Extra resources (online version only)

Topic 1 Cells and microorganisms

Chapter 1.1 Living things consist of cells

Science Understanding

Living things are distinguishable from non-living things.

The cell theory unifies all living things.

Living things are made up of one or more cells.

Cells:

- are the structural and functional units of life
- come from pre-existing cells
- contain hereditary material.

The cell is the smallest independent unit of life.

The cell membrane defines a cell; it separates the cell from its surroundings.

The cell theory

The invention of the microscope enabled the discovery of the microscopic structures that make up organisms. These microscopic structures were named “cells” by Robert Hooke because the cork cells he viewed under the microscope reminded him of the cells (rooms) in monasteries. The discovery of cells led to the formation of the original cell theory, which was proposed by Theodore Schwann in the 19th century. The original cell theory is a set of principles that explains how all living things are made up of cells and can be used to distinguish between living and non-living things.

The original cell theory states that:

- all organisms are made of cells
- cells are the basic units of life
- cells come from pre-existing cells that have multiplied.

There have been many scientific advancements since the development of the original cell theory in the 19th century. These advancements have led to a greater understanding of cells and some subsequent additions to the original cell theory. The three modern additions state that:

- DNA is passed between cells during cell division
- the cells of all organisms within a similar species are mostly the same, both structurally and chemically
- energy flow occurs within cells.

Helpful online resources

Scio-ology: Cell Theory | Cell Biology

https://www.youtube.com/watch?v=ogQyN4_ruUA

MinuteEarth: An Egg Is Just One Cell

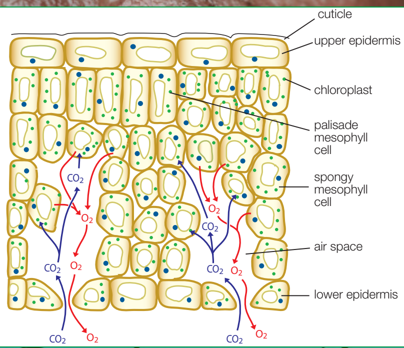
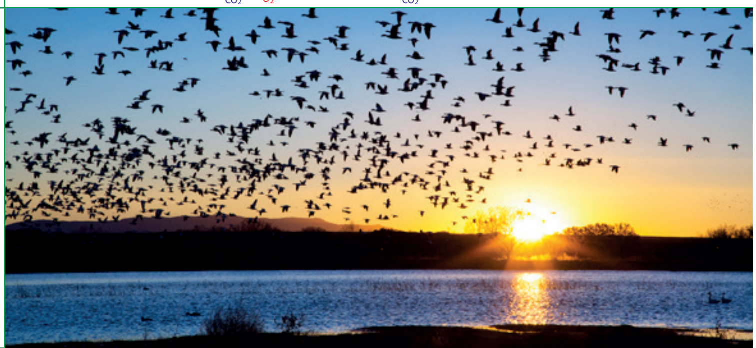
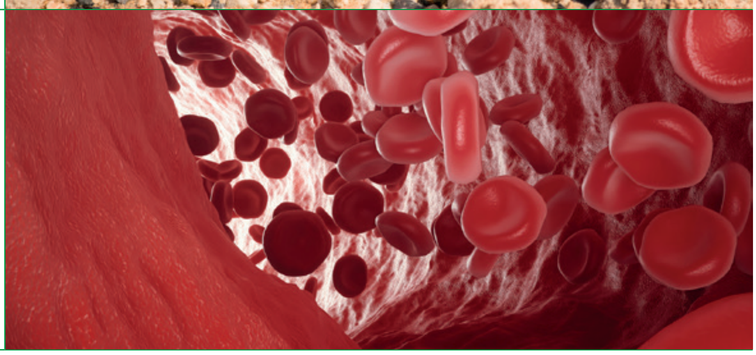
https://www.youtube.com/watch?v=bfGJw-t706o

Living things

The Earth is the only place known to sustain life. The term ‘life’ refers to the vast diversity of living things that inhabit the planet. The scientific study of living things is called biology and scientists who study living things are called biologists. But what exactly is a living thing?

One way to define living things is to ask what makes living things alive. To most biologists, something is alive if it carries out fundamental processes associated with life called **life processes** (see Table 1.1.1). All living things carry out these same fundamental life processes. Conversely, the organelles within cells cannot carry out these fundamental life processes independently and are therefore considered non-living.

Table 1.1.1: The main life processes and some specific examples.

Life process	Example	Image
Maintaining a stable internal environment	Humans sweating on a hot day	
Controlled exchange of materials	Plants absorbing carbon dioxide and releasing oxygen in daylight hours	
Response to stimuli	Birds migrating for winter	
Obtaining energy and chemical elements	Reptiles catching, killing and consuming prey	
Transport of materials	Blood carrying oxygen to muscle cells	

Life process	Example	Image
Removal of waste	Human kidneys producing urine	
Cell division	A fertilised ovum dividing many times to form an embryo	
Growth and development	The metamorphosis of a caterpillar into a butterfly	
Independent movement	A turtle swimming	
Reproduction	A bacterium dividing by binary fission	

An organism is the name given to a living thing. Organisms can be **unicellular** (made up of one cell) **or multicellular** (made up of many cells), sometimes many billions, even trillions of cells. It has been estimated that there are about 35 trillion cells in an adult human being.

The cell is the fundamental or basic unit of life. It is often stated that the cell is the unit of structure and function of organisms. As such, **the cell is the smallest independent unit of life that can carry out life's processes.**

Cells

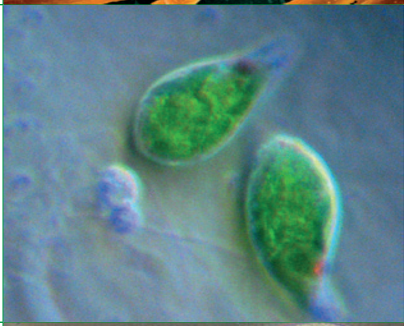
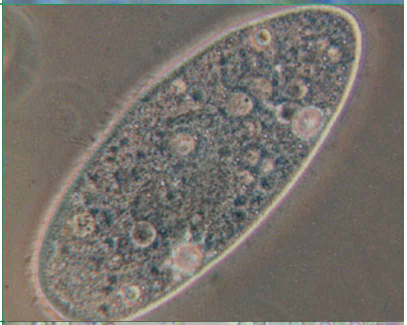
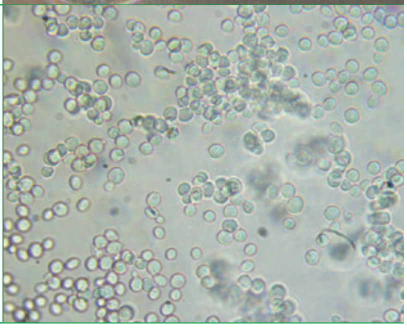
There are two major types of cells: prokaryotic and eukaryotic. **Prokaryotic cells**, such as bacteria, are less specialised than eukaryotic cells such as plant and animal cells. All cells consist of a volume of fluid (cytoplasm) enclosed by a cell membrane. The cytoplasm is mostly made up of water in which substances are dissolved and some insoluble proteins. **Eukaryotic cells** also have structures called membrane-bound organelles that reside in the cytoplasm. Each organelle has a specific function; for example, a nucleus stores DNA and controls the overall function of the cell. These cell types, organelles and their functions are discussed in further detail in Chapter 1.2.

Unicellular organisms

All life in earth has evolved from a single cell over millions of years. Living things that consist of one cell are known as unicellular organisms. They are also called microorganisms because they generally cannot be seen with the naked eye.

Unicellular organisms can be prokaryotes or eukaryotes and can be found in almost all habitats including thermal vents, caves and even deep underground. They usually reproduce asexually and obtain their nutrients through a process called diffusion. Some examples are highlighted in Table 1.1.2.

Table 1.1.2: Some examples of unicellular organisms.

Unicellular organism	Kingdom	Type of cell	Image
Escherichia coli	Bacteria	Prokaryotic	
Euglena	Protista	Eukaryotic	
Paramecium	Protista	Eukaryotic	
Baker's yeast (*Saccharomyces cerevisiae*)	Fungi	Eukaryotic	

Multicellular organisms

Living things that consist of more than one cell are called multicellular organisms. They are eukaryotes and some examples include mushrooms, animals and plants. Multicellular organisms are more complex than unicellular organisms. They generally consist of large numbers of different types of cells. The different cells within multicellular organisms are specialised cells with different structures and functions (see Figure 1.1.1). They are produced through a process called differentiation, which involves stem cells. As the different cells have different functions, coordination is required between cells to carry out the life processes. As a result, they generally have organs and organ systems to help control and facilitate these life processes. This is explored further in Topic 3: Multicellular organisms.

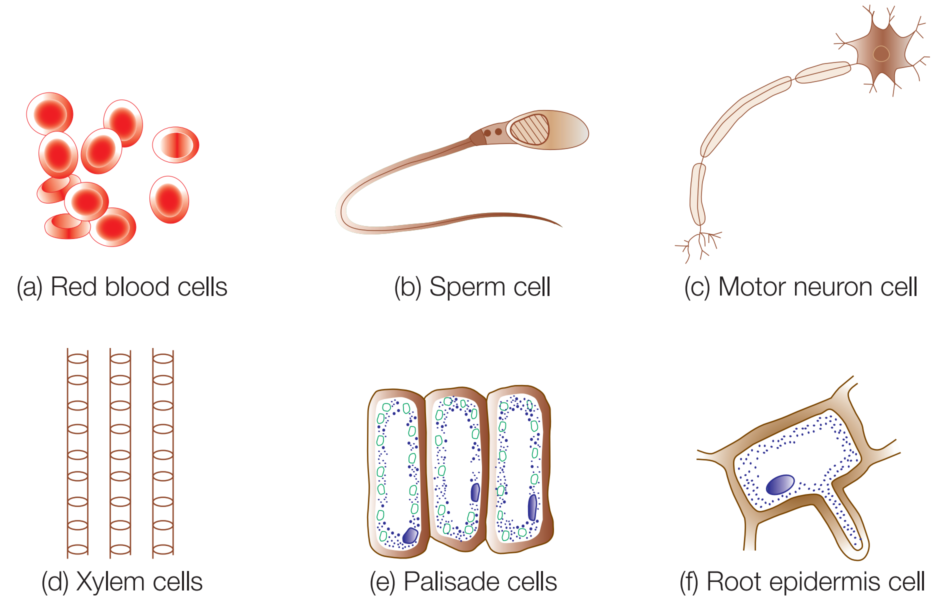


Figure 1.1.1: Some examples of specialised animal cells (a),(b),(c) and some specialised plant cells (d),(e),(f)

Hereditary material in cells

Heredity is defined as the passing on of characteristics genetically from one generation to the next. All cells contain hereditary material known as **DNA** (deoxyribonucleic acid). DNA is essential to life as it enables cells to synthesise important molecules like proteins for cellular function and divide to produce new cells.

DNA molecules consist of **two complementary** strands. Each strand consists of a phosphate backbone and a specific sequence of DNA bases. There are 4 bases: adenine (A), thymine (T), cytosine (C) and guanine (G), but A only pairs with T and C only pairs with G (see Figure 1.1.2). The complementary nature of the two DNA strands allows it to be replicated prior to cellular division so the genetic information can be passed from parents to their offspring.

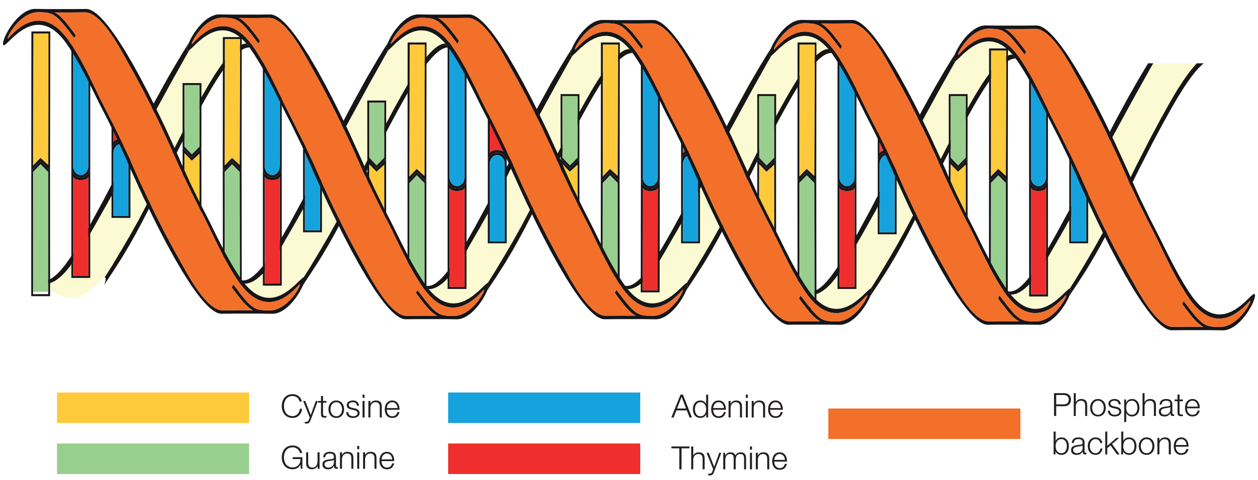


Figure 1.1.2: The basic structure of a DNA molecule showing the two complementary strands and double helix shape.

1.1

DNA molecules are generally very long; for example, human cells contain approximately 2 metres of DNA. It is remarkable that this amount of DNA can fit into a single microscopic cell, but it does so by being packed into structures called chromosomes. **Chromosomes** are the structural unit of information in cells and consist of a DNA molecule wrapped around proteins (see Figure 1.1.3). This packaging structure condenses the DNA molecule significantly and helps to protect the genetic code from mutations.

The number of chromosomes, their shape and location in a cell differs between prokaryotes and eukaryotes. This is explored further in Chapter 1.2.

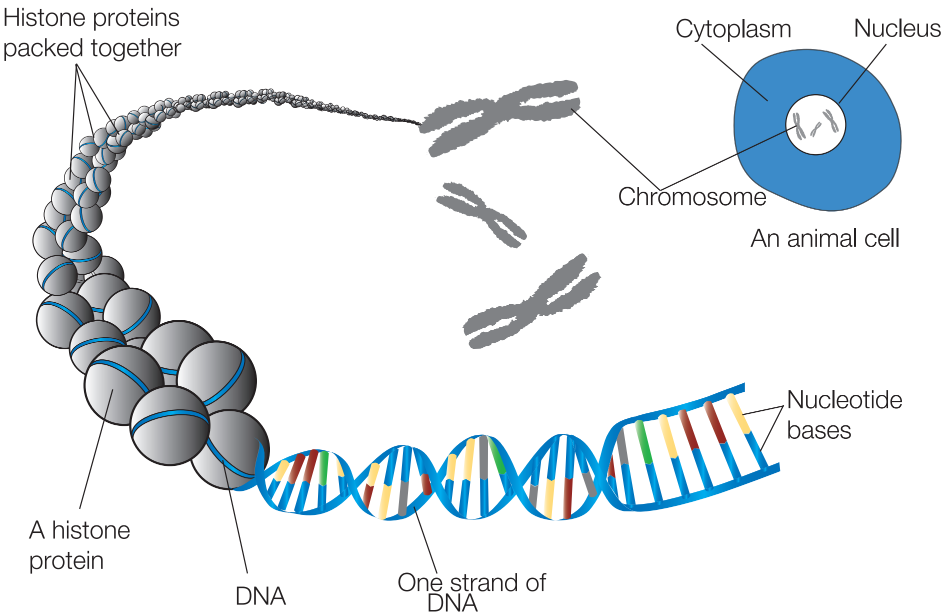


Figure 1.1.3: Chromosomes consist of a DNA molecule wrapped around histone proteins allowing the long DNA molecule to fit inside microscopic cells.

The cell membrane

The cell membrane is a structure found in all cells. It defines a cell and separates the intracellular environment from its extracellular environment (see Figure 1.1.4). The cell membrane is a thin layer (0.01µm) consisting of two layers of phospholipid molecules with a range of different proteins embedded in it. As the boundary between the intracellular and extracellular environments, the cell membrane controls the entry and exit of materials to and from the cell. This will be discussed further in Chapter 1.5.

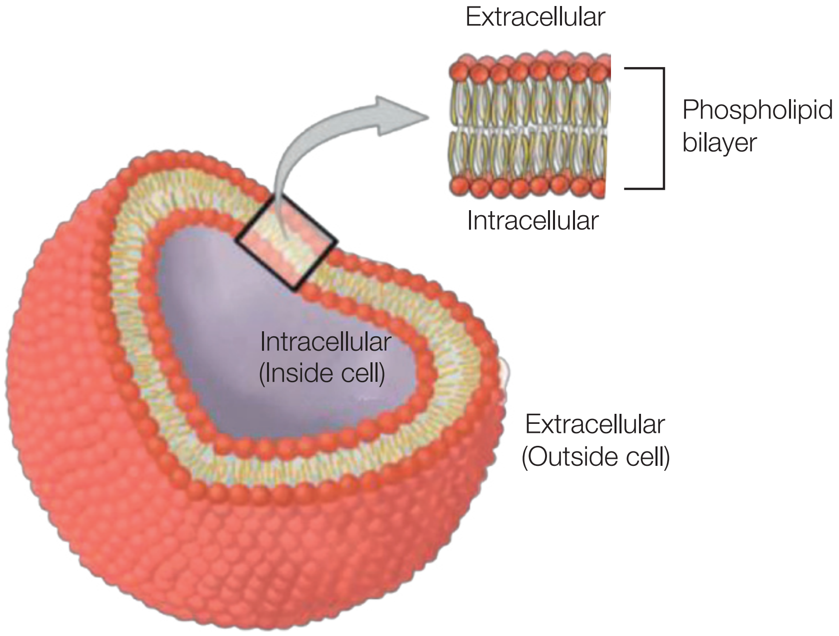


Figure 1.1.4: A model of a cell membrane highlighting that it is the boundary of the cell that separates the cell from its surroundings.

Microscopes

As cells are microscopic and cannot be seen with the naked eye, a microscope is required to view them. There are two major types of microscopes: light and electron microscopes. These two types of microscopes have different applications as they vary in magnification power, resolution and portability.

The light microscope

Light microscopes use visible light to illuminate specimens and lenses to magnify an image (see Figure 1.1.5). Light microscopes are therefore essential tools in scientific research, offering a window into the microscopic world. Scientists use light microscopes across various fields like biology, medicine and more, to study cells, tissues, microorganisms, and other small structures. They're valued for their versatility, ease of use, and ability to provide real-time imaging of living samples.

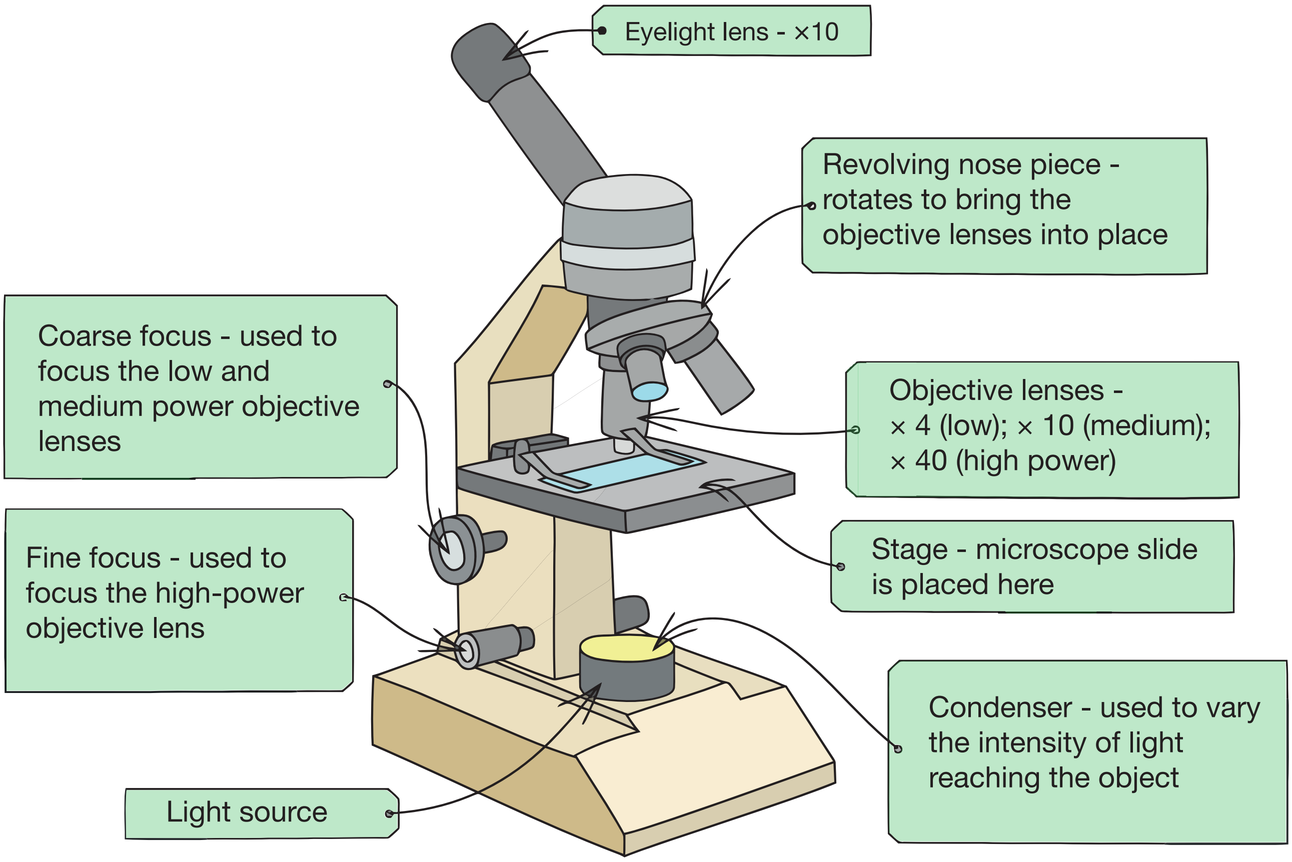
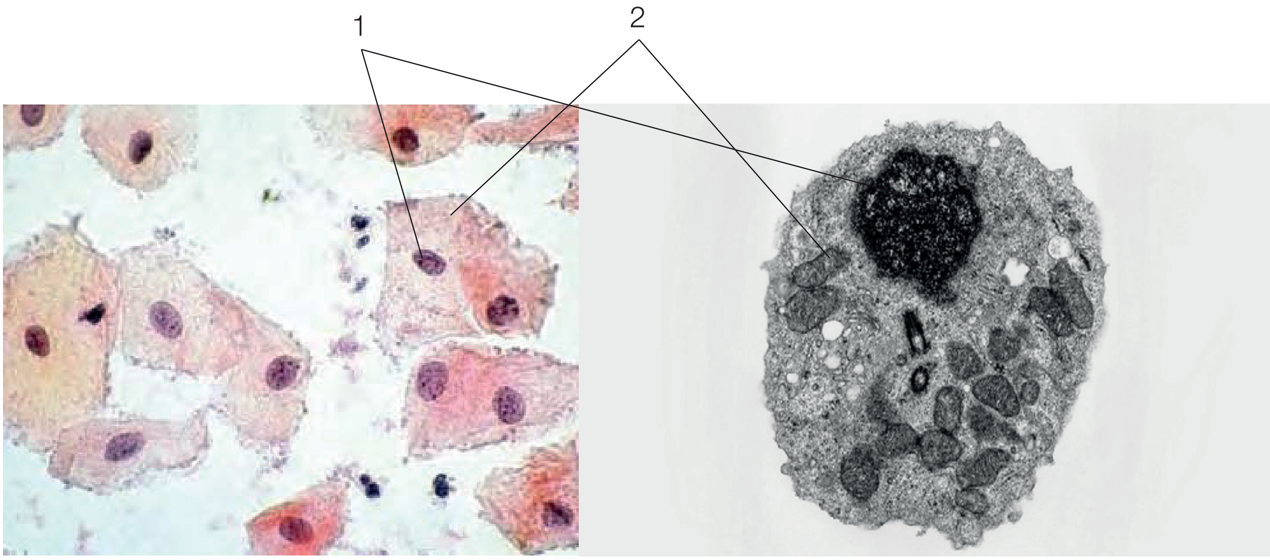


Figure 1.1.5: A summary of the main components of a light microscope and their functions.

The electron microscope

Electron microscopes are powerful instruments used in scientific research to study objects at an extremely high resolution. Unlike light microscopes, which use visible light, electron microscopes use a beam of electrons to illuminate specimens. This allows for much higher magnification and resolution, revealing details at the nanoscale level (see Figure 1.1.6). Electron microscopes are commonly used by scientists in laboratories where detailed imaging of the components of cells are required. There are two main types of electron microscopes: Scanning Electron Microscopes (SEM) and Transmission Electron Microscopes (TEM). SEMs produce detailed 3D images of the surface of specimens, while TEMs create high-resolution images by passing electrons through thin sections of specimens, offering insights into internal structures. Refer to Table 1.1.3 for a comparison of some features of light and electron microscopes.



Light microscope vs Electron microscope

Figure 1.1.6: A comparison of the magnification of the nucleus (1) and mitochondria (2) of some animal cells when viewed under a light microscope and electron microscope.

Table 1.1.3: A comparison of some features of light and electron microscopes.

Light microscope	Electron microscope
Small, compact and portable	Big, bulky and requires permanent installation
Light energy used to illuminate specimens	Beams of electrons used to illuminate specimens
Generally ×400 magnification but most powerful magnification is approximately ×2000	Generally ×500,000 but most powerful magnification is approximately ×2,000,000
Low resolution (200 nm)	High resolution (0.5 nm)
Living and non-living specimens can be viewed (must be thin to allow light through)	Only non-living (dead) specimens can be viewed
Affordable and low maintenance required	Expensive and requires high maintenance

Helpful online resources

Insider Science: Award-Winning Footage Of The Microsopic World Around Us

https://www.youtube.com/watch?v=ZyXrtODhJEA

Magnification calculations

To calculate the actual size of a cell using the image size and magnification of a light microscope lens, you can use the formula:

π Formula

Actual size = Image size ÷ Magnification

First, measure the size of the cell in the microscope's field of view (image size). Then, divide this measurement by the magnification of the microscope lens being used. This calculation provides an estimation of the actual size of the cell being observed.

This formula can be rearranged to find the magnification and image size when required.

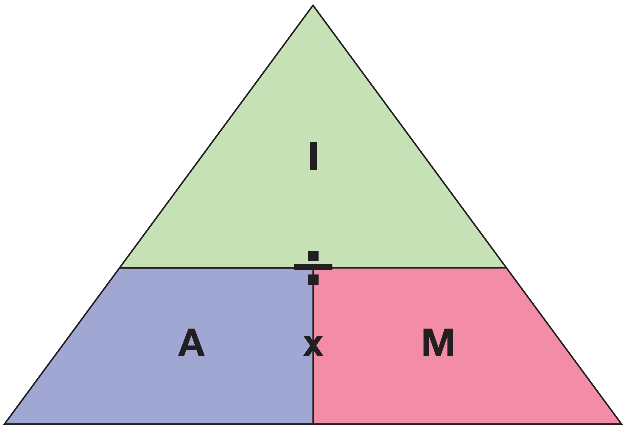
π Formula

Magnification = Image size ÷ Actual size

Image size = Actual size × Magnification

Note: magnification does not have any units and is just written as '×10' or '×5000'

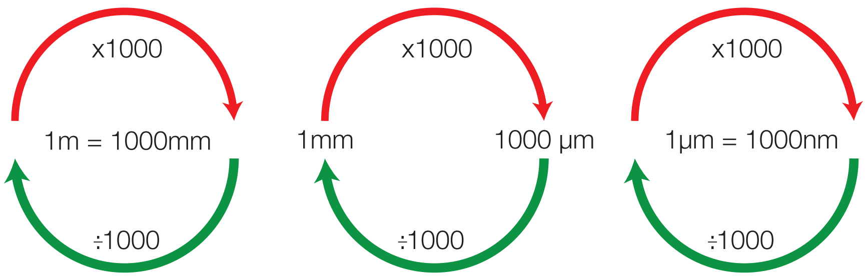
An easy way to complete microscopy calculations is to use the 'I AM' triangle method (see Figure 1.1.7). To use this method, you must first determine what you are trying to find and then place your finger over it in the triangle (e.g. if you are trying to find the actual size, you would put your finger over the 'A'). This will leave two other variables that will be multiplied or divided depending on their position in the triangle. You may also need to convert units where appropriate (see Figure 1.1.8). Refer to the example calculation below for further information.



I - Image size | A - Actual size | M - Magnification

Figure 1.1.7: The 'I AM' triangle method, where the horizontal line below 'I' represents a division symbol (÷) and the vertical line between the 'A' and 'M' represents a multiplication symbol (x).

To convert mm ⟶ µm



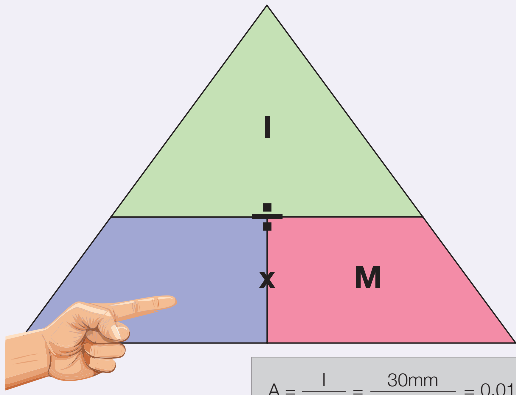
To convert µm ⟶ mm

Figure 1.1.8: A length conversion chart

Example calculation

An **image** of an animal cell is 30 mm in size and it has been **magnified** by a factor of ×3000. Determine the **actual** size of the cell.

To find the **actual** size of the cell:



$$A = \frac{I}{M} = \frac{30mm}{3000} = 0.01mm$$

$$0.01mm = 10\mu m$$

1.1 Review questions

Multiple choice questions

1. *Refer to the diagrams in the table below to answer the following question.*

			
A	B	C	D

Identify the non-living thing in the table above.

J A
K B
L C
M D

2. Which of the following options is **not** a unicellular organism?

J Sea urchin
K Streptococcus
L Escherichia coli
M Paramecium

3. Unicellular organisms

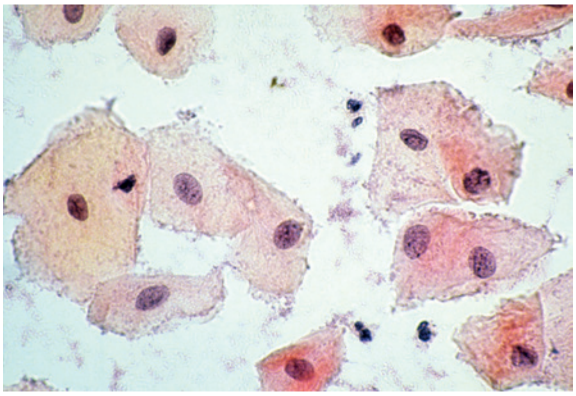
J do not adhere to every principle of the cell theory.
K cannot be seen with the naked eye.
L do not respond to stimuli.
M are only found living on other organisms.

4. Which of the following options is the least likely to be considered as a fundamental life process to classify an organism as living?

J Independent cell division.
K Ability to reproduce.
L Ability of sight.
M Move independently.

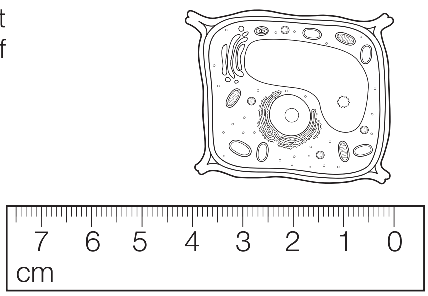
5. Which of the following is **not** a principle of the cell theory?
   - J All living organisms are multicellular.
   - K Cells contain genetic information.
   - L All cells arise from pre-existing cells.
   - M All living organisms are made up of one or more cells.
6. Which of the following options best explains why all cells contain hereditary material?
   - J Because containing hereditary material is a principle of the cell theory.
   - K Hereditary material is required for cells to make proteins and to reproduce.
   - L Hereditary material is required to divide and produce new cells, but it is not required for anything else.
   - M Having hereditary material is a fundamental life process required to be classified as a living cell.

Refer to the image below to answer question 7.



7. The image of some human cheek cells above is likely to have been magnified using
   - J a light microscope.
   - K a magnifying glass.
   - L a transmission electron microscope.
   - M a scanning electron microscope.
8. The cell membrane defines a cell. This means that
   - J the cell membrane is the boundary between the intracellular and extracellular environments.
   - K only the cells that make up multicellular organisms have cell membranes.
   - L something is classified as a cell if it has a membrane.
   - M the cell membrane is where the DNA is located.
9. The human endocrine system consists of glands that communicate through the secretion of hormones into the blood. These hormones have specific shapes and only bind to specific receptors that have a complementary shape.

   The most correct reason why humans require an endocrine system, but bacteria do not is because
   - J bacteria only respond to antibiotics.
   - K living things require hormones to exhibit every fundamental life process.
   - L humans are multicellular.
   - M if humans did not have an endocrine system, they would not be classified as living in accordance with the cell theory.
10. A plant cell with an actual size of 80μm was viewed under a light microscope. Use the adjacent image to determine the magnification of this plant cell.
   - J ×400
   - K ×500
   - L ×1500
   - M ×3200



Free response questions

1. State **three** life processes performed by all forms of life.

2. Using examples, explain the difference between a unicellular and multicellular organism.

3. State the **three** features of the original cell theory.

4. Cells vary in size. State **one** example of:
   a) very small cell in a human
   b) a large cell in a human

5. Explain why the cell theory was not formulated until after the invention of the light microscope.

6. State **two** functions of the cell membrane.

7. State why specimens observed using a light microscope must be very thin.

8. State **two** properties of the molecule DNA that explain why it is found in virtually all forms of life.

9. Explain why the cell is described as the unit of structure and function in a multicellular organism.

10. A student found a scaly leafy type structure growing on a rock surface. Describe **two** pieces of evidence they could collect or observe to enable them to determine if this was a living organism.

11. Explain **one** likely reason why all the leaves of an indoor plant have grown towards the window it faces.

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12. A student was examining two sets of photographs one taken with a light microscope and the other with an electron microscope. Explain the evidence to the student that would enable them to determine which one was which.

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13. *Refer to the table below of some ty pical sizes of cells to answer the questions that follow*:

Cell	Human skin cell	Bacteria	Human ovum	Amoeba
Approximate size	50 µm	2 µm	0.12 mm	50 µm

a) Use data from the table above to determine if a human ovum or an amoeba is bigger.

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b) Determine how many times bigger an ovum is than a skin cell.

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c) Approximately how many *E. coli* bacteria would fit across a human skin cell?

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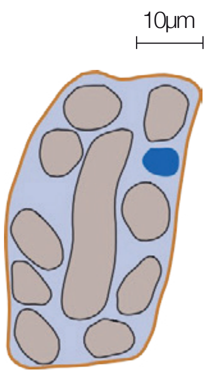
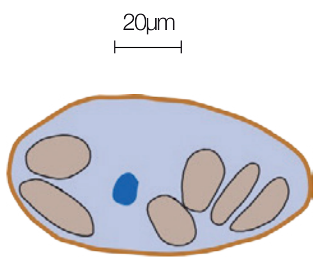
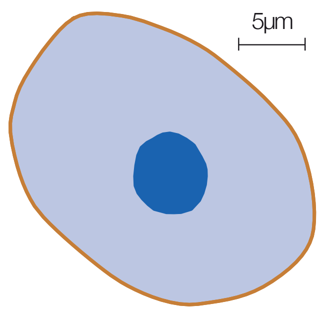
14. The diagrams below show three types of cells. Use the scale bars to select the longest cell **and** explain your reasoning.



Moss cell



Banana cell



Liver cell

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15. Use the scale bars on the diagram to the right to determine:

a) the actual size of this animal cell.

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b) the magnification used to view this animal cell.

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