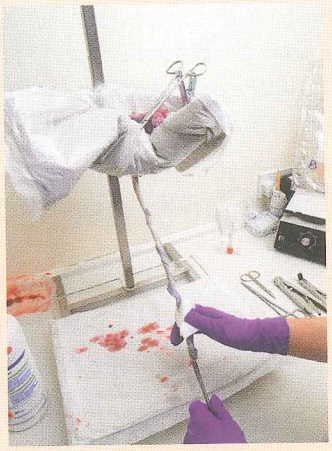
Stem cell research has been very controversial. Many ethical objections have been raised. There are most objections to the use of embryonic stem cells, because current techniques usually involve the death of the embryo when the stem cells are taken. The main question is whether an early stage embryo is as much a human individual as a new-born baby, in which case killing the embryo is undoubtedly unethical.

When does a human life begin? There are different views on this. Some consider that when the sperm fertilizes the egg, a human life has begun. Others say that early stage embryos have not yet developed human characteristics and cannot suffer pain, so they should be thought of simply as groups of stem cells. Some suggest that a human life truly begins when there is a heartbeat, or bone tissue or brain activity. These stages take place after a few weeks of development. Another view is that it is only when the embryo has developed into a fetus that is capable of surviving outside the uterus.

Some scientists argue that if embryos are specially created by **in vitro fertilization (IVF)** in order to obtain stem cells, no human that would otherwise have lived has been denied its chance of living. However, a counterargument is that it is unethical to create human lives solely for the purpose of obtaining stem cells. Also, IVF involves hormone treatment of women, with some associated risk, as well as an invasive surgical procedure for removal of eggs from the ovary. If women are paid for supplying eggs for IVF this could lead to the exploitation of vulnerable groups such as college students.

We must not forget ethical arguments in favour of the use of embryonic stem cells. They have the potential to allow methods of treatment for diseases and disabilities that are currently incurable, so they could greatly reduce the suffering of some individuals.



▲ Figure 22 Harvesting umbilical cord blood

1.2 Ultrastructure of cells

Understanding

- Prokaryotes have a simple cell structure without compartments.
- Eukaryotes have a compartmentalized cell structure.
- Prokaryotes divide by binary fission.
- Electron microscopes have a much higher resolution than light microscopes.

Applications

- The structure and function of organelles within exocrine gland cells of the pancreas.
- The structure and function of organelles within palisade mesophyll cells of the leaf.

Nature of science

- Developments in scientific research follow improvements in apparatus: the invention of electron microscopes led to greater understanding of cell structure.

Skills

- Drawing the ultrastructure of prokaryotic cells based on electron micrographs.
- Drawing the ultrastructure of eukaryotic cells based on electron micrographs.
- Interpretation of electron micrographs to identify organelles and deduce the function of specialized cells.

The invention of the electron microscope

Developments in scientific research follow improvements in apparatus: the invention of electron microscopes led to greater understanding of cell structure.

Much of the progress in biology over the last 150 years has followed improvements in the design of microscopes. In the second half of the 19th century improved light microscopes allowed the discovery of bacteria and other unicellular organisms. Chromosomes were seen for the first time and the processes of mitosis, meiosis and gamete formation were discovered. The basis of sexual reproduction, which had previously eluded William Harvey and many other biologists, was seen to be the fusion of gametes and subsequent development of embryos. The complexity of organs such as the kidney was revealed and mitochondria, chloroplasts and other structures were discovered within cells.

There was a limit to the discoveries that could be made though. For technical reasons that are explained later in this sub-topic, light microscopes cannot produce clear images of structures smaller than 0.2 micrometres (μm). (A micrometre is a thousandth of a millimetre.) Many biological structures are smaller than this. For example, membranes in cells are about 0.01 μm thick. Progress was hampered until a different type of microscope was invented – the electron microscope.

Electron microscopes were developed in Germany during the 1930s and came into use in research laboratories in the 1940s and 50s. They allowed images to be produced of things as small as 0.001 μm – 200 times smaller than with light microscopes. The structure of eukaryotic cells was found to be far more intricate than most biologists had expected and many previous ideas were shown to be wrong. For example, in the 1890s the light microscope had revealed darker green areas in the chloroplast. They were called grana and interpreted as droplets of chlorophyll. The electron microscope showed that grana are in fact stacks of flattened membrane sacs, with the chlorophyll located in the membranes. Whereas mitochondria appear as tiny structureless rods or spheres under the light microscope, the electron microscope revealed them to have an intricate internal membrane structure.

The electron microscopes revealed what is now called the ultrastructure of cells, including previously unknown features. Ribosomes, lysosomes and the endoplasmic reticulum were all discovered and named in the 1950s, for example. It is unlikely that there are structures as significant as these still to be discovered, but improvements in the design of electron microscopes continue and each improvement allows new discoveries to be made. A recent example, described in sub-topic 8.2, is electron tomography – a method of producing 3-D images by electron microscopy.

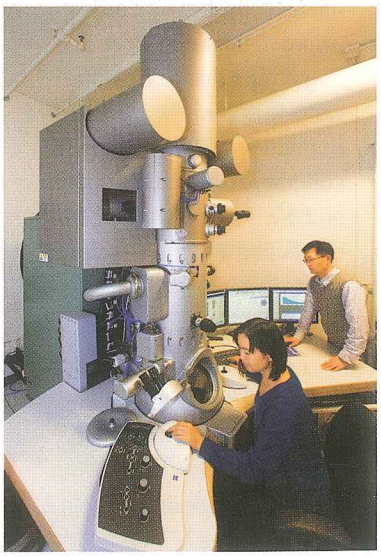
The resolution of electron microscopes

Electron microscopes have a much higher resolution than light microscopes.

If we look at a tree with unaided eyes we can see its individual leaves, but we cannot see the cells within its leaves. The unaided eye can see things with a size of 0.1 mm as separate objects, but no smaller. To see the cells within the leaf we need to use a light microscope. This allows us to see things with a size of down to about 0.2 μm as separate objects, so cells can become individually visible – they can be distinguished.

Making the separate parts of an object distinguishable by eye is called **resolution**.

The maximum resolution of a light microscope is 0.2 μm, which is 200 nanometres (nm). However powerful the lenses of a light microscope are, the resolution cannot be higher than this because it is limited by the wavelength of light (400–700 nm). If we try to resolve smaller objects by



▲ Figure 1 An electron microscope in use

making lenses with greater magnification, we find that it is impossible to focus them properly and get a blurred image. This is why the maximum magnification with light microscopes is usually × 400.

Beams of electrons have a much shorter wavelength, so electron microscopes have a much higher resolution. The resolution of modern electron microscopes is 0.001 μm or 1 nm. Electron microscopes therefore have a resolution that is 200 times greater than light microscopes. This is why light microscopes reveal the structure of cells, but electron microscopes reveal the ultrastructure. It explains why light microscopes were needed to see bacteria with a size of 1 micrometre, but viruses with a diameter of 0.1 micrometres could not be seen until electron microscopes had been invented.

	Resolution		
	Millimetres (mm)	Micrometres (μm)	Nanometres (nm)
Unaided eyes	0.1	100	100,000
Light microscopes	0.0002	0.2	200
Electron microscopes	0.000001	0.001	1

Activity

Commerce and science

While still a young student in Berlin in the late 1920s Ernst Ruska developed magnetic coils that could focus beams of electrons. He worked on the idea of using these lenses to obtain an image as in a light microscope, but with electron beams instead of light. During the 1930s he developed and refined this technology. By 1939 Ruska had designed the first commercial electron microscope. In 1986 he was awarded the Nobel Prize in Physics for this pioneering work. Ruska worked with the German firm Siemens. Other companies in Britain, Canada and the United States also developed and manufactured electron microscopes.

- Scientists in different countries usually cooperate with each other but commercial companies do not. What are the reasons for this difference?

Prokaryotic cell structure

Prokaryotes have a simple cell structure without compartments.

All organisms can be divided into two groups according to their cell structure. Eukaryotes have a compartment within the cell that contains the chromosomes. It is called the nucleus and is bounded by a nuclear envelope consisting of a double layer of membrane. Prokaryotes do not have a nucleus.

Prokaryotes were the first organisms to evolve on Earth and they still have the simplest cell structure. They are mostly small in size and are found almost everywhere – in soil, in water, on our skin, in our intestines and even in pools of hot water in volcanic areas.

All cells have a cell membrane, but some cells, including prokaryotes, also have a cell wall outside the cell membrane. This is a much thicker and stronger structure than the membrane. It protects the cell, maintains its shape and prevents it from bursting. In prokaryotes the cell wall contains peptidoglycan. It is often referred to as being extracellular.

As no nucleus is present in a prokaryotic cell its interior is entirely filled with cytoplasm. The cytoplasm is not divided into compartments by membranes – it is one uninterrupted chamber. The structure is therefore simpler than in eukaryotic cells, though we must remember that it is still very complex in terms of the biochemicals that are present, including many enzymes.

Organelles are present in the cytoplasm of eukaryotic cells that are analogous to the organs of multi-cellular organisms in that they are distinct structures with specialized functions. Prokaryotes do not have cytoplasmic organelles apart from ribosomes. Their size, measured in Svedberg units (S) is 70S, which is smaller than those of eukaryotes.

Part of the cytoplasm appears lighter than the rest in many electron micrographs. This region contains the DNA of the cell, usually in the form of one circular DNA molecule. The DNA is not associated with proteins, which explains the lighter appearance compared with other parts of the cytoplasm that contain enzymes and ribosomes. This lighter area of the cell is called the nucleoid – meaning nucleus-like as it contains DNA but is not a true nucleus.

Cell division in prokaryotes

Prokaryotes divide by binary fission.

All living organisms need to produce new cells. They can only do this by division of pre-existing cells. Cell division in prokaryotic cells is called binary fission and it is used for asexual reproduction. The single circular chromosome is replicated and the two copies of the chromosome move to opposite ends of the cell. Division of the cytoplasm of the cell quickly follows. Each of the daughter cells contains one copy of the chromosome so they are genetically identical.

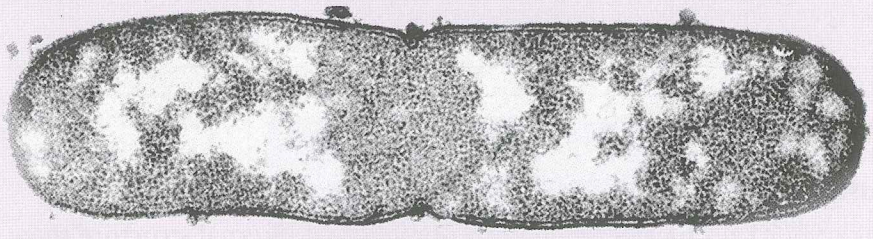
Drawing prokaryotic cells

Draw the ultrastructure of prokaryotic cells based on electron micrographs.

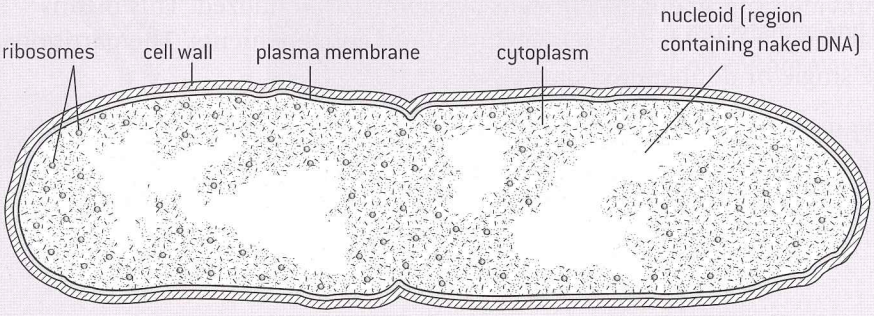
Because prokaryotes are mostly very small, their internal structure cannot be seen using a light microscope. It is only with much higher magnification in electron micrographs that we can see the details of the structure, called the ultrastructure. Drawings of the ultrastructure of prokaryotes are therefore based on electron micrographs.

Shown below and on the next page are two electron micrographs of *E. coli*, a bacterium found in our intestines. One of them is a thin section and shows the internal structure. The other has been prepared by a different technique and shows the external structure. A drawing of each is also shown. By comparing the drawings with the electron micrographs you can learn how to identify structures within prokaryotic cells.

Electron micrograph of *Escherichia coli* (1–2μm in length)



Drawing to help interpret the electron micrograph



Activity

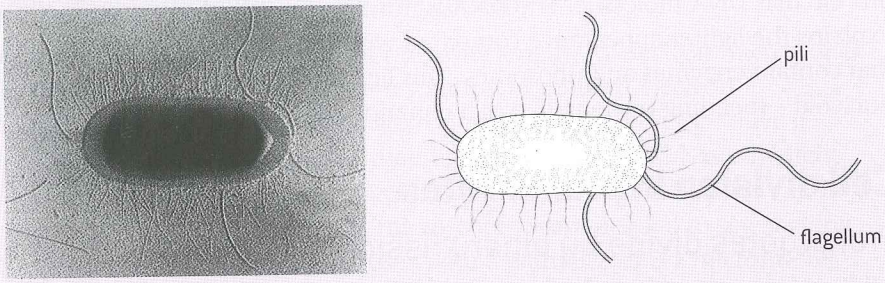
Other names for prokaryotes

Biologists sometimes use the term "bacteria" instead of "prokaryote". This may not always be appropriate because the term prokaryote encompasses a larger group of organisms than true bacteria (Eubacteria). It also includes organisms in another group called the Archaea.

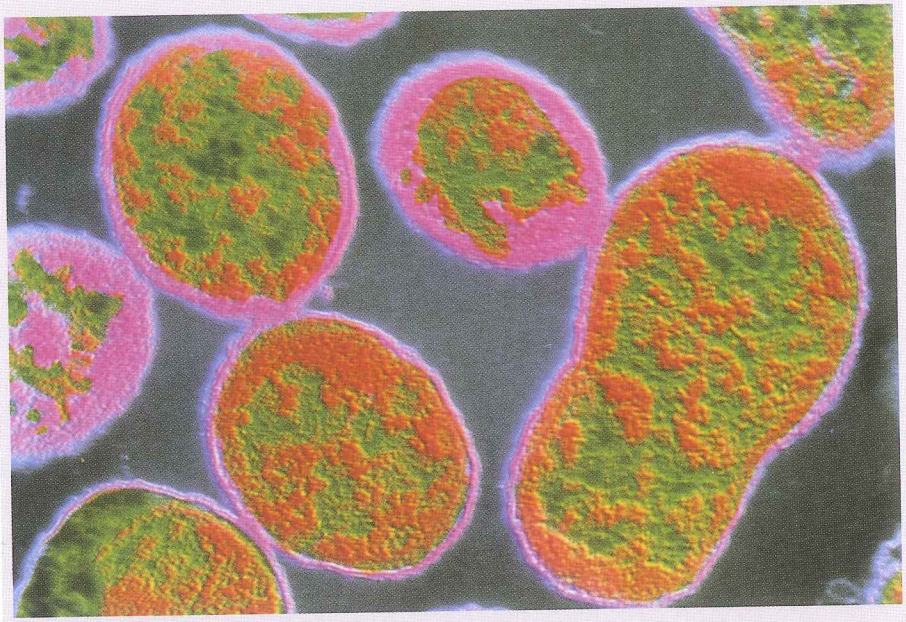
There is a group of photosynthetic organisms that used to be called blue-green algae, but their cell structure is prokaryotic and algae are eukaryotic. This problem has been solved by renaming them as Cyanobacteria.

- What problems are caused by scientists using different words for things than non-scientists?

Electron micrograph of *Escherichia coli* showing surface features



Shown below is another micrograph of a prokaryote. You can use it to practice your skill at drawing the ultrastructure of prokaryotic cells. You can also find other electron micrographs of prokaryotic cells on the internet and try drawing these. There is no need to spend a long time drawing many copies of a particular structure, such as the ribosomes. You can indicate their appearance in one small representative part of the cytoplasm and annotate your drawing to say that they are found elsewhere.



▲ Figure 2 *Brucella abortus* (Bang's bacillus), 2 μm in length

Activity

Garlic cells and compartmentalization

Garlic cells store a harmless sulphur-containing compound called alliin in their vacuoles. They store an enzyme called alliinase in other parts of the cell. Alliinase converts alliin into a compound called allicin, which has a very strong smell and flavour and is toxic to some herbivores. This reaction occurs when herbivores bite into garlic and damage cells, mixing the enzyme and its substrate. Perhaps surprisingly, many humans like the flavour, but to get it garlic must be crushed or cut, not used whole.

- You can test this by smelling a whole garlic bulb, then cutting or crushing it and smelling it again.

Eukaryotic cell structure

Eukaryotes have a compartmentalized cell structure.

Eukaryotic cells have a much more complicated internal structure than prokaryotic cells. Whereas the cytoplasm of a prokaryotic cell is one undivided space, eukaryotic cells are compartmentalized. This means that they are divided up by partitions into compartments. The partitions are single or double membranes.

The most important of these compartments is the nucleus. It contains the cell's chromosomes. The compartments in the cytoplasm are known as organelles. Just as each organ in an animal's body is specialized

to perform a particular role, each organelle in a eukaryotic cell has a distinctive structure and function.

There are several advantages in being compartmentalized:

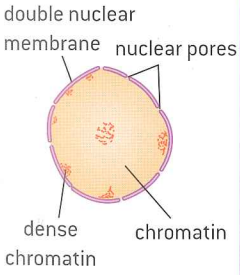
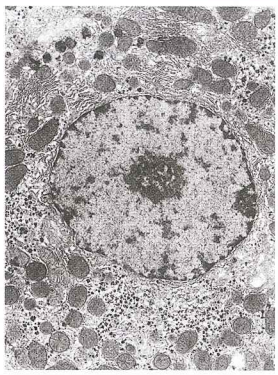
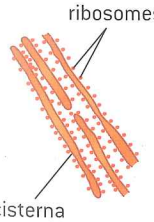
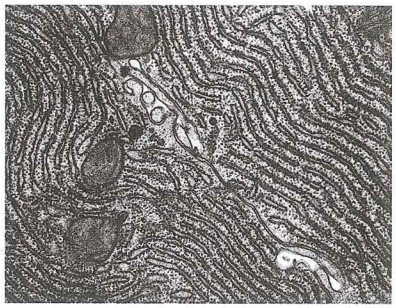
- Enzymes and substrates for a particular process can be much more concentrated than if they were spread throughout the cytoplasm.
- Substances that could cause damage to the cell can be kept inside the membrane of an organelle. For example, the digestive enzymes of a lysosome could digest and kill a cell, if they were not safely stored inside the lysosome membrane.
- Conditions such as pH can be maintained at an ideal level for a particular process, which may be different to the levels needed for other processes in a cell.
- Organelles with their contents can be moved around within the cell.

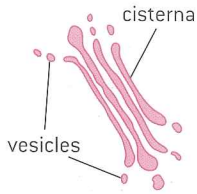
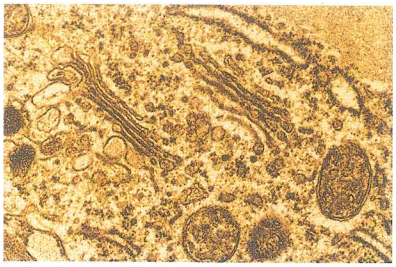
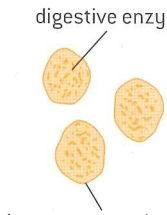
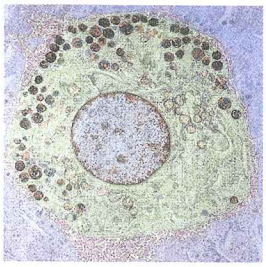
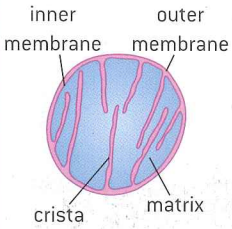
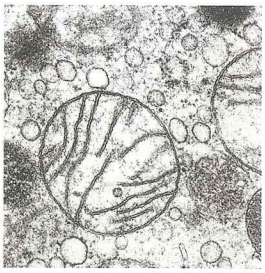
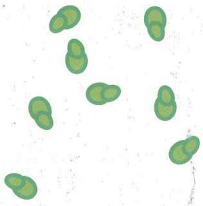
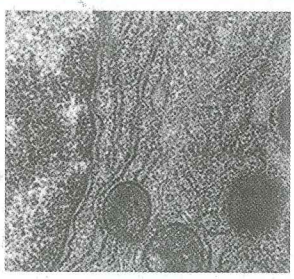
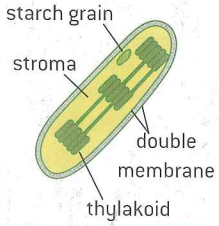
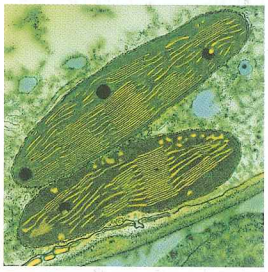
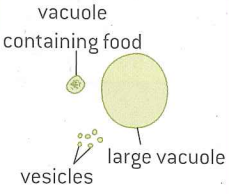
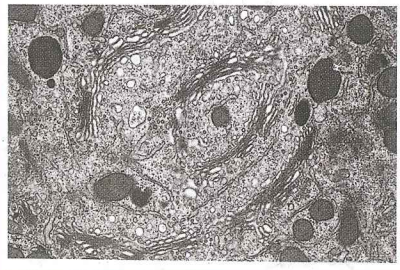
Drawing eukaryotic cells

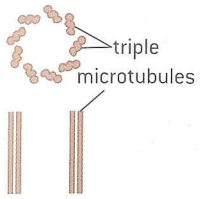
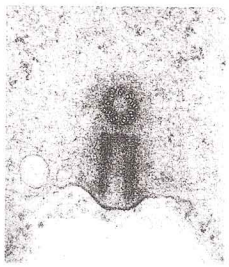
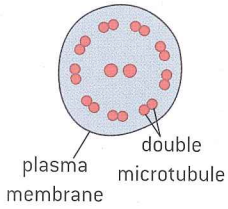
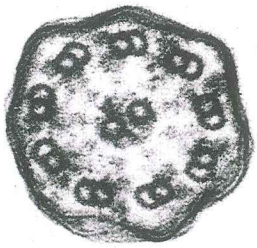
Draw the ultrastructure of eukaryotic cells based on electron micrographs.

The ultrastructure of eukaryotic cells is very complex and it is often best to draw only part of a cell. Your drawing is an interpretation of the structure, so you need to understand the structure of the organelles that might be present.

The table below contains an electron micrograph of each of the commonly occurring organelles, with a drawing of the structure. Brief notes on recognition features and the function of each organelle are included.

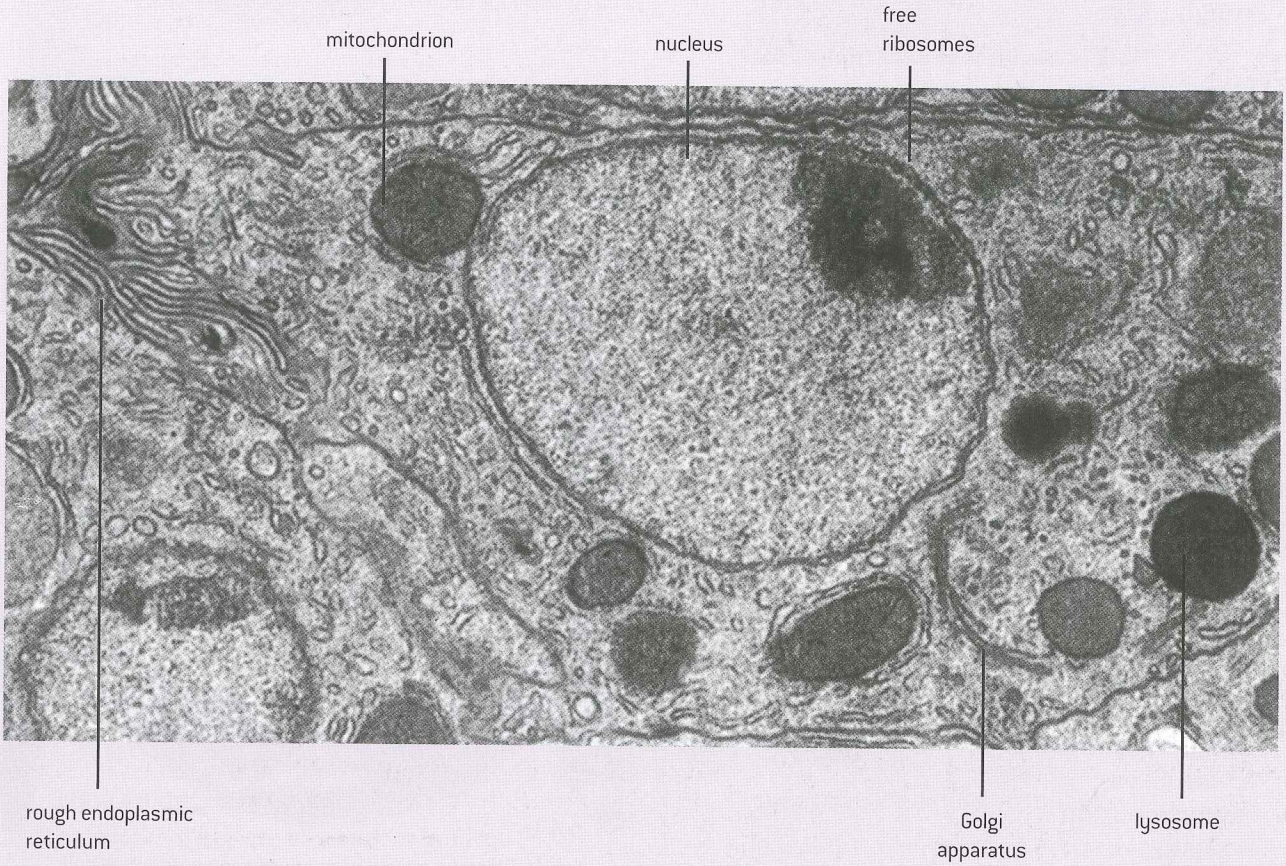
Nucleus  		The nuclear membrane is double and has pores through it. The nucleus contains the chromosomes, consisting of DNA associated with histone proteins. Uncoiled chromosomes are spread through the nucleus and are called chromatin. There are often densely staining areas of chromatin around the edge of the nucleus. The nucleus is where DNA is replicated and transcribed to form mRNA, which is exported via the nuclear pores to the cytoplasm.
Rough endoplasmic reticulum  		The rER consists of flattened membrane sacs, called cisternae. Attached to the outside of these cisternae are ribosomes. They are larger than in prokaryotes and are classified as 80S. The main function of the rER is to synthesize protein for secretion from the cell. Protein synthesized by the ribosomes of the rER passes into its cisternae and is then carried by vesicles, which bud off and are moved to the Golgi apparatus.

Golgi apparatus 		This organelle consists of flattened membrane sacs called cisternae, like rER. However the cisternae are not as long, are often curved, do not have attached ribosomes and have many vesicles nearby. The Golgi apparatus processes proteins brought in vesicles from the rER. Most of these proteins are then carried in vesicles to the plasma membrane for secretion.
Lysosome 		These are approximately spherical with a single membrane. They are formed from Golgi vesicles. They contain high concentrations of protein, which makes them densely staining in electron micrographs. They contain digestive enzymes, which can be used to break down ingested food in vesicles or break down organelles in the cell or even the whole cell.
Mitochondrion 		A double membrane surrounds mitochondria, with the inner of these membranes invaginated to form structures called cristae. The fluid inside is called the matrix. The shape of mitochondria is variable but is usually spherical or ovoid. They produce ATP for the cell by aerobic cell respiration. Fat is digested here if it is being used as an energy source in the cell.
Free ribosomes 		These appear as dark granules in the cytoplasm and are not surrounded by a membrane. They have the same size as ribosomes attached to the rER – about 20nm in diameter, and known as 80S. Free ribosomes synthesize protein, releasing it to work in the cytoplasm, as enzymes or in other ways. Ribosomes are constructed in a region of the nucleus called the nucleolus.
Chloroplast 		A double membrane surrounds the chloroplast. Inside are stacks of thylakoids, which are flattened sacs of membrane. The shape of chloroplasts is variable but is usually spherical or ovoid. They produce glucose and a wide variety of other organic compounds by photosynthesis. Starch grains may be present inside chloroplasts if they have been photosynthesizing rapidly.
Vacuoles and vesicles 		These are organelles that consist simply of a single membrane with fluid inside. Many plant cells have large vacuoles that occupy more than half of the cell volume. Some animals absorb foods from outside and digest them inside vacuoles. Some unicellular organisms use vacuoles to expel excess water. Vesicles are very small vacuoles used to transport materials inside the cell.

Microtubules and centrioles  		In the cytoplasm of cells there are small cylindrical fibres called microtubules that have a variety of roles, including moving chromosomes during cell division. Animal cells have structures called centrioles, which consist of two groups of nine triple microtubules. Centrioles form an anchor point for microtubules during cell division and also for microtubules inside cilia and flagella.
Cilia and flagella  		These are whip-like structures projecting from the cell surface. They contain a ring of nine double microtubules plus two central ones. Flagella are larger and usually only one is present, as in a sperm. Cilia are smaller and many are present. Cilia and flagella can be used for locomotion. Cilia can be also be used to create a current in the fluid next to the cell.

The electron micrograph below shows a liver cell with labels to identify some of the organelles that are present.

- Using your understanding of these organelles, draw the whole cell to show its ultrastructure.



▲ Figure 3 Electron micrograph of part of a liver cell

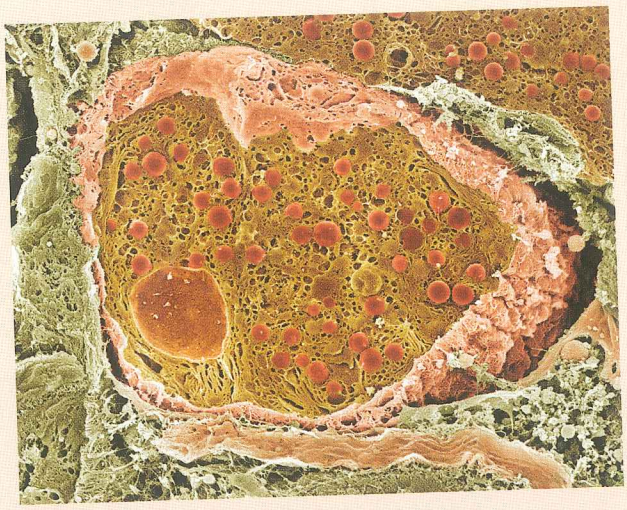
Exocrine gland cells of the pancreas

The structure and function of organelles within exocrine gland cells of the pancreas.

Gland cells secrete substances – they release them through their plasma membrane. There are two types of gland cells in the pancreas. Endocrine cells secrete hormones into the bloodstream. Exocrine gland cells in the pancreas secrete digestive enzymes into a duct that carries them to the small intestine where they digest foods.

Enzymes are proteins, so the exocrine gland cells have organelles needed to synthesize proteins in large quantities, process them to make them ready for secretion, transport them to the plasma membrane and then release them. The electron micrograph on the right shows these organelles:

- plasma membrane
- mitochondrion
- nucleus
- rough ER
- Golgi apparatus
- vesicles
- lysosomes



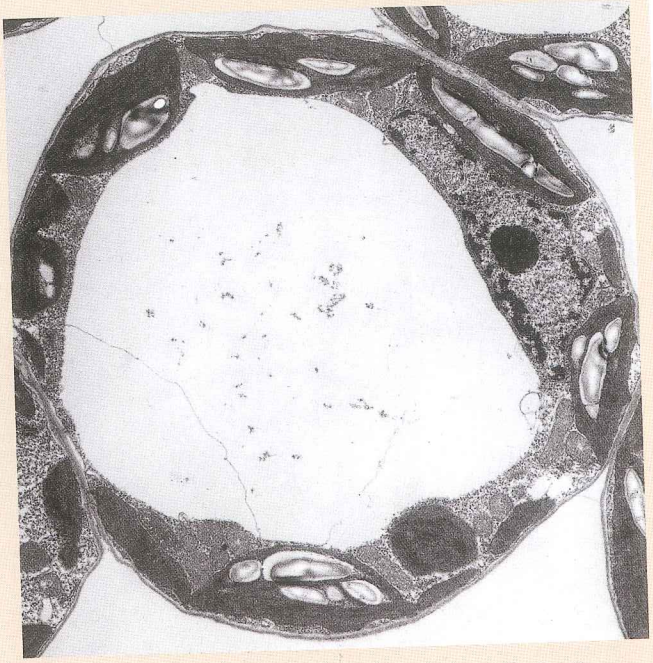
▲ Figure 4 Electron micrograph of pancreas cell

Palisade mesophyll cells

The structure and function of organelles within palisade mesophyll cells of the leaf.

The function of the leaf is photosynthesis – producing organic compounds from carbon dioxide and other simple inorganic compounds, using light energy. The cell type that carries out most photosynthesis in the leaf is palisade mesophyll. The shape of these cells is roughly cylindrical. Like all living plant cells the cell is surrounded by a cell wall, with a plasma membrane inside it. The electron micrograph on the right shows the organelles that a palisade mesophyll cell contains:

- cell wall
- plasma membrane
- chloroplasts
- mitochondrion
- vacuole
- nucleus



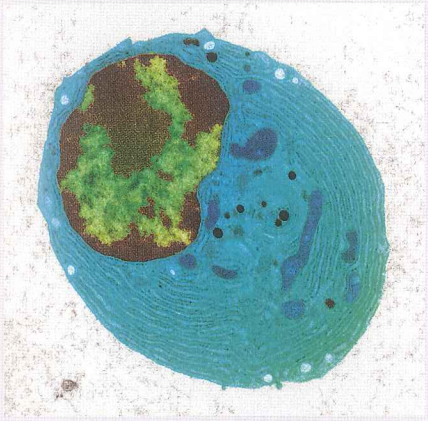
▲ Figure 5 Electron micrograph of palisade mesophyll cell

Interpreting the structure of eukaryotic cells

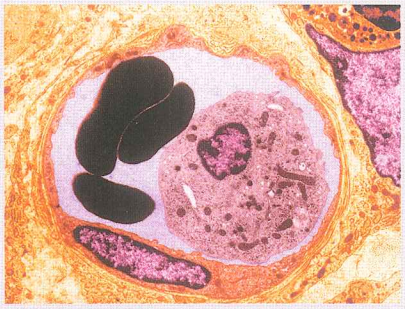
Interpret electron micrographs to identify organelles and deduce the function of specialized cells.

If the organelles in a eukaryotic cell can be identified and their function is known, it is often possible to deduce the overall function of the cell.

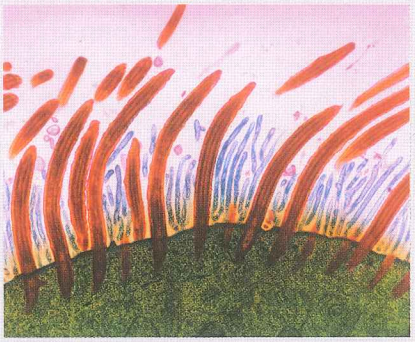
- Study the electron micrographs in figures 6, 7 and 8. Identify the organelles that are present and try to deduce the function of each cell.



▲ Figure 6



▲ Figure 7



▲ Figure 8

1.3 Membrane structure

Understanding

- Phospholipids form bilayers in water due to the amphipathic properties of phospholipid molecules.
- Membrane proteins are diverse in terms of structure, position in the membrane and function.
- Cholesterol is a component of animal cell membranes.

Applications

- Cholesterol in mammalian membranes reduces membrane fluidity and permeability to some solutes.

Nature of science

- Using models as representations of the real world: there are alternative models of membrane structure.
- Falsification of theories with one theory being superseded by another: evidence falsified the Davson–Danielli model.

Skills

- Drawing the fluid mosaic model.
- Analysis of evidence from electron microscopy that led to the proposal of the Davson–Danielli model.
- Analysis of the falsification of the Davson–Danielli model that led to the Singer–Nicolson model