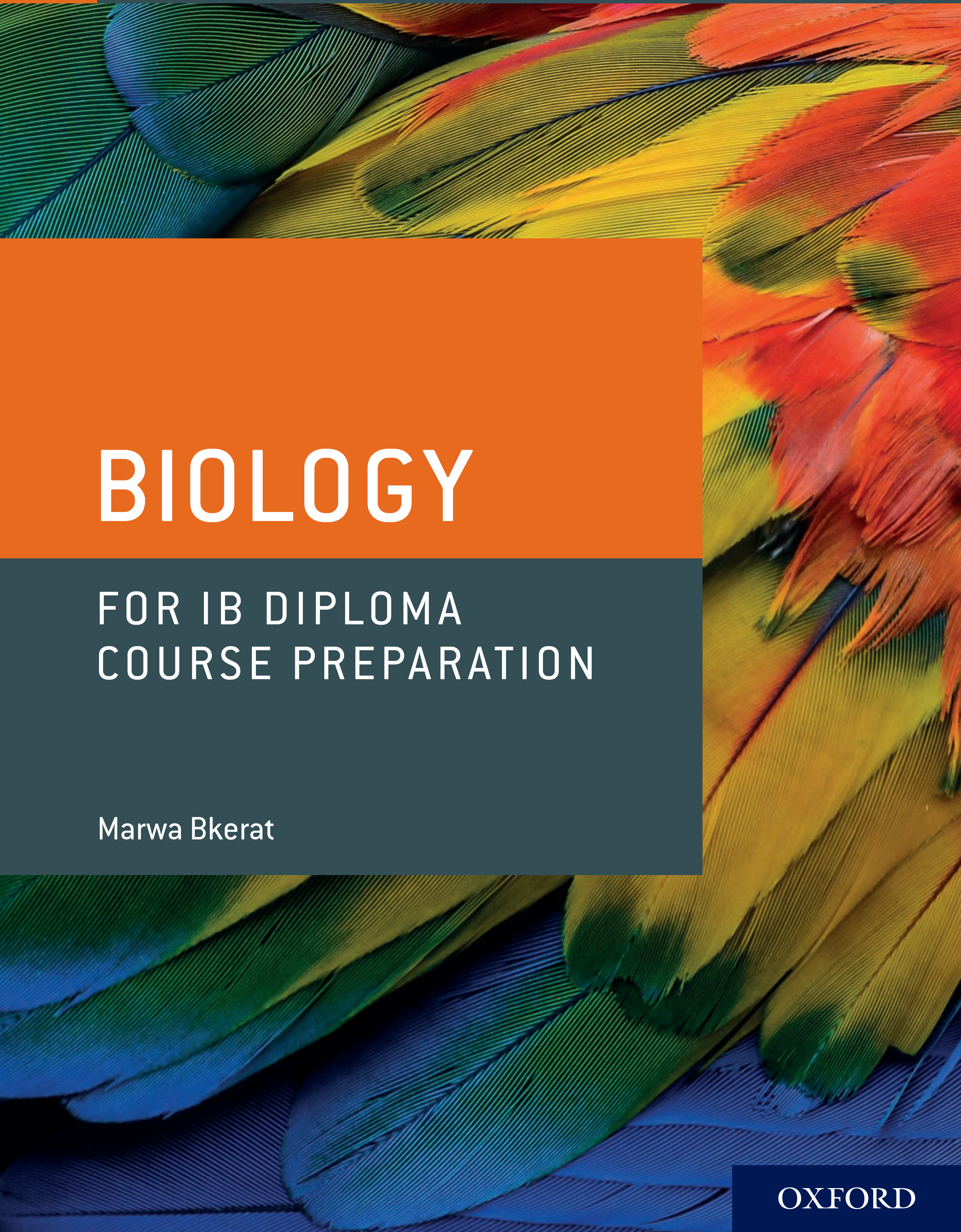
OXFORD IB COURSE PREPARATION



BIOLOGY

FOR IB DIPLOMA COURSE PREPARATION

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OXFORD

Contents

Answers to questions in this book can be found at **www.oxfordsecondary.com/9780198423508**

1 Cells

> A cell has a history; its structure is inherited, it grows, divides, and, as in the embryo of higher animals, the products of division differentiate on complex lines. Living cells, moreover, transmit all that is involved in their complex heredity.

Sir Frederick Gowland Hopkins, 'Some Aspects of Biochemistry', *The Irish Journal of Medical Science* (1932), **79**, 346

Chapter context

All living **organisms** are made of **cells**. Since the 17th century, tissues from different living organisms have been examined under **microscopes** and have shown that cells are the smallest unit of life. Some organisms are made of one cell, while others are made of many. Evolution has resulted in a great diversity between cells from the very simple **prokaryotic** cells to the most complex **eukaryotic** cells. Regardless of the differences between cells, there are many common features among them. All cells contain **genetic material, cytoplasm** and a **plasma membrane** that controls the composition of the cell. New cells come from pre-existing cells by **cell division.**

Learning objectives

In this chapter you will learn about:

- the cell theory
- the **basic structure** of cells
- **transport** in cells
- **cell division** in prokaryotes and eukaryotes.

Key terms introduced

- Cells
- Differentiation
- Organelles
- Prokaryotic cells and prokaryotes
- Eukaryotic cells and eukaryotes
- Magnification and resolution
- Stem cells
- Hydrophilic (polar) and hydrophobic (non-polar) substances
- Integral and peripheral proteins
- Aqueous, concentrated and dilute solutions
- Hypotonic, hypertonic and isotonic solutions
- Endosymbiotic theory
- Interphase and DNA replication
- Mitosis
- Cytokinesis
- Mutations and metastasis

1.1 Cell structure and function

Since the 17th century, microscopes have been used to examine tissues from different living organisms. This resulted in the development of the cell theory, which states that:

1. All living organisms are composed of *cells*.
2. Cells are the smallest unit of life.
3. Cells come from pre-existing cells and cannot be created from non-living material. Division of cells results in the formation of new cells.

Regardless of the differences between cells, all cells share some common features. All cells are surrounded by a *plasma membrane*, which separates the contents of the cell from its surroundings. All cells contain genetic material, which holds the information needed for the cell to carry out its activities. All cells contain *cytoplasm* where chemical reactions take place.

DP link

The structure and function of cells will be explained further in **1.1 Introduction to cells** in the IB Biology Diploma Programme.

Key term

Cells are the building blocks of life.

DP ready | Nature of science

Trends and discrepancies

Most organisms conform to cell theory, some do not. The cell theory was based on the work of several scientists over many years where various trends among the cells of living organisms were discovered. Some discrepancies have been discovered but they were not enough to discard the cell theory. Many organisms consist of cells that are considered atypical. Examples of atypical cells include the striated muscle fibres which are larger than most animal cells and have many nuclei. Another example is giant algae (such as acetabularia) which are single-celled organisms with a much larger size than a normal cell.

Unicellular versus multicellular

Unicellular organisms, which are also known as single-celled organisms, are made up of a single cell. Examples of unicellular organisms include bacteria, amoeba, chlorella, paramecium and euglena. In unicellular organisms, the single cell is responsible for carrying out all the functions of life that are necessary for its survival. Table 1 indicates the seven functions of life that are necessary for the survival of any organism.

Table 1. The seven functions of life necessary for the survival of any organism

Function of life	Description
Metabolism	The chemical reactions that take place inside the cell
Response	The ability to react towards a stimulus
Homeostasis	Keeping the internal environment of the cell within limits
Growth	The increase in size
Reproduction	The production of offspring (sexual or asexual)
Excretion	The removal of waste products from the cell
Nutrition	Getting the material needed for growing and producing energy

Key term

The **plasma membrane (cell membrane)** surrounds the cell and separates the contents of the cell from its surroundings.

Cytoplasm is found within all cells, it is where the cellular chemical reactions take place.

Multicellular organisms, which are also known as multi-celled organisms, are made up of more than a single cell. Examples of multicellular organisms include plants and animals. The cells of multicellular organisms differentiate to make different tissues that perform specialized functions. For example, red blood cells are specialized to carry oxygen, whereas nerve cells are specialized to pass a nerve impulse.

Differentiation is the process by which a cell becomes more specialized. During the process of differentiation, some genes in the cell are “switched on”. This means the gene starts to be used in the function of the cell, and we refer to the gene as being *expressed*. Other genes are switched off (or *unexpressed*). This results in cells that are more specialized and perform different functions. Differentiated cells form tissues, tissues form organs, organs form organ systems and organ systems form the multicellular organism.

Prokaryotes versus eukaryotes

Living organisms can be divided into two main groups based on the presence or absence of a nucleus and membrane-bound *organelles*: *prokaryotes* and *eukaryotes*.

Prokaryotic cells have a simple structure as they lack a nucleus and membrane-bound organelles. The genetic material (**DNA**) is not enclosed inside a **nucleus** but rather found in a region called the **nucleoid**. Prokaryotes include bacteria and archaea (ancient bacteria). *Escherichia coli* (*E. coli*) is an example of a bacterium. The structures found in most prokaryotic cells are described in figure 1 and table 2.

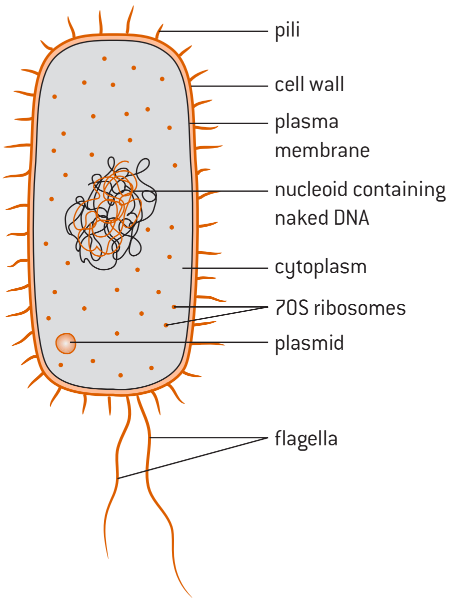

Figure 1. Prokaryotic cell structure (*E. coli*)

Table 2. The function of the main structures of prokaryotic cells

Structure	Description	Function
Cell wall	Made of peptidoglycan (a polysaccharide)	Maintains the shape of the cell and prevents the cell from bursting
Plasma membrane	A selectively permeable membrane	Controls the substances moving into and out of the cell
Cytoplasm	A gel-like substance enclosed within the cell	Contains enzymes to catalyse chemical reactions taking place inside the cell
Pili	Hair-like structures found on the surface	Help bacteria to adhere to each other for the transfer of DNA from one cell to another by a process called conjugation
Flagella (singular flagellum)	A whip-like structure	Helps bacteria move around
Ribosomes	70S type	Protein synthesis
Nucleoid	A region containing the naked DNA	Contains the DNA which holds the genetic information that controls the cell
Plasmid	A small ring of DNA	Helps bacteria adapt to unusual situations such as antibiotic resistance

Eukaryotic cells are more complex than prokaryotic cells as they contain a nucleus and membrane-bound organelles. The genetic material (DNA) is enclosed in a nucleus. Eukaryotes include plants, animals, fungi and protists.

Key term

Differentiation is the process by which a cell becomes more specialized. When a gene is switched on during this process, we say the gene is being expressed. When a gene is switched off, it is unexpressed.

DP link

The prokaryotic and eukaryotic cells will be explained further in **1.2 Ultrastructure of cells** in the IB Biology Diploma Programme.

Key term

Organelles are structures found inside cells that perform a specific function.

Key term

Prokaryotic cells are simple cells that lack a cell nucleus and membrane-bound organelles.

Prokaryotes, such as bacteria and archea, are single-celled organisms that do not contain a nucleus or any membrane-bound cell organelles.

Internal link

DNA will be explained in more detail in section **2.5 Nucleic acids** of this book.

Key term

Eukaryotic cells are complex cells that contain a cell nucleus and membrane-bound organelles.

Eukaryotes are single-celled or multicellular organisms whose cells contain a cell nucleus and membrane-bound cell organelles.

Key term

When discussing ribosomes, the S in **70S** or **80S** stands for the Svedberg unit, which is named after the Swedish chemist Theodor Svedberg. The value of S refers to how fast the molecule will sediment if centrifuged. The speed of the molecule to sediment is related to its density, mass and shape. The higher the value of S, the more dense and massive it is and the faster it will sediment when centrifuged.

Key term

ATP (adenosine triphosphate) is a high-energy molecule that is composed of adenosine and three phosphate groups. Its main function is to supply energy for the chemical reactions that take place in cells.

Internal link

Aerobic respiration and using glucose to make ATP will be discussed in **3.3 Breathing and respiration**.

Eukaryotes may be unicellular or multicellular. An amoeba is an example of a unicellular eukaryote. Animals and plants are examples of multicellular eukaryotes.

The structures found in most eukaryotic cells in animals and plants are described in figure 2 and table 3, and figure 3 and table 4, respectively.

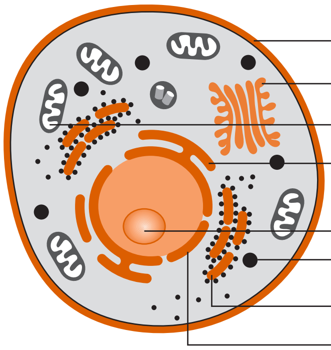

Figure 2. Eukaryotic cell structure (animal cell)

Table 3. The function of the main structures of eukaryotic cells (animal cells)

Structure	Description	Function
Ribosomes	Found either as 70S or 80S. Could be found free in the cytoplasm or attached to the rough endoplasmic reticulum	Protein synthesis
Smooth endoplasmic reticulum	No ribosomes on the surface	Lipid synthesis and transport
Rough endoplasmic reticulum	A network of tubules that extend from the nucleus to the rest of the cell	Protein synthesis and transport
Lysosome	Contains many enzymes	Digests waste structures within the cell such as dead organelles and foreign particles
Golgi apparatus	Consists of many flattened sacs stacked on top of each other. Has two sides, the cis side, which receives products from endoplasmic reticulum. The trans side, which is the side through which vesicles are released	Processing of proteins received from the rough endoplasmic reticulum. This includes packaging and modifying proteins to be used either inside the cell or excreted outside the cell
Mitochondrion	Contains its own ribosomes and DNA. It is made of two membranes: an outer membrane and an inner membrane that is folded inward to increase surface area	Production of ATP in aerobic respiration
Nucleus	It is surrounded by a porous double membrane	Contains the genetic material (DNA) which hold the genetic information that controls the cell
Nucleolus	Found inside the nucleus	Ribosomes synthesis

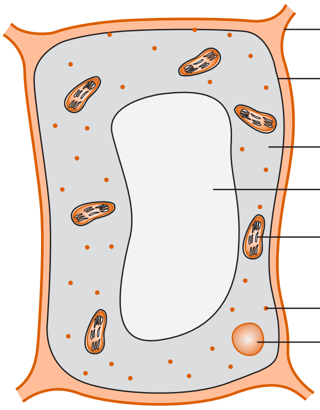

Figure 3. Eukaryotic cell structure (plant cell)

Table 4. Structures that are only found in plant cells

Structure	Description	Function
Cell wall	Made of cellulose (a polysaccharide)	Strengthens and supports the cell, maintains the shape of the cell and prevents the cell from bursting
Chloroplasts	Surrounded by two membranes. It contains its own ribosomes and DNA	Photosynthesis
Vacuoles	Storage organelles that come from the Golgi apparatus	Store water and food (cell sap)

DP ready **Nature of science**

Improved tools allow for new scientific discoveries

The electron microscope has a much greater magnification and higher resolution than the light microscope. It enables scientists to see the details of the organelles inside the cell.

Key term

Magnification is the size of image enlarged.

Resolution is the clarity of the view or image.

Table 5. Differences between prokaryotic cells and eukaryotic cells

Feature	Prokaryotic cells	Eukaryotic cells
Nucleus	No nucleus	Have nucleus
DNA	Found in the cytoplasm in a region named the nucleoid. Circular DNA Single strand	DNA found in the nucleus enclosed in a nuclear envelope. Linear DNA Double helix
Mitochondria	No mitochondria	Have mitochondria
Ribosomes	70S (smaller)	80S (larger)
Membrane-bound organelles	No membrane-bound organelles	Membrane-bound organelles such as Golgi apparatus and the endoplasmic reticulum
Plasmid	May have plasmid	No plasmid
Size	Small < 10 µm	Large > 10 µm
Complexity	Simple	Complex

Key term

Compare and contrast means to state the similarities and differences.

Compare means to state the similarities.

Distinguish means to state the differences.

Command terms and their meanings are available in the appendix.

Table 6. Differences between animal cells and plant cells

Feature	Animal cell	Plant cell
Cell wall	No cell wall	Have a cell wall (made of cellulose)
Chloroplasts	No chloroplasts	Have chloroplasts
Vacuoles	Do not usually contain any vacuoles and if present they are small or temporary	Have a large central vacuole
Shape	Rounded	Angular

Question

1 Distinguish between the genetic material present in prokaryotes and eukaryotes.

2 Compare and contrast the structure of animal cells with plant cells.

Maths skills: Standard form

You can use "standard form" to write very big or very small numbers in a more condensed form. When writing in "standard form" we use exponents of base 10.

Here are two examples:

1. The number 2 500 000 can be written as 2.5×10^6.
2. The number 0.0000543 can be written as 5.43×10^{-5}.

Follow these steps to express a number in standard form:

- Write down the first few significant figures (numbers including and following the first digit that is not zero) that appear in the number as a number between 1 and 10 (the first example above would give 2.5, and the second example 5.43).
- Write $\times$ 10 after this number.
- Count the number of places the decimal point would have to move from its original position to be between the first two significant figures of the number. This number becomes the exponent that you apply to 10.
- If the decimal point is moved to the left, then the exponent is positive.
- If the decimal point is moved to the right, then the exponent is negative.

So, for the examples above:

1. 2 500 000: In this case, the decimal point is at the end of the number (2 500 000.0). The decimal point would have to move six places to the left to be between digits 2 and 5, so it is therefore written as 2.5×10^6.
2. 0.0000543: The decimal point moves five places to the right, so it is therefore written as 5.43×10^{-5}.

Maths skills: Significant figures

The significant figures of a number are the digits of a number starting from the first non-zero digit. Significant figures are a good indication of the accuracy of a measurement. For example, if the number is 3.0 it indicates that the measurement was made accurate to the tenth (0.1) and if the number is 3.00 it indicates that the measurement was made accurate to the hundredth (0.01). Therefore, those numbers after the decimal point are considered significant.

For example:

- 2.3—has two significant figures
- 234—has three significant figures
- 5.0—has two significant figures
- 0.023—has two significant figures
- 1000—has one significant figure (it is unlikely the zeros are significant; they may have resulted from rounding off)
- 1000.0—has five significant figures (the number after the decimal point indicates that the measurement is accurate to the tenth).

When you get a number with many digits in a calculation, you often have to round it up or down to give the correct number of significant figures. The rules for rounding are:

- Round up if the number after your final significant figure is 5 or higher.
- Round down if the number after your final significant figure is 4 or lower.

In calculations, we give the answer to the same number of significant figures as the number used in the calculation with the least significant figures.

For example:

$34.322 \times 2.2 = 75.5084$

Since 2.2 has two significant figures, then the answer should be given as 76 (correct to two significant figures). The number following the second significant figure is 5, so we round up to 76.

Question

3 Write 75 330 000 in standard form.

4 Write 0.000074 in standard form.

5 How many significant figures does 0.045 have?

6 What is 4.564 to two significant figures?

Practical skills: Using a light microscope to observe onion cells

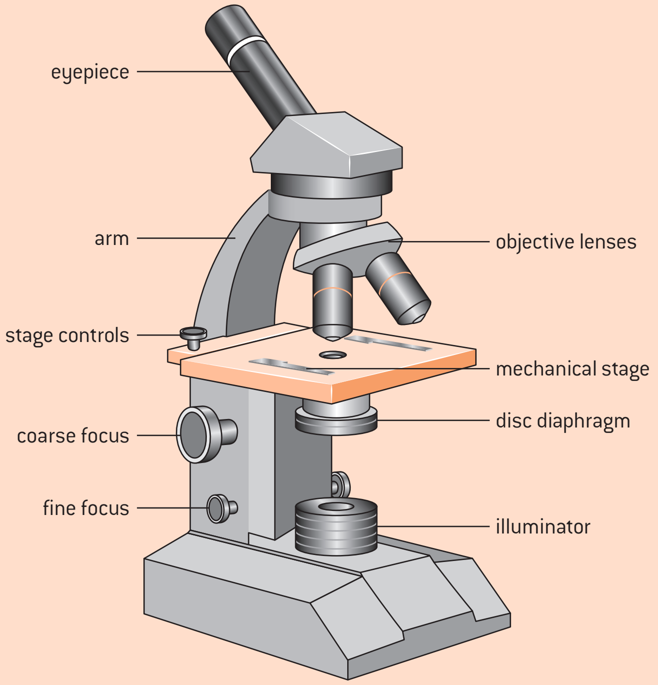

Figure 4. Compound light microscope

Onion cells are often chosen as an example of plant cells since they can be easily seen using a light microscope.

To prepare the slide to be observed, you need to cut the onion open and use forceps to peel a thin layer from the inside. Spread the thin layer on a microscope slide. Add a drop of iodine solution to stain the layer to make it easier to view its parts. Carefully place a cover slip over the layer and ensure no bubbles are trapped inside.

To view the slide, ensure that you move from one objective lens to another very carefully while adjusting the fine or coarse focus.

Maths skills: Calculating magnification and the actual size of cells

$$\text{Magnification} = \frac{\textit{image size}}{\textit{actual size}}$$

Image size is the measured size and can be found by measuring the micrograph size using a ruler.

Actual size is the real size of the cell which is either given or to be calculated.

Magnification will be given or must be calculated.

When solving questions, ensure that the same units are used for both the image and actual size.

Convert units when needed:

cm	x 10 → / ← ÷ 10	mm	x 1000 → / ← ÷ 1000	μm	x 1000 → / ← ÷ 1000	nm

Worked example: Calculations involving magnification

1. Calculate the actual size of the dividing bacteria cell shown in figure 5.

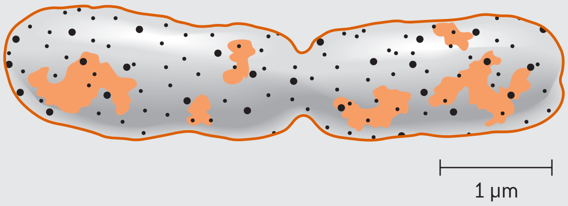

Figure 5. A prokaryote undergoing binary fission

Solution

The first step is always to find the magnification. Since the magnification is not given, it must be calculated using the scale bar given.

$$\text{Magnification} = \frac{\textbf{\textit{image size}}\ \textit{(of the scale bar – measured)}}{\textbf{\textit{actual size}}\ \textit{(of the scale bar – indicated on the diagram)}}$$

$$\text{Magnification} = \frac{\mathbf{1.5\,cm}}{\mathbf{1\,\mu m}}$$

Make sure the units are the same: 1.5 cm = 15 mm = 15 000 μm

$$\text{Magnification} = \frac{\mathbf{15\,000\,\mu m}}{\mathbf{1\,\mu m}}$$

Magnification = 15 000 ×

After finding the magnification, the actual size of the bacterium can be calculated by rearranging the formula used above, but this time using size of the amoeba.

$$\text{Actual size of the dividing bacterium} = \frac{\textbf{\textit{image size}}}{\textbf{\textit{Magnification}}}$$

$$\text{Actual size of the dividing bacterium} = \frac{\mathbf{7.5\,cm}}{\mathbf{\times 15\,000}}$$

Actual size of the dividing bacterium = 0.0005 cm
= 0.005 mm = 5 μm

Question

7 The length of a chloroplast is 50 μm and a drawing of it is 10 cm in length. Determine the magnification of the drawing.

8 Find the maximum length of the cheek cell in figure 6.

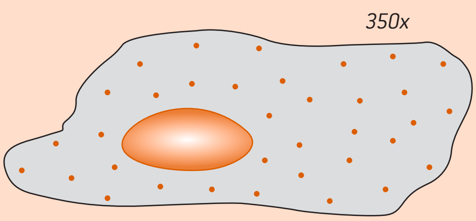

Figure 6. Cheek cell

9 The magnification of an image is 2000 × . The length of the drawn image is 30 mm. Calculate the actual length of the image.

DP link

Examples of diseases treated using stem cells will be discussed in detail in **1.1 Introduction to cells** in the IB Biology Diploma Programme.

Key term

Stem cells are undifferentiated cells that can divide and differentiate into different types of cells.

Plant stem cells are found in the **meristems** at the tips of roots and shoots.

Hematopoietic cells are stem cells which produce blood cells.

Stem cells

Stem cells are undifferentiated cells that can divide and differentiate into many different types of cell. Stem cells can be found in both plants and animals.

In plants, stem cells are found in *meristems* (the tips of roots and shoots).

In animals, stem cells can be found in different places including embryos, some adult cells such as *hematopoietic* cells (in bone marrow) and cord blood cells. Stem cells can be used for the treatment of many diseases such as leukemia, lymphoma and diabetes.

DP ready **Nature of science**

Ethics and research

As research involving stem cells increases in importance, so does the need to understand and resolve the ethical issues such research raises. Many objections were raised against stem cell research, mainly embryonic stem cell research. Table 7 indicates the ethical considerations about the use of the three types of stem cells.

Table 7. The ethical considerations about the use of the three types of stem cells

Stem cells	Arguments for	Arguments against
Embryonic stem cells	• Easy to obtain • Pluripotent; can differentiate to many types of cells	• Involves the destruction of an embryo • May result in tumour development
Adult stem cells	• Does not involve the destruction of an embryo • Low chance of tumour development	• Limited differentiation • Sometimes not easily obtained
Cord blood stem cells	• Easy to obtain • Does not involve the destruction of an embryo • Can differentiate to many types of cells • Low chance of tumour development	• Must be obtained immediately after birth

Question

10 Discuss the ethical issues considered with the use of embryonic stem cells.

DP link

The membrane structure and transport will be studied in detail in **1.3 Membrane structure** and topic **1.4 Membrane transport** in the IB Biology Diploma Programme.

1.2 The cell membrane

The cell membrane is a complex structure that carries out a range of functions, such as acting as a barrier to keep cell contents inside the cell, and facilitating the transport of specific molecules into or out of the cell.

The phospholipid bilayer

The cell membrane is made up of a bilayer of phospholipid molecules (figure 7). Each phospholipid molecule is made of a head and a tail. The head is *hydrophilic* (attracted to water) and faces the outside of the cell whereas the tail is *hydrophobic* (repelled by water) and faces the inside of the membrane. This results in the phospholipid bilayer acting as a hydrophobic barrier; this means that *non-polar* (hydrophobic) substances can pass easily while *polar* (hydrophilic) substances cannot. Therefore, the phospholipid bilayer is a partially selective membrane. The structure of the phospholipid bilayer allows the cell membrane to change shape easily, which is required in endocytosis and exocytosis.

There are different types of membrane proteins that differ in structure, position and function. Some membrane proteins penetrate the phospholipid bilayer and are known as *integral proteins*. The integral proteins mostly act as pumps in active transport, or channels in facilitated diffusion, and therefore control the entry or exit of specific substances across the membrane. In contrast, there are membrane proteins that remain on the surface and are known as *peripheral proteins*. These proteins usually play a role in cell recognition which is involved in immune response.

Animal cell membranes contain cholesterol, which is a lipid component that is found in the hydrophobic region of the bilayer. Cholesterol has a role in decreasing the fluidity of the cell membrane and lowering its permeability to some molecules.

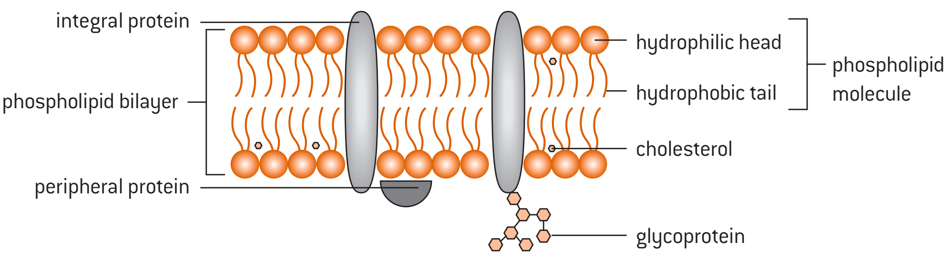

Figure 7. The phospholipid bilayer

Key term

Hydrophilic substances are attracted to water and tend to be **polar**.

Hydrophobic substances are repelled by water and tend to be **non-polar**.

Internal link

Endocytosis and exocytosis will be discussed in **1.3 Cell transport**.

Key term

Integral proteins are membrane proteins that penetrate the phospholipid bilayer.

Peripheral protiens are membrane proteins that remain on the surface of the phopholipid bilayer.

DP ready | Nature of science

Scientists use models to represent concepts or ideas. There were various models that were developed to represent cell membrane structure. The phospholipid bilayer model shown in figure 7 was developed by Singer and Nicolson in 1972; this model is known as the fluid mosaic model or Singer–Nicolson model.

The Singer–Nicolson model was not the first model to describe the cell membrane structure. In 1935, Hugh Davson and James Danielli proposed a model for the cell membrane that was known as the lipo-protein sandwich model (figure 8). The model shows a phospholipid bilayer adjacent to layers of proteins on both sides of the membrane. When the cell membrane was viewed under the electron microscope, the electron micrograph showed two dark lines and a lighter band in between. Davson and Danielli proposed that the two dark lines are the protein layers on both sides of the membrane, and the light band is the phospholipid bilayer in the middle. The Davson–Danielli model was falsified after many experiments resulted in findings that did not fit with the model. For example, it was found that the membrane proteins are not fixed in a layer outside the phospholipid bilayer but rather are moving freely within the membrane.

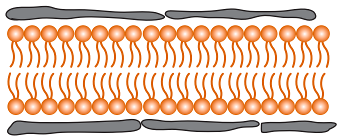

Figure 8. The Davson–Danielli lipoprotein sandwich model

The limitations noted with the Davson–Danielli model led to the proposal of the Singer–Nicolson model, or the fluid mosaic model. "Mosaic" refers to the different components that make up the membrane including proteins, carbohydrates and lipids. This model is currently considered the best model to describe the structure of the cell membrane.

DP ready **Theory of knowledge**

Our understanding of the structure of the plasma membrane has changed over the years as new discoveries cause scientists to revise and update their theories. Why is it important to learn about theories that were later discredited?

Key term

A **solution** is made up of a solute dissolved homogenously in a solvent.

An **aqueous solution** is a solution where the solvent is water.

A **concentrated solution** is a solution that has high amount of solute dissolved in the solvent.

A **dilute solution** is a solution that has a small amount of solute dissolved in the solvent.

1.3 Cell transport

Cell transport is the movement of particles across the cell membrane (the phospholipid bilayer). The phospholipid bilayer is a partially permeable membrane that allows some particles to pass through. Cell transport includes passive and active transport. Passive transport does not require energy and includes *simple diffusion*, *facilitated diffusion* and *osmosis*. Active transport requires energy and includes transport through pumps, *endocytosis* and *exocytosis*.

Particles move across cell membranes continuously. Such particles are usually found dissolved in a *solution*, mainly *aqueous solution*. This solution contains water as the solvent and various particles as solutes. If the amount of solute is high, the solution is described as a *concentrated solution*. If the amount of solute is little, the solution is described as a *dilute solution*.

Simple diffusion

Diffusion is the passive movement of particles from a region of high concentration to a region of low concentration until evenly distributed (figure 9). Diffusion does not require energy and takes place across a concentration gradient.

The concentration gradient is the difference in concentration between the two regions.

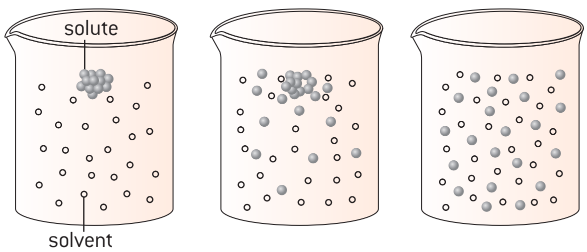

Figure 9. Diffusion

Which particles are transported by simple diffusion?

The movement of particles by diffusion across the cell membrane does not involve a channel and therefore, small hydrophobic (non-polar) molecules can easily pass through the phospholipid bilayer.

Examples of diffusion across the cell membrane (figure 10):

- the movement of O_2 from the blood capillaries to the body cells to carry out cellular respiration
- the movement of CO_2 (which is a by-product of cellular respiration) from the body cells to the blood capillaries to be transported and removed out of the body.

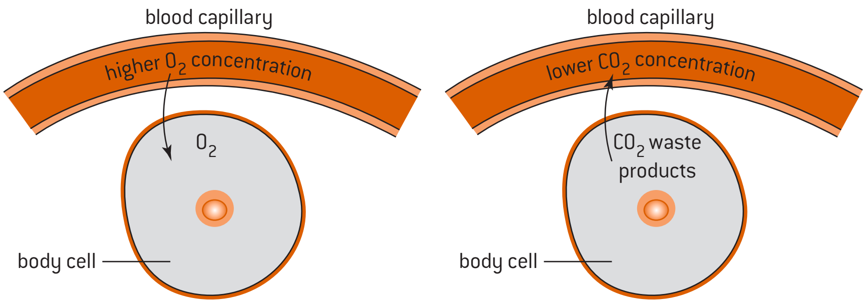

Figure 10. Oxygen and carbon dioxide diffusion

Osmosis

Osmosis is the passive movement of water molecules, across a partially permeable membrane, from a region of lower solute concentration (*hypotonic*) to a region of higher solute concentration (*hypertonic*) (figure 11). Water molecules are small enough to pass through the partially permeable cell membrane. Osmosis can also maintain a balanced or *isotonic solution* where the solute concentration level inside the cell is the same as the solute concentration level outside the cell.

Key term

A **hypotonic solution** is a solution that has lower solute concentration.

A **hypertonic solution** is a solution that has higher solute concentration.

An **isotonic solution** is a solution that has the same solute concentration.

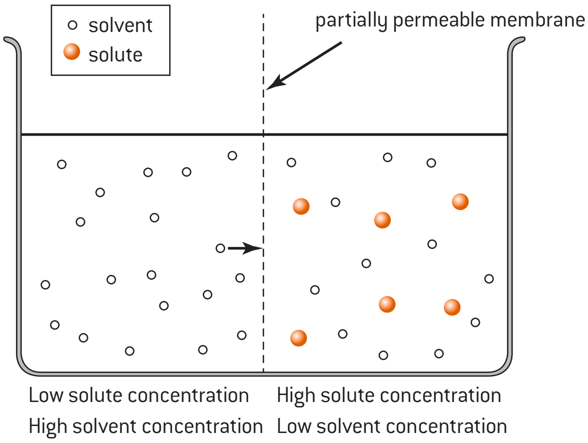

Figure 11. Osmosis

Osmosis in plant cells

The cell membrane of the plant cell acts as a partially permeable membrane. The cell sap inside the vacuole is a highly concentrated solution. Plant cells are surrounded by a rigid cell wall.

When a plant cell is placed in a hypotonic (lower solute concentration) solution, water molecules move from the solution into the cell by osmosis. This causes the cell to swell but the cell wall prevents it from bursting. The plant cell becomes **turgid**.

When a plant cell is placed in a hypertonic (higher solute concentration) solution, water molecules move out of the cell by osmosis. This causes the cell to shrink and pull away from the cell wall. The plant cell becomes **flaccid**. When the cytoplasm is pulled away from the cell wall, the cell becomes **plasmolysed** (figure 12).

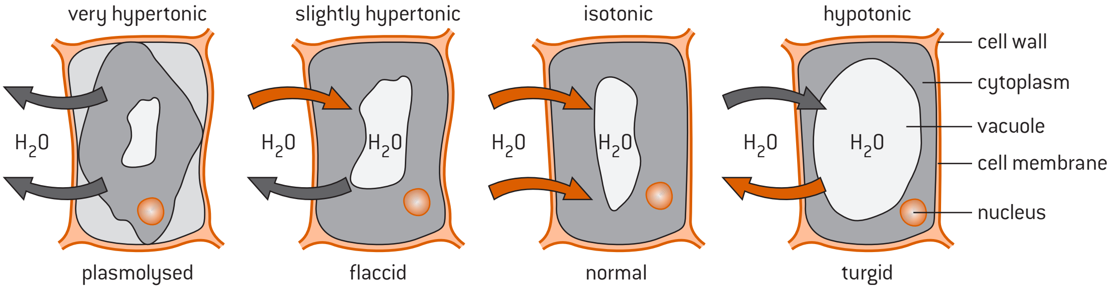

Figure 12. Osmosis in plant cells

When an animal cell is placed in a hypotonic (lower solute concentration) solution, water molecules move from the solution into the cell by osmosis. This causes the cell to swell up and explode as there is no cell wall to prevent the cell from bursting.

When an animal cell is placed in a hypertonic (higher solute concentration) solution, water molecules move out of the cell by osmosis. This causes the cell to shrink and become **shrivelled** (figure 13).

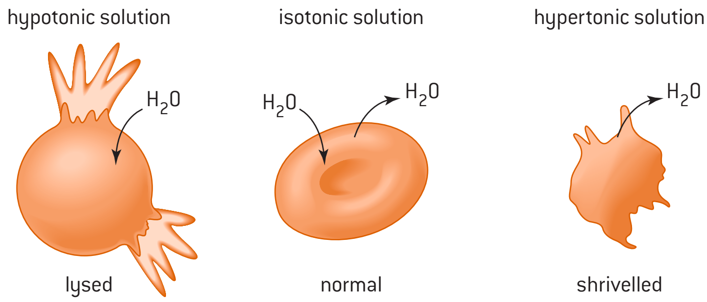

Figure 13. Osmosis in animal cells

Practical skills: Osmosis in potato cells

You can observe the effect of osmosis in potato cells by placing potato strips in different concentrations of saline (salt) solution. The concentrations must range from pure water to highly concentrated saline solution. Ensure that you control some variables such as the volume of the solution, size of potato strips, time soaking the strips in the saline solution and temperature. You need to identify your dependent variable; what are you measuring? You can measure the mass of the potato strips before and after placing them in the saline solution. Collect observations about the texture and colour of the potato strips—these observations are your qualitative data. Record the mass of the potato strips before and after placing them for a period of time in the different saline concentrations—these measurements are your quantitative data.

Question

11 Potato strips were soaked in a highly concentrated saline solution. How do you think this will affect the mass of the potato strips? Explain your answer.

Facilitated diffusion

Facilitated diffusion is the passive movement of particles from a region of high concentration to a region of low concentration via a channel protein (figure 14). Molecules that are large and polar cannot directly pass through the phospholipid bilayer and therefore require a channel protein that is embedded in the membrane to transport them.

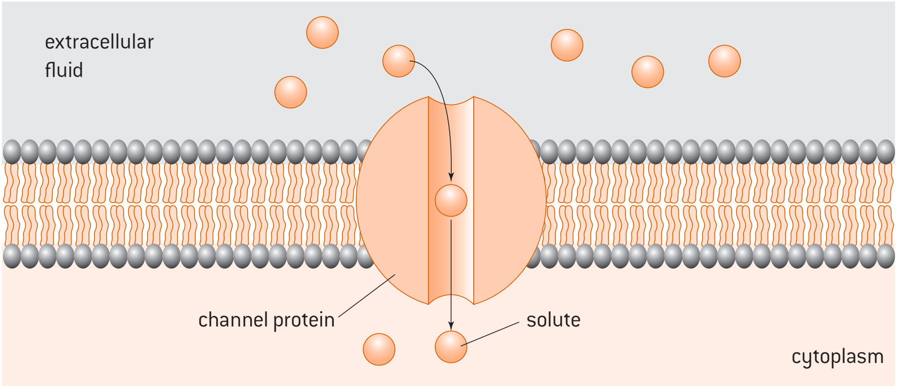

Figure 14. Facilitated diffusion

An example of facilitated diffusion across a cell membrane is the diffusion of potassium ions across the axon of a neuron through potassium channels. Neurons, also known as nerve cells, are the primary components of the nervous system.

Question

12 Compare and contrast between simple diffusion and facilitated diffusion.

Active transport

Active transport is the movement of substances through a membrane from a region of low concentration to a region of high concentration. This process occurs against a concentration gradient and therefore requires energy and protein pumps that are embedded in the cell membrane.

Each protein pump is specific and can only transport specific substances. The pump is provided with energy from ATP. ATP molecules that attach to the pump cause a conformational change in the shape of the pump, and molecules that are large and polar may be transported by active transport.

Internal link

ATP was introduced in **1.1 Cell structure and function**.

An example of active transport is the sodium–potassium pump which is embedded in the cell membrane of the axon in neurons (figure 15).

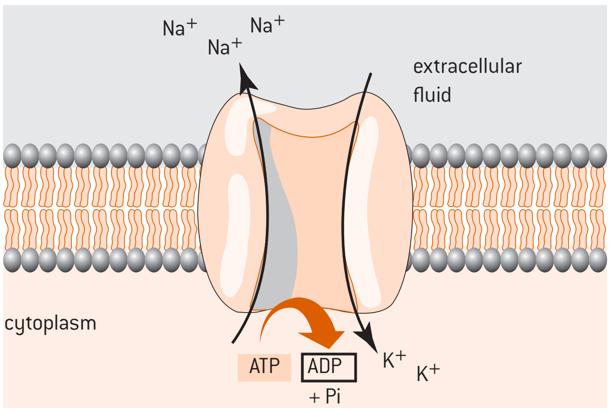

Figure 15. The sodium–potassium pump

The pump transports three sodium ions to the outside of the axon and two potassium ions into the axon.

Endocytosis

Endocytosis is the process by which large molecules enter the cell. This process requires energy.

The process begins when the cell membrane is pulled inwards due its fluidity. A vesicle pinches off into the cell membrane, carrying the material to be taken into the cell. The vesicle enters the cell and releases its contents (figure 16).

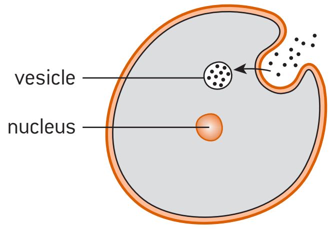

Figure 16. Endocytosis

An example of endocytosis is phagocytosis. This is when foreign organisms such as bacteria are engulfed by macrophages (a type of white blood cell), that have a role in immune response. The bacterium is engulfed by endocytosis, and then it is moved towards the lysosome where it is digested by enzymes.

Exocytosis

Exocytosis is the process by which large molecules are released out of the cell. This process requires energy.

The process begins when the proteins synthesized in the rough endoplasmic reticulum are released in vesicles that are transported to the cis side of the Golgi apparatus for further modification. The vesicles carrying the proteins bud off the Golgi apparatus and are moved towards the cell membrane. The vesicle fuses with the cell membrane due to its fluidity, thus releasing the materials as it carries them out of the cell (figure 17).

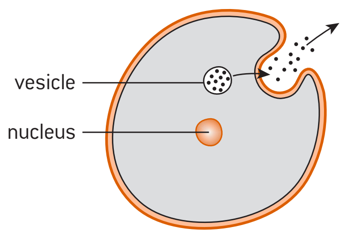

Figure 17. Exocytosis

An example of exocytosis is the secretion of insulin from the pancreatic cells into the blood stream.

Question

13 Explain why liver cells contain high amounts of mitochondria.

1.4 Origin of cells

Prokaryotic cells divide by binary fission to make new cells. Eukaryotic cells divide by mitosis to produce genetically identical body cells, and by meiosis to produce sex cells including sperm and eggs.

DP link

The movement of potassium and sodium ions across the axon of the neuron will be discussed in **6.5 Neurons and synapses** in the IB Biology Diploma Programme.

Internal link

Phagocytosis will be discussed further in **3.4 Body defence**.

DP link

The origin of cells will be explained further in **1.5 The origin of cells** in the IB Biology Diploma Programme.

Evidence from experiments conducted by various scientists in the past have shown that cells come from the division of pre-existing cells. Louis Pasteur (figure 18), the French chemist and microbiologist, designed an experiment to test if microbes could generate spontaneously inside chicken broth. Pasteur was able to disprove the theory of spontaneous generation developed by Aristotle by conducting his famous swan-neck flask experiment.

Internal link

Mitosis will be discussed in **1.5 Cell division**.
Meiosis will be discussed in **5.2 Reproduction and meiosis**.

Figure 18. Louis Pasteur (1822–1895)

In his experiment, Pasteur boiled chicken broth in two set-ups of swan-neck flasks to ensure that all microorganisms were killed. In the first set-up, the neck of the flask was broken off and the broth inside became contaminated (experiment 1, figure 19). In the second set-up, the curved neck of the flask prevented air from contaminating the broth inside, and so the broth inside remained sterile (experiment 2, figure 19). Pasteur concluded that cells come from pre-existing cells and do not spontaneously generate. This was a great discovery with regard to microbes and the origin of cells.

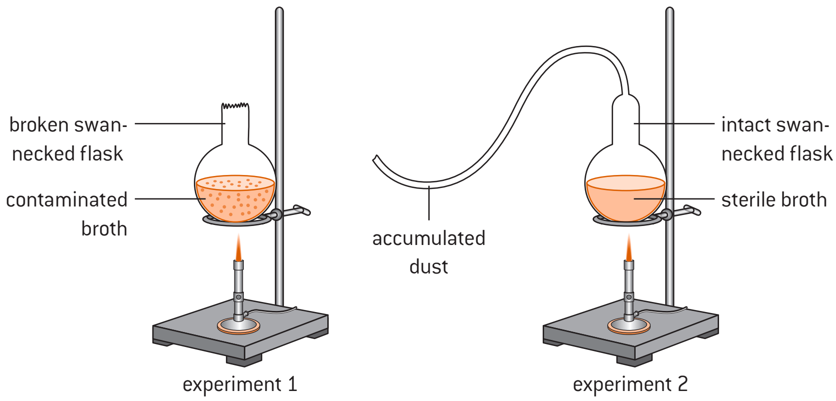

Figure 19. Pasteur's experiments

Pasteur's experiments provided evidence that cells come from pre-existing cells, but how were the first cells formed? Many scientists believe that the first cells may have come from non-living material. In 1950, biochemists Stanley Miller and Harold Urey were able to produce simple organic compounds from inorganic compounds when simulating the conditions of the Earth.

Key term

Endosymbiotic theory is an evolutionary theory that describes the endosymbiotic relationship between organisms and how it resulted in the evolution of eukaryotic cells from prokaryotic cells.

DP link

Cell division will be explained further in **1.6 Cell division** in the IB Biology Diploma Programme.

The origin of eukaryotic cells

Scientists use the *endosymbiotic theory* to describe how eukaryotic cells evolved from prokaryotic cells through a symbiotic relationship between organisms. It is believed that a large host cell engulfed a bacterium through endocytosis which resulted in a symbiotic relationship where both cells benefited from each other for survival. Scientists believe that mitochondria evolved from energy-producing bacteria that were engulfed by larger bacteria to supply the cell with the energy needed, while chloroplasts evolved from photosynthetic bacteria that were engulfed by larger bacteria to supply the cell with food.

Evidence that supports the development of mitochondria and chloroplasts by the process described in the endosymbiotic theory includes:

- Both organelles have their own DNA
- Both organelles have 70S ribosomes similar to prokaryotes
- Both organelles have the same size and shape of bacteria
- Both organelles have a double membrane.

1.5 Cell division

Cells reach a certain size and then divide. As cells grow, the surface area to volume ratio decreases. The surface area of the cell controls the rate of material exchange, while the volume of the cell controls the rate of resource consumption, and waste and heat production. When the cell grows, the volume increases much faster than the surface area (so the ratio decreases). As a result, material cannot be exchanged fast enough to provide enough resources for the cell to consume, and to get rid of the waste and heat produced in the cell. Therefore, the cell stops growing and divides.

The cell cycle

The cell cycle describes the behaviour of cells as they grow and divide. The cell cycle involves three main stages, *interphase*, *mitosis* and *cytokinesis* (figure 20).

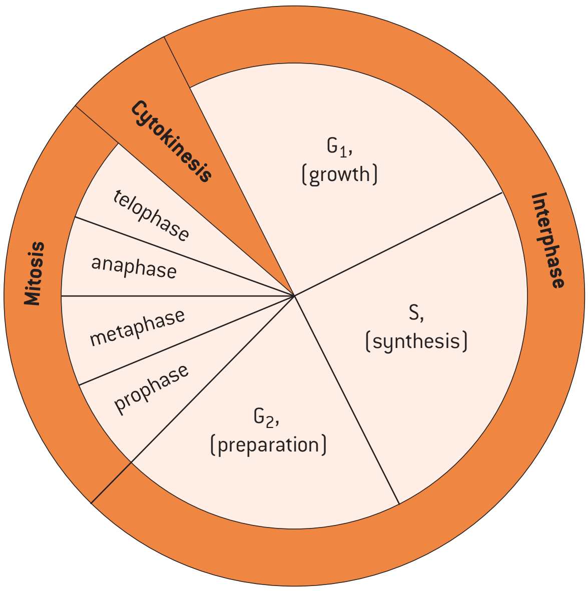

Figure 20. The cell cycle

Stage 1—Interphase

Interphase is the longest phase of the cell cycle. During this phase, the nucleus and cytoplasm pass through many processes such as *DNA replication*, protein synthesis and an increase in the number of organelles. It is divided into three phases: G1, S and G2. The main activities in each phase include:

- G1 phase: The cell grows in size, protein synthesis takes place in the cytoplasm and organelles increase in number.
- S phase: DNA replication takes place in the nucleus.
- G2 phase: The cell grows in size and prepares for mitosis.

Stage 2—Mitosis

Mitosis is the division of the nucleus to form two genetically identical *daughter nuclei*. Mitosis is divided into four main phases: prophase, metaphase, anaphase and telophase (figure 21).

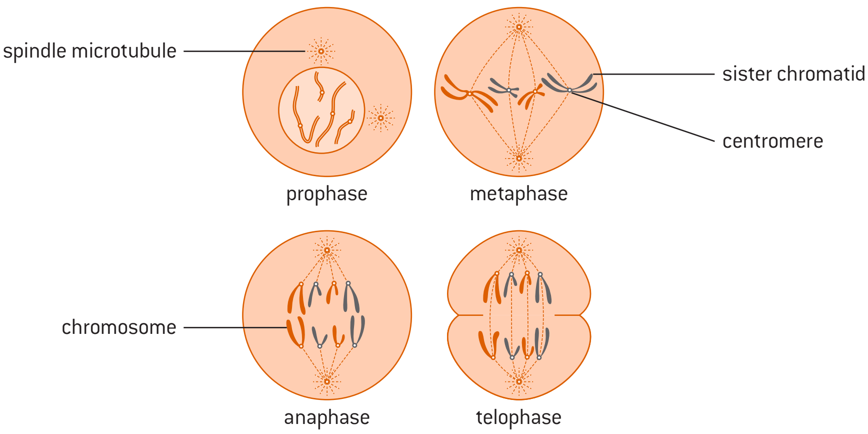

Figure 21. The four phases of mitosis

1 **Prophase**
- The spindle microtubules (a component of the cytoplasm) start growing and extend from each pole to the equator.
- *Sister chromatids* condense, thicken, shorten and become visible.
- The nuclear membrane starts breaking down.

2 **Metaphase**
- The sister chromatids move to the equator and line up separately.
- The spindle microtubules from each pole attach to each *centromere* on opposite sides.
- The spindle microtubules are fully developed.

3 **Anaphase**
- The spindle microtubules contract to pull the sister chromatids apart splitting the centromeres.
- This splits the sister chromatids into chromosomes.
- Each identical chromosome is pulled to opposite poles.

4 **Telophase**
- The spindle microtubules break down.
- The chromosomes decondense and are no longer individually visible.
- The nuclear membrane reforms.

Key term

Interphase is the longest phase of the cell cycle.

DNA replication is the production of two identical copies of DNA.

Internal link

DNA replication will be studied in detail in **2.5 Nucleic acids**.

Key term

Sister chromatids are the identical copies formed by the replication (duplication) of a chromosome. They are joined together by what is known as a **centromere**.

When sister chromatids separate, we refer to them as chromosomes.

> **Key term**
>
> **Mitosis** refers to the division of the nucleus into two genetically identical daughter nuclei.

The cell then divides by cytokinesis to form two daughter cells with identical genetic nuclei.

Mitosis occurs in processes such as growth, embryonic development, tissue repair and asexual reproduction.

Stage 3—Cytokinesis

Cytokinesis is the last stage of the cell cycle during which the cytoplasm divides to develop two identical daughter cells. In plant cells, the cell wall forms a *plate* between the dividing cells. In animal cells, the cell pinches in the middle of the two dividing cells forming a *cleavage furrow* (figure 22).

> **Key term**
>
> **Cytokinesis** is the division of the cytoplasm to split the cell into two daughter cells. Cytokinesis takes place in meiosis and mitosis.

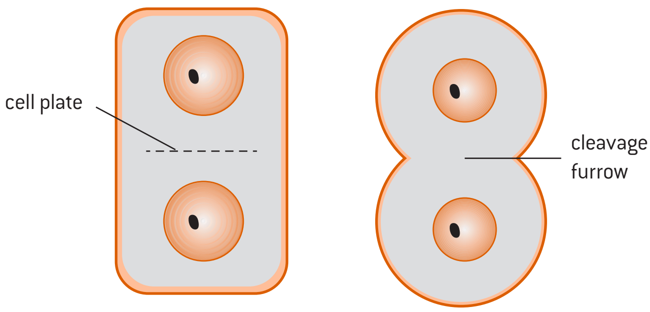

Figure 22. Cytokinesis in plant and animal cells

Maths skills: Calculating the mitotic index

The mitotic index is a tool that is used to predict the response of cells to chemotherapy. Chemotherapy is used as a treatment for cancer cells. A high mitotic index indicates that there are many cells dividing, which is the case with cancer cells.

The mitotic index can be calculated using the formula:

$$\frac{\text{number of cells in mitosis counted in a micrograph}}{\text{total number of cells in a micrograph}} \times 100\%$$

Worked example: Calculating the mitotic index

2. Calculate the mitotic index of the micrograph below (figure 23):

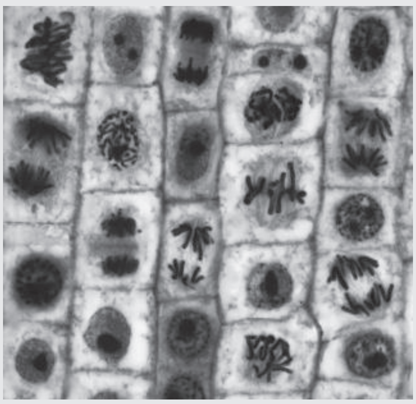

Figure 23. Micrograph of cells undergoing mitosis

Solution

1. Count the number of cells undergoing mitosis = 13
2. Count the total number of cells = 25
3. Use the formula:

$$\frac{\text{number of cells in mitosis counted in a micrograph}}{\text{total number of cells in a micrograph}} \times 100\%$$

$$\text{Mitotic index} = \frac{13}{25} \times 100 = 52\%$$

Question

14 Distinguish between cytokinesis in plant cells and animal cells.

Cell division in prokaryotes

Most prokaryotic cells divide by binary fission. Binary fission is an asexual method that involves the splitting of the parent cell to produce two genetically identical cells (figure 24).

Binary fission involves the following steps:

1. DNA replication takes place in which the DNA strand and the plasmid are duplicated.
2. Each DNA copy separates and moves to an opposite direction.
3. The cell grows and elongates.
4. Cytokinesis: the cell membrane pinches in the middle to divide the cell into two identical daughter cells.

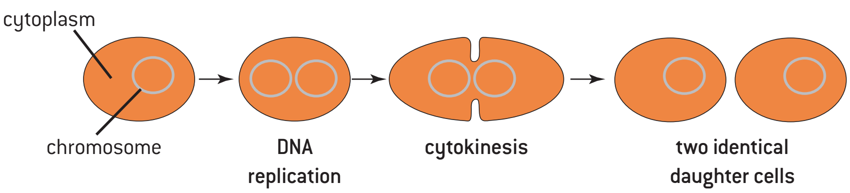

Figure 24. Binary fission

Tumour formation

Cell division is a controlled process in the body. Tumours form because of uncontrolled cell division. There are two types of tumours:

- **Benign tumours** which do not invade any body tissue. These tumours are usually inactive and harmless.
- **Malignant tumours** which are detached and carried in the bloodstream to other parts of the body. This will result in a secondary tumour or *metastasis*. These tumours are known as **cancer** because they are dangerous and life-threatening.

What causes tumour formation?

The cell cycle is controlled by specific genes. If these genes mutate, the cell cycle is no longer controlled, and the cell will divide in an abnormal way. *Mutation* occurs because of several factors including smoking, high exposure to radiation such as X-rays and *ultraviolet (UV) light*, some viruses, and carcinogens such as benzene and asbestos.

Key term

Mutations are random changes to the base sequence of genes.

Metastasis is the movement of cells from a primary tumour that are carried in the bloodstream and form secondary tumours in other parts of the body.

UV light or **ultraviolet light** is electromagnetic radiation of wavelengths shorter than visible light. It is found between the violet light and X-rays on the electromagnetic spectrum.

Chapter summary

In this chapter, you have learned about the cell theory, the basic structure of cells, transport in cells and cell division in prokaryotes and eukaryotes. Make sure that you have a working knowledge of the following concepts and definitions:

- ☐ Cells are the smallest unit of life of which all living organisms are made.
- ☐ Unicellular organisms are made up of a single cell and carry out the seven functions of life.
- ☐ Multicellular organisms are made up of many cells that differentiate to perform specialized functions.
- ☐ Prokaryotic cells have a simple structure as they lack a nucleus and membrane-bound organelles, whereas eukaryotic cells have a more complex structure as they have a nucleus and membrane-bound organelles.
- ☐ Animal cells and plant cells are examples of eukaryotic cells but they have some differences.
- ☐ Stem cells are undifferentiated cells that can divide and differentiate into many different types of cells and can be used in the treatment of many diseases.
- ☐ Cell transport is the movement of particles across the cell membrane.
- ☐ The cell membrane is made up of a bilayer of phospholipid molecules, which acts as a hydrophobic barrier that controls the material going in and out of the cell.
- ☐ Cell transport includes passive and active transport.
- ☐ Passive transport does not require energy and includes simple diffusion, facilitated diffusion and osmosis.
- ☐ Active transport requires energy and includes transport through pumps, endocytosis and exocytosis.
- ☐ The surface area to volume ratio limits the growth of the cell and therefore the cell divides when it reaches a certain size.
- ☐ The cell cycle describes the behaviour of cells as they grow and divide, and involves three main stages: interphase, mitosis and cytokinesis.
- ☐ Prokaryotes divide by binary fission.
- ☐ Tumours form because of uncontrolled cell division.

Additional questions

1. Evaluate the cell theory.
2. Distinguish between the light microscope and the electron microscope.
3. Compare and contrast between prokaryotes and eukaryotes.
4. Calculate the magnification of a sperm cell that has a tail measuring 40 μm in length which is drawn as 4 cm long.
5. State the name of the process by which bacteria pass their genetic material from one cell to another.
6. List the factors that determine the ease by which a molecule crosses the plasma membrane.
7. Deduce what will happen if a skin cell is placed in a concentrated saline solution for a long period of time.
8. Compare and contrast between passive and active transport.
9. Explain why *E. coli* does not burst when it is placed in water.
10. Explain how the surface area to volume ratio limits the growth of cells.
11. State where DNA replication takes place.
12. Describe the stages involved in mitosis.
13. State which processes involve mitosis.
14. Explain tumour formation.