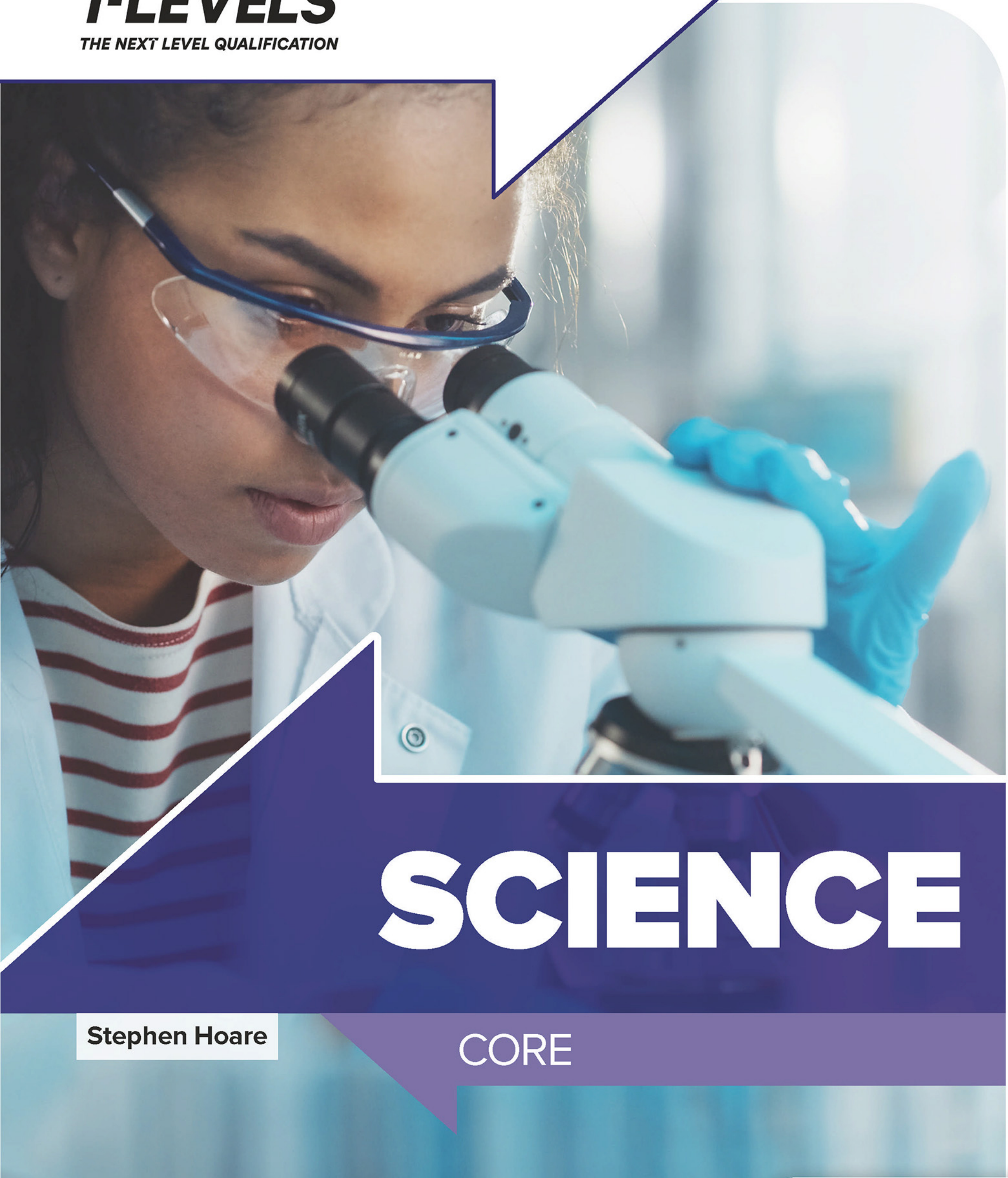
T-LEVELS

THE NEXT LEVEL QUALIFICATION



SCIENCE

CORE

Stephen Hoare

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Contents

Answers can be found online at: www.hoddereducation.co.uk/subjects/science/products/t-level/science-t-level-core

Guide to the book

The following features can be found in this book.

Learning outcomes

Core knowledge outcomes that you must understand and learn. These are presented at the start of every chapter.

Key term

Definitions to help you understand important terms.

Reflect

Tasks and questions providing an opportunity to reflect on the knowledge learned.

Test yourself

A knowledge consolidation feature containing short questions and tasks to aid understanding and guide you to think about a topic in detail.

Research

Research-based activities – either stretch and challenge activities, enabling you to go beyond the course, or industry placement-based activities encouraging you to discover more about your placement.

Practice points

Helpful tips and guidelines to help develop professional skills during the industry placement.

Case study

Placing knowledge into a fictionalised, real-life context. Useful to introduce problem-solving and dilemmas.

Health and safety

Important points to ensure safety in the workplace.

Project practice

Short scenarios and 1–3 focused activities at the end of each chapter, reflecting one or more of the tasks that you will need to undertake during completion of the ESP. These support the development of the four core skills required.

Assessment practice

Core content containing knowledge-based practice questions at the end of each chapter.

Answers can be found online at: www.hoddereducation.co.uk/subjects/science/products/t-level/science-t-level-core

B1.1–B1.32: Core science concepts: Biology

Introduction

Biology is the study of living organisms, which makes it an enormous subject! In this chapter we will cover some important basics, such as the structure of cells and the way in which they are organised. We cannot really understand how organisms work without understanding cells, and we cannot understand how cells work without learning about the main types of biological molecules: proteins, carbohydrates and lipids. Exchange and transport mechanisms – the ways in which substances enter or leave – are essential for the working of individual cells and multicellular organisms. Genetics helps us understand how characteristics are inherited and introduces the fourth main type of biological molecules – the nucleic acids – as well as providing a basis for our understanding of evolution. Microbiology is not just the study of very small organisms; it helps us to understand infectious diseases. Finally, immunology helps to explain how our bodies protect themselves against infection.

Learning outcomes

The core knowledge outcomes that you must understand and learn:

Cells and tissues

B1.1 the 3 principles of cell theory
B1.2 the different types of cells that make up living organisms
B1.3 the structure and function of the organelles found within eukaryotic cells
B1.4 the similarities and differences between plant and animal cells in relation to the presence of specific organelles and their function:
B1.5 how eukaryotic cells become specialised in complex multi-cellular organisms
B1.6 how prokaryotic cells differ from eukaryotic cells

Proteins, carbohydrates and lipids

B1.7 the relationship between the structure, properties and functions of proteins
B1.8 the relationship between the structure, properties and functions of carbohydrates
B1.9 the relationship between the structure, properties and functions of lipids

Exchange and transport mechanisms

B1.10 how the surface area to volume ratio affects the process of exchange and gives rise to specialised systems
B1.11 the principles of cellular exchange and the transport mechanisms which exist to facilitate this exchange
B1.12 the advantages of having specialised cells in relation to the rate of transport across internal and external membranes

Genetics

B1.13 the purpose of deoxyribonucleic acid (DNA) and ribonucleic acid (RNA) as the carrying molecules of genetic information and the role they play in the mechanism of inheritance
B1.14 the relationship between the structure of DNA and RNA and their role in the mechanism of inheritance
B1.15 the function of complementary base pairing in forming the helical structure of DNA
B1.16 the process and stages of semi-conservative replication of DNA
B1.17 how this semi-conservative replication process ensures genetic continuity between generations of cells
B1.18 the link between the semi-conservative replication process and variation
B1.19 the difference between genetics and genomics

Microbiology

B1.20 the classification and characteristics (size of cell, type of cell, presence of organelles) of the following micro-organisms
B1.21 the benefits of using light and electron microscopes when investigating micro-organisms.
B1.22 how to calculate magnification from the size of the image and the size of the object
B1.23 the uses of differential staining techniques

Immunology

B1.24 the nature of infection
B1.25 causative agents of infection and examples of resulting diseases
B1.26 the different ways in which causative agents may enter the body
B1.27 how infectious diseases can spread among populations and communities
B1.28 the definition of an antigen and an antibody

Learning outcomes

B1.29 the link between antigens and the initiation of the body's response to invasion by a foreign substance
B1.30 the stages and cells involved in the body's response to an antigen
B1.31 the differences between cell-mediated immunity and antibody-mediated immunity
B1.32 the role of T and B memory cells in the secondary immune response.

Cells and tissues

We can study and understand biology at different levels of organisation. Starting with the whole **organism**, we can move upwards to study the ways in which organisms interact in populations and ecosystems. Alternatively, we can look at the way in which organisms work in increasing levels of detail. The cell is the basic unit of all organisms. We need to learn the structure and organisation of the cell to get a proper understanding of how cells work together and also understand the environment in which the chemical reactions of the cell take place.

Key terms

Organism: an individual plant, animal or single-celled lifeform.

Membrane: all membranes consist of a **phospholipid** bilayer together with proteins and other components. They are selectively permeable (meaning they let some things through and not others) and can control movement of substances across the membrane as well as being the sites of many important processes in the cell.

Phospholipid: a large molecule formed from a glycerol molecule covalently bound to two fatty acid molecules and a phosphate group. It has a **hydrophilic** (can interact with water) head group (because of the phosphate) and a **hydrophobic** (repels water) tail (because of the fatty acids).

Cytoplasm: is the fluid component of the cell, enclosed by the cell membrane and surrounding the organelles.

Organelles: specialised structures within plant and animal cells that have specific functions. Some types of organelle are also found within bacterial cells.

B1.1 The 3 principles of cell theory

Robert Hooke (1635–1703) was the first person to recognise cells, although the 'cells' in cork that he saw using his microscope were the empty spaces between the cell walls of the cork. Hooke laid the foundations for what we now know as the three principles of cell theory. This states that:

- All living things are made up of one or more cells. This means that living things can be **unicellular** (single cells) or **multicellular** (made up of more than one cell).
- Cells are the most basic unit of structure and function in all living things. Cells contain many components (nuclei, mitochondria, etc.) but these cannot exist or reproduce on their own.
- All cells are created by pre-existing cells, i.e. cells cannot just appear from nowhere. New cells are created from pre-existing cells in the process of **mitosis** (cell division).

B1.2 The different types of cells that make up living organisms

There are two types of cell: **prokaryotic** cells and **eukaryotic** cells. Eukaryotic cells are complex and include all animal and plant cells as well as yeasts, other fungi and algae. Prokaryotic cells are simpler and smaller and include the bacteria. Both types of cell have **membranes**, **cytoplasm** and DNA. However, eukaryotic cells have membrane-bound **organelles**, such as mitochondria or chloroplasts. Also, the DNA is contained within the nucleus. The DNA is bound to proteins known as histones and together they form a complex known as chromatin (see below). In prokaryotic cells, the DNA just floats freely in the cytoplasm, or is found as small circular molecules known as plasmids, and is not associated with proteins.

B1.3 The structure and function of the organelles found within eukaryotic cells

Plasma membrane

Also called the **cell surface membrane**, this is found around the outside of the cell and consists of a **phospholipid bilayer** together with proteins and other components. The **plasma membrane** controls entry and exit of substances into and out of the cell.

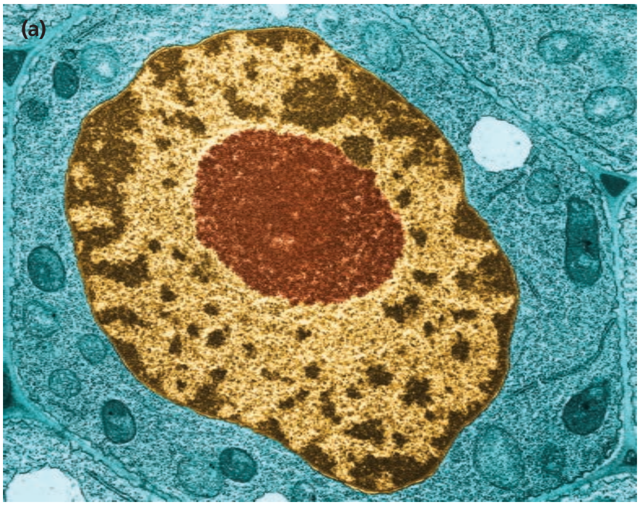
Key terms

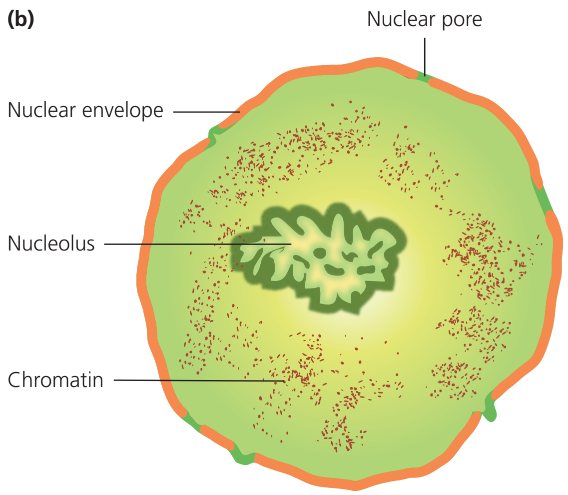
Phospholipid bilayer: a double layer of phospholipids with the hydrophobic tails arranged towards the middle and the hydrophilic head groups on the outside. It forms the basis of all biological membranes.

Plasma membrane: sometimes called the cell-surface membrane, it is the membrane that surrounds all types of cell; animal, plant and bacterial. Like all membranes, the plasma membrane consists of a phospholipid bilayer together with proteins and other components.

Nucleus (containing chromosomes)

The nucleus is the largest organelle and is surrounded by the **nuclear envelope.** This is a double membrane that has many gaps or **pores**.





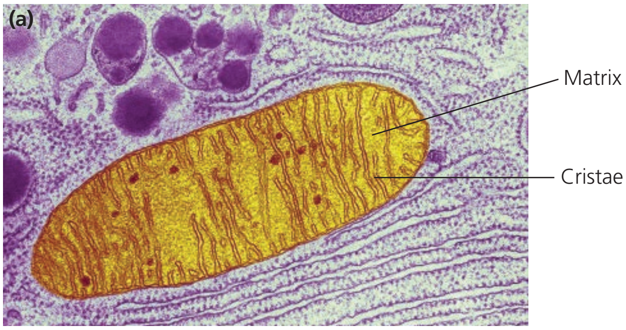
▲ Figure 11.1 A nucleus: (a) an electron micrograph (x 25 000) and (b) a diagram, showing the structure of the nucleus

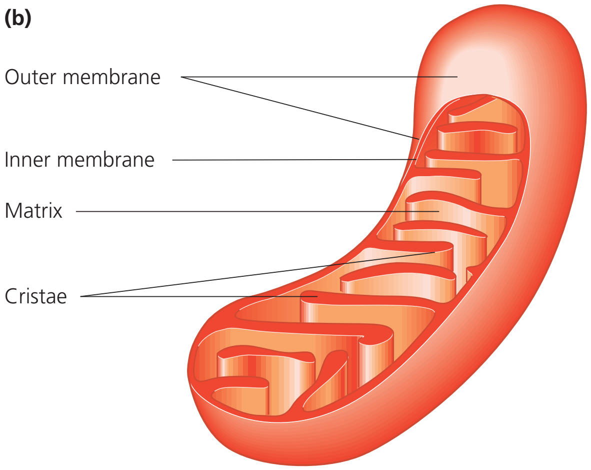
The nucleus contains the genetic information, in the form of DNA. The DNA is combined with proteins known as histones; this forms the complex known as **chromatin**. The chromatin is coiled and super-coiled to form the chromosomes.

Mitochondria

Mitochondria (the singular is mitochondrion) are the site of **aerobic respiration** and therefore the site of adenosine triphosphate (ATP) production. Aerobic respiration is the process where glucose is reacted with oxygen to produce carbon dioxide and water. As this reaction is exothermic, the energy transferred from this reaction is used to produce ATP, the 'energy currency' of the cell. Almost all processes in the cell that require energy obtain it from ATP.

Like nuclei and chloroplasts, mitochondria are enclosed by a double membrane (envelope). The inner membrane is folded into structures called **cristae**.





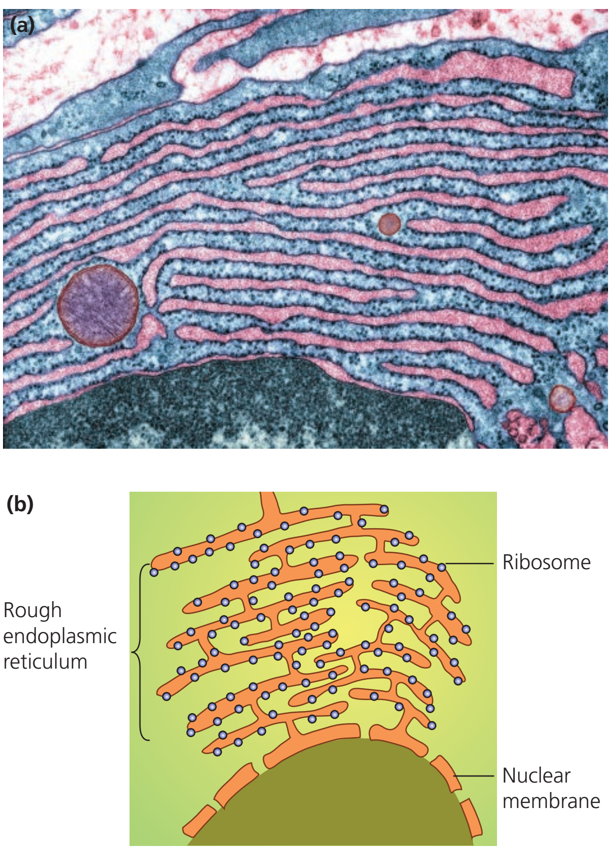
▲ Figure 11.2 A mitochondrion: (a) an electron micrograph (x 1100) and (b) a diagram

Ribosomes

Ribosomes are the smallest of the organelles and are the site of protein synthesis. Some float free in the cytoplasm and make the proteins needed within the cell, whereas others are attached to the rough endoplasmic reticulum. Ribosomes use the information coded in an mRNA molecule to assemble the correct order of amino acids in the protein.

Rough and smooth endoplasmic reticulum

The **endoplasmic reticulum (ER)** is a system of membrane-bound flattened sacs that fills a large part of the cytoplasm. The **rough ER (RER)** has ribosomes attached to its outer surface. Proteins that will be released from the cell or incorporated into the plasma membrane are made on these attached ribosomes and then folded and transported in the RER to the Golgi apparatus.

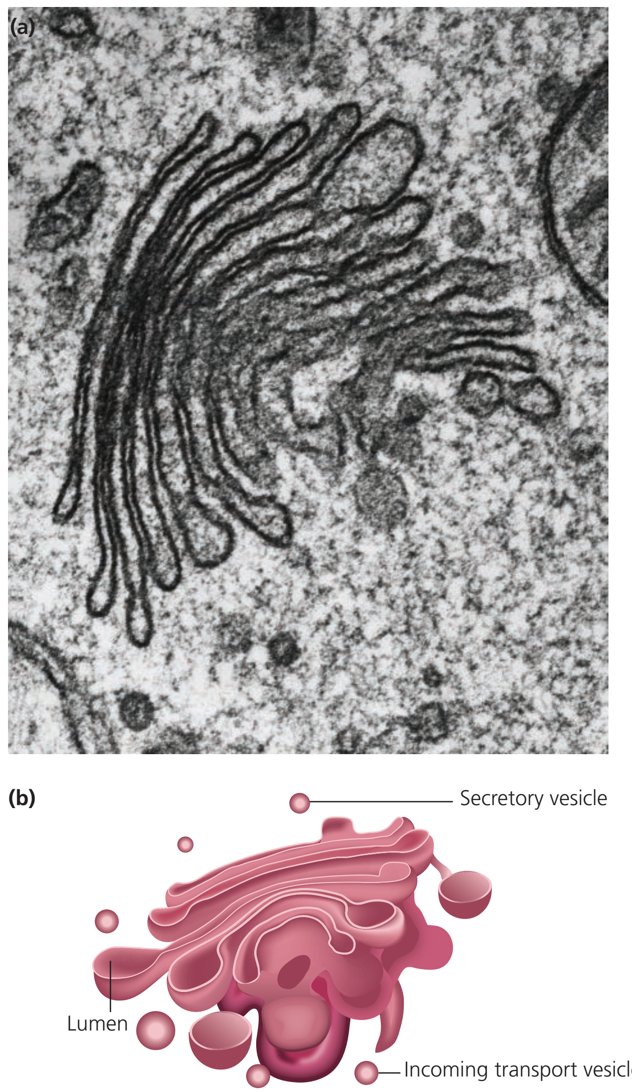


▲ Figure 11.3 Rough endoplasmic reticulum: (a) an electron micrograph (x18 000) and (b) a diagram

The **smooth ER** does not have attached ribosomes and is responsible for synthesising, storing and transporting lipids and some carbohydrates.

Golgi apparatus and Golgi vesicles

The Golgi apparatus is a stack of flattened sacs, known as cisternae (singular is cisterna). Each cisterna is surrounded by a single membrane and filled with fluid. The Golgi modifies proteins that have been transported from the RER, for example by adding carbohydrates to them. These modified proteins are then transported by **Golgi vesicles** that form when the ends of the cisternae are pinched off. These vesicles can form **lysosomes** (see below). Others, called **secretory vesicles**, carry their contents to the plasma membrane where they can be released to the outside of the cell.



▲ Figure 11.4 The Golgi apparatus: (a) an electron micrograph (x50 000) and (b) a diagram showing the Golgi vesicles and secretory vesicles

Lysosomes

These are the cell's recycling facility. When proteins and other cell components get worn out, they are moved into lysosomes. Digestive enzymes break these down into their constituents, e.g. amino acids that can be re-used to make new proteins. It is important that these enzymes are kept separate from the rest of the cytoplasm because of the damage they could do. Lysosomes are also involved in digestion of invading **pathogens** (bacteria and viruses) that are taken into the cell by the process of **phagocytosis** (see page 198 later in this chapter).

Centrioles

Centrioles are structures made of a tubular protein called tubulin. They are involved in the formation of the spindle in **mitosis** as well as formation of **cilia** and **flagella**. They are not present in many types of plant cells.

Key terms

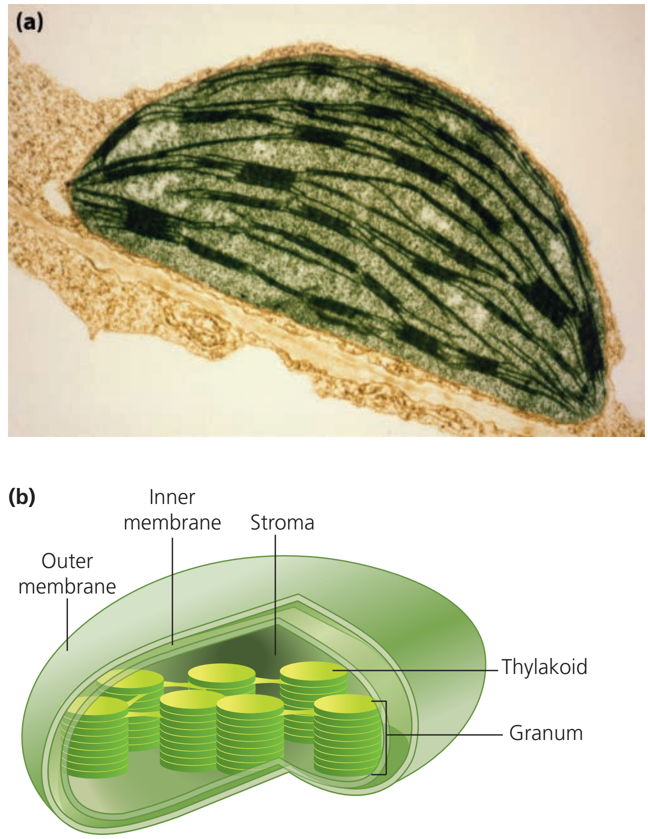
Pathogen: a micro-organism that causes illness or disease by damaging host tissues and/or by producing toxins.

Cilia: (singular **cilium**) are hair-like structures found on the plasma membrane of some types of cell, particularly in the lungs.

Flagella: (singular **flagellum**) are similar in structure to cilia but are much longer and are involved in propulsion of the cell.

Chloroplasts (in plants)

Like mitochondria, chloroplasts are enclosed by an **envelope** (double membrane) and contain membranes called **thylakoids** arranged in stacks called **grana** (singular is **granum**). The chloroplast is the site of photosynthesis, the process whereby plants and algae use light energy to make complex organic molecules from carbon dioxide and water. There are two stages to photosynthesis. The first stage occurs in the thylakoid membranes which contain chlorophyll and other pigments that absorb light energy as well as proteins involved in the production of ATP. The rest of the chloroplast consists of a fluid called the **stroma**, which is where the second stage of photosynthesis take place.



▲ Figure 11.5 A chloroplast: (a) an electron micrograph (x 13 750) and (b) a diagram

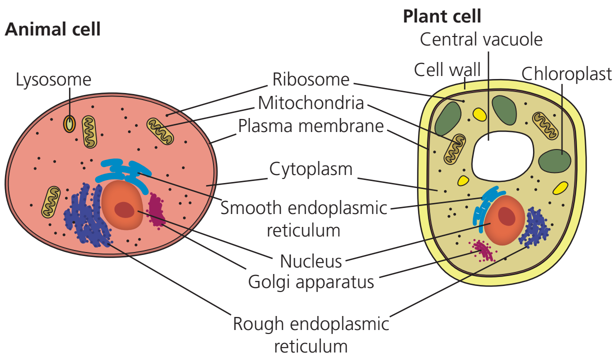
Cell wall (in plants)

Plant cell walls consist mainly of the carbohydrate **cellulose.** Cell walls provide strength and rigidity for protection and support. If animal cells take up too much water they burst, whereas in plants the cell wall prevents this.

Cell vacuole (in plants)

Cell vacuoles are fluid-filled sacs surrounded by a single membrane. Their size varies; in some cells the vacuole almost fills the cell. The fluid is a dilute solution of molecules and ions. The vacuole can be used to store mineral salts, amino acids, sugars and waste products. Vacuoles are also involved in maintaining the water balance of the cell.

B1.4 The similarities and differences between plant and animal cells



▲ Figure 11.6 Components of plant and animal cells

If you compare the animal and plant cells shown in Figure 11.6 you will see that there are many similarities. In fact, the main difference between the two types is that plant cells have structures such as the cell wall, chloroplasts and vacuoles that are not found in animal cells.

The cell wall provides support to plant cells and helps to keep them rigid. This also means that they have similar shapes. There are some types of highly specialised plant cells, but there is a much greater variety of types of animal cells. Animal cells also have a larger variety of shapes as they do not have a cell wall to keep them rigid and hence the need for skeletons in larger organisms.

Key term

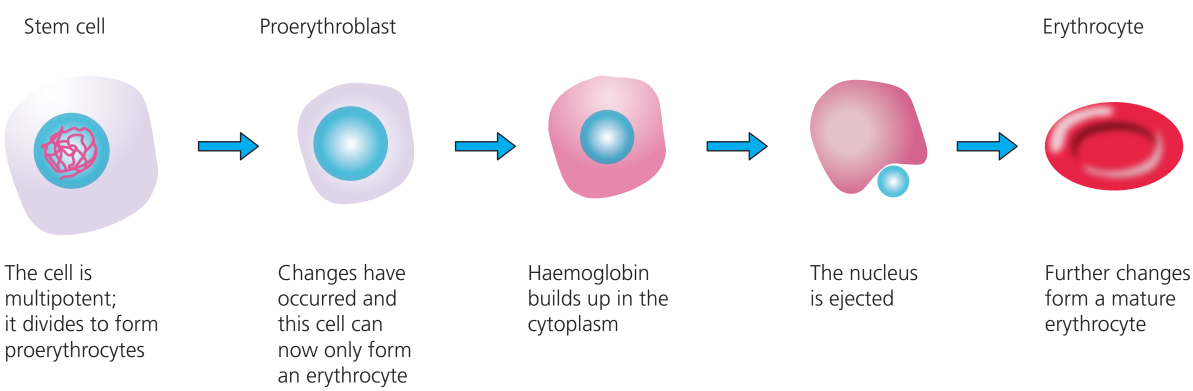
Stem cells: undifferentiated (non-specialised) cells that can give rise to one or more types of differentiated (specialised) cell.

B1.5 How eukaryotic cells become specialised in complex multi-cellular organisms

In multicellular organisms, different cells are specialised to fulfil different functions. This is controlled by which genes are expressed (i.e. genes that are switched on and therefore have an effect). Every **somatic** cell (i.e. all cells excluding gametes) contains in its nucleus the whole **genome** (all the genes) of the organism. How the cell functions is determined by which of the many genes are expressed and which are not.

The process by which a cell changes from one cell type to another is known as **cell differentiation.** To understand this, consider how a **zygote** (fertilised egg cell) develops into an embryo and how one single cell gives rise to not just many cells, but many different types of cell.

Stem cells can differentiate to form specialised cells. The human embryo contains stem cells that can give rise to the more than 200 cell types of the adult human body. By the time a baby is born, most cells have already differentiated. This is why the term 'adult cells' applies to cells in babies and children as well as in adults. However, adult stem cells persist and are responsible for cell turnover, e.g. production of red blood cells from bone marrow cells (see Figure 11.7). These bone marrow cells also differentiate to form the various types of lymphocytes involved in the immune response (see Section B1.30). Most epithelial cells (see B1.12) need to be replaced throughout the life of an organism. Examples include cells in the skin, lungs, cornea and intestine. In each case, stem cells are responsible for replacement of worn-out cells.



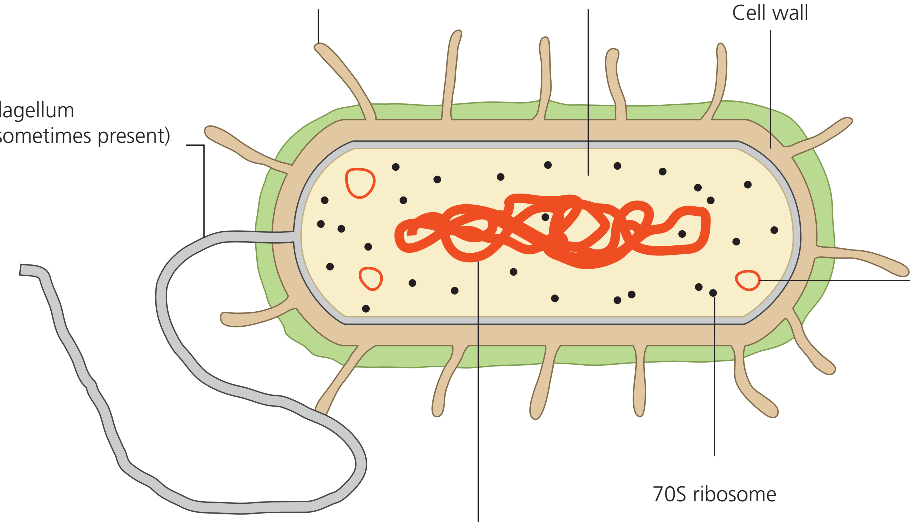
▲ Figure 11.7 Differentiation of red blood cells (erythrocytes)

B1.6 How prokaryotic cells differ from eukaryotic cells

You need to be able to distinguish between prokaryotic and eukaryotic cells based on drawings.

Differences can also be identified on electron micrographs.

Figure 11.8 shows a diagram of a typical prokaryotic cell. The table summarises the differences between prokaryotic and eukaryotic cells.



▲ Figure 11.8 A typical prokaryotic cell: some features are not present in all prokaryotic cells.

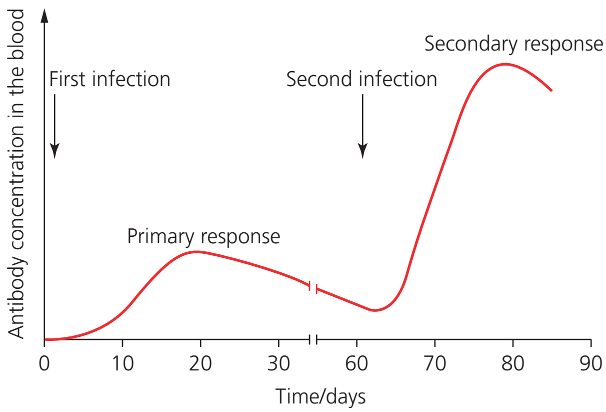
Prokaryotic cells	Eukaryotic cells
They have cytoplasm that lacks membrane-bound organelles.	They have cytoplasm containing membrane-bound organelles.
They have smaller ribosomes.	They have larger ribosomes.
They have no nucleus; instead, they have a single circular DNA molecule that is free in the cytoplasm and is not associated with proteins.	Chromosomes are linear and contained within the nucleus. The DNA is associated with proteins called histones.
They have a cell wall that contains murein/peptidoglycan, a glycoprotein.	Plant cells have a cellulose cell wall while fungi have a cell wall made of chitin.
They may have one or more plasmids.	There are no plasmids.
They may have a capsule surrounding the cell.	There is no capsule, even in plant cells. Some fungal cells can form a carbohydrate capsule.
They may have one or more simple flagella.	Flagella, where present, are more complex.

Test yourself

1 What are the three principles of cell theory?
2 State two differences between prokaryotic and eukaryotic cells.
3 State two differences between plant and animal cells.

Proteins, carbohydrates and lipids

Proteins, carbohydrates and lipids are three of the main classes of large biological molecules. We will encounter the fourth class in section B1.14 (page 186).



▲ **Figure 11.34 The change in the concentration of antibodies during the primary and secondary immune responses**

We saw how memory T cells and memory B cells were produced during the primary immune response. These remain in the body for a long time. When they encounter the pathogen for a second time, they multiply much more rapidly to form clones of plasma cells and T_C cells. The plasma cells produce high concentrations of antibodies in just a few days. In this way, the secondary immune response can clear pathogens from the body before we even show symptoms of the disease.

The secondary immune response is the basis of how vaccines work. A vaccine will stimulate the primary immune response without needing exposure to the pathogen, so the body is ready when it is exposed to the same pathogen later.

Test yourself

1. Give two examples of diseases caused by each of the following types of pathogen:
   a Bacteria b Viruses
2. Explain the difference between a pathogen and a vector.
3. Give two examples of each of the following methods of disease transmission:
   a Direct b Airborne c Indirect
4. Describe two factors that cause infections to spread within populations.
5. What is an antigen?
6. Give two differences between the specific and non-specific immune responses.
7. What is meant by an antigen presenting cell (APC)?
8. Give two differences between the primary and secondary immune responses.

Project practice

You are working in a lab that analyses ingredients for use in food manufacture. It is important that these meet required standards of identity, purity and safety. Choose one of the following areas.

- DNA analysis of meat to confirm species (lamb, beef, pork, etc.)
- Microbiological analysis of ingredients for contamination with pathogens.
- Immunological techniques for confirming identity and purity of ingredients.

You then need to carry out the following:

1. Research a strategy.
   a Carry out a literature review.
   b Justify why you have chosen specific sources and not others.
2. Plan a project using the sources that you selected in your literature review.
   a Set out the techniques you would use in your chosen form of analysis.
   b Include all appropriate risk assessments.
   c Identify the data that you would need to collect and how you would record the data.
3. Analyse the data.
   a You will normally be presented with the data you need, as there will not be time to actually carry out the investigation.
   b Produce a report of your analysis; think about what statistical tests you might need to apply.
4. Present your outcomes and conclusions in the form of a scientific poster showing:
   a the techniques being used
   b the strengths and weaknesses of your chosen technique
   c your conclusions about the technique you have chosen.
5. Group discussion covering topics such as:
   a the need for food analysis
   b the practicality of different techniques
   c do these techniques help to reassure consumers?
6. Reflection – write a reflective evaluation of your work.

Assessment practice

1 For each of the following organelles, state whether they are found in eukaryotes, prokaryotes, or both:
   a Nuclei
   b Plasma membrane
   c Ribosomes
   d DNA associated with proteins
   e Plasmids

2 Which of the following statements is true?
   A Lipids are polymers of fatty acids and glycerol.
   B Polysaccharides are highly soluble molecules which makes them suitable as energy stores.
   C Proteins are used as a form of storage molecule.
   D Proteins, polysaccharides and lipids are all formed by condensation reactions.

3 A short section of DNA has the following base sequence.
   A G C T T A G C T
   Give the base sequence of the complementary strand of DNA.

4 Explain how semi-conservative replication ensures genetic continuity from one generation of cells to the next.

5 A student was using a light microscope to study a stained section of animal tissue. Explain what type of stain is likely to have been used in preparing the section.

6 A class was studying micrographs of animal cells.
   a One micrograph showed a mitochondrion that was labelled as being 1.5 μm long. A student measured the micrograph and found that the image of the mitochondrion was 11.3 cm long. Calculate the magnification of the microscope.
   b Another micrograph was labelled 'x500 000'. The student measured the thickness of the plasma membrane on the micrograph and found it was 2 mm wide. Calculate the actual width of the plasma membrane in nm.
   c Explain what type of microscope will have been used to create the micrographs.

7 Antibiotics can be used to treat bacterial infections because they do not harm eukaryotic cells.
   a Explain why antibiotics cannot be used to treat malaria.
   b Explain why malaria can be controlled using insecticides.

8 During the COVID-19 pandemic, the UK government's advice was built around the slogan 'Hands, face, space'. This was later amended, adding 'fresh air'. Evaluate the use of this slogan.

9 Which of the following are involved in antibody-mediated immunity?
   A B cells, T helper cells, plasma cells, phagocytes
   B B cells, T killer cells, plasma cells
   C Phagocytes, T killer cells, plasma cells
   D Phagocytes, T killer cells, T helper cells

10 During the early stages of development of a COVID-19 vaccine, the concentration of antibodies in the blood of volunteers was measured in the weeks after vaccination. One vaccine produced significantly more antibodies than another type of vaccine. However, both were found to be similarly effective in preventing COVID-19 infection. Suggest an explanation for this finding.

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T-LEVELS
THE NEXT LEVEL QUALIFICATION

SCIENCE
CORE

Start your journey towards a career in science.

Covering all the Core content you need to know with clear definitions alongside practice questions, this T level textbook gives you the skills and confidence to succeed in your written assessment and industry placement.

Created in partnership with NCFE and written by highly respected author Stephen Hoare.

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- Develop the scientific, mathematical, technical and communication skills you need
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This textbook covers the Core content for Science T Level.

The Occupational Specialisms for this course are:
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- Food Sciences
- Metrology Sciences.

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