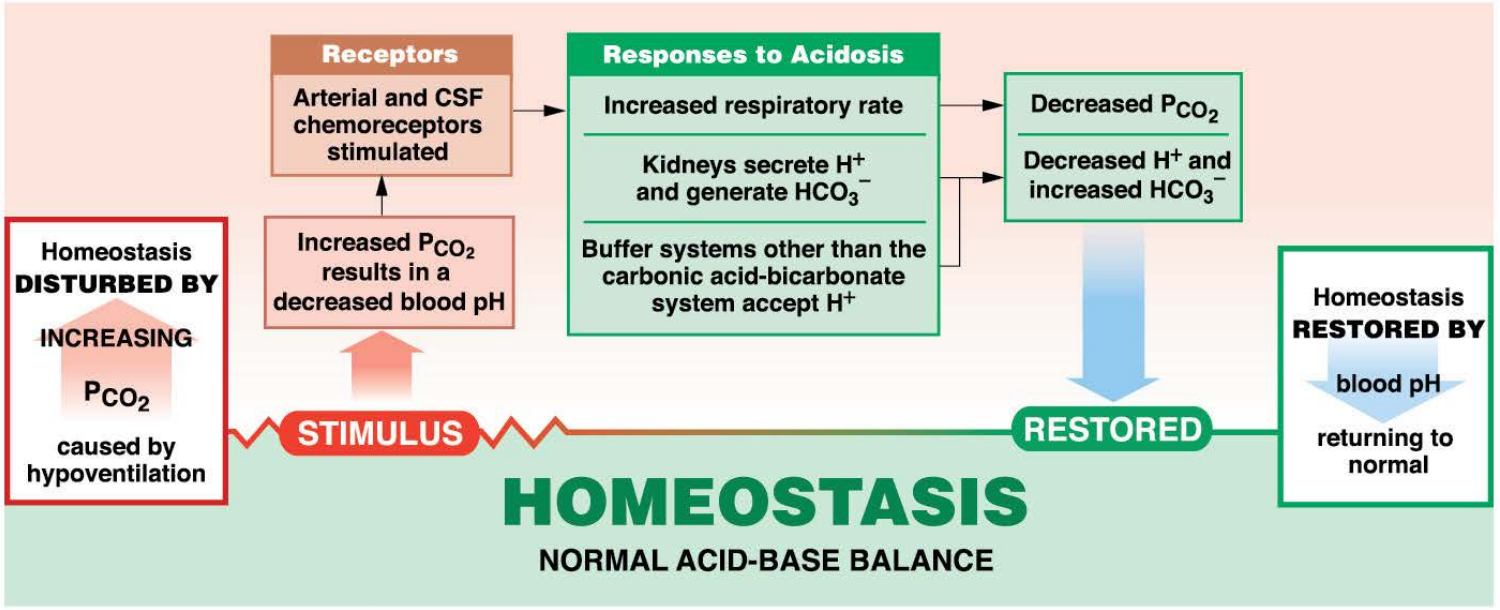
# Module 25.10: Respiratory acid-base disorders

## **Respiratory acidosis** (continued)

- Responses to restore homeostasis
  - Increasing respiratory rate
  - Increased $H^+$ secretion by kidneys and reabsorption of $HCO_3^-$ ions
  - Other buffer systems accepting $H^+$ ions

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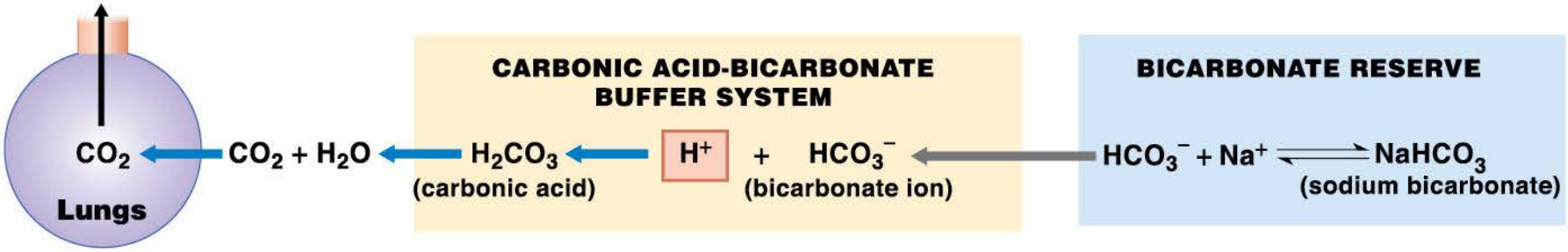
# Module 25.10: Respiratory acid-base disorders

## Respiratory alkalosis

- Rate of $CO_2$ elimination exceeds the rate of $CO_2$ generation
  - Relatively uncommon condition; rarely severe
  - Most cases related to anxiety and hyperventilation
    - Often self-limiting because when a person faints, respiratory rate returns to normal levels
- Shifts carbonic acid–bicarbonate buffer system to the left
  - $H^+$ ions removed as $CO_2$ is exhaled and water is

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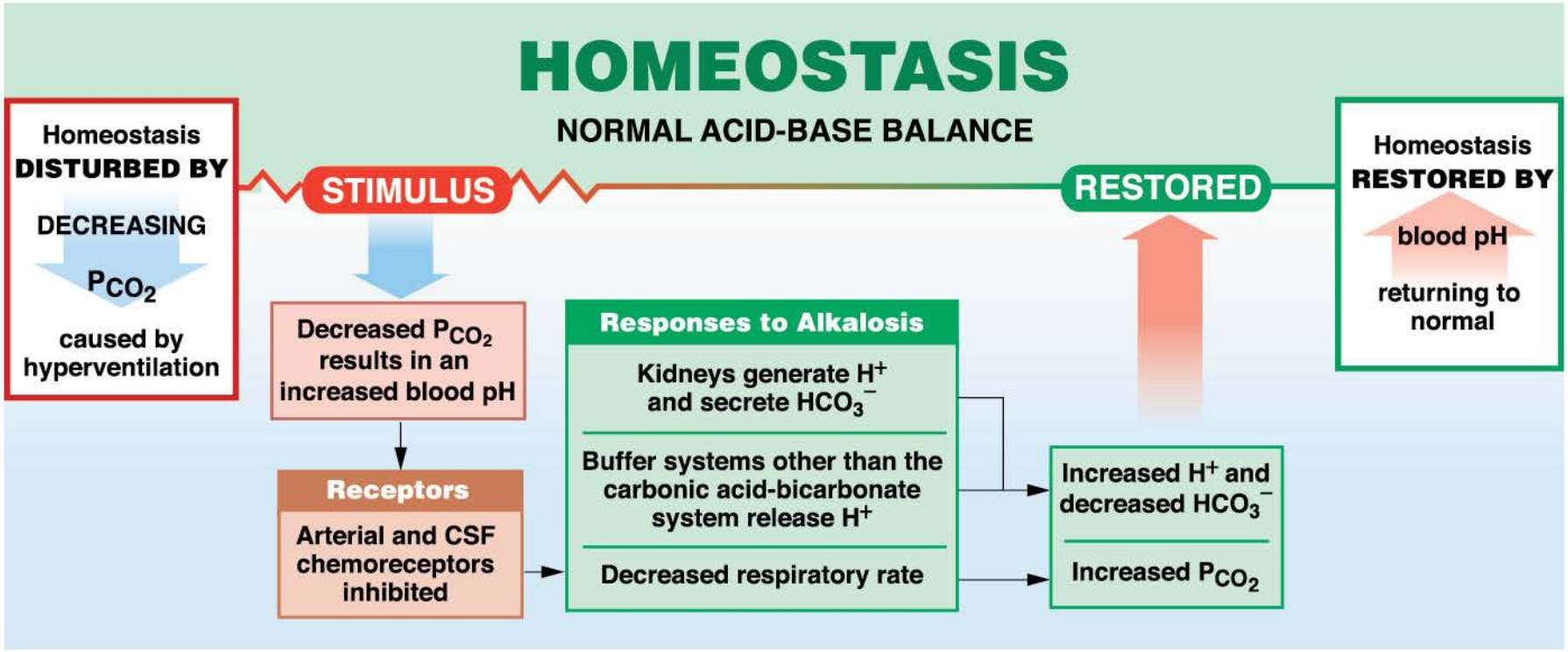
# Module 25.10: Respiratory acid-base disorders

## **Respiratory alkalosis** (continued)

- Responses to restore homeostasis
  - Respiratory response
    - Decrease in respiratory rate

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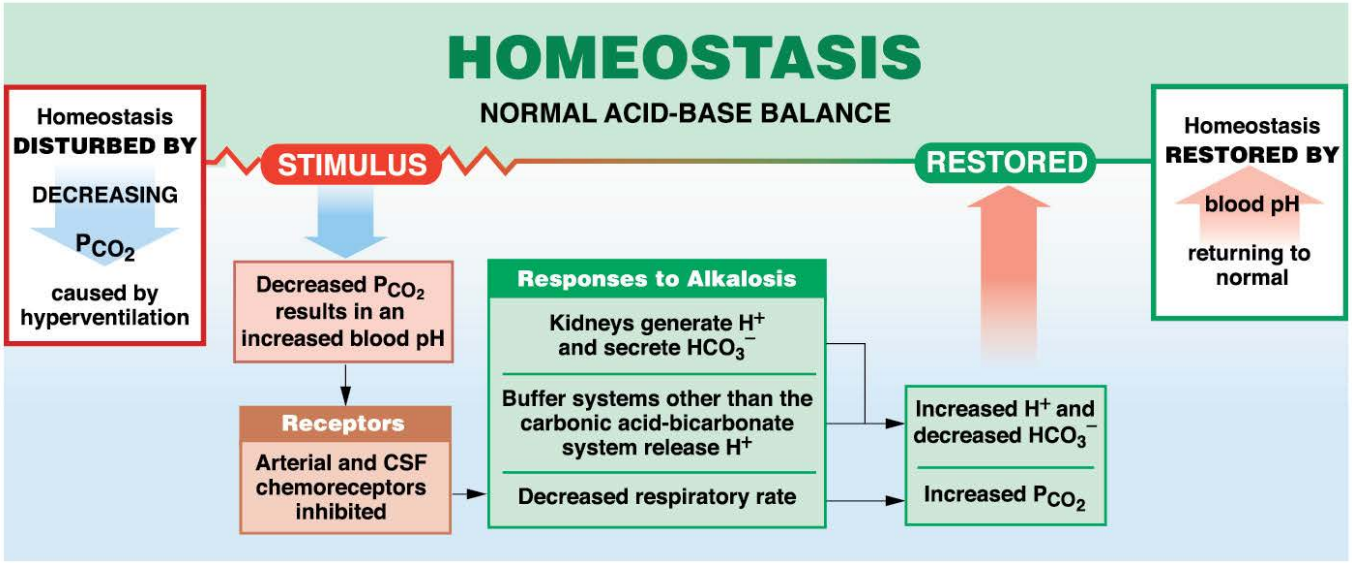
# Module 25.10: Respiratory acid-base disorders

## **Respiratory alkalosis** (continued)

- Responses to restore homeostasis (continued)
  - Renal response
    - Decreased $H^+$ secretion
    - Increased excretion of bicarbonate ions
  - Other buffer systems release $H^+$ ions

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# Module 25.10: Review

A. What would happen to the blood $P_{CO_2}$ of a patient who has an airway obstruction?
B. How would a decrease in the pH of body fluids affect the respiratory rate?

*Learning Outcome:* Describe respiratory acidosis and respiratory alkalosis.

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