

ESAT

Biology

Cells and organisation

Free lesson notes

Covers	B1.1, B1.2 and B1.3
Format	Lesson, worked examples, self-check
Price	Free

About this lesson

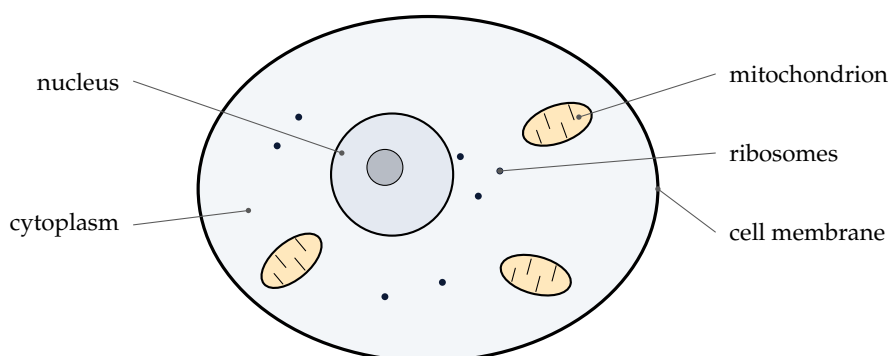
Every living thing is made of cells, and almost every question in ESAT Biology starts from them. This lesson covers the first block of the specification: the parts of **eukaryotic** cells (animal and plant), the simpler **prokaryotic** cell of a bacterium, and how cells are organised into **tissues, organs and organ systems**. Along the way you will learn how to **calculate magnification and real sizes**, which turns up as a calculation question in nearly every Biology paper and rewards a clear method.

We build everything from first principles. Each structure is introduced with what it *looks like*, what it *does*, and why a cell that does a particular job has more or fewer of it. Cover each worked example and try it before reading the solution. There is no calculator in the real ESAT, so the numbers here are friendly. Finish with the self-check, then the practice set.

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1 Eukaryotic cells: animal cells (B1.1)

All cells are small units of living material surrounded by a thin boundary. They are divided into two big groups. **Eukaryotic** cells have their genetic material (DNA) enclosed inside a **nucleus**. Animals, plants, fungi (such as yeast) and algae are all made of eukaryotic cells. **Prokaryotic** cells, the bacteria, have no true nucleus; we meet them in section 3. First, a typical animal cell.



Each part is called a **sub-cellular structure** (or organelle), and each has a job:

Structure	What it does
nucleus	contains the DNA (the genetic material) and so controls the activities of the cell
cytoplasm	a jelly-like liquid in which most chemical reactions of the cell take place
cell membrane	a thin, flexible layer that controls which substances enter and leave the cell
mitochondria (singular: mitochondrion)	the site of aerobic respiration , which releases the energy the cell needs
ribosomes	tiny structures where proteins are made (protein synthesis); they are too small to see with a light microscope

Why does the number of a structure vary? A cell has more of the structures that do the job it specialises in. A muscle cell needs lots of energy to contract, so it contains very many mitochondria. A cell that makes a lot of protein (such as one that secretes digestive enzymes) contains very many ribosomes. A cell that is not very active contains few. This idea, *structure matches function*, is behind many ESAT questions.

Key ideas

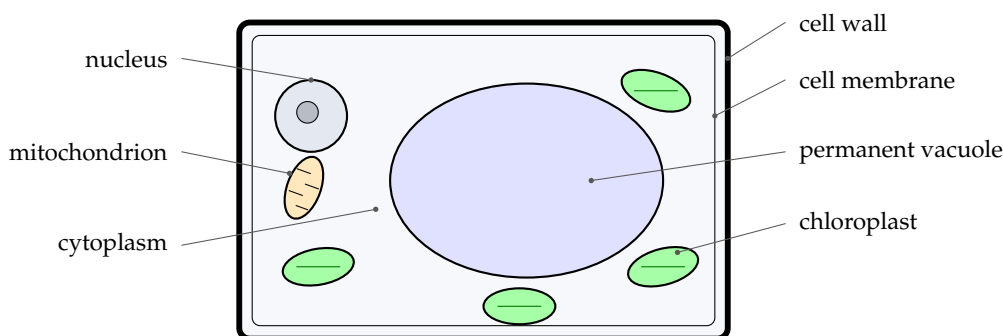
- Eukaryotic cells have a **nucleus** containing the DNA. Animal cells have a nucleus, cytoplasm, cell membrane, mitochondria and ribosomes.
- Mitochondria: aerobic respiration (energy). Ribosomes: protein synthesis. Membrane: controls what goes in and out. Cytoplasm: where reactions happen. Nucleus: holds DNA and controls the cell.

Common mistakes

- Saying the mitochondria “make energy”. Energy cannot be made; mitochondria *release* energy from glucose by respiration, and the energy is transferred to molecules the cell can use.
- Saying the cell membrane is a “barrier”. It is *partially permeable*: it lets some substances through and controls others.
- Confusing the cytoplasm (the whole jelly, where reactions happen) with the nucleus.

2 Plant cells (B1.1)

Plants are also eukaryotes, so a plant cell has everything an animal cell has (nucleus, cytoplasm, membrane, mitochondria, ribosomes) *plus* three further structures that are linked to how plants live: they are fixed in place, they are held up without a skeleton, and they make their own food.



Extra structure	What it does
cell wall	a rigid layer outside the membrane, made of cellulose ; it supports and strengthens the cell
permanent vacuole	a space filled with cell sap (a solution of sugars and salts); it keeps the cell firm (turgid) and stores substances
chloroplasts	contain the green pigment chlorophyll ; the site of photosynthesis , which makes glucose from carbon dioxide and water using light

Notice that the cell wall is *outside* the cell membrane. The wall is fully permeable and just gives strength; the membrane underneath is the part that controls what enters and leaves.

Not every plant cell has chloroplasts. Chloroplasts are found in the parts that are exposed to light, such as leaf cells. A root cell in the dark soil has no use for photosynthesis, and typically has no chloroplasts. Exam questions use this.

Yeast is a single-celled fungus and is eukaryotic: it has a nucleus, cytoplasm, membrane, mitochondria and ribosomes, and a cell wall (not made of cellulose), but it has no chloroplasts. It is an example of a cell that is neither a typical animal cell nor a plant cell.

Key ideas

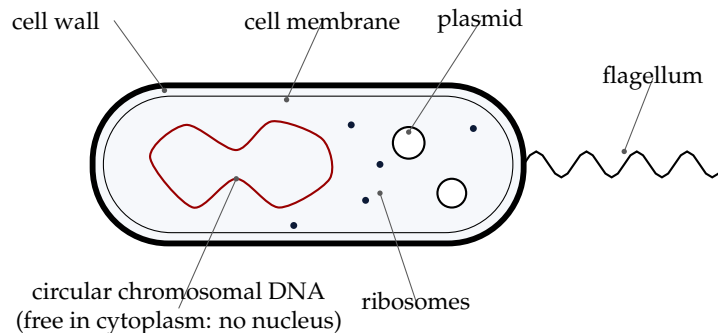
- Plant cell = animal cell structures + **cellulose cell wall**, **permanent vacuole**, **chloroplasts** (in cells exposed to light).
- Animal cells never have a cell wall, a permanent vacuole or chloroplasts.

Common mistakes

- Giving every plant cell chloroplasts. Root cells do not have them.
- Saying “the cell wall controls what enters and leaves”. That is the membrane’s job.
- Thinking plant cells have no mitochondria: they do, because plants respire as well as photosynthesise.

3 Prokaryotic cells: bacteria (B1.2)

A bacterium is a **prokaryotic** cell. It is much smaller than a typical eukaryotic cell (about 1 to 5 μm) and simpler. The crucial difference: **its DNA is not enclosed in a nucleus**.



A bacterial cell has:

- a **cell wall** (not made of cellulose) that protects and supports the cell;
- a cell membrane that controls what enters and leaves, and cytoplasm containing ribosomes;
- its main **chromosomal DNA**, a single loop lying free in the cytoplasm (there is no true nucleus);
- often one or more **plasmids**: small, extra rings of DNA, separate from the main loop, which carry a few additional genes (for example, genes that make the bacterium resistant to an antibiotic);
- sometimes a **flagellum**, a whip-like tail that rotates to move the cell.

Bacteria do **not** have mitochondria or chloroplasts. They still respire: the reactions simply happen without mitochondria.

	animal	plant	bacterium
nucleus	yes	yes	no ; DNA free
cell membrane	yes	yes	yes
cell wall	no	yes (cellulose)	yes (not cellulose)
mitochondria	yes	yes	no
ribosomes	yes	yes	yes
chloroplasts	no	some cells	no
plasmids	no	no	often
permanent vacuole	no	yes	no

Why this matters in medicine. Because bacterial cells have walls and human cells do not, a drug that stops a bacterium building its cell wall (as some antibiotics do) damages the bacteria but leaves human cells unharmed.

Key ideas

- Prokaryote: **no nucleus**; DNA is a free loop in the cytoplasm, plus (often) plasmids; cell wall, membrane, cytoplasm, ribosomes; no mitochondria or chloroplasts.
- Eukaryote: DNA inside a nucleus.

Common mistakes

- “Bacteria have no DNA.” They do have DNA; it is simply not inside a nucleus.
- Calling the bacterial wall “cellulose”. Plant cell walls are cellulose; bacterial walls are made of a different material.
- Putting mitochondria in bacteria.

4 Microscopes, units and magnification (B1.1)

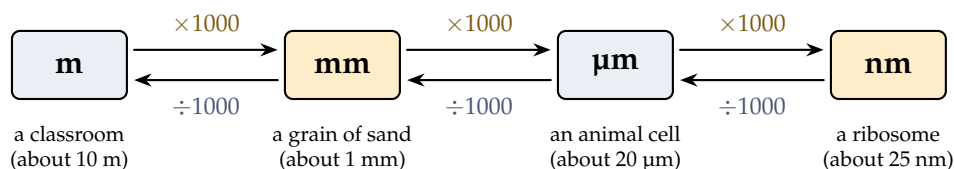
Most cells are too small to see. To study them we use microscopes, which produce a magnified **image**.

Two ideas: magnification and resolution. **Magnification** is how many times larger the image is than the real object. **Resolution** is the smallest distance between two points that can still be seen as two separate points; it decides how much *detail* you see. Magnifying a blurred image more just makes a bigger blur.

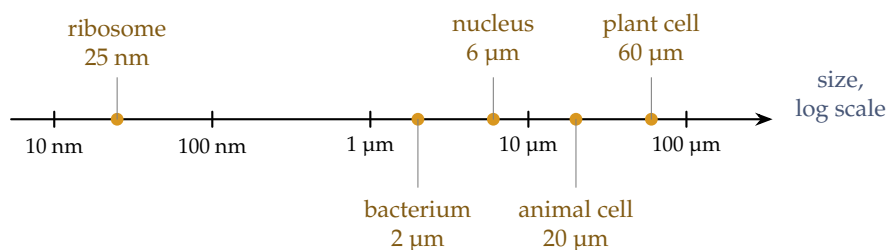
	light microscope	electron microscope
uses	light and glass lenses	a beam of electrons
maximum useful magnification	about $\times 1500$	more than $\times 500\,000$
resolution	lower (about $0.2\ \mu\text{m}$)	far higher (about 1000 times better)
shows	nuclei, cell walls, chloroplasts, vacuoles	also mitochondria in detail, ribosomes, plasmids
specimen	can be living	must be dead (in a vacuum)

The invention of the electron microscope let scientists see sub-cellular structures like ribosomes for the first time, which is why our knowledge of cell structure improved so much.

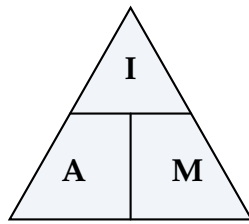
Units. Cell sizes need small units. Each unit in this ladder is a thousand times smaller than the one before.



To go to a *smaller* unit, multiply by 1000 (more of them fit into the same length): $0.5\ \text{mm} = 0.5 \times 1000 = 500\ \mu\text{m}$. To go to a *larger* unit, divide by 1000: $3500\ \text{nm} = 3.5\ \mu\text{m}$. For scale, here are typical sizes (approximate).



The magnification equation.



$$I = A \times M$$

I = size of the **image**
(measure it with a ruler)

$$M = \frac{I}{A}$$

A = **actual** size of the object

$$A = \frac{I}{M}$$

M = **magnification** (no unit)

I and A must be in the *same unit*

If an object of actual size A appears with size I in the image, the magnification is $M = I/A$. If you know any two of I , A and M , you can find the third. The **units of I and A must match**: this is the step that most often goes wrong, so always convert first. Measure I with a ruler, usually in millimetres, and convert to micrometres by multiplying by 1000.

Worked example: finding the magnification

A drawing of a cell is 30 mm long. The real cell is 0.06 mm long. What is the magnification?

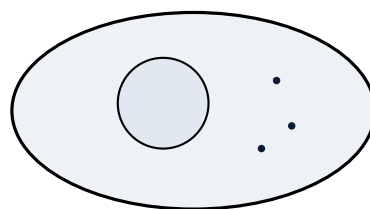
Both lengths are already in millimetres. $M = \frac{I}{A} = \frac{30}{0.06} = 500$, so the magnification is $\times 500$.

Worked example: finding the real size

An electron micrograph of a mitochondrion has a length of 9 mm and a magnification of $\times 4500$. What is its real length in micrometres?

$A = \frac{I}{M} = \frac{9}{4500} = 0.002$ mm. Convert: $0.002 \times 1000 = 2 \mu\text{m}$.

Scale bars. Many micrographs show a scale bar instead of a magnification. Measure the bar and the object on the image with a ruler. Then the real size is (object length on image) $\div$ (bar length on image) $\times$ (value on the bar).



length on the image = 48 mm



scale bar: 12 mm on the image represents $4 \mu\text{m}$

Worked example: using a scale bar

In the picture the cell is 48 mm long on the image and the scale bar is 12 mm long and stands for $4 \mu\text{m}$. How long is the real cell?

The cell is $48 \div 12 = 4$ bar-lengths long, so the real length is $4 \times 4 = 16 \mu\text{m}$.

Exam tip

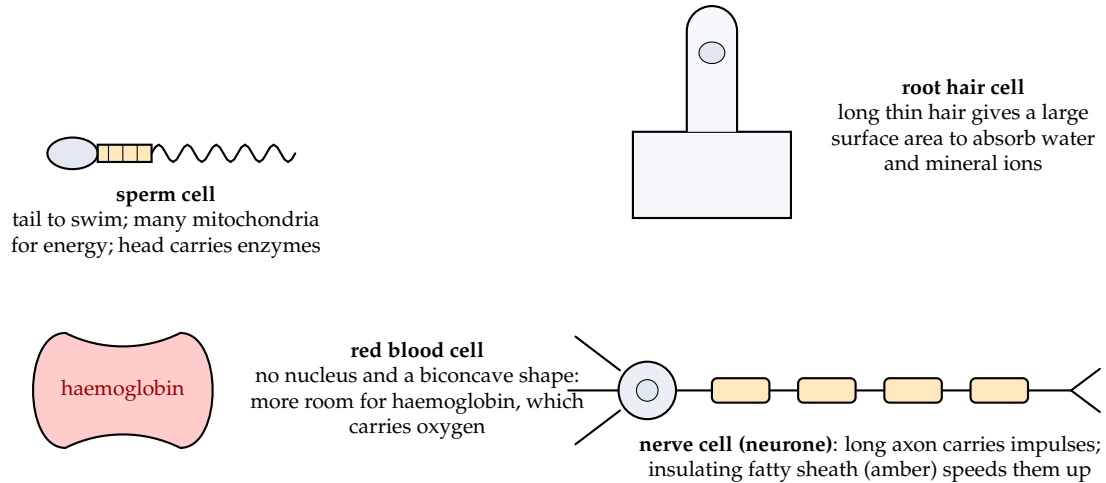
Write the equation $I = A \times M$ first, then substitute. Convert *before* you divide. Check that your answer is sensible: a bacterium of $2 \mu\text{m}$ is not 2 mm or 2 m.

Common mistakes

- Mixing units: dividing 12 mm by $6 \mu\text{m}$ without converting.
- Multiplying the image size by the magnification instead of dividing to find the real size.
- Mixing up the " $\times 1000$ or $\div 1000$ " direction: going to a smaller unit gives a bigger number.

5 Specialised cells (B1.3)

A human body starts as a single cell, yet it contains over two hundred different types of cell. Cells become different by **differentiation**: as an embryo grows, cells develop the structures they need for a particular job and become **specialised**. A specialised cell has features that suit its function (structure matches function). The commonest examples are below.



- **Sperm cell** (carries the male's DNA to the egg): a tail to swim, many mitochondria to release the energy for swimming, and enzymes in the head to break into the egg.
- **Root hair cell** (takes in water and mineral ions): the long hair-like extension greatly increases surface area for absorption.
- **Red blood cell** (carries oxygen): contains haemoglobin, which binds oxygen; has no nucleus, leaving more room for haemoglobin; its flattened, dented shape gives a large surface area for oxygen to diffuse in and out.
- **Nerve cell** (carries electrical impulses): very long extension (the axon) to carry impulses over long distances, with an insulating fatty sheath that speeds up the impulse.

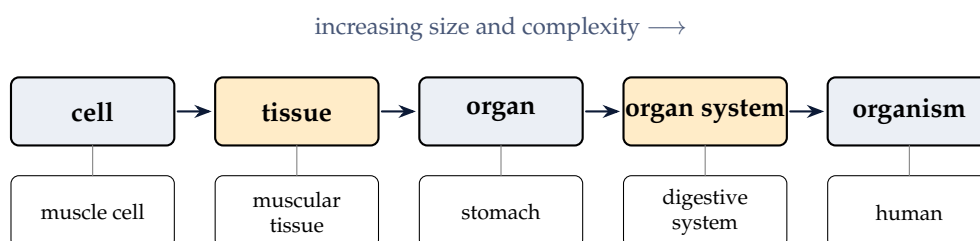
To answer a "why does this cell have..." question, first say what the cell *does*, then link the structure to it: *many mitochondria* → *lots of aerobic respiration* → *lots of energy for swimming*.

Common mistakes

- Saying a sperm cell has many mitochondria "to make energy". Say they *release energy by respiration for the tail to move*.
- Describing the structure without saying why it helps ("it has a long hair" does not score; "long hair increases the surface area for absorbing water" does).
- Thinking specialised cells have different DNA. All the body cells of one person contain the same DNA; they use different parts of it.

6 Tissues, organs and organ systems (B1.3)

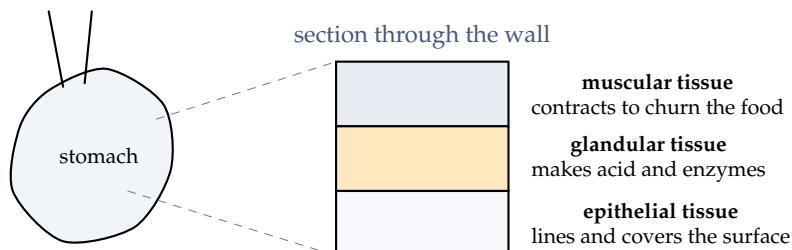
Specialised cells do not work alone. They are organised in levels, each built from the one below:



- A **tissue** is a group of similar cells working together to do a job (muscular tissue, glandular tissue, epithelial tissue).

- An **organ** is a group of different tissues working together to carry out a particular function.
- An **organ system** is a group of organs working together to do a job for the body as a whole.
- An **organism** is a complete living thing: many organ systems working together.

Take the stomach. It is an organ because it is made of several tissues:



Muscular tissue contracts to churn the food; **glandular tissue** makes the digestive juices (acid and enzymes); **epithelial tissue** covers the inside and outside surfaces. The stomach is one organ of the **digestive system**, along with the salivary glands, pancreas, liver, small and large intestines. The digestive system breaks down food into small soluble molecules that can be absorbed into the blood.

Other organ systems you should be able to describe at this level: the **circulatory system** (heart, blood vessels and blood, carrying substances around the body), the **respiratory system** (lungs and airways, gas exchange) and the **nervous system** (brain, spinal cord and nerves, coordination).

Worked example: naming the level

Classify each: (a) a single red blood cell; (b) the heart; (c) cardiac muscle; (d) the circulatory system.
 (a) a *cell*. (b) an *organ*: it contains muscle, connective and other tissues. (c) a *tissue*: many similar cells. (d) an *organ system*: the heart, blood vessels and blood working together. In order of size: (a) < (c) < (b) < (d).

Common mistakes

- Using “tissue” and “organ” interchangeably. A tissue contains one type of cell; an organ contains several tissues.
- Calling blood an organ: it is a tissue (a fluid tissue of different cells in plasma).
- Listing the wrong organs in a system, for example putting the heart in the respiratory system.

7 Putting it together: exam technique

Cell structure questions usually ask: name a structure from its function, say which structure is present or absent in a given cell, or compare cells. Make a mental table (like the one in section 3) with the four columns *animal*, *plant*, *bacterium*, *yeast* and the structures down the side.

If the question says...	...think
“no nucleus”	prokaryote (bacterium); or a mature red blood cell
“cell wall, nucleus, no chloroplasts”	yeast or a plant root cell
“releases energy”	mitochondria (aerobic respiration)
“makes protein”	ribosomes
“photosynthesis”	chloroplasts
“can see with a light microscope”	nucleus, cell wall, chloroplasts, vacuole
“can only be seen with an electron microscope”	ribosomes, plasmids, mitochondrial detail

Calculation questions: write $I = A \times M$, convert both lengths to the same unit, then rearrange. Estimate first: if the cell looks 50 times wider than a bacterium, expect a size about 50 times bigger.

Spec coverage (B1.1 to B1.3). This lesson covers eukaryotic components, prokaryotic components (including plasmids and the absence of a true nucleus), and cells, tissues, organs and organ systems.

Check yourself

Try these without looking back, then compare with the answers on the next page.

1. Name the structure where aerobic respiration takes place, and the structure where proteins are made.
2. State two structures found in a plant leaf cell but not in an animal cell.
3. Give two differences between a bacterial cell and an animal cell.
4. An onion cell appears 20 mm wide in a drawing with magnification $\times 100$. What is its real width in micrometres?
5. Convert 0.004 mm to micrometres and 2500 nm to micrometres.
6. Why can a light microscope not show ribosomes?
7. Explain why a sperm cell has many mitochondria.
8. Put in order, smallest to largest: organ, cell, organ system, tissue.

Answers to the self-check

1. Mitochondria; ribosomes.
2. Any two of: cell wall (cellulose), permanent vacuole, chloroplasts.
3. Bacteria have no nucleus (DNA is a free loop, possibly with plasmids) and they have a cell wall; animal cells have a nucleus and no cell wall. (Also: no mitochondria in bacteria.)
4. $A = 20/100 = 0.2 \text{ mm} = 200 \mu\text{m}$.
5. $0.004 \times 1000 = 4 \mu\text{m}$; $2500 \div 1000 = 2.5 \mu\text{m}$.
6. Ribosomes are smaller than the smallest separation (the resolution) of a light microscope; only an electron microscope has enough resolution.
7. They carry out aerobic respiration, releasing the energy needed for the tail to move the cell.
8. Cell, tissue, organ, organ system.

Next step

Heurisco's *ESAT Biology: Cells and Organisation Practice Set* has twenty original exam-style questions on this lesson, with diagrams and magnification calculations, in order of difficulty, with a full worked solution and a note on the trap in each.