

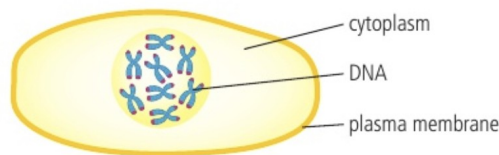
1.1 (A.2.2) Cell Structure

The cell theory states that:

- all living organisms are composed of one or more cells
- cells are the smallest units of life
- all cells come from pre-existing cells

We will examine some cases where there are exceptions to cell theory later on!

Structures common to all cells



Typical cells have:

1. DNA as genetic material
2. A cytoplasm composed mainly of water
3. Are enclosed by a plasma membrane composed of lipids

*Understand the reasons for these structures.

Before we move on, some definitions...

Unicellular means an organism consisting of a single cell (incl. prokaryotes, protists and some fungi).

Prokaryotes are unicellular organisms that lack a true nucleus and membrane-bounded organelles.

*We also call prokaryotes **bacteria**.

Eukaryotes are cells that contain a true nucleus and membrane-bound organelles.

*Eukaryotic cells can form unicellular or multicellular organisms.

Protists are unicellular eukaryotic organisms (e.g. *Chlamydomonas* and *Amoeba*).

Multicellular means an organism consisting of many cells.

For multicellular life to arise (e.g. humans), cells form tissues, then organs and organ systems.

cells → tissues → organs → organ systems → organism

Tissue: A group of similar cells, which perform a specific function.

Organ: A structural & functional unit composed of a number of tissues, performing a variety of functions.

Organ systems: Organs functioning in groups (e.g. circulatory system, respiratory system, etc.).

Prokaryote cell structure

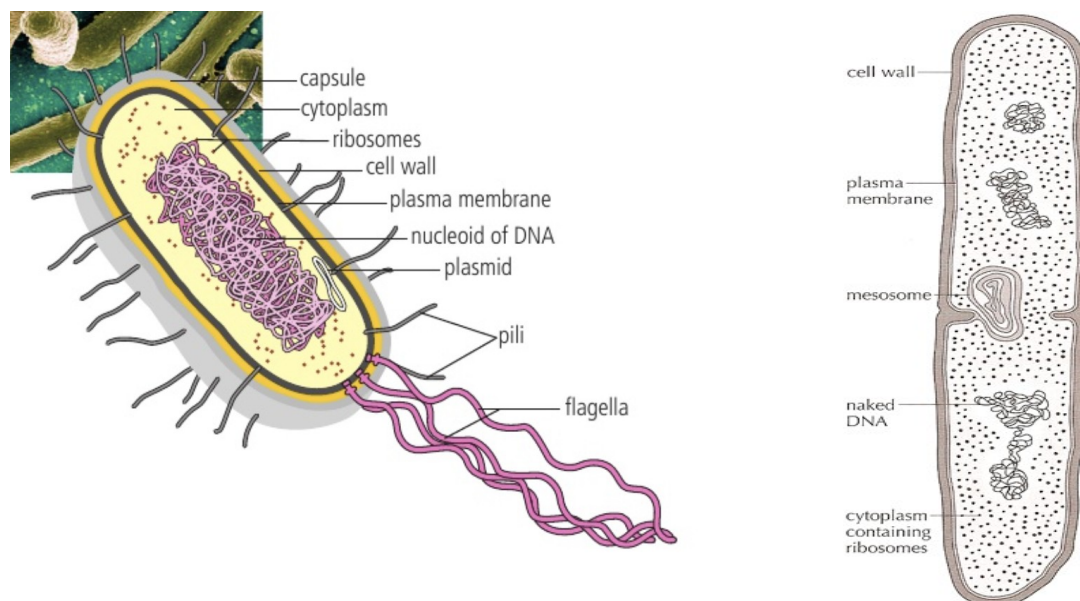


Table 1: Description of prokaryotic cell components (appreciate that prokaryote cell structure varies).

Structure	Function
Cell wall	Protection from bursting, maintenance of shape.
Plasma membrane	Controls entry and exit of substances.
Naked DNA (loop)	Stores the genetic information that controls the cell.
Cytoplasm	Mostly liquid, with enzymes, sugars, proteins for metabolic processes.
70S Ribosomes (free)	Perform protein synthesis (DNA translation). 70S refers to their size.
Nucleoid	The region in the cytoplasm where the DNA is found.
Capsule*	Cover that helps cells avoid dehydration and adhere to surfaces.
Flagellum* (pl = flagella)	Long, whiplike structure that aids movement through fluids (locomotion).
Pilus* (pl = pili)	Short structure that helps cells stick to surfaces, move and share DNA.
*components that may or may not be found in a prokaryote	

Prokaryotic cells divide by a very simple process called **binary fission**.

Examples of prokaryotic cells:

- *Bacillus* is a genus of bacteria widely found in soil and water, widely used in industrial production.
- can cause skin sores, food poisoning, or blood infections if they enter the body.

Challenge yourself

1. Prepare a drawing of the ultrastructure of a prokaryotic cell based on electron micrographs. Remember to use a sharp pencil; use simple, narrow lines, and do not use shading. Label each of the structures, including their function.



Eukaryote cell structure

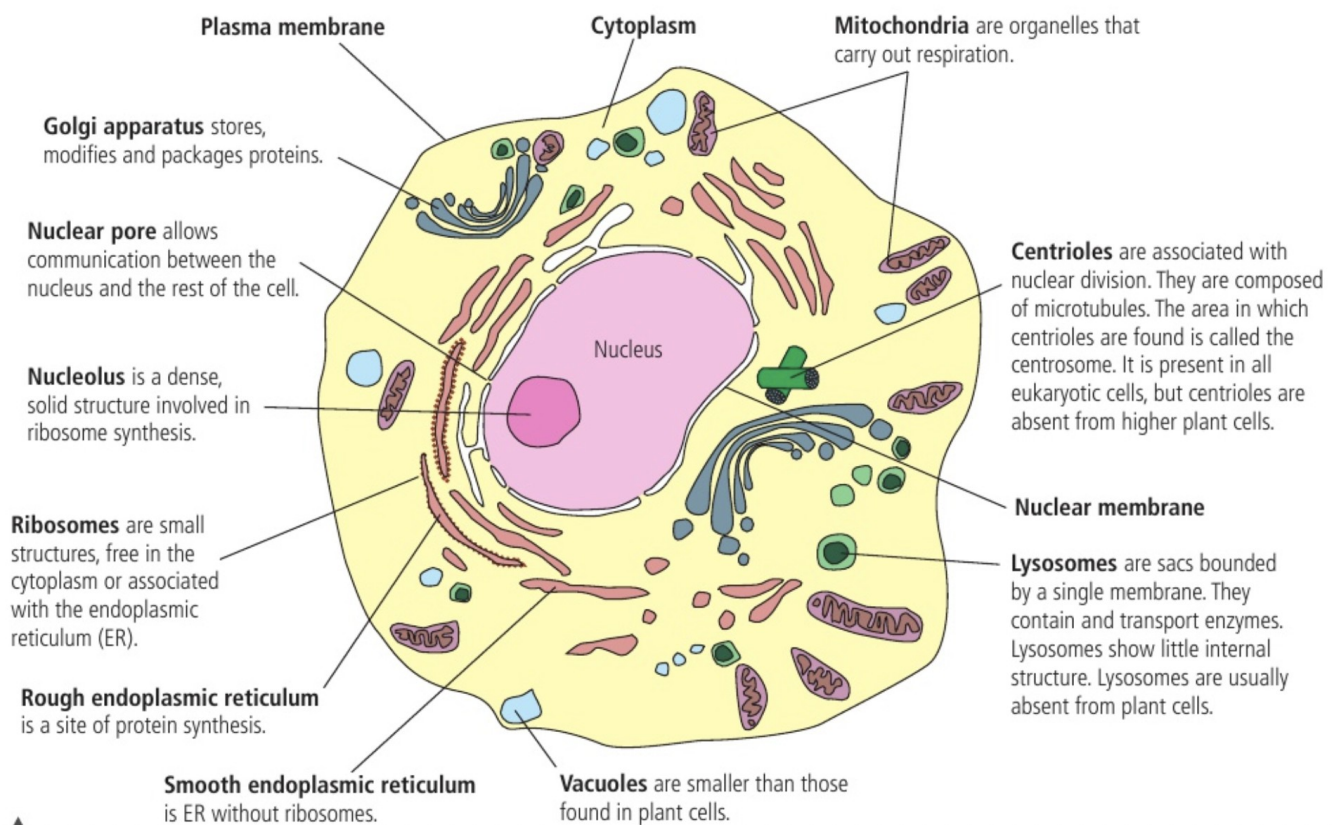
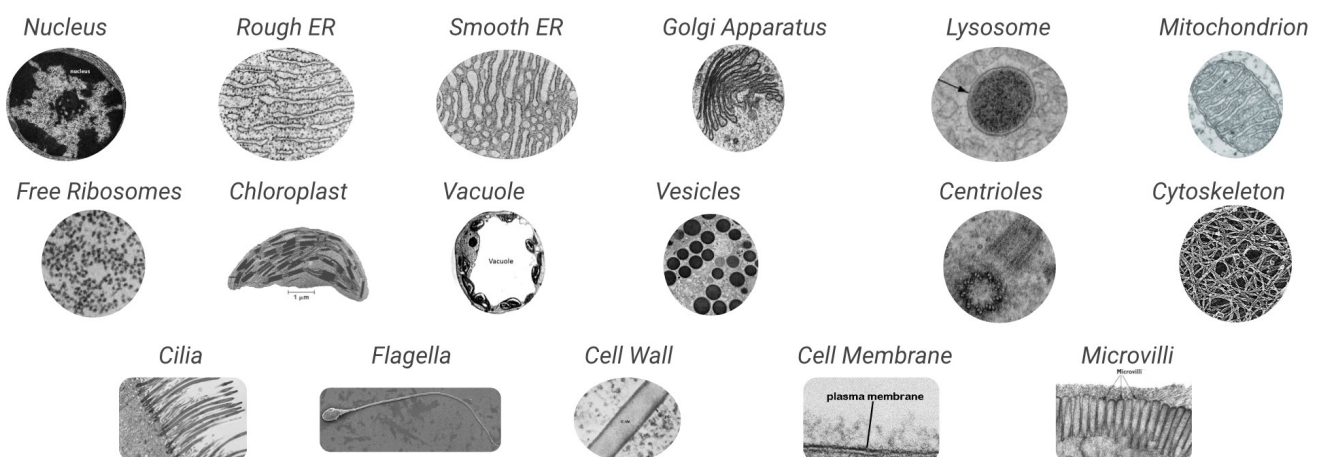


Table 2: Description of eukaryotic cell components.

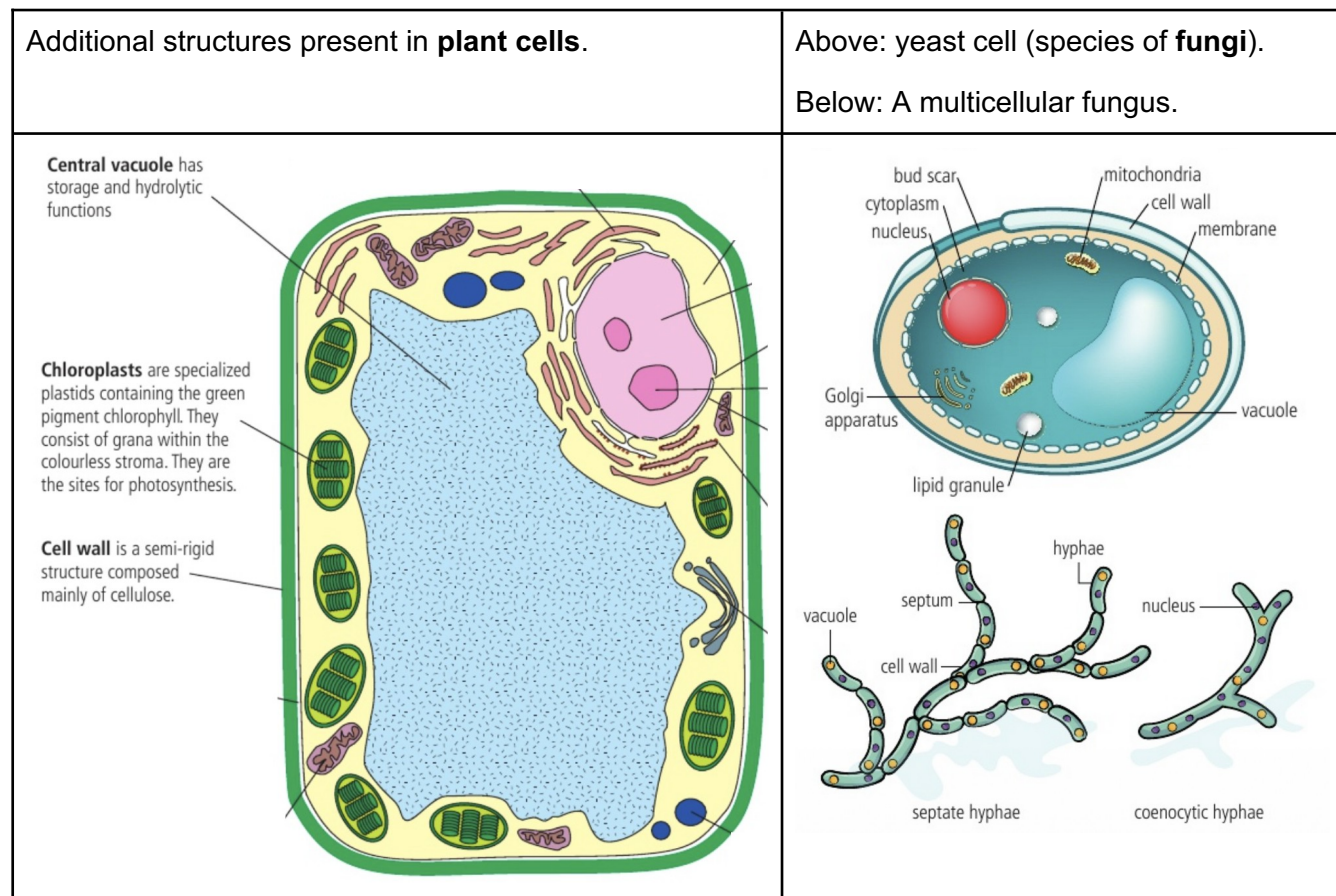
Structure	Function
Cell/plasma membrane	Responsible for the entry and exit of substances.
Nucleus	Consists of a double membrane with pores, holds DNA in the form of chromosomes. It is the control centre of the cell.
80S Ribosomes	For protein synthesis (DNA translation of), may be “free” or “bound”.
Mitochondria	Aerobic cell respiration (ATP). Production of energy!
Endoplasmic Reticulum (ER)	An extensive network of channels from the nucleus to the plasma membrane. Its function is the transportation of materials internally in the cell. There are two types: smooth and rough ER. Smooth ER does not have ribosomes. Rough ER has bound ribosomes on its surface. Most cells contain both types, the rough ER being closer to the nucleus.
Golgi Apparatus	Packaging, modification and distribution of cell materials.
Lysosomes	Vesicles with digestive enzymes that break down harmful substances.
Microtubules	They transport organelles and separate chromosomes during mitosis.
Centrioles	Anchor points for the microtubules.
Cilia and flagella	Cilia are short and numerous. Flagella are long and few.

Eukaryotic cell organelles micrographs:

A little on plant and fungal cells...

***Plants** are eukaryotic (unicellular or multicellular) organisms that produce their own food (autotrophs) in a special plastid called the chloroplast.

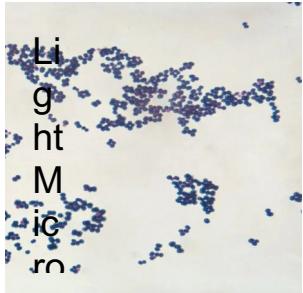
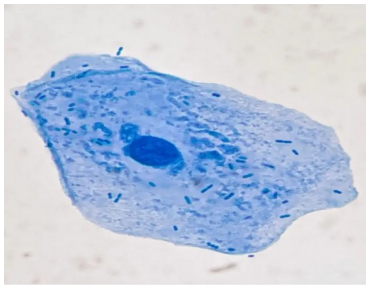
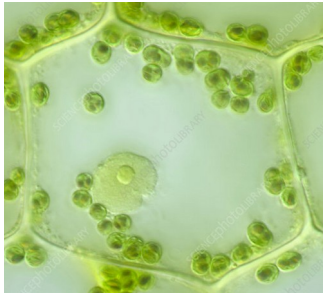
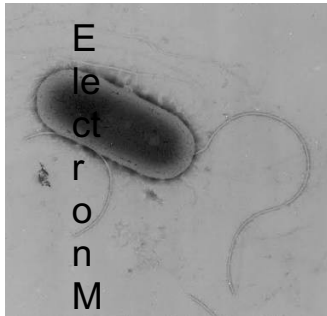
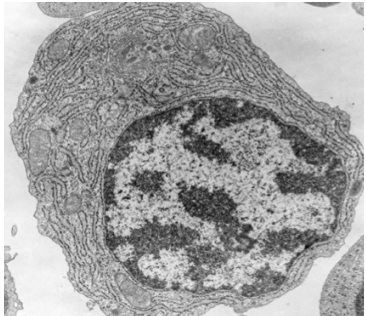
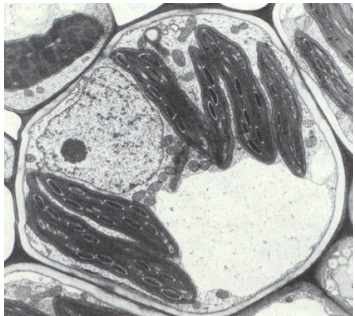
***Fungi** are eukaryotic (unicellular or multicellular), and have a cell wall made of chitin. They include yeasts, mushrooms, truffles and bread moulds. They retrieve food from their environment (parasitic or decomposers).



Differences in eukaryotic cell structure between animals, fungi and plants.

Feature	Animal	Plant	Fungi
Cell wall	No	Yes	Yes (chitin)
Vacuole	Not really!	Yes	Yes
Chloroplast (photosynthesis)	No	Yes	No
Centrioles	Yes (for cell division)	Yes (in male gametes)	No
Ribosomes	80S	80S	80S
Cilia / flagellum	Yes	Yes	No

Application of skills: Identify cells in light and electron micrographs as prokaryote, plant or animal.

Cell Type	Bacterium (prokaryote)	Animal (eukaryote)	Plant (eukaryote)
Light Micro			
Electron Micro			

Atypical cell structures in eukaryotes (Exceptions to the cell theory)

- The first cell did not originate from a pre-existing cell!
- Animal examples
 - Red blood cells do not have a nucleus nor mitochondria!
 - Skeletal Muscle fibre cells
 - can be longer than 300 mm long!
 - contain hundreds of nuclei!
 - have their own genetic material and their own energy release system
- Plant examples
 - Many algae grow to a large size but they are composed of a single cell.
 - The giant algae (*Acetabularia*) can be 100 mm long and contain only one nucleus
 - Phloem sieve tube elements are atypical as they lack a nucleus and most major organelles, they depend entirely on adjacent cells for their survival.
- Fungi
 - They consist of narrow thread-like structures called hyphae.
 - Each hypha can contain many nuclei.
- Special case for organelles: Mitochondria and chloroplasts have their own genetic material and reproduce independently from the rest of the cell! - yet they are not cells

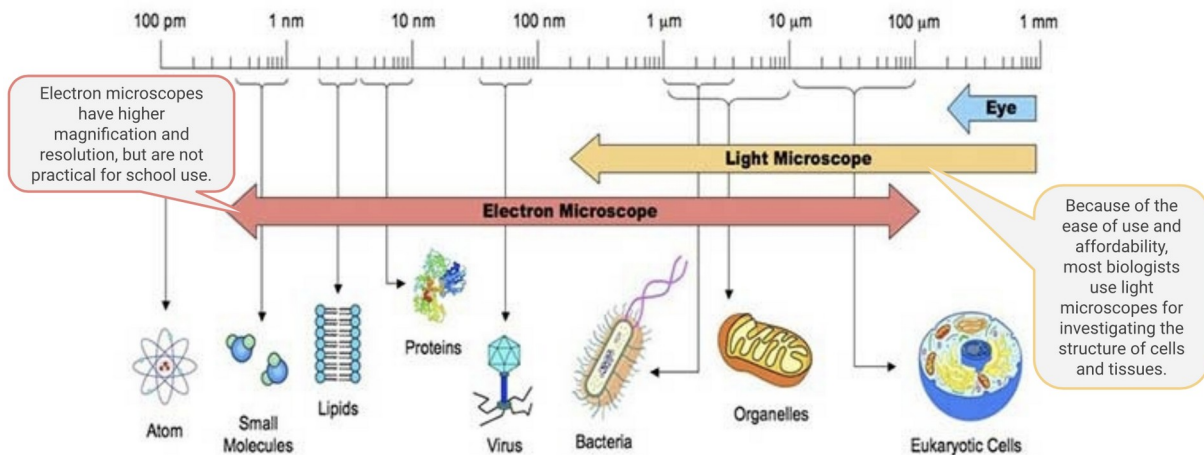
Functions of life in unicellular organisms

Unicellular organisms carry out all 8 functions of life: reproduction, nutrition, growth, metabolism, homeostasis, excretion, response to stimuli and (sometimes) movement.

Paramecium <i>*a unicellular eukaryote, Protist (freshwater)</i>	Chlamydomonas <i>*a unicellular eukaryote alga (soil & freshwater habitat)</i>
Reproduction: The nucleus of the cell divides to produce the extra nuclei needed when the cell reproduces. Often reproduction is asexual with the parent cell dividing to form two daughter cells. Nutrition: Food vacuoles contain smaller organisms consumed. These are gradually digested and nutrients absorbed into the cytoplasm to provide energy and materials for growth. Homeostasis: The contractile vacuoles fill with water and then expel it through the plasma membrane of the cell, to keep the cell's water content within tolerable limits. Metabolism: Metabolic reactions take place in the cytoplasm, including respiration. Enzymes in the cytoplasm are catalysts that cause reactions. Excretion: The cell membrane controls what enters or leaves. It allows the entry of oxygen for respiration. Excretion happens simply by waste products diffusing out through the membrane. Response: Beating of the cilia moves the Paramecium in response to changes in the environment.	Reproduction: The nucleus of the cell can divide to produce genetically identical nuclei for asexual reproduction. Nuclei can also fuse and divide to carry out a sexual form of reproduction. Metabolism: Metabolic reactions take place in the cytoplasm, enzymes present speed them up. Homeostasis: The contractile vacuoles fill with water or expel it through the plasma membrane, to keep water content within tolerable limits. Nutrition: Photosynthesis occurs inside chloroplasts. Carbon dioxide is converted into compounds needed for growth. In the dark, compounds from other organisms may be absorbed through the membrane if available. Excretion: The cell wall is freely permeable and it is the membrane inside it that controls what chemicals enter and leave. Oxygen is a waste product of photosynthesis and excreted by diffusing out through the membrane. Response: Beating the flagella moves Chlamydomonas through water. A light-sensitive "eyespot" allows the cell to sense the brightest light and respond by swimming towards it.
	

Developments in microscopy

Microscopes are devices that produce a magnified image of objects too small to be seen directly by eyes. Developments in microscopy have led to discoveries in biology ([A2.2.3](#)).



- Light Microscopes** work by shining a visible light beam through a thin specimen and using a series of glass lenses to bend and enlarge the image for the human eye.

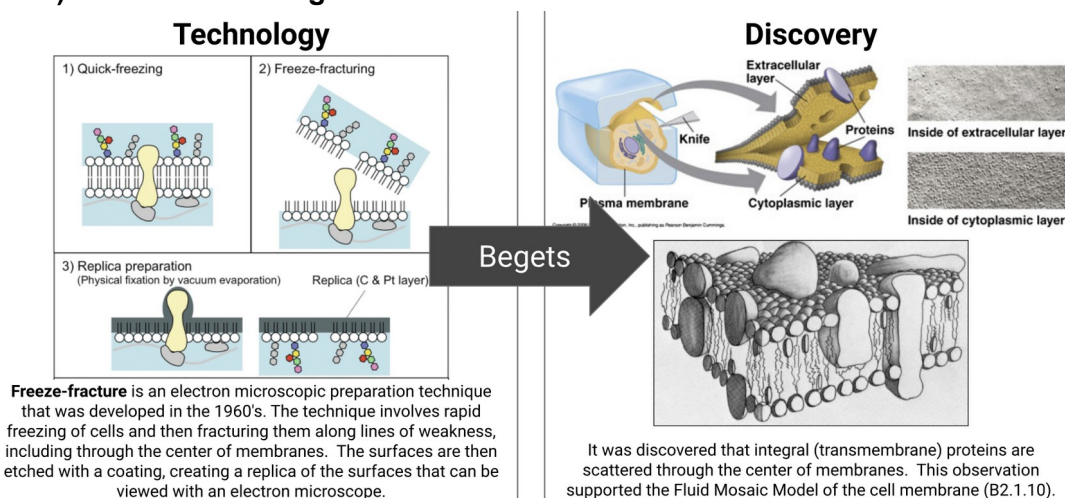
In light microscopy, we use the following techniques for more effective visualisations of structures:

- Stains** are colored substances that bind to specific chemicals and generate a particularly bright image. They allow targeted cell structures to be visualized against a dark background
- Immunofluorescence** is a technique that uses fluorescently stained antibodies to bind to specific proteins (usually antigens) within a cell. That protein can be tracked if it moves in the cell. Fluorescent technology allows for live cell imaging (tracking processes in a living cell!) and high specificity in identifying proteins.

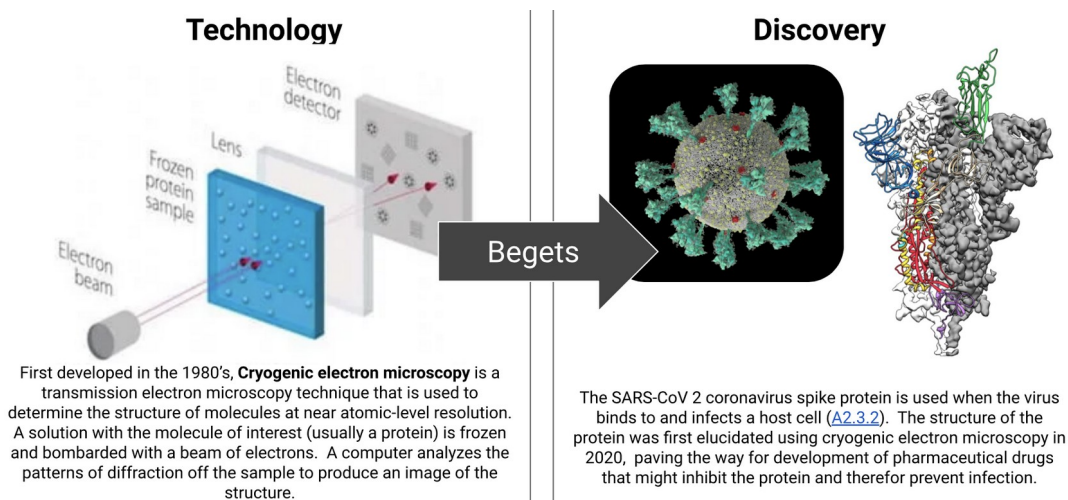
- Electron Microscopes** use a beam of electrons instead of visible light. Electrons have a much shorter wavelength than light, so produce images with **higher resolution** and **greater magnification**.

In electron microscopy, we use the following techniques for more effective visualisations of structures:

- Freeze fracturing**



b) Cryogenic electron microscopy



Microscopy skills

Since cells are so small, we need appropriate units to measure them.

→ The dimensions of cells are expressed in the unit **micrometre** or **micron** (μm).

*Notice this unit is one thousandth (10^{-3}) of a millimetre.

- Bacteria are really small, typically 0.1 to 2 μm in size
- The cells of plants and animals are often in the range of 50 to 150 μm or larger.

Try this out! Calculate how many cells of 100 μm diameter will fit side by side along a millimetre.

Application of skills: Students should calculate actual size, magnification, and produce scale bars.

Calculating Magnifications

Magnification = How much larger an object appears under a microscope, compared to its real size.

A highly magnified electron micrograph of the bacterium *Escherichia coli* was accompanied by a scale bar of length 23 mm and labelled 1 μm . The following features were measured. Complete the following table. Express their actual size in appropriate units.

$$\rightarrow \text{Magnification} = \frac{\text{Length of image}}{\text{Actual length of specimen}}$$

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

$$\text{So, } M = I/A \quad A = I/M \quad I = A \times M$$

1. Choose an obvious length, e.g. the maximum diameter of a cell. Measure it on the drawing
2. Measure the same length on the actual specimen.
3. Convert units.
4. Divide the length of the drawing by the length of the actual specimen.
5. The result is the magnification.

Calculating **Magnification** Example:

The length of an image is 30 mm. It represents a structure that has an actual size of 3 μm . Determine the magnification of the image.

Either: 30 mm = 30×10^{-3} m & 3 μm = 3×10^{-6} m (convert everything to **m**)

$$\rightarrow \text{Magnification} = 30 \times 10^{-3} / 3 \times 10^{-6} = 10,000 \times$$

Or: 30 mm = 30,000 μm (convert everything to **μm**)

$$\rightarrow \text{Magnification} = 30,000 / 3 = 10,000 \times$$

Calculating **Actual Size** Example:

The length of an image of a plant cell is 36 mm. The image was viewed at a magnification of $\times 600$. Determine the actual size of the plant cell.

Either:

$$36 \text{ mm} = 36 \times 10^{-3} \text{ m (convert everything to m)}$$

$$\rightarrow \text{Actual size} = 36 \times 10^{-3} / 600 = 6 \times 10^{-5} \text{ m (do not forget to convert to } \mu\text{m!)}$$

$$= 60 \times 10^{-6} \text{ m} = 60 \mu\text{m}$$

Or:

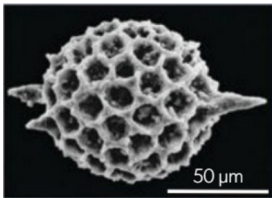
$$36 \text{ mm} = 36,000 \mu\text{m (convert everything to } \mu\text{m)}$$

→ Actual size = $36,000 / 600 = 60 \mu\text{m}$

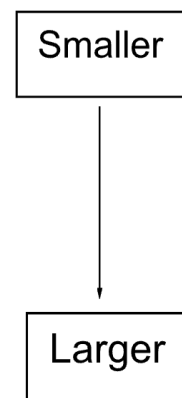
Your turn!

The length of an image you are looking at is 50 mm. If the actual length of the subject of the image is 5 μm , what is the magnification of the image?

The diameter of the radiolarian below is 100 μm . What is the magnification of the electron micrograph?

**RELATIVE SIZES**

Molecules	1 nm
Cell membrane thickness	10 nm
Viruses	100 nm
Bacteria (Prokaryotic)	1 μm
Organelles	Up to 10 μm
Eukaryotic cells	Up to 100 μm



$$1 \mu\text{m} = 10^{-6} \text{ m}$$

1000 mm = 1 m	1000 μm = 1 mm	1000 nm = 1 μm
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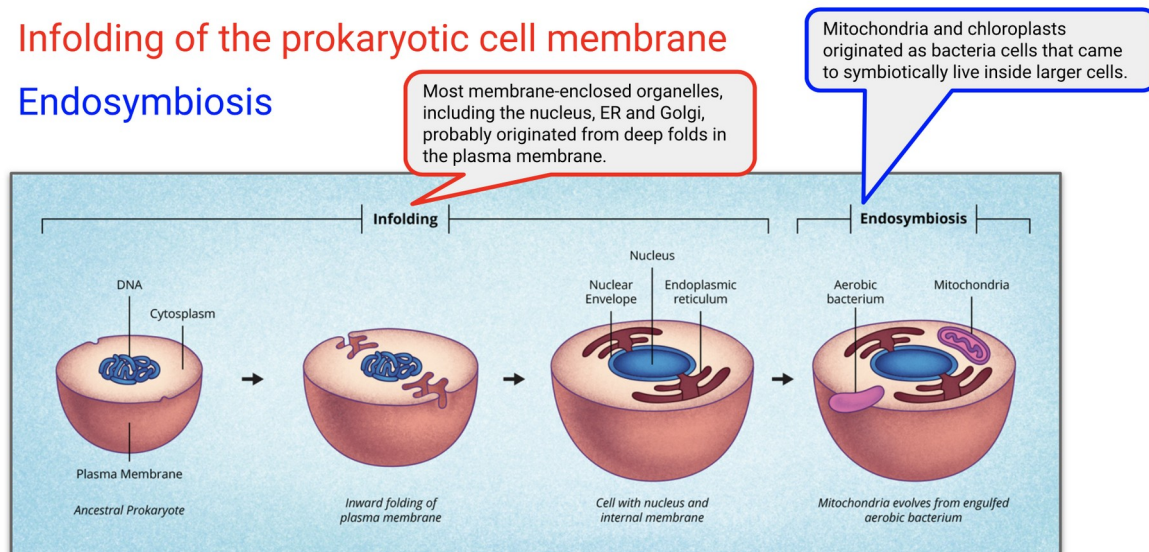
Higher Level

Origin of eukaryotic cells by endosymbiosis

The endosymbiosis theory states that mitochondria and chloroplasts were once free-living prokaryotes capable of aerobic cell respiration. Larger prokaryotes that could only respire anaerobically, took them in by endocytosis. Instead of killing and digesting the smaller prokaryotes, they allowed them to live in their cytoplasm. They persisted over millions of years to become the plastids inside eukaryotic cells today...

Two processes are thought to have led to the origin of eukaryotes....

1. Infolding of the prokaryotic cell membrane
2. Endosymbiosis



Evolution of multicellularity ([video](#)).

Multicellular means an organism consisting of many cells (may be animals, plants or fungi).

Evidence of multicellular eukaryotes (fossils) dates back to 1.2 billion years ago. Many fungi, eukaryotic algae, plants and animals are multicellular, indicating that multicellularity **evolved repeatedly**. Multicellularity has the advantages of allowing larger body size and cell specialization. The frequent occurrence of multicellularity is most probably due to strong selective pressures favouring it.

Cell differentiation as the process for developing specialized tissues in multicellular organisms.

The nucleus of a cell contains the DNA in thread-like chromosomes, which are linear sequences of genes. In a multicellular organism, although they all contain the same DNA, cells are differentiated to carry out specialised functions. They **express**, meaning 'switch on' different sets of genes. When a cell is becoming specialized, we say the cell is differentiating: some of its genes are being activated and expressed. Differentiation can be observed in action in stem cells, which will be discussed later...