Unit 1

Answers: Cell Biology

Quick checks

1 c Every cell needs ribosomes to make its proteins, so prokaryotes have them too (smaller, 70S ones). What prokaryotes lack are the parts enclosed by membranes: a nucleus, mitochondria, a Golgi body.

2 b Animal cells have no wall, so nothing in them needs peptidoglycan. Cellulose walls belong to plant cells, not animal ones.

3 b The wall lets water and dissolved substances through freely; the membrane chooses what passes, which is why the beetroot's pigment stayed in until the membrane was damaged.

4 c Amyloplasts are leucoplasts (colorless plastids) that store starch (*amylon*, starch). Aleuroplasts store protein, chromoplasts hold colored pigments, and chloroplasts are green.

5 c Red, purple and blue anthocyanins dissolve in water, so they are carried in the cell sap of the vacuole. Chromoplasts hold the fat-soluble yellow, orange and some reds (carotenoids, such as a tomato's lycopene).

6 b Proteins to be sent out are made by the ribosomes of the rough ER, finished in the Golgi body, then carried in vesicles to the membrane. The smooth ER makes lipids, not proteins.

1 a. **c** *Nostoc* is a cyanobacterium, a prokaryote. *Amoeba* is a protist, yeast a fungus and *Spirogyra* a green alga: all eukaryotes.

1 b. **c** Bacterial walls are peptidoglycan (murein). Cellulose is in plant walls, chitin in fungal walls, and pectin in the middle lamella between plant cells.

1 c. **b** Singer and Nicolson's model (1972) pictures the cell membrane as a fluid bilayer of lipids with proteins set in it like a mosaic.

1 d. **b** F_1 particles, the ATP synthase of respiration, cover the inner membrane's cristae, facing the matrix. (Chloroplasts have a similar enzyme on their thylakoids, but the names F_1 particle and oxysome are used for the mitochondrion's.)

1 e. **c** The nucleolus makes ribosomal RNA and puts it together with proteins into the subunits of ribosomes, which leave through the nuclear pores.

1 f. **c** Vesicles from the Golgi bodies (dictyosomes) gather across the middle of the dividing cell and join into the cell plate, which becomes the new wall.

1 g. **b** A centriole is 9 + 0: nine triplets and nothing in the middle. Nine pairs round two central ones (9 + 2) is a cilium or flagellum.

1 h. **b** When a cell is badly damaged, its lysosomes can burst and their enzymes digest the cell itself (autolysis).

1 i. **b** The smooth ER makes lipids, including steroid hormones. The rough ER makes proteins.

2 a. Water enters both cells by osmosis. The plant cell swells until its cytoplasm presses against its firm **cell wall**, which pushes back and stops more water entering: the cell becomes turgid but doesn't burst. A red blood cell, like every animal cell, has **no cell wall**, only its thin membrane, which stretches until it tears.

2 b. Most of a cell's **aerobic respiration** happens in mitochondria: the Krebs cycle in the matrix and the making of **ATP** on the cristae. ATP carries energy to every part of the cell that needs it, so mitochondria supply most of the cell's usable energy, as a powerhouse supplies a town with electricity.

2 c. They have their own **DNA** and **70S ribosomes**, so they make some of their own proteins, and they grow and **divide by themselves**. But most of their proteins are made from genes in the cell's nucleus, so they can't live on their own: they are only partly (semi) independent.

2 d. The enzymes of respiration that make ATP, including the F_1 particles, sit on the **inner membrane**. Folding it into **cristae** packs a far larger area into the same small mitochondrion, room for many more of these enzymes, so the mitochondrion can make more ATP.

2 e. A lysosome is a bag of powerful **digestive enzymes**. When a cell is badly damaged or dying, its lysosomes burst, and the enzymes digest the cell's own contents (**autolysis**): the cell destroys itself.

2 f. Pancreas cells make large amounts of **digestive enzymes**, which are proteins, and **secrete** them. Proteins to be sent out are made by the ribosomes of the **rough ER**, then finished, packed and sent out by the **Golgi bodies**. So these cells need plenty of both.

2 g. Chloroplasts photosynthesize, which needs **light**, and roots grow in the dark soil, where photosynthesis is impossible. Root cells have leucoplasts instead, which store the food the leaves make and send down (starch in amyloplasts).

2 h. A ribosome is only about **25 nm** across, and a light microscope can't show detail smaller than about **0.2 μm (200 nm)**, however much it magnifies. A ribosome is about eight times smaller than that limit; it can be seen only with an electron microscope.

3 a.

Prokaryotic cell	Eukaryotic cell
No true nucleus; DNA in a nucleoid.	A true nucleus with a nuclear envelope.
No membrane-bound organelles.	Membrane-bound organelles (mitochondria, ER, Golgi bodies…).
70S ribosomes.	80S ribosomes in the cytoplasm.
Usually one circular chromosome, often plasmids.	Several linear chromosomes.
Small, mostly 1–5 μm.	Larger, mostly 10–100 μm.
Examples: bacteria, cyanobacteria.	Examples: *Amoeba*, fungi, plants, animals.

3 b.

Cell wall	Cell membrane
Outermost layer, outside the membrane, of plant, fungal and most bacterial cells.	Present in every cell, inside the wall if there is one.
Not living, made by the cell.	Living, part of the cell.
Made of cellulose (plants), chitin (fungi) or peptidoglycan (bacteria).	Made of a lipid bilayer with proteins.
Thick and firm.	Very thin (about 8 nm) and flexible.
Fully permeable.	Selectively permeable.

3 c.

Mitochondrion	Chloroplast
In almost all eukaryotic cells, plant and animal.	Only in green cells of plants and algae.
Inner membrane folded into cristae.	Inner membrane smooth; inside are thylakoids stacked in grana.
Fluid inside called the matrix.	Fluid inside called the stroma.
No pigment.	Contains chlorophyll.
Releases energy from food by respiration, making ATP; uses oxygen, gives out carbon dioxide.	Traps light energy to make food by photosynthesis; uses carbon dioxide, gives out oxygen.

3 d.

Rough ER	Smooth ER
Ribosomes on its outer surface.	No ribosomes.
Mostly flattened cisternae.	Mostly tubules.
Makes proteins to be secreted or put into membranes.	Makes lipids and steroid hormones; detoxifies drugs and poisons.
Plentiful in cells that secrete proteins (pancreas).	Plentiful in cells that make lipids and in liver cells.

3 e.

Chloroplast	Chromoplast
Green, with chlorophyll.	Yellow, orange or red, with carotenoids (carotene, xanthophyll, lycopene).
Found in leaves and green stems.	Found in petals, ripe fruits and carrots.
Makes food by photosynthesis.	Gives color, attracting animals for pollination and seed dispersal.

3 f.

Lysosome	Vacuole
Small (0.1–1 μm), many in a cell.	In a plant cell usually one, very large (up to 80–90% of the cell).
Filled with digestive enzymes, acidic.	Filled with cell sap: water, sugars, salts, pigments, wastes.
Digests worn-out parts and things taken in; autolysis.	Keeps the cell turgid; stores food, water, wastes and pigments.
Mainly in animal cells.	Mainly in plant cells (small or none in animal cells).

3 g.

70S ribosome	80S ribosome
In prokaryotes, and in mitochondria and chloroplasts.	In the cytoplasm (and on the ER) of eukaryotic cells.
Subunits 50S and 30S.	Subunits 60S and 40S.
Smaller, about 20 nm across.	Larger, about 25–30 nm across.
Jammed by antibiotics such as streptomycin.	Not affected by those antibiotics.

4 a. **Organelles** are the parts inside a cell, each with its own structure and job, most of them enclosed by membranes. Found in plant cells but not animal cells: the **cell wall** and **plastids** (chloroplasts); a **large central vacuole** (animal cells have only small ones). Found in animal cells but not most plant cells: the **centrosome** (centrioles) and **lysosomes** (plant cells' vacuoles do their work).

4 b. **Structure:** it is made mainly of **cellulose** fibrils set in hemicellulose and pectin. It has three layers: the **middle lamella** of calcium and magnesium pectate, shared with the neighboring cell, which glues them together; the thin, stretchy **primary wall** of a growing cell; and in some cells, once they stop growing, a thick **secondary wall**, often hardened with **lignin**. Fine channels, **plasmodesmata**, cross it and join neighboring cells' cytoplasm.

Functions: it gives the cell shape and strength, protects it, stops it bursting when water enters (keeping it turgid, which keeps the plant's soft parts upright), and, being fully permeable, lets water and dissolved substances pass freely; plasmodesmata let materials pass between cells.

4 c. The **fluid mosaic model** was put forward by **Singer and Nicolson in 1972**. The membrane, about 8 nm thick, is a **double layer of phospholipids**: their water-loving heads face the watery outside and inside, and their water-avoiding tails meet in the middle. **Proteins** are set in it like the tiles of a mosaic: integral proteins cross it, some forming channels and carriers, and peripheral proteins sit on one face. **Cholesterol** lies among the tails in animal cells, and **sugar chains** stick out from proteins and lipids on the outer face, for recognition. It is **fluid** because the lipids and many proteins move sideways within their layer, and a **mosaic** because of the scattered proteins. (Diagram: as in Figure 1.5, labeling the phospholipid head and tails, bilayer, integral protein, channel protein, peripheral protein, cholesterol and carbohydrate chain.)

4 d. **Structure** (diagram as Figure 1.6): a rod or grain 0.5–1 μm wide and up to 10 μm long, bounded by two membranes. The **outer membrane** is smooth; the **inner membrane** is folded into **cristae**, whose inner face carries **F_1 particles** (ATP synthase). Between them is the **intermembrane space**. The **matrix** inside holds the enzymes of the Krebs cycle, circular **DNA** and **70S ribosomes**.
Functions: it carries out aerobic **respiration**, breaking down food with oxygen to carbon dioxide and water and making most of the cell's **ATP** (the powerhouse of the cell); with its own DNA and ribosomes it makes some of its own proteins and divides by itself.

4 e. **Plastids** are double-membraned organelles of plant and algal cells, with their own DNA. By color there are three kinds:

1. **Chloroplasts**, green, with chlorophyll, in leaves and green stems: they photosynthesize.
2. **Chromoplasts**, yellow, orange or red, with carotenoids, in petals, ripe fruits (a ripe tomato) and carrots: they give color.
3. **Leucoplasts**, colorless, in roots, tubers and seeds: they store food: **amyloplasts** starch (potato), **elaioplasts** oils and fats, **aleuroplasts** proteins.

One kind can become another: a tomato's chloroplasts become chromoplasts as it ripens.

4 f. A chloroplast (diagram as Figure 1.8) is a lens-shaped body about 5 μm long, bounded by a double **envelope** (outer and inner membrane). Inside is the fluid **stroma**, with enzymes, starch grains, circular **DNA** and **70S ribosomes**. In the stroma lie flat sacs of membrane, **thylakoids**, stacked like coins into **grana**; single thylakoids, the **stroma lamellae**, join the grana. **Chlorophyll** is in the thylakoid membranes, where light is trapped; sugar is made in the stroma.

4 g. **Structure:** a round body 5–10 μm across bounded by a double **nuclear envelope**, its outer membrane joined to the ER, crossed by **nuclear pores**. Inside is **nucleoplasm**, with **chromatin** (DNA wound round histones; lightly staining, active **euchromatin** and dark, packed **heterochromatin**), which coils into chromosomes when the cell divides, and one or more **nucleoli**, with no membrane.

Functions: it holds the cell's hereditary DNA and controls the cell through it, deciding which proteins are made; it makes RNA copies of genes; its nucleolus makes ribosome parts; and it copies its DNA and passes a set to each new cell when the cell divides.

4 h. **Structure:** a stack of 4–8 flattened, curved sacs (**cisternae**) with small **vesicles** budding off their edges. Its **cis face** receives vesicles from the ER; its **trans face** sends finished products away in vesicles. In plants there are many small Golgi bodies, called dictyosomes.

Functions: (any four) it modifies proteins and lipids from the ER (often adding sugars); sorts and packs them into vesicles; secretes enzymes, hormones and mucus out of the cell; makes lysosomes; makes cell wall materials and the cell plate in plant cells; forms the acrosome of a sperm.

4 i. **Structure:** the centrosome, near the nucleus of animal cells, has two **centrioles** lying at **right angles** to each other in a cloud of dense material. Each centriole is a short hollow cylinder (about 0.25 μm by 0.5 μm) whose wall is **nine triplets of microtubules**, with none in the middle (**9 + 0**), joined in a young centriole by a hub and spokes.

Functions: in cell division the centrosomes move to opposite ends of the cell and form the **spindle**, which separates the chromosomes; it organizes the cell's microtubules; and centrioles form the **basal bodies** of cilia and flagella. Most flowering plants have no centrosome.

4 j. **Ribosomes** are tiny organelles, about 20–30 nm, with **no membrane**, made of ribosomal RNA and protein in a large and a small subunit (80S, 60S + 40S, in eukaryotes; 70S, 50S + 30S, in prokaryotes, mitochondria and chloroplasts). They lie free in the cytoplasm or bound to the ER. They are called **protein factories** because they make every protein of the cell: each reads a messenger RNA copy of a gene from the nucleus and joins amino acids in the order it gives.

4 k.

1. **Nucleus:** the gene is copied into messenger RNA, which leaves through a nuclear pore.
2. **Ribosomes on the rough ER:** read the RNA and make the enzyme, which passes into the ER's lumen and is folded.
3. **Vesicles** carry it from the ER to the cis face of the **Golgi body**, which finishes it (often adding sugars), and sends it out of the trans face in a new vesicle.
4. The vesicle joins the **cell membrane** and releases the enzyme outside (exocytosis).

Mitochondria supply the ATP for every step.

4 l. **Respiration:** glucose + oxygen → carbon dioxide + water + energy (ATP). Glucose is split in the **cytoplasm** (glycolysis); the pieces are broken down in the **mitochondria**, in the matrix (Krebs cycle), and most ATP is made on the cristae using oxygen. The **cell membrane** lets oxygen in and carbon dioxide out. It goes on in every living cell, day and night.

Photosynthesis: carbon dioxide + water → glucose + oxygen, using light and chlorophyll. It happens in the **chloroplasts**: light is trapped by chlorophyll in the **thylakoids** (where water is split and oxygen given off), and glucose is made in the **stroma**. The wall and membrane let carbon dioxide in and oxygen out.

The two are linked: the products of photosynthesis (glucose, oxygen) are what respiration uses, and the products of respiration (carbon dioxide, water) are what photosynthesis uses.

4 m. **Excretion: lysosomes** digest worn-out parts and the cell's waste; the **smooth ER** (in liver cells) detoxifies drugs and poisons; the **Golgi body** packs substances in vesicles that leave the cell; **vacuoles** store wastes (in plants, tannins and crystals) or pump out extra water (contractile vacuole of *Amoeba*); the **cell membrane** lets carbon dioxide and urea out.

Reproduction: the **nucleus** copies its DNA and shares the chromosomes equally between the two new cells; the **centrosome** forms the spindle in animal cells; **mitochondria** supply ATP and divide themselves; the **cell membrane** pinches in (animal cells) or vesicles of the **Golgi body** build the cell plate (plant cells); **ribosomes** make the new proteins.

4 n. The **endosymbiotic theory** (Lynn Margulis, 1967) says that mitochondria and chloroplasts were once free-living bacteria that were taken into a larger cell and lived on inside it, to the benefit of both. Evidence (any three): they are about the size of bacteria; they have **two membranes**; they have their own **circular DNA**, like bacteria; they have **70S ribosomes**, like bacteria; they **divide by splitting** and can't be made by the cell from nothing; their DNA is most like that of particular bacteria (purple bacteria and cyanobacteria).

5 a. Total magnification = 10 × 100 = **1,000×**.
Image size = 2 μm × 1,000 = 2,000 μm = **2 mm**.

5 b. Length = 120 mm ÷ 400 = 0.3 mm = **300 μm**.
Width = 20 mm ÷ 400 = 0.05 mm = **50 μm**.

5 c. 4 cm = 40,000 μm.
Magnification = image size ÷ real size = 40,000 μm ÷ 8 μm = **5,000×**.

5 d. 0.45 mm = 450 μm.
Width of one cell = 450 μm ÷ 9 = **50 μm**.

5 e.

Side	Surface area	Volume	Ratio
1 µm	6 µm²	1 µm³	6 per µm
5 µm	150 µm²	125 µm³	1.2 per µm
10 µm	600 µm²	1,000 µm³	0.6 per µm

As the cell gets bigger, the ratio gets **smaller**: ten times the width gives ten times less surface for each unit of volume. A cell takes in food and oxygen and lets out wastes through its surface, so a cell that grew too big couldn't supply its inside fast enough. That is one reason cells stay small, and why big organisms are made of many cells instead of one huge one.

5 f. 30 cm = 300,000 µm, so the scale is 300,000 ÷ 2 = **150,000 times**.
Ribosome = 0.02 µm × 150,000 = 3,000 µm = **3 mm**, the size of a small bead or a large mustard seed: yes, easily seen. (In a eukaryotic cell model, which has to be scaled down much more to fit, a ribosome would be too small to see.)