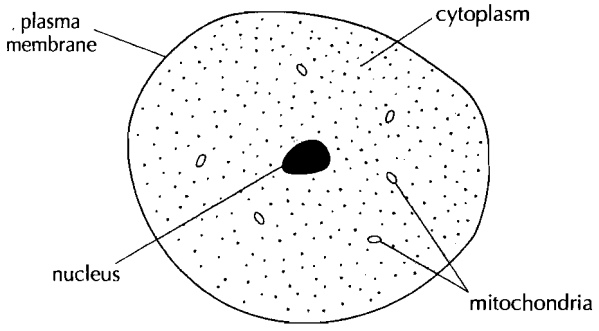
Cells, tissues and organs

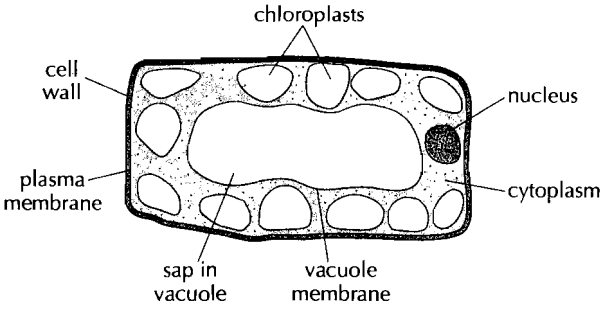
INTRODUCING CELLS

Cells consist of **cytoplasm**, enclosed in a **plasma membrane**, usually controlled by a single **nucleus**. Two cell types that can be easily looked at under a light microscope are human cheek cells, scraped from inside the mouth (left) and moss leaf cells (right).

Human cheek cell



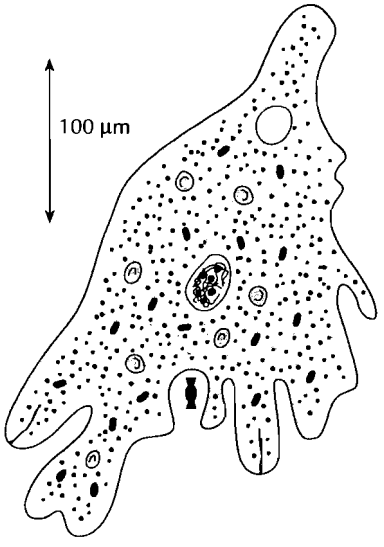
Moss leaf cell



UNICELLULAR ORGANISMS

Some organisms such as *Amoeba* (below), *Chlorella and Euglena* have only one cell. This single cell has to carry out all the activities essential to living organisms, including obtaining food, excreting waste products and producing offspring.

Amoeba



MULTICELLULAR ORGANISMS

Multicellular organisms consist of many cells. These cells do not have to carry out many different functions. Instead, they can become specialized for one particular function and carry it out very efficiently. Cells in a multicellular organism therefore develop in different ways. This is called **differentiation**. The cells need different genes to develop in different ways. Each cell has all of these genes, so could develop in any way, but it only uses the ones that it needs to follow its pathway of development.

ORGANELLES

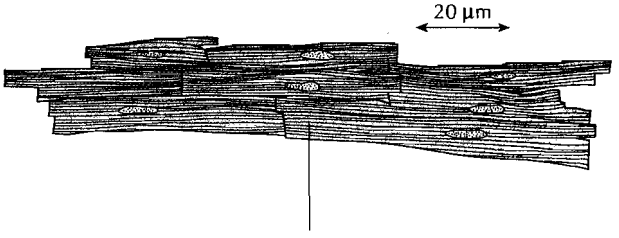
Cells contain many tiny structures called organelles (little organs). Each one has a specific function in the cell. It is often possible to deduce what the function of a cell is by finding out what organelles it contains. Organelles are discrete structures. This means that they are individually distinct. Many types are enclosed in their own membrane. If the cells of a tissue are burst open (**lysed**), the organelles can be separated using a centrifuge. Mitochondria and chloroplasts are examples of organelles.

TISSUES AND ORGANS

In multicellular organisms the cells are often organized into tissues, organs and organ systems.

- **Tissues** are groups of cells that develop in the same way, with the same structure and function. Heart muscle is an example (below).
- **Organs** are groups of tissues that have combined to form a single structure. In an organ the tissues work together to perform an overall function. The heart is an example.
- **Organ systems** are groups of organs within an organism that together carry out a process. The cardiovascular system is an example.

Heart muscle tissue



All heart muscle cells contain structures made from protein fibres that are used to contract the cell and help to pump blood in the heart.

Light and electron microscopes

LIGHT MICROSCOPES

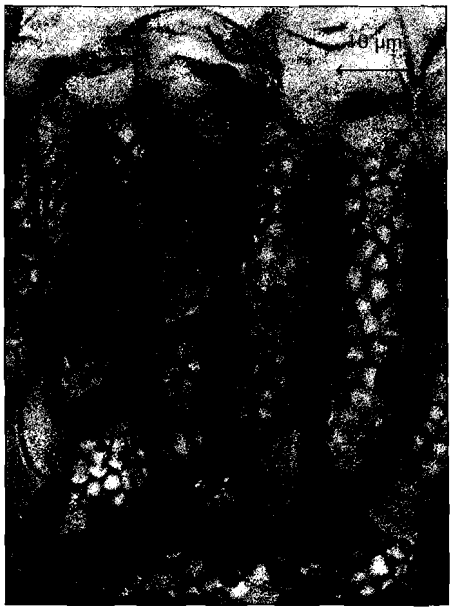
Microscopes are used to study very small structures because they can produce images of them that are larger than the structures themselves. This is called magnification. Light microscopes were the first type to be developed and are still widely used.
The figure (below left) shows a light microscope view of leaf cells.

ELECTRON MICROSCOPES

There are different types of electron microscope. In a transmission electron microscope (TEM), an electron beam passes through a very thin section of material. An image is formed because the electrons pass through some parts of the section but not others. In a scanning electron microscope (SEM) a narrow beam of electrons is scanned in a series of lines across the surface of the specimen. The electrons that are reflected or emitted from the surface are collected by a detector and converted into an electrical signal, which is used to build up a three-dimensional image, line by line on a television screen.

In every type of microscope a magnification is eventually reached above which the image can no longer be focused sharply. This is because the resolution of the microscope has been exceeded. The resolution is the ability of the microscope to show two close objects separately in the image. The resolution of a microscope depends on the wavelength of the rays used to form the image – the shorter the wavelength the better the resolution.
The figure (below right) shows an electron microscope view of a leaf cell.

Light micrograph of leaf cells

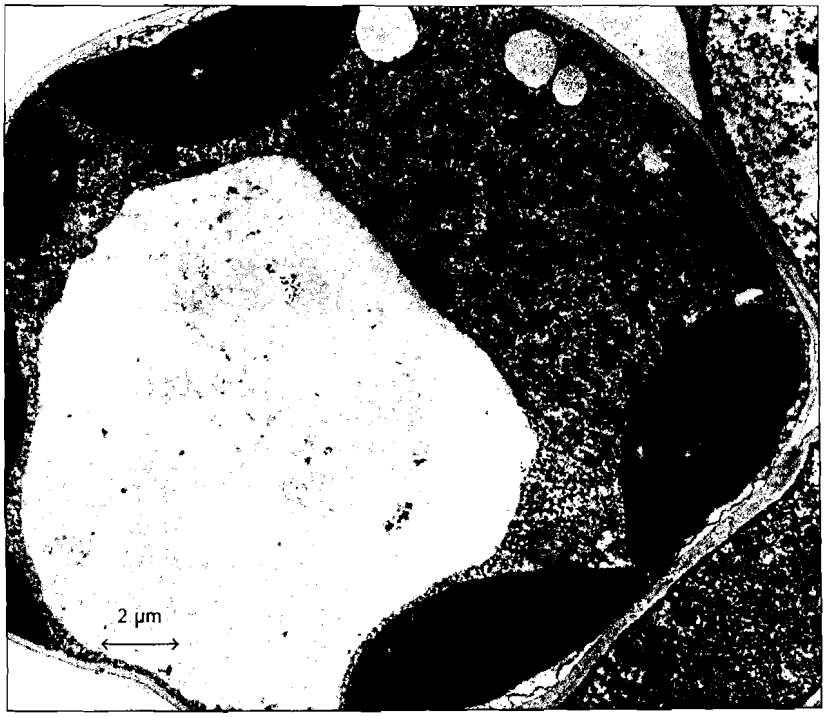


ADVANTAGES OF LIGHT AND ELECTRON MICROSCOPES

Biologists use both light and electron microscopes to investigate the structure and activities of living organisms. The two types both have strengths and weaknesses so they are used for different purposes.

Light microscopes	Electron microscopes
Material can be prepared easily for examination. Often, a sample can simply be placed on a slide with a few drops of water and a cover slip. An image can be obtained within seconds	Preparation of material for examination always involves a long series of procedures. These take several days to complete and often involve the use of toxic chemicals
Living material can be examined, so specimens do not always have to be killed. There is less danger of artificial structures appearing and causing confusion if the specimen is still alive	Living material cannot survive in the vacuum inside electron microscopes. Tissues therefore have to be killed as the first stage in the preparation of them for examination
Movement can be observed if living material is examined, including the flow of blood, streaming of cytoplasm inside cells and the locomotion of microscopic organisms	No movement can be observed as the material is always dead. Movement can only be deduced indirectly by complex experiments, often involving radioactive tracers
Colours can be seen – both natural colours and artificial colours caused by staining	Only monochrome images are produced, with black, white and shades of grey
The field of view (the area which can be observed at once) is relatively large – 2 mm across at low power with typical microscopes	Only a small field of view can be examined at once – in a TEM the maximum uninterrupted view is about 100 µm across
The resolution of light microscopes is relatively poor – about 0.25 µm so the maximum useful magnification is only about × 600. Many structures within cells cannot be seen clearly	The short wavelength of electrons gives very good resolution – about 0.25 nm. This allows magnification of up to × 500 000. Very small objects therefore become visible including many of the details of cell structure

Electron micrograph of a leaf cell



Size in cell biology

LIMITATIONS TO CELL SIZE

Cells do not carry on growing indefinitely. They reach a maximum size and then may divide. If a cell became too large, it would develop problems because its surface area to volume ratio would become too small.

As the size of any object is increased, the ratio between the surface area and the volume decreases. Consider the surface area to volume ratio of cubes of varying size as an example.

The rate at which materials enter or leave a cell depends on the surface area of the cell. However, the rate at which materials are used or produced depends on the volume. A cell that becomes too large may not be able to take in essential materials or excrete waste substances quickly enough.

The same principle works for heat. Cells that generate heat may not be able to lose it quickly enough if they grow very large.

Surface area to volume ratios are important in biology. They help to explain many phenomena apart from maximum cell sizes.

UNITS FOR SIZE MEASUREMENTS

Most S.I. units differ from each other by a factor of 1000.

One millimetre is a thousand times smaller than 1 metre.

One micrometre is a thousand times smaller than 1 millimetre.

One nanometre is a thousand times smaller than 1 micrometre.

The most useful units for measuring the sizes of cells and structures within them are nanometres (nm) and micrometres (μm).

The typical sizes of some important structures in biology are shown opposite.

CALCULATING MAGNIFICATION

Photographs or drawings of structures seen under the microscope show them larger than they really are – they magnify them. It is useful to know how much larger the image is than the actual specimen. This factor is called the magnification. It is always helpful to show the magnification on a drawing of a biological structure.

Follow these instructions to calculate magnification.

1. Choose an obvious length, for example the maximum diameter of a cell. Measure it on the drawing.
2. Measure the same length on the actual specimen.
3. If the units used for the two measurements are different, convert one of them into the same units as the other one.
4. Divide the length on the drawing by the length on the actual specimen. The result is the magnification.

$$\text{Magnification} = \frac{\text{size of image}}{\text{size of specimen}}$$

This equation can also be used to calculate the actual size of a specimen if the magnification and size of the image are known.

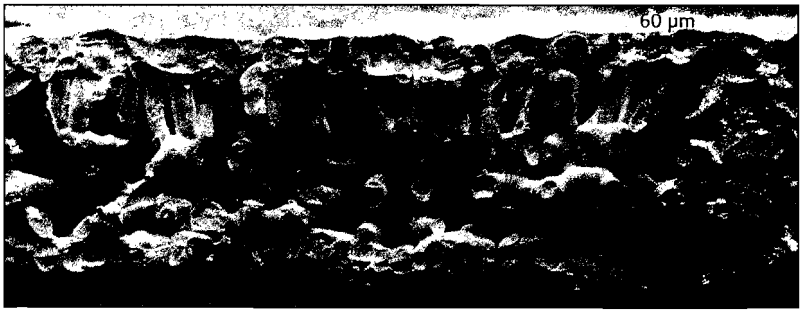
SCALE BARS

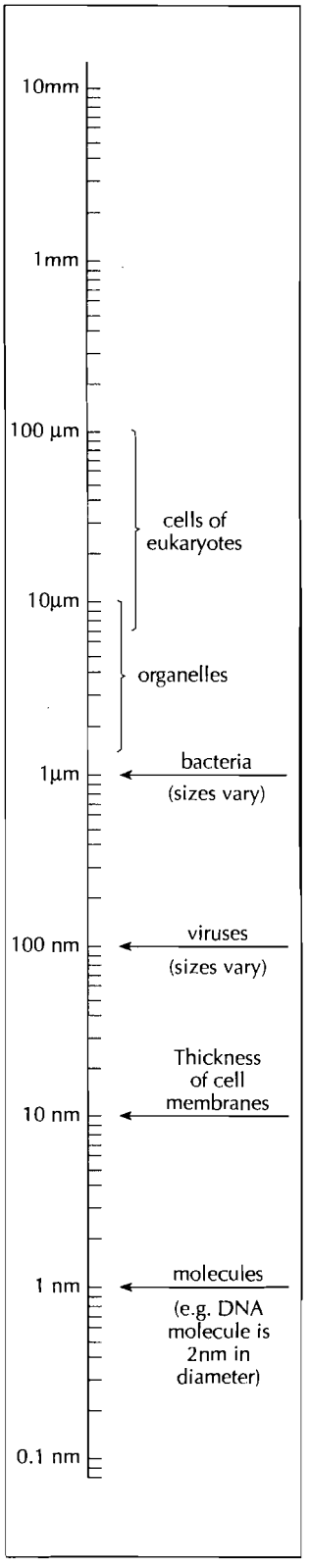
A scale bar is a line added to a micrograph or a drawing to help to show the actual size of the structures.

For example, a 10 μm bar shows how large a 10 μm object would appear.

The figure below shows is a scanning electron micrograph of a leaf with the magnification and a scale bar both shown.

Scanning electron micrograph of leaf (× 480)





1000 mm = 1 m

1000 μm = 1 mm

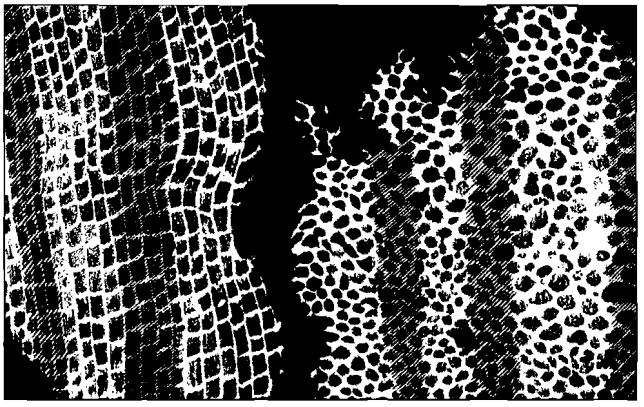
1000 nm = 1 μm

The cell theory

THE ORIGIN OF THE CELL THEORY

When biologists started looking at the structure of animals and plants using microscopes, they found tiny box-like structures making up the tissues (right). They called these cells. More and more living organisms were examined and biologists found that these were also made of cells.
The cell theory was developed, which states that all living organisms are made of cells.

Robert Hooke's drawing of cork cells (1665)

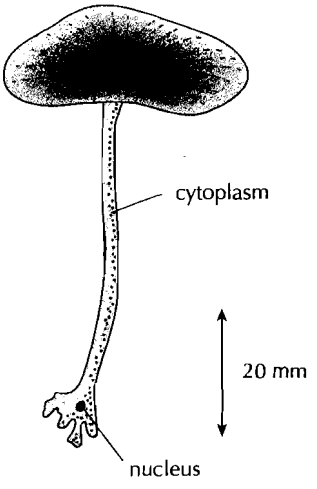


POSSIBLE EXCEPTIONS TO THE CELL THEORY

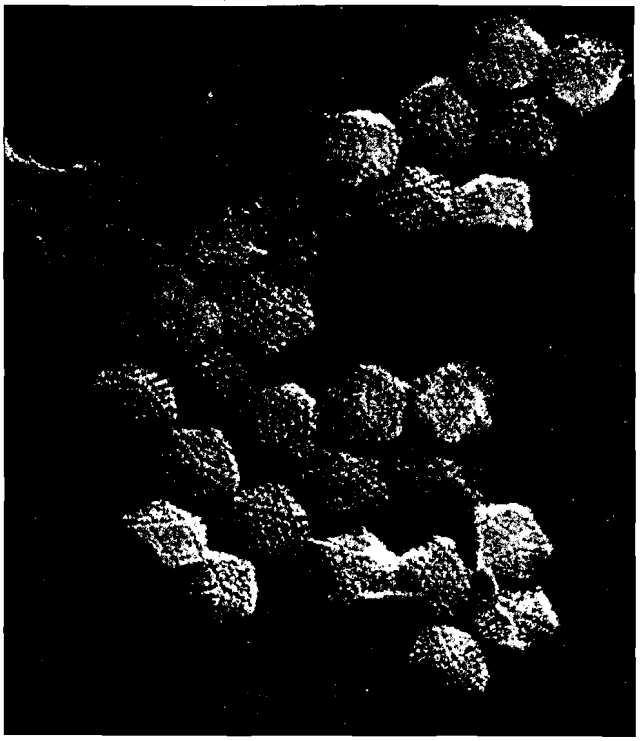
There are some cases where the idea of living organisms consisting of tiny box-like structures does not seem to fit.

- Skeletal muscle is made up of muscle fibres. These have a membrane around the outside, like a single cell, but contain hundreds of nuclei. They are also much larger than most cells. In humans they can be up to 60 μm in diameter and up to 300 mm long.
- Most fungi consist of thread-like structures called **hyphae**, with a cell membrane and cell wall around the outside. The hyphae often contain many nuclei, without dividing walls between them.
- Many tissues contain **extracellular material** – material outside the cell membrane. In some cases, such as bone and tooth dentine, there is so much of this extracellular material that the cells only make up a very small percentage of the volume of the tissue.
- Some organisms such as *Amoeba* have only one region of cytoplasm, surrounded by a membrane. They are often called unicellular organisms but there are some reasons for considering them to be **acellular**. Instead of having separate cells to carry out different functions, the cytoplasm has to carry out all of the vital functions. These organisms are also usually much larger than typical cells. For example, *Acetabularia* (a giant alga) can be over 70 mm in length (right).

***Acetabularia* – a giant alga**

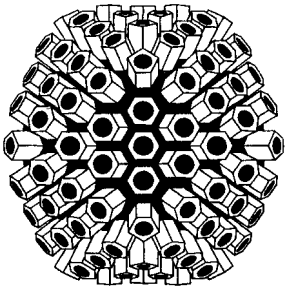


Electron micrograph of adenoviruses (× 120 000)

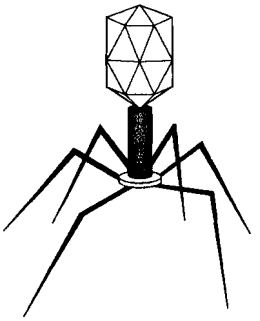


THE STRUCTURE OF VIRUSES

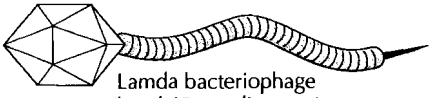
Viruses are certainly not cells. They are very small, simple particles consisting of some DNA or RNA wrapped up in a protein coat (left and below).
The status of viruses is interesting. They use the same genetic material as living organisms. They can evolve by natural selection. However, they have few other characteristics that biologists expect living organisms to possess. They are therefore not usually considered to be living organisms and they are not named or classified in the same way.



Herpes virus
(150 nm diameter)



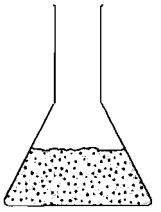
T_4 bacteriophage
(head 85 nm diameter)



Lamda bacteriophage
(head 65 nm diameter)

THE ORIGIN OF CELLS

New cells are formed by the division of a parent cell.
Billions of years ago, when there were no living cells on Earth, cells presumably developed from non-living chemical substances. This does not now happen. Cells can only be formed from other cells.
If a fluid such as some soup in a sealed container is sterilized to kill all cells present, no cells will ever appear unless they are allowed to enter from outside (see right).
The first cells had a simple structure which is called **prokaryotic** (meaning before the nucleus).



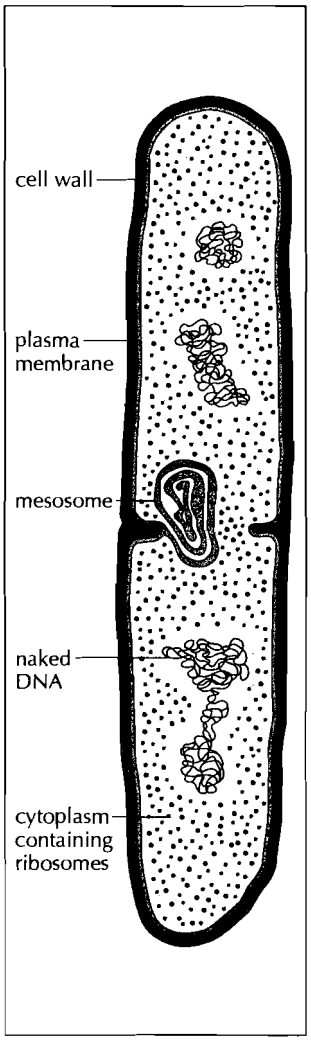
Sterilized soup in an open container decays because bacteria float in

Sterilized soup in a sealed container does not decay as no bacteria are present

STRUCTURE OF PROKARYOTIC CELLS

Figures below show the structure of a prokaryotic cell as seen in an electron micrograph and a drawing to interpret the structure.

Electron micrograph and drawing of *Bacillus licheniformis*
(× 45 000)



FUNCTIONS OF THE PARTS OF A PROKARYOTIC CELL

Prokaryotic cell structure	Function
Cell wall	Forms a protective outer layer that prevents damage from outside and bursting if internal pressure is high
Plasma membrane (cell surface membrane)	Controls entry and exit of substances, pumping some of them in by active transport
Mesosome	Increases the area of membrane for ATP production. May move the DNA to the poles during cell division
Cytoplasm	Contains enzymes that catalyse the chemical reactions of metabolism and DNA in a region called the nucleoid
Ribosomes	Synthesize proteins by translating messenger RNA. Some proteins stay in the cell and others are secreted
Naked DNA	Stores the genetic information that controls the cell and is passed on to daughter cells

TYPES OF PROKARYOTE

Prokaryotes are more commonly called bacteria.
Although small and relatively simple in structure,they show a formidable range of metabolic activity.

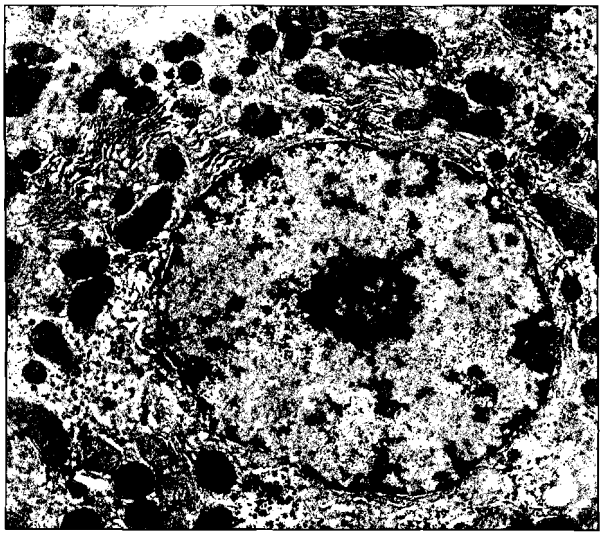
- **Photosynthesis** Blue–green bacteria make their own food by photosynthesis.
- **Nitrogen fixation** Nitrogen-fixing bacteria convert nitrogen from the air into nitrogen compounds.
- **Fermentation** Many bacteria absorb organic substances, convert them into other organic substances and release them. For example, in yoghurt production, bacteria convert lactose into lactic acid. There are many other types of fermentation in bacteria.

Eukaryotic cells

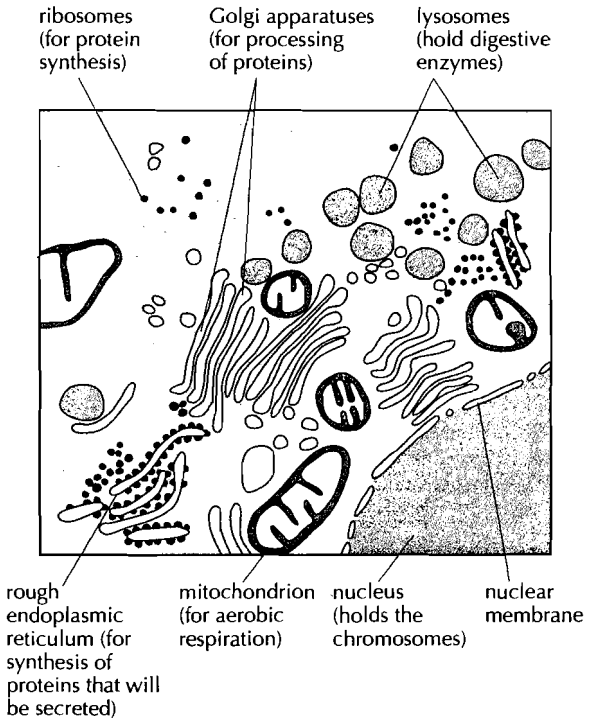
EUKARYOTIC CELL STRUCTURE

The figure (below) is an electron micrograph of a liver cell. The figure (right) is an annotated drawing to interpret part of the structure. Liver cells show many typical features of animal cells. Animal and plant cells are eukaryotic.

Electron micrograph of part of a liver cell (× 8000)



Drawing of part of the electron micrograph



COMPARING PROKARYOTIC AND EUKARYOTIC CELLS

Feature	Prokaryotic cells	Eukaryotic cells
Type of genetic material	A naked loop of DNA	Chromosomes consisting of strands of DNA associated with protein. Four or more chromosomes
Main location of genetic material	In the cytoplasm in a region called the nucleoid	In the nucleus inside a double nuclear membrane called the nuclear envelope
Mitochondria	Not present. The cell surface membrane and mesosome are used instead	Always present
Ribosomes	Small sized. 70S (S = svedburg units, a measure of the size of organelles)	Larger sized. 80S
Organelles bounded by a single membrane	Few or none are present	Many are present including endoplasmic reticulum, Golgi apparatus and lysosomes

COMPARING PLANT AND ANIMAL CELLS

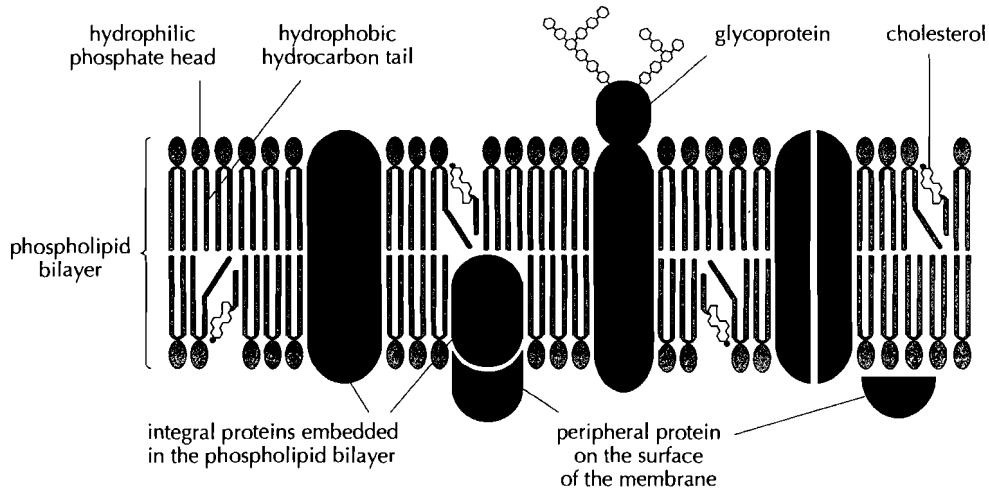
Plants and animal cells have many similarities because they are both eukaryotic. They also show some differences.

Feature	Animal	Plant
Cell wall	Not present. Animal cells only have a cell surface membrane	Cell wall and cell surface membrane are both present
Chloroplasts	Not present	Present in plant cells that photosynthesize
Carbohydrate storage	Glycogen	Starch
Vacuole	Not usually present. Small or temporary vacuoles are sometimes found	Large fluid-filled vacuole often present
Shape	Able to change shape. Usually rounded	Fixed shape. Usually rather regular

THE PLANT CELL WALL

The main component of plant cell walls is cellulose. Cellulose molecules are arranged in bundles called microfibrils. These give the cell wall great tensile strength and allow high pressures to develop inside the cell.

Fluid mosaic model of a biological membrane



PHOSPHOLIPIDS

Hydrophilic molecules are attracted to water. Hydrophobic molecules are not attracted to water, but are attracted to each other. Phospholipid molecules are unusual because they are partly hydrophilic and partly hydrophobic.

The phosphate head is hydrophilic and the two hydrocarbon tails are hydrophobic. In water, phospholipids form double layers with the hydrophilic heads in contact with water on both sides and the hydrophobic tails away from water in the centre. This arrangement is found in biological membranes. The attraction between the hydrophobic tails in the centre and between the hydrophilic heads and the surrounding water makes membranes very stable.

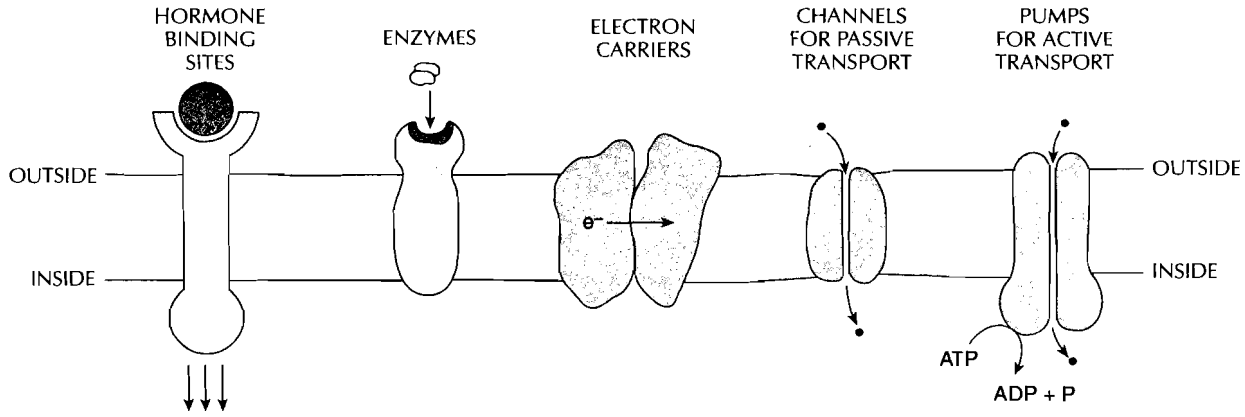
FLUIDITY OF MEMBRANES

Phospholipids in membranes are in a fluid state. This allows membranes to change shape in a way that would be impossible if they were solid. The fluidity also allows vesicles to be pinched off from membranes or fuse with them.

MEMBRANE PROTEINS

Some electron micrographs show the positions of proteins within membranes. The proteins are seen to be dotted over the membrane. This gives the membrane the appearance of a mosaic. Because the protein molecules float in the fluid phospholipid bilayer, biological membranes are called fluid mosaics. The figure (above) is a diagram showing the fluid mosaic model of a biological membrane. Some of the functions of membrane proteins are shown below.

Functions of membrane proteins



A site exposed on the outside of the membrane allows one specific hormone to bind. A signal is then transmitted to the inside of the cell

Enzymes located in membranes either catalyse reactions inside or outside the cell, depending on whether the active site is on the inner or outer surface

Electron carriers are arranged in chains in the membrane so that electrons can pass from one carrier to another

Channels are passages through the centre of membrane proteins. Each channel allows one specific substance to pass through

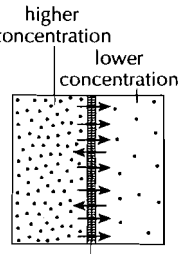
Pumps release energy from ATP and use it to move specific substances across the membrane

Transport across membranes

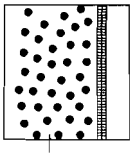
PASSIVE TRANSPORT ACROSS MEMBRANES

Diffusion is the passive movement of particles from a region of higher concentration to a region of lower concentration, as a result of the random motion of particles.

In liquids and gases particles are in continual motion. The direction that they move in is random. Particles can diffuse across membranes if the membrane is permeable to them.



Some particles do move from a lower to a higher concentration but more move from a higher to a lower concentration. There is a net movement from the lower to the higher concentration until the concentrations are equal.

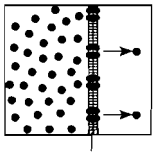


Solute unable to diffuse through membrane

Partially permeable membrane

Membranes are partially permeable because they allow some substances to diffuse through but not others.

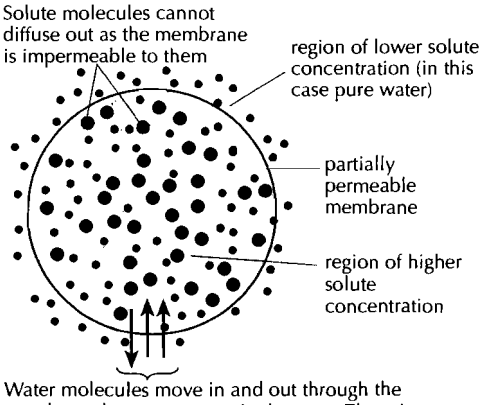
To allow some substances to diffuse through, channel proteins are needed. This is called facilitated diffusion.



Facilitated diffusion through membrane containing channel proteins.

OSMOSIS

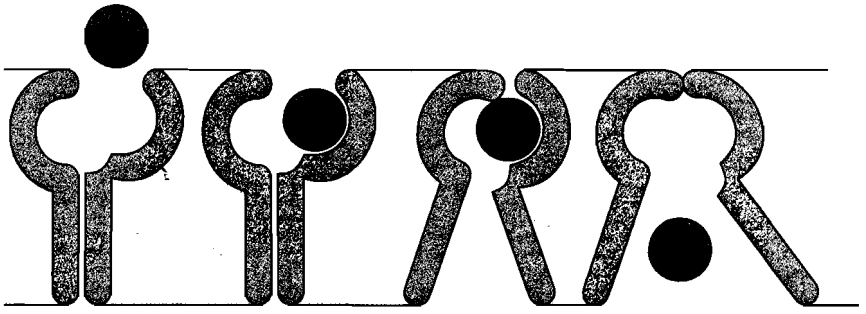
Osmosis is the passive movement of water molecules from a region of lower solute concentration to a region of higher solute concentration, across a partially permeable membrane.



Water molecules move in and out through the membrane but more move in than out. There is a net movement from the region of lower solute concentration to the region of higher solute concentration

ACTIVE TRANSPORT ACROSS MEMBRANES

Active transport is the movement of substances across membranes using energy from ATP. Active transport can move substances against the concentration gradient – from a region of lower concentration to a region of higher concentration. Protein pumps in the membrane are used for active transport. Each pump only transports particular substances, so cells can control what is absorbed and what is expelled.



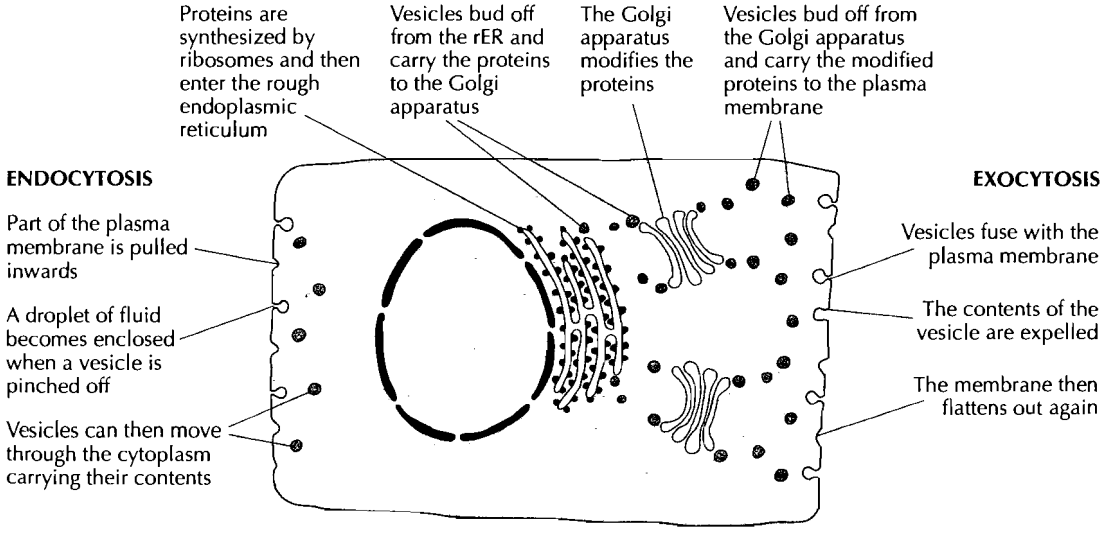
Particle enters the pump from the side with a lower concentration

Particle binds to a specific site. Other types of particle cannot bind

Energy from ATP is used to change the shape of the pump

Particle is released on the side with a higher concentration and the pump then returns to its original shape

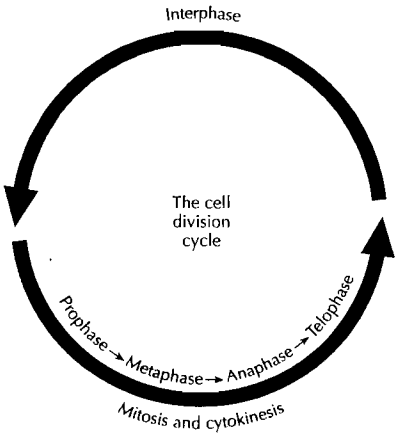
TRANSPORT OF MATERIALS BY VESICLES IN THE CYTOPLASM



THE CELL DIVISION CYCLE IN EUKARYOTES

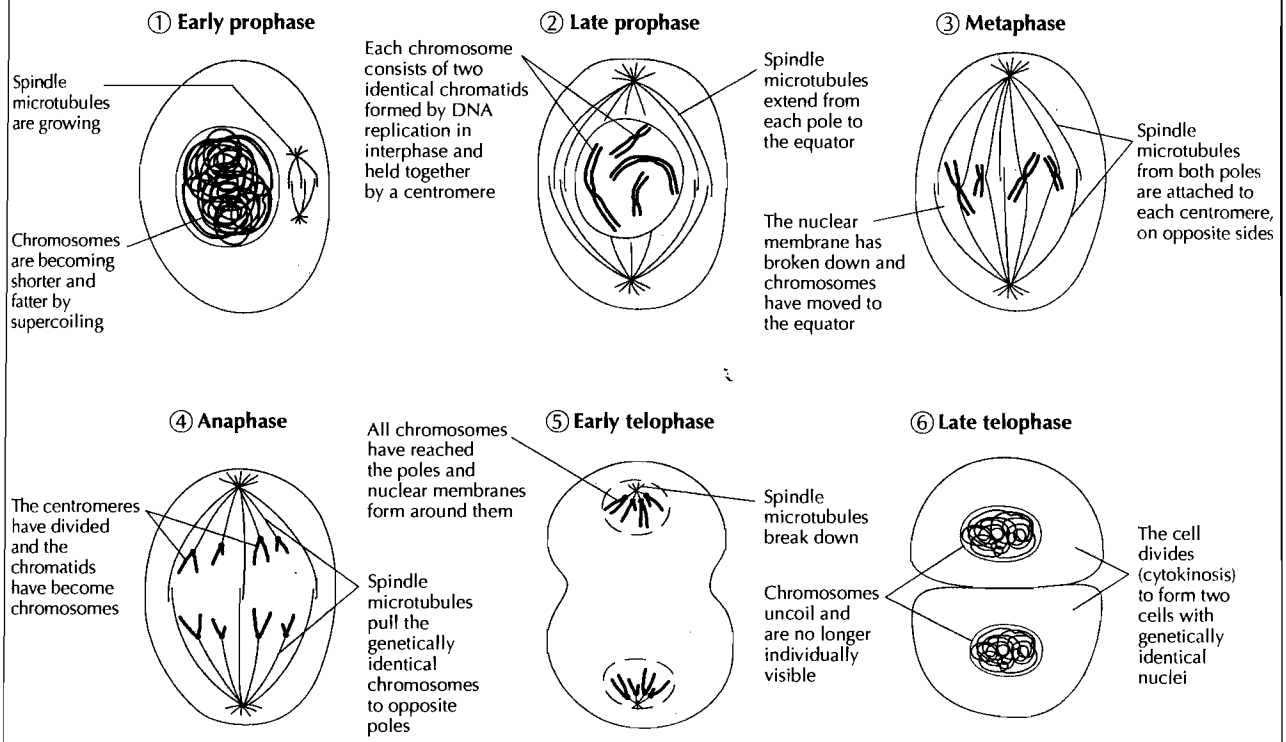
New cells are produced by division of existing cells. If many new cells are needed, cells go through a cycle of events again and again. This is called the cell division cycle. The longest phase in this cycle is **interphase**. During interphase the cell carries out many biochemical reactions and grows larger. The DNA molecules in the chromosomes are not coiled up and the genes on them can be transcribed, to allow protein synthesis. If the cell is going to divide again, the DNA is all replicated. These and other processes make interphase a very active period for a cell.

At the end of interphase when DNA replication as been completed, the cell begins **mitosis**. In mitosis, the nucleus divides to form two genetically identical nuclei. Towards the end of mitosis, the cytoplasm of the cell starts to divide and eventually two cells are formed, each containing one nucleus. The process of dividing the cytoplasm to form two cells is **cytokinesis**. The two cells begin interphase when mitosis and cytokinesis have been completed.



THE PHASES OF MITOSIS

This figure shows how genetically identical nuclei are formed during the four phases of mitosis.



USES OF MITOSIS

Mitosis is used in eukaryotes whenever genetically identical cells are needed:

- during growth
- when tissues have been damaged and need to be repaired
- to reproduce asexually.

TUMOUR FORMATION

Sometimes the normal control of mitosis in a cell fails. This cell divides into two. The two daughter cells divide to form four cells. Repeated divisions soon produce a mass of cells called a tumour. This can happen in any organ. Tumours can grow to a large size and can spread to other parts of the body. The diseases caused by the growth of tumours are called cancer.

DIFFERENCES IN CELL DIVISION BETWEEN PLANT AND ANIMAL CELLS

Plant cells	Animal cells
There are no centrioles in plant cells	Centrioles are found at each pole of animal cells during mitosis
After anaphase, a new cell wall is formed across the equator of the cell, with plasma membrane on both sides. This divides the cell into two	After anaphase, the plasma membrane at the equator is pulled inwards until it meets in the centre of the cell, dividing it into two