PEARSON

BIOLOGY

QUEENSLAND

STUDENT BOOK

11

UNITS 1 & 2

Pearson

Contents

ONLINE CHAPTER

Chapter 1 Biology Skills and Assessment toolkit

Go to your eBook to access this chapter.
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Topic 1: Cells as the basis of life

Topic 2: Multicellular organisms

Unit 2: Maintaining the internal environment

Topic 1: Homeostasis

Topic 2: Infectious disease

How to use this book

PEARSON BIOLOGY 11 UNITS 1 & 2 QUEENSLAND

Pearson Biology 11 Queensland has been written to the new QCE Biology Syllabus. The book is an easy-to-use resource that covers Units 1 & 2 as well as comprehensively addresses the Skills and Assessment. Explore how to use this book below.

Design

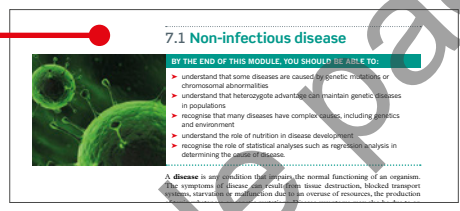
The best-practice literacy and instructional design supports all learners.
A simple to navigate, predictable design enables ease of use. The high-quality, relevant photos and illustrations assist the student understanding of the concepts.

Chapter opener

The Syllabus subject matter addressed in each chapter is clearly listed, along with any Science as a Human Endeavour features and Mandatory practicals.

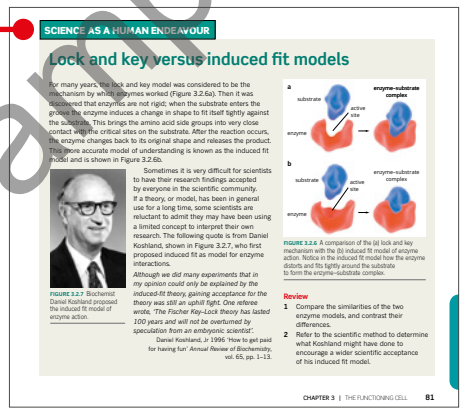
Module opener

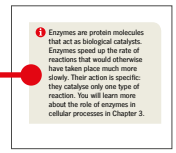
Module openers outline the key concepts and skills to be developed and link to the syllabus subject matter listed in the Chapter opener.



Science as a Human Endeavour

The SHE feature provides an opportunity for students to appreciate the development of science and its use and influence on society. The SHE features provide a segue into the development of claims and research questions for the Research investigation.





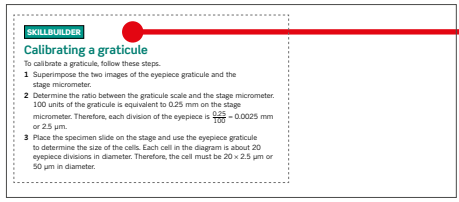
Highlight box

Highlight features focus students' attention on important information such as key definitions, formulas and salient points.

Worked examples

Worked examples use sequential steps of thinking and working to enhance student understanding of subject matter. Each Worked example is followed by a Try yourself task where students apply their learning to a mirrored problem.

Fully worked solutions to all Try yourself problems are available on *Pearson Biology 11 Queensland* Teacher Support.


SKILLBUILDER

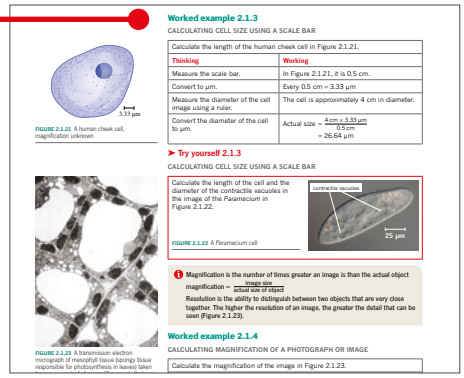
Calibrating a graticule

To calibrate a graticule, follow these steps.

1 Superimpose the two images of the eyepiece graticule and the stage micrometer.

2 Determine the ratio between the graticule scale and the stage micrometer. 100 units of the graticule is equivalent to 0.25 mm on the stage micrometer. Therefore, each division of the eyepiece is $\frac{0.25}{100} = 0.0025$ mm or 2.5 µm.

3 Place the specimen slide on the stage and use the eyepiece graticule to determine the size of the cells. Each cell in the diagram is about 20 eyepiece divisions in diameter. Therefore, the cell must be 20 × 2.5 µm or 50 µm in diameter.


Worked example 2.1.3

CALCULATING CELL SIZE USING A SCALE BAR

FIGURE 2.1.21 A human cheek cell, magnification unknown

Calculate the length of the human cheek cell in Figure 2.1.21.	
Thinking	**Working**
Measure the scale bar.	In Figure 2.1.21, it is 0.5 cm.
Convert to µm.	Every 0.5 cm = 3.33 µm
Measure the diameter of the cell image using a ruler.	The cell is approximately 4 cm in diameter.
Convert the diameter of the cell to µm.	Actual size = $\frac{4\text{ cm} \times 3.33\text{ µm}}{0.5\text{ cm}}$ = 26.64 µm

Try yourself 2.1.3

CALCULATING CELL SIZE USING A SCALE BAR

Calculate the length of the cell and the diameter of the contractile vacuoles in the image of the Paramecium in Figure 2.1.22.

FIGURE 2.1.22 A Paramecium cell

FIGURE 2.1.23 A transmission electron micrograph of mesophyll tissue (spongy tissue responsible for photosynthesis in leaves) taken

Magnification is the number of times greater an image is than the actual object

$\text{magnification} = \frac{\text{image size}}{\text{actual size of object}}$

Resolution is the ability to distinguish between two objects that are very close together. The higher the resolution of an image, the greater the detail that can be seen (Figure 2.1.23).

Worked example 2.1.4

CALCULATING MAGNIFICATION OF A PHOTOGRAPH OR IMAGE

Calculate the magnification of the image in Figure 2.1.23.

Skillbuilder

A Skillbuilder outlines a method or technique. Each is instructive and self-contained. Skillbuilders step students through the skill to support science application, required when analysing or utilising knowledge.

Case studies

Case studies provide opportunities to engage with current applications and research in biology and address essential syllabus objectives beyond typical learning and understanding conventions. Case studies develop skills in analysing, interpreting, evaluating, decision-making and predicting. Skills are modelled for students in the Case studies and then learning is applied in the Case study review.


CASE STUDY 9.1.2

Measles outbreak originating from Disneyland, USA, December 2014

Figure 9.1.14 shows the confirmed cases of measles reported to the California Department of Public Health from a single original infection. All cases were traced back to the original infection in Disneyland on 16–21 December, in which rash onset was 16 December.

A total of 110 California residents were confirmed to have measles between 27 December and 8 February. Thirty-nine visited one or both of the two Disney theme parks during 17–20 December, where it is thought they were exposed to measles. Thirty-four are secondary cases from the first wave of 38 infections, while 37 have an unknown exposure source. Twenty-six of the 34 secondary cases were household or close contacts, and eight received the virus in a community setting. Five of the California patients reported being in one or both of the two Disney theme parks during their exposure period outside of 17–20 December, but their source of infection is unknown.

Among this outbreak of the 110 patients, a total of 96 were either unvaccinated or had unknown or undocumented vaccination status for measles. Within this group, there were 12 infants who were too young to be vaccinated. The infected patients were of various ages, ranging from 6 weeks to 70 years.

Review

1 Provide a plausible model that shows three waves of infections for the outbreak from Disneyland in December 2014, including dates (or date ranges) to February 2015, using information from case studies 9.1.1 and 9.1.2.

2 Estimate the number of initial infectious individuals who may have caused the measles outbreak from Disneyland, assuming the reported R_0 of 15–16 by the CDC for measles.

3 Research the vaccination rate for measles in California and predict the spread of disease after 8 February.

4 Estimate the total number of exposed local individuals in Disneyland during 16–23 December, using the vaccination rate for measles in California.

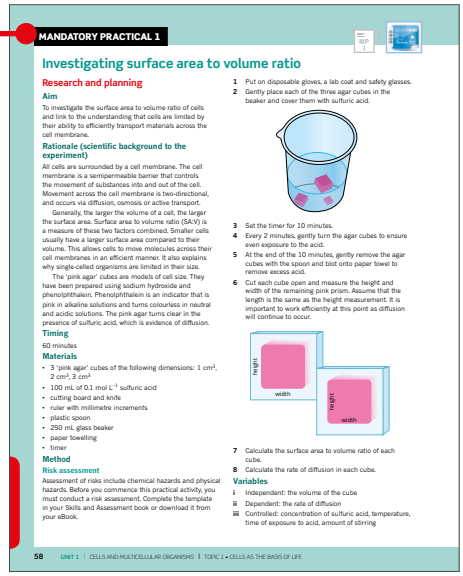
5 Identify the limitations to estimating the number of individuals exposed in Question 4.

Confirmed cases of measles reported to the California Department of Public Health, December 2014 to February 2015

FIGURE 9.1.14 The confirmed cases of measles reported to the California Department of Public Health from December 2014 to February 2015

Mandatory practicals

The Student Book includes all mandatory practicals. Each practical has been trialled and tested to ensure it can be safely performed and yields effective results.


MANDATORY PRACTICAL 1

Investigating surface area to volume ratio

Research and planning

Aim

To investigate the surface area to volume ratio of cells and link to the understanding that cells are limited by their ability to efficiently transport materials across the cell membrane.

Rationale (scientific background to the experiment)

All cells are surrounded by a cell membrane. The cell membrane is a semipermeable barrier that controls the movement of substances into and out of the cell. Movement across the cell membrane is two-directional, and occurs via diffusion, osmosis or active transport.

Generally, the larger the volume of a cell, the larger the surface area. Surface area to volume ratio (SA:V) is a measure of these two factors combined. Smaller cells usually have a larger surface area compared to their volume. This allows cells to move molecules across their cell membranes in an efficient manner. It also explains why single-celled organisms are limited in their size.

The 'pink agar' cubes are models of cell size. They have been prepared using sodium hydroxide and phenolphthalein. Phenolphthalein is an indicator that is pink in alkaline solutions and turns colourless in neutral and acidic solutions. The pink agar turns clear in the presence of sulfuric acid, which is evidence of diffusion.

Timing

60 minutes

Materials

- 3 'pink agar' cubes of the following dimensions: 1 cm^3, 2 cm^3, 3 cm^3
- 100 mL of 0.1 mol L^{-1} sulfuric acid
- cutting board and knife
- ruler with millimetre increments
- plastic spoon
- 250 mL glass beaker
- paper towelling
- timer

Method

Risk assessment

Assessment of risks include chemical hazards and physical hazards. Before you commence this practical activity, you must conduct a risk assessment. Complete the template in your Skills and Assessment book or download it from your eBook.

1 Put on disposable gloves, a lab coat and safety glasses.

2 Gently place each of the three agar cubes in the beaker and cover them with sulfuric acid.

3 Set the timer for 10 minutes.

4 Every 2 minutes, gently turn the agar cubes to ensure even exposure to the acid.

5 At the end of the 10 minutes, gently remove the agar cubes with the spoon and blot onto paper towel to remove excess acid.

6 Cut each cube open and measure the height and width of the remaining pink prism. Assume that the length is the same as the height measurement. It is important to work efficiently at this point as diffusion will continue to occur.

7 Calculate the surface area to volume ratio of each cube.

8 Calculate the rate of diffusion in each cube.

Variables

i Independent: the volume of the cube

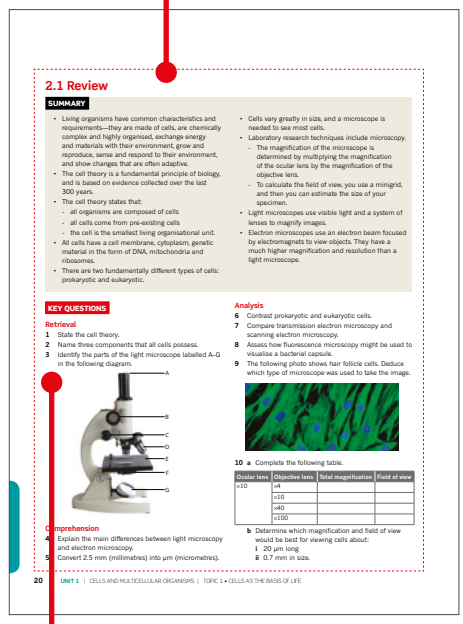
ii Dependent: the rate of diffusion

iii Controlled: concentration of sulfuric acid, temperature, time of exposure to acid, amount of stirring

58 UNIT 1 | CELLS AND MULTICELLULAR ORGANISMS | TOPIC 1 • CELLS AS THE BASIS OF LIFE

Module summary

Each module concludes with a summary to help students consolidate the key points and concepts.


2.1 Review

SUMMARY

- Living organisms have common characteristics and requirements—they are made of cells, are chemically complex and highly organised, exchange energy and materials with their environment, grow and reproduce, sense and respond to their environment, and show changes that are often adaptive.
- The cell theory is a fundamental principle of biology, and is based on evidence collected over the last 300 years.
- The cell theory states that:
  - all organisms are composed of cells
  - all cells come from pre-existing cells
  - the cell is the smallest living organisational unit.
- All cells have a cell membrane, cytoplasm, genetic material in the form of DNA, mitochondria and ribosomes.
- There are two fundamentally different types of cells: prokaryotic and eukaryotic.
- Cells vary greatly in size, and a microscope is needed to see most cells.
- Laboratory research techniques include microscopy.
  - The magnification of the microscope is determined by multiplying the magnification of the ocular lens by the magnification of the objective lens.
  - To calculate the field of view, you use a minigrid, and then you can estimate the size of your specimen.
- Light microscopes use visible light and a system of lenses to magnify images.
- Electron microscopes use an electron beam focused by electromagnets to view objects. They have a much higher magnification and resolution than a light microscope.

KEY QUESTIONS

Retrieval

1 State the cell theory.

2 Name three components that all cells possess.

3 Identify the parts of the light microscope labelled A–G in the following diagram.

Analysis

6 Contrast prokaryotic and eukaryotic cells.

7 Compare transmission electron microscopy and scanning electron microscopy.

8 Assess how fluorescence microscopy might be used to visualise a bacterial capsule.

9 The following photo shows hair follicle cells. Deduce which type of microscope was used to take the image.

10 a Complete the following table.

Ocular lens	Objective lens	Total magnification	Field of view
×10	×4		
	×10		
	×40		
	×100		

Comprehension

4 Explain the main differences between light microscopy and electron microscopy.

5 Convert 2.5 mm (millimetres) into µm (micrometres).

b Determine which magnification and field of view would be best for viewing cells about:

i 20 µm long

ii 0.7 mm in size.

20 UNIT 1 | CELLS AND MULTICELLULAR ORGANISMS | TOPIC 1 • CELLS AS THE BASIS OF LIFE

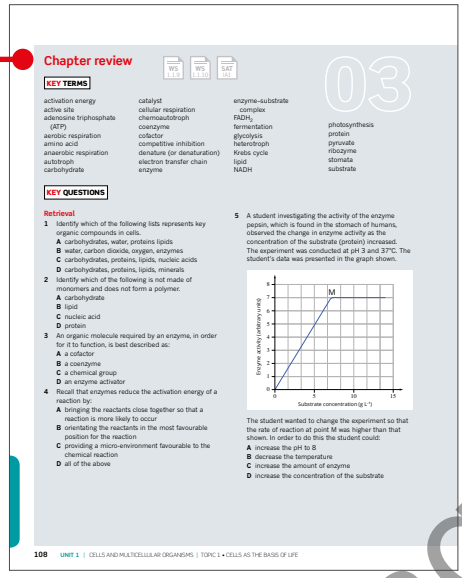
Module review

Key instructions are provided to test students' understanding of concepts of the module. Tasks are carefully categorised under the relevant cognitive level: Retrieval, Comprehension, Analysis and are developed to assess the syllabus requirements.

How to use this book

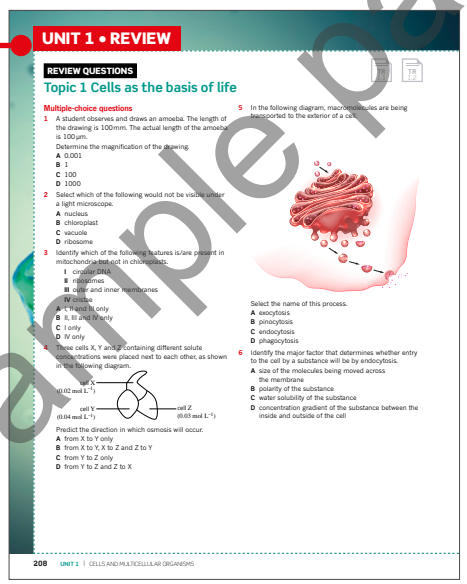
Chapter review

Each chapter finishes with a list of key terms covered in the chapter and a set of tasks to test students' abilities to apply the knowledge gained from the chapter.



Unit review

Each Unit finishes with a comprehensive set of exam-style instructions, including multiple choice, short answer and extended response. These review tasks assist students to draw together their knowledge and understanding of the whole unit.



Glossary

Key terms are shown in **bold** throughout the Student Book and are listed at the end of each chapter. A comprehensive glossary at the end of the book defines all the key terms. The glossary aligns with the syllabus context and includes the QCAA defined terminology.

Answers

Comprehensive answers and fully worked solutions for all Module review tasks, Try yourself, Science as a Human Endeavour, Case studies, Chapter reviews and Unit reviews are provided via the Teacher Reader+ eBook.

Icons

Go To icons make important links to relevant content within the student books in the course. The Go To icons indicate where to engage with Chapter 1 in your eBook.

GO TO ➤

Every Mandatory practical is supported by a complementary **SPARKlab** alternative practical.

The ***Pearson Biology Skills and Assessment Book*** icons indicate the best time to engage with an activity for practice, application and revision.
The type of activity is indicated as follows:

Worksheet (WS) — WS 3.1.1

Mandatory practical (MP) — MP 4

Practical activity (PA) — PA 3.2.1

Sample Assessment Task (SAT) — SAT IA1

Topic review (TR) — TR 1.2

The **Reader+** icon indicates when to engage with an asset via your Reader+ eBook. Assets may include videos and interactive activities.

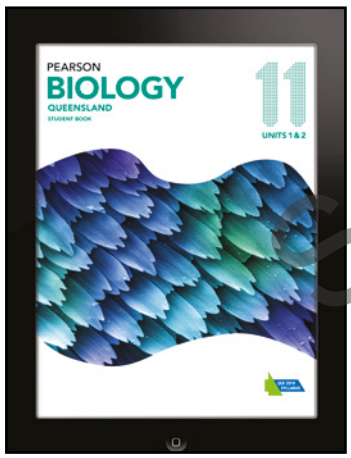
Pearson Biology 11 Units 1 & 2 Queensland

Student Book

Pearson Biology 11 Units 1 & 2 Queensland has been developed by experienced Queensland teachers to address all the requirements of the new QCE Biology 2019 Syllabus. The series features the very latest developments and applications of biology, literacy and instructional design to ensure the content and concepts are fully accessible to all students.

Skills and Assessment Book

The *Skills and Assessment Book* gives students the edge in preparing for all forms of assessment. Specifically prepared to provide opportunities to consolidate, develop and apply subject matter and science inquiry skills, this resource features a toolkit, key knowledge summaries, worksheets, practical activities and guidance, assessment practice and exam-style Topic review sets.



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Teacher Support

Pearson Biology 11 Units 1 & 2 Queensland Teacher Support provides:

- complete answers, fully worked solutions or suggested answers to all *Student Book* and *Skills and Assessment Book* tasks
- mandatory practical expected results, common mistakes, suggested answers and full safety notes and risk assessments
- teaching, learning and assessment programs

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CHAPTER

02 The fundamental cell

By the end of this chapter, you will understand the importance of cells as the basic structural and functional units of life on Earth and how the development of new technology continues to enhance our understanding of the structure of the cell and cellular processes. You will learn about the components of different types of cells, and how the structures and systems of cells function to sustain life. You will also have an understanding of the fluid mosaic model of the cell membrane and of the different processes by which a cell moves substances across this membrane.

Syllabus subject matter

WS 1.1.1

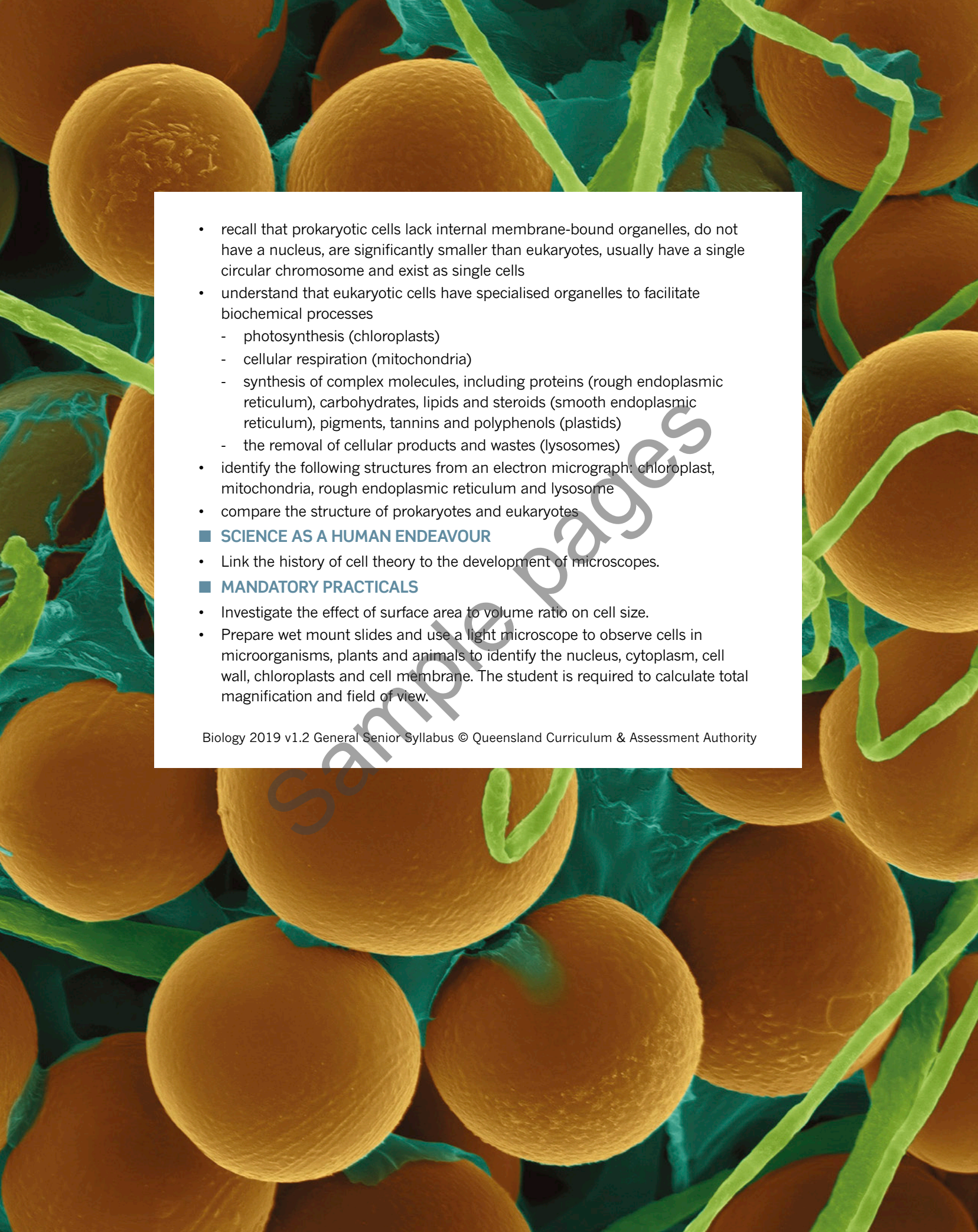
Topic 1 • Cells as the basis of life

CELL MEMBRANE

- describe the structure of the cell membrane (including protein channels, phospholipids, cholesterol and glycoproteins) based on the fluid mosaic phospholipid bilayer model
- describe how the cell membrane maintains relatively stable internal conditions via the passive movement (diffusion, osmosis) of some substances along a concentration gradient
- explain how the cell membrane maintains relatively stable internal conditions via the process of active transport of a named substance against a concentration gradient
- understand that endocytosis is a form of active transport that usually moves large polar molecules that cannot pass through the hydrophobic cell membrane into the cell
- recognise that phagocytosis is a form of endocytosis
- predict the direction of movement of materials across cell membranes based on factors such as concentration, physical and chemical nature of the materials
- explain how the size of a cell is limited by the relationship between surface area to volume ratio and the rate of diffusion

PROKARYOTIC AND EUKARYOTIC CELLS

- recognise the requirements of all cells for survival, including:
  - energy sources (light or chemical)
  - matter (gases such as carbon dioxide and oxygen)
  - simple nutrients in the form of monosaccharides, disaccharides, polysaccharides
  - amino acids, fatty acids, glycerol, nucleic acids, ions and water
  - removal of wastes (carbon dioxide, oxygen, urea, ammonia, uric acid, water, ions, metabolic heat)
- recognise that prokaryotic and eukaryotic cells have many features in common, which is a reflection of their common evolutionary past



- recall that prokaryotic cells lack internal membrane-bound organelles, do not have a nucleus, are significantly smaller than eukaryotes, usually have a single circular chromosome and exist as single cells
- understand that eukaryotic cells have specialised organelles to facilitate biochemical processes
  - photosynthesis (chloroplasts)
  - cellular respiration (mitochondria)
  - synthesis of complex molecules, including proteins (rough endoplasmic reticulum), carbohydrates, lipids and steroids (smooth endoplasmic reticulum), pigments, tannins and polyphenols (plastids)
  - the removal of cellular products and wastes (lysosomes)
- identify the following structures from an electron micrograph: chloroplast, mitochondria, rough endoplasmic reticulum and lysosome
- compare the structure of prokaryotes and eukaryotes

SCIENCE AS A HUMAN ENDEAVOUR

- Link the history of cell theory to the development of microscopes.

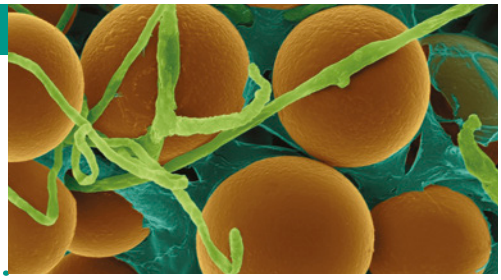
MANDATORY PRACTICALS

- Investigate the effect of surface area to volume ratio on cell size.
- Prepare wet mount slides and use a light microscope to observe cells in microorganisms, plants and animals to identify the nucleus, cytoplasm, cell wall, chloroplasts and cell membrane. The student is required to calculate total magnification and field of view.

2.1 Cell theory and microscopy

BY THE END OF THIS MODULE, YOU SHOULD BE ABLE TO:

- understand the importance of cells as the basic structural and functional units of life on Earth
- understand the difference between light microscopy and electron microscopy
- calculate magnification of microscope images and field of view.



Cells are the basic structural units of all living things. The cell theory is one of the fundamental principles of biology. It is based on microscopic and experimental studies of tissues, from all types of organisms, carried out over the last 300 years.

In this module, you will learn about cell theory, the differences between plant and animal cells, and the microscopy techniques that are used to view cells and their components.

CELL THEORY

The cell theory was developed over hundreds of years by scientists of various nationalities and depended on the technology available at the time.

Cells are the basic structural units of living organisms. The cell theory states that:

- all organisms are composed of cells
- all cells come from pre-existing cells
- the cell is the smallest living organisational unit.

BIOGENESIS

The cell theory states that all cells arise from pre-existing cells. This is known as **biogenesis**.

Until the 1850s, the idea of spontaneous generation was accepted as the origin of small organisms, such as maggots. According to the theory of spontaneous generation, some organisms could suddenly form from certain types of matter, such as a grain of sand or dead flesh.

However, experiments by Francesco Redi on maggots in the 17th century and Lazzaro Spallanzani on microorganisms in the 18th century refuted spontaneous generation. These scientists showed that the presence of maggots and microorganisms was a result of contamination rather than spontaneous generation.

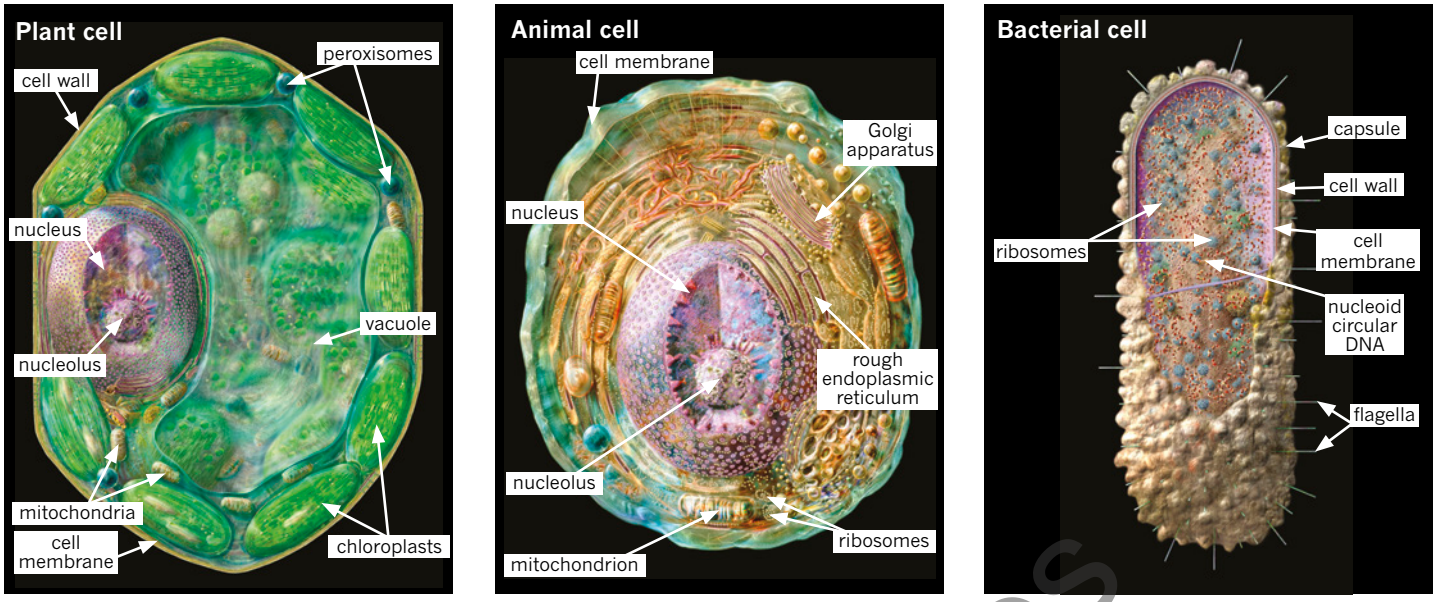


FIGURE 2.1.1 The cells in a plant, an animal and a bacterium have common features, including a cell membrane, cytoplasm, DNA and ribosomes. Not all features are visible here.

THE CELL

Cells are the basic structural unit of all living things. There are two fundamentally different cell types: prokaryotic cells and eukaryotic cells. The differences between the types of cells are explained in more detail in the next module.

Although there are different types of cells, the cells of plants, animals and bacteria have a number of common features. Some of these features are shown in Figure 2.1.1 and include:

- a **cell membrane**, which separates the interior of the cell from the outside environment
- **cytoplasm**, which consists of the **cytosol** and, in eukaryotes, the **organelles**; cytosol is a gel-like substance that is made up of more than 80% water and contains ions, salts and organic molecules
- **DNA** (**deoxyribonucleic acid**), which carries hereditary information, directs the cell's activities and is passed accurately from generation to generation
- **ribosomes**, which are organelles responsible for the synthesis of **proteins**.

Cells contain **organelles**, which have specialised functions. Organelles are subcellular structures involved in specific functions of the cell. This compartmentalisation of the cell ensures that the chemical processes of the cell can occur efficiently. Each organelle is functionally and structurally distinct. Organelles are surrounded by membranes to separate their processes from other parts of the cell and to provide an optimal cellular environment for the biochemical reactions occurring in the cell. Prokaryote cells do not contain any membrane-bound organelles.

Proteins are large molecules composed of one or more polypeptides. Polypeptides are long, chain-like molecules consisting of many amino acids linked together.

CELL SIZE

Cells vary greatly in size, as can be seen in Figure 2.1.2. Most cells are microscopic and, thus, you need a microscope to see them. Cell size is usually measured in micrometres. There are 1000 micrometres (μm) in 1 millimetre (mm). There are exceptions, such as the egg cell of some bird species, which can be many centimetres in diameter. Some typical cell sizes are as follows:

- bacterium: 0.1–5 μm long
- human: 10–200 μm long
- *Paramecium* (a single-celled eukaryote): about 150 μm long.

The thickness of cell membranes also differs and can be between 0.004 and 0.1 µm.

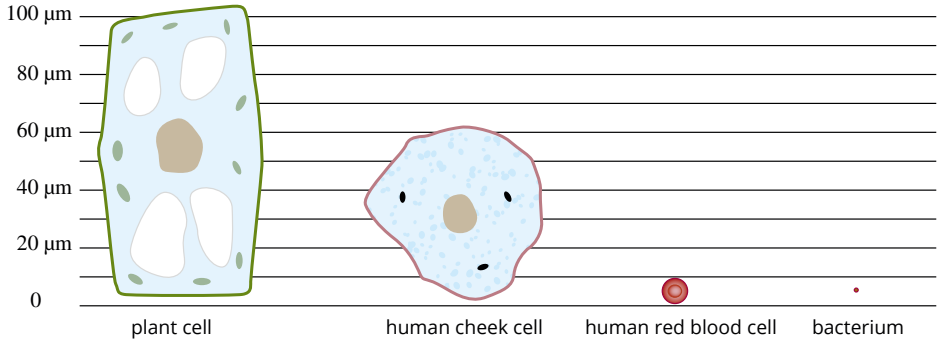


FIGURE 2.1.2 A typical plant cell, human cheek cell, human red blood cell and bacterium. Note the great difference in size between the eukaryotic cells and the prokaryotic cell (bacterium).

The size of the cell is determined by its ability to efficiently move substances into, out of and around the cell. Unicellular (single-celled) organisms, such as bacteria, must be able to absorb their requirements from their environment quickly and then move these materials around the cell to perform the necessary functions of life. These functions include basic metabolic processes such as cellular respiration, homeostasis and reproduction. However, as cells become larger, this movement becomes less efficient. Multicellular organisms have overcome this problem by developing complex transport systems to ensure that each cell is efficiently supplied with the nutrients and gases needed to sustain life.

Units of measurement

The development of sophisticated microscopy technology to observe cells and intracellular particles has allowed scientists to measure increasingly smaller objects (Figure 2.1.3). This has led to the development of appropriate units of measurement to describe microscopic lengths.

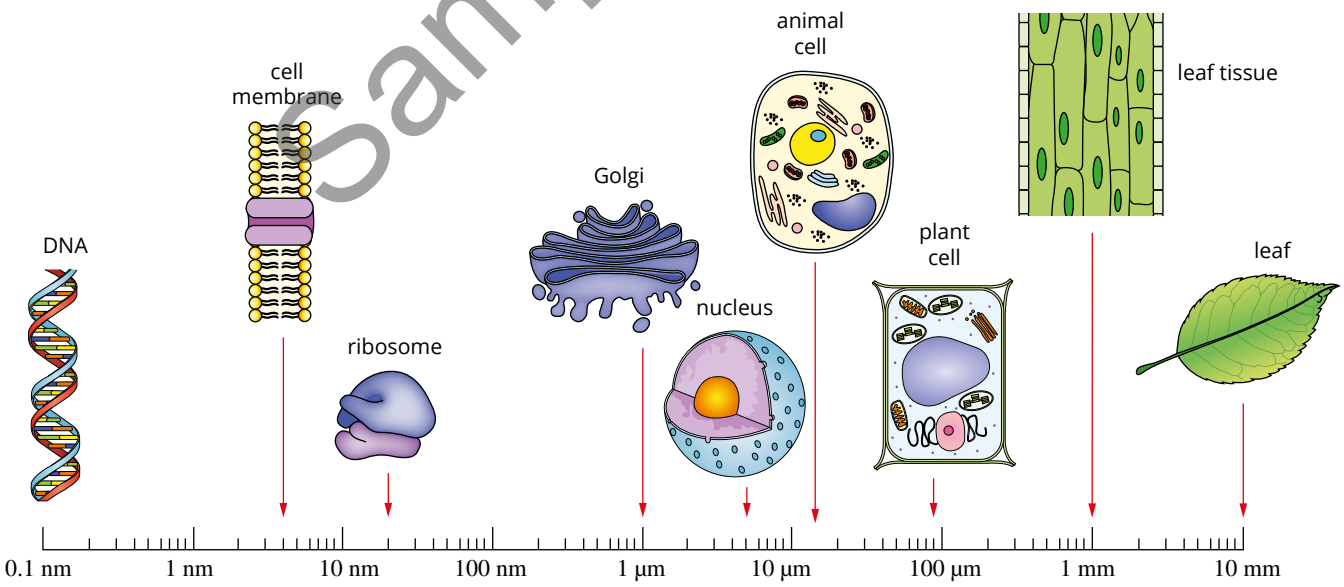
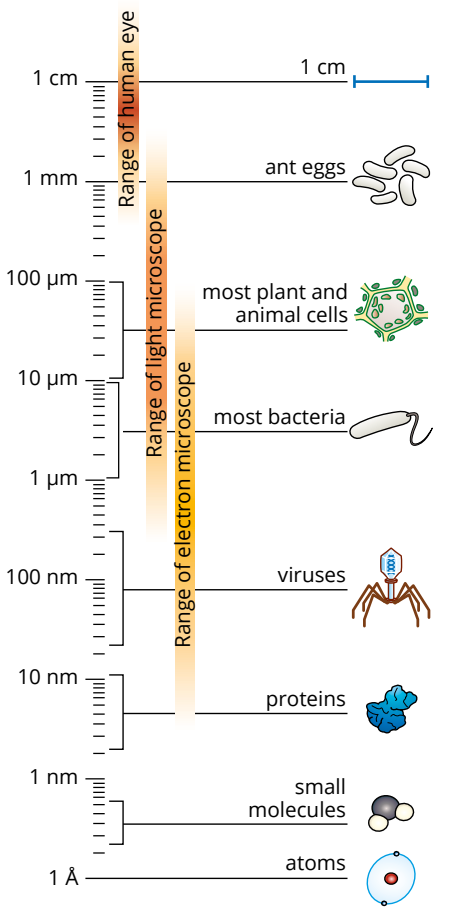


FIGURE 2.1.3 The scale shows the range of size of a variety of cells, organelles and molecules within a cell. The scale is logarithmic to accommodate the range of sizes shown.



$1\text{ cm} = 10\text{ mm} = 10^4\ \mu\text{m} = 10^7\text{ nm} = 10^8\ \text{Å}$

FIGURE 2.1.4 A comparison of the ranges of the light and electron microscopes (the scale is logarithmic)

In the International System of Units (SI units), the unit for length is the metre (m). Table 2.1.1 illustrates the derivation of the smaller units of length in relation to the metre. Refer to Chapter 1 (Part A) for detailed assistance with units of measurements.

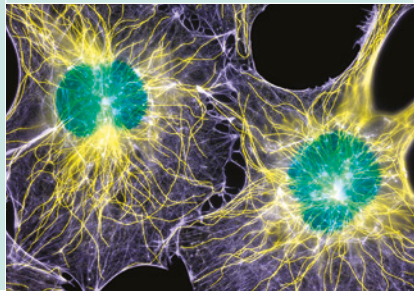
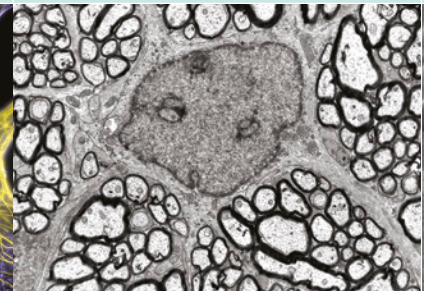
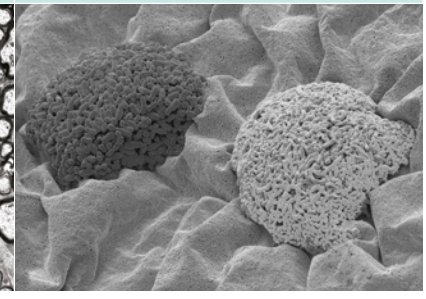
TABLE 2.1.1 SI units for smaller units of length relative to the metre

Fraction of a metre	Units	Symbol	
one hundredth = $\frac{1}{100}$ = 0.01 = 10^{-2} m	centimetre	cm	1 m = 10^2 cm
one thousandth = $\frac{1}{1000}$ = 0.001 = 10^{-3} m	millimetre	mm	1 m = 10^3 mm
one millionth = $\frac{1}{1\,000\,000}$ = 0.000 001 = 10^{-6} m	micrometre	µm	1 m = 10^6 µm
one thousand millionth = $\frac{1}{1\,000\,000\,000}$ = 0.000 000 001 = 10^{-9} m	nanometre	nm	1 m = 10^9 nm

INVESTIGATING CELLS

Cytology is the study of cells. Cytologists (scientists who study cell structure and function) and histologists (scientists who study tissue structure) use a variety of tools and techniques, including several microscopy techniques. Modern microscopy techniques, including light and electron microscopy (Table 2.1.2), have greatly advanced our understanding of the structure and function of cells. The type of microscope used depends on the characteristics and properties of the specimen to be observed, such as the size of cell or cell component and whether it is living or dead (Figure 2.1.4). Scientists also consider the access to and costs of using specialist facilities and preparing specimens when deciding which microscopy technique to use.

TABLE 2.1.2 A comparison of modern microscopy techniques

	Light microscope	Transmission electron microscope	Scanning electron microscope
Radiation source	light	electrons	electrons
Wavelength (nm)	400–700	0.005	0.005
Lenses	glass	electromagnetic	electromagnetic
Specimen	living or non-living supported on glass slide	non-living supported on a small copper grid in a vacuum	non-living supported on a metal disc within a vacuum
Maximum resolution (nm)	200	1	10
Maximum magnification	1500×	250 000×	100 000×
Stains	coloured dyes	impregnated with heavy metals	coated with carbon or gold
Type of image	may be coloured	monochrome unless stained	monochrome unless stained
			

LIGHT MICROSCOPY

Most cells are so small that they can only be seen with a microscope like the one shown in Figure 2.1.5. The light microscope uses light and a system of lenses to magnify the image. One lens is called the objective lens and the other is the eyepiece or ocular lens.

One of the main advantages of light microscopy is that it allows you to view living cells in colour.

Sample preparation is usually quick and simple. Stains can be used to highlight different components of cells in colour. A thin specimen is mounted on a glass slide and placed on the stage under the lenses. Light travels through the specimen and into the lens system, and the image is viewed by eye or with a digital camera (Figure 2.1.6).

The condenser lens beneath the movable stage concentrates light from the light source onto the specimen, and the image is focused by the coarse and fine adjusters. Different parts of the specimen can be viewed by moving the specimen on the stage.

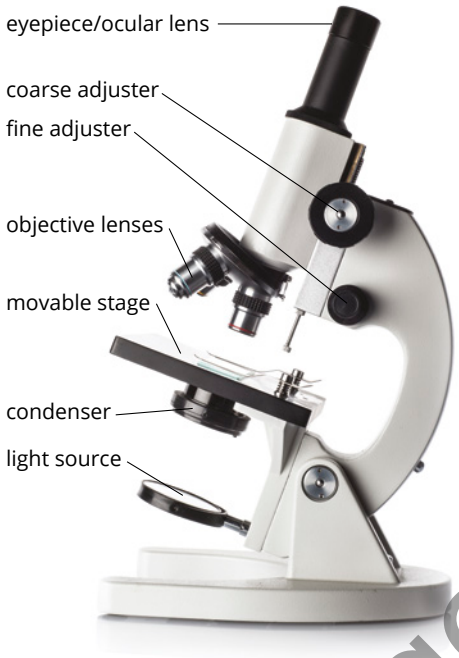


FIGURE 2.1.5 A light microscope and its parts

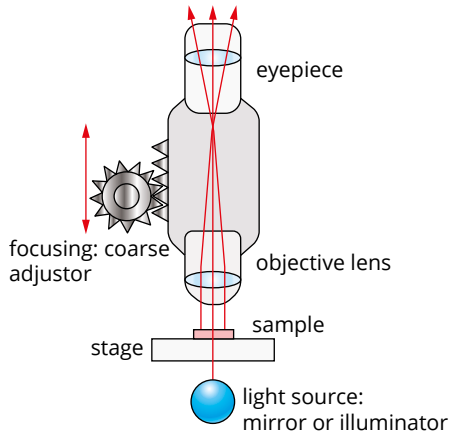


FIGURE 2.1.6 The lenses of a light microscope magnify the image.

Light microscopy techniques used in cytology include histology, autoradiography, fluorescence and confocal microscopy. Each of these uses visible light to examine cells and tissues.

Fluorescence microscopy

Figure 2.1.7 shows a fluorescent microscope, which is used to examine cells that are naturally or artificially fluorescent. Fluorescent cells contain molecules that absorb light of one wavelength (called the exciting wavelength, which is usually ultraviolet) and emit another wavelength (and therefore a different colour). By using filters to block out the exciting wavelength, the light emitted by the fluorescing molecules can then be seen against a black background, as shown in Figure 2.1.8. If the cells do not contain fluorescent molecules, fluorescent dyes (called markers) can be added that attach to the structures being investigated, such as DNA, particular proteins or cell wall components.

Immunofluorescence involves using a fluorescent tag that is linked to an antibody (see Chapter 7), which then attaches to its particular target antigen in the cell.

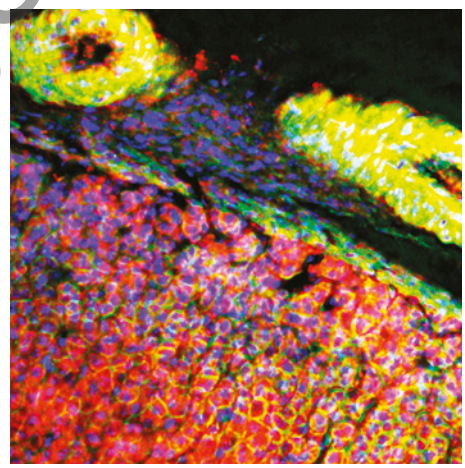


FIGURE 2.1.8 A fluorescence light micrograph of a stained section through an adrenal gland. This section through an adrenal gland has been stained with a fluorescent dye. The red parts are a particular enzyme, the blue parts are cell nuclei and the green–yellow parts are proteins in blood vessels.

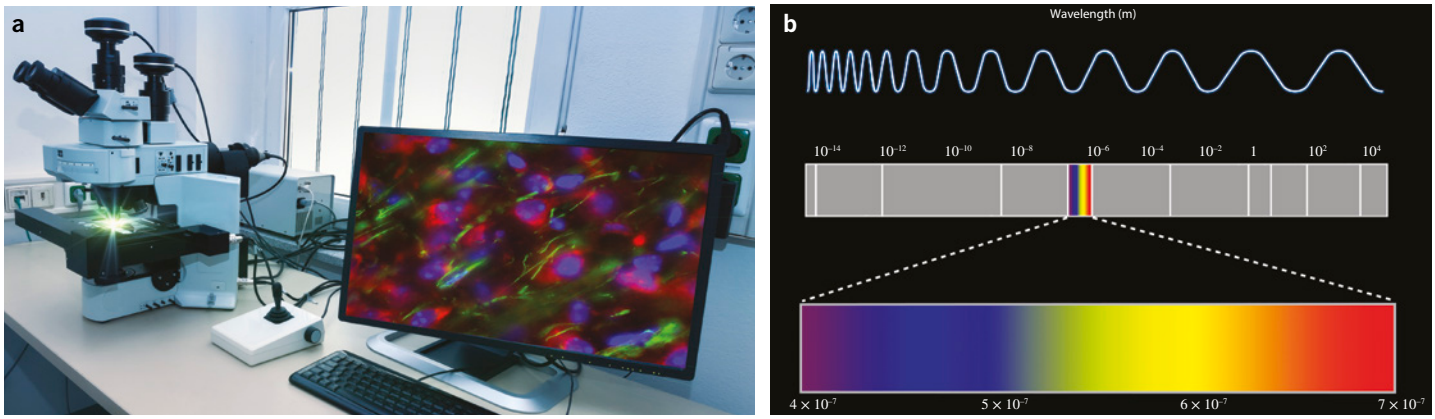


FIGURE 2.1.7 (a) A fluorescent microscope uses filters to alter the emitted wavelength of light to enable the cell components to be more easily seen in contrast with those surrounding it. (b) Visible light spectrum is part of the electromagnetic spectrum.

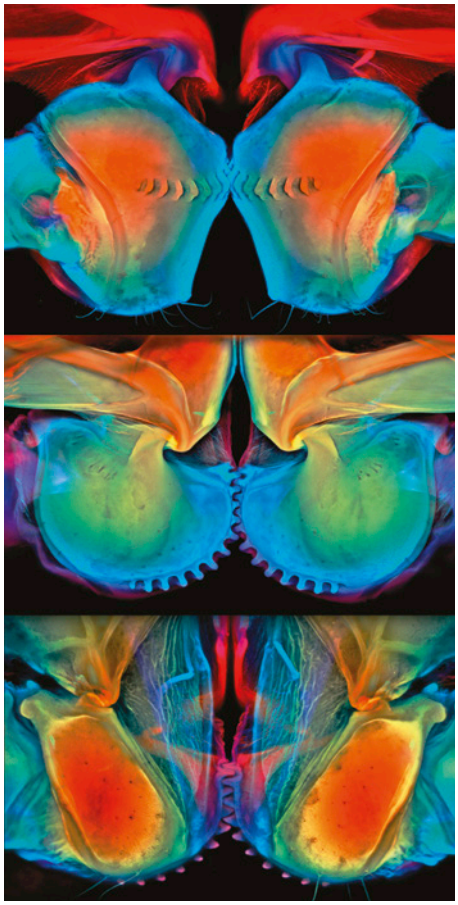


FIGURE 2.1.9 A confocal laser scanning micrograph of the green cone-headed planthopper (*Acanalonia conica*). The image (top to bottom: posterior, dorsal and ventral views) shows cog or gear-like structures of the structure at the top of each hind leg, which allows the hind legs to interlock and move together in perfect synchrony. Laser light from the microscope causes the stained specimen to fluoresce and reveal variations in the chitin (the main component in the exoskeleton) structures.

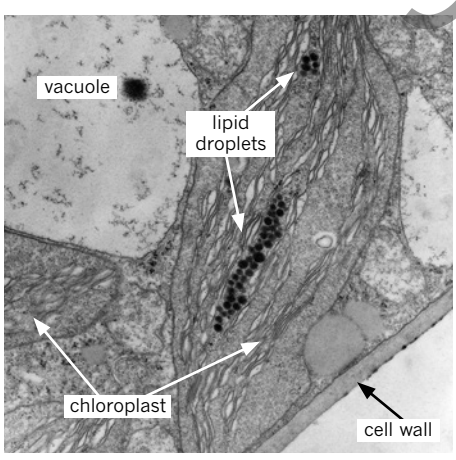


FIGURE 2.1.11 A transmission electron micrograph of a plant leaf, showing chloroplasts, with lipid droplets showing in one. The pale area to the upper left is a vacuole and the cell wall is also visible at the lower right.

Confocal microscopy

Confocal microscopy is a relatively new technique that allows scientists to obtain 'optical sections' of a cell or tissue, stained with fluorescent markers, without actually sectioning or slicing the cells. Confocal microscopy produces high-resolution images of very thin sections of a specimen. An example is shown in Figure 2.1.9. Laser light is passed through a pinhole and lens, which directs highly focused light onto only a tiny part of the specimen. This eliminates light reflecting from adjacent parts of the section, which normally blurs the image. When the object is slowly scanned in this way, an optical section of the sample is viewed on a computer screen. Thicker samples can be imaged in thin sections and then reconstructed in three dimensions by image analysis software. Confocal microscopes and the required computer software are very expensive, and the production of images is slow. However, they can produce startling three-dimensional views of living structures.

ELECTRON MICROSCOPY

In electron microscopy, an object is viewed by using an electron beam instead of light. This allows you to see structures in far more detail than is possible with light microscopy. An electron microscope produces a narrow beam of electrons that is maintained by electromagnetic lenses, which are coils that surround the tube and emit an electromagnetic field. Electrons striking the specimen are absorbed or scattered, or pass through it. The image is then recorded digitally and processed.

The image obtained with an electron microscope has a much higher resolution and greater depth of field than an image from a light microscope. Electron microscopy produces only black and white images, but these are often coloured later to highlight important features.

FIGURE 2.1.10 A transmission electron microscope. Specimens are specially prepared and the image is taken within a vacuum to ensure the electron beam remains focused. Therefore, only non-living materials can be observed under the transmission electron microscope.

Transmission electron microscopy

Figure 2.1.10 shows a transmission electron microscope. In transmission electron microscopy (TEM), the electron beam travels through an ultrathin section (less than 100 nm thick) of a specimen. This allows very fine details of cellular structures to be seen, like those shown in Figure 2.1.11.

Because the specimen must be in a vacuum in the transmission electron microscope, the specimen is first chemically fixed to stop the structures from collapsing and then dehydrated with alcohol. It is then embedded in a plastic resin, sectioned with a diamond cutter called an ultramicrotome, and stained.

Scanning electron microscopy

Figure 2.1.12 shows a scanning electron microscope. In scanning electron microscopy (SEM), the electrons bounce off a specimen that has been coated with an extremely thin layer of an electrically conducting material such as gold. This gives a high-resolution image of the surface features but cannot show internal details (Figure 2.1.13).

Autoradiography

Autoradiography is a method that allows scientists to identify specific organelles or the location of molecules within a cell or tissue. The tissue is first treated with a radioactively labelled substance that is taken up into the part of the cell that is being investigated, such as the nerve tissue shown in Figure 2.1.14. The tissue is sliced into very thin sections that are placed against a very thin high-resolution photographic film. The radioactive substance emits beta particles that produce an image on the film. The tissue sections are stained so that the photographic image can be located in relation to cellular structures. This technique can be used to indicate which organelles are active under particular circumstances.

Although autoradiography is still sometimes used with light microscopy, it is more commonly used with electron microscopy.

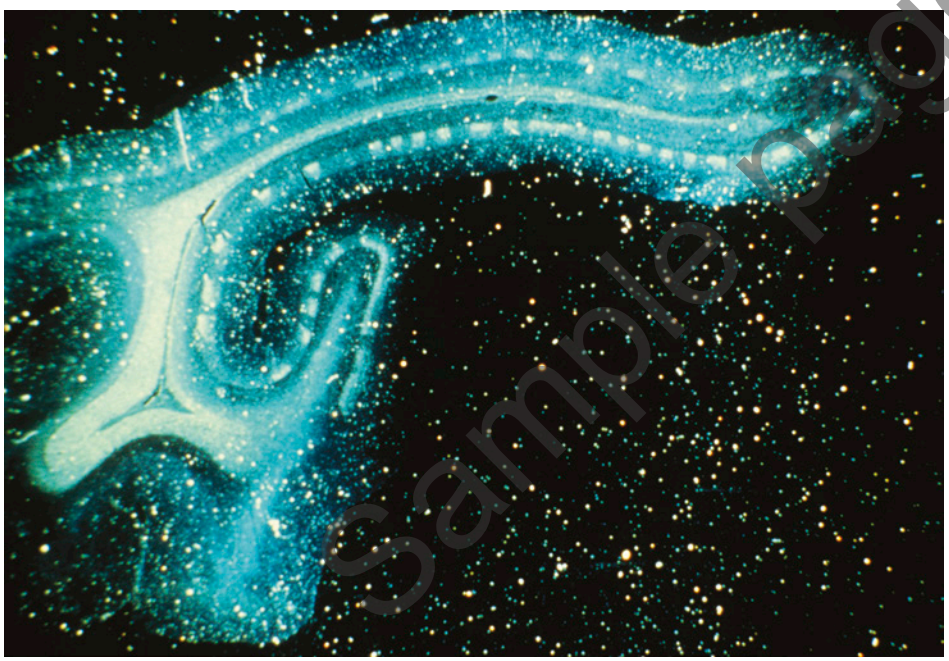


FIGURE 2.1.14 An autoradiograph of a slice through nerve tissue from the visual centre of the brain, showing how visual messages from one eye are received by the brain. Rows of neuron (nerve cell) cubes are laid out in columns on the outside of the brain tissue, and the active areas of the brain have absorbed a radioactive chemical. The glow is developed onto photographic paper and produces an autoradiograph.

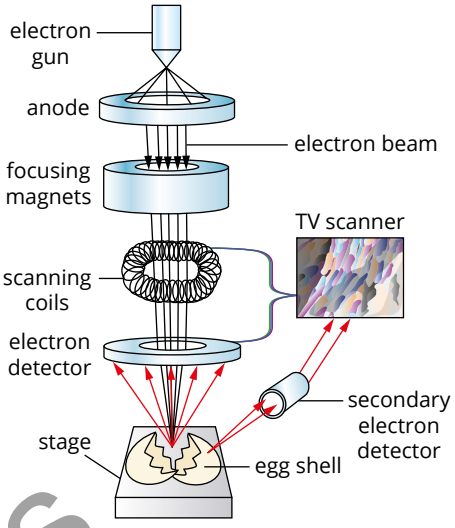


FIGURE 2.1.12 The scanning electron microscope detects secondary electrons emitted by atoms excited by the electron beam. The specimen is prepared by coating it with an electron-dense, electrically conductive material such as gold and therefore can only be used on non-living objects.

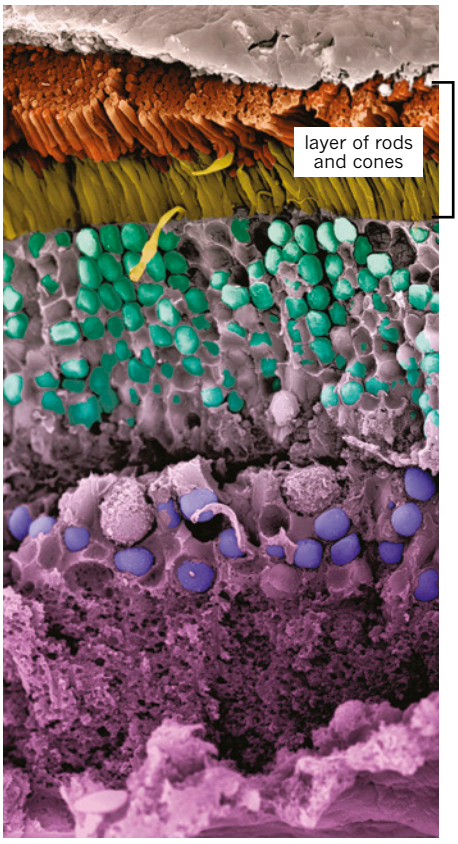


FIGURE 2.1.13 A coloured scanning electron micrograph of a section through the retina of an eye, showing cone and rod cells

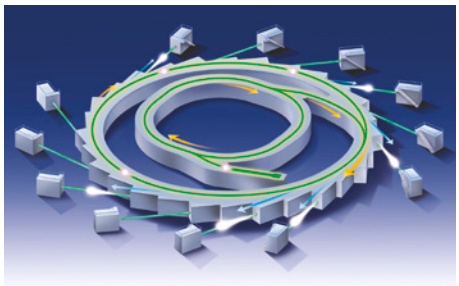


FIGURE 2.1.15 The Australian Synchrotron is about the size of the Brisbane Cricket Ground. The large diameter is needed to accelerate particles to almost the speed of light. Synchrotron light of different wavelengths can be obtained from several points around the circumference.

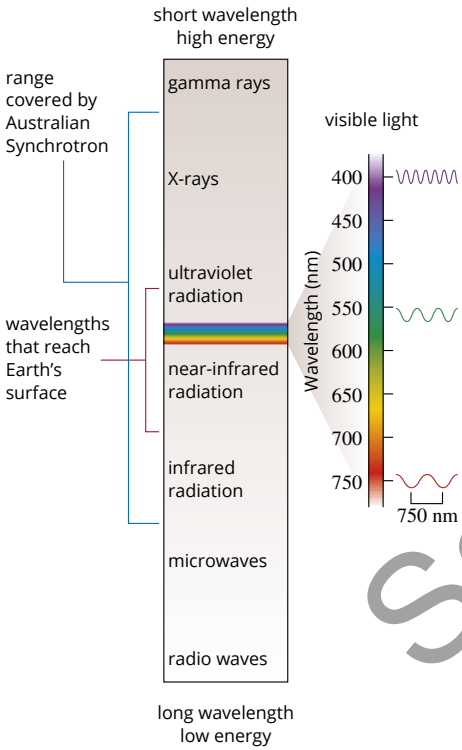


FIGURE 2.1.16 The electromagnetic spectrum, showing the range generated by the Australian Synchrotron and the range of visible light

The synchrotron and its use in biology

A synchrotron is a machine in which a beam of electrons is accelerated almost to the speed of light. Powerful magnets guide the beam into a particular path, usually a circle.

The first synchrotron was built in 1945 and was the size of a small room. The largest synchrotron is the Large Hadron Collider in Switzerland, which has a circumference of 27 km. Figure 2.1.15 shows a diagram of the Australian Synchrotron in Melbourne, which is one of the most advanced synchrotrons, and can produce an extremely intense beam of radiation in a wide range of wavelengths.

Most biological investigations using synchrotrons involve visible light. Visible light is a small part of the electromagnetic wavelengths that can be generated by a synchrotron. It lies between the longer wavelengths (radio waves, microwaves and infrared) and the shorter wavelengths of ultraviolet light, X-rays and gamma rays. This is shown in Figure 2.1.16.

Synchrotron light allows matter to be seen at the atomic scale, including the nanosecond-by-nanosecond behaviour of protein molecules such as antibodies. Scientists can collect, in hours, data on the structure of proteins that would once have taken weeks or months. While structural biology is their most important application, synchrotrons are useful in many other areas, such as nanotechnology and materials science.

Synchrotrons allow complex protein structures to be determined quickly and are central to drug design and development. They allow further development of medical imaging technologies and the analysis of biological samples to potentially help diagnose diseases.

MEASURING CELLS

A compound light microscope can be used to examine in detail thin sections of plant and animal tissues and determine the size of the cell and its visible components. To do this, you need to determine the magnification and field of view of the microscope.

Total magnification of a microscope

The total magnification of a microscope is calculated by multiplying the magnifying powers of the objective and the eyepiece. The eyepiece (or ocular lens) of a microscope is the lens closest to the eye, and usually magnifies objects by 10 times (×10) their actual size. The other lens is the objective lens and is located on the rotating part of the microscope barrel. There are usually three or four objective lenses, each allowing for a different degree of magnification.

For example, a ×10 objective used with a ×10 eyepiece gives a total magnification of ×100.

Worked example 2.1.1

CALCULATING TOTAL MAGNIFICATION OF A MICROSCOPE

Determine the total magnification of a compound light microscope if a ×10 ocular lens and a ×10 objective lens were used.	
Thinking	**Working**
Determine the magnification of the ocular lens by reading the markings on the outside of the eyepiece.	Ocular lens = ×10
Determine the magnification of the objective lens by reading the markings on the outside of the lens.	Objective lens = ×10
Multiply the ocular lens by the objective lens to calculate the total magnification	Total magnification = 10 × 10 = ×100

➤ Try yourself 2.1.1

CALCULATING TOTAL MAGNIFICATION OF A MICROSCOPE

Calculate the total magnification of a light microscope if a ×10 ocular lens and a ×40 objective lens were used.

Field of view and size of specimens

To estimate the size of specimens viewed, you need to calculate the field of view under the microscope. Also, all biological drawings require a scale. You can measure the initial field of view by using a stage micrometer slide, which is a minigrid on a microscope slide, as shown in Figures 2.1.17 and 2.1.18.

The minigrids or micrometers can be moved so that the edges of the grid lines are against the side of the field of view (circle of light visible when looking through the ocular lens). Then you can count the number of divisions across the field of view and measure the diameter of the circle of light visible.

If you change the field of view (what you see) by doubling it, then the magnification decreases by half; that is, you see more (field of view) but you see it in less detail.

If you change the field of view by halving it, then the magnification increases twofold; that is, you see less, but you see it in more detail (Figure 2.1.19).

Increase field of view = decrease magnification
Decrease field of view = increase magnification

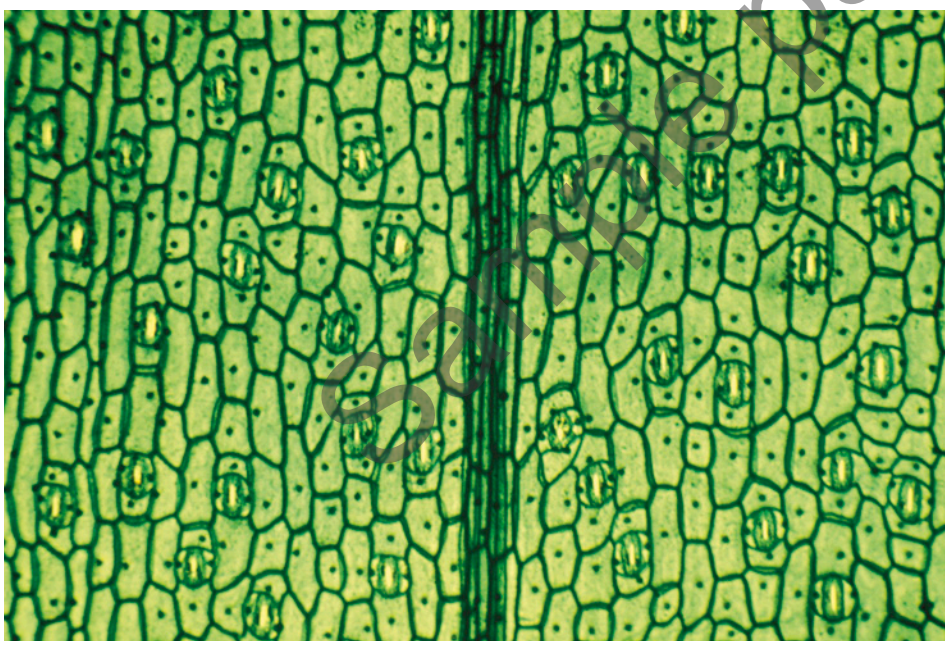
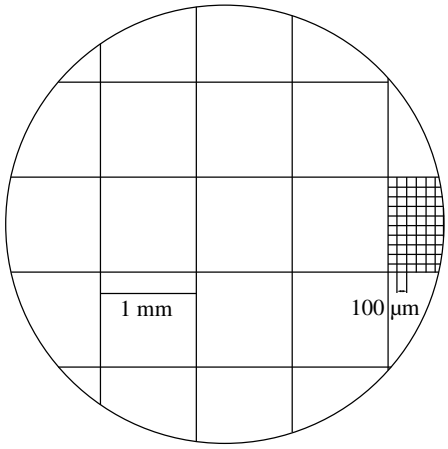


FIGURE 2.1.19 Leaf epidermis cells under a high power lens (×40). The field of view is 450 µm. There are about 30 cells across the field of view, so the average width of a leaf epidermis cell is 450/30 = 15 µm.



Field of view = 4000 µm + 600 µm
= 4600 µm
= 4.6 mm

FIGURE 2.1.17 The field of view of this microscope using the ×4 lens is 4.6 mm (or 4600 µm). You can work this out by using the minigrid.

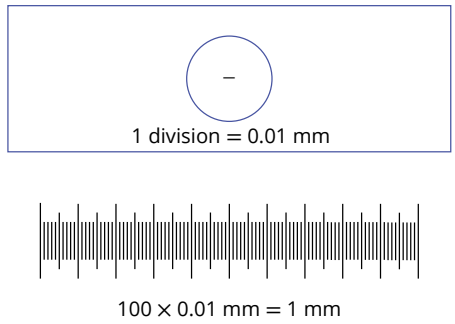


FIGURE 2.1.18 A stage micrometer slide for determining field of view

School microscopes typically have the following magnifications and fields of view. Microscopes usually have ×10 eyepieces. The total magnification is the product of the eyepiece and objective lenses.

Objective lens	Total magnification	Field of view
×4	×40	4.5 mm
×10	×100	1.5 mm
×40	×400	450 µm
×100	×1000	150 µm

SKILLBUILDER

Measuring the field of view

To measure the field of view, follow these steps.

1. Place the micrometer grid on the microscope stage.
2. Focus using the ×4 objective lens so that you can see the grid clearly. Record this in Table 2.1.3.
3. Adjust the micrometer grid position so that it is in the field of view.
4. Adjust the slide position so that one line is on the edge of the field of view, as shown in Figure 2.1.17.
5. Count the grid lines across and estimate the diameter of the circle you see. On the lowest magnification, the field of view should be about 4.5 mm or 4500 µm.
6. Change to the ×10 objective lens and estimate the size again. The field of view should now be about 1.5 mm or 1500 µm. You should be able to use the microgrid to measure the exact distance across the field of view.
7. Move the microgrid to the centre of the field of view.
8. Focus on the microgrid using the ×40 objective lens, remembering that the microgrid lines are 100 µm apart. The field of view on high power should be about 450 µm.

TABLE 2.1.3 Measurement of field of view for three different magnifications

Microscope magnification	Field of view diameter

Worked example 2.1.2

DETERMINING FIELD OF VIEW

Thinking	Working
Calculate the total magnification at low power.	Magnification = ocular lens × objective lens = 10 × 4 = ×40
Calculate the total magnification at high power.	Magnification = ocular lens × objective lens = 10 × 40 = ×400
Measure the field of view using the stage micrometer at the lowest magnification.	Field of view = 4.5 mm = 4500 µm at low power
Increase the magnification of the image by changing the objective lens. Calculate the ratio between the initial magnification and the new magnification.	Ratio = $\frac{\text{high power}}{\text{low power}}$ = $\frac{400}{40}$ = 10
Reduce the field of view under high magnification by the same ratio.	If magnification has increased by 10 times, then field of view has reduced by 10 times. New field of view = $\frac{4500}{10}$ = 450 µm

It is important to measure the field of view every time you use a different microscope because there are differences between microscopes, which affect the estimates of the size of specimens. Once you have calculated the field of view for each lens, you can estimate the size of a whole specimen or the size of individual features, such as cells.

Knowing the field of view, you can estimate the size of the specimen. For example, if you are looking at a transverse section of a leaf and you can see exactly half of the leaf under extra low power, then you can estimate that the leaf is 2×4.5 mm = 9 mm long.

If you wish to calculate the size of the individual cells in the leaf, then you can count the number of cells across the high power field of view, as shown in Figure 2.1.19.

When measuring specimens, it may also be possible to use an eyepiece graticule. This apparatus is placed in the microscope eyepiece. The image appears as a transparent scale (usually with 100 divisions) at the same time as the specimen on the microscope slide. Before use, you must calibrate the graticule against a stage micrometer, as illustrated in Figure 2.1.20.

Determining the magnification of cells in images

We often see images of cells with an indication of the magnification scale beside them, as shown in Figure 2.1.21. Magnification refers to the number of times an image is larger than the original. This can be calculated using the formula:

$$\text{magnification} = \frac{\text{observed size of image (measured with a ruler)}}{\text{actual size (before magnification, usually in μm)}}$$

$$\text{or } M = \frac{I}{A}$$

SKILLBUILDER

Calibrating a graticule

To calibrate a graticule, follow these steps.

1. Superimpose the two images of the eyepiece graticule and the stage micrometer.
2. Determine the ratio between the graticule scale and the stage micrometer. 100 units of the graticule is equivalent to 0.25 mm on the stage micrometer. Therefore, each division of the eyepiece is $\frac{0.25}{100} = 0.0025$ mm or 2.5 μm.
3. Place the specimen slide on the stage and use the eyepiece graticule to determine the size of the cells. Each cell in the diagram is about 20 eyepiece divisions in diameter. Therefore, the cell must be 20×2.5 μm or 50 μm in diameter.

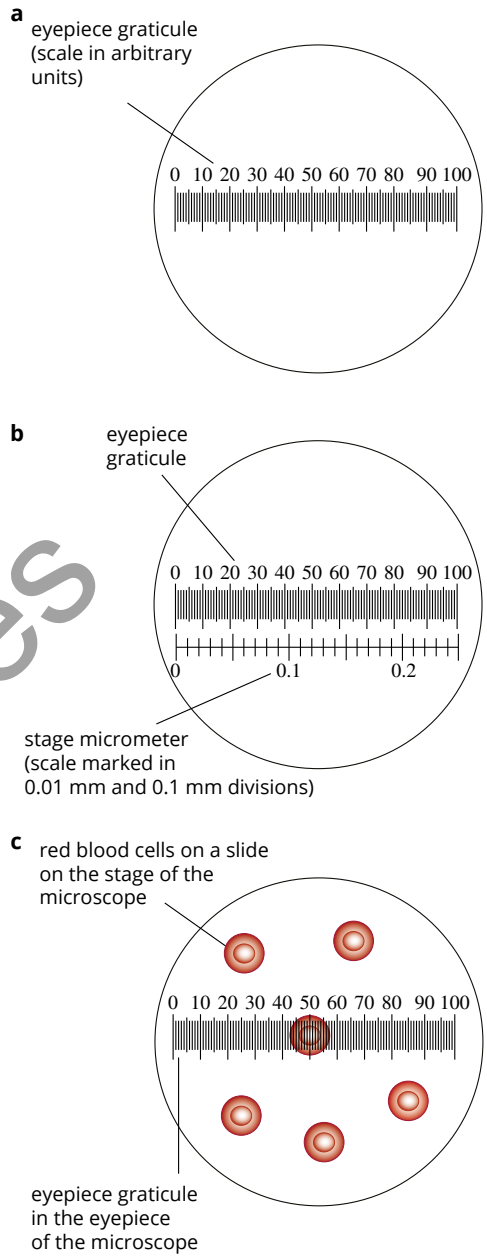


FIGURE 2.1.20 Using the eyepiece graticule and stage micrometer to determine size of specimen under a light microscope

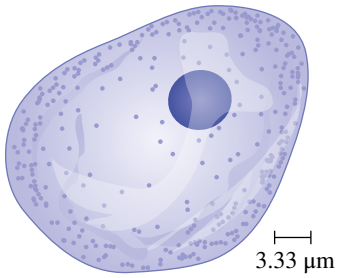


FIGURE 2.1.21 A human cheek cell, magnification unknown

Worked example 2.1.3

CALCULATING CELL SIZE USING A SCALE BAR

Calculate the length of the human cheek cell in Figure 2.1.21.	
Thinking	**Working**
Measure the scale bar.	In Figure 2.1.21, it is 0.5 cm.
Convert to µm.	Every 0.5 cm = 3.33 µm
Measure the diameter of the cell image using a ruler.	The cell is approximately 4 cm in diameter.
Convert the diameter of the cell to µm.	Actual size $= \frac{4\text{ cm} \times 3.33\text{ µm}}{0.5\text{ cm}}$ $= 26.64\text{ µm}$

➤ Try yourself 2.1.3

CALCULATING CELL SIZE USING A SCALE BAR

Calculate the length of the cell and the diameter of the contractile vacuoles in the image of the *Paramecium* in Figure 2.1.22.

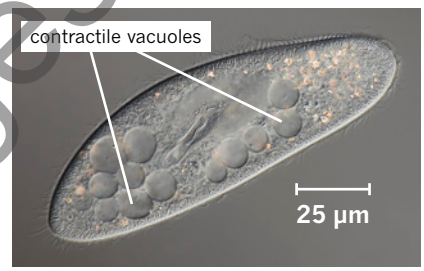


FIGURE 2.1.22 A *Paramecium* cell

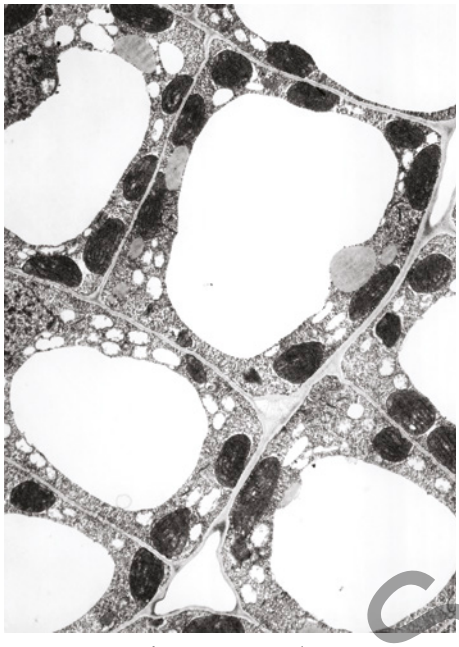


FIGURE 2.1.23 A transmission electron micrograph of mesophyll tissue (spongy tissue responsible for photosynthesis in leaves) taken from a young leaf of maize (*Zea mays*). It shows large central vacuoles (white), thin cell walls and air spaces. Each cell is about 80 µm in length.

Magnification is the number of times greater an image is than the actual object

$$\text{magnification} = \frac{\text{image size}}{\text{actual size of object}}$$

Resolution is the ability to distinguish between two objects that are very close together. The higher the resolution of an image, the greater the detail that can be seen (Figure 2.1.23).

Worked example 2.1.4

CALCULATING MAGNIFICATION OF A PHOTOGRAPH OR IMAGE

Calculate the magnification of the image in Figure 2.1.23.	
Thinking	**Working**
Remember the formula for the determination of magnification.	$M = \frac{\text{image size}}{\text{actual size}}$
Use a ruler to measure the size of the cell in the image and convert to µm.	1 mm = 1000 µm So 60 mm = 60 000 µm
Use the equation to calculate the magnification.	$M = \frac{60\,000\text{ µm}}{80\text{ µm}}$ $= \times 750$

➤ Try yourself 2.1.4

CALCULATING MAGNIFICATION OF A PHOTOGRAPH OR IMAGE

Calculate the magnification of the image of the human cheek cell in Figure 2.1.21.

CELL REQUIREMENTS FOR LIFE

Like organisms, all cells have certain requirements. All life requires a source of energy. The amount of energy required depends on the type of cell, its stage of growth, and its level of activity. Cells also require nutrients and water for growth, maintenance and repair. The nutrients are organic compounds (including proteins, carbohydrates, lipids and vitamins) and minerals. These materials, or simpler substances from which they can be made, must be obtained from the surrounding environment. Cells also require constant environmental conditions to be maintained so that they survive and reproduce. Plants can use inorganic materials from their environment to manufacture their own organic materials in the process of photosynthesis. All cells use these organic materials to produce energy in the process of cellular respiration. This relationship is shown in Figure 2.1.24.

In using energy (e.g. from monosaccharides, disaccharides and polysaccharides, lipids and proteins, all explained in Module 3.1) and carrying out the processes of growth, maintenance and repair, cells produce substances that are of no use to them or may be harmful to the cell. These waste substances (e.g. carbon dioxide, oxygen, urea, ammonia, uric acid, water, ions and metabolic heat) are often removed by releasing them into the external cellular environment. The ways that cells exchange substances with their environment depend upon the type of material being exchanged. Cells must also be able to sense and respond to changes in their internal and external environments.

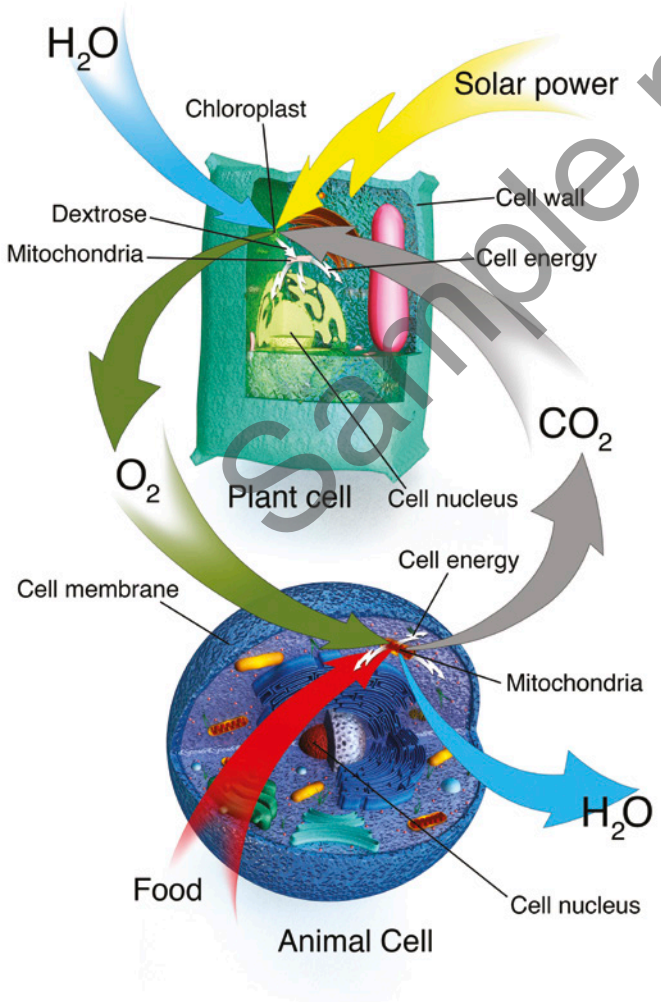


FIGURE 2.1.24 The relationship between photosynthesis and cellular respiration for the production of cellular energy in plant and animal cells

History of cell theory

Today, cells can be studied by many different types of microscopes. The two main types of microscopes are the light microscope and the electron microscope. The development of this technology over many centuries has led to our understanding of the fundamental principles of cell biology and the structure of the cell, and how the cellular processes are coordinated and controlled. Below is a brief outline of the history of cell theory, and demonstrates how our understanding of cells depends on advances in microscopy.

Hooke: the discovery of cells

The first description of cells was made by Robert Hooke in his book *Micrographia*, published in 1665. Hooke made a thin slice of cork from the bark of a tree and examined it under a very simple compound microscope he had made himself, as shown in Figure 2.1.25. He saw that the bark was made up of hundreds of little 'empty boxes', which gave it a honeycomb appearance. He called the boxes 'cells'. Hooke was looking at empty dead cells and could only see the plant cell walls with this microscope. When he later looked at fresh plant tissue, he noted the cells appeared to contain water. A few years later, Marcello Malpighi produced more detailed descriptions of plant cells.

FIGURE 2.1.25 Robert Hooke's drawing of his light microscope in *Micrographia*, published in 1665

Leeuwenhoek: first observations of living cells

In 1676, Anton van Leeuwenhoek observed many living cells under the microscope, including bacteria, blood cells and egg and sperm cells. He used compound light microscopes with improved lenses to view the cells magnified 270 times. Leeuwenhoek was the first scientist to describe the reproduction of unicellular organisms, which he called 'animalcules'. As a result of this discovery, he was able to infer that the sperm needed to enter the egg for fertilisation, questioning the theory of spontaneous generation for the formation of new organisms.

Pasteur: disproving the theory of spontaneous generation

In 1859, Louis Pasteur experimented with boiling beef broth in two flasks. Each flask had a glass 'swan-neck' (or 'goose-neck') to prevent contaminants in the air from reaching the broth (Figure 2.1.26). No microorganisms grew in either of the swan-neck flasks. When the swan neck was broken on one flask and the broth was exposed to the air, microorganisms began to grow in the broth. The unbroken flask remained free of microorganisms. Pasteur had finally disproved the theory of spontaneous generation.

Pasteur also showed that boiling and cooling wine and milk killed any microorganisms that may have been present in them. This process has been named after him and is called pasteurisation.

An important implication of Pasteur's experiment is that it provided the scientific basis for the germ theory of infection. This theory states that germs are widely present in the environment and are the cause of many diseases. Understanding germ theory eventually led to the development of antiseptic procedures in medicine.

Lamarck and Dutrochet: all living things are composed of cells

By the early 19th century, the compound light microscope had become a standard tool of biologists, and living animal and plant cells were easy to observe. In the early 19th century, Jean Lamarck stated that all living things consisted of a mass of cells, and that complex solutions move in and out of cells. René Dutrochet supported this idea, stating, 'plants are composed entirely of cells, or of organs that are obviously derived from cells ... the same is true for animals'.

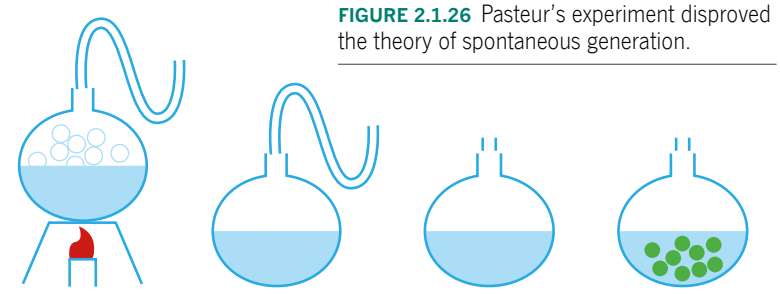


FIGURE 2.1.26 Pasteur's experiment disproved the theory of spontaneous generation.

Schleiden and Schwann: cells are organised into tissues

By the middle of the 19th century, the fundamental principle that entire organisms are composed of highly organised groups of cells was broadly accepted. This was largely due to the work of Matthias Schleiden (Figure 2.1.27) on plant tissues, and Theodor Schwann (Figure 2.1.28) on animal tissues. Working in collaboration in the 1830s, Schleiden and Schwann recognised that the organelle they had been independently studying played an important role in the development of both plant and animal cells and the formation of specialised tissue. The two scientists had been investigating the role of the nucleus and were able to identify that the cells develop or transform over time into the 'different and necessary elements of structure for the adult state'. Schwann defined the cell as containing a nucleus, fluid and a wall (even if not visible) and proposed a general cell theory that was to become the basis for our modern understanding of cell theory.

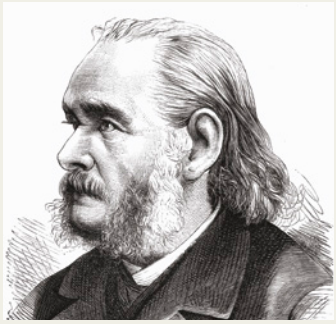


FIGURE 2.1.27 Matthias Jakob Schleiden (1804–1881)

FIGURE 2.1.28 Theodor Schwann (1810–1882)

Remak and Virchow: the theory of biogenesis

Until the 1840s, most biologists still believed that cells formed spontaneously from body fluids or from the nucleus, which they thought was the embryo of a new cell. Then Robert Remak discovered that new cells were formed by a single cell dividing in two, with the nucleus dividing at the same time, as shown in Figure 2.1.29. He did this by staining the cell membrane so the cell could be observed during cell division, proving that some cells originated from pre-existing cells. In the 1850s, Rudolph Virchow used

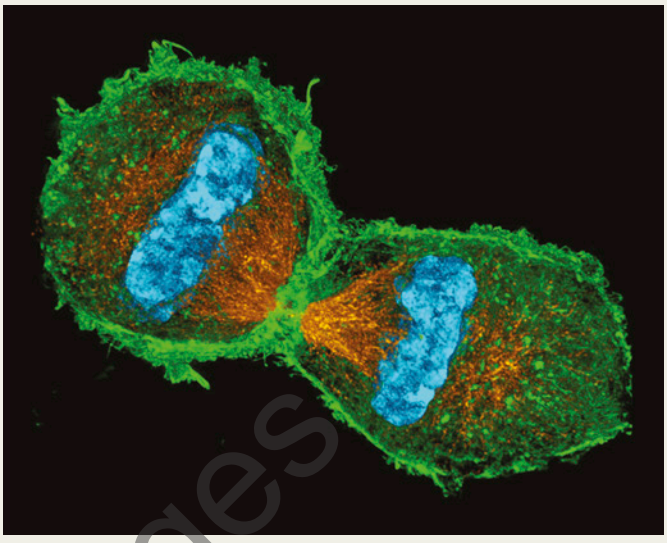


FIGURE 2.1.29 A cell dividing to form a new cell

Remak's discovery to popularise the theory of biogenesis: that all cells come from pre-existing cells. Because of Virchow's great popularity, this theory was quickly accepted in Europe, and then the rest of the world to become the third tenet in modern cell theory.

The development of cell theory over the centuries clearly illustrates how the use, development and improvement in microscope technology has influenced the evolution of scientific ideas. As microscopy techniques and lens quality improved, greater resolution and magnification of specimens was possible. This allowed new processes and structures to be observed and the development of cell theory. This process of scientific discovery continues with the development of new microscope technology such as electron microscopes and immunofluorescent microscopy to enable scientists to observe particles inside the cell at the nanoscale.

Review

1 Draw a timeline illustrating the historical development of the cell theory and the contributions of important scientists such as Hooke, Leeuwenhoek, Pasteur, Remak, Schleiden and Schwann.

2 Scientists have continued using light microscopy to observe cells despite the technological advances of electron microscopy. Discuss what advantages light microscopy has over electron microscopy and how this will continue to be of benefit for cytologists in the future.

2.1 Review

SUMMARY

- Living organisms have common characteristics and requirements—they are made of cells, are chemically complex and highly organised, exchange energy and materials with their environment, grow and reproduce, sense and respond to their environment, and show changes that are often adaptive.
- The cell theory is a fundamental principle of biology, and is based on evidence collected over the last 300 years.
- The cell theory states that:
  - all organisms are composed of cells
  - all cells come from pre-existing cells
  - the cell is the smallest living organisational unit.
- All cells have a cell membrane, cytoplasm, genetic material in the form of DNA, mitochondria and ribosomes.
- There are two fundamentally different types of cells: prokaryotic and eukaryotic.
- Cells vary greatly in size, and a microscope is needed to see most cells.
- Laboratory research techniques include microscopy.
  - The magnification of the microscope is determined by multiplying the magnification of the ocular lens by the magnification of the objective lens.
  - To calculate the field of view, you use a minigrid, and then you can estimate the size of your specimen.
- Light microscopes use visible light and a system of lenses to magnify images.
- Electron microscopes use an electron beam focused by electromagnets to view objects. They have a much higher magnification and resolution than a light microscope.

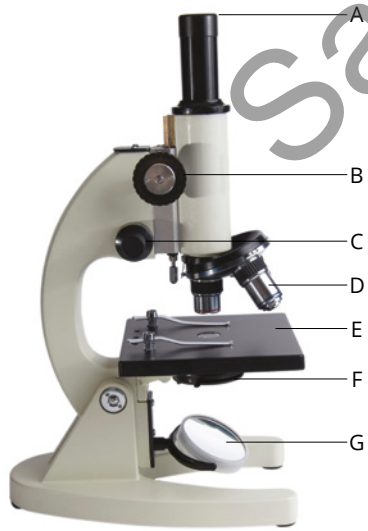
KEY QUESTIONS

Retrieval

1 State the cell theory.

2 Name three components that all cells possess.

3 Identify the parts of the light microscope labelled A–G in the following diagram.



Comprehension

4 Explain the main differences between light microscopy and electron microscopy.

5 Convert 2.5 mm (millimetres) into µm (micrometres).

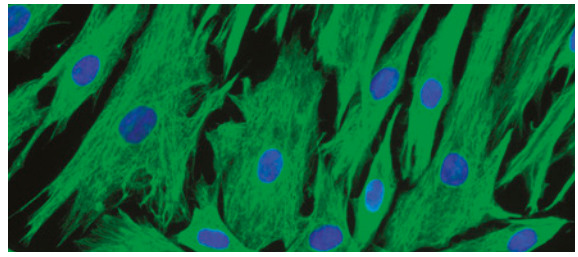
Analysis

6 Contrast prokaryotic and eukaryotic cells.

7 Compare transmission electron microscopy and scanning electron microscopy.

8 Assess how fluorescence microscopy might be used to visualise a bacterial capsule.

9 The following photo shows hair follicle cells. Deduce which type of microscope was used to take the image.



10 a Complete the following table.

Ocular lens	Objective lens	Total magnification	Field of view
×10	×4		
	×10		
	×40		
	×100		

b Determine which magnification and field of view would be best for viewing cells about:

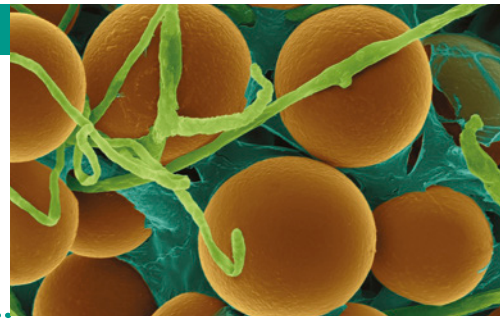
i 20 µm long

ii 0.7 mm in size.

2.2 Cell types

BY THE END OF THIS MODULE, YOU SHOULD BE ABLE TO:

- understand the difference between prokaryotic and eukaryotic cells
- understand the classification of organisms into domains and kingdoms
- understand the importance of cell compartmentalisation and specialisation in multicellular eukaryotic organisms
- identify the differences between prokaryote and eukaryote cells
- sketch and label simple cell diagrams of plant and animal cells.



The two fundamentally different cell types are prokaryotic cells and eukaryotic cells. Organisms are classified according to which cell type they have. Protists, fungi, plants and animals are composed of eukaryotic cells and are classified as **eukaryotes**. Bacteria and archaea are composed of prokaryotic cells and are classified as **prokaryotes**. Prokaryotic cells are small and lack membrane-bound organelles, but they still have a number of features in common with eukaryotic cells. Figure 2.2.1 shows typical prokaryotic and eukaryotic cells.

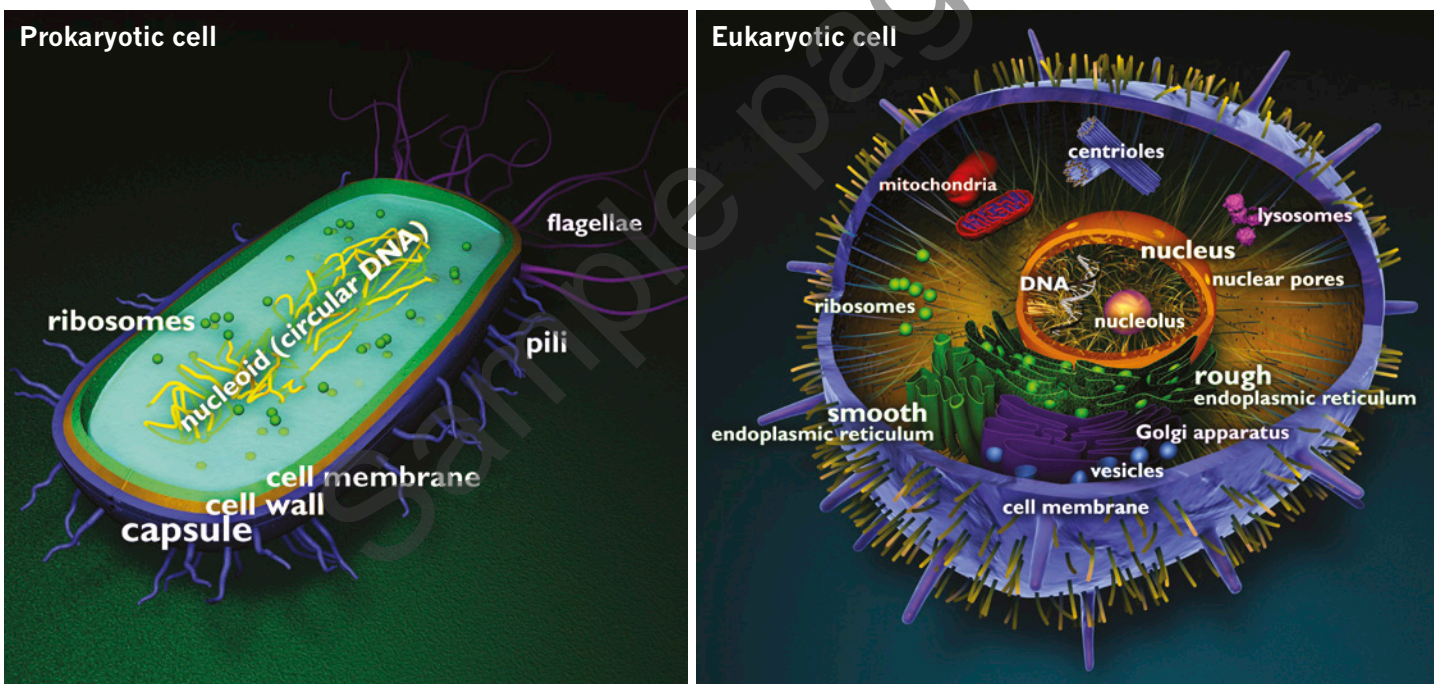


FIGURE 2.2.1 A typical prokaryotic cell and eukaryotic cell. Note the different membrane-bound organelles in the eukaryotic cell and the lack of such organelles in the prokaryotic cell.

CLASSIFICATION

In older classification systems, all organisms were divided into five ranks, called kingdoms. Prokaryotic organisms were placed in the kingdom Monera and eukaryotic organisms were placed in the kingdoms Protista, Plantae, Fungi and Animalia. These systems were based on the morphology (appearance and structure) of organisms.

However, in the late 1970s, the use of DNA techniques in the emerging field of evolutionary genetics led to the discovery of two different types of prokaryotic cells. This resulted in the development of a system with three domains and six kingdoms (Figure 2.2.2). Domains are now the highest rank in **taxonomy**, instead of kingdoms. Prokaryotes are divided into two domains: Bacteria and Archaea. All eukaryotic organisms are placed in a third domain called Eukarya. The four kingdoms within the Eukarya domain remain the same: Protista, Plantae, Fungi and Animalia. This is shown in Figure 2.2.2.

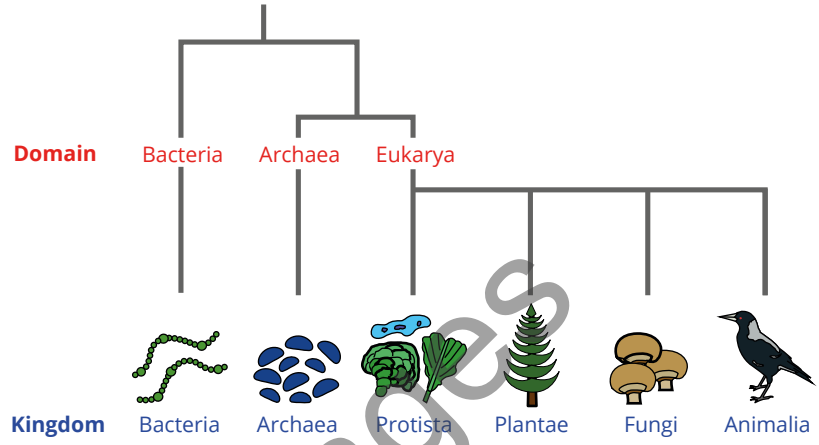


FIGURE 2.2.2 The classification of living things, showing the three domains based on cell types, and the six kingdoms. Bacteria and Archaea have prokaryotic cells. Protista, Plantae, Fungi and Animalia have eukaryotic cells.

PROKARYOTES

Prokaryotic organisms are unicellular and have a simple cell structure. Bacteria, cyanobacteria (photosynthetic bacteria) and archaea, such as methanogens, are examples of prokaryotes. Prokaryotic organisms can be found everywhere, even in extreme environments such as volcanoes.

Most prokaryotic cells are small and therefore have a large surface area relative to their volume (see Module 2.3 for a discussion of surface area to volume ratio). This allows the cells to take in and release materials efficiently and replicate quickly.

The structure of a typical prokaryotic cell is shown in Figure 2.2.3. Prokaryote cells lack membrane-bound organelles, and their cytoplasm contains scattered ribosomes that are involved in the synthesis of proteins. The genetic material of prokaryotic cells is usually a single, circular DNA **chromosome** called a **genophore**. The genophore is contained in an irregularly shaped region called the **nucleoid**. Unlike the nucleus of eukaryotes, the nucleoid does not have a nuclear membrane.

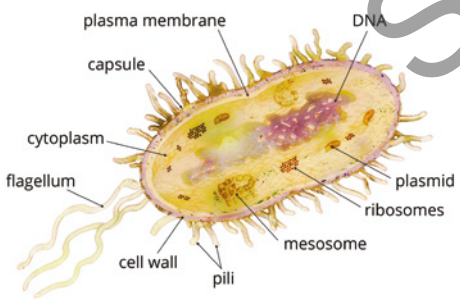


FIGURE 2.2.3 A typical prokaryotic bacterial cell

The chromosomal DNA of prokaryote cells is attached to the cell membranes by a region of the chromosome called the origin. In addition to this chromosomal DNA, many prokaryotic cells also contain small rings of double-stranded DNA called **plasmids**.

The cell membrane of prokaryotic cells is surrounded by an outer cell wall. Many bacteria also have a capsule outside the cell wall. The capsule protects the cell from damage and dehydration.

Many prokaryotes have flagella that enable them to move freely. Some also have small hair-like projections called pili, which are involved in the transfer of DNA between organisms and help movement. Specialised pili that can attach to surfaces are called fimbriae.

Bacteria

Most prokaryotes in the domain Bacteria are microscopic single-celled organisms. Fossil evidence dated at 3.5 billion years old confirms that bacteria were the first type of living organisms on Earth. Today, bacteria are still the most numerous type of organism in the biosphere.

Bacteria have very diverse metabolisms and can survive in a great range of habitats and conditions. For example, numerous species of bacteria are common in environments of moderate temperature that are moist and low in salt, where sunlight or **organic compounds** are plentiful, and in or on plants and animals.

Other species of bacteria need little oxygen to survive because they have evolved specialised chemical pathways to extract energy from their environment and manufacture complex energy-rich molecules such as carbohydrates (see Chapter 3). Bacteria can obtain energy from sunlight (photosynthesis) or by reducing **inorganic compounds** such as sulfates or ferric ions (chemosynthesis).

Bacteria play an important role in ecosystems because they break down many kinds of substances, including plant and animal remains and wastes. Bacteria are also widely used in industry to manufacture foods such as cheeses and yoghurt, and in medicine, to produce antibiotics, drugs and even human insulin. Some bacteria can break down oils and plastics, which makes them useful for pollution control.

Carbohydrates are organic compounds of carbon, hydrogen and oxygen, with the number of hydrogen and oxygen atoms in the ratio 2:1. This ratio of 2:1 is the same ratio of hydrogen to oxygen for water. Sugars and starches are examples of carbohydrates. Proteins and carbohydrates molecules sometimes combine as complex structures (peptidoglycans) to become part of the cell wall of bacteria.

Gram-positive and gram-negative bacteria

The cell walls of prokaryotes are distinctive for containing **murein** (also known as a peptidoglycan), which is a complex molecule consisting of sugars linked by **amino acids**. In most bacteria, the murein forms a cell wall in a mesh-like layer outside the cell membranes. Prokaryotic bacteria are commonly identified as either gram-negative or gram-positive depending upon the structure of their cell wall. A purple stain called crystal violet is used for this purpose.

Gram-positive bacteria have a thicker layer of murein that absorbs and holds the stain, so they give a purple or 'positive' result. Gram-negative bacteria have a much thinner layer of murein that does not retain the stain as well, so they give a pink or 'negative' result, as shown in Figure 2.2.4. The difference in colour on staining the bacterial cell wall is one way that cytologists identify the type of bacteria present in a sample. Other structural features of bacteria used for identification include their shape. Some bacterial shapes are shown in Figure 2.2.5.

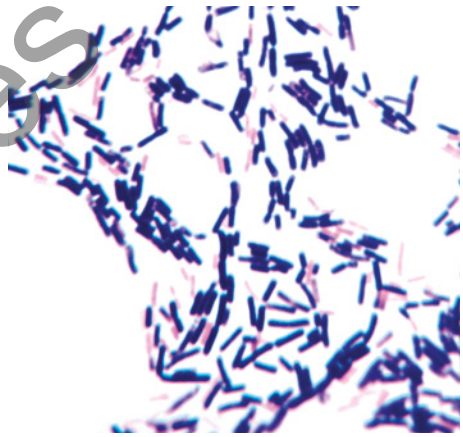


FIGURE 2.2.4 A light micrograph showing gram-positive (stained purple) and gram-negative (stained pink) bacteria

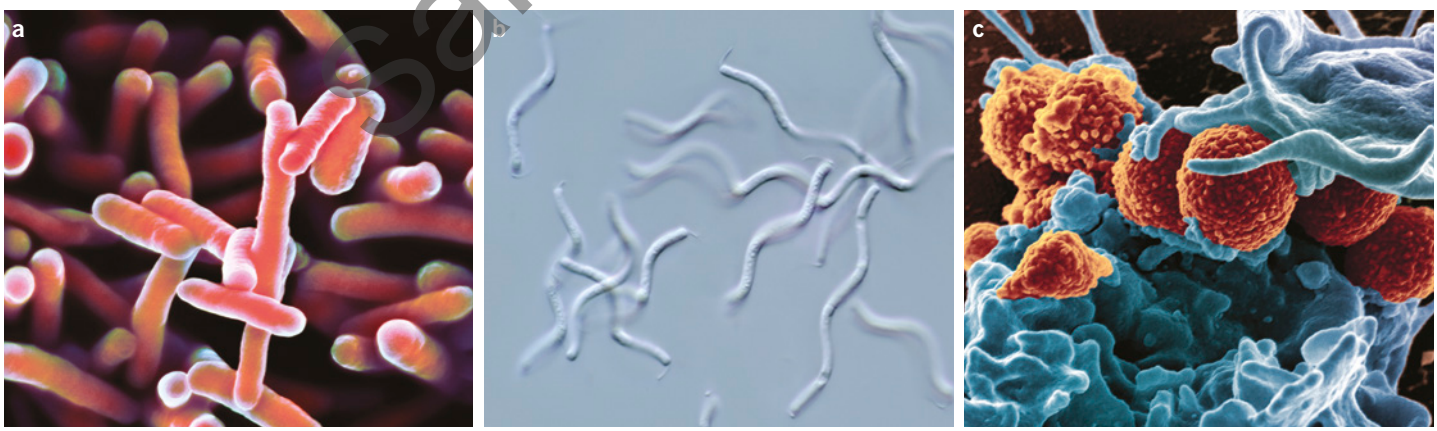


FIGURE 2.2.5 (a) A scanning electron micrograph of *Shigella dysenteria* bacteria—rod-shaped gram-negative bacteria that cause disease in humans. *Shigella dysenteria* is found in contaminated water supplies. (b) A light micrograph of a *Spirulli* species of bacteria—spiral-shaped bacteria found in marine environments. (c) A scanning electron micrograph of *Staphylococcus aureus* (commonly called 'golden staph')—spherical-shaped bacteria that cause disease in humans. Here the bacterial cells are being engulfed by a white blood cell. The bacteria are coloured orange in this image to represent their actual colour.

There are numerous types of gram-negative and gram-positive bacteria. For example, gram-positive cocci are spherical bacteria and include *Staphylococcus* (Figure 2.2.5c) and *Streptococcus*, which can cause serious diseases or death in humans. Antibiotic medicines such as penicillin have been used to treat diseases caused by bacterial infections. The different types of antibiotics are effective at preventing the formation of the murein cell wall or at disrupting other metabolic activities. You will learn more about the types of diseases and their treatments in Chapter 7.

An example of a gram-negative bacterium is a cyanobacterium, like those shown in Figure 2.2.6. Cyanobacteria were once called blue-green algae because they contain chlorophyll, but they are prokaryotes and are placed in the Bacteria domain. Cyanobacteria often form dense colonies in shallow estuaries or fresh water. Some species can form large colonies ('blooms') that produce toxins capable of killing fish and other aquatic life and cause illness in humans.

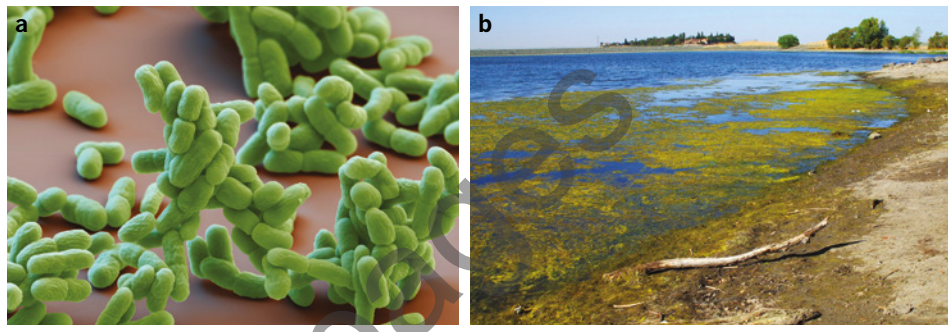


FIGURE 2.2.6 (a) A scanning electron micrograph of *Synechococcus* cyanobacteria. (b) A colony of *Synechococcus* cyanobacteria in a lake.

Archaea

The prokaryotes in the domain Archaea include **extremophiles**. These are organisms that can live in extreme conditions, such as:

- areas of high temperatures (thermophiles)
- areas of low temperatures
- the upper atmosphere
- very alkaline environments
- very acidic environments (acidophiles)
- very salty environments (halophiles)
- environments with little or no oxygen
- areas without light
- petroleum deposits deep underground.

Archaea hold records for living in the hottest places (121°C), the most acidic environments (pH 0), and the saltiest water (about 30% salt). However, some archaea live in less extreme environments, such as open seas.

The unique place of archaea among living organisms was not recognised for a long time. The main reason for this was because the extreme habitats where they live made it difficult for scientists to find archaea organisms and also to culture them in a laboratory. Another reason is that most archaea look very similar to bacteria, even though they are as different from bacteria as humans are.

The ability of archaea to live in extreme environments is partly due to their unique cell membranes. Like other living organisms, archaea possess a cell membrane composed mainly of lipids. Cell membranes need to be fluid to respond to external deformations and damage and allow proteins to move around.

The lipids in eukaryotic cell membranes have fluidity and selective permeability, but only in a narrow range of temperatures and pressure. The lipids in archaean membranes are different because they form a unique cell membrane structure.

Lipids are 'fatty' organic compounds, including fats and oils, composed mainly of carbon, hydrogen and oxygen. Lipids have proportionally less oxygen than carbohydrates, and may contain other elements. Lipids are an integral structural component of cell membranes.

The structure remains fluid and permeable over a wide range of temperatures, from freezing cold to boiling hot, and at extreme depths of the ocean floor.

There are many different types of extremophiles. Hyperthermophiles such as *Pyrococcus furiosus*, which is shown in Figure 2.2.7, can survive in very hot environments such as undersea vents, where temperatures are often above 100°C. *Pyrococcus* can also thrive under high pressure—they are barophilic. This means they can withstand the extremely high pressure at the ocean floor. *Sulfolobus* species, which live in volcanic springs, are thermophiles as well as acidophiles—they can survive both high temperatures and high acidity. You can see *Sulfolobus* in Figure 2.2.8. Extremophiles have evolved many unique adaptations to ensure their continued existence in environments where most organisms are not able to survive.

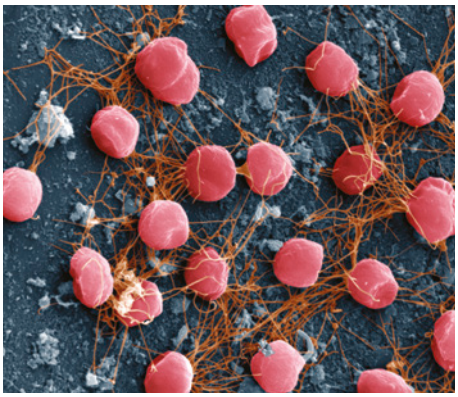


FIGURE 2.2.7 A scanning electron micrograph of hyperthermophile *Pyrococcus furiosus*. *Pyrococcus* can only exist in very hot environments such as hot undersea vents.

Differences between bacteria and archaea

Despite their name, archaea are not the most ancient group of organisms. DNA studies have shown that bacteria are the most ancient group. The evolutionary relationship between archaea, eukaryotes and bacteria remains unclear. While archaea and gram-positive bacteria share many structural features and metabolic pathways, suggesting a common ancestor, many other archaea genes are more similar to the genes found in eukaryotic cells.

The cells of bacteria and archaea are different in a number of ways.

- Archaea have a different type of lipid structure in the cell membranes.
- Bacterial cell walls contain murein; archaean cell walls do not contain murein (although there is a similar compound in some archaea).
- Both have diverse metabolic systems, but methanogenesis (in which methane is produced) is unique to archaea.

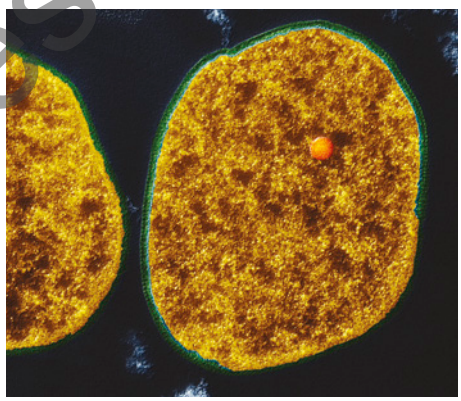


FIGURE 2.2.8 *Sulfolobus* are thermophiles as well as acidophiles. They thrive in hot, acidic environments.

EUKARYOTIC CELLS

Eukaryotic cells are relatively large and more complex than prokaryotic cells. They possess membrane-bound organelles such as a nucleus and mitochondria. Protists, fungi, plants and animals are called eukaryotes because they are composed of eukaryotic cells.

As well as a cell membrane surrounding the cytoplasm, eukaryotes have internal membranes that form specialised compartments within the cell. This is known as **cell compartmentalisation**. The membrane-bound compartments are organelles, which are specialised structures that have specific functions, as shown in Figure 2.2.9. However, not all organelles have membranes; for example, ribosomes and centrioles.

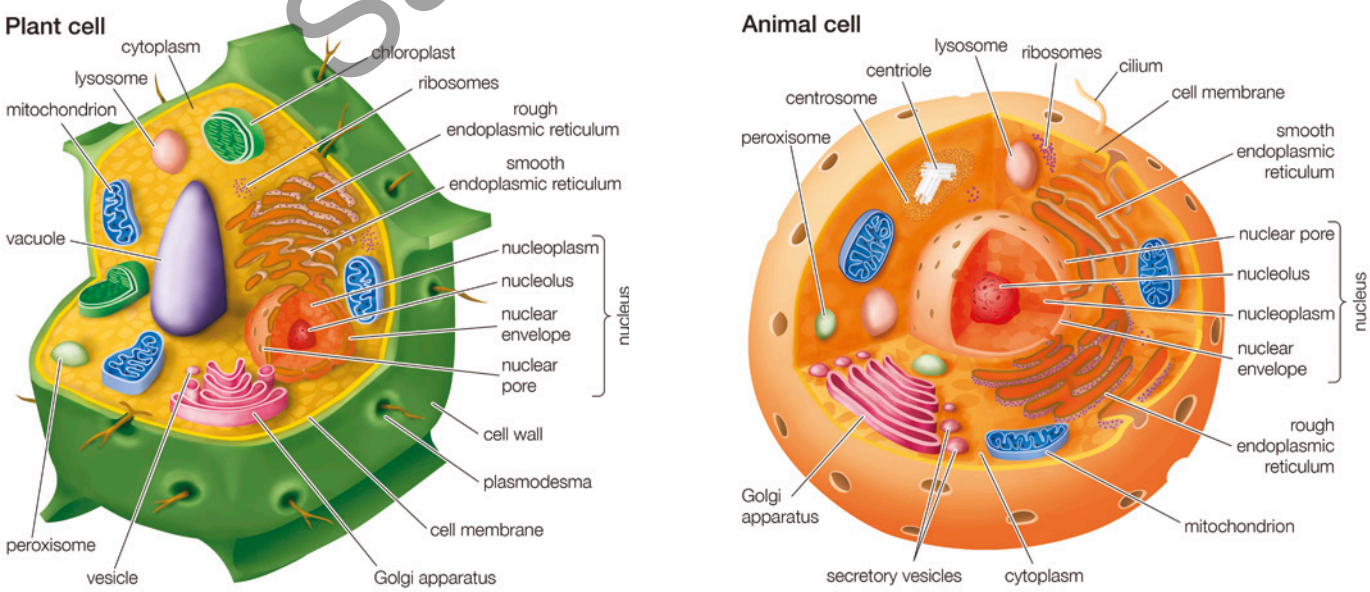


FIGURE 2.2.9 The many membrane-bound organelles of eukaryotic cells can be seen in these illustrations of a plant cell and an animal cell.

COMPARISON OF PROKARYOTIC AND EUKARYOTIC CELLS

There are a number of differences between prokaryotic and eukaryotic cells (Table 2.2.1). In eukaryotic cells, the DNA is contained in the nucleus, in the form of linear chromosomes. Their cytoplasm contains many different membrane-bound organelles. Some eukaryotic cells are surrounded by a cell wall composed of carbohydrates. You can identify the nucleus, cytoplasm and organelles in the diagram of typical eukaryotic cells illustrated in Figure 2.2.10.

TABLE 2.2.1 Comparison of prokaryotic and eukaryotic cells

Feature	Prokaryotic cells	Eukaryotic cells
Size	• Very small	• Larger, with large variation in size
Surface area to volume ratio (SA:V)	• Large • Allows materials to diffuse in and out of the cell rapidly	• Smaller • Results in slower diffusion
Membrane-bound organelles	• Absent	• Many organelles bound by membranes, forming an organised internal structure
Chromosomal DNA	• DNA chromosome in the form of a single-stranded loop • Located in a region of cytoplasm called the nucleoid, lacking a membrane	• DNA in the form of linear, thread-like chromosomes • Located in the nucleus, which is separated from the cytoplasm by a double-layered membrane
Ribosomes	• Many tiny ribosomes scattered in the cytoplasm	• Many ribosomes, either attached to the endoplasmic reticulum, or free in the cytoplasm
Cell membrane	• Bilayer of phospholipid molecules enclosing the cytoplasm in bacteria • Phospholipids are different and sometimes fuse into a monolayer in archaea	• Bilayer of phospholipid molecules enclosing the cytoplasm
Cell wall	• In bacteria, consists of a protein–carbohydrate compound called murein	• Present in fungi, plants and some protists • Consists mainly of carbohydrates: chitin in fungi and cellulose in plants
Flagella	• May have flagella to provide movement • Consist of three protein fibrils coiled in a helix and protruding through the cell membrane and wall	• May have flagella or cilia for motility (but not in fungi) • Consist of a highly organised array of microtubules (hollow protein tubes) enclosed by the extended cell membrane

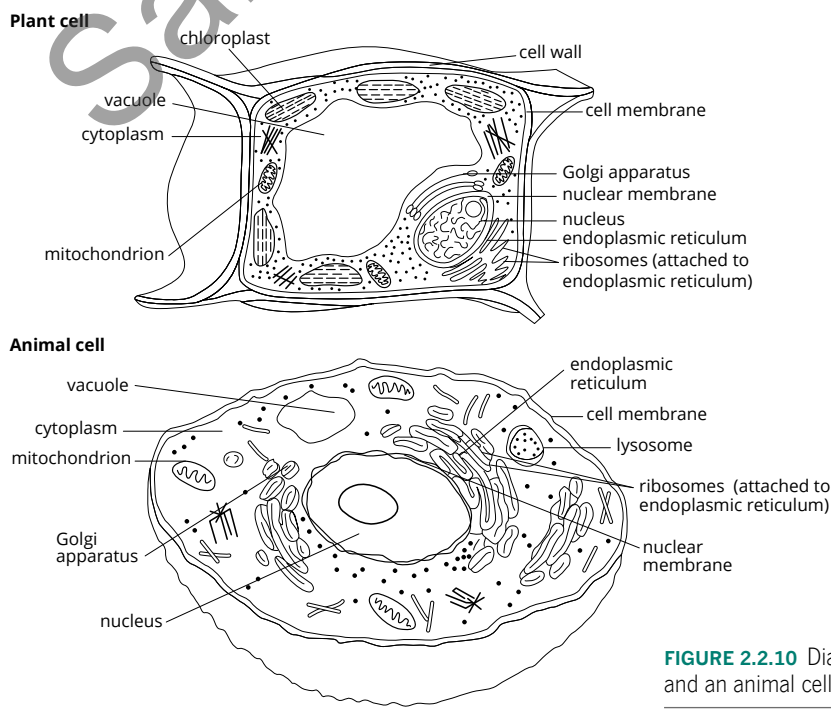


FIGURE 2.2.10 Diagram of a typical plant cell and an animal cell, showing major organelles

Each membrane-bound organelle has a different function, so each organelle requires a different internal composition, including a high concentration of enzymes and reactants.

Role of organelle membranes

The membranes surrounding organelles control the movement of substances between the organelle and the cell's cytosol. Just as cell membranes enable the cytosol to have a different composition from the cell's surrounding environment, membrane-bound organelles can have a different composition from the surrounding cytosol and other organelles. Because the environment on either side of the membrane is regulated, different types of biochemical reactions can occur in each region. Therefore, the metabolic reactions performed within the cells can occur efficiently within regions of optimal environmental conditions. The role of membranes to regulate cell function will be explored in Module 2.4.

Benefits of compartmentalisation

Cellular compartmentalisation benefits the cell in several ways. It:

- allows enzymes and reactants for a particular function to be close together in high concentrations and under the right conditions, such as optimum pH levels, so that the processes within the organelles are very efficient
- allows processes that require different environments to occur at the same time, in the same cell
- makes the cell less vulnerable to changes in its external environment, because changes affect the cytosol much more than the membrane-bound organelles such as mitochondria or chloroplasts.

Cell specialisation

In unicellular organisms, one cell must perform all functions. However, in multicellular organisms, such as animals and plants, there are many different types of cells, each with their specialised function. Muscle cells and red blood cells in mammals, and palisade cells in plants, are examples of specialised cells. These are shown in Figure 2.2.11.

Enzymes are proteins that act as biological catalysts. Enzymes speed up rates of biochemical reactions that would otherwise take place much more slowly. Their action is specific: they catalyse (cause or accelerate) only one type of reaction. You will learn more about enzymes and the factors affecting enzyme activity in Chapter 3.

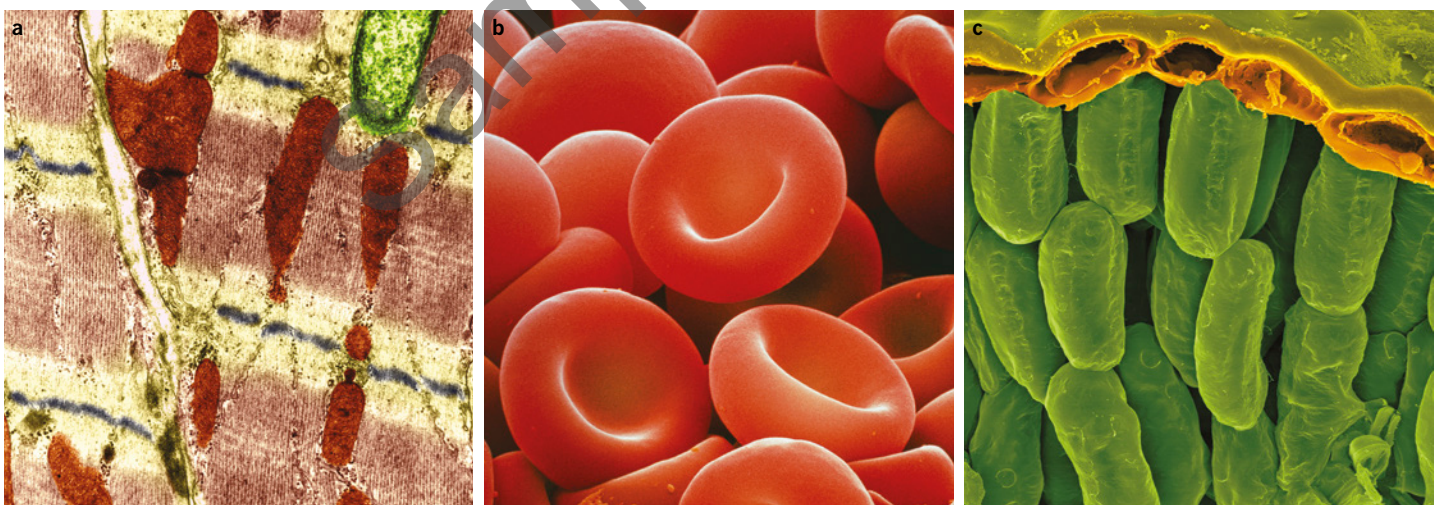


FIGURE 2.2.11 (a) A coloured transmission electron micrograph of a human heart muscle cell. (b) A coloured scanning electron micrograph of human red blood cells. (c) A coloured scanning electron micrograph of a cross-section of a rosemary leaf, showing palisade cells.

All the cells of an organism contain the same genetic instructions. During the early development of a multicellular organism, all of its cells look similar. As the organism develops, cells differentiate to become structurally and functionally distinct and produce different proteins and enzymes. The various proteins present in different cells arise from differences in the pattern of gene activity—certain genes are 'switched on' and others are 'switched off'. This is illustrated in Figure 2.2.12. Differentiated cells are said to be specialised. You will learn more about the process of cell specialisation in Chapter 4. Biologists have determined that certain proteins bind to some genes so that they are not 'switched on'.

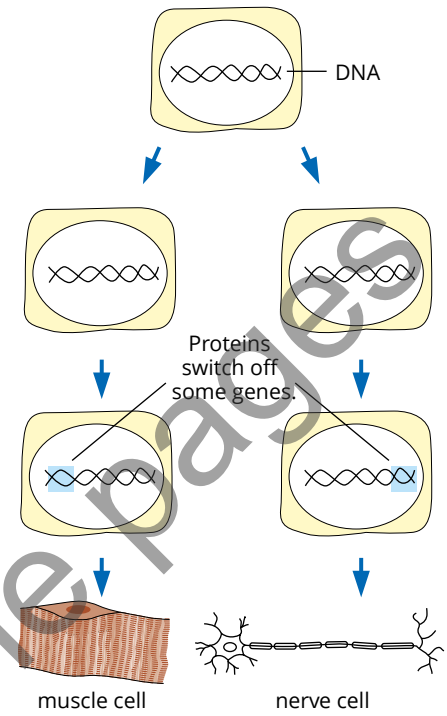


FIGURE 2.2.12 Cell differentiation occurs because different genes become active, and others become inactive, and produce the different types of cells, which are then specialised.

Cell specialisation is found in all multicellular organisms. Cells are more efficient if they carry out a single function rather than many functions. A nerve cell is specialised to carry signals rapidly across large distances. It could not do this if it also had to break down food to obtain nutrients or protect against disease.

Plants have cells specialised for photosynthesis, exchange, transport, strength and protection. Animal cells are specialised to conduct messages, to provide protection, movement and support, and for exchange and transport. The human body is composed of more than 200 different types of cells.

2.2 Review

SUMMARY

- There are two fundamentally different types of cells—prokaryotic and eukaryotic.
- Organisms with prokaryotic cells are called prokaryotes. They are classified into two domains: Bacteria and Archaea.
- Organisms with eukaryotic cells are called eukaryotes. They are classified into the domain Eukarya, which is divided into four kingdoms: Protista, Fungi, Plantae and Animalia.
- Prokaryotic cells have a simple structure, with a nucleoid lacking a membrane, scattered ribosomes, and DNA mainly in a single-stranded loop in the nucleoid.
- Eukaryotic cells have a complex structure, membrane-bound nucleus, many organelles in the cell cytoplasm, and DNA mainly in chromosomes in the nucleus.
- Archaea (the extremophiles) are often found in very harsh environments where their unique cell membrane structure protects them.
- Compartmentalisation in eukaryotic cells:
  - allows enzymes and reactants to be concentrated in particular organelles of the cell
  - maintains the right conditions for enzymes and reactants to function
  - allows incompatible chemical reactions to take place simultaneously within the cell
  - reduces the cell's vulnerability to environmental changes.

KEY QUESTIONS

Retrieval

1 Describe the differences between prokaryotes and eukaryotes.

2 Identify which kingdoms contain organisms that are composed of eukaryotic cells. Recall some examples from each kingdom.

Comprehension

3 Draw and label a typical plant and animal cell.

4 Explain what is meant by 'cell specialisation'.

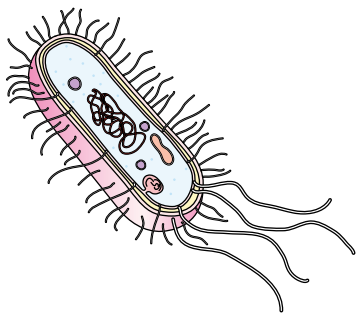
5 Explain what is meant by 'cell compartmenalisation'.

Analysis

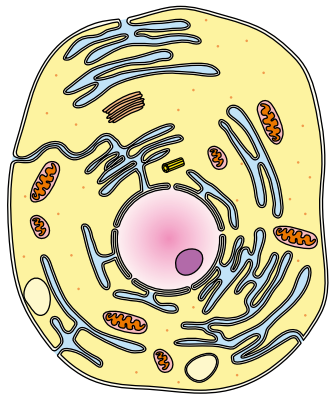
6 The following diagrams are of two cells observed with an electron microscope.

a Describe evidence that cell A is prokaryotic.

b Describe evidence that cell B is eukaryotic.



cell A (4500×)



cell B (3000×)

Investigating surface area to volume ratio

Research and planning

Aim

To investigate the surface area to volume ratio of cells and link to the understanding that cells are limited by their ability to efficiently transport materials across the cell membrane.

Rationale (scientific background to the experiment)

All cells are surrounded by a cell membrane. The cell membrane is a semipermeable barrier that controls the movement of substances into and out of the cell. Movement across the cell membrane is two-directional, and occurs via diffusion, osmosis or active transport.

Generally, the larger the volume of a cell, the larger the surface area. Surface area to volume ratio (SA:V) is a measure of these two factors combined. Smaller cells usually have a larger surface area compared to their volume. This allows cells to move molecules across their cell membranes in an efficient manner. It also explains why single-celled organisms are limited in their size.

The 'pink agar' cubes are models of cell size. They have been prepared using sodium hydroxide and phenolphthalein. Phenolphthalein is an indicator that is pink in alkaline solutions and turns colourless in neutral and acidic solutions. The pink agar turns clear in the presence of sulfuric acid, which is evidence of diffusion.

Timing

60 minutes

Materials

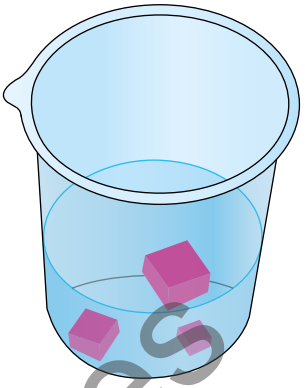
- 3 'pink agar' cubes of the following dimensions: 1 cm^3, 2 cm^3, 3 cm^3
- 100 mL of 0.1 mol L^{-1} sulfuric acid
- cutting board and knife
- ruler with millimetre increments
- plastic spoon
- 250 mL glass beaker
- paper towelling
- timer

Method

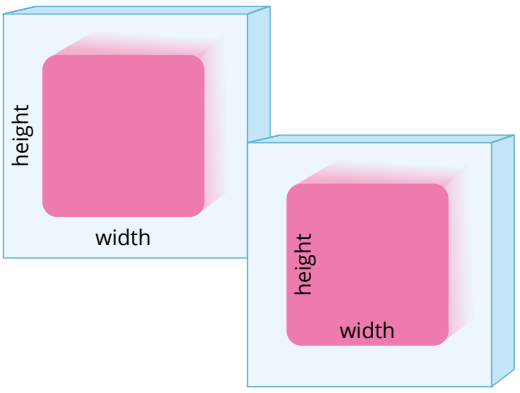
Risk assessment

Assessment of risks include chemical hazards and physical hazards. Before you commence this practical activity, you must conduct a risk assessment. Complete the template in your Skills and Assessment book or download it from your eBook.

1. Put on disposable gloves, a lab coat and safety glasses.
2. Gently place each of the three agar cubes in the beaker and cover them with sulfuric acid.



3. Set the timer for 10 minutes.
4. Every 2 minutes, gently turn the agar cubes to ensure even exposure to the acid.
5. At the end of the 10 minutes, gently remove the agar cubes with the spoon and blot onto paper towel to remove excess acid.
6. Cut each cube open and measure the height and width of the remaining pink prism. Assume that the length is the same as the height measurement. It is important to work efficiently at this point as diffusion will continue to occur.



7. Calculate the surface area to volume ratio of each cube.
8. Calculate the rate of diffusion in each cube.

Variables

i. Independent: the volume of the cube
ii. Dependent: the rate of diffusion
iii. Controlled: concentration of sulfuric acid, temperature, time of exposure to acid, amount of stirring

Analysing

Raw data

1 Complete the following table. In the final column, calculate the SA:V so that the volume ratio is 1.

Length of each side of cube (cm)	Surface area (SA) (cm^2)	Volume (V) (cm^3)	SA:V	SA:V, where V is 1
10	$6 \times 10^2 = 600$	$10^3 = 1000$	600:1000	0.6:1
3				
2				
1				
0.1				

Note: 10 cm and 0.1 cm cubes are for comparison only.
Guide to calculations:
- surface area = length × width × number of sides
- volume = length × width × height

Processed data

2 Calculate the percentage of each block that has been reached by the diffusion of acid.

Cube	Dimensions of coloured prism remaining (length, width, height) (cm)	Volume of coloured prism remaining (X) (cm^3)	Volume of whole cube (Y) (cm^3)	Volume of uncoloured portion ($Y - X$) (cm^3)	% of cube uncoloured ($\frac{Y-X}{Y} \times 100$)
3 cm					
2 cm					
1 cm					

➤ Reflect and check that your data analysis demonstrates these characteristics

- ☐ Effective investigation of phenomena is demonstrated by the collection of sufficient and relevant raw data
- ☐ Accurate application of algorithms, visual and graphical representations of data is demonstrated by appropriate processing and presentation of data to aid the analysis and interpretation of data

Analysis

3 Create a new table that shows the relationship between SA:V and percentage of cube uncoloured for each cube.
Compare the percentages of cube uncoloured you obtained with those of three other groups.

a Explain why the results should be similar for each group.

b If a group did not obtain similar results, suggest a reason for this.

4 Identify two potential errors encountered in the procedure. Suggest how these could be minimised if the procedure were modified.

➤ Reflect and check that your analysis demonstrates these characteristics

- ☐ Systematic and effective analysis of evidence is demonstrated by a thorough and appropriate error analysis
- ☐ Systematic and effective analysis of evidence is demonstrated by a thorough identification of relevant trends, patterns and relationships
- ☐ Insightful and valid interpretation of evidence is demonstrated by drawing a valid and defensible conclusion based on the analysis

Interpreting and communicating

Conclusion

1 State the relationship between surface area to volume ratio and rate of diffusion.

2 Outline the data that you have collected that supports this conclusion.

3 Explain why cells are limited in their ability to grow larger over time.

Evaluation

4 Identify at least one assumption that this activity makes about the shape of cells.

5 Explain whether the potential errors you identified above had a significant effect on your conclusions. In other words, do you consider the level of uncertainty caused by the potential errors reasonable?

Improvements

6 If you were to repeat this experiment, identify the steps that you would do differently. Consider how you could:

a change the methodology

b improve your technique

c reduce error and uncertainty.

Extension

7 If a single-celled organism, such as an amoeba, were to split in half, thus reducing the volume of each compared to the original, what would happen to the SA:V ratio of each new cell compared to the original?

8 In general, motile animal cells are significantly smaller than plant cells. Using the evidence collected in this activity, suggest why.

9 Investigate the cells that line the small intestine. Name the extensions that increase the SA:V ratio. Explain the purpose of these cells in relation to the role of the small intestine.

➤ Reflect and check that your evaluation demonstrates these characteristics

- ☐ Critical evaluation of processes is demonstrated by a discussion of the reliability and validity of the experimental process supported by evidence such as the quality of the data (as quantified in the error analysis)
- ☐ Critical evaluation of the conclusion is demonstrated by a discussion of the veracity of the conclusions with respect to the error analysis and limitations or sufficiency of the data
- ☐ Insightful evaluation of processes and conclusions is demonstrated by a suggestion of improvements or extensions to the experiment which are logically derived from the analysis of the evidence

MP 2

Observing cells

Research and planning

Aim

- To view different examples of cells under the light microscope and further understand cell structure and specialisation.
- To practise calculating total magnification, field of view and cell size.

Rationale (scientific background to the experiment)

Cells are the basic building blocks of life. Whether it is a unicellular organism or a complex multicellular organism, all cells have some common features. At the most basic level this includes a cell membrane, cytoplasm, DNA and ribosomes.

Cells are generally classified broadly into prokaryotes and eukaryotes. Eukaryotes are often grouped as either plant or animals cells. In this practical activity, you will view a range of plant and animal cells. Consider how the cells are both similar and specialised to allow each particular cell type to perform a specific role within the organism. You will also calculate the total magnification and field of view to determine cell size.

Timing

60 minutes

Materials

- light microscope
- microscope lamp
- micrometer grid
- teat pipette
- toothpick
- mounted needle
- small beaker of water
- white tile
- scalpel
- glass microscope slides and coverslips
- paper towel
- onion segment
- small piece of banana
- iodine stain in dropper bottle
- tweezers
- sample *Elodea* plant
- prepared slides of human cheek cells, human blood, mammalian nerve cell/s, and any other cell types available.

Method

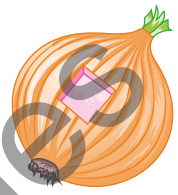
Risk assessment

Assessment of risks include chemical hazards and physical hazards. Before you commence this practical activity, you must conduct a risk assessment. Complete the template in your Skills and Assessment book or download it from your eBook.

Part A Preparing slides

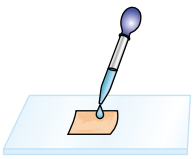
Onion cells

1 Cut off a thin piece of onion.

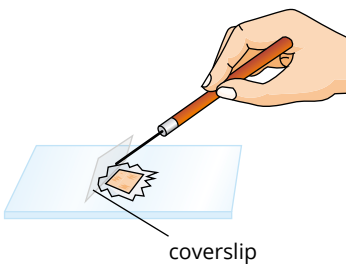


2 Use the tweezers to peel a very thin layer of epidermis (this looks like tissue paper).

3 Place the sample on a clean glass slide and flatten it as much as possible. Add a single drop of iodine.



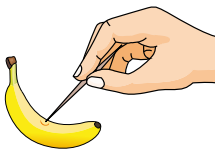
4 Gently lower the coverslip onto the slide, using a mounted needle. Try to minimise any air bubbles. Blot any excess stain at the edge of the coverslip as required.



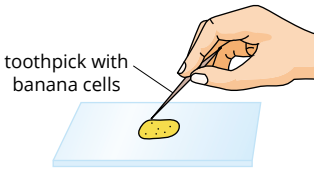
5 Set the sample aside until you are ready to view it under the microscope.

Banana cells

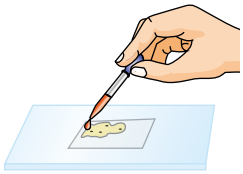
6 Smear some banana on the toothpick.



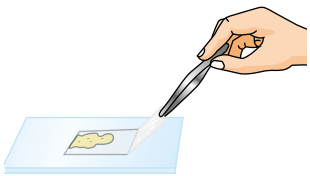
7 Put the banana cells on a clean glass slide.



8 Add a single drop of iodine solution and cover with a glass coverslip.



9 Blot any excess stain at the edge of the coverslip as required.



10 Set the sample aside until you are ready to view it under the microscope.

***Elodea* cells**

11 Select a small, thin leaf from the *Elodea* plant.

12 Place the leaf gently onto a glass slide and cover it gently with a coverslip.

13 Set the sample aside until you are ready to view it under the microscope.

Part B Viewing and drawing slides under the light microscope

14 Set up your microscope on the workbench.

15 Calculate the field of view diameter using the ×4, ×10 and ×40 objective lenses.

16 View each of the slides (those that you prepared and also the pre-prepared ones).

17 Sketch two or three cells accurately, showing the position of the cells in relation to each other. Try to select cells that are not overlapping one another.

18 Include the magnification and a scale of size for each sketch.

19 Note and label the visible organelles within each cell. For the slide of human blood, try to identify the different cell types.

Analysing

Raw data

1 Complete the table.

Microscope magnification	Field of view diameter

Processed data

2 Sketch two or three cells for each slide. For each diagram, include: slide title, magnification, scale, labelled organelles.

➤ Reflect and check that your data analysis demonstrates these characteristics

- ☐ Effective investigation of phenomena is demonstrated by the collection of sufficient and relevant raw data
- ☐ Accurate application of algorithms, visual and graphical representations of data is demonstrated by appropriate processing and presentation of data to aid the analysis and interpretation of data

Analysis

3 Explain why it is important that the specimens used to prepare a slide are as thin as possible.

4 List any organelles you did not see. Explain why you did not see these organelles.

5 Plant cells often contain chloroplasts. Suggest why chloroplasts were present in the *Elodea* cells but absent from the banana and onion.

6 Account for why chloroplasts tend to be found around the outer edge of the *Elodea* cells.

7 Suggest why bananas show a large number of leucoplasts in the cells of the fruit.

8 Suggest how the shape of a typical nerve cell (or neuron) enables it to communicate messages within the nervous system.

9 Mature human red blood cells lack a nucleus. Propose why. Summarise the role of red blood cells within the body.

➤ Reflect and check that your analysis demonstrates these characteristics

- ☐ Systematic and effective analysis of evidence is demonstrated by a thorough and appropriate error analysis
- ☐ Systematic and effective analysis of evidence is demonstrated by a thorough identification of relevant trends, patterns and relationships
- ☐ Insightful and valid interpretation of evidence is demonstrated by drawing a valid and defensible conclusion based on the analysis

Interpreting and communicating

Conclusion

1 Name the visible features that were common to all cells viewed.

2 Summarise the main ways that plant cells are different from animal cells.

Evaluation

3 Explain why it is necessary to look at multiple cell types before you make generalisations about cells and organelles.

4 Explain whether the potential errors you identified above had a significant effect on your conclusions. In other words, do you consider the level of uncertainty caused by the potential errors reasonable?

Improvements

5 If you were to repeat this experiment, identify the steps that you would do differently. Consider how you:

- **a** might change the methodology
- **b** might improve your technique
- **c** could reduce error and uncertainty.

Extension

6 There are a variety of white blood cells found in human blood. Research the name and role of two specific types of white blood cells.

7 Search the internet for electron micrographs of various cells. Print out the micrographs and label the organelles.

➤ Reflect and check that your evaluation demonstrates these characteristics

- ☐ Critical evaluation of processes is demonstrated by a discussion of the reliability and validity of the experimental process supported by evidence such as the quality of the data (as quantified in the error analysis)
- ☐ Critical evaluation of the conclusion is demonstrated by a discussion of the veracity of the conclusions with respect to the error analysis and limitations or sufficiency of the data
- ☐ Insightful evaluation of processes and conclusions is demonstrated by a suggestion of improvements or extensions to the experiment that are logically derived from the analysis of the evidence

Chapter review

02

KEY TERMS

active transport
amino acid
biogenesis
carrier protein
cell
cell compartmentalisation
cell membrane
channel protein
chloroplast
cholesterol
chromosome
concentration gradient
cytology
cytoplasm
cytosol
diffusion
DNA (deoxyribonucleic acid)
endocytosis
eukaryote
exocytosis
extracellular fluid
extremophile
facilitated diffusion
genophore
glycolipid
glycoprotein
Golgi apparatus
hydrophobic
inorganic compound
integral protein
intracellular fluid
lysosome
mitochondria
mRNA
murein
non-permeable
nucleoid
nucleolus
organelle
organic compound
osmosis
osmotic gradient
osmotic pressure
passive transport
peripheral protein
phagocytosis
phospholipid
pinocytosis
plasmid
prokaryote
protein
ribosome
RNA (ribonucleic acid)
rough endoplasmic reticulum
rRNA
semipermeable
solute
solvent
taxonomy
tonoplast
transmembrane protein
vesicle

KEY QUESTIONS

Retrieval

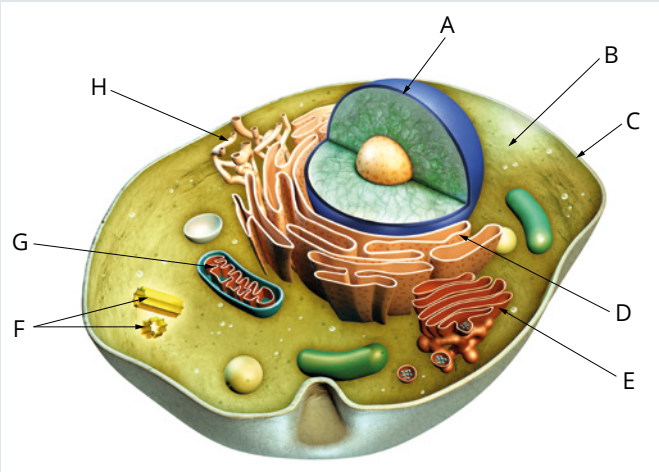
1 The cell theory states that:
- **A** all organisms are made up of cells.
- **B** all cells arise from pre-existing cells.
- **C** the cell is the smallest functional unit of living things.
- **D** all of the above.

2 Select the statement that accurately describes eukaryotic cells.
- **A** Eukaryotic cells have circular chromosomes and membrane-bound organelles, and some also have cell walls.
- **B** Eukaryotic cells have linear chromosomes but not membrane-bound organelles, and some have cell walls.
- **C** Eukaryotic cells have linear chromosomes and membrane-bound organelles, and some also have cell walls.
- **D** Eukaryotic cells have linear chromosomes and membrane-bound organelles, but not cell walls.

3 Identify which of the following is/are never found in prokaryotic cells.
- **A** DNA
- **B** mitochondria
- **C** cytosol
- **D** cell wall

4 List three features that distinguish prokaryotic from eukaryotic cells.

5 Label the parts of the animal cell in this diagram.



6 Draw and prepare a table to summarise the major functions of phospholipids, cholesterol, glycolipids, glycoproteins, and proteins in cell surface membranes.

7 Many single-celled organisms such as *Amoeba* feed by a process in which the cell membrane engulfs solid food particles to form a food vacuole. This process is called:

A phagocytosis.
B active transport.
C pinocytosis.
D osmosis.

8 The organelle on which proteins are assembled is called the:

A nucleus.
B endoplasmic reticulum.
C Golgi apparatus.
D ribosome.

Comprehension

9 Explain which type of microscope would be best for the study of:

a changes in a white blood cell
b details of surface texture of a hair.

10 Summarise the properties of archaean cell walls that allow them to be extremophiles.

11 Explain how the compartmental organisation of a eukaryotic cell contributes to its biochemical functioning.

12 According to the fluid mosaic model of membrane structure, proteins of the membrane are mostly:

A spread in a continuous layer over the inner and outer surfaces of the membrane.
B confined to the hydrophobic interior of the membrane.
C embedded in a lipid bilayer.
D randomly orientated in the membrane, with no fixed inside–outside polarity.
E free to depart from the fluid membrane and dissolve in the surrounding solution.

13 Identify which of the following factors would tend to increase membrane fluidity.

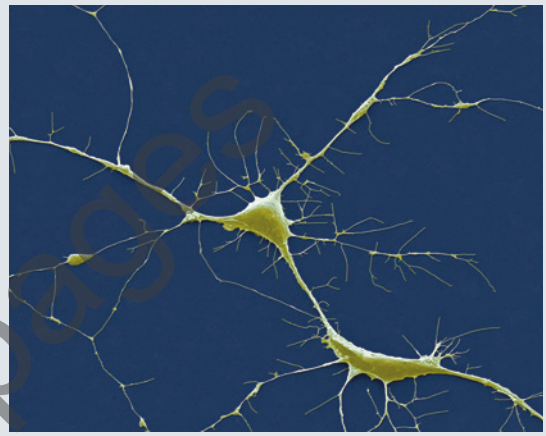
A a greater proportion of unsaturated phospholipids
B a greater proportion of saturated phospholipids
C a lower temperature
D a relatively high protein content in the membrane
E a greater proportion of relatively large glycolipids compared with lipids having smaller molecular masses

14 Explain why the phospholipid heads of the cell membrane are always pointed towards the cytosol and extracellular fluid, whereas the 'tails' are always orientated toward the middle of the membrane.

15 Describe the two types of proteins used in facilitated diffusion.

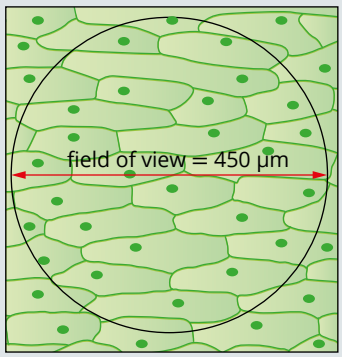
Analysis

16 The following image is a nerve cell. With specific reference to the visible structures of the cell, deduce whether this image was taken using an electron microscope or a light microscope.



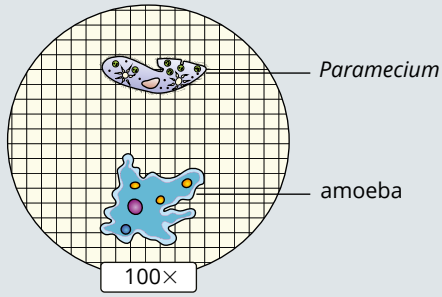
17 A microscope was set up to view some cells as illustrated in the following diagram.

a A microscope is set up with an ocular lens of ×10 magnification and an objective lens of ×4 magnification. Calculate the total magnification.
b Looking down a microscope, the field of view is determined to be 450 µm. Calculate the actual length of each cell measured in µm.

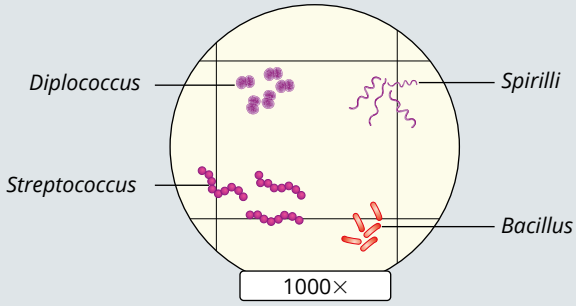


18 The following diagrams represent the field of view visible when a variety of cell types is viewed at different magnifications. The lines in the grids are 100 µm apart.

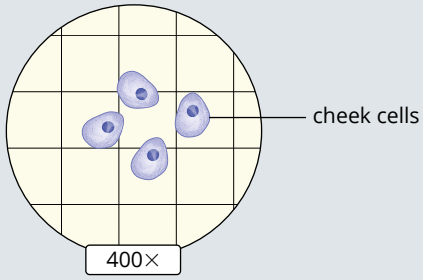
A Protozoans



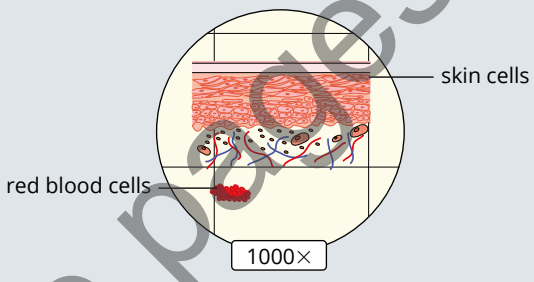
B Bacterial cells



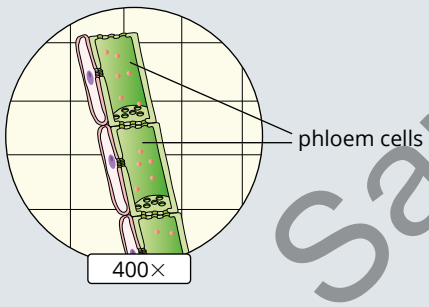
C Animal cells



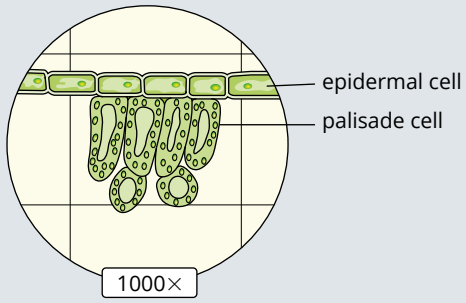
D Animal cells



E Cells from a plant stem



F Cells from the leaf of a plant

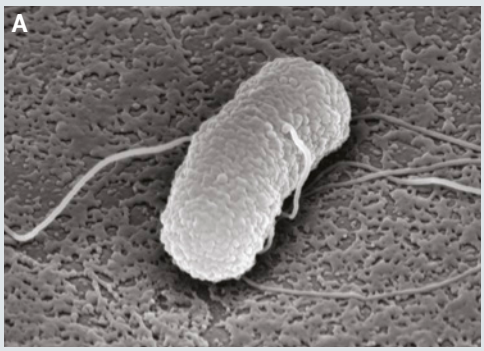


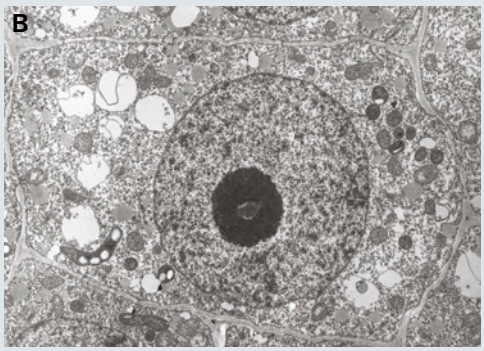
a Use the information in each image to estimate the length of each type of cell from the list below. In this instance, the length of the cell is the longest dimension of the cell, top to bottom or left to right.

b Organise the cells in the list below in order of size from smallest to largest.

phloem, palisade, *Diplococcus*, epidermal, *Spirilli*, cheek cells, human skin cells, *Streptococcus*, red blood cells, amoeba, *Paramecium*, *Bacillus*

19 Below are two cells observed under a scanning or a transmission electron microscope.





a One of the two cells is from a prokaryote. Explain which one.

b Determine if the eukaryotic cell is from an animal or a plant.

20 You are given a microscope slide with a sample of cells smeared on it and asked to identify the cell type. The cells are circular with a dark round mass at their centre. You estimate that the cells are approximately 20 µm in diameter.

a Classify the cells as prokaryotic or eukaryotic cells.

b Infer what organelle the dark round mass at the centre of the cells could be.

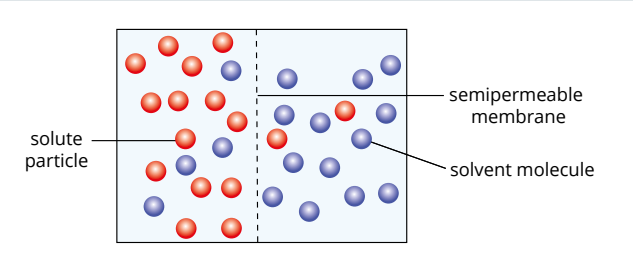
21 For each of the following responses to envrionmental factors, infer the most effective body shape and surface area to volume ratio of an organism for survival.

a gaining heat from its environment

b preventing heat loss

c maximising heat loss.

22 Two solutions are separated by a semipermeable membrane as illustrated below.



Deduce in which direction (if any) there would be a net movement of particles.

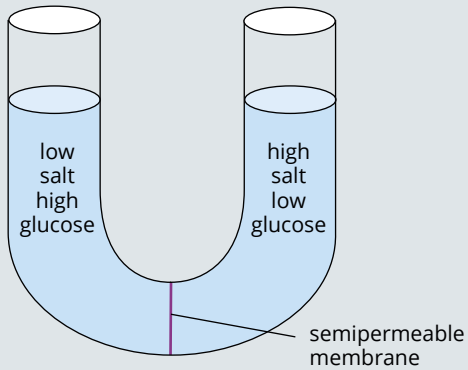
23 Two different solutions with the same volume are placed on either side of a semipermeable membrane in a U-shaped glass tube, as shown in the following diagram. The membrane is permeable to salt but not glucose.

The tube is then left to stand for several days. Predict what would happen to the:

a salt concentration on each side of the membrane

b glucose concentration on each side of the membrane

c fluid levels on each side of the membrane.



24 In mammals, cells lining the:

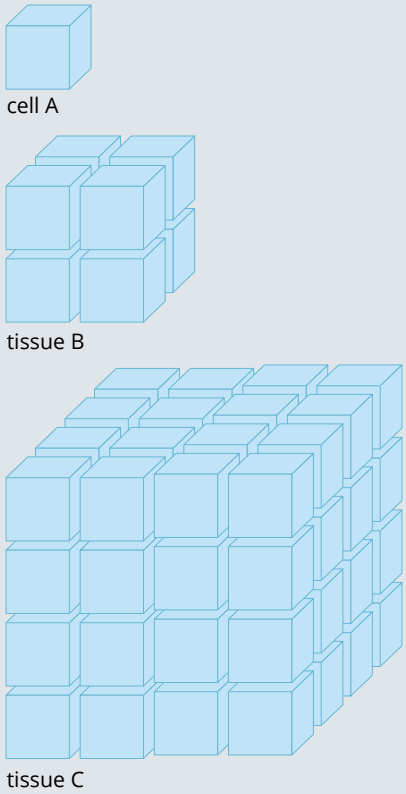
a alveoli of the lung take up oxygen by diffusion

b tubules of the kidney take up glucose by active transport

c small intestine take up fat droplets by pinocytosis.

Explain why the different methods of uptake are appropriate for the substances taken up in each case.

25 The following diagram represents living cells. Cell A, tissue B and tissue C all have the same volume.



Determine which one of the follow statements is correct.

A In distilled water, tissue B would gain water at a greater rate than cell A.

B In distilled water, the cells in tissue C would shrink at a greater rate than cell A.

C In a concentrated salt solution, tissue C would gain water at a greater rate than cell A.

D In a concentrated salt solution, tissue C would lose water more slowly than tissue B.

26 Solutions of different sugar concentrations were prepared and a rod of peeled potato tissue of the same known mass was put into each solution. After 1 hour, the potato was removed and its mass was measured again. Results are summarised in the following table.

Concentration of sugar (g/100 mL)	Change in mass (g)	
20	0.68	Decrease
18	0.40	Decrease
14	0.01	Increase
12	0.18	Increase
10	0.32	Increase
6	0.59	Increase
2	0.84	Increase

a Use this data to plot a graph showing the change in mass of the potato tissue with changes of the concentration of sugar.

b Use the graph to predict the mass change if a rod of potato tissue was placed in a sugar solution of 8 g/100 mL.

c Identify any trends and patterns in the data and explain these results making specific reference to the data.

Knowledge utilisation

27 A new unicellular organism has been discovered by light microscopy. Its characteristics include:

- internal membrane-bound circular structures composed of DNA
- two whip-like structures located close to each other at one end of the cell
- a semirigid structure outside the cell membrane
- a length greater than its width
- a chloroplast.

In your studies on cell biology, you have identified six main groups of organisms based on their cell structures: plant cells, animal cells, fungal cells, protists, bacteria and archaea.

Hypothesise which group this new organism would most likely belong to and give two reasons to support your answer.

28 At the cellular level, materials move through the cell membrane by several processes. At the organ level, the exchange of materials is facilitated by the arrangement of cells, which provides a large surface area. Discuss this statement with specific reference to the processes by which materials move through the cell membrane.

Outline three of the processes. For each process:

a give an example of a material taken up

b state where this uptake occurs

c explain why the process is appropriate.