PARAMEDIC CARE • PRINCIPLES & PRACTICE, 6E

Disease & the Chemical Level

Chapter 19, Sections 1–2 + Fluids & Electrolytes — An Extended Session

6 hours 45 minutes • 4 scheduled breaks

Bledsoe · Porter · Cherry

SESSION ROADMAP

How Today Breaks Down

0:00–0:15	**Welcome, Hook & Learning Objectives**
0:15–1:15	**Part 1: Disease** Vocabulary, risk factors, and classification — the language of pathophysiology.
1:15–1:30	**BREAK**
1:30–2:45	**Part 2A: Chemistry of Life** Atoms, bonds, and the four biological molecule classes.
2:45–3:00	**BREAK**
3:00–4:00	**Part 2B: Acids, Bases & pH Balance** The buffer systems and disorders you'll manage in the field.
4:00–4:15	**BREAK**
4:15–5:15	**Part 3A: Go With the Flow — Hemodynamics & Fluid Physiology** Vasopressors, blood flow control, fluid compartments, and the regulators that hold it all together.
5:15–5:25	**BREAK**
5:25–6:15	**Part 3B: Electrolyte Imbalances & IV Fluid Therapy** Sodium, potassium, calcium, magnesium — and what's actually in the bag you're hanging.
6:15–6:30	**Case Applications & Final Knowledge Check**
6:30–6:45	**Wrap-Up & Key Takeaways**

PREPARATORY — PATHOPHYSIOLOGY, SECTIONS 1–2

What You're Accountable For Today

EMS Systems Standard

“Pathophysiology” — today builds the vocabulary and chemistry foundation everything later in this chapter depends on.

Competency

Integrates comprehensive knowledge of pathophysiology to form the foundation for the assessment and management of emergency patients of all ages.

WHY THIS ACTUALLY MATTERS

Every Assessment You'll Ever Run Starts Here

You will never see “pathophysiology” written on a run sheet

- But every sign, every symptom, every treatment decision you make is downstream of what you learn today.

This isn't memorization for a test

- It's the reason a patient in DKA breathes the way they do, why a septic patient's blood pressure crashes, and why glucagon doesn't work on an empty tank.

By the end of today, you'll be able to explain the “why” behind the “what”

- That's the difference between following a protocol and understanding your patient.

Zooming Out, One Level at a Time

Cell

The smallest unit of life, built from molecules, which are built from atoms.

Tissue

A group of similar cells performing a common function.

Organ

A group of tissues working together toward a shared function.

Organ System

A group of organs working together — humans have 11 of them.

PART 1 • 60 MINUTES

Disease

01

The vocabulary every clinician needs before anything else makes sense.

Five Words That Run This Chapter

Homeostasis

The body's steady internal balance — everything in this chapter is a story about it being disrupted or restored.

Pathology

The medical science that deals with all aspects of disease.

Pathophysiology

Specifically, the study of how disease disrupts normal function.

Pathologist

A physician who specializes in pathology.

Disease

An abnormal structural or functional change within the body.

Predisposing Factors

Age

Gender

Genetics

Lifestyle

Environment

Risk Analysis: What You Can and Can't Control

Can't Control

- Genetics
- Gender
- Age

Can Control

- Lifestyle choices
- Environment
- Minimizing these can slow the effects of age
- Risk analysis looks at a person's whole life, not one factor in isolation

Obesity: A Modifiable Risk Factor

- Obesity contributes to cardiovascular disease, diabetes, and joint disease — but it's a lifestyle-linked, modifiable factor.
- It's also a practical field consideration — airway management, extrication, and moving patients safely.
- This is risk analysis in action: you can't change a patient's genetics, but prevention and management target what's controllable.

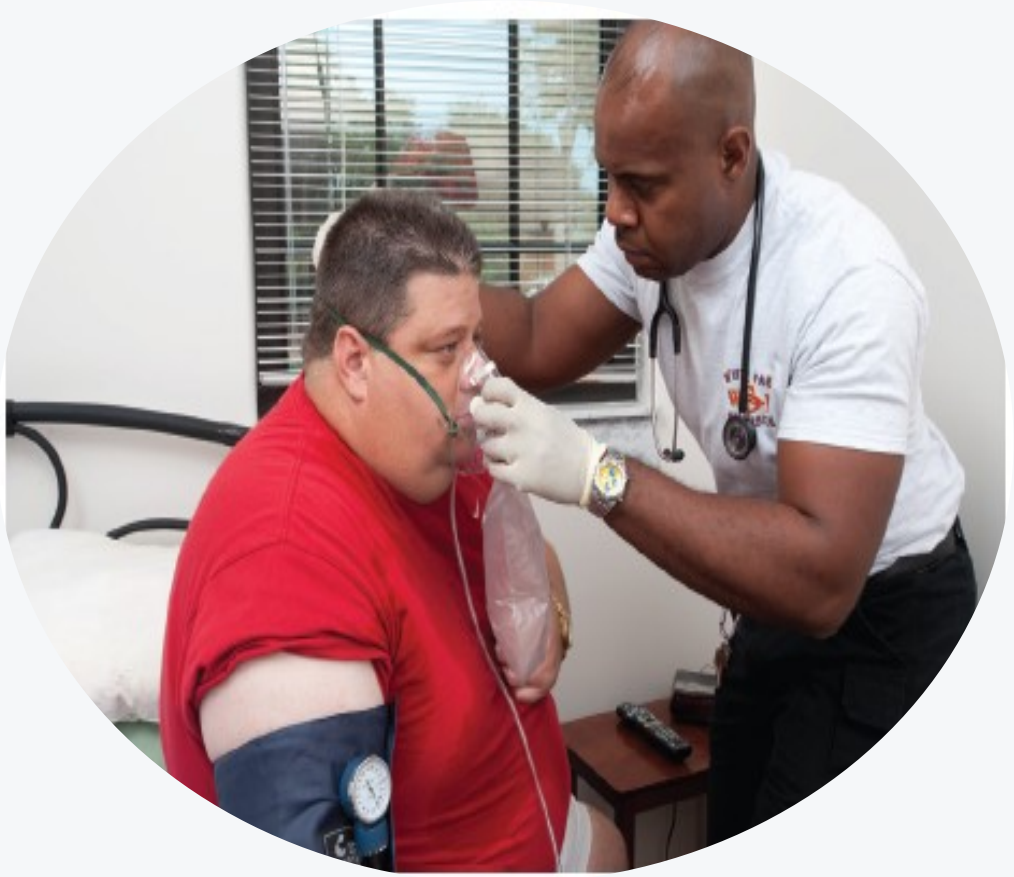


Figure 19-1: Obesity is one of many risk factors for cardiovascular disease.

The Vocabulary of a Disease Course

How It's Described

- Pathogenesis — the sequence of events leading to disease
- Etiology — the occurrences, reasons, and variables behind it
- Idiopathic — predisposing factors can't be identified
- Clinical presentation — how the disease manifests

How It's Assessed

- Symptom — what the patient tells you (subjective)
- Sign — what you find on exam (objective)
- Syndrome — a specific constellation of signs & symptoms
- Diagnosis — the assumption the disease follows a known course

Acute, Chronic, and What Comes After

- **Acute**

  Sudden onset.

- **Chronic (insidious)**

  A slower, creeping onset.

- **Complications**

  Abnormalities that result from the original problem.

- **Sequelae**

  Complications that are common or expected.

- **Prognosis**

  The expected outcome.

Classifying Disease (1 of 2)

Infectious

Caused by pathogens invading the body.

Immunologic

Overreactions of the immune system, like anaphylaxis.

Inflammatory

Inflamed secondary to another disease process.

Ischemic

Diminished blood flow, lack of oxygen.

Metabolic

Like diabetes — a breakdown in body chemistry.

Nutritional

Caused by a vitamin or nutrient deficiency.

Genetic

Inherited, like hemophilia or color blindness.

Classifying Disease (2 of 2)

Congenital

Present at birth — developed in the fetus.

Neoplastic

Cancers — uncontrolled cell growth.

Trauma

Caused by external forces.

Physical Agents

Chemicals and poisons.

Iatrogenic

Caused by medical treatment itself — e.g. a pneumothorax from central line placement.

Idiopathic

Unknown cause.

Congenital Disease, Up Close

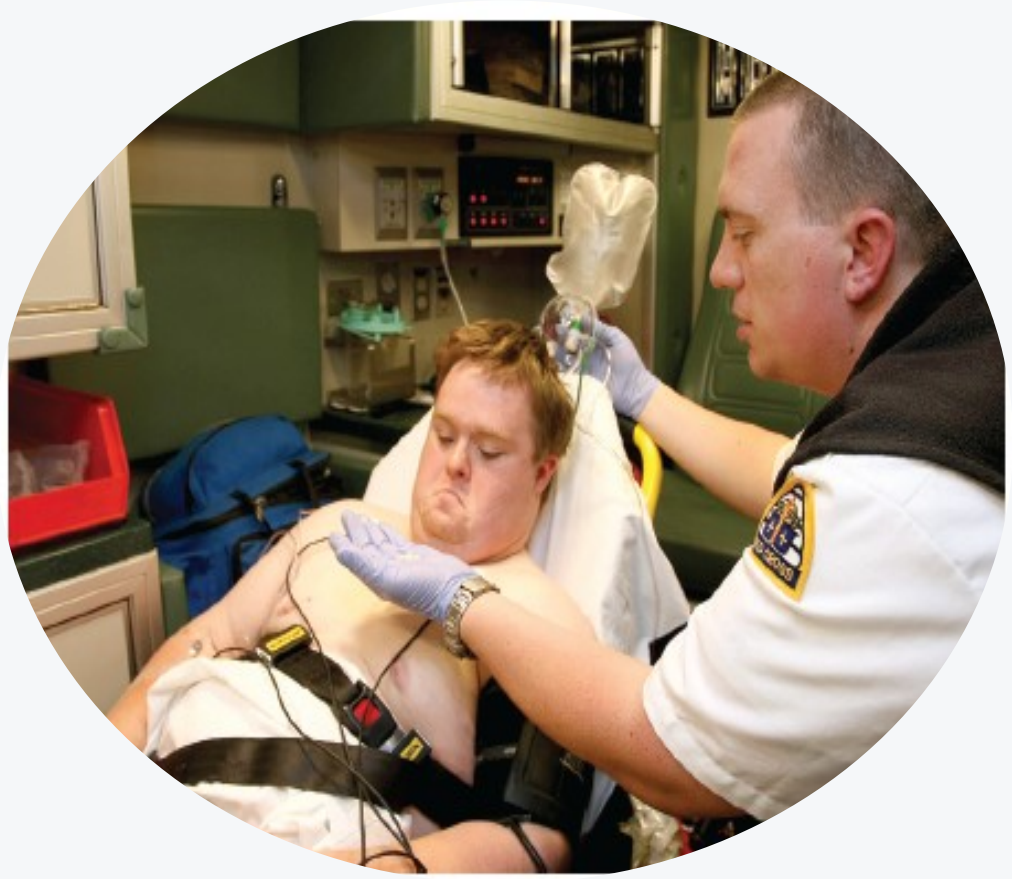


Figure 19-2: Down syndrome is a congenital disease. (© Daniel Limmer)

- Down syndrome develops in the fetus — it's present from birth, making it congenital by definition.
- Congenital doesn't mean genetic in every case — some congenital conditions come from in-utero exposures, not inherited genes.
- As a paramedic, you'll care for congenital-disease patients across their entire lifespan, not just as infants.

How Cancer Grows

- Genetic predisposition, smoking, pollution, and UV or radiation exposure can all trigger abnormal cell growth.
- Normal cells accumulate changes over time — becoming progressively more deformed and disorganized.
- This is neoplastic disease from Part 1's classification list, made visual — we'll return to this process in far more depth in a later session.

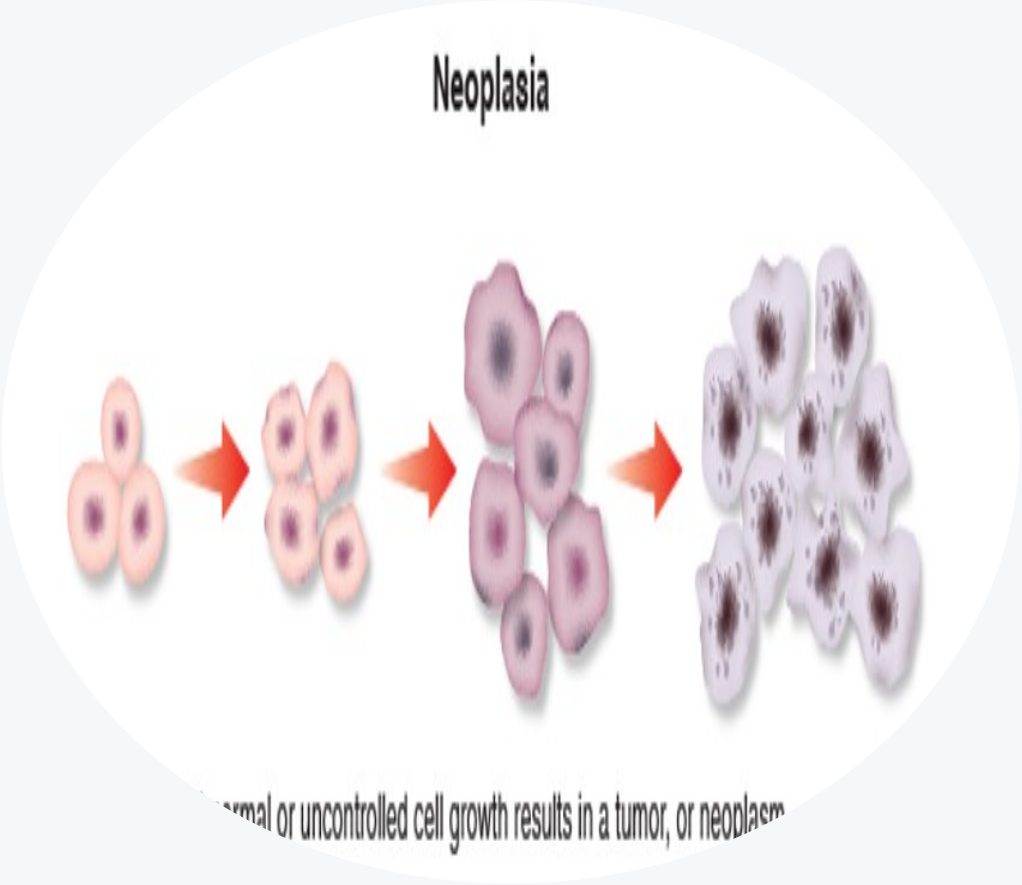


Figure 19-3: Abnormal or uncontrolled cell growth results in a tumor, or neoplasm.

CASE IN POINT

The Patient Who “Just Has Bad Luck”

You respond to a 58-year-old with chest pain. He tells you his father died young of a heart attack, he's smoked for 30 years, and he was just diagnosed with type 2 diabetes. He says, “I guess it's just bad luck — nothing I can do about it.”

DISCUSS

- Which of his risk factors are predisposing (uncontrollable) vs. modifiable (controllable)?
- Is his diabetes better classified as metabolic, genetic, or both — and does that classification change how you'd counsel him?
- How would you explain risk analysis to this patient in a way that's honest but not dismissive of his family history?

QUICK CHECK

A patient tells you, “My chest feels tight.” You then observe he is diaphoretic and his heart rate is 128. Which term describes the diaphoresis and heart rate?

A. Symptom — a subjective complaint

B. Sign — an objective finding

C. Syndrome — a constellation of findings

D. Sequela — an expected complication

Answer key: B

PART 1 — RECAP

Before We Move On…

Disease is any abnormal structural or functional change in the body

- And it's shaped by predisposing factors you can and can't control.

You now have a shared vocabulary for describing any disease course

- Pathogenesis, etiology, signs, symptoms, syndromes, and diagnosis.

And a working classification system

- 13 categories, from infectious to idiopathic — you'll use this framework for the rest of your career.

BREAK

15 minutes

Grab water, stretch, and get ready — next up: the chemistry that runs every cell in the body.

Back at 1:30

PART 2A • 75 MINUTES

Disease at the Chemical Level

02

Every clinical process you'll ever manage starts with atoms, bonds, and molecules.

From the Big Bang to the First Cell

- The Big Bang theory: the universe began with the explosion of a primeval atom.
- Chemical evolution: simple chemicals in the primordial atmosphere and ocean combined to form larger, more complex chemicals.
- Eventually, a self-replicating chemical surrounded by a membrane appeared — and cellular life began.

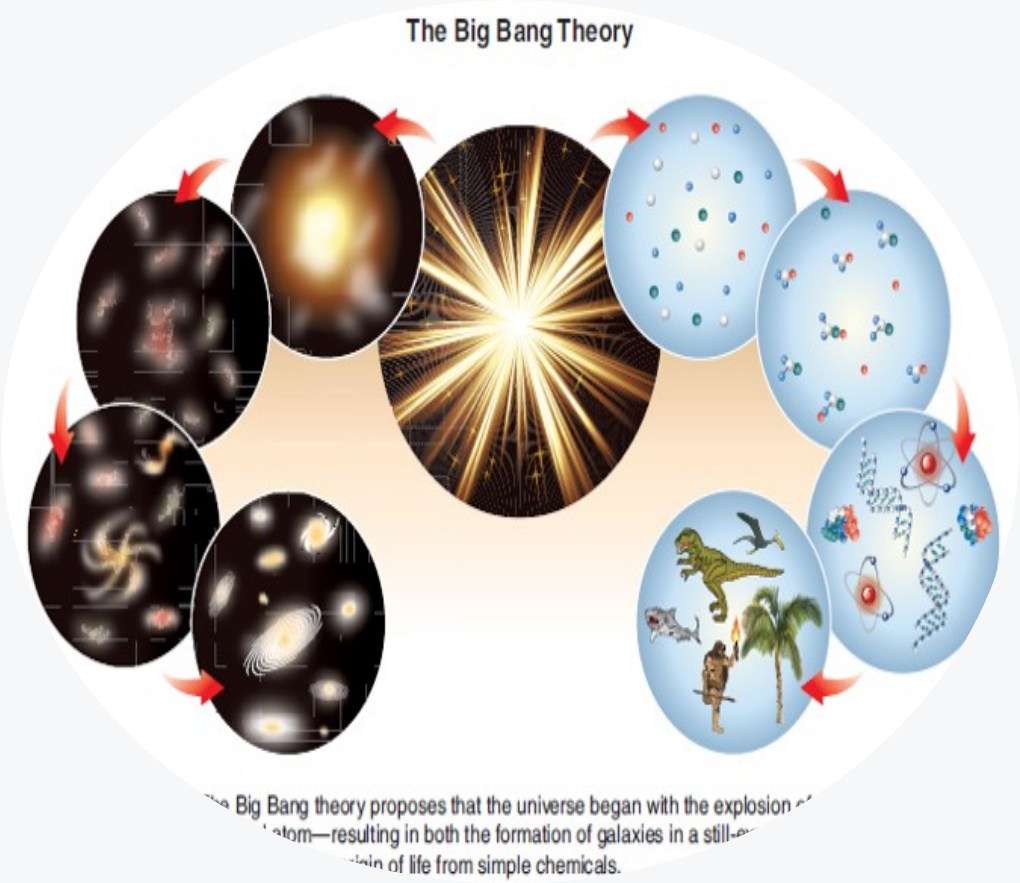
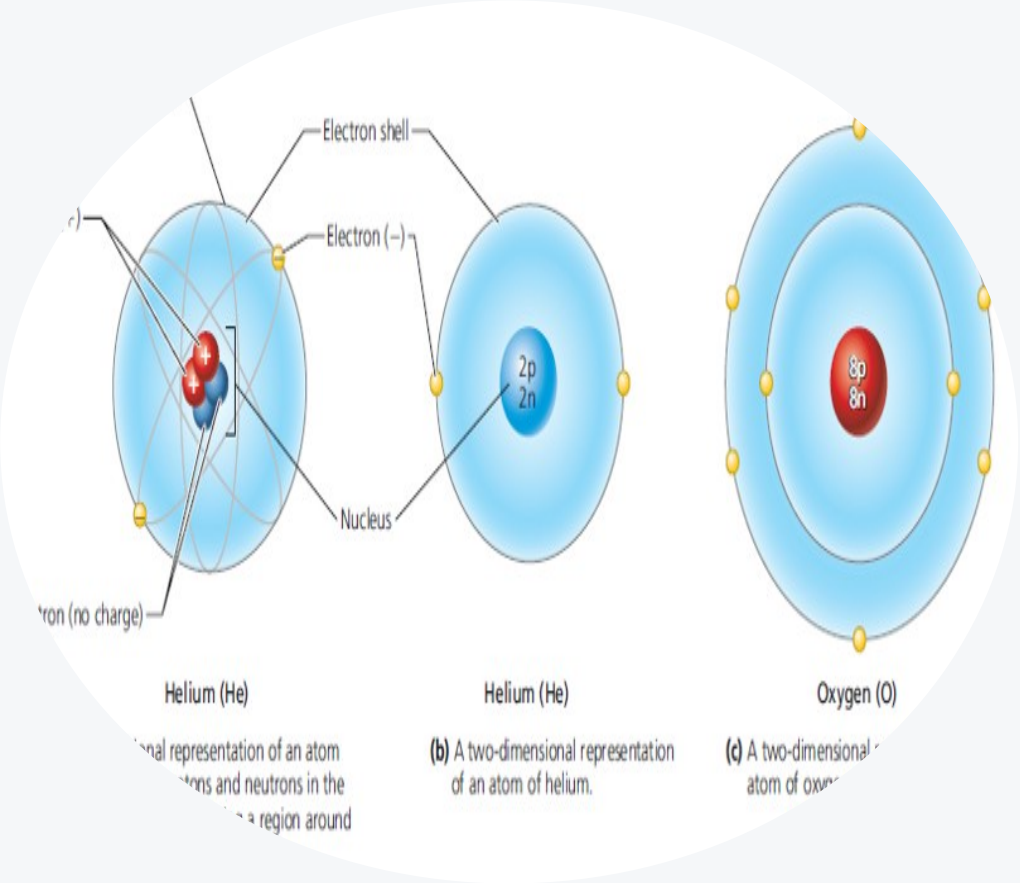


Figure 19-4: The Big Bang theory — from primeval atom to galaxies, and from simple chemicals to life.

Rebuilding the Atom



- Atom — the fundamental chemical unit.
- Protons and neutrons sit in the nucleus; protons carry a positive charge, neutrons are neutral.
- Electrons are smaller particles that orbit the nucleus — negatively charged.

Figure 19-5: Atoms can be represented in various ways — helium and oxygen shown here.

Elements, the Periodic Table & Isotopes

- Element — a substance that cannot be separated into simpler substances.
- Atomic number — the number of protons in the nucleus; this defines the element.
- Isotopes — atoms of the same element with the same number of protons but a different number of neutrons.

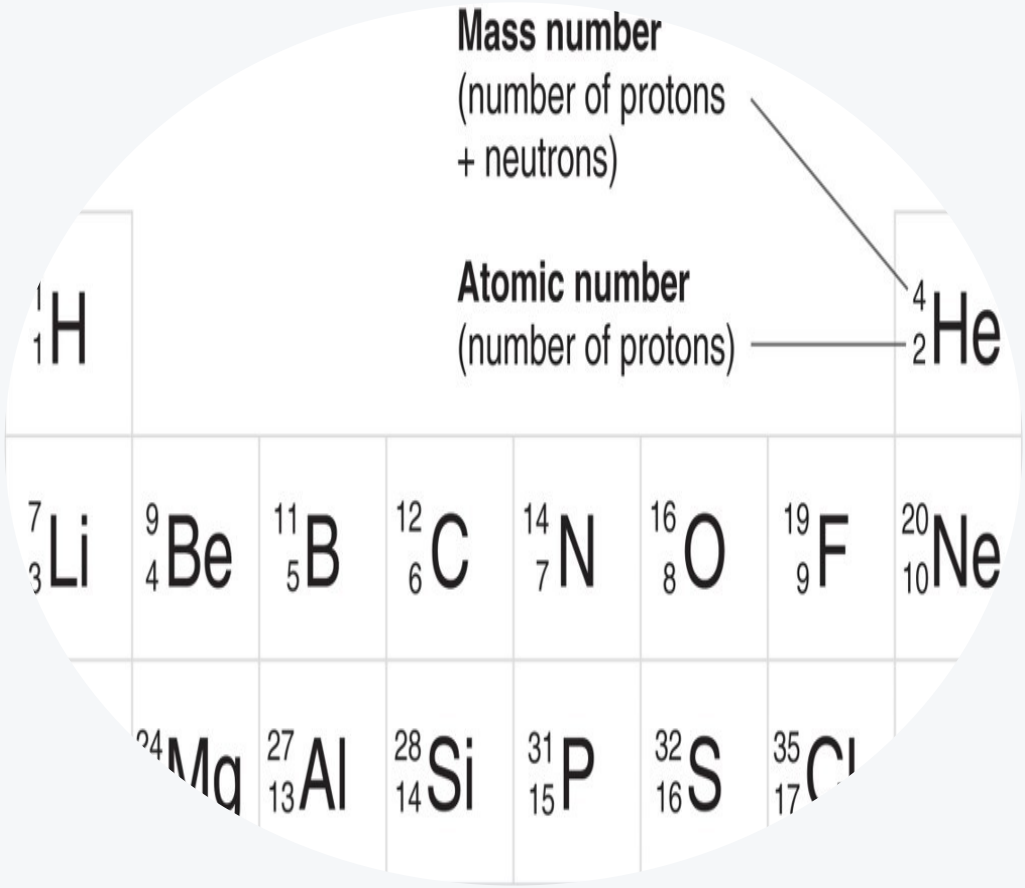


Figure 19-6: A portion of the periodic table — atomic number, mass number, and symbol for each element.

Radioactive Decay & Half-Life

- **Mass number**

  The total number of neutrons and protons in an atom.

- **Radioactive isotopes**

  Unstable combinations of neutrons and protons in the nucleus.

- **Radioactive decay**

  The nucleus breaks down and emits radiation (alpha, beta, gamma) until the atom regains stability.

- **Half-life**

  The time it takes for a parent isotope to decrease by one-half — the same concept used clinically for drug elimination.

Electron Shells & the Valence Shell

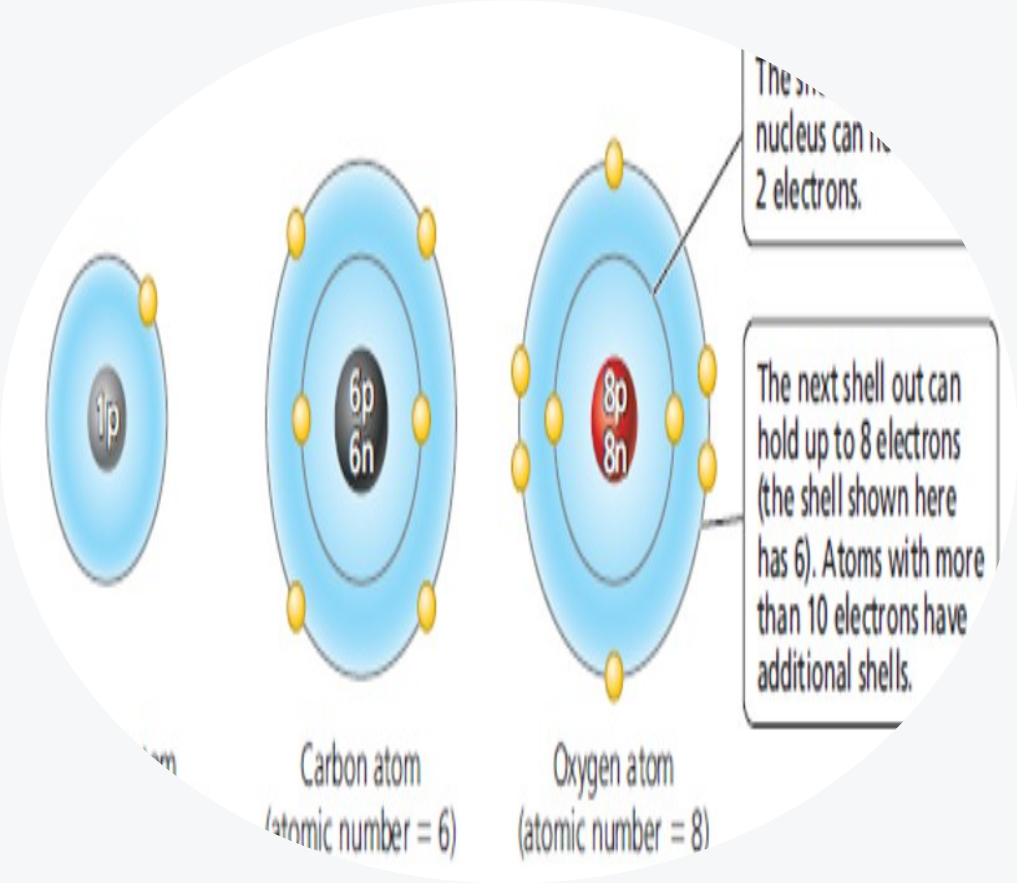


Figure 19-8: Hydrogen, carbon, and oxygen atoms — each ring is an electron shell.

- Orbital — a specific shape that can hold two or more electrons.
- Electron shells — numbered starting with the shell closest to the nucleus.
- Valence shell — the outermost shell; its electrons (valence electrons) determine how an atom bonds.
- Noble gases (helium, neon, argon, krypton, xenon, radon) have full valence shells — which is why they don't bond.

Covalent Bonds: Sharing Electrons

- Atoms become stable by bonding to other atoms.
- Covalent bond — an equal sharing of electrons between atoms.
- Molecule — a substance made of atoms held together by covalent bonds.
- Ion — an atom or molecule that has acquired an electrical charge.

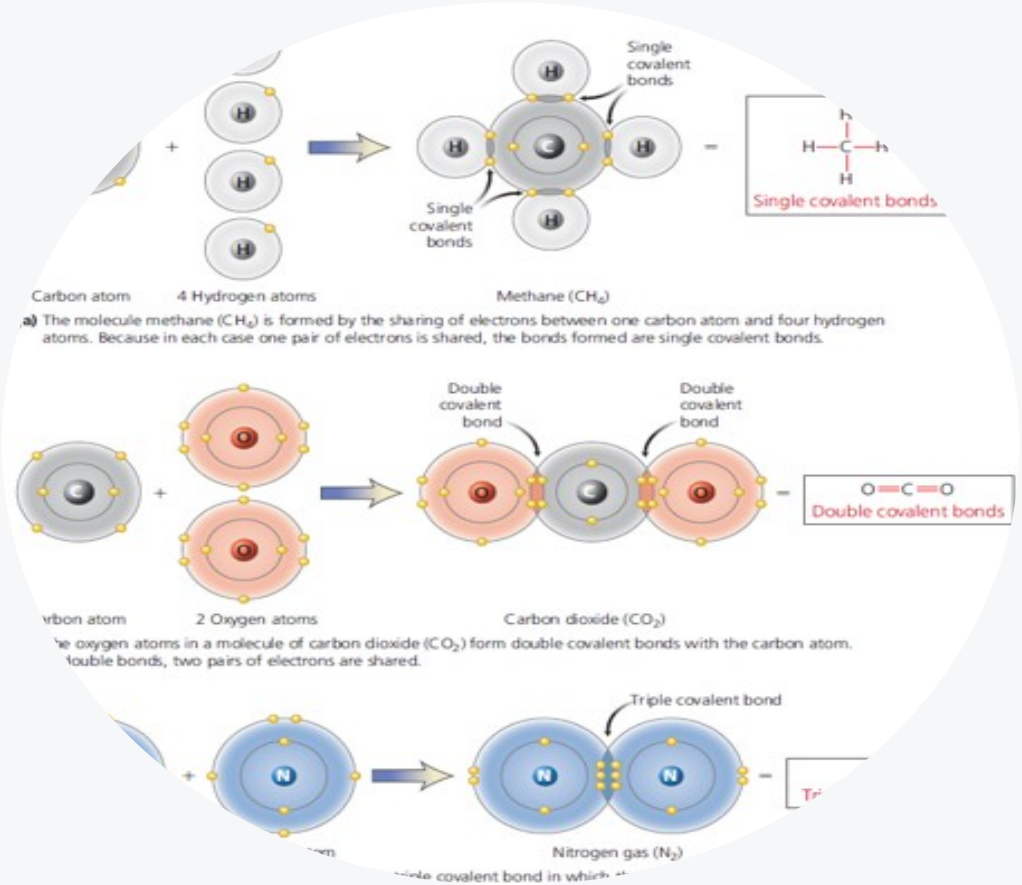


Figure 19-9: Single, double, and triple covalent bonds — methane, carbon dioxide, and nitrogen gas.

Ionic Bonds: Transferring Electrons

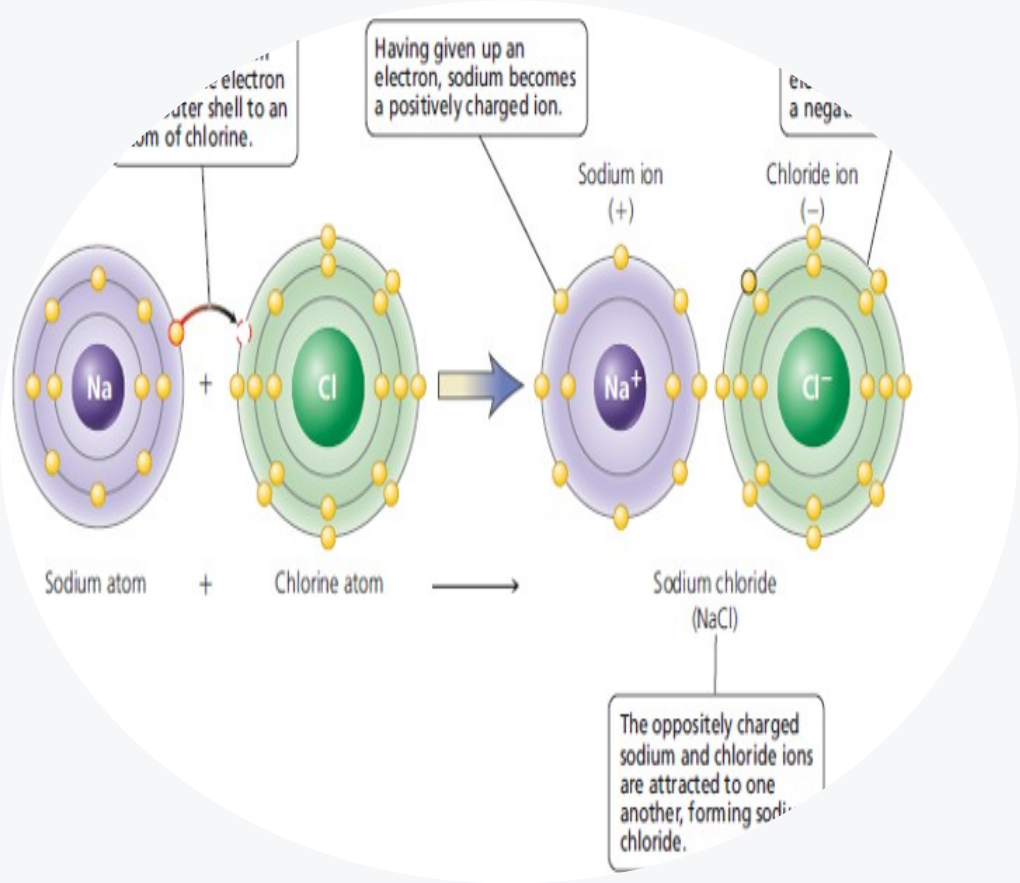


Figure 19-10: An ionic bond — sodium transfers an electron to chlorine, forming sodium chloride.

- Cation — an atom or molecule missing electrons; net positive charge.
- Anion — an atom or molecule with extra electrons; net negative charge.
- Ionic bond — opposite charges attract, forming a bond between a cation and an anion.
- This is the same chemistry behind the electrolytes (Na^+, K^+, Cl^-) you'll monitor in every IV fluid decision.

Hydrogen Bonds & Why Water Is Special

- Polar bond — an unequal covalent bond, creating a polar molecule.
- Hydrogen bond — attraction between a slightly positive hydrogen atom and a slightly negative atom (often oxygen).
- This weak attraction gives water its special physical properties — properties every fluid and electrolyte decision you make depends on.

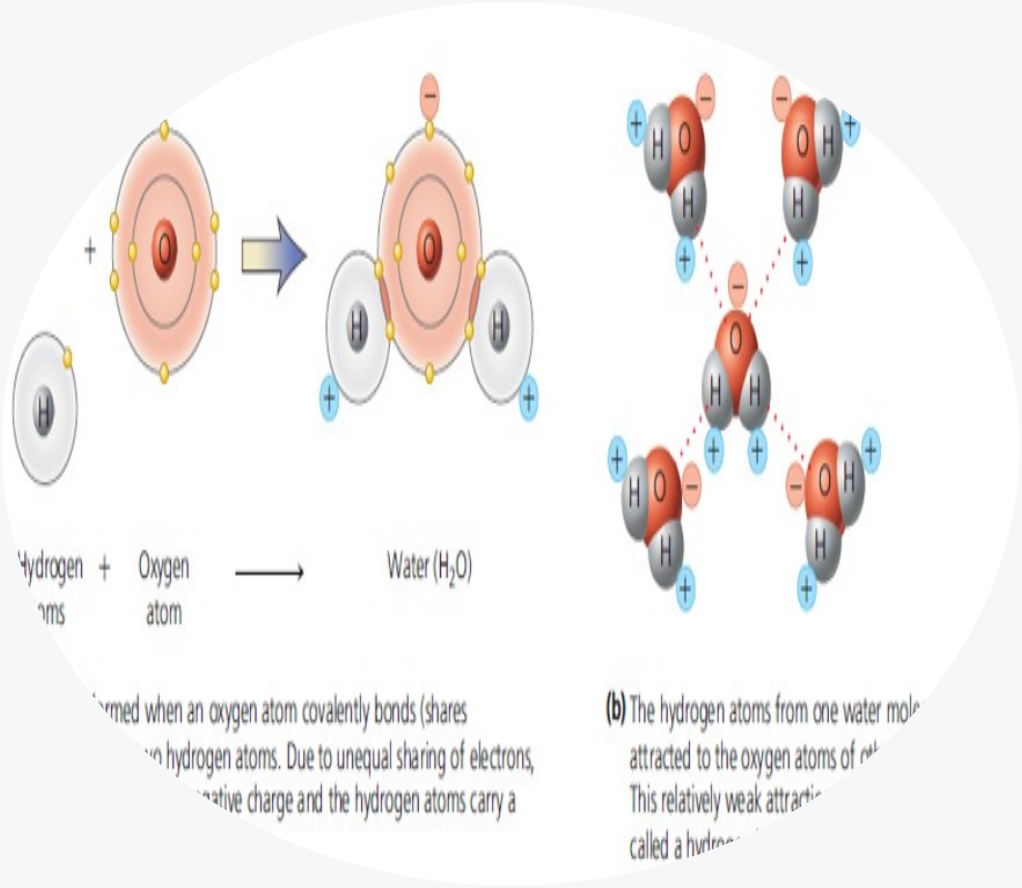


Figure 19-11: Hydrogen bonds of water — a weak attraction with an outsized effect.

Compounds: More Than the Sum of Their Elements

Figure 19-12: Table salt (NaCl) — neither a silvery metal nor a yellow gas, but something entirely new.

- Inorganic chemicals don't contain carbon; organic chemicals do (about 90% of all known chemicals).
- The major elements of living systems: carbon, hydrogen, oxygen, and nitrogen.
- Compound — the chemical union of two or more elements. The major compounds of living systems: carbohydrates, proteins, nucleic acids, and lipids.

Four Classes of Biological Chemicals

Carbohydrates

Sugars & starches — the body's primary calorie source (glucose, glycogen).

Proteins

Built from amino acids; enzymes, antibodies, structure, and transport.

Nucleic Acids

DNA and RNA — the genetic instructions for life.

Lipids

Triglycerides, phospholipids, and steroids — energy storage and membranes.

Sugars, Starches & Stored Energy

- Monosaccharides — simple sugars: glucose, fructose, galactose.
- Disaccharides — two simple sugars joined: sucrose, lactose, maltose.
- Polysaccharides — starches, cellulose, and glycogen.

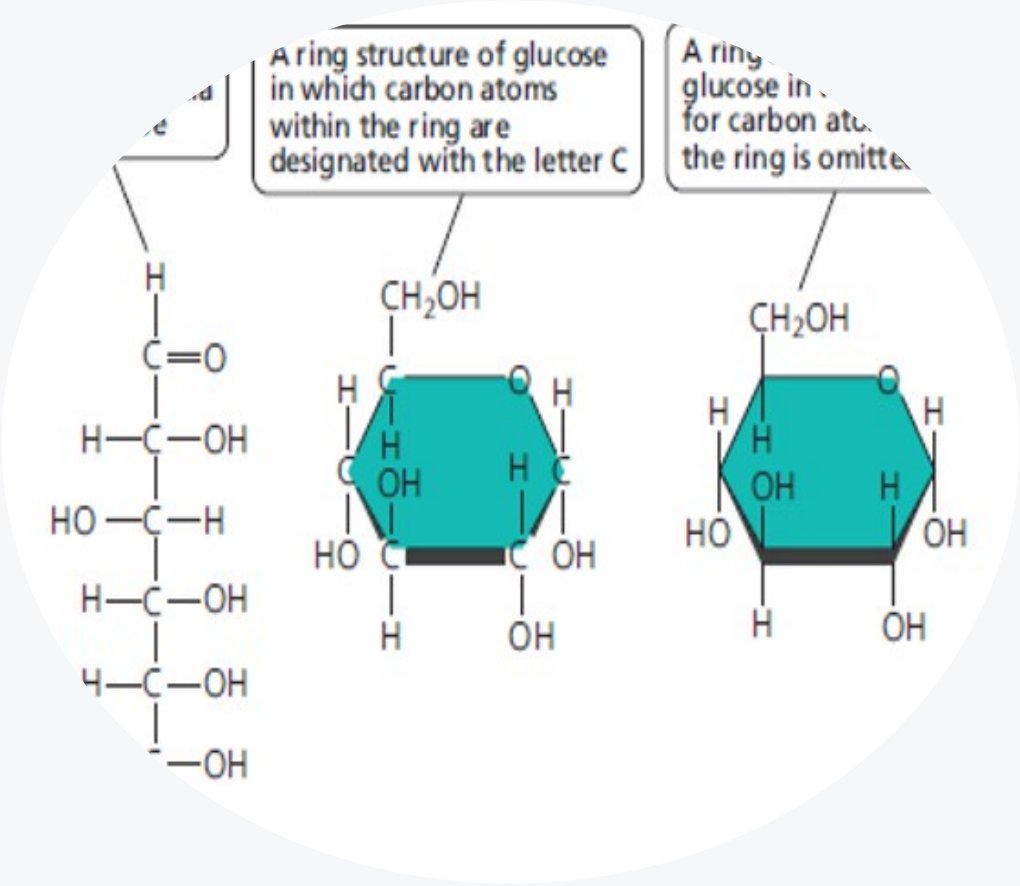
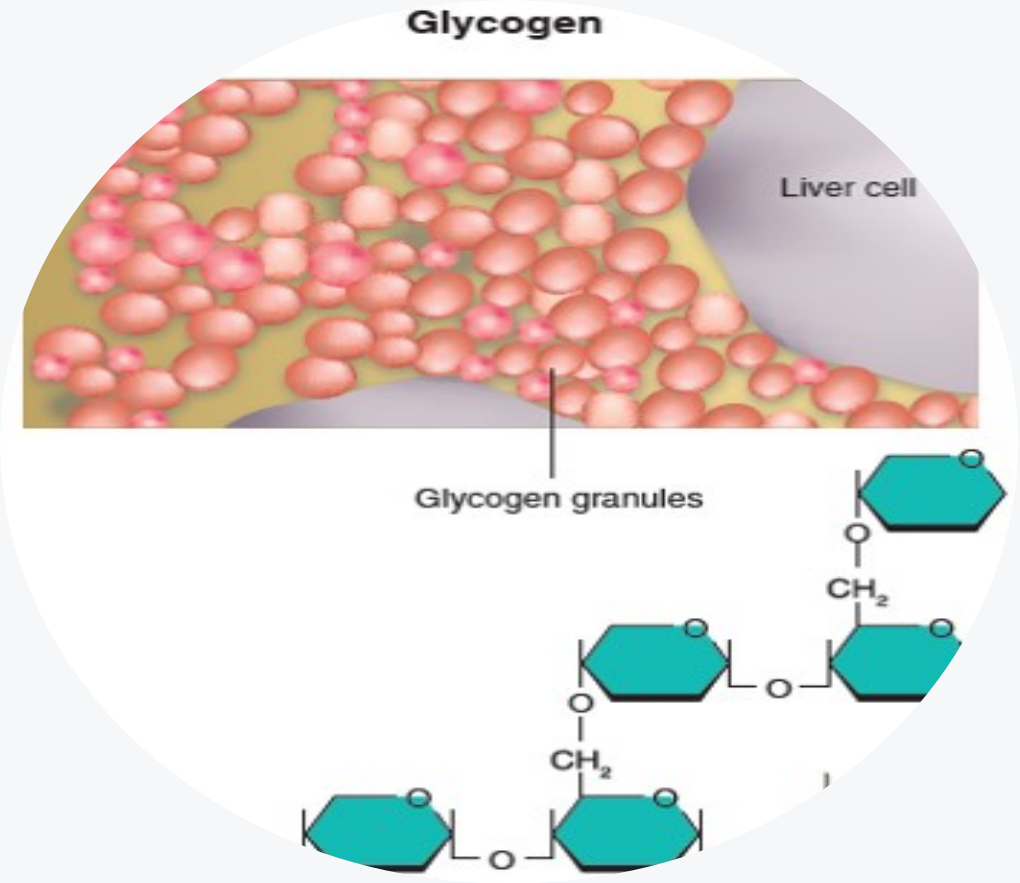


Figure 19-13: Glucose — a six-carbon sugar and the principal energy source for the human body.

Glycogen: The Body's Sugar Reserve



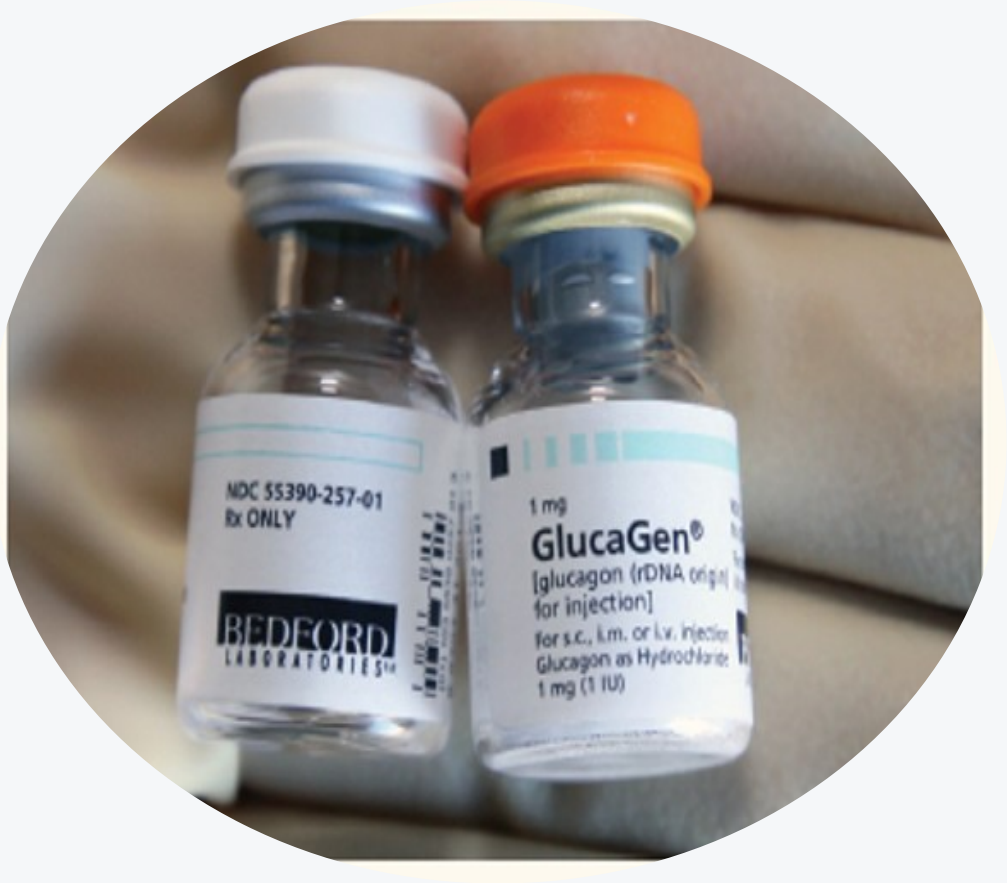
- Glycogen — the important storage polysaccharide in animals.
- Stored primarily in the liver and skeletal muscle.
- Glycogenolysis — the breakdown of glycogen into glucose, controlled by the hormones glucagon and epinephrine.

Figure 19-15: Glycogen is stored primarily in the liver and skeletal muscle.

PART 2A — CLINICAL TIE-IN

Why Glucagon Doesn't Always Work

- Glucagon can only release glucose that's already stored as glycogen.
- In patients with limited glycogen stores — chronic alcoholics, liver disease, malnutrition — glucagon can be ineffective.
- If you suspect limited glycogen stores, give glucose directly to raise blood glucose levels.



© Dr. Bryan E. Bledsoe — glucagon administration in the field.

QUICK CHECK

Your patient is a known alcoholic found unresponsive with a blood glucose of 32. You administer glucagon IM with no effect. What's the most likely explanation?

A. Glucagon was given at the wrong dose

B. The patient has depleted glycogen stores, so there's nothing for glucagon to mobilize

C. Glucagon only works in pediatric patients

D. The patient's blood pH is too alkalotic for glucagon to function

Answer key: B

Proteins Do Almost Everything

Built Up From

- Amino acids, joined by peptide bonds
- Peptide: chain under 10 amino acids
- Polypeptide: chain over 10 amino acids
- Four levels of structure: primary → secondary → tertiary → quaternary

What They Do

- Enzymes speed up chemical reactions by binding a substrate
- Antibodies and complement proteins defend the body
- Receptor and transport proteins move signals and substances
- Structural proteins support cells and tissues

Four Levels of Protein Structure

- Primary — the sequence of amino acids, held by peptide bonds.
- Secondary — alpha helices and beta sheets, stabilized by hydrogen bonding.
- Tertiary — the overall 3D shape of one polypeptide.
- Quaternary — the shape formed by multiple polypeptide subunits together, like hemoglobin's four subunits.

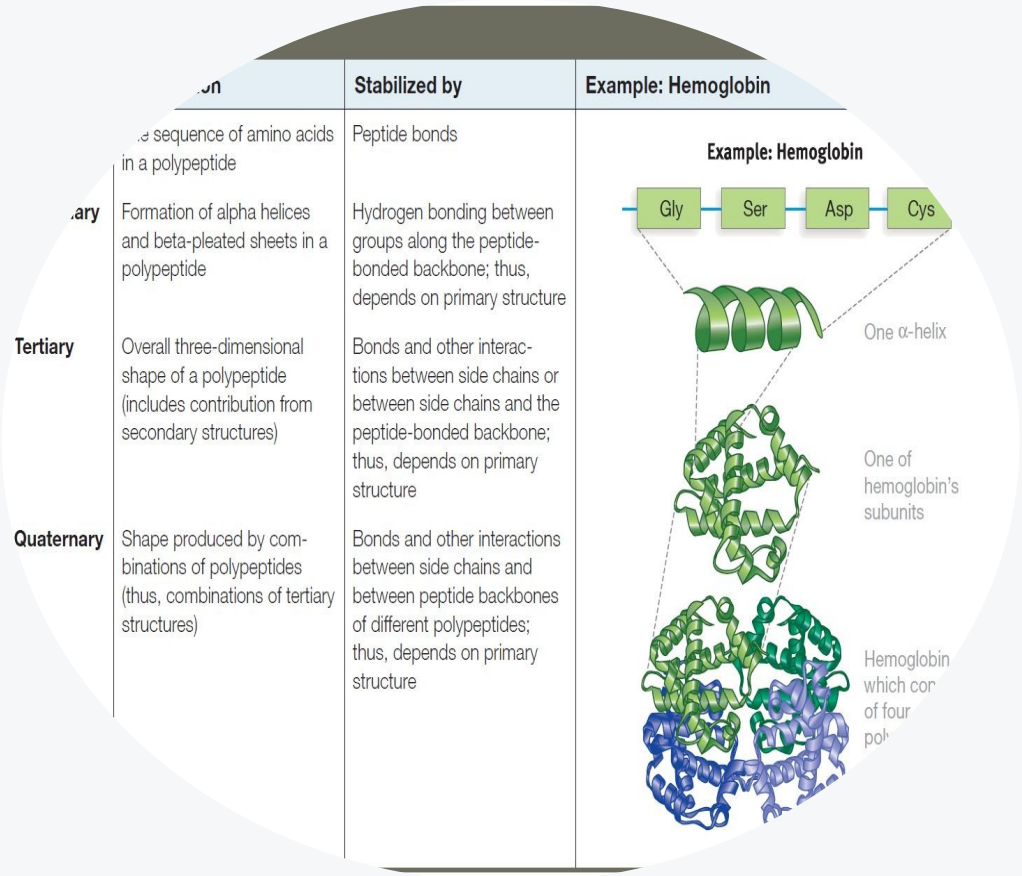


Table 19-2: Primary, secondary, tertiary, and quaternary protein structure, using hemoglobin as the example.

Enzymes: The Body's Reaction Accelerators

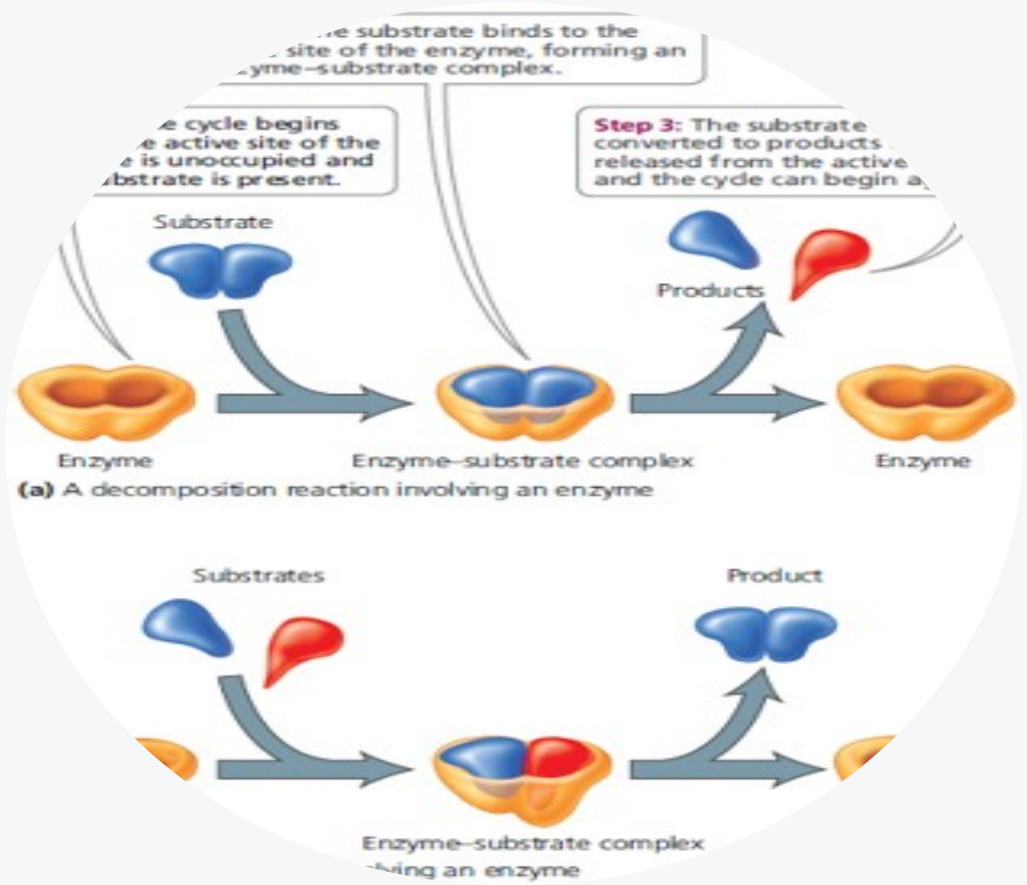


Figure 19-18: The working cycle of an enzyme — substrate binds, reacts, and releases as product.

- Enzymes are proteins that speed up chemical reactions without being consumed.
- A substrate binds to the enzyme, forming an enzyme-substrate complex.
- Cofactors are nonprotein substances that help convert substrate to product; coenzymes are organic cofactors.

DNA: The Genetic Instructions for Life

- DNA carries the genetic instructions for life, built from two long polymer chains (nucleotides) joined by paired nucleobases.
- The genetic code: four nucleobases — adenine (A), thymine (T), cytosine (C), guanine (G).
- The sequence of these bases encodes all the information needed to build and run the body.

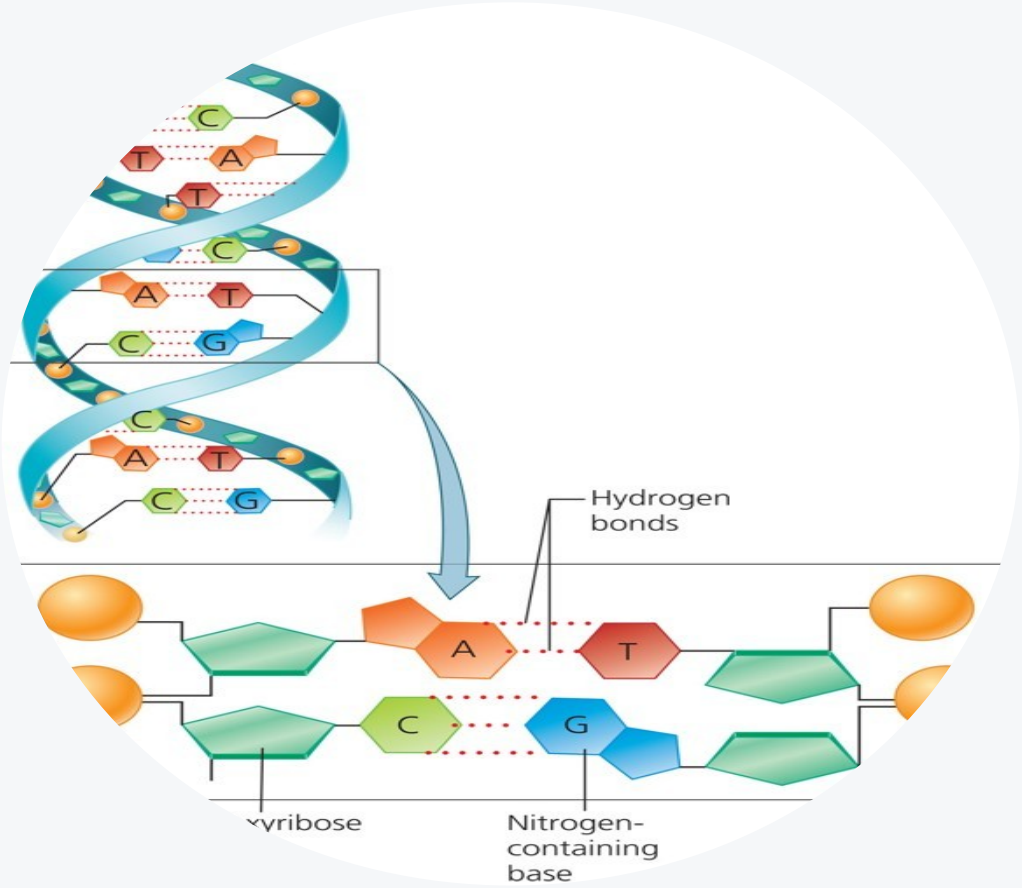


Figure 19-20: DNA — two chains of nucleotides twisted into a double helix.

RNA: Turning Code Into Protein

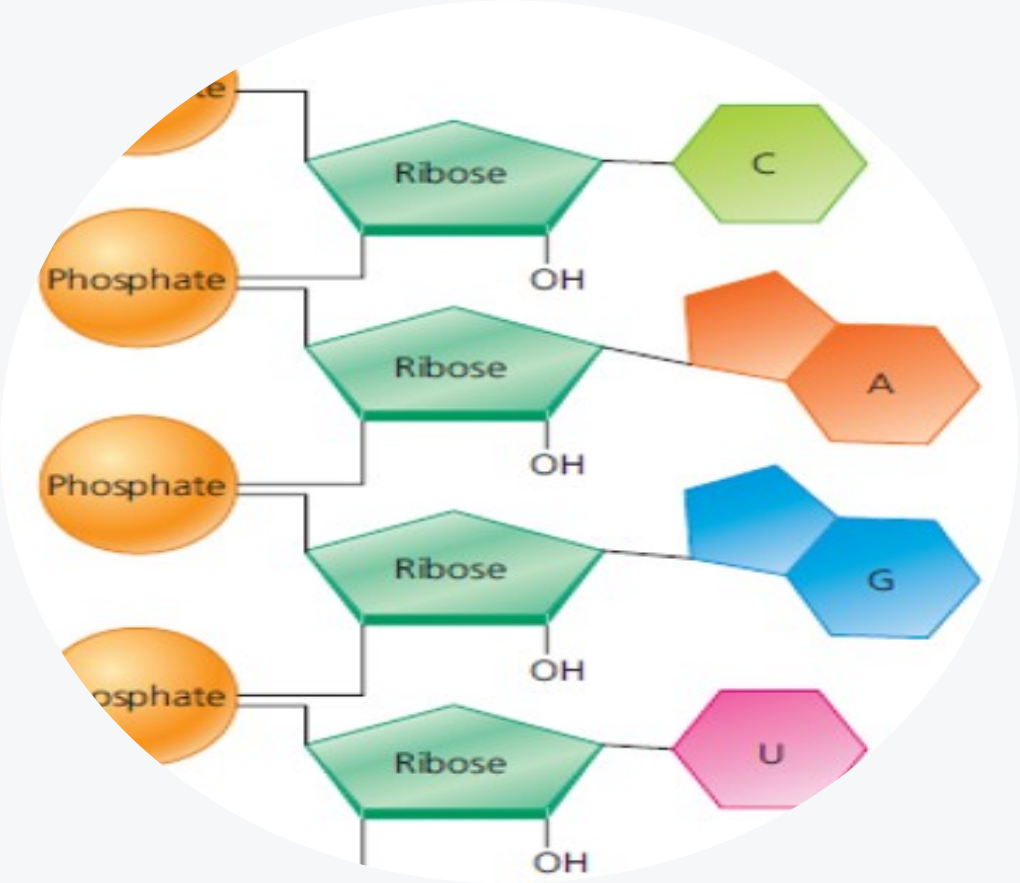


Figure 19-21: RNA — single-stranded, using uracil (U) in place of thymine.

- RNA is chemically similar to DNA, but single-stranded, and plays the major role in protein synthesis.
- Its nucleobases: adenine (A), cytosine (C), guanine (G), and uracil (U) — no thymine.

Nucleotides: The Shared Building Block

- Genes — sequences that code for a specific amino acid sequence, which becomes a specific protein.

- The number of chromosomes in a cell's nucleus varies by organism — humans have 46.

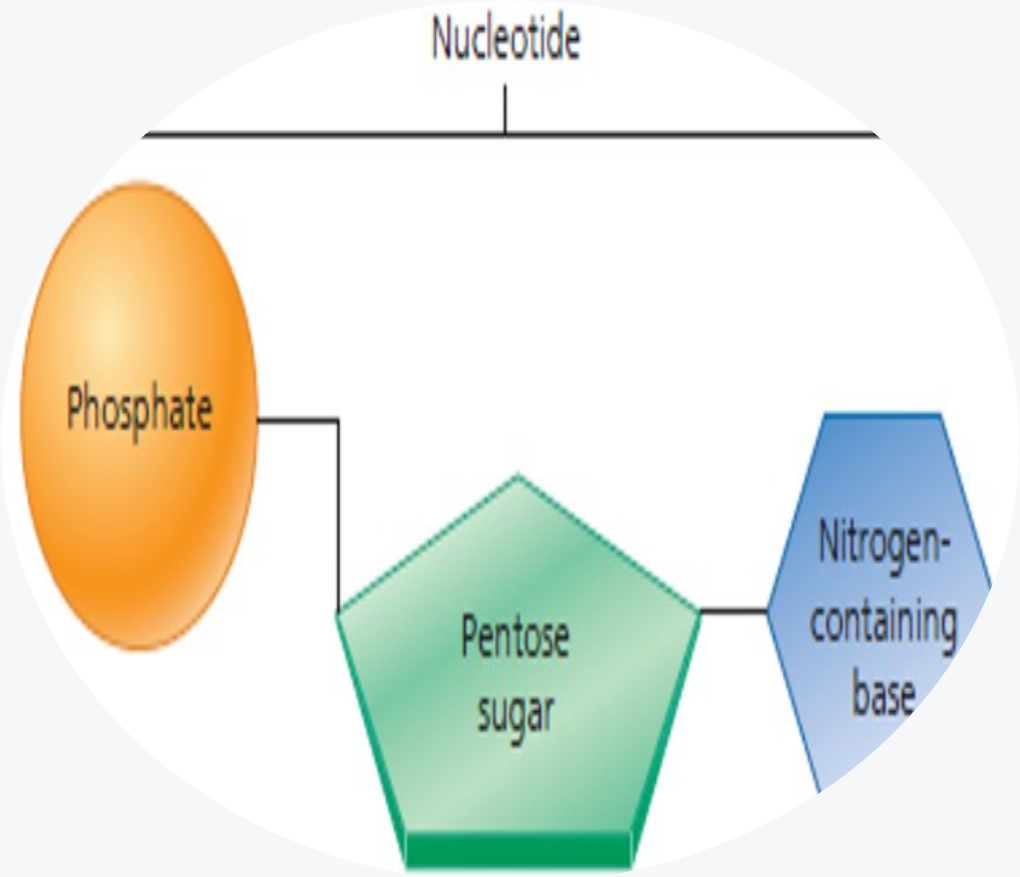


Figure 19-22: A nucleotide — a five-carbon sugar, a phosphate group, and a nitrogen-containing base.

ATP: The Energy Currency of the Cell

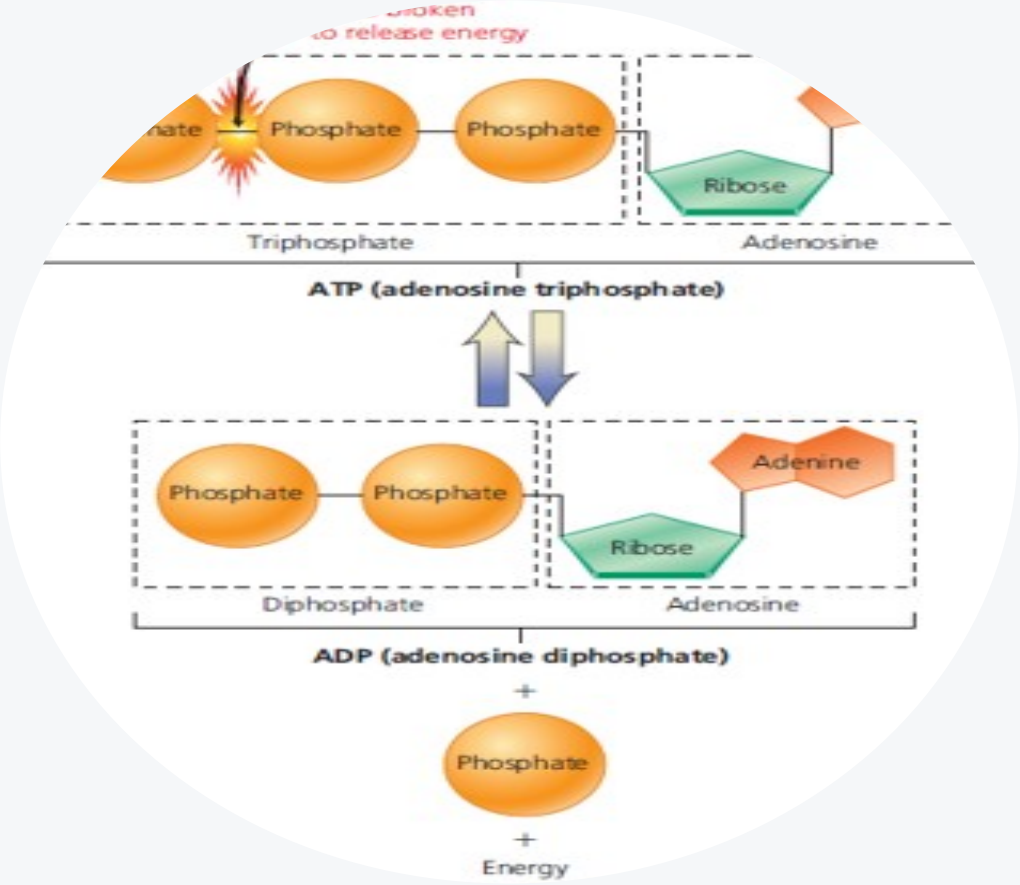


Figure 19-23: ATP breaks its last phosphate bond to release energy, becoming ADP.

- Adenosine triphosphate (ATP) — a nucleotide and the principal energy source for nearly every cellular activity.
- Its phosphate bonds are highly unstable — breaking the last one releases usable energy, yielding ADP plus a free phosphate.

Fats: Energy Storage, Insulation & Structure

- Lipids don't dissolve in water (nonpolar) and function in long-term energy storage, insulation, structure, and control.
- Triglycerides — rich energy sources, saturated or unsaturated.
- Phospholipids form the membrane that surrounds every cell.
- Steroids — built on a cholesterol backbone; includes HDL (“good”), LDL (“bad”), and VLDL (mainly carries triglycerides).

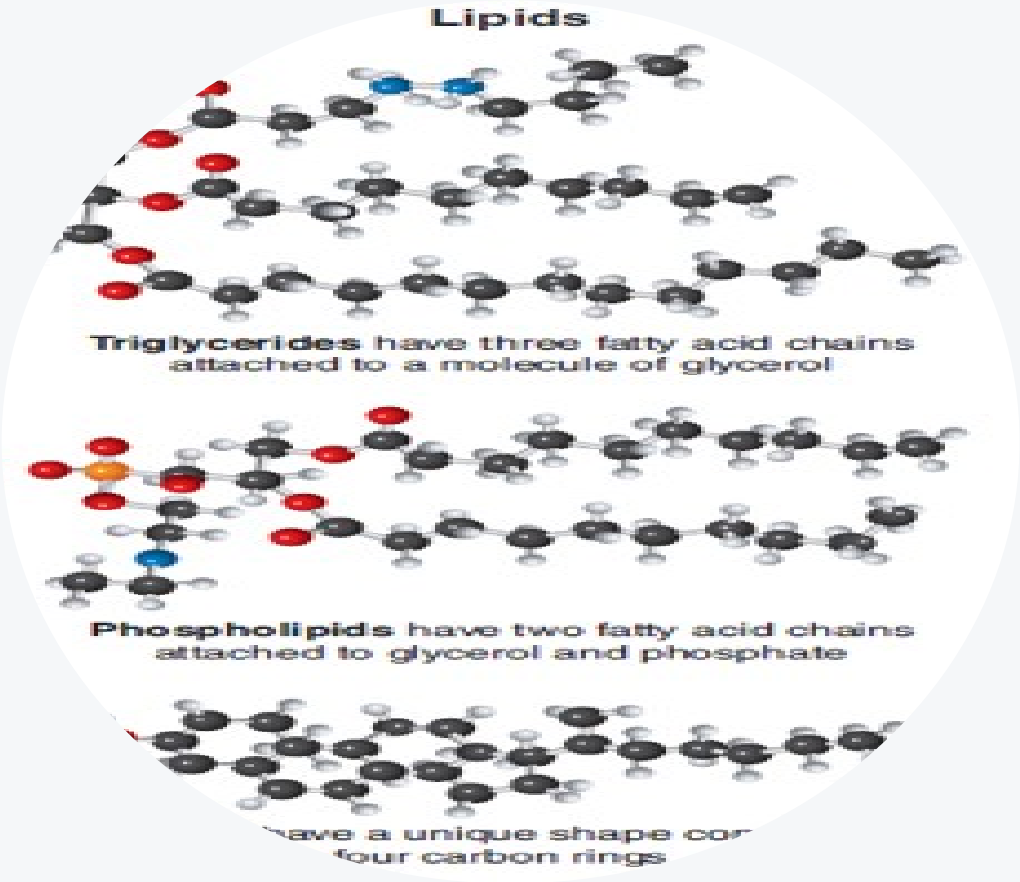


Figure 19-24: Triglycerides, phospholipids, and steroids — the three lipid types relevant to pathophysiology.

The Universal Solvent

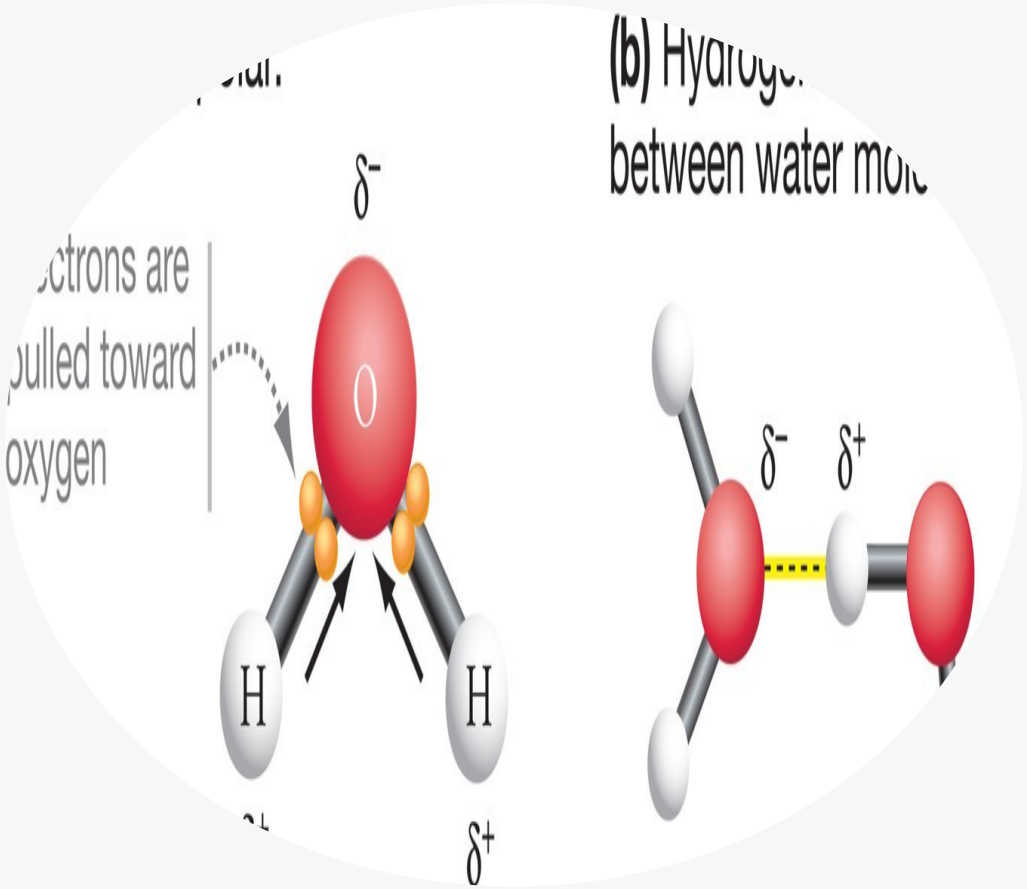


Figure 19-31: Water is polar and participates in hydrogen bonds.

- Water is a polar molecule and the universal solvent — it transports substances throughout the body.
- It also helps maintain a constant body temperature.
- Every buffer system, every IV fluid decision, and every cell in the body depends on water's unique chemistry.

CASE IN POINT

Reading the Chemistry Behind the Chart

A 45-year-old with a history of chronic alcohol use presents confused, tachycardic, and hypoglycemic (BGL 38). His partner says he hasn't eaten in three days. You give glucagon 1mg IM with no improvement in mental status or blood glucose after 10 minutes.

DISCUSS

- Using what you just learned about glycogen and glycogenolysis, why might glucagon have failed here?
- What's your next chemistry-informed treatment step?
- How would you explain to a new EMT why 'just give glucagon' isn't always the right answer?

PART 2A — RECAP

Before We Move On…

Atoms bond in three main ways

- Covalent (sharing), ionic (transferring), and hydrogen bonds (weak attraction) — and these bonds explain everything from electrolytes to why water behaves the way it does.

Four classes of biological chemicals run the body

- Carbohydrates for fuel, proteins for structure and function, nucleic acids for genetic instruction, lipids for storage and membranes.

ATP is the energy currency behind every one of your interventions

- And glycogen is the fuel tank it draws from — which is exactly why an empty tank means glucagon won't help.

BREAK

15 minutes

Next up: acids, bases, and the pH balance behind every blood gas you'll ever read.

Back at 3:00

PART 2B • 60 MINUTES

Acids, Bases & pH Balance

03

The narrowest window in the whole body — and the one you'll manage constantly.

It All Comes Down to Protons

Dissociation reaction

- A compound or molecule breaks apart into separate components.

Acids

- Substances that give up protons during chemical reactions.

Bases

- Substances that acquire protons during chemical reactions.

Acid–base reaction

- At its core, simply a transfer of protons.

0 to 14: Where Common Substances Fall

0 — Hydrochloric acid

2 — Lemon juice

4 — White wine

6 — Coffee, urine, saliva

7 — Distilled water (neutral)

7.4 — Blood (normal)

9 — Bile

The Body's First Line Against pH Swings

Carbonic Acid–Bicarbonate

Regulates blood pH; buffers organic and fixed acids, but only works while respiration is normal and bicarbonate is available.

Protein Buffer

Amino acids in the protein chain react to pH shifts — hemoglobin is the key player here.

Phosphate Buffer

Limited role in ECF, but a major stabilizer of urine pH.

Four Systems, Four Speeds

Immediate

Buffer pairs — carbonic acid/bicarbonate, proteins/hemoglobin, phosphate — release or absorb hydrogen ions instantly

Slower, but Powerful

- Respiratory system — retains or removes CO_2 within minutes to hours
- Electrolyte shifts — exchange Na^+/K^+ for H^+ in the ECF, minutes to hours
- Renal system — secretes or absorbs H^+, HCO_3^-, phosphate, and ammonia, over hours to days

Acidosis vs. Alkalosis

Acidosis

- An excess of acids in the body
- pH deviates below the normal range of 7.35–7.45
- Can be respiratory or metabolic in origin

Alkalosis

- An excess of base in the body
- pH deviates above the normal range of 7.35–7.45
- Can also be respiratory or metabolic in origin

When the Lungs Are the Problem

Respiratory Acidosis

The lungs can't clear enough CO_2 — pH falls, hypercapnia develops. Caused by decreased rate, tidal volume, or both.

Respiratory Alkalosis

Hyperventilation clears too much CO_2 — hypocapnia develops. Often triggered by anxiety, a metabolic disorder, or environmental factors.

When the Kidneys Are the Problem

Metabolic Acidosis

A deficiency of bicarbonate in the body — the kidneys play the major role in maintaining stable pH here.

Metabolic Alkalosis

Uncommon — due to an increase in bicarbonate levels or a decrease in circulating acids.

QUICK CHECK

A COPD patient's ABG shows pH 7.30, CO_2 60 mmHg. Which acid–base disorder does this represent?

A. Metabolic acidosis

B. Metabolic alkalosis

C. Respiratory acidosis

D. Respiratory alkalosis

Answer key: C51

CASE IN POINT

The Fruity-Smelling Breath

You're called for a 19-year-old type 1 diabetic who is confused, tachypneic with deep, rapid respirations, and has a fruity odor to his breath. His blood glucose is 480. His family says he ran out of insulin four days ago.

DISCUSS

- What acid–base disorder is this patient's breathing pattern compensating for?
- Is this a respiratory or a metabolic problem at its root — and how can you tell from the presentation alone?
- Which buffer and organ systems are being overwhelmed here?

PART 3 • 120 MINUTES • GUEST LECTURE

04

FLUIDS AND ELECTROLYTES — GO WITH THE FLOW

Adapted from a critical care lecture by Raeann M. Fuller, MSN, RN, CCRN-K.

Two Systems Keep Blood Moving Where It Needs to Go

Nervous system control

- The sympathetic nervous system drives it — through epinephrine, norepinephrine, and dopamine.

Hormonal control

- Works alongside the nervous system to fine-tune vessel tone and cardiac activity.

Autonomic balance

- Sympathetic (adrenergic) speeds things up; parasympathetic (cholinergic), via the vagus nerve, slows them back down.

Four Receptors, Four Different Jobs

Alpha-1

Stimulates smooth muscle contraction — vasoconstriction.

Alpha-2

Inhibits release of norepinephrine.

Beta-1

Primarily a cardiac stimulant.

Beta-2

Primarily a pulmonary stimulant.

Two Reflexes That Watch Your Blood Pressure

Baroreceptors

- Located in the carotid sinus and aortic arch
- Maintain BP through negative feedback
- Decrease BP in response to increased arterial pressure, and vice versa
- Stop responding below a pressure of about 60 mmHg

Chemoreceptor Reflexes

- Also located in the carotid sinus and aortic arch
- Respond to low arterial pressure causing hypoxemia and/or acidosis
- Control respiratory responses more than circulatory ones

What Pushes Vascular Resistance Up or Down

Increased SVR

- Left ventricular failure
- Physiologic stress
- Treated with vasoconstrictors: epinephrine, norepinephrine, midodrine

Decreased SVR

- Septic shock
- Neurogenic shock
- Anaphylactic shock
- Treated with vasodilators — beta blockers, calcium channel blockers — to manage hypertension

The Pressures Behind Every Hemodynamic Number

Hydrodynamic pressure

- Fluid in motion — the pressure exerted on a monitoring catheter by flowing blood.

Hydrostatic pressure

- Stationary fluid — pressure exerted on the transducer based on its position relative to the monitored site. Both are present in every monitoring system.

Cardiac output (CO)

- Liters of blood pumped into the aorta per minute — normal is 4–8 L/min.

Cardiac index (CI)

- CO divided by body surface area — normal is 2.5–4.0 L/min/m^2. Affected by contractility, heart rate, rhythm, O_2 consumption, age, sex, and temperature.

The Body Is Mostly Water — But Less As You Age

Infancy

~75% total body water

Adulthood

~60–65% total body water (a 70kg adult male ≈ 42L)

Elderly

~50% total body water

Separated by a Semi-Permeable Membrane

Intracellular

28–30 L — the largest compartment, inside the cells.

Interstitial

3.5–5 L — fluid between cells, outside the vasculature.

Intravascular

10.5 L — the plasma volume, inside the blood vessels.

Ions, Anions, Cations & Salts

Cations (+)

- Sodium (Na^+) — extracellular
- Potassium (K^+) — intracellular
- Calcium (Ca^{2+}) — extracellular
- Magnesium (Mg^{2+}) — intracellular

Anions (–)

- Chloride (Cl^-) — extracellular
- Bicarbonate (HCO_3^-) — extracellular
- Sulfate (SO_4^{2-}) — intracellular
- Phosphate (HPO_4^{2-}) — intracellular

Solvents, Solutes, Colloids & Pressure

Solvents (fluids), solutes (particles), colloids (proteins)

- The three players in every fluid-balance equation.

Three pressures determine homeostasis

- Oncotic, osmotic, and hydrostatic pressure — the same forces behind edema and third-spacing.

Normal daily balance is a closed loop

- ~2,500 mL in (liquids, food, oxidation) must equal ~2,500 mL out (urine, lungs, skin, feces) to maintain homeostasis.

Passive Movement: Osmosis & Diffusion

Osmosis

- Movement of solvents (fluids)
- From lesser to greater concentration
- Through a selectively permeable membrane

Diffusion

- Movement of solutes (particles)
- From greater to lesser concentration
- Through a selectively permeable membrane

Active Movement: Costs the Cell Energy

Active transport

- Moves solutes against the gradient, requiring ATP — the sodium pump on the cell wall is the classic example. Faster than diffusion.

Facilitated diffusion

- Moves particles against the gradient using a carrier molecule plus energy — think insulin moving glucose into cells.

Aerobic vs. anaerobic yield

- Glucose + oxygen → 36 ATP. Glucose without oxygen → just 2 ATP — the same efficiency gap you saw in Part 2.

Who's Actually in Charge of Your Fluid Status

Thirst

- The first indicator of fluid need.

Renal control

- The #1 primary regulating organ.

Sodium (Na^+)

- Promotes water retention.

Protein / albumin

- Promotes body fluid retention by maintaining oncotic pressure.

The Hormone That Tells Kidneys to Hold On

Stimulates Release

- Mediated by osmo- and baroreceptors in the brain, atria, and aorta
- Secreted when ECF is deficient
- Promotes water retention in the distal renal tubules
- SIADH can follow head injuries

Inhibits Release

- Decreased serum osmolality
- Alcohol consumption
- Caffeine
- Cold exposure
- Certain drugs: morphine, anesthetics, Diabinese

One Cascade, One Goal: Hold Onto Sodium

Triggered by low blood flow to the kidney.

One Hormone, Several Downstream Effects

Metabolic alkalosis

- Sodium is reabsorbed and hydrogen is secreted — bicarbonate is released into the body.

Hypertension risk with birth control pills

- Steroids can be converted to aldosterone.

Other triggers for aldosterone release

- Increased potassium, hyponatremia, hypovolemia, and low-output CHF.

Hypervolemia vs. Hypovolemia: Opposite Responses

Hypervolemia

- Inhibits ADH and aldosterone release
- Suppresses thirst
- Result: dilute urine

Hypovolemia

- Brain mediates and stimulates ADH release
- Stimulates aldosterone release and thirst
- Result: concentrated urine

QUICK CHECK

Your patient is hypovolemic from a GI bleed. Which hormonal response would you expect to see?

A. Inhibited ADH and dilute urine

B. Increased ADH and aldosterone release, with concentrated urine

C. Suppressed thirst and increased urinary sodium loss

D. No hormonal response until blood pressure drops below 40 mmHg

Answer key: B

BREAK

10 minutes

Up next: electrolyte imbalances and what's actually in the IV bag you're hanging.

Back at 5:25

PART 3B • 50 MINUTES

Electrolyte Imbalances & IV Fluid Therapy

05

From osmolality to the bag on the pole — the clinical side of fluid balance.

The Numbers Behind Tonicity

Osmolarity

- The osmotic pull exerted by all particles per unit of solution.

Quick formula

- 2 × serum Na^+ + (BUN/3) + (glucose/18) — normal serum osmolality is 280–295 mOsm/kg.

IV solution tonicity

- Hypo-osmolar, iso-osmolar, or hyper-osmolar — normal IV osmolality runs about 240–340 mOsm/L.

Two Different Ways to Lose Fluid

Iso-Osmolar Loss

- Equal parts sodium and water lost
- Vomiting/diarrhea, GI fistula, GI suction
- Fever, profuse diaphoresis, hemorrhage
- Burns, ascites, third-spacing from bowel obstruction

Hyper-Osmolar Loss

- Water loss exceeds sodium loss
- Inadequate fluid intake
- Increased solute intake
- Severe vomiting/diarrhea, DKA, sweating

The Severity Scale You'll Triage Against

Fatal — 22–30% total body water loss — anuria, coma leading to death

Severe — 8% body weight loss — flushed skin, systolic BP ≤ 60, irritability/delirium

Marked — 5% body weight loss — dry mucous membranes, tenting, tachycardia, urine < 25mL/hr

Mild — 2% body weight loss — thirst, 1–2L water deficit

When Fluid Doesn't Stay Where It Should

Extracellular fluid volume excess — edema or hypervolemia

- Abnormal fluid retention in interstitial spaces or serous cavities, when hydrostatic pressure exceeds oncotic pressure.

Common causes

- Increased plasma hydrostatic pressure (CHF, renal failure), decreased oncotic pressure (malnutrition, cirrhosis), increased capillary permeability (burns, allergic reaction, sepsis).

Classic presentation

- Pulmonary edema, JVD, bounding pulses, pitting peripheral edema, cough, and dyspnea.

Fluid That's Technically “There” — But Useless

Extracellular fluid volume shift

- Fluid, electrolytes, and protein shift from intravascular to interstitial space — nonfunctional and physiologically useless.

Common causes

- Abdominal surgery, ascites, trauma, burns.

The timeline matters clinically

- Edema may not appear for 24–48 hours; fluid re-enters the vascular space 3–5 days later — and if the kidneys can't handle that returning volume, the patient can suddenly present hypervolemic.

The Major Intracellular Cation

What It Does

Muscle contraction, enzymatic reactions, nerve impulses, cell membrane function. Controlled by insulin and aldosterone.

Hypokalemia

GI losses, diuretics, malnutrition, alkalosis. IV replacement should not exceed 20 mEq/hr for 24–72 hours.

Hyperkalemia

Excess intake, decreased renal function, acidosis, hemolysis (pseudohyperkalemia).

Read It on the Monitor Before the Lab Confirms It

Hyperkalemia

- Peaked T waves
- Depressed ST segment
- P wave disappears
- Widened QRS → asystole

Hypokalemia

- Low voltage across all waves
- Flattened T wave, depressed ST
- Presence of a U wave
- Dysrhythmias: PACs, V-fib, and more

The Main Extracellular Cation

What It Does

Water distribution, the Na^+/K^+ pump, and acid-base regulation — controlled by the kidneys, pituitary (ADH), and adrenals.

Hyponatremia

Renal failure, low-Na^+ diet, GI losses, head trauma, Addison's disease, CHF, burns.

Hypernatremia

High Na^+ intake, decreased water intake, decreased glomerular function, excess corticosteroid.

Mostly in Bone, But Doing a Lot Elsewhere

99% is in bone; only 1% circulates

- Of that circulating calcium: 45% is free/ionized (biologically active), 40% is protein-bound to albumin, 15% is complexed to other ions.

pH affects how much is free

- Acidosis increases free calcium; alkalosis decreases it.

Necessary for

- Neuromuscular transmission, cardiac depolarization (SA/AV nodes), clotting, bone formation, and cellular permeability.

Regulated by the Parathyroid

Hypocalcemia

Poor dietary intake, renal failure, decreased PTH, calcium-binding from citrated blood transfusions.

Chvostek's Sign

Tap the facial nerve (CN VII) — spasmodic contraction of facial muscles on the same side.

Trousseau's Sign

Inflate a BP cuff for 3 minutes — watch for carpal spasm with thumb and finger contraction.

Mostly Intracellular — and Often Overlooked

Necessary for

- Neuromuscular transmission, myocardial contractility, enzymatic reactions, and glycolysis — also influences potassium, calcium, and protein use.

Hypomagnesemia — #1 cause: chronic alcoholism

- Also: poor absorption, malnutrition, chronic diarrhea, diuresis, DKA, acute MI, CHF.

Hypermagnesemia — very rare

- Excessive IV administration, renal dysfunction, severe dehydration. Treated by cutting off the source, giving calcium, or dialysis if renal function is impaired.

Why You Always Check Electrolytes on a Cardiac Patient

Cardiac changes

- Prolonged PR and QT intervals; dysrhythmias from SVT and A-fib to PVCs, monomorphic VT, and torsades.

Other effects

- Increased sensitivity to digoxin, coronary artery spasm, hypertension, and sudden death — electrolyte imbalance is rarely “just a lab value.”

QUICK CHECK

You're treating a patient with peaked T waves, a widening QRS, and an absent P wave on the monitor. Which electrolyte imbalance does this most likely represent?

A. Hypokalemia

B. Hyperkalemia

C. Hypocalcemia

D. Hypomagnesemia

Answer key: B

What's Actually in Each Bag

Normal Saline

Isotonic. About 2/3 diffuses out of the vascular space (the “3:1 rule”). High chloride load can cause hyperchloremic acidosis — avoid in hypernatremic patients.

Lactated Ringer's

Isotonic — the best plasma mimic. Can correct lactic acidosis with good perfusion, or worsen it with anaerobic metabolism. Avoid with blood products or potassium.

D5W

Not isotonic once dextrose is metabolized — not a volume expander. Best use is keep-vein-open (KVO).

Fewer Liters, More Cost

Albumin & Plasma Expanders

- 5% albumin is isotonic; 25% is hypertonic
- Pulls fluid into the vascular bed — but is costly and can leak into interstitial space
- Plasmanate, dextran, and hetastarch are synthetic alternatives

Crystalloids vs. Colloids

- Colloids: less volume needed, better oncotic pressure, but costly and can precipitate pulmonary edema
- The lymph system cannot drain colloids the way it drains crystalloids
- Both ultimately leak into the interstitial space over time

CASE IN POINT

Choosing the Right Bag

You're treating a trauma patient in hemorrhagic shock, 20 minutes from the trauma center. Your partner reaches for a liter of D5W. You stop him and grab lactated Ringer's instead.

DISCUSS

- Why is D5W the wrong choice for volume resuscitation here?
- Given the “3:1 rule,” how much crystalloid would you need to replace 1 liter of blood loss?
- At what point would a colloid, rather than more crystalloid, become the better choice?

PART 3 — RECAP

Before We Wrap...

- **Fluid balance is a constant negotiation between three pressures**

  Oncotic, osmotic, and hydrostatic — tip any one of them, and fluid moves.

- **ADH and the renin-angiotensin-aldosterone system are the body's fluid thermostats**

  Both aim at the same target: hold onto sodium, hold onto water.

- **Every electrolyte has a cardiac signature**

  Potassium and calcium especially — read the monitor, don't just wait on the lab.

- **The bag you hang is a clinical decision, not a formality**

  Isotonic crystalloids, colloids, and D5W all behave differently once they're in the vein.

CHAPTER 2 — WRAP-UP

The Throughline

1. Disease is any abnormal structural or functional change — shaped by factors you can and can't control.

2. Every cell in the body runs on chemistry — atoms, bonds, and four classes of biological molecules — and ATP is the energy currency behind it all.

3. pH balance is one of the narrowest windows in the body — buffered first, then corrected by the lungs and kidneys.

4. Fluid balance is a constant negotiation between oncotic, osmotic, and hydrostatic pressure, regulated by ADH and the renin-angiotensin-aldosterone system.

5. Every electrolyte imbalance has a clinical and often a cardiac signature — and the IV fluid you choose is a clinical decision, not a formality.

LOOKING AHEAD

Where We Pick Up Next Time

Part 4: Disease at the Cellular & Tissue Level

- The cell's organelles, how cells adapt and get injured, and how tissue growth goes wrong — neoplasia and cancer.

Part 5: Disease at the Organ Level

- The circulatory system and the pathophysiology of shock.

Part 6: The Body's Defenses

- Infection, inflammation, immunity, and stress.

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