GENERAL BIOLOGY · STUDY GUIDE

Exam 1 Study Guide

This guide covers the first two chapters. You start with the chemistry every cell runs on: atoms, bonds, water, pH and the four families of large molecules. Then you open the cell itself, from the microscope that shows it to the membrane that decides what gets in. Work one chapter at a time. Read the "what to know" paragraphs, copy the tables out by hand, then try each worked case with the steps covered. Finish each chapter with its ten self-test items. The cram sheet at the end puts the whole exam on one page.

WHAT THIS GUIDE COVERS

- Chapter 1 · atoms and isotopes, bond types, the four properties of water, pH and buffers, carbon and functional groups, carbohydrates, lipids, proteins and nucleic acids.
- Chapter 2 · microscopes and the cell theory, surface area to volume, prokaryotic versus eukaryotic cells, the endomembrane system, mitochondria and chloroplasts, the cytoskeleton, junctions, membranes and transport.

CHAPTER 1

The Chemistry of Life and Biological Macromolecules

Read it in full: **Chapter 1 in the textbook**. See it in motion: **Chemistry of Life Lab** and **Macromolecules Lab**.

What to know

Living things are chemical systems that follow the same rules as a beaker of salt water. Just four elements, oxygen, carbon, hydrogen and nitrogen, make up about 96 percent of the mass of the human body. Trace elements such as iron and iodine are needed in tiny amounts but are still essential: iodine is built into thyroid hormone and iron sits in the heme of hemoglobin.

An atom has a nucleus of protons and neutrons with electrons around it. The **atomic number** is the number of protons, and it defines the element. The **mass number** is protons plus neutrons. **Isotopes** of one element differ only in neutrons, so they react almost the same way, because

chemistry depends on electrons. Radioactive isotopes decay at a fixed half-life. Carbon-14 has a half-life of about 5,730 years.

The electrons in the outer shell are **valence electrons**, and they decide how an atom bonds. Remember HONC 1234: hydrogen forms 1 bond, oxygen 2, nitrogen 3 and carbon 4. A **covalent bond** is a shared pair of electrons. When the two atoms pull equally (C to C, C to H) the bond is nonpolar. When one atom is much more **electronegative** (O or N), the sharing is unequal and the bond is polar, with partial charges.

An **ionic bond** is the attraction between ions of opposite charge. It is strong in a dry crystal but weak in water. A **hydrogen bond** forms when a hydrogen on O or N is drawn to another O or N. It is only about 5 to 10 percent as strong as a covalent bond, but there are huge numbers of them. Van der Waals interactions are weaker still, and the hydrophobic effect is not a true bond at all: water bonds to itself and pushes nonpolar molecules together.

Water is bent and polar, so each molecule can hydrogen bond with up to four neighbors. Four properties follow. **Cohesion** holds water together and pulls water up xylem. A **high specific heat** (1 calorie per gram per degree Celsius) steadies temperature, and evaporative cooling carries heat away as sweat dries. **Ice floats** because its open lattice is about 10 percent less dense than liquid water. Water is a strong **solvent** for ions and polar molecules.

A mole is 6.02×10^{23} particles, and its mass in grams equals the molecular mass in daltons. Glucose is 180 daltons, so 180 g is 1 mole, and 1 mole per liter is a 1 M solution. **pH** = $-\log[H^+]$. Pure water is pH 7. Each pH unit is a tenfold change. Blood is held between 7.35 and 7.45 by the carbonic acid and bicarbonate **buffer**, which soaks up H^+ when it rises and releases it when it falls.

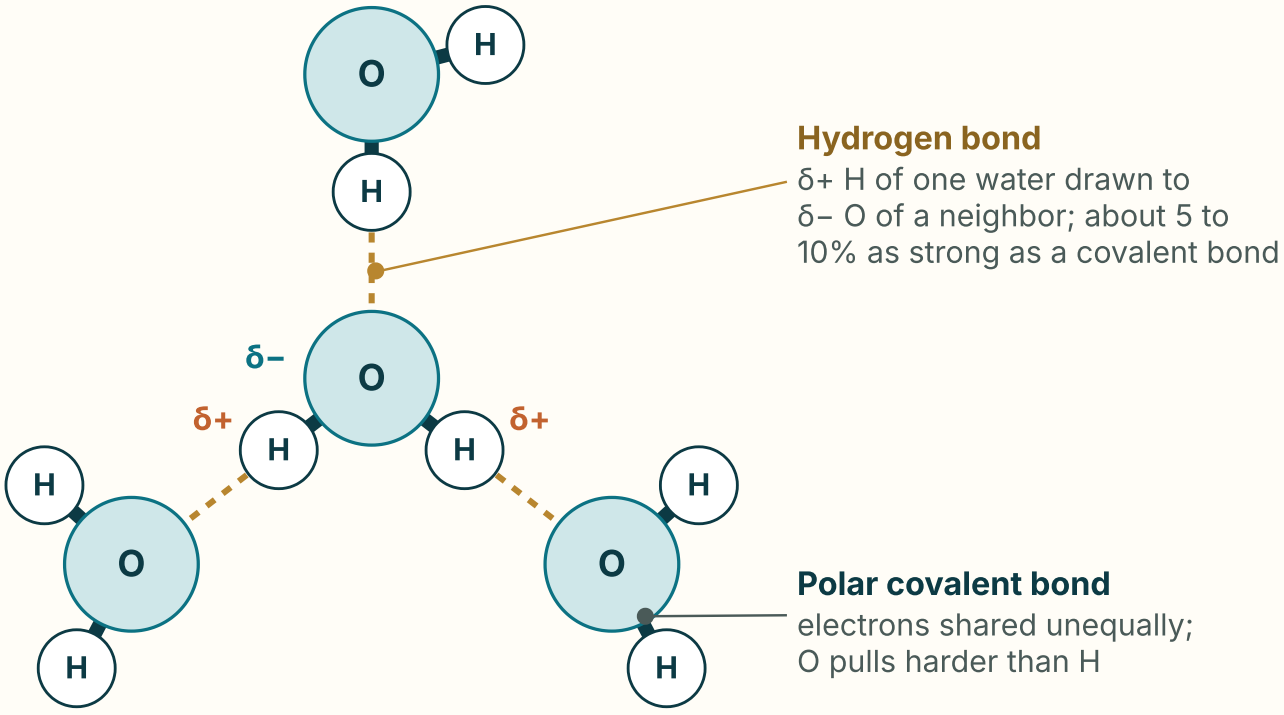
Carbon forms four bonds and links to itself, so it builds chains, branches and rings. **Isomers** share a formula but differ in structure: structural isomers (glucose and fructose), cis trans isomers around a double bond, and enantiomers, mirror images around an asymmetric carbon. Seven **functional groups** set chemical behavior: hydroxyl, carbonyl, carboxyl (acidic), amino (basic), sulfhydryl, phosphate and methyl. ATP stores energy in its three phosphates and releases it when the end one is removed by hydrolysis.

Carbohydrates, proteins and nucleic acids are polymers of monomers. Lipids are large but are not true polymers. **Dehydration synthesis** joins monomers and releases water. **Hydrolysis** adds water to break the bond. Starch (plants) and glycogen (animals) store energy as alpha glucose. Cellulose and chitin are structural and use beta linkages, which human enzymes cannot cut. That one alpha versus beta difference is why starch is food and cellulose is wood.

A triglyceride is glycerol plus three fatty acids. Saturated fatty acids have no double bonds and pack into solids such as butter. Unsaturated ones have cis double bonds that kink the chain, so oils stay liquid. Trans fats from partial hydrogenation raise LDL cholesterol. A **phospholipid** has a charged phosphate head and two hydrophobic tails, so it forms a bilayer in water. **Steroids** such as cholesterol have four fused rings.

Proteins are chains of 20 amino acids joined by **peptide bonds**, built from the N-terminus to the C-terminus. Primary structure is the sequence. Secondary structure (alpha helix, beta sheet) comes from hydrogen bonds between backbone atoms only. Tertiary structure comes from R group interactions, including disulfide bridges. Quaternary structure joins subunits, as in hemoglobin. One swap, glutamate to valine in the beta chain, causes sickle cell disease. **Denaturation** breaks the weak bonds but leaves peptide bonds intact.

Nucleic acids are polymers of **nucleotides**: a pentose sugar, a nitrogenous base and phosphate. DNA uses deoxyribose and thymine; RNA uses ribose and uracil. Purines (A, G) have two rings and pyrimidines (C, T, U) have one. DNA is an antiparallel double helix: A pairs with T by two hydrogen bonds and G with C by three. Strands are written 5′ to 3′. Information flows DNA to RNA to protein, the **central dogma**.



Every water can hydrogen-bond to up to four neighbors. Together these weak bonds give cohesion, a high specific heat, evaporative cooling and floating ice.

Water and its hydrogen bonds. Each O to H bond is polar, so every water molecule has a slightly negative end and two slightly positive ends. The weak pull between neighbors is the hydrogen bond.

LOCK THESE IN

- HONC 1234: hydrogen 1 bond, oxygen 2, nitrogen 3, carbon 4.
- Isotopes differ in neutrons only; atomic number (protons) defines the element.
- Bond strength in a cell: covalent is strong; ionic is weak in water; hydrogen bonds are about 5 to 10 percent of covalent.
- Water: cohesion, high specific heat, floating ice, versatile solvent. All come from polarity and hydrogen bonds.
- pH = $-\log[H^+]$; one pH unit is tenfold. Blood 7.35 to 7.45.
- Dehydration builds polymers and releases water; hydrolysis adds water and breaks them.
- Alpha glucose stores energy (starch, glycogen); beta linkages build structure (cellulose, chitin).
- Secondary structure uses backbone hydrogen bonds; tertiary uses R groups. Denaturation spares peptide bonds.

Key terms and comparisons: bonds and water

Item	What it is	Example or number
Nonpolar covalent	Electrons shared equally	C to H bonds in fats
Polar covalent	Electrons shared unequally; partial charges	O to H bonds in water
Ionic bond	Attraction of full opposite charges	NaCl crystal; weak once dissolved
Hydrogen bond	H on O or N drawn to another O or N	DNA base pairs; water network
Van der Waals	Fleeting charge attractions	Gecko feet
Hydrophobic effect	Water excludes nonpolar groups	Protein core; lipid bilayer
Specific heat of water	1 cal raises 1 g by 1 °C	Slow temperature change
Ice	About 10% less dense than liquid water	Densest water is at about 4 °C
Mole	6.02×10^{23} particles	Glucose: 180 g per mole
pH	$-\log[H^+]$; tenfold per unit	Pure water 7; blood 7.35 to 7.45; gastric juice 1.5 to 3.5
Carbon-14 half-life	About 5,730 years	Dates remains up to about 50,000 years

Key terms and comparisons: the four macromolecules

Family	Monomer and bond	Examples	Main roles
Carbohydrates	Monosaccharides; glycosidic linkage	Glucose, sucrose, starch, glycogen, cellulose, chitin	Fuel, storage, structure
Lipids	Not true polymers; ester linkages in fats	Triglycerides, phospholipids, steroids, waxes	Energy store, membranes, hormones
Proteins	Amino acids (20); peptide bond	Enzymes, collagen, hemoglobin, antibodies	Catalysis, structure, transport, signaling, defense
Nucleic acids	Nucleotides; phosphodiester linkage	DNA, RNA, ATP, NAD^+	Heredity, gene expression, energy carriers

Worked cases

WORKED CASE 1 · COMPARING TWO PH VALUES

Gastric juice is about pH 2 and pure water is pH 7. How many times more H^+ is in the gastric juice? What is $[H^+]$ in a pH 5 solution?

STEP 1 · SUBTRACT THE PH VALUES

$7 - 2 = 5$ units.

STEP 2 · RAISE 10 TO THAT POWER

10^5 = **100,000 times** more H^+ at pH 2.

STEP 3 · USE THE DEFINITION FOR PH 5

$pH = -\log[H^+]$, so $[H^+] = 10^{-5}$ M, or **0.00001 M**.

CHECK IT

A change of one unit is ten times, not "a little." Lower pH always means more H^+.

WORKED CASE 2 · CHARGAFF AND A COMPLEMENTARY STRAND

A double stranded DNA sample is 28 percent thymine. Find the other three bases. Then write the partner of 5′-ATTGCAC-3′ in the 5′ to 3′ direction and count the hydrogen bonds holding the pair together.

STEP 1 · USE A = T

A = T = 28%, so A plus T = 56%.

STEP 2 · SPLIT WHAT IS LEFT

100 − 56 = 44%, shared equally, so G = C = **22%**. A is **28%**.

STEP 3 · PAIR AND FLIP

Pairing base by base gives 3′-TAACGTG-5′. Read it the other way: **5′-GTGCAAT-3′**.

STEP 4 · COUNT HYDROGEN BONDS

The strand has 4 A or T bases (2 bonds each = 8) and 3 G or C bases (3 bonds each = 9). Total **17**.

WORKED CASE 3 · MOLES AND A RADIOACTIVE CLOCK

How many grams of glucose (180 daltons) make 2 liters of a 0.25 M solution? A bone has 12.5 percent of its original carbon-14. About how old is it?

STEP 1 · FIND THE MOLES

0.25 mol per liter × 2 L = 0.5 mol.

STEP 2 · CONVERT TO GRAMS

0.5 mol × 180 g per mol = **90 g** of glucose.

STEP 3 · COUNT HALF-LIVES

100% to 50% to 25% to 12.5% is three half-lives.

STEP 4 · MULTIPLY

3 × 5,730 = **17,190 years**, well inside the 50,000 year range of the method.

WORKED CASE 4 · NAMING THE LEVEL OF PROTEIN STRUCTURE

Four changes hit a protein: (a) heat breaks hydrogen bonds between backbone atoms in a helix; (b) a reducing agent breaks a disulfide bridge; (c) a mutation swaps one amino acid; (d) two subunits fall apart. Which level does each hit first?

STEP 1 · BACKBONE HYDROGEN BONDS

Helix and sheet bonds are **secondary** structure.

STEP 2 · DISULFIDE BRIDGE

It links R groups of two cysteines, so it is **tertiary**.

STEP 3 · AMINO ACID SWAP

The sequence changes, so it is **primary**, and higher levels may follow.

STEP 4 · SUBUNITS SEPARATE

Fit between polypeptides is **quaternary**.

THE RULE

If the question mentions R groups, it is not secondary structure.

TRAPS PEOPLE FALL INTO

- **Thinking isotopes react differently.** They differ in neutrons, and chemistry depends on electrons. They react almost the same.
- **Calling pH 6 "a little" more acidic than pH 7.** It has ten times the H^+.
- **Treating ionic bonds as strong inside cells.** In water, ions are surrounded by water and ionic bonds are weak.
- **Calling the hydrophobic effect a bond.** It is water bonding to itself and excluding nonpolar groups.
- **Labeling carboxyl as carbonyl plus hydroxyl.** Together they act as an acid, which neither part does alone.
- **Calling lipids polymers.** They are large molecules but have no repeating monomer.
- **Putting R groups in secondary structure.** Secondary structure is backbone hydrogen bonds only.
- **Writing the complement without flipping it.** Pair the bases, then reverse the order to read 5′ to 3′.

Chapter 1 self-test · ten items

1. Nitrogen-14 and nitrogen-15 are isotopes. What do they differ in?

A. The number of valence bonds
B. The number of protons
C. The number of neutrons
D. The number of electrons

C. The number of neutrons Isotopes keep the same protons (and so the same element) but differ in neutrons and mass.

2. Why does an O to H bond carry partial charges while a C to H bond does not?

A. Hydrogen gives up its electron fully to oxygen
B. Oxygen is far more electronegative than hydrogen
C. The O to H bond is ionic rather than covalent
D. Oxygen has fewer valence electrons than carbon

B. Oxygen is far more electronegative than hydrogen Oxygen pulls the shared pair toward itself, so the bond is polar covalent. Carbon and hydrogen pull about equally.

3. A lake freezes on top in winter while fish survive below. Which property of water explains this?

A. Ice is less dense than liquid water
B. Water has a very high heat of vaporization
C. Water molecules show strong adhesion
D. Water dissolves many ionic compounds

A. Ice is less dense than liquid water Ice forms an open lattice about 10 percent less dense than liquid water, so it floats and insulates the water below.

4. A solution goes from pH 8 to pH 5. What happened to its hydrogen ion concentration?

A. It rose 3 times
B. It rose 30 times
C. It fell 1,000 times
D. It rose 1,000 times

D. It rose 1,000 times A drop of 3 units means 10^3 = 1,000 times more H^+.

5. Glucose and fructose share the formula $C_6H_{12}O_6$. What kind of isomers are they?

A. Isotopes of each other
B. Cis trans isomers
C. Structural isomers
D. Enantiomers

C. Structural isomers Glucose has an aldehyde and fructose a ketone, so their atoms are bonded in different arrangements.

6. Which functional group releases H^+ and makes a molecule acidic?

A. Carboxyl
B. Amino
C. Methyl
D. Hydroxyl

A. Carboxyl Carboxyl ionizes to $-COO^-$ at cell pH. Amino groups pick up H^+, and methyl is nonpolar.

7. How many water molecules are released when a polypeptide of 50 amino acids is built?

A. 51
B. 49
C. 25
D. 50

B. 49 Each peptide bond releases one water. A chain of 50 has 49 bonds.

8. Cows digest grass, but humans cannot digest cellulose. What is the reason?

A. Human enzymes cannot cut any glucose bonds
B. Cellulose is built from fructose units
C. Cellulose is a lipid, not a carbohydrate
D. Human enzymes cannot cut beta linkages

D. Human enzymes cannot cut beta linkages Our amylase fits alpha linkages. Cows rely on gut microbes that make cellulase for beta linkages.

9. Heating an enzyme to 90 °C destroys its activity. Which bonds survive?

A. Peptide bonds in the primary structure
B. The hydrogen bonds of the alpha helices
C. The ionic bonds between R groups
D. The contacts between its subunits

A. Peptide bonds in the primary structure Denaturation breaks the weak bonds of higher levels. The covalent peptide bonds remain.

10. A DNA sample is 35 percent guanine. What percent is adenine?

A. 30 percent
B. 35 percent
C. 65 percent
D. 15 percent

D. 15 percent G = C = 35%, so G plus C = 70%. The remaining 30% splits into A = T = 15%.

CHAPTER 2

Cell Structure, Membranes and Transport

Read it in full: **Chapter 2 in the textbook**. See it in motion: **Cell Structure Lab** and **Membranes Lab**.

What to know

Most cells are 1 to 100 micrometers across, too small for the eye. Three numbers describe a microscope. **Magnification** is how much bigger the image is. **Resolution** is how close two points can be and still look separate. **Contrast** is how much parts differ in brightness. A light microscope resolves about 200 nm and can show living cells. An electron microscope resolves a few nanometers or better because electrons have a shorter wavelength, but the sample must be dead and in a vacuum. SEM shows surfaces; TEM shows the inside.

The **cell theory** has three parts: all living things are made of cells; the cell is the basic unit of structure and function; and all cells come from earlier cells. Schleiden (plants, 1838), Schwann (animals, 1839) and Virchow (every cell from a cell, 1855) built it.

Cells stay small because of the **surface area to volume ratio**. For a cube of side s, surface area is $6s^2$ and volume is s^3, so the ratio is 6/s. As a cell grows, volume outruns surface, and the membrane can no longer supply the inside. Cells answer by staying small, getting long and thin, or folding their surfaces into microvilli.

Every cell has a plasma membrane, cytosol, DNA chromosomes and ribosomes. **Prokaryotic** cells (bacteria and archaea) keep DNA in a nucleoid with no membrane, have 70S ribosomes, usually a cell wall (peptidoglycan in bacteria) and no membrane-enclosed organelles. **Eukaryotic** cells (protists, fungi, plants, animals) have a nucleus, 80S ribosomes and many organelles, which keeps incompatible jobs apart. Plant cells add a cellulose wall, chloroplasts, a large central vacuole and plasmodesmata. Animal cells have lysosomes, centrioles and an extracellular matrix. Plants have mitochondria too.

The **nucleus** holds DNA as chromatin inside a double nuclear envelope with pores. The nucleolus builds ribosomal subunits. Free ribosomes make proteins for the cytosol. Bound ribosomes on the rough ER make proteins for membranes, lysosomes or secretion, once a signal peptide sends them there.

The **endomembrane system** is the nuclear envelope, ER, Golgi, lysosomes, vacuoles and plasma membrane, linked by vesicles. Rough ER makes secretory and membrane proteins and adds sugars. Smooth ER makes lipids and steroids, detoxifies drugs in the liver and stores calcium in

muscle. The Golgi receives at its cis face, modifies, tags and ships from its trans face. Lysosomes digest at about pH 5. The plant central vacuole stores ions and pigments and takes up water to grow the cell. A secreted protein goes rough ER, vesicle, Golgi, vesicle, exocytosis.

Mitochondria run cellular respiration. Their inner membrane folds into cristae around the matrix. **Chloroplasts** run photosynthesis. Their thylakoids, stacked into grana, sit in the stroma. Both have two membranes, circular DNA without histones, 70S ribosomes and divide by a fission-like process. That is the evidence for the **endosymbiont theory**: mitochondria came from engulfed alphaproteobacteria and chloroplasts from cyanobacteria. Peroxisomes make H_2O_2 and break it down with catalase.

The **cytoskeleton** has three fibers. Microtubules (about 25 nm, hollow, tubulin) resist compression, guide vesicles, form the spindle and make the 9 + 2 core of cilia and flagella, bent by dynein. Microfilaments (about 7 nm, actin) bear tension and work with myosin in muscle, the cleavage furrow and crawling. Intermediate filaments (8 to 12 nm) are permanent ropes made of different proteins in different cells, such as keratin and lamins.

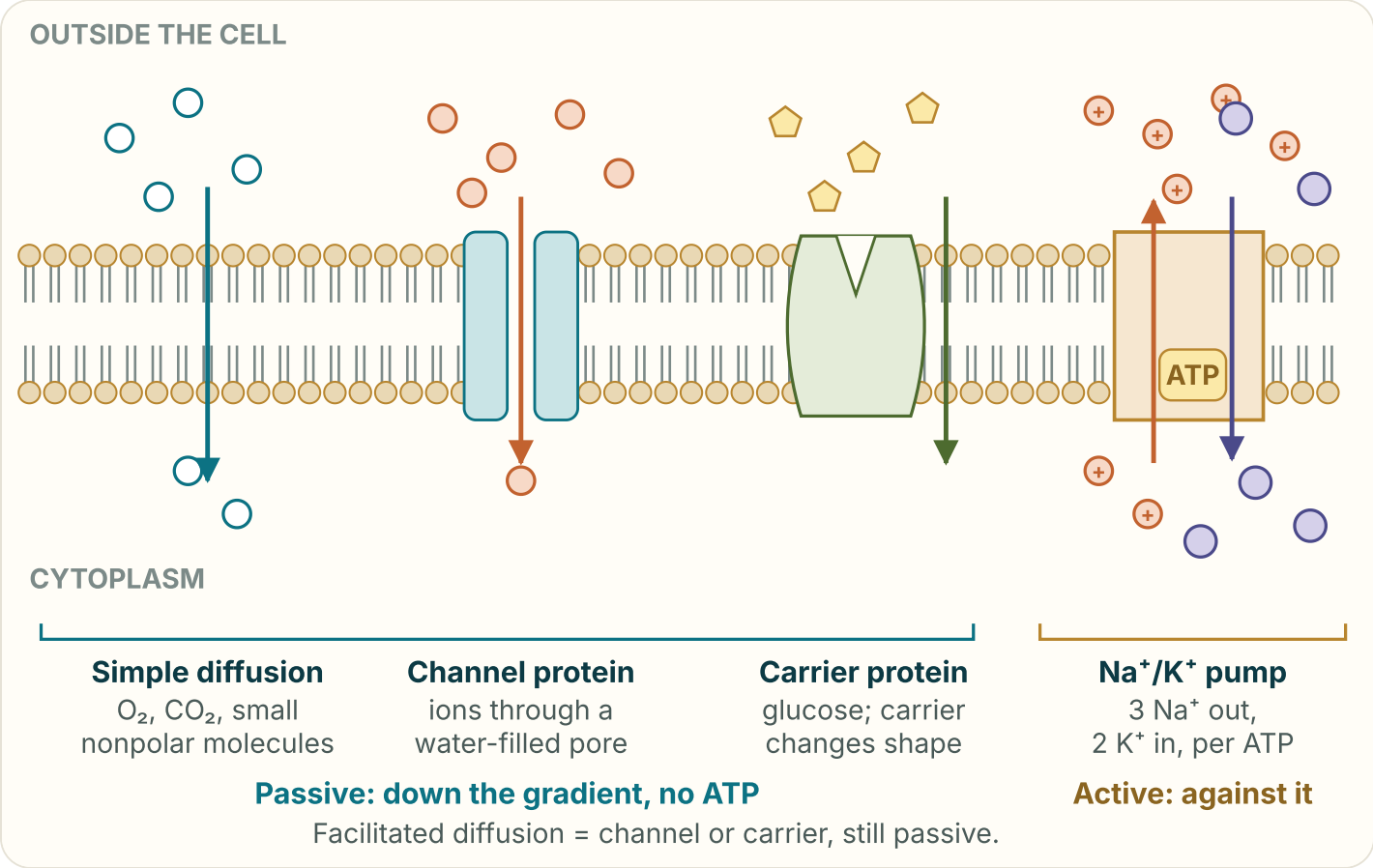
Outside the cell, plants have walls of cellulose with a pectin-rich middle lamella. Animals have an **extracellular matrix** of collagen and proteoglycans linked through fibronectin to integrins. Junctions: tight junctions seal, desmosomes rivet cells into sheets, gap junctions let ions pass between cells. Plasmodesmata are the plant version of gap junctions.

The membrane follows the **fluid mosaic model**: a fluid phospholipid bilayer with proteins embedded or attached. Unsaturated tails keep it fluid in the cold, and cholesterol buffers fluidity. Carbohydrates face only the outside. Small nonpolar molecules (O_2, CO_2) cross the bilayer directly. Ions and polar molecules need channels or carriers.

Osmosis is diffusion of free water toward the side with more nonpenetrating solute. Tonicity describes the outside solution. In a hypotonic solution an animal cell swells and may burst, while a plant cell becomes turgid. In a hypertonic solution the animal cell shrivels and the plant cell plasmolyzes. 0.9% NaCl is isotonic to human cells.

Passive transport runs down a gradient with no energy: simple diffusion, osmosis and facilitated diffusion, which saturates because carriers are limited. **Active transport** pushes against a

gradient. The sodium-potassium pump uses one ATP to move 3 Na^+ out and 2 K^+ in, which helps make the inside negative (about −50 to −70 mV). In **cotransport**, a pump-built gradient drives a second solute uphill, as the sodium-glucose cotransporter does. Bulk cargo leaves by exocytosis and enters by phagocytosis, pinocytosis or receptor-mediated endocytosis (how cells take up LDL).



Four ways across the membrane. Diffusion, channels and carriers all run downhill and need no ATP. Only the pump spends ATP to move ions uphill.

LOCK THESE IN

- Light microscope: about 200 nm, living cells. EM: a few nm or better, dead samples. SEM surface, TEM inside.
- Surface area to volume ratio of a cube is 6/s; it falls as the cell grows.
- Prokaryotes: nucleoid, 70S ribosomes, no membrane-enclosed organelles. Eukaryotes: nucleus, 80S ribosomes, organelles.
- Secretory path: rough ER, vesicle, Golgi cis to trans, vesicle, plasma membrane.
- Endosymbiosis evidence: two membranes, circular DNA, 70S ribosomes, fission, bacterial DNA sequences.
- Microtubules resist compression; microfilaments and intermediate filaments bear tension.
- Tight junctions seal, desmosomes anchor, gap junctions communicate; plants use plasmodesmata.
- Na^+/K^+ pump: 3 Na^+ out, 2 K^+ in, 1 ATP. Cotransport uses the gradient, not ATP directly.

Key terms and comparisons: organelles

Structure	Membranes	Main job	A cell rich in it
Nucleus	Double, with pores	Stores DNA; nucleolus makes ribosomal subunits	All eukaryotic cells except mature red blood cells
Rough ER	Single	Secretory and membrane proteins; adds sugars	Pancreatic and plasma cells
Smooth ER	Single	Lipids and steroids; detox; Ca^{2+} storage	Liver, steroid-making cells, muscle
Golgi apparatus	Single, stacked	Modifies, tags, sorts and ships	Secretory cells
Lysosome	Single	Digests at about pH 5; autophagy	Macrophages
Peroxisome	Single	Oxidation; catalase breaks down H_2O_2	Liver and kidney
Mitochondrion	Double; cristae	Cellular respiration; ATP	Heart muscle, sperm
Chloroplast	Double, plus thylakoids	Photosynthesis	Leaf mesophyll

Key terms and comparisons: crossing the membrane

Mechanism	Direction	Protein?	Energy	Example
Simple diffusion	Down	No	None	O_2, CO_2
Osmosis	Water toward more solute	Partly aquaporins	None	Cell swelling in hypotonic fluid
Facilitated diffusion	Down	Channel or carrier	None	GLUT glucose carrier
Primary active	Against	Pump	ATP directly	Na^+/K^+ pump
Secondary active	Against, for the second solute	Cotransporter	Ion gradient	Sodium-glucose cotransporter
Bulk transport	In or out in vesicles	Vesicles, clathrin	ATP	Insulin secretion; LDL uptake

Numbers and formulas

Item	Value
Surface area of a cube	$6s^2$
Volume of a cube	s^3
Surface area to volume	6/s
Cytoskeleton widths	Microtubule 25 nm; microfilament 7 nm; intermediate 8 to 12 nm
Membrane potential	About −50 to −70 mV
Isotonic saline	0.9% NaCl

Worked cases

WORKED CASE 1 · WHY BIG CELLS STRUGGLE

Compare a cube-shaped cell 4 µm on a side with one 40 µm on a side.

STEP 1 · SMALL CELL

Surface $6 \times 4^2 = 96$ µm^2. Volume $4^3 = 64$ µm^3. Ratio $96 \div 64 =$ **1.5**.

STEP 2 · LARGE CELL

Surface $6 \times 40^2 = 9{,}600$ µm^2. Volume $40^3 = 64{,}000$ µm^3. Ratio **0.15**.

STEP 3 · COMPARE

The large cell has one tenth the membrane for each unit of volume.

SHORTCUT

6/s gives the same answers: 6/4 = 1.5 and 6/40 = 0.15.

WORKED CASE 2 · PREDICTING OSMOSIS

Red blood cells (about 0.9% NaCl inside) go into three beakers: 0.9% NaCl, 3% NaCl and distilled water. A wilted plant cell goes into distilled water. Predict each.

STEP 1 · 0.9% NACL

Same nonpenetrating solute as the cell: **isotonic**, no net water flow.

STEP 2 · 3% NACL

More solute outside: **hypertonic**. Water leaves and the cells shrivel (crenate).

STEP 3 · DISTILLED WATER

Less solute outside: **hypotonic**. Water rushes in and the cells may burst (lyse).

STEP 4 · PLANT CELL

Hypotonic for it too, but the wall pushes back. The cell becomes **turgid**, its healthy state.

RULE

Water follows solute, and tonicity always describes the outside solution.

WORKED CASE 3 · COUNTING WHAT THE PUMP MOVES

A sodium-potassium pump runs 200 cycles. How many ions does it move, how much ATP does it use, and what is the net charge moved?

STEP 1 · SODIUM OUT

$3 \times 200 =$ **600 Na^+** out.

STEP 2 · POTASSIUM IN

$2 \times 200 =$ **400 K^+** in.

STEP 3 · ATP

One per cycle: **200 ATP**.

STEP 4 · NET CHARGE

600 − 400 = **200 positive charges** leave, so the inside becomes more negative. That makes the pump electrogenic.

WORKED CASE 4 · FOLLOWING A SECRETED PROTEIN

Trace a digestive enzyme from its gene to the outside of a pancreatic cell.

STEP 1 · NUCLEUS

The gene is transcribed and the mRNA leaves through a nuclear pore.

STEP 2 · ROUGH ER

A ribosome reads the signal peptide and docks on the ER. The protein is threaded into the lumen and may get sugars.

STEP 3 · GOLGI

A transport vesicle carries it to the cis face. It is modified and tagged on the way to the trans face.

STEP 4 · OUT

A secretory vesicle fuses with the plasma membrane: **exocytosis**.

TRAPS PEOPLE FALL INTO

- **Confusing magnification with resolution.** A blurry photo blown up is magnified but not resolved. The EM wins on resolution.
- **Saying prokaryotes have no organelles.** They have ribosomes. They lack membrane-enclosed organelles.
- **Thinking plant cells lack mitochondria.** They have both chloroplasts and mitochondria.
- **Calling a shrinking cell "hypertonic."** Tonicity describes the outside solution compared with the cell.
- **Treating plasmodesmata like tight junctions.** They are channels, the plant match for gap junctions.
- **Saying cotransporters use ATP.** They use an ion gradient. The pump that built it used the ATP.
- **Putting mitochondria in the endomembrane system.** They are separate, with their own DNA and ribosomes.
- **Expecting facilitated diffusion to rise forever.** Carriers saturate once every one is busy.

Chapter 2 self-test · ten items

1. A student needs to see the internal membranes of a mitochondrion. Which instrument fits best?

A. A phase contrast light microscope
B. A brightfield light microscope
C. A transmission electron microscope
D. A scanning electron microscope

C. A transmission electron microscope Cristae are far below the 200 nm light limit. TEM passes electrons through thin sections to show internal structure; SEM shows surfaces.

2. Which statement belongs to the cell theory?

A. All cells can make their own food from light
B. All cells come from preexisting cells
C. All cells contain a membrane-bound nucleus
D. All cells are surrounded by a cell wall

B. All cells come from preexisting cells Virchow added "every cell from a cell." Many cells have no nucleus, no wall or no chloroplasts.

3. A cube-shaped cell is 5 µm on a side. What is its surface area to volume ratio?

A. 5.0
B. 2.4
C. 0.6
D. 1.2

D. 1.2 The ratio for a cube is 6/s, and 6 ÷ 5 = 1.2.

4. A cell has a nucleoid, a peptidoglycan wall and 70S ribosomes. What is it?

A. A bacterium
B. A fungal cell
C. A plant cell
D. An archaeon

A. A bacterium A nucleoid marks a prokaryote, and peptidoglycan walls are found in bacteria, not archaea.

5. Which organelle would be most abundant in liver cells that detoxify a drug?

A. Golgi apparatus
B. Central vacuole
C. Smooth ER
D. Rough ER

C. Smooth ER Smooth ER enzymes add hydroxyl groups to drugs, and it proliferates with repeated exposure.

6. Which observation supports the endosymbiont theory for mitochondria?

A. They are made fresh by the Golgi apparatus
B. They are built from the rough ER membrane
C. They contain linear chromosomes with histones
D. They have circular DNA and 70S ribosomes

D. They have circular DNA and 70S ribosomes Bacteria-like DNA and ribosomes, two membranes and fission-like division all point to an engulfed bacterium.

7. Colchicine blocks tubulin assembly. Which process fails first?

A. Forming the mitotic spindle
B. Cytoplasmic streaming in plants
C. Holding the nuclear lamina
D. Muscle contraction by myosin

A. Forming the mitotic spindle The spindle is built from microtubules. Contraction and streaming use actin, and the lamina is intermediate filaments.

8. Which junction lets ions pass directly so heart cells beat together?

A. The middle lamella
B. Gap junctions
C. Tight junctions
D. Desmosomes

B. Gap junctions Gap junctions are channels joining the cytoplasm of neighboring cells.

9. Glucose uptake rises with outside glucose and then levels off. What does that show?

A. Glucose crosses the bilayer directly
B. Glucose moves by pinocytosis
C. The membrane has become impermeable
D. A limited number of carrier proteins

D. A limited number of carrier proteins Saturation is the mark of carrier-mediated transport. Simple diffusion keeps rising with the gradient.

10. A poison stops ATP production. Why does the sodium-glucose cotransporter stop soon after?

A. Glucose cannot cross any membrane
B. The cotransporter is digested by lysosomes
C. The Na^+ gradient that powers it runs down
D. It needs ATP bound to each glucose

C. The Na^+ gradient that powers it runs down The pump keeps the Na^+ gradient. Without ATP the gradient fades, and the cotransporter has no driving force.

ONE PAGE

Cram sheet

Everything from chapters 1 and 2 in one place. Cover the right column and see if you can rebuild each row.

Numbers to know

Item	Value	Note
Body elements	O, C, H, N about 96% of mass	Trace elements still essential
Valence	H 1, O 2, N 3, C 4	HONC 1234
Hydrogen bond	About 5 to 10% of a covalent bond	Weak but numerous
pH	$-\log[H^+]$; tenfold per unit	Blood 7.35 to 7.45
Mole	6.02×10^{23}	Glucose 180 g/mol
Carbon-14	Half-life about 5,730 years	Dating to about 50,000 years
Base pairs	A to T 2 bonds; G to C 3 bonds	Chargaff: A = T, G = C
Helix	One turn per about 10 bp (3.4 nm); 2 nm wide	Antiparallel strands
Resolution	Light about 200 nm; EM about 2 nm or better	Super-resolution 10 to 20 nm
Cell sizes	Prokaryotes 1 to 5 µm; eukaryotes 10 to 100 µm	Ratio 6/s
Cytoskeleton	25, 7 and 8 to 12 nm	Tubulin, actin, varied proteins
Pump	3 Na^+ out, 2 K^+ in, 1 ATP	−50 to −70 mV inside

Key terms and comparisons

Pair	How to tell them apart
Dehydration vs hydrolysis	Dehydration releases water and builds; hydrolysis adds water and breaks.
Starch vs cellulose	Alpha glucose for storage; beta glucose for structure.
Saturated vs unsaturated	No double bonds, straight, solid; cis double bonds, kinked, liquid.
Secondary vs tertiary	Backbone hydrogen bonds; R group interactions.
DNA vs RNA	Deoxyribose and T, double; ribose and U, single.
Purine vs pyrimidine	A and G, two rings; C, T and U, one ring.
SEM vs TEM	Surface views; internal thin sections.
Free vs bound ribosomes	Cytosol proteins; membrane, lysosome and secreted proteins.
Hypotonic vs hypertonic	Water enters the cell; water leaves the cell.
Primary vs secondary active	ATP directly; gradient made by a pump.

Rules that win points

Topic	The rule
Comparing pH	Subtract, then raise 10 to that power.
Complement strand	Pair the bases, then flip to read 5′ to 3′.
Water count	A polymer of n units releases n − 1 waters.
Protein path	Free ribosomes stay in; bound ribosomes go ER, Golgi, out.
Osmosis	Water follows nonpenetrating solute.
Endosymbiosis	Two membranes, circular DNA, 70S ribosomes, fission.

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