1

CELL BIOLOGY

This chapter covers the following topics:

- ☐ The cell theory and cell size
- ☐ Ultrastructure of cells
- ☐ Membrane structure
- ☐ Membrane transport
- ☐ Origin of cells
- ☐ Cell division

1.1 The cell theory and cell size

Key information you should revise:

- What 'the cell theory' is and how it relates to single-celled organisms.
- How surface area to volume ratio limits cell size.
- How cell differentiation leads to specialised tissues in multi-cellular organisms.
- What emergent properties are and how they develop in multi-cellular organisms.
- What stem cells are and why they are so important in development.

What is the cell theory?

Key principles of the **cell theory** are:

- Living organisms are made of one or more cells.
- Cells are the smallest units of life.
- All cells come from pre-existing cells.

One cell can carry out all the functions of life and anything which cannot is not considered to be a cell. Viruses are not made of cells and are not considered to be living organisms.

Human red blood cells are sometimes suggested as an exception to the cell theory because they have no nucleus, but nuclei are present as they form, and red blood cells of other animals do have nuclei.

Are there exceptions to the cell theory?

The cell theory, like all scientific theories, is accepted until significant exceptions to it are found and a new theory is formulated. Remind yourself about what is meant by a scientific theory from your theory of knowledge (TOK) studies.

Many millions of different cells have been studied and the cell theory has been supported by these observations. A few examples have been found which do not fit it perfectly. These include:

- Fungal hyphae have many nuclei in their long threads.
- Skeletal muscle is made of fibres that are much larger than normal cells and contain many nuclei.
- Giant algae are uni-cellular but associate with other cells in a matrix.

At present these few exceptions have not led to a new theory.

TEST YOURSELF 1.1

What are the three key parts of the cell theory?

1 Cell biology

What functions do all cells carry out?

hint

Memorise this list of cell functions and be ready to give a short explanation of each process.

All cells must carry out these functions:

- metabolism
- homeostasis
- growth
- excretion
- reproduction
- nutrition.
- response (or showing sensitivity)

Some cells have additional functions such as the ability to move.

How do single-celled (unicellular) organisms live?

hint

You should be able to outline the way that life processes take place in *Paramecium* and *Chlorella*.

Paramecium is a unicellular aquatic organism and *Chlorella* is a unicellular photosynthetic organism.

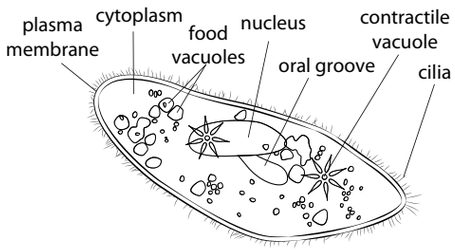

Figure 1.1 *Paramecium* carries out all the life functions within its single cell (×300).

hint

Make sure you can draw and label a diagram of *Paramecium* showing the gullet, oral groove, a food vacuole, a contractile vacuole, the nucleus and surface cilia.

Table 1.1 Life processes in *Paramecium* and *Chlorella*.

Function	*Paramecium*	*Chlorella*
respiration	by diffusion of gases large surface area to volume ratio	
growth and reproduction	binary fission	
response	surface sensitive to touch and chemicals	responds to light
homeostasis	excretory products diffuse out	carbon dioxide leaves by diffusion
nutrition	feeds using cilia	photosynthesis
movement	cilia propel the organism	floats in water

Why is surface area to volume ratio important in determining the size of cells and organisms?

Surface area to volume ratio is an important concept and relates to topics such as breathing and **absorption** of food where surface area is important.

Think about a simple cube.

- A cube with a side 1 cm long has a surface area of 6 cm^2 and a volume of 1 cm^3 – a ratio of 6:1.
- A cube with a side 2 cm long has a surface area of 24 cm^2 and a volume of 8 cm^3 – a ratio of only 3:1.

As the cube gets larger it has proportionately less surface area available. For a cell this means that it has less surface area to obtain the materials it needs through its surface and to dispose of waste. The rate of exchanging materials becomes limiting and cannot keep up with the needs of a cell, so beyond a certain size the cell could not survive.

Once you understand the concept of surface area to volume ratio you will be able to explain how living things solve the problem and are able to become larger.

Living things may develop structures, such as folds or villi on their cell surfaces but even so a single cell's size is limited. The cell must divide, so many organisms have become multicellular to overcome problems of the limited size of a cell.

A multicellular organism has many advantages, it can grow to a larger size and its cells can differentiate so that different cells do different jobs.

TEST YOURSELF 1.2

What happens to the surface area to volume ratio of a cell as it grows larger?

DEFINITION

DIFFERENTIATION involves the expression of some genes in a cell's genome but not others.

In your body you have muscle cells and pancreatic cells, which do very different jobs. They both contain the same genome but differentiation means they have different functions in the body.

TEST YOURSELF 1.3

Explain the importance of surface area to volume ratio in limiting the size of cells. **[3]**

hint

In Test yourself **1.3** you need to include three important points in your answer. This could be part of a short answer question or an essay.

What is an emergent property?

DEFINITION

EMERGENT PROPERTIES are new properties that appear in multicellular organisms as a result of interactions of the components of their cells.

Unicellular organisms must carry out all the functions of life but cells in a group with others can interact to perform a range of more complicated tasks. These are **emergent properties**. Cells form tissues and organs, which carry out functions such as breathing and reproduction in a different way. Use the analogy of a musical group to help you remember emergent properties. One instrument can play a simple tune but several instruments playing as a group produce a wider variety of sounds and effects.

Annotated exemplar answer 1.1

Figure **1.2** shows a section through the root of a maize plant under a microscope.

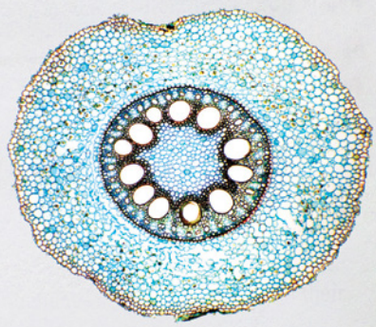

Figure 1.2

a List two visible features of the photograph, which are common to the structure of all complex organisms. **[2]**

b Define the term 'emergent property'. **[1]**

c Outline two emergent properties shown by a root, which are not present in a unicellular plant. **[2]**

a 1. Cells 2. Tissues

'Cells' is a correct answer, as all organisms have cells, but a better response would be 'The plant is multicellular'.

'Tissues' is correct but it would be better to say 'Cells are specialised into tissues and have different functions within the stem'.

b New properties that are present in multicellular organisms.

Adding 'so that the organism can carry out a range of more complex tasks than an individual cell' would gain marks here.

c 1. Transport – some specialised cells transport water and others transport nutrients. 2. Structure.

3/5

It would be better to name the cell types xylem and phloem.

To make this a good answer, add 'specialised cells form the root hairs and cortex'.

1 Cell biology

What is special about stem cells?

Unlike differentiated cells, stem cells retain the ability to turn into a great many different cell types and they are:

- unspecialised
- can divide repeatedly to make large numbers of new cells
- can differentiate into several cell types.

hint

Be prepared to put forward views from both sides of an ethical debate.

Embryonic stem cells come from the blastocyst (a ball of cells from a fertilised egg, which are all alike).

Adult stem cells, for example those found in bone marrow, are different and can only differentiate into a limited number of cell types.

Scientists must consider the ethics of any research involving living cells. Some people consider all stem cell research as unethical but different sources of stem cells have different properties and should be considered separately.

Medical uses of stem cells

hint

To demonstrate your knowledge ensure that you can outline a few examples of stem cell use in treating medical conditions.

Here are a few important examples for each type of stem cell:

1 Stem cells from umbilical cord blood to treat certain types of leukaemia.
2 Embryonic stem cells have recently been used to treat Stargardts disease, which leads to macular degeneration and blindness.
3 Stem cells from bone marrow from living donors are used to treat leukaemia in carefully matched recipients.

TEST YOURSELF 1.4

hint

Read multiple choice questions carefully before you make your selection. If you are not sure always make a calculated guess.

1 How do stem cells differ from other cells?
2 Why do some people think that stem cell research is unethical?
   A Organisms can be produced from stem cells.
   B Stem cells are living organisms.
   C Use of stem cells involves growing modified cells.
   D Use of embryonic stem cells involves early-stage embryos.

1.2 Ultrastructure of cells

Key information you should revise in this subtopic is:

- The detailed structure of a prokaryotic cell and a eukaryotic cell, including the structures inside these cells.
- How electron microscopes differ from light microscopes and how they have helped in our understanding of cell structure.
- How to draw a cell from a microscope image.

What are prokaryotic cells?

Prokaryotic cells are cells with no nucleus or internal membrane-bound organelles. They are smaller than **eukaryotic** cells. All bacteria are prokaryotes.

Study Figure **1.3** then try to redraw it from memory including all nine labels. You must remember the functions of all the structures too.

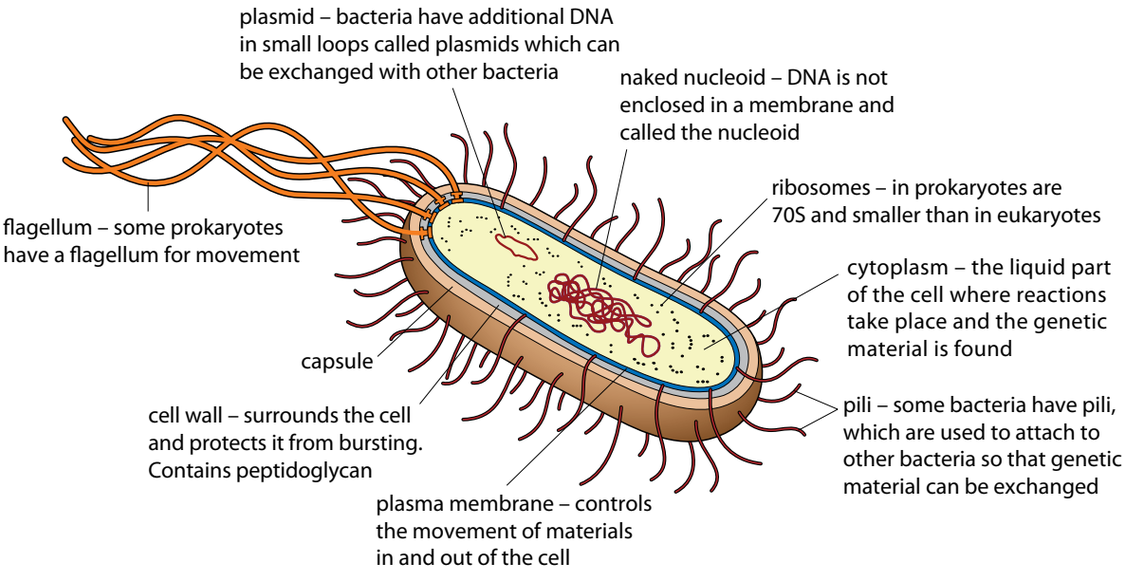

Figure 1.3 The structure of a prokaryotic cell.

How are eukaryotic cells different from prokaryotes?

Eukaryotes have structures, which prokaryotes do not. See Figure **1.4**.

Notice that the cell has internal structures that are 'compartments' or organelles with their own membranes.

DEFINITION

ORGANELLES are cell structures that have their own specific functions. Examples include ribosomes, nucleus and mitochondria.

TEST YOURSELF 1.5

Which of the following is a characteristic of organelles?

A They are only found in eukaryotic cells.
B They are only found in prokaryotic cells.
C They are subcellular structures.
D They are all membrane bound.

hint

Read multiple choice questions carefully. In Test yourself **1.5** think about the word 'only' in answers A and B.

TEST YOURSELF 1.6

What is the function of the rough endoplasmic reticulum (RER)?

hint

Drawings of cells should not have any shading. Use clear lines and a ruler for labels.

Plant cells have additional structures:

- Cell wall – made of cellulose that encloses the cell membrane and its contents.
- Chloroplasts – are the site of photosynthesis.
- Large vacuole – contains water and salts.

1 Cell biology

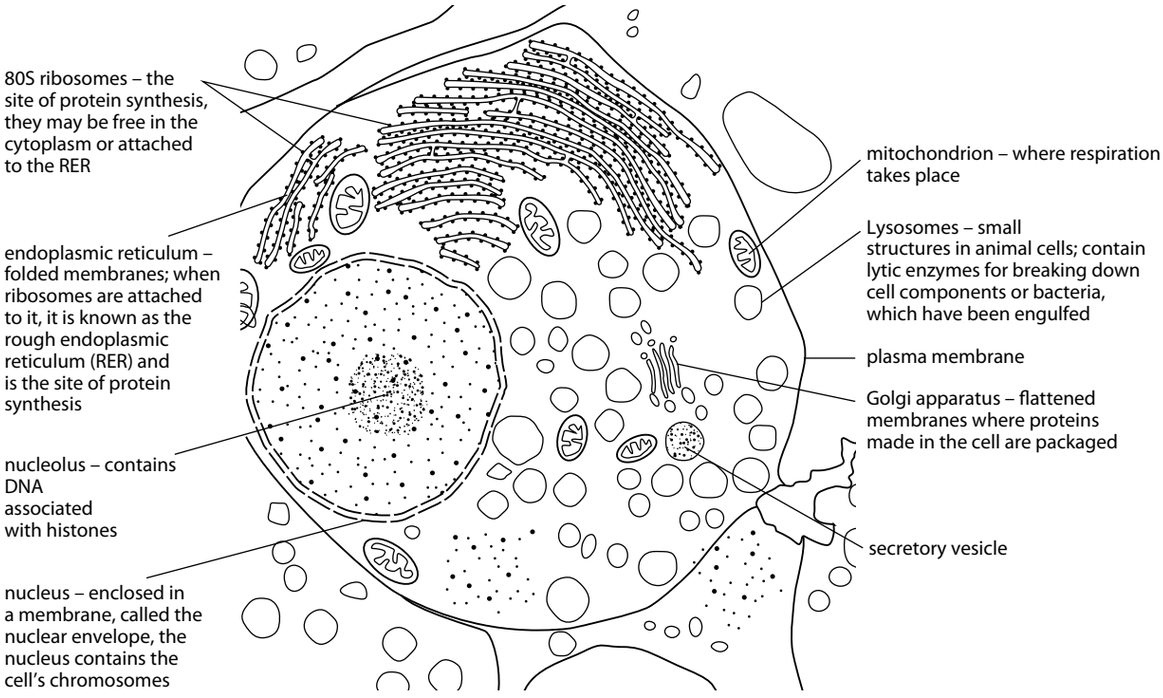

Figure 1.4 Interpretive drawing of an electron micrograph of an exocrine cell from the pancreas (× 12 000) showing some of the cell structures that are visible.

hint

You must be able to draw a line diagram of a eukaryotic cell like the one in Figure **1.4** from an electron microscope image.

hint

Exam questions may ask you to draw prokaryotic and eukaryotic cells and to label their structures. If you're asked to compare the cells, you can use a table like Table **1.2**

hint

For Test yourself **1.7** you are asked only to name the structures, so you do not need to add any other information.

Table 1.2

Structure	Eukaryotic cell	Prokaryotic cell
nucleus	surrounded by a nuclear envelope, contains chromosomes and a nucleolus	no nucleus, no nuclear envelope or nucleolus
mitochondria	present	never present
chloroplasts	present in plant cells	never present
endoplasmic reticulum	present	never present
ribosomes	relatively large, about 30 nm in diameter, or 80S	relatively small, about 20 nm in diameter, or 70S
chromosomes	DNA arranged in long strands, associated with histone proteins	DNA present, not associated with proteins, circular plasmids may also be present
cell wall	always present in plant cells, made of cellulose, never present in animal cells	always present, made of peptidoglycan
flagella	sometimes present	some have flagella, different in structure from those in eukaryotic cells

TEST YOURSELF 1.7

The electron micrograph here shows part of a liver cell.

a Name the organelles labelled A and B. **[2]**

b State the main function of these organelles. **[2]**

c Calculate the magnification of the micrograph. **[2]**

d Calculate the actual length of organelle A. **[2]**

Figure 1.5

1.3 Membrane structure

Key information you should revise in this subtopic is:

- How membranes are constructed including the arrangement of the phospholipid layers and the fluid mosaic model which explains this.
- The range of proteins that membranes contain and their functions.
- The importance of cholesterol in animal membranes.

What are the important features of a membrane?

Can you explain what **hydrophilic** and **hydrophobic** mean?

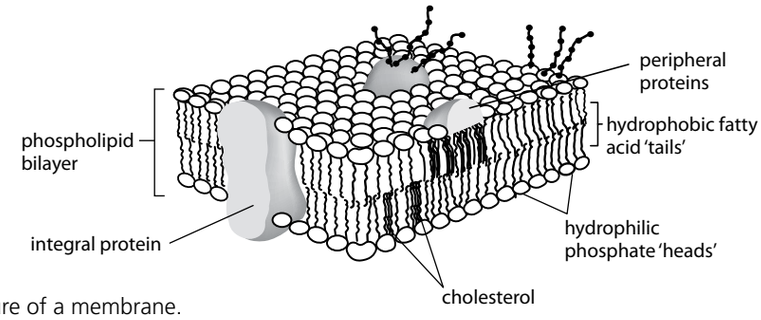

Figure 1.6 The structure of a membrane.

hint

Figure **1.6** shows the structure of a membrane in three dimensions. You will only need to be able to draw a two dimensions version of this in an examination.

DEFINITIONS

HYDROPHILIC MOLECULES (the phosphate groups in the phospholipid) are 'water-loving' and can appear on the outside of the membrane where water is present.

HYDROPHOBIC MOLECULES (the fatty acids in the phospholipid) are 'water-hating' and are found on the inside of the membrane.

What is the fluid mosaic model and how does it explain a membrane's properties?

The **fluid mosaic model** is used to explain our understanding of membrane structure. The most up to date model is based on Singer and Nicolson's model, which was proposed in 1972. The membrane mosaic is formed of many small separate units, the phospholipids. Each one can appear in any area of the membrane and thus it is said to be fluid. The membrane can fold and form **vesicles**, which can rejoin the main structure at any point because the phospholipid units can fit into a new area anywhere in its structure.

The phospholipids form two layers with the hydrophilic heads on the outside and the hydrophobic tails on the inside. There is more information about phospholipids in Chapter **2**.

TEST YOURSELF 1.8

What is meant by the term hydrophobic?

What are the functions of proteins and cholesterol?

Integral proteins are embedded in the bilayer and form protein channels for transport (see below). Peripheral proteins are attached to the surface and some of them have carbohydrates attached and act as hormone binding sites or for cell-to-cell communication. Some of the proteins embedded in a membrane are enzymes.

Cholesterol molecules are embedded between the non-polar fatty acid chains and make the membrane more rigid.

TEST YOURSELF 1.9

What is the importance of cholesterol in a cell membrane?

1.4 Membrane transport

hint

Learn the definitions of transport shown here as you may need to explain them in an exam.

Key information you should revise in this subtopic is:

- How particles move across membranes by active transport, osmosis, simple diffusion and facilitated diffusion.
- How materials are taken in by endocytosis and leave by exocytosis.
- How vesicles move substances around inside a cell.

DEFINITIONS

DIFFUSION is the passive movement of molecules such as oxygen, carbon dioxide or glucose down a concentration gradient.

FACILITATED DIFFUSION is a special case of diffusion across a membrane through specific protein channels.

OSMOSIS is the passive diffusion of water molecules from a region of higher concentration of water molecules to a region of lower concentration of water molecules.

ACTIVE TRANSPORT is the movement of substances against a concentration gradient. This process requires energy in the form of ATP.

What are the key features of each method of transport across membranes?

These four methods of transport are vital to many life processes, including nerve impulses (Chapter **6**), absorption by plant roots (Chapter **9**) and gas exchange (Chapters **6** and **11**). Be sure you can describe each method.

Table 1.3 Four methods of transport.

Simple **diffusion**	• passive • needs a **concentration gradient** • occurs until particles of a substances are in equilibrium • important in the movement of oxygen, carbon dioxide • membrane must be fully permeable to the substance
Facilitated diffusion	• passive • needs a concentration gradient • important for polar substances (e.g. glucose and amino acids) • involves a carrier protein and a protein channel • allows faster diffusion to take place
Osmosis	• is the diffusion of water molecules • passive • needs a concentration gradient • occurs until there is equilibrium on each side of the membrane
Active transport	• requires energy from **ATP** • can move substances against the concentration gradient • specific proteins may act as carriers • many carriers are specific to a particular molecules

You should be able to explain what happens if plant or animal cells are bathed in very salty or sugary solutions and observed under a microscope.

TEST YOURSELF 1.10

Distinguish between diffusion and osmosis. **[1]**

What are endocytosis and exocytosis and how do they work?

Endocytosis involves infolding of the **plasma membrane** to form a small vesicle within the cell. The vesicle may contain either liquid or solid items that the cell takes in from its external environment. For example, a white blood cell will engulf a bacterium by endocytosis so that it can be destroyed inside the cell.

Exocytosis is a method a cell uses to export something from within a cell. This may be an enzyme for digestion that the cell has made on the RER or a waste product, such as the digested remains of a bacterium. Vesicles formed inside the cell move towards the membrane and fuse with it, opening up so they can release their contents outside.

Remember both these process work because the membrane is a fluid mosaic, so vesicles can break away or rejoin the main membrane in any position.

hint

For Test yourself **1.10**, make sure that you include a comparative word in your answer to distinguish between the terms. **Whereas, on the other hand** and **but** are all suitable. Without comparative words you would score no marks even if you define the terms correctly.

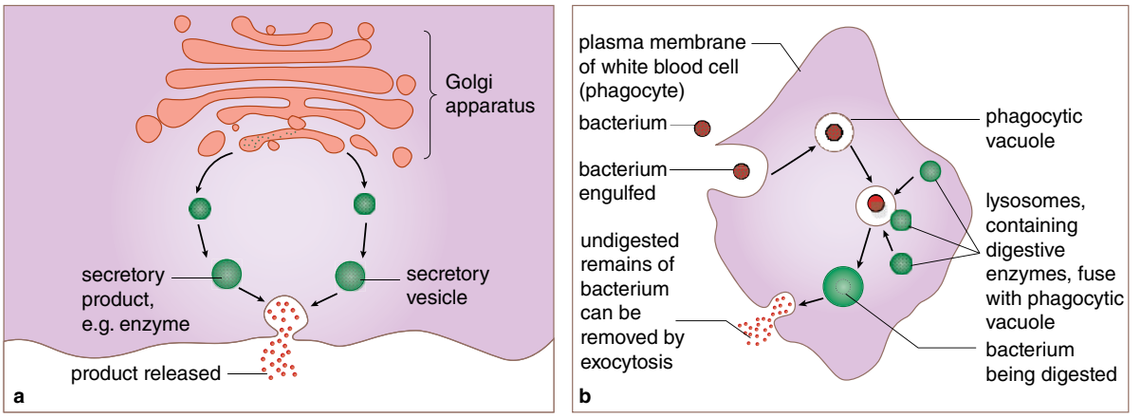

Figure 1.7 a Endocytosis and **b** exocytosis.

TEST YOURSELF 1.11

What is the function of proteins in passive transport?

A to act as electron carriers in the membrane
B to interact with hormones and influence cell processes
C to act as channels for specific molecules to diffuse across the membrane
D to release energy from ATP so that specific substances cross the membrane

1.5 Origin of cells

Key information you should revise:

- Cells form from the division of pre-existing cells.
- Non-living material must have given rise to cells long ago.
- **Endosymbiosis** explains the origin of eukaryotic cells.

1 Cell biology

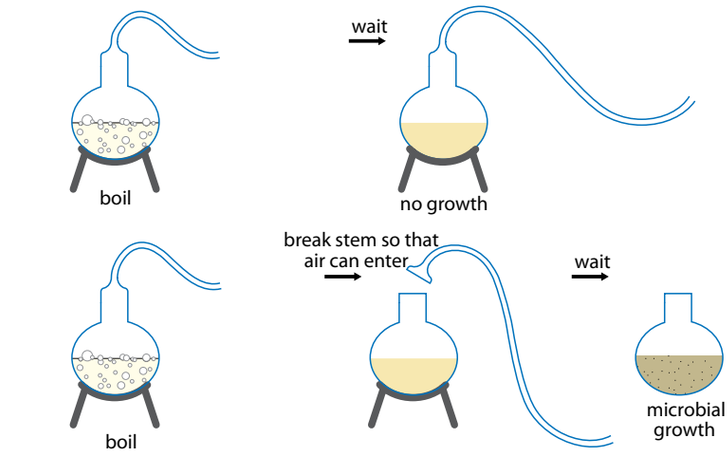

Figure 1.8 Pasteur's experiment demonstrating that living cells cannot 'spontaneously generate', but must originate from pre-existing living cells.

How are new cells formed and how did Pasteur demonstrate this?

Louis Pasteur used experiments to demonstrate that living cells cannot spontaneously generate (appear) and must be produced from existing cells, as shown in Figure **1.8**.

How did the first cells originate?

The first cells probably appeared about 3.5 billion years ago and must have arisen from chemicals present at that time. Certain steps must have occurred in the process.

- Organic molecules must have formed, and larger molecules been assembled from the basic organic molecules.
- Some molecules must have been able to reproduce themselves and have formed membranes from mixtures of larger molecules.

What is the endosymbiosis theory and how does the origin of eukaryotic cells depend on it?

DEFINITION

ENDOSYMBIOSIS THEORY suggests that some organelles, notably mitochondria and chloroplasts that are found inside eukaryotic cells, were once simple free-living prokaryotes.

Evidence to support the theory includes the observations that both chloroplasts and mitochondria:

- contain smaller 70S ribosomes that are found in prokaryotes
- contain small circular pieces of DNA rather like plasmids
- have their own membrane
- can replicate by binary fission.

hint

To remember the term **endosymbiosis**, recall that symbiosis means 'living together' and endo- means 'inside'.

This theory suggests that long ago simple prokaryotes were engulfed by larger cells and remained inside them. There are critics of the theory and because it is a scientific theory, if strong evidence is found to refute it then the theory will have to change.

TEST YOURSELF 1.12

Why did Pasteur's experiment provide evidence for the cell theory?

1.6 Cell division

The cell division described here is **mitosis**. This is the type of division which produces two identical daughter cells. Do not confuse it with meiosis, which is the cell division that produces haploid gametes and is described in Chapter **3**.