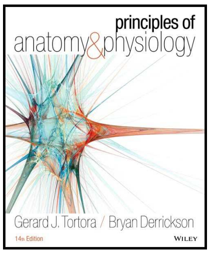


Principles of Anatomy and Physiology

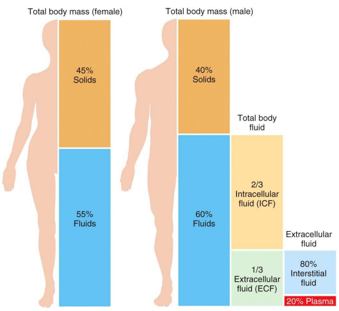
14th Edition

CHAPTER 27
Fluid, Electrolyte, and Acid–Base Homeostasis

Fluid Compartments and Fluid Homeostasis

- In adults, **body fluids** make up between 55% and 65% of total body mass.
- Body fluids are present in two main **compartments—inside cells (2/3) and outside cells (1/3)**.
- **Intracellular fluids** is **cytosol**.
- **Extracellular fluid** is **interstitial fluid** (80%) and **blood plasma** (20%)

Fluid Compartments and Fluid Homeostasis

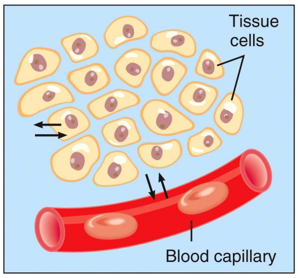


(a) Distribution of body solids and fluids in average lean adult female and male

Fluid Compartments and Fluid Homeostasis

- The **plasma membrane** of cells separates intracellular fluid from interstitial fluid.
- **Blood vessel walls** divide the interstitial fluid from blood plasma.
- **Capillary walls** are thin enough to allow exchange of water and solutes between blood plasma and interstitial fluid.

Fluid Compartments and Fluid Homeostasis

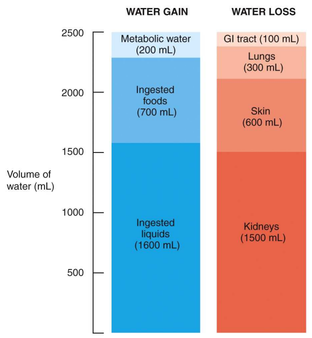


(b) Exchange of water among body fluid compartments

Fluid Compartments and Fluid Homeostasis

- **Filtration**, **reabsorption**, **diffusion** and **osmosis** allow continuous exchange of water and solutes among body fluid compartments.
- The balance of inorganic compounds that dissociate into ions (**electrolytes**) is closely related to fluid balance.
- The body gains water by **ingestion** and **metabolic synthesis**.
- The body loses water via **urination**, **perspiration**, **exhalation** and in **feces**.

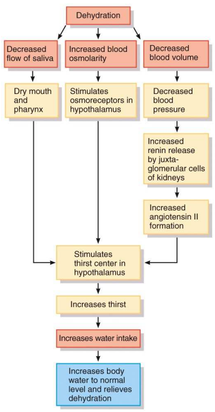
Fluid Compartments and Fluid Homeostasis



Fluid Compartments and Fluid Homeostasis

- The level of **aerobic respiration** determines the volume of **metabolic water** formed. The amount of water formed is directly proportional to the amount of ATP produced.
- When water loss is greater than water gain, **dehydration** occurs leading to increased **thirst**.

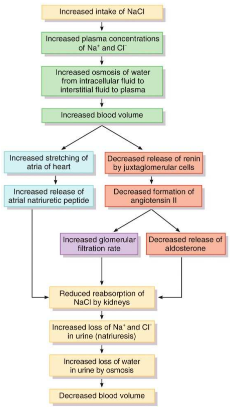
Fluid Compartments and Fluid Homeostasis



Fluid Compartments and Fluid Homeostasis

- Elimination of **excess body water** occurs through **urine production**.
- The amount of **urinary salt loss** is the main factor determining **body fluid volume**.
- The two main **solutes** in urine are **sodium ions (Na^+)** and **chloride ions (Cl^-)**.
- Wherever solutes go, water follows.

Fluid Compartments and Fluid Homeostasis



Fluid Compartments and Fluid Homeostasis

- 3 major **hormones** control renal Na^+ and Cl^-:
  1. **Angiotensin II**
  2. **Aldosterone**
  3. **Atrial natriuretic peptide (ANP)**
- The major hormone that regulates water loss is **antidiuretic hormone (ADH)**

Fluid Compartments and Fluid Homeostasis

TABLE 27.1

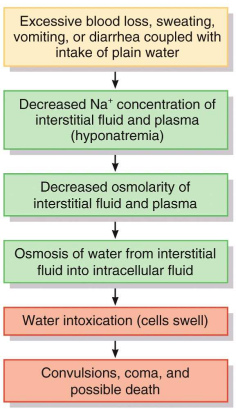
Summary of Factors That Maintain Body Water Balance

FACTOR	MECHANISM	EFFECT
Thirst center in hypothalamus	Stimulates desire to drink fluids.	Water gained if thirst is quenched.
Angiotensin II	Stimulates secretion of aldosterone.	Reduces loss of water in urine.
Aldosterone	By promoting urinary reabsorption of Na^+ and Cl^-, increases water reabsorption via osmosis.	Reduces loss of water in urine.
Atrial natriuretic peptide (ANP)	Promotes natriuresis, elevated urinary excretion of Na^+ (and Cl^-), accompanied by water.	Increases loss of water in urine.
Antidiuretic hormone (ADH), also known as vasopressin	Promotes insertion of water-channel proteins (aquaporin-2) into apical membranes of principal cells in collecting ducts of kidneys. As a result, water permeability of these cells increases and more water is reabsorbed.	Reduces loss of water in urine.

Fluid Compartments and Fluid Homeostasis

- **Water intoxication** occurs when excess body water causes cells to swell dangerously.
- This may occur when a person consumes water faster than the kidneys can excrete it.

Fluid Compartments and Fluid Homeostasis



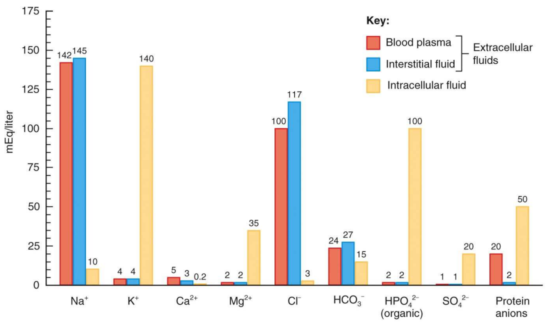
Electrolytes in Body Fluids

- Ions formed when electrolytes dissociate and dissolve:
  - Control osmosis of water between fluid compartments
  - Help maintain the acid-base balance
  - Carry electrical current
  - Serve as cofactors

Electrolytes in Body Fluids

- The concentration of ions is expressed in units of **milliequivalents per liter (mEq/liter)**.
- **Blood plasma**, **interstitial fluid** and **intracellular fluid** have different concentrations of electrolytes and protein ions.
- Blood plasma contains many protein ions and interstitial fluid contains only a few.

Electrolytes in Body Fluids



Electrolytes in Body Fluids

Sodium: most abundant cations in extracellular fluid

- Used for impulse transmission, muscle contraction, fluid and electrolyte balance.
- It's level is controlled by aldosterone, ADH and ANP

Chloride: the major extracellular anion

- Helps regulate osmotic pressure between compartments
- Forms HCl in the stomach
- Regulation of Cl^- balance is controlled by aldosterone

Electrolytes in Body Fluids

Potassium: most abundant cation in intracellular fluid

- Involved in fluid volume, impulse conduction, muscle contraction and regulating pH
- Mineralocorticoids (mainly aldosterone) regulate the plasma level

Bicarbonate: important plasma ion

- Major member of the plasma acid-base buffer system
- Kidneys reabsorb or secrete it for final acid-base balance

Electrolytes in Body Fluids

Calcium: most abundant mineral in the body

- Structural component of bones and teeth
- Used for blood coagulation, neurotransmitter release, muscle tone, excitability of nerves and muscles
- Level in plasma regulated by parathyroid hormone

Phosphate: occurs as calcium phosphate salt

- Used in the buffer system
- Regulated by parathyroid hormone and calcitriol

Electrolytes in Body Fluids

Magnesium: an intracellular cation

- Activates enzymes involved in carbohydrate and protein metabolism
- Used in myocardial function, transmission in the CNS and operation of the sodium pump

Electrolytes in Body Fluids

TABLE 27.2

Blood Electrolyte Imbalances

	DEFICIENCY		EXCESS	
ELECTROLYTE*	NAME AND CAUSES	SIGNS AND SYMPTOMS	NAME AND CAUSES	SIGNS AND SYMPTOMS
Sodium (Na^+) 136–148 mEq/liter	**Hyponatremia** (hī′-pō-na-TRĒ-mē-a) may be due to decreased sodium intake; increased sodium loss through vomiting, diarrhea, aldosterone deficiency, or taking certain diuretics; and excessive water intake.	Muscular weakness; dizziness, headache, and hypotension; tachycardia and shock; mental confusion, stupor, and coma.	**Hypernatremia** may occur with dehydration, water deprivation, or excessive sodium in diet or intravenous fluids; causes hypertonicity of ECF, which pulls water out of body cells into ECF, causing cellular dehydration.	Intense thirst, hypertension, edema, agitation, and convulsions.
Chloride (Cl^-) 95–105 mEq/liter	**Hypochloremia** (hī′-pō-klō-RĒ-mē-a) may be due to excessive vomiting, overhydration, aldosterone deficiency, congestive heart failure, and therapy with certain diuretics such as furosemide (Lasix®).	Muscle spasms, metabolic alkalosis, shallow respirations, hypotension, and tetany.	**Hyperchloremia** may result from dehydration due to water loss or water deprivation; excessive chloride intake; or severe renal failure, hyperaldosteronism, certain types of acidosis, and some drugs.	Lethargy, weakness, metabolic acidosis, and rapid, deep breathing.
Potassium (K^+) 3.5–5.0 mEq/liter	**Hypokalemia** (hī′-pō-ka-LĒ-mē-a) may result from excessive loss due to vomiting or diarrhea, decreased potassium intake, hyperaldosteronism, kidney disease, and therapy with some diuretics.	Muscle fatigue, flaccid paralysis, mental confusion, increased urine output, shallow respirations, and changes in electrocardiogram, including flattening of T wave.	**Hyperkalemia** may be due to excessive potassium intake, renal failure, aldosterone deficiency, crushing injuries to body tissues, or transfusion of hemolyzed blood.	Irritability, nausea, vomiting, diarrhea, muscular weakness; can cause death by inducing ventricular fibrillation.

Electrolytes in Body Fluids

TABLE 27.2

Blood Electrolyte Imbalances

	DEFICIENCY		EXCESS	
ELECTROLYTE*	NAME AND CAUSES	SIGNS AND SYMPTOMS	NAME AND CAUSES	SIGNS AND SYMPTOMS
Calcium (Ca^{2+}) Total = 9.0–10.5 mg/dL; ionized = 4.5–5.5 mEq/liter	**Hypocalcemia** (hī′-pō-kal-SĒ-mē-a) may be due to increased calcium loss, reduced calcium intake, elevated phosphate levels, or hypoparathyroidism.	Numbness and tingling of fingers; hyperactive reflexes, muscle cramps, tetany, and convulsions; bone fractures; spasms of laryngeal muscles that can cause death by asphyxiation.	**Hypercalcemia** may result from hyperparathyroidism, some cancers, excessive intake of vitamin D, and Paget's disease of bone.	Lethargy, weakness, anorexia, nausea, vomiting, polyuria, itching, bone pain, depression, confusion, paresthesia, stupor, and coma.
Phosphate (HPO_4^{2-}) 1.7–2.6 mEq/liter	**Hypophosphatemia** (hī′-pō-fos-fa-TĒ-mē-a) may occur through increased urinary losses, decreased intestinal absorption, or increased utilization.	Confusion, seizures, coma, chest and muscle pain, numbness and tingling of fingers, decreased coordination, memory loss, and lethargy.	**Hyperphosphatemia** occurs when kidneys fail to excrete excess phosphate, as in renal failure; can also result from increased intake of phosphates or destruction of body cells, which releases phosphates into blood.	Anorexia, nausea, vomiting, muscular weakness, hyperactive reflexes, tetany, and tachycardia.
Magnesium (Mg^{2+}) 1.3–2.1 mEq/liter	**Hypomagnesemia** (hī′-pō-mag-ne-SĒ-mē-a) may be due to inadequate intake or excessive loss in urine or feces; also occurs in alcoholism, malnutrition, diabetes mellitus, and diuretic therapy.	Weakness, irritability, tetany, delirium, convulsions, confusion, anorexia, nausea, vomiting, paresthesia, and cardiac arrhythmias.	**Hypermagnesemia** occurs in renal failure or due to increased intake of Mg^{2+}, such as Mg^{2+}-containing antacids; also occurs in aldosterone deficiency and hypothyroidism.	Hypotension, muscular weakness or paralysis, nausea, vomiting, and altered mental functioning.

*Values are normal ranges of blood plasma levels in adults.

Acid–Base Balance

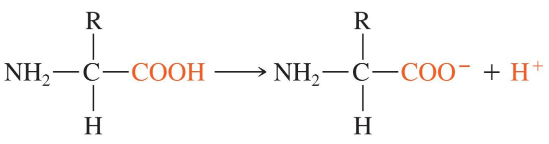
The pH of arterial blood ranges from 7.35 to 7.45. Several mechanisms maintain this range.

- Buffer systems
- Exhalation of carbon dioxide
- Kidney excretion of H^+

Acid–Base Balance

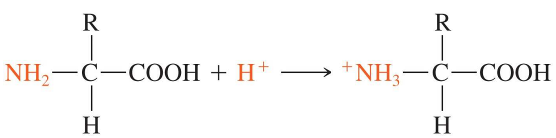
Buffer systems include:

- **Protein buffer system**: most abundant in intracellular fluid and blood plasma. When pH rises, the COOH group dissociates to act like an acid.



Acid–Base Balance

- When pH falls, the free amino group dissociates to act like a base.



Acid–Base Balance

Hemoglobin in red blood cells acts as a buffer:

$$\underset{\text{Water}}{H_2O} + \underset{\text{Carbon dioxide (entering RBCs)}}{CO_2} \longrightarrow \underset{\text{Carbonic acid}}{H_2CO_3}$$

$$\underset{\text{Carbonic acid}}{H_2CO_3} \longrightarrow \underset{\text{Hydrogen ion}}{H^+} + \underset{\text{Bicarbonate ion}}{HCO_3^-}$$

$$\underset{\text{Oxyhemoglobin (in RBCs)}}{Hb\text{–}O_2} + \underset{\text{Hydrogen ion (from carbonic acid)}}{H^+} \longrightarrow \underset{\text{Reduced hemoglobin}}{Hb\text{–}H} + \underset{\text{Oxygen (released to tissue cells)}}{O_2}$$

Acid–Base Balance

Carbonic acid-bicarbonate buffer system: this is based on the **bicarbonate ion (HCO_3^-)** which acts as a **weak base**, and **carbonic acid (H_2CO_3)** which acts as **a weak acid**.

If the pH falls, the HCO_3^- removes excess H^+:

$$\underset{\text{Hydrogen ion}}{H^+} + \underset{\text{Bicarbonate ion (weak base)}}{HCO_3^-} \longrightarrow \underset{\text{Carbonic acid}}{H_2CO_3}$$

Acid–Base Balance

If the pH rises, H_2CO_3 can provide H^+:

$$\underset{\text{Carbonic acid (weak acid)}}{H_2CO_3} \longrightarrow \underset{\text{Hydrogen ion}}{H^+} + \underset{\text{Bicarbonate ion}}{HCO_3^-}$$

Acid–Base Balance

Phosphate buffer system: this system acts similarly to the carbonic acid-bicarbonate buffer system. **Dihydrogen phosphate ($H_2PO_4^-$)** and **monohydrogen phosphate (HPO_4^{2-})** are the ions used in this system. $H_2PO_4^-$ acts as a weak acid:

$$\underset{\substack{\text{Hydroxide ion}\\\text{(strong base)}}}{OH^-} + \underset{\substack{\text{Dihydrogen}\\\text{phosphate}\\\text{(weak acid)}}}{H_2PO_4^-} \longrightarrow \underset{\text{Water}}{H_2O} + \underset{\substack{\text{Monohydrogen}\\\text{phosphate}\\\text{(weak base)}}}{HPO_4^{2-}}$$

Acid–Base Balance

HPO_4^{2-} acts as a weak base:

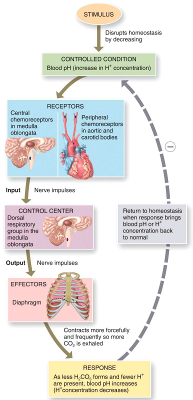
$$\underset{\substack{\text{Hydrogen ion}\\\text{(strong acid)}}}{H^+} + \underset{\substack{\text{Monohydrogen}\\\text{phosphate}\\\text{(weak base)}}}{HPO_4^{2-}} \longrightarrow \underset{\substack{\text{Dihydrogen}\\\text{phosphate}\\\text{(weak acid)}}}{H_2PO_4^-}$$

Acid–Base Balance

Exhalation of carbon dioxide: CO_2 mixes with water in the blood to form **carbonic acid (H_2CO_3)**. Exhaling CO_2 leads to less acid production and a rise in pH. Retaining CO_2 leads to more acid production and a drop in pH.

$$\underset{\substack{\text{Carbon}\\\text{dioxide}}}{CO_2} + \underset{\text{Water}}{H_2O} \rightleftharpoons \underset{\substack{\text{Carbonic}\\\text{acid}}}{H_2CO_3} \rightleftharpoons \underset{\substack{\text{Hydrogen}\\\text{ion}}}{H^+} + \underset{\substack{\text{Bicarbonate}\\\text{ion}}}{HCO_3^-}$$

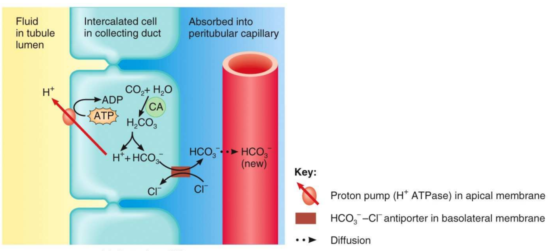
Acid–Base Balance



Acid–Base Balance

Kidney excretion of H^+: Excreting H^+ in the urine removes **nonvolatile acids**. The **proximal convoluted tubules** and **collecting ducts** of the kidneys secrete H^+ into the tubular fluid.

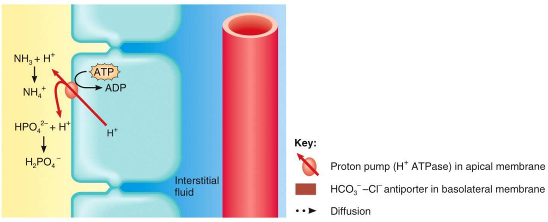
Acid–Base Balance



(a) Secretion of H^+

Acid–Base Balance

Some H^+ secreted into the tubular fluid of the collecting duct is buffered by $\mathbf{HPO_4^{2-}}$ and $\mathbf{NH_3}$. The buffers are excreted in the urine.



(b) Buffering of H^+ in urine

Acid–Base Balance

TABLE 27.3

Mechanisms That Maintain pH of Body Fluids

MECHANISM	COMMENTS
Buffer systems	Most consist of a weak acid and its salt, which functions as a weak base. They prevent drastic changes in body fluid pH.
Proteins	The most abundant buffers in body cells and blood. Hemoglobin inside red blood cells is a good buffer.
Carbonic acid–bicarbonate	Important regulator of blood pH. The most abundant buffers in extracellular fluid (ECF).
Phosphates	Important buffers in intracellular fluid and urine.
Exhalation of CO_2	With increased exhalation of CO_2, pH rises (fewer H^+). With decreased exhalation of CO_2, pH falls (more H^+).
Kidneys	Renal tubules secrete H^+ into urine and reabsorb HCO_3^- so it is not lost in urine.

Acid–Base Balance

- **Acid-base imbalances** may occur.
- **Acidosis**: blood pH is below 7.35
- **Alkalosis**: blood pH is above 7.45
- **Respiratory acidosis**: blood pH drops due to excessive retention of CO_2 leading to excess H_2CO_3.
- **Respiratory alkalosis**: blood pH rises due to excessive loss of CO_2 as in hyperventilation.
- **Metabolic acidosis**: arterial blood levels of HCO_3^- falls.
- **Metabolic alkalosis**: arterial blood levels of HCO_3^- rises.

Acid–Base Balance

TABLE 27.4

Summary of Acidosis and Alkalosis

CONDITION	DEFINITION	COMMON CAUSES	COMPENSATORY MECHANISM
Respiratory acidosis	Increased P_{CO_2} (above 45 mmHg) and decreased pH (below 7.35) if no compensation.	Hypoventilation due to emphysema, pulmonary edema, trauma to respiratory center, airway obstructions, or dysfunction of muscles of respiration.	Renal: increased excretion of H^+; increased reabsorption of HCO_3^-. If compensation is complete, pH will be within normal range but P_{CO_2} will be high.
Respiratory alkalosis	Decreased P_{CO_2} (below 35 mmHg) and increased pH (above 7.45) if no compensation.	Hyperventilation due to oxygen deficiency, pulmonary disease, cerebrovascular accident (CVA), or severe anxiety.	Renal: decreased excretion of H^+; decreased reabsorption of HCO_3^-. If compensation is complete, pH will be within normal range but P_{CO_2} will be low.
Metabolic acidosis	Decreased HCO_3^- (below 22 mEq/liter) and decreased pH (below 7.35) if no compensation.	Loss of bicarbonate ions due to diarrhea, accumulation of acid (ketosis), renal dysfunction.	Respiratory: hyperventilation, which increases loss of CO_2. If compensation is complete, pH will be within normal range but HCO_3^- will be low.
Metabolic alkalosis	Increased HCO_3^- (above 26 mEq/liter) and increased pH (above 7.45) if no compensation.	Loss of acid due to vomiting, gastric suctioning, or use of certain diuretics; excessive intake of alkaline drugs.	Respiratory: hypoventilation, which slows loss of CO_2. If compensation is complete, pH will be within normal range but HCO_3^- will be high.

Acid–Base Balance

Interactions Animation:

- Regulation of pH

You must be connected to the Internet and in Slideshow Mode to run this animation.

Aging and Fluid, Electrolyte, and Acid-Base Homeostasis

- Significant differences exist between adults and infants in respect to **fluid distribution, regulation of fluid and electrolyte balance and acid-base homeostasis**. Differences exist due to: **proportion and distribution of water**
- Metabolic rate
- Functional development of the kidneys
- Body surface area
- Breathing rate
- Ion concentrations

Aging and Fluid, Electrolyte, and Acid-Base Homeostasis

- **Older adults** often have impaired ability to maintain fluid, electrolyte and acid-base balance. Basically, all systems slow down and function less efficiently.
- Older adults often suffer with: **dehydration and hypernatremia** – inadequate fluid intake, loss of more water than Na^+
- **Hypokalemia** – chronic use of laxatives, drugs that cause K^+ loss

Aging and Fluid, Electrolyte, and Acid-Base Homeostasis

Acidosis – impaired ability of lungs and kidneys to compensate for acid-base imbalances.

End of Chapter 27