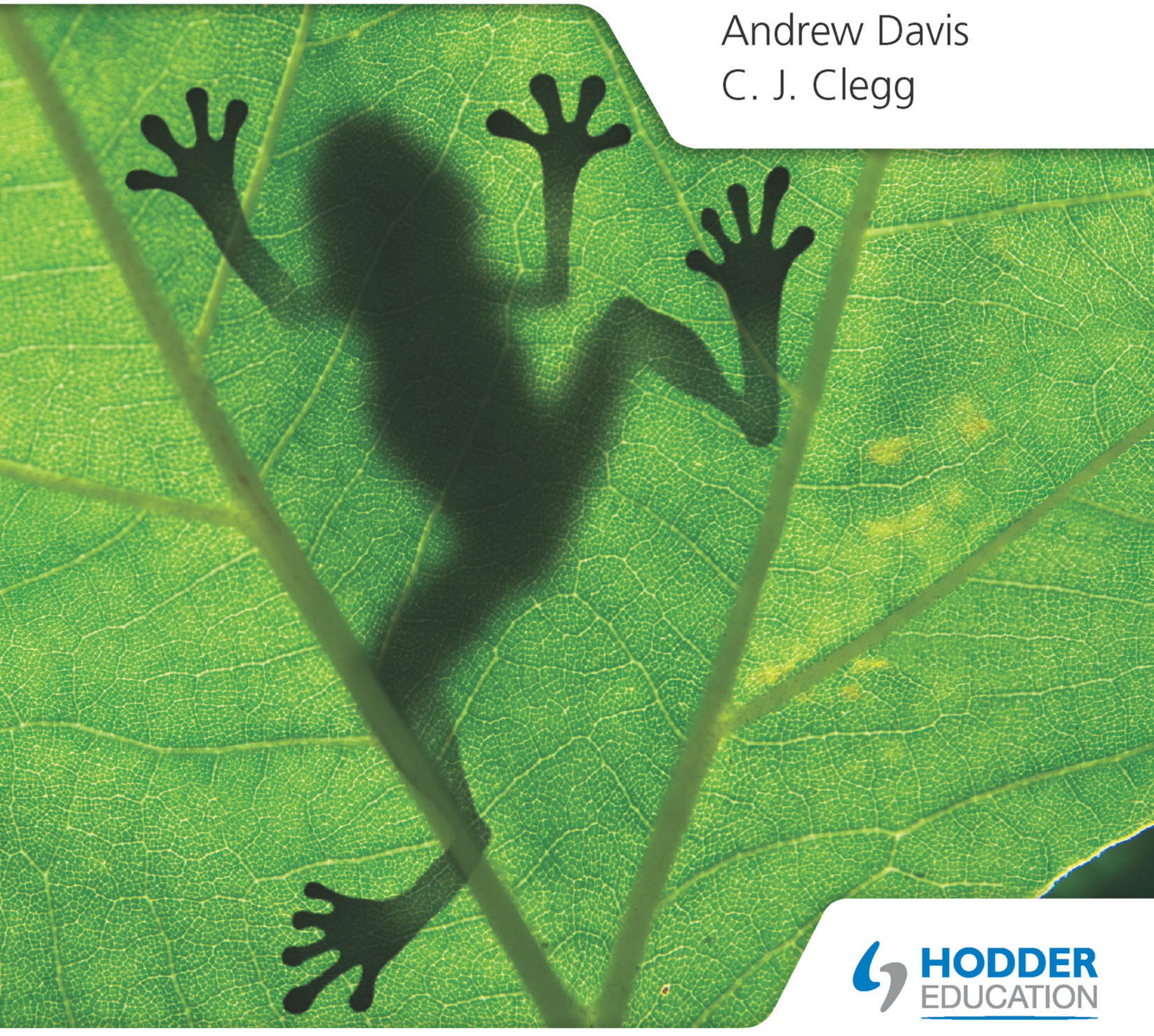
FOR THE
IB DIPLOMA

Biology

Study and Revision Guide

Andrew Davis
C. J. Clegg



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Dedication

For Jenny and Peter, with love.

Acknowledgements

My thanks to Chris Clegg for giving me free rein to construct a revision book based on his superb IB Biology course book. He has been encouraging and supportive throughout. I am grateful to Lucy Baddeley, Louise Bowen and Aaron Gruen for invaluable feedback, and to Al Summers for his guidance on memory and learning. Anna Bardong and Ros Woodward carefully checked the text and suggested adjustments which have materially improved the text, artwork, and design. My thanks also to the team at Hodder who have worked tirelessly to ensure the best possible outcome: So-Shan Au, Megan Price, and Emilie Kerton.

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ISBN: 9781471899706

Hodder Education,
An Hachette UK Company
Carmelite House
50 Victoria Embankment
London EC4Y 0DZ

www.hoddereducation.com

Impression number 5 4 3 2 1

Year 2021 2020 2019 2018 2017

Cover photo © Patryk Kosmider – Fotolia

Illustrations by Aptara, Inc.

Typeset in Aptara, Inc.

Printed in Spain

A catalogue record for this title is available from the British Library.

Contents

How to use this revision guide 5

Topic 1 Cell biology 7
- 1.1 Introduction to cells 7
- 1.2 Ultrastructure of cells 10
- 1.3 Membrane structure 15
- 1.4 Membrane transport 19
- 1.5 The origin of cells 24
- 1.6 Cell division 27

Topic 2 Molecular biology 33
- 2.1 Molecules to metabolism 33
- 2.2 Water 37
- 2.3 Carbohydrates and lipids 40
- 2.4 Proteins 47
- 2.5 Enzymes 50
- 2.6 Structure of DNA and RNA 56
- 2.7 DNA replication, transcription and translation 59
- 2.8 Cell respiration 65
- 2.9 Photosynthesis 69

Topic 3 Genetics 76
- 3.1 Genes 76
- 3.2 Chromosomes 81
- 3.3 Meiosis 85
- 3.4 Inheritance 90
- 3.5 Genetic modification and biotechnology 102

Topic 4 Ecology 114
- 4.1 Species, communities and ecosystems 114
- 4.2 Energy flow 122
- 4.3 Carbon cycle 127
- 4.4 Climate change 130

Topic 5 Evolution and biodiversity 136
- 5.1 Evidence for evolution 136
- 5.2 Natural selection 141
- 5.3 Classification of biodiversity 144
- 5.4 Cladistics 151

Topic 6 Human physiology 157

- 6.1 Digestion and absorption 157
- 6.2 The blood system 161
- 6.3 Defence against infectious disease 169
- 6.4 Gas exchange 176
- 6.5 Neurons and synapses 183
- 6.6 Hormones, homeostasis and reproduction 189

Additional higher level (AHL)

Topic 7 Nucleic acids 199

- 7.1 DNA structure and replication 199
- 7.2 Transcription and gene expression 205
- 7.3 Translation 211

Topic 8 Metabolism, cell respiration and photosynthesis 218

- 8.1 Metabolism 218
- 8.2 Cell respiration 223
- 8.3 Photosynthesis 230

Topic 9 Plant biology 237

- 9.1 Transport in the xylem of plants 237
- 9.2 Transport in the phloem of plants 245
- 9.3 Growth in plants 250
- 9.4 Reproduction in plants 256

Topic 10 Genetics and evolution 264

- 10.1 Meiosis 264
- 10.2 Inheritance 268
- 10.3 Gene pools and speciation 276

Topic 11 Animal physiology 282

- 11.1 Antibody production and vaccination 282
- 11.2 Movement 291
- 11.3 The kidney and osmoregulation 299
- 11.4 Sexual reproduction 310

How to use this revision guide

Welcome to the Biology Study and Revision Guide for the IB Diploma! This book will help you plan your revision and work through it in a methodological way. The guide follows the Biology syllabus topic by topic, with revision questions at the end of each section to help you check your understanding.

There are 11 topics in the full Biology syllabus. Topics 1–6 form the Core of the syllabus and are tested at both Standard Level (SL) and Higher Level (HL). Topics 7–11 are Additional Higher Level (AHL) and need to be covered by Higher Level candidates only.

There are four optional topics in Biology, one of which you will study as part of your course. Option topics are divided into sub-topics; some are Core and some AHL only. The Option topic is tested in Paper 3.

The syllabus is divided into several components; each component is highlighted throughout this guide:

Essential idea: These are found at the start of each numbered subsection and summarize the key concepts on which each subtopic is based.

These are the main scientific concepts that you need to know.

APPLICATIONS

This applies the 'Understandings' you have learnt and gives specific applications for this knowledge. Applications can also involve demonstrating mathematical calculations or practical skills.

These are specific skills that are developed from the understandings. For example, you will be asked to draw and annotate specific diagrams throughout the course.

NATURE OF SCIENCE

The Nature of Science (NoS) is an overarching theme in all the sciences, providing a comprehensive account of the nature of science in the twenty-first century. Each subtopic has a NoS point, giving a specific example in context illustrating some aspect of the nature of science, linked to part of the syllabus. These can be tested in exams.

Key fact

These boxes highlight important information you need to know and revise.

Expert tip

These tips give advice that will help you boost your final grade.

Common mistake

These identify typical mistakes that candidates make and explain how you can avoid them.

Key definitions

The definitions of essential key terms are provided on the page where they appear. These are words that you can be expected to define in exams. The glossary available on-line contains a list of all key definitions.

CASE STUDY

Case studies are used to illustrate specific parts of the course. Examples are given in the relevant sections of the book.

QUICK CHECK QUESTIONS

Use these questions at the end of each section to make sure you have understood a topic. They are short, knowledge-based questions that use information directly from the text.

EXAM PRACTICE

Practice exam questions are provided. Use them to consolidate your revision and practise your exam skills.

Features to help you succeed

You can keep track of your revision by ticking off each topic heading in the book. Tick each box when you have:

- revised and understood a topic
- tested yourself using the **Quick check questions**
- used the **Exam practice** questions and gone online to check your answers.

Online material can be found on the website accompanying this book: www.hoddereducation.com/IBextras

Online material includes:

- Option chapters
- exam advice
- a list of useful past paper questions
- answers to Quick check questions and exam practice questions
- glossary of key definitions
- checklists
- mindmaps.

Use this book as the cornerstone of your revision. Don't hesitate to write in it and personalize your notes. Use a highlighter to identify areas that need further work. You may find it helpful to add your own notes as you work through each topic. Good luck!

Topic 1 Cell biology

1.1 Introduction to cells

Revised

Essential idea: The evolution of multicellular organisms allowed cell specialization and cell replacement.

Cell theory and life processes

Revised

Cell theory states that:

- all living organisms are made of cells
- cells are the smallest unit of life
- existing cells have come from other cells.

All living organisms carry out the following functions: nutrition, metabolism, growth, response to stimuli, excretion, homeostasis, and reproduction.

Expert tip

You are expected to be able to name and briefly explain these functions of life: nutrition, metabolism, growth, response, excretion, homeostasis, and reproduction.

Expert tip

The presence of genetic material in a structure does not necessarily indicate life, as DNA is chemically stable and can persist in dead organic matter. Also, viruses, which are usually considered to be non-living, contain genetic material.

Cell size and cell growth

Revised

As cells increase in size, their surface area: volume ratio decreases. This limits cell size as cells with smaller surface areas compared to their size cannot absorb sufficient nutrients and remove waste at sufficient rate to support life.

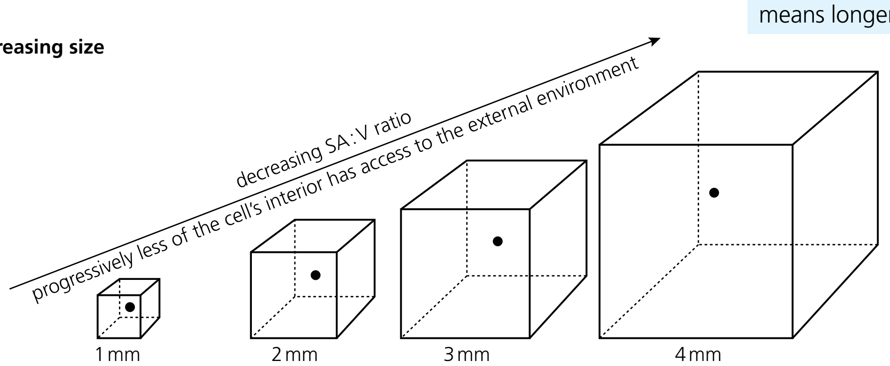
In order to form multicellular organisms, cells join together. Whereas single-celled organisms must carry out all life processes, the cells of multicellular organisms can become specialized and have specific roles. Specialized cells are organized into tissues and organs.

- A tissue is a group of similar cells that are specialized to perform a particular function, such as heart muscle tissue of a mammal.
- An organ is a collection of different tissues which performs a specialized function, such as the heart of a mammal.

Expert tip

Both surface area and volume get larger as cells increase in size, although the volume gets larger at a faster rate and so the surface area : volume ratio decreases. This limits cell size as the smaller surface area compared with cell size in larger cells means that oxygen and food cannot be transported into the cell and wastes removed at sufficient rate to maintain metabolic activities: the surface area is insufficient in size and a larger volume means longer diffusion time.

cubic cell of increasing size



dimensions/mm	1 × 1 × 1	2 × 2 × 2	3 × 3 × 3	4 × 4 × 4
surface area/mm^2	6	24	54	96
volume/mm^3	1	8	27	64
surface area : volume ratio	6 : 1 = 6/1 = 6	24 : 8 = 24/8 = 3	54 : 27 = 54/27 = 2	96 : 64 = 96/64 = 1.5

Figure 1.1 How surface area compared to size changes as objects such as cells increase in size

Multicellular organisms

Revised

Cells, tissues, organs, and organ systems have their own properties, and multicellular organisms themselves have properties that emerge from the interaction of their cellular components (see Figure 1.2).

Expert tip

The cells and tissues of the small intestine (Figure 1.2) have their own properties and functions, but when they work together they allow the whole organ to carry out the emergent properties of peristalsis, digestion, food absorption, and transport.

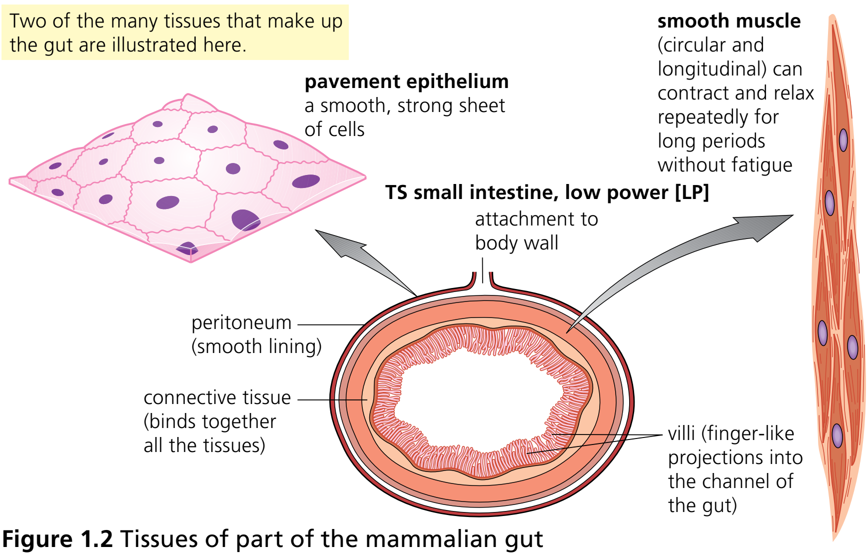


Figure 1.2 Tissues of part of the mammalian gut

Stem cells

Revised

A stem cell is a cell that has the capacity for repeated cell division while maintaining an undifferentiated state, and the subsequent capacity to differentiate into mature cell types.

The capacity of stem cells to divide and differentiate along different pathways:

- allows for embryological development
- makes stem cells suitable for therapeutic uses.

Embryological development

All cells in a multicellular organism contain the same genetic code, as they are produced from the same original parent cell. Cell differentiation takes place when some genes and not others are expressed in a cell's genome. For example, to make a muscle cell, the genes involved with creating muscle cells are switched on and other genes that are not needed are not activated.

Embryonic stem (ES) cells	Adult stem cells
these are undifferentiated cells capable of continual cell division and of developing into all the cell types of an adult organism	undifferentiated cells capable of cell divisions, these give rise to a limited range of cells within a table, for example blood stem cells give rise to red and white blood cells and platelets only
these make up the bulk of the embryo as it commences development	occurring in the growing and adult body, within most organs, they replace dead or damaged cells, such as in bone marrow, brain and liver

Table 1.1 Differences between embryonic and adult stem cells

If stem cells can be isolated in large numbers and maintained in viable cell cultures, they have uses in medical therapies to replace or repair damaged organs.

Key facts

- Stem cells are undifferentiated cells present in all multicellular organisms.
- By division they are capable of giving rise to more cells of the same type.
- From these, differentiated cells are then formed.

Expert tip

Stem cells have the ability to divide repeatedly.

Expert tip

At later stages of embryological development most cells lose the ability to differentiate as they develop into the tissues and organs that make up the organism, such as blood, nerves, liver, brain, and many others. However, a very few cells within these tissues do retain many of the properties of embryonic stem cells, and these are called adult stem cells.

APPLICATIONS

Stem cells can be used to treat genetic diseases

Revised

Disease	The effects	Source of stem cells	Treatment
Stargardt's macular dystrophy	Breakdown of light-sensitive cells in the retina in area where focusing occurs. A recessive inherited condition due to mutation of gene. Mutation causes an active transport protein on photoreceptor cells to malfunction, leading to degeneration of these cells and loss of central vision.	Embryonic stem cells	Stem cells are treated so that they divide and differentiate to become retinal cells. These cells are injected into the retina. The retinal cells attach and become functional. Because there are more functional retinal cells, central vision improves.
Leukemia	Cancer of the blood or bone marrow, resulting in abnormally high levels of diseased white blood cells that do not function properly.	Hematopoietic stem cells (HSCs) harvested from bone marrow or umbilical cord blood	Chemotherapy and radiotherapy are used to destroy the diseased white blood cells. HSCs are transplanted into the bone marrow, where they differentiate to form new healthy white blood cells.

Table 1.2 Examples of diseases that may be treated by stem cell technology

Expert tip

You need to be able to explain the use of stem cells in the treatment of Stargardt's disease and one other named condition.

APPLICATIONS

Questioning cell theory

Revised

NATURE OF SCIENCE

Looking for trends and discrepancies – although most organisms conform to cell theory, there are exceptions.

In addition to the familiar unicellular and multicellular organization of living things, there are a few multinucleate organs and organisms that are not divided into separate cells. This type of organization is called acellular. Examples include:

- the pin mould *Rhizopus*, in which the body consists of fine, thread-like structures called hyphae
- the striped muscle fibres that make up the skeletal muscles of mammals provide an example of an acellular organ
- the internodal cells of the giant alga *Nitella* are also multinucleate.

Measuring microscopic objects (Practical 1)

Revised

Expert tip

You need to know how to use a light microscope to investigate the structure of cells and tissues, and how to draw cells and their internal structure as seen with a light microscope (Practical 1).

The size of cells, or components of cells, can be calculated given the amount of magnification and a scale drawing of the object. Simple equations can be used to calculate the magnification or actual size of the specimen.

Expert tip

You need to know how to calculate the magnification of drawings and the actual size of structures and ultrastructures shown in drawings or micrographs (Practical 1).

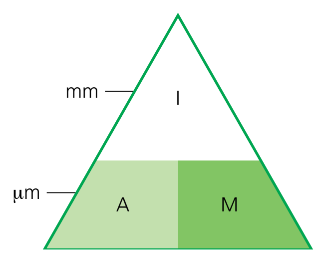


Figure 1.3 Memory diagram showing how to calculate the magnification, actual size, or image size of an object. Remember the equation as AIM or I AM, and remember to convert units so that they are the same for both I and A

- **I** = size of image (drawing of an object on paper)
- **A** = actual size of the object being measured
- **M** = magnification (the size of an object compared to its actual size, i.e. the number of times larger an image is than the specimen)

So, M = I/A; A = I/M and I = A × M.

For example, for a particular plant cell of 150 μm diameter, photographed with a microscope and then enlarged photographically, the magnification in a print showing the cell at 15 cm diameter (150 000 μm) is: 150 000/150 = 1000×.

Expert tip

You need to be able to understand the functions of life in *Paramecium* and one named photosynthetic unicellular organism. Make sure you choose examples of typical unicellular photosynthetic organisms such as *Chlorella* or *Scenedesmus*, rather than organisms that can feed both heterotrophically and photosynthetically (i.e. *Euglena*).

QUICK CHECK QUESTIONS

1. What are the seven life processes?
2. Outline how the functions of life are carried out by *Paramecium* and one named photosynthetic unicellular organism.
3. Research involving stem cells is growing in importance and raises ethical issues.

   Outline ethical issues concerning the therapeutic use of stem cells. Evaluate the use of stem cells from specially created embryos, from the umbilical cord blood of a new-born baby, and from an adult's own tissues.

Common mistake

If you do not convert values to the same unit of measurement your results will be incorrect by a factor of 100, 1000 or even 1 000 000. Make sure you convert values to the same unit before carrying out the calculation:

- Convert mm into μm by multiplying by 1000.
- Convert μm into mm by dividing by 1000.

Expert tip

Scale bars can be used as a way of indicating actual sizes in drawings and micrographs, and can be used to calculate magnification. Magnification is calculated by dividing the actual length of the scale bar by the length indicated on the scale bar.

1.2 Ultrastructure of cells

Revised

Essential idea: Eukaryotes have a much more complex cell structure than prokaryotes.

Prokaryotic and eukaryotic organization

Revised

Eukaryotes have a compartmentalized cell structure. This means that the internal cell structure contains organelles, such as mitochondria and endoplasmic reticulum. Each organelle has a different function (see Table 1.3), carrying out a specific biological process.

Expert tip

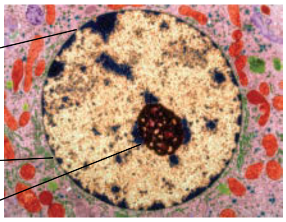
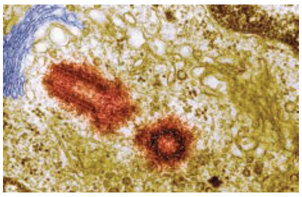
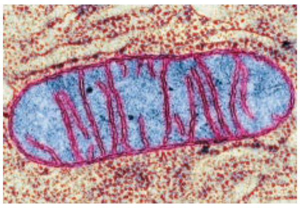
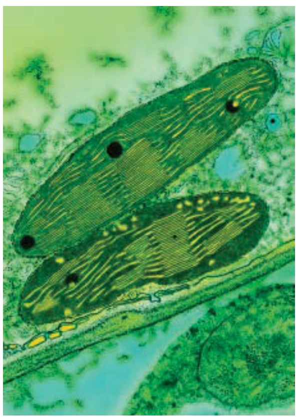
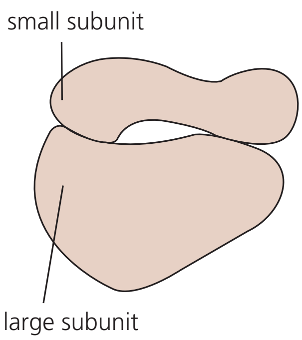
The purpose of compartmentalization is:

- To group together chemicals that need to produce specific metabolic reactions (e.g. the reactants of respiration are found within the mitochondria). The relatively large size of these cells means that without such compartmentalization, reactants would be less likely to meet up and metabolize.
- To establish physical boundaries for chemical reactions and thus enable the cell to carry out different metabolic activities at the same time.
- To establish specific locations for processes within the cell.

Key fact

Eukaryotic cells: These types of cells contain a large, obvious nucleus. They include cells of plants, animals, fungi, and protoctista. The surrounding cytoplasm contains many different membranous organelles.

Prokaryotic cells: These cells contain no true nucleus and their cytoplasm does not have the organelles of eukaryotes. They are bacterial cells.

Organelle	Image	Structure	Function
Nucleus		Largest organelle in the eukaryotic cell, typically 10–20 μm in diameter. It is surrounded by a double-layered membrane, the nuclear envelope. This contains many pores. These pores are tiny, about 100 nm in diameter. The nucleus contains the chromosomes. These thread-like structures are visible at the time the nucleus divides. At other times, the chromosomes appear as a diffuse network called chromatin. One or more nucleoli are present in the nucleus, too.	The everyday role of the nucleus is cell management, and its behaviour when the cell divides. The nucleoli are the site of ribosome manufacture. DNA is transcribed into mRNA which travels through the pores in the nuclear membrane into the cytosol. The mRNA molecules are transcribed at ribosomes.
Centriole		A tiny organelle consisting of nine paired microtubules, arranged in a short, hollow cylinder. In animal cells, two centrioles occur at right angles, just outside the nucleus, forming the centrosome.	Before an animal cell divides, the centrioles replicate, and their role is to grow the spindle fibres – the spindle is the structure responsible for movement of chromosomes during nuclear division.
Mitochondria		Appear mostly as rod-shaped or cylindrical organelles in electron micrographs. They are relatively large organelles, typically 3–5 μm long. The mitochondrion also has a double membrane. The outer membrane is a smooth boundary, the inner membrane is folded to form cristae. The interior of the mitochondrion contains an aqueous solution of metabolites and enzymes called the matrix.	The mitochondrion is the site of the aerobic stages of respiration. The cristae increase surface area for production of ATP. The matrix is the site of chemical reactions of respiration. Mitochondria are found in all cells and are usually present in very large numbers. Metabolically very active cells contain thousands of them in their cytoplasm – for example, muscle fibres and hormone-secreting cells.
Chloroplasts		Large organelles, typically biconvex in shape, about 4–5 μm long. They occur in green plants, where most occur in the mesophyll cells of leaves. Each chloroplast has a double membrane. The outer layer of the membrane is a continuous boundary, but the inner layer is folded into a branching system of membranes called thylakoids. Thylakoids are arranged in flattened circular piles called grana (singular granum). It is here that the chlorophylls and other pigments are located. The thylakoids are in an aqueous matrix, usually containing small starch grains. This part of the chloroplast is called the stroma.	Photosynthesis is the process that occurs in chloroplasts. Thylakoids/grana are the site of the light-dependent reactions of photosynthesis. Light is trapped in the pigments within the membrane. The stroma is the site of the light-independent reactions of photosynthesis.
Ribosomes		Tiny structures, approximately 25 nm in diameter, built of two subunits. They do not have membranes as part of their structures. They consist of protein and a nucleic acid known as RNA. Ribosomes are found free in the cytoplasm and bound to rough endoplasmic reticulum. The sizes of ribosomes are recorded in Svedberg units (S). Ribosomes of mitochondria and chloroplasts are slightly smaller (70S) than those in the rest of the cell (80S).	Ribosomes are the sites where proteins are made in cells. RNA is translated into protein. Many different types of cell contain vast numbers of ribosomes. Ribosomes on the endoplasmic reticulum are used to produce proteins for export. Ribosomes found free-floating in the cytoplasm are used to synthesize proteins used within the cell.

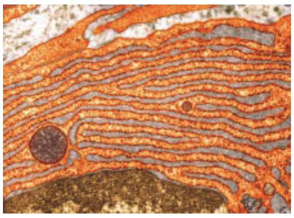
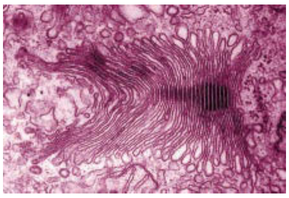
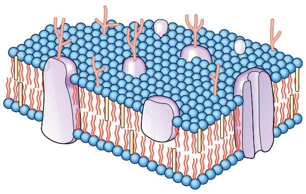
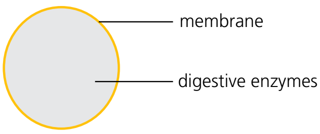
Rough endoplasmic reticulum (RER)		Has ribosomes attached. At its margin, vesicles are formed from swellings. A vesicle is a small, spherical organelle bounded by a single membrane, which becomes pinched off as it separates. Digestive enzymes are discharged in this way.	RER is the site of synthesis of proteins that are 'packaged' in vesicles and then typically discharged from the cell. Vesicles are used to store and transport substances around the cell.
Smooth endoplasmic reticulum (SER)		Endoplasmic reticulum without ribosomes attached.	SER is the site of synthesis of substances needed by cells. For example, SER is important in the manufacture of lipids. In the cytoplasm of voluntary muscle fibres, a special form of SER is the site of storage of calcium ions which have an important role in the contraction of muscle fibres.
Golgi apparatus		Consists of a stack-like collection of flattened membranous sacs (cisternae). One side of the stack of membranes is formed by the fusion of membranes of vesicles from SER. At the opposite side of the stack, vesicles are formed from swellings at the margins that, again, become pinched off.	The Golgi apparatus occurs in all cells, but it is especially prominent in metabolically active cells – for example, secretory cells. It is the site of synthesis of specific biochemicals, such as hormones and enzymes. These are then packaged into vesicles. In animal cells these vesicles may form lysosomes. Those in plant cells may contain polysaccharides for cell wall formation.
Cell membrane		The plasma membrane is an extremely thin structure 7 nm thick. It consists of a phospholipid bilayer in which proteins are embedded.	The membrane has a number of roles. Firstly, it surrounds and retains the fluid cytosol. The cell surface membrane also forms the barrier across which all substances entering and leaving the cell must pass. In addition, it is where the cell is identified by surrounding cells.
Lysosome		Lysosomes are tiny spherical vesicles bound by a single membrane. They are produced in the Golgi apparatus or by the rough ER.	They contain a concentrated mixture of 'digestive' enzymes. These are known as hydrolytic enzymes. Lysosomes are involved in the breakdown of the contents of 'food' vacuoles. For example, harmful bacteria that invade the body are taken up into tiny vacuoles (they are engulfed) by special white cells called macrophages.

Table 1.3 Cell organelles – structure and function

Expert tip

Vesicles form from RER and carry proteins to the Golgi apparatus. Once proteins have been processed, vesicles bud from the Golgi apparatus and travel to the membrane. Vesicles fuse with the plasma membrane to transport materials outside the cell.

Common mistake

Do not confuse the terms 'nucleus' and 'nucleolus'.

Prokaryotes have a simple cell structure without compartmentalization. This is because:

- The cells are very small, ca. 1 μm in length. This means that chemical reactions in cells can take place without reactants having to be enclosed within organelles.
- The total sum of all the chemicals within the cytoplasm can carry out all the functions of life.
- Many organelles, such as mitochondria and chloroplasts, are the same size as prokaryotic cells.

There are many differences between eukaryotic and prokaryotic cells:

Common mistake

Cell walls are not only found in plant cells – prokaryote cell walls exist as well.

Common mistake

Do not confuse 70S and 80S ribosomes: 70S ribosomes are found in prokaryotic cells and 80S in eukaryotic cells.

Prokaryotic cells	Eukaryotic cells
much smaller (<5 micrometres)	larger than 10 micrometres (up to 100 micrometres, although egg cells can be much larger)
DNA is circular	DNA is linear
naked DNA	DNA associated with histone proteins
no membrane-bound organelles	membrane-bound organelles, such as mitochondria
DNA not in nucleus but free-floating in cytoplasm	DNA enclosed in nuclear envelope
70S ribosomes	80S ribosomes
cell wall made of peptidoglycan (murein)	cell wall present in plants (made of cellulose) and fungi (made of chitin) but not animals

Table 1.4 Comparing prokaryotic and eukaryotic cells

Some prokaryotic cells have a flagellum for motility (Figure 1.4).

Both eukaryotic and prokaryotic cells have a plasma membrane, cytoplasm, and ribosomes.

Expert tip

If asked to compare or distinguish between the structure of eukaryotic and prokaryotic cells, a table can be used so that a point by point comparison can be made. Make sure that valid, precise comparisons of the features are made, for example when referring to differences in ribosomes or cell sizes, a quantified answer is required such as '70S ribosomes' (prokaryotes) paired with '80S ribosomes' (eukaryotes), and 'smaller than 5 micrometres' (prokaryotes) paired with 'larger in size, up to 100 micrometres' (eukaryotes). Note, the command term 'compare' includes both similarities and differences.

Drawing prokaryotic and eukaryotic cells

Revised

You need to be able to draw a labelled diagram of the ultrastructure of prokaryotic cells based on electron micrographs.

Drawings of prokaryotic cells should show the cell wall, pili, and flagella, and plasma membrane enclosing cytoplasm that contains 70S ribosomes and a nucleoid with naked DNA.

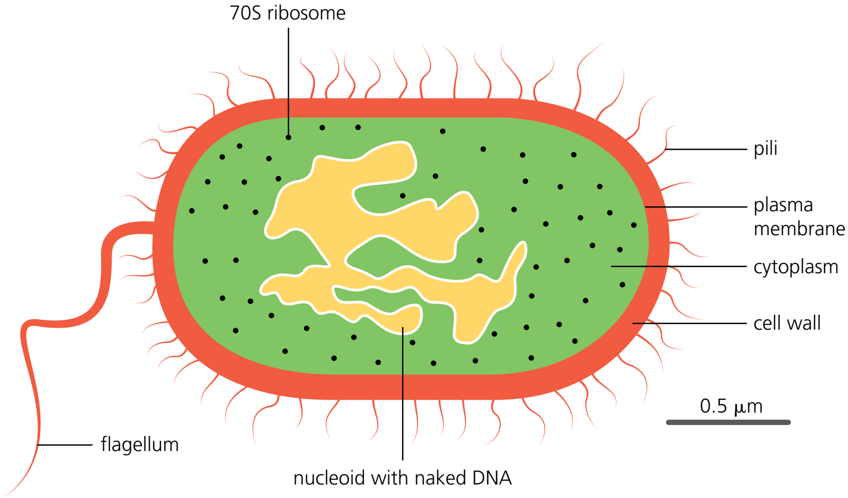


Figure 1.4 Drawing of a prokaryotic cell

You need to be able to draw a labelled diagram of the ultrastructure of eukaryotic cells based on electron micrographs.

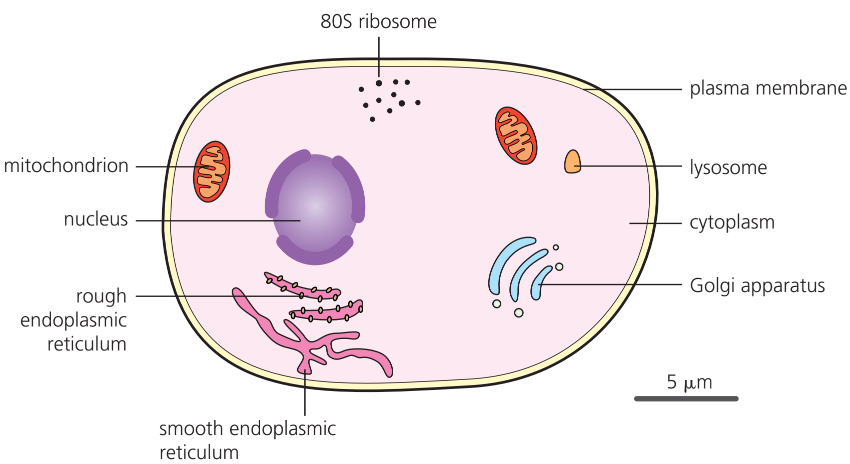


Figure 1.5 Drawing of a eukaryotic cell

Common mistake

Pili and flagella are sometimes drawn by candidates as floating around outside the cell, not touching the cell wall. Make sure these structures are drawn so they attach to the cell wall. Flagella are often drawn too short in relation to the overall length of the cell. The diameter of ribosomes should not be too large in relation to the rest of the cell structures.

Common mistake

The term 'naked DNA' refers to DNA without histone proteins, and does not mean DNA that is not surrounded by a nuclear membrane.

Expert tip

Some eukaryotic cells have a cell wall, such as those found in the plant and fungi kingdoms. The cell wall is an extracellular structure (i.e. is found outside the plasma membrane) and should not be confused with the intracellular organelles.

Expert tip

- Flagella are used in cell motility – they rotate in a clockwise or counter-clockwise direction, in a motion similar to that of a propeller. The term 'corkscrew' is a standard way of describing the appearance of a flagellum.
- Pili are made of protein and are used to attach a bacterial cell to specific surfaces or to other cells.
- Nucleoid refers to a lighter area of the prokaryotic cytoplasm that contains the DNA of the cell.

Common mistake

Flagella are not only found in prokaryotic cells – some protoctistans have them also.

Expert tip

Drawings of eukaryotic cells should show a plasma membrane enclosing cytoplasm that contains 80S ribosomes and a nucleus; mitochondria and other membrane-bound organelles should be present in the cytoplasm. Some eukaryotic cells have a cell wall (shown in Figure 1.5, on the outside of the plasma membrane).

The impact of electron microscopy on cell biology

Revised

NATURE OF SCIENCE

Developments in scientific research follow improvements in apparatus – the invention of electron microscopes led to greater understanding of cell structure.

Electron microscopes have a much higher **resolution** than light microscopes.

The electron microscope uses electrons to make a magnified image in much the same way as the optical microscope uses light. However, because an electron beam has a much shorter wavelength, its resolving power is much greater.

Most organelles cannot be viewed (i.e. resolved) by light microscopy and none is large enough for internal details to be seen. It is by means of the electron microscope that we have learnt about the fine details of cell structure. This is why the electron microscope is used to resolve the fine detail of the contents of cells, the organelles, and cell membranes, collectively known as cell ultrastructure.

Key definition

Resolution – the ability to tell that two objects that are very close together are distinct objects rather than just one. The amount of detail that can be seen.

Expert tip

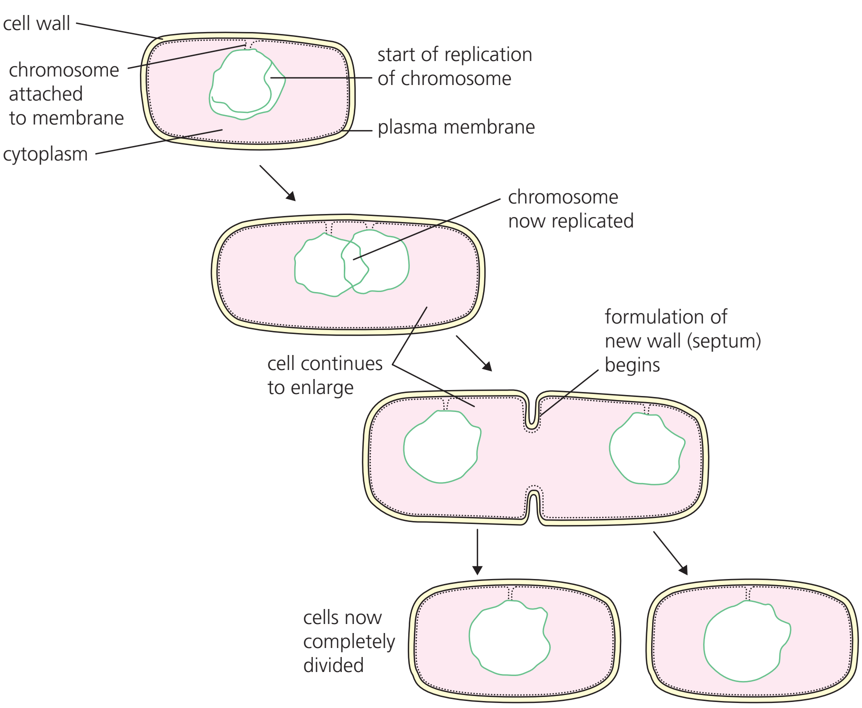
Resolution and magnification are two different factors in a microscope. Magnification is how many more times larger an object appears, and resolution means the amount of detail that can be seen. There is no point magnifying an object if the resolution is lost.

APPLICATIONS

Binary fission

Revised

Prokaryotes grow to full size and then divide in two by a process called binary fission.



Escherichia coli (X 14 500)

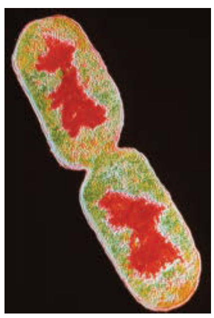


Figure 1.6 The steps of the cell cycle and binary fission

Common mistake

Bacteria do not divide by mitosis – this process occurs only in eukaryotes.

QUICK CHECK QUESTIONS

1. Outline the structure and function of organelles within the following two types of cell, and explain how specific organelles adapt them to their specific function:
   a. exocrine gland cells of the pancreas
   b. palisade mesophyll cells of the leaf.
2. Interpret the following electron micrographs to identify the organelles present. Deduce the function of these specialized cells.

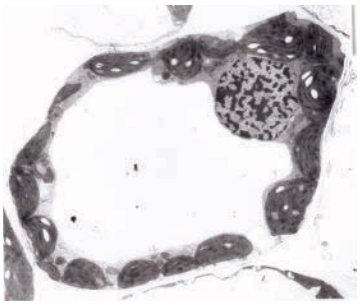


Figure 1.7 Electron micrograph of cell A, ×5 200

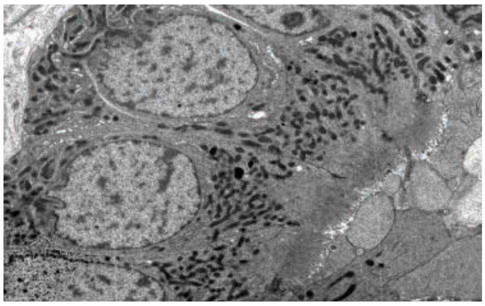


Figure 1.8 Electron micrograph of cell B, ×4000

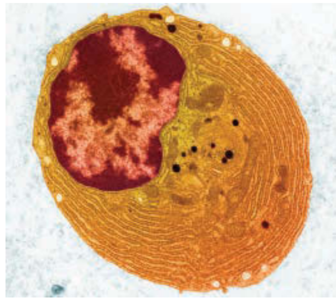


Figure 1.9 Electron micrograph of cell C, ×23 300

1.3 Membrane structure

Revised

Essential idea: The structure of biological membranes makes them fluid and dynamic.

The structure of the plasma membrane

Revised

A plasma membrane is a structure common to both eukaryotic and prokaryotic cells. The plasma membrane:

- maintains the integrity of the cell (it holds the cell's contents together)
- is a barrier across which all substances entering and leaving the cell pass.

Key fact

Cell membranes have four components:

- phospholipid
- protein
- carbohydrate
- cholesterol.

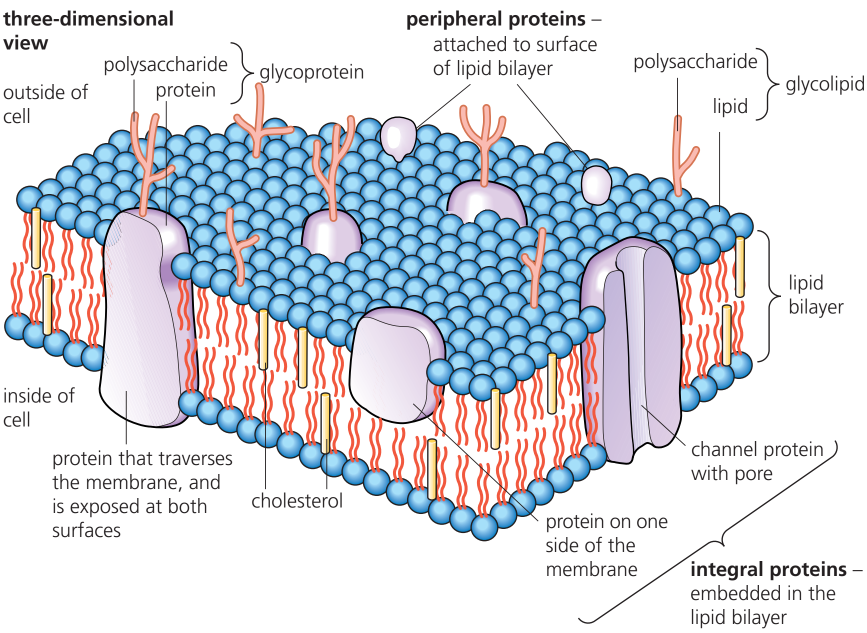


Figure 1.10 The plasma membrane

The membrane is said to have a 'fluid mosaic' structure because:

- the phospholipids and proteins, when viewed from above the membrane, form a mosaic structure (i.e. a sea of phospholipids with proteins interspersed between them)
- the components of the membrane, i.e. the proteins and phospholipids, are weakly bonded to one another and so can move between each other, i.e. the structure is 'fluid'.

The phospholipid component

The lipid of membranes is phospholipid. A phospholipid has a 'head' composed of a glycerol group to which is attached one ionized phosphate group. This latter part of the molecule has **hydrophilic** properties. The remainder of the phospholipid consists of two long, fatty acid residues consisting of hydrocarbon chains. These 'tails' have **hydrophobic** properties. Phospholipids form **bilayers** in water due to the **amphipathic** properties of phospholipid molecules.

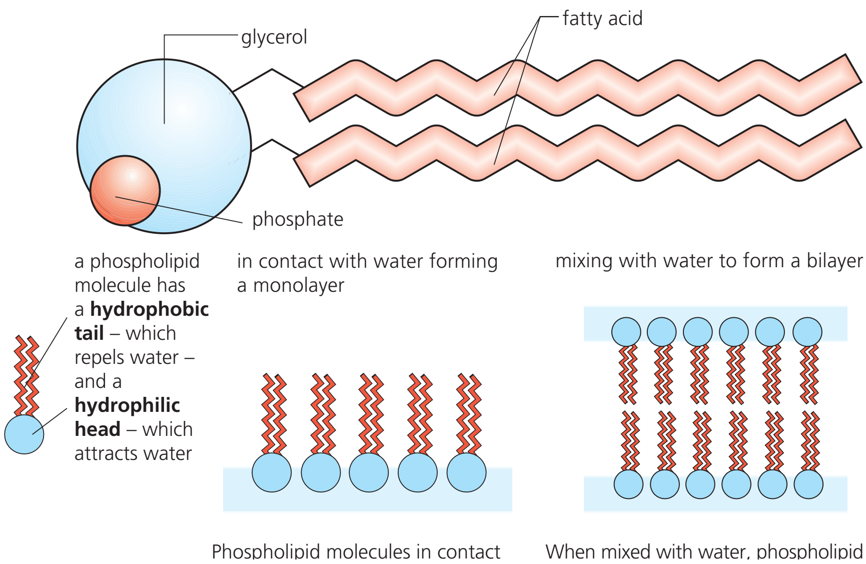


Figure 1.11 The amphipathic nature of phospholipids

In the lipid bilayer, attractions between the hydrophobic hydrocarbon tails on the inside and between the hydrophilic glycerol/phosphate heads and the surrounding water on the outside make a stable and strong barrier.

The protein component

Membrane proteins are diverse in terms of structure, position in the membrane, and function.

The proteins of plasma membranes are globular proteins (see page 51). The proteins can be divided into two groups:

- integral proteins: proteins partially or fully buried in the lipid bilayer
- peripheral proteins: proteins superficially attached on either surface of the lipid bilayer (see Figure 1.10).

Some of these membrane proteins may act as channels for transport of metabolites, or be enzymes and carriers, and some may be receptors or antigens.

The carbohydrate component

The carbohydrate molecules of the membrane are relatively short-chain polysaccharides. They occur only on the outer surface of the plasma membrane. Some of these molecules are attached to the proteins (glycoproteins) and some to

Expert tip

You need to be able to draw a labelled diagram of the fluid mosaic model of the plasma membrane. Drawings of the fluid mosaic model of membrane structure can be two dimensional rather than three dimensional. Individual phospholipid molecules should be shown using the symbol of a circle with two parallel lines attached. A range of membrane proteins should be shown including glycoproteins.

Common mistake

When asked to draw a plasma membrane, do not misinterpret the question and draw a diagram of a whole eukaryotic cell with a plasma membrane around its margin. Draw a section through a membrane as shown in Figure 1.10. On diagrams showing structure the commonest errors are to place particular types of proteins or cholesterol in the wrong position – make sure you position these features correctly:

- Do not place cholesterol molecules next to the phosphate heads; they should be embedded in the bilayer and appear smaller than the hydrophobic tails.
- Peripheral proteins should be positioned on the membrane surface, not fully embedded and flush with the surface.
- Channel proteins, by definition, require a channel or pore.

Key definitions

Hydrophilic – attracted to water (i.e. 'water-loving'); hydrogen bonds readily form between the phosphate head and water molecules.

Hydrophobic – repelled by water (i.e. 'water-hating').

Bilayer – two rows of phospholipids, with the fatty acids pointing towards each other and the phosphates on the outside.

Amphipathic – a molecule that is partly hydrophilic and partly hydrophobic.

the lipids (glycolipids). Collectively, they are known as the glycocalyx. Its various functions include:

- cell–cell recognition
- acting as receptor sites for chemical signals
- acting as the binding of cells into tissues.

Common mistake

Do not confuse membrane fluidity with membrane permeability.

APPLICATIONS

The role of cholesterol

Revised

Cholesterol has the effect of disturbing the close-packing of the phospholipids, thereby increasing the flexibility of the membrane. Cholesterol in mammalian membranes reduces membrane fluidity and permeability to some solutes. Cholesterol is a steroid, with a hydroxyl (OH) group and hydrocarbon chain on either side of the carbon ring structure (Figure 1.12).

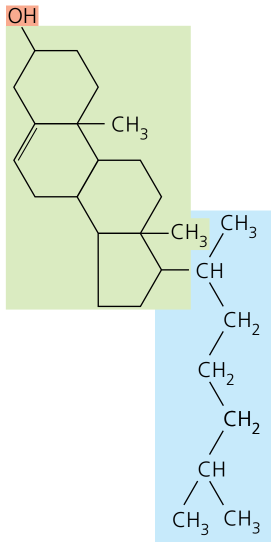


Figure 1.12 Molecular structure of cholesterol

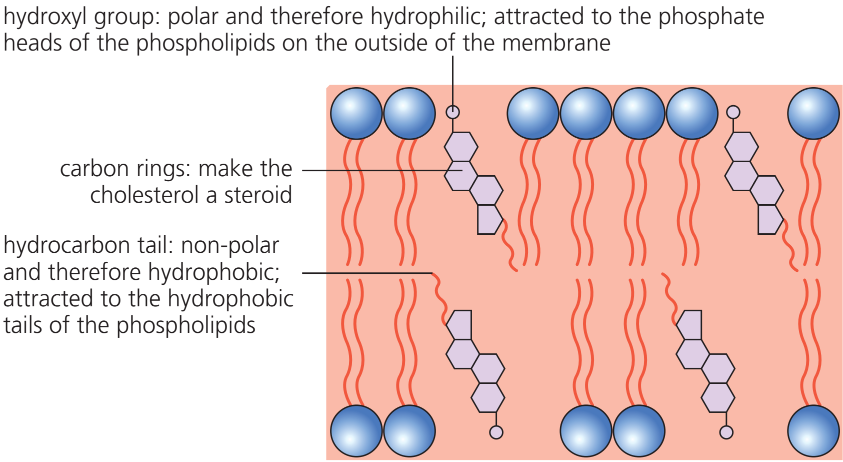


Figure 1.13 The interaction between cholesterol and the phospholipid bilayer

The quantity of cholesterol present varies with the ambient temperatures that cells experience.

- In low temperatures, the cholesterol maintains the fluidity of the membrane by forcing apart the phospholipids and maintaining distance between them, thereby sustaining movement between the components of the membrane.
- In higher temperatures, bonds between the cholesterol and phospholipids maintain the structural integrity of the membrane and prevent them from becoming too fluid, and potentially disintegrating under high temperatures.

Analysing evidence: Contrasting models of membrane structure

Revised

NATURE OF SCIENCE

Using models as representations of the real world – there are alternative models of membrane structure.

Davson–Danielli model

In 1935, chemical analysis of cell membranes indicated the presence of large amounts of protein, along with phospholipid molecules.

Scientists Hugh Davson and James Danielli suggested that the phospholipid bilayer was located between two layers of proteins (i.e. is sandwiched between them). Pores were thought to be present in places in the membrane.

The Davson–Danielli model was accepted for many years.

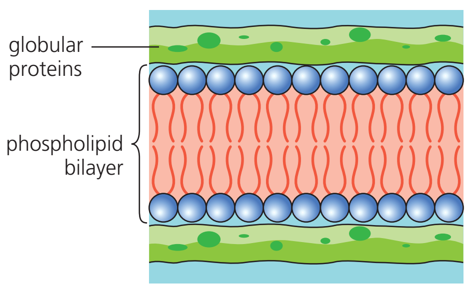


Figure 1.14 The Davson–Danielli model

Evidence from electron microscopy led to the proposal of the Davson–Danielli model:

- electron micrographs appeared to show a three-layered structure (Figure 1.15)
- the three layers were taken to be the phospholipid bilayer (the lighter central section) surrounded by two layers of protein (dark layers either side of the lighter area).

There were several problems with the Davson–Danielli model:

- The amount and type of membrane proteins vary a great deal among different cells. Improved biochemical tests showed that they were globular and varied in size, and so unlikely to form structural protein layers.
- Membrane proteins are mainly hydrophobic and would therefore not have been found where the model positioned them, i.e. facing the aqueous cytoplasm or extracellular environment (they would have to be mainly hydrophilic to do that). The hydrophobic part of the protein would be attracted to the fatty acid tails of the phospholipids.

The model was ultimately proved to be incorrect (i.e. it was falsified):

- Attempts to extract the protein from plasma membranes indicated that, while some occurred on the external surfaces and were easily extracted, others were buried within or across the lipid bilayers; these proteins were more difficult to extract.
- **Freeze-etching** studies of plasma membranes show that when a membrane is, by chance, split open along its mid-line, some proteins are seen to occur buried within or across the lipid bilayers (Figure 1.16), confirming the existence of transmembrane/integral proteins.
- Experiments in which specific components of membranes were 'tagged' by reaction with marker chemicals (typically fluorescent dyes) showed component molecules to be continually on the move within membranes. If cells tagged with a red marker were fused with cells tagged with a green marker, the red and green markers became mixed within the membrane of the fused cell. This evidence shows that a plasma membrane could be described as strong but 'fluid', and that the proteins are not fixed in a peripheral layer but are free to move within the membrane.

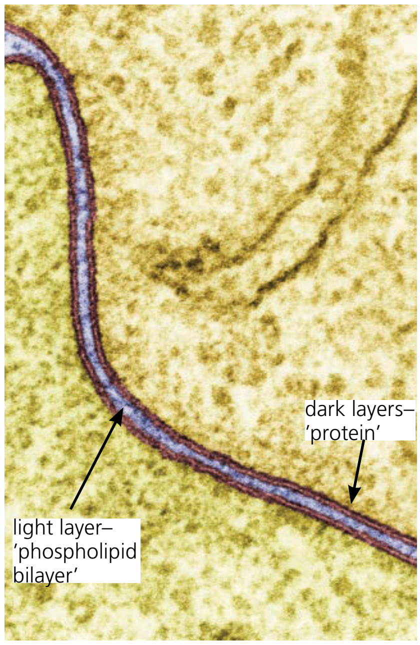
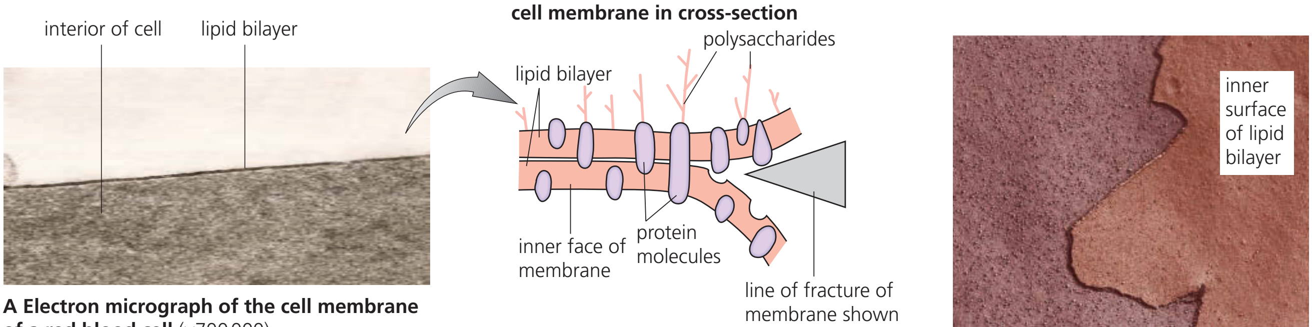


Figure 1.15 Electron micrograph that seems to support the Davson–Danielli model

> **Key definition**
>
> **Freeze-etching** – cells are rapidly frozen and then fractured.



A Electron micrograph of the cell membrane of a red blood cell (×700 000)

B Electron micrograph of the cell membrane (freeze-etched)

Figure 1.16 Plasma membrane structure; evidence from the electron microscope (A = electron micrograph of plasma membrane; B = by freeze-etching)

> **QUICK CHECK QUESTIONS**
>
> 1 Explain why the cell membrane is described as having a 'fluid mosaic' structure.
>
> 2 State the difference between a lipid bilayer and the double membrane of many organelles.
>
> 3 Outline the evidence that was used to falsify the Davson–Danielli model of membrane structure.

NATURE OF SCIENCE

Falsification of theories with one theory being superseded by another – evidence falsified the Davson–Danielli model.

Singer–Nicolson model

Analysis of the falsification of the Davson–Danielli model led to the Singer–Nicolson model. This fluid mosaic model (page 16), proposed by Jonathan Singer and Garth Nicholson in 1972, is the model accepted today.

1.4 Membrane transport

Revised

Essential idea: Membranes control the composition of cells by active and **passive transport**.

Passive and active transport

Revised

Particles move across membranes by simple **diffusion**, **facilitated diffusion**, **osmosis**, and **active transport**. The fluidity of membranes also allows materials to be taken into cells by **endocytosis** or released by **exocytosis**. Vesicles move materials within cells.

- Particles that move through the phospholipid bilayer are small or non-polar (non-charged) – this includes the processes of diffusion and osmosis.
- Polar (charged) or larger molecules must move through the membrane via carrier or channel proteins – this includes the processes of facilitated diffusion and active transport (see page 22).

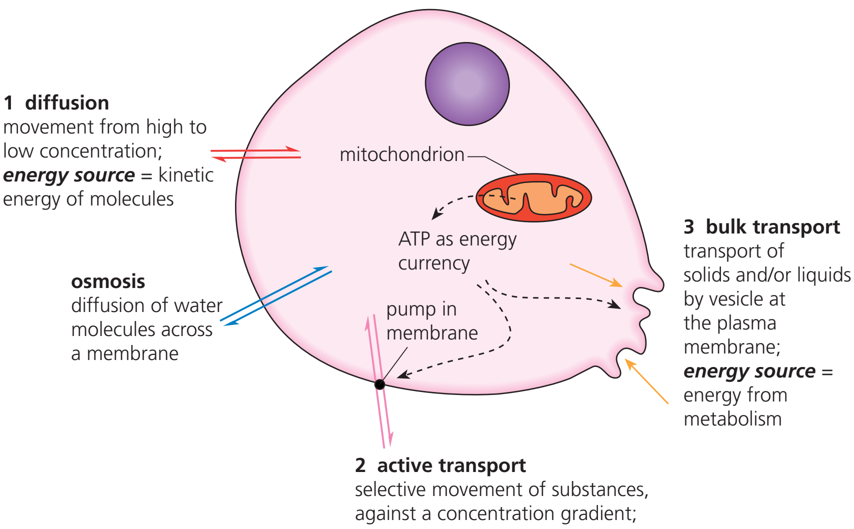


Figure 1.17 Mechanisms of movement across membranes

Method	Uses ATP	Uses proteins	Specific	Controllable
simple diffusion	✗	✗	✗	✗
osmosis	✗	✗	✓ (water only)	✗
facilitated diffusion	x	✓	✓	✓
active transport	✓	✓	✓	✓
vesicles	✓	✗	✓	✓

Table 1.5 Summary of membrane transport

Endocytosis and exocytosis use vesicles to move materials out from or into the cell. Vesicle formation relies on the fluidity in membranes, which is due to weak bonding between the phospholipid tails and the presence of cholesterol (page 16). Bends/kinks in the phospholipid tails prevent close packing, thereby contributing to flexibility. Without this flexibility, the membrane would be unable to pinch off from or fuse with the plasma membrane.

Common mistake

Many candidates state that diffusion happens without the need for energy instead of without the need for ATP. Substances moving by diffusion travel using thermal/kinetic energy. You need to say that diffusion happens *without the need for ATP.*

Key definitions

Diffusion – movement of particles from higher to lower concentration through the phospholipid bilayer. Movement is passive (i.e. no direct energy needed).

Facilitated diffusion – movement of particles from higher to lower concentration through integral proteins (carrier or channel proteins). Movement is passive.

Osmosis – the diffusion of water molecules across a partially permeable membrane, from lower to higher solute concentration (Figure 1.19). Movement is passive**.**

Active transport – movement of particles from lower to higher concentration, using energy from ATP that has been created during respiration. Movement is through carrier proteins.

Passive transport – no direct energy needed.

Endocytosis – formation of vesicles as the plasma membrane pinches inwardly, taking material into the cell.

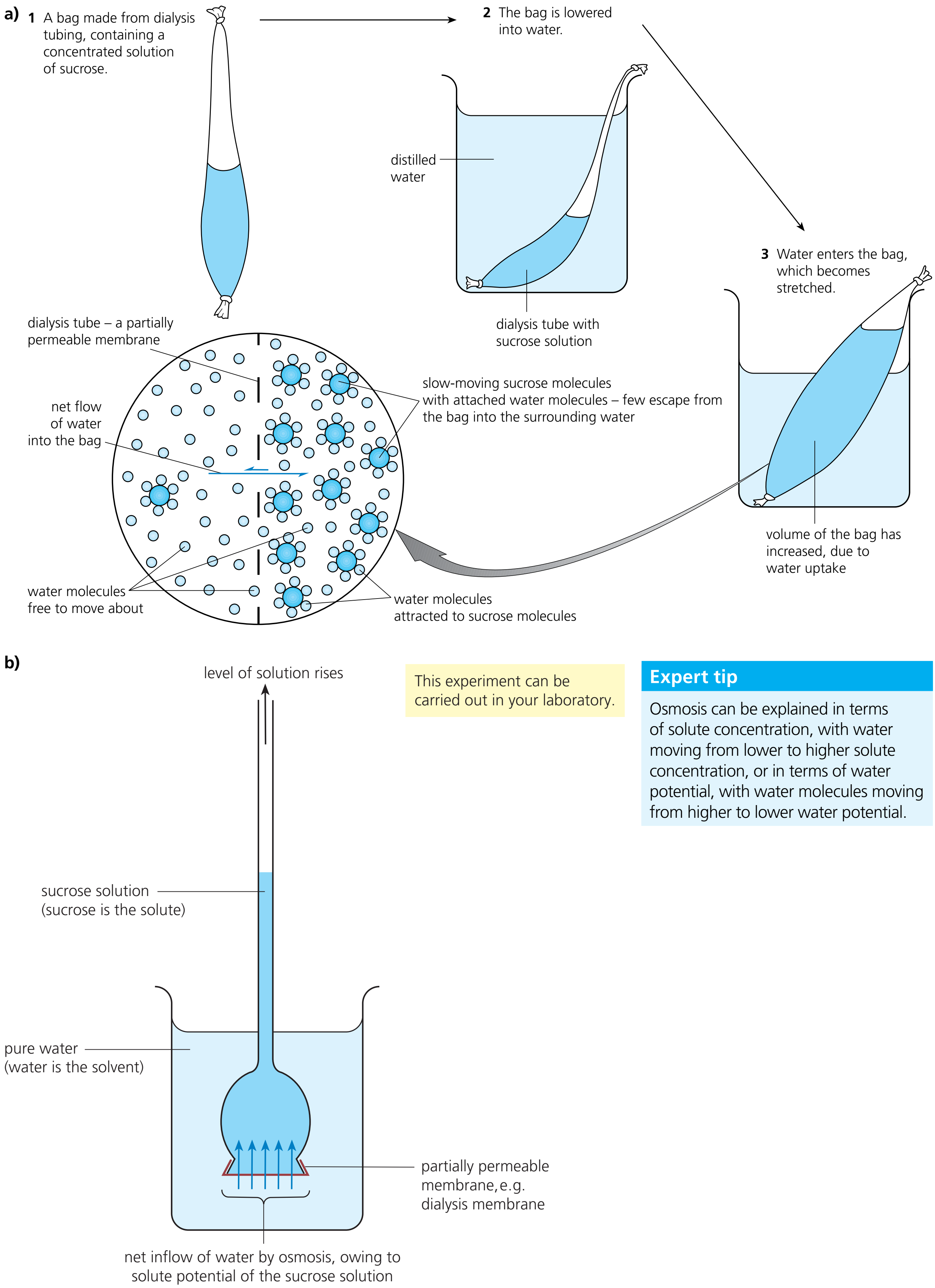
Exocytosis – vesicles fuse with the membrane and material is exported from the cell.

Common mistake

Osmosis involves the movement of water molecules, not just 'particles', from lower to higher solute concentration across semi-permeable membranes.

Common mistake

It is not enough to say that 'energy' is needed for active transport – ATP must be mentioned.



This experiment can be carried out in your laboratory.

Figure 1.18 Demonstrations of osmosis: a) using dialysis tubing; b) using an osmometer

Expert tip

Osmosis can be explained in terms of solute concentration, with water moving from lower to higher solute concentration, or in terms of water potential, with water molecules moving from higher to lower water potential.

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About the authors
Andrew Davis teaches IB Diploma Biology and Environmental Systems and Societies (ESS), and is the author of our online teaching and learning resource, *Biology for the IB Diploma Teaching and Learning* and our MYP title, *Biology for the IB MYP 4 & 5: By Concept*.

C.J. Clegg is an experienced teacher of Biology and has written many internationally-respected bestselling textbooks for pre-university courses. He is the author of the bestselling textbook, *Biology for the IB Diploma*, Second Edition.

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ISBN 978-1-4718-9970-6