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Overview

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TOPIC A2
UNITY AND DIVERSITY: CELLS

SUBTOPIC A2.2

CELL STRUCTURE

A2.2.0 The big picture



A2.2.1-2 Using microscopes

Table of
contents

A2.2.3 Developments in microscopy



Notebook

A2.2.4-6 Prokaryotic and eukaryotic
cells

Glossary

A2.2.7 Processes of life in unicellular
organismsReading
assistance

A2.2.8-11 Animal, plant and fungal cells

A2.2.12-14 Endosymbiosis, cell
differentiation and the evolution
of multicellular organisms (HL)

A2.2.15 Summary and key terms

A2.2.16 Checklist

A2.2.17 Investigation

A2.2.18 Reflection

Student
view

Show all topics





Overview
(/study/app/
422-
cid-
755105/o

Teacher view

Index

- The big picture
- Using microscopes
- Developments in microscopy
- Prokaryotic and eukaryotic cells
- Processes of life in unicellular organisms
- Animal, plant and fungal cells
- Endosymbiosis, cell differentiation and the evolution of multicellular organisms (HL)
- Summary and key terms
- Checklist
- Investigation
- Reflection

A2. Unity and diversity: Cells / A2.2 Cell structure

The big picture

? Guiding question(s)

- What are the features common to all cells and the features that differ?
- How is microscopy used to investigate cell structure?

Keep the guiding questions in mind as you learn the science in this subtopic. You will be ready to answer them at the end of this subtopic. The guiding questions require you to pull together your knowledge and skills from different sections, to see the bigger picture and to build your conceptual understanding.

In 1665, Robert Hooke, an English scientist and inventor, made a ground-breaking discovery while examining a piece of cork through a primitive microscope (**Figure 1**). He observed that the cork was made up of small compartments, which he referred to as ‘cells’, because they reminded him of the small rooms or ‘cellula’ in a monastery. This discovery was an important milestone in the field of biology, as it provided the first evidence that living organisms are made up of small, discrete units.



Student
view

Home
Overview
(/study/app/
422-
cid-
755105/o

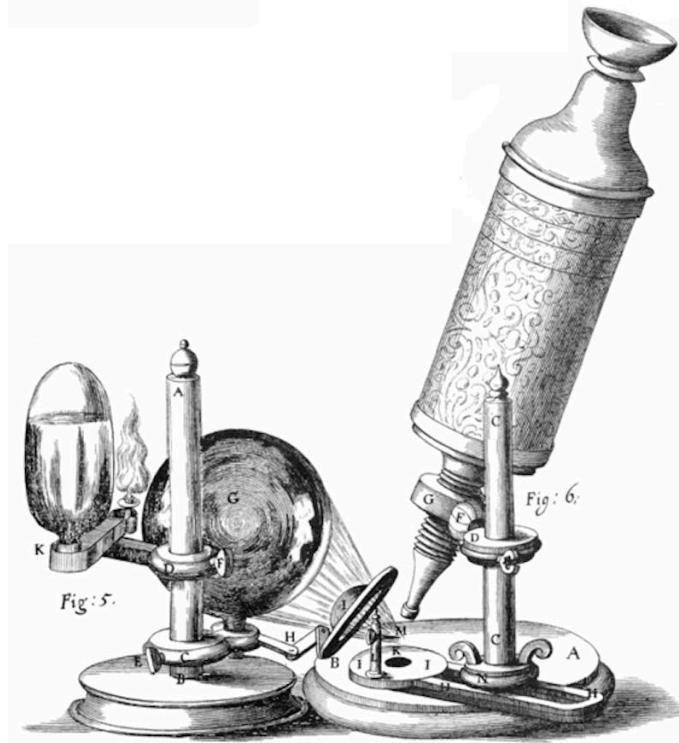


Figure 1. An original illustration showing Robert Hooke's microscope.

Source: ["Robert Hooke's microscope"](#)

(https://commons.wikimedia.org/wiki/File:Robert_Hooke%27s_microscope.png) by the Royal Society of London is in the public domain (https://en.wikipedia.org/wiki/Public_domain)

More information for figure 1

Cells are the smallest units of self-sustaining life, and they come in a wide range of shapes, sizes and functions. They can range from the tiny crescent-shaped bacteria such as *Pelagibacter ubique*, which measure about $0.5\text{ }\mu\text{m}$ in length, to long and thin animal nerve cells that can reach over 1 m in length (**Figure 2**).

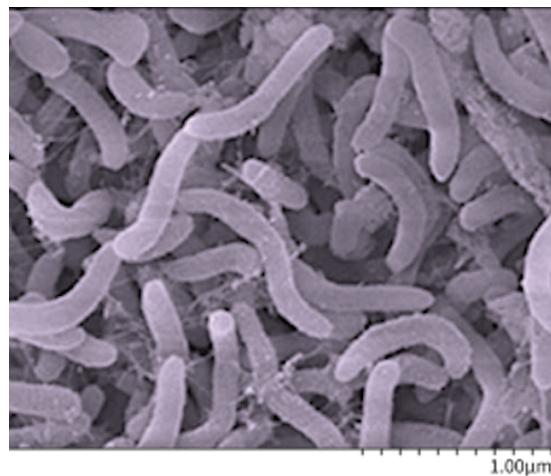
Most cells are too small to be seen with the naked eye, so we rely on microscopes to view them. As technology has advanced, scientists have developed various techniques to produce detailed images of cells, allowing us to understand the different types of cells, their functions and the components within them.

But what are these techniques, and what have scientists discovered about cells? What have they found inside cells, and how has this knowledge impacted our understanding of the natural world? These are just a few of the many questions that continue to drive research in the field of biology.



Student
view

Home
Overview
(/study/app/
422-
cid-
755105/o



Source: [Pelagibacter](https://commons.wikimedia.org/wiki/File:Pelagibacter.jpg) (<https://commons.wikimedia.org/wiki/File:Pelagibacter.jpg>) by NOAA Ocean Exploration and research is in the public domain (https://en.wikipedia.org/wiki/Public_domain)



Credit: PIXOLOGICSTUDIO, Getty Images (<https://www.gettyimages.com/detail/illustration/nerve-cell-artwork-royalty-free-illustration/478188147>)

ⓘ More information

Figure 2. Cells can range from the tiny crescent-shaped bacteria such as *Pelagibacter ubique*, to long and thin animal nerve cells.

☰ Prior learning

Before you study this subtopic make sure that you understand the following:

- Cells are the smallest units of self-sustaining life ([section A2.1.2–6](#) ↗
(/study/app/bio/sid-422-cid-755105/book/the-origins-of-cell-hl-id-43955/)).

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Student
view

- DNA is the genetic material of all living organisms ([section A1.2.1 \(/study/app/bio/sid-422-cid-755105/book/nucleic-acids-and-their-structure-id-43580/\)](#)).

Practical skills

Once you have completed this subtopic, you can gain microscopy skills by going to [Practical 1: Using microscopes and calculating magnification \(/study/app/bio/sid-422-cid-755105/book/using-microscopes-and-calculating-magnification-id-46529/\)](#).

A2. Unity and diversity: Cells / A2.2 Cell structure

Using microscopes

A2.2.1: Cells as the basic structural unit of all living organisms A2.2.2: Microscopy skills

Learning outcomes

By the end of this section you should be able to:

- Outline cell theory and describe the structure and components of a typical cell.
- Summarise how to make and stain temporary mounts of cells and tissues.
- Describe how to use an eyepiece graticule and stage micrometre to measure sizes of a specimen.
- Perform calculations involving actual size, image size and magnification.

Microscopes are scientific instruments used to magnify objects or images that are too small to be seen with the unaided eye. The first microscopes were thought to have been developed in the 17th century, and they were initially used to view small objects and animals, such as insects.

In the 17th century, two scientists, Robert Hooke and Antoni van Leeuwenhoek, were independently credited with discovering microorganisms using light microscopes (**Figure 1**), which are similar to the microscopes commonly found in schools today. These microscopes use lenses and light to magnify objects by 10–400 times their actual size.

Home
Overview
(/study/app/
422-
cid-
755105/o

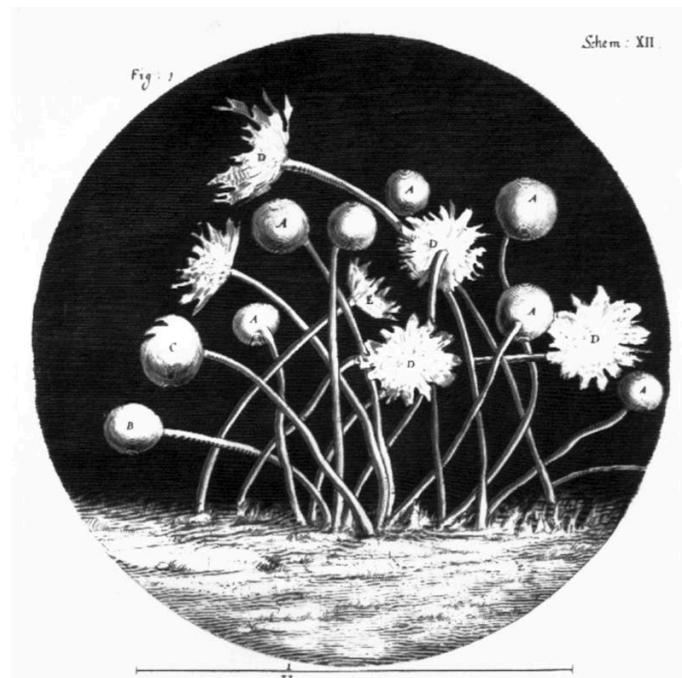


Figure 1. The first published illustration of a microorganism, a 'hairy mould', published by Robert Hooke in 1665 in his book *Micrographia*. Note the scale bar at the bottom of this image that shows the actual size of this part of the specimen as 1/32 inch (0.8 mm).

Source: ["Robert Hooke Micrographia Schematic 12 Upper Part"](#)

(https://commons.wikimedia.org/wiki/File:Robert_Hooke_Micrographia_Schematic_12_Upper_Part.png)
is in the public domain (https://en.wikipedia.org/wiki/Public_domain)

More information for figure 1

This is an illustration depicting a microscopic view of a mold, referred to as 'hairy mold,' by scientist Robert Hooke in his work, *Micrographia*, published in 1665. The illustration shows several stalk-like structures rising from a base, each terminating in various spherical and spiny formations. Some spheres are marked with letters such as 'A' and 'B'. There is a scale bar at the bottom of the image indicating that the area shown in the picture is 1/32 inch (0.8 mm).

[Generated by AI]

Since their development, microscopes have become an essential tool in a wide range of fields, including biology, medicine and materials science. There are several types of microscopes, including light microscopes, also called compound microscopes, which use lenses to magnify the image, and electron microscopes, which use a beam of electrons to create an image of a sample. Electron microscopes will be covered in more detail in [section A2.2.3](#) (/study/app/bio/sid-422-cid-755105/book/developments-in-microscopy-id-44718/).



Student
view

Home
Overview
(/study/app/
422-
cid-
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At the beginning of the 19th century, scientists developed light microscopes with sufficient power to allow observation that plant and animal tissue is made up of many individual cells. Since the invention of microscopes, technological advancements of methods and tools have continued to allow scientists to see the structures that make cells in increasing detail.

In your lessons you will probably view cells and tissues using a light microscope. When we are viewing an object using a microscope, we call the object being viewed a specimen. You may also make temporary mounts of specimens such as onion tissue and cheek cells.

When using a microscope, start with the lowest magnification possible and the stage at the highest position. To get a clear image of the specimen you will need to adjust the focus of the microscope using the coarse focus and the fine focus. Look through the eyepiece and use the coarse focus knob/wheel to adjust the distance between the specimen and the objective lens until the object comes into focus. Turn the knob anticlockwise to move the specimen further from the lens, and if you need to move it back up, turn the knob clockwise. At this point your specimen may still be slightly blurry, so use the fine focus knob/wheel to make smaller adjustments in the distance between the objective lens and the specimen to bring your object into focus. Now that you have a clear image you can adjust the magnification by rotating the nosepiece to use a different objective lens.

You can learn more about using light microscopes using this Virtual Microscope  (<https://www.ncbi.nlm.nih.gov/iet/microscope/>) laboratory simulation. Choose 'Explore' and select a slide to view from the 'Slide Catalog' box (marked with a '?'). You can view a range of slides at different magnifications. Use the coarse and fine sliders to focus the image.

Cell theory

People used to believe that living organisms could spontaneously appear from non-living matter, the theory of 'spontaneous generation'. With Robert Hooke and Antoni van Leeuwenhoek's discovery of cells using the light microscope in 1665, this theory was called into question. Robert Hooke's observations led to the development of a new theory, cell theory.

Nature of Science

 X
Student
view

Aspect: Theories

Home
Overview
(/study/app/
422-
cid-
755105/o

Theories are explanations of how things work based on scientific observation and evidence. They can change or be disproved over time based on new and updated scientific evidence.

Cell theory states that all living things are made of individual units, cells, which are the basic units of life, and that all cells arise from other cells. There was much debate over which theory was correct, and it was not until 1859 that the theory of spontaneous generation was conclusively debunked.

❖ Theory of Knowledge

Many different scientists have contributed to our understanding of cell theory:

- In 1665, Robert Hooke discovered cork cells (non-living) using his microscope.
- In 1674, Antoni van Leeuwenhoek first observed living cells under the microscope.
- In 1838, Matthias Schleiden and Theodor Schwann compared their observations of plant and animal cells.
- In 1858, Rudolf Virchow stated '*omnis cellula e cellula*' (all cells come from cells).
- In 1839, Theodor Schwann first proposed cell theory.

To what extent does scientific collaboration need to occur in the same time frame or location?

❖ Nature of Science

Aspect: Theories

Deductive reasoning can be used to generate predictions from theories. Based on cell theory, we can predict that a newly discovered organism will consist of one or more cells.

X
Student
view



Making temporary mounts of cells and tissues

Overview

(/study/app

422-

cid-

755105/o

Temporary mounts are commonly referred to as wet mounts. See the instructions below and **Figure 2** to prepare a temporary mount of onion tissue.

1. Using a sharp scalpel, cut a small square of onion.
2. Using tweezers, peel off a thin inside layer of the onion.
3. Transfer the thin layer of onion onto a glass slide.
4. Using a pipette, add a small drop of iodine onto your specimen.
5. Starting with the cover slip at a 90° angle, gently lower the cover slip over the specimen to avoid bubbles.
6. If bubbles do occur, gently press the cover slip with the eraser end of a pencil to push out the bubble.

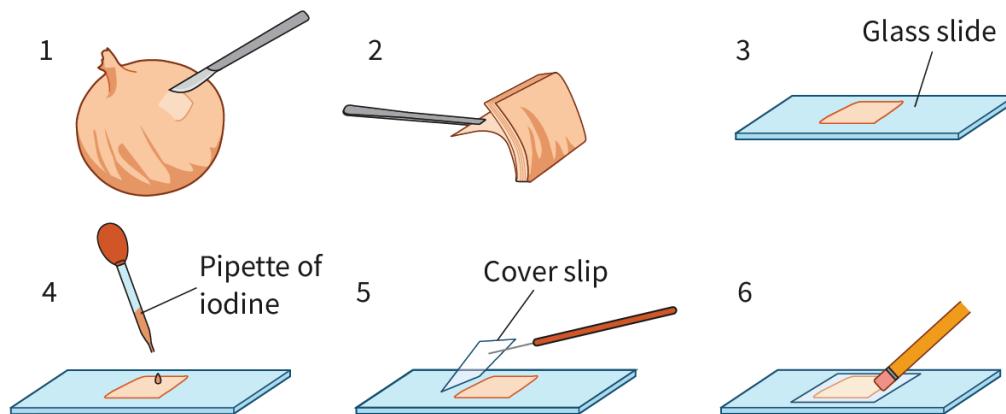


Figure 2. Steps involved in preparing a temporary mount of onion tissue.

More information for figure 2

The image illustrates six steps involved in preparing a temporary mount of onion tissue.

1. An onion bulb is shown with the top layer being peeled using a tool.
2. A piece of onion skin is depicted being removed.
3. The onion skin is placed on a glass slide.
4. A pipette of iodine is added to the onion skin on the slide.
5. A cover slip is placed over the onion skin on the glass slide.
6. A pencil is used to gently press and remove any air bubbles from the slide with the cover slip in place.

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Student
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Overview

(/study/app

422-

cid-

755105/0

As cells and their structures are usually transparent, it can be hard to distinguish different parts using a light microscope. To help visualise certain structures, we use stains. Stains bind preferentially to particular structures or areas on a cell, making that structure easier to see.

We use different stains to view different cell types. Iodine is a stain used to prepare slides of plant cells because it binds to the starch present in plant cells. Methylene blue (**Figure 3**) is an example of a stain that is commonly used to view animal cells, as it binds to the nuclei of cells. Gram staining is commonly used when viewing bacteria.

Sometimes colour is added to digital micrographs to help the viewer to see the different structures.

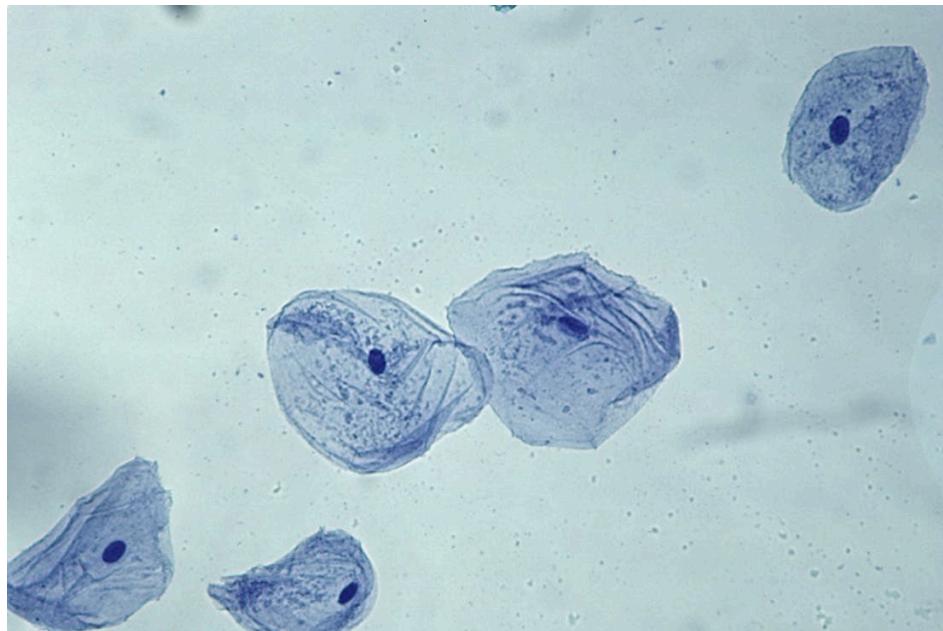


Figure 3. Epithelial (cheek) cells, stained with methylene blue and viewed under a magnification of $\times 100$.

Credit: Ed Reschke, Getty Images (<https://www.gettyimages.com/detail/photo/epithelial-cells-oral-cavity-methylene-blue-stain-royalty-free-image/139803215>)

Cover slips, sometimes called cover slides, are small, thin and fragile pieces of glass that are used to flatten and hold the specimen in place. Cover slides also prevent the specimen from drying out too quickly. If the specimen is accidentally brought to touch the objective lens of the microscope, the cover slip will protect the lens.

Home
Overview
(/study/app/
422-
cid-
755105/o

Watch **Video 1** to learn how to make a temporary (wet) mount of a specimen of *Elodea*, an aquatic plant. Note that you should only handle glass slides and coverslips by their edges. This avoids leaving fingerprints, which could distort the image formed of your specimen.

How To Prepare A Wet Mount Slide



Video 1. Making a temporary (wet) mount of *Elodea*.

Video 2 explains how to make a temporary (wet) mount of human cheek cells. Note that a different stain is used to view human cheek cells from that used to view onion tissue. Why might this be?

Cheek Epithelial Cells: How to Prepare a Wet Mount Microscope Slide



Video 2. Making a temporary (wet) mount of human cheek cells.

X
Student
view

Practical skills

Tool 1: Experimental techniques — Addressing safety of self, others and the environment

Whenever you carry out a practical activity you should take the time to consider potential hazards, and the precautions you will take to reduce the risks posed by these hazards.

In this practical you should consider what you will do to minimise the risk posed by:

- a sharp scalpel
- iodine solution, which can be harmful and a potential hazard
- broken glass.

CLEAPSS  (<https://science.cleapss.org.uk/resources/student-safety-sheets/>) provides resources and information sheets that you can use to understand hazards and risks posed by common laboratory chemicals and processes, as well as guidelines for ethical and safe disposal of used materials  (<https://science.cleapss.org.uk/resource/sss099-waste-disposal.pdf>).

It is important to remember that precautions should be taken during any investigations involving any body fluids, such as harvesting cheek cells for microscopy, due to the risk of transmission of pathogens. You should not collect samples yourself. Your teacher will advise and may provide pre-prepared slides for you to work with.

Using eyepiece graticules and stage micrometres

Often, the eyepiece lens of light microscopes will be fitted with an eyepiece graticule. Eyepiece graticules contain a scale or grid. When we look through the eyepiece lens this scale will be superimposed on the image of the specimen.

To be able to work out the size of the specimen we are viewing, we can use a stage micrometre to calibrate an eyepiece graticule. Stage micrometres are small, calibrated rulers that are mounted onto the stage of the microscope.

The stage micrometre shows the actual size of the image using divisions that are each 100 µm (0.1 mm) apart.



Overview
(/study/app/
422-
cid-
755105/o

- Each 100 µm division of the stage micrometre is equivalent to 20 eyepiece graticule divisions, which means that one graticule division is equal to 5 µm.

$$20 \text{ graticule divisions} = 100 \mu\text{m}$$

$$1 \text{ graticule division} = \frac{\text{number of micrometres}}{\text{number of graticule division}}$$

$$\begin{aligned} 1 \text{ graticule division} &= \frac{100}{20} \\ &= 5 \mu\text{m} \end{aligned}$$

We can see on **Figure 4** that the cell overlaps 4 eyepiece graticules, which means that the diameter of the cell is $4 \times 5 \mu\text{m} = 20 \mu\text{m}$.

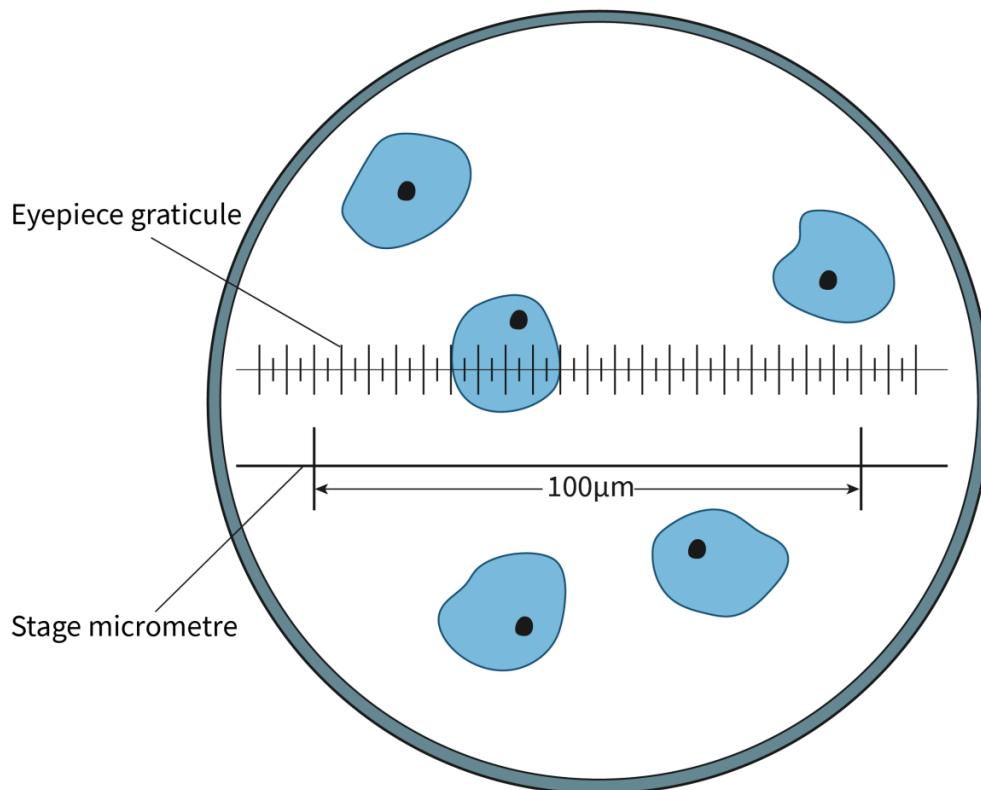


Figure 4. Using a stage micrometre and an eyepiece graticule.

More information for figure 4

The image is a circular diagram depicting a stage micrometre and an eyepiece graticule used for measuring cells.

Inside the circle, the diagram shows a linear scale representing the eyepiece graticule, with equidistant divisions marked both above and below a central horizontal line. There are five cells placed above and below this scale, represented as irregular blue shapes with black dots signifying their nuclei. The cells overlap the graticule lines, illustrating measurement. The scale includes a double-headed arrow labeled '100µm' that indicates the total length measured by the graticule. Labels on the outside point to 'Eyepiece graticule' and 'Stage micrometre'.

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Overview
 (/study/app/
 422-
 cid-
 755105/o)

平淡 Study skills

Make sure that all your measurements are in the same SI units before you carry out calculations.

Converting between units

Microscopes magnify small objects and organisms that we are unable to see with the unaided eye. Cells and cell structures are usually too small to be measured using millimetres, so instead we usually use micrometres (μm) as a unit of measurement. One millimetre is equal to 1000 micrometres. We can think of this in two ways:

- There are 1000 micrometres in one millimetre.
- There are 0.001 millimetres in one micrometre.

Although it is not common to measure cells or cell structures in nanometres, as most cells range from around 0.1 to 100 micrometres, you will also come across the unit nanometres in other parts of this course as measurements involving proteins, viruses and wavelengths of light are often given in nanometres. One micrometre is equal to 1000 nanometres (**Figure 5**). Similarly, we can think of this in two ways:

- There are 1000 nanometres in one micrometre.
- There are 0.001 micrometres in one nanometre.

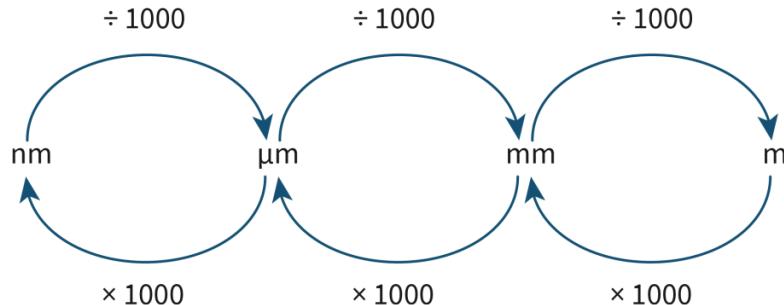


Figure 5. Converting between nanometres (nm), micrometres (μm), millimetres (mm) and metres (m). There are 1000 nm in 1 μm . To convert from nm to μm , divide by 1000. To convert from μm to

nm, multiply by 1000. There are 1000 μm in 1 mm. To convert from μm to mm, divide by 1000. To convert from mm to μm , multiply by 1000.

Overview
(/study/app/
422-
cid-
755105/o

 More information for figure 5

This image is a diagram showing the process of converting between nanometres (nm), micrometres (μm), millimetres (mm), and metres (m). It depicts three cyclical flows, each with arrows pointing in opposite directions, indicating back-and-forth conversion. The first cycle between nm and μm shows a process of dividing by 1000 to go from nm to μm and multiplying by 1000 to convert back from μm to nm. The second cycle between μm and mm follows the same pattern, dividing by 1000 to switch from μm to mm, and multiplying by 1000 for the reverse conversion. Similarly, the third cycle illustrates conversion between mm and m with the same operation of dividing and multiplying by 1000 for directional changes. This reflects a hierarchical conversion process across different metric units of length measurement, emphasizing the factor of 1000 for scaling between each unit.

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Worked example 1

How many millimetres are found in 76 000 μm ?

There are 1000 micrometres (μm) in one millimetre (mm).

To convert from micrometres (μm) to millimetres (mm), divide your value by 1000.

$$\frac{76\,000 \mu\text{m}}{1000} = 76 \text{ mm}$$

Worked example 2

A plasma cell measures 0.02 mm in diameter. Find the diameter of the cell in micrometres (μm).

To convert from millimetres (mm) to micrometres (μm), multiply your value by 1000.

$$0.02 \text{ mm} \times 1000 = 20 \mu\text{m}$$



Student
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Magnification calculations

Overview

(/study/app/422-cid-755105/o) We use the following equation to calculate how much an image has been magnified:

$$\text{magnification} = \frac{\text{image size}}{\text{actual size}}$$

If you know magnification and actual size, you can rearrange this equation to calculate the size of the image:

$$\text{image size} = \text{magnification} \times \text{actual size}$$

If you know the image size and the magnification, you can rearrange this equation to calculate the actual size

$$\text{actual size} = \frac{\text{image size}}{\text{magnification}}$$

Nature of Science

Aspect: Measurements

Measurement using instruments is a form of quantitative observation. Quantitative observations are numerical values, examples of which might be measurements of time, length and temperature.

In contrast, qualitative observations describe a quality, such as colour, behaviour or texture.

Worked example 3

A student observes and draws an amoeba. The diameter of the amoeba in the drawing is 90 mm. The actual diameter of the amoeba is 100 µm. What is the magnification of the drawing?

The question tells you the **image size** of the amoeba (90 mm) and the **actual size** (100 µm). This means you will use the equation:



$$\text{magnification} = \frac{\text{image size}}{\text{actual size}}$$

Before you carry out the magnification calculation, you need to convert the measurements into the same units.

There are 1000 μm in 1 mm, so to convert from μm to mm we divide by 1000.

$$\frac{100 \mu\text{m}}{1000} = 0.1 \text{ mm}$$

Now that your measurements are in the same units, substitute them into the equation:

$$\text{magnification} = \frac{\text{image size}}{\text{actual size}}$$

$$\text{magnification} = \frac{90}{0.1}$$

$$\text{magnification} = \times 900$$

Worked example 4

A white blood cell is viewed under a microscope using a magnification of $\times 400$. The graticule measures the actual size of the cell to be 11 μm . Calculate the size of the image produced in mm.

In this question you are given the magnification as $\times 400$ and the actual size as 11 μm .

To calculate the size of the image, use the equation:

$$\text{image size} = \text{magnification} \times \text{actual size}$$

Substitute your values into the equation:

$$\text{image size} = 400 \times 11 \mu\text{m} \quad \text{image size} = 4400 \mu\text{m}$$

The question has asked us to give our answer in millimetres. To convert from micrometres to millimetres, divide the value by 1000.





Overview

(/study/app

422-

cid-

755105/o

$$\frac{4400 \mu\text{m}}{1000} = 4.4 \text{ mm}$$

Worked example 5

A type of bacterium called *Escherichia coli* is viewed under the microscope using a magnification of $\times 50\,000$. The size of the image produced is 70 mm.

Calculate the actual size of this cell. Give your answer in micrometres.

To calculate actual size, use the equation

$$\text{actual size} = \frac{\text{image size}}{\text{magnification}}$$

The question tells you that the image size is 70 mm and the magnification is $\times 50\,000$.

Substitute these values into your equation

$$\text{actual size} = \frac{70}{50\,000}$$

$$\text{actual size} = 0.0014$$

The units for the actual size will be the same as the units for image size. This means that the actual size is 0.0014 mm.

The question has asked us to give our answer in micrometres. To convert from millimetres to micrometres, multiply the value by 1000.

$$0.0014 \times 1000 = 1.4 \mu\text{m}$$

⚠ Practical skills

Tool 1: Experimental techniques — Measuring variables

Student
view

Just like writing, drawing is a way in which we can communicate our observations to others. Follow these conventions when drawing your observations:



Overview
(/study/app/
422-
cid-
755105/o

- Draw your image as large as possible in the space provided.
- Always use a pencil. This means that if you make a mistake, you can correct it.
- When drawing the plasma membrane, or the membrane of organelles, make sure you use continuous lines.
- Only draw the structures that you can actually see. Do not add in things that you think should be there, but cannot see.
- Label important structures such as organelles and the plasma membrane using straight lines, drawn with a ruler and pencil. Make sure your line touches the structure that you are identifying and that label lines do not cross over one another.
- Indicate the magnification used to view the specimen.
- You may also want to add a scale bar. See **Video 3** for a detailed guide for constructing scale bars.

How to make scale bars for your biological sketches!

Section

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Feedback



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Assign

Video 3. Scale bars for biological sketches.

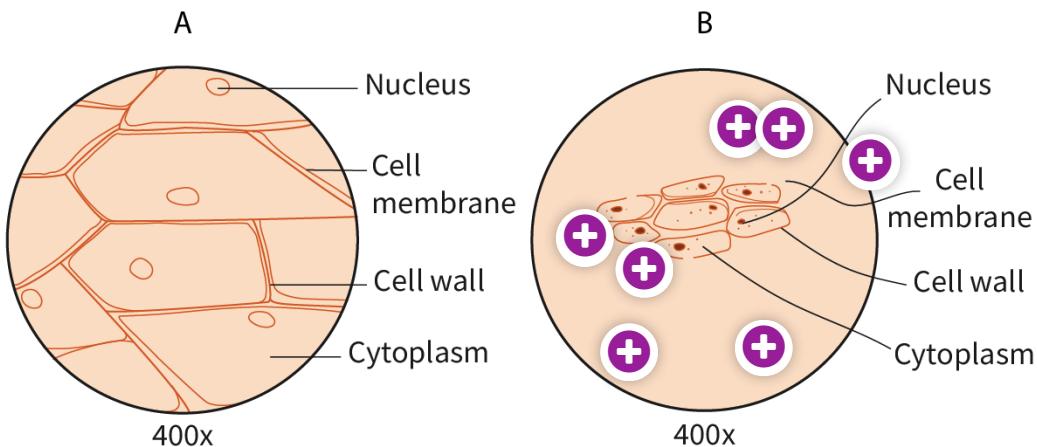
Interactive 1 shows an example and a non-example of a drawing of an onion cell.



Student
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Onion skin cell



Interactive 1. Comparison of Correct and Incorrect Onion Cell Drawings.

More information for interactive 1

An interactive feature compares two schematic diagrams of onion cells, labeled A and B. Both diagrams depict microscopic views at 400 \times magnification, with labeled cellular parts.

Diagram A represents the onion cell correctly. It displays an irregularly shaped outer layer labeled the cell wall, which surrounds the cell membrane. Inside the cell, a circular nucleus is present in the cytoplasm.

Diagram B does not represent the onion cell correctly. It shows cells only in the center. The cell wall is marked correctly, but the cell membrane is labelled inaccurately, pointing to an empty space. The circular nucleus is present in the cytoplasm.

Diagram B features plus icons representing interactive hotspots. Selecting a hotspot reveals the error associated with that part of the diagram:

Hotspot below the cells: Straight lines are required

Hotspot on empty space below the cells: Fill the space with your drawing

Hotspot on the cell: Incorrect to use shading

Hotspot on the space next to the cell: Features such as ribosomes should not be included as they cannot be seen at this magnification.

Hotspot on the empty space above the cells: Gap in the cell membrane

Hotspot on the line for labels: Gap in the cell membrane

Hotspot on the label line: Label lines should not cross over each other

This interactivity helps users recognize common errors made when drawing and labeling plant cells.



A scientific convention is an agreed rule followed by scientists throughout the world, whatever their language. Examples of scientific conventions include using element symbols and units.

How can these scientific conventions promote international mindedness and collaboration among scientists from different cultural and language backgrounds?

Try the questions in this activity to complete your understanding of microscopy.

Activity

- **IB learner profile attribute:** Thinker
- **Approaches to learning:** Thinking skills — Reflecting at all stages of the assessment and learning cycle
- **Time required to complete activity:** 10 minutes
- **Activity type:** Individual activity

Below are three questions to complete using your understanding from this section.

1. **Interactive 2** is a magnified image of kidney tissue, viewed using an eyepiece graticule. Use the draggable ruler to measure the image size of the graticule and then calculate the magnification used to view this tissue. Make sure your image and actual size are in the same units before you carry out the calculation.
2. **Interactive 3** is a magnification of a type of bacterium called *E. coli*, taken using an electron microscope. Use the draggable ruler to calculate the magnification and then measure the length of the bacteria in the image, and then calculate the actual size of the bacterium.
3. **Interactive 4** shows a type of plant cell from the epidermis of an onion, viewed using an eyepiece graticule.
 - (a) Move the ruler to measure the image size of the graticule and then calculate the magnification used to view this tissue. Make sure your image and actual size are in the same units before you carry out the calculation.
 - (b) This image was viewed using a stain called iodine. Write a sentence explaining what a stain is and why iodine is a suitable stain to use for viewing plant cells, but not animal cells.





Overview
(/study/app/
422-
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4. Interactive 2. Light micrograph of human kidney tissue.

More information for interactive 2

This interactive provides a microscopic view of human kidney tissue, highlighting tissue tubules, which are essential structures involved in filtration and secretion. These tubules play a crucial role in kidney function by facilitating the movement of fluids and waste.

The interactive includes measurement tools to help users analyze the scale of these microscopic structures.

A movable ruler below the image displays a millimeter scale ranging from 0 to 3 millimeters, while a micrometer scale bar in the lower right corner spans from 0 to 100 micrometers. By using these measurement tools, users can explore the relative size of kidney tubules and calculate magnification, reinforcing key concepts in histology and microscopy.

This hands-on approach helps users develop an understanding of scale in biological tissues and the importance of microscopic structures in organ function.



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Overview
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5. Interactive 3. Electron micrograph of *E. coli* bacteria.

More information for interactive 3

This high-resolution, black-and-white micrograph, captured using a scanning electron microscope (SEM), provides a detailed view of rod-shaped bacterial cells.

These cells closely resemble *Escherichia coli* (*E. coli*), a widely studied bacterium found in various environments, including the human gut. The image is magnified 15,000 times, as indicated by the "X15.0K" label, revealing intricate details of the bacterial outer membrane. At this magnification, users can observe the cell shape, surface texture, and structural organization of the bacteria.

A movable scale bar at the bottom measures distances in micrometers (μm), with each major division representing $2 \mu\text{m}$. By analyzing the scale and magnification, users can gain a deeper understanding of bacterial size, structure, and the capabilities of electron microscopy in visualizing microscopic life forms.



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Overview
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6. Interactive 4. Light micrograph of onion skin (epidermis) cells.

More information for interactive 4

This microscopic image showcases plant cells from the epidermal layer of an onion. The distinct rectangular or polygonal structures outlined by darker lines represent individual plant cells. These darker lines are the cell walls, which are primarily composed of cellulose, providing structural support and rigidity to the plant tissue. Inside each cell, the pale, translucent area is the cytoplasm, a gel-like substance that fills the cell and contains various organelles.

Some cells feature small, darker, circular structures, which are likely nuclei, the control centers of the cell that house genetic material (DNA).

The overall pale appearance suggests minimal staining, allowing the natural cellular structures to remain visible. Subtle variations in shading and texture within the cytoplasm may indicate the presence of other organelles or cellular components.

The scale bar in the upper right corner measures 25 micrometers (μm), enabling users to estimate the size of the cells and their internal structures. Additionally, the ruler at the bottom provides a millimeter (mm) scale, allowing for a direct comparison between microscopic and macroscopic measurements.

5 section questions



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A2. Unity and diversity: Cells / A2.2 Cell structure



Developments in microscopy

Overview
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A2.2.3: Developments in microscopy

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Section

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Feedback



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Assign

Learning outcomes

By the end of this section, you should be able to:

- Outline the applications of electron microscopy.
- Describe the application of techniques that are commonly used in microscopy.

The microscopes that you use in school are probably light microscopes: microscopes that pass light through a specimen and then use lenses to magnify the image produced. How can we visualise the smaller components of a cell that cannot be seen with a light microscope?

Electron microscopy

Another type of microscope that is commonly used to view cells and cellular structures is an electron microscope. Rather than passing light through a specimen, electron microscopes pass a beam of electrons through a specimen (**Figure 1**). Electrons will be absorbed by the denser parts of the sample, and scattered or able to pass through less dense areas, after which they are picked up by an electron detector and used to form an image.



Student
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Home
Overview
(/study/app/
422-
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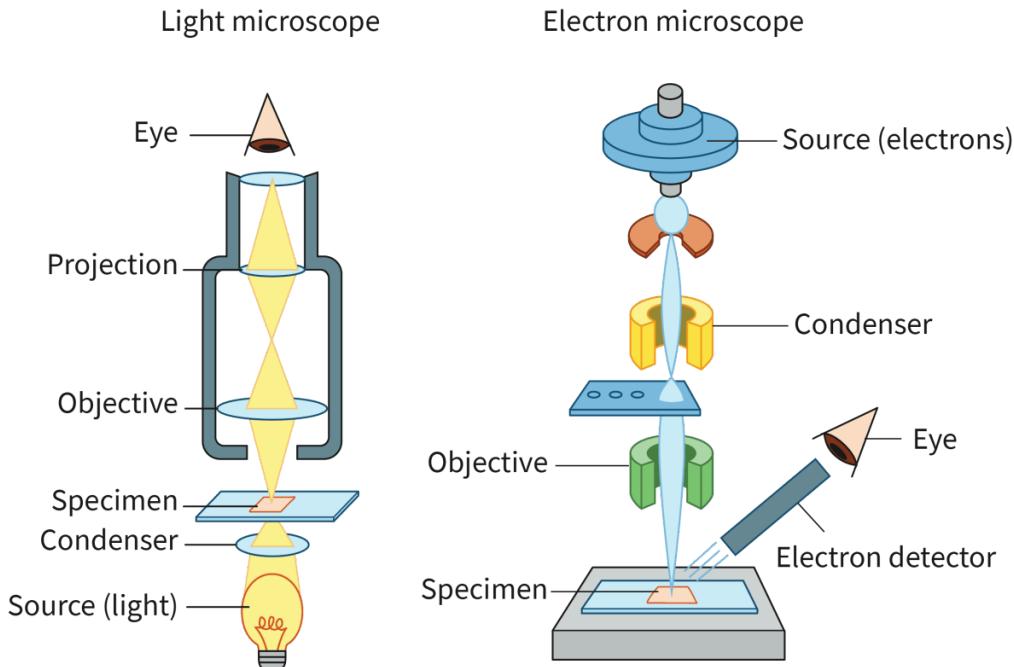


Figure 1. Light microscopes use light and lenses to create a magnified image of an object, whereas electron microscopes use a beam of electrons and a detector to form an image.

More information for figure 1

The image shows a side-by-side comparison of a light microscope and an electron microscope, illustrating their structural components. On the left side, the light microscope is depicted with labeled parts: a light source at the bottom that emits light through a condenser, then through a specimen, objective lens, projection lens, and finally reaching the eye. The image formed is based on light passing through the specimen.

On the right side, the electron microscope is shown. It uses a source of electrons that are focused through a condenser, then passed through the specimen, and detected by an electron detector before being visualized. This setup is labeled with components including the electron source, condenser, objective, specimen, and detector. The electron microscope relies on a beam of electrons passing through the sample, allowing visualization of higher resolutions due to shorter wavelength electrons, compared to the light from the light microscope.

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Because electrons have a much shorter wavelength than light, electron microscopes have a much higher resolution than light microscopes (**Figure 2**). The resolution of a light microscope is 200 nm compared with 0.1 nm for an electron microscope. This means that if

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Student
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Overview
(/study/app/
422-
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755105/o

two points are 100 nm apart, they will not be well-defined and their positions will be unclear when viewed using a light microscope, but they will appear much clearer under an electron microscope.

Study skills

Microscope resolution is the shortest distance between two separate points in a microscope's field of view that can still be distinguished as distinct objects.

A resolution of 0.1 nm is higher than a resolution of 200 nm. The greater the value, the lower the resolution.

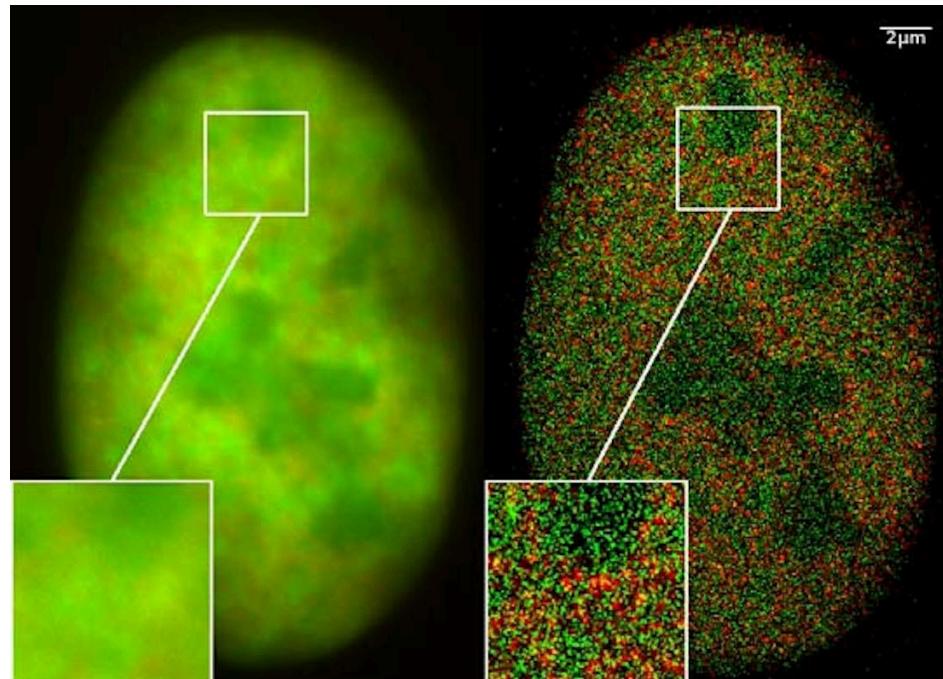


Figure 2. A low resolution image on the left and a high resolution image on the right.

Source: "GFP Superresolution Christoph Cremer

(https://commons.wikimedia.org/wiki/File:GFP_Superresolution_Christoph_Cremer.JPG) by Andy Nestl is licensed under CC BY-SA 3.0 (<https://creativecommons.org/licenses/by-sa/3.0/deed.en>)

Because of their high resolution, an electron microscope can magnify very small objects by about 500 000 times (**Figure 3**). This makes them suitable for studying small cellular structures, as well as disease-causing particles, such as viruses and prions.



Student
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Overview
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422-
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Light microscopes, with a magnification of about 2000 times, are useful for studying tissues and living cells in colour because they do not damage the specimen as electrons do. In contrast, electron microscopes, which can only be used to observe non-living or dead specimens in black and white, offer higher resolution and are often used to study the internal structure of a wide variety of specimens. However, both types of microscopes have their own advantages and are essential tools in scientific research.



Figure 3. An image of mitochondria produced using an electron microscope. Because electron microscopes have much higher resolution than light microscopes, it is possible to see much smaller structures such as organelles inside the cell.

Credit: Dlumen, [Getty Images \(https://www.gettyimages.com/detail/photo/photograph-of-mitochondria-showing-all-the-cells-in-royalty-free-image/175461301\)](https://www.gettyimages.com/detail/photo/photograph-of-mitochondria-showing-all-the-cells-in-royalty-free-image/175461301)

Techniques that are commonly used in microscopy

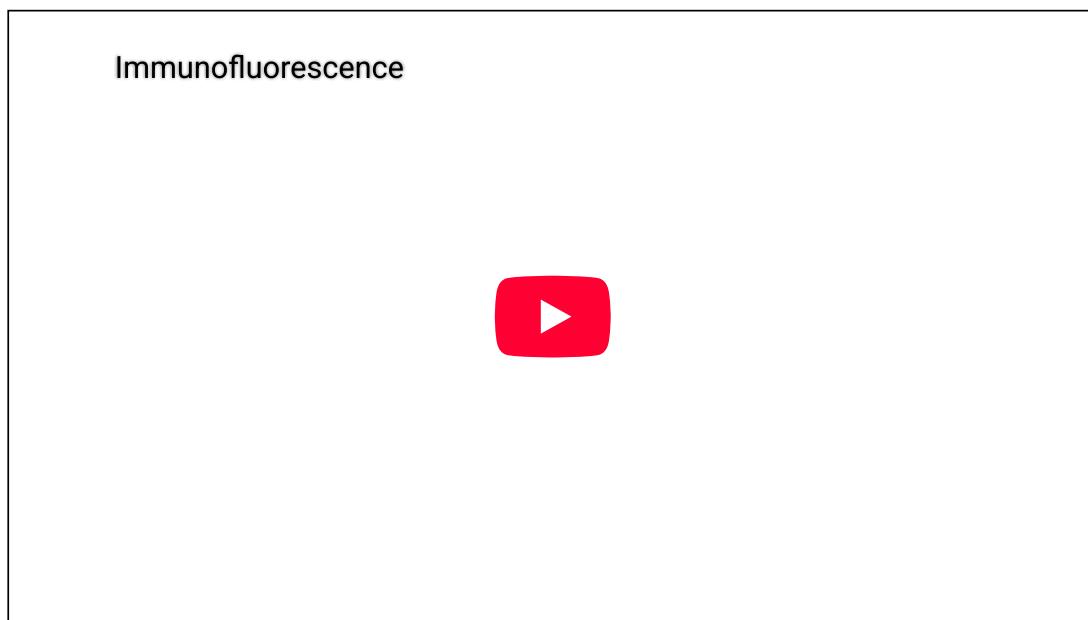
The following techniques have been developed to improve microscopy by enabling scientists to visualise and study biological samples at higher resolution, and with greater specificity and accuracy.

- Freeze fracture microscopy involves freezing a sample and then using a specialised tool to break the sample into small pieces. These small pieces are then observed using an electron microscope to see the internal structure. This is a particularly useful technique for being able to visualise structures that are not normally visible, such as the internal plasma membrane.

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- Cryogenic electron microscopy involves freezing a sample to cryogenic temperatures to fix the molecules, making them more firm or stable. The specimen is then viewed using electron microscopy. Freezing the sample improves the resolution of the image formed and reduces damage that may occur from the electron beam.
- Immunofluorescence is a technique used in light microscopy to better visualise certain structures. A fluorescent tag, called a fluorophore, is attached to antibodies specific for antigens on a structure or cell being viewed. When the antibody binds to the antigen, the structure is then ‘tagged’ with immunofluorescence. When a certain wavelength of light is shone onto the fluorescence tag, the tag will emit light of a different wavelength that can then appear as brightly coloured spots, allowing the visualisation of the location of these target molecules.
- Fluorescent dyes can be used in light microscopy. When the dye is added to the sample it will preferentially attach to certain structures. As in immunofluorescence, the labelled areas will appear as brightly coloured spots, allowing visualisation of the target molecule throughout the specimen.

Video 1 shows how immunofluorescence can be used to visualise certain parts of a cell.



Video 1. How immunofluorescence is used to visualise parts of a cell.

Try **Interactive 1** to explore different microscopy techniques.



Overview
(/study/app/
422-
cid-
755105/o

Interactive 1. Microscopy Techniques.

More information for interactive 1

A slideshow viewer with four images, each accompanied by a descriptive text panel on the right side. The slideshow navigation bar is located at the bottom, displaying the current slide number (1 / 4 or 2 / 4) and providing buttons to move between slides. A blue progress indicator shows the position within the slideshow. In the bottom right corner, there is an expand button to view the images in full screen"

The first slide presents a freeze-fracture image of the small intestine. The high-magnification image reveals a cross-sectional view where the outer yellow surface represents the intestinal lining exposed to food. Deep invaginations known as villi are visible, with the purple inner texture showing internal membrane detail. This technique is used to study membrane structures by physically splitting biological samples at the lipid bilayer. The accompanying content reads, "Freeze-fracture microscopy is useful for studying the structure of membranes. The image shows a freeze fracture of the small intestine. The surface consists of deep folds, called villi. The intestinal surface (yellow) is exposed to food."

The second slide features a cryo-electron microscopy (cryo-EM) image. The image displays a three-dimensional molecular surface with a textured, ice-like appearance in bluish hues. This cryo-EM structure represents a novel vaccine candidate for the Epstein-Barr virus, captured at near-atomic resolution, useful for studying protein shape and interaction in native hydrated conditions. The accompanying content reads, "Cryogenic electron microscopy is commonly used to visualize the 3D structure of molecules. The image shows a cryo-EM visual of a novel candidate for the Epstein Barr vaccine."

The third slide showcases an immunofluorescence image of the eye of a mouse. The photoreceptor-like cells are highlighted in green, located toward the upper portion of the tissue section. The red and blue staining in surrounding regions marks other cellular structures. The contrast reveals how specific proteins or cell types are targeted using fluorescent antibodies, commonly used in pathology to detect disease markers. The accompanying content reads,

Student view



Overview
(/study/app/
422-
cid-
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"Immunofluorescence is commonly used in pathology (the study of the causes and effects of diseases). This image shows how immunofluorescence is used to confirm the presence of photoreceptor-like (green) cells in the eye of a mouse." The fourth slide displays a fluorescent microscopy image of fibroblasts. The red thread-like structures are mitochondria, green spots show polydopamine nanoparticles and the blue circular regions indicate cell nuclei. The dyes clearly delineate internal cellular components and are often used to monitor drug delivery or study cellular architecture in biomedical research. The accompanying content reads, "Fluorescence dyes are commonly used to visualize biological structures and monitor drug delivery within the body. The image of fluorescent dyes shows the structure of fibroblasts, a type of connective cell, and polydopamine nanoparticles and mitochondria within the cell."

Try this activity to use a simulation of electron microscopy.

Activity

- **IB learner profile attribute:** Inquirer
- **Approaches to learning:** Research skills — Comparing, contrasting and validating information
- **Time required to complete activity:** 10 minutes
- **Activity type:** Individual activity

Visit the simulation at [MyScope Explore ↗](https://myscope-explore.org/virtualSEM_explore.html) (https://myscope-explore.org/virtualSEM_explore.html) and select a sample to explore. Load and evacuate the sample and then adjust the features to produce an image of the highest magnification and resolution. Repeat for three to five different samples.

5 section questions ▾

A2. Unity and diversity: Cells / A2.2 Cell structure

Prokaryotic and eukaryotic cells

A2.2.4: Structures common to cells in all living organisms. A2.2.5: Prokaryote cell structure A2.2.6: Eukaryote cell structure

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Feedback

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Overview
(/study/app/
422-
cid-
755105/o

Learning outcomes

By the end of this section you should be able to:

- Outline the structures that are common to cells in all living organisms.
- Describe the structure of a typical prokaryotic cell and the function of prokaryotic cell structures and components.
- Describe the structure of a typical eukaryotic cell and the function of eukaryotic cell structures and components.

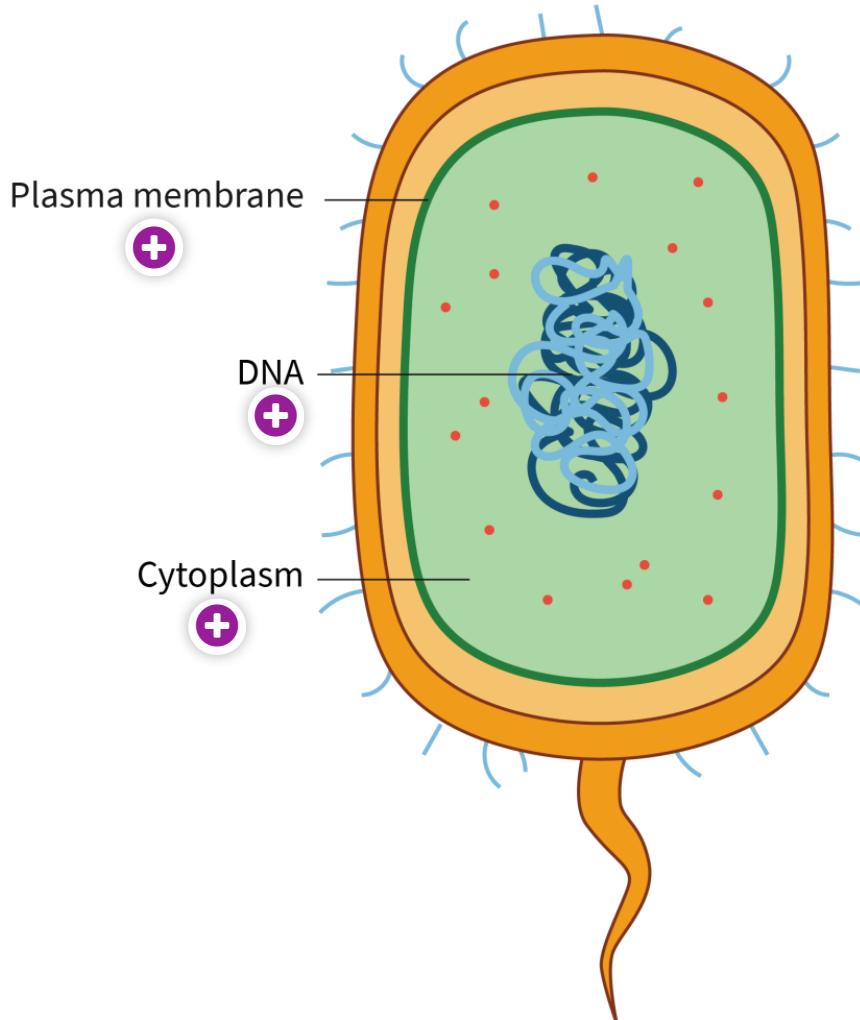
We have seen some of the components of cells with light microscopy and electron microscopy but what are the differences and similarities between types of cells?

Structures and components of a typical cell

Typical prokaryotic and eukaryotic cells contain DNA as genetic material, a cytoplasm composed mainly of water and a plasma membrane made of lipids encapsulating the cell contents. **Interactive 1** shows the features of a typical cell.



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Interactive 1. A Typical Cell.

More information for interactive 1

An interactive illustration displays a typical cell with various parts marked. The cell has an outer layer with hair-like structures representing pili, followed by a middle layer, and an inner layer labeled as the plasma membrane, which contains DNA in the center of the cytoplasm. A few colored spots represent cellular organelles.

A tail-like structure at the bottom of the cell represents flagellum.

The illustration has three plus signs, representing interactive hotspots. Selecting a hotspot reveals a description of the corresponding part.

Hotspot on plasma membrane reads, The plasma membrane is composed of a bilayer of phospholipids that surround the cell, separating the interior of the cell from the exterior environment.

Hotspot on DNA reads, Most cells contain genetic information in the form of DNA. This DNA contains the instructions needed for the cell to survive, mature and replicate.





Overview
(/study/app
422-
cid-
755105/o

Hotspot on cytoplasm reads, The cell cytoplasm is a jelly-like fluid made mostly of water. It contains many dissolved solutes, including nutrients and waste products, and it suspends other cell structures. Many chemical reactions occur in the cytoplasm.

This illustration helps users identify key structural components of a typical cell and their basic functions.

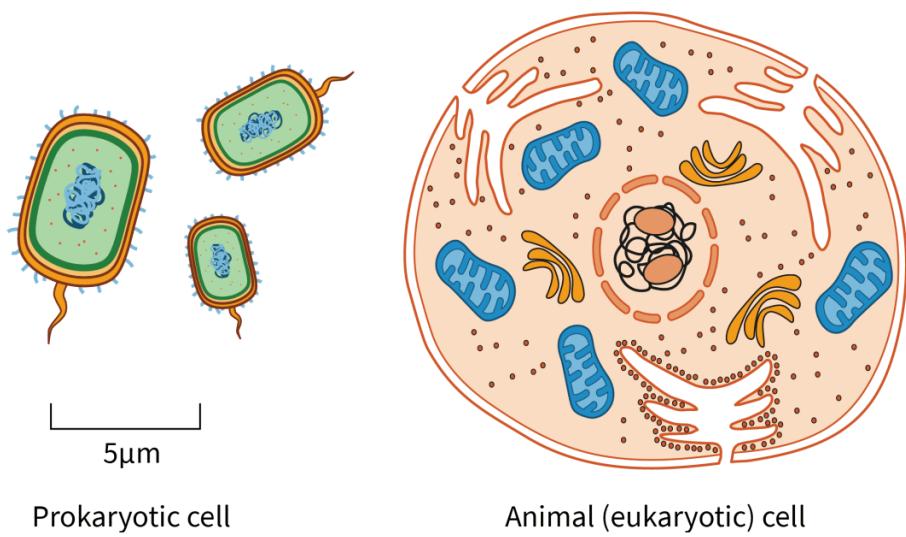
Structures and components of a typical prokaryotic cell

Study skills

The prefix *pro* means before and the suffix *kary* means nucleus.

Prokaryotic cells do not have a nucleus.

Prokaryotes are considered to be the earliest and most primitive type of cell, originating around 3.5 billion years ago. Prokaryotes are unicellular organisms that do not contain membrane-bound organelles. Like eukaryotes, prokaryotes contain ribosomes, the site of protein synthesis ([subtopic D1.2 \(/study/app/bio/sid-422-cid-755105/book/big-picture-id-43547/\)](#)). However, prokaryotic ribosomes (70S) are smaller than eukaryotic ribosomes (80S), where the unit 'S' refers to Svedberg unit ([subtopic B2.2 \(/study/app/bio/sid-422-cid-755105/book/big-picture-id-43532/\)](#)). Additionally, while some eukaryotic ribosomes may be bound to membranes and some are free in the cytoplasm, all prokaryotic ribosomes are free in the cytoplasm. Prokaryotic cells usually range in diameter between 0.1 and 5.0 μm , whereas eukaryotic cells are typically between 10 and 100 μm (**Figure 1**).



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Student
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Figure 1. Prokaryotic cells typically range between 0.1 and 5.0 μm in diameter, whereas eukaryotic cells typically have diameters ranging between 10 and 100 μm .

Overview
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More information for figure 1

The image illustrates a comparison between a prokaryotic cell and an animal (eukaryotic) cell. On the left, three prokaryotic cells are depicted. Each cell has a simple structure with an outer membrane and internal components, but no nucleus. These cells are labeled with a scale bar indicating 5 μm .

On the right is a larger, more complex depiction of an animal (eukaryotic) cell. This cell contains multiple internal structures, including mitochondria, endoplasmic reticulum, Golgi apparatus, and a nucleus with genetic material inside. The organelles in the eukaryotic cell are labeled and organized within the membrane, highlighting the structural complexity compared to the prokaryotic cells.

[Generated by AI]

Theory of Knowledge

Ada Yonath and her contribution to membrane structure

Ada Yonath is a biochemist and crystallographer who is best known for her work in producing the first high resolution X-ray crystal structure of ribosomes. In 2009, she was jointly awarded the Nobel Prize in Chemistry (<https://www.nobelprize.org/prizes/chemistry/2009/ceremony-speech/>). Ada Yonath is the first woman from the Middle East to be awarded a Nobel Prize in science, and the first woman in 45 years to be awarded the Nobel Prize in Chemistry.

To what extent is scientific research becoming more representative of the global population? What are the reasons behind this? What factors continue to limit proportional representation of gender and culture in scientific research?

Bacteria and archaea are both types of prokaryotes (see section A3.2.7–9 (</study/app/bio/sid-422-cid-755105/book/applying-cladistics-hl-id-44215/>)). Within prokaryotes, there is enormous variation and number of species. Prokaryotes are found everywhere, including the most inhospitable places; from boiling wells to deep mine shafts, to the ocean floor.

Student view



Typical components (parts) of prokaryotic cells (**Interactive 2**):

Overview
(/study/app/
422-
cid-
755105/o)

- Cell wall: the cell wall is found outside the cell membrane. It has an important role in protecting the prokaryotic cell against toxins that may be in the external environment, resisting high osmotic pressures and maintaining the shape of the cell.
- Plasma membrane: the plasma membrane separates the cell's interior from its external environment and controls what can enter and exit the cell.
- Cytoplasm: the cytoplasm is a water-based jelly-like fluid that fills the cell, suspends ions, organic molecules, DNA and ribosomes, and is the site of metabolic reactions.
- Naked DNA in a loop: DNA stores the information necessary for synthesising proteins. In prokaryotes, the DNA is *naked*, which means that it is not associated with histone proteins (as it is in eukaryotic cells, see [section A1.2.13 \(/study/app/bio/sid-422-cid-755105/book/checklist-id-44731/\)](#)) and is mostly found in a region called the nucleoid. However, recent studies have identified hundreds of candidate histone-like proteins in various bacterial species. These proteins share structural similarities with eukaryotic histones and are involved in DNA packaging and organization. For example, the bacterium

Bdellovibrio bacteriovorus

has been found to possess a histone-like protein called HBb, which binds to DNA and helps organize it within the cell.

- 70S ribosomes: where translation (protein synthesis) occurs. Prokaryotic ribosomes are smaller and lower mass than eukaryotic ribosomes.
- Plasmid: small, circular pieces of DNA that can be transferred from one prokaryotic cell to another. This is known as horizontal gene transfer (in contrast to the vertical gene transfer that occurs from reproduction).

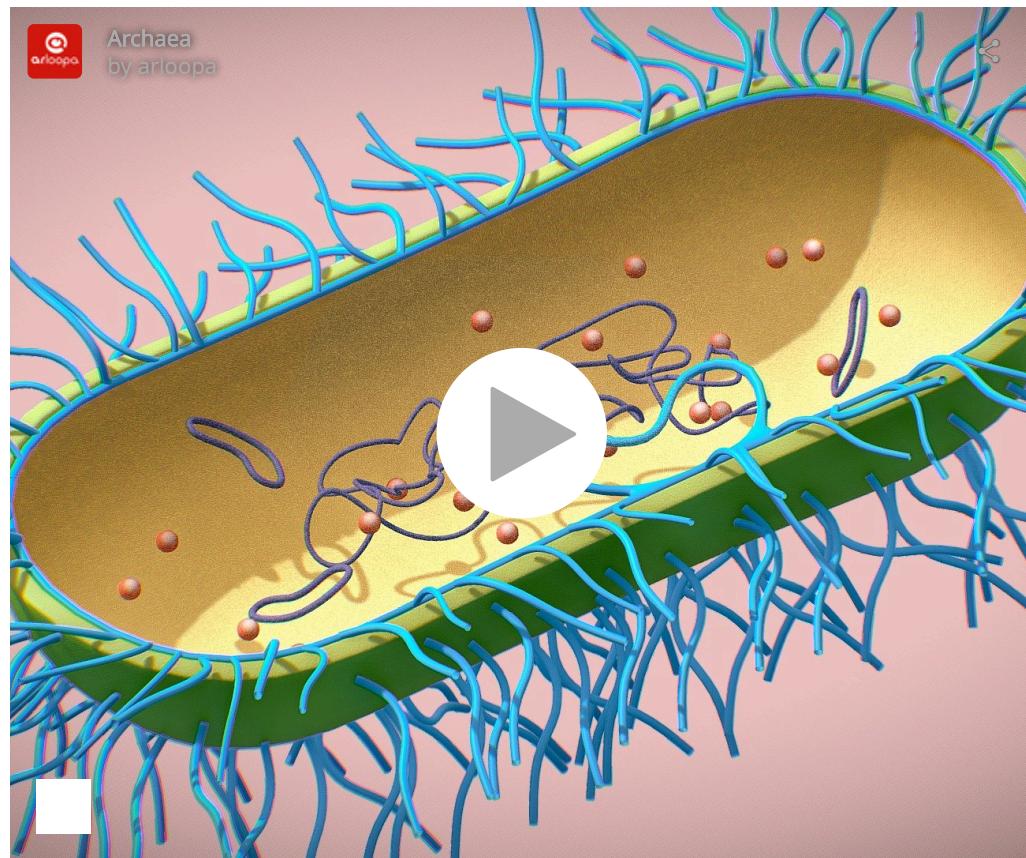
In addition to these typical features, many prokaryotic cells also contain a capsule, an outer layer of polysaccharides that protect the organism and allow it to adhere to surfaces. Some prokaryotic cells have a flagellum (plural: flagella). The flagellum is responsible for the locomotion of the organism, spinning to propel the cell through its medium. Some prokaryotic cells contain pili on their surface (singular: pilus). Pili are protein filaments on the cell wall that help in cell adhesion and in transferring of DNA between two cells.

Explore the 3D animated model of a bacterial cell in **Interactive 2**, by rotating and zooming in and out. Click on the annotations to learn about the different structures.



Student
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Home
Overview
(/study/app/
422-
cid-
755105/o



Interactive 2. Model of a bacterial cell.

⚠ Practical skills

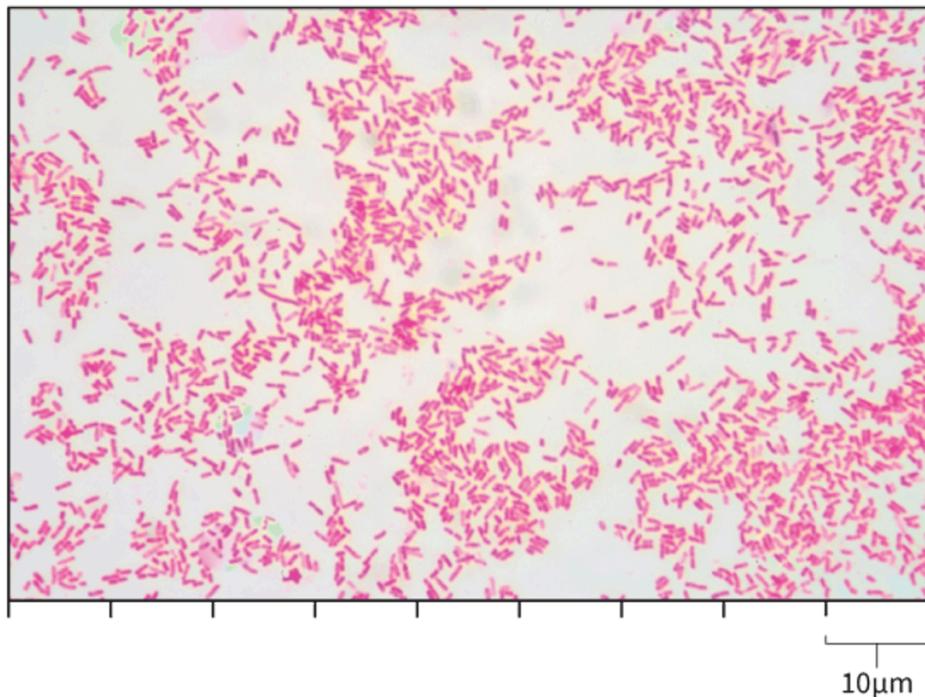
Tool 1: Experimental techniques — Measuring variables

You need to be able to identify cells in light or electron micrographs as prokaryote, plant or animal (**Figure 2**). In electron micrographs, you should be able to identify the following structures in prokaryotic cells: nucleoid region, cell wall, ribosomes and plasma membrane.



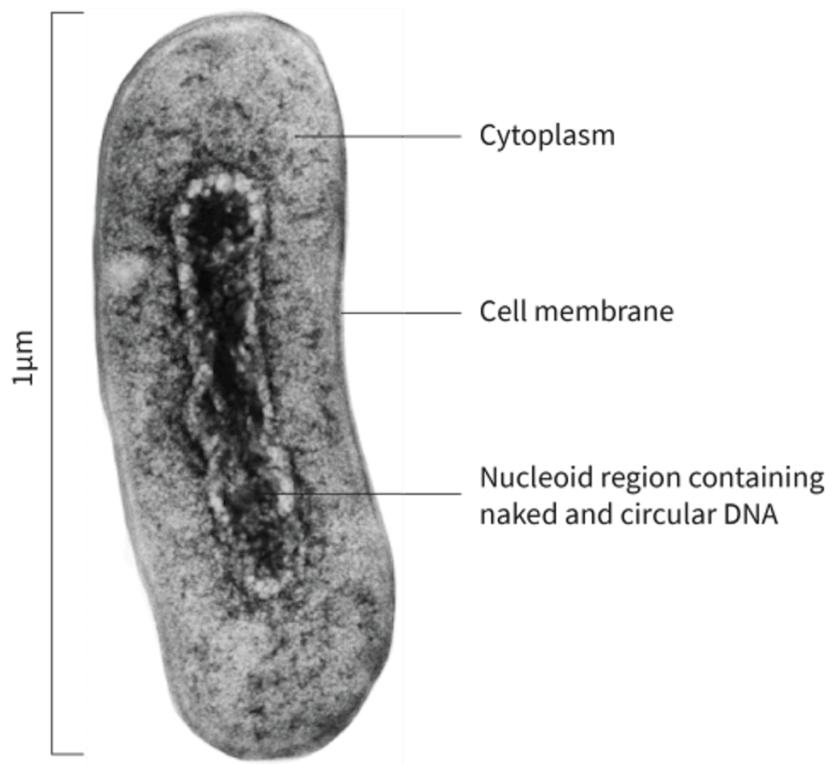
Student
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Home
Overview
(/study/app/
422-
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(a)

Credit: emarys, Getty Images (<https://www.gettyimages.com/detail/photo/electron-microscopy-of-bacteria-royalty-free-image/934825758>)



(b)

Credit: toeytoey2530, Getty Images (<https://www.gettyimages.com/detail/photo/gram-staining-gram-negative-bacilli-royalty-free-image/470685746>)

Figure 2. (a) A prokaryotic cell viewed using a light microscope. (b) A prokaryotic cell viewed using an electron microscope. Note the difference in resolution and how this allows you to see the cell structures more clearly in the electron micrograph.

X
Student view



Overview
(/study/app
422-
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More information for figure 2

The image is an electron micrograph of a prokaryotic cell. It highlights three main structures with labels: the cytoplasm, the cell membrane, and the nucleoid region. The cytoplasm is indicated in the upper part of the cell, where a dense internal structure is visible. Below it is the cell membrane, which outlines the cell, providing a clear boundary. At the center, the nucleoid region is visible and is labeled as containing naked and circular DNA. The scale bar on the left shows the size of the cell as approximately 1 micrometer in length.

[Generated by AI]

Not all of the features described previously will be found in all prokaryotic cells, and you will not always be able to see all of the structures in a cell from a micrograph. What structures are visible from the micrographs in **Interactive 3**?

Interactive 3. Micrographs of Different Prokaryotic Cells.

More information for interactive 3

An interactive slideshow with four slides depicts micrographs of different prokaryotic cells. Each slide contains a micrograph along with a description of its magnification.

Users can switch between slides using the arrows present at the bottom of each slide.

Slide 1: A group of straight, rod-shaped *Escherichia coli* (bacteria) cells on the surface.

The description below the slide reads Magnification $\times 6000$ when printed at 10cm wide.

Student view



Slide 2: A group of two differently colored spherical Streptococcus mutans (bacteria) cells on a sponge-like surface.

The description below the slide reads, Magnification $\times 8000$ when printed at 10cm wide

Slide 3:

Micrograph: A spiral-shaped Helicobacter pylori (bacteria) cell with multiple flagella.

The description below the slide reads, Magnification $\times 14000$ when printed at 10cm tall

Slide 4:

Micrograph: Clusters of spherical Staphylococcus aureus (bacteria) on a white background.

The description below the slide reads, Magnification $\times 500$ at 35mm

This slideshow helps users identify and distinguish between different shapes and arrangements of typical prokaryotic cells.

Structures and components of a typical eukaryotic cell

Unlike prokaryotic cells, eukaryotic cells contain a nucleus and membrane-bound cytoplasmic organelles (see [subtopic B2.2 \(/study/app/bio/sid-422-cid-755105/book/big-picture-id-43532/\)](#)). Eukaryotic cells are more complex and usually much larger than prokaryotic cells (**Figure 4**). Unlike prokaryotes, which are all unicellular, some eukaryotes are multicellular, meaning that the body of the organism consists of more than one cell.

Study skills

The prefix *eu* means ‘well’ and the suffix *kary* means ‘nucleus’.

Typical eukaryotic cells have a well-defined nucleus.

There is huge diversity within the eukaryotes (**Figure 3**) (see [subtopic B2.3 \(/study/app/bio/sid-422-cid-755105/book/big-picture-id-43533/\)](#)).

Figure 3(a) shows moss leaf cells, the cells responsible for carrying out photosynthesis in this group of plants. Notice the high number of chloroplasts in these cells. **Figure 3(b)** shows a motor neuron, a type of cell found in animals which transports electrical messages around

Overview
(/study/app
422-
cid-
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the body. Notice the long axon which allows the motor neuron to extend from one part of the body to another, transporting electrical signals long distances. **Figure 3(c)** shows a yeast called *Candida albicans*, a unicellular fungus which lives on human skin. In this image the cell is forming hyphae, long thread-like filaments.

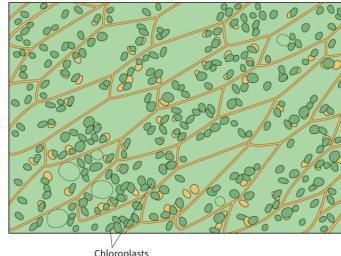


Figure 3a. A moss leaf cells

🔗 More information for figure 3

The image is a diagram showing multiple cells of a moss leaf. The cells are outlined with orange lines, creating a grid-like structure of elongated shapes. Inside each cell, there are numerous small green circles and a few yellow-green circles labeled as chloroplasts. These elements are scattered throughout the cells, representing their distribution within a moss leaf. The overall layout demonstrates how chloroplasts are positioned within the leaf cells.

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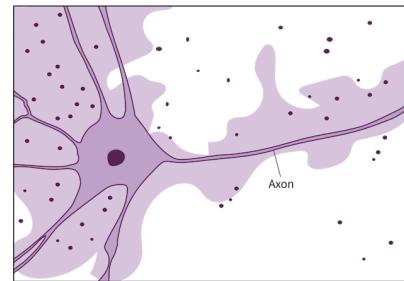


Figure 3b. A motor neuron

More information for figure 3

The diagram shows a motor neuron with a focus on the axon. The main body of the neuron is depicted on the left side with a central nucleus, surrounded by a cell body that has numerous branching dendrites. Extending from the cell body is a long, thin structure labeled as the "Axon," which runs horizontally across the image from left to right. The axon is shown as a smooth, elongated tube surrounded by a lighter shaded area indicating surrounding structures or myelin sheath. Numerous small dots are present throughout the background, representing other cellular components or background elements. The diagram highlights the axon as a major feature of the neuron.

[Generated by AI]



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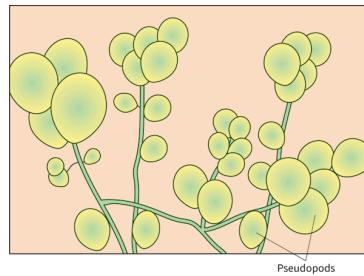


Figure 3c. *Candida albicans*

Compartmentalisation

Eukaryotic cells contain membrane-bound cytoplasmic organelles, such as mitochondria and chloroplasts. This compartmentalisation ([subtopic B2.2 \(/study/app/bio/sid-422-cid-755105/book/big-picture-id-43532/\)](#)) allows for the interior of the organelles to have separate conditions to the cytoplasm of the cell. The advantages of compartmentalisation include:

- the ability to create higher concentrations of certain substances within organelles
- the ability to separate toxins and potentially damaging substances from the rest of the cell. For example, hydrolytic enzymes can be stored in structures called lysosomes, away from the cell cytoplasm
- control over conditions inside organelles (such as pH) to maintain the optimal conditions for the enzymes that function in those parts of the cell (see [section C1.1.8 \(/study/app/bio/sid-422-cid-755105/book/thermodynamics-of-enzymes-id-44899/\)](#)).

Eukaryotic cell structure

Although there are many different types of eukaryotic cells, most eukaryotic cells have the following components (**Figure 4**):

- Plasma membrane: the plasma membrane separates the cell's interior from its external environment and controls what can enter and exit the cell.
- Cytoplasm: a water-based jelly-like fluid that fills the cell, suspends ions, organic molecules, organelles and ribosomes, and is the site of metabolic reactions.
- Mitochondria: double-membrane-bound organelles that convert glucose into ATP (the cell's energy currency) in the process of respiration.
- 80S ribosomes: where translation (protein synthesis) occurs. Both attached and free-floating eukaryotic ribosomes are larger and have a higher mass than prokaryotic

ribosomes.

- Nucleus: contains the DNA which is associated with histone proteins and is organised into chromosomes. The nucleus contains the nucleolus, which is involved in the production of ribosomes. The nucleus has a double membrane which contains pores through which certain molecules can pass, including glucose, RNA and ions.
- Smooth endoplasmic reticulum: produces and stores lipids, including steroids.
- Rough endoplasmic reticulum: has ribosomes attached to its surface which produce proteins that are usually destined for use outside the cell.
- Golgi apparatus: processes and packages proteins, which are then released in Golgi vesicles.
- Vesicle: small sac that transports and releases substances produced within the cell by fusing with the cell membrane.
- Vacuole: helps to maintain the osmotic balance of the cell. It may also be used to store substances and sometimes has hydrolytic functions similar to lysosomes.
- Cytoskeleton: a system of protein fibres called microtubules and microfilaments. The cytoskeleton helps to hold organelles in place and maintain the structure and shape of the cell.

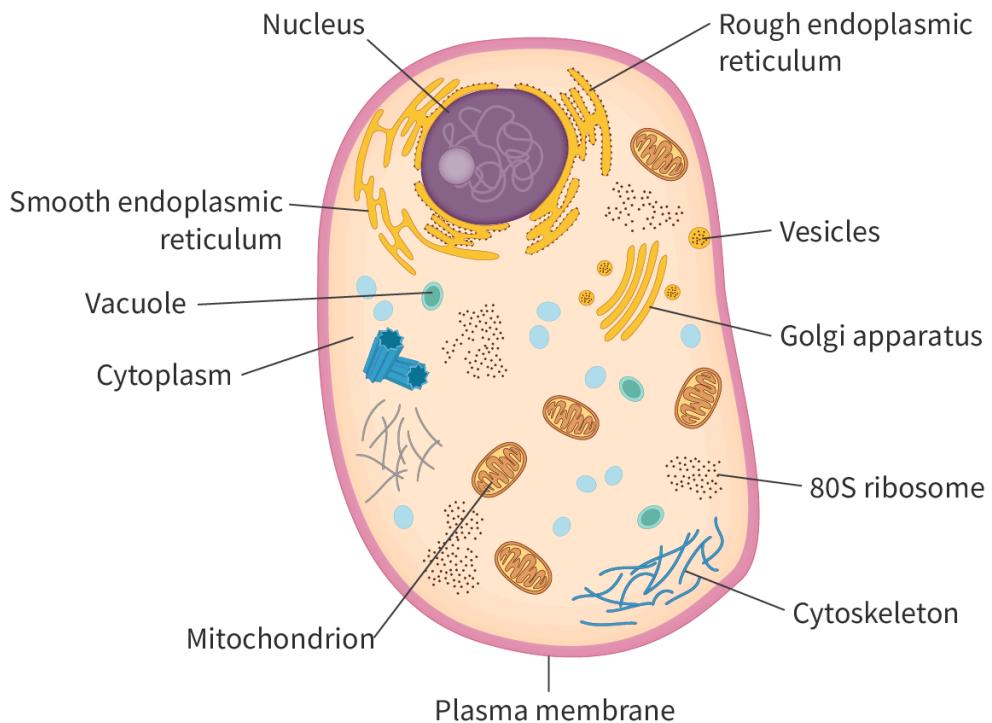


Figure 4. A typical eukaryotic cell.

More information for figure 4



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The diagram shows a typical eukaryotic cell with labeled components. At the center is the nucleus, which is represented as a large circular structure. Surrounding the nucleus is the rough endoplasmic reticulum, depicted with small dots on its surface, and the smooth endoplasmic reticulum, shown with a wavy pattern. Adjacent to the nucleus is the Golgi apparatus, which is portrayed as stacked curved lines. The mitochondrion, visible as oval structures with internal folds, is also labeled within the cell.

Other labeled components include: - Vacuole: Shown as a small circular shape. - Vesicles: Small round shapes distributed around the cell. - 80S ribosome: Small dots indicating their presence within the cell. - Cytoskeleton: Displayed as long thin lines crossing the cell. - Plasma membrane: Outlines the entire cell.

The cytoplasm fills the space around these organelles, providing the matrix in which they are suspended.

[Generated by AI]

平淡 Study skills

Whenever labelling diagrams, make sure your label is drawn with a straight line, right up to the structure you are labelling.

Try this modelling activity to test your understanding of prokaryotic and eukaryotic cell structure.

齿轮 Activity

- **IB learner profile attribute:** Thinker
- **Approaches to learning:** Thinking skills — Experimenting with new strategies for learning
- **Time required to complete activity:** 20 minutes
- **Activity type:** Individual activity



Student
view

Using modelling clay, or any other suitable materials you have at your disposal, make a model of a prokaryotic cell and another of a eukaryotic cell. Include the features of these two cell types outlined in **Table 1**.

Table 1. Components to include in the cell models.

Prokaryotic cell	Eukaryotic cell
Cell wall	Plasma membrane
Plasma membrane	Cytoplasm
Cytoplasm	Mitochondria
Naked DNA	Nucleus
70S ribosomes	80S ribosomes
Plasmid	Smooth and rough ER
	Golgi apparatus
	Vesicle
	Vacuole
	Cytoskeleton

Consider your models and discuss with your class. What have you done well? How could the accuracy of your models be improved?

5 section questions ▾

A2. Unity and diversity: Cells / A2.2 Cell structure

Processes of life in unicellular organisms

A2.2.7: Processes of life in unicellular organisms

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Section

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Feedback



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755105/book/processes-of-life-in-unicellular-organisms-id-44688/print/)

Assign



Learning outcomes

By the end of this section, you should be able to:

- Name the eight processes that all living things carry out.
- Identify how different unicellular organisms carry out each of the eight life processes.

All prokaryotic cells, and some eukaryotic cells are unicellular. Unicellular organisms have a body composed of only one cell. A single cell can be classed as an organism if it can carry out the life processes. What are the life processes common to all living things?

The single cell that makes up the unicellular organism will be capable of carrying out all of the eight life processes:

- **Metabolism:** chemical reactions that take place within the cell(s) of an organism (see [subtopic C1.1 \(/study/app/bio/sid-422-cid-755105/book/the-big-picture-id-43208/\)](#)).
- **Response to stimuli:** reacting to changes in the external environment (see [subtopic C3.1 \(/study/app/bio/sid-422-cid-755105/book/big-picture-id-43542/\)](#)).
- **Homeostasis:** the maintenance of constant internal conditions, despite changes in their external environments (see [subtopic D3.3 \(/study/app/bio/sid-422-cid-755105/book/the-big-picture-id-43551/\)](#)).
- **Movement:** living things have some control over their place and position(see [subtopic B3.3 \(/study/app/bio/sid-422-cid-755105/book/big-picture-hl-id-43535/\)](#)).
- **Growth:** cells can increase in size over a period of time. In multicellular organisms, growth can also refer to an increase in the number of cells that make up an organism (see [subtopic D2.1 \(/study/app/bio/sid-422-cid-755105/book/big-picture-id-43548/\)](#)).
- **Reproduction:** the production of offspring. Reproduction can be sexual or asexual (see [subtopic D3.1 \(/study/app/bio/sid-422-cid-755105/book/the-big-picture-id-43252/\)](#)).
- **Excretion:** the removal of metabolic waste products (see [subtopic D3.3 \(/study/app/bio/sid-422-cid-755105/book/the-big-picture-id-43551/\)](#)).
- **Nutrition:** the intake or production of nutrients. Heterotrophic organisms obtain their nutrients from the external environment, whereas autotrophic organisms are able to produce nutrients from inorganic material (see [subtopic B4.2 \(/study/app/bio/sid-422-cid-755105/book/big-picture-id-43537/\)](#)).



Study skills

You can use the acronym MR HM GREN to help you to remember these eight life processes

Examples of unicellular organisms

Paramecium is a genus (group) of unicellular protozoa (**Figure 1**). *Paramecia* are usually less than 0.25 mm in size and are widespread in aquatic environments, particularly in stagnant ponds. They are heterotrophs, feeding on food particles they encounter in their environment. They can move in all directions using their cilia, small hair-like structures that cover the whole body and beat rhythmically to propel the cell in a given direction.

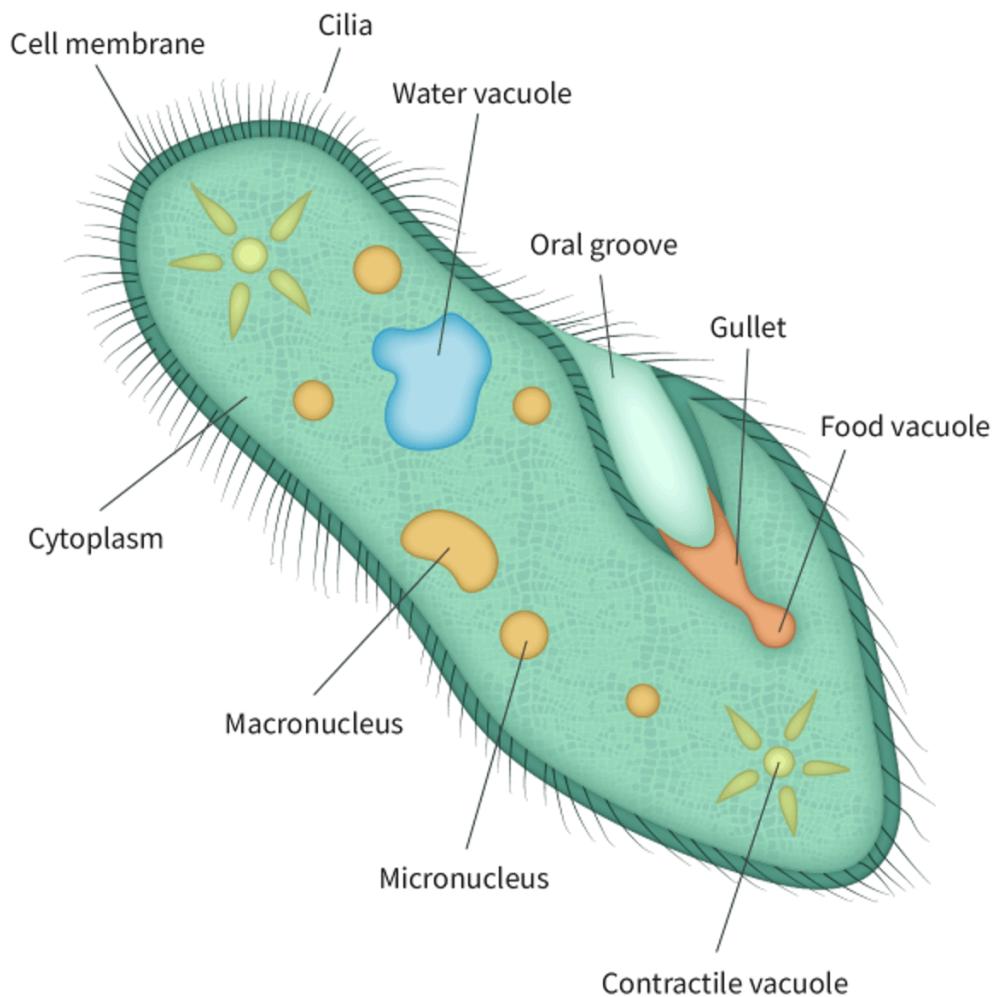


Figure 1. *Paramecium*, highlighting the important structures that carry out all the functions of life in a single cell.

More information for figure 1





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The image is a detailed diagram of a paramecium, highlighting its important structures. It includes the following labeled parts: cilia that cover the cell, the cell membrane, cytoplasm, two types of vacuoles (water and food vacuoles), the oral groove, gullet, macronucleus, micronucleus, and contractile vacuole. Each of these parts is identified with lines connecting to their respective locations on the paramecium. Cilia are shown as small hair-like projections along the body, and the shape of the cell is elongated and oval with various internal structures depicted.

[Generated by AI]

Chlamydomonas is a genus of unicellular green algae (Chlorophyta) distributed all over the world, in soil, fresh water, oceans and even in snow on mountain tops. The algae in this genus range in size from 10 to 30 µm in diameter and have a cell wall, a chloroplast, an 'eye' that detects light, as well as two flagella (whip-like structures), which they use to swim using a breaststroke-type motion (**Figure 2**).

Chlamydomonas are autotrophs; they can manufacture their own food using their large chloroplast to photosynthesis.

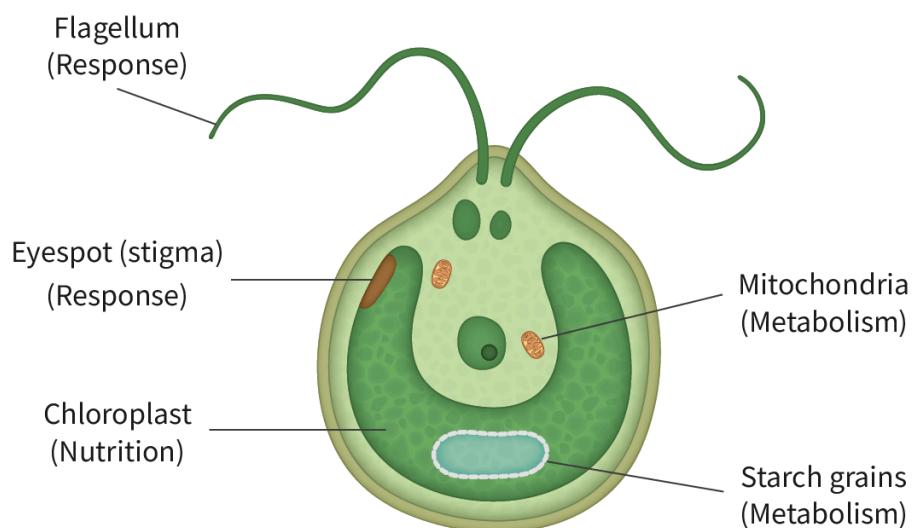


Figure 2. Cellular structure of *Chlamydomonas*; the functions of life are in parentheses.

More information for figure 2

Student view

This diagram illustrates the cellular structure of Chlamydomonas, a eukaryotic algae. It includes several labeled organelles and their functions in parentheses:



- 1. Flagellum (Response):** Extending from the top of the diagram, this structure is responsible for the cell's movement and can respond to environmental stimuli.
- 2. Eyespot (stigma) (Response):** Positioned to the left within the cell, this small, pigmented area is involved in detecting light, aiding in phototaxis (movement in response to light).
- 3. Chloroplast (Nutrition):** Occupying a large central and peripheral area within the cell, the chloroplast is responsible for photosynthesis, allowing the cell to produce its own food.
- 4. Mitochondria (Metabolism):** Depicted as smaller structures to the right inside the cell, mitochondria are essential for energy production through cellular respiration.
- 5. Starch grains (Metabolism):** Located towards the center, these represent stored carbohydrates produced via photosynthesis for energy reserve.
- 6. Contractile vacuoles:** Two small contractile vacuoles, which have an excretory function, are located near the flagella.

The diagram uses arrows to point to these specific organelles, providing a clear representation of their locations within the *Chlamydomonas* cell.

[Generated by AI]

Paramecium and *Chlamydomonas* exemplify how unicellular organisms carry out all the life processes within the one cell that makes up their whole body.

Table 1. Summary of how *Paramecium* and *Chlamydomonas* carry out all the functions of life.

Life functions	<i>Paramecium</i>	<i>Chlamydomonas</i>
Growth	As it consumes food, the <i>Paramecium</i> enlarges. Once it reaches a certain size it will divide into two daughter cells	Production of organic molecules during photosynthesis and absorption of minerals causes the organism to increase in size. Once it reaches a certain size it will divide into two daughter cells
Movement	The wave action of the beating cilia helps to propel <i>Paramecium</i> in response to changes in the environment, for example, towards warmer water and away from cool temperatures	The flagella of the <i>Chlamydomonas</i> rotates, moving the organism towards more favourable conditions, such as higher light intensity



Life functions	<i>Paramecium</i>	<i>Chlamydomonas</i>
Response to stimuli	<i>Paramecium</i> are able to detect changes in the water temperature around them and move in response to seek warmer temperatures	<i>Chlamydomonas</i> senses light changes in its environment using its eye spot and then moves toward a brighter region to increase the rate of photosynthesis
Homeostasis	A constant internal environment is maintained by collecting excess water in the contractile vacuoles and then expelling it through the plasma membrane. This process is called osmoregulation and helps <i>Paramecium</i> and <i>Chlamydomonas</i> to maintain their water balance	
Nutrition	<i>Paramecium</i> is a heterotroph. It engulfs food particles in vacuoles where digestion takes place. The soluble products are then absorbed into the cytoplasm of the cell. It feeds on microorganisms, such as bacteria, algae and yeasts	<i>Chlamydomonas</i> is an autotroph; it uses its large chloroplast to carry out photosynthesis to produce its own food
Reproduction	It can carry out both sexual and asexual reproduction, though the latter is more common. The cell divides into two daughter cells in a process called binary fission (asexual reproduction)	It can carry out both sexual and asexual reproduction. When <i>Chlamydomonas</i> reaches a certain size, each cell reproduces, either by binary fission or sexual reproduction
Excretion	Metabolic waste from the cytoplasm collects in vacuoles. The vacuole then moves to the anal pore. Once there, it ruptures, expelling its waste contents into the environment. Some metabolic waste is also removed through the contractile vacuole along with excess water.	It uses the whole surface of its plasma membrane to excrete its waste products
Metabolism	Metabolism involves breaking down nutrients obtained from their environment. They rely on external organic sources for energy and carbon compounds.	Flexible metabolism: It can grow heterotrophically using a chemical carbon source (such as acetate) or mixotrophically by utilizing both CO ₂ and acetate.



Home
Overview
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The following video shows a living *Paramecium* under a light microscope while it is feeding itself. The oral groove, gullet, filling and detachment of food vacuoles are all clearly visible. What other characteristics of life can you see in **Video 1**?

Amazing Microscopic HD Video! Paramecium Feeding!!



0:00 / 0:35



Video 1. *Paramecium* Feeding.

 More information for video 1

The interactive features a user-friendly video player interface. On the bottom left, a play/pause button allows users to control playback, while a draggable progress bar displays the current position with tick markers indicating key points in the video. On the right side, a timestamp shows the elapsed and total duration, and a fullscreen button enables users to expand the video for a better viewing experience.

The video opens with a high-magnification microscopic view of a Paramecium, a single-celled ciliate organism. In the early part of the video, viewers observe the feeding mechanism in action. The oral groove guides food particles toward the gullet, where they are encapsulated into food vacuoles. These vacuoles are then transported through the cytoplasm in a continuous, observable cycle, providing a visual demonstration of intracellular digestion.

As one gets further in the video, the video provides a clearer, more dynamic view of the Paramecium's internal activity. Not only is the movement of food vacuoles more pronounced, but their circular path along the cytoplasmic streaming becomes visible, showcasing the organism's internal organization. Additionally, viewers can spot contractile vacuoles actively pulsing as they expel excess water — a critical part of osmoregulation in freshwater protozoans.

The Paramecium's outer surface, covered with rows of cilia, is also clearly shown propelling it forward, demonstrating locomotion while continuing to feed. These coordinated movements, captured in high resolution, highlight key life processes such as nutrition, transport, excretion, and movement, all within a single-celled organism.

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Activity

- **IB learner profile attribute:** Inquirer
- **Approaches to learning:** Research skills — Comparing, contrasting and validating information
- **Time required to complete activity:** 20 minutes
- **Activity type:** Pair activity

Choose a unicellular species and research how this organism carries out its life functions. Compile your findings in a table like **Table 2**. Once you have completed your research, share your findings with another student who has researched a different unicellular organism.

Unicellular organism chosen: _____

Is this unicellular organism prokaryotic or eukaryotic?

Table 2. Summary of life functions.

Process	How this is shown in your chosen organism
Homeostasis	
Metabolism	
Nutrition	
Movement	
Excretion	
Growth	
Response to stimuli	
Reproduction	.



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Overview

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755105/o A2. Unity and diversity: Cells / A2.2 Cell structure

5 section questions ▾

Animal, plant and fungal cells

A2.2.8: Cell structure differences in animals, fungi and plants

A2.2.9: Atypical cell structure in eukaryotes

A2.2.10: Cell types and structures in light and electron micrographs

A2.2.11: Drawing and annotation based on electron micrographs

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Feedback



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Learning outcomes

By the end of this section you should be able to:

- Outline how there may be differences in the cell structure of animal, plant and fungal cells.
- Give examples of eukaryotic cells with atypical cell structure.

Animals, plants and fungi are all eukaryotic; typical cells contain a nucleus, 80S ribosomes and membrane-bound organelles (see [section A2.2.3 \(/study/app/bio/sid-422-cid-755105/book/developments-in-microscopy-id-44718/\)](#) and [subtopic B2.2 \(/study/app/bio/sid-422-cid-755105/book/big-picture-id-43532/\)](#)). They are similar in some ways but what distinguishes each cell type from the other?

Animal cell structure

In addition to the organelles and cell structures outlined below (**Figure 1**), animal cells also contain centrioles. Centrioles are two cylindrical organelles that help to establish and organise the microtubules, playing an important role in cell division. Lysosomes are also found in animal cells. Lysosomes are membrane-bound bags of hydrolytic enzymes that break down and destroy biological molecules and old cellular organelles. Lysosomes are found in high concentrations in phagocytic white blood cells where they will fuse with and destroy ingested pathogens.

Some animal cells contain vacuoles. These tend to be much smaller than vacuoles found in plant cells. Animal vacuoles store water, nutrients and waste products.

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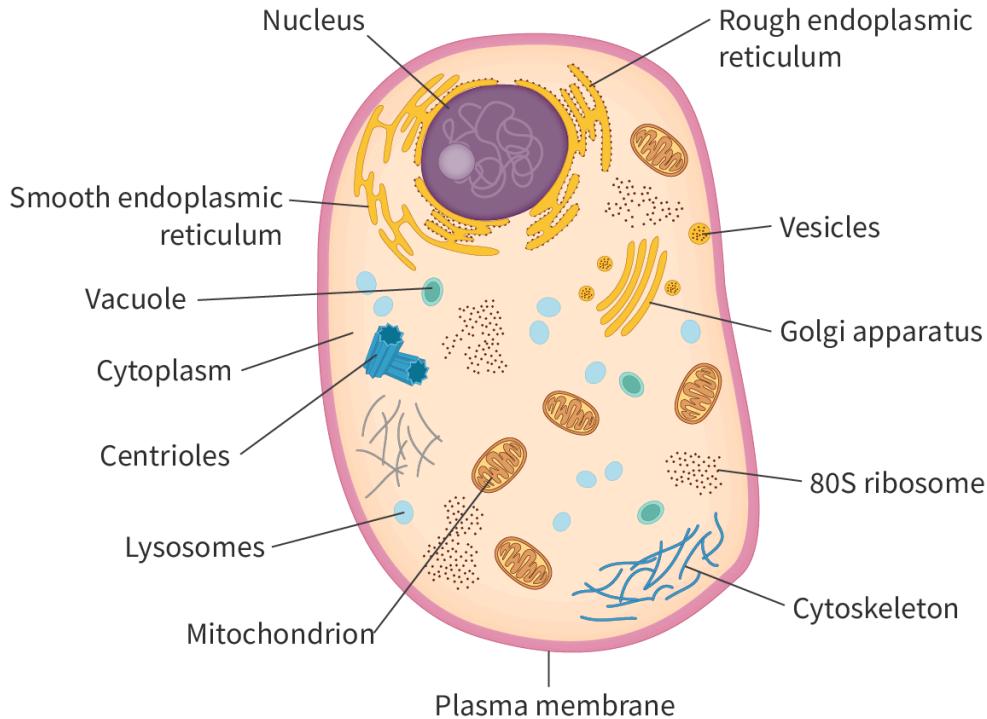


Figure 1. A typical animal cell.

More information for figure 1

The image is a detailed illustration of an animal cell. It shows various components labeled clearly to identify their structure and function. At the center, there is the nucleus, which is labeled. Surrounding the nucleus, there are the rough and smooth endoplasmic reticulum. To the right, vesicles and the Golgi apparatus are highlighted. Below the nucleus, mitochondrion and lysosomes are indicated. The image also includes 80S ribosome, centrioles, cytoskeleton, and vacuole, each with a line pointing to its location. The cell's boundaries are defined by the plasma membrane.

[Generated by AI]

Some animal cells contain cilia, hair-like structures made of microtubules, important for the movement of substances past the cell. For example, there are many cilia on the epithelial cells of the bronchi, which beat in unison to move microbes and debris up and out of the respiratory tract (**Figure 2**).



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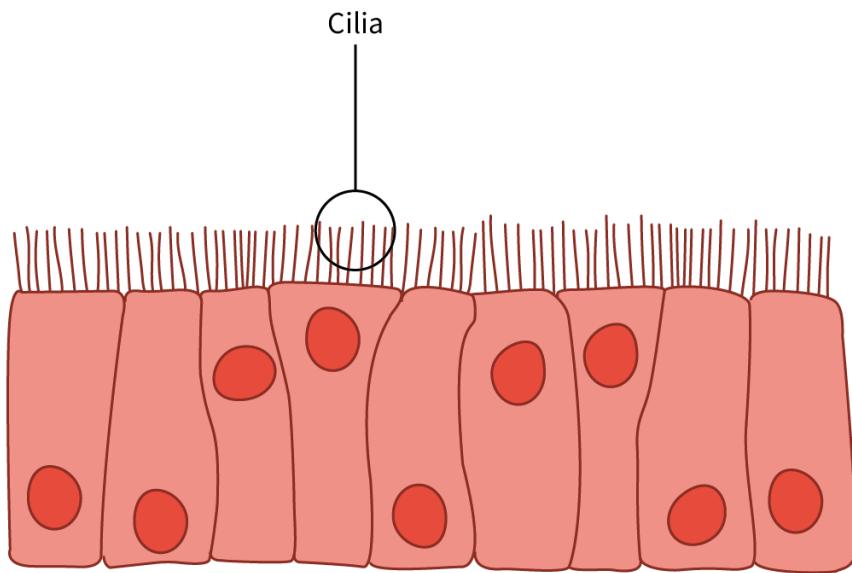


Figure 2. Epithelial cells in the bronchi have many smaller cilia, which beat in unison to move debris and microbes out of the respiratory tract.

More information for figure 2

The diagram illustrates a row of epithelial cells, each depicted as elongated ovals in pink with a central red circular nucleus. At the top of the cells, numerous short, hair-like structures known as cilia are shown. A black line points to these structures with a nearby label reading 'Cilia!' The cilia are demonstrated as thin, straight lines extending from the surface of the cells, indicating their role in moving substances across the cell's surface.

[Generated by AI]

⚠ Practical skills

Inquiry 2: Collecting and processing data — Collecting data

After studying this subtopic you need to be able to identify cells in light or electron micrographs as prokaryote, plant or animal (**Figure 3**).

In electron micrographs of eukaryotic cells, you should be able to identify these structures: nucleus, mitochondrion, chloroplast, sap vacuole, Golgi apparatus, rough and smooth endoplasmic reticulum, chromosomes, ribosomes, cell wall, plasma membrane and microvilli.



Student
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Home
Overview
(/study/app/
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You also need to be able to draw and annotate diagrams of organelles (nucleus, mitochondria, chloroplasts, sap vacuole, Golgi apparatus, rough and smooth endoplasmic reticulum and chromosomes) as well as other cell structures (cell wall, plasma membrane, secretory vesicles and microvilli) shown in electron micrographs. When annotating these diagrams, you should include the function of the labelled structures.

Figure 3 shows animal cells viewed with a light microscope and an electron microscope. Notice the difference in magnification and resolution and how this allows you to see the cell structures more clearly in the electron micrograph.

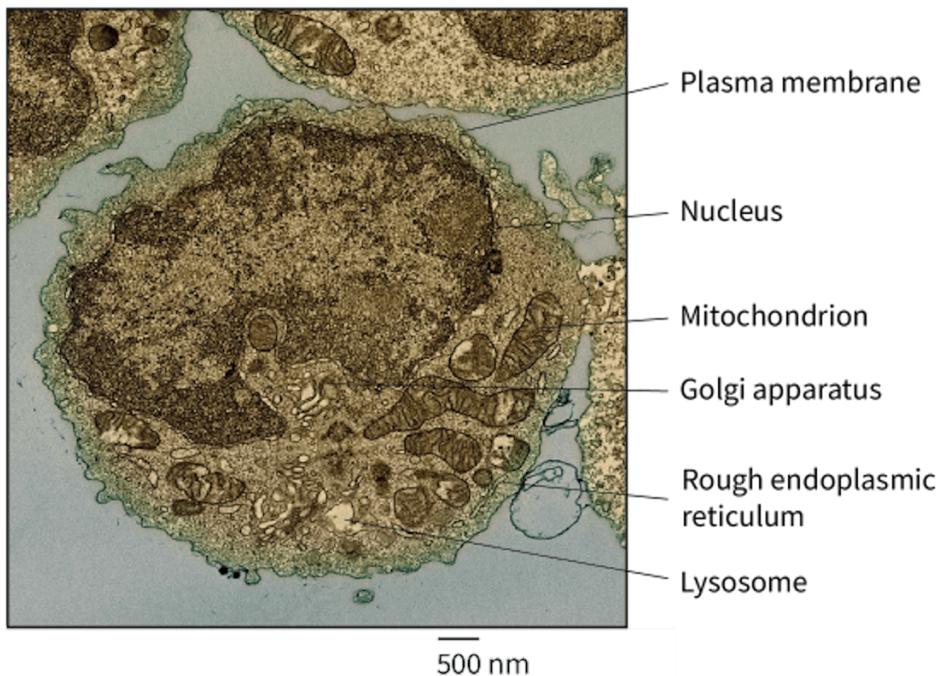


(a)

Source “Cheekcells stained (https://commons.wikimedia.org/wiki/File:Cheekcells_stained.jpg)” by Mulletsrokk is licenced under CC BY-SA 3.0 (<https://creativecommons.org/licenses/by-sa/3.0/deed.en>)

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Home
Overview
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(b)

Source "[Human B Lymphocyte \(28942386960\)](#)"

([https://commons.wikimedia.org/wiki/File:Human_B_Lymphocyte_\(28942386960\).jpg](https://commons.wikimedia.org/wiki/File:Human_B_Lymphocyte_(28942386960).jpg)) by NIAD is licensed under CC BY 2.0 (<https://creativecommons.org/licenses/by/2.0/deed.en>)

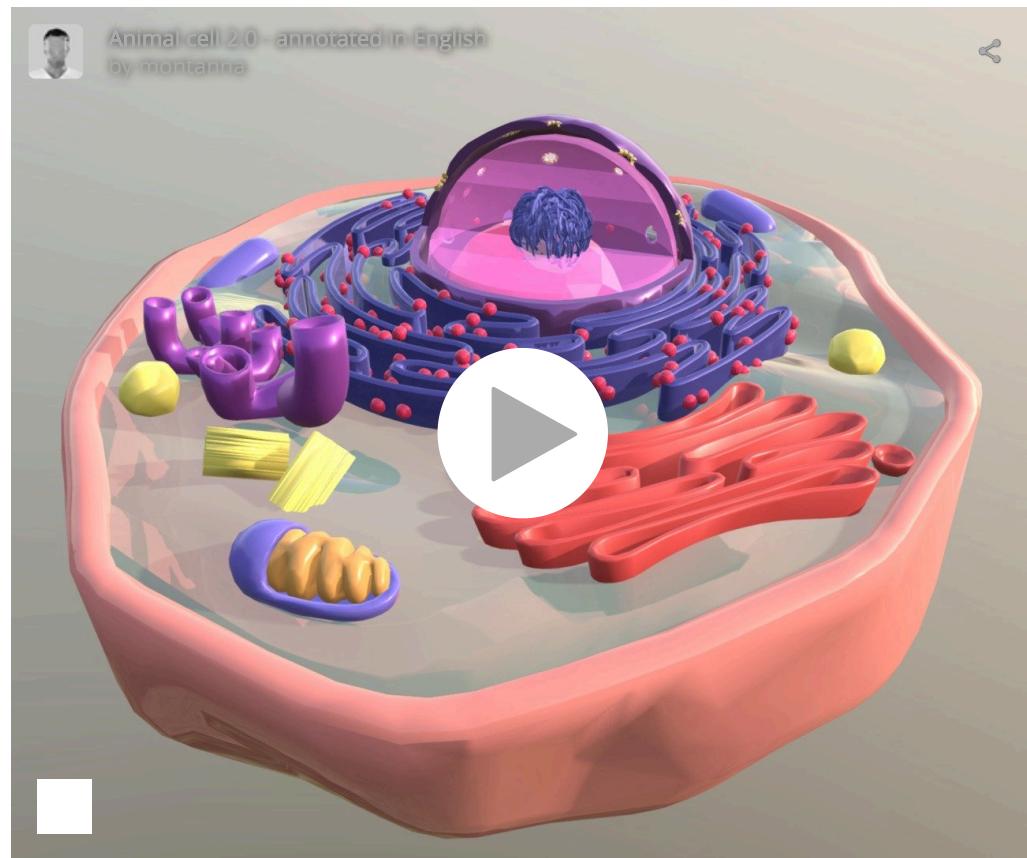
Figure 3. (a) Animal cells viewed using a light microscope at 500 \times magnification and (b) an animal cell viewed with an electron microscope.

Explore **Interactive 1** to see the typical features of an animal cell, rotating and zooming in and out. Click on the annotations to learn about the different structures.



Student
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Home
Overview
(/study/app/
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Interactive 1. Model of an animal cell.

More information for interactive 1

A 3D interactive of an animal cell. Animal cells are eukaryotic; typical cells contain a nucleus, 80S ribosomes, and membrane-bound organelles. In addition, animal cells also contain centrioles and lysosomes. Some animal cells also contain vacuoles. Users can rotate the 3D interactive, as well as zoom in and out.

There are 5 annotations represented by numbers at different structures. Annotation 1 on the Golgi apparatus.

Annotation 2 on the mitochondria. Annotation 3 on the rough endoplasmic reticulum. Annotation 4 on the nucleus.

Annotation 5 on the smooth endoplasmic reticulum. Clicking on the annotations reveals the description of the animal cell structures.

The following items are revealed in respective annotations:

Annotation 1: The Golgi apparatus (also known as the Golgi body or Golgi complex) packages proteins and lipids into vesicles, preparing them to be delivered throughout the cell.

Annotation 2: The mitochondria (plural), or mitochondrion (singular), is the only organelle that has its own genome and can reproduce by fission. It has two membranes and is responsible for releasing energy, storing calcium, and controlling functions like cell growth and death.

Annotation 3: The Rough Endoplasmic Reticulum, or rough ER, differs from the smooth ER in that its surface has a bumpy appearance caused by attached ribosomes. These help the ER synthesize and target proteins. Since it's so close to the nucleus, it is able to communicate with it about protein synthesis.

Annotation 4: The nucleus is the main control center of the cell. It has its own double membrane and contains a gel-like substance called nucleoplasm, which holds internal structures like the nucleolus. The nucleolus is made up of tightly coiled chromosomes that hold the cell's entire genetic code and is the location where ribosomes are

Student view

assembled. The nucleus uses this information to communicate with the rough ER about protein synthesis.

Annotation 5: The smooth endoplasmic reticulum differs from the smooth ER or SER in that it has no ribosomes on its surface. It synthesizes lipids and hormones.

Plant cell structure

In addition to the features shared by typical eukaryotic cells, plant cells also contain a cell wall made of a polysaccharide called cellulose (**Figure 4**). It protects the cell and resists osmotic pressure, maintaining the shape of the cell. Some plant cells also contain chloroplasts – double-membrane-bound organelles that convert light energy into chemical energy in the process of photosynthesis (**Figure 5**). The chloroplast is one of many types of plastid – a small organelle responsible for manufacturing and storing chemical energy. The green colour of chloroplasts comes from chlorophyll, the pigment found within chloroplasts. The vacuole in plant cells is much larger than the vacuoles found in animal cells, and they have an important role in regulating the osmotic potential of the cell.

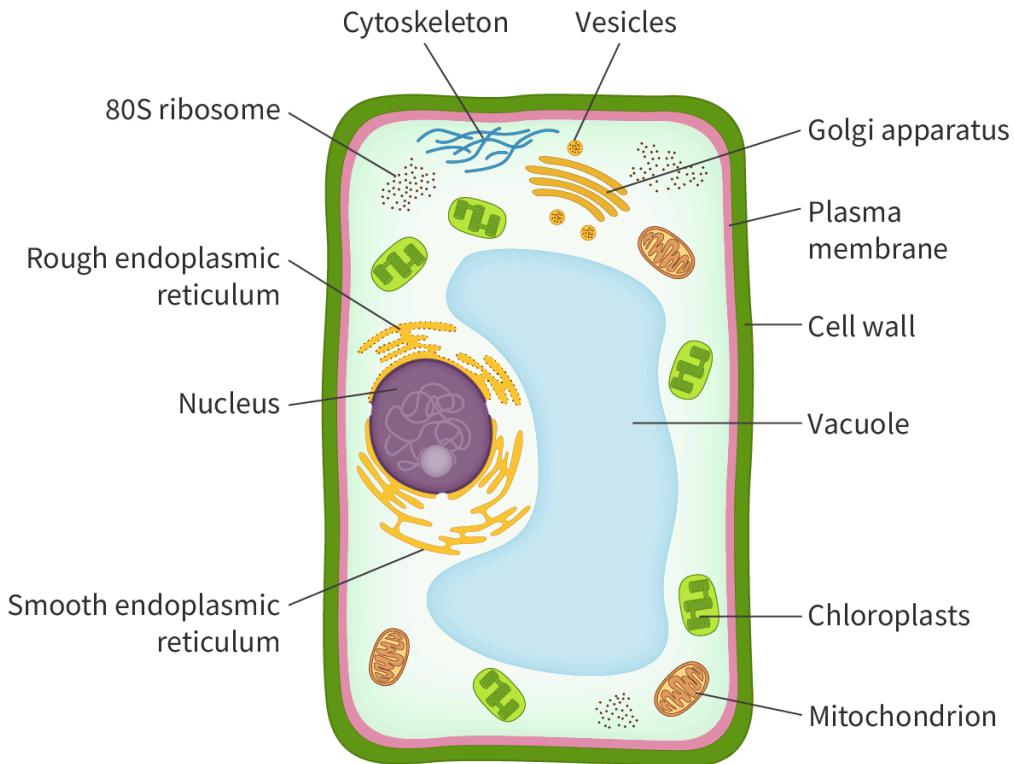


Figure 4. Ultrastructure of a palisade mesophyll cell, found in the leaves of plants.

More information for figure 4

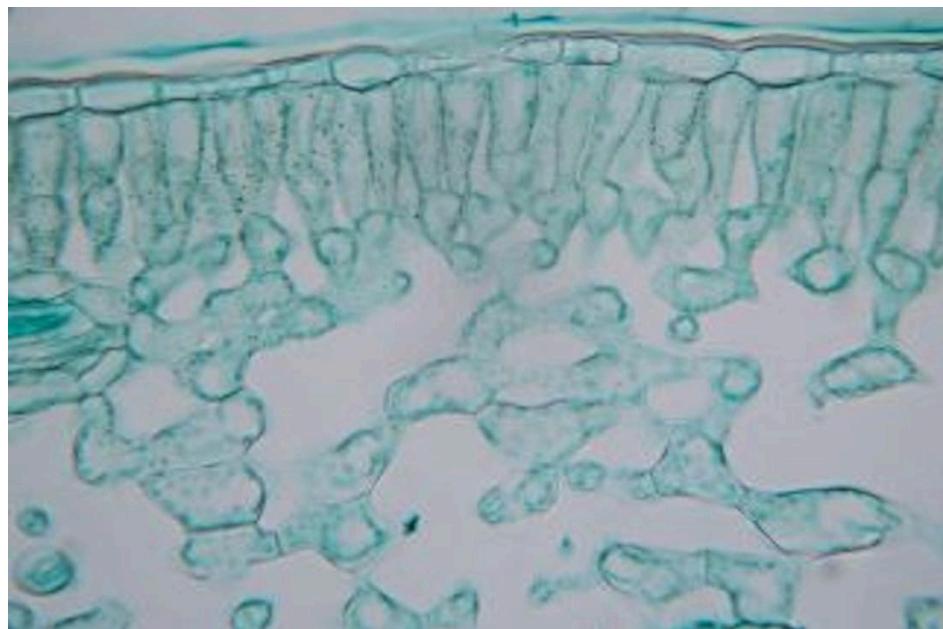


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This image is a diagram illustrating the ultrastructure of a palisade mesophyll cell, commonly found in plant leaves. It is labeled with various cell components including the cytoskeleton, vesicles, Golgi apparatus, plasma membrane, cell wall, vacuole, chloroplasts, mitochondrion, 80S ribosome, rough endoplasmic reticulum, nucleus, and smooth endoplasmic reticulum. The cell is bordered by a cell wall made of cellulose, providing protection and shape. Inside, the large central vacuole helps in maintaining osmotic balance and cell rigidity. Chloroplasts, responsible for photosynthesis, are indicated with their defining feature of chlorophyll pigments. The nucleus, depicted centrally in purple, contains genetic material.

[Generated by AI]

Figure 5 shows plant cells viewed with a light microscope and an electron microscope. Note the difference in magnification and resolution and how this allows you to see the cell structures more clearly in the electron micrograph.



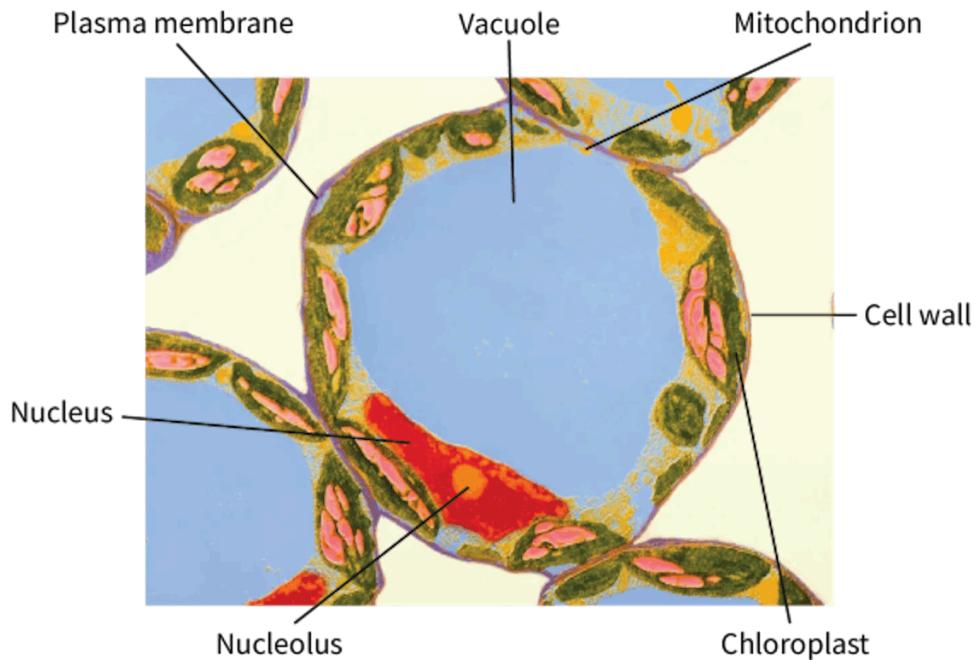
(a)

Credit: Sinhyu, Getty Images (<https://www.gettyimages.com/detail/photo/cross-section-leaf-plant-of-under-the-microscope-royalty-free-image/1199417411>)



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Home
Overview
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(b)

Credit: sdIPxWM_z8f4ww, "Chloroplasts in mesophyll cells of leaves", Science Photo Library, TT NEWS AGENCY

Figure 5. (a) Plant cells viewed using a light microscope and (b) a plant cell viewed using an electron microscope.

Explore **Interactive 2** to see the typical features of a plant cell, by rotating and zooming in and out. Click on the annotations to learn about the different structures.

Plant Cell | Biology
by Oliver

An interactive 3D model of a plant cell. The cell is shown from a top-down perspective, revealing its internal components. A large green nucleus is at the center, surrounded by various organelles like chloroplasts (green), mitochondria (pink), and endoplasmic reticulum (light blue). The cell is bounded by a green membrane. A prominent feature is a large white play button in the center of the cell, indicating it can be interacted with. The entire model is set against a dark background. In the bottom left corner, there is a small 'X' icon and the text 'Student view'. In the top right corner, there is a share icon.



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Interactive 2. Model of a plant cell.

Fungal cell structure

Like plant cells, fungal cells have a cell wall, but their cell wall is made of a polysaccharide called chitin. Fungal cells contain large vacuoles, which degrade (break down) molecules in the cell, as well as acting as a storage site for small molecules such as ions (**Figure 6**).

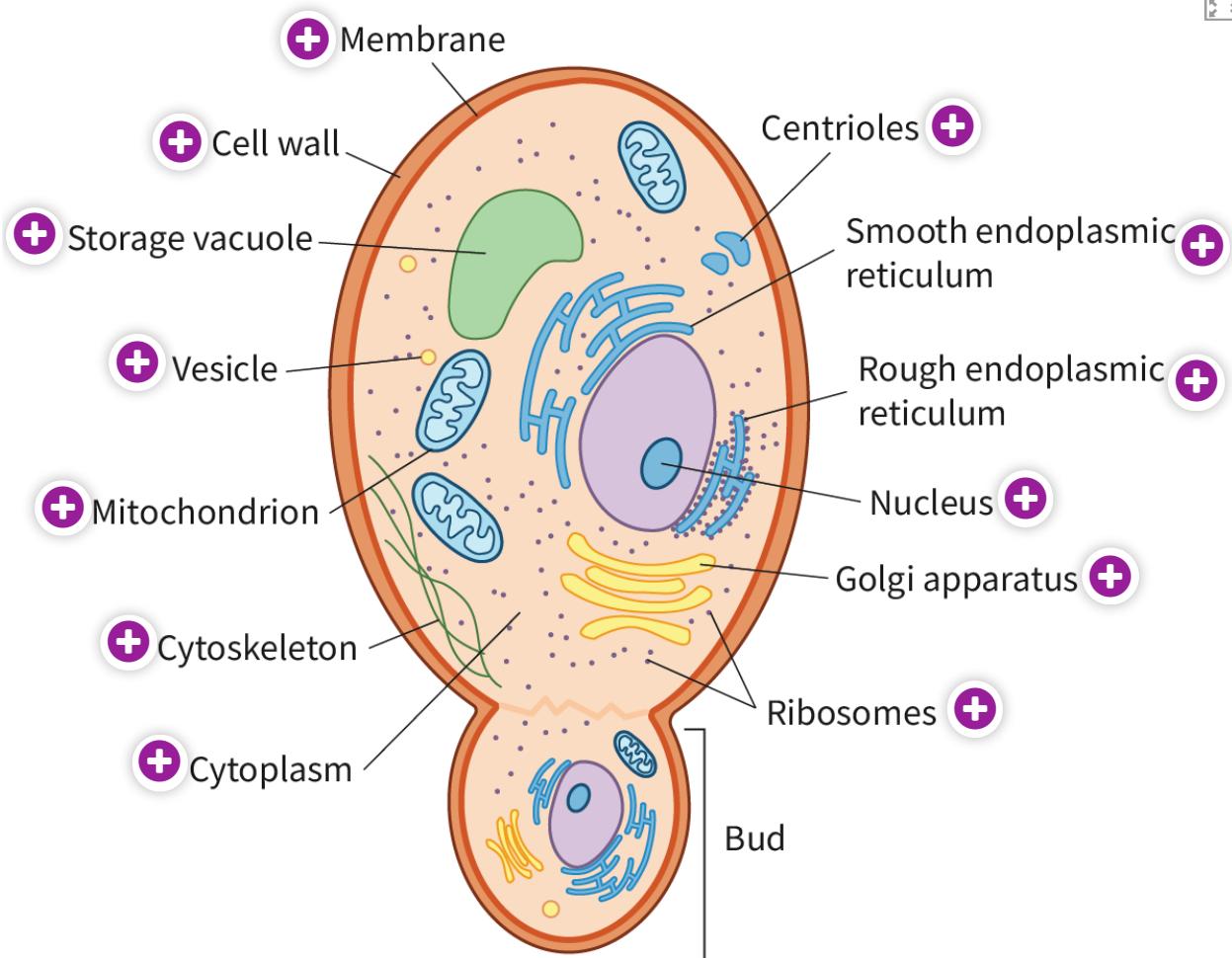
Like animal cells, fungal cells may also contain centrioles for producing and organising the cytoskeleton and playing a key role in cell division (**Figure 7**). However, they are not present in most fungi, except for the male gametes of some fungi. The main function of centrioles is to produce cilia during interphase and the aster and the spindle during cell division.

Some fungi are unicellular, such as *Saccharomyces cerevisiae*, and some are multicellular such as mushrooms and toadstools.

Explore **Interactive 3** to see the typical features of a fungal cell. Click on the hotspots to learn about the different structures.



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Interactive 3. A Fungal Cell.

More information for interactive 3

This interactive is a labelled diagram of a fungal cell, a type of eukaryotic cell. The diagram highlights the major organelles within the cell, each labelled along with a hotspot represented by a plus sign. Clicking on these hotspots provides information about the corresponding organelle function.

The cell looks like a large sphere with another small sphere emerging from it at the bottom. Read below to learn how each organelle looks along with a description of each organelle provided in the hotspot.

Hotspot 1: This hotspot is located near the label “Cell membrane” (plasma membrane). It is characterized by a red-coloured border between the cell wall and cytoplasm. Clicking on this hotspot reveals the text “Plasma membrane — separates the cell's interior from its external environment and controls what can enter and exit the cell.”

Hotspot 2: This hotspot is located near the label “Centrioles” and is shown as small blue-colored molecules with an irregular shape at the top right side of the cell. Clicking on this hotspot reveals the text “Centrioles — Important in organising the cytoskeleton and in cell division.”



Overview
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Hotspot 3: This hotspot is located near the label “cell wall”. It is the outermost structure of the cell characterized by an orange-coloured border at the outermost part of the cell. Clicking on the hotspot 3 reveals the text “Cell wall — made of chitin. Protects and strengthens the cell and maintains its shape.”

Hotspot 4: This hotspot is for storage vacuole in the cell. The storage vacuole in the cell is shown as a green-coloured structure that is almost spherical in shape. Clicking on this hotspot reveals the text “Large vacuole — the site of degradation of many other molecules in the cell.”

Hotspot 5: This hotspot is located near the label “Smooth endoplasmic reticulum.” It is located in the centre of the cell around the nucleus

and is characterized by a network of interconnected tubules. Clicking on the hotspot 5 reveals the text “The Smooth endoplasmic reticulum — produces and stores lipids, including steroids.”

Hotspot 6: Hotspot 6 is located near the label “vesicle”. This hotspot is for vesicles in the cell which are represented as small yellow circles with a red border located inside the cell. Clicking on this hotspot reveals the text “Vesicle — A small sac that transports and releases substances produced by the cell by fusing with the cell membrane.”

Hotspot 7: This hotspot is located near the label “Rough endoplasmic reticulum”. The rough endoplasmic reticulum is located around the nucleus of the cell. It is characterized by a network of interconnected tubules with ribosomes attached to them. Clicking on the hotspot reveals the text “Rough endoplasmic reticulum — contains ribosomes which produce proteins that are usually destined for use outside the cell.”

Hotspot 8: This hotspot is located near the label “nucleus”. The nucleus is located in the middle of the cell. It is characterized by a purple sphere with another small blue sphere inside. Clicking on the hotspot reveals the text “Nucleus — contains the DNA which is organised into chromosomes. Also contains the nucleolus, which is involved in the production of ribosomes.”

Hotspot 9: This hotspot is located near the label “Mitochondria”. Mitochondria are represented as blue rod-shaped structures with folds (cristae) inside. Clicking on this hotspot reveals the text “Mitochondria — double-membrane-bound organelles that convert glucose into ATP (the cell's energy currency) in the process of respiration.”

Hotspot 10: This hotspot is located near the label “Golgi apparatus”. The Golgi apparatus is represented as a series of flat, disc-shaped membranes in yellow colour. Clicking on this hotspot reveals the text “Golgi apparatus — processes and packages proteins, which are then released in Golgi vesicles.”

Hotspot 11: This hotspot is located near the label “Cytoskeleton”. The cytoskeleton is represented as green-coloured filaments that look like threads. Clicking on this hotspot reveals the text “Cytoskeleton — a system of protein fibres called microtubules and microfilaments. The cytoskeleton helps to hold organelles in place and maintain the structure

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Student view



and shape of the cell."

Overview
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Hotspot 12: This hotspot is located near the label "Ribosomes". Ribosomes are represented as small purple-coloured dots that are scattered throughout the cytoplasm. Clicking on this hotspot reveals the text "80S ribosomes — where translation (protein synthesis) occurs. Eukaryotic ribosomes are larger and have a higher mass than prokaryotic ribosomes."

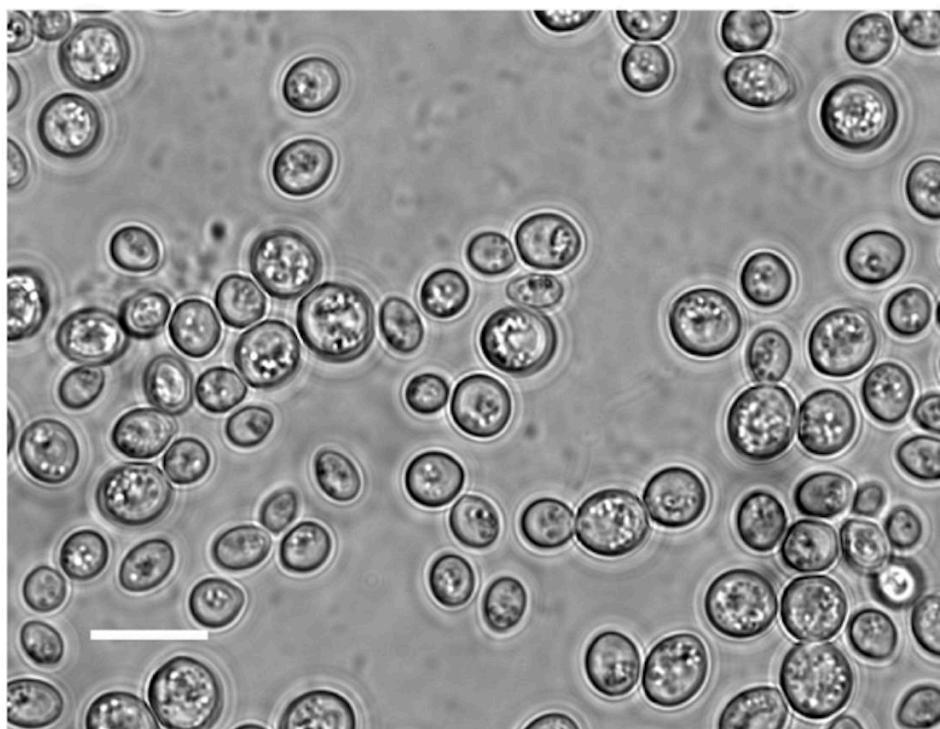
Hotspot 13: This hotspot is located near the label "Cytoplasm". Cytoplasm is the fluid inside the cell membrane and outside the nucleus. Clicking on this hotspot reveals the text "Cytoplasm — a water-based jelly-like fluid that fills the cell, suspends ions, organic molecules, organelles, and ribosomes, and is the site of metabolic reactions."

Bud: A small outgrowth forming on the fungal cell, indicating a process called budding. This outgrowth gets detached and then grows into a new cell.

This interactive diagram helps viewers understand the internal structure of a fungal cell and how each organelle contributes to its survival and function.

Figure 6 shows fungal cells viewed using a light microscope and an electron microscope.

Fungi reproduce by a process called budding. The budding scar is a crater-like ring of tissue that forms when a daughter cell buds from a parent cell. The number of budding scars on a fungal cell is indicative of how many times the cell has divided.

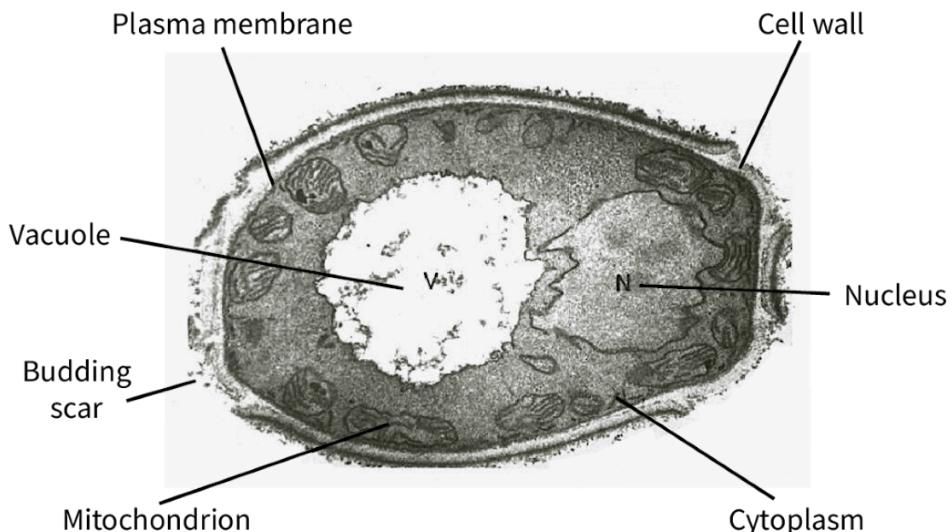


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(a)

Source: "S. boulardii Mutants Express Functional GFP"

(https://commons.wikimedia.org/wiki/File:Pone.0112660.g007.PNG_L_cropped_S_boulardii.png)



(b)

Credit: Sinhyu, Getty Images

Figure 6. (a) Fungal cells viewed with a light microscope and (b) a fungal cell viewed with an electron microscope. Note the difference in resolution and how this allows you to see the cell structures more clearly in the electron micrograph.

More information for figure 6

The image is an electron micrograph of a fungal cell showcasing detailed structural components. The cell has various labeled parts, each marked by lines connecting to different regions of the cell. The labels include 'N' representing the nucleus, and 'V' likely indicating a vacuole. You can also see membranous structures and organelles dispersed throughout the cell. The high resolution of the electron microscopy provides clarity on the internal organization of the cell, distinguishing each component distinctively.

[Generated by AI]

Figure 7 shows animal, fungal and plant cells side by side. Note the common and unique features for these cell types.



Figure 7. What features are common to all three cell types? What features are unique to just one cell type?

More information for figure 7

The image shows three detailed illustrations side by side of animal, plant, and fungal cells, each highlighting their unique and common structures. The animal cell on the left has a flexible outline and contains organelles such as a large nucleus, mitochondria, ribosomes, and endoplasmic reticulum. The plant cell in the middle has a rigid cell wall and features, including a large central vacuole, chloroplasts, and a nucleus. The fungal cell on the right is oval with a budding structure, containing a nucleus, mitochondria, and ribosomes. All three cells share common features like the presence of a nucleus, mitochondria, and ribosomes, but differ in structures like chloroplasts in plant cells and bud structures in fungal cells.

[Generated by AI]

Atypical cell structure in eukaryotes

We have learnt that prokaryotic cells do not contain a nucleus, and typical eukaryotic cells do have a single nucleus.

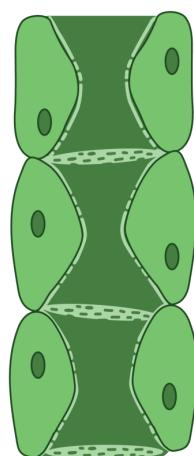
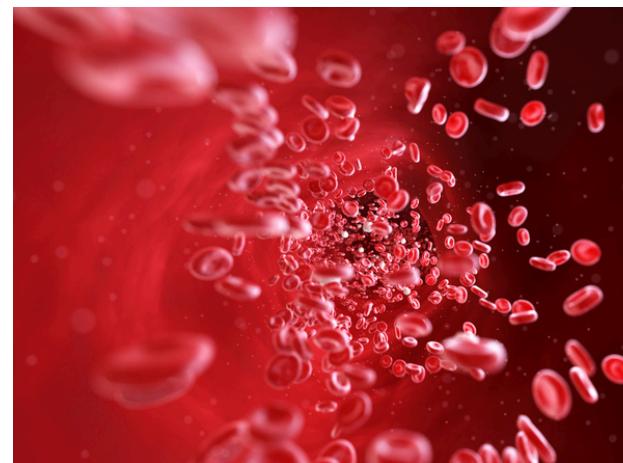
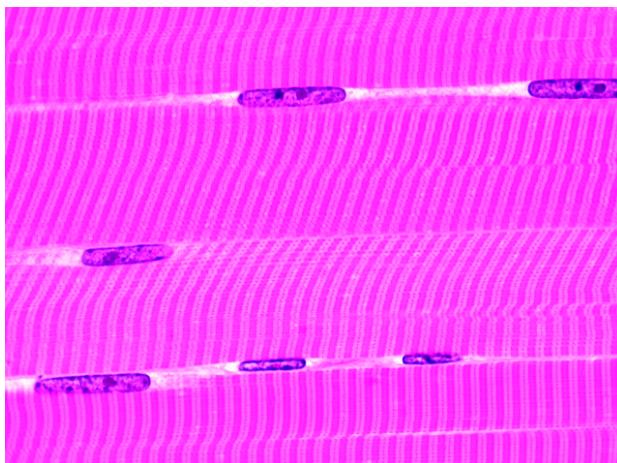
However, there are some atypical eukaryotic cells. This means they do not contain, or contain abnormal numbers of the cell structures and organelles that are found in most other eukaryotic cells. The following are examples of anucleate and multinucleate eukaryotic cells (see **Interactive 4**):

- Skeletal muscle is multinucleated – one single cell contains many nuclei. This is because the muscle cell has formed from many smaller myocytes that have fused



together.

- Mature red blood cells are anucleate – they do not contain a nucleus. This means that the cell has a greater haemoglobin capacity and can transport more oxygen.
- Normally, the hyphae of fungi contain septates which separate cellular structures and organelles whilst still allowing the movement of substances between cells. Aseptate hyphae in fungi do not have the cellular partitions that are normally present, and so there are many nuclei in a single cellular unit and we can think of the aseptate hyphae as multinucleated.
- Sieve tube elements in the phloem of plants are anucleate. They also contain very little cytoplasm and few organelles. This means that there is a very low resistance for substances moving through a sieve tube element.



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Interactive 4. Examples of Anucleate and Multinucleate Eukaryotic Cells: (A) Skeletal Muscle; (B) Red Blood Cells; (C) Hyphae of Fungi; (D) Sieve Tube Elements.





Overview
(/study/app/
422-
cid-
755105/o

Study skills

In science the prefixes ‘a-’ and ‘an-’ mean ‘not’ or ‘without’. For example, *anaerobic* means without oxygen, *abiotic* means not living, *atypical* means not typical and *anucleate* means without a nucleus.

Try the activity below to compare the features of plant, animal and fungal cells.



Activity

- **IB learner profile attribute:** Thinker
- **Approaches to learning:** Thinking — Reflecting at all stages of the assessment and learning cycle
- **Time required to complete activity:** 20 minutes
- **Activity type:** Individual activity

Organise the statements on the Venn diagram in **Interactive 5** to compare and contrast between these three kingdoms of eukaryotic organisms.

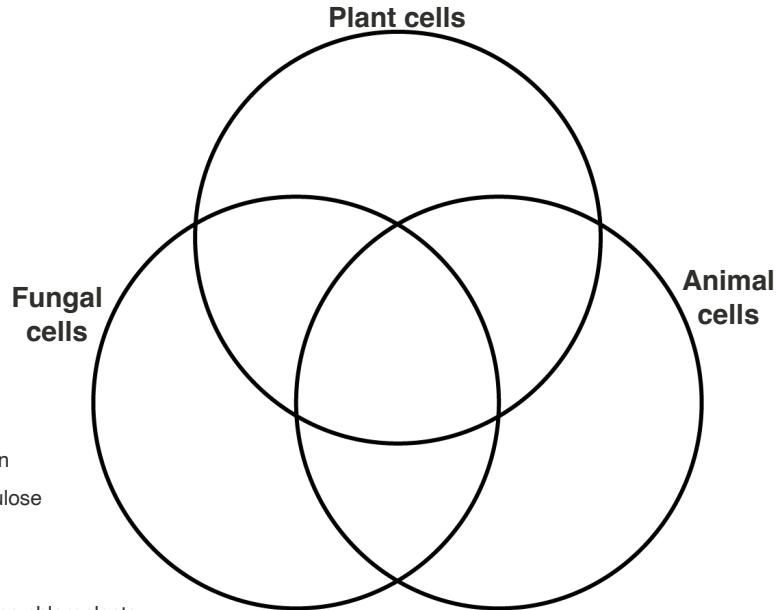


Student
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Overview
(/study/app/
422-
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- A
- B
- C
- D
- E
- F
- G
- H
- I
- J
- K
- L



- A Contains a nucleus
- B Cell wall made of chitin
- C Cell wall made of cellulose
- D Centrioles
- E Chloroplasts
- F Contain plastids such as chloroplasts
- G Can contain vacuoles
- H Contain mitochondria
- I Contain 70S ribosomes in the cytoplasm
- J Plasma membrane
- K Lysosomes
- L Cilia

Check

Interactive 5. Venn diagram for animal, plant and fungal cell features.

Once you have completed the Venn diagram, write a paragraph comparing and contrasting plants, animals and fungi. Ensure that you are using comparative language in your answer and that you have included all of the points from the Venn diagram.

70S ribosomes are found in prokaryotic cells, but eukaryotic cells only contain 80S ribosomes in the cytoplasm

5 section questions ▼



Student
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A2. Unity and diversity: Cells / A2.2 Cell structure

Endosymbiosis, cell differentiation and the evolution of multicellular organisms (HL)

A2.2.12: Origin of eukaryotic cells by endosymbiosis (HL) A2.2.13: Cell differentiation in multicellular organisms (HL)
A2.2.14: Evolution of multicellularity (HL)

Section

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Feedback



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Higher level (HL)

Learning outcomes

By the end of this section you should be able to:

- Describe the theory of endosymbiosis.
- Outline the evidence supporting the theory of endosymbiosis.
- Outline that changes in the environment of a cell can trigger changes in gene expression, and this process can lead to cell differentiation.
- Outline the benefits of multicellularity.

Evidence suggests that all eukaryotes evolved from a common unicellular ancestor around 2.7 billion years ago. This common ancestor of all eukaryotic organisms had a nucleus and reproduced sexually.

The theory of endosymbiosis posits that eukaryotic organisms evolved when this common ancestor endocytosed a prokaryotic cell capable of generating energy from oxygen (**Figure 1**). Rather than being digested, these cells remained inside the host cell, carrying out aerobic respiration and providing energy to their host cells, evolving into mitochondria.

For some eukaryotes, subsequent endocytosis of a prokaryotic cell that could convert light energy into chemical energy, probably a cyanobacterium, resulted in the evolution of chloroplasts.

Study skills

The prefix ‘endo-’ means within or inside.



The term 'symbiosis' refers to a close and usually mutually beneficial relationship between two organisms or different species.

In the context of endosymbiosis, symbiosis refers to the relationship between the host cell and the smaller prokaryotic cell that became incorporated into it. The host cell benefits from the relationship by receiving certain nutrients from the engulfed cell, such as ATP or glucose, and in return the engulfed cell receives a protected environment and access to resources from the host cell.

💡 Theory of Knowledge

How does our understanding of the role of mitochondria in cellular respiration, and the role of chloroplasts in photosynthesis inform our understanding of the evolution of eukaryotic cells?

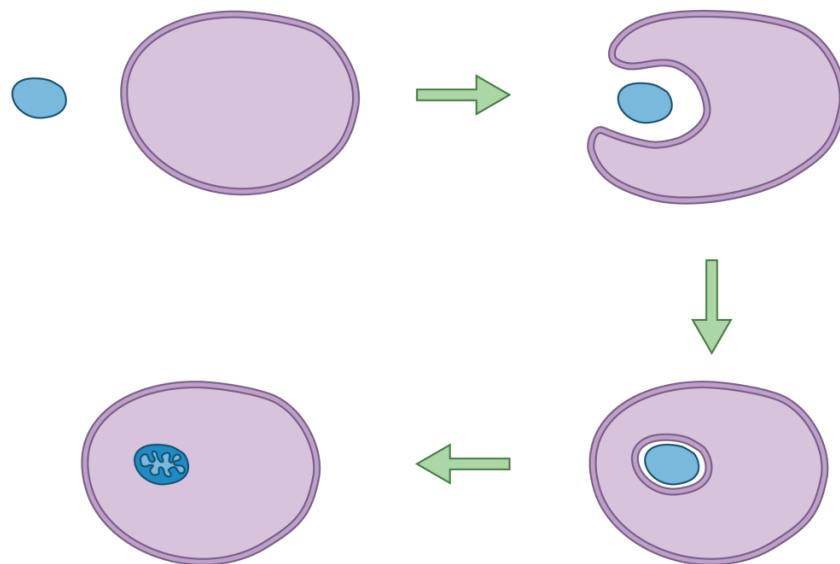


Figure 1. Endosymbiosis.

[More information for figure 1](#)

This diagram illustrates the process of endosymbiosis in a series of steps. Starting at the top left, a smaller blue cell approaches a larger purple cell. The next image shows the larger cell beginning to engulf the smaller cell, with an arrow indicating the direction of the process. Below, in the third image, the smaller blue cell is now entirely inside the larger cell. The final image on the bottom left depicts the smaller cell now functioning as an organelle within the larger cell, specifically represented as a mitochondrion-like shape. Arrows indicate the flow from one stage to the next, showing a clockwise pattern of progression.



Evidence for endosymbiosis

The following evidence supports the endosymbiotic theory (**Figure 2**). Both mitochondria and chloroplasts:

- measure around $8 \mu\text{m}$ in length, the same size as many prokaryotic organisms
- have double membranes. It is thought that the inner membrane was formed from plasma membrane of the endocytosed prokaryotic cell, and the outer membrane is thought to have formed from the vesicle in which the cell was taken up into the ancestor of eukaryotic organisms
- have circular naked DNA, as is found in prokaryotes
- have 70S ribosomes, the same size as the ribosomes in prokaryotes, rather than the 80S ribosomes in eukaryotic cells
- divide by binary fission like prokaryotic cells, unlike eukaryotic cells, which divide by mitosis
- are susceptible to some antibiotics, compounds that target prokaryotic structures and metabolic processes.

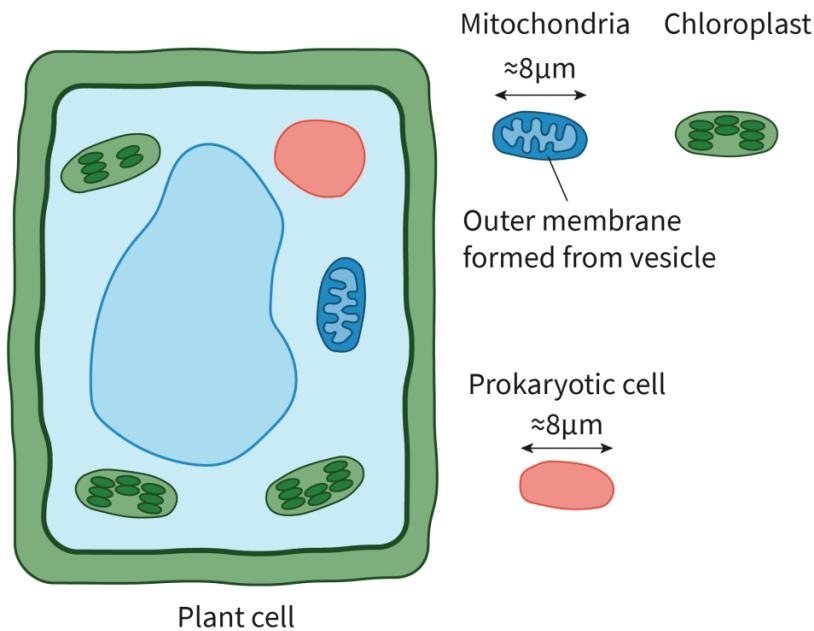


Figure 2. Evidence supporting the theory of endosymbiosis.

More information for figure 2

The image is a diagram of a plant cell with a labeled illustration highlighting the theory of endosymbiosis. It shows a plant cell with a double-lined green border representing the cell wall. Inside, there is a large, irregular, light blue shape indicating a central vacuole, and several smaller structures. On the left and bottom inside the cell, there are two green elliptical shapes labeled as chloroplasts. A blue bean-shaped structure labeled as a mitochondrion is placed below the central vacuole. The diagram also includes a comparison of mitochondrion, chloroplast, and a prokaryotic cell outside the plant cell on the right side. The mitochondrion and prokaryotic cell are annotated with a size of approximately 8 micrometers (μm)



Home
Overview
(/study/app/
422-
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each, with arrows indicating this measurement across their diameters. There is also a label stating "Outer membrane formed from vesicle". The text reads: "Mitochondria $\approx 8\mu\text{m}$ ", "Chloroplast", "Prokaryotic cell $\approx 8\mu\text{m}$ ", and "Plant cell."

[Generated by AI]

🔗 Nature of Science

Aspect: Theories

The strength of a theory comes from the observations the theory explains and the predictions it supports. A wide range of observations are accounted for by the theory of endosymbiosis.

Ἑ Theory of Knowledge

Is prediction the primary purpose of scientific knowledge? Cell theory and endosymbiosis allow important predictions to be made about newly discovered organisms and their composition.

Cell differentiation

While all prokaryotic organisms are unicellular, many fungi and eukaryotic algae, and all plants and animals are multicellular. Within a multicellular organism, different cells have different roles, and these cells work together to form the tissues and organs that make up the multicellular organism. We refer to these cells as specialised cells, meaning they have a distinct set of structures and functions. To become a specialised cell, differentiation must occur (Figure 3).



Student
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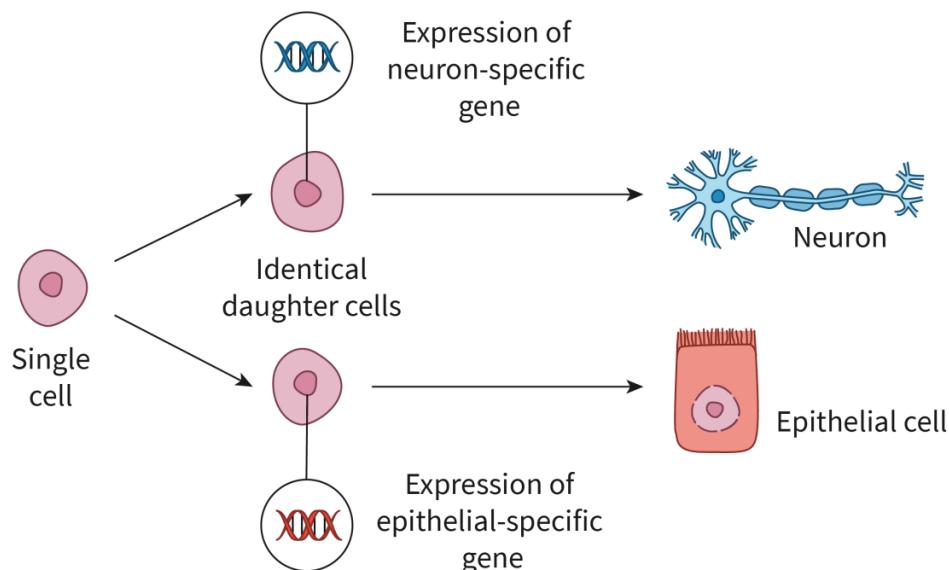


Figure 3. When undifferentiated cells are exposed to particular environmental conditions they can be triggered to differentiate to become a certain type of specialised cell.

More information for figure 3

The diagram represents the process of cell differentiation, showing how a single cell undergoes division to form identical daughter cells. These daughter cells can then differentiate into specific cell types through gene expression. The top path illustrates the expression of neuron-specific genes, leading to the formation of a neuron. The bottom path shows the expression of epithelial-specific genes, resulting in the development of an epithelial cell. All elements, including labels like "Identical daughter cells," "Expression of neuron-specific gene," and "Expression of epithelial-specific gene," help explain the transformation process from a singular cell to specialized forms like neurons and epithelial cells.

[Generated by AI]

Cell differentiation involves the turning on of genes necessary for the function of the specialised cell, and the turning off of genes that are not necessary for the function of the specialised cell. This regulation of gene expression within a cell can be controlled by changes in the environment of the cell.

For example, during human development, early embryonic cells are undifferentiated, and so are unable to perform any specific functions. As the embryo develops, genes within the cell will be turned on or off by changes in the cellular environment, such as the presence of proteins called growth factors, causing the cells to differentiate into specialised cell types such as muscle cells and nerve cells.

Because of cell differentiation, multicellular organisms have a larger body size and are more complex and adaptable to changes in their environment.

 **Theory of Knowledge**

How might our understanding of the development and organisation of multicellular organisms shape our ethical and moral considerations related to issues such as stem cell research and tissue engineering?

The evolution of multicellular organisms

Scientists think that multicellularity has evolved repeatedly through a process called cell aggregation. This is where individual cells cluster together, more efficiently obtaining and sharing nutrients and benefiting from group protection from predators. Over time, some of the cells within the cluster were thought to have differentiated to play more specialised roles.

 **Theory of Knowledge**

When a structure or process has repeatedly evolved, what does that indicate about the usefulness of that feature to the survival of the organisms in which it evolved?

Try this activity to check your understanding of endosymbiosis.

 **Activity**

- **IB learner profile attribute:** Communicator
- **Approaches to learning:** Communication skills — Reflecting on the needs of the audience when creating engaging presentations
- **Time required to complete activity:** 20 minutes
- **Activity type:** Pair activity

Use modelling clay and an app such as Stop Motion Studio to make a stop motion animation to detail the process of endosymbiosis. Alternatively, you could make a cartoon to summarise the process.





Overview

(/study/app/bio/sid-422-cid-755105/o)

422-

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755105/o A2. Unity and diversity: Cells / A2.2 Cell structure

5 section questions ▾

Section

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Feedback



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Summary and key terms

- Microscopes are instruments used to magnify very small objects, cells and organisms. The type of microscopes used in schools are light microscopes, which use rays of light and a series of lenses to magnify the specimen being viewed. Immunofluorescence and fluorescence tagging are techniques used in light microscopy. Electron microscopes use electrons instead of light and are able to produce images of a higher resolution and magnification. Freeze fracture and cryogenic electron microscopy are techniques used in electron microscopy.
- Magnification can be calculated by dividing the size of an image by the size of the object. When carrying out these calculations, it is important to make sure the image size and the object size are given in the same units.
- All cells, whether eukaryotic or prokaryotic contain DNA as the genetic material, cytoplasm and a plasma membrane composed of phospholipids.
- There are eight processes that are carried out by all living things: homeostasis, metabolism, nutrition, movement, excretion, growth, response to stimuli and reproduction.
- Prokaryotic cells do not contain a nucleus, their DNA is naked and free in the cytoplasm. They do not contain membrane-bound organelles and their ribosomes are 70S. In addition to DNA as the genetic material, cytoplasm and a plasma membrane, typical prokaryotic cells contain a cell wall and plasmids. Some prokaryotic cells contain a capsule, a flagellum and/or pili.
- Eukaryotic cells contain a nucleus, membrane-bound organelles and 80S ribosomes. The DNA in eukaryotic cells is bound to histone proteins. In addition to DNA as the genetic material, cytoplasm and a plasma membrane, typical eukaryotic cells contain mitochondria, smooth endoplasmic reticulum, rough endoplasmic reticulum, Golgi apparatus, vesicles, vacuole and cytoskeleton.
- There are three types of eukaryotic organisms: plants, animals and fungi. Each of these groups has additional features. Animal cells contain centrioles and lysosomes, and some animal cells contain vacuoles and have cilia. Plant cells contain a cell wall and have much larger vacuoles than animal cells. Some plant cells contain chloroplasts.



Student view



Like plant cells, fungal cells contain a cell wall and large vacuoles. Fungal cells generally do not contain centrioles, but have evolved a centriole-less microtubule organizing center known as the spindle pole body (SPB). However, there are exceptions, as some fungi may possess centrioles in specific contexts

- Protists are not a natural group or a formal classification, but a diverse collection of organisms that are not animals, plants, or fungi. Protists may share some characteristics with these other kingdoms, but they also have unique features and evolutionary histories
- Some eukaryotic cells are atypical; for example they may not contain a nucleus, such as red blood cells and phloem sieve tube elements, or they may be multinucleate such as skeletal muscle cells and aseptate hyphae in fungi.

Higher level (HL)

- The theory of endosymbiosis states that all eukaryotes evolved from a common ancestor which had a nucleus and reproduced sexually. It is thought that this common ancestor endocytosed a prokaryotic cell capable of generating energy from oxygen, which then evolved into the mitochondria. Some eukaryotes also endocytosed a prokaryotic cell which could convert light energy into chemical energy, resulting in the evolution of chloroplasts. Evidence supporting this theory includes mitochondria and chloroplasts both having double membranes, being approximately the same size as a bacterium, containing 70S ribosomes, dividing by binary fission, containing naked, circular DNA and being susceptible to antibiotics.
- Cell differentiation is the process by which a cell becomes specialised to carry out a particular function. It involves the turning on of genes necessary for that function, and the turning off of genes that are not necessary for that function. This regulation of genes can be controlled by changes in the environment of the cell. Cell differentiation has allowed for the development of multicellularity, which is thought to have evolved repeatedly.





Overview
(/study/app/
422-
cid-
755105/o

↓ A Key terms

Review these key terms. Do you know them all? Fill in as many gaps as you can using the terms in this list.

1. Cells are not visible to the unaided eye. It is necessary to use a **microscopes** use lenses to magnify an image, whereas electron microscopes use beams of electrons to produce images of much higher magnification and
2. **cells** such as plant and animal cells contain a **and membrane-bound organelles**. These structures are not found in **organisms** such as
3. **, flagella and pili** are examples of structures that can be found in prokaryotic cells. Mitochondria, **and Golgi apparatus** are examples of structures typically found in eukaryotic cells.
4. Both eukaryotic and prokaryotic cells contain **; however**, they are larger in eukaryotic cells.
5. All living things carry out eight processes at some stage of their life cycle: **homeostasis, metabolism, nutrition, movement, , growth, response to stimuli and reproduction.**
6. [HL] Eukaryotic cells are thought to have evolved through the process of **, in which prokaryotic cells were endocytosed and formed the mitochondria and chloroplasts.**
7. [HL] Many eukaryotic organisms are **, containing specialised cells that have differentiated from unspecialised cells due to changes in the , which cause certain genes within the cell to be switched on or off.**

multicellular **resolution** **microscope** **vacuoles** **excretion**
environment **Eukaryotic** **endosymbiosis** **nucleus** **prokaryotic**
ribosomes **Light** **bacteria** **Plasmids**

Check

Interactive 1. Cell Structure: Important Concepts and Terminology.



Student
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Overview
(/study/app/

A2. Unity and diversity: Cells / A2.2 Cell structure

422-
cid-

755105/o

Checklist

[Section](#)

Student... (0/0)

Feedback



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What you should know

After studying this subtopic you should be able to:

- Outline cell theory and describe the structure and components of a typical cell.
- Summarise how to make and stain temporary mounts of cells and tissues.
- Describe how to use an eyepiece graticule and stage micrometre to measure sizes of a specimen.
- Perform calculations involving actual size, image size and magnification.
- Outline the applications of electron microscopy.
- Describe the application of techniques that are commonly used in microscopy.
- Outline the structures that are common to cells in all living organisms.
- Describe the structure of a typical prokaryotic cell and the function of prokaryotic cell structures and components.
- Describe the structure of a typical eukaryotic cell and the function of eukaryotic cell structures and components.
- Name the eight processes that all living things carry out.
- Identify how different unicellular organisms carry out each of the eight life processes.
- Outline how there may be differences in the cell structure of plant, animal and fungal cells.
- Give examples of eukaryotic cells with atypical cell structure.

Higher level (HL)

- Describe the theory of endosymbiosis.
- Outline the evidence supporting the theory of endosymbiosis.
- Outline that changes in the environment of a cell can trigger changes in gene expression, and this process can lead to cell differentiation.

Student
view



- Outline the benefits of multicellularity.

⚠ Practical skills

Once you have completed this subtopic, go to [Practical 1: Using microscopes and calculating magnification \(/study/app/bio/sid-422-cid-755105/book/using-microscopes-and-calculating-magnification-id-46529/\)](#) to prepare, measure and analyse samples using a light microscope.

A2. Unity and diversity: Cells / A2.2 Cell structure

Investigation

Section

Student... (0/0)



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755105/book/investigation-id-44723/print/)

Assign

- **IB learner profile attribute:** Communicators
- **Approaches to learning:** Thinking skills – Providing a reasoned argument to support conclusions
- **Time required to complete activity:** 20–30 minutes
- **Activity type:** Individual activity

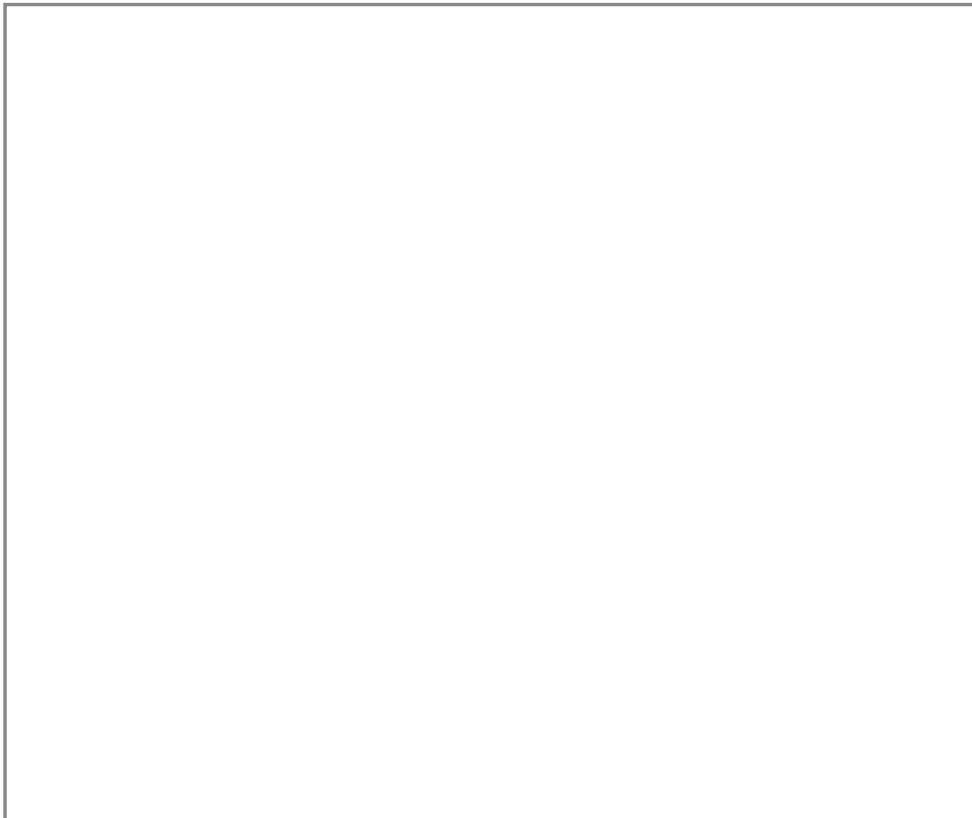
Your task

In this activity you are given micrographs of two cell types, each viewed using a different type of microscope (**Interactives 1 and 2**). For each image:

1. Identify and explain whether it comes from a unicellular or a multicellular organism.
2. Identify whether the cell(s) shown are eukaryotic or prokaryotic. Explain which features lead you to this conclusion.
3. Use the ruler to measure the image size of both micrographs. From this, calculate the magnification or actual size.
4. Identify if the specimen has been viewed using a light microscope or an electron microscope. Justify your choice.
5. Using the guidance detailed in this subtopic, draw the cell structures as shown in these images. Remember to follow the guidance detailed in the skills box.

Home
Overview
(/study/app/
422-
cid-
755105/o

6. Label the visible cell structures. Remember that your labels should be drawn with a straight line, touching the structure that is being identified. You should also include the function of the structures labelled.
7. In one colour, highlight the images shown that are common to both prokaryotic and eukaryotic cells. Write a list of common features that are not shown in both of these micrographs.



Interactive 1. Cell type 1.

More information for interactive 1

This image shows a microscopic image of a rod-shaped bacterium.

The cell is rod-shaped, with rounded ends. The outer cell wall is visible and the cytoplasm is present inside, which appears darker. The dark, elongated area in the center is the nucleoid, where the bacterial DNA is located.

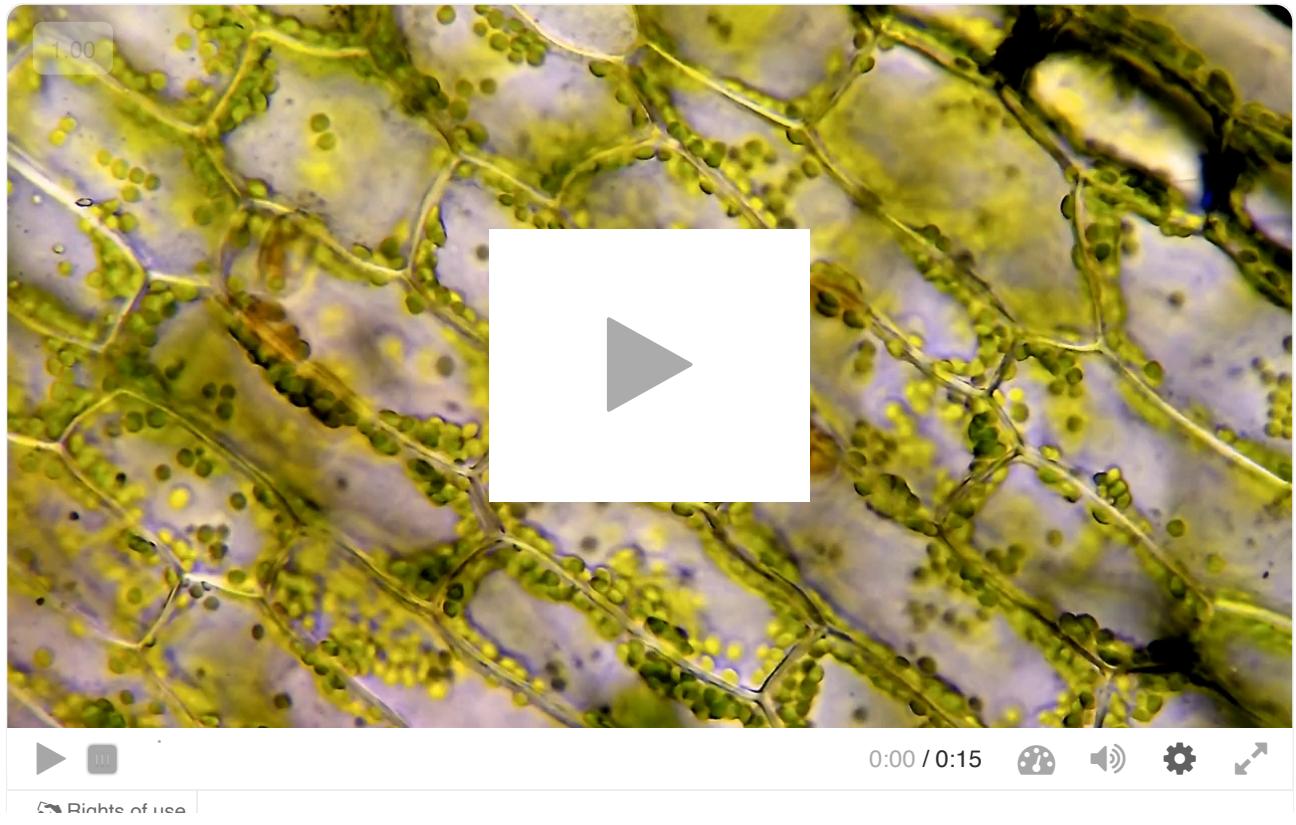
To the right, there is a scale labeled in micrometers (μm). Below the image, there is a millimeter scale (mm). This scale can be moved around the screen, allowing the user to measure the bacterium's length and width.

The image helps us visualize the microscopic world of bacteria and understand their basic structure.



Student
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Home
Overview
(/study/app/
422-
cid-
755105/o



Interactive 2. Cell Type 2 at X40 Magnification.

More information for interactive 2

The interactive consists of a video. Users can play or pause the video using the playback controls, and the timeline at the bottom allows them to navigate through the footage. At the bottom right corner, there is a full-screen toggle that enhances the viewing experience, allowing users to see microscopic details more clearly in an expanded format. The video opens with a high-resolution, close-up microscopic view of cell type 2 at x40 magnification. The intricate network of cell walls is clearly visible, along with numerous chloroplasts, small, green, disc-shaped organelles—within each cell. These chloroplasts exhibit cytoplasmic streaming, a dynamic process in which they circulate along the inner walls of the cells. Notably, the direction of movement varies across different cells: in some, the chloroplasts move in a clockwise direction, while in others, the motion is distinctly anticlockwise. This bidirectional streaming highlights active intracellular transport and offers a vivid demonstration of cell vitality. During the video, a scale bar appears temporarily, offering viewers a reference for measurement before it disappears near the end of the recording.

A2. Unity and diversity: Cells / A2.2 Cell structure

Reflection

Student view

Section

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Teacher instructions

The goal of this section is to encourage students to reflect on their learning and conceptual understanding of the subject at the end of this subtopic. It asks them to go back to the guiding questions posed at the start of the subtopic and assess how confident they now are in answering them. What have they learned, and what outstanding questions do they have? Are they able to see the bigger picture and the connections between the different topics?

Students can submit their reflections to you by clicking on 'Submit'. You will then see their answers in the 'Insights' part of the Kognity platform.



Reflection

Now that you've completed this subtopic, let's come back to the guiding questions introduced in [The big picture \(/study/app/bio/sid-422-cid-755105/book/the-big-picture-id-43253/\)](#).

- What are the features common to all cells and the features that differ?
- How is microscopy used to investigate cell structure?

With these questions in mind, take a moment to reflect on your learning so far and type your reflections into the space provided.

You can use the following questions to guide you:

- What main points have you learned from this subtopic?
- Is anything unclear? What questions do you still have?
- How confident do you feel in answering the guiding questions?
- What connections do you see between this subtopic and other parts of the course?

Once you submit your response, you won't be able to edit it.





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