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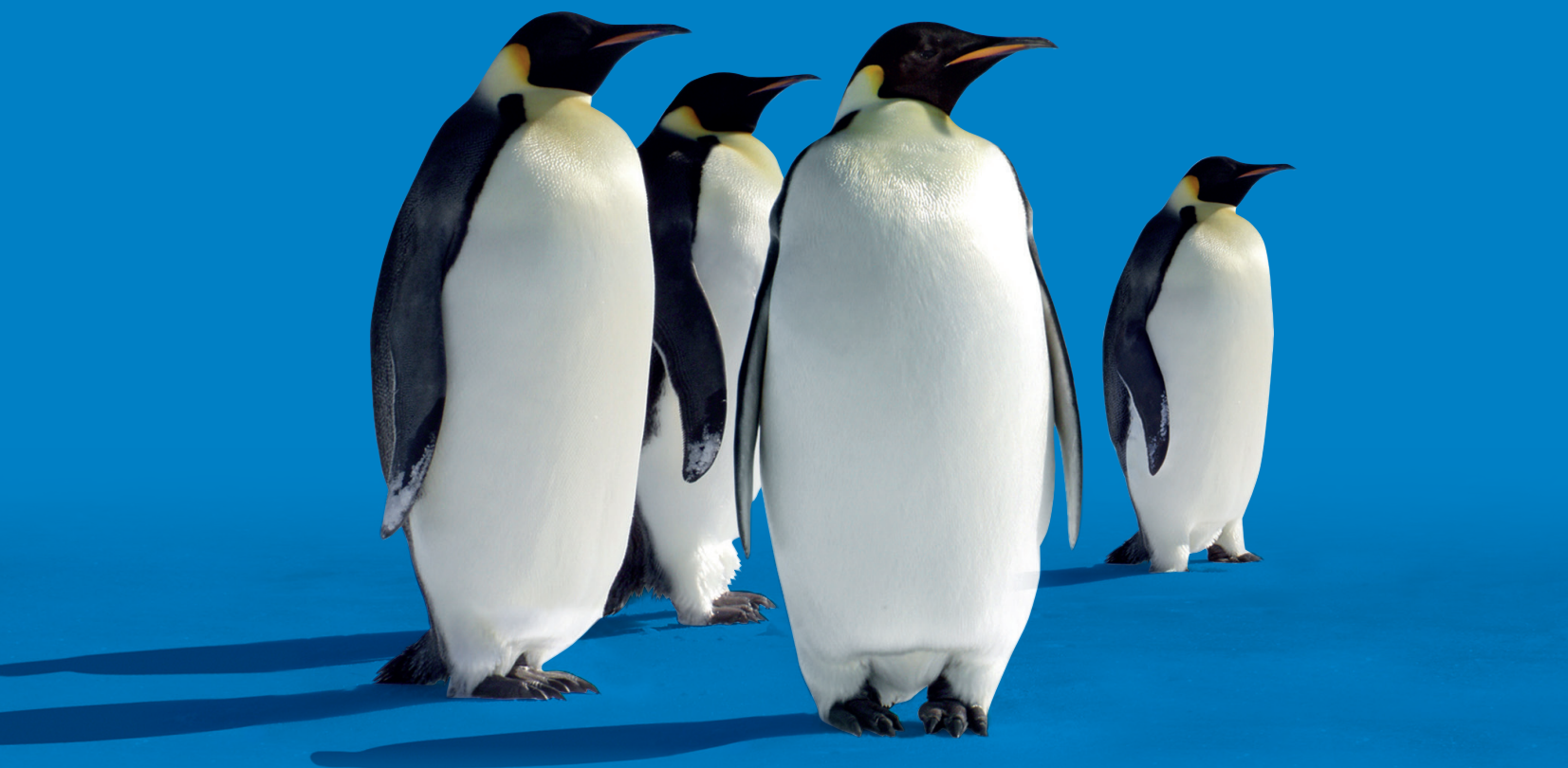
Executive Preview

Biology

for Cambridge International AS & A Level

MULTI-COMPONENT SAMPLE

Mary Jones, Richard Fosbery, Dennis Taylor & Jennifer Gregory



Fifth edition

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Brighter Thinking
Better Learning

At Cambridge University Press, we put you at the heart of our teaching and learning resources. This new series has been developed using extensive research with our exclusive teacher community (the Cambridge Science Panel), as well as teacher interviews and lesson observations around the world. It meets the real needs that we have discovered in our research – solving and supporting the biggest classroom challenges that you have told us about. We want to help you deliver engaging lessons that use the best practical pedagogies to enable your students to achieve their learning goals. In essence, we want to make your teaching time easier and more effective.

At the heart of this new series, our completely revised and expanded teacher's resource helps you to use each of the resources in the series effectively. This includes teaching activity, assessment and homework ideas, suggestions on how to tackle common misconceptions, and support with running practical activities. This resource will inspire and support you while saving much-needed time.

For this new edition of the coursebook, we have added new features. These include reflection opportunities and self-evaluation checklists that develop responsible learners, a broader range of enquiry questions that support practical activities, as well as group work and debate questions that develop 21st century skills. The 'Science in Context' features now include open-ended discussion questions that enable students to practise their English skills, interpret ideas in a real-world context and debate concepts with other learners. There is also extra support to help English as a second language learners successfully engage with their learning (including improved and expanded support for learning the all-important scientific vocabulary) alongside simple definitions of key terms and command words. Active lesson ideas and multi-part exam-style questions ensure student engagement and helps them feel confident approaching assessment.

The workbook is the perfect companion for the coursebook. You can use it to reinforce learning, promote application of theory and help students practise the essential skills of handling data, evaluating information and problem solving. The workbook now includes frequent tips to support students' understanding, alongside a range of formative exercises that map directly onto, and build on, coursebook topics and concepts. Multi-part exam-style questions also provide students with practice in a familiar format.

To support the syllabus focus on practical work and the scientific method, the practical workbook contains step-by-step guided investigations and practice questions. These give students the chance to test their knowledge and help build confidence in preparation for assessment. Practical investigation helps to develop key skills – such as planning, identifying equipment, creating hypotheses, recording results, and analysing and evaluating data. This workbook is ideal for teachers who find running practical experiments difficult due to lack of time, resources or support. It contains help and guidance on setting up and running practical investigations in the classroom, as well as sample data for when students can't do the experiments themselves.

We're very pleased to share with you draft chapters from our forthcoming coursebook, teacher's resource, workbook and practical workbook. We hope you enjoy looking through them and considering how they will support you and your students.

If you would like more information or have any questions, please contact your local sales representative: cambridge.org/education/find-your-sales-consultant

Steve Temblett
Head of Publishing – Science, Technology & Maths, Cambridge University Press

Hello, I am Mary Jones and I am part of the author team for the revised Cambridge International AS & A Level Biology syllabus (9700). I am an experienced teacher, lecturer, author and examiner. I am very pleased to give you some information about the content in the new series.

As you may be aware, there have been some revisions to the syllabus for first examination in 2022. You will find the full syllabus document online at cambridgeinternational.org.

The series has four components – a coursebook, workbook, practical workbook and teacher's resource. We have made sure that they work together to give you and your students full support in every aspect of the Cambridge International AS & A Level Biology course.

- We have revised the coursebook so that it perfectly covers all of the learning objectives in the revised syllabus. This includes reviewing the language level, to make it more accessible for students whose first language is not English.
- Each chapter begins with context to stimulate discussion. Within the text, questions encourage students to deepen their understanding of topics, and exam-style questions at the end of chapters build learner confidence.
- Biology is renowned for its large number of technical terms, and we have made sure these are all fully explained when they first appear. They are highlighted in 'Key Words' boxes and can also be found in the glossary. Summaries, a self-evaluation table and a reflection feature, encourage learners to reflect and take action if needed.
- While the coursebook covers the *content* of the syllabus, the **workbook** helps learners to develop the many *skills* that they need in order to be able to prepare for examination questions. These include the Assessment Objective 2 skills and also some of the skills that are used in practical work (AO3).
- We know that finding time and facilities for doing practical work can be a challenge, but we also know its importance to help learners reach their full potential. We have therefore provided a **practical workbook** to give detailed guidance in doing practical work. We have trialed all of the experiments in a school laboratory, and provided comprehensive step-by-step instructions.
- We have completely revised the **teacher's resource** to ensure that it provides the teacher with extensive support for all aspects of the course, including sample data for the practicals.

All the authors for this series are experienced teachers of biology. I hope that you and your students will enjoy using these new editions and wish you every success.

Kind regards,
Mary Jones

We are working with Cambridge Assessment International Education towards endorsement of these titles.

Series overview

FPO

We are working with Cambridge Assessment International Education towards endorsement of these titles.

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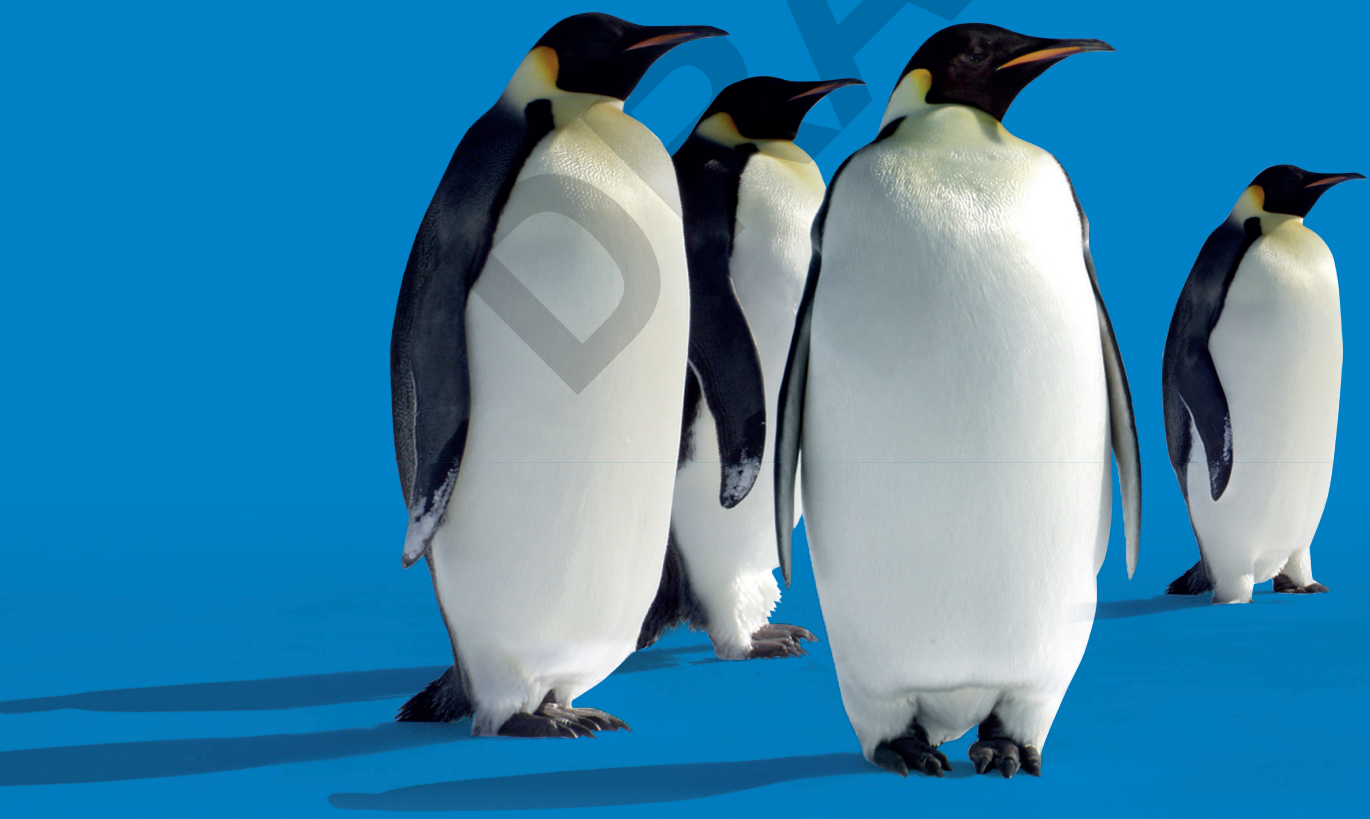
Biology

for Cambridge International AS & A Level

COURSEBOOK

Mary Jones, Richard Fosbery, Dennis Taylor & Jennifer Gregory



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Contents

How to use this book

Throughout this book, you will notice lots of different features that will help your learning. These are explained below.

LEARNING INTENTIONS

These set the scene for each chapter, help with navigation through the coursebook and indicate the important concepts in each topic.

BEFORE YOU START

This contains questions and activities on subject knowledge you will need before starting this chapter.

SCIENCE IN CONTEXT

This feature presents real-world examples and applications of the content in a chapter, encouraging you to look further into topics. There are discussion questions at the end which look at some of the benefits and problems of these applications.

PRACTICAL INVESTIGATIONS

This book does not contain detailed instructions for doing particular experiments, but you will find background information about the practical work you need to do in these boxes. There are also two chapters, P1 and P2, which provide detailed information about the practical skills you need to develop during the course.

Questions

Appearing throughout the text, questions give you a chance to check that you have understood the topic you have just read about. You can find the answers to these questions in the Elevate edition of the coursebook.

KEY WORDS

Key vocabulary is highlighted in the text when it is first introduced. Definitions are then given in the margin, which explain the meanings of these words and phrases.

You will also find definitions of these words in the Glossary at the back of this book.

COMMAND WORDS

Command words that appear in the syllabus and might be used in the exams are highlighted in the exam-style questions when they are first introduced. In the margin, you will find the Cambridge International definition. You will also find these definitions in the Glossary at the back of the book with some further explanation on the meaning of these words.*

*The information in this section is taken from the Cambridge International syllabus for examination from 2022. You should always refer to the appropriate syllabus document for the year of your examination to confirm the details and for more information. The syllabus document is available on the Cambridge International website.

WORKED EXAMPLES

Wherever you need to know how to use a formula to carry out a calculation, there are worked examples boxes to show you how to do this.

REFLECTION

These activities ask you to look back on the topics covered in the chapter and test how well you understand these topics and encourage you to reflect on your learning.

IMPORTANT

Important equations, facts and tips are given in these boxes.

EXAM-STYLE QUESTIONS

Questions at the end of each chapter provide more demanding exam-style questions, some of which may require use of knowledge from previous chapters. Some questions are taken from past papers. Where this is the case, they include references to the relevant past paper. All other questions are written by the authors. Answers to all questions can be found in the Elevate digital coursebook.

SUMMARY CHECKLISTS

There is a summary of key points at the end of each chapter.

SELF-EVALUATION CHECKLIST

The summary checklists are followed by 'I can' statements which match the Learning intentions at the beginning of the chapter. You might find it helpful to rate how confident you are for each of these statements when you are revising. You should revisit any topics that you rated "Needs more work" or "Almost there".

I can	See topic...	Needs more work	Almost there	Ready to move on

Chapter 1
Cell structure

LEARNING INTENTIONS

In this chapter you will learn how to:

- explain that cells are the basic units of life
- use the units of measurement relevant to microscopy
- recognise the common structures found in cells as seen with a light microscope and outline their structures and functions
- compare the key structural features of animal and plant cells
- use a light microscope and make temporary preparations to observe cells
- recognise, draw and measure cell structures from temporary preparations and micrographs
- calculate magnifications of images and actual sizes of specimens using drawings or micrographs
- explain the use of the electron microscope to study cells with reference to the increased resolution of electron microscopes
- recognise the common structures found in cells as seen with an electron microscope and outline their structures and functions
- outline briefly the role of ATP in cells
- describe the structure of bacteria and compare the structure of prokaryotic cells with eukaryotic cells
- describe the structure of viruses.

BEFORE YOU START

- Make a list of structures that could be found in a cell.
- Try to write down the functions of the structures you have listed.
- Which structures are found in plant cells and which are found in animal cells?
- Are there any cells that are not animal or plant cells?

THINKING OUTSIDE THE BOX

Progress in science often depends on people thinking 'outside the box' – original thinkers who are often ignored or even ridiculed when they first put forward their radical new ideas. One such individual, who battled constantly throughout her career to get her ideas accepted, was the American biologist Lynn Margulis (1938–2011; Figure 1.1). Her greatest achievement was to use evidence from microbiology to help firmly establish an idea that had been around since the mid-19th century – that new organisms can be created from combinations of existing organisms. Importantly, the existing organisms are not necessarily closely related. The organisms form a symbiotic partnership (they live together in a partnership in which both partners benefit). Margulis imagined that one organism engulfed ('ate') another. Normally the engulfed organism would be digested and killed, but sometimes the organism engulfed may survive and even be of benefit to the organism in which it finds itself. This type of symbiosis is known as endosymbiosis ('endo' means inside). A completely new type of organism is created, representing a dramatic evolutionary change.

The best-known example of Margulis' ideas is her suggestion that mitochondria and chloroplasts were originally free-living bacteria (prokaryotes). She suggested that these bacteria invaded the ancestors of modern eukaryotic cells, which are much larger and more complex cells than bacteria, and entered into a symbiotic relationship with the cells. This idea has been confirmed as true by later work. Margulis saw such symbiotic unions as a major driving cause of evolutionary change. Throughout her life, she continued to challenge the traditional view, first put forward by Charles Darwin, that evolution occurs mainly as a result of competition between species.

Figure 1.1: Lynn Margulis: 'My work more than didn't fit in. It crossed the boundaries that people had spent their lives building up. It hits some 30 sub-fields of biology, even geology.'

Questions for discussion

- Can you think of any ideas people have had which were controversial at the time but are now accepted? Try to think of scientific examples. You may also like to consider why the ideas were controversial.
- Can you think of any scientific ideas people have now which are controversial and not accepted by everybody?

1.1 Cells are the basic units of life

Towards the middle of the 19th century, scientists made a fundamental breakthrough in our understanding of how life 'works'. They realised that the basic unit of life is the **cell**.

The origins of this idea go back to the early days of microscopy when an English scientist, Robert Hooke, decided to examine thin slices of plant material. He chose cork as one of his examples. Looking down the microscope, he made a drawing to show the regular appearance of the structure, as you can see in Figure 1.2. In 1665 he published a book containing this drawing.

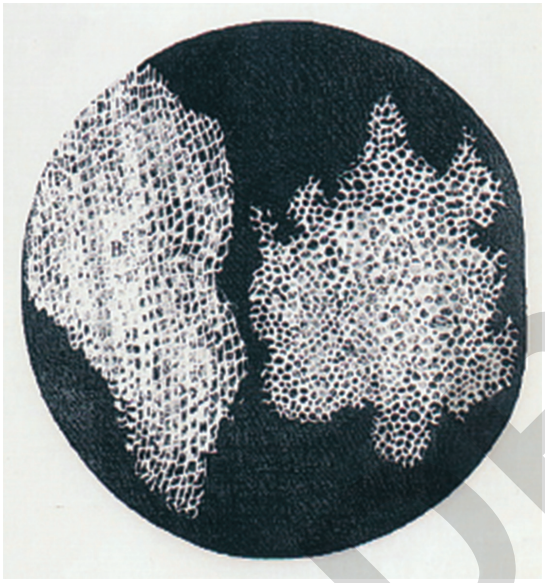


Figure 1.2: Drawing of cork cells published by Robert Hooke in 1665.

If you examine the drawing you will see the regular structures that Hooke called 'cells'. Each cell appeared to be an empty box surrounded by a wall. Hooke had discovered and described, without realising it, the fundamental unit of all living things.

Although we now know that the cells of cork are dead, Hooke and other scientists made further observations of cells in *living* materials. However, it was not until almost 200 years later that a general cell theory emerged from the work of two German scientists. In 1838 Schleiden, a botanist, suggested that all plants are made of cells. A year later Schwann, a zoologist, suggested the same for animals. It was soon also realised that all cells come from pre-existing cells by the process of cell division. This raises the obvious question of where the original cell came from. There are many hypotheses, but we still have no definite answers to this question.

Why cells?

A cell can be thought of as a bag in which the chemistry of life occurs. The activity going on inside the cell is therefore separated from the environment outside the cell. The bag, or cell, is surrounded by a thin membrane. The membrane is an essential feature of all cells because it controls exchange between the cell and its environment. It can act as a barrier, but it can also control movement of materials across the membrane in both directions. The membrane is therefore described as partially permeable. If it were freely permeable, life could not exist, because the chemicals of the cell would simply mix with the surrounding chemicals by diffusion and the inside of the cell would be the same as the outside.

Two types of cell

During the 20th century, scientists studying the cells of bacteria and of more complex organisms such as plants and animals began to realise that there were two fundamentally different kinds of cells. Some cells were very simple, but some were much larger and more complex. The complex cells contained a **nucleus** (plural: **nuclei**) surrounded by two membranes. The genetic material, DNA, was in the nucleus. In the simple cells the DNA was not surrounded by membranes, but apparently free in the cytoplasm.

KEY WORDS

cell: the basic unit of all living organisms; it is surrounded by a cell surface membrane and contains genetic material (DNA) and cytoplasm containing **organelles**

organelle: a functionally and structurally distinct part of a cell, e.g. a ribosome or mitochondrion

nucleus (plural: **nuclei**): a relatively large organelle found in eukaryotic cells, but absent from prokaryotic cells; the nucleus contains the cell's DNA and therefore controls the activities of the cell; it is surrounded by two membranes which together form the nuclear envelope

Organisms made of cells with membrane-bound nuclei are now known as **eukaryotes**, while the simpler cells lacking membrane-bound nuclei are known as **prokaryotes** ('eu' means true, 'karyon' means nucleus, 'pro' means before). Eukaryotes are thought to have evolved from prokaryotes more than two billion years ago. Prokaryotes include bacteria. Eukaryotes include animals, plants, fungi and some other organisms.

KEY WORDS

eukaryote: an organism whose cells contain a nucleus and other membrane-bound organelles

prokaryote: an organism whose cells do not contain a nucleus or any other membrane-bound organelles

1.2 Cell biology and microscopy

The study of cells has given rise to an important branch of biology known as cell biology. Cell biologists study cells using many different methods, including the use of various types of microscope.

There are two fundamentally different types of microscope: the light microscope and the electron microscope. Both use a form of radiation in order to see the specimen being examined. The light microscope uses light as a source of radiation, while the electron microscope uses electrons, for reasons which are discussed later.

Units of measurement

In order to measure objects in the microscopic world, we need to use very small units of measurement, which are unfamiliar to most people. Before studying light and electron microscopy further, you need to become familiar with these units.

According to international agreement, the International System of Units (SI units) should be used. In this system, the basic unit of length is the metre (symbol, m). More units are created by going a thousand times larger or smaller. Standard prefixes are used for the units. For example, the prefix 'kilo' means 1000 times. Thus, 1 kilometre = 1000 metres. The units of length relevant to cell studies are shown in Table 1.1.

The smallest structure visible with the human eye is about 50–100 μm in diameter (roughly the diameter of the sharp end of a pin). The cells in your body vary in size from about 5 μm to 40 μm. It is difficult to imagine how small these cells are, especially when they are clearly visible using a microscope. An average bacterial cell is about 1 μm across. One of the smallest structures you will study in this book is the ribosome, which is only about 25 nm in diameter! You could line up about 20 000 ribosomes across the full stop at the end of this sentence.

1.3 Plant and animal cells as seen with a light microscope

Microscopes that use light as a source of radiation are called light microscopes. Figure 1.3 shows how the light microscope works. Note: you do not need to learn this structure.

Fraction of a metre	Unit	Symbol
one thousandth = 0.001 = 1/1000 = 10^{-3}	millimetre	mm
one millionth = 0.000 001 = 1/1000 000 = 10^{-6}	micrometre	μm
one thousand millionth = 0.000 000 001 = 1/1000 000 000 = 10^{-9}	nanometre	nm

Table 1.1: Units of measurement relevant to cell studies: 1 micrometre is a thousandth of a millimetre; 1 nanometre is a thousandth of a micrometre.

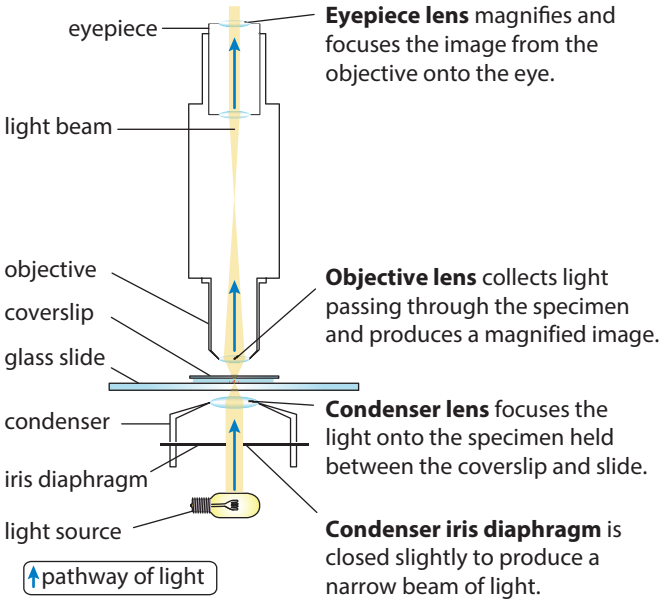


Figure 1.3: How the light microscope works. The coverslip is a thin sheet of glass used to cover the specimen. It protects specimens from drying out and also prevents the objective lens from touching the specimen.

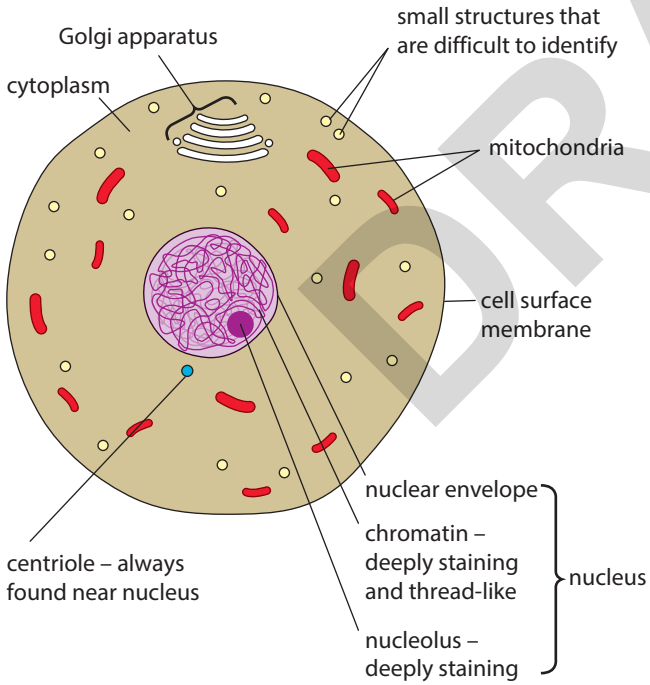


Figure 1.4: Structure of a generalised animal cell (diameter about 20 µm) as seen with a very high quality light microscope.

Figure 1.4 is a drawing showing the structure of a generalised animal cell and Figure 1.5 is a drawing showing the structure of a generalised plant cell, both as seen with a light microscope. (A generalised cell shows all the structures that may commonly be found in a cell.) Figures 1.6 and 1.7 are photomicrographs. A photomicrograph is a photograph of a specimen as seen with a light microscope. Figure 1.6 shows some human cells. Figure 1.7 shows a plant cell taken from a leaf. Both figures show cells magnified 400 times, which is equivalent to using the high-power objective lens on a light microscope. See also Figures 1.8a and 1.8b for labelled drawings of these figures.

Many of the cell contents are colourless and transparent so they need to be stained with coloured dyes to be seen. The human cells in Figure 1.6 have been stained. The chromatin in the nuclei is particularly heavily stained. The plant cells in Figure 1.5 have not been stained because the chloroplasts contain the green pigment chlorophyll and are easily visible without staining.

Question

1 Using Figures 1.4 and 1.5, name the structures that:
- **a** animal and plant cells have in common
- **b** are found only in plant cells
- **c** are found only in animal cells.

Features that animal and plant cells have in common

Cell surface membrane

All cells, including those of both eukaryotes and prokaryotes, are surrounded by a very thin **cell surface membrane**. This is also sometimes referred to as the plasma membrane. As mentioned before, it is partially permeable and controls the exchange of materials between the cell and its environment.

Nucleus

All eukaryotic cells contain a nucleus. The nucleus is a relatively large structure. It stains intensely and

KEY WORD

cell surface membrane: a very thin membrane (about 7 nm diameter) surrounding all cells; it is partially permeable and controls the exchange of materials between the cell and its environment

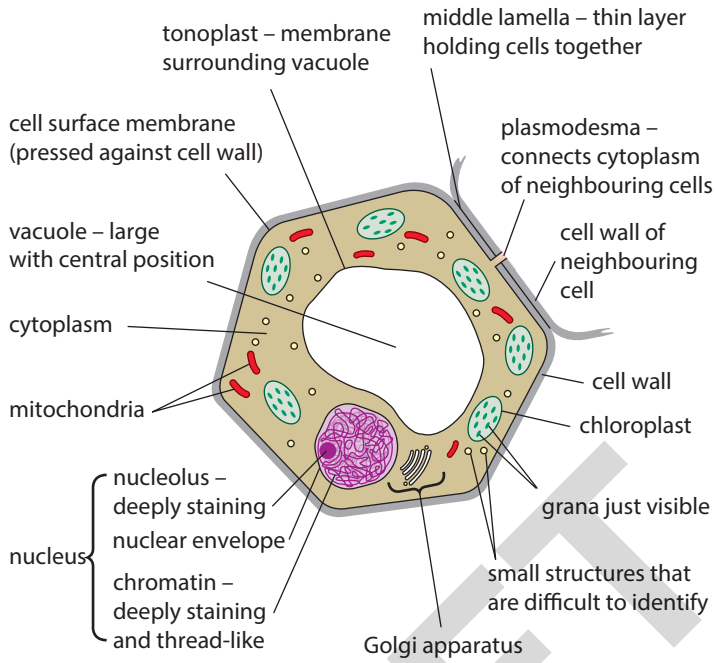


Figure 1.5: Structure of a generalised plant cell (diameter about 40 μm) as seen with a very high quality light microscope.

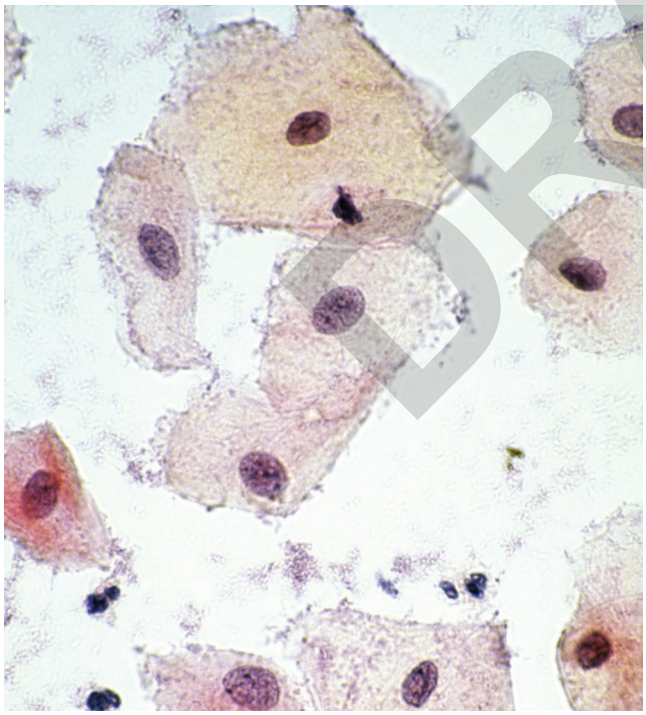


Figure 1.6: Cells from the lining of the human cheek (×400). Each cell shows a centrally placed nucleus, which is typical of animal cells. The cells are part of a tissue known as squamous (flattened) epithelium.

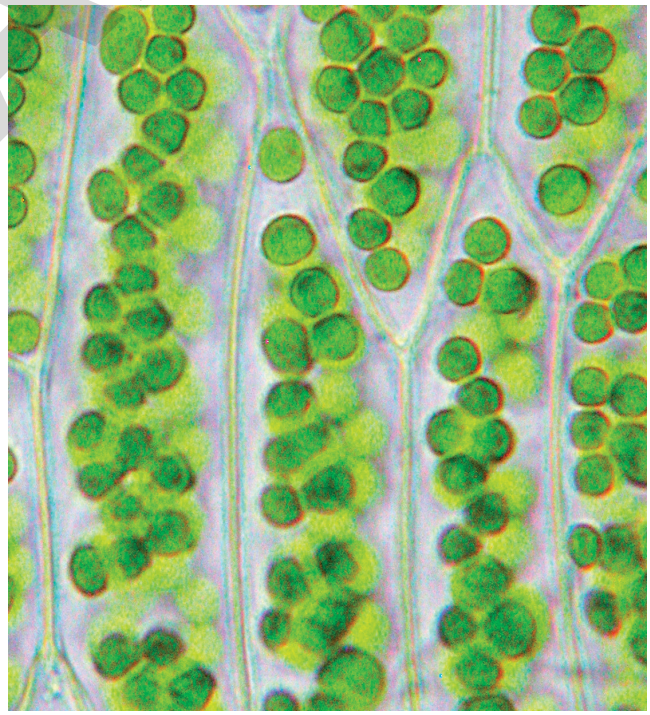


Figure 1.7: Cells in a moss leaf (×400). Many green chloroplasts are visible inside each cell. The grana are just visible as black grains inside the chloroplasts ('grana' means grains). Cell walls are also clearly visible (animal cells lack cell walls).

is therefore very easy to see when looking down the microscope. The deeply staining material in the nucleus is called **chromatin** ('chroma' means colour). Chromatin is a mass of coiled threads. The threads are seen to collect together to form **chromosomes** during nuclear division (Chapter 5, Section 5.2, Chromosomes). Chromatin contains DNA (deoxyribonucleic acid), the molecule which contains the instructions (genes) that control the activities of the cell (Chapter 6).

Inside the nucleus an even more deeply staining area is visible, the **nucleolus**. This is made of loops of DNA from several chromosomes. The number of nucleoli is variable, one to five being common in mammals. One of the main functions of nucleoli is to make ribosomes.

Cytoplasm

All the living material inside the cell is called **protoplasm**. It is also useful to have a term for all the living material outside the nucleus; it is called **cytoplasm**. Therefore, cytoplasm + nucleus = protoplasm.

Cytoplasm is an aqueous (watery) material, varying from a fluid to a jelly-like consistency. Using a light microscope, many small structures can be seen within it. These have been likened to small organs and are therefore known as organelles (meaning 'little organs'). An organelle can be defined as a functionally and structurally distinct part of a cell. Organelles are often, but not always, surrounded by one or two membranes so that their activities can be separated from the surrounding cytoplasm. Organising cell activities in separate compartments is essential for a structure as complex as an animal or plant cell to work efficiently.

Mitochondria (singular: mitochondrion)

The most numerous organelles seen with the light microscope are usually **mitochondria** (singular: **mitochondrion**). Mitochondria are only just visible using a light microscope. Videos of living cells, taken with the aid of a light microscope, have shown that mitochondria can move about, change shape and divide. They are specialised to carry out aerobic respiration.

Golgi apparatus

The use of special stains containing silver resulted in the Golgi apparatus being discovered in 1898 by Camillo Golgi. The Golgi apparatus Note: you do not need to learn this structure. It is sometimes called the Golgi body or Golgi complex.

KEY WORDS

chromatin: the material of which chromosomes are made, consisting of DNA, proteins and small amounts of RNA; visible as patches or fibres within the nucleus when stained

chromosome: in the nucleus of the cells of eukaryotes, a structure made of tightly coiled chromatin (DNA, proteins and RNA) visible during cell division; the term 'circular DNA' is now also commonly used for the circular strand of DNA present in a prokaryotic cell

nucleolus: a small structure, one or more of which is found inside the nucleus; the nucleolus is usually visible as a densely stained body; its function is to manufacture ribosomes using the information in its own DNA

protoplasm: all the living material inside a cell (cytoplasm plus nucleus)

cytoplasm: the contents of a cell, excluding the nucleus

mitochondrion (plural: **mitochondria**): the organelle in eukaryotes in which aerobic respiration takes place

cell wall: a wall surrounding prokaryote, plant and fungal cells; the wall contains a strengthening material which protects the cell from mechanical damage, supports it and prevents it from bursting by osmosis if the cell is surrounded by a solution with a higher water potential

Differences between animal and plant cells

One of the structures commonly found in animal cells which is absent from plant cells is the centriole. Plant cells also differ from animal cells in possessing cell walls, large permanent vacuoles and chloroplasts.

Centrioles

Under the light microscope the centriole appears as a small structure close to the nucleus (Figure 1.4). Centrioles are discussed later in this chapter.

Cell walls and plasmodesmata

With a light microscope, individual plant cells are more easily seen than animal cells. This is because they are usually larger and, unlike animal cells, are surrounded by a **cell wall**. Note that the cell wall is an extra

structure which is outside the cell surface membrane. The wall is relatively rigid because it contains fibres of cellulose, a polysaccharide which strengthens the wall. The cell wall gives the cell a definite shape. It prevents the cell from bursting when water enters by osmosis, allowing large pressures to develop inside the cell (Chapter 4, Section 4.5, Movement of substances across membranes). Cell walls may be reinforced with extra cellulose or with a hard material called lignin for extra strength (Chapter 7). Cell walls are freely permeable, allowing free movement of molecules and ions through to the cell surface membrane.

Plant cells are linked ot neighbouring cells by means of pores containing fine strands of cytoplasm. These structures are called **plasmodesmata** (singular: **plasmodesma**). They are lined with the cell surface membrane. Movement through the pores is thought to be controlled by the structure of the pores.

Vacuoles

Vacuoles are sac-like structures which are surrounded by a single membrane. Although animal cells may possess small vacuoles such as phagocytic vacuoles (Chapter 4, Section 4.5, Movement of substances across membranes), which are temporary structures, mature plant cells often possess a large, permanent, central vacuole. The plant vacuole is surrounded by a membrane, the **tonoplast**, which controls exchange between the vacuole and the cytoplasm. The fluid in the vacuole is a solution of pigments, enzymes, sugars and other organic compounds (including some waste products), mineral salts, oxygen and carbon dioxide.

In plants, vacuoles help to regulate the osmotic properties of cells (the flow of water inwards and outwards) as well as having a wide range of other functions. For example, the pigments which colour the petals of certain flowers and the parts of some vegetables, such as the red pigment of beetroots, may be found in vacuoles.

Chloroplasts

Chloroplasts are organelles specialised for the process of **photosynthesis**. They are found in the green parts of the plant, mainly in the leaves. They are relatively large organelles and so are easily seen with a light microscope. It is even possible to see tiny 'grains' or **grana** (singular: **granum**) inside the chloroplasts using a light microscope (Figure 1.7). These are the parts of the chloroplast that contain chlorophyll, the green pigment which absorbs light during the process of photosynthesis. Chloroplasts are discussed further in Chapter 13 (Section 13.2, Structure and function of chloroplasts).

KEY WORDS

plasmodesma (plural: **plasmodesmata**): a pore-like structure found in plant cell walls; plasmodesmata of neighbouring plant cells line up to form tube-like pores through the cell walls, allowing the controlled passage of materials from one cell to the other; the pores contain ER and are lined with the cell surface membrane

vacuole: an organelle found in eukaryotic cells; a large, permanent central vacuole is a typical feature of plant cells, where it has a variety of functions, including storage of biochemicals such as salts, sugars and waste products; temporary vacuoles, such as phagocytic vacuoles (also known as phagocytic vesicles), may form in animal cells

tonoplast: the partially permeable membrane that surrounds plant vacuoles

chloroplast: an organelle, bounded by an envelope (i.e. two membranes), in which photosynthesis takes place in eukaryotes

photosynthesis: the production of organic substances from inorganic ones, using energy from light

grana (singular: **granum**): stacks of membranes inside a chloroplast

IMPORTANT

- You can think of a plant cell as being very similar to an animal cell but with extra structures.
- Plant cells are often larger than animal cells, although cell size varies enormously.
- Do not confuse the cell wall with the cell surface membrane. Cell walls are relatively thick and physically strong, whereas cell surface membranes are very thin. Cell walls are freely permeable, whereas cell surface membranes are partially permeable. All cells have a cell surface membrane, but animal cells do not have a cell wall.
- Vacuoles are not confined to plant cells; animal cells may have small vacuoles, such as phagocytic vacuoles, although these are not usually permanent structures.

PRACTICAL ACTIVITY 1.1

Making temporary slides

A common method of examining material with a light microscope is to cut thin slices of the material called 'sections'. The advantage of cutting sections is that they are thin enough to allow light to pass through the section. The section is laid ('mounted') on a glass slide and covered with a cover slip to protect it. Light passing through the section produces an image which can then be magnified using the objective and eyepiece lenses of the microscope.

Biological material may be examined live or in a preserved state. Prepared slides contain material that has been killed and preserved in a life-like condition.

Temporary slides are quicker and easier to prepare and are often used to examine fresh material containing living cells. In both cases the sections are typically stained before being mounted on the glass slide.

Temporary preparations of fresh material are useful for quick preliminary investigations. Sometimes macerated (chopped up) material can be used, as when examining the structure of wood (xylem). A number of temporary stains are commonly used. For example, iodine in potassium iodide solution is useful for plant specimens. It stains starch blue-black and will also colour nuclei and cell walls a pale yellow. A dilute solution of methylene blue can be used to stain animal cells such as cheek cells.

Viewing specimens yourself with a microscope will help you to understand and remember structures. Your understanding can be reinforced by making a pencil drawing on good quality plain paper. Remember always to draw what you see, and not what you think you should see.

Procedure

Place the biological specimen on a clean glass slide and add one or two drops of stain. Carefully lower a cover over the specimen to protect the microscope lens and to help prevent the specimen from drying out. Adding a drop of glycerine and mixing it with the stain can also help prevent drying out.

- Suitable animal material: human cheek cells obtained by gently scraping the lining of the cheek with a finger nail
- Suitable plant material: onion epidermal cells, lettuce epidermal cells, *Chlorella* cells, moss slip leaves

(See Practical Investigation X.X in the *Practical Workbook* for additional information)

PRACTICAL ACTIVITY 1.2

Biological drawing

To reinforce your learning, you will find it useful to make labelled drawings of some of your temporary and permanent slides, as well as labelled drawings of photomicrographs.

Practical Activity 7.1 in Chapter 7 provides general guidance on biological drawing. Read the relevant sections of Practical Activity 7.1 before answering the question below, which is relevant to this chapter. Figures 1.8a and b show examples of good drawing and labelling technique based on Figures 1.6 and 1.7. Note that it is acceptable to draw only a representative portion of the cell contents of Figure 1.7, but add a label explaining this.

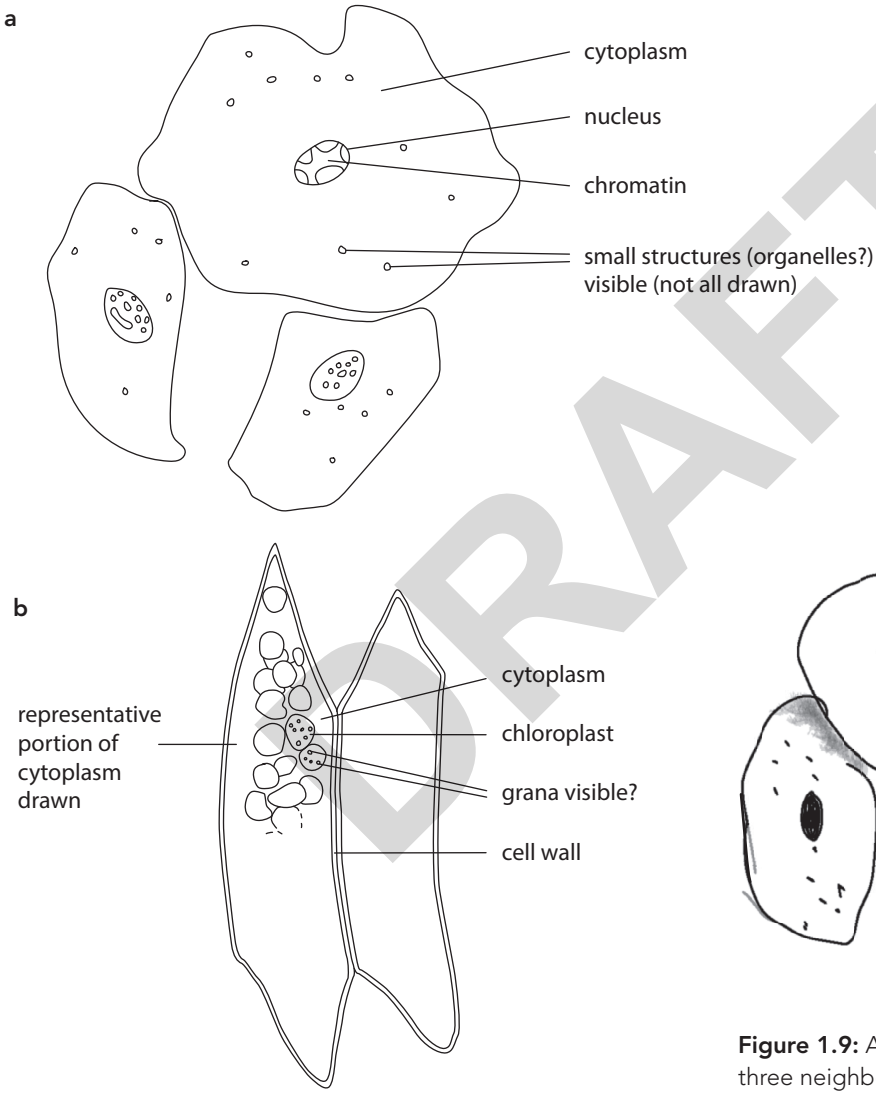


Figure 1.8: Examples of good drawing technique: **a** high-power drawing of three neighbouring animal cells from Figure 1.6; **b** high-power drawing of two neighbouring plant cells from Figure 1.7.

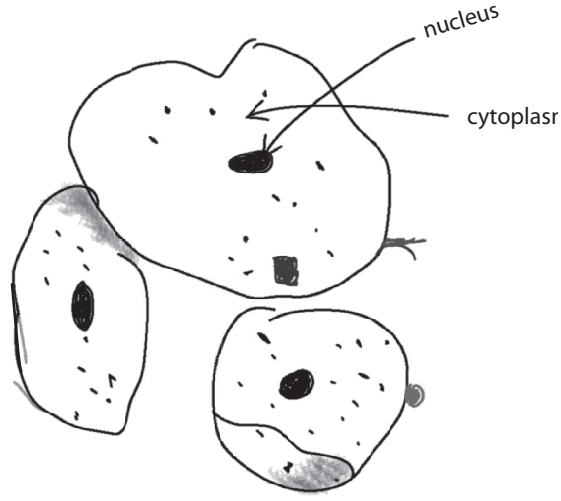


Figure 1.9: A student's high-power drawing of three neighbouring cells from Figure 1.6.

(See Practical Investigation X.X in the *Practical Workbook* for additional information)

Question

2 A student was asked to make a high-power drawing of three neighbouring cells from Figure 1.6. Figure 1.9 shows the drawing made by the student.

Using Practical Activity 7.1 to help you, suggest how the drawing in Figure 1.9 could be improved.

1.4 Measuring size and calculating magnification

Magnification is the number of times larger an image of an object is than the real size of the object.

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

or

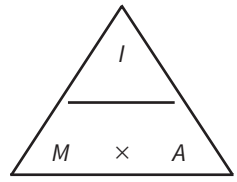
$$M = \frac{I}{A}$$

M = magnification

I = observed size of the image (what you can measure with a ruler)

A = actual size (the real size – for example, the size of a cell before it is magnified).

If you know two of the values M, I and A, you can work out the third one. For example, if the observed size of the image and the magnification are known, you can work out the actual size $A = \frac{I}{M}$. If you write the formula in a triangle as shown below and cover up the value you want to find, it should be obvious how to do the right calculation.



Measuring cell size

Cells and organelles can be measured with a microscope by means of an **eyepiece graticule**. This is a transparent scale. It usually has 100 divisions (see Figure 1.10a). The eyepiece graticule is placed in the microscope eyepiece so that it can be seen at the same time as the object to be measured, as shown in Figure 1.10b. Figure 1.10b shows the scale over one of a group of six human cheek epithelial cells (like those shown in Figure 1.6). The cell selected lies between 40 and 60 on the scale. We therefore say it measures 20 eyepiece units in diameter (the difference between 60 and 40). We will not know the actual size of the eyepiece units until the eyepiece graticule is calibrated.

KEY WORDS

magnification: the number of times larger an image of an object is than the real size of the object; magnification = image size ÷ actual (real) size of the object

eyepiece graticule: small scale that is placed in a microscope eyepiece

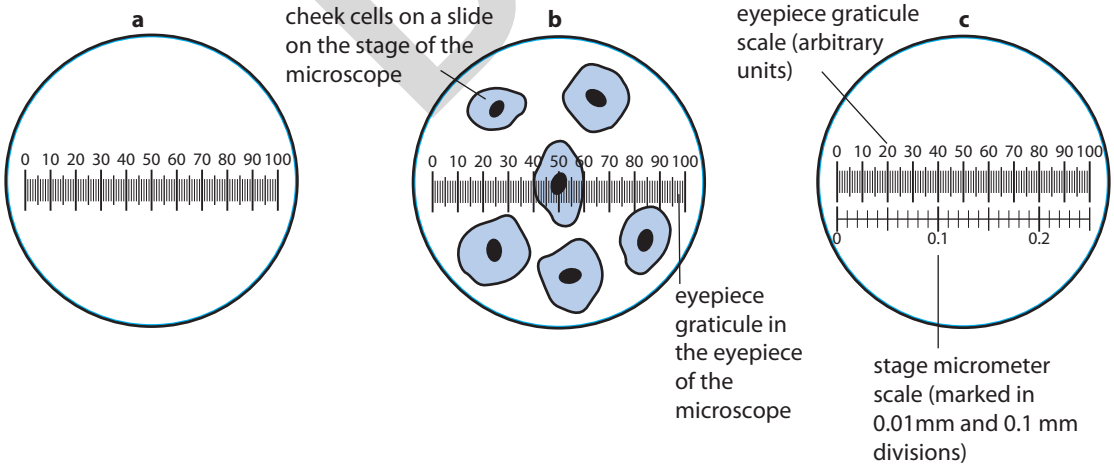


Figure 1.10: Microscopical measurement. Three fields of view seen using a high-power (×40) objective lens: **a** an eyepiece graticule scale; **b** superimposed images of human cheek epithelial cells and the eyepiece graticule scale; **c** superimposed images of the eyepiece graticule scale and the stage micrometer scale.

To calibrate the eyepiece graticule, a miniature transparent ruler called a **stage micrometer** is placed on the microscope stage and is brought into focus. This scale may be etched onto a glass slide or printed on a transparent film. It commonly has subdivisions of 0.1 and 0.01 mm. The images of the stage micrometer and the eyepiece graticule can then be superimposed (placed on top of one another) as shown in Figure 1.10c.

Calculating magnification

Figure 1.11 shows **micrographs** of two sections through the same plant cell. The difference in appearance of the two micrographs is explained in the next section.

If we know the actual (real) length of a cell in such a micrograph, we can calculate its magnification, M, using the formula:

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

KEY WORDS

stage micrometer: very small, accurately drawn scale of known dimensions, engraved on a microscope slide

micrograph: a picture taken with the aid of a microscope; a photomicrograph (or light micrograph) is taken using a light microscope; an electron micrograph is taken using an electron microscope

WORKED EXAMPLE

1 In the eyepiece graticule shown in Figure 1.10, 100 units measure 0.25 mm. Hence, the value of each eyepiece unit is:

$$\frac{0.25}{100} = 0.0025 \text{ mm}$$

Or, converting mm to μm:

$$\frac{0.25 \times 1000}{100} = 2.5 \text{ μm}$$

The diameter of the cell shown superimposed on the scale in Figure 1.8b measures 20 eyepiece units and so its actual diameter is:

$20 \times 2.5 \text{ μm} = 50 \text{ μm}$

This diameter is greater than that of many human cells because the cell is a flattened epithelial cell.

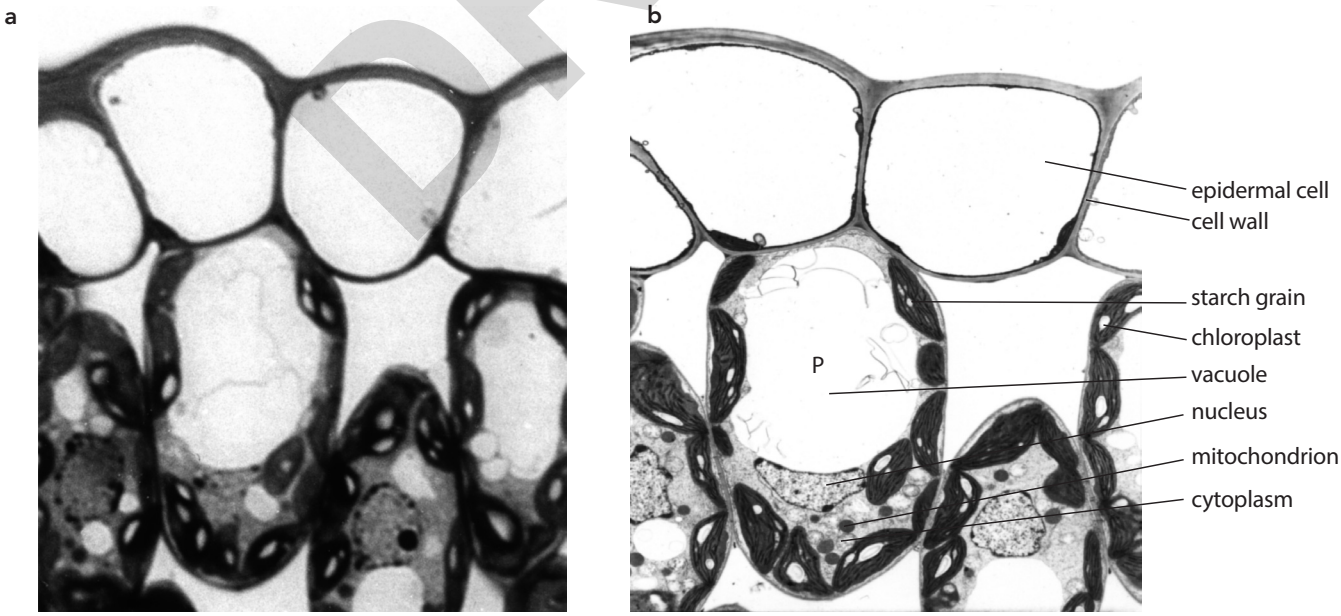


Figure 1.11: Micrographs of two sections of the same plant cells, as seen **a** with a light microscope, and **b** with an electron microscope. Both are shown at the same magnification (about ×750).

WORKED EXAMPLE

2 Suppose we want to know the magnification of the plant cell labelled P in Figure 1.11b. The real length of the cell is 80 µm.

Step 1 Measure the length in mm of the cell in the micrograph using a ruler. You should find that it is about 60 mm.

Step 2 Convert mm to µm. (It is easier if we first convert all measurements to the same units – in this case micrometres, µm.)

So: 1 mm = 1000 µm

60 mm = 60 × 1000 µm

= 60 000 µm

Step 3 Use the equation to calculate the magnification.

$$\text{magnification, } M = \frac{\text{image size, } I}{\text{actual size, } A}$$

$$= \frac{60\,000\ \mu\text{m}}{80\ \mu\text{m}}$$

$$= \times\ 750$$

The multiplication sign (×) in front of the number 750 means 'times'. We say that the magnification is 'times 750'.

Question

3 **a** Calculate the magnification of the drawing of the animal cell in Figure 1.4.

b Calculate the actual (real) length of the chloroplast labelled **X** in Figure 1.34.

WORKED EXAMPLE

3 Figure 1.12 shows a lymphocyte with a scale bar. We can use this scale bar to calculate the magnification.

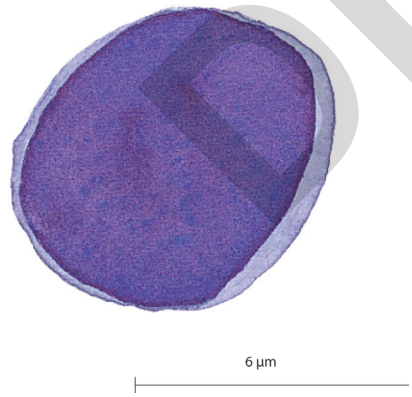


Figure 1.12: A lymphocyte.

Step 1 Measure the scale bar. Here, it is 36 mm.

Step 2 Convert mm to µm:

36 mm = 36 × 1000 µm = 36 000 µm

Step 3 The scale bar represents 6 µm. This is the actual size, *A*. Use the equation to calculate the magnification:

$$\text{magnification, } M = \frac{\text{image size, } I}{\text{actual size, } A}$$

$$= \frac{36\,000\ \mu\text{m}}{6\ \mu\text{m}}$$

$$= \times\ 6000$$

Calculating the real size of an object from its magnification

To calculate the real or actual size of an object, we can use the same magnification equation.

WORKED EXAMPLE

4 Figure 1.20 shows parts of three plant cells magnified ×5600. Suppose we want to know the actual length of the labelled chloroplast in this electron micrograph.

Step 1 Measure the observed length of the image of the chloroplast (I), in mm, using a ruler. The maximum length is 40 mm.

Step 2 Convert mm to µm:

40 mm = 40 × 1000 µm = 40 000 µm

Step 3 Use the equation to calculate the actual length:

$$\text{actual size, } A = \frac{\text{image size, } I}{\text{magnification, } M}$$

$$= \frac{40\,000\ \mu\text{m}}{5600}$$

= 7.1 µm (to one decimal place)

1.5 Electron microscopy

Before studying what cells look like with an electron microscope, you need to understand the difference between magnification and resolution.

Magnification and resolution

Look again at Figure 1.11. Figure 1.11a is a light micrograph. Figure 1.11b is an electron micrograph. Both micrographs are of the same cells and both have the same magnification. However, you can see that Figure 1.11b, the electron micrograph, is much clearer. This is because it has greater resolution. **Resolution** can be defined as the ability to distinguish between two separate points. If the two points cannot be resolved, they will be seen as one point. In practice, resolution is the amount of detail that can be seen – the greater the resolution, the greater the detail.

The maximum resolution of a light microscope is 200 nm. The reason for this is explained in the next section, 'The electromagnetic spectrum'. A resolution of 200 nm means that, if two points or objects are closer together than 200 nm, they cannot be distinguished as separate.

You might imagine that you could see more detail in Figure 1.11a by magnifying it (simply making it larger). In practice you would be able to see what is already there more easily, but you would not see any more detail. The image would just get more and more blurred as magnification increased. The resolution would not be greater.

The electromagnetic spectrum

How is resolution linked with the nature of light? One of the properties of light is that it travels in waves. The lengths of the waves of visible light vary, ranging from about 400 nm to about 700 nm. The human eye can distinguish between these different wavelengths, and in the brain the differences are converted to colour differences. Waves that are 400 nm in length are seen as violet. Waves that are 700 nm in length are seen as red.

Visible light is a form of electromagnetic radiation. The range of different wavelengths of electromagnetic radiation is called the electromagnetic spectrum. Visible light is only one part of this spectrum. Figure 1.13 shows some of the parts of the electromagnetic spectrum. The longer the waves, the lower their frequency. (All the waves travel at the same speed, so imagine them passing a post: shorter waves pass at higher frequency.) In theory, there is no limit to how short or how long the waves can be. Wavelength changes with energy: the greater the energy, the shorter the wavelength.

KEY WORD

resolution: the ability to distinguish between two objects very close together; the higher the resolution of an image, the greater the detail that can be seen

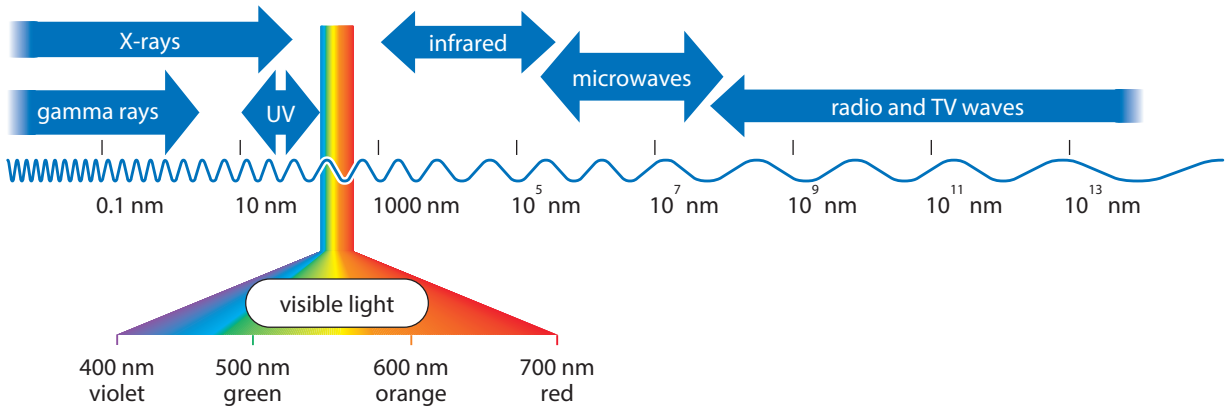


Figure 1.13: Diagram of the electromagnetic spectrum. The numbers indicate the wavelengths of the different types of electromagnetic radiation. Note the waves vary from very short to very long. Visible light is part of the spectrum. The double-headed arrow labelled UV is ultraviolet light.

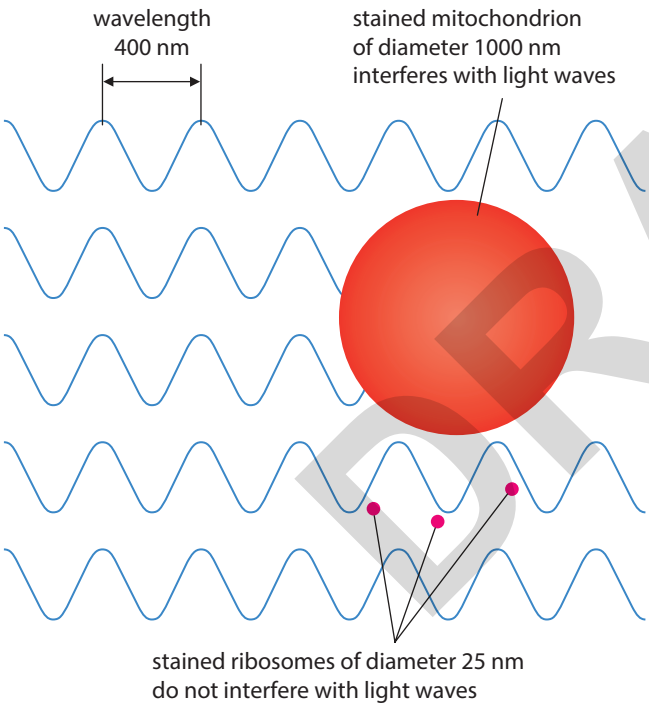


Figure 1.14: A mitochondrion and some ribosomes in the path of light waves of 400 nm length.

Now look at Figure 1.14. It shows a mitochondrion and some very small cell organelles called ribosomes. It also shows some wavy blue lines that represent light of 400 nm wavelength. This is the shortest visible wavelength. The mitochondrion is large enough to interfere with the light waves. However, the ribosomes are far too small to have any effect on the light waves.

The general rule when viewing specimens is that the limit of resolution is about one half the wavelength of the radiation used to view the specimen. In other words, if an object is any smaller than half the wavelength of the radiation used to view it, it cannot be seen separately from nearby objects. This means that the best resolution that can be obtained using a microscope that uses visible light (a light microscope) is 200 nm, since the shortest wavelength of visible light is 400 nm (violet light). Ribosomes are approximately 25 nm in diameter and can therefore never be seen using a light microscope.

If an object is transparent, it will allow light waves to pass through it and therefore will still not be visible. This is why many biological structures have to be stained before they can be seen.

Question

4 Explain why ribosomes are not visible using a light microscope.

The electron microscope

So how can we look at things smaller than 200 nm? The only solution to this problem is to use radiation of a shorter wavelength than visible light. If you study Figure 1.13, you will see that ultraviolet light or X-rays look like possible candidates. A much better solution, though, is to use electrons. Electrons are negatively charged particles which orbit the nucleus of an atom. When a metal becomes very hot, some of its electrons

gain so much energy that they escape from their orbits, similar to a rocket escaping from Earth's gravity. Free electrons behave like electromagnetic radiation. They have a very short wavelength: the greater the energy, the shorter the wavelength. Electrons are a very suitable form of radiation for microscopy for two major reasons. First, their wavelength is extremely short (at least as short as that of X-rays). Second, unlike X-rays, they are negatively charged, so they can be focused easily using electromagnets (a magnet can be made to alter the path of the beam, the equivalent of a glass lens bending light).

Using an electron microscope, a resolution of 0.5 nm can be obtained, 400 times better than a light microscope.

Transmission and scanning electron microscopes

Two types of electron microscope are now in common use. The transmission electron microscope (TEM) was the type originally developed. The beam of electrons is passed through the specimen before being viewed. Only those electrons that are transmitted (pass through the specimen) are seen. This allows us to see thin sections of specimens, and thus to see inside cells. In the scanning electron microscope (SEM), the electron beam is used to scan the surfaces of structures and only the reflected beam is observed.

An example of a scanning electron micrograph is shown in Figure 1.15. The advantage of this microscope is that surface structures can be seen. Because much of the specimen is in focus at the same time, a three-dimensional appearance is achieved. A disadvantage of the SEM is that it cannot achieve the same resolution as a TEM. Using an SEM, resolution is between 3 nm and 20 nm.

Figure 1.15: Scanning electron micrograph (SEM) of a tardigrade. Tardigrades or water bears, are about 0.5 mm long, with four pairs of legs. They are common in soil and can survive extreme environmental conditions (×86).

Viewing specimens with the electron microscope

Figure 1.16 shows how a TEM works and Figure 1.17 shows one in use.

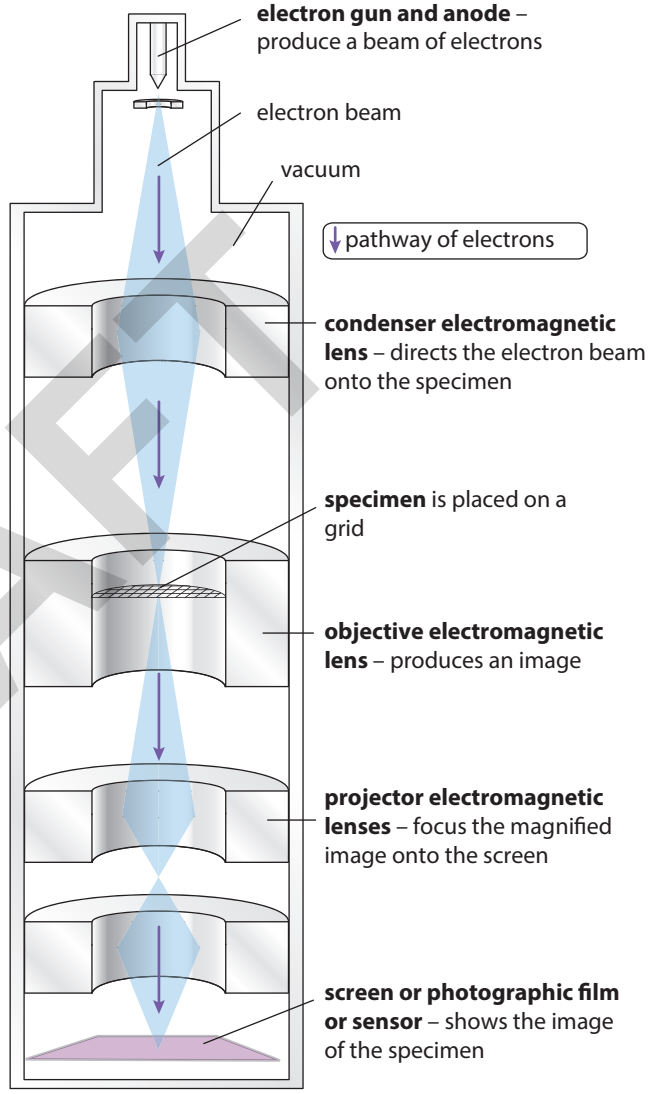


Figure 1.16: How a TEM works.

Note: you do not need to learn the structure of an electron microscope.

It is not possible to see an electron beam, so to make the image visible the electron beam has to be projected onto a fluorescent screen. The areas hit by electrons shine brightly, giving overall a black and white picture.

Figure 1.17: A TEM in use.

The stains used to improve the contrast of biological specimens for electron microscopy contain heavy metal atoms, which stop the passage of electrons. The resulting picture is like an X-ray photograph, with the more densely stained parts of the specimen appearing blacker. 'False-colour' images can be created by colouring the standard black and white image using a computer.

The electron beam, and therefore the specimen and the fluorescent screen, must be in a vacuum. If the electrons collided with air molecules, they would scatter, making it impossible to achieve a sharp picture. Also, water boils at room temperature in a vacuum, so all specimens must be dehydrated before being placed in the microscope. This means that only dead material or non-living can be examined. Great efforts are therefore made to try to preserve material in a life-like state when preparing it for electron microscopy.

Question

5 Copy and complete Table 1.2, which compares light microscopes with electron microscopes. Some boxes have been filled in for you.

1.6 Plant and animal cells as seen with an electron microscope

The fine (detailed) structure of a cell as revealed by the electron microscope is called ultrastructure and is shown in Figures 1.18–1.21.

Feature	Light microscope	Electron microscope
source of radiation		
wavelength of radiation used		*about 0.005 nm*
maximum resolution		*0.5 nm in practice*
lenses	*glass*	
specimen		*non-living or dead*
stains	*coloured dyes*	
image	*coloured*	

Table 1.2: Comparison of light microscopes and electron microscopes.

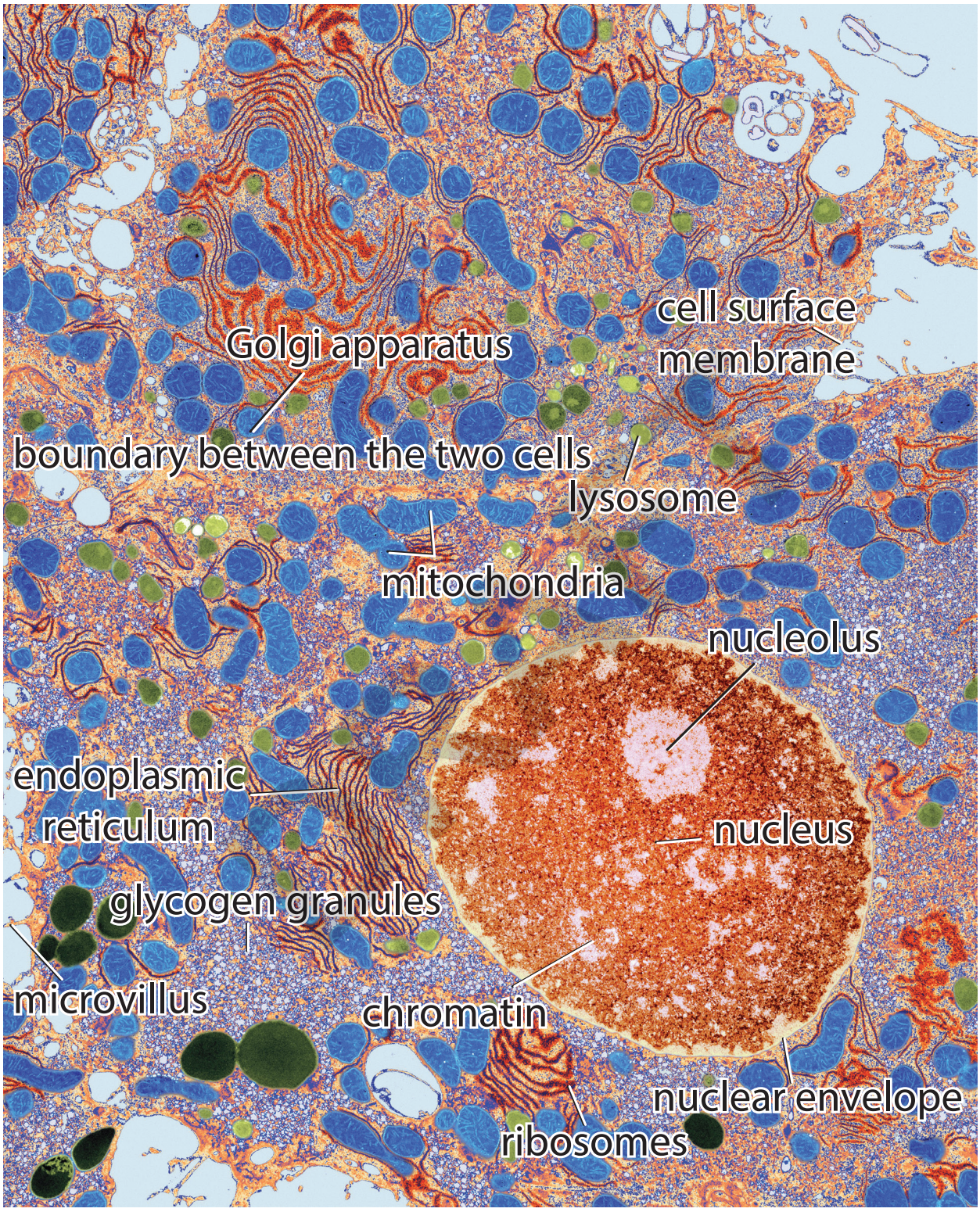


Figure 1.18: Parts of two representative animal cells as seen with a TEM. The cells are liver cells from a rat (×9600). The nucleus is clearly visible in one of the cells. The boundary between the two cells is difficult to see because the cell surface membranes are so thin.

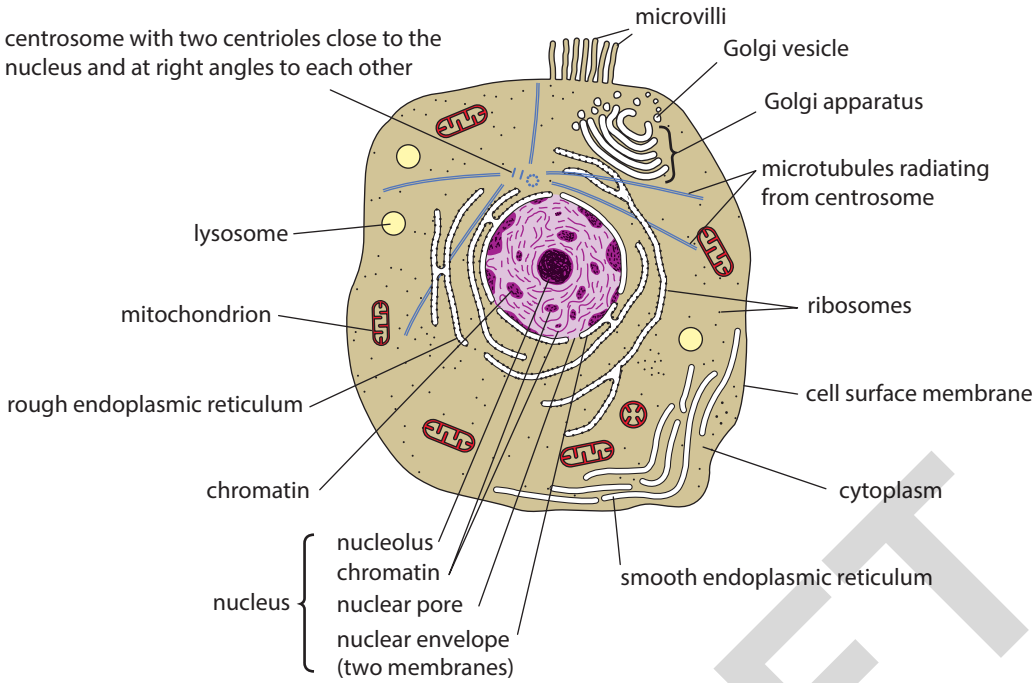


Figure 1.19: Ultrastructure of a typical animal cell as seen with an electron microscope. This drawing is based on many micrographs of animal cells. In reality, the endoplasmic reticulum is more extensive than shown here, and free ribosomes may be more extensive. Glycogen granules are sometimes present in the cytoplasm.

Question

6 Compare Figure 1.19 with Figure 1.4. Name the structures in an animal cell that can be seen with the electron microscope but not with the light microscope.

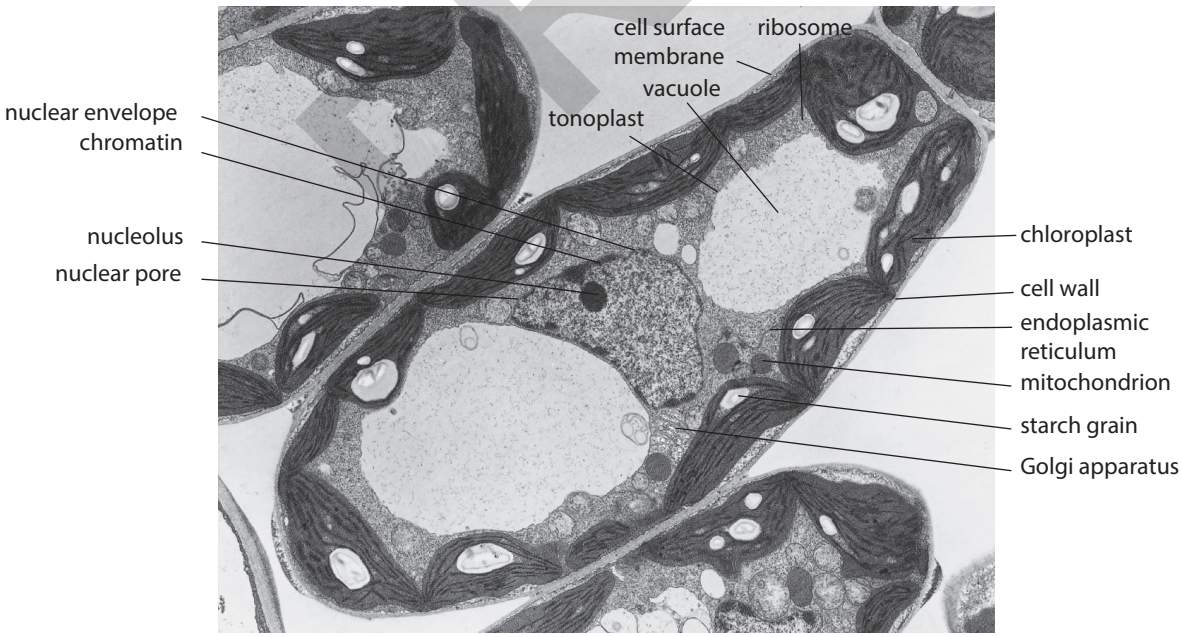


Figure 1.20: Representative plant cells as seen with a TEM. The cells are palisade cells from a soya bean leaf. The boundaries between the cells can clearly be seen due to the presence of cell walls (×5600).

Question

7 Compare Figure 1.21 with Figure 1.5. Name the structures in a plant cell that can be seen with the electron microscope but not with the light microscope.

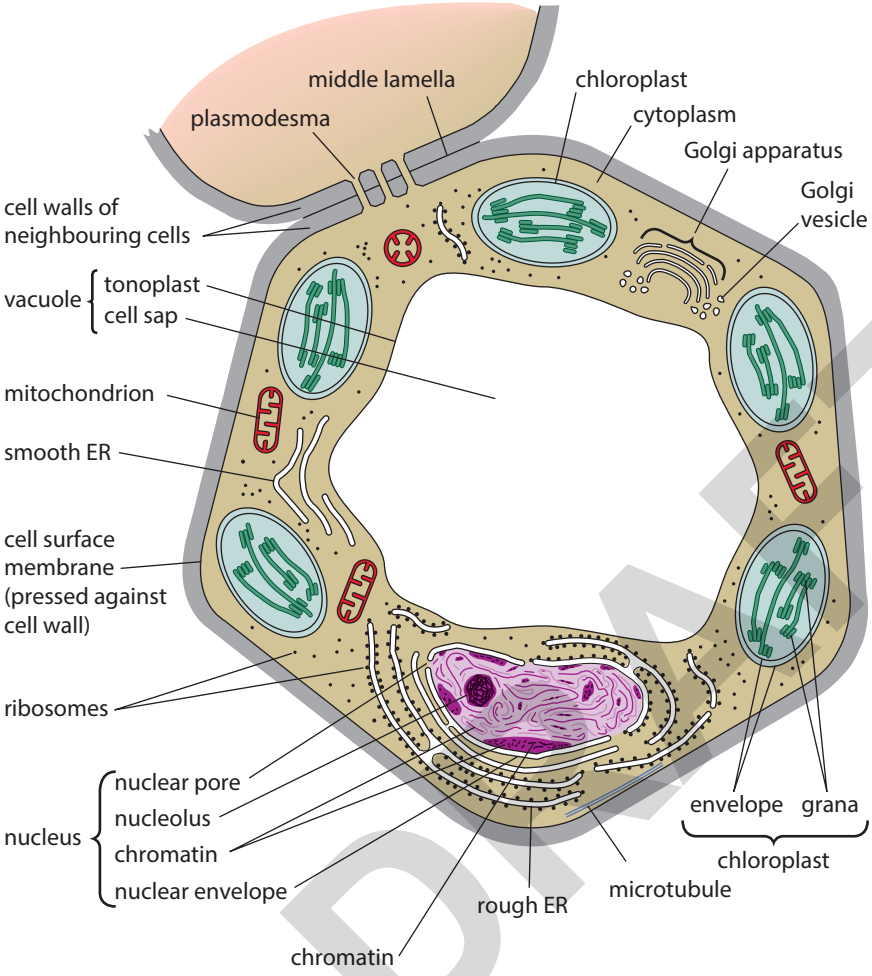


Figure 1.21: Ultrastructure of a typical plant cell as seen with the electron microscope. This drawing is based on many micrographs of plant cells. In reality, the ER is more extensive than shown. Free ribosomes may also be more extensive.

Cell surface membrane

The cell surface membrane is extremely thin (about 7 nm). However, at very high magnifications it can be seen to have three layers – two dark (heavily stained) layers surrounding a narrow, pale interior (Figure 1.22). The membrane is partially permeable and controls exchange between the cell and its environment. Membrane structure is discussed further in Chapter 4.

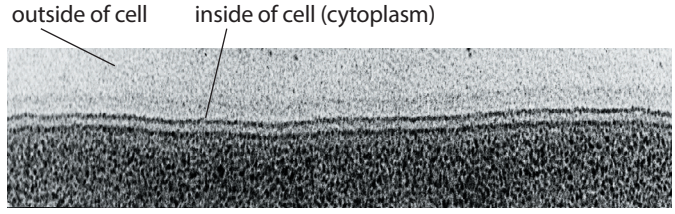


Figure 1.22: Cell surface membrane (×250 000). At this magnification the membrane appears as two dark lines at the edge of the cell.

Microvilli

Microvilli (singular: **microvillus**) are finger-like extensions of the cell surface membrane. They are typical of certain animal cells, such as epithelial cells. Epithelial cells cover the surfaces of structures. The microvilli greatly increase the surface area of the cell surface membrane, as shown in Figure 1.19. This is useful, for example, for reabsorption in the proximal convoluted tubules of the kidney and for absorption of digested food into cells lining the gut.

Nucleus

The nucleus (Figure 1.23) is the largest cell organelle.

Question

8 a Using the magnification given, determine the actual diameter of the nucleus shown in Figure 1.23.

b The diameter you have calculated for the nucleus shown in Figure 1.23 is not necessarily the maximum diameter of this nucleus. Explain why this is the case.

Tip: Use modelling clay to make a spherical shape (a ball), like a nucleus. Try cutting it into two at different places and looking at the sizes of the cut surfaces. This represents the process of sectioning material for examination using a microscope.

The nuclear envelope

The nucleus is surrounded by two membranes, forming the **nuclear envelope**. The outer membrane of the nuclear envelope is continuous with the endoplasmic reticulum (Figures 1.19 and 1.21).

KEY WORDS

microvilli (singular: **microvillus**): small, finger-like extensions of a cell which increase the surface area of the cell for more efficient absorption or secretion

nuclear envelope: the two membranes, situated close together, that surround the nucleus; the envelope is perforated with nuclear pores

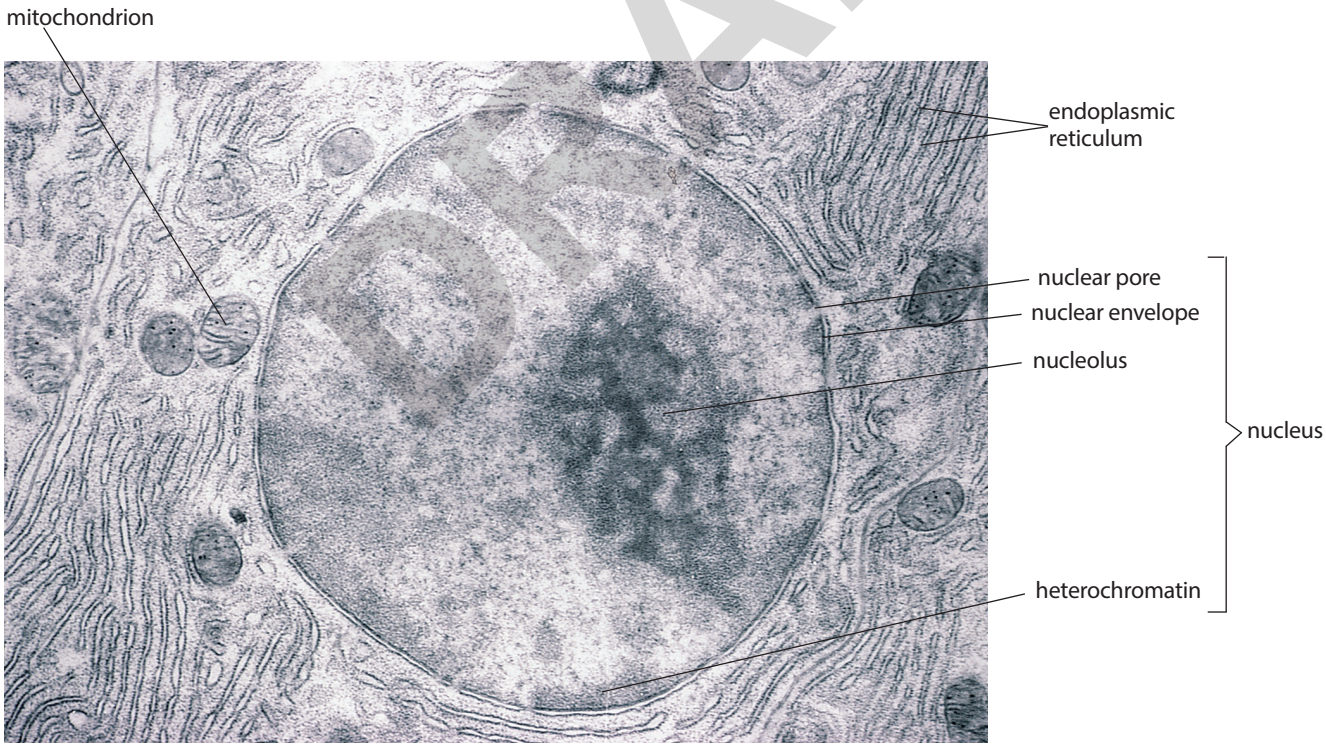


Figure 1.23: Transmission electron micrograph (TEM) of a nucleus. This is the nucleus of a cell from the pancreas of a bat (×7500). The circular nucleus is surrounded by a double-layered nuclear envelope containing nuclear pores. The nucleolus is more darkly stained. Rough ER is visible in the surrounding cytoplasm.

The nuclear envelope has many small pores called **nuclear pores**. These allow and control exchange between the nucleus and the cytoplasm. Examples of substances leaving the nucleus through the pores are messenger RNA (mRNA), transfer RNA (tRNA) and ribosomes for protein synthesis. Examples of substances entering through the nuclear pores are proteins (to help make ribosomes), nucleotides, ATP (adenosine triphosphate) and some hormones such as thyroid hormone T3.

Chromosomes and chromatin

The nucleus contains the chromosomes. Chromosomes contain DNA, the genetic material. DNA is organised into functional units called genes. Genes control the activities of the cell and inheritance; thus the nucleus controls the cell's activities.

The DNA molecules are so long (a human cell contains about two metres of DNA) that they have to be folded up into a more compact shape to prevent the strands becoming tangled. This is achieved by combining with proteins, particularly with proteins known as histones. The combination of DNA and proteins is known as chromatin. Chromatin also contains some RNA. Thus, chromosomes are made of chromatin (Chapter 5, Section 5.2 Chromosomes).

When a cell is about to divide, the nucleus divides first so that each new cell will have its own nucleus (Chapters 5 and 16).

Also within the nucleus, the nucleolus makes ribosomes, using the information in its own DNA.

Nucleolus

The nucleolus appears as a darkly stained, rounded structure in the nucleus (Figure 1.23). As mentioned earlier, one or more may be present, although one is most common. Its function is to make ribosomes using the information in its own DNA. It contains a core of DNA from one or more chromosomes which contain the genes that code for ribosomal RNA (rRNA), the form of RNA used in the manufacture of ribosomes. It also contains genes for making tRNA. Around the core are less dense regions where the ribosomal subunits are assembled, combining the rRNA with ribosomal proteins imported from the cytoplasm. The more ribosomes a cell makes, the larger its nucleolus.

The different parts of the nucleolus only come together during the manufacture of ribosomes. They separate when, as during nuclear division, ribosome synthesis ceases. The nucleolus as a structure then disappears.

Endoplasmic reticulum

When cells were first seen with the electron microscope, biologists were amazed to see so much detailed structure. The existence of much of this had not been suspected. This was particularly true of the **endoplasmic reticulum** (**ER**) (Figures 1.23, 1.24 and 1.28). The membranes of the ER form flattened compartments called sacs or cisternae. Processes can take place inside the cisternae separated from the cytoplasm. Molecules, particularly proteins, can be transported through the ER separate from the rest of the cytoplasm. The ER is continuous with the outer membrane of the nuclear envelope (Figures 1.19 and 1.21).

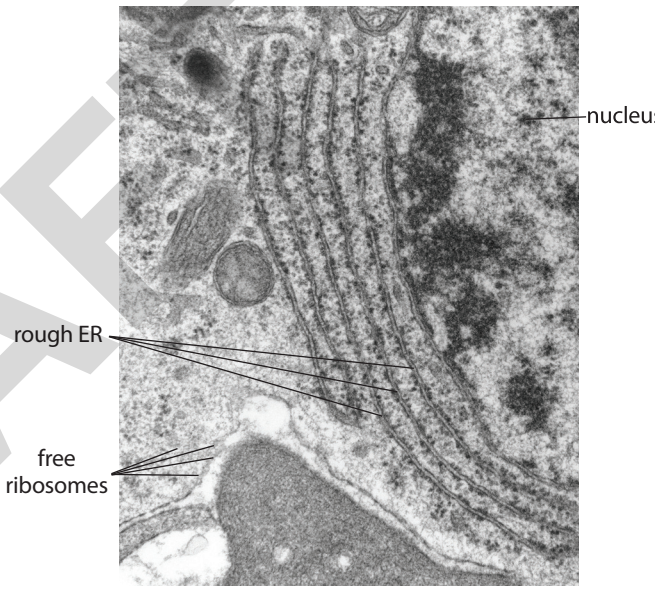


Figure 1.24: TEM of rough ER covered with ribosomes (black dots) (×17 000). Some free ribosomes can also be seen in the cytoplasm on the left.

KEY WORD

nuclear pores: pores found in the nuclear envelope which control the exchange of materials, e.g. mRNA, between the nucleus and the cytoplasm

endoplasmic reticulum (ER): a network of flattened sacs running through the cytoplasm of eukaryotic cells; molecules, particularly proteins, can be transported through the cell inside the sacs separate from the rest of the cytoplasm; ER is continuous with the outer membrane of the nuclear envelope

Rough endoplasmic reticulum

There are two types of ER: rough ER (RER) and smooth ER (SER). RER is so called because it is covered with many tiny organelles called ribosomes (described later). These are just visible as black dots in Figures 1.23 and 1.24. Ribosomes are the sites of protein synthesis (Chapter 6). They can be found free in the cytoplasm as well as on the RER.

Smooth endoplasmic reticulum

SER has a smooth appearance because it lacks ribosomes. It has a completely different function to RER. It makes lipids and steroids, such as cholesterol and the reproductive hormones oestrogen and testosterone. SER is also a major storage site for calcium ions. This explains why it is abundant in muscle cells, where calcium ions are involved in muscle contraction (Chapter 15, Section 15.3, Muscle contraction). In the liver, SER is involved in drug metabolism.

Ribosomes

Ribosomes are very small and are not visible with a light microscope. At very high magnifications using an electron microscope they can be seen to consist of two subunits: a large and a small subunit. The sizes of structures this small are often quoted in S units (Svedberg units). S units are a measure of how rapidly substances sediment in a high speed centrifuge (an ultracentrifuge). The faster they sediment, the higher the S number. Eukaryotic ribosomes are 80S ribosomes. The ribosomes of prokaryotes are 70S ribosomes, so are slightly smaller. Mitochondria and chloroplasts contain 70S ribosomes, revealing their prokaryotic origins (see the sections on mitochondria and chloroplasts).

Ribosomes are made of roughly equal amounts by mass of ribosomal RNA (rRNA) and protein. Their three-dimensional structure has now been worked out (Figure 1.25). Ribosomes allow all the interacting molecules involved in protein synthesis, such as mRNA, tRNA, amino acids and regulatory proteins, to gather together in one place (Chapter 6, Section 6.5, Protein synthesis).

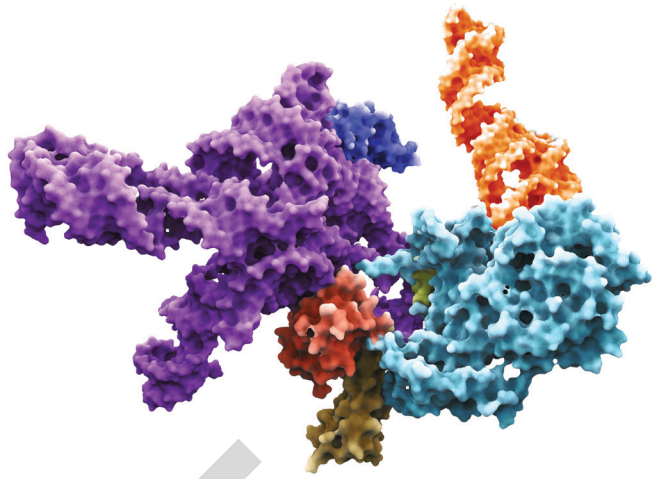


Figure 1.25: Structure of the human 80S ribosome.

Golgi apparatus

The **Golgi apparatus** is a stack of flattened sacs called cisternae (Figure 1.26). More than one Golgi apparatus may be present in a cell. The stack is constantly being formed at one end from vesicles which bud off from the ER, and are broken down again at the other end to form **Golgi vesicles**. The stack of sacs together with the associated vesicles is referred to as the Golgi apparatus or Golgi complex.

KEY WORDS

ribosome: a tiny organelle found in large numbers in all cells; prokaryotic ribosomes are about 20 nm in diameter while eukaryotic ribosomes are about 25 nm in diameter

Golgi apparatus (Golgi body, Golgi complex): an organelle found in eukaryotic cells; the Golgi apparatus consists of a stack of flattened sacs, constantly forming at one end and breaking up into Golgi vesicles at the other end

Golgi vesicles: carry their contents to other parts of the cell, often to the cell surface membrane for secretion; the Golgi apparatus chemically modifies the molecules it transports, e.g. sugars may be added to proteins to make glycoproteins

The Golgi apparatus collects and processes molecules, particularly proteins from the RER. It contains hundreds of enzymes for this purpose. After processing, the molecules can be transported in Golgi vesicles to other parts of the cell or out of the cell. Releasing molecules from the cell is called secretion and the pathway followed by the molecules is called the secretory pathway. These are some examples of the functions of the Golgi apparatus

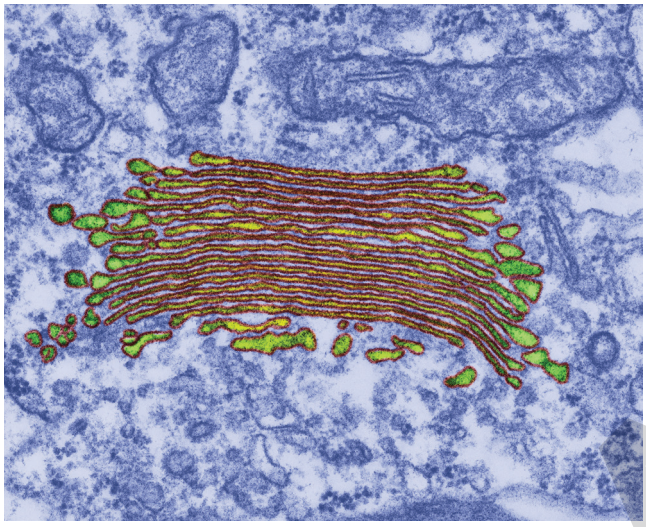


Figure 1.26: TEM of a Golgi apparatus. A central stack of saucer-shaped sacs can be seen budding off small Golgi vesicles (green). These may form secretory vesicles whose contents can be released at the cell surface by exocytosis (Chapter 4).

- Golgi vesicles are used to make lysosomes.
- Sugars are added to proteins to make molecules known as glycoproteins.
- Sugars are added to lipids to make glycolipids. Glycoproteins and glycolipids are important components of membranes (Chapter 4, Section 4.2, Structure of membranes) and are important molecules in cell signalling (Chapter 4, Section 4.4, Cell signalling).
- During plant cell division, Golgi enzymes are involved in the synthesis of new cell walls.
- In the gut and the gas exchange system, cells called goblet cells release a substance called mucin from the Golgi apparatus (Chapter 9, Section 9.4, Warming and cleaning the air). Mucin is one of the main components of mucus.

Lysosomes

Lysosomes are simple sacs, surrounded by a single membrane. In animal cells they are usually 0.1–0.5 μm in diameter (Figure 1.27). In plant cells the large central vacuole may act as a lysosome, although lysosomes similar to those in animal cells are also seen in the cytoplasm.

KEY WORD

lysosome: a spherical organelle found in eukaryotic cells; it contains digestive (hydrolytic) enzymes and has a variety of destructive functions, such as removal of old cell organelles

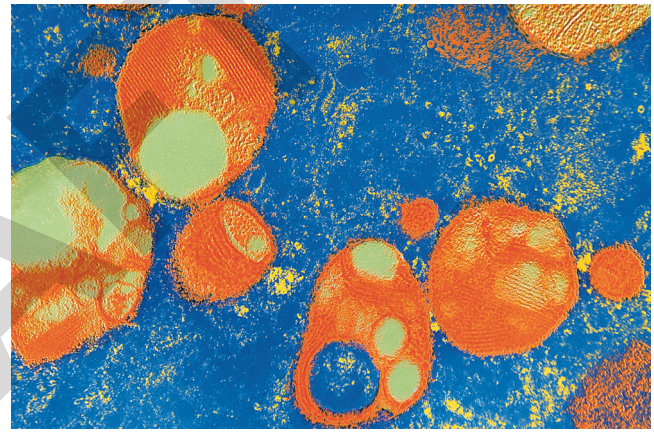


Figure 1.27: Lysosomes (orange) in a mouse kidney cell (×55 000). They contain cell structures in the process of digestion. Cytoplasm is coloured blue here.

Lysosomes contain digestive enzymes. The enzymes are called hydrolases because they carry out hydrolysis reactions. These enzymes must be kept separate from the rest of the cell to prevent damage. Lysosomes are responsible for the breakdown (digestion) of unwanted substances and structures such as old organelles or even whole cells. Hydrolysis works fastest in an acid environment so the contents of lysosomes are acidic, pH 4–5 compared with 6.5–7.0 in the surrounding cytoplasm. Among the 60+ enzymes contained in lysosomes are proteases, lipases and nucleases which break down proteins, lipids and nucleic acids respectively. The enzymes are synthesised on RER and delivered to lysosomes via the Golgi apparatus.

The activities of lysosomes can be split into the four categories discussed below.

Getting rid of unwanted cell components

Lysosomes can engulf and destroy unwanted cell components, such as molecules or organelles, that are located inside the cell.

Endocytosis

Endocytosis is described in more detail in Chapter 4 (Section 4.5, Movement of substances across membranes). Material may be taken into the cell by endocytosis, for example when white blood cells engulf bacteria. Lysosomes may fuse with the endocytic vacuoles formed and release their enzymes to digest the contents.

Exocytosis

Lysosomal enzymes may be released from the cell for extracellular digestion. An example is the replacement of cartilage by bone during development. The heads of sperms contain a special lysosome, the acrosome, for digesting a path through the layers of cells surrounding the egg just before fertilisation.

Self-digestion

The contents of lysosomes are sometimes released into the cytoplasm. This results in the whole cell being digested (a process called autolysis). This may be part of normal development, as when a tadpole tail is reabsorbed during metamorphosis or when a uterus is restored to its normal size after pregnancy. It also occurs after the death of an individual as membranes lose their partial permeability.

Mitochondria

Structure

The structure of the mitochondrion (plural: mitochondria) as seen with the electron microscope is visible in Figures 1.18, 1.28 and 12.10. Mitochondria are usually about 1 μm in diameter and can be various shapes, often sausage-shaped as in Figure 1.28. They are surrounded by two membranes (an envelope). The inner membrane is folded to form finger-like **cristae** (singular: **crista**) which project into the interior of the mitochondrion which is called the matrix. The space between the two membranes is called the intermembrane space.

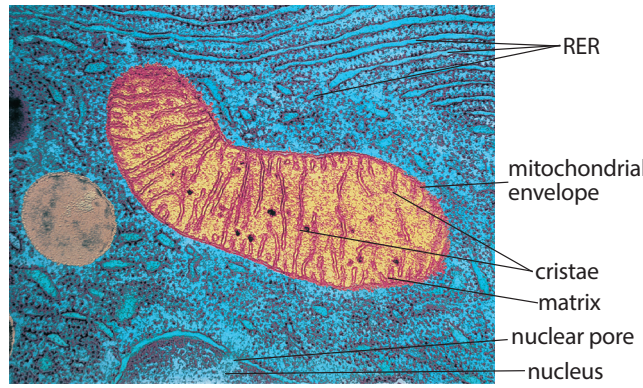


Figure 1.28: Mitochondrion (orange) with its double membrane (envelope); the inner membrane is folded to form cristae (×20 000). Mitochondria are the sites of aerobic cell respiration. Note also the RER.

The number of mitochondria in a cell is very variable. As they are responsible for aerobic respiration, it is not surprising that cells with a high demand for energy, such as liver and muscle cells, contain large numbers of mitochondria. A liver cell may contain as many as 2000 mitochondria. If you exercise regularly, your muscles will make more mitochondria.

Functions of mitochondria and the role of ATP

The main function of mitochondria is to carry out aerobic respiration, although they do have other functions, such as the synthesis of lipids. During respiration, a series of reactions takes place in which energy is released from energy-rich molecules such as sugars and fats. Most of the energy is transferred to molecules of **ATP** (**adenosine triphosphate**). This is the energy-carrying molecule found in all living cells. It is known as the universal energy carrier.

KEY WORDS

cristae (singular: **crista**): folds of the inner membrane of the mitochondrial envelope on which are found stalked particles of ATP synthase and electron transport chains associated with aerobic respiration

ATP (**adenosine triphosphate**): the molecule that is the universal energy currency in all living cells; the purpose of respiration is to make ATP

The reactions of respiration take place in solution in the matrix and in the inner membrane (cristae). The matrix contains enzymes in solution, including those of the Krebs cycle. Electron carriers are found in the cristae. For more detail, see Chapter 12 (Section 12.2, Aerobic respiration).

Once made, ATP leaves the mitochondrion and, as it is a small, soluble molecule, it can spread rapidly to all parts of the cell where energy is needed. Its energy is released by breaking the molecule down to **ADP** (**adenosine diphosphate**). This is a hydrolysis reaction. The ADP can then be recycled in a mitochondrion for conversion back to ATP during aerobic respiration.

The endosymbiont theory (extension material)

In the 1960s, it was discovered that mitochondria and chloroplasts contain ribosomes which are slightly smaller than those in the cytoplasm and are the same size as those found in bacteria. Cytoplasmic ribosomes are 80S, while those of bacteria, mitochondria and chloroplasts are 70S. It was also discovered in the 1960s that mitochondria and chloroplasts contain small, circular DNA molecules, also like those found in bacteria. It was later proved that mitochondria and chloroplasts are, in effect, ancient bacteria which now live inside the larger cells of animals and plants (see 'Thinking outside the box' at the beginning of this chapter). This is known as the endosymbiont theory. 'Endo' means 'inside' and a 'symbiont' is an organism which lives in a mutually beneficial relationship with another organism. The DNA and ribosomes of mitochondria and chloroplasts are still active and responsible for the coding and synthesis of certain vital proteins, but mitochondria and chloroplasts can no longer live independently.

Mitochondrial ribosomes are just visible as tiny dark orange dots in the mitochondrial matrix in Figure 1.28.

Microtubules and microtubule organising centres (MTOCs)

Microtubules are long, rigid, hollow tubes found in the cytoplasm. They are very small, about 25 nm in diameter. Together with actin filaments and intermediate filaments (not discussed in this book), they make up the cytoskeleton, an essential structural component of cells which helps to determine cell shape.

Microtubules are made of a protein called tubulin. Tubulin has two forms, α-tubulin (alpha-tubulin) and β-tubulin (beta-tubulin). α- and β-tubulin molecules combine to form dimers (double molecules). These dimers are then joined end to end to form long 'protofilaments'. This is an example of polymerisation, the process by which giant molecules are made by joining together many identical subunits. Thirteen protofilaments line up alongside each other in a ring to form a cylinder with a hollow centre. This cylinder is the microtubule. Figure 1.29a shows the helical pattern formed by neighbouring α- and β-tubulin molecules.

Apart from their mechanical function of support, microtubules have a number of other functions.

- Secretory vesicles and other organelles and cell components can be moved along the outside surfaces of the microtubules, forming an intracellular transport system, as in the movement of Golgi vesicles during exocytosis.
- During nuclear division (Chapter 5), a spindle made of microtubules is used for the separation of chromatids or chromosomes.
- Microtubules form part of the structure of centrioles.
- Microtubules form an essential part of the mechanism involved in the beating movements of cilia and flagella.

The assembly of microtubules from tubulin molecules is controlled by special locations in cells called microtubule organising centres (MTOCs). These are discussed further in the following section on centrioles. Because of their simple construction, microtubules can be formed and broken down very easily at the MTOCs, according to need.

KEY WORDS

ADP (**adenosine diphosphate**): the molecule that is converted to ATP by addition of phosphate (a reaction known as phosphorylation) during cell respiration; the enzyme responsible is ATP synthase; the reaction requires energy

microtubules: tiny tubes made of a protein called tubulin and found in most eukaryotic cells; microtubules have a large variety of functions, including cell support and determining cell shape; the 'spindle' on which chromatids and chromosomes separate during nuclear division is made of microtubules

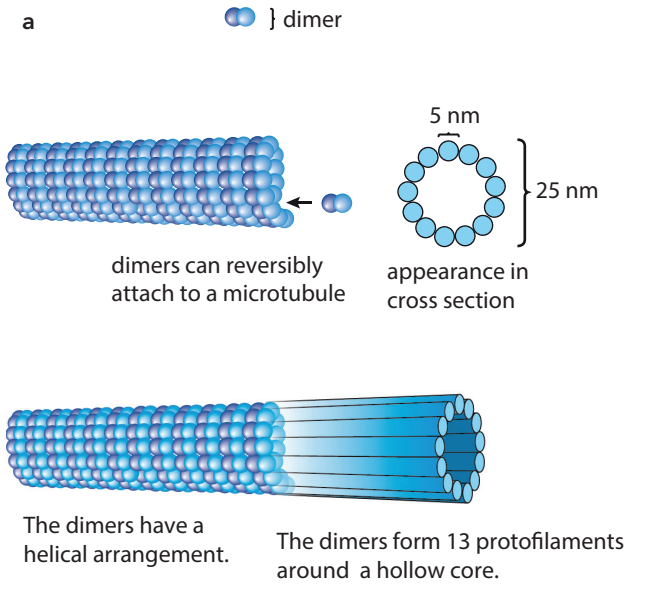


Figure 1.29: a The structure of a microtubule and **b** the arrangement of microtubules in two cells. The microtubules are coloured yellow.

Centrioles and centrosomes

The extra resolution of the electron microscope reveals that just outside the nucleus of animal cells there are really *two* **centrioles** and not one as it appears under the light microscope (compare Figures 1.4 and 1.19). They lie close together and at right angles to each other in a region known as the **centrosome**. Centrioles and the centrosome are absent from most plant cells.

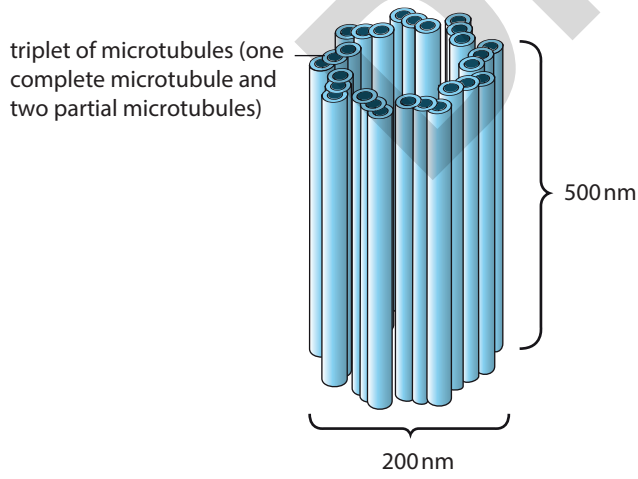


Figure 1.30: The structure of a centriole. It consists of nine groups of microtubules. Each group is made up of three microtubules, a triplet.

A centriole is a hollow cylinder about 500 nm long, formed from a ring of short microtubules. Each centriole contains nine triplets of microtubules (Figures 1.30 and 1.31).

Until recently, it was believed that centrioles acted as MTOCs for the assembly of the microtubules that make up the spindle during nuclear division (Chapter 5). It is now known that this is done by the centrosome, but does not involve the centrioles. However, centrioles are needed for the production of cilia. Centrioles are found at the bases of cilia and flagella, where they are known as basal bodies. The centrioles act as MTOCs. The microtubules that extend from the basal bodies into the cilia and flagella are essential for the beating movements of these organelles.

KEY WORDS

centriole: one of two small, cylindrical structures, made from microtubules, found just outside the nucleus in animal cells, in a region known as the centrosome; they are also found at the bases of cilia and flagella

centrosome: the main microtubule organising centre (MTOC) in animal cells

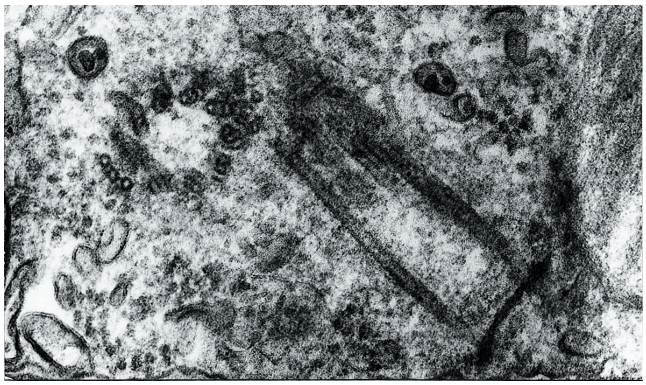


Figure 1.31: Centrioles in transverse and longitudinal section (TS and LS) (×86 000). The one on the left is seen in TS and clearly shows the nine triplets of microtubules which make up the structure.

KEY WORDS

cilia (singular: **cilium**): whip-like structures projecting from the surface of many animal cells and the cells of many unicellular organisms; they beat, causing locomotion or the movement of fluid across the cell surface

flagella (singular: **flagellum**): whip-like structures projecting from the surface of some animal cells and the cells of many unicellular organisms; they beat, causing locomotion or the movement of fluid across the cell surface; they are identical in structure to cilia, but longer

Cilia and flagella

Cilia (singular: **cilium**) and **flagella** (singular: **flagellum**) have identical structures. They are whip-like, beating extensions of many eukaryotic cells. Each is surrounded by an extension of the cell surface membrane. They were given different names before their structures were discovered: flagella are long and found usually one or two per cell, whereas cilia are short and often numerous.

Structure

Cilia and flagella are extremely complicated structures, composed of over 600 different polypeptides. This complexity results in very fine control of how they beat.

The structure of a cilium is shown in Figure 1.32. Cilia have two central microtubules and a ring of nine microtubule doublets (MTDs) around the outside. This is referred to as a '9 + 2' structure. Each MTD contains an A and a B microtubule (Figure 1.32a). The wall of the A microtubule is a complete ring of 13 protofilaments and the B microtubule attached is an incomplete ring with only 10 protofilaments (see Figure 1.32a). Figure 1.32a shows that each A microtubule has inner and outer arms. These are made of the protein dynein. They connect with the B microtubules of neighbouring MTDs during beating. If you imagine the microtubule in three dimensions, there are two rows of several hundred dynein arms along the outside of each A microtubule. The whole cylindrical structure inside the cell surface membrane is called the axoneme.

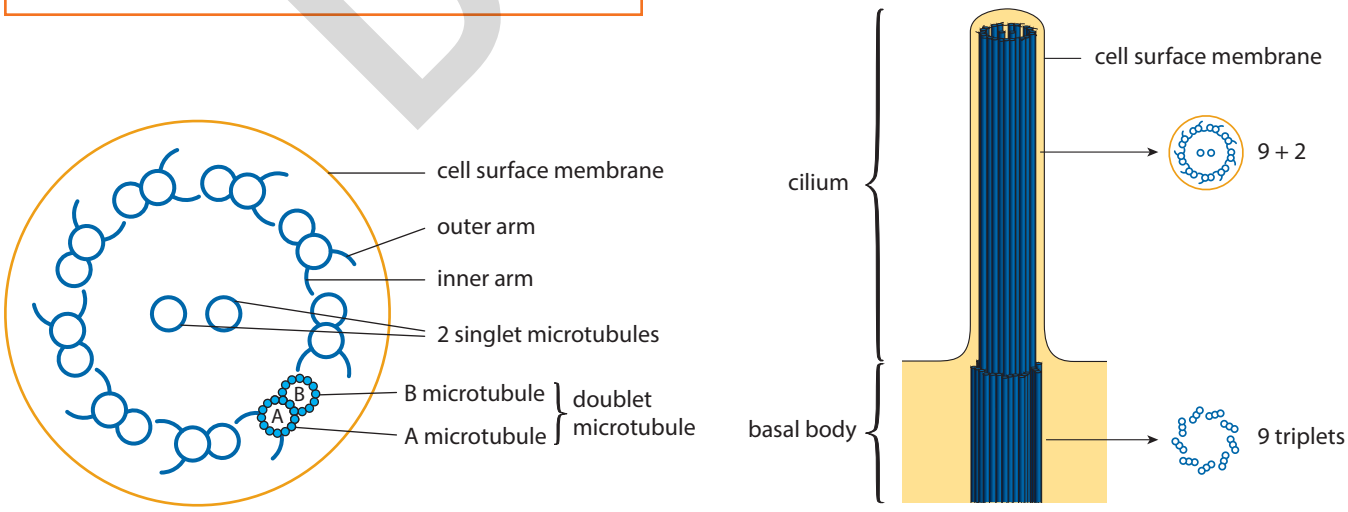


Figure 1.32: The structure of a cilium. **a** A cilium seen in TS. Note the '9 + 2' arrangement of microtubules. **b** A cilium. TSs of the cilium (9 + 2) and basal body (9 triplets) are also shown.

At the base of each cilium and flagellum is a structure called the basal body which is identical in structure to the centriole. We now know that centrioles replicate themselves to produce these basal bodies, and that cilia and flagella grow from basal bodies. Figure 1.33 is a scanning electron micrograph of cilia in the respiratory tract.

Figure 1.33: Scanning electron micrograph of cilia in the respiratory tract

Beating mechanism

The beating motion of cilia and flagella is caused by the dynein (protein) arms making contact with, and moving along, neighbouring microtubules. This produces the force needed for cilia to beat. As neighbouring MTDs slide past each other, the sliding motion is converted into bending by other parts of the cilium.

Functions

If the cell is attached to something so that it cannot move, fluid will move past the cell. If the cell is not attached, the cell will swim through the fluid. Single-celled organisms can therefore use the action of cilia and flagella for locomotion. You will easily be able to find videos of such motion on the internet. In vertebrates, beating cilia are found on some epithelial cells, such as those lining the airways (Chapter 9). Here more than 10 million cilia may be found per mm^2. They maintain a flow of mucus which removes debris such as dust and bacteria from the respiratory tract.

Question

9 In vertebrates, beating cilia are also found on the epithelial cells of the oviduct (the tube connecting the ovary to the uterus). Suggest what function cilia have in the oviduct.

Chloroplasts

The structure of the chloroplast as seen with the electron microscope is shown in Figures 1.20, 1.21 and 1.34. You can also see a higher-resolution micrograph in Figure 13.4. Chloroplasts tend to have an elongated shape and a diameter of about 3–10 μm (compare 1 μm diameter for mitochondria). Like mitochondria, they are surrounded by two membranes, which form the chloroplast envelope.

The main function of chloroplasts is to carry out photosynthesis. During the first stage of photosynthesis (the light-dependent stage), light energy is absorbed by photosynthetic pigments, particularly chlorophyll. The pigments are found on the membranes of the chloroplast.

The membrane system consists of fluid-filled sacs called **thylakoids**, which spread out like sheets in three dimensions. In places, the thylakoids form flat, disc-like structures that stack up like piles of coins, forming structures called grana (from their appearance in the light microscope; 'grana' means grains).

KEY WORD

thylakoid: a flattened, membrane-bound, fluid-filled sac which is the site of the light-dependent reactions of photosynthesis in a chloroplast

The second stage of photosynthesis (the light-independent stage) uses the energy and reducing power generated during the first stage to convert carbon dioxide into sugars. This takes place in the stroma. The sugars made may be stored in the form of starch grains in the stroma (Figures 1.20 and 13.3 and 13.4).

Lipid droplets are also seen in the stroma. They appear as black spheres in electron micrographs (Figure 1.34). They are reserves of lipid for making membranes or are formed from the breakdown of internal membranes as the chloroplast ages.

Like mitochondria, chloroplasts have their own protein synthesising machinery, including 70S ribosomes and circular DNA. In electron micrographs, the ribosomes can just be seen as small black dots in the stroma (Figure 1.4).

As with mitochondria, it has been shown that chloroplasts originated as endosymbiotic bacteria, in this case photosynthetic blue-green bacteria. The endosymbiont theory is discussed in more detail in the earlier section on mitochondria.

Cell walls

Structure

The first walls formed by plant cells are known as primary walls. They are relatively rigid. The primary wall consists of parallel fibres of the polysaccharide cellulose running through a matrix of other polysaccharides such as pectins and hemicelluloses. Cellulose fibres are inelastic and have high tensile strength, meaning they are difficult to break by pulling on each end. This makes it difficult to stretch the wall, for example when water enters the cell by osmosis. The structure of cellulose is described in Chapter 2.

In most cells extra layers of cellulose are added to the first layer of the primary wall, forming a secondary wall. In a given layer the cellulose fibres are parallel, but the fibres of different layers run in different directions forming a cross-ply structure which is stronger as a result (see Figure 2.10).

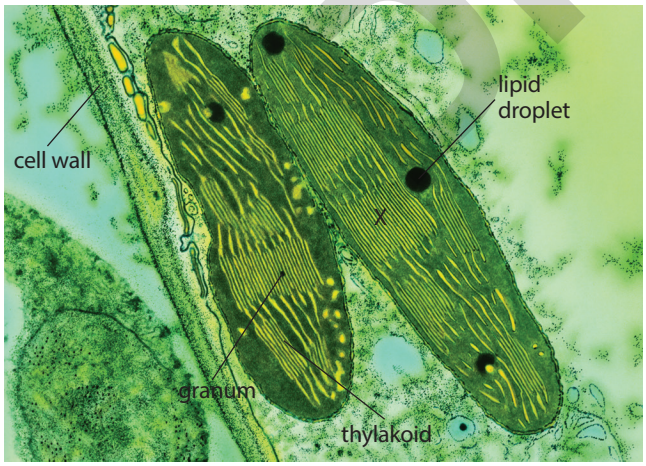


Figure 1.34: Two chloroplasts (×16 000). Thylakoids (yellow) run through the stroma (dark green) and are stacked in places to form grana. Black circles among the thylakoids are lipid droplets. See also Figure 13.3 and 13.4. Chloroplast **X** is referred to in Question 3b.

Some cell walls become even stronger and more rigid by the addition of lignin. Xylem vessel elements and sclerenchyma are examples (Chapter 7). Lignin adds compressional strength to tensile strength (it prevents buckling). It is what gives wood (secondary xylem) its strength and is needed for support in shrubs and trees.

Functions

Some of the main functions of cell walls are summarised below.

- Mechanical strength and support for individual cells and the plant as a whole. Lignification is one means of support. Turgid tissues are another means of support that is dependent on strong cell walls.
- Cell walls prevent cells from bursting by osmosis if cells are surrounded by a solution with a higher water potential (Chapter 2).
- Different orientations of the layers of cellulose fibres help determine the shapes of cells as they grow.
- The system of interconnected cell walls in a plant is called the apoplast. It is a major transport route for water, inorganic ions and other materials (Chapter 7).
- Living connections through neighbouring cell walls, the plasmodesmata, help form another transport pathway through the plant known as the symplast (Chapter 7).
- The cell walls of the root endodermis are impregnated with suberin, a waterproof substance that forms a barrier to the movement of water, thus helping in the control of water and mineral ion uptake by the plant (Chapter 7).
- Epidermal cells often have a waterproof layer of waxy cutin, the cuticle, on their outer walls. This helps reduce water loss by evaporation.

Vacuoles

As we have seen, animal cell vacuoles are relatively small and include phagocytic vacuoles, food vacuoles and autophagic vacuoles.

Unlike animal cells, plant cells typically have a large central vacuole (Figure 1.20). Some examples of the functions of the large central vacuole of plants are listed below. It is useful to try to remember one or two of these examples.

Support

The solution in the vacuole is relatively concentrated. Water therefore enters the vacuole by osmosis, inflating the vacuole and causing a build-up of pressure. A fully inflated cell is described as turgid. Turgid tissues help to support the stems of plants that lack wood (wilting demonstrates the importance of this).

Lysosomal activity

Plant vacuoles may contain hydrolases and act as lysosomes.

Secondary metabolites

Plants contain a wide range of chemicals known as secondary metabolites which, although not essential for growth and development, contribute to survival in various ways. These are often stored in vacuoles. Examples of their functions are:

- Anthocyanins are pigments that are responsible for most of the red, purple, pink and blue colours of flowers and fruits. They attract pollinators and seed dispersers.
- Certain alkaloids and tannins deter herbivores from eating the plant.
- Latex, a milky fluid, can accumulate in vacuoles, for example in rubber trees. The latex of the opium poppy contains alkaloids such as morphine from which opium and heroin are obtained.

Food reserves

Food reserves, such as sucrose in sugar beet, or mineral salts, may be stored in the vacuole. Protein-storing vacuoles are common in seeds.

Waste products

Waste products, such as crystals of calcium oxalate, may be stored in vacuoles.

Growth in size

Osmotic uptake of water into the vacuole is responsible for most of the increase in volume of plant cells during growth. The vacuole occupies up to a third of the total cell volume.

PRACTICAL ACTIVITY 1.3

Work in groups of ten. Each group should make one copy of the following table on stiff card.

START	Photosynthesis occurs in this organelle
Chloroplast	Chromosomes are found in this structure in eukaryotic cells
Nucleus	These are found on rough endoplasmic reticulum (RER)
Ribosomes	This structure contains cellulose as a strengthening material
Cell wall	Makes ribosomes
Nucleolus	Site of ATP synthesis in aerobic respiration
Mitochondrion	Makes lysosomes
Golgi apparatus	Has a '9 + 2' arrangement of microtubules
Cilium	Mainly contains digestive enzymes
Lysosome	END

Cut up the card so that each piece of card has one **term** and one description (one row of the table). There are therefore ten cards.

Shuffle the cards and take one each. The student with the **START** card reads out the description and the student who has the correct matching term reads out **THE** from their card. They then read out the description on their card. This continues until it reaches the **END** card. Your teacher will help if you get stuck.

The cards can be reshuffled and the activity repeated to see if you can do it faster the second time.

1.7 Bacteria

You will recall that there are two fundamental types of cell: prokaryotes and eukaryotes. The plant and animal cells you have studied so far are eukaryotic cells. Bacteria are prokaryotes and their cells are much simpler than those of eukaryotes. Prokaryotic cells are generally about 1000 times smaller in volume and lack a nucleus that is surrounded by a double membrane. Prokaryotes are thought to have been the first living organisms on Earth. The earliest known fossil prokaryotes are about 3.5 billion years old (the Earth was formed about 4.5 billion years ago). Most biologists believe that eukaryotes evolved from prokaryotes about 2 billion years ago. There are two groups of prokaryotes, known as Bacteria and Archaea. (The classification of living organisms is discussed in Chapter 18.) We consider only Bacteria in this book.

Structure of bacteria

Figure 1.35 shows the structure of a typical **bacterium** (plural: **bacteria**). The left side of the diagram shows the structures that are always present. The right side of the diagram shows the structures which are sometimes found in bacteria.

KEY WORD

bacteria (singular: **bacterium**): a group of single-celled prokaryotic microorganisms; they have a number of characteristics, such as the ability to form spores, which distinguish them from the other group of prokaryotes known as Archaea

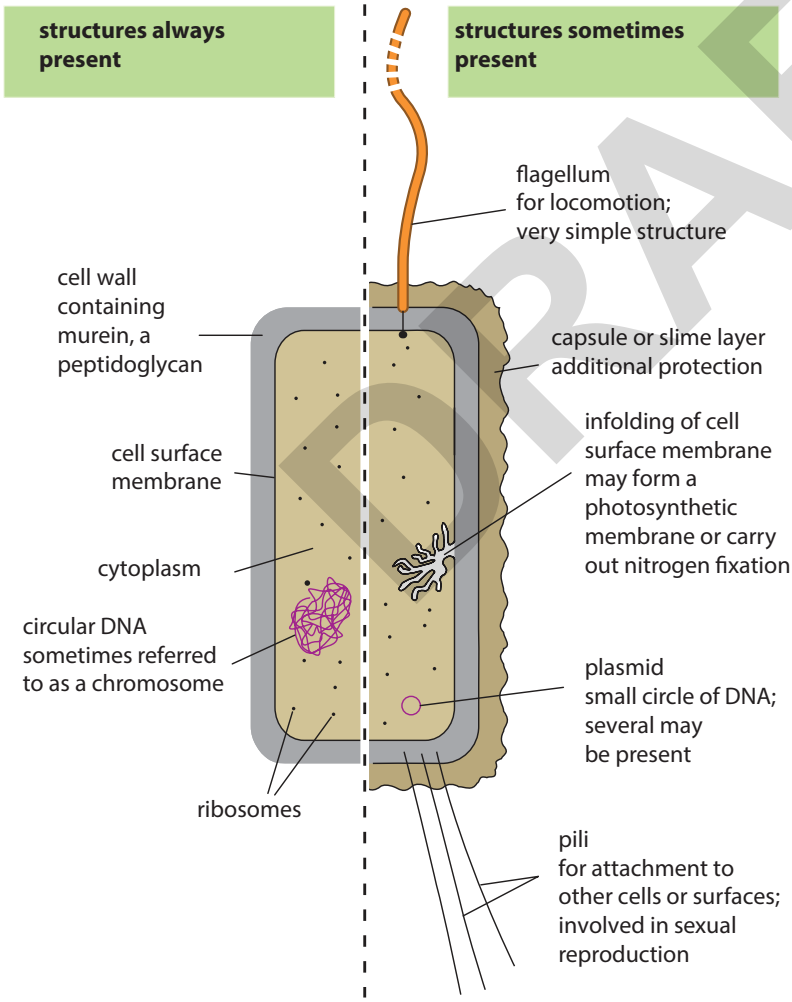


Figure 1.35: Diagram of a bacterium. Cells are generally about 1–5 μm in diameter.

Cell wall

Bacterial cell walls contain a strengthening material called **peptidoglycan**. The cell wall protects the bacterium and is essential for its survival. It prevents the cell from swelling up and bursting if water enters the cell by osmosis.

KEY WORD

peptidoglycan: a polysaccharide combined with amino acids; it is also known as murein; it makes the bacterial cell wall more rigid

Cell surface membrane

Like all cells, bacterial cells are surrounded by a cell surface membrane.

Cytoplasm

The cytoplasm does not contain any double membrane-bound organelles (such as mitochondria).

Circular DNA

The DNA molecule in bacteria is circular. It is sometimes referred to as a chromosome, but it has a much simpler structure than chromosomes in eukaryotes. It is found in a region called the nucleoid, which also contains proteins and small amounts of RNA. It is not surrounded by a double membrane, unlike the nucleus of eukaryotes. There may be more than one copy of the DNA molecule in a given cell.

Ribosomes

Bacterial ribosomes are 70S ribosomes, slightly smaller than the 80S ribosomes of eukaryotes.

Flagellum

Some bacteria are able to swim because they have one or more flagella. Bacterial flagella have a much simpler structure than eukaryotic flagella. The bacterial flagellum is a simple hollow cylinder made of identical protein molecules. It is a rigid structure, so it does not bend, unlike the flagella in eukaryotes. It is wave-shaped and works by rotating at its base like a propeller to push the bacterium through its liquid environment. As a result, the bacterium moves forward with a corkscrew-shaped motion.

Infolding of cell surface membrane

In some bacteria, the cell surface membrane folds into the cell forming an extra surface on which certain biochemical reactions can take place. In blue–green bacteria, for example, the infolded membrane contains photosynthetic pigments which allow photosynthesis to take place. In some bacteria, nitrogen fixation takes place on the infolded membrane. Nitrogen fixation is the ability to convert nitrogen in the air to nitrogen-containing compounds, such as ammonia, inside the cell. All life depends on nitrogen fixation. Eukaryotes cannot carry out nitrogen fixation.

Capsule

Some bacteria are surrounded by an extra layer outside the cell wall. This may take the form of a capsule or a slime layer. A capsule is a definite structure, made mostly of polysaccharides. A slime layer is more diffuse and is easily washed off. Both help to protect the bacterium from drying out and may have other protective functions. For example, a capsule helps protect some bacteria from antibiotics. Some capsules prevent white blood cells known as phagocytes from engulfing disease-causing bacteria.

Plasmid

A **plasmid** is a small circle of DNA separate from the main DNA of the cell. It contains only a few genes. Many plasmids may be present in a given cell. The genes have various useful functions. Commonly, plasmids contain genes that give resistance to particular antibiotics, such as penicillin. Plasmids can copy themselves independently of the chromosomal DNA and can spread rapidly from one bacterium to another. Plasmid DNA is not associated with protein and is referred to as 'naked' DNA.

KEY WORD

plasmid: a small circular piece of DNA in a bacterium (not its main chromosome); plasmids often contain genes that provide resistance to antibiotics

Pili (singular: pilus)

Pili are fine protein rods. They vary in length and stiffness. One to several hundred may be present on the outside of the cell. They are used for attachment and interactions with other cells or surfaces. They allow the transfer of genes, including plasmids, from one bacterium to another during conjugation.

1.8 Comparing prokaryotic cells with eukaryotic cells

Table 1.3 compares prokaryotic cells with eukaryotic cells.

Prokaryotes	Eukaryotes
Prokaryotes are thought to have evolved about 3.5 billion years ago.	Eukaryotes are thought to have evolved about 1.5 billion years ago.
Their typical diameter is 1–5 μm.	Cells are up to 40 μm diameter and up to 1000 times the volume of prokaryotic cells.
DNA is circular and free in the cytoplasm; it is not surrounded by a double membrane.	DNA is not circular and is contained in a nucleus. The nucleus is surrounded by a double membrane (the nuclear envelope).
70S ribosomes are present (smaller than those of eukaryotes).	80S ribosomes are present (larger than those of prokaryotes).
Very few types of cell organelle are present. No separate membrane-bound organelles are present.	Many types of cell organelle are present. • Some organelles are surrounded by a single membrane (e.g. lysosomes, Golgi apparatus, vacuoles, ER). • Some are surrounded by an envelope of two membranes (e.g. nucleus, mitochondrion, chloroplast). • Some have no membrane (e.g. ribosomes, centrioles, microtubules).
The cell wall contains peptidoglycan (a polysaccharide combined with amino acids).	A cell wall is sometimes present (e.g. in plants and fungi); it contains cellulose or lignin in plants, and chitin (a nitrogen-containing polysaccharide similar to cellulose) in fungi.
Flagella are simple and lack microtubules; they project outside the cell surface membrane so they are extracellular (outside the cell).	Flagella (and cilia) are complex with a '9 + 2' arrangement of microtubules; they are surrounded by the cell surface membrane so they are intracellular (inside the cell).
Cell division occurs by binary fission (the cell splits into two); it does not involve a spindle (see Chapter 6).	Cell division takes place by mitosis or meiosis and involves a spindle (see Chapter 6).
Some carry out nitrogen fixation.	None carries out nitrogen fixation.

Table 1.3: Comparing prokaryotic cells and eukaryotic cells.

Question

10 List the structural features that prokaryotic and eukaryotic cells have in common. Briefly explain why each of the structures you have listed is essential.

1.9 Viruses

In 1852, a Russian scientist discovered that certain diseases could be transmitted by agents that, unlike bacteria, could pass through very fine filters. This was the first evidence for the existence of viruses. **Viruses** are tiny 'particles' which are much smaller than bacteria and are on the boundary between what we think of as living and non-living. Unlike prokaryotes and eukaryotes,

KEY WORD

virus: a very small (20–300 nm) infectious particle which can replicate only inside living cells; it consists of a molecule of DNA or RNA (the genome) surrounded by a protein coat; an outer lipid envelope may also be present

viruses do not have a cell structure. In other words, they are not surrounded by a partially permeable membrane containing cytoplasm with ribosomes. They are much simpler in structure. They consist only of the following:

- a self-replicating molecule of DNA or RNA (the genome or complete genetic instructions)
- a protective coat of protein molecules called a capsid
- (some viruses only) a membrane-like outer layer, called the envelope, that is made of **phospholipids**. (The structure of phospholipids is described in Chapter 2.) Proteins may project from the envelope.

Figure 1.36 shows the structure of a virus with an envelope. Viruses typically have a very symmetrical shape. The protein coat (or capsid) is made up of separate protein molecules, each of which is called a capsomere.

KEY WORD

phospholipid: a lipid to which phosphate is added; the molecule is made up of a glycerol molecule, two fatty acids and a phosphate group; a double layer (a bilayer) of phospholipids forms the basic structure of all cell membranes

Viruses range in size from about 20 nm to 300 nm (about 50 times smaller on average than bacteria).

All viruses are parasitic because they can only reproduce by infecting and taking over living cells. The virus DNA or RNA takes over the protein synthesising machinery of the host cell, which then helps to make new virus particles.

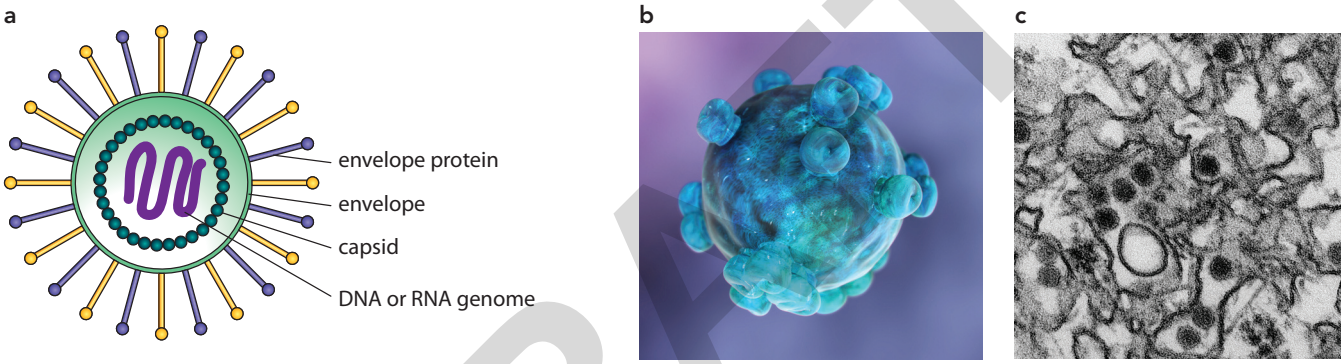


Figure 1.36: a The structure of a virus with an envelope; **b** model of a virus; **c** electron micrograph of a virus.

REFLECTION

Think about everything you know about cells. What answers would you give to the following questions?

- What is a cell?
- Why are all living things made of cells?

Look back at the differences between eukaryotic and prokaryotic cells.

- Write down a list of criteria to compare the success of prokaryotic and eukaryotic cells.
- Suggest why trying to compare the success of prokaryotic and eukaryotic cells may be a meaningless exercise. (Tip: think about the meaning of the word 'success'.)

Personal reflection questions

Changing from studying at GCSE to studying at AS Level is a big jump. Has anything surprised you about the change? Are you confident about being able to adapt the way you work? If not, what particular concerns do you have?

You have studied cells in Chapter 1 and learnt a lot about their structure and function. The Reflection activity above gives you a chance to use this information to think again about cells from a slightly different point of view.

How did the Reflection activity improve your understanding of what you have studied in Chapter 1?

Final reflection

Discuss with a friend which, if any, parts of Chapter 1 you need to:

- read through again to make sure you really understand
- seek more guidance on, even after going over it again.

EXAM-STYLE QUESTIONS

1 Which **one** of the following cell structures can be seen with a light microscope?

A mitochondrion
B ribosome
C rough ER
D smooth ER [1]

2 What property of electrons allows high resolution to be achieved by electron microscopes?

a Electrons are negatively charged.
b Electrons can be focused using electromagnets.
c Electrons have a very short wavelength.
d Electrons travel at the speed of light. [1]

3 Which **one** of the following structures is found in animal cells but not in plant cells?

A cell surface membrane
B centriole
C chloroplast
D Golgi apparatus [1]

4 List **ten** structures you could find in an electron micrograph of an animal cell which would be absent from the cell of a bacterium. [10]

5 Distinguish between the following pairs of terms:

a magnification and resolution [3]
b light microscope and electron microscope [2]
c nucleus and nucleolus [4]
d chromatin and chromosome [3]
e membrane and envelope [3]
f smooth ER and rough ER [4]
g prokaryote and eukaryote [4]
h cell wall and cell surface membrane [4]
i capsid and cell wall [4]
j capsid and capsomere [3]

Total: 34

6 List:

a **three** organelles each lacking a boundary membrane [3]
b **three** organelles each surrounded by a single membrane [3]
c **three** organelles each surrounded by two membranes (an envelope). [3]

Total: 9

7 **Identify** each cell structure or organelle from its description below.

a manufactures lysosomes
b manufactures ribosomes
c site of protein synthesis
d can bud off vesicles which form the Golgi apparatus
e can transport newly synthesised protein round the cell

COMMAND WORD

identify: name / select / recognise

CONTINUED

f manufactures ATP in animal and plant cells

g controls the activity of the cell because it contains the DNA

h carries out photosynthesis

i can act as a starting point for the growth of spindle microtubules during cell division

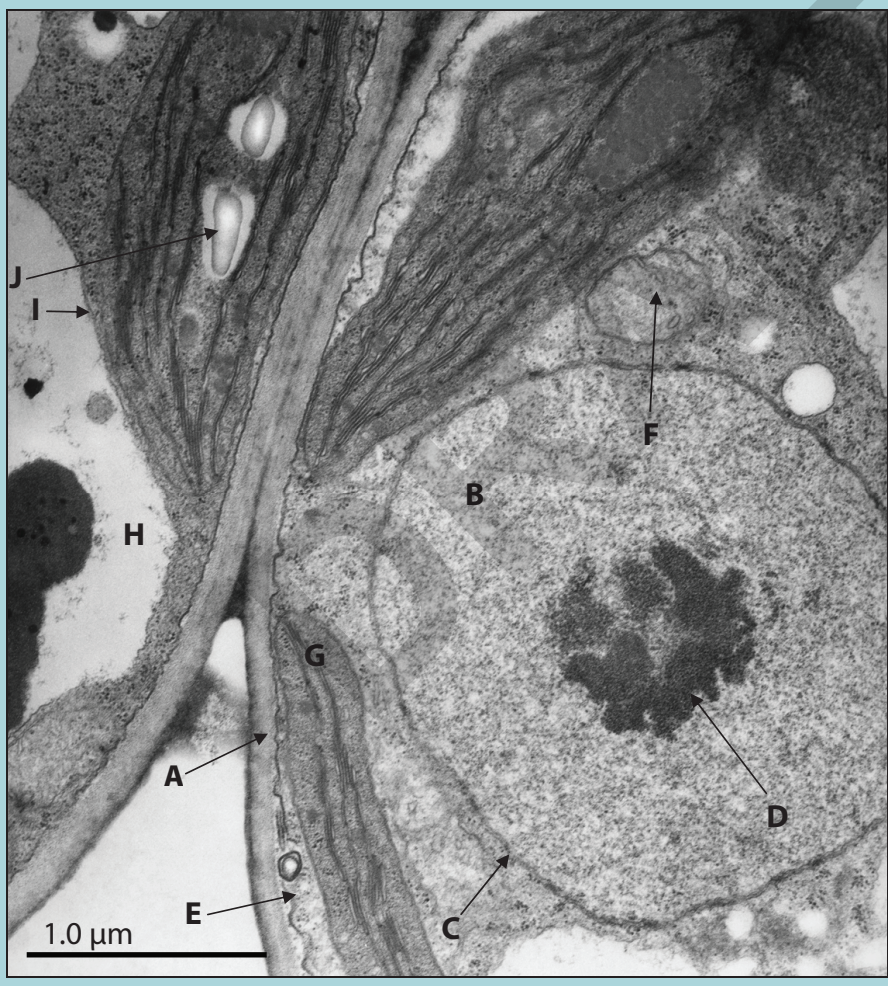
j contains chromatin

k partially permeable barrier only about 7 nm thick

l organelle about 25 nm in diameter

m organelle with a '9 + 2' arrangement of microtubules **[13]**

8 The transmission electron micrograph shows parts of two palisade cells from a leaf.



CONTINUED

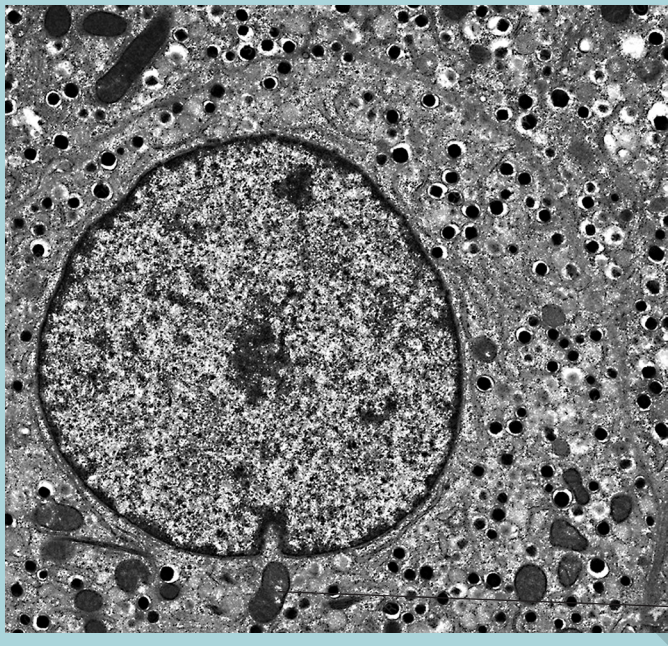
Copy the table. Identify the labelled structures **A–J** and write a brief statement about their functions.

Label	Name of structure	Function	
A			[3]
B			[3]
C			[2]
D			[2]
E			[3]
F			[3]
G			[3]
H			[2]
I			[2]
J			[2]

Total: 25

9 The electron micrograph shows part of a secretory cell from the pancreas. You are not expected to have seen a micrograph of this type of cell before. The secretory vesicles are Golgi vesicles and appear as dark round structures. The magnification is ×8000.

CONTINUED



a Copy the table. **Calculate** the actual sizes of the structures listed in the table. Use a ruler with mm divisions to help you. Show your measurements and calculations. When you have your answers, complete the table with the required information. **Give** your answers in micrometres.

Structure	Observed diameter (measured with ruler)	Actual size
maximum diameter of a Golgi vesicle		
maximum diameter of nucleus		
maximum length of the labelled mitochondrion		

[9]

b Make a fully labelled drawing of representative parts of the cell. You do not have to draw everything, but enough to show the structures of the main organelles. Use a full page of plain paper and a sharp pencil. Use Figures 1.18 and 1.19 in this book and the simplified diagram in **d** below to help you identify the structures. **[14]**

c The mitochondria in pancreatic cells are mostly sausage-shaped in three dimensions. **Suggest** why some of the mitochondria in the electron micrograph here appear roughly circular. **[1]**

COMMAND WORDS

calculate: work out from given facts, figures or information

give: produce an answer from a given source or recall/memory

suggest: apply knowledge and understanding to situations where there is a range of valid responses in order to make proposals / put forward considerations

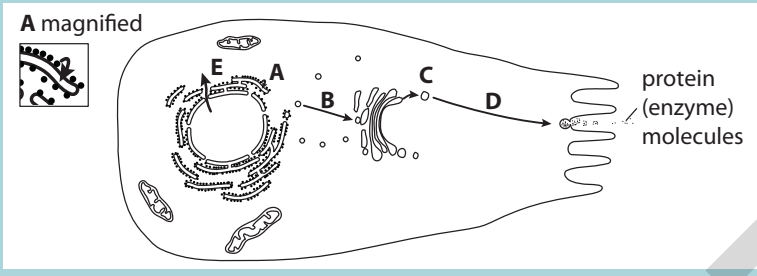
TIP

Use modelling clay to make a sausage shape to represent a mitochondrion (or use a real sausage). Try cutting the sausage with a knife at different angles. This represents the process of sectioning material for examination using a microscope. The cut surfaces will reveal the variation you can expect to see in sections.

CONTINUED

d The figure is a diagram based on an electron micrograph of a secretory cell from the pancreas. This type of cell is specialised for secreting (exporting) proteins. Some of the proteins are digestive enzymes of the pancreatic juice. The cell is very active, requiring a lot of energy. The arrows **A**, **B**, **C** and **D** show the route taken by the protein molecules.

Note that arrow **A** is shown magnified in a separate diagram.



i **Describe** briefly what is happening at each of the stages **A**, **B**, **C** and **D**. **[8]**

ii Arrow **E** shows the path of a molecule or structure leaving the nucleus through the nuclear envelope. Name **one** molecule or structure which leaves the nucleus by route **E**. **[1]**

iii The molecule or structure you named in **ii** passes through the nuclear envelope. Name the structure in the nuclear envelope through which the molecule or structure passes. **[1]**

iv Name the molecule which leaves the mitochondrion in order to provide energy for the cell. **[1]**

Total: 35

10 One technique used to investigate the activity of cell organelles is called differential centrifugation. In this technique, a tissue is homogenised (ground in a blender), placed in tubes and spun in a centrifuge. This makes organelles sediment (settle) to the bottom of the tubes. The larger the organelles, the faster they sediment. By repeating the process at faster and faster speeds, the organelles can be separated from each other according to size. Some liver tissue was treated in this way to separate ribosomes, nuclei and mitochondria. The centrifuge was spun at 1000 *g*, 10 000 *g* or 100 000 *g* (*g* is gravitational force).

*(**Note:** To answer this question you have to apply your knowledge to a new situation.)*

a **State** in which of the three sediments (1000 *g*, 10 000 *g* or 100 000 *g*) you would expect to find the following:

i ribosomes

ii nuclei

iii mitochondria **[1]**

b Liver tissue contains many lysosomes. Suggest why this makes it difficult to study mitochondria using the differential centrifugation technique. **[4]**

Total: 5

COMMAND WORDS

describe: state the points of a topic / give characteristics and main features

state: express in clear terms

SUMMARY

The basic unit of life is the cell. The simplest cells are prokaryotic cells, which are thought to have evolved before and given rise to, the much more complex and much larger eukaryotic cells.
Cells can be seen clearly only with the aid of microscopes. The light microscope uses light as a source of radiation, whereas the electron microscope uses electrons. The electron microscope has greater resolution (allows more detail to be seen) than the light microscope because electrons have a shorter wavelength than light.
With a light microscope, cells may be measured using an eyepiece graticule and a stage micrometer. Using the formula $A = \frac{I}{M}$ the actual size of an object (A) or its magnification (M) can be found if its observed (image) size (I) is measured and A or M, as appropriate, is known.
All cells are surrounded by a partially permeable cell surface membrane that controls exchange between the cell and its environment. All cells contain genetic material in the form of DNA, and ribosomes for protein synthesis.
All eukaryotic cells possess a nucleus containing DNA. The DNA is linear (not circular) and bound to proteins and RNA to form chromatin.
The cytoplasm of eukaryotic cells contains many organelles, some of which are surrounded by one or two membranes. Organelles of eukaryotic cells include endoplasmic reticulum (ER), 80S ribosomes, Golgi apparatus, lysosomes and mitochondria. Animal cells also contain a centrosome and centrioles and may contain cilia. Plant cells have a cell wall containing cellulose. They may contain chloroplasts and often have a large central vacuole.
Prokaryotic cells lack a true nucleus and have smaller (70S) ribosomes than eukaryotic cells. They also lack membrane-bound organelles. Their DNA is circular and lies free in the cytoplasm.
Viruses do not have a cellular structure. They are extremely small and simple. They consist of a molecule of DNA or RNA, a protein coat and sometimes an outer envelope.

SELF-EVALUATION CHECKLIST

After studying this chapter, complete a table like this:

I can	See topic...	Needs more work	Almost there	Ready to move on
explain that cells are the basic units of life	1.1			
use the units of measurement relevant to microscopy	1.2			
recognise the common structures found in cells as seen with a light microscope and outline their structures and functions	1.3			
compare the key structural features of animal and plant cells	1.3			

CONTINUED

I can	See topic...	Needs more work	Almost there	Ready to move on
use a light microscope and make temporary preparations to observe cells	1.3			
recognise, draw and measure cell structures from temporary preparations and micrographs	1.3, 1.4			
calculate magnifications of images and actual sizes of specimens using drawings or micrographs	1.4			
explain the use of the electron microscope to study cells with reference to the increased resolution of electron microscopes	1.5			
recognise the common structures found in cells as seen with an electron microscope and outline their structures and functions	1.6			
outline briefly the role of ATP in cells	1.6			
describe the structure of bacteria and compare the structure of prokaryotic cells with eukaryotic cells	1.7, 1.8			
describe the structure of viruses	1.9			

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Contents

1 Cell structure

Syllabus overview

- This chapter introduces cells as the simplest unit of life. It explores how the light microscope can be used in the school laboratory to view them, and how electron micrographs provide us with further insight into the ultrastructure of cells, including the existence of organelles.
- There are many practical opportunities in this chapter and occasions for students to develop analytical, application and mathematical skills.

Topic teaching plan

Syllabus topic	Number of lessons	Outline of lesson content	Resources
1.1.1	2	Light microscopy	**Coursebook:** Figures 1.2–1.7, Practical Activity 1.1 **Practical Workbook and Practical Teacher's Guide:** Practical Investigation 1.1
1.1.2 1.1.3 1.1.4	2	Measuring and drawing cells	**Coursebook:** Figures 1.10–1.12, Table 1.1, Worked Examples 1.1–1.3, Questions 2, 3, 8, ESQs 8, 9 **Workbook:** Exercises 1.1–1.3, 1.5 **Practical Workbook and Practical Teacher's Guide:** Practical Investigation 1.2
1.1.5	1	Electron microscopy and ultrastructure	**Coursebook:** Figures 1.3, 1.10, 1.11, 1.13–1.21, Table 1.2, Questions 4–8, ESQs 1, 2, 9 **Workbook:** Exercises 1.2, 1.4
1.2.1 1.2.2 1.2.3 1.2.4 1.2.5 1.2.6	2	Prokaryotes and eukaryotes	**Coursebook:** Figures 1.22–1.35, Practical Activity 1.3, Question 10, ESQs 5, 6, 10 **Workbook:** Exercise 1.6, ESQs 1–4 **Practical Workbook and Practical Teacher's Guide:** Practical Investigation 1.3
1.2.7	1	Viruses	**Coursebook:** Figure 1.36

Topic 1.1.1

This topic introduces the light microscope and the preparation of temporary slides of cellular material for study.

- Make temporary preparations of cellular material suitable for viewing with a light microscope.

Suggested teaching time

This content should take around two hours to cover.

Links to other components in this series

Component	Resource	Description
Coursebook	Figures 1.2–1.7 Practical Activity 1.1	• Figures that concern the discovery of cells by Hooke, and how the light microscope can be used to produce photomicrographs
Workbook	Not applicable	• Not applicable
Practical Workbook	Practical Investigation 1.1	• Making a temporary slide and drawing cells
Teacher's Resource	Practical Teacher's Guide: Practical Investigation 1.1	• Making a temporary slide and drawing cells

Common misconceptions

- Students commonly overlook the fact that there is a lens in the eyepiece of most light microscopes (usually ×10), and so the actual magnification of an image is equal to that listed on the objective lens (e.g. ×40) multiplied by 10 (e.g. ×400).
- The terms *photograph*, *photomicrograph* and *electron micrograph* are often incorrectly used interchangeably by students.

Lesson starters

Students need to understand the structure and function of the light microscope so that they can work individually. Even if students have some previous experience of microscope work, revision of the microscope's structure and function is important. At A Level, it is important that students have the opportunity to conduct microscope work on an individual basis.

Two suggestions for lesson starters are given here. The choice of activity used will depend on the resources available, the time available and how the class is progressing with this topic.

1 Idea A

Refresh students' knowledge of key words related to light microscopy by hosting a brief quiz using the summary of assumed prior knowledge. Print (and laminate) A4 pieces of paper with one letter – A, B, C or D – written on each side of the paper. Students can 'vote' for their choice of answer by holding up the piece of paper they think identifies the correct answer to each of a series of multiple-choice questions on the board.

Examples of multiple-choice questions could include the following:

- *(low demand: expect many correct answers):* What is the name of the precisely shaped glass structure in a microscope that magnifies objects?
  - **A** eyepiece
  - **B** lens *(correct)*
  - **C** stage
  - **D** light source

- *(intermediate demand: expect some correct answers):* Which of the following can be seen with a light microscope?
  - **A** plant cells *(correct)*
  - **B** bacteria
  - **C** viruses
  - **D** DNA molecules
- *(high demand: expect few correct answers):* What is the maximum magnification power found on most school light microscopes?
  - **A** ×40
  - **B** ×100
  - **C** ×400 *(correct)*
  - **D** ×4000

› **Assessment idea:** This activity can be used to formatively assess students before they begin the topic. Discuss the answers submitted by the students and encourage them to keep the correct answers in mind throughout the lesson.

2 Idea B

Provide students with an unlabelled diagram of a light microscope. Through class discussion, elicit some of the names of the key components, and discuss their features and functions.

› **Assessment idea:** Students copy down the labels with words that 'I knew' in green and words that 'are new' in red. This can be referred to at the end of the lesson to show students how much progress they have made.

Main activities

Below are several teaching activities which you can pick and choose from in order to tailor the lesson to your class's needs.

1 Practical Investigation 1.1: Making a temporary slide and drawing cells (90 minutes)

Refer to Practical Investigation 1.1 in the Practical Workbook. This activity gives students the opportunity to use a light microscope and make a temporary stained mount of plant tissue (onion epidermis). Students observe their preparation using the microscope and make a drawing of some of the cells. The expected quality of drawings is well described in the instructions for this exercise. Discuss with students the important precautions that they must follow to reduce the chance of damaging the microscope or the slide.

› **Assessment idea:** The development of drawing skills is important as a means of assessing observational skills. Provide clear success criteria and set students the task of peer assessing their drawings.

2 Circus of activities (90 minutes)

One way of approaching this section of the syllabus is to provide a 'circus' of activities. Set up a number of different workstations in the teaching room. A single student or small group works at each station but moves on to the next station after a given time interval. Eventually, students will have carried out a piece of work at each station. The advantages of this approach include efficient use of scarce resources, efficient use of time, provision of a stimulating variety of activities, interactivity, and encouragement of group discussion. Several topics could be included in the circus, including the following.

- **Task 1 (15 minutes)**

  Students compare animal and plant cells shown on electron micrographs of more than ×20 000 (e.g. a rat liver cell and a mesophyll cell). Suitable figures from the Coursebook could be used.

- **Task 2 (30 minutes)**

  Set up a practical exercise such as a temporary preparation, preferably with an opportunity for students to prepare a drawing. Provide sharp pencils and paper at this station.

- **Task 3 (30 minutes)**

  Students calculate dimensions and magnifications of cells and organelles from photographs or drawings. Provide rulers at this station.

› **Assessment idea:** This activity introduces many of the skills and concepts that students will encounter during this topic. Encourage students to reflect on their experiences and make five recommendations for their future study on this topic. These could be of the form 'The next time I do . . . I must remember to . . .'. To increase discussion, ask students to write these on sticky notes, which they must add to the class board. Allow students to consider the recommendations of others and highlight common mistakes that students made.

3 The timeline of the microscope (40 minutes)

Students refer to the Coursebook (e.g. Figures 1.2–1.7) and conduct internet research to prepare a timeline showing how the light microscope was developed. Students must include the work of Malpighi, Hooke, Schleiden and Schwann, and how their work led to the theory that all cells come from pre-existing cells by the process of cell division.

› **Assessment idea:** Provide a series of cards showing objects – tissues, cells and organelles – which students place onto their timeline at the time points at which they became visible to human eyes. For example, capillaries were first seen by Malpighi; cells were first seen by Hooke.

Differentiation

Stretch and challenge

- Challenge students to prepare for the subsequent lesson on electron microscopy by providing a series of questions for them to research using the Coursebook and the internet. These may include:
  - Why is it impossible to see small organelles with a light microscope?
  - What is the difference between magnification and resolution?
- Extend understanding by referring to unfamiliar applications. Many sophisticated light microscope techniques now exist (e.g. fluorescence microscopy, phase contrast, reflected light, dark field, bright field, confocal/multiphoton, Kohler illumination and polarised light). Students could research examples, advantages and procedural details.

Support

- Students vary enormously in their ability to acquire the relevant skills, and a patient step-by-step approach, possibly supported by more confident students, will be needed with some to maintain confidence. Refer some students to Practical Activity 1.1: Making temporary slides, in the Coursebook. This is a step-by-step account of how to prepare a slide of tissue.
- Many students will find it challenging to use a microscope properly. Teachers will find it difficult to support a large group of students when many need personal assistance. Here are two strategies which may prove useful.
  - The teacher carries out the procedure step by step with a demonstration microscope, requiring students to keep pace while using their own microscopes.
  - Pair more confident students with those needing more help and employ them as demonstrators. Both 'learner' and 'demonstrator' benefit, the 'demonstrator' by reinforcing their microscopy skills and developing communication skills, and the 'learner' by having more detailed and personalised help.
- Help students to arrange their thoughts by constructing a table to summarise the information in this lesson. Include the biological molecules, test reagent, negative result and positive result in separate columns. Alternatively, help students to write a 'recipe' by encouraging them to list the steps they take in order to conduct a biochemical test.

WRAP-UP AND REFLECTION IDEAS

- Prepare three or four questions, ideally multiple-choice or short-answer, which students complete and pass to you as they leave the room. This 'exit card' technique can provide an opportunity for formative assessment, enabling you to judge if further reinforcement of the material is necessary in the next lesson.
- This is likely to be an early lesson of A Level study for most students, so confidence levels may be low. Encourage students to ask for help at an early stage in the course by hosting a reflection activity. Ask students to each write down one issue they are sure of, one they are unsure of, and one they need to know more about – being specific. You can then join students together into groups, based on who is confident on different aspects of the lesson, to initiate discussion among the class members.

CROSS-CURRICULAR LINKS

Literacy
If possible, reinforce the names of the different parts of the microscope by displaying them on the board in the form of a labelled diagram. Alternatively, fix printed sheets showing a labelled diagram of a microscope to each desk. Insist that students use the terms during the lesson in their discussions. This helps students become familiar with the terms.

Numeracy
Calculations involving magnification will be encountered in the next lesson. However, multiplying the value of the eyepiece lens by the value of the objective lens can provide an opportunity for students to engage in mathematical manipulation during this lesson.

Topics 1.1.2; 1.1.3; 1.1.4

These topics extend students' experience of working with a light microscope. Students explore how to use an eyepiece graticule and stage micrometer scale to measure specimens, and calculate the magnification of images and actual size of objects.

- Draw cells from microscope slides and photomicrographs.
- Calculate magnifications of images and actual size of specimens using drawings, photomicrographs and electron micrographs (scanning and transmission).
- Use an eyepiece graticule and stage micrometer scale to make measurements and use the appropriate units, millimetre (mm), micrometre (μm) and nanometre (nm).

Suggested teaching time

This content should take around two hours to cover.

Links to other components in this series

Component	Resource	Description
Coursebook	Figures 1.10–1.12 Table 1.1 Worked Examples 1.1–1.3 Questions 2, 3, 8 ESQs 8, 9	• Figures, examples and questions that focus on the measurement of size of objects and their magnification
Workbook	Exercise 1.1 Exercise 1.2 Exercise 1.3 Exercise 1.5	• Units for measuring small objects • Magnification calculations • Drawing from light micrographs • Using an eyepiece graticule and stage micrometer
Practical Workbook	Practical Investigation 1.2	• Measuring cells, using an eyepiece graticule and stage micrometer
Teacher's Resource	Practical Teacher's Guide: Practical Investigation 1.2	• Measuring cells, using an eyepiece graticule and stage micrometer

Common misconceptions

- Students commonly measure images/specimens in centimetres and forget to multiply by 10 to provide a value in millimetres before converting to micrometres. Recommend that students always measure in millimetres, to minimise the opportunity for this mistake to occur.
- Although students need to know the term *stage micrometer*, it is helpful at the beginning to explain that it is simply a 'microscopic ruler' – and perhaps to refer to it this way in the first instance.

Lesson starters

This topic builds on students' experience of using a light microscope in the first lesson. The starter activities must therefore reinforce the content that was encountered previously.

Two suggestions are given here. The choice of activity used will depend on the resources available, the time available and how the class is progressing with this topic.

1 Idea A

Create and display a word board showing all the key terms with which students should be familiar from the previous lesson. These include the names of parts of a light microscope, for example. As you call out a word, ask for a show of hands to see who has heard of it, and then inform students to keep their hand raised if they would like to link at least two of the words together.

› **Assessment idea:** Ask students to identify the 'odd one out' in a series of words. For example, the odd one out in the series 'eyepiece, stage and objective' is the stage, because light does not pass through.

2 Idea B

Provide students with a series of unfinished sentences that are written to refresh their knowledge of their learning in the previous lesson. Initiate a 'think, pair, share' activity and then ask them to construct an ending or a beginning. Ask students to read out their ideas and ask for comments from other pairs. This activity is good for revisiting prior knowledge. Examples would include:

- A total magnification of ×100 is achieved if . . .
- . . . so, a cover slip is used.
- . . . so, a stain is required to view objects such as animal and plant cells.

› **Assessment idea:** Students copy down the sentences with things 'I knew' in green and things that 'are new' in red. This can be referred to at the end of the lesson to show students how much progress they have made.

Main activities

Below are several teaching activities which you can pick and choose from in order to tailor the lesson to your class's needs.

1 Practical Investigation 1.2: Measuring cells, using an eyepiece graticule and stage micrometer (90 minutes)

Refer to Practical Investigation 1.2 in the Practical Workbook. This activity provides students with an opportunity to use an eyepiece graticule and stage micrometer to measure two types of plant cell. An eyepiece graticule is a small scale that fits inside the eyepiece of the microscope. When you look through the eyepiece, it is possible to see the scale on the graticule at the same time as the object on the microscope stage. The size of the object is measured in 'eyepiece graticule units'. These units are calibrated using the stage micrometer, which is placed onto the microscope stage. This activity helps students to set up this arrangement, step by step.

› **Assessment ideas:** Peer assess students' calculations, over the eight steps listed, of the mean width of one onion epidermis cell. Alternatively, Workbook Exercise 1.5, which provides questions and images concerning the use of this apparatus, can be used to summarise learning.

2 Flash card measurements (30 minutes)

Encourage students to prepare a series of flash cards that help them interchange measurements. Use Table 1.1 in the Coursebook to help them convert between units. For example, a numerical value in millimetres (e.g. 0.06 mm) written on one side of the card could be restated in micrometres on the other side (e.g. 6 µm). As you move around the classroom, elicit discussion with students to help them appreciate the very small size of some objects. For example, 20 000 ribosomes could be lined up along the full stop at the end of this sentence.

› **Assessment idea:** Ask students a series of questions to diagnose misunderstandings and misconceptions that may have arisen during this activity. For example, 'One million nanometres are equivalent to one millimetre – true or false?'

3 Creative recipe following (60 minutes)

This topic requires students to learn how to calibrate an eyepiece graticule, often by following a series of steps in a 'recipe' fashion. Encourage students to be more creative in designing a step-by-step guide. This could be in the form of a series of diagrams, a flow diagram with statements separated by arrows, a short story, or an animation produced on the computer.

› **Assessment idea:** Select the best two or three creative guides and ask all students to appraise them, identifying 'what went well' and 'even better if' to give collective feedback. An alternative is the 'two stars and a wish' approach, whereby students identify two points of positive feedback, and one point of constructive criticism. The very best examples can be bound in a book or put onto the school's virtual platform, for students to refer to throughout the course.

Differentiation

Stretch and challenge

- It is easy to provide a greater variety of measurement exercises. Students may prefer to select their own examples for measurement. There are plenty of suitable figures in the Coursebook which could be used. For example:
  - What is the diameter of a nerve cell body and its axon?
  - What is the magnification of some of the figures in the Coursebook?
- It is useful to collect and display class results for measuring cells on a board or screen. Anomalies can soon be picked up and addressed. Discussion of themes such as variability of cell size and appropriate sample sizes can also be facilitated.

Support

- Help students to distinguish the eyepiece graticule from the stage micrometer by informing them that the scale that rotates when the eyepiece is rotated is the eyepiece graticule.
- Refer students to Worked Example 1.1 in the Coursebook, which is about measuring cells. This focuses on Figure 1.10, which shows students how to use the eyepiece graticule and stage micrometer.
- Worked Examples 1.2 and 1.3 and Question 3 in the Coursebook are based on Figures 1.11 and 1.12. They provide helpful step-by-step instructions that illustrate how to undertake measurements using these items.
- Exercise 1.1 in the Workbook helps students to convert between units including mm, μm and nm. Questions of increasing difficulty are provided.

WRAP-UP AND REFLECTION IDEAS

- Question 2 in the Coursebook challenges students to assess three cell drawings, produced by an imaginary student. A similar activity is provided by Exercise 1.3 in the Workbook.
- Draw a table or Venn diagram to compare the eyepiece graticule and the stage micrometer.
- Challenge students to write the shortest sentence possible using the following key terms: *eyepiece graticule*, *stage micrometer*, *magnification*, *actual size* and *image size*. This is a good way to focus students on developing their higher-order thinking skills to make sense of the meaning of these terms, rather than simply recalling them. To scaffold this activity for some students, provide the first and final phrases or reduce the number of words that they are expected to use.

CROSS-CURRICULAR LINKS

Literacy
A number of key terms are introduced in this topic; these need to be clearly defined for students. It can be helpful to display diagrams of the eyepiece graticule and stage micrometer in this lesson, to which the key terms are added as labels as they are encountered.

Numeracy
Conversion between units and magnification calculations provide opportunities to develop mathematical skills. Students must rearrange the formula to find actual sizes. Workbook Exercise 1.2 is helpful.

Topic 1.1.5

This topic develops students' knowledge of the techniques of light and electron microscopy.

- Define resolution and magnification and explain the differences between these terms, with reference to light microscopy and electron microscopy.

Suggested teaching time

This content should take around one hour to cover.

Links to other components in this series

Component	Resource	Description
Coursebook	Figures 1.3, 1.10, 1.11, 1.13–1.21 Table 1.2 Questions 4–8 ESQs 1, 2, 9	• Figures and questions that show electron micrographs of various specimens, and focus on the difference in image magnification and resolution between a light and electron microscope and how it works

Workbook	Exercise 1.2 Exercise 1.4 ESQ 2	• Magnification calculations • Electron microscopes and optical (light) microscopes • Question on structures visible using a microscope
Practical Workbook	Not applicable	• Not applicable

Common misconceptions

- Understanding of the electromagnetic spectrum requires discussion of *short* and *long wavelengths*. Students often use the terms 'small' and 'large' for short and long. This is a very good opportunity to stress the need for scientists to use language precisely. Try to make sure the students use the correct terms in discussion.
- Students sometimes find it difficult to understand that an electromagnet can act as a lens – the concept of a lens is associated with glass. Instead, a lens is any device that focuses beams of light or electrons.
- In studying organelles in static images, students can fail to see how complex eukaryotic cells are and how the different components interact. Secretion by the pancreatic acinar cell is a good example (to use towards the end of this topic) to show a holistic view of organelle activity (see ESQ 9 in the Coursebook). Alternatively, show students video footage of actual living cells (not animations) with activities such as cytoplasmic streaming or mitochondrial movement and division. Many such videos are available on the internet.

Lesson starters

This topic builds on the knowledge and understanding that students developed earlier in this chapter, but with fewer practical opportunities. It is important to refresh their understanding of the magnification formula and how it can be rearranged to find the actual size of objects.

Two suggestions for lesson starters are given here. The choice of activity used will depend on the resources available, the time available and how the class is progressing with this topic.

1 Idea A

Show students a series of images of varying magnification and resolution (low resolution images can be produced by zooming into a thumbnail photograph and taking a screenshot). Discuss how biologists would be able to gain much more information from a high-resolution image than a low-resolution image – and why.

› **Assessment idea:** A carefully chosen series of hinge questions could be asked to elicit higher-order thinking skills among students. One option is to ask them to compare key words, to reinforce their knowledge of key definitions, including magnification versus resolution.

2 Idea B

Hold a brief round of closed true/false questions, which are aimed at refreshing prior knowledge of their experience of light microscopy. Statements could include the following examples.

- A light microscope can allow us to see all of the organelles in a cell. *(false)*
- The highest magnification that can be achieved using a light microscope is ×400. *(true)*

If the class is large, then students could be provided with a sheet of paper with 'true' printed on one side and 'false' printed on the other, to hold up for you to see all at once.

› **Assessment idea:** This activity can be used as the basis of formative assessment of prior learning to prepare for the content that students will encounter in this chapter.

Main activities

Below are several teaching activities which you can pick and choose from in order to tailor the lesson to your class's needs.

1 Determining differences (30 minutes)

Show an electron micrograph and a light photomicrograph, side by side. These could be taken from the Coursebook (Figures 1.11, 1.13–1.21 are examples), and others can be downloaded from https://cellpics.cimr.cam.ac.uk and www.histologyguide.org/index.html. Start a discussion: can students recognise structures common to both and what new structures can only be seen in the electron micrograph? Refer students to the workings of the light microscope (Figure 1.3) and the electron microscope (Figure 1.16). Ask students to prepare a table that compares the advantages and disadvantages of light microscopy and electron microscopy. Table 1.2 in Question 5 in the Coursebook provides an example table that students could complete.

› **Assessment idea:** To reinforce their tables, prepare a piece of paper for each student that has 'light microscope' on one side and 'electron microscope' on the other. They must hold the correct side up when a question is asked. Here are some examples of suitable questions.

- Which microscope can be used to watch cilia moving? *(light)*
- Which microscope has a resolution of 0.5 nm? *(electron)*
- Which microscope shows that chloroplasts look green? *(light)*
- Which microscope can produce three-dimensional images? *(electron)*

2 Upsizing sectioning (40 minutes)

Thinking in three dimensions can be difficult for students, especially when they are asked why organelles look different when sectioned in different planes (e.g. Coursebook Question 8, regarding the transverse sectioning of a nucleus). To help, encourage students to make shapes out of modelling clay. Cutting these at different angles will clearly illustrate how objects can look different when viewed with a microscope, depending on how the specimen was prepared (e.g. mitochondria often look sausage-shaped). Another possibility is to enclose a piece of modelling clay of one colour inside a ball of a different colour. A section may reveal the internal colour or not, mimicking, for example, the fact that sectioning a nucleus may or may not reveal a nucleolus.

› **Assessment idea:** Challenge students to put their findings from this activity into words – how can we explain that different mitochondria look different when viewed in one electron micrograph? Encourage students to compare their explanations with each other in an 'open forum'. To do this, allow students to walk around the class and speak with at least three people, in order to refine their statement.

Differentiation

Stretch and challenge

- Ask students to research why small organelles, such as ribosomes, cannot be seen with the light (optical) microscope. Students research the electromagnetic spectrum and find out that this relates to the fact that light waves have a wavelength which is longer than many of the smallest organelles in a cell. This means the smallest organelles do not cause any interference to light waves and are not detected. Figure 1.14 in the Coursebook is helpful here.
- Show students a greater range of electron micrographs. Some interesting extensions of standard material include:
  - scanning electron micrograph of a 'stripped' chloroplast showing the membrane system, including grana, seen from above
  - comparison of C3 and C4 chloroplasts
  - chloroplasts from algae (variations in stacking of thylakoids occur in different algal groups)
  - gut cells for microvilli
  - gland cells for secretory vesicles (possibly a pancreatic acinar cell)

  - muscle for mitochondria, sarcolemma, sarcomeres and myofibrils
  - nerve plus Schwann cells showing cell surface membrane of Schwann cell
  - plant cell stained with potassium permanganate for membranes
  - high power details of small structures such as nuclear pores, centrioles and plasmodesmata
  - cell wall synthesis involving microtubules and Golgi vesicles during plant cell division.
- What are the stages in preparation of material for an electron microscope and the purpose of each stage? How do these stages compare with the stages used for light microscopy?
- Ask students to investigate electron microscopy techniques such as shadowing, negative staining, freeze fracturing and freeze etching.
  - What are the advantages of these techniques?
  - What structures are the techniques suitable for?
  - Why are pictures obtained by shadowing often published as negatives?
- If possible, organise a visit to a university department or research institute that has an electron microscope. Students would find this experience inspiring and informative.

Support

- Help students to appreciate that the magnification formula can be rearranged, by using a triangle. Exercise 1.2 in the Workbook is useful in this regard, and provides a series of step-by-step instructions to help students calculate magnification, with subsequent worked examples and questions.
- Offer low-demand questions related to this topic, such as ESQs 1 and 2 in the Coursebook, and ESQ 2 in the Workbook. These questions concern structures visible with a light and electron microscope.

WRAP-UP AND REFLECTION IDEAS

- Set students Workbook Exercise 1.4, which compares the images produced by light and electron microscopes, and the organelles that are visible with each.
- Encourage students to ask 'What's the question?' when given an answer. Select a range of single-word terms and simple sentences related to this. For example:
  - magnification
    (This could be the answer to a question that requires the name of the concept, or what factor would be provided if actual size is divided by image size.)
  - 500 nm
    (This could be the answer to a question that asks for the approximate size of a bacterial cell, or another measurement expressed in a different unit.)
  - eyepiece graticule.
    (This could be the answer to a question that asks for the name of the described device.)
- Prepare a written text that summarises the concepts that students have studied in this subtopic and those previously. Include between five and ten spelling mistakes and conceptual errors. Encourage students to spot and circle as many mistakes as possible, and offer corrections. This activity could be made into a competition, with the first student who identifies all mistakes deemed the winner. Suitable deliberate mistakes could include the following.
  - Light microscopes can produce images with a greater resolution compared with electron microscopes.
  - Electron microscopes can be used to prepare photomicrographs.
  - To find the magnification of an image, divide the actual size by the image size.

CROSS-CURRICULAR LINKS

Literacy
There are a number of new key terms in this topic. Techniques such as 'Taboo' can be useful to promote learning. In 'Taboo', students work in pairs to describe key words to each other without using other (listed) key words. It would be challenging, for example, for students to describe the advantages of using an electron microscope without using the three key terms: *resolution*, *electrons* and *three-dimensional*.

Numeracy
Converting between units and doing magnification calculations – including rearranging the formula to find image sizes – provide opportunities to develop mathematical skills.

Topics 1.2.1; 1.2.2; 1.2.3; 1.2.4; 1.2.5; 1.2.6

These topics explore the names, structures and functions of the organelles that are most common in animal and plant cells. Students will also explore how eukaryotic cells differ in structure from prokaryotic cells.

- Recognise the following organelles and other cell structures found in eukaryotic cells and outline their structures and functions:
  - cell surface membrane
  - nucleus, nuclear envelope and nucleolus
  - rough endoplasmic reticulum
  - smooth endoplasmic reticulum
  - Golgi apparatus (you may also see this called Golgi body or Golgi complex)
  - mitochondria (including small circular DNA)
  - ribosomes (80S in the cytoplasm and 70S in chloroplasts and mitochondria)
  - lysosomes
  - centrioles and microtubules
  - cilia
  - microvilli
  - chloroplasts (including small circular DNA)
  - cell wall, plasmodesmata, large permanent vacuole and tonoplast of plant cells.
- Describe and interpret photomicrographs, electron micrographs and drawings of typical animal and plant cells.
- Compare the structure of typical plant and animal cells.
- State that cells use ATP from respiration for processes that require energy.
- Outline key structural features of a prokaryotic cell as found in a typical bacterium, including:
  - unicellular
  - generally 1–5 µm diameter
  - peptidoglycan cell walls
  - naked circular DNA
  - 70S ribosomes
  - absence of organelles surrounded by double membranes.
- Compare the structure of a prokaryotic cell as found in a typical bacterium with a typical eukaryotic cell.

Suggested teaching time

This content should take around two hours to cover.

Links to other components in this series

Component	Resource	Description
Coursebook	Figures 1.22–1.35 Practical Activity 1.3 Question 10 ESQ 5, 6, 10	• Figures, activity and questions concerning the organelles present in eukaryotic and prokaryotic cells
Workbook	Exercise 1.6 ESQs 1–4	• Membranes in different types of cells • Questions on the ultrastructure of cells and their organelles
Practical Workbook	Practical Investigation 1.3	• Comparing animal cells and plant cells
Teacher's Resource	Practical Teacher's Guide: Practical Investigation 1.3	• Comparing animal cells and plant cells

Common misconceptions

- In comparison tables, some students tend to make the error of placing non-comparable features alongside each other, for example 'has circular DNA' alongside 'not all have cell walls'. An example of a table containing such errors could be projected and students asked to spot the errors.
- The term *cell membrane* is often used instead of *cell surface membrane* or *plasma membrane*. It is worth stressing the need for precision. Similarly, sometimes the term *cytoplasm* is thought to include the nucleus. Distinguish the term *protoplasm* from the term *cytoplasm*.
- *Cell walls* and *cell surface membranes* are sometimes mixed up. Students might imagine that plant cells have walls, whereas animal cells have cell surface membranes (implying that plant cells lack a cell surface membrane). Providing or constructing a table of comparison can help here.
- Students commonly state that the nucleus is surrounded by a nuclear membrane (rather than a nuclear envelope – a double membrane). Similarly, it is a very common mistake for students to think that, if DNA is described as 'naked', this means it is not surrounded by a nuclear envelope (rather than lacking histone proteins, which is the correct explanation).

Lesson starters

If activities with microscopes in recent lessons have focused on specific examples, students may remember the names of some organelles and how they achieve specific functions inside a cell. Starter activities should refresh their prior knowledge.

Two suggestions are given here. The choice of activity used will depend on the resources available, the time available and how the class is progressing with this topic.

1 Idea A

Go round the class and ask for each student to name a part of a cell that they remember from their previous studies. Build a list on the board until students can go no further. The list is likely to include the nucleus, cell surface membrane and cell wall, chloroplasts and mitochondria.

› **Assessment idea:** Discuss the answers that students provided, and encourage students to work in pairs to categorise the terms. For example, which are found in animal cells and which in plant cells? Are some organelles found only once inside cells, whereas others are found many times?

2 Idea B

Challenge students to brainstorm in pairs a list of structures they know are present inside cells. After two or three minutes of discussion, the pairs join together into fours and then eights to discuss this further and come up with an agreed list of points. One or two students from each group then draw and label the group's ideas on the class board to form a 'summary cell'.

› **Assessment idea:** Students copy down the summary cell with organelles 'I knew' in green and things that 'are new' in red. This can be referred to at the end of the lesson to show students how much progress they have made.

Main activities

Below are several teaching activities which you can pick and choose from in order to tailor the lesson to your class's needs.

1 Practical Investigation 1.3: Comparing animal cells and plant cells (90 minutes)

Refer to Practical Investigation 1.3 in the Practical Workbook. This activity enables students to practise some of the skills they have developed earlier in this topic, by preparing temporary slides of human cheek cells, and comparing their size and structure with palisade cells and onion epidermis cells.

› **Assessment idea:** Encourage students to reflect on the problems they encountered in this practical, and how they overcame them. Elicit a discussion that focuses on how best to identify solutions to problems in a practical situation. Set students Coursebook ESQ 5 to summarise. This challenges them to distinguish (state the differences between) key terms from this chapter. These include:

- nucleus and nucleolus
- smooth ER and rough ER
- prokaryote and eukaryote.

2 Creative comparisons (90 minutes)

Students work in groups to prepare Venn diagrams or tables on posters comparing prokaryotes and eukaryotes, in terms of overall structure and the organelles found within them. Tables could be interactive including links to diagrams, photographs and text. These can be prepared on a large piece of paper or card with a range of materials. Then hold a 'marketplace' activity in which one member of each group stands by their poster and offers an explanation to other groups as they circulate around the room. An alternative, which could take longer to share, is for students to prepare a PowerPoint presentation. Students must use the Coursebook, especially figures such as Figure 1.35, which shows the structures always present and sometimes present in a bacterium.

› **Assessment idea:** Display or draw a large schematic diagram of a cell with all organelles present but obscured by 12–15 small numbered 'jigsaw' pieces. (This can be done virtually with computer software or physically by affixing A3 sheets to the whiteboard.) Students are asked to choose which pieces to remove and then identify the organelle exposed. To add extra challenge to this activity, students who identify the organelles can choose another student to state the organelle's function. When any student thinks he or she knows whether the cell is eukaryotic or prokaryotic, they are required to shout out the answer. This could form the basis of a competition, with the class divided into two teams.

Differentiation

Stretch and challenge

- Ask students to read the feature at the start of Chapter 1 in the Coursebook. This describes how the biologist Lynn Margulis (d. 2011) developed the theory that new organisms can be created from combinations of existing organisms. Margulis' theory is based on a symbiotic partnership (two organisms living together in a relationship in which both benefit). Develop students' understanding by asking further questions such as:
  - Can you give any examples of molecules whose structure is key to their function?
  - Why is this called 'endosymbiosis'?
  - Discuss why her idea was not immediately accepted at the time.

- Set students Workbook Exercise 1.6, which explores the mean percentage of all membranes in two different types of cell, to explore the relative number of organelles they contain.
- Encourage students to research how organelles obtained their name. Some are named after the scientist who discovered them (e.g. Camillo Golgi first identified the Golgi apparatus), whereas others are based on the names of structures of other components of the cell (e.g. plasmodesmata).
- Mesosomes were once thought to be organelles associated with the cell surface membrane of prokaryotes. Discuss the case of the proposal and then disproof of the mesosome hypothesis as an example of how a scientific idea can be falsified and the hypothesis then rejected.
- High-demand questions related to this topic are Coursebook ESQ 10 and Workbook ESQ 3, which concern the process of differential centrifugation and how it can be used to separate organelles for study.

Support

- Providing 'mind hooks' can be of great benefit to some students. For example, the rough endoplasmic reticulum does indeed look more 'rough' than the smooth ER, and the Golgi apparatus somewhat resembles the symbol for Wi-Fi.
- Help students to categorise organelles, to help distinguish their structures. One option is to use ESQ 6 in the Coursebook. This challenges students to list three organelles lacking a boundary membrane, three that are surrounded by a single membrane, and three surrounded by two membranes (an envelope).
- During the 'Creative comparisons' activity, provide students with an opportunity to seek support. This can be done by producing a series of 'clue cards', available on request. If a student feels they need support, they can request a card from the teacher. Each card provides a 'hint' that is intended to give the student just enough information to help them move on with their work (e.g. 'Compare the number of membranes around the organelles' or 'Have you considered the number of organelles in the cells?')

WRAP-UP AND REFLECTION IDEAS

- Make a loop activity using some or all of the terms used in this chapter. Type some or all of the terms used in this chapter with their definitions into a spreadsheet. Now, move all the terms down by one cell so that term and definition no longer match. Type START against the first definition and END against the last term (see diagram).

START	Definition term 1
Term 1	Definition term 2
Term 2	Definition term 3
Term 3	END

  Print the spreadsheet onto stiff card and then cut up the card so that each piece has a term and a definition. Shuffle the cards and then hand them out to the class. The student with the START card reads out the definition and the person with the matching term identifies themselves, reads out the term and then reads the definition on their card. This continues until the END card is reached. The cards can be shuffled and the loop activity repeated to see if the students can do it faster the second time. Have a master copy of the loop to correct any mistakes that happen. Refer to Practical Activity 1.3 in the Coursebook for further information. This activity reinforces the functions of organelles.

- Students prepare a series of five statements that can be classified as 'always true', 'sometimes true' or 'never true'. Examples could include:
  - All cells have a surface membrane. *(always true)*
  - Eukaryotic cells contain a nucleus. *(sometimes true – not red blood cells)*
  - Prokaryotic cells have membrane-bound organelles. *(never true)*

CROSS-CURRICULAR LINKS

Literacy
There are a very large number of new key terms introduced during this topic. Preparing a crossword or sheet of anagrams to help students become familiar with them would be a valuable exercise.

Numeracy
Opportunities to practise mathematical skills are less obvious in this topic than others, but students could be asked, for example, to calculate the ratio of volume of prokaryote cell to volume of eukaryote cell by assuming spherical cells of 1 µm and 20 µm diameter, respectively.

Topic 1.2.7

This topic develops students' understanding of how genes are used to make proteins, and how changes in the primary structure can cause changes in function.

- State that all viruses are non-cellular structures with a nucleic acid core (either DNA or RNA) and a capsid made of protein, and that some viruses have an outer envelope made of phospholipids.

Suggested teaching time

This content should take around one hour to cover.

Links to other components in this series

Component	Resource	Description
Coursebook	Figure 1.36	• Figure showing the structure of a virus
Workbook	Not applicable	• Not applicable
Practical Workbook	Not applicable	• Not applicable

Common misconceptions

- It is common for students to believe that viruses have cell walls (rather than protein coats). Figure 1.36 in the Coursebook shows the structure of a virus.

Lesson starters

This topic completes the range of what might be considered living organisms and gives students the opportunity to consider what is meant by the term *living organism*. Students may have already encountered the 'characteristics of life', and may be familiar with the idea that viruses are not technically considered to be alive.

Two suggestions for lesson starters are given here. The choice of activity used will depend on the resources available, the time available and how the class is progressing with this topic.

1 Idea A

Start with a specific disease, perhaps influenza and the pandemic of 1918–19. Use this to consider the historical discovery of non-cellular disease-inducing agents (viruses). Then discuss the fact that viruses became visible only with the introduction of electron microscopy. This provides a useful additional link with the previous topics.

› **Assessment idea:** Engage students in a 'think, pair, share' activity to summarise three very simple points from the discussion. Examples could include:

- Viruses cause disease.
- Viruses are smaller than cells.
- Viruses are non-cellular.

2 Idea B

Provide students with marker pens and ask them to come to the class board to write down as many human diseases as they can. Circle those that are caused by viruses – common ones include HIV (AIDS), measles, influenza (flu), chicken pox and hepatitis. Add some emerging diseases of crop plants that threaten our food security.

› **Assessment ideas:** Through a class discussion, encourage ideas from students in order to arrive at a consensus to explain the key differences between cells and viruses. As an extension, host a debate to explore whether viruses are living or non-living.

Main activity

Below is a suggestion for a teaching activity.

1 Top trumps (50 minutes)

Provide an opportunity for each student to research one virus (ensure that different students find out information about different viruses). Students each prepare a card that lists the key features of 'their' virus. It is a good idea to provide a scaffold (text with missing words) to maintain consistency. Photocopy the cards and provide them to students working in pairs. The students examine two cards at a time to compare the features of two different viruses.

- Which one is more pathogenic?
- Which one is larger?
- Which one has the more effective way of infecting host cells?

› **Assessment idea:** Summarise the activity by encouraging students to write a paragraph to summarise the key structural features that all viruses have in common. This could be provided as a missing word exercise, or a series of statements that have the beginning or the end missing.

Differentiation

Stretch and challenge

- Host a debate regarding viruses, perhaps by grouping students into teams. For example: 'Sir Peter Medawar described a virus as "a piece of bad news wrapped in a protein coat". Is this a fair description?'
- Students could research techniques for identifying viruses and explore the range of structures.

Support

- www.johnkyrk.com/virus.html provides animations that help students appreciate the unique nature of viruses.
- Show images of viruses, which are always produced by electron microscopes (why?). The symmetry is a fascination for many students. This could be extended into a model-making activity.

WRAP-UP AND REFLECTION IDEAS

- With an initial emphasis on viruses, challenge students to a game of 'Bingo' to consolidate the key terms from previous topics. Provide each student with a grid of nine squares. Then provide 20 key terms on the board, taken from the topics studied so far. Students select nine words at random to fill in the grid. Then call out definitions of each of the 20 key terms – in random order. The first student to tick off all their nine words calls 'Bingo!' and wins the contest. For your reference during this activity, key words in Chapter 1 of the Coursebook have definitions listed in the Glossary and are emboldened throughout the chapter.
- 'Heads and tails' is a useful technique to use after this lesson. Ask each student to write a question about something from the chapter on a coloured paper strip and the answer on another coloured paper strip. Put students into groups of six to eight, and hand out the strips so that each student gets a question and an answer. One student reads out their question, and the student with the right answer then reads it out, followed by their question.

CROSS-CURRICULAR LINKS

Literacy
There are fewer new key terms for this topic. Write the key words (e.g. *capsid*, *capsomeres*, *protein coat*) on the board for the duration of the study.

Numeracy
Students could calculate the ratio of size between a virus and a bacterium, or between a virus and a human cell.

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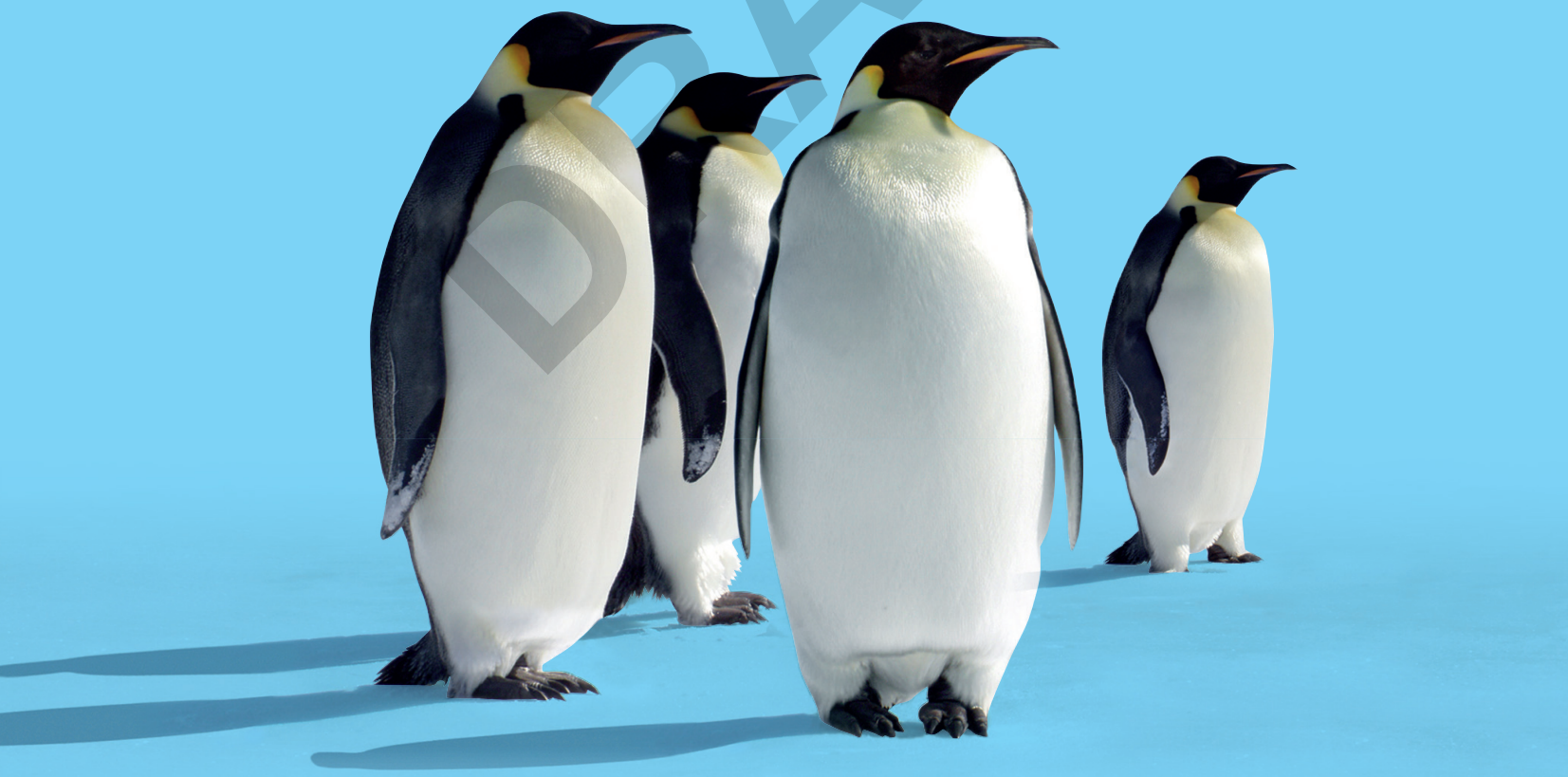
WORKBOOK

Mary Jones & Matthew Parkin



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Contents

Chapter 1

Cell structure

CHAPTER OUTLINE

The questions in this chapter cover the following topics:

- the structure of animal, plant and bacterial cells, and of viruses
- the use of light microscopes and electron microscopes to study cells
- drawing and measuring cell structures
- the variety of cell structures and their functions
- the organisation of cells into tissues and organs.

Exercise 1.1 Units for measuring small objects

Cells are small, and the organelles that they contain are sometimes very, very small. In this exercise, you will practise converting between the different units that we use for measuring very small objects. You will also make sure that you are able to write numbers in **standard form**.

KEY WORDS

standard form: a way of writing a number as a value that is always between 1 and 10, and using the power of ten to show how large or small the number is.

digit: a single whole number, e.g. 2.

TIP

Standard form is a way of writing down large or small numbers simply.

The rules are:

- Write down the **digits** as a number between 1 and 10
- Then write × $10^{\text{power of the number}}$.

1 mm = 1000 μm = 10^3 μm

So 1 μm = 1/1000 mm = 10^{-3} mm

1 The units that we use when measuring cells are millimetres (mm), micrometres (μm) and nanometres (nm).

Copy and complete:

a 1 μm = 1000 nm = $10^{\cdots\cdots}$ nm

b 1 nm = ... μm = $10^{\cdots\cdots}$ μm

c 1 nm = ... mm = $10^{\cdots\cdots}$ mm

TIP

To work out the correct power, imagine moving the decimal point to the right or left, until you get a number between 1 and 10. Count how many moves you have to make, and that is the power of ten you should write.

For example, if your number is 4297, you would move the decimal point as shown.

So we write this number as 4.297×10^3.

Here are some examples of writing large numbers in standard form:

$6000 = 6 \times 10^3$

$6248 = 6.248 \times 10^3$

$82\,910 = 8.291 \times 10^4$

$547.5 = 5.475 \times 10^2$

2 Write these numbers in standard form:

- **a** 5000
- **b** 63
- **c** 63 000
- **d** 63 497
- **e** 8521.89

3 Write these numbers in standard form:

- **a** 0.1257
- **b** 0.0006
- **c** 0.0104

4 A cell measures 0.094 mm in diameter.

- **a** Convert this to micrometres.
- **b** Express this value in standard form.

5 A cell organelle is 12 nm long.

Express this value in μm, in standard form.

6 A mitochondrion is 1.28×10^2 μm long.

Express this value in nm.

7 A chloroplast is 2.7×10^3 nm in diameter.

Express this value in μm.

TIP

Here are some examples of writing small numbers in standard form:

$0.678 = 6.78 \times 10^{-1}$

$0.012 = 1.2 \times 10^{-2}$

$0.0057 = 5.7 \times 10^{-3}$

Exercise 1.2 Magnification calculations

This exercise will help you to gain confidence in doing magnification calculations, as well as providing further practice in using different units and converting numbers to standard form. You will also need to think about selecting a suitable number of significant figures to give in your answers. In general, you should use the same number of significant figures as there are in the value with the smallest number of significant figures that you used in your calculations.

TIP

Remember – magnification has no units

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

1 A light micrograph of a plant cell shows the cell to be 5.63 cm long. The real size of the cell is 73 μm.

Follow the steps to find the **magnification** of the micrograph.

Step 1 Convert 5.63 cm to μm.

Step 2 Substitute into the magnification equation: magnification = ...

Step 3 Calculate the magnification. Write the answer as ×.....

2 An electron micrograph of a nucleus shows it to be 44 mm in diameter. The actual diameter of the nucleus is 6 μm. Calculate the magnification of the electron micrograph.

3 An electron micrograph of a **mitochondrion** shows its diameter as 28 mm. The magnification of the image is given as ×22 700. Follow the steps to find the actual diameter of the mitochondrion.

Step 1 Convert 28 mm to μm.

Step 2 Rearrange the magnification equation, and then substitute into it:

$$\text{actual size} = \frac{\text{image size}}{\text{magnification}} = ...$$

Step 3 Calculate the actual diameter of the mitochondrion. Remember to give your answer to the same number of significant figures as the value with the smallest number of significant figures that you used in your calculation.

4 An image of a chloroplast in an electron micrograph is 36 mm long. The magnification of the micrograph is ×1285. Calculate the actual length of the chloroplast.

KEY WORDS

magnification: the number of times greater that an image is than the actual object; magnification = image size ÷ actual (real) size of the object

mitochondrion: the organelle in eukaryotes in which aerobic respiration takes place

5 The micrograph shows a group of *Legionella* bacteria. The image has been magnified ×980.

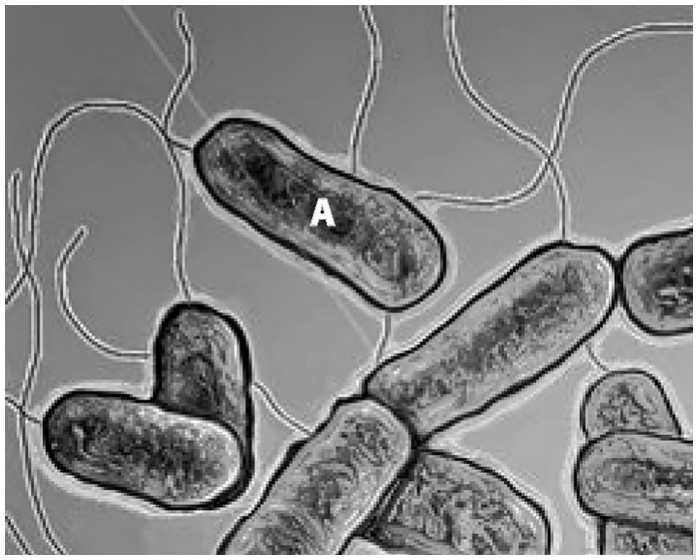

Figure 1.1: Micrograph of *Legionella* bacteria.

a Measure the maximum length of bacterium **A**.

b Calculate the actual length of this bacterium. Show all the steps in your working.

6 The micrograph shows some plant cells containing starch grains. There is a scale bar beneath the image.

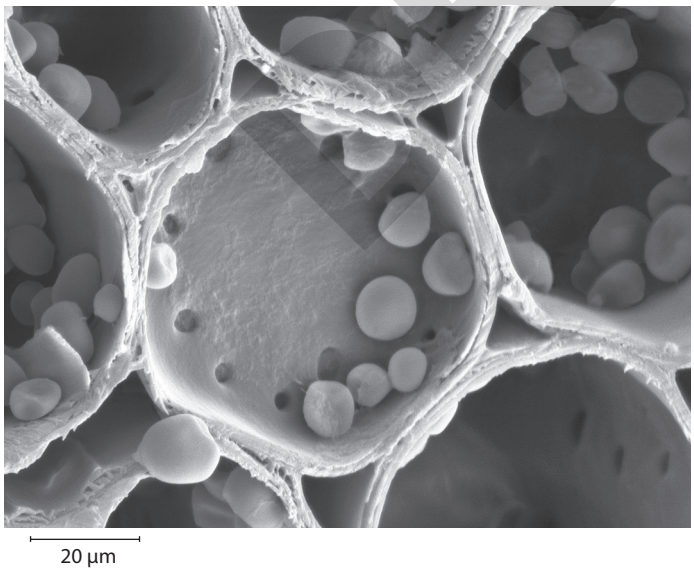

Figure 1.2: Micrograph of plant cells with starch grains.

a Measure the length of the scale bar in mm.

b Convert this measurement to μm.

c Use this image size of the scale bar, and the actual size that we are told it represents, to calculate the magnification of the image.

d Measure the maximum diameter of the central cell in the micrograph.

e Use the value of the magnification you have calculated to find the actual diameter of this cell.

7 The micrograph shows a cell from the pancreas of a mammal. Several mitochondria are visible.

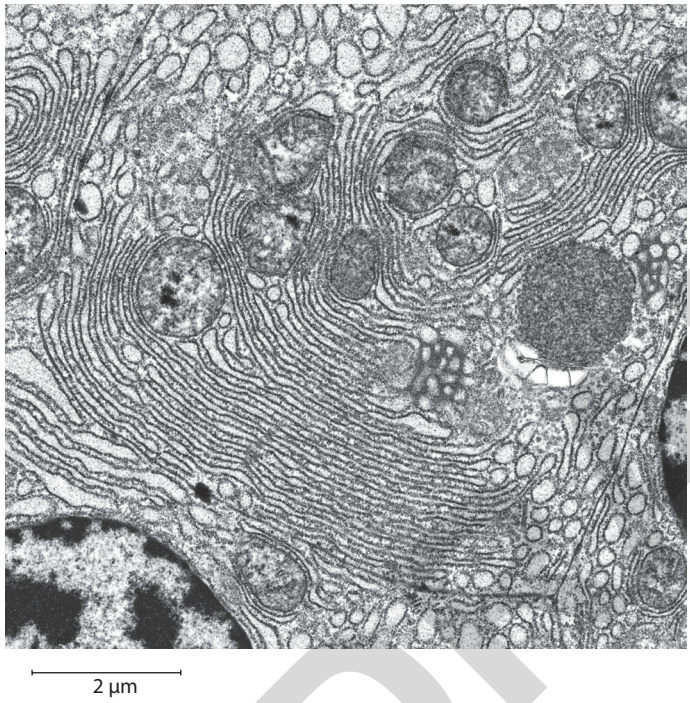

Figure 1.3: Micrograph of a cell from the pancreas.

Use the scale bar to calculate the actual diameter of the largest mitochondrion.

Exercise 1.3 Drawing from light micrographs

Being able to draw good diagrams from micrographs or from what you can see when using a microscope is nothing to do with being good at art. Your task as a biologist is to make a clear, simple representation of what you can see. Use a sharp, medium-hard (HB) pencil and have a good eraser to hand. Each line should be clean and not have breaks in it – unless there really are breaks that you want to represent.

1 This drawing was made from the electron micrograph of the plant cells shown in Figure 1.2 (see question 6 in Exercise 1.2).

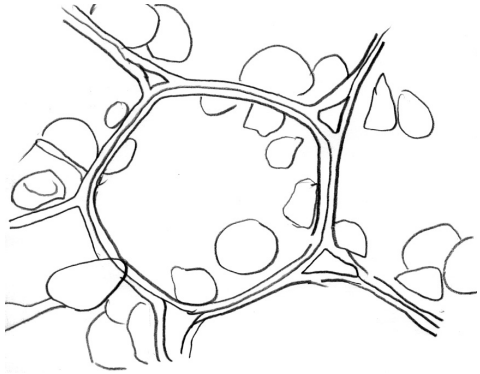

Figure 1.4: Drawing of plant cells.

a Use these criteria to assess the quality of the drawing. Copy Table 1.1, and put a tick in one box in each row. You could also add a brief comment explaining why you made each decision.

Feature	Done very well	Done fairly well	Poorly done
suitably large diagram – makes good use of space available but does not extend over any text			
clean, clear, continuous lines			
overall shape and proportions look approximately correct			
correct number of starch grains shown, each carefully drawn the right shape and size			
relative sizes of starch grains and cell size correctly shown			
no shading has been used			
good and correct detail of cell walls shown			

Table 1.1: Assessment grid for drawing.

b Now make your own drawing of the cells shown in Figure 1.2. Take care to meet all of the criteria fully.

2 The micrograph in Figure 1.5 shows a lymphocyte, a type of white blood cell found in mammals.

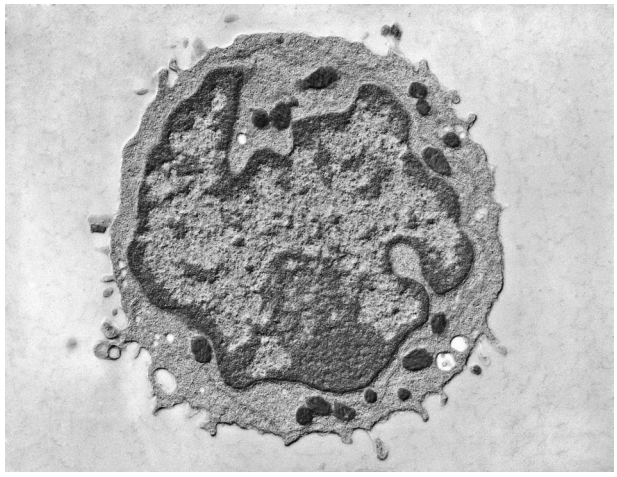

Figure 1.5: Micrograph of a lymphocyte.

a Make a drawing of the lymphocyte.

b Construct a list of criteria for your drawing, using the criteria from question **1a** as a guide.

c Assess the standard of your drawing against your criteria. Alternatively, or as well, you could exchange your drawing with a partner, and assess each other's drawings.

d The magnification of the micrograph of the lymphocyte is ×4750.

Calculate the actual diameter of the lymphocyte. Give your answer in μm, using standard form.

e Use your answer to **d** to calculate the magnification of your drawing.

Exercise 1.4 Electron microscopes and optical (light) microscopes

The micrographs in this chapter have been made using different kinds of microscope. In this exercise, you will practise identifying features that distinguish images taken with different types of microscope, and then summarise the differences between what we can see using optical (light) microscopes and electron microscopes.

1 Copy and complete Table 1.2. In the 'type of microscope' column, choose from **optical microscope**, **transmission electron microscope** or **scanning electron microscope**.

Micrograph	Type of microscope used to produce the micrograph	Reason for your decision
Figure 1.2		
Figure 1.3		
Figure 1.5		

Table 1.2: Results table.

2 Copy and complete Table 1.3, to compare what can be seen in typical animal cells and plant cells using optical microscopes and electron microscopes. Put a tick or a cross in each box.

Organelle	Visible in plant cells		Visible in animal cells	
	Visible using optical microscope	Visible using electron microscope	Visible using optical microscope	Visible using electron microscope
nucleus				
mitochondrion				
membranes within mitochondrion				
Golgi body				
ribosomes				
endoplasmic reticulum				
chloroplast				
internal structure of chloroplast				
centriole				

Table 1.3: What can be seen in typical animal cells and plant cells using optical microscopes and electron microscopes.

KEY WORDS

optical microscope: a microscope that uses light to view a specimen; maximum resolution down to 200 nm

transmission electron microscope: a microscope that uses a beam of electrons to view a very thin section; maximum resolution down to 0.5 nm

scanning electron microscope: an electron microscope that provides a three-dimensional view of the surface of a specimen; maximum resolution down to 2 nm

Exercise 1.5 Using an eyepiece graticule and stage micrometer

An **eyepiece graticule**, calibrated using a stage micrometer, enables you to work out the actual size of objects you can see using a microscope. This exercise provides practice in this technique, and also involves decisions about how many **significant figures** to give in your answers.

Figure 1.6 shows a group of palisade cells, as they look through a light microscope with an eyepiece graticule fitted inside the eyepiece. The highest power objective lens of the microscope is being used.

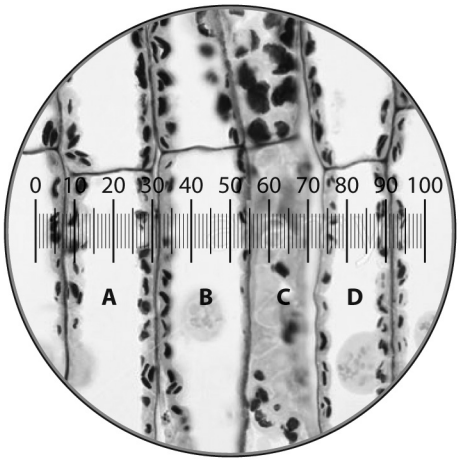

Figure 1.6: Micrograph of palisade cells seen using an eyepiece graticule. The small divisions on the graticule scale can be referred to as 'graticule units'.

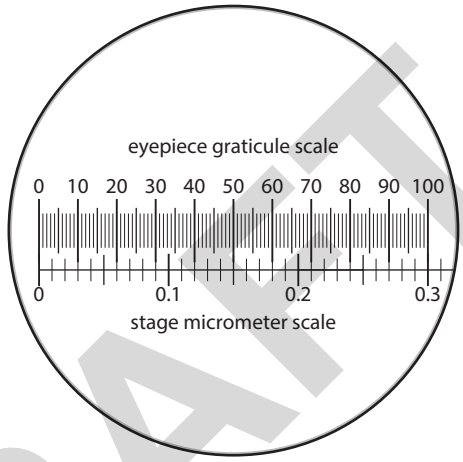

Figure 1.7: Stage micrometer seen using an eyepiece graticule.

1 Measure the total width of the four palisade cells A, B, C and D in graticule units.

In order to find out the true size represented by one eyepiece graticule unit, we now need to calibrate the eyepiece graticule using a **stage micrometer**. This is a slide that is accurately marked off in small divisions of 0.01 mm. Figure 1.7 shows what is seen when the slide with the palisade cells is replaced on the microscope stage by a stage micrometer.

2 **a** Look for a good alignment of marks on the two scales, as far apart as possible. The 0s of both scales match up, and there is another good match at 80 small divisions on the eyepiece graticule.

How many small divisions on the micrometer equal 80 small divisions on the eyepiece graticule?

b Remember that one small division on the micrometer is 0.01 mm. Use your answer to **a** to calculate how many micrometres (μm) are represented by one small division on the eyepiece graticule.

TIP

When you are doing this using your own microscope, you will need to swivel the eyepiece and/or move the slide, so that your eyepiece graticule scale lies neatly over the thing you want to measure.

KEY WORDS

significant figures: the digits that carry meaningful information about the size of the number.

eyepiece graticule: small scale that is placed in a microscope eyepiece.

stage micrometer: very small, accurately drawn scale of known dimensions, engraved on a microscope slide.

TIP

It is essential to use the same objective lens – the one that you used when you measured the palisade cells in eyepiece graticule units. Again, you may need to swivel the eyepiece, and move the slide on the stage, to get them lined up against one another.

c Use your answer to **b** to find the total width of the four palisade cells in the micrograph.

d Now calculate the mean width of a palisade cell.

3 Explain why it is not possible to see both the palisade cells and the stage micrometer scale at the same time.

4 Figure 1.8 shows a light micrograph of some villi in the small intestine, seen using an eyepiece graticule.

Figure 1.9 shows the same eyepiece graticule, using the same objective lens, but this time with a stage micrometer on the microscope stage.

Use the two images to calculate the length of the villus that can be seen beneath the eyepiece graticule. Show each step in your working.

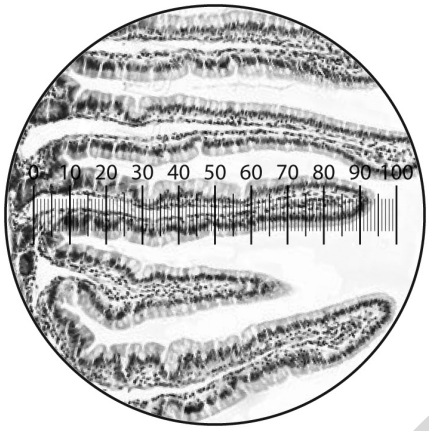

Figure 1.8: Light micrograph of villi seen using an eyepiece graticule.

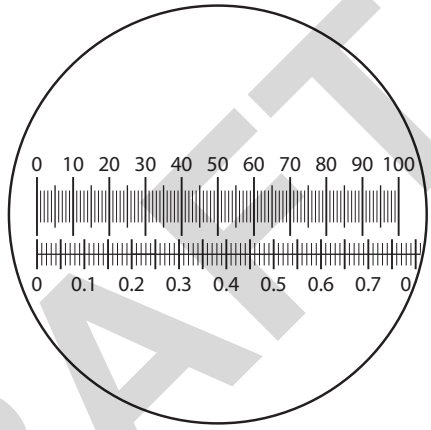

Figure 1.9: Stage micrometer seen using the eyepiece graticule.

Exercise 1.6 Membranes in different types of cell

Most cells in multicellular organisms become specialised for a particular set of functions. In this exercise, you will consider data relating to the membranes in two different types of cell, and use your biological knowledge to suggest explanations for patterns that you can pick out in these data.

All cells are surrounded by a cell surface membrane, and also contain many other membranes within them. Researchers estimated the total quantity of membranes in 20 liver cells and 20 exocrine pancreas cells, and then calculated the percentage of these membranes in all the different membrane-containing structures in the cells. Their results are shown in Table 1.4.

Source of membrane	Mean percentage of all membranes	
	Liver cells	Exocrine pancreas cells
cell surface membrane	1.8	4.7
mitochondrial membranes	39.4	22.3
nuclear membrane	0.5	0.7
rough endoplasmic reticulum	33.4	61.9
smooth endoplasmic reticulum	16.3	0.1
Golgi body	7.9	10.3
lysosomes	0.4	0
other small vesicles	0.3	0

Table 1.4: Percentage of membranes in all the different membrane-containing structures in the cells.

1 Explain why we cannot use these results to draw the conclusion that the mean quantity of cell surface membrane in liver cells is less than that in exocrine pancreas cells.

2 Which of the sources of membranes listed in the table are made up of two membranes (an envelope)?

3 Using the data in the table, state the organelle that contains the greatest mean percentage of membrane in:

   a liver cells

   b pancreas cells.

4 Liver cells have a wide variety of functions in metabolism, including synthesising proteins, breaking down toxins, synthesising cholesterol and producing bile. Exocrine pancreas cells have a single main role, which is the production and secretion of digestive enzymes.

   Use this information to suggest explanations for the differences between the percentages for mitochondria and rough endoplasmic reticulum in the liver cells and the pancreas cells.

Exercise 1.7 Command words

Command words are the instructional words in a question that tell you what you need to do. It is a good idea to identify the command word in each question part, and make sure that you understand what it means so that you can then write a strong answer.

1 Some of the command words used in questions are listed below. You have already met several of them in this chapter.

assess	**calculate**	**comment**	**compare**	**contrast**	**define**
describe	**discuss**	**explain**	**give**	**identify**	
outline	**predict**	**sketch**	**state**	**suggest**	

Match the correct command word in the list above to the description given:

a express in clear terms – that is, give a short, precise answer

b give the precise meaning – that is, provide a short but complete description of what the term means

c state the points of a topic / give characteristics and main features – for example, use words to say clearly what is shown by a graph, or give a step-by-step account of something

d produce an answer from a given source or recall/memory – for example, using information provided in the question, or from knowledge you have learnt during your course

e make a simple drawing showing the key features

f set out the main points – that is, give a brief account, picking out the most important points and omitting detail

g set out purposes or reasons / make the relationships between things evident / provide why and/or how and support with relevant evidence – note that you will often need to use your knowledge of biology to say why or how something happens

h write about issue(s) or topic(s) in a structured way; it is often a good idea to state points on both sides of an argument, for example, reasons for and against a particular viewpoint, or how a set of results could be interpreted to support or reject a hypothesis

i make an informed judgement

j apply knowledge and understanding to situations where there is a range of valid responses, in order to make proposals – that is, use information provided, and your biological knowledge, to put forward possible answers; there is often more than one possible correct answer

k work out from given facts, figures or information – it is usually a good idea to show all of the steps in your working

l give an informed opinion – you will often need to use your biological knowledge and understanding to make a range of statements about the topic

m identify/comment on similarities and/or differences – you can often use a table for this; if writing sentences, then use comparative words

n identify/comment on differences – you can often use a table for this; if writing sentences, then use comparative words

o name/select/recognise – for example, labelling a structure on a diagram or micrograph

p suggest what may happen based on available information.

EXAM-STYLE QUESTIONS

This question relies on your recall of facts and concepts. You could answer part **b** either in words, or by using a labelled diagram. Note that the command word for **b** is 'outline'.

1 Table 1.5 lists some features of prokaryotic and eukaryotic cells.

Feature	Prokaryotic cell	Eukaryotic cell
cell surface membrane		
nucleus		
ribosomes		
mitochondria		
chloroplasts		

Table 1.5

a Copy and complete Table 1.5. If a feature can be present in the cell, write a tick in the box. If it cannot be present, write a cross. You should write either a tick or a cross in each box. **[5]**

b Viruses are not usually considered to be living organisms and are not made of cells. **Outline** the key features of the structure of a virus. **[2]**

[Total: 7]

COMMAND WORD

outline: set out the main points.

This question asks you to identify structures within an animal cell. You should find this relatively straightforward, although you may have to think carefully about part **b**.

2 The diagram is a drawing of a cell from the body of a mammal.

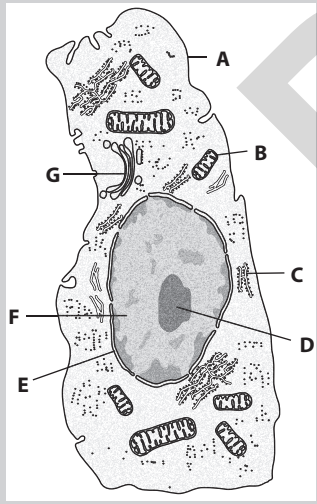

Figure 1.10

CONTINUED

a **State** the type of microscope that would be used to allow this amount of detail to be seen in the cell. **[1]**

b List the letters of the structures in the drawing which are made up of, or are surrounded by, phospholipid membranes. **[3]**

c **Describe** the functions of:

i structure **B** **[2]**

ii structure **E** **[2]**

iii structure **G**. **[2]**

[Total: 10]

3 The diagram shows a method for separating the different components of cells. This technique is called **ultracentrifugation**.

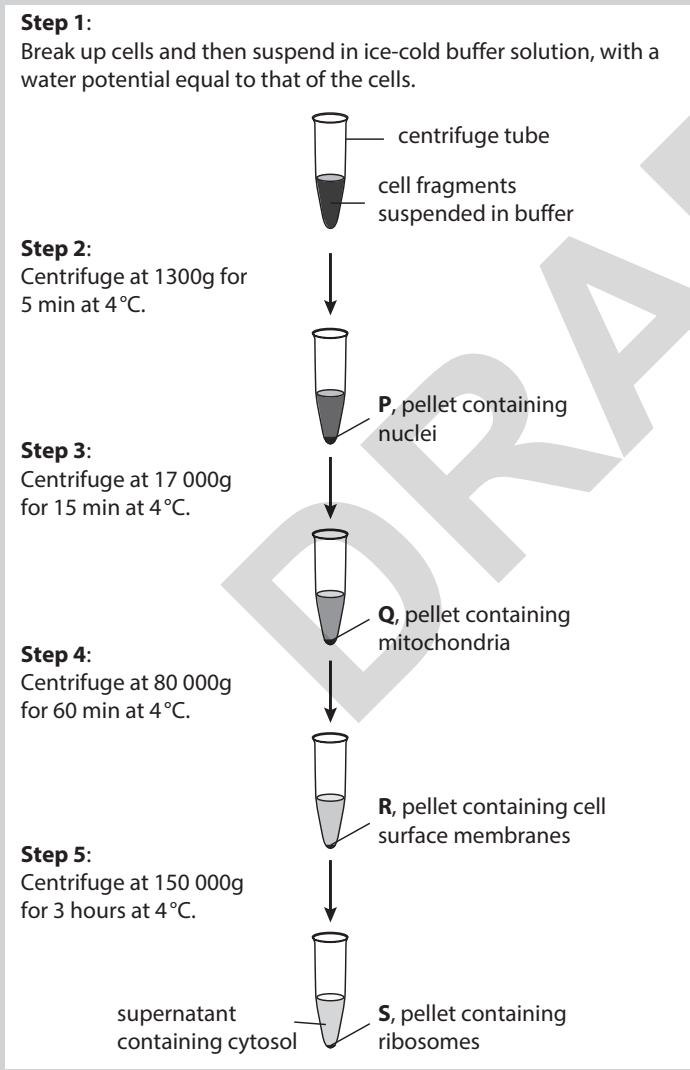

Figure 1.11

COMMAND WORDS

state: express in clear terms.

describe: state the points of a topic / give characteristics and main features.

KEY WORD

ultracentrifugation: spinning a suspension at very high speed, so that more dense components settle to the bottom and can be separated.

CONTINUED

a **Suggest** why the solution in which the broken-up cells were suspended:

i was ice-cold **[1]**

ii contained a buffer **[2]**

iii had the same water potential as the cells. **[2]**

b Suggest why ribosomes do not collect in the pellet until the final stage of the ultracentrifugation. **[1]**

c Give the letter of the component or components in which you would expect to find:

i DNA **[1]**

ii phospholipids. **[1]**

d If this process were carried out using plant cells, which other cell organelles might you expect to find in the pellet containing mitochondria? Explain your answer. **[2]**

[Total: 10]

COMMAND WORD

suggest: apply knowledge and understanding to situations where there are a range of valid responses, in order to make proposals / put forward considerations.

Some questions will contain something new, such as an unfamiliar micrograph. But a combination of your own knowledge and the information in the question should help you work out suitable answers. Look carefully at the mark allocations, which guide you in how detailed an answer you need to give.

4 The photograph shows a micrograph of parts of two cells from the small intestine of a mammal. The structures along the surfaces of the two cells are microvilli.

a State the type of microscope that was used to obtain this micrograph. Give a reason for your answer. **[2]**

b **Identify** organelle A. **[1]**

c The magnification of the micrograph is ×12 500.

i **Calculate** the length of the microvillus between points **X** and **Y**. Show your working. **[3]**

ii Microvilli greatly increase the surface areas of the cells. Suggest why the cells lining the small intestine have microvilli. **[2]**

[Total: 8]

COMMAND WORD

identify: name/ select/recognise.

calculate: work out from given facts, figures or information.

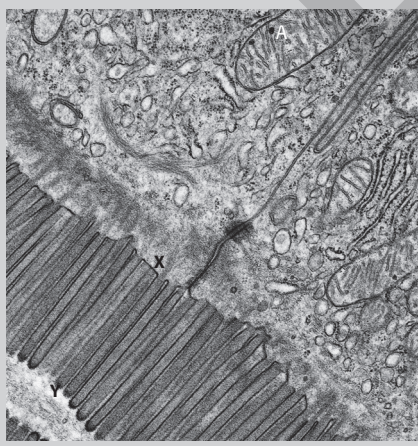

Figure 1.12

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PRACTICAL WORKBOOK

Mary Jones & Matthew Parkin

Fifth edition

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Chapter 1

Microscopy

CHAPTER OUTLINE

This chapter relates to Chapter 1: Cell structure, in the Coursebook.

In this chapter, you will complete practical investigations on:

- 1.1 Making a temporary slide and drawing cells
- 1.2 Measuring cells, using an eyepiece graticule and stage micrometer
- 1.3 Comparing animal cells and plant cells.

Practical Investigation 1.1: Making a temporary slide and drawing cells

In this activity, you will practise using a light microscope. You will also make a temporary mount of plant tissue, observe it using the microscope and make a drawing of some of the cells.

EQUIPMENT

You will need:

• a light microscope • a source of light (this could be built into the microscope, or a lamp, or bright light from a window) • two or three microscope slides • two or three coverslips • a dropper pipette • a mounted needle or seeker • forceps (tweezers) • sharp scissors or a blade (safety razor or scalpel) • filter paper or paper towel • tile • some pieces cut from an onion bulb • a medium–hard (HB) pencil • a good quality eraser

Safety considerations

- Make sure you have read the Safety advice section at the beginning of this book and listen to any advice from your teacher before carrying out this investigation.
- Take care when using a sharp blade to cut the onion epidermis.

Method

Part 1: Making a temporary slide and viewing it through a microscope

Figure 1.1 shows the parts of a microscope.

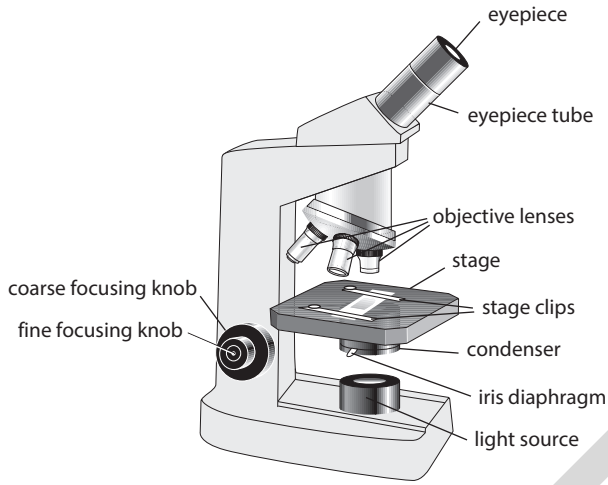

Figure 1.1: A light microscope.

1 Set up your microscope on the bench. Look for each of the parts that are labelled on the diagram.

2 You are now going to make a slide that you can view through your microscope.

- Take a piece of one of the layers from inside an onion bulb. Using scissors or a sharp blade, cut out one piece measuring approximately 1 cm × 1 cm.
- Using a dropper pipette, place a drop of water onto the centre of a clean microscope slide.
- Using forceps, gently peel away the very thin layer of epidermis on the inside surface of the piece of onion. *Immediately* place the epidermis into the drop of water on the slide. Use a mounted needle or seeker to gently spread out the epidermis, so that it is not folded over and is covered by water. You may need to add another drop of water to it.
- Gently lower a coverslip onto the slide, to cover the onion epidermis. It's a good idea to use a mounted needle (see Figure 1.2) as this helps to avoid trapping any air bubbles. If any air bubbles do occur, you should ignore these when making drawings – they will resemble car tyres under the microscope.

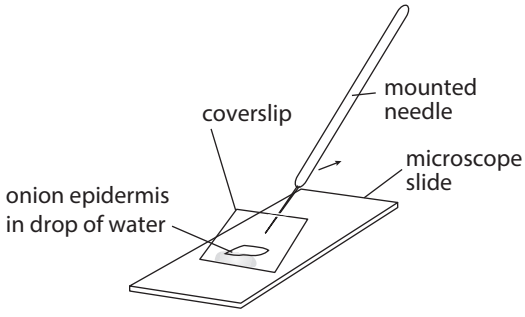

Figure 1.2: Lowering a coverslip.

TIP

Your microscope will almost certainly not be the same as the one in Figure 1.1. For example, it may have a mirror instead of a light source.

- Use filter paper to gently remove any water from the top of the coverslip or on the surface of the slide.

3 Now you can look at your slide through the microscope.

- Turn the objective lenses so that the smallest one is over the hole in the stage.
- Look down through the eyepiece and make sure that you can see light. If you cannot see light, adjust the light source or the mirror.
- Place your slide on the microscope stage, with the epidermis over the hole.
- Looking from the side of the microscope, turn the coarse focusing knob to lower the objective lens, until the objective lens is almost touching the slide.
- Look down the eyepiece again. Slowly turn the coarse focusing knob the other way, to raise the objective lens. Stop when you can see the epidermis. It will probably not look clear.
- Now turn the fine focusing knob until you can see the epidermis clearly. You should be able to see something similar to Figure 1.3.

TIP

If you leave water on the surface of the slide, this may get onto the objective lens. Over time, deposits may form on the lens.

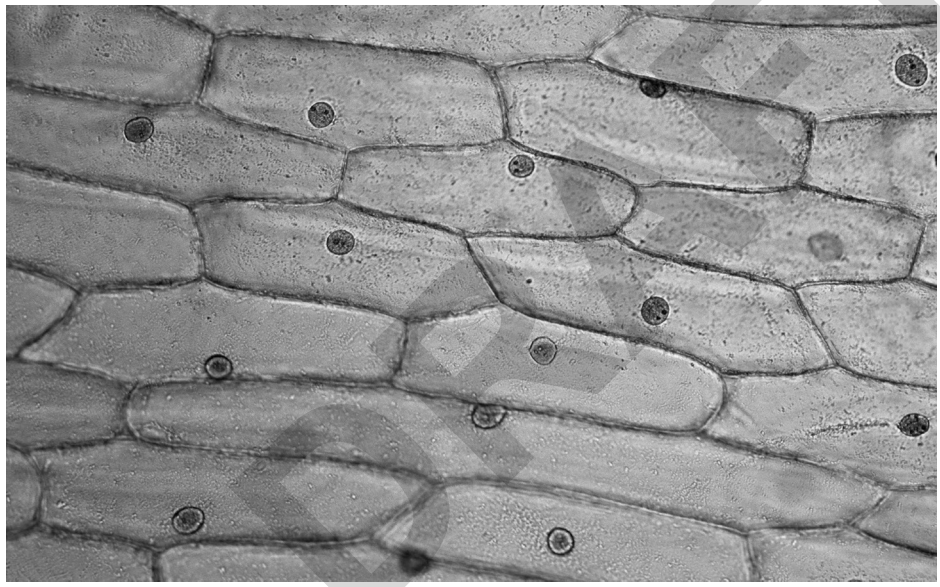

Figure 1.3: Micrograph of epidermal cells.

TIP

With some microscopes, it is possible to lower the objective lens so much that you can crash into the slide and break the coverslip. If you look from the side, it is less likely you will do this.

Part 2: Making a high-power drawing of onion epidermis

1 Focus on the onion epidermis using the lowest power objective, as described previously. Carefully swing the objective lenses around until the next largest one is over the slide. Focus using the fine focusing knob.

2 Decide which objective provides the best view of the epidermis. If you have an even higher power objective lens, you could try that one as well.

3 Make a drawing of the epidermis in the space that follows.

- Use a medium–hard (HB), sharp pencil.
- Use a high-quality eraser, so that you can completely remove any mistakes in your drawing.

TIP

It is sometimes a good idea to keep changing the objective lens as you do your drawing. For example, you may decide to use the lowest power lens, but occasionally change up to the higher power lenses to check on the detail.

- Your drawing should be large, using at least 50% of the space available – but make sure you leave enough space around it for your labels.
- Take care to get the shapes and proportions of the cells correct.
- All lines should be single and clear. Do not leave any gaps, however small, in the lines.
- Always show the cell walls with two lines – cell walls have thickness.
- Do not shade anything at all in your drawing.
- Draw what you can see, not what you think you should see.

4 Label the cytoplasm, nucleus and cell wall on your drawing.

- Use a pencil for the label lines. You may also like to use a pencil to write the names.
- Use a ruler to draw the label lines. Make sure that the end of the label line touches the part that you are labelling.
- Keep label lines separate from each other.
- The label lines can go in any direction, but the written labels should be horizontal.

Part 3: Adding a stain to a temporary slide

You are going to add some iodine in potassium iodide solution to your onion epidermis slide. This will stain (colour) any starch grains in the onion cells blue–black.

1 Place a small drop of iodine solution on the microscope slide, touching the edge of the coverslip.

2 Very carefully place one edge of a piece of a filter paper against the *opposite* side of the coverslip, as shown in Figure 1.4. The water underneath the coverslip will soak into the filter paper, bringing through the iodine solution.

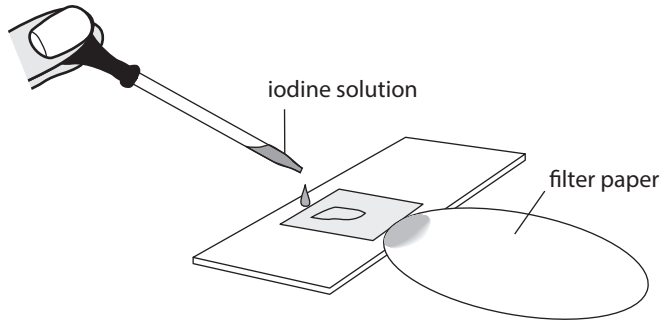

Figure 1.4: Adding iodine solution.

3 Clean the slide, and then observe the stained onion epidermis through the microscope. Describe any differences you can see in the stained cells compared with their appearance before staining.

……

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Practical Investigation 1.2: Measuring cells, using an eyepiece graticule and stage micrometer

In this activity, you will use an **eyepiece graticule** and **stage micrometer** to measure two types of plant cell. An eyepiece graticule is a little scale that fits inside the eyepiece of your microscope. When you look through the eyepiece, you can see the scale on the graticule at the same time as the object on the microscope stage. You can measure the size of the object in 'eyepiece graticule units'.

You then need to **calibrate** these graticule units. You do this using a stage micrometer. This is a slide with a scale with very small divisions on it, which you place on the microscope stage. The markings on this scale are very precisely drawn, and we know exactly how far apart they are.

KEY WORDS

eyepiece graticule: small scale that is placed in a microscope eyepiece.

stage micrometer: very small, accurately drawn scale of known dimensions, engraved on a microscope slide.

calibrate: convert the readings on a scale to a standard scale with known units.

EQUIPMENT

You will need:

• microscope, with a graticule in the eyepiece • prepared slide of section through a leaf • onion epidermis slide from Practical Investigation 1.1

Access to:

• a stage micrometer

Safety considerations

- Make sure you have read the Safety advice section at the beginning of this book and listen to any advice from your teacher before carrying out this investigation.
- There are no significant safety issues for this practical investigation.

Method

Part 1 : Measuring cells using an eyepiece graticule

1 Place a prepared slide of a transverse section through a leaf onto the stage of your microscope.

2 Check that there is an eyepiece graticule inside the eyepiece of your microscope. Look down through the eyepiece and turn it around. You should see the scale on the eyepiece graticule turning around.

3 Using the smallest objective lens, focus on the leaf section. Move the slide until you can see palisade cells. If necessary, change to a different objective lens, until you can see a group of palisade cells clearly. Move the slide until the cells are placed vertically.

4 Turn the eyepiece graticule until the scale lies horizontally across the group of cells, as shown in Figure 1.5.

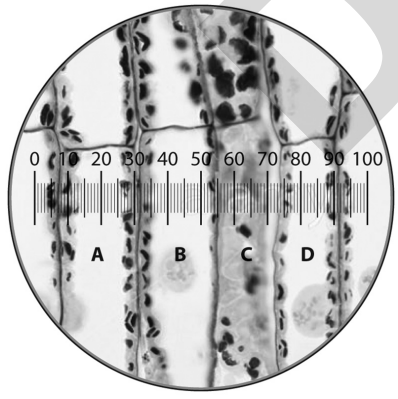

Figure 1.5: Micrograph of palisade cells seen using an eyepiece graticule.

5 Move the slide until the 0 on the graticule scale lies exactly over the cell wall of one cell. Use the scale to measure the width of three or four cells in eyepiece graticule units.

..... palisade cells measure ..... graticule units.

Part 2: Calibrating the eyepiece graticule

1 Keeping the same objective lens over the slide, remove the slide from the stage and replace it with a stage micrometer.

2 Look down the eyepiece and focus on the stage micrometer scale. Move the eyepiece and/or the slide until the eyepiece graticule scale and the stage micrometer scale lie exactly next to each other, as shown in Figure 1.6.

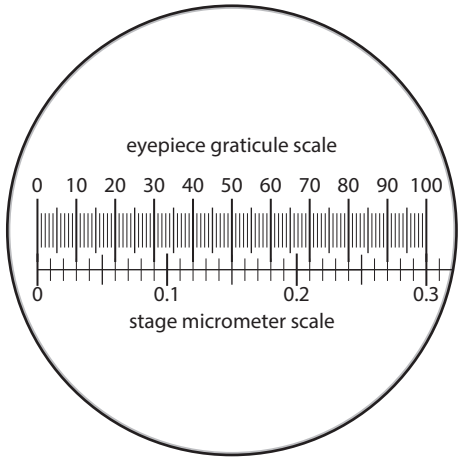

Figure 1.6: Stage micrometer seen using an eyepiece graticule.

3 Look for a good alignment of marks on the two scales, as far apart as possible. In the example in Figure 1.6, there is alignment at 0, 0 and at 80 on the eyepiece graticule scale and 0.24 on the stage micrometer scale.

Write down the alignments on your scales:

4 The large divisions on the stage micrometer scale are 0.1 mm apart. The small divisions are 0.01 mm apart.

$$0.01\,\text{mm} = 0.01 \times 10^{3}\,\text{m} = 10\,\mu\text{m}$$

Use this information to calculate how many μm are represented by one small division on the eyepiece graticule scale.

1 small eyepiece graticule unit = ... μm

TIP

If you get confused about which scale is the eyepiece graticule, and which is the stage micrometer, just turn the eyepiece. The scale that goes round is the eyepiece graticule scale.

5 Go back to the measurement you made at the end of Part 1, where you measured the width of three or four cells in eyepiece graticule units.

Convert this measurement to μm.

..... palisade cells measure ..... μm.

6 Divide this value by the number of cells, to find the mean width of one palisade cell.

Mean width of one palisade cell = ... μm

7 Remove the stage micrometer from the microscope. Place a slide of onion epidermis cells onto the stage. *Using the same objective lens* as you did for the palisade cells, measure the width of a group of cells in graticule units.

..... onion epidermis cells measure ..... eyepiece graticule units.

8 Convert this measurement to μm, and then calculate the mean width of one onion epidermis cell.

Mean width of one onion epidermis cell = ... μm

Part 3: Calculating the magnification of a drawing

The **magnification** of an image is the number of times larger it is than the actual object.

magnification = size of image ÷ size of actual object

KEY WORD

magnification: the number of times larger an image of an object is than the real size of the object.

1 Measure the width of the group of onion cells in your drawing in Practical Investigation 1.1. Record your answer in mm, and then multiply by 10^3 to convert it to μm.

Width of ..... cells in the drawing is ..... mm = ... μm.

2 Use your answer in Step 8 in Part 2 of this practical investigation to calculate the magnification of your drawing.

…….

Practical Investigation 1.3: Comparing animal cells and plant cells

In this activity, you will prepare a temporary slide of human cheek cells, and compare their size and structure with palisade cells and onion epidermis cells.

EQUIPMENT

You will need:

• microscope, with a graticule in the eyepiece • prepared slide of section through a leaf • onion epidermis slide from Practical Investigation 1.1 (or you can make a new one) • clean microscope slides and coverslips • dropper pipette • iodine in potassium iodide solution • methylene blue stain • cotton bud or similar

Access to:

• a stage micrometer

Safety considerations

- Make sure you have read the Safety advice section at the beginning of this book and listen to any advice from your teacher before carrying out this investigation.
- There is a very small risk of pathogenic organisms in the saliva and cheek cell sample on the cotton bud. Place the bud in a container of disinfectant immediately after use.

Method

Part 1: Observing, recording and measuring cheek cells

1 Gently rub a cotton bud around the inside of your cheeks, as shown in Figure 1.7.

2 Rub the cotton bud onto the centre of a clean microscope slide. Note: you will not be able to see very much on the slide, but there should be a few cheek cells present. Place the bud in a container of disinfectant immediately after use.

3 Add a small drop or two of methylene blue stain to the part of the slide where you rubbed the cotton bud. This stain is absorbed by living cells. More is taken up by the nucleus than by the cytoplasm, so it makes the nucleus look dark blue and the cytoplasm pale blue.

4 Carefully lower the coverslip onto the slide (see Figure 1.2), trying to avoid trapping air bubbles. Clean the slide and coverslip using filter paper.

Figure 1.7: Method for taking a sample of cheek cells.

5 Look at the slide through the microscope. These cells are much smaller than the plant cells you have looked at earlier, so you may need to use a larger objective lens to view them.

In the space below, make a large labelled drawing of three or four cheek cells.

6 Use the eyepiece graticule to measure the diameter of three cheek cells in graticule units. (The cells will not be arranged in a neat row as in Practical Investigation 1.2, so you will have to measure each one separately.) Calculate the mean diameter of one cheek cell, in eyepiece graticule units.

……

7 Now use the stage micrometer scale to convert the eyepiece graticule units to μm. (If you used the same objective lens as for the calculation in Practical Investigation 1.2, you can use the same conversion factor. However, if you have used a different objective lens when measuring the cheek cells, you will need to follow Steps 1–4 in Practical Investigation 1.2, Part 2 for this objective lens.)

……..

8 Use your answers to Steps 7 and 8 to calculate the mean diameter of a cheek cell in μm.

……..

9 Calculate the magnification of your drawing from Step 5. Show your working.

……..

Part 2: Comparing cheek cells, palisade cells and onion epidermis cells

You are going to construct a table to compare the size and visible structures in the three types of cell you have been observing and measuring.

1 Using a ruler and pencil, draw a table with four columns in the space that follows. Label the first column 'Feature', and the other three columns with the type of cell.

2 On a piece of rough paper, make a note of possible features that you can compare. These could include the sizes of the cells, their shapes, the relative size of the nucleus compared with the size of the entire cell, the structures visible inside the cells, and the way the cells are grouped together. Remember that a comparison includes similarities as well as differences.

3 Complete your table to compare the three types of cell. Draw a ruled line beneath each set of features, so that it is easy for someone else to understand the information you are listing.

TIP

If you have time, you could try staining cheek cells with iodine solution, or onion epidermis cells with methylene blue stain.