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NATURE OF BIOLOGY

VCE UNITS 1 AND 2 **FIFTH EDITION**

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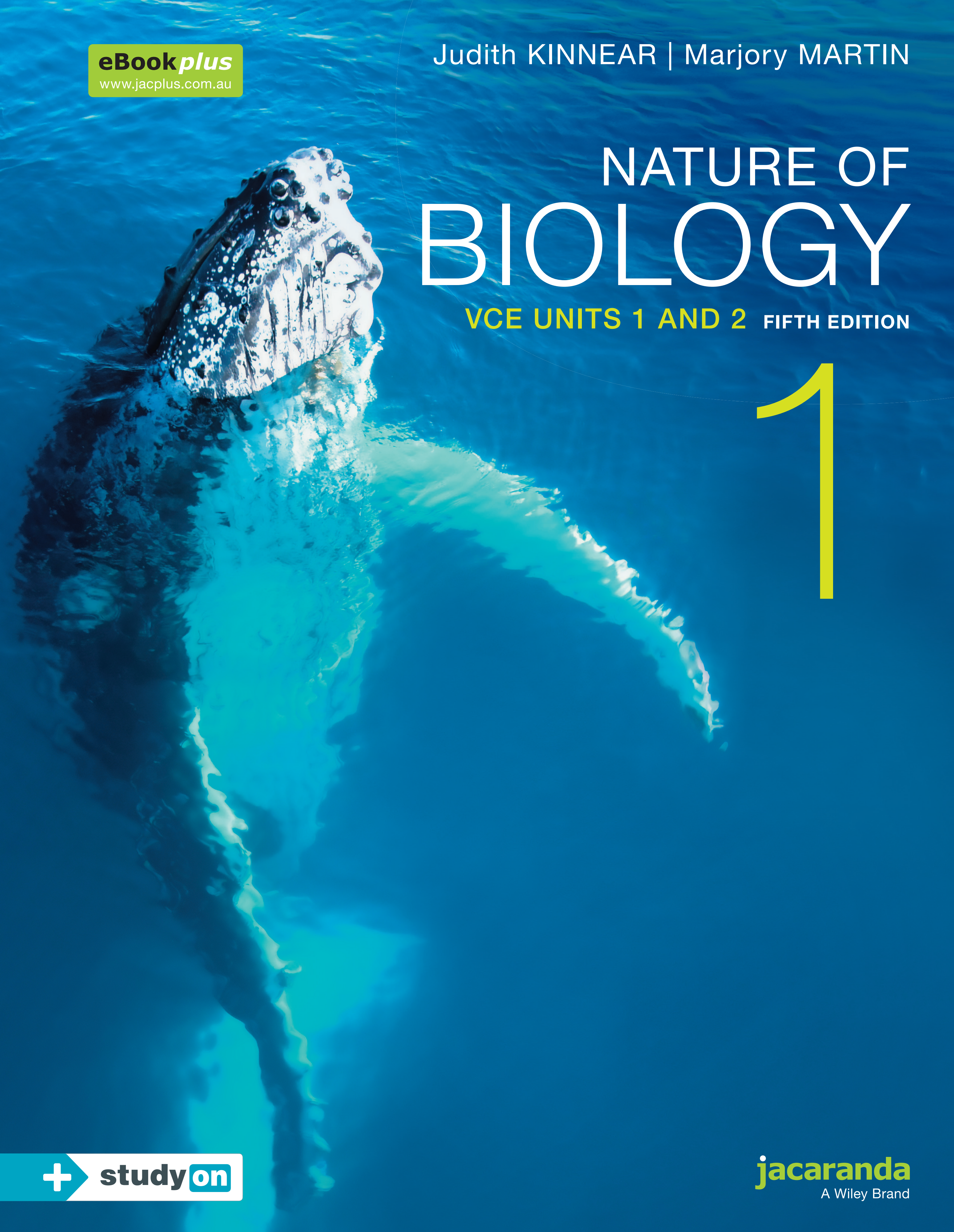

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This book is dedicated to friends and colleagues who generously shared their stories.

Contents

Preface

This fifth edition of *Nature of Biology Book 1* builds on previous editions that were positively received by teachers and students of biology. It has been thoroughly revised and updated and reflects current curriculum decisions with regard to key knowledge and skills expected of biology students.

This book continues to seek to convey a multifaceted sense of biology: as a rigorous scientific discipline with explanatory models that organise the living world for us in a meaningful way; as a dynamic science whose explanations are subject to testing and change, rather than as a fixed and unchanging body of knowledge; as a science that influences everyday life, at the level of the individual where it can inform personal choices and at a societal level where it can inform community and government decisions.

We continue to emphasise recent developments in biotechnology as exemplified by developments in kidney dialysis and the advances in microscopy, such as the use of STED (**st**imulated **e**mission **d**epletion) to create super-resolved fluorescence microscopy, the subject of a Nobel Prize in 2014. We have placed emphasis on case studies relevant to Australia, such as heat stroke deaths in Australian deserts, as well as cases of global interest such as the discovery of complex microbial ecosystems deep under the Antarctic ice sheet.

This fifth edition includes both updated material relating to pre-existing curriculum topics and new material that reflects curriculum changes, such as exploration of key body systems and their malfunctions, the homeostatic mechanisms that regulate body temperature, water balance and blood glucose levels, and an introduction to Mendelian genetics. Relevant sites from the internet are identified for further investigation and research.

Included in each unit are examples to assist students to understand how biological knowledge and skills are applied in a variety of settings. The profiles of 'Biologists at work' are intended to increase student awareness of vocational opportunities. Updated or new profiles introduce a range of persons working in diverse roles such as a TV science reporter, a cardiac specialist, and a palaeontologist and astrobiologist whose discoveries in Western Australia include the oldest fossilised cells found on Earth. We hope that the range of 'Biologist at work' profiles may inspire some readers to explore the domain of biology further through their tertiary studies and become the researchers and the practitioners of the future, or the inspiring teachers of future students of biology.

We have enjoyed writing this book and we hope that our readers will also enjoy reading the text and exploring the visual images, and gain confidence as they grapple with and master the questions associated with each chapter.

This project was greatly enhanced by the generous cooperation of many academic colleagues and friends. In particular, we owe a special debt of gratitude to the following:

Dr John Priscu (Chief Scientist WISSARD project, University of Montana), JT Thomas (WISSARD photographer), Dr Brent C Christner (Louisana State University & WISSARD project), Mark McGrouther (Australian Museum), Dr Bruce Maslin (Department of Environment and Conservation WA), Dr Jonica Newby (ABC Catalyst), Dr Dave Wacey (University of Western Australia), Professor Andrew Taylor (Baker IDI Heart and Diabetes Research Institute), Mary and Jane Rice, Dr Sue Forrest (Australian Genome Research Facility), Dr Jan West (Deakin University), Dr Alison Murray (Nevada's Desert Research Institute), Dr Ian Miller, (Australian Institute of Marine Science), Karyn Jones (Head of Dialysis Unit Epworth Hospital), Carlos Pizzorna, Professor J Colin Murrell (University of East Anglia), Lisette Curnow (Royal Children's Hospital Melbourne), Dave Noble (NSW NPWS), Anthony Walker (ThermoSurvey, UK), Dr Brian Kubicki (Costa Rican Amphibian Research Center), Professor Stefan Hell (Max Planck Institute for Biophysical Chemistry), Dr Julian Sachs (University of Washington), Dr Jane Stout (Indiana University), Dr Torsten Wittmann (University of California, San Francisco), Dr Jan Peters and Dr Heidemarie Hurtl (Research Institute of Molecular Pathology, Vienna), Dr Jorg Reichwein (ATTO-TEC GmbH, Seigen Germany), Dr Alexia Loynton-Ferrand (University of Basel), Dr Kieran Boyle (University of Glasgow), Christopher F Hansen, Dr Carrine Blank (University of Montana), Dr Ewald R Weibel (University of Bern), Libby Sakker, Shane Williams (Arctic Heat), Stan Sheldon, Andrew Lock OAM, Dr Christine Cooper (Curtin University), Dr Fiona Wood (Royal Perth Hospital), Harry Chartomatsidis (Theo's Fish Bar) and Jethro Harcourt.

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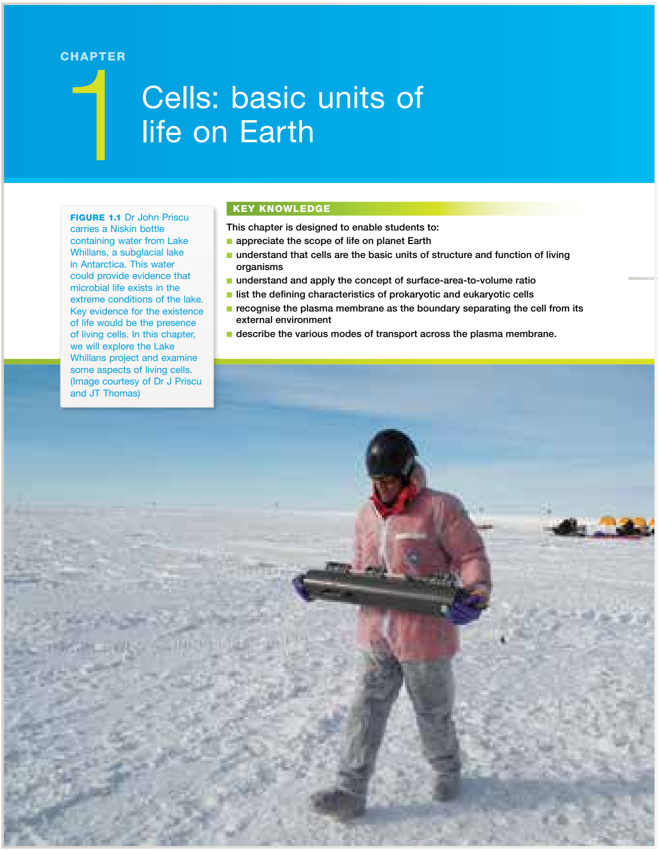
Nature of Biology 1 VCE Units 1 and 2 has the following features.



CHAPTER 1

Cells: basic units of life on Earth

FIGURE 1.1 Dr John Priscu carries a Niskin bottle containing water from Lake Whillans, a subglacial lake in Antarctica. This water could provide evidence that microbial life exists in the extreme conditions of the lake. Key evidence for the existence of life would be the presence of living cells. In this chapter, we will explore the Lake Whillans project and examine some aspects of living cells. (Image courtesy of Dr J Priscu and JT Thomas)

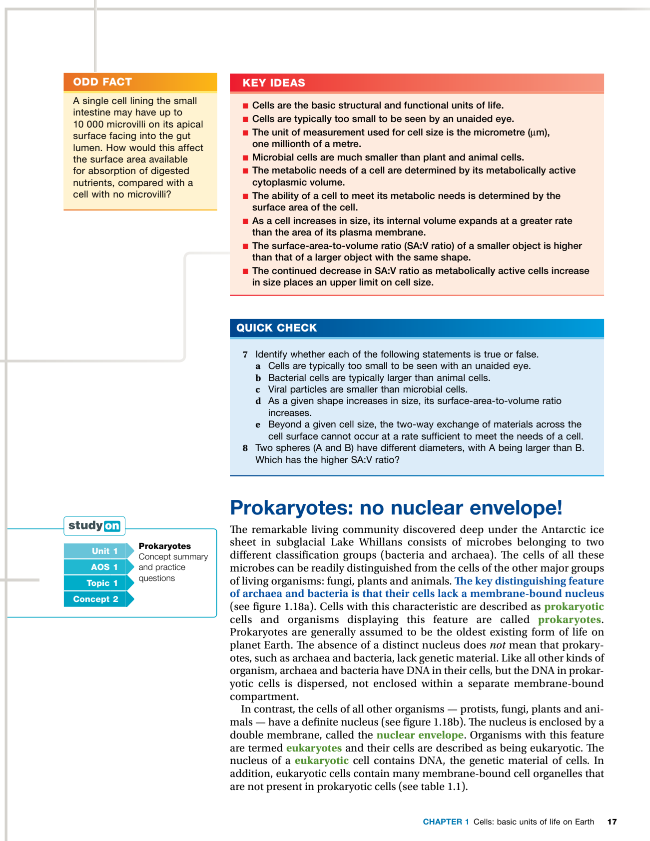
KEY KNOWLEDGE

This chapter is designed to enable students to:

- appreciate the scope of life on planet Earth
- understand that cells are the basic units of structure and function of living organisms
- understand and apply the concept of surface-area-to-volume ratio
- list the defining characteristics of prokaryotic and eukaryotic cells
- recognise the plasma membrane as the boundary separating the cell from its external environment
- describe the various modes of transport across the plasma membrane.

An overview of the Key knowledge and outcomes addressed in this chapter

Odd facts provide real-life, engaging, biological examples.



ODD FACT

A single cell lining the small intestine may have up to 10 000 microvilli on its apical surface facing into the gut lumen. How would this affect the surface area available for absorption of digested nutrients, compared with a cell with no microvilli?

KEY IDEAS

- Cells are the basic structural and functional units of life.
- Cells are typically too small to be seen by an unaided eye.
- The unit of measurement used for cell size is the micrometre (μm), one millionth of a metre.
- Microbial cells are much smaller than plant and animal cells.
- The metabolic needs of a cell are determined by its metabolically active cytoplasmic volume.
- The ability of a cell to meet its metabolic needs is determined by the surface area of the cell.
- As a cell increases in size, its internal volume expands at a greater rate than the area of its plasma membrane.
- The surface-area-to-volume ratio (SA:V ratio) of a smaller object is higher than that of a larger object with the same shape.
- The continued decrease in SA:V ratio as metabolically active cells increase in size places an upper limit on cell size.

QUICK CHECK

7 Identify whether each of the following statements is true or false.
  a Cells are typically too small to be seen with an unaided eye.
  b Bacterial cells are typically larger than animal cells.
  c Viral particles are smaller than microbial cells.
  d As a given shape increases in size, its surface-area-to-volume ratio increases.
  e Beyond a given cell size, the two-way exchange of materials across the cell surface cannot occur at a rate sufficient to meet the needs of a cell.
8 Two spheres (A and B) have different diameters, with A being larger than B. Which has the higher SA:V ratio?

studyon

Unit 1 | AOS 1 | Topic 1 | Concept 2

Prokaryotes Concept summary and practice questions

Prokaryotes: no nuclear envelope!

The remarkable living community discovered deep under the Antarctic ice sheet in subglacial Lake Whillans consists of microbes belonging to two different classification groups (bacteria and archaea). The cells of all these microbes can be readily distinguished from the cells of the other major groups of living organisms: fungi, plants and animals. **The key distinguishing feature of archaea and bacteria is that their cells lack a membrane-bound nucleus** (see figure 1.18a). Cells with this characteristic are described as **prokaryotic** cells and organisms displaying this feature are called **prokaryotes**. Prokaryotes are generally assumed to be the oldest existing form of life on planet Earth. The absence of a distinct nucleus does *not* mean that prokaryotes, such as archaea and bacteria, lack genetic material. Like all other kinds of organism, archaea and bacteria have DNA in their cells, but the DNA in prokaryotic cells is dispersed, not enclosed within a separate membrane-bound compartment.

In contrast, the cells of all other organisms — protists, fungi, plants and animals — have a definite nucleus (see figure 1.18b). The nucleus is enclosed by a double membrane, called the **nuclear envelope**. Organisms with this feature are termed **eukaryotes** and their cells are described as being eukaryotic. The nucleus of a **eukaryotic** cell contains DNA, the genetic material of cells. In addition, eukaryotic cells contain many membrane-bound cell organelles that are not present in prokaryotic cells (see table 1.1).

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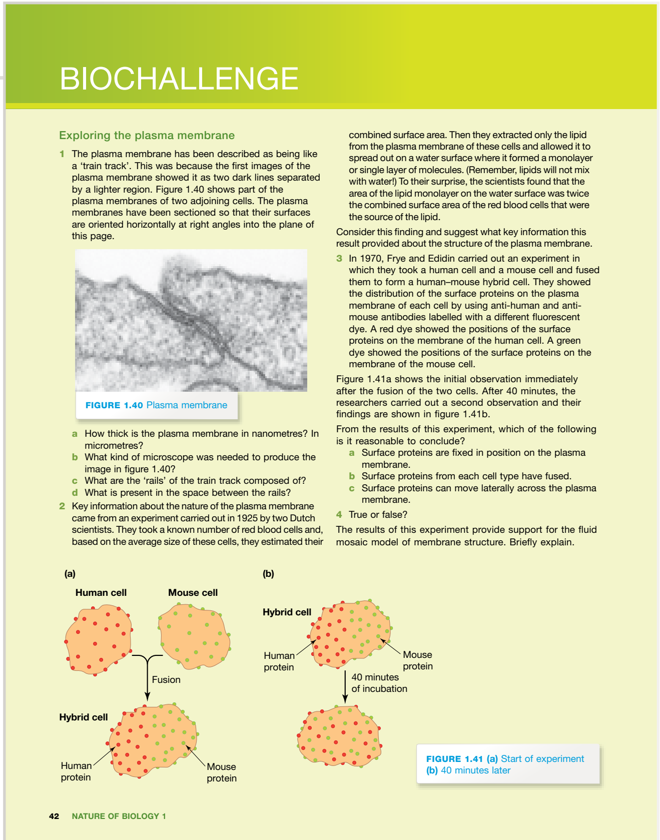
Key ideas panels provide a summary of the main points covered in this section. These are followed by Quick check revision questions.

References to studyON summary screens encapsulate key knowledge and provide questions with answers and worked solutions, to reinforce learning.

Biochallenge sections focus on applying knowledge in response to visual stimuli and data.



BIOCHALLENGE

Exploring the plasma membrane

1 The plasma membrane has been described as being like a 'train track'. This was because the first images of the plasma membrane showed it as two dark lines separated by a lighter region. Figure 1.40 shows part of the plasma membranes of two adjoining cells. The plasma membranes have been sectioned so that their surfaces are oriented horizontally at right angles into the plane of this page.

FIGURE 1.40 Plasma membrane

a How thick is the plasma membrane in nanometres? In micrometres?
b What kind of microscope was needed to produce the image in figure 1.40?
c What are the 'rails' of the train track composed of?
d What is present in the space between the rails?

2 Key information about the nature of the plasma membrane came from an experiment carried out in 1925 by two Dutch scientists. They took a known number of red blood cells and, based on the average size of these cells, they estimated their combined surface area. Then they extracted only the lipid from the plasma membrane of these cells and allowed it to spread out on a water surface where it formed a monolayer or single layer of molecules. (Remember, lipids will not mix with water!) To their surprise, the scientists found that the area of the lipid monolayer on the water surface was twice the combined surface area of the red blood cells that were the source of the lipid.

Consider this finding and suggest what key information this result provided about the structure of the plasma membrane.

3 In 1970, Frye and Edidin carried out an experiment in which they took a human cell and a mouse cell and fused them to form a human–mouse hybrid cell. They showed the distribution of the surface proteins on the plasma membrane of each cell by using anti-human and anti-mouse antibodies labelled with a different fluorescent dye. A red dye showed the positions of the surface proteins on the membrane of the human cell. A green dye showed the positions of the surface proteins on the membrane of the mouse cell.

Figure 1.41a shows the initial observation immediately after the fusion of the two cells. After 40 minutes, the researchers carried out a second observation and their findings are shown in figure 1.41b.

From the results of this experiment, which of the following is it reasonable to conclude?
a Surface proteins are fixed in position on the plasma membrane.
b Surface proteins from each cell type have fused.
c Surface proteins can move laterally across the plasma membrane.

4 True or false?

The results of this experiment provide support for the fluid mosaic model of membrane structure. Briefly explain.

FIGURE 1.41 (a) Start of experiment (b) 40 minutes later

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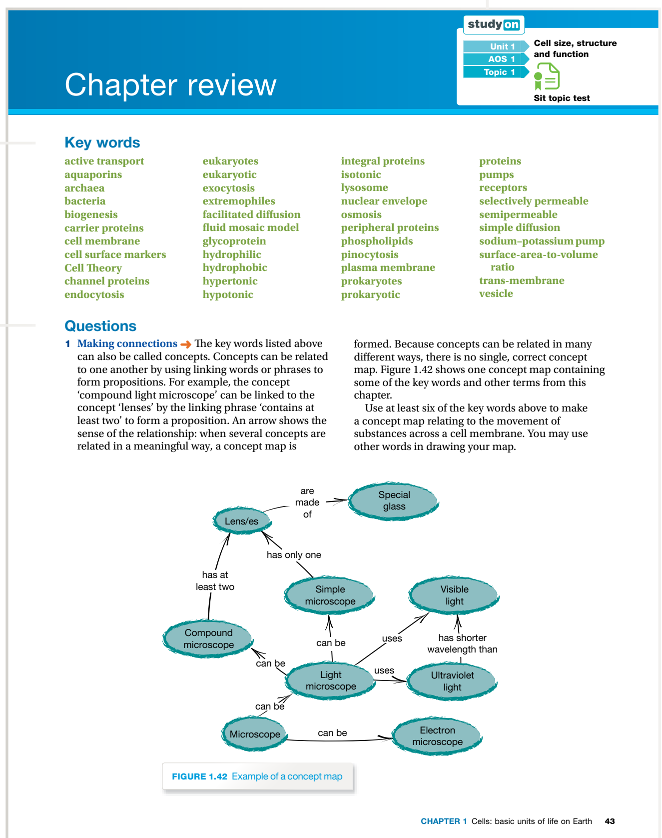
The studyON topic review has additional multiple choice, short answer and extended response questions; these are different to the end-of-chapter review questions.

A list of the key words used in the chapter to enhance the vocabulary of the student is provided.

Chapter review questions check and challenge students' understanding.



Chapter review

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Unit 1
AOS 1
Topic 1
Cell size, structure and function
Sit topic test

Key words

active transport
aquaporins
archaea
bacteria
biogenesis
carrier proteins
cell membrane
cell surface markers
Cell Theory
channel proteins
endocytosis
eukaryotes
eukaryotic
exocytosis
extremophiles
facilitated diffusion
fluid mosaic model
glycoprotein
hydrophilic
hydrophobic
hypertonic
hypotonic
integral proteins
isotonic
lysosome
nuclear envelope
osmosis
peripheral proteins
phospholipids
pinocytosis
plasma membrane
prokaryotes
prokaryotic
proteins
pumps
receptors
selectively permeable
semipermeable
simple diffusion
sodium–potassium pump
surface-area-to-volume ratio
trans-membrane
vesicle

Questions

1 **Making connections** → The key words listed above can also be called concepts. Concepts can be related to one another by using linking words or phrases to form propositions. For example, the concept 'compound light microscope' can be linked to the concept 'lenses' by the linking phrase 'contains at least two' to form a proposition. An arrow shows the sense of the relationship: when several concepts are related in a meaningful way, a concept map is formed. Because concepts can be related in many different ways, there is no single, correct concept map. Figure 1.42 shows one concept map containing some of the key words and other terms from this chapter.

Use at least six of the key words above to make a concept map relating to the movement of substances across a cell membrane. You may use other words in drawing your map.

FIGURE 1.42 Example of a concept map

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CHAPTER

1 Cells: basic units of life on Earth

KEY KNOWLEDGE

This chapter is designed to enable students to:

- appreciate the scope of life on planet Earth
- understand that cells are the basic units of structure and function of living organisms
- understand and apply the concept of surface-area-to-volume ratio
- list the defining characteristics of prokaryotic and eukaryotic cells
- recognise the plasma membrane as the boundary separating the cell from its external environment
- describe the various modes of transport across the plasma membrane.

FIGURE 1.1 Dr John Priscu carries a Niskin bottle containing water from Lake Whillans, a subglacial lake in Antarctica. This water could provide evidence that microbial life exists in the extreme conditions of the lake. Key evidence for the existence of life would be the presence of living cells. In this chapter, we will explore the Lake Whillans project and examine some aspects of living cells. (Image courtesy of Dr J Priscu and JT Thomas)

Searching for life

Life abounds on planet Earth. In every habitat on this planet where life exists, living organisms are built of one or more cells.

Living organisms can exist only where:

- an **energy source** is available that can be trapped and utilised by an organism for metabolic processes that maintain its living state
- **liquid water** is available to allow biochemical reactions to occur, and to dissolve chemicals and transport them both within cells and to and from cells
- **the chemical building blocks required for life** are available for use by an organism in cellular repair, growth and reproduction. These chemical building blocks include carbon, oxygen, nitrogen and hydrogen, and each is able to form chemical bonds with other elements (see Odd fact). Carbon, in particular, is the most versatile chemical building block, as it can bond with many other elements, forming a variety of complex biomolecules, including long chains.
- **stable environmental conditions exist** within the range of tolerance of an organism, such as pressure, temperature, light intensity, pH and salinity.

Where these conditions are met, living organisms can use energy to perform the complex set of chemical transformations (metabolic activities) within their cells that sustains their living state. These activities include not only capturing energy but also taking up nutrients and water and removing wastes, so that their internal environment is kept within narrow limits.

ODD FACT

Carbon (C) atoms can each form 4 bonds, oxygen (O) can form 2 bonds and hydrogen (H) can form 1 bond.

Provided the above conditions can be met, life is possible even in extreme and hostile environments, such as:

- around superheated hydrothermal vents at crushing pressures deep in the mid-ocean (the world record holder is an archaeon that survives at high pressure and temperatures of 122 °C)
- in volcanic hot springs waters
- kilometres below the Earth's surface in mines
- in very acidic or very alkaline or extremely salty, or even radioactive bodies of water (see figure 1.2).

FIGURE 1.2 The Paralana radioactive hot springs near Arkaroola in the Flinders Ranges, South Australia. These radioactive hot springs are one of only three radioactive hot springs in the world. The waters are hot from the heat produced by the decay of underlying uranium-rich rocks that emit gamma radiation, and the water contains radon, a highly radioactive gas. Several microbial species including cyanobacteria thrive in these radioactive waters.

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Weblink
Extreme Slime: a *Catalyst* story

Organisms that live in these extreme environments are termed **extremophiles**. Most commonly, they are unicellular microbes — **bacteria** and **archaea**. Until the late 1970s all microbes were classified as bacteria. However, the microbiologist Carl Woese (1928–2012) was the first to recognise that, based on many biochemical differences, the group once known as 'bacteria' included two different groups of microbes. Members of this new group of microbes were given the label 'archaea' to differentiate them from classical bacteria.

Given the existence of extremophiles in many harsh environments, one group of scientists set out to answer the question:

> Could living organisms thrive under nearly a kilometre of ice sheet in Antarctica in a frigid environment, in complete darkness and having been isolated from direct contact with the atmosphere, probably for thousands of years?

The answer to this question was to be found at Lake Whillans.

Reaching Lake Whillans

It is 28 January 2013. A scientist walks across the icy surface of Antarctica carrying a specialised container, known as a Niskin bottle, with its precious contents (refer to figure 1.1). (A Niskin bottle is a specialised water sampler that consists of an open tube with valves at each end that can be closed by remote control.) The scientist is Dr John Priscu, chief scientist for the WISSARD (**W**hillans **I**ce **S**tream **S**ubglacial **A**ccess **R**esearch **D**rilling) project. The Niskin bottle that he carries contains a sample of water collected from Lake Whillans.

Collecting water from a lake sounds like an easy task — just toss an empty container on a rope into a lake and pull the container out, full of water. However, this was not the case at Lake Whillans.

Obtaining a water sample from this lake was an enormous challenge because Lake Whillans is a subglacial lake in Antarctica and is buried under the pressure of an 800-metre-thick layer of ice. The lake is cold, is in complete darkness and, for at least tens of thousands of years, has been isolated from direct contact with the atmosphere (see figure 1.3a & b). The team that faced the challenge of reaching the lake comprised 50 scientists, drillers, technicians and other support staff. Not only did the team have to reach the lake, they then had to avoid introducing any contamination from the surface or the overlying ice into the lake.

How can subglacial water lakes exist in Antarctica? The water in these lakes remains liquid because of the flow of heat from the Earth's interior and the overlying pressure of the ice sheet. The heat causes very slow melting at the base of the ice sheet and the resulting water drips into the lake. Air bubbles trapped in the melting ice supply oxygen to the lake.

One of the questions that the scientists set out to answer was: does life exist in the extreme conditions of Lake Whillans? **To answer 'Yes' to this question requires demonstrating the key evidence for the existence of life, that is, the presence of living cells.** Evidence of living cells comes from demonstrating the existence of cells that show metabolic activity and are capable of self-replication.

In the process of drilling into the lake the scientists took extreme care to ensure that:

- the drilling equipment, Niskin bottles and other equipment that would enter the borehole and penetrate the lake were ultra-clean. This was achieved by sterilising this equipment using intense UV radiation and hydrogen peroxide spray (see figure 1.4). Following decontamination, the equipment was enclosed in sterile plastic wrapping for transport to the drilling site.
- the hot water used to drill through the ice sheet was sterilised using ultra-filtration and microbe-killing UV radiation.

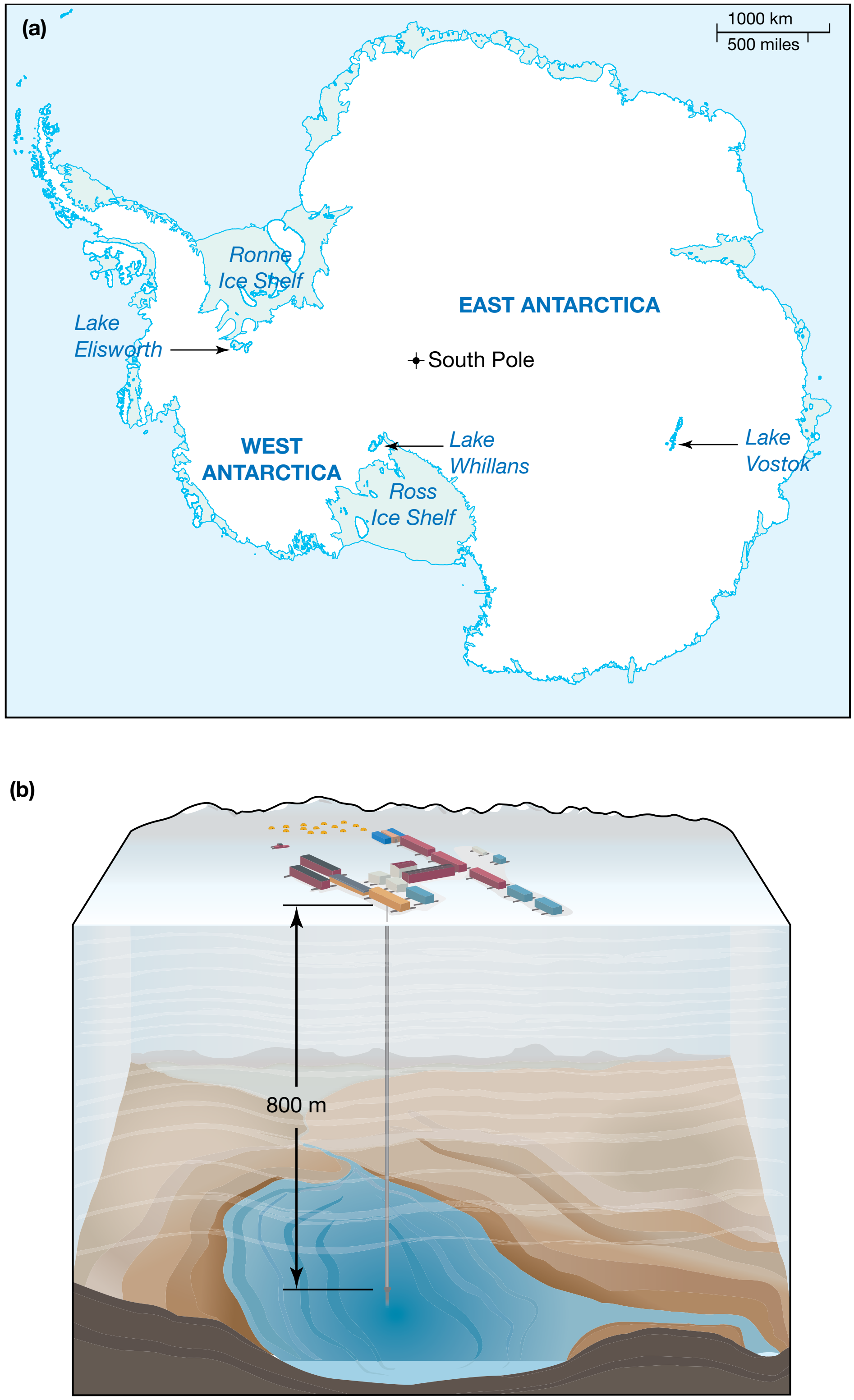

FIGURE 1.3 **(a)** Lake Whillans is located near the edge of the Ross Ice Shelf, 640 km from the South Pole. The lake is one of hundreds of subglacial lakes that have been identified in Antarctica using techniques such as air-borne radar and satellite-based radar altimetry. **(b)** Lake Whillans lies under an ice sheet that is 800 m thick.

Why were these precautionary steps taken? These rigorous sterile precautions were designed to prevent any cells from the surface or the overlying ice reaching the lake. This ensured that any living cells found in the samples from the lake originated from the lake itself and were not introduced contaminant cells from the surface.

Pressurised hot water was used to drill through the 800 m of ice overlying Lake Whillans. After seven days of drilling, the last layers of ice were broken

FIGURE 1.4 A piece of equipment is sterilised by spraying with hydrogen peroxide. This chemical is a powerful oxidising agent that acts as a biocide, or cell killer. Why was this precaution taken?

through and the lake was reached through a 60-centimetre-wide borehole. A Niskin bottle was inserted down the borehole into the water to obtain a water sample. The valves on the Niskin bottle were remotely closed and the bottle was raised to the surface (see figure 1.5a). Had the valves on the Niskin bottle closed? Was there a sample of lake water in the bottle? A quick check showed that the valves had closed, trapping the first water sample from Lake Whillans.

In total, the scientific team collected about 30 litres of lake water and eight samples of sediment from the lake bottom. These samples would allow the scientists to discover if living organisms were present in Lake Whillans.

The first sample of lake water from the Niskin bottle was carefully carried to a temporary field laboratory. Scientists extracted samples of lake water and began their examination (see figure 1.5b).

FIGURE 1.5 **(a)** Scientists Brent Christner (left) and John Priscu (right) retrieve the first water-sampling Niskin bottle from the borehole in subglacial Lake Whillans. (Image courtesy of JT Thomas) **(b)** Scientists processing water samples from Lake Whillans in the field laboratory

Signs of life under the ice?

The first test was to add a DNA-sensitive dye to a sample of the lake water. DNA is the genetic material of all cells. If cells were present in the lake water, this DNA-sensitive dye would reveal them as glowing green dots when viewed under a microscope. Imagine the scientists' delight when this test gave a positive result (see figure 1.6a). The presence of cells was a strong indication that microbial life existed in Lake Whillans … but were they living cells?

Scanning electron microscopy of the lake water samples showed that the microbial cells varied in shape and included rod-shaped, curved and spherical microbial cells. Figure 1.6b, for example, shows a spherical microbial cell against a background of sediment particles.

However, it was necessary to confirm that the cells were living. Living cells carry out a diverse range of metabolic activities, including uptake of nutrients, and synthesising DNA and proteins. When cells from samples of lake water were exposed to thymidine, one of the building blocks of DNA, the cells took up this compound and incorporated it into their DNA. This observation confirmed that the cells were living and undergoing cell division. Similar confirmation that the cells were metabolically active came from showing that they were synthesising proteins.

Active cell division of the lake microbes was revealed when samples of lake water were plated onto a nutrient medium and incubated. Individual microbial cells, too small to be seen with an unaided eye, underwent multiple cycles of cell division and produced visible colonies comprising millions of cells (see figure 1.6c).

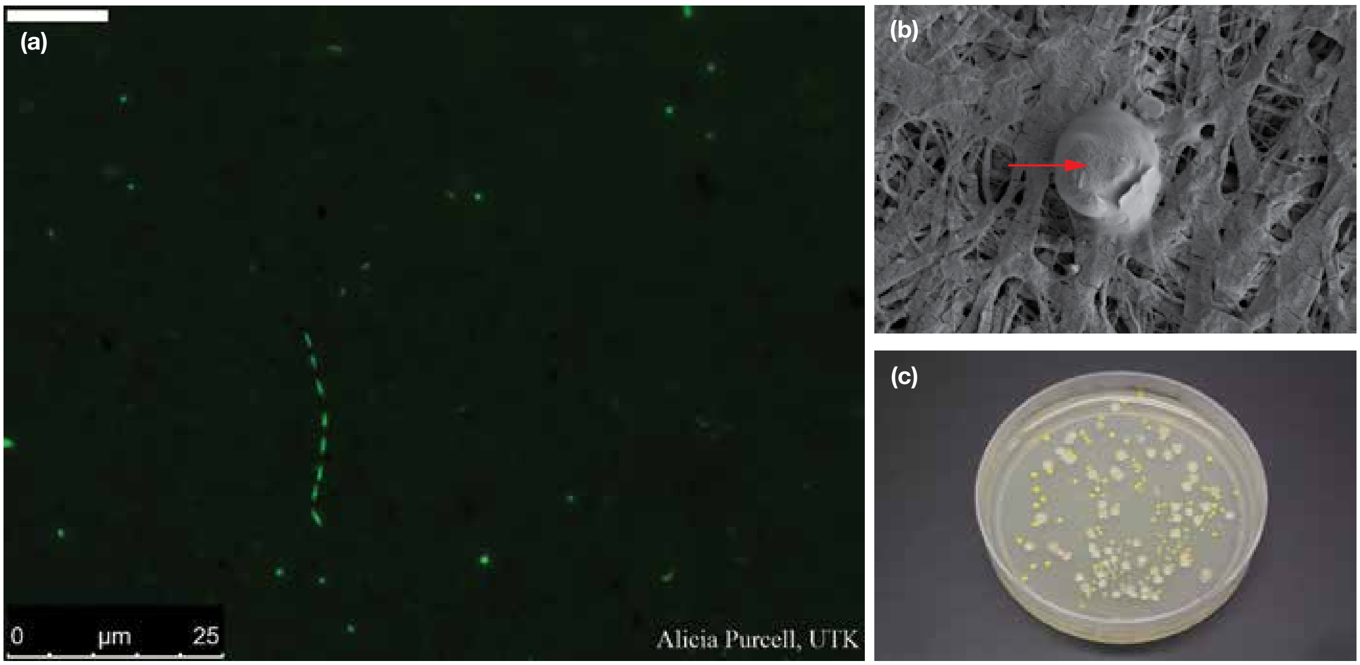

FIGURE 1.6 **(a)** Epifluorescence microscopy image of DNA-containing microbial cells (green) from the subglacial Lake Whillans water sample (Image courtesy of Dr A Purcell) **(b)** Scanning electron microscope image showing a coccoid-shaped microbial cell with an attached sediment particle from the subglacial Lake Whillans water column (Image courtesy of Trista Vick-Majors, Priscu Research Group, Montana State University) **(c)** Microbial colonies produced by multiple divisions of microbial cells from subglacial Lake Whillans. Different colours and shapes of the colonies indicate different microbial species. (Image courtesy of Dr B Christner)

After showing that living microbial cells existed in Lake Whillans, the scientists then set out to identify the different species. Back in the United States they used DNA sequencing techniques and identified more than 3900 different microbial species — bacteria and archaea — as part of the living community. The discovery of a living microbial community that obtains energy and the chemical building blocks required for life in the cold, dark environment of subglacial Lake Whillans is significant because:

- it provides the first unequivocal evidence of a complex ecosystem in a subglacial lake under the Antarctic ice sheet
- it highlights the possibility that life might exist beyond planet Earth, such as on distant ice-covered bodies in our solar system that conceal oceans below their frozen surfaces.

Life beyond Earth?

The discovery of a diverse microbial ecosystem hidden deep under the Antarctic ice sheet and away from sunlight raises the possibility that life may exist beyond planet Earth. Possible locations for extraterrestrial life include ice-covered moons that circle planets in our solar system. One such location is Europa, one of the large moons of the giant planet Jupiter.

Europa, with a diameter of 3144 kilometres, is a little smaller than Earth's moon (see figure 1.7a). Europa is a frozen world with an ice-covered surface, many kilometres thick and criss-crossed by long fractures (see figure 1.7b). In the period from 1996–99 the *Galileo* spacecraft made 11 flybys past Europa, capturing high-resolution images of the moon's surface and using its remote-sensing instruments to gain information about Europa. *Galileo* gathered strong evidence of a possible sub-surface ocean of salty water on Europa that is sandwiched between the moon's icy surface and its underlying rocky core. The surface of Europa constantly stretches and relaxes in tidal movements as it moves in an elliptical orbit around Jupiter every 3.5 days. The constant flexing of the surface generates heat that would keep a sub-surface ocean in the liquid state.

ODD FACT

The *Galileo* spacecraft was deliberately plunged into Jupiter's crushing atmosphere on 21 September 2003.

FIGURE 1.7 **(a)** Europa, a moon of Jupiter. This composite image, taken by the *Galileo* spacecraft, shows the long fractures on the moon's ice-covered surface. This ice may conceal what is regarded as 'perhaps the most promising place in our solar system beyond Earth to look for present-day environments that are suitable for life' (NASA Media Release, www.jpl.nasa.gov/news/news.php?feature=4386). **(b)** Close-up of the surface of Europa showing its fractured ice surface. The blue–white areas are pure water ice, while the ice in the reddish bands is mixed with salts such as magnesium sulfate or with sulfuric acid.

NASA: National Aeronautic and Space Administration

Dr Robert Pappalardo, a scientist from NASA, has described Europa as 'the most likely place to find life beyond Earth.' He continued:

> We think Europa is the most likely place for being habitable because of its relatively thin ice shell, its liquid ocean and that fact that it is in contact with the rock below which is geologically active . . . Europa has the right ingredients for life: it has water and the right chemical elements, as well as an environment that is probably stable over time.
>
> *Source:* As cited in *The Independent*, 15 February 2013.

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Weblink
NASA video — Europa

What might the future bring? If the presence of a sub-surface ocean on Europa is proved and if the conditions appear suitable for life, an unmanned probe might be sent to land on this moon, drill down to its ocean, sample its waters and look for signs of life. What would the most powerful signs of life be? Yes, cells.

KEY IDEAS

- On planet Earth, life exists in hostile and extreme environments and the organisms that survive there are termed extremophiles.
- For life to exist, a set of conditions must be met, including the availability of a source of energy and the presence of liquid water.
- Living cells have been found in a subglacial lake in Antarctica under hundreds of metres of ice sheet.
- The discovery of a diverse microbial ecosystem in a subglacial lake in Antarctica raises the possibility that life might exist under the surface of ice-covered moons in our solar system.
- Critical direct evidence of life (as we know it) is the presence of metabolically active cells.

QUICK CHECK

1 List the conditions that must be met for life to exist.
2 In drilling into Lake Whillans, great care was taken to ensure that the equipment that entered the borehole was sterilised. Why was this precaution taken?
3 What was the first evidence that indicated that it was possible life existed in Lake Whillans?
4 Identify the follow-up experiment that confirmed this finding.
5 What kinds of organism live in the Lake Whillans ecosystem?
6 Why is Europa, one of the moons of planet Jupiter, of interest as a possible location for life beyond planet Earth?

study on

Unit 1 | AOS 1 | Topic 1 | Concept 1

Cells: structural units of life
Concept summary and practice questions

Cells: the basic units of life

Cells are the basic structural and functional units of life, and all living organisms are built of one or more cells. Cells, with only a very few exceptions, are too small to be seen with an unaided eye. Their existence was not recognised until after the development of the first simple microscopes. This enabled the first observations of cells to be made in the 1660s. However, the recognition of cells as the basic unit of life did not occur until almost 200 years later.

1 millimetre (mm) = 1000 micrometres (μm)

1 micrometre (μm) = 1000 nanometres (nm)

study on

Unit 1 | AOS 1 | Topic 1 | Concept 4

Cell size
Concept summary and practice questions

Cells: how big?

Cells are typically microscopic (not visible with an unaided eye). Only a few single cells are large enough to be seen with an unaided human eye, for example, human egg cells with diameters about 0.1 mm and the common amoeba (*Amoeba proteus*), a unicellular organism with an average size ranging from 0.25 to 0.75 mm. (You would see an amoeba as about the size of a full stop on this page.) Contrast this with one of the smallest bacteria, *Plelagibacter ubique*, consisting of a cell just 0.2 μm diameter. How many of these bacteria could fit across an amoeba that is 0.5 mm wide?

- Most animal cells fall within the size range of 10 to 40 μm. Among the smallest human cells are red blood cells with diameters for normal cells in the range of 6 to 8 μm.

- Plant cells typically fall in the range of 10 to 100 μm.
- Microbial cells, both bacterial and archaeal, are much smaller than plant and animal cells. Most bacterial cells have diameters in the range of 0.4 to 2.0 μm and 0.5 to 5 μm in length. **On average, microbial cells are about 10 times smaller than plant and animal cells, with sizes typically in the few micrometres range.**

A *non-living* microworld exists beyond that of microbes. This is occupied by viruses that are non-cellular particles that are generally regarded as belonging to the grey area between living and non-living. Why? Because viruses do not have a cellular structure, they cannot carry out metabolic activities in isolation and they cannot self-replicate. (Viruses can replicate only inside and with the assistance of living cells.) Viruses range in diameter from 20 to 300 nanometres (nm); for example, the cold-causing rhinovirus is about 30 nm in diameter and the measles-causing virus is about 220 nm in diameter. Figure 1.8 shows a sample of the range of sizes seen in selected cells. (Other non-cellular structures are included for size comparison.)

Microbial cells are relatively much smaller than the cells of animals and plants, so some animal bacterial infections can involve the invasion of bacterial cells into the cells of the host, where they multiply. Examine figure 1.9 of a human lung fibroblast and note the presence of numerous bacterial cells in a single cell. This image highlights the size difference between microbial cells and the cells of animals (and plants).

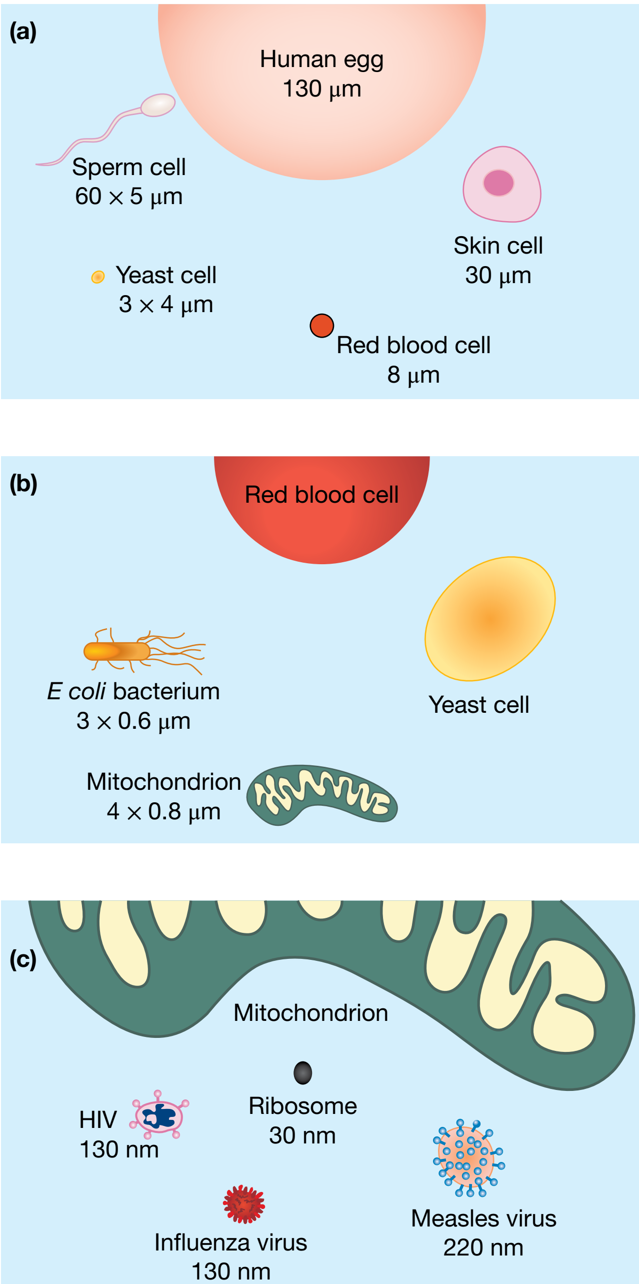
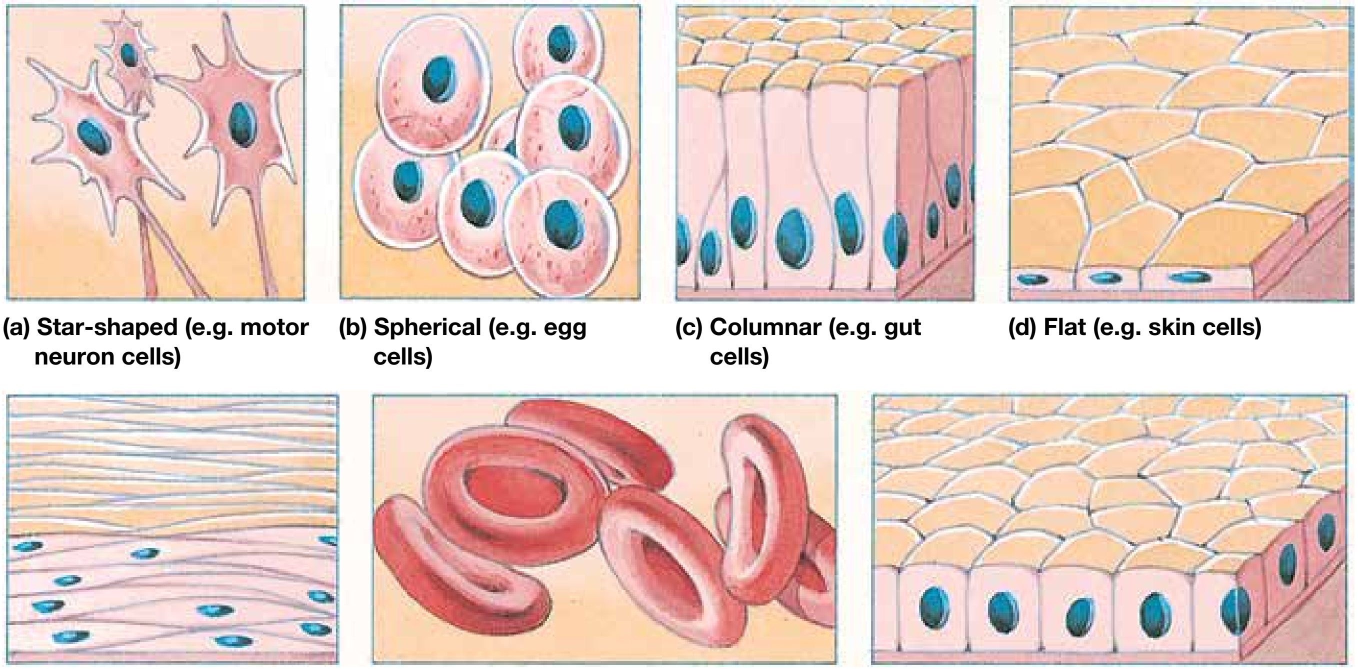


FIGURE 1.8 Diagrams, at increasing levels of magnification, showing cells, cell organelles and viruses. Note the extreme differences in size.
(a) Some human cells showing variation in cell size
(b) A bacterial cell with a mitochondrion, a cell organelle and other small cells shown for comparison
(c) A mitochondrion compared with some viruses

FIGURE 1.9 Transmission electron microscope (TEM) image of a lung fibroblast infected with many bacterial cells (shown as small dark circular and ovoid shapes). The bacteria are *Legionella pneumophila*, the cause of several infections in people, including Legionnaires' disease.

Cells: all sorts of shapes

There is no fixed shape for cells. Cells vary in shape and their shapes often reflect their functions. Figure 1.10 shows some examples of cell shapes. Scan this figure and note that some cells are thin and flattened, others are column-shaped, yet others are spherical.



(a) Star-shaped (e.g. motor neuron cells)

(b) Spherical (e.g. egg cells)

(c) Columnar (e.g. gut cells)

(d) Flat (e.g. skin cells)

(e) Elongated (e.g. human smooth muscle cells)

(f) Disc-shaped (e.g. human red blood cells)

(g) Cuboidal (e.g. human kidney cells)

FIGURE 1.10 Examples of variations in cell shape: **(a)** star-shaped **(b)** spherical **(c)** columnar **(d)** flat **(e)** elongated **(f)** disc-shaped **(g)** cuboidal

Look at figure 1.10a. Note the long axon that is a distinctive feature of motor neuron cells. These cells transmit nerve impulses from a person's spinal cord to voluntary muscles throughout the body. In this case, the shape of the nerve cell is fitted to its conductive function. Can you estimate the approximate length of a motor neuron that has its cell body in the lower spinal cord with its axon reaching to your big toe?

Look at figure 1.10e. Note the spindle-shaped smooth muscle cells. Smooth muscle cells contain special proteins that criss-cross the cell, and when these proteins contract the smooth muscle fibres shorten. The spindle shape of these cells is suited to their contractile function. Bundles of smooth muscle cells are found in the gut wall, in the walls of blood vessels, in ducts of secretory glands and in the wall of the uterus. These bundles of smooth muscle cells can generate sustained involuntary contractions in these organs.

Microbial cells also vary in shape (see figure 1.11). Note that some bacteria are rod-shaped, such as the gut-dwelling bacterium *Escherichia coli*; some are corkscrew-shaped, such as *Borrelia burgdorferi,* the causative agent of Lyme disease; while others are more or less spherical, such as *Streptococcus pneumonia*, the cause of many infections, including pneumonia.

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Motor neurons in animals, such as the giant squid (*Architeuthis* sp.), may be as long as 12 metres.

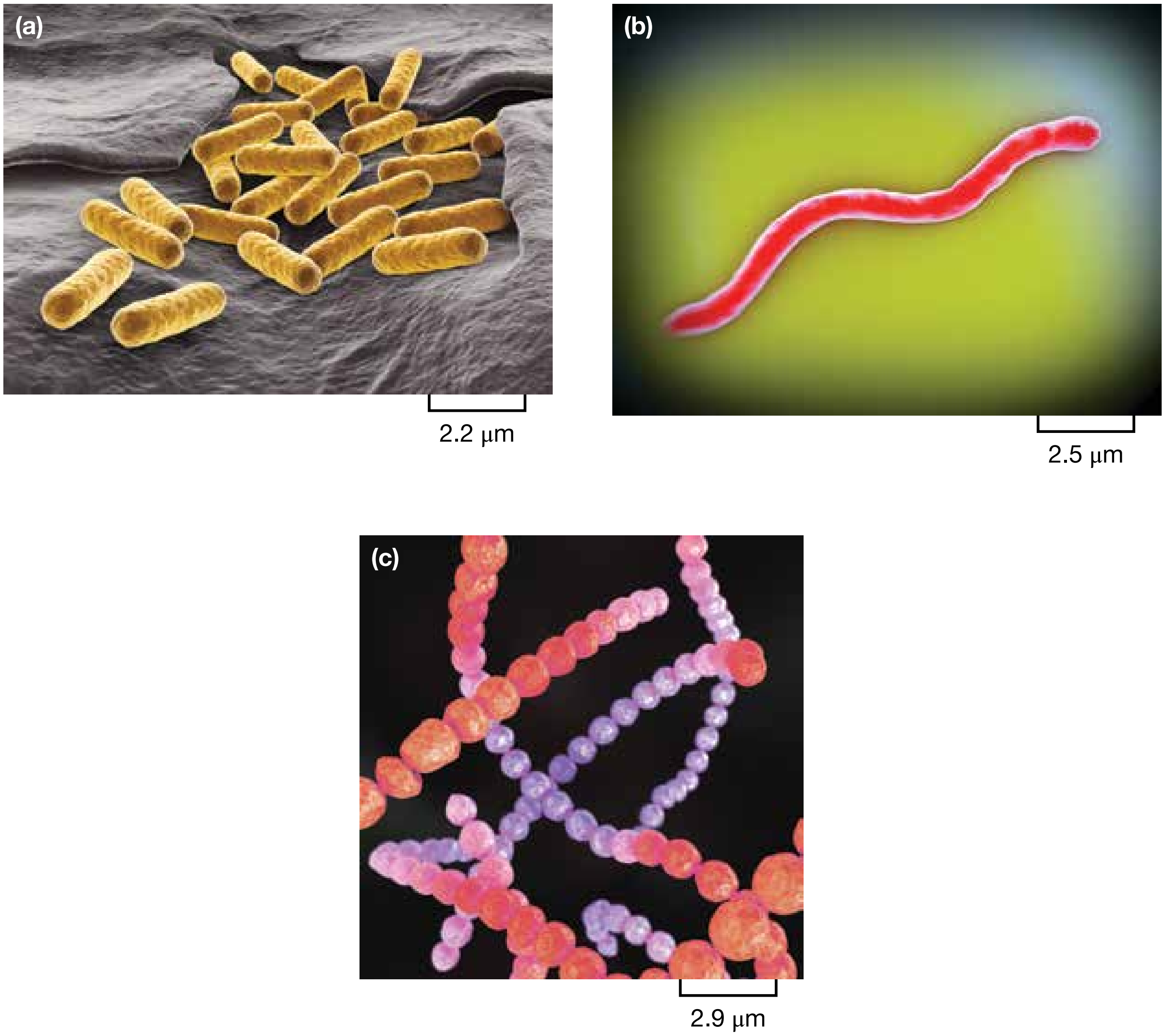
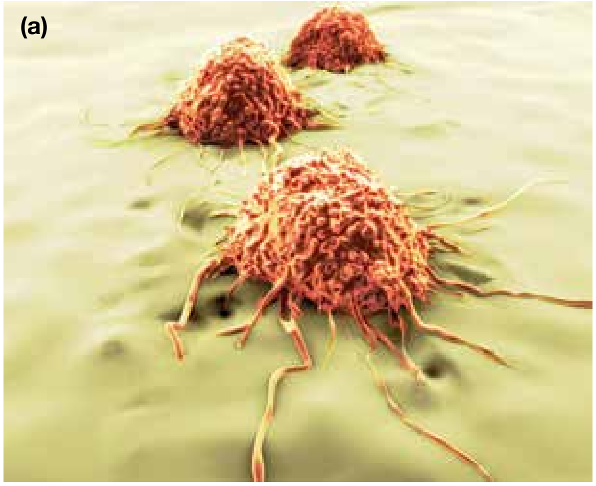


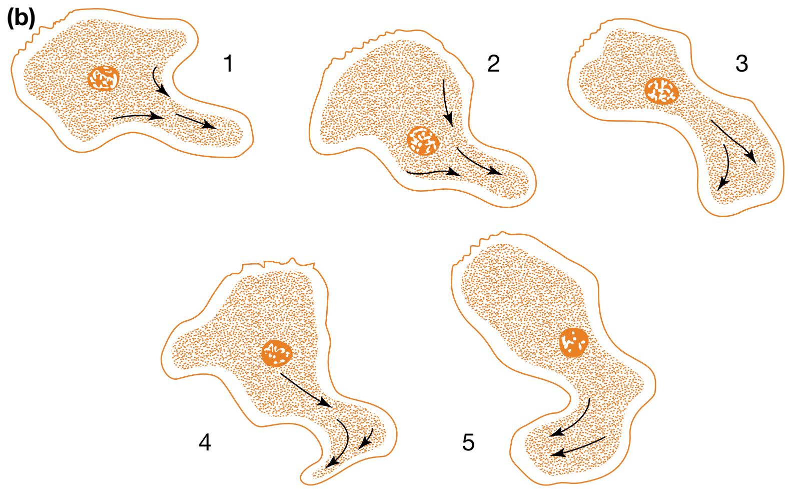
FIGURE 1.11 Bacterial cells come in many shapes. Some are **(a)** rod-shaped bacilli (singular: bacillus) **(b)** spiral-shaped and **(c)** spherical cocci (singular: coccus).

Not all cells have a fixed shape. For example, some cells are able to move actively, and these self-propelled cells do not have fixed shapes because their outer boundary is their flexible plasma membrane. So, as these cells move, their shapes change. Examples of cells capable of active self-propelled movement include:

- cancer cells that migrate into capillaries and move around the body when a malignant tumour undergoes metastasis (see figure 1.12a). The thread-like protrusions (known as filopodia) that fold out from the plasma membrane of cancer cells make a cancer cell self-mobile and able to migrate from a primary tumour and invade other tissues.
- white blood cells that can squeeze from capillaries into the surrounding tissues where they travel to attack infectious microbes (refer to figure 1.21, p. 22)
- amoebas as they move across surfaces (see figure 1.12b).

Some other cells that have a fixed shape because of the presence of a rigid cell wall outside their plasma membranes can self-propel. However, this ability depends on the presence of cilia or flagella to power their movement. For example, the green alga, *Chlamydomonas* sp., moves due to the beating of its two flagella (see figure 1.12c).





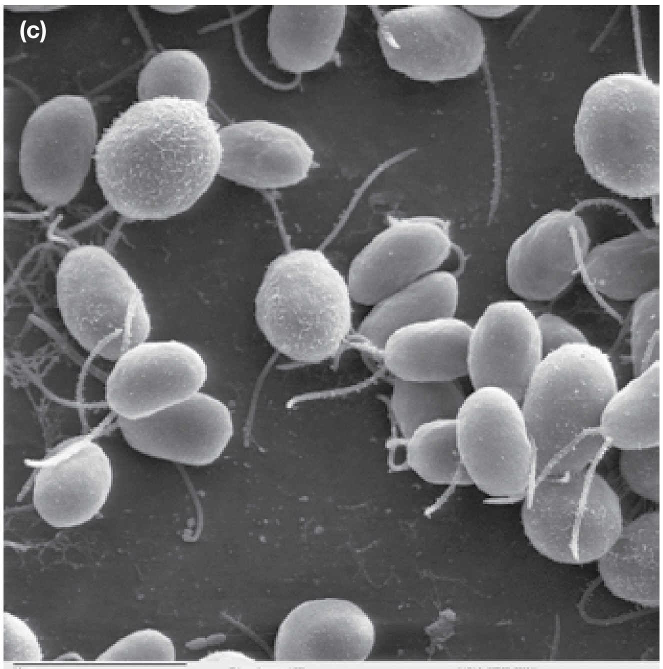


FIGURE 1.12 (a) Cancer cells. Note the many thread-like projections (filopodia) that enable these cancer cells to be mobile or self-propelling. The ability to move is an important factor in the spread of a malignant cancer. **(b)** Outlines showing the changing shape of an amoeba as it moves **(c)** Scanning EM image of *Chlamydomonas reinhardtii*, a single-celled green alga. Note the presence of two flagella that make this organism able to self-propel. What is the reason for the fixed shape of this organism? Like all algae, this organism has a rigid cell wall that defines its shape.

Cells: why so small?

Why are cells microscopically small? Would it be more efficient to have a larger macroscopic unit to carry out cellular processes rather than many smaller units occupying the same space? To answer these questions we need to look at the concept of surface-area-to-volume ratio.

Surface-area-to-volume ratio

Every living cell must maintain its internal environment within a narrow range of conditions, such as pH and the concentrations of ions and chemical compounds. At the same time, a cell must carry out a variety of functions that are essential for life. These functions include trapping a source of energy, obtaining the chemical building blocks needed for cellular repair, growth and reproduction, taking up water and nutrients, and removing wastes.

- These essential functions require a constant exchange of material between the cell and its external environment.
- The site of exchange where materials are moved into or out of a cell is the plasma membrane, also termed the cell membrane. The plasma membrane