Chapter 3

Cell division and cellular organisation

Background

e-Learning

Objectives

The cell cycle

Like most animals, you began your life as a single cell. This cell was a **zygote** – a cell that forms when two gametes fuse. The zygote contained a set of chromosomes from your father and a set of chromosomes from your mother.

All the cells in your body have developed from this single original cell. Soon after it was formed, the zygote divided to form two cells, which then each divided to form a total of four cells. This division went on and on, eventually forming your body containing many millions of cells. Some cells continue to divide even in an adult.

The repetitive process of growing and dividing, growing and dividing is called the **cell cycle** (Figure 3.1). The cell cycle is made up of two main phases, **interphase** and **mitosis**.

Extension

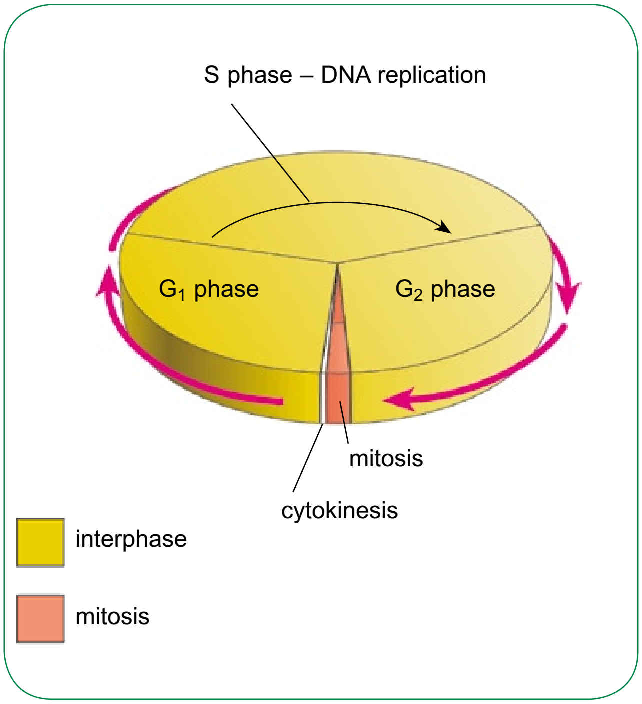


Figure 3.1 The cell cycle.

Interphase

In a cell in a human embryo, one complete cell cycle lasts about 24 hours. About 95% of this time is spent in **interphase**. During interphase, the cell is carrying out all the normal cell activities, such as respiration and protein synthesis. The DNA that makes up its chromosomes is duplicated – a perfect copy is made, so that the DNA can be divided up equally into the two new cells that will be made when the cell divides.

In a human cell, there are 46 **chromosomes**, each of which is made up of one enormously long molecule of DNA. Some time before the cell divides, each DNA molecule is copied. The pair of identical DNA molecules that are now contained in each chromosome remain attached to each other, at a point called the **centromere**. The two identical strands of DNA are called **chromatids** (Figure 3.2 and Figure 3.3).

It is very important that the new DNA molecules that are made are the same as the old ones. Even a small error – a **mutation** – could have harmful effects on the cell. Cells therefore run a 'checking' process on the new DNA. Special proteins work along the DNA molecules, checking for any errors and, where possible, correcting them.

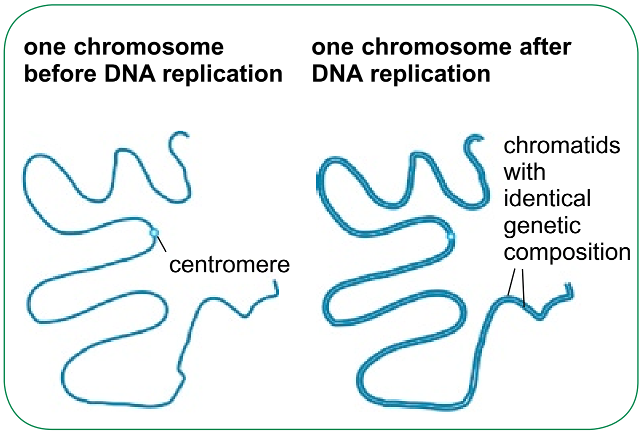


Figure 3.2 Chromosomes in interphase.

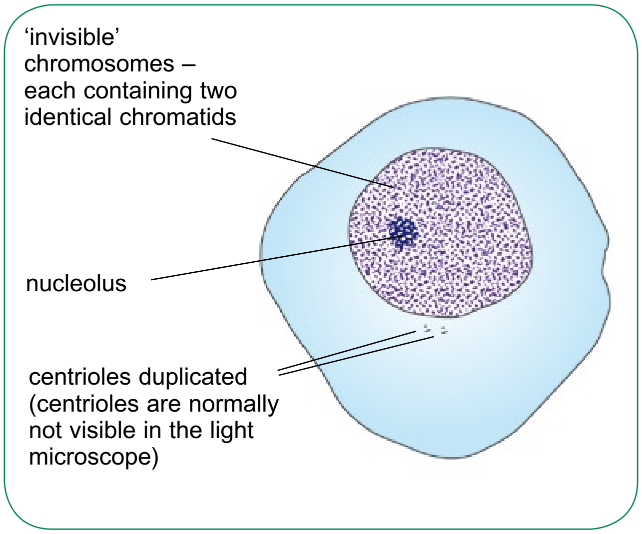


Figure 3.3 Late interphase.

Mitosis

The cell then moves into the next stage of the cell cycle, called **mitosis**. This is the stage during which the nucleus of the cell divides into two nuclei. During mitosis, the two chromatids which make up each chromosome break apart. One of them goes into one new nucleus and one into the other. In this way, the new cells will be genetically identical to each other and to the original parent cell.

Mitosis is made up of four stages: **prophase**, **metaphase**, **anaphase** and **telophase**. The four stages run into one another, without breaks between them.

Prophase

During prophase (Figure 3.4), the chromosomes become visible. Up to now, they have been lying in the nucleus as extremely long and thin threads, so thin that they cannot be seen at all with a light microscope. As prophase begins to get under way, the DNA molecules coil and supercoil, shortening and getting thicker until they eventually form threads that are thick enough to be visible if they are stained.

When the chromosomes appear, they can sometimes be seen to be made of two threads – the chromatids. The chromatids are held together at the centromere. The two chromatids of each chromosome contain identical molecules of DNA, formed in DNA replication during interphase.

As prophase proceeds, the nucleolus disappears. It is also at this stage that the **spindle** begins to form. The **centrioles** move away from each other to opposite ends of the cell. The centrioles organise the formation of the microtubules – long, thin tubes of protein (Figure 3.4).

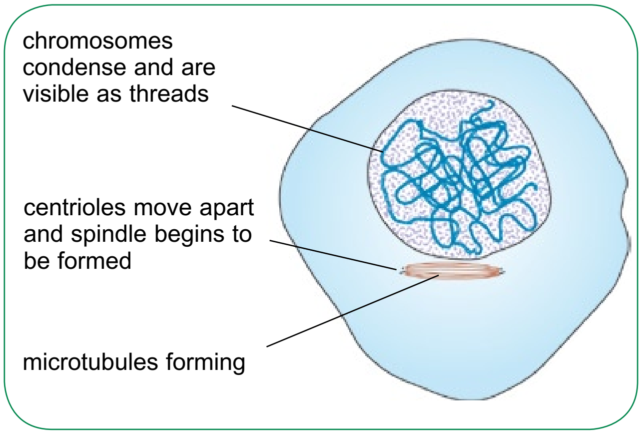


Figure 3.4 Prophase.

Metaphase

Now the nuclear membrane breaks down. Its loss means that the whole of the space in the cell is available for manoeuvring the chromosomes. By the time the nuclear membrane breaks down, many of the microtubules have attached themselves to the centromeres of the chromosomes. Each centromere is grabbed by one microtubule on either side. The microtubules pull in opposite directions on the centromeres, bringing the chromosomes to lie at the **equator** of the cell (Figure 3.5).

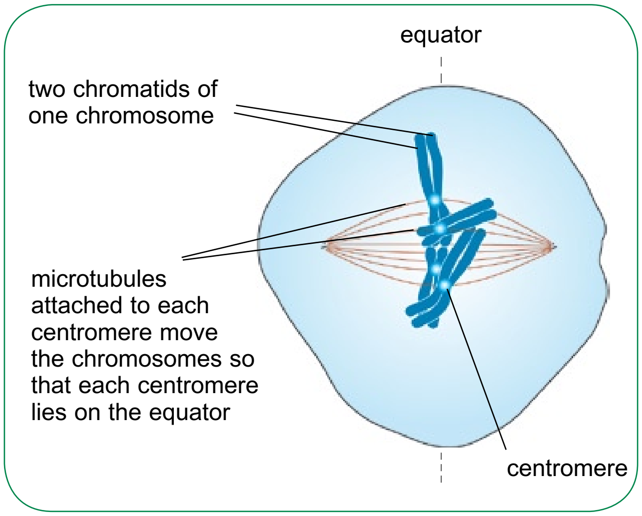


Figure 3.5 Metaphase.

Anaphase

Now the centromeres split. The microtubules are still pulling on them, so the centromeres and the chromatids are pulled apart and moved to either end, or **pole**, of the cell (Figure 3.6).

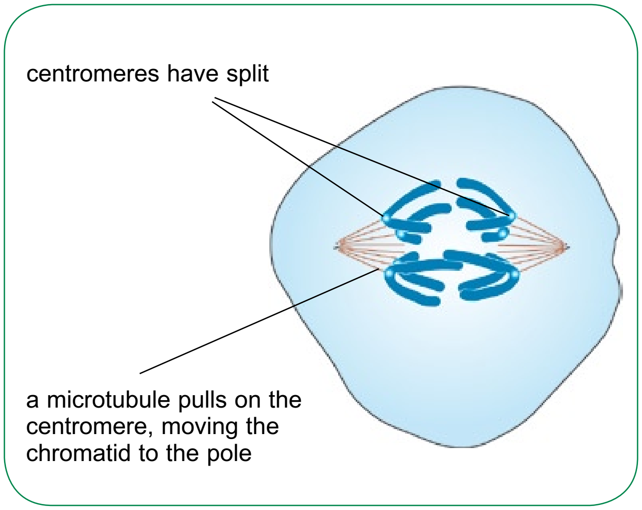


Figure 3.6 Anaphase.

Telophase

The two groups of chromatids have now arrived at the poles. Each group contains a complete set of chromatids, which we can now call chromosomes again. The microtubules making up the spindle fibres break down, so the spindle disappears. New nuclear envelopes form around each group of chromosomes. The chromosomes slowly uncoil and become thinner again, so they effectively disappear (Figure 3.7).

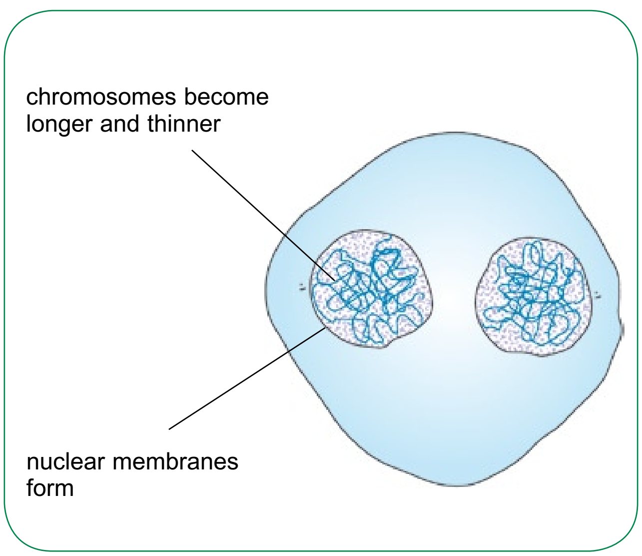


Figure 3.7 Telophase.

Cytokinesis

Usually, the cytoplasm now divides (Figure 3.8). This forms two new cells, each with a nucleus containing a complete set of chromosomes, and each with a centriole. The new cells are genetically identical to each other and to the original, parent cell.

A summary of mitosis and cytokinesis is shown in Figure 3.9, while Figure 3.10 shows micrographs of mitosis and cytokinesis taking place in plant cells.

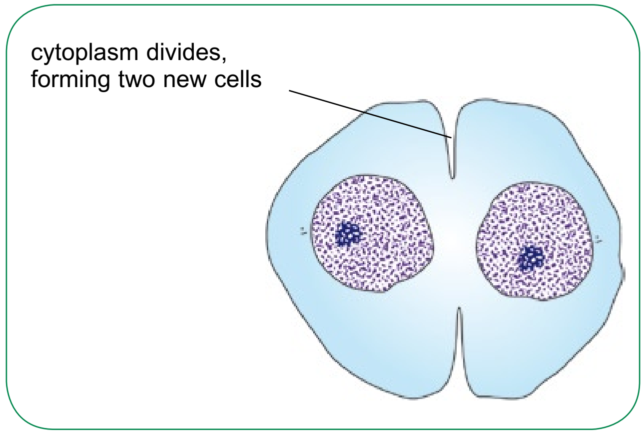


Figure 3.8 Cytokinesis.

SAQ

1 A student looked at a prepared slide of a group of cells in various stages of cell division. He identified the stage in 200 cells and counted up how many cells he could see in each stage. The table shows his results.

Stage	Number of cells
interphase	188
prophase	6
metaphase	3
anaphase	1
telophase	2

a How many cells were in a stage of mitosis?

b Explain what these data tell us about the relative lengths of time spent in each stage of the cell cycle in this group of cells.

Hint

Answer

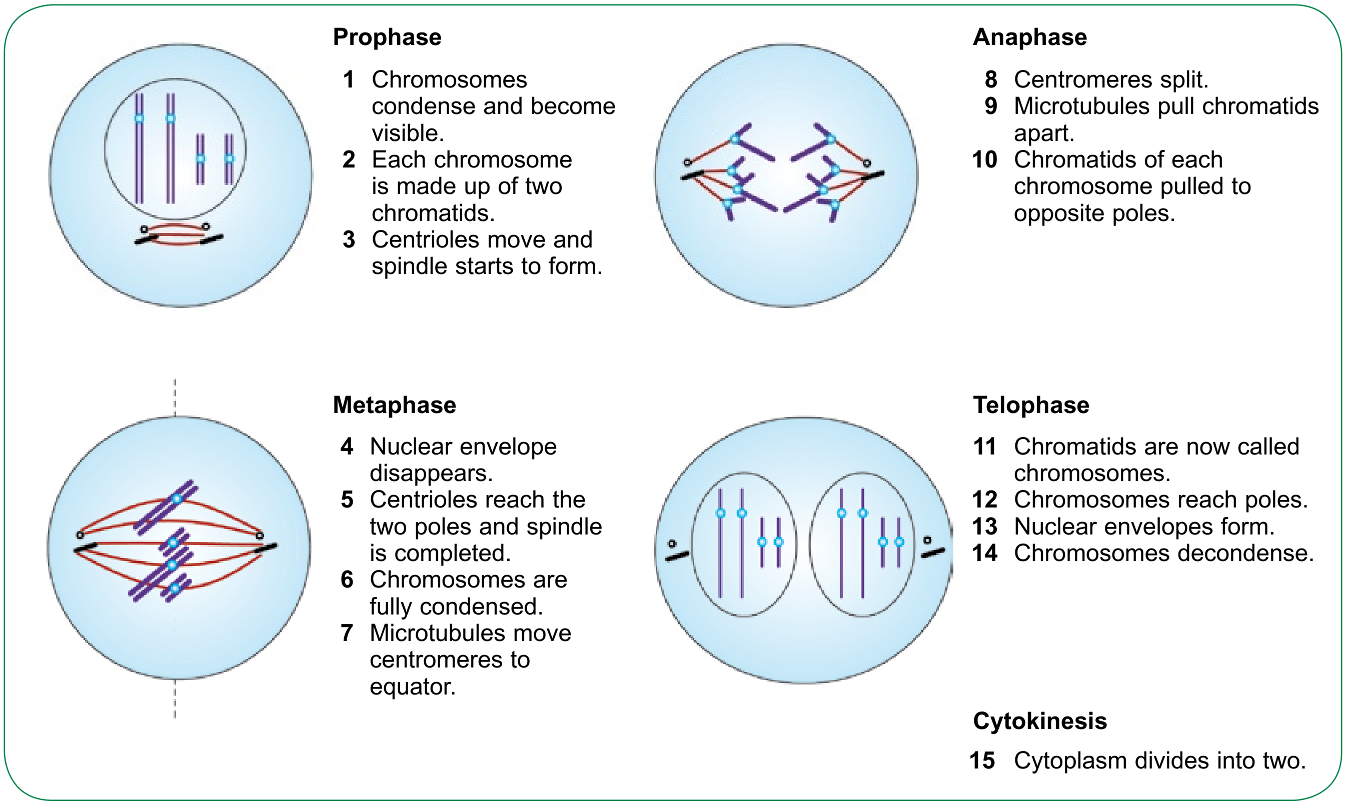


Figure 3.9 Summary of mitosis and cytokinesis.

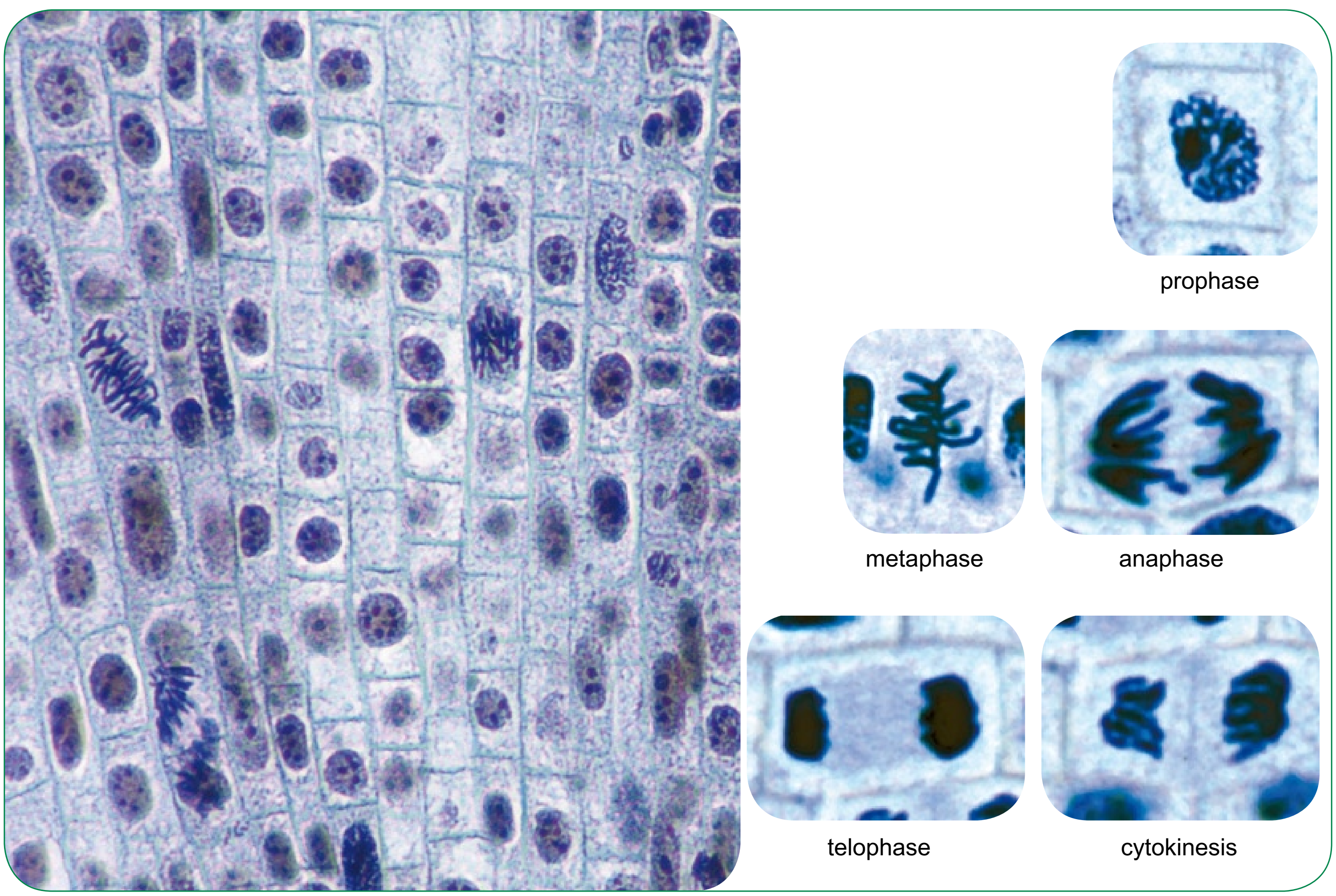


Figure 3.10 Stages of mitosis in an onion root tip (×100 and ×230).

The significance of mitosis

We have seen that mitosis produces new cells that are genetically identical to the parent cell. Each of these cells has the same number of chromosomes and identical DNA.

This is how cells divide when the body needs more of the same. Mitosis is the type of cell division that occurs in a developing embryo and throughout the growth of a human being.

Mitosis continues to occur in many parts of the body even when we are fully grown. For example, cells in the lining of the alimentary canal divide to provide new cells to replace those which get rubbed off as food moves past them. Mitosis also comes into play when part of the body is damaged and needs repair. For example, if you cut yourself, cells in the skin will produce new cells which spread across the wound to produce a new, protective layer of skin.

In some organisms, mitosis is used for reproduction. For example, strawberry plants grow runners which put down roots and produce new, genetically identical plants. This is **asexual** reproduction, which does not involve gametes or fertilisation. Some animals, for example *Hydra*, can also reproduce in this way.

Single-celled organisms can also reproduce by mitosis. The single-celled fungus, *Saccharomyces cerevisiae*, yeast, reproduces by budding. A new cell is formed from the old one by mitosis, and then breaks away (Figure 3.11).

Figure 3.11 Budding in yeast. The cell at the centre shows traces of two buds starting to form. A later stage of budding is seen with the large parent cell and smaller daughter cell at the left.

Differentiation

Your body contains about 10^{13} cells. They have all developed from the single cell with which you began your life – the zygote that was formed by the fusion of an egg cell and a sperm cell. The zygote divided to form a tiny ball of cells called a **blastocyst**, which continued to divide to form an embryo.

In multicellular organisms, there are usually many different kinds of cells. These cells have become specialised to carry out different functions. There is 'division of labour' amongst them.

The body is made up of 'teams' of cells, usually grouped together into **tissues**, which work together closely while each performing their own specialist functions. The specialisation of a cell to carry out a particular function is called **differentiation**.

Once a human cell has differentiated, it usually cannot change into another kind of cell. A heart muscle cell cannot change into a bone cell. A bone cell cannot change into a skin cell.

This is very different from the abilities of the cells in the blastocyst. These cells have the potential to become any of the many different kinds of cells within a human. They are **stem cells**. Stem cells differ from most human cells because:

- they are unspecialised
- they can divide repeatedly to make new cells
- they can differentiate into several kinds of specialised cells.

All the cells in a blastocyst are stem cells, and they can differentiate into any kind of specialised cell. They are therefore said to be '**totipotent**'. Even in an adult person, there are still some stem cells. So far, all the ones that have been found are only able to differentiate into a limited range of cells – for example, there are stem cells in bone marrow that can form white and red blood cells. But they cannot differentiate into neurones, or any other kind of cell.

There is much interest in stem cells, as they could cure many diseases. For example, Parkinson's disease is caused by the death of a particular group of cells in the brain. One day, it may be possible to use stem cells to replace these brain cells.

Extension

Some specialised animal cells

Erythrocytes, otherwise known as red blood cells, transport oxygen in the blood. They have a very short life span. Every second, around 10 million old erythrocytes are destroyed in your spleen, and 10 million new ones are made. They are made from stem cells in the **bone marrow**, especially in the ribs, vertebrae, pelvic bones and skull. These stem cells also make **leucocytes**, the white blood cells. There are several types of these, including **neutrophils** – cells that attack and destroy invading microorganisms by phagocytosis.

Figure 3.12 and Figure 3.13 show the structures of neutrophils and erythrocytes, and explain how their structures are adapted for their functions.

Spermatozoa, sperm for short, are the male gametes (Figure 3.14). They are made in the testes throughout a man's life. They are adapted to find and fertilise a female gamete.

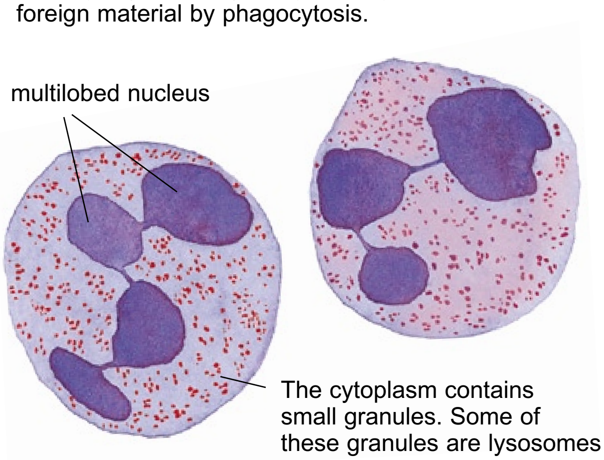


Figure 3.12 Neutrophils.

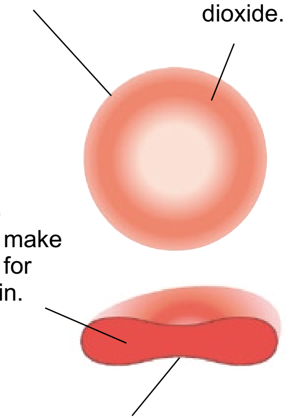


Figure 3.13 Erythrocytes.

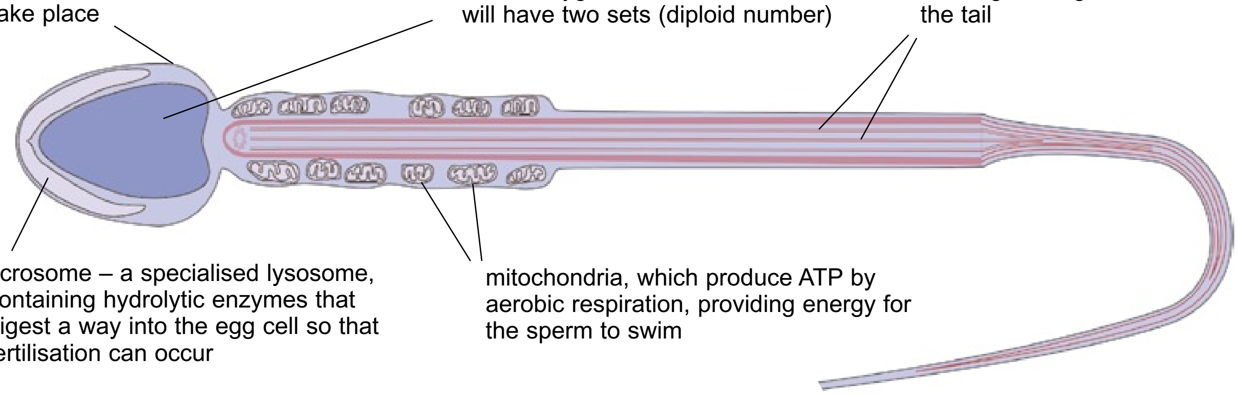


Figure 3.14 A spermatozoan.

Some specialised plant cells

Plants do not have stem cells – most of their cells retain the ability to differentiate into other kinds of cells throughout their lives. However, there are several parts of a plant where cells are able to divide, and places where this occurs at a high rate are called **meristems**. The meristem just behind the root tip is a good place to find cells in various stages of mitosis, which you can prepare and stain as a 'root tip squash'.

There is another meristem that forms a ring of tissue in the stem, called **cambium**. These cells can divide to form **xylem vessels** on the inside of the ring and phloem sieve tubes on its outside, which help to form these two transport tissues. Figure 3.15 and Figure 3.16 show the structures and functions of these tissues and where they are found in a stem.

The cells that are often considered to be 'typical' plant cells are the **palisade cells** – the main type of photosynthetic cell found in plant leaves. They are, in fact, highly specialised, containing many chloroplasts in which photosynthesis takes place.

Root hair cells are found near the tips of roots. They are specialised epidermal cells – that is, cells that cover the outside of a plant organ. They have long, thin extensions that grow between the soil particles, providing a large surface area that is in contact with the layer of water that is usually present on and between these particles. The water contains various mineral ions in solution, which root hairs absorb. They have a short life, being easily broken as the root grows through the soil. Recently divided cells near the root tip differentiate to form new root hair cells (Chapter 6).

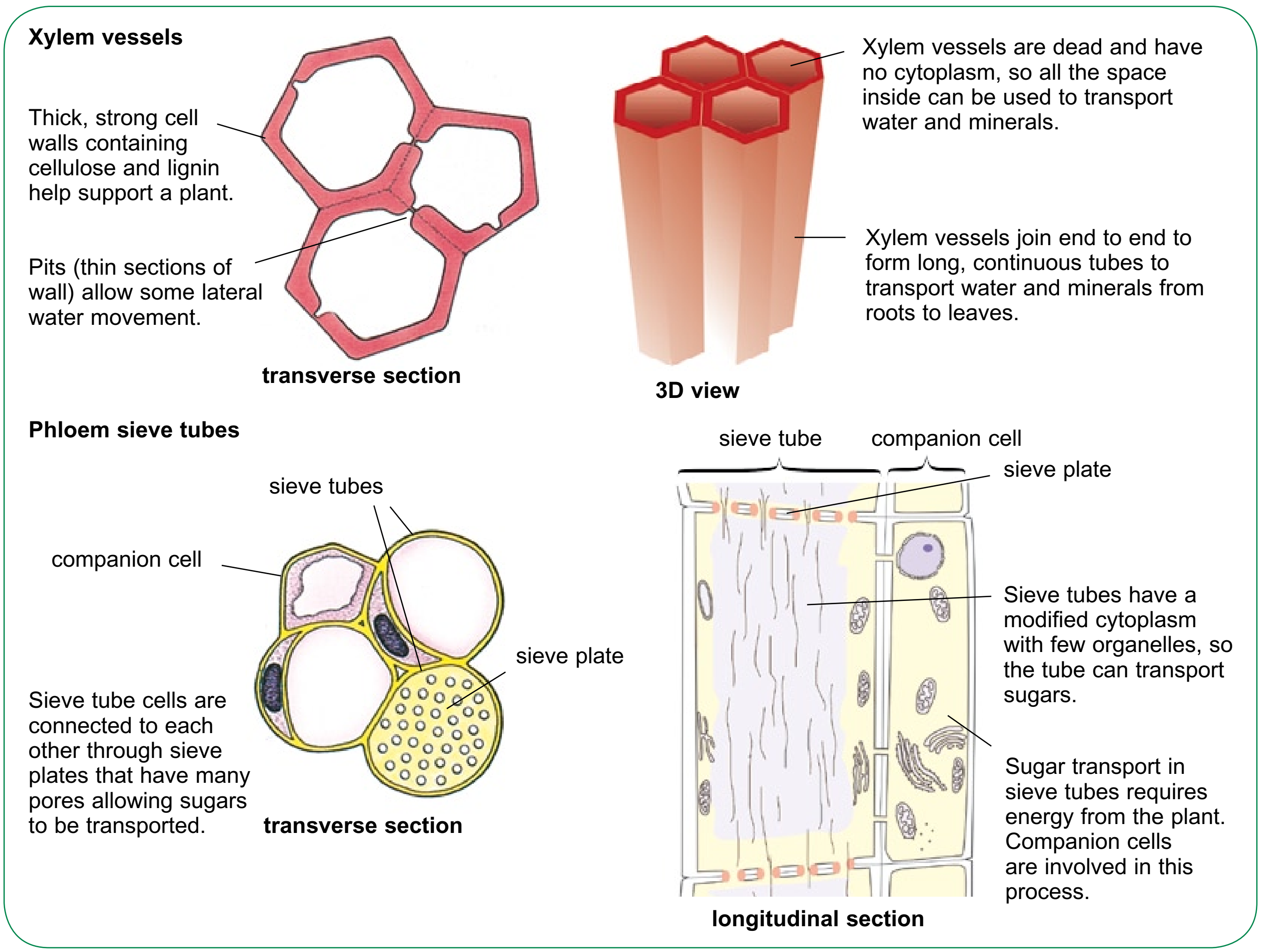


Figure 3.15 Xylem and phloem tissues. You can see micrographs of xylem tissue and phloem tissue in Chapter 6.

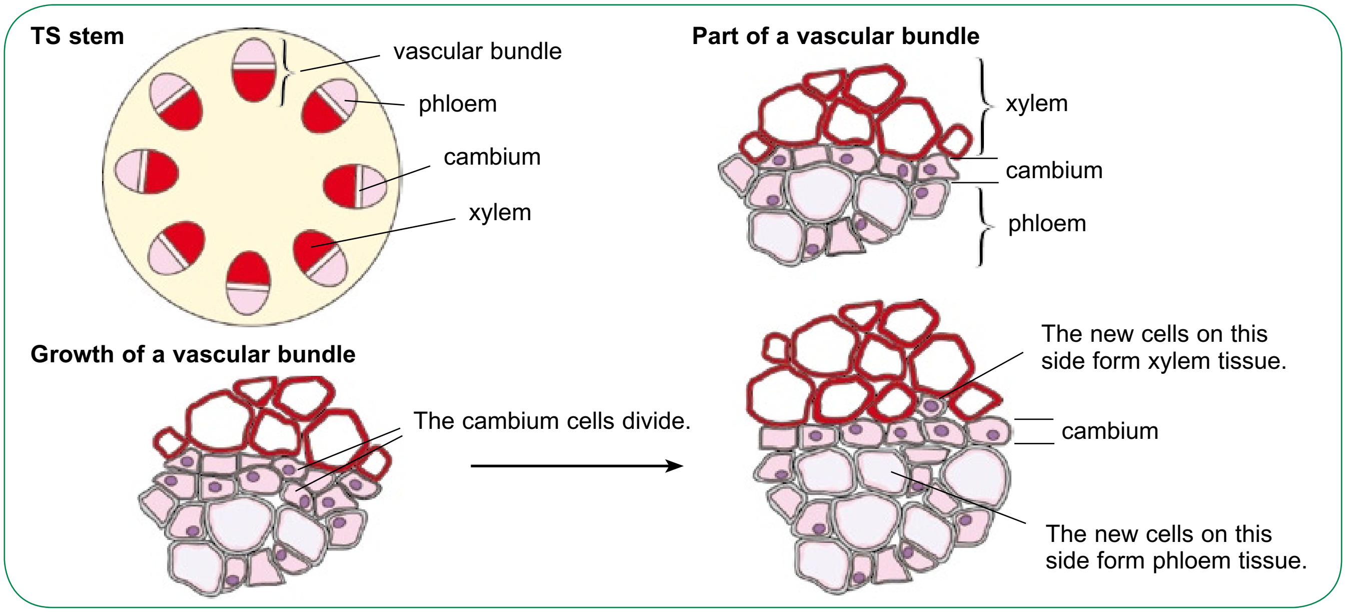


Figure 3.16 Cambium, xylem and phloem in a plant stem.

Dendrochronology

Each spring, as the weather warms up and there is more daylight, trees begin to grow after resting through the winter. Cells in the ring of cambium in the trunk divide, producing new phloem tissue on the outside of the ring, and new xylem tissue on the inside. This process continues throughout the summer, but the new cells produced later in the year are smaller than the ones produced during the period of maximum growth in spring.

The xylem tissue makes up the wood of the trunk. A slice across a tree trunk reveals rings in the wood, corresponding to the yearly growth cycle. The xylem tissue made in spring usually looks light in colour, because the vessels are larger. The summer xylem tissue forms a narrower, darker stripe.

The width of the stripes is determined by how well the tree grew that year, which depends on the weather conditions. In a dry year, the tree will grow less than in a wet year, so the ring for that year will be narrower. This will be true for all the trees growing in that place at that time.

Once the ring patterns of some samples of wood of known age have been analysed, then other samples of wood can be matched against them, looking for matching patterns of narrow and wide rings. This can be used to date the wood – a procedure known as 'dendrochronology'. Dendrochronologists have now built up enough data to establish patterns of growth going back to around 9000 years ago. These can be used to determine when a tree was felled to provide the wood that has been used to build an ancient ship or an old house, for example, as well as showing where the tree grew.

The *Mary Rose* contained wood from trees felled in southern England in 1510.

Tissues, organs and organ systems

The millions of cells inside a multicellular organism such as yourself are not scattered randomly about. Cells that carry out the same function are usually grouped together, forming a tissue. Tissues may be further grouped into organs, and organs into systems. We can define these terms as follows:

- A **tissue** is a collection of cells, together with any intercellular ('between cells') secretion produced by them, that is specialised to perform one or more particular functions. The cells are often of the same type, such as palisade tissue in a plant leaf or squamous epithelium (page 46) in animals.
- An **organ** is a part of the body which forms a structural and functional unit and is composed of more than one tissue. A leaf is an example of a plant organ, and the brain is an example of an animal organ.
- A **system** is a collection of organs with particular functions, such as the excretory, reproductive, cardiovascular and digestive systems in humans.

Figure 3.17 shows the tissues in a leaf.

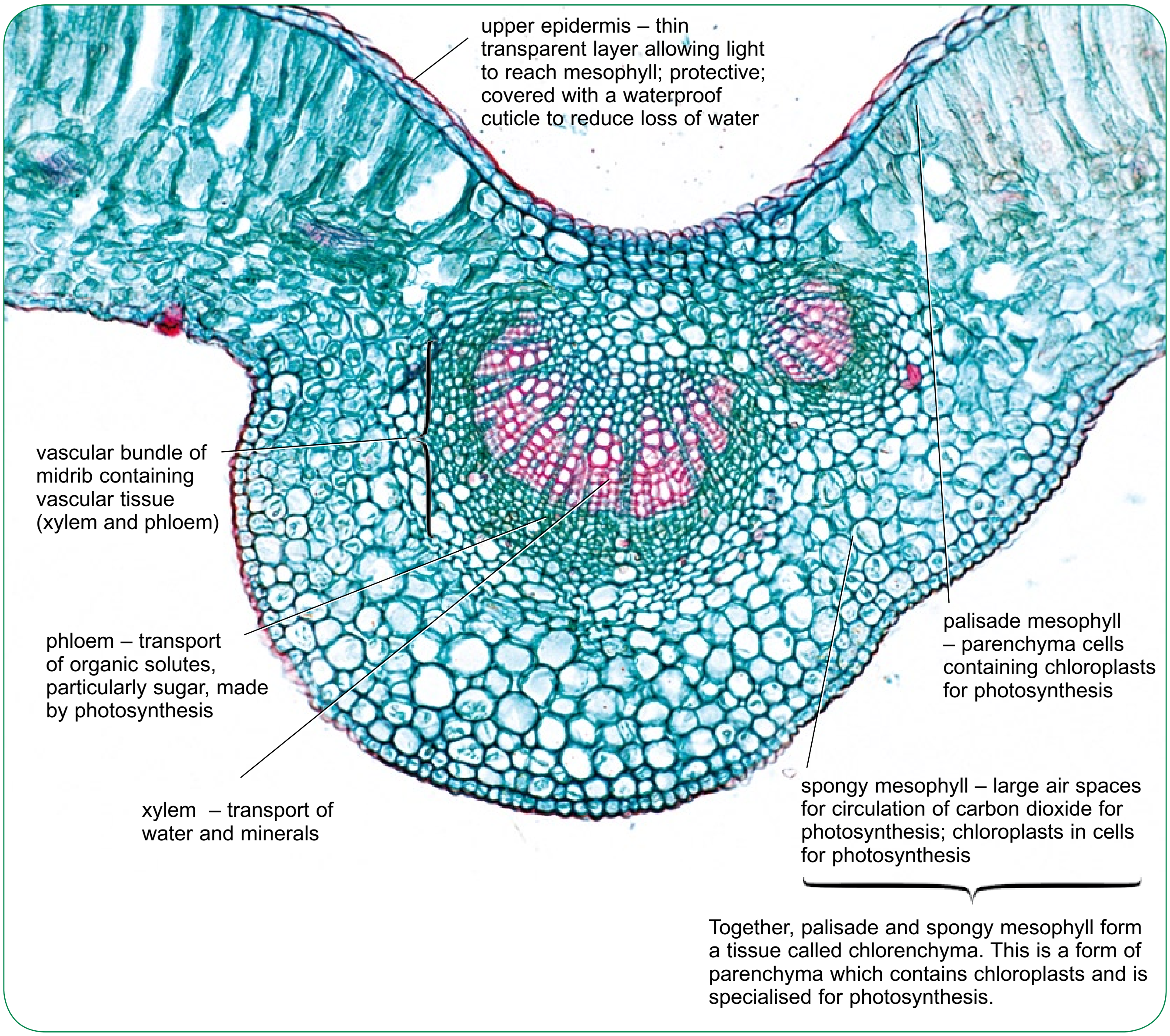


Figure 3.17 Transverse section through the midrib of a dicotyledonous leaf, *Ligustrum* (privet) (× 50).

Sponges

Sponges are believed to be amongst the very earliest multicellular animals to have appeared on Earth. The oldest fossil sponges that have so far been discovered are 600 million years old, and it is likely that sponges were around for some time before then.

Sponges are found in seas all over the world, and a few species live in fresh water. At first sight, sponges don't look like animals at all. They remain apparently motionless, generally fixed permanently to the sea bed or a coral reef. Under the microscope, however, they can be seen to have cells with no cell walls – a feature typical of animal cells.

Some of a sponge's cells have long flagella, which beat rhythmically, creating a water current that flows through the sponge's body, and from which the sponge's cells extract food material. The flagellated cells also have microvilli (tiny projections on the cell surface) to increase their surface area and therefore make food absorption more efficient. Other cells are tubular, providing pores through which the water current can circulate. Others secrete the protein collagen, and yet another type secrete little spicules of calcium carbonate or silica, which provide a skeleton for the sponge.

So, like most multicellular organisms, sponges have a range of different types of cells that are specialised for different functions. However, unlike all other groups of animals, sponges do not possess true tissues, organs or systems. The different cells are scattered throughout the sponge's body. This suggests that perhaps they were some of the earliest animals to evolve from the single-celled organisms that lived on Earth long ago.

Sponges have not been of great interest to humans in the past, except as a source of soft, rubbery absorbent material for washing – and even this function has now been almost entirely taken over by plastic sponges. But recently, sponges have become of great interest to pharmaceutical companies.

Unable to move, sponges cannot flee from other animals that eat them. Many of them have evolved a defence mechanism – they secrete toxic chemicals that deter predators, and also prevent other sponges from growing too close to them. Indeed, some other kinds of marine organisms, such as some species of crabs, carry sponges around on their bodies as a defence against predators.

Some of these chemicals show promise as drugs to fight human diseases. For example, a compound called halichondrin, derived from the sponge *Lissodendoryx*, is being developed as a possible anti-cancer drug. The sponge *Dysidea avara* produces a chemical called avarol, which could be used to treat psoriasis – a chronic condition in which red and scaly areas form on the skin. So far, we have only touched the tip of the iceberg, and there may be thousands of chemicals with pharmaceutical potential to be found in sponges.

Some examples of animal tissues

Tissues that cover a surface in an animal are called **epithelial tissues**. The two examples shown in Figure 3.18 are only one cell thick, and so they are *simple* epithelia. The cells rest on a **basement membrane**, which, despite its name, is not a cell membrane at all. It is a network of collagen and glycoproteins that is secreted by the underlying cells, and that holds the epithelial cells in position.

Squamous epithelium covers many surfaces in the human body, including the inner lining of the cheeks, the inner surfaces of blood vessels, and the inner surfaces of the atria and ventricles in the heart. It also forms the walls of the alveoli in the lungs. The individual cells are smooth, flat and very thin. They fit closely together, providing a smooth, low-friction surface over which fluids can move easily. In the alveoli, the thinness of the cells allows rapid diffusion of gases between the alveoli and the blood (Chapter 4).

Ciliated epithelium is made up of cells that possess cilia. Sometimes these cells are shaped like cubes, making up *cuboidal* ciliated epithelium. This tissue lines the ends of the bronchioles in the lungs. Sometimes the cells are tall and narrow, making up *columnar* ciliated epithelium, found in the oviducts.

SAQ

2 Suggest the functions of the ciliated epithelium in:

a the bronchioles

b the oviducts.

Answer

Some examples of plant tissues

We have seen how xylem vessels and phloem sieve tubes are specialised for their functions of transporting substances within plants (Figure 3.15). These specialised cells form tissues within plant stems, roots and leaves. Their distribution and structures are also shown in Chapter 6.

Coordination

Division of labour within a multicellular organism means that every cell has its own set of functions in which it specialises. However, it is clearly essential that there is communication and cooperation between cells within a tissue, and between tissues, organs and systems in different parts of the body. Pulling the activities of all the different parts of the body together, so that they work with each other and do appropriate things at appropriate times, is essential if a multicellular organism is to survive.

As we have seen, this communication involves cell signalling. Much of it is done by means of molecules that are produced by one cell and that affect the behaviour of another. These include hormones. In animals, electrical signals, carried by neurones, are another method of communication. Even plants use electrical signals for communication in some circumstances – for example, in the closing of the leaf of a Venus fly trap around a fly that it has captured.

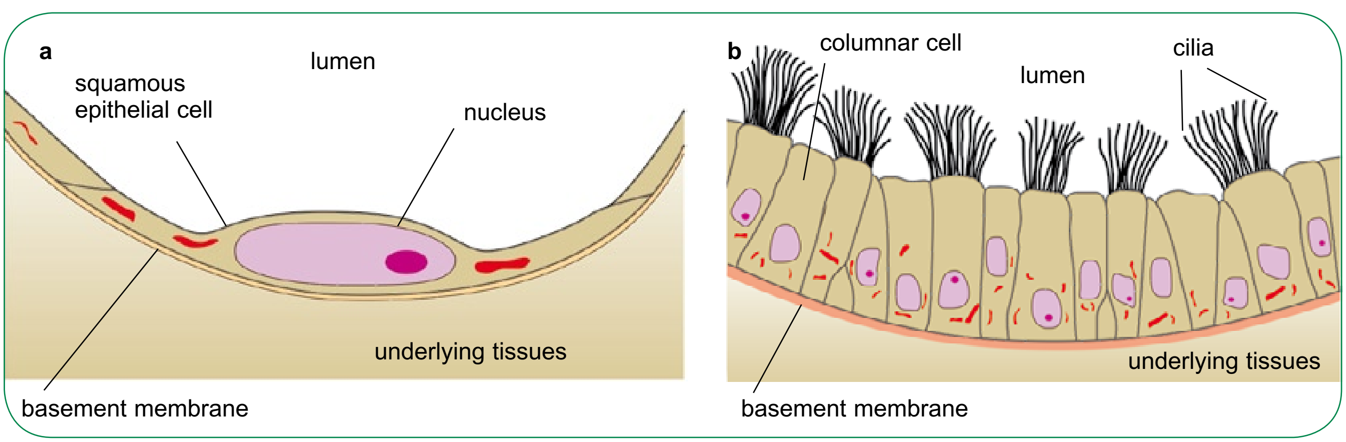


Figure 3.18 Some examples of epithelial tissues, as seen with a light microscope: **a** diagram of a section through squamous epithelium; **b** diagram of a section through ciliated columnar epithelium.

Another type of cell division

All of the specialised cells that are produced as an organism grows are formed by mitosis. As we have seen, this is the type of cell division that is used when the new cells are required to be genetically identical to the parent cell.

However, there is another type of cell division that is needed if an organism has a stage of sexual reproduction in its life cycle. This is called **meiosis**.

In the nucleus of each of your body cells, there are 46 chromosomes. These are actually two *sets* of chromosomes. One set of 23 came from your father, and the other set of 23 came from your mother.

We can see this if images of the chromosomes are 'cut and pasted' to arrange them in order. An arrangement like this is called a **karyotype** (Figure 3.19).

The chromosomes have been arranged and numbered by size, largest first. There are two of each kind, because there are two complete sets. Cells that have two complete sets of chromosomes are called **diploid cells**. The two chromosomes of a kind are said to be **homologous**. This means 'same position', and it refers to the fact that the chromosomes have genes for the same features in the same positions. However, these genes are unlikely to be identical on each chromosome. Most genes have several different varieties, called **alleles**, and some of the alleles on one of a pair of homologous chromosomes are very likely to differ from some of the alleles on the other.

When gametes are formed, a body cell divides by meiosis and produces new cells that have only *one* set of chromosomes. They are **haploid cells**. The new cells get just one chromosome of each homologous pair. They could get either one – the one that originally came from the father, or the one that came from the mother. So there are a very large number of different combinations of chromosomes that could end up in a gamete.

Gametes are therefore **genetically different** from each other. Moreover, any male gamete can fuse with any female gamete at fertilisation, so this offers even more possibilities for different mixtures of genes (Figure 3.20).

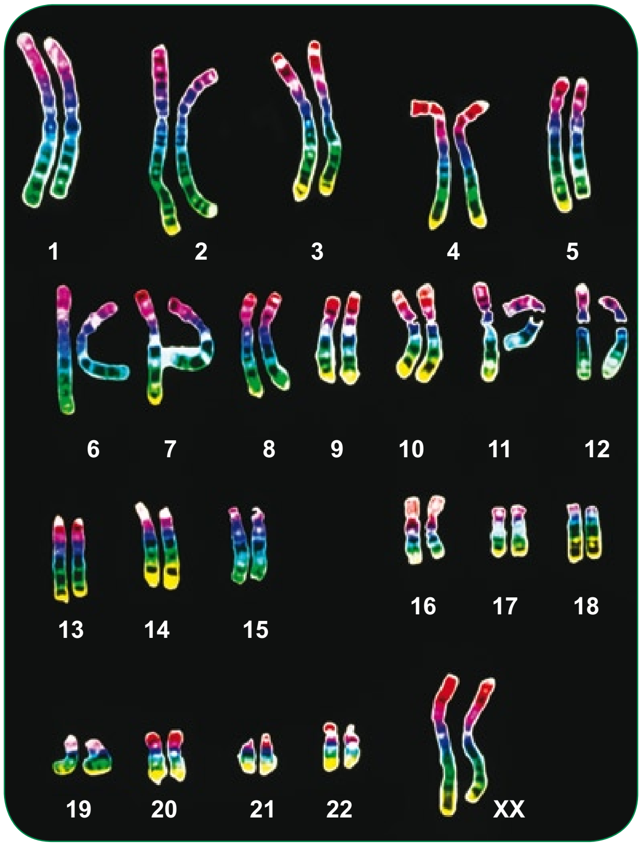


Figure 3.19 A karyotype (×2800).

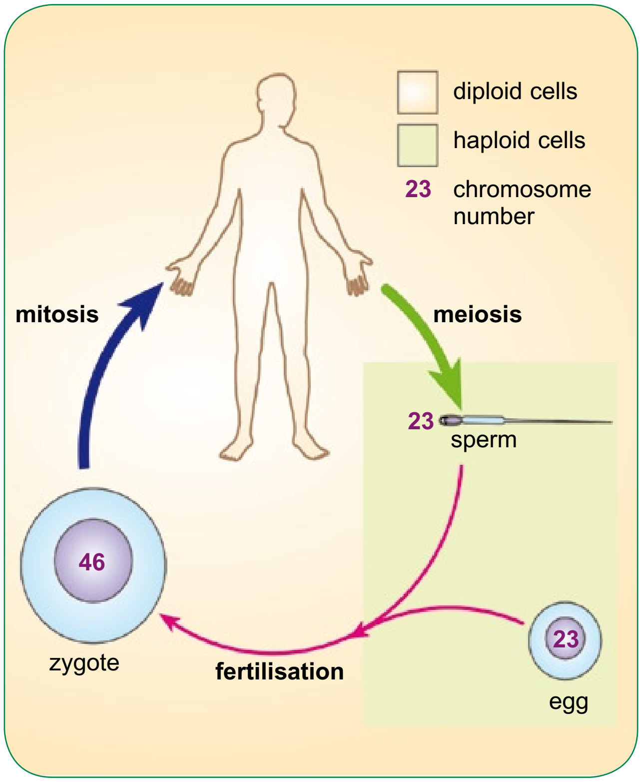


Figure 3.20 The human life cycle. Mitosis produces diploid body cells, and meiosis produces haploid gametes.

Summary

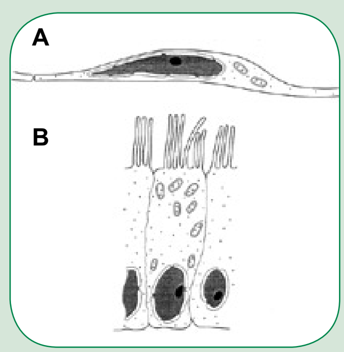
Glossary

- The cell cycle consists of interphase, mitosis and cytokinesis. Mitosis occupies only about 5% of the time, while the rest is used for the duplication and checking of DNA.
- In interphase, DNA replicates, so that each chromosome is made up of two identical chromatids joined at the centromere.
- During mitosis, the nuclear membrane breaks down, spindle fibres form, attach themselves to the condensed chromosomes and manoeuvre them to the equator of the cell. The centromeres then break, and the spindle fibres pull the separated chromatids to opposite ends of the cell. New nuclear membranes form around each group of chromatids. The phases of mitosis are prophase, metaphase, anaphase and telophase.
- During cytokinesis, the cytoplasm splits and two new cells are formed.
- Mitosis produces two daughter cells that are genetically identical to each other and to the parent cell. Mitosis is used for growth, repair and asexual reproduction.
- Multicellular organisms usually contain many types of cells, which have become differentiated to perform different functions. They are often grouped into tissues, containing cells that have the same function – for example, squamous and ciliated epithelium in animals, xylem and phloem in plants. Tissues are grouped into organs, and organs into organ systems.
- When an animal cell has become differentiated, it is normally unable to become any other type of cell. Some cells, however, called stem cells, retain the ability to divide and differentiate. Stem cells in a young embryo are able to differentiate into any kind of cell; in an adult, stem cells appear to have a limited range of specialised cells that they can form. For example, stem cells in bone marrow produce erythrocytes and leucocytes. In plants, cambium cells produce xylem vessels and phloem sieve tubes. These cells are highly adapted for their functions.
- Cells may divide by meiosis, which produces genetically different cells with half the number of chromosomes of the parent cell. Body cells are diploid, meaning that they have two complete sets of chromosomes. Matching, or homologous, chromosomes pair up in meiosis and are then shared out into the daughter cells. These are haploid, meaning that they have only one set of chromosomes.

Questions

1 **a** Explain what is meant by the term *tissue*. [2]

The diagram shows cells from two types of epithelial tissue, A and B, as seen under the electron microscope. The cells are not drawn to the same scale.



b **i** Name the types of epithelial tissue A and B. [2]

ii Explain why the cells of tissue B contain many more mitochondria than those in tissue A. [2]

c State two ways in which the cells of tissues A and B differ from prokaryotic cells. [2]

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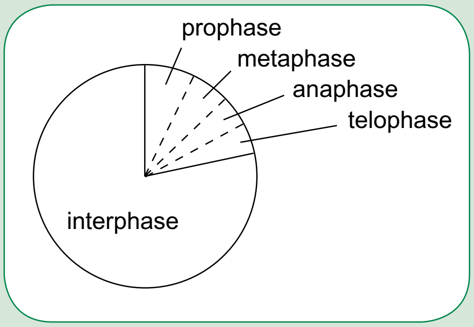
[Total 8]

Answer

continued

2 a Describe the role of mitosis. [3]

The diagram shows the stages of the mitotic cell cycle.



b i Which processes must occur in a cell during interphase before mitosis can take place? [3]

ii In which direction, clockwise or anticlockwise, does the sequence shown in the diagram occur during the mitotic cell cycle? [1]

c Name the stage of mitosis shown in the diagram in which each of the following events occurs.

i Chromosomes split at centromeres. [1]

ii Chromosomes become visible. [1]

iii Nuclear envelope re-forms. [1]

iv Chromatids move to opposite poles of the cell. [1]

v Chromosomes line up along the equator of the spindle. [1]

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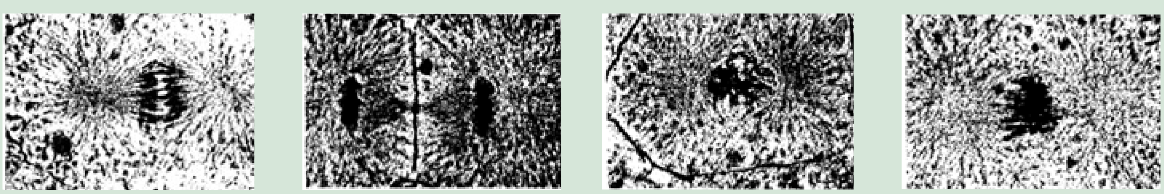
Answer

3 During the development of the embryo, cells divide by mitosis, grow and differentiate. The cells gradually become organised into tissues and organs.

a i State what is meant by the term *cell differentiation*. [2]

ii Describe the relationship between tissues and organs. [2]



A B C D

b The photographs show an animal cell at different stages of mitosis.

i Arrange the stages shown in the photographs in the correct order by writing their letters in sequence. [1]

ii Compare the genetic makeup of the daughter cells produced by mitosis with that of the original parent cell. [2]

OCR Human Biology AS (2857) January 2005 [Total 7]

Answer