MDCAT Biology Unit 4: Cell structure and function, study guide with practice MCQs

What MDCAT asks

This unit covers the plasma membrane and how substances cross it, the organelles of a eukaryotic cell, and how prokaryotic, eukaryotic, plant and animal cells differ, with cell specialisation and the microscope. Its three subtopics carry equal weight and together account for about three to four of the 81 Biology questions, mostly recall or one-step application: which organelle does a job, which way water moves, what a prokaryote lacks.

B4.1 Cell membrane and transport

B4.1.1 Describe the fluid mosaic model of the plasma membrane

The accepted picture of the plasma membrane is the **fluid mosaic model** of Singer and Nicolson (1972). Its framework is a **phospholipid bilayer** about 7 to 8 nm thick: hydrophilic phosphate heads face the watery cytoplasm and tissue fluid, hydrophobic fatty acid tails point inwards. The membrane is **fluid** because phospholipids and most proteins drift sideways within their layer, and a **mosaic** because proteins of many kinds are scattered through it.

- **Integral (intrinsic) proteins** span the bilayer: channels, carriers, pumps and receptors.
- **Peripheral (extrinsic) proteins** sit on either surface, often as enzymes.
- **Cholesterol** lies between the phospholipids of animal cell membranes and regulates fluidity.
- **Glycoproteins and glycolipids** carry carbohydrate chains on the outer surface only: receptors and cell recognition markers.

The membrane is **selectively permeable**. Small non-polar molecules such as O_2, CO_2 and steroids dissolve in the lipid and pass straight through. Water crosses slowly through the bilayer and faster through channels called aquaporins. Ions (Na^+, K^+, Cl^-) and polar molecules such as glucose and amino acids cannot cross the hydrophobic core and depend on proteins.

B4.1.2 Explain diffusion, facilitated diffusion, osmosis, active transport, endocytosis and exocytosis

Simple diffusion is the net movement of particles from higher to lower concentration by their own random motion; no protein, no ATP. The rate rises with a steeper gradient, higher temperature, larger surface area and thinner membrane.

Facilitated diffusion is also passive and down the gradient, but the particle passes through a specific **channel protein** (a water-filled pore) or **carrier protein** (which binds it, changes shape and releases it on the other side). Glucose enters red blood cells this way. Because carriers are limited in number, the rate levels off when every carrier is busy, which simple diffusion never does.

Osmosis is the net movement of water through a selectively permeable membrane from higher water potential to lower water potential. **Water potential** (ψ, in kPa) is the tendency of water to leave a system: pure water is zero, every solution is negative, and the more concentrated the solution the

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more negative its value, so water moves towards the more concentrated solution. A solution is **isotonic** (same solute concentration as the cell), **hypotonic** (more dilute, water enters) or **hypertonic** (more concentrated, water leaves). In a hypotonic solution an animal cell bursts (**haemolysis** of red blood cells) while a plant cell swells until the wall resists and becomes **turgid**; in a hypertonic solution an animal cell shrinks (**crenation**) while the plant protoplast pulls away from the wall (**plasmolysis**).

Active transport moves ions or molecules against their gradient through a specific carrier protein powered by ATP, so it stops if respiration is poisoned. The **sodium-potassium pump** moves three Na^+ out and two K^+ in for each ATP; root hairs take up mineral ions the same way.

Bulk transport moves material too large for any protein; both directions need ATP. In **endocytosis** the membrane folds in around the material and pinches off as a vesicle: **phagocytosis** for solids such as a bacterium engulfed by a white blood cell, **pinocytosis** for droplets of fluid. In **exocytosis** a Golgi vesicle fuses with the membrane and releases its contents outside, as in secretion of enzymes and hormones.

Process	Direction	Protein?	ATP?	Example
Simple diffusion	Down the gradient	No	No	O_2 in, CO_2 out
Facilitated diffusion	Down the gradient	Channel or carrier	No	Glucose into red blood cells
Osmosis	High to low water potential	Not essential (aquaporins help)	No	Water into root hairs
Active transport	Against the gradient	Carrier pump	Yes	Na+/K+ pump
Endocytosis, exocytosis	Bulk, in or out	Membrane itself moves	Yes	Phagocytosis; insulin secretion

MDCAT trap: "water moves from high concentration to low concentration"

That sentence is only right if you add "of water", and most students mean the solute. Safe wording: water moves from higher to lower water potential, that is, from the more dilute solution to the more concentrated one. Three rules. Pure water is 0 and every solution is negative, so –800 kPa is lower than –200 kPa and water goes to the more negative value. The direction is set by water potential, not by where any solute is going. Osmosis is passive, so "pumped in by active transport" is always wrong.

Worked example

Red blood cells are placed in three tubes: tube 1 holds 0.9% sodium chloride (isotonic with the cytoplasm), tube 2 distilled water, tube 3 3% sodium chloride. In which tube will the suspension turn clear red, and why?

Step 1: Tube 1 is isotonic: no net osmosis, the suspension stays cloudy.

Step 2: In tube 2 the water potential outside (0 kPa) is higher than inside, so water enters. With no wall to resist, the cells burst and release haemoglobin: haemolysis, a clear red solution.

Step 3: Tube 3 is hypertonic; water leaves, the cells crenate but stay intact and cloudy.

Answer: tube 2, because the hypotonic surroundings cause haemolysis.

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B4.2 Organelles

B4.2.1 Describe the structure and function of the nucleus, ER, ribosomes, Golgi apparatus, lysosomes, mitochondria and chloroplasts

Learn the main **organelles** as a production line: the nucleus holds the instructions, ribosomes on the rough ER build proteins, vesicles carry them to the Golgi apparatus for finishing and packing, and secretory vesicles release them by exocytosis or stay inside as lysosomes.

Nucleus. The largest organelle, bounded by the **nuclear envelope**, a double membrane continuous with the rough ER and pierced by **nuclear pores** that let mRNA and ribosomal subunits out. Inside, DNA wound around histone proteins forms **chromatin**, which condenses into chromosomes at division, and the dense **nucleolus** makes rRNA and ribosomal subunits. It is the site of DNA replication and transcription.

Endoplasmic reticulum. A network of flattened sacs (cisternae) and tubes. **Rough ER** carries ribosomes and makes and transports proteins for export; it is abundant in secretory cells. **Smooth ER** has no ribosomes; it makes lipids and steroid hormones, stores Ca^{2+} in muscle, and detoxifies drugs in liver cells.

Ribosomes. Granules of rRNA and protein with no membrane, each a large and a small subunit that join during translation. Eukaryotic cytoplasmic ribosomes are **80S** (60S + 40S); those of prokaryotes, mitochondria and chloroplasts are **70S** (50S + 30S). Free ribosomes make proteins for use inside the cell; attached ones make proteins for export.

Golgi apparatus. A stack of curved cisternae; vesicles from the rough ER fuse with the forming (**cis**) face; proteins pass through the stack, where carbohydrate is added to make glycoproteins, and leave in vesicles from the maturing (**trans**) face. It also forms lysosomes.

Lysosomes. Spherical sacs with a **single** membrane, filled with hydrolytic enzymes (acid hydrolases). They digest material taken in by phagocytosis, break down worn-out organelles (**autophagy**) and digest the whole cell when it dies (**autolysis**).

Mitochondria. Rod-shaped, about 1 to 10 µm long, with a **double** membrane. The inner membrane is folded into **cristae** carrying the electron transport chain and ATP synthase, and encloses the **matrix** where the Krebs cycle runs. They carry out aerobic respiration and make most of the cell's ATP, so active cells have many. They have circular DNA and 70S ribosomes and divide independently.

Chloroplasts. Lens-shaped, 2 to 10 µm, with a double membrane. Inside, flattened sacs called **thylakoids** are stacked into **grana**; their membranes hold chlorophyll and run the light-dependent reactions. The surrounding fluid, the **stroma**, holds the Calvin cycle enzymes, starch grains, circular DNA and 70S ribosomes. Chloroplasts are one type of **plastid**.

Organelle	Membranes	Main function
Nucleus (chromatin, nucleolus)	Double, with pores	Holds genes; DNA replication and transcription; makes ribosomal subunits
Rough ER	Single	Proteins for export
Smooth ER	Single	Lipids and steroids; detoxification
Ribosome, 80S or 70S	None	Translation

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Golgi apparatus (cis and trans faces)	Single	Modifies, sorts and packs proteins; makes lysosomes
Lysosome	Single	Intracellular digestion, autophagy
Mitochondrion (cristae, matrix)	Double	Aerobic respiration, ATP
Chloroplast (grana, stroma)	Double	Photosynthesis

B4.2.2 Describe the cytoskeleton, centrioles, vacuoles and the cell wall

Cytoskeleton. A network of protein fibres, none with a membrane, that gives the cell its shape and moves organelles and the whole cell.

- **Microtubules**: hollow tubes of **tubulin**; form the spindle, the core of cilia and flagella, and the centrioles; tracks for vesicle transport.
- **Microfilaments**: solid threads of **actin**; drive cytoplasmic streaming (cyclosis), amoeboid movement, the cleavage furrow and muscle contraction.
- **Intermediate filaments**: rope-like fibres such as keratin, for strength.

Centrioles. A pair of short hollow cylinders at right angles near the nucleus of animal cells, each built of **nine triplets** of microtubules in a ring. Before division they replicate and move to opposite poles to organise the spindle; they also form the **basal bodies** of cilia and flagella. Flowering plants lack centrioles but still build a spindle.

Vacuoles. Fluid-filled sacs with a single membrane. A mature plant cell has one large **central vacuole**, up to 90% of the cell volume, bounded by the **tonoplast** and filled with **cell sap** (water, sugars, ions, wastes, pigments); it keeps the cell **turgid** and stores substances. Animal cells have only small temporary vacuoles; *Amoeba* has a **contractile vacuole** that pumps out water entering by osmosis.

Cell wall. A rigid layer outside the plasma membrane of plant, fungal and bacterial cells; animal cells never have one. The plant wall is **cellulose** microfibrils in a matrix of hemicellulose and pectin: a **middle lamella** shared between neighbours, a thin **primary wall** and sometimes a thick **secondary wall** hardened with **lignin**, as in xylem. The wall is **fully permeable**; only the membrane inside it is selective. Strands of cytoplasm called **plasmodesmata** pass through it to link neighbouring cells. The wall stops the cell bursting in a hypotonic solution. Fungal walls are chitin, bacterial walls peptidoglycan.

> **MDCAT trap: counting membranes**
>
> Options such as "ribosomes are membrane-bound" or "the lysosome has a double membrane" catch students every year. Learn three groups. Double membrane: nucleus, mitochondrion, chloroplast and other plastids. Single membrane: ER, Golgi apparatus, lysosome, vacuole and every vesicle. No membrane: ribosomes, centrioles, cytoskeleton and nucleolus. So ribosomes are present in prokaryotes, and when a stem asks which structure a prokaryote lacks the answer is never ribosomes.

> **Worked example**
>
> Cell P, from the pancreas, secretes digestive enzymes. Cell Q is a white blood cell that engulfs

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and destroys bacteria. Which organelle is more abundant in P, and which in Q?

Step 1: Digestive enzymes are proteins for export, made on the rough ER and packed by the Golgi apparatus, so P is rich in both.

Step 2: A phagocyte takes bacteria in by endocytosis and digests them with lysosomal enzymes, so Q is rich in lysosomes.

Answer: rough ER (with Golgi apparatus) in P; lysosomes in Q.

B4.3 Prokaryotic and eukaryotic cells

B4.3.1 Compare prokaryotic and eukaryotic cells, and plant and animal cells

Prokaryotic cells (bacteria and cyanobacteria) are the older and simpler type. The name means "before the nucleus": the single circular chromosome, without histones, lies free in a region called the **nucleoid**. There are no membrane-bound organelles; respiratory enzymes sit on the plasma membrane and its infoldings (**mesosomes**). The cytoplasm holds 70S ribosomes and often small DNA rings called **plasmids**. Outside is a wall of **peptidoglycan** (murein), sometimes a **capsule**, flagellum and pili. They divide by **binary fission**.

Eukaryotic cells (protists, fungi, plants, animals) keep linear chromosomes with histones in a **true nucleus** with a double envelope; the cytoplasm holds membrane-bound organelles and 80S ribosomes, and division is by mitosis or meiosis.

Feature	Prokaryotic cell	Eukaryotic cell
Size	About 1 to 10 µm	About 10 to 100 µm
Nucleus	None; DNA in the nucleoid	True nucleus with envelope and pores
DNA	One circular chromosome, no histones; plasmids	Linear chromosomes with histones
Membrane-bound organelles	None	Mitochondria, ER, Golgi, lysosomes, plastids
Ribosomes	70S	80S (70S inside mitochondria and chloroplasts)
Cell wall	Peptidoglycan	Cellulose (plants), chitin (fungi), none (animals)
Division	Binary fission	Mitosis or meiosis

Plant and animal cells are both eukaryotic; the differences follow from the plant making its own food and supporting itself by water pressure.

Feature	Plant cell	Animal cell
Cell wall	Cellulose	Absent
Plastids (chloroplasts)	Present	Absent

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Vacuole	One large central vacuole with tonoplast	Small and temporary, if any
Centrioles	Absent (flowering plants)	Present
Storage carbohydrate	Starch	Glycogen
In a hypotonic solution	Turgid	Bursts
Cytokinesis	Cell plate	Cleavage furrow

B4.3.2 Relate cell specialisation to function and describe the use of the microscope in cell study

Cells become **specialised** for one job and their structure reflects it: match the feature in the stem to the job.

- **Red blood cell:** biconcave disc for surface area; no nucleus or mitochondria, so more haemoglobin fits in.
- **Sperm:** flagellum, midpiece packed with mitochondria to power it, acrosome with enzymes to enter the egg.
- **Muscle fibre:** many mitochondria, actin and myosin. **Neuron:** long axon, myelin sheath. **Secretory cells:** extensive rough ER and Golgi apparatus.
- **Root hair cell:** long thin extension for surface area, many mitochondria for active ion uptake, no chloroplasts.
- **Palisade cell:** packed with chloroplasts. **Xylem vessel:** dead, hollow, lignified for support and water transport.

Magnification is how many times larger the image is than the object. **Resolution** is the smallest distance between two points at which they still appear separate; it decides how much detail can be seen, and magnification beyond the resolution limit only gives a bigger blur. Resolution is limited by wavelength, which is why electron beams, with far shorter wavelengths than light, resolve so much more.

Property	Light microscope	Electron microscope
Useful magnification	Up to about × 1500	Up to about × 500 000
Resolution	About 0.2 µm (200 nm)	Below 1 nm
Specimen	Can be living; colour seen	Dead, in a vacuum; black and white image
Types	Compound, phase-contrast	TEM (section, internal detail); SEM (surface, 3-D view)

- Magnification = image size ÷ actual size; so actual size = image ÷ magnification.
- Total magnification of a compound microscope = eyepiece × objective (× 10 with × 40 gives × 400).
- 1 mm = 1000 µm; 1 µm = 1000 nm. Put image and object in the same unit before dividing.

> **MDCAT trap: what a prokaryote does and does not have**

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Students over-correct. Having learned that bacteria are "simple", they tick options saying a prokaryote has no DNA, no ribosomes, no wall or no plasma membrane. All are false. A prokaryote has DNA (a circular chromosome, often with plasmids), 70S ribosomes, a plasma membrane carrying its respiratory enzymes and, nearly always, a peptidoglycan wall. What it lacks is any **membrane-bound** structure: no nuclear envelope, mitochondria, ER, Golgi apparatus, lysosomes or chloroplasts. The wall is peptidoglycan, never cellulose, and "no nucleus" does not mean "no chromosome".

Worked example

In a light micrograph at × 400, a cheek cell measures 24 mm across. What is its actual diameter in micrometres? Could a ribosome inside it be seen with this microscope?

Step 1: actual size = image size ÷ magnification = 24 mm ÷ 400 = 0.06 mm.

Step 2: 0.06 mm × 1000 = 60 µm, a normal size for a eukaryotic cell.

Step 3: A ribosome is about 20 to 25 nm across, far below the 200 nm resolution of a light microscope; more magnification would not help.

Answer: 60 µm; no, it is below the resolving power of a light microscope.

Practice MCQs

1. In the fluid mosaic model, the "mosaic" refers to:
   A. the two layers of phospholipid facing each other
   B. the lateral movement of phospholipids within each layer
   C. the proteins scattered through the phospholipid bilayer
   D. the carbohydrate chains on the outer surface
2. Which of these crosses the plasma membrane by simple diffusion through the lipid bilayer, with no transport protein?
   A. Glucose
   B. Sodium ions
   C. Amino acids
   D. Oxygen
3. The rate of uptake of a substance into a cell rises with its concentration and then levels off, and a respiratory poison has no effect. The substance enters by:
   A. simple diffusion
   B. facilitated diffusion
   C. active transport
   D. endocytosis
4. Three plant cells lie side by side. Cell 1 has a water potential of –600 kPa, cell 2 of –200 kPa and cell 3 of –900 kPa. Net water movement by osmosis is:
   A. from 2 to 1 and from 1 to 3
   B. from 3 to 1 and from 1 to 2
   C. from 1 to both 2 and 3
   D. from 2 to 3 and from 3 to 1
5. Which organelle is bounded by a single membrane and contains hydrolytic enzymes?

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A. Mitochondrion
B. Lysosome
C. Nucleus
D. Ribosome

6. A cell has a well-developed Golgi apparatus and extensive rough endoplasmic reticulum. Its most likely function is:
   A. secretion of a protein hormone
   B. synthesis of a steroid hormone
   C. storage of glycogen
   D. aerobic respiration at a high rate
7. A cell has a cellulose wall, a large central vacuole and chloroplasts, but no centrioles. It is from:
   A. a bacterium
   B. a fungus
   C. an animal
   D. a flowering plant
8. A cell contains 70S ribosomes, a circular chromosome without histones and a wall of peptidoglycan. Which structure will it also contain?
   A. Mitochondria
   B. A nuclear envelope
   C. A plasma membrane
   D. A Golgi apparatus
9. A chloroplast 5 µm long appears 25 mm long in an electron micrograph. The magnification of the micrograph is:
   A. × 500
   B. × 5000
   C. × 50 000
   D. × 125
10. Which statement correctly relates structure to function?
    A. Red blood cells have many mitochondria to supply ATP for carrying oxygen
    B. The midpiece of a sperm is packed with mitochondria to power the flagellum
    C. Root hair cells have chloroplasts to make sugar for ion uptake
    D. Pancreatic secretory cells have mostly smooth ER to make enzymes

1. C. The mosaic is the pattern of proteins in the bilayer; fluidity is the sideways movement of the molecules.

2. D. Oxygen is small and non-polar, so it dissolves in the lipid; glucose, amino acids and ions all need proteins.

3. B. Levelling off shows limited carrier proteins, and the poison has no effect, so no ATP is used: facilitated diffusion.

4. A. Water moves from higher (less negative) to lower (more negative) water potential: –200 to –600 kPa, then –600 to –900 kPa.

5. B. Lysosomes are single-membrane sacs of acid hydrolases; mitochondrion and nucleus have double membranes, the ribosome none.

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6. A. Rough ER makes proteins for export and the Golgi apparatus packs them; a steroid would need smooth ER.

7. D. A cellulose wall and chloroplasts rule out bacteria, fungi (chitin wall) and animals; no centrioles fits a flowering plant.

8. C. The features describe a prokaryote, which lacks membrane-bound organelles but, like every cell, has a plasma membrane.

9. B. Same unit first: 25 mm = 25 000 µm; 25 000 ÷ 5 = 5000.

10. B. Midpiece mitochondria power the flagellum; mature red blood cells lack mitochondria, root hairs lack chloroplasts, and export enzymes are made on rough ER.

Before the test: 12 facts to recite

1. Fluid mosaic model (Singer and Nicolson, 1972): phospholipid bilayer, heads out, tails in, with proteins scattered through it.
2. Passive transport (diffusion, facilitated diffusion, osmosis) goes down the gradient with no ATP; active transport goes against it with a carrier protein and ATP.
3. Facilitated diffusion is passive but needs a channel or carrier protein, so its rate levels off when the carriers are saturated.
4. Osmosis: water moves from higher to lower water potential; pure water is 0 kPa, every solution is negative, more solute means more negative.
5. Hypotonic: animal cell bursts, plant cell turgid. Hypertonic: animal cell crenates, plant cell plasmolyses.
6. Sodium-potassium pump: 3 Na^+ out, 2 K^+ in, per ATP. Phagocytosis takes in solids, pinocytosis liquids, exocytosis releases; all need ATP.
7. Double membrane: nucleus, mitochondrion, chloroplast. Single: ER, Golgi, lysosome, vacuole. None: ribosome, centriole, nucleolus, cytoskeleton.
8. Rough ER makes proteins for export; smooth ER makes lipids and steroids; the Golgi apparatus modifies, sorts and packs proteins and forms lysosomes.
9. Ribosomes: 80S (60S + 40S) in eukaryotic cytoplasm; 70S (50S + 30S) in prokaryotes, mitochondria and chloroplasts.
10. Mitochondrion: cristae and matrix, aerobic respiration. Chloroplast: grana and stroma, photosynthesis. Both have circular DNA and 70S ribosomes.
11. Prokaryote: 1 to 10 µm, circular DNA without histones, no membrane-bound organelles, peptidoglycan wall, binary fission. Eukaryote: 10 to 100 µm, true nucleus, linear DNA with histones, organelles.
12. Plant cell only: cellulose wall, plastids, large central vacuole, starch. Animal cell only: centrioles, glycogen. Magnification = image size ÷ actual size; 1 mm = 1000 µm; resolution, not magnification, limits detail.

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