

Unit 2: Cell Structure and Function

Unit 2 covers the organelles inside cells, why cells stay small, how the plasma membrane is built, and the ways substances cross membranes. CED topics 2.1 through 2.10.

AP Biology

Cell Structure and Function

About 12 minutes to read

How to use this guide

Read it in order the first time because the topics build on each other. The organelles give you the parts, cell size explains the limits those parts work under, the membrane sections explain the boundary, and transport explains what crosses it. Tonicity and the transport mechanisms then apply those ideas, and the last two topics step back to ask why eukaryotic cells are organized this way at all. Exam questions usually give a scenario, such as a cell placed in a solution, and ask you to predict or explain what happens.

After the first read, use the trap boxes and the tables to review the distinctions that exam questions test most often. Finish with the practice questions, then complete the recall check on the last page out loud and note any items you cannot explain yet.

What this unit is worth. The ideas in Unit 2 do not stay in Unit 2. Membrane proteins return in cell signaling, transport returns in osmoregulation and homeostasis, and compartmentalization returns in energetics. Later units assume you know these parts, so learn them here and those units start from familiar ground.

2.1 Cell Structure and Function

Every eukaryotic cell is a set of compartments, each with a job. The **endomembrane system** is the group of membrane-bound parts that modify, package, and move proteins, lipids, and polysaccharides around the cell. Its members are the endoplasmic reticulum, the Golgi complex, lysosomes, vacuoles, transport vesicles, the nuclear envelope, and the plasma membrane itself. Mitochondria and chloroplasts are not members. They have their own story, which comes in topic 2.10.

Protein traffic follows a fixed route. **Ribosomes** sitting on the **rough ER** build proteins and feed them into the system. **Transport vesicles** carry them to the **Golgi complex**, which folds them, chemically modifies them, and packages them for delivery. From the Golgi, vesicles head to the plasma membrane, to lysosomes, or out of the cell entirely. The **smooth ER** carries no ribosomes and does different work. It builds lipids and detoxifies chemicals.

STRUCTURE	JOB TO ATTACH TO IT
Ribosome	Builds proteins from mRNA. Found in all cells, including prokaryotes. Not membrane-bound.
Rough ER	Protein synthesis on membrane-bound ribosomes. Entry point of the secretory pathway.
Smooth ER	Lipid synthesis and detoxification. No ribosomes.
Golgi complex	Folds, modifies, and packages products. Ships vesicles to their destinations.
Lysosome	Digests material with hydrolytic enzymes. Involved in programmed cell death.
Vacuole	Storage. In plants, one large central vacuole holds water and keeps the cell firm.
Mitochondrion	Aerobic respiration. Double membrane with a folded inner membrane for ATP synthesis.
Chloroplast	Photosynthesis in plants and photosynthetic algae. Double membrane.
Nuclear envelope	Double membrane around the nucleus. Part of the endomembrane system.

Trap. Rough and smooth ER are not two versions of the same job. Rough ER makes proteins because it carries ribosomes. Smooth ER makes lipids and detoxifies because it does not. When a question describes a cell that secretes large amounts of protein, the answer runs through rough ER and the Golgi, never smooth ER.

Two more parts deserve their own sentences. **Lysosomes** hold hydrolytic enzymes that digest material the cell no longer needs, and they take part in **apoptosis**, the programmed death of a cell. In plant cells, one large central **vacuole** stores water and pushes it against the cell wall. That push is **turgor pressure**, and it is what keeps a non-woody plant standing upright.

2.2 Cell Size

Cells stay small for a physical reason. Materials enter and leave across the surface, but the whole volume needs supplying. As a cell grows, its volume increases faster than its surface area, so the **surface area-to-volume ratio** falls. A falling ratio means less membrane per unit of interior, and exchange cannot keep up with demand. Small cells exchange materials with the environment more efficiently than large ones.

The math is simple enough to check. A cube 1 unit on a side has a surface area of 6 and a volume of 1, a ratio of 6 to 1. A cube 2 units on a side has a surface area of 24 and a volume of 8, a ratio of 3 to 1. Doubling the width cut the ratio in half. The same pattern shows up in whole organisms. **Metabolic rate and body size** are linked. Smaller multicellular organisms tend to have higher metabolic rates per unit of body mass, because a higher surface area-to-volume ratio exchanges heat with the environment faster.

Trap. When a question asks why cells are small, or why a large cell struggles, it is asking about the surface area-to-volume ratio. Answers about the nucleus, DNA amount, or energy supply miss the mechanism the course tests.

2.3 Plasma Membrane

The membrane is a **phospholipid bilayer**. Each phospholipid has a polar hydrophilic head that faces the watery environments inside and outside the cell, and two nonpolar hydrophobic tails that face each other in the middle of the membrane. The **fluid mosaic model** describes what sits in that framework. Proteins, steroids such as cholesterol in vertebrates, **glycoproteins**, and **glycolipids** are all embedded in the bilayer, and all of them can drift sideways within it. The membrane is fluid, not fixed.

2.4 Membrane Permeability

The membrane shows **selective permeability**. It lets some substances cross and blocks others, and that selectivity comes from the hydrophobic interior. Small nonpolar molecules slip through. Ions and large polar molecules cannot, and they need protein help, which is the subject of the next topics. Many cells add a **cell wall** outside the membrane. Bacteria, archaea, fungi, and plants all have one. It acts as a permeability barrier for some substances and protects the cell from osmotic lysis. Animal cells have no cell wall.

2.5 Membrane Transport

A **concentration gradient** is a difference in solute concentration across the membrane, and selective permeability is what creates it. **Passive transport** is the net movement of molecules from high concentration to low concentration with no direct input of metabolic energy. **Active transport** moves molecules with a direct input of metabolic energy, often from low concentration to high concentration, against the gradient.

Large substances cannot use either route. They cross in vesicles instead. In **endocytosis** the plasma membrane folds inward and pinches off a vesicle that carries material into the cell. In **exocytosis** a vesicle fuses with the membrane and releases large substances, or large amounts of substances, out of the cell. Both processes require energy.

2.6 Facilitated Diffusion

Facilitated diffusion is passive transport with help. Charged ions and large polar molecules move down their concentration gradient through channel or transport proteins, with no energy input. A **channel protein** forms a passage for ions such as Na^+ and K^+ . **Aquaporins** are channel proteins that move large quantities of water. Ion movement across the membrane also creates the **membrane potential**, the electrical charge difference between the inside and outside of the cell.

Trap. Facilitated diffusion and active transport both use membrane proteins, which is exactly why questions pair them. Separate them by energy and direction. Facilitated diffusion moves substances down a gradient and spends nothing. Active transport spends metabolic energy, usually to move substances against a gradient.

TYPE	ENERGY	DIRECTION AND NOTES
Simple diffusion	None	High to low concentration. Small nonpolar molecules cross the bilayer on their own.
Facilitated diffusion	None	High to low, through a channel or transport protein. Glucose and ions use this route.
Osmosis	None	Water only, from high to low water potential.
Active transport	ATP	Often low to high concentration. The sodium-potassium pump is the model example.
Endocytosis	ATP	Into the cell in vesicles. A white blood cell engulfing a bacterium.
Exocytosis	ATP	Out of the cell in vesicles. A gland cell releasing its products.

2.7 Tonicity and Osmoregulation

Tonicity words describe the solution, compared against the cell. In a **hypotonic** solution the solute concentration outside is lower than inside, so water moves into the cell. In a **hypertonic** solution the outside concentration is higher, so water moves out. In an **isotonic** solution the concentrations match and there is no net water movement.

Osmosis is the movement of water from regions of high water potential to regions of low water potential, which is the same as saying from hypotonic toward hypertonic regions. **Water potential** is the tendency of water to move, and it follows a simple equation. Water potential equals pressure potential plus solute potential. Adding solute lowers water potential. Adding pressure raises it. Water always moves from higher to lower.

Osmoregulation is how organisms maintain water balance, controlling their internal solute composition and water potential. The related measure is **osmolarity**, the solute concentration of a solution. Water moves by osmosis from regions of low osmolarity to regions of high osmolarity.

SOLUTION	WATER MOVES	ANIMAL CELL	PLANT CELL
Hypotonic	Into the cell	Swells, and can burst	Becomes firm and rigid
Isotonic	No net movement	Stays normal	Stays normal
Hypertonic	Out of the cell	Shrivels	Loses water and wilts

Trap. Hypotonic and hypertonic describe the solution, not the cell. A frequent wrong answer calls the cell hypertonic when the question stated the solution was. Check which side of the membrane the word attaches to before you predict which way water moves.

2.8 Mechanisms of Transport

The **sodium-potassium pump** is the clearest example of active transport in this unit. It uses ATP to pump Na^+ out of the cell and K^+ into the cell, both against their gradients, and that work helps maintain the membrane potential. The enzyme that hydrolyzes ATP to supply this kind of energy is an **ATPase**. The pump's work builds an **electrochemical gradient**, a combined concentration and electrical difference across the membrane. Active transport builds the gradient, and membrane proteins are needed both to build it and to use it.

Trap. The sodium-potassium pump and a channel protein are both membrane proteins that move ions, but they run on opposite terms. The pump spends ATP to move ions against their gradients. A channel protein lets ions flow down their gradients for free.

2.9 Cell Compartmentalization

Compartmentalization is the partitioning of the eukaryotic cell by membranes and membrane-bound organelles. It separates metabolic processes and enzymatic reactions that would interfere with each other. Digestive enzymes stay inside lysosomes instead of drifting through the cell. The mitochondrion's folded inner membrane creates a dedicated compartment where ATP synthesis runs efficiently. Without compartments, the cell would be one mixed space where incompatible chemistry collides.

2.10 Origins of Cell Compartmentalization

A **prokaryote** typically lacks internal membrane-bound organelles, though it has internal regions with specialized structures and functions. Bacteria and archaea are prokaryotes. A **eukaryote** keeps internal membranes that partition it into organelles. **Endosymbiosis** explains how two of those organelles got there. Mitochondria and chloroplasts began as free-living prokaryotic cells that were engulfed by a host cell and stayed. Their double membranes are the structural clue that points to that history.

Trap. Endosymbiosis explains mitochondria and chloroplasts. It does not explain the nucleus. The nuclear envelope belongs to the endomembrane system, which is a separate account of how the cell organized itself.

Confusions That Cost Points

Most missed questions in this unit come from a short list of pairs that look alike under time pressure. Review each pair carefully so you can tell them apart when you see them in a question.

PAIR	HOW TO SEPARATE THEM
Rough ER vs smooth ER	Rough makes proteins on its ribosomes. Smooth makes lipids and detoxifies. Secretion questions point to rough.
Hypotonic vs hypertonic	Both describe the solution. Hypotonic has less solute, so water enters the cell. Hypertonic has more, so water leaves.
Facilitated diffusion vs active transport	Both use proteins. Facilitated is passive and moves down the gradient. Active spends ATP and usually moves against it.
Endocytosis vs exocytosis	Endo brings material in by folding the membrane inward. Exo ships material out by vesicle fusion. Both need energy.
Osmosis vs diffusion	Diffusion is any molecules moving down a gradient. Osmosis is water only, moving by water potential.
Channel protein vs sodium-potassium pump	A channel lets ions flow down gradients for free. The pump spends ATP to move them against gradients.
Prokaryote vs eukaryote	Prokaryotes lack membrane-bound organelles. Eukaryotes are partitioned into them.
Turgor pressure vs water potential	Turgor is the push of stored water against a plant cell wall. Water potential is the tendency of water to move, which decides the direction.
Passive vs active transport	Passive moves down gradients with no energy input. Active uses metabolic energy, often to move against gradients.

Practice Questions

Original questions written for this guide in the style of the AP exam. Answers and explanations are on the next page, so complete the questions before checking them.

- 1.** A pancreatic cell secretes large amounts of digestive enzymes, which are proteins. Which sequence correctly traces a newly made enzyme from synthesis to release?
 - A. Ribosome to rough ER to Golgi complex to transport vesicle to plasma membrane
 - B. Ribosome to smooth ER to Golgi complex to lysosome to plasma membrane
 - C. Golgi complex to rough ER to transport vesicle to plasma membrane
 - D. Ribosome to lysosome to Golgi complex to transport vesicle

- 2.** Two spherical cells are compared. Cell X has twice the diameter of cell Y. Which statement is correct?
 - A. Cell X has a higher surface area-to-volume ratio than cell Y
 - B. Cell Y exchanges materials with its environment more efficiently than cell X
 - C. Cell X supplies its interior more easily because it has more total membrane
 - D. Both cells have the same surface area-to-volume ratio

- 3.** Small nonpolar molecules cross the plasma membrane easily, while ions cannot cross without protein help. The best explanation is that
 - A. the hydrophobic interior of the bilayer blocks charged substances
 - B. ions are too large to fit between the phospholipids
 - C. channel proteins actively pump ions out as fast as they enter
 - D. the membrane is solid and only nonpolar molecules can dissolve through it

- 4.** A red blood cell takes up glucose from the blood plasma, where glucose is more concentrated than inside the cell. The glucose crosses through a membrane protein and no ATP is spent. This is an example of
 - A. active transport
 - B. simple diffusion
 - C. facilitated diffusion
 - D. osmosis

- 5.** A plant cell is placed in a solution with a higher solute concentration than the cell interior. What will happen?
- A. Water moves into the cell and turgor pressure rises
 - B. Water moves out of the cell and the cell loses firmness
 - C. Solutes move into the cell until the concentrations equalize
 - D. Nothing changes because the cell wall blocks all water movement
- 6.** A poison blocks ATPase activity in a cell. Which immediate effect is expected?
- A. Facilitated diffusion of glucose stops
 - B. The sodium-potassium pump can no longer maintain the ion gradients
 - C. Water stops crossing the membrane through aquaporins
 - D. Oxygen diffuses across the membrane more slowly
- 7.** Which observation best supports the endosymbiosis hypothesis for the origin of mitochondria?
- A. Mitochondria are surrounded by a double membrane
 - B. The nucleus is also surrounded by a double membrane
 - C. Mitochondria are larger than ribosomes
 - D. Plant cells contain both mitochondria and chloroplasts
- 8.** A white blood cell engulfs a bacterium by folding its plasma membrane inward around it. This process is
- A. exocytosis, because material crosses the membrane
 - B. endocytosis, and it requires energy
 - C. passive transport, because it moves down a concentration gradient
 - D. carried out by aquaporins admitting the bacterium

Answer Key

- 1. A.** The secretory pathway runs ribosome to rough ER to Golgi to vesicle to membrane, in that order. B puts the protein through smooth ER, which handles lipids, and into a lysosome, which digests rather than ships. C starts at the Golgi, but the Golgi can only modify what the ER already made. D sends the protein to a lysosome, where it would be broken down instead of delivered.
- 2. B.** Exchange happens across the surface while demand comes from the volume, so the smaller cell's higher ratio wins. A reverses the ratio. C confuses total membrane with the ratio, which is the measure that matters. D ignores that volume grows faster than surface area as size increases.
- 3. A.** Charge is the barrier. The bilayer's hydrophobic interior blocks ions while letting small nonpolar molecules through. B makes it about size, but small ions are small. The problem is their charge. C invents active pumping that is not happening. D contradicts the fluid mosaic model. The membrane is fluid, not solid.
- 4. C.** Glucose moves down its gradient through a protein with no ATP spent, which is facilitated diffusion exactly. A requires energy, and none is used here. B is for small nonpolar molecules that cross the bilayer on their own. Glucose is large and polar and needs the protein. D moves water only, not glucose.
- 5. B.** The outside has more solute, so the solution is hypertonic and water leaves the cell. The cell loses firmness as water leaves. A reverses the water movement. Turgor rises when water enters, not when it leaves. C describes solute diffusion, but the question is about water, and the membrane's selective permeability keeps the focus on osmosis. D is wrong because the wall does not stop water. It protects against lysis, which is a different job.
- 6. B.** The pump runs on ATP hydrolyzed by ATPase, so blocking ATPase stops the pump and the gradients run down. A and C are passive processes. Facilitated diffusion and aquaporin water flow use no ATP. D is simple diffusion, which needs no energy either.
- 7. A.** A double membrane fits the story of one cell engulfed by another, each contributing a membrane. B is about the nucleus, which belongs to the endomembrane system, not to endosymbiosis. C compares sizes, which says nothing about origins. D is true but does not show engulfment. Coexistence is not evidence of how something arrived.
- 8. B.** Folding the membrane inward to take material in is endocytosis, and vesicle formation costs energy. A names the outward process. The direction is the whole question. C mislabels bulk transport as gradient-driven. No gradient is involved. D gives the job to aquaporins, which move water only, not bacteria.

When you check your answers, note which distinction each miss came from. Make a flashcard for that distinction and drill it spaced out over the next few days instead of rereading the whole section. If you missed one of these questions, the same distinction is worth practicing again in Rycal, where the Cell Structure and Function deck covers these terms and the practice questions target the same traps.

One-Page Recall Check

Say each answer out loud before you look back, and mark the ones you cannot finish. Anything you cannot say out loud yet belongs in your flashcard deck. In Rycal, add those items to the Cell Structure and Function deck and let spaced review bring them back over the next few days.

- Trace a secreted protein from ribosome to outside the cell, naming each stop in order.
- State the difference between rough and smooth ER in one sentence each.
- Explain what the Golgi complex does to a newly made protein.
- Explain why a large cell has trouble supplying its interior, using the surface area-to-volume ratio.
- Describe the phospholipid bilayer. Which parts face water and which face inward.
- Name three mobile components of the fluid mosaic model besides phospholipids.
- Explain selective permeability in terms of the hydrophobic interior.
- Sort these into passive or active. Diffusion, facilitated diffusion, osmosis, the sodium-potassium pump, endocytosis.
- Explain the difference between facilitated diffusion and active transport.
- Define hypotonic, hypertonic, and isotonic from the solution's point of view.
- Predict what happens to an animal cell in a hypotonic solution and to a plant cell in a hypertonic one.
- Write the water potential equation and state which way water moves.
- Explain how the sodium-potassium pump builds an electrochemical gradient.
- Explain why compartmentalization lets a cell run incompatible reactions at the same time.
- Tell the endosymbiosis story for mitochondria in two sentences.
- State one structural difference between prokaryotes and eukaryotes.

Where to go next. Turn every missed item above into flashcards and drill them spaced out over several days rather than in one sitting. In Rycal, open the Cell Structure and Function deck under AP Biology. The deck covers the terms in this guide, and its practice questions target the same traps named in the answer key. When you have a test date, enter it in the Test Planner and let it build your study sessions around the units you need.

Key terms for this unit

Ribosome, Endomembrane system, Rough ER, Smooth ER, Golgi complex, Mitochondrion, Lysosome, Vacuole, Turgor pressure, Chloroplast, Nuclear envelope, Transport vesicle, Glycosylation, Surface area-to-volume ratio, Metabolic rate and body size, Phospholipid bilayer, Fluid mosaic model, Glycoprotein, Glycolipid, Selective permeability, Cell wall, Concentration gradient, Passive transport, Active transport, Endocytosis, Exocytosis, Facilitated diffusion, Channel protein, Embedded protein, Cholesterol, Membrane potential, Aquaporin, Hypotonic, Hypertonic, Isotonic, Osmosis, Water potential, Osmoregulation, Osmolarity, Electrochemical gradient, Sodium-potassium pump, ATPase, Compartmentalization, Endosymbiosis, Prokaryote, Eukaryote

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