

**MO001/4/2018**

**Animal and Plant Diversity**

**BLG1502**

**Semesters 1 & 2**

**Department of Life and Consumer Sciences**

**IMPORTANT INFORMATION**

Please register on myUnisa and activate your myLife e-mail address and ensure that you have regular access to the myUnisa module site BLG1502/17/S1 OR BLG1502/17/S2, depending on which semester you are registered for, as well as your group site.

**Note:** This is an **online module**; therefore your module is available on myUnisa. However, to support you in your studies, you will also receive certain study material in print format.

BAR CODE

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## **Preface**

Welcome to Animal and Plant Diversity (BLG1502).

This module is online, but you can also use this document for your studies. It is a convenient document that you can consult at any time, and you can make notes on it. I would nevertheless encourage you to also make use of the module site, because it has several advantages. You can access any part of the study material by clicking on the links in the table of contents of the study units (learning units), and you can communicate with your lecturer and fellow students on the course website's discussion forum.

This document contains the text of the Animal and Plant Diversity module learning units. You must definitely read learning unit 0 because it contains important information about the module. Remember to read Tutorial Letter 101, where you will find essential information about the module and the assignments.

I wish you all the best in your studies.

Your lecturer

M H Mkhombo

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<p><b>0.1</b></p>	<p><b>Getting started</b></p> <p>Welcome to Animal and Plant Diversity (BLG1502). This module is offered by Unisa's Department of Life and Consumer Sciences.</p> <p>This is an online module, which means that you will find everything you need to complete the module on the module site. Check this site regularly for updates, posted announcements and additional resources uploaded throughout the semester.</p> <p>The university's online platform, myUnisa, allows you to</p> <ul style="list-style-type: none"> <li>• submit assignments (<b>I recommend that you submit your assignment online, as this will ensure that you receive rapid feedback and comments</b>)</li> </ul>	

- access your official study material
- access the Unisa Library functions
- "chat" to your lecturer or to fellow students and participate in online discussion forums
- access a variety of learning resources

Please take some time to familiarise yourself with the site so that you get to know where the different options and resources are. I will give you more information about this later in this learning unit.

Although I really encourage you to study this module online, I realise that some of you don't have online access at all, while others may have online access only from time to time. For this reason, Unisa has provided a printed study pack for this module.

Your study material for this module consists of

- your prescribed textbook
- these learning units
- Tutorial Letter 101
- any other tutorial letters you may receive throughout the year

Details of your prescribed book are given in the **Prescribed Books** menu option, which you can access on the left-hand side of this screen, and also in Tutorial Letter 101.

Tutorial Letter 101 will be posted to you, but you can also access it on this site. Do this by clicking on **Official study material** in the menu on the left. Once there, select **Tutorial Letter 101**.

Tutorial Letter 101 is just one of the tutorial letters you will be receiving during the semester. **Please read it carefully.** You will also receive further tutorial letters shortly after the due dates for submission of the assignments; these will contain suggested solutions to the assignments.

In this learning unit, I will give you an overview of and some general information about this module. I will also tell you more about possible study strategies, how to use myUnisa and about the assessment in the module.

Click on "Next" to go to the next screen, where you will find more information about contact details.

## 0.2

### Lecturer and contact details

In this section I will give you my own contact details, as well as details of the Department of Life and Consumer Sciences at Unisa, which is the academic department that offers this module. I will also give you the university's contact details, as well as some information about the student support services at Unisa, which you are welcome to use.

Whenever you contact the university, whether in writing or by phone, always provide the **module code** and your **student number**.

If you write to Unisa, you may enclose more than one letter in an envelope, but do not direct enquiries to different departments (e.g. Despatch and Library Services) in the same letter as this will cause a delay in the replies to your enquiries. Please write a separate letter to each department and mark each letter clearly for the attention of that department. **You may not include letters to lecturers together with assignments.**

### 0.2.1

#### Lecturer and department

Lecturer: Mr Mfana Henry Mkhombo

Telephone number: +27 11 471 3921 (during office hours 8:00 – 16:00)

E-mail address: [mkhommf@unisa.ac.za](mailto:mkhommf@unisa.ac.za)

Postal address:

	<p>The Lecturer (BLG1502)</p> <p>Department of Life and Consumer Sciences</p> <p>Private Bag X6</p> <p>Florida</p> <p>1710</p> <p>The department offering this module is the Department of Life and Consumer Sciences.</p> <p>Telephone number (departmental secretary): +27 11 471 2230</p> <p>Fax number: +27 11 471 2796</p>	
<p><b>0.2.2</b></p>	<p><b>University</b></p> <p>If you need to contact the university about matters not related to the content of this module, consult <i>my Studies @ Unisa</i>. This brochure contains information on how to contact the university (e.g. to whom you can write for different queries, important telephone and fax numbers, addresses and details of the opening and closing times of particular facilities). You may access this site at <a href="http://www.unisa.ac.za/contents/study2012/docs/myStudies-Unisa-2014.pdf">www.unisa.ac.za/contents/study2012/docs/myStudies-Unisa-2014.pdf</a></p> <p>You can also use the following contact routes:</p> <ul style="list-style-type: none"> <li>• Unisa website: <a href="http://www.unisa.ac.za">http://www.unisa.ac.za</a> &amp; <a href="http://mobi.unisa.ac.za">http://mobi.unisa.ac.za</a></li> <li>• E-mail (general enquiries): <a href="mailto:info@unisa.ac.za">info@unisa.ac.za</a>.</li> </ul> <p>International students can also use the e-mail address <a href="mailto:info@unisa.ac.za">info@unisa.ac.za</a></p> <ul style="list-style-type: none"> <li>• <a href="mailto:study-info@unisa.ac.za">study-info@unisa.ac.za</a> for enquiries related to application and registration</li> <li>• <a href="mailto:assign@unisa.ac.za">assign@unisa.ac.za</a> for assignment enquiries</li> <li>• <a href="mailto:exams@unisa.ac.za">exams@unisa.ac.za</a> for examination enquiries</li> <li>• <a href="mailto:despatch@unisa.ac.za">despatch@unisa.ac.za</a> for study material enquiries</li> <li>• <a href="mailto:finan@unisa.ac.za">finan@unisa.ac.za</a> for student account enquiries</li> <li>• <a href="mailto:myUnisaHelp@unisa.ac.za">myUnisaHelp@unisa.ac.za</a> for assistance with myUnisa</li> <li>• <a href="mailto:myLifeHelp@unisa.ac.za">myLifeHelp@unisa.ac.za</a> for assistance with myLife e-mail accounts</li> <li>• SMS 32695 – South Africa only</li> </ul> <p>You will receive an auto response SMS with the various SMS options. The cost per SMS is R1,00.</p> <ul style="list-style-type: none"> <li>• Fax 012 429 4150</li> </ul>	
<p><b>0.2.3</b></p>	<p><b>Student support services</b></p> <p>For information about the various student support systems and services available at Unisa (e.g. student counselling, tutorial classes, language support), consult <i>my Studies @ Unisa</i> at <a href="http://www.unisa.ac.za/contents/study2012/docs/myStudies-Unisa-2014.pdf">www.unisa.ac.za/contents/study2012/docs/myStudies-Unisa-2014.pdf</a></p> <ul style="list-style-type: none"> <li>• <b>Fellow students</b></li> </ul>	

It's always a good idea to have contact with fellow students. You can do this using the **Discussion** menu option on myUnisa. You can also use the Discussion forum to find out whether there are students in your area who would like to form study groups.

- **Library**

*my Studies @ Unisa* lists all the services offered by the Unisa Library at the site [www.unisa.ac.za/contents/study2012/docs/myStudies-Unisa-2014.pdf](http://www.unisa.ac.za/contents/study2012/docs/myStudies-Unisa-2014.pdf)

To log in to the Library website, you need to provide your login details, i.e. your student number and your myUnisa password, in order to access the Library's online resources and services. This will enable you to

- request library material
- view and renew your library material
- use the Library's e-resources

- **Unisa Directorate for Counselling and Career Development (DCCD)**

DCCD supports prospective and registered students before, during and after their Unisa studies. There are resources on its website (<http://www.unisa.ac.za/Default.asp?Cmd=ViewContent&ContentID=15974>), and also printed booklets available to assist you with

- career advice and how to develop your employability skills
- study skills
- academic literacy (reading, writing and quantitative skills)
- assignment submission
- exam preparation

- **Advocacy and Resource Centre for Students with Disabilities (ARCSWiD)**

You will find more information about this centre on its web page at <http://www.unisa.ac.za/default.asp?Cmd=ViewContent&ContentID=19553>. You can also contact Ms Vukati Ndlovu on 012 441 5470.

0.3

### **Purpose and outcomes of this module**

This module forms part of the BSc Life Sciences. It will focus on the fundamental concepts and theory relating to the biology of plants and animals in the field of biological sciences. Students who complete this module can also explain the origins of diversity and can justify the ecological importance of plants and animals in an interrelated ecosystem.

More specifically, after completing the module, you should be able to

- describe the structure, composition and function of prokaryotic cell walls
- draw a flow diagram of the life cycles, indicating the gamete and sporophyte generation
- identify and discuss the structure of the three basic organs of a plant body, namely the stems, leaves and roots
- describe the characteristics of three tissue systems that the organs are composed of, namely dermal, vascular and ground tissue
- define and name the classes of essential nutrients
- explain the major functions of the organs that make up the mammalian digestive system

The next section will give you a better idea of how the content of the module is structured and how the various ideas expressed in the learning outcomes are related.

0.4

### **How the content of this module is structured?**

This module covers a wide range of subject areas. We will start with **learning unit 1**. This unit traces the phylogeny or evolutionary history of a species or a group of species. It will teach you the principles of studying biological diversity and also how this is done.

**Learning unit 2** focuses on the aspects of prokaryotes. Prokaryotes were the earliest organisms. They have continued to adapt and evolve and have helped change the earth. In this unit we will show you their morphology and environmental importance.

In **learning unit 3** you will learn about the history of the plant kingdom, which is a story of adaptation and changing terrestrial conditions. This unit concentrates on the development of different groups of plants to live exclusively on land. Then we will look at basic patterns of plant growth.

**Learning unit 4** continues with the theme of how plants have adapted to life on land. It deals with the development of seed plants and the importance of seed plants to humans.

In **learning unit 5**, you will learn about fungi, which are responsible for recycling the organic (dead) material back to the environment in forms that other organisms can use. This unit concentrates on the general morphology of fungi and investigates two groups of fungi in particular.

In **learning unit 6**, we focus on a group of plants known as angiosperms. Angiosperms are the most widespread and economically important plants on earth. This unit introduces the structural organisation of flowering plants and their development from a single cell.

Plants have the ability to use the energy from sunlight together with CO<sub>2</sub> and to convert it to chemical energy stored in sugar. In **learning unit 7**, we will explain the process of this conversion, namely photosynthesis.

Animal form and function are major themes in biology and, to understand both, we will be examining body plans and the external environment in **learning unit 8**. After you have worked through this unit, you will have a basic knowledge of animal structure and function that will enable you to understand the more complex bodily functions of animals.

In **learning unit 9**, you will learn that every mealtime is a reminder that we are heterotrophs who depend on a regular supply of food derived from other organisms. A balanced diet provides fuel for cellular work, as well as all the materials the body needs to construct its own organic molecules. In this unit we will examine the nutritional requirements of animals and look at some of the diverse adaptations used by animals to obtain and process food.

In **learning unit 10**, you will realise that every organism must exchange materials and energy with its environment and that this exchange ultimately occurs at cellular level. In this unit you will learn about the mechanisms of internal transport in animals.

**Learning unit 11** deals with an animal's defences. An animal has to defend itself against a variety of pathogens. There are three cooperative lines of defence that counter the threat of pathogens. The first line of non-specific (innate) defence is external, and consists of epithelial tissues that cover and line our bodies. The second, which is triggered by chemical signals, involves phagocytic cells and antimicrobial proteins that indiscriminately attack invaders. The third line of defence is the immune system, which comes into play simultaneously with the second line of defence. In this unit we examine how an animal's non-specific and specific defences work together to protect the body from invaders.

In **learning unit 12**, you will see that one of the most remarkable characteristics of animals is that they can maintain physiologically favourable internal environments even when external conditions undergo dramatic shifts that would be lethal to individual cells. Animals' ability to regulate their internal environment is called homeostasis. In this unit, we focus on thermoregulation, water balance and excretion.

Now that you have a better idea of how the module is structured, let's look at what your studies will involve.

0.5

### Learning resources

Your main learning resources for this module will be your prescribed textbook and the learning units. These resources will be supported by tutorial letters.

The prescribed textbook that you need to use in conjunction with the online material is as follows:

*Biology: a global approach*, 10th edition, 2015, by NA Campbell, JB Reece, LS Urry, ML Cain, SA Wasserman, PV Minorsky & RB Jackson, published by Pearson Benjamin Cummings (San Francisco). ISBN-10:1-292-00865-



2 or ISBN-13: 978-1-292-00865-3. If you cannot get hold of the 10th edition, you can buy the 9th or 8th edition. The two editions are very close to the 10th edition.

You will find more details about the textbook in the menu option **Prescribed books** to the left of this screen, and also in Tutorial Letter 101.

The textbook is a comprehensive guide that covers a large scope in the field of plants and animals, such as plant anatomy and physiology, taxonomy, plant systematics, invertebrates, animal structure and function, animal nutrition, circulation and gas exchange. You don't have to learn everything in the textbook, so please follow the guidelines I will be giving you in terms of what to study. Also, use the online learning material to guide you in what you need to learn. You will need to study the chapters listed at the beginning of each learning unit and any recommended reading sections. If you find a topic particularly interesting, you're very welcome to do further reading about it.

For the sake of convenience, in the learning units I will refer to the textbook as "Campbell et al (2015)".

## 0.6

### Study plan

Consult *my Studies @ Unisa* for suggestions on general time management and planning skills. Access this at [www.unisa.ac.za/contents/study2012/docs/myStudies-Unisa-2014.pdf](http://www.unisa.ac.za/contents/study2012/docs/myStudies-Unisa-2014.pdf).

This is a semester module offered over 15 weeks and requires at least 120 hours of study time. This means that you will have to study at least 8 hours per week for this module.

Here is a suggested schedule that you could use as a **guideline** for studying this module.

ACTIVITY	HOURS
Reading and rereading Tutorial Letter 101 and learning unit 0	3
Skimming learning units and textbook, forming a thorough general impression of the whole module	5
First reading of learning units 1–12 and textbook (2 hours per learning unit)	16
In-depth study of learning units 1–12: making mind maps and summaries, and doing learning activities (10 hours per learning unit)	64
Completing two assignments (Note: Assignment 01 should take less time than Assignment 02)	14
Revising for the examination	16
Writing the examination	2
Total	120

This schedule is an example of how you could structure your study plan.

Week	Activity (each week represents 8 hours of study time)
1 (January/July)	<ul style="list-style-type: none"> <li>Read and reread Tutorial Letter 101 and learning unit (LU) 0</li> <li>Skim the learning units and textbook, forming a thorough general impression of the whole module</li> </ul>
2	Read through the learning units and textbook and identify all key areas
3	
4	Study LU 1-6 in depth (make mind maps and summaries and do learning activities)
5	

6	Complete and submit Assignment 01 (depending on how you will submit the completed assignment, allow sufficient time for the assignment to reach Unisa on or before the due date)
7	<ul style="list-style-type: none"> <li>• In-depth study of LU 6-8 (make mind maps and summaries and do learning activities)</li> <li>• If possible, participate in the online discussion activities</li> </ul>
8	
9	
10	Complete and submit Assignment 02 (depending on how you will submit the completed assignment, allow sufficient time for the assignment to reach Unisa on or before the due date)
11	<ul style="list-style-type: none"> <li>• Study LU 8-12 in depth (make mind maps and summaries and do learning activities)</li> <li>• If possible, participate in the online discussion activities</li> </ul>
12	
13	
14	Revise and prepare for exam
15 (April/October)	

#### 0.7 How should you go about studying this module?

Distance studies are unique, with particular requirements for success that you should not underestimate. Once you have received your study material, plan how you will approach and complete this module. You can use the study plan in the previous section as a guideline to draw up a reasonable study schedule to guide you through the module. Remember to take into consideration the due dates for the assignments, which I supplied in Tutorial Letter 101 for this module.

A crucial phase in the process of understanding and learning the basics of botany, ethnobotany, biology and plant taxonomy is to articulate your ideas about the principles you are learning, both orally and in writing. Only when you have tried this process for yourself will you understand the full value of this exercise.

The assignments in this module will take the form of written work, and they should give you an idea of how well you are progressing in terms of achieving the learning outcomes.

Work through the learning units, using the learning strategies explained in the sections that follow. In each case

- skim through the unit and draw your own basic mind map of the content, and then expand this map as your knowledge and understanding of the unit increase
- make your own summary of every unit
- do a reflection exercise at the end of every unit (I will explain this in more detail in a later section)

As you work through the units, build up your own study and exam preparation **portfolio**. This portfolio won't be assessed, but it will be an extremely valuable tool as you complete your assignments and revise for the examination.

**What is a portfolio?** A portfolio is a folder/file in which you gather and compile additional and/or summarised information during the year as you work through the learning material.

#### Your portfolio should comprise

- answers to each activity in each learning unit
- a mind map/summary of each learning unit
- your marked assignments (or a copy you made prior to submitting your assignment)

	<ul style="list-style-type: none"> <li>• your reflections on each learning unit</li> <li>• extra reading material taken from the internet, additional books and medical and/or scientific journals</li> <li>• a new vocabulary of words or glossary of new terms in your own words</li> </ul> <p>To ensure that you achieve the learning outcomes for this module, you can use the learning strategies explained in the following section. After explaining these, I will also say more about managing your study time, finding articles for further reading and avoiding plagiarism.</p>	
<b>0.7.1</b>	<p><b>Learning strategies you can apply: the SSS method</b></p> <p>There are a number of strategies that can help you study, one of which is the SSS strategy. The three techniques in the SSS strategy are</p> <ul style="list-style-type: none"> <li>• <b>skimming</b></li> <li>• <b>scanning and outlining</b></li> <li>• <b>study-reading and active learning</b></li> </ul> <p>To help you understand what these steps involve, I will give you more detail in the sections that follow.</p>	
<b>0.7.1.1</b>	<p><b>Skimming</b></p> <p>Skimming involves moving your eyes quickly over a piece of text to get a general overview of what the text is about.</p> <p><b>1. Page through and explore.</b> First, read the section quickly, forming a rough idea of what it is about. Concentrate on headings and subheadings, any words or phrases that are in bold or italic type, text in boxes, tables and illustrations, and – in the case of a chapter or learning unit – introductions and summaries. The outcomes for a learning unit are important. (Think of how you would page through a magazine. When starting a new learning unit, scan it and concentrate on the concepts that catch your eye.)</p> <p><b>2. Make a cursory survey.</b> As you read, ask yourself: What key terms occur in this learning unit or chapter? Stop when you identify a key term, and carefully read what is said about it. Mark it in the book or in your printed study text. What you are trying to do is help yourself to remember the location of important information so that you can draw on it later. The key question is: <b>Where</b> is it?</p>	
<b>0.7.1.2</b>	<p><b>Scanning and outlining</b></p> <p>Scanning also involves moving your eyes quickly over a text, but in this case you are doing it to find specific key words or specific items of information.</p> <p><b>1. Basing yourself on the key concepts you identified during skimming, scan</b> the chapter, learning unit or section.</p> <p>If you have internet access, you can find more information on skimming and scanning here: <a href="https://www.aacc.edu/tutoring/file/skimming.pdf">https://www.aacc.edu/tutoring/file/skimming.pdf</a></p> <p><b>2. Outline</b> the section by <b>starting a mind map</b> (for the whole learning unit or chapter or for parts of it, as in starting a summary). You are looking for items and concepts while reading the information in the section or chapter in a more evaluative way. Reflect on relationships between concepts. The question now is: <b>What</b> is the main topic of this section/unit? What are the key concepts, and how do they relate to the topic?</p> <p>If you have access to the internet, you can find a great deal of information about drawing mind maps, and also see examples. Some good sites to start with are</p> <ul style="list-style-type: none"> <li>• <a href="http://www.wikihow.com/Make-a-Mind-Map">http://www.wikihow.com/Make-a-Mind-Map</a></li> <li>• <a href="http://www.mind-mapping.co.uk/make-mind-map.htm">http://www.mind-mapping.co.uk/make-mind-map.htm</a></li> </ul> <p><b>3. Extend your outline.</b> Start by giving your mind map a structure. As you work through the prescribed activities of the section or chapter, keep returning to the mind map to fill in the detail. Think about the value and meaning of categories, concepts and key terms.</p>	
<b>0.7.1.3</b>	<p><b>Study-reading and active learning</b></p> <p><b>1. Study-reading and completing activities.</b> This follows directly from what you have done so far, and you need to be careful, thorough and thoughtful. You have to make connections between the key terms and concepts you have identified, and here the mind map and summaries are important. (Remember to include your detailed mind</p>	

map in your portfolio.) Pause while reading, consolidate what you remember, and consider how new information fits in with the information you already have. This will give you a good representation of the whole.

Your learning will be enhanced if you are **active** throughout this process. Whenever you get to an activity in your study guide, complete it in full on loose pages which you then insert in your portfolio, grouped together according to section and learning unit. Supplement this with your own notes from your portfolio. (You don't need to submit activities or the portfolio to me, but these are essential for exam preparation.)

Take time to **understand what you read**. Note new vocabulary words. Consult a dictionary to understand the meaning of new words, or use Google to find definitions. You could compile a page of new words and terms and their definitions for each learning unit, and add it to your portfolio.

**2. Communicate.** If you have access to the internet, use the **Discussions** option to raise any issues you find difficult, or even just interesting. If you cannot find help from your fellow students, feel free to contact me. Also respond to other students' postings by means of the **Discussions** option. Communicating with others about what you are learning is an important part of the learning process.

**3. Reflect.** At the end of every learning unit, reflect on what you have learnt. This involves asking yourself questions such as these:

- What are the main new insights I gained in this learning unit? (Write down two or three.)
- What did I already know and find quite easy?
- What did I find difficult? Why might I have found this difficult? What can I do to resolve these difficulties?
- Has the new knowledge I gained perhaps changed my thinking about issues such as how the body functions, how my own health is or should be maintained and what the uses of biological knowledge might be in my life or career? (Either write down your thoughts on this, or share them with fellow students by means of the **Discussions** option.)

Reflection has enormous potential to enhance your learning by making you aware of your individual learning strategies and progress, of the wider context in which you can apply your learning, and also of the impact of your learning process on yourself and your circumstances.

0.7.2

### Managing your self-paced study time

As I mentioned in an earlier section, to achieve the outcomes for this module you need to devote at least 120 hours to your studies (although some of you may need a bit more time, and some slightly less). As you will have about 15 weeks to complete a semester module, you should plan to devote at least 8 study hours per week to a module.

Remember that if you have registered for more than one module, you need to plan time for **each** module.

I recommend that you draw up a study schedule or keep a diary so that you have a clear idea of the time you have available for study. This will help you to manage your studies within the time you have available and balance your studies with work and family life.

In Tutorial Letter 101 and on myUnisa you will find a list of due dates for various assignments. Record these in your diary. Divide the large assignments into a series of smaller, manageable tasks, and then complete these one at a time.

0.7.3

### Finding research/scientific articles

One of the easiest ways to find scientific and scholarly articles is to use the site Google Scholar, which you can access at <http://scholar.google.com>.

On this site, you will see that there is a down arrow within the search bar where you are to enter your search terms. If you click on this arrow, you will get a menu, "Advanced Search", which will allow you to make your search much more specific. When you have entered your search terms and clicked on "search" (or on the icon representing this, which is a magnifying glass), a number of websites relating to your query will appear. The advantage of using this portal is that you can access most journal references in this way.

Certain journals, such as *Science Direct*, however, can only be accessed through a tertiary academic institution such as Unisa. To access this journal, you need to do the following:

1. Go to Unisa online at <http://www.unisa.ac.za/>
2. Click on "Library" at the top of the page.

	<ol style="list-style-type: none"> <li>3. In the menu on the left-hand side of the screen, click on "Search library resources".</li> <li>4. Follow the guidelines if you are a first-time user.</li> <li>5. Click on the option "Find e-resources".</li> <li>6. Now click on "A–Z list of electronic resources".</li> <li>7. Various links for databases will now be on your screen. Click on any database to do a search. For molecular biology/biochemistry we recommend clicking on Science Direct, Nature or SpringerLink. (Remember, to find Science Direct, select S at the top and a list of all the databases starting with s will appear; if you want to go to Nature, select N, etc.)</li> <li>8. When you have entered one of these databases, you can search for scientific articles by typing in the relevant keywords in the "search" box. Be very specific in terms of the keywords you use. If you type in just one very general word, this will usually result in too much information that does not relate to the specific topic you are looking for.</li> <li>9. You will need to do some independent searches yourself, as part of your portfolio, assignments and exam preparation. This is especially true because this is a distance education course, which needs to be supplemented with information from internet sources.</li> </ol> <p>Contact the Unisa Library if you have any difficulties or for assistance: +27 12 429 3206 or see the Library website for the local branch library's telephone number.</p>	
0.7.4	<p><b>Avoiding plagiarism</b></p> <p>Never try to pass off other people's work (or our learning units and study material) as your own. If you want to incorporate other people's words and ideas or our notes in your own answers, enclose these in quotation marks if you are quoting directly, and <b>always</b> acknowledge your source. Use the Harvard referencing method. You can search for more information on this method online; a good source is <a href="http://www.staffs.ac.uk/assets/harvard_quick_guide_tcm44-47797.pdf">http://www.staffs.ac.uk/assets/harvard_quick_guide_tcm44-47797.pdf</a>. If you are unsure about the correct way to acknowledge sources, contact Unisa's Library Information Desk.</p> <p>Students who do not acknowledge quotations, or who plagiarise from lecture notes and outside sources, or who copy someone else's answers may be refused permission to write the examination, or may be penalised in the assignment.</p>	
0.8	<p><b>Using myUnisa</b></p> <p>I explained the advantages of online learning in section 0.1 of this learning unit. In the sections that follow, I will give you an orientation to using myUnisa. You will see how the Unisa menu options work, and I will draw your attention to the "rules" or "etiquette" of online communications. Finally, you will have the opportunity to try using one of the most important tools on myUnisa, the <b>Discussions</b> options.</p>	
0.8.1	<p><b>The myUnisa menu options</b></p> <p>You need to be able to use the various menu options on this course site, as they will enable you to participate actively in the learning process.</p> <p>Click on the links that follow to see where the various options are located.</p> <ul style="list-style-type: none"> <li>• <b>Learning Units:</b> The learning units are your main learning resource in this module. They contain the content and learning activities that you need to work through to achieve the module outcomes.</li> <li>• <b>Official Study Material:</b> A copy of Tutorial Letter 101 as well as past examination papers will be stored as printable PDF versions under this option.</li> <li>• <b>Announcements:</b> From time to time I will use this facility to give you important information about this module. You should receive e-mail notification of new announcements posted on myUnisa.</li> </ul>	

	<ul style="list-style-type: none"> <li>• <b>Schedule:</b> This option gives you access to important dates and details about events, such as examination dates and deadlines for your assignments. You will need this information to help you manage your time and plan your own schedule.</li> <li>• <b>Course Contact:</b> If you want to send me e-mails in connection with this module, use this option to communicate with me.</li> <li>• <b>Additional Resources:</b> A copy of the learning units will be stored as printable PDF versions under this option. This option allows you to access any additional learning support material that might help you in your studies for this module. I will send an e-mail alert or announcement to inform you if I add anything to this folder.</li> <li>• <b>Discussions:</b> This option allows us to hold discussions as if we were in a contact setting, and I hope that this will give you clarity on many of the issues that students tend to struggle with. I will set up a number of discussion forums that you can visit to discuss specific topics. There will also be a forum for students, where you can discuss issues among yourselves, or just support one another.</li> <li>• <b>Assignments:</b> This option allows you to submit your assignments electronically, and to monitor your results. If you can, please submit your assignments via myUnisa. If you don't know how to do this, consult Tutorial Letter 101.</li> </ul>	
0.8.2	<p><b>myUnisa etiquette</b></p> <p>myUnisa is the university's online platform, where lecturers and students meet, interact and participate in an ongoing process of learning and teaching. In interacting online, always remember to be respectful towards your fellow students and your lecturers. The rules of polite behaviour on the internet are referred to as <b>netiquette</b> – a term that means "online manners".</p> <p>You can access these websites to learn more about netiquette:</p> <ul style="list-style-type: none"> <li>• <a href="http://networketiquette.net/">http://networketiquette.net/</a></li> <li>• <a href="http://www.studygs.net/netiquette.htm">http://www.studygs.net/netiquette.htm</a></li> <li>• <a href="http://www.carnegiecyberacademy.com/facultyPages/communication/netiquette.html">http://www.carnegiecyberacademy.com/facultyPages/communication/netiquette.html</a></li> </ul> <p>Please observe the rules of netiquette during your normal, everyday online communication with colleagues, lecturers and friends. In particular, remember to be courteous to your fellow students when using the Discussions option.</p>	
0.8.3	<p><b>Activity 0.1: Introduce yourself</b></p> <p>At this point, I would like you to do an activity called an icebreaker.</p> <p><b>What is an icebreaker?</b></p> <p>An icebreaker helps you to</p> <ul style="list-style-type: none"> <li>• get to know the myUnisa online environment</li> <li>• get to know and connect with your fellow students</li> </ul> <p>To do the activity, click on the <b>Discussions</b> option in the menu on the left-hand side of the screen. From here, click on the forum <b>Module-related discussions</b>, and then on the topic "Introducing yourself".</p> <p>Once inside the topic, post a short entry in which you</p> <ul style="list-style-type: none"> <li>• tell us who you are and where you live</li> <li>• share what the subject area you are studying means to you, and why you chose to study it</li> </ul> <p>Also respond to at least one posting by one of your fellow students.</p>	
0.9	<p><b>Assessment in this module</b></p> <p>Your work in this module will be assessed by the following:</p>	

- two written assignments, which will be used to calculate a year mark that will count 30% towards your final mark
- one written examination of 2 hours, which will count 70% towards your final mark

**Please consult Tutorial Letter 101** for details about the assessment in this module. Be sure to read the following information in the tutorial letter:

- how your assignment and exam marks will be calculated
- the due dates for and unique numbers of your assignments
- how to submit your assignments
- examination periods, admission and marks

Tutorial Letter 101 also contains the actual assignment questions.

Remember that although Tutorial Letter 101 will be sent to you, you can also access an electronic version by using the link on this page, or else going to **Official Study Material**.

I wish you well in your studies. Enjoy the course!

## Learning unit 1

## Phylogeny and systematics

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### 1.9 Summary

## 1.1

## Introduction

**To complete the learning unit, you will need to refer to pages 523–542 of chapter 22 in Campbell et al (2015)**

You may wonder why and how biologists distinguish between and categorise the millions of species on earth. In this unit we will focus on how biologists trace phylogeny, the evolutionary history of a species or group of species. A phylogeny of snakes and lizards, for example, shows that both eastern glass lizards and snakes evolved from lizards with legs – but they evolved from different lineages of legged lizards. This is demonstrated in figure 22.2 in your prescribed textbook. So it appears that their legless condition evolved independently. We will look at how biologists reconstruct and interpret phylogenies using systematics. Systematics is a discipline focused on

classifying organisms and determining their evolutionary relationships. We then focus on how systematists develop hypotheses about the evolutionary relationship of all the branches, twigs and leaves on the tree of life.

1.2

## Learning outcomes

By the end of this learning unit, you should be able to

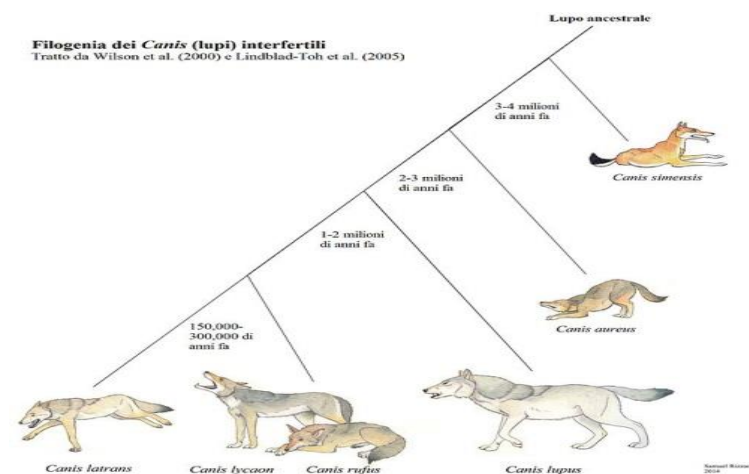
- explain the determination of phylogeny from common ancestries
- describe the binomial nomenclature system
- explain the hierarchical system of classification
- list the different hierarchical classification groupings
- discuss cladistic analysis on which systematics is based
- discuss the principle of parsimony and maximum likelihood
- construct the phylogeny tree

1.3

## Phylogenies show evolutionary relationships

**Recommended reading:** pages 524–527 of chapter 22 in Campbell et al (2015)

Organisms share many characteristics because of common ancestry. As a result, you can learn a great deal about a species if you have explored its evolutionary history. For example, an organism is likely to share many of its genes, metabolic pathways and structural proteins with its close relatives (figure 1.1). We will consider practical applications of this information later in this unit, but first we will examine how organisms are named and classified, the scientific discipline taxonomy. We will also look at how we can interpret and use diagrams that represent evolutionary history.



**Figure 1.1:** Relationships between wolf-like canids (*Canis* species) capable of hybridising

([https://commons.wikimedia.org/wiki/File:Wolf-like\\_canids\\_phylogeny\\_\(ita\).jpg](https://commons.wikimedia.org/wiki/File:Wolf-like_canids_phylogeny_(ita).jpg))

1.3.1

## Binomial nomenclature

Born in Sweden, Carl von Linné (1707-1778), better known as the Latinised name, Carolus Linnaeus, was the first modern practitioner of taxonomy, the science that identifies, names and classifies new species. Linnaeus invented the system of binomial nomenclature, in which species are assigned a Latinised two-part name, or binomial. The first part of a binomial is the name of the genus (plural, genera) to which the species belongs. Note that genus is a group of species with similar characteristics. The first letter of the genus is capitalised. The second part of the binomial is called the specific epithet, and is unique for each species within the genus. It is always written in small letters. Both genus and specific epithet are always underlined or italicised. For biologists to avoid ambiguity and confusion when communicating about their research, Latin scientific names are used. There are many binomial names today, for example *Panthera pardus* and *Homo sapiens* are the scientific names of the leopard and humans, respectively.



1.3.1.1	<p><b>Activity 1.1</b></p> <p><b>Do this activity and add it to your portfolio.</b></p> <p><b>Remember, this could serve as part of your summary to use in preparing for the exam!</b></p> <p>Refer to your textbook, and answer the following questions:</p> <ol style="list-style-type: none"> <li>How does the system of binomial nomenclature minimise ambiguity in the naming and identification of species?</li> <li>Are the following scientific names correct? Give reasons. <ol style="list-style-type: none"> <li><u>Acacia aerioloba</u></li> <li><u>Panthera pardus</u></li> <li><i>Ophisaurus ventralis</i></li> <li><i>Homo sapie</i></li> </ol> </li> </ol>
1.3.1.2	<p><b>Feedback on activity 1.1</b></p> <ol style="list-style-type: none"> <li>The system of binomial nomenclature avoids ambiguity in the naming of species because it assigns a unique two-part name to each species.</li> <li>Were you able to easily recognise the rules of binomial nomenclature before you attempted any of these scientific names? If yes, keep up the good work! If not, make sure that you go back to the binomial nomenclature section and revise the simple rules on scientific names. The answers to the questions are as follows: <ol style="list-style-type: none"> <li>Yes, because the scientific name is written correctly and the first letter of the genus has been written with a capital letter, and both the genus and specific epithet are underlined.</li> <li>No, though the name has been correctly spelt, both genus and specific epithet should be either underlined or italicised.</li> <li>Yes, all the rules have been followed.</li> <li>No, the scientific name must always be spelt correctly. The correct way is <i>Homo sapiens</i>.</li> </ol> </li> </ol>
1.3.2	<p><b>Hierarchical classification</b></p> <p>In addition to naming species, Linnaeus also grouped living organisms into a hierarchy of increasingly inclusive categories. Linnaeus's classification, called the taxonomic hierarchy, includes a nested series of formal categories which are domain, kingdom, phylum, class, order, family, genus, species and lastly, subspecies. The biological classification of a particular organism is like a postal address identifying a person in a particular flat, in a building with many flats, on a street with many buildings of flats, in a city with many streets, and so on. Note that the organisms included within any category of the taxonomic hierarchy comprise a taxon (plural, taxa). Leopard, for example, is a taxon (Felidae) at family level, and Panthera is a taxon at genus level (refer to figure 22.4 in your textbook). Species that are included in the same taxon at the bottom of the hierarchy (that is, in the same genus or family) generally share many characteristics. By contrast, species that are included in the same taxon only near the top of the hierarchy (that is, the same kingdom or phylum) generally share fewer traits. Very important, in the Linnaean system, taxa broader than the genus are not italicised or underlined, though they are capitalised.</p>
1.3.2.1	<p><b>Activity 1.2</b></p> <p><b>Do this activity and add it to your portfolio.</b></p> <p>Refer to your textbook and answer the following questions:</p> <ol style="list-style-type: none"> <li>How does the taxonomic hierarchy help biologists organise information about different species?</li> <li>List the major taxonomic categories from most to least inclusive.</li> </ol>
1.3.2.2	<p><b>Feedback on activity 1.2</b></p> <ol style="list-style-type: none"> <li>The taxonomic hierarchy helps biologists organise information about different species because it categorises them into increasingly inclusive groups. Species that are included in a lower taxonomic</li> </ol>

- category share many characteristics, whereas those included only in the same higher category share fewer characteristics.
- b) kingdom, phylum, class, order, family, genus, species

1.3.3

### Linking classification and phylogeny

Systematists explore phylogeny by examining various characteristics in living and fossil organisms. They construct branching diagrams called phylogenetic trees to depict their hypotheses about evolutionary relationships. The branching of the tree reflects the hierarchical classification of groups nested within more inclusive groups. Methods for tracing phylogeny began with Darwin, who realised the evolutionary implications of Linnaean hierarchy. Darwin introduced phylogenetic systematics in *On the origin of species* when he wrote: "Our classifications will come to be, as far as they can be so made, genealogies."

1.4

### Construction of phylogeny trees

**Recommended reading:** pages 529–535 of chapter 22 in Campbell et al (2015)

Patterns of shared characteristics can be drawn in a cladogram. If shared characteristics are homologous and therefore explained by common ancestry, then the cladogram forms the basis of a phylogenetic tree. A **clade** is defined as a group of species that includes an ancestral species and all its descendants. The study of resemblances among clades is called cladistics. Each branch, or clade, can be nested within larger clades. A valid clade is monophyletic, consisting of an ancestral species and all its descendants. When we lack information about some members of a clade, the result is a paraphyletic grouping that consists of some, but not all, of the descendants. The result may also be several polyphyletic groupings that lack a common ancestor. These situations need further reconstruction to uncover species that tie these groupings together into monophyletic clades. It is difficult to determine which similarities between species are relevant to grouping the species in a clade. It is especially important to distinguish similarities that are based on shared ancestry or homology from those that are based on convergent evolution or analogy.

Systematists must also sort through homologous features, or characters, to separate shared derived characters from shared primitive characters. A "character" refers to any feature that a particular taxon has. A shared derived character is unique to a particular clade. A shared primitive character is found not only in the clade being analysed, but also in older clades. For example, the presence of hair is a good character to distinguish the clade of mammals from other tetrapods. It is a shared derived character that uniquely identifies mammals. However, the presence of a backbone can qualify as a shared derived character, but at a deeper branch point that distinguishes all vertebrates from other mammals. Among vertebrates, the backbone is a shared primitive character because it evolved in the ancestor common to all vertebrates. Shared derived characters are useful in establishing a phylogeny, but shared primitive characters are not. The status of a shared derived character versus a shared primitive character may depend on the level at which the analysis is being performed. A key step in cladistic analysis is outgroup comparison, which is used to differentiate shared primitive characters from shared derived ones. To do this, we need to identify an outgroup, a species or group of species that is closely related to the species that we are studying, but known to be less closely related than any members of the study group are to one another.

To study the relationships between an ingroup of five vertebrates (a leopard, a turtle, a salamander, a tuna and a lamprey) on a cladogram, let's use the example of an animal called the lancelet. The lancelet is a small member of the phylum Chordata that lacks a backbone. The species making up the ingroup display a mixture of shared primitive and shared derived characters.

In an outgroup analysis, the assumption is that any homologies shared by the ingroup and outgroup are primitive characters that were present in the common ancestor of both groups. Homologies present in some or all of the ingroup taxa are assumed to have evolved after the divergence of the ingroup and outgroup taxa. In our example, a notochord, present in lancelets and in the embryos of the ingroup, is a shared primitive character and therefore not useful for sorting out relationships between members of the ingroup. The presence of a vertebral column, shared by all members of the ingroup but not the outgroup, is a useful character for the whole ingroup. The presence of jaws, absent in lampreys and present in the other ingroup taxa, helps to identify the earliest branch in the vertebrate cladogram.

Analysing the taxonomic distribution of homologies enables us to identify the sequence in which derived characters evolved during vertebrate phylogeny. A cladogram presents the chronological sequence of branching during the evolutionary history of a set of organisms. However, this chronology does not indicate the time of origin of the species that we are comparing, only the groups to which they belong. For example, a particular species in an old group may have evolved more recently than a second species that belongs to a newer group. A cladogram is not a phylogenetic tree.

To convert it to a phylogenetic tree, we need more information from sources such as the fossil record, which can indicate when and in which groups the characters first appeared. Any chronology represented by the branching pattern of a phylogenetic tree is relative (earlier versus later) rather than absolute (so many millions of years ago).

Some kinds of tree diagrams can be used to provide more specific information about timing. In a phylogram, the length of a branch reflects the number of genetic changes that have taken place in a particular DNA or RNA sequence in a lineage. Even though the branches in a phylogram may have different lengths, all the different lineages that descend from a common ancestor have survived for the same number of years. Humans and bacteria had a common ancestor that lived more than 3 billion years ago. This ancestor was a single-celled prokaryote and was more like a modern bacterium than a human. Even though bacteria have apparently changed little in structure since that common ancestor, there have nonetheless been 3 billion years of evolution in both the bacterial and eukaryotic lineages. These equal amounts of chronological time are represented in an ultrametric tree.

In an ultrametric tree, the branching pattern is the same as in a phylogram, but all the branches that can be traced from the common ancestor to the present are of equal lengths. Ultrametric trees do not contain the information about different evolutionary rates that can be found in phylograms. However, they draw on data from the fossil record to place certain branch points in the context of geological time.

### **The principles of maximum parsimony and maximum likelihood help systematists reconstruct phylogeny**

According to the principle of maximum parsimony, we look for the simplest explanation that is consistent with the facts. In the case of a tree based on morphological characters, the most parsimonious tree is the one that requires the fewest evolutionary events to have occurred in the form of shared derived characters. For phylograms based on DNA sequences, the most parsimonious tree requires the fewest base changes in DNA. The principle of maximum likelihood states that, given certain rules about how DNA changes over time, a tree should reflect the most likely sequence of evolutionary events. Maximum likelihood methods are designed to use as much information as possible. Many computer programs have been developed to search for trees that are parsimonious and likely: "distance" methods minimise the total of all the percentage differences among all the sequences. More complex "character-state" methods minimise the total number of base changes or search for the most likely pattern of base changes among all the sequences. Although we can never be certain precisely which tree truly reflects phylogeny, if they are based on a large amount of accurate data, the various methods usually yield similar trees.

### **Phylogenetic trees are hypotheses**

Any phylogenetic tree represents a hypothesis about how the organisms in the tree are related. The best hypothesis is the one that best fits all the available data. A hypothesis may be modified when new evidence compels systematists to revise their trees. Many older phylogenetic hypotheses have been changed or rejected since the introduction of molecular methods for comparing species and tracing phylogeny. Often, in the absence of conflicting information, the most parsimonious tree is also the most likely. Sometimes there is compelling evidence that the best hypothesis is not the most parsimonious. Nature does not always take the simplest course.

In some cases, the particular morphological or molecular character we are using to sort taxa actually did evolve multiple times. For example, the most parsimonious assumption would be that the four-chambered heart evolved only once in an ancestor common to birds and mammals but not to lizards, snakes, turtles and crocodiles. But

abundant evidence indicated that birds and mammals evolved from different reptilian ancestors. The hearts of birds and mammals develop differently, supporting the hypothesis that they evolved independently. The most parsimonious tree is not consistent with the above facts, and must be rejected in favour of a less parsimonious tree. The four-chambered hearts of birds and mammals are analogous, not homologous. Occasionally misjudging an analogous similarity in morphology or gene sequence as a shared derived homology is less likely to distort a phylogenetic tree if several derived characters define each clade in the tree. The strongest phylogenetic hypotheses are those supported by multiple lines of molecular and morphological evidence as well as by fossil evidence.

1.5

### An organism's evolutionary history is documented in its genome

**Recommended reading:** pages 535–536 of chapter 22 in Campbell et al (2015)

Molecular systematics is a valuable tool for tracing an organism's evolutionary history. The molecular approach helps us to understand phylogenetic relationships that cannot be measured by comparative anatomy and other non-molecular methods. For example, molecular systematics helps us uncover evolutionary relationships between groups that have no grounds for morphological comparison, such as mammals and bacteria.

Molecular systematics enables scientists to compare genetic divergence within a species. Molecular biology has helped to extend systematics to evolutionary relationships far above and below the species level. Its findings are sometimes inconclusive, as in cases where a number of taxa diverged at nearly the same time. The ability of molecular trees to encompass both short and long periods of time is based on the fact that different genes evolve at different rates, even in the same evolutionary lineage. For example, the DNA that codes for ribosomal RNA (rRNA) changes relatively slowly, so comparisons of DNA sequences in these genes can be used to sort out relationships between taxa that diverged hundreds of millions of years ago. In contrast, mitochondrial DNA (mtDNA) evolved relatively recently and can be used to explore recent evolutionary events, such as relationships between groups within a species.

#### Gene duplication has provided opportunities for evolutionary change

Gene duplication increases the number of genes in the genome, providing opportunities for further evolutionary change. Gene duplication has resulted in gene families, which are groups of related genes within an organism's genome. Like homologous genes in different species, these duplicated genes have a common genetic ancestor. There are two types of homologous genes: orthologous genes and paralogous genes. The term "orthologous" refers to homologous genes that are found in different gene pools because of speciation. The  $\beta$  haemoglobin genes in humans and mice are orthologous.

#### Paralogous genes result from gene duplication and are found in more than one copy in the same genome

Olfactory receptor genes have undergone many gene duplications in vertebrates. Humans and mice each have huge families of more than 1 000 of these paralogous genes. Now that we have compared entire genomes of different organisms, two remarkable facts have emerged. Orthologous genes are widespread and can extend over enormous evolutionary distances. Approximately 99% of the genes of humans and mice are demonstrably orthologous, and 50% of human genes are orthologous with those of yeast. All living things share many biochemical and development pathways. The number of genes does not seem to have increased at the same rate as phenotypic complexity. Humans have only five times as many genes as yeast, a simple unicellular eukaryote, although we have a large, complex brain and a body that contains more than 200 different types of tissues. Many human genes are more versatile than yeast and can carry out a wide variety of tasks in various body tissues.

1.6

### Molecular clocks help track evolutionary time

**Recommended reading:** pages 536–540 of chapter 22 in Campbell et al (2015)

In the past, the timing of evolutionary events has rested primarily on the fossil record. One of the goals of evolutionary biology is to understand the relationships between all living organisms, including those for which there is no fossil record. Molecular clocks serve as yardsticks for measuring the absolute time of evolutionary change. They are based on the observation that some regions of the genome evolve at constant rates. For these

regions, the number of nucleotide substitutions in orthologous genes is proportional to the time that has elapsed since the two species last shared a common ancestor. In the case of paralogous genes, the number of substitutions is proportional to the time since the genes became duplicated.

We can calibrate the molecular clock of a gene by graphing the number of nucleotide differences against the timing of a series of evolutionary branch points that are known from the fossil record. The slope of the best line through these points represents the evolution rate of that molecular clock.

This rate can be used to estimate the absolute date of evolutionary events that have no fossil record.

No molecular clock is completely accurate. Genes that make good molecular clocks have fairly smooth average rates of change. No genes mark time with precise accuracy in the rate of base changes.

Over time there may be chance deviations above and below the average rate. Rates of change of various genes vary greatly. Some genes evolve a million times faster than others. The molecular clock approach assumes that much of the change in DNA sequences is due to genetic drift and is selectively neutral. Neutral theory suggests that a great deal of evolutionary change in genes and proteins has no effect on fitness and is therefore not influenced by Darwinian selection. Researchers supporting this theory point out that many new mutations are harmful and are removed quickly.

However, if most of the rest are neutral and have little or no effect on fitness, the rate of molecular change should be clocklike in their regularity. Differences in the rates of change of specific genes are a function of the importance of the gene. If the exact sequence of amino acids specified by a gene is essential to survival, most mutations will be harmful and will be removed by natural selection. If the sequence of genes is less critical, more mutations will be neutral, and mutations will accumulate more rapidly. Some DNA changes are favoured by natural selection. This leads some scientists to question the accuracy and utility of molecular clocks for timing evolution.

Evidence suggests that almost 50% of the amino acid differences in proteins of two *Drosophila* species have resulted from directional natural selection. Over very long periods, fluctuations in the rate of accumulation of mutations caused by natural selection may even out. Even genes with irregular clocks can mark elapsed time approximately. Biologists are sceptical of conclusions derived from molecular clocks that have been extrapolated to time spans beyond the calibration in the fossil record. Few fossils are older than 550 million years old. Estimates for evolutionary divergences prior to that time may assume that molecular clocks have been constant over billions of years. These estimates have a high degree of uncertainty.

The molecular clock approach has been used to date the jump of HIV from related simian immunodeficiency viruses (SIVs) that infect chimpanzees and other primates to humans. SIV has spread to humans more than once. The multiple origins of HIV are reflected in the variety of strains of the virus. HIV-1 M is the most common HIV strain. Investigators have calibrated the molecular clock for the virus by comparing samples of the virus collected at various times. From their analysis, they project that the HIV-1 M strain invaded humans in the 1930s.

### **There is a universal tree of life**

The genetic code is universal in all forms of life. From this, researchers infer that all living things have a common ancestor. Researchers are working to link all organisms into a universal tree of life.

Two criteria identify regions of DNA that can be used to reconstruct the branching pattern of this tree. The regions must be able to be sequenced. They must have evolved slowly, so that even distantly related organisms show evidence of homologies in these regions. Ribosomal-RNA genes, coding for the RNA component of ribosomes, meet these criteria.

### **Two points have emerged from this effort:**

i) The tree of life consists of three great domains: Bacteria, Archaea and Eukarya.

Most prokaryotes belong to Bacteria. Archaea includes a diverse group of prokaryotes that inhabit many different habitats. Eukarya includes all organisms with true nuclei, including many unicellular organisms as well as the multicellular kingdoms.

ii) The early history of these domains is not yet clear.

Early in the history of life, there were many interchanges of genes between organisms in the different domains. One mechanism for these interchanges was horizontal gene transfer, in which genes are transferred from one genome to another by mechanisms such as transposable elements. Different organisms fused to produce new, hybrid organisms. It is likely that the first eukaryote arose through fusion between an ancestral bacterium and an ancestral archaean.

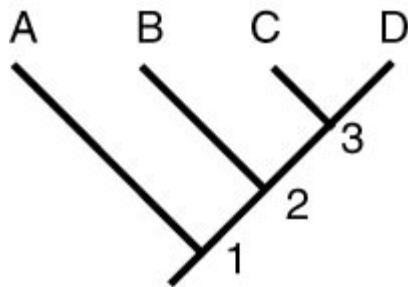
1.7

### Activity 1.3

**Do this activity and add it to your portfolio.**

Refer to your textbook and answer the following questions:

- Distinguish between phylogeny and systematics.
- In the following cladogram, which node occurred earliest in time?



- In the cladogram for question (b), which node represents the most recent common ancestor of terminal taxa B and C?
- In the cladogram for question (b), which terminal taxon is B more closely related to, A or C?
- Explain how shared derived characteristics can be used to construct a phylogenetic diagram.
- Describe the evidence that suggests that there is a universal tree of life.

1.8

### Feedback on activity 1.3

- Phylogeny is the evolutionary history of a species or group of related species. Systematics is the study of biological diversity in an environmental context, encompassing taxonomy and involving the reconstruction of phylogenetic history.
- Since the common ancestor is located at the base, your answer should be node 1.
- Node 2.
- Terminal taxon C.
- Biologists hypothesise that all of the chromosomes were inherited from the same ancestor. It's possible that in one of the descendants, one chromosome became two or two chromosomes became one; therefore, they can conclude that there is evolutionary history between the two species.
- The tree of life is based on ribosomal RNA sequences. All life on earth can be placed in one of the three major categories, leading biologists to believe that all life started from a common ancestor.

1.9

### Summary

Linnaeus's binomial classification system gives organisms two-part names: a genus and specific epithet. Species are grouped in increasingly broad taxa. Related genera are placed in the same family, families in orders, orders in classes, classes in phyla, phyla in kingdoms and, lastly, kingdoms in domains. Systematics depicts evolutionary relationships as branching phylogenetic trees. However, many systematists propose that classification be based entirely on evolutionary relationships.

A clade is a monophyletic grouping that includes an ancestral species and all of its descendants. Clades can be distinguished by their shared derived characters. Among phylogenies, the most parsimonious tree is the one that requires the fewest evolutionary changes.

Orthologous genes are homologous genes found in different species as a result of speciation. Paralogous genes are homologous genes within a species that result from gene duplication. Distantly related species often have many

orthologous genes. Some regions of DNA change at a rate consistent enough to serve as a molecular clock, in which the number of genetic changes are used to estimate the date of past evolutionary events. Molecular clock analyses suggest that the most common strain of HIV transmitted from primates to humans in the early 1900s.

<p><b>Learning unit 2</b></p>	<p><b>Prokaryotes and the origins of metabolic diversity</b></p> <p>Contents</p> <p><b>2.1 Introduction</b></p> <p><b>2.2 Learning outcomes</b></p> <p><b>2.3 Structure, function and reproduction of bacteria</b></p> <p>2.3.1 Activity 2.1</p> <p>2.3.2 Feedback on activity 2.1</p> <p><b>2.4 Nutritional and metabolic adaptations</b></p> <p>2.4.1 Activity 2.2</p> <p>2.4.2 Feedback on activity 2.2</p> <p><b>2.5 Prokaryotes have radiated into a diverse set of lineages</b></p> <p>2.5.1 Activity 2.3</p> <p>2.5.2 Feedback on activity 2.3</p> <p><b>2.6 Prokaryotes play crucial roles in the biosphere</b></p> <p>2.6.1 Chemical recycling</p> <p>2.6.2 Ecological interactions</p> <p>2.6.3 Pathogenic bacteria</p> <p>2.6.4 Prokaryotes in research and technology</p> <p>2.6.5 Activity 2.4</p> <p>2.6.6 Feedback on activity 2.4</p> <p><b>2.7 Summary</b></p>
<p><b>2.1</b></p>	<p><b>Introduction</b></p> <p><b>To complete the learning unit, you will need to refer to pages 629–648 of chapter 27 in Campbell et al (2015)</b></p> <p>Organisms informally called prokaryotes have inhabited planet earth for more than 3.5 billion years. They have existed for much longer than eukaryotes, which evolved at least 2.2 billion years ago. Although prokaryotes are microscopic, they are so numerous that they probably account for more than half of earth's biomass. Prokaryotes can tolerate extreme conditions, such as very low pH, too cold and/or too hot, and some have even been found living within rocks 3.2 km below the earth's surface. Their ability to adapt to a broad range of habitats helps scientists to explain why prokaryotes are the most abundant organisms on earth.</p> <p>Members of the domains Bacteria and Archaea cause many diseases, such as tuberculosis, tetanus, respiratory infections and food poisoning in humans. However, both Bacteria and Archaea play essential roles in the biosphere. As decomposers they break down organic molecules into their components. Without these remarkable microorganisms, certain elements such as carbon, nitrogen and phosphorus would remain locked up in the wastes and dead bodies of plants and animals.</p>

In this learning unit, we will describe the structure of bacteria and archaea. We will also examine the adaptations, diversity and enormous ecological impact of these remarkable organisms.

2.2

### Learning outcomes

By the end of this learning unit, you should be able to

- name the two main branches of prokaryotic evolution
- describe the structure, function and reproduction of bacteria
- discuss the ecological impact of bacteria
- describe the organisation and specialisation of a bacterial cell
- describe the structure, composition and function of prokaryotic cell walls
- distinguish between the staining properties of gram-positive and gram-negative bacteria
- explain how the genetic organisation of the prokaryotic genome differs from that of eukaryotic cells

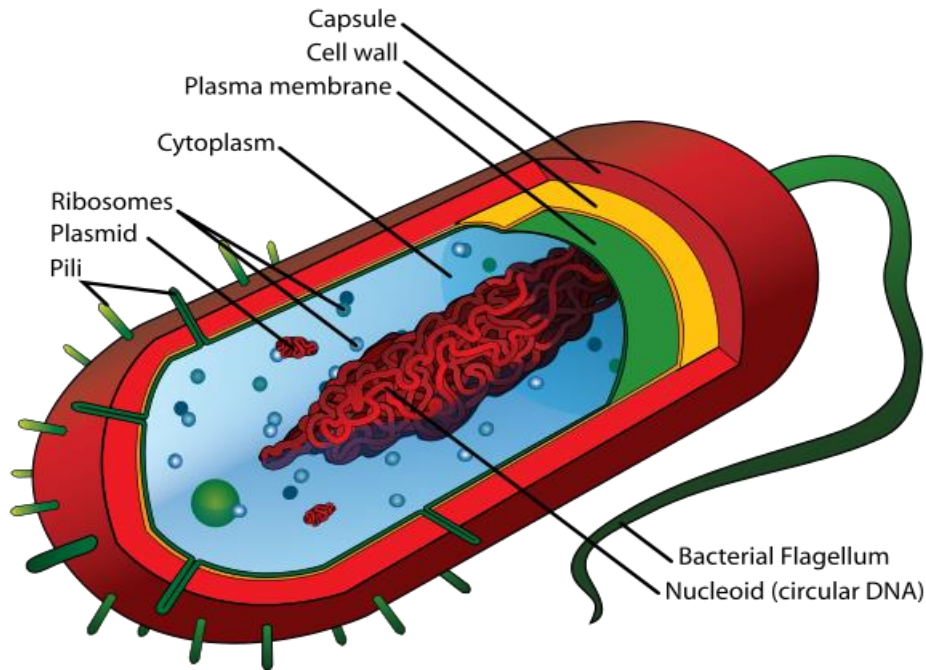
2.3

### Structure, function and reproduction of bacteria

**Recommended reading:** pages 630–636 of chapter 27 in Campbell et al (2015)

Prokaryotes seem to be found everywhere. Collective prokaryote biomass outweighs all eukaryotes combined by at least tenfold. They exist almost everywhere, including places where eukaryotes cannot. Most prokaryotes are beneficial; humans could not live without them, for example nitrogen-fixing bacteria. There are approximately 5 000 species of prokaryotes that have been identified, but estimations of prokaryote diversity range from 400 000 to 4 000 000 species. Bacteria and Archaea are the two main branches of prokaryote evolution. Archaea are thought to be more closely related to eukaryotes than to Bacteria. Most prokaryotes are unicellular. Although, they are unicellular and small, prokaryotes are well organised, achieving all of an organism's life functions within a single cell (figure 2.1). Some species form aggregates of two or more individuals. Prokaryotes are typically 0.5-5  $\mu\text{m}$  in diameter, but some can be seen with the naked eye. Eukaryotic cells are typically 10-100  $\mu\text{m}$  in diameter. Almost all prokaryotes have cell walls external to the plasma membrane.





**Figure 2.1:** Prokaryotic cell

([https://commons.wikimedia.org/wiki/File:Average\\_prokaryote\\_cell-\\_en.svg](https://commons.wikimedia.org/wiki/File:Average_prokaryote_cell-_en.svg))

A key feature of nearly all prokaryotic cells is the cell wall, which maintains cell shape, protects the cell and prevents it from bursting in a hypotonic environment. There are three common shapes: cocci (round), bacilli (rod) and helical (spiral). Refer to your textbook, page 630, figure 27.2. Cell walls are composed of peptidoglycan. There are two types of cell walls. Bacteria are grouped according to cell wall type, and that is gram-positive bacteria and gram-negative bacteria. Gram-positive bacteria have simple, thick cell walls. Their cell walls are composed of a relatively large amount of peptidoglycan. Gram-negative bacteria have less peptidoglycan and are more complex. They have a peptidoglycan layer surrounded by the plasma membrane and an outer membrane. Gram-negative bacteria are typically more resistant to host immune defence and antibiotics. Note that the two types of bacteria can be stained to determine which is gram-negative (pink) and gram-positive (purple) using a gram stain.

Most prokaryotes secrete sticky substances that form a protective layer and enable them to adhere to substrates. The sticky protective layer secreted by prokaryotes is called the **capsule**. Endospores are resistant cells formed by certain bacteria as a way to withstand harsh conditions. The cell replicates its chromosome and wraps it in a durable wall that can protect the chromosome from adverse conditions, e.g. boiling water, desiccation. When the environment is good again, the cell will revive to a new vegetative (growing) spore. Some prokaryotes adhere to substrates using pili (singular, pilus). Some pili are specialised for DNA transfer. This process is called **conjugation**.

Many prokaryotes are motile. Moreover, some exceed speeds 100 times their body length per second. The mode of movement is executed by three types, namely flagellum - basal apparatus rotates the flagellum and propels the cell; corkscrew movement of spirochetes (helical) and, finally, some prokaryotes glide over jets of slimy secretions.

Many prokaryotes move towards or away from stimulus-taxis. Chemotaxis is the movement towards or away from a chemical.

Neither mitosis nor meiosis occur in the prokaryotes. Reproduction is asexual by *binary fission*. DNA synthesis is almost continuous. Prokaryotes grow and adapt rapidly. The doubling time for *E. coli* is 20 minutes. If you started with one *E. coli* cell, after 48 hours of doubling every 20 minutes, the mass of *E. coli* would be 10 000 times the mass of the earth. Bacteria do not have gene transfer by sexual reproduction, but do transfer genes. Why? This is an aid in adapting (evolving). There are three ways for genes to be transferred between cells:

- **Transformation** – cell takes up genes from the surrounding environment.
- **Conjugation** – direct transfer of genes from one prokaryote to another; use the sex pilus to conjugate.
- **Transduction** – viruses transfer genes between prokaryotes.

2.3.1

### Activity 2.1

Do this activity and add it to your portfolio.

Refer to your textbook and answer the following questions:

- Describe the differences between eukaryotic cells and prokaryotic cells.
- Discuss the structure of the prokaryotic cell wall and explain how the structure could be of medical value.
- What is a Gram stain and why is it important to doctors?

2.3.2

### Feedback on activity 2.1

You may answer a) in the form of table like this:

	Eukaryotic cell	Prokaryotic cell
Nucleus	Present	Absent
Number of chromosomes	More than one	One, but not true chromosome
Cell type	Usually multicellular	Usually unicellular
Mitochondria	Present	Absent
Chloroplasts	Present (in plants)	Absent
Cell size	Large (10-100 um)	Small (1-10 um)
Structural complexity	Complex	Much simpler
DNA found in the region	Nucleus	Nucleoid
Membrane-enclosed organelles	Present	Absent
Lysosomes and peroxisomes	Present	Absent
Endoplasmic reticulum	Present	Absent
Golgi apparatus	Present	Absent

Permeability of nuclear membrane	Selective	Not present
Plasma membrane	Present	Present
Cytosol	Present	Present
Cell division	Mitosis	Binary fission
Ribosomes	Present (larger)	Present (smaller)

- b) A cell wall is a layer located outside the cell membrane found in plants, fungi, bacteria, algae and archaea. A peptidoglycan cell wall composed of disaccharides and amino acids gives bacteria structural support. The bacterial cell wall is often a target for antibiotic treatment.
- c) A Gram stain is a method of staining bacteria using a dye called crystal violet. It is important in that it helps distinguish between different types of bacteria.

## 2.4

**Nutritional and metabolic adaptations**

**Recommended reading:** pages 637-638 of chapter 27 in Campbell et al (2015)

All prokaryotes (as well as eukaryotic species) are grouped into four categories according to how they obtain energy and carbon. Refer to your textbook, table 27.1, page 638. Species that use light energy are *phototrophs*. Species that obtain energy from chemicals in their environment are *chemotrophs*. Organisms that need only CO<sub>2</sub> as a carbon source are *autotrophs*. Organisms that require at least one organic nutrient as a carbon source are *heterotrophs*. These categories of energy source and carbon source can be combined to group prokaryotes according to four major modes of nutrition.

Mode	Energy source	Carbon source	Types of organisms
Autotroph			
Photoautotrophs	Since they are photosynthetic species, they use light as the energy source	CO <sub>2</sub> , HCO <sub>3</sub> <sup>-</sup> , or related compound is the carbon source	Cyanobacteria; plants (eukaryotic)
Chemoautotrophs	Energy from oxidation of inorganic substances (e.g. NH <sub>4</sub> , and S)	CO <sub>2</sub> is the carbon source	<i>Sulfolobus</i> , <i>Beggiatoa</i>
Heterotroph			
Photoheterotrophs	Light as energy source	Organic compounds are source of carbon	Unique to certain aquatic and salt-loving prokaryotes (e.g. <i>Rhodobacter</i> , <i>Chloroflexus</i> )
Chemoheterotrophs	Organic compounds are energy source	Organic compounds are source of carbon (this includes humans)	Many prokaryotes ( <i>Clostridium</i> ), animals and fungi (eukaryotic); some plants

**The role of oxygen in metabolism**

	<p>Prokaryotic metabolism also varies with regard to oxygen (O<sub>2</sub>). The following are the three different groups:</p> <ul style="list-style-type: none"> <li>• Obligate aerobes - Use O<sub>2</sub> for respiration; cannot grow without it. (Humans are obligate aerobes.)</li> <li>• Facultative aerobes - Use O<sub>2</sub> when available; ferment when O<sub>2</sub> is not available.</li> <li>• Obligate anaerobes - Poisoned by O<sub>2</sub>; use fermentation or live by anaerobic respiration. In anaerobic respiration, inorganic molecules like SO<sub>4</sub><sup>2-</sup>, NO<sub>3</sub>, and Fe<sup>3+</sup> are used instead of oxygen.</li> </ul> <p>Note that photosynthesis evolved early in prokaryotic life. Cyanobacteria started to produce O<sub>2</sub> about 2.7 billion years ago. There are contrasting hypotheses for the taxonomic distribution of photosynthesis among prokaryotes.</p>
2.4.1	<p><b>Activity 2.2</b> Do this activity and add it to your portfolio.</p> <p>Refer to your textbook and answer the following questions:</p> <ol style="list-style-type: none"> <li>Describe the differences between photoautotrophs and photoheterotrophs.</li> <li>List and describe the three groups of prokaryotes with regard to oxygen.</li> </ol>
2.4.2	<p><b>Feedback on activity 2.2</b></p> <ol style="list-style-type: none"> <li>Photoautotrophs convert inorganic materials into organic materials for use in cellular functions such as biosynthesis and respiration and provide nutrition for many other forms of life. Photoheterotrophs depend on light for their source of energy and mostly organic compounds from the environment for their source of carbon.</li> <li>You should be able to name obligate aerobes, facultative aerobes and obligate anaerobes. You should also describe how they differ from one another.</li> </ol>
2.5	<p><b>Prokaryotes have radiated into a diverse set of lineages</b> <b>Recommended reading:</b> pages 639–643 of chapter 27 in Campbell et al (2015)</p> <p>Since their origin 3.5 billion years ago, prokaryotic populations have radiated extensively as a wide range of structural and metabolic adaptations have evolved in them. Collectively, these adaptations have enabled prokaryotes to inhabit every environment known to support life. In recent decades, advances in genomics are beginning to reveal the extent of prokaryotic diversity.</p> <p>Early on, prokaryotes diverged into two lineages, the domains Archaea and Bacteria. A comparison of the three domains -- Archaea, Bacteria, and Eukarya -- demonstrates that Archaea have at least as much in common with eukaryotes as with Bacteria (refer to your textbook, page 642, table 27.2). Archaea also have many unique characteristics. Most species of archaea have been sorted into the kingdom Euryarchaeota or the kingdom Crenarchaeota. However, much of the research on archaea has focused not on phylogeny, but on their ecology - their ability to live where no other life can. Archaea are <b>extremophiles</b>, "lovers" of extreme environments. Based on environmental criteria, archaea can be classified into <b>methanogens</b>, <b>extreme halophiles</b> and <b>extreme thermophiles</b>. Methanogens obtain energy by using CO<sub>2</sub> to oxidise H<sub>2</sub>, replacing methane as a waste. Methanogens are among the strictest anaerobes. They live in swamps and marshes where other microbes have consumed all the oxygen. Methanogens are important decomposers in sewage treatment. Other methanogens live in the anaerobic guts of herbivorous animals, playing an important role in their nutrition. They may contribute to the greenhouse effect, through the production of methane.</p> <p>Extreme halophiles live in saline places such as the Great Salt Lake and the Dead Sea. Some species merely tolerate elevated salinity; others require an extremely salty environment to grow.</p> <p>Colonies of halophiles form a purple-red scum from bacteriorhodopsin, a photosynthetic pigment very similar to the visual pigment in the human retina. Extreme thermophiles thrive in hot environments. The optimum temperatures for most thermophiles are 60 °C - 80 °C. Sulfolobus oxidises sulphur in hot sulphur springs in Yellowstone National Park. Another sulphur-metabolising thermophile lives at 105 °C water near deep-sea hydrothermal vents.</p> <p>If the earliest prokaryotes evolved in extremely hot environments like deep-sea vents, then it would be more accurate to consider most life as "cold-adapted" rather than viewing thermophilic archaea as "extreme". Recently, scientists have discovered an abundance of marine archaea among other life forms in more moderate habitats.</p>
2.5.1	<p><b>Activity 2.3</b> Do this activity and add it to your portfolio.</p>

	<p>Refer to your textbook and answer the following questions:</p> <p>a) Describe the difference between extreme halophiles and extreme thermophiles. b) In your understanding, what makes archaea "lovers" of extreme environments?</p>
2.5.2	<p><b>Feedback on activity 2.3</b></p> <p>a) Did you note that the major difference is that halophiles live in environments with plenty of salt concentration and thermophiles live in geothermal areas where there is plenty of heat? b) Don't forget to consider their physiological aspects and their extreme tolerance.</p>
2.6	<p><b>Prokaryotes play crucial roles in the biosphere</b></p> <p><b>Recommended reading:</b> pages 643–646 of chapter 27 in Campbell et al (2015)</p> <p>If people were to disappear from the planet tomorrow, life on earth would change for many species, but few would become extinct. In contrast, prokaryotes are so important to the biosphere that if they were to disappear, the prospects of survival for many other species would be dim.</p>
2.6.1	<p><b>Chemical recycling</b></p> <p>Ongoing life depends on the recycling of chemical elements between the biological and chemical components of ecosystems. If it were not for decomposers, especially prokaryotes, carbon, nitrogen and other elements essential for life would become locked in the organic molecules of corpses and waste products. Prokaryotes also mediate the return of elements from the non-living components of the environment to the pool of organic compounds.</p> <p>Prokaryotes have many unique metabolic capabilities. They are the only organisms able to metabolise inorganic molecules containing elements such as iron, sulphur, nitrogen and hydrogen. Cyanobacteria not only synthesise food and restore oxygen to the atmosphere, but they also fix nitrogen. This stocks the soil and water with nitrogenous compounds that other organisms can use to make proteins. When plants and animals die, other prokaryotes return the nitrogen to the atmosphere.</p>
2.6.2	<p><b>Ecological interactions</b></p> <p>Prokaryotes often interact with other species of prokaryotes or eukaryotes with complementary metabolisms. Organisms involved in an ecological relationship with direct contact (<b>symbiosis</b>) are known as <b>symbionts</b>. If one symbiont is larger than the other, it is also termed the host.</p> <p>In <b>commensalism</b>, one symbiont receives benefits while the other is not harmed or helped by the relationship. In <b>parasitism</b>, one symbiont, the parasite, benefits at the expense of the host. In <b>mutualism</b>, both symbionts benefit.</p> <p>For example, while a fish provides bioluminescent bacteria under its eye with organic materials, the fish uses its living flashlight to lure prey and to signal potential mates. Prokaryotes are involved in all three categories of symbiosis with eukaryotes. Legumes (peas, beans, alfalfa and others) have lumps in their roots which are the homes of mutualistic prokaryotes (<i>Rhizobium</i>) that fix nitrogen used by the host. The plant provides sugars and other organic nutrients to the prokaryote.</p> <p>Fermenting bacteria in the human vagina produce acids that maintain a pH between 4.0 and 4.5, suppressing the growth of yeast and other potentially harmful microorganisms. However, other bacteria are pathogens.</p>
2.6.3	<p><b>Pathogenic bacteria</b></p> <p>Exposure to pathogenic prokaryotes is a certainty. Most of the time our defences check the growth of these pathogens. Occasionally, the parasite invades the host, resists internal defence long enough to begin growing and then harms the host. Pathogenic prokaryotes cause about half of all human disease, including pneumonia caused by <i>Haemophilus influenzae</i> bacteria. Some pathogens are opportunistic. These are normal residents of the host, but only cause illness when the host's defences are weakened.</p> <p>Louis Pasteur, Joseph Lister and other scientists began linking disease to pathogenic microbes in the late 1800s. Robert Koch was the first to connect certain diseases to specific bacteria. He identified the bacteria responsible for anthrax and the bacteria that cause tuberculosis. Koch's methods established four criteria, Koch's postulates, that still guide medical microbiology:</p>

- (i) Find the same pathogen in each diseased individual investigated.
- (ii) Isolate the pathogen from the diseased subject and grow the microbe in pure culture.
- (iii) Induce the disease in experimental animals by transferring the pathogen from culture.
- (iv) Isolate the same pathogen from experimental animals after the disease develops.

These postulates work for most pathogens, but exceptions do occur. Some pathogens produce symptoms of disease by invading the tissues of the host. The actinomycete that causes tuberculosis is an example of this source of symptoms. More commonly, pathogens cause illness by producing poisons, called **exotoxins** and **endotoxins**. Exotoxins are proteins secreted by prokaryotes. Exotoxins can produce disease symptoms even if the prokaryote is not present. *Clostridium botulinum*, which grows anaerobically in improperly canned foods, produces an exotoxin that causes botulism.

An exotoxin produced by *Vibrio cholerae* causes cholera, a serious disease characterised by severe diarrhoea. Even strains of *E. coli* can be a source of exotoxins, causing traveller's diarrhoea.

Endotoxins are components of the outer membranes of some gram-negative bacteria. The endotoxin-producing bacteria in the genus *Salmonella* are not normally present in healthy animals. *Salmonella typhi* causes typhoid fever. Other *Salmonella* species, including some that are common in poultry, cause food poisoning. Since the discovery that "germs" cause disease, improved sanitation and treatments have reduced mortality and extended life expectancy in developed countries. More than half of our antibiotics (such as streptomycin and tetracycline) come from the soil bacteria *Streptomyces*. The decline (but not removal) of bacteria as threats to health may be due more to public-health policies and education than to "wonder drugs". For example, Lyme disease, caused by a spirochete spread by ticks that live on deer, field mice and occasionally humans, can be cured if antibiotics are administered within a month of exposure.

If untreated, Lyme disease causes arthritis, heart disease and nervous disorders. The best defence is avoiding tick bites and seeking treatment if bitten and a characteristic rash develops. Today, the rapid evolution of antibiotic-resistant strains of pathogenic bacteria is a serious health threat aggravated by imprudent and excessive antibiotic use. Although declared illegal by the United Nations, the selective culturing and stockpiling of deadly bacterial disease agents for use as biological weapons remains a threat to world peace.

2.6.4

### Prokaryotes in research and technology

Humans have learnt to exploit the diverse metabolic capabilities of prokaryotes for scientific research and for practical purposes. Much of what we know about metabolism and molecular biology has been learnt using prokaryotes, especially *E. coli*, as simple model systems. Prokaryotes are increasingly used to solve environmental problems.

The application of organisms to remove pollutants from air, water and soil is bioremediation. The most familiar example is the use of prokaryote decomposers to treat human sewage. Anaerobic bacteria decompose the organic matter into sludge (solid matter in sewage), while aerobic microbes do the same to liquid wastes. Soil bacteria, called pseudomonads, have been developed to decompose petroleum products at the site of oil spills or to decompose pesticides.

Humans also use bacteria as metabolic "factories" for commercial products. The chemical industry produces acetone, butanol and other products from bacteria. The pharmaceutical industry cultures bacteria to produce vitamins and antibiotics. The food industry uses bacteria to convert milk to yoghurt and various kinds of cheese. The development of DNA technology has allowed genetic engineers to modify prokaryotes to achieve specific research and commercial outcomes.

2.6.5

### Activity 2.4

**Do this activity and add it to your portfolio.**

Refer to your textbook and answer the following questions:

- a) Explain why all life on earth depends on the metabolic diversity of prokaryotes.
- b) Distinguish between mutualism, commensalism and parasitism. Describe examples of prokaryotes in each of these relationships.
- c) List Koch's postulates that are used to substantiate a specific pathogen as the cause of a disease.
- d) Describe the role of prokaryotes in recycling within ecosystems.

2.6.6	<p><b>Feedback on activity 2.4</b></p> <ul style="list-style-type: none"> <li>a) They possess strange metabolic diversity — <i>E. coli</i>, for example, is found in the intestines and excretion of animals BUT if found in drinking water or post-plant sewage, the sewage system is bad. Earth's metabolic diversity is greater among the prokaryotes than all of the eukaryotes.</li> <li>b) Mutualism <ul style="list-style-type: none"> <li>i. Close association in which both benefit</li> <li>ii. Intestinal flora completes digestion, makes vitamins</li> <li>iii. Nitrogen-fixing bacteria live in legume root nodules</li> </ul>           Commensalism <ul style="list-style-type: none"> <li>i. One benefits, the other is neutral</li> <li>ii. Most bacteria on and in humans are commensals</li> </ul>           Parasitism <ul style="list-style-type: none"> <li>i. One benefits, one is harmed</li> <li>ii. Bacterial diseases like tuberculosis, leprosy and anthrax</li> </ul> </li> <li>c) - Find the suspected pathogen in each individual with the disease  - Isolate it from a diseased individual and grow it in the laboratory  - Cause the disease by infecting from the culture  - Reisolate the pathogen from the experimental infection</li> <li>d) Prokaryotic decomposers release essential nutrients from dead organisms. Others convert essential nutrients into usable forms. Others replenish the "starting" forms.</li> </ul>
2.7	<p><b>Summary</b></p> <p>Prokaryotes (<i>bacteria</i>) appeared about 3.5 billion years ago, and were the earliest living organisms and the only forms of life for 2 billion years. Prokaryotes dominate the biosphere; they are the most numerous organisms and can be found in all habitats. Many prokaryotic species can reproduce quickly by binary fission, leading to the formation of populations containing enormous numbers of individuals. Some form endospores, which can remain viable in harsh conditions for centuries.</p> <p>Because prokaryotes can often proliferate rapidly, mutations can quickly increase a population's genetic variation. As a result, prokaryotic populations can often evolve in short periods in response to changing conditions.</p> <p>Nutritional diversity is much greater in prokaryotes than in eukaryotes. In general, prokaryotes perform all four modes of nutrition, namely photoautotrophy, chemoautotrophy, photoheterotrophy and chemoheterotrophy. Within prokaryotic species, obligate aerobes require O<sub>2</sub>, obligate anaerobes are poisoned by O<sub>2</sub> and facultative anaerobes can survive with or without O<sub>2</sub>. Unlike eukaryotes, prokaryotes can metabolise nitrogen in many different forms. Some can convert atmospheric nitrogen to ammonia, a process called nitrogen fixation.</p> <p>Decomposition by heterotrophic prokaryotes and the synthetic activities of autotrophic and nitrogen-fixation prokaryotes contribute to the recycling of elements in ecosystems. Many prokaryotes have a symbiotic relationship with a host. It is important to note that the relationships between prokaryotes and their hosts range from mutualism, commensalism to parasitism.</p> <p>Humans depend on mutualistic prokaryotes, including hundreds of species that live in our intestines and help to digest food. Pathogenic bacteria typically cause disease by either releasing exotoxins or endotoxins.</p>
Learning unit 3	<p><b>How plants colonised land</b></p> <p>Contents</p> <p><b>3.1 Introduction</b></p> <p><b>3.2 Learning outcomes</b></p> <p><b>3.3 Evolutionary adaptations to terrestrial living and the phyla of extant plants</b></p> <ul style="list-style-type: none"> <li>3.3.1 Terrestrial adaptation of land plants</li> <li>3.3.2 Derived traits of plants</li> </ul>

	<p>3.3.3 Origin of land plants</p> <p><b>3.4 The gametophyte and sporophyte generation of the bryophytes</b></p> <p><b>3.5 Origin of vascular plants - the gametophyte and sporophyte generation of the pteridophytes</b></p> <p>3.5.1 The origin of vascular plants</p> <p>3.5.2 Classification of seedless vascular plants</p> <p>3.5.3 The significance of seedless vascular plants</p> <p><b>3.6 Activity 3.1</b></p> <p><b>3.7 Feedback on activity 3.1</b></p> <p><b>3.8 Summary</b></p>	
3.1	<p><b>Introduction</b></p> <p><b>To complete the learning unit, you will need to refer to pages 674–691 of chapter 29 in Campbell et al (2015)</b></p> <p>Looking at a lush landscape, it is difficult to imagine the land without any plants or other organisms. For more than the first 3 billion years of earth's history, the terrestrial surface was lifeless. Since colonising land, plants have diversified into approximately 290 000 living species. They can inhabit all but the harshest environments, such as some mountaintop and desert areas and the polar ice sheets.</p> <p>We will refer to all plants as land plants, even those that are now aquatic, in order to distinguish them from algae, which are photosynthetic protists.</p> <p>Land plants make it possible for other life forms to survive on land. Plants supply oxygen during the photosynthesis process and ultimately most of the food eaten by terrestrial animals. Moreover, plant roots create habitats for other organisms by stabilising the soil. The history of the plant kingdom is a story of adaptation and changing terrestrial conditions. In this learning unit, we are going to trace the first 100 million years of plant evolution, including the emergence of seedless plants such as mosses and ferns. We concentrate on the development of different groups of plants to live exclusively on land.</p>	
3.2	<p><b>Learning outcomes</b></p> <p>By the end of this learning unit, you should be able to</p> <ul style="list-style-type: none"> <li>• name and discuss the evolutionary adaptations to living on land characteristic of the four main groups of land plants</li> <li>• distinguish between the main groups of land plants</li> <li>• discuss derived characters unique to land plants</li> <li>• name the characteristics common to land plants and charophycean algae</li> <li>• describe the life cycle of mosses as well as the structure of their gametophyte and sporophyte generations</li> <li>• describe the life cycle of ferns as well as the structure of their gametophyte and sporophyte generations</li> </ul>	
3.3	<p><b>Evolutionary adaptations to terrestrial living and the phyla of extant plants</b></p> <p><b>Recommended reading:</b> pages 674–680 of chapter 29 in Campbell et al (2015)</p> <p><b>Land plants evolved from green algae</b></p>	



Charophyceans are the green algae most closely related to land plants. Land plants are probably derived from a group of green algae called charophytes. They share the following traits with the charophyceans:

- Rosette cellulose-synthesising complexes: Land plants and charophyceans possess a rosette-shape array of proteins that synthesise cellulose microfibrils in their cell wall. Other algae containing cellulose wall (e.g. brown algae, dinoflagellates) have linear arrays of cellulose-producing proteins. This suggests a common ancestor between the charophytes and land plants. This rosette-synthesising system evolved independently of the cellulose-making system of other green algae.
- Peroxisome enzymes: The charophyceans and land plants have enzymes in their peroxisomes that minimise the loss of carbohydrate caused by photorespiration. Other alga groups do not have these enzymes in their peroxisomes.
- Structure of the flagellate sperm: Details of the sperm of charophyceans resemble those of land plants that have flagellated sperms.
- Cell plate formation during cytokinesis: Cell division features a complex network of microtubules and Golgi vesicles, the phragmoplast, again as found in all land plants.
- DNA and RNA sequences support their close relation to the charophytes, especially *Chara* and *Coleochaete*.

## 3.3.1

### Terrestrial adaptation of land plants

A layer of sporopollenin protects charophytes from desiccation; sporopollenin is found in the spore wall of land plants. Danger of desiccation required new adaptations: transport tissue, cuticle, etc.

Plants are eukaryotic, multicellular, mostly autotrophic organisms, with haploid-diploid life cycles, which retain the embryo within the female sex organ on the parent plant; the cell wall contains cellulose. Scientists are studying the ultrastructure of cells, analysing macromolecules and comparing morphology with life cycles.

There are several proposals to rearrange the boundaries of the kingdom Plantae:

- Only the embryophytes; the present and traditional system.
- Expand it to include the charophyceans: kingdom Streptophyta.
- Expand it further to include all the green algae, Chlorophyta: kingdom Viridiplantae.

## 3.3.2

### Derived traits of plants

The following characteristics are common to all four groups of land plants but are absent in the charophyceans:

- **Apical meristem:** Cluster of embryonic cells found at the tip of shoots and roots.
- **Alternation of generations:** A characteristic life cycle. Alternation of generation does not occur in the charophyceans. This suggests that alternation of generation arose independently in land plants. The life cycle is characterised by a multicellular haploid gametophyte stage followed by a multicellular diploid sporophyte stage.
- **Multicellular, dependent embryos:** The zygote is retained surrounded by tissues of the gametophyte. The parental tissue provides the embryo with nutrients. Placental transfer cells present in the embryo, and sometimes in the gametophyte as well, enhance the transfer of nutrients.
- **Spores produced in sporangia:** Haploid reproductive cells become a multicellular haploid gametophyte by mitosis. The multicellular sporangium contains sporocytes, the cells that undergo meiosis to form spores. Sporopollenin, the most durable organic material known, makes the walls of the spores.
- **Multicellular gametangia:** The gametes of land plants are produced in multicellular organs called gametangia. Algae produce their gametes in unicellular gametangia, inside a single cell.

#### Adaptations for water transport and conservation

- waxy cuticle to protect against desiccation
- stomata (singular, stoma) for gas exchange and control of transpiration
- transport system or vascular tissue

### Secondary metabolic compounds

Land plants make many metabolic compounds that are produced by side branches off the primary metabolic pathways that make lipids, carbohydrates, proteins and other compounds common to all organisms. Cell wall contains lignin, a polymer, to strengthen and support upright structures. Other secondary compounds are alkaloids, tannins and phenolics (flavonoids). These compounds function as protection against herbivores, absorb harmful UV radiation and are involved in the symbiotic relationship with soil microbes.

3.3.3

### Origin of land plants

About 475 million years ago, in the mid-Ordovician period, plants were widespread all over the world as shown by the many spores found in sediments of this period.

In a relatively short time of about 50 million years, plants diversified abundantly and colonised many land areas.

There are four main groups of land plants:

- bryophytes, including mosses
- pteridophytes, including ferns and seedless vascular plants
- gymnosperms, including conifers
- angiosperms, including flowering plants

Land plants are distinguished from algae by the *production of multicellular embryos* that remain attached to the mother plant, which protects and nourishes the embryos.

Bryophytes are distinguished from the other three groups of land plants by *the lack of vascular tissue* made of special cells called xylem and phloem. Some bryophytes have water and nutrient transport systems made of a different kind of cell.

Pteridophytes do not produce seeds. Gymnosperms and angiosperms produce seeds. A seed consists of a plant embryo with a food-storing tissue and a surrounding coat for protection. The first vascular plants to produce seeds evolved about 360 million years ago. Their seeds were not enclosed in any specialised chamber.

Angiosperms produce flowers and conifers produce "cones", a specialised reproductive structure. Angiosperms produce their seeds in specialised chambers called ovaries. Gymnosperms do not produce seed in ovaries. The word "grade" is used to designate a collection of organisms that share a common level of biological organisation or adaptation.

3.4

### The gametophyte and sporophyte generation of the bryophytes

**Recommended reading:** pages 680–684 of chapter 29 in Campbell et al (2015)

There are about 17 000 species worldwide divided into three divisions or phyla: **Bryophyta**, the mosses; **Hepatophyta**, the liverworts; and **Anthoceroophyta**, the hornworts. Their life cycle is similar but the three groups may not be closely related. The bryophytes may form a polyphyletic group. Bryophyta refers to the phylum of mosses only; bryophytes refer to the three phyla mentioned above.

#### Characteristics of the bryophytes

- They are small plants found in moist environments, lack woody tissue and usually form mats spread over the ground.
- Gametophyte generation is dominant; sporophyte is parasitic on the gametophyte.
- Bryophytes have cuticle, stomata and multicellular gametangia that allow them to survive on land.
- Bryophytes need water to reproduce and most species lack vascular tissue (xylem and phloem).
- Water transport is mostly through capillary action, diffusion and cytoplasmic streaming. They lack true roots, stems and leaves.

The gametophyte of mosses is a one-cell-thick filament known as the protonema that eventually produces buds having meristematic tissue. These meristems produce an upright structure called the gametophore. These gametophytes are one to a few cells thick and obtain nutrients and water by direct absorption from the environment.

Most mosses do not have conducting tissue. Some species have specialised cells that conduct water and nutrients but lack lignin in their cell walls. The gametophores are anchored by fragile rhizoids. Rhizoids are either single elongated cells such as those found in liverworts and hornworts, or filaments of cells such as those of mosses.

Rhizoids are not made of tissues and do not absorb any significant amount of water. In that way they differ from roots.

Bryophytes have the smallest and simplest sporophyte of any group. The sporophyte remains attached to the gametophyte throughout its lifetime, dependent on the gametophyte for food, water and minerals. The mature sporophyte of mosses consists of a foot embedded in the archegonium, a seta or stalk is present in the phylum Bryophyta, and a capsule or sporangium. The cap or calyptra closes the peristome or opening of the capsule.

3.5

### Origin of vascular plants - the gametophyte and sporophyte generation of the pteridophytes

**Recommended reading:** pages 684–690 of chapter 29 in Campbell et al (2015)

During the first 100 million years of plant evolution, bryophytes were prominent types of vegetation. But it is vascular plants that dominate most landscapes today. As in bryophytes, however, the sperm of ferns and all other seedless vascular plants are flagellated and swim through a film of water to reach eggs. In part because of these swimming sperm, seedless vascular plants today are most common in damp environments.

3.5.1

### The origin of vascular plants

Ferns and other seedless vascular plants formed the first forests.

The next step in land plant evolution included the development of an independent sporophyte. At first this sporophyte was the same size as the gametophyte. *Cooksonia caledonica*, from the Silurian (~420 million years ago) rocks of Europe and North America, is the oldest known land plant. It has small, leafless, rootless, dichotomous axes with terminal sporangia.

Transport in xylem and phloem. Phloem transports dissolved carbohydrates. Xylem transports water and minerals. Lignin strengthens the vascular tissue cells.

Evolution of roots. Roots anchor plants and allow the absorption of water and nutrients from the soil. Root tissues of living plants closely resemble stem tissues of early vascular plants preserved in fossils. Roots may have evolved from the lowest subterranean parts of the stem. The oldest lycophyte fossil had simple roots 400 million years ago.

From an evolutionary perspective, there are two kinds of leaves: Microphylls are single veined leaves associated and evolved as superficial outgrowth of the stem. They first appeared in the fossil record about 410 million years ago. Megaphylls have a complex venation pattern, and evolved from a branch system. They appeared about 370 million years ago, at the end of the Devonian period.

The sporophyte became the dominant generation. Sporophylls are modified leaves that bear spores. Sporophylls may be grouped into cone-like structures called strobili (singular, strobilus).

Homospory: Production of one kind of spore. Spores produce a bisexual gametophyte that produces eggs and sperms.

Heterospory: Production of two kinds of spores. Haploid megaspores develop into a female gametophyte. Haploid microspores develop into a male gametophyte.

3.5.2

### Classification of seedless vascular plants

There are two phyla of pteridophytes found in the modern flora: Licophyta and Pterophyta.

#### Phylum Lycophyta

There are about 15 genera of lycophytes and approximately 1 000 living species. This phylum includes the *Lycopods* (club mosses), *Selaginella* (spike moss) and *Isoetes* (quillwort). This evolutionary line extends back into the Devonian period (409-363 million years ago - mya) but was most prevalent in the wet swamps of the Carboniferous period (363-290 mya). They eventually split up into two evolutionary lines.

The first were very large woody trees that did not survive in the drier climate at the end of and after the Carboniferous age. In the Carboniferous age some lycophytes were forest-forming trees more than 35 m tall. The second and the surviving group of *Lycopods* are the small and herbaceous trees. Lycophyta became the largest coal deposits of all geologic time. The sporophytes of lycophytes consist of true roots, stems and leaves

(microphylls). Some *Selaginella* are heterosporous; *Lycopodium* is homosporous. Sporophylls are specialised leaves that bear sporangia and are organised into a structure called the strobilus.

### Phylum Pterophyta

**Psilophytes (whisk ferns):** These include two living genera, *Psilotum* and *Tmesipteris*, from tropical and subtropical regions of the world. They are a sporophyte with a dichotomously branching aerial and subterranean stem system. True roots are lacking and they have underground stems with rhizoids and a fungal association. Aerial stems lack leaves but have scale-like or larger leaf-like structures (enations). Until recently, they were placed in a phylum of their own, but DNA sequence analysis and sperm ultrastructure study has shown that they are related to the present-day fern. The lack of roots and leaves may be due to simplification, a derived or secondary characteristic, rather than a maintained characteristic from ancient ancestors, a primitive characteristic.

**Sphenophytes (horsetails):** Sphenopsids extend back to the Devonian period (409-363 mya) and reached their maximum development in the Carboniferous period (363-290 mya). They are a family of one extant genus, *Equisetum* (ca. 15 species), of nearly worldwide distribution in damp habitats such as riverbanks, lakeshores and marshes. Michigan is a centre of diversity for the genus with nine native species.

The sporophyte of *Equisetum* is differentiated into an underground rhizome that bears adventitious roots and an upright, photosynthetic stem with whorls of microphylls. They are tough perennial herbs with jointed, ridged aerial stems with distinct nodes. Stems are rough, accumulating silica and metals, and complex anatomically. The aerial stems contain a large central pith region, which in mature plants is hollow. Surrounding the pith cavity are discrete bundles of vascular tissue; this arrangement of conducting tissue is known as a eustele. Recent molecular data suggests that they are closely related to ferns and should be classified with them.

**“True” ferns:** The fossil record of ferns extends back into the Carboniferous age (363-290 mya) but their origins are in the Devonian age (409-363 mya). There are about 12 000 species of ferns in the world. Most species are tropical. Sporophytes are differentiated into true roots, stem (rhizome) and leaves (megaphylls). Leaves are usually differentiated into stipe (petiole) and a blade with a central rachis or vein. Most ferns are homosporous; a few aquatic genera are heterosporous. The sporangia are produced in clusters called sori (singular, sorus) which can be arranged in various patterns, e.g. rows or lines.

3.5.3

### The significance of seedless vascular plants

The Lycopphyta and Pterophyta represent the modern lineages of seedless vascular plants that formed forests during the Carboniferous period about 290-363 million years ago. The coal beds, oil fields and natural gas deposits that are mined in modern times are derived from these ancient forests. From there comes the name fossil fuels. During the Carboniferous period, Europe and North America were closer to the equator and covered with extensive swamps. As plants died, their bodies did not completely decay in the stagnant water and great depths of organic material accumulated, forming peat.

3.6

### Activity 3.1

**Do this activity and add it to your portfolio.**

Refer to your textbook and answer the following questions:

- Which group of algae is believed to be the ancestors of land plants?
- How are spores dispersed?
- How do mosses absorb water? How is it distributed?
- Like the Bryophyta, ferns are most common in damp environments. What feature of their reproduction requires them to live in a moist habitat?
- Ferns are vascular plants. Why can vascular plants grow to be very tall, but non-vascular plants can't?

3.7

### Feedback on activity 3.1

- Charophytes which are a lineage of green algae.

Try to answer the remaining questions (from b to e) on your own.

3.8

### Summary

Evolutionary adaptations to terrestrial living characterise the four main groups of land plants. Charophyceans are the green algae most closely related to land plants. Several terrestrial adaptations distinguish land plants from charophycean algae. Land plants evolved from charophycean algae over 500 million years ago.

The three phyla of bryophytes are mosses, liverworts and hornworts. The gametophyte is the dominant generation in the life cycles of bryophytes. Bryophyte sporophytes disperse enormous numbers of spores. Bryophytes provide many ecological and economic benefits.

Additional terrestrial adaptations evolved as vascular plants descended from moss-like ancestors. A diversity of vascular plants evolved over 400 million years ago. Pteridophytes provide clues to the evolution of roots and leaves. A sporophyte-dominant life cycle evolved in seedless vascular plants. Lycophyta and Pterophyta are the two phyla of modern seedless vascular plants. Seedless vascular plants formed vast "coal forests" during the Carboniferous period.

<b>Learning unit 4</b>	<p><b>Plant diversity II: the evolution of seed plants</b></p> <p>Contents</p> <p><b>4.1 Introduction</b></p> <p><b>4.2 Learning outcomes</b></p> <p><b>4.3 Seeds and pollen grains are key adaptations for life on land</b></p> <p><b>4.4 Gymnosperms</b></p> <p><b>4.5 Angiosperms</b></p> <p><b>4.6 Human welfare depends on seed plants</b></p> <p><b>4.7 Activity 4.1</b></p> <p><b>4.8 Feedback on activity 4.1</b></p> <p><b>4.9 Summary</b></p>
<b>4.1</b>	<p><b>Introduction</b></p> <p><b>To complete the learning unit, you will need to refer to pages 692–709 of chapter 30 in Campbell et al (2015)</b></p> <p>This learning unit will focus mainly on plants that reproduce by means of spores and haploid cells that disperse and germinate to produce gametophytes. Although gymnosperms and angiosperms also produce spores, their primary means of reproduction and dispersal is by seeds. Fossils and comparative studies of living plants offer clues about the origin of seed plants some 360 million years ago. As this new group became established, they dramatically altered the course of plant evolution. Seed plants have become dominant producers on land, and they make up the majority of plant biodiversity today.</p> <p>In this learning unit, we will first present the general features of seed plants — both gymnosperms and angiosperms. Then we will study their evolutionary history and enormous impact on human society.</p>

4.2	<p><b>Learning outcomes</b></p> <p>By the end of this learning unit, you should be able to</p> <ul style="list-style-type: none"> <li>• give an overview of the three variations of gametophyte/sporophyte relationships</li> <li>• define the term “seed” and discuss the structure of a seed</li> <li>• describe the life cycle of gymnosperms, clearly distinguishing between the gametophyte and sporophyte generations</li> <li>• discuss the structure and function of flowers and fruits, as well as their reproductive adaptations</li> <li>• describe the life cycle of angiosperms, clearly distinguishing between the gametophyte and sporophyte generations</li> </ul>
4.3	<p><b>Seeds and pollen grains are key adaptations for life on land</b></p> <p><b>Recommended reading:</b> pages 693–695 of chapter 30 in Campbell et al (2015)</p> <p>Three life cycle modifications led to the success of terrestrial plants:</p> <ul style="list-style-type: none"> <li>• <b>Reduction of the gametophyte:</b> Retained in the moist reproductive tissue of the sporophyte.</li> <li>• <b>Origin of the seed:</b> Zygotes developed into embryos packaged with a food supply within a protected seed coat. Seeds replaced spores as the main means of dispersal.</li> <li>• <b>Evolution of pollen:</b> Plants were no longer tied to water for fertilisation.</li> </ul> <p>Both mosses and ferns require water for fertilisation. However, the presence of vascular (water-conducting) tissue in ferns has allowed the sporophyte to become independent of the gametophyte, to grow taller and to exploit drier habitats.</p> <p>In their relatively harsh terrestrial environment, bryophytes and seedless vascular plants release spores. Seeds are hardier because of their multicellular nature. Seed is defined as a reproductive structure consisting of an embryo enclosed in its food supply and protected with a seed coat (integument). Seed is a sporophyte embryo and a food supply surrounded by a protective coat. All seed plants are heterosporous. The development of seed is associated with megasporangia: seed plant megasporangia are fleshy structures called nucelli. Additional tissues (integuments) surround the megasporangium. The resulting structure is called an ovule. The female gametophyte develops in the wall of the megaspore, it is fertilised (embryo) and the resulting ovule develops into a seed.</p> <p><b>Advantages of seed</b></p> <ul style="list-style-type: none"> <li>• seed with food supply can remain dormant a long time until favourable conditions warrant germination</li> <li>• the seed is a dispersal unit</li> <li>• male gametophyte (=microgametophyte) of seed plants</li> <li>• develops within microspore</li> <li>• microspore of seed plants develops into pollen grain (male gametophyte)</li> </ul> <p>Microspores develop into pollen grains which mature to form the male gametophytes of seed plants. Pollen grains are coated with a resistant polymer, sporopollenin, and can be carried away by wind or animals (e.g. bees) following release from microsporangia. A pollen grain near an ovule will extend a tube and discharge sperm cells into the female gametophyte within the ovule. In some gymnosperms, sperm are flagellated (ancestral). Other gymnosperms (including conifers) and angiosperms do not have flagellated sperm cells.</p>
4.4	<p><b>Gymnosperms</b></p>

**Recommended reading:** pages 695–699 of chapter 30 in Campbell et al (2015)

The ovules and seeds of gymnosperms ("naked seeds") develop on the surfaces of modified leaves that usually form cones (strobili). In contrast, ovules and seeds of angiosperms develop in enclosed chambers called ovaries. The most familiar gymnosperms are the conifers, cone-bearing trees such as pine, fir and redwood.

The four phyla of extant gymnosperms are Cycadophyta, Ginkgophyta, Gnetophyta and Coniferophyta.

Phylum Ginkgophyta consists of only a single extant species, *Ginkgo biloba*. This popular ornamental species has fan-like leaves that turn gold before they fall off in the autumn. Landscapers usually plant male trees only, because the coats of seeds produced by female plants produce a repulsive odour as they decay.

Cycads (phylum Cycadophyta) have large cones and palm-like leaves. There are 130 species of cycads today. Cycads flourished in the Mesozoic era, which was known as the Age of Cycads.

Phylum Gnetophyta consists of three very different genera. *Welwitschia* plants, from deserts in southwestern Africa, have strap-like leaves that are among the largest known leaves. *Gentum* species are tropical trees or vines. *Ephedra* (Mormon tea) is a shrub of the American deserts.

The conifers belong to the largest gymnosperm phylum, the phylum Coniferophyta. The term "conifer" comes from the reproductive structure, the cone, which is a cluster of scale-like sporophylls. Although there are only about 600 species of conifers, a few species dominate vast forested regions in the northern hemisphere where the growing season is short. Conifers include pines, firs, spruces, larches, yews, junipers, cedars, cypresses and redwoods. Most conifers are evergreen, retaining their leaves and photosynthesising throughout the year. Some conifers, like the dawn redwood and tamarack, are deciduous, dropping their leaves in autumn. The needle-shaped leaves of some conifers, such as pines and firs, are adapted for dry conditions. A thick cuticle covering the leaf and the placement of stomata in pits further reduce water loss. Much of our lumber and paper comes from the wood (actually xylem tissue) of conifers.

#### **The Mesozoic era was the age of gymnosperms**

The gymnosperms probably descended from progymnosperms, a group of Devonian plants that were heterosporous but lacked seeds. The first seed plants to appear in the fossil record were gymnosperms dating from about 360 million years ago. Angiosperms arose more than 200 million years later.

4.5

## **Angiosperms**

**Recommended reading:** pages 700–707 of chapter 30 in Campbell et al (2015)

Angiosperms, commonly known as flowering plants, are vascular seed plants that produce flowers and fruits. They are the most diverse and geographically widespread of all plants, including more than 90% of plant species. There are about 250 000 known species of angiosperms. All angiosperms are placed in a single phylum, the phylum Anthophyta. The flower is the defining reproductive adaptation of angiosperms.

The flower is an angiosperm structure specialised for sexual reproduction. In many species of angiosperms, insects and other animals transfer pollen from one flower to the female sex organs of another. Some species that occur in dense populations, like grasses, are wind pollinated. A flower is a specialised shoot with up to four circles of modified leaves: sepals, petals, stamens and carpals.

The sepals at the base of the flower are modified leaves that are usually green and enclose the flower before it opens. The petals lie inside the ring of sepals. A style leads to the ovary at the base of the carpal. Ovules are protected within the ovary. Fruits help disperse the seeds of angiosperms. A fruit usually consists of a mature ovary. As seeds develop from ovules after fertilisation, the wall of the ovary thickens to form the fruit. Fruits protect dormant seeds and aid in their dispersal.

Mature fruits can be fleshy or dry. Oranges and grapes are fleshy fruits, in which one or more pericarp layers soften during ripening. Dry fruits include beans and grains. The dry, wind-dispersed fruits of grasses are major food staples for humans. The cereal grains of wheat, rice and maize are fruits with a dry pericarp that adheres to

the seed coat of the seed. Fruits are classified according to whether they develop from a single ovary, from multiple ovaries, or from more than one flower.

Fruits are adapted to disperse seeds. Winged seeds may function as kites or propellers to assist wind dispersal. Coconuts are specialised for water dispersal. Some fruits are modified as burrs that cling to animal fur. Many fruits are edible, nutritious, sweet tasting and colourful. These fruits rely on animals to eat the fruit and deposit the seeds, along with a supply of fertiliser, some distance from the parent plant.

The life cycle of an angiosperm is a highly refined version of the alternation of generations common to all plants. All angiosperms are heterosporous, producing microspores that form male gametophytes and megaspores that form female gametophytes. Each pollen grain has two haploid cells: a generative cell that divides to form two sperm and a tube cell that produces a pollen tube. The ovule, which develops in the ovary, contains the female gametophyte, the embryo sac. The embryo sac consists of only a few cells, one of which is the egg.

The life cycle of an angiosperm begins with the formation of a mature flower on a sporophyte plant and culminates in a germinating seed. Anthers contain microsporangia, with microspore mother cells that produce microspores by meiosis. Microspores form pollen grains, which are immature male gametophytes. In the ovule, the megaspore mother cell produces four megaspores by meiosis. One megaspore survives and forms a female gametophyte, or embryo sac. The pollen is released from the anther and carried to the sticky stigma of the carpel. Most flowers have mechanisms to ensure cross-pollination. The pollen grain germinates and is now a mature male gametophyte. The pollen tube grows down within the style. After reaching the ovary, the pollen tube penetrates the micropyle, a pore in the integuments of the ovule. Two sperm are discharged into the female gametophyte. One fertilises the egg to form a diploid zygote. The other fuses with two polar nuclei in the large central cell of the embryo sac to form the triploid endosperm nucleus.

Double fertilisation is unique to angiosperms. The zygote develops into an embryo that is packaged with food into the seed. The embryo has a rudimentary root and one or two seed leaves, or cotyledons. When a seed germinates, the embryo develops into a mature sporophyte.

Monocots store most of the food for the developing embryo as endosperm, which develops as a triploid tissue in the centre of the embryo sac. Beans and many dicots transfer most of the nutrients from the endosperm to the developing cotyledons. One hypothesis for the function of double fertilisation is that it synchronises the development of food storage in the seed with development of the embryo.

Double fertilisation may prevent flowers from squandering nutrients on infertile ovules. Another type of double fertilisation, in which two embryos are formed, has evolved independently in gymnosperms of the phylum Gnetophyta. The seed consists of the embryo, endosperm, remnants of the sporangium and a seed coat derived from the integuments.

Until the late 1990s, flowering plants were divided into monocots and dicots on the basis of the number of cotyledons or seed leaves. Current research supports the view that monocots form a clade but reveals that dicots are not monophyletic. The majority of plants traditionally called "dicots" form a clade now known as "eudicots".

Ever since they colonised the land, animals have influenced the evolution of terrestrial plants and vice versa. Plants and animals have been important selective agents on one another. Natural selection favoured plants that kept their spores and gametophytes above the ground, rather than dropping them within the reach of hungry ground animals.

This may, in turn, have been a selective factor in the evolution of flying insects. Some herbivores were beneficial to plants by dispersing their pollen and seeds. The animals received a benefit in turn, as they ate the nectar, seeds and fruits of plants.

These linked adaptations, involving reciprocal genetic modifications in two species, are co-evolution. The expansion of grasslands over the past 65 million years has increased the diversity of grazing animals such as horses. Grasses are C<sub>4</sub> photosynthesisers that spread as declining atmospheric CO<sub>2</sub> levels gave them a selective advantage.



4.6

### Human welfare depends on seed plants

**Recommended reading:** pages 707–708 of chapter 30 in Campbell et al (2015)

Flowering plants provide nearly all our food. Only six crops — wheat, rice, maize, potatoes, cassava and sweet potatoes — yield 80% of all calories consumed by humans.

Modern crops are the products of a relatively recent burst of genetic change, resulting from artificial selection after the domestication of plants 13 000 years ago. In maize, key changes such as increased cob size and removal of the hard coating of the kernels may have been initiated by as few as five gene mutations.

How did wild plants change so dramatically so quickly? The answer is likely a combination of deliberate and unconscious selection for plants with desirable traits, such as large fruits and lack of toxins. Angiosperms also provide important non-stable foods such as coffee, chocolate and spices. Gymnosperms and angiosperms are sources of wood, which is absent in all living seedless plants, and consists of an accumulation of tough-walled xylem cells. Wood is the primary source of fuel for much of the world. It is used to make paper, and is the world's most widely used construction material. Humans depend on seed plants for medicines.

Scientific research has identified the relevant secondary compounds in many of these plants, leading to the synthesis of many modern medicines. **Plant diversity is a non-renewable resource.** Although plants are a renewable resource, plant diversity is not. The demand for space and natural resources resulting from the exploding human population is extinguishing plant species at an unprecedented rate. This is especially acute in the tropics, where more than half the human population lives and where population growth rates are highest. Owing primarily to the slash-and-burn clearing of forests for agriculture, tropical forests may be completely eliminated within 25 years. As the forests disappear, thousands of plant species and the animals that depend on these plants also become extinct. The destruction of these areas is an irrevocable loss of these non-renewable resources. The rate of loss is faster than in any other period, even during the Permian and Cambrian extinctions. While the loss of species is greatest in the tropics, the threat is global.

In addition to the ethical concerns that many people have concerning the extinction of living forms, there are also practical reasons to be concerned about the loss of plant diversity. We depend on plants for food, building materials and medicines. We have explored the potential uses for only a tiny fraction of the 290 000 known plant species. Almost all of our food is based on the cultivation of only about two dozen species. Researchers have investigated fewer than 5 000 plant species as potential sources of medicines. Pharmaceutical companies were led to most of these species by local people who used the plants in preparing their traditional medicines. The tropical rainforests and other plant communities may be a medicine chest of healing plants that could be extinct before we even know they exist.

4.7

### Activity 4.1

- Name five terrestrial adaptations that contributed to the success of seed plants.
- Compare the size and independence of the gametophytes of bryophytes with those of seed plants.
- Explain why pollen grains were an important adaptation for successful reproduction on land.
- Describe the life history of a pine. Indicate which structures are part of the gametophyte generation and which are part of the sporophyte generation.
- Describe the role of the generative cell and the tube cell within the angiosperm pollen grain.
- Explain the process and function of double fertilisation.
- Describe the current threat to plant diversity caused by human population growth.

4.8

### Feedback on activity 4.1

- The five terrestrial adaptations are the seed, reduction of the gametophyte generation, heterospory, ovules and pollen.
- Seedless vascular plants have tiny gametophytes that are visible to the naked eye. The gametophytes of seed plants are microscopically small and develop from spores in the sporangia of the parental sporophyte. The gametophytes of seed plants obtain nutrients from their parents, while the gametophytes of seedless vascular plants must fend for themselves.

	<ul style="list-style-type: none"> <li>c) Pollen grains were an important adaptation because the evolution of pollen allowed for pollination and contributed to the diversity of seed plants.</li> <li>d) In most conifer species, each tree has both ovulate and pollen cones. The pine tree is the sporophyte. Each ovulate cone contains a megasporangium. The microsporangium undergoes meiosis, producing haploid microspores that develop into pollen grains. A pollen grain enters through the micropyle and germinates, forming a pollen tube that digests through the megasporangium. By meiosis, four haploid cells are produced. One survives as a megaspore. The female egg develops. Fertilisation occurs as sperm and egg nuclei unite. The ovule becomes a seed.</li> <li>e) A generative cell divides to form two sperm and a tube cell produces a pollen tube.</li> <li>f) Double fertilisation is a mechanism of fertilisation in angiosperm in which two sperm cells unite with two cells in the embryo sac to form the zygote and endosperm. One hypothesis for the function of double fertilisation is that it synchronises the development of food storage in the seed with development of the embryo.</li> <li>g) The demand for space and natural resources resulting from the exploding human population is extinguishing plant species at an unprecedented rate. Owing primarily to the slash-and-burn clearing of forests for agriculture, tropical forests may be completely eliminated within 25 years.</li> </ul>	
4.9	<p><b>Summary</b></p> <p>Among others, seeds and pollen grains are key adaptations for life on land. Dominance of the sporophytes generation, the development of seed-fertilised ovules and the role of pollen in transferring sperm to ovules are key features of a typical gymnosperm life cycle.</p> <p>Flowers generally consist of four types of modified leaves: sepals, petals, stamens and carpels. Ovaries ripen into fruits, which often carry seeds by wind, water, or animals to new locations. Flowering plants originated about 140 million years ago. Pollination and other interactions between angiosperms and animals may have contributed to the success of flowering plants during the last 100 million years.</p> <p>It is no longer a secret that humans depend heavily on seed plants for products such as food, wood and many medicines. Destruction of habitats threatens the extinction of many plant species and the animal species they support.</p>	
Learning unit 5	<p><b>Fungi</b></p> <p>Contents</p> <p><b>5.1 Introduction</b></p> <p><b>5.2 Learning outcomes</b></p> <p><b>5.3 Fungi are heterotrophs that feed by absorption</b></p> <ul style="list-style-type: none"> <li>5.3.1 Activity 5.1</li> <li>5.3.2 Feedback on activity 5.1</li> </ul> <p><b>5.4 Fungi produce spores through sexual or asexual life cycles</b></p> <p><b>5.5 The ancestor of fungi was an aquatic, flagellated protist</b></p> <p><b>5.6 Fungi have radiated into a diverse set of lineages</b></p> <p><b>5.7 Fungi play key roles in the environment as well as human welfare</b></p> <p><b>5.8 Activity 5.2</b></p> <p><b>5.9 Feedback on activity 5.2</b></p> <p><b>5.10 Summary</b></p>	
5.1	<p><b>Introduction</b></p>	

	<p><b>To complete the learning unit, you will need to refer to pages 710–728 of chapter 31 in Campbell et al (2015)</b></p> <p>The science of mycology, the study of fungi, is concerned with all these diverse life forms. Fungi are a huge and important component of the biosphere. About 100 000 species, most of which are terrestrial, have been described, but it is estimated that there are more than 1.5 million species. These diverse organisms are found in just about every terrestrial and aquatic habitat imaginable. Fungi grow best in moist habitats, but they are found universally wherever organic material is available. Apart from being diverse, fungi are essential for the wellbeing of most ecosystems. They break down organic material and recycle nutrients, allowing other organisms to assimilate essential chemical elements. When they decompose organic compounds, carbon and other elements are released into the environment, where they are recycled. Humans make use of fungi as a food source, for application in agriculture and forestry, and in manufacturing products ranging from bread to antibiotics. But it is also true that some fungi are as bad as poison as they cause disease in both plants and animals.</p> <p>In this learning unit we investigate the structure and evolutionary history of fungi. We will also explore the major groups of fungi, and discuss their ecological and commercial significance.</p>	
5.2	<p><b>Learning outcomes</b></p> <p>By the end of this learning unit, you should be able to</p> <ul style="list-style-type: none"> <li>• explain why fungi are adapted to be decomposers and symbionts</li> <li>• explain the life cycle of fungi</li> <li>• describe the life cycle of the Zygomycota, clearly indicating plasmogamy, karyogamy and meiosis</li> <li>• describe the life cycle of the Basidiomycota, clearly indicating plasmogamy, karyogamy and meiosis</li> <li>• discuss the ecological importance of fungi</li> </ul>	
5.3	<p><b>Fungi are heterotrophs that feed by absorption</b></p> <p><b>Recommended reading:</b> pages 711–713 of chapter 31 in Campbell et al (2015)</p> <p>Fungi are heterotrophs that acquire their nutrients by means of absorption. They absorb small organic molecules from the surrounding medium. Fungi use exoenzymes, powerful hydrolytic enzymes, break down food outside their body into simpler compounds that the fungi can absorb and utilise further. The absorptive mode of nutrition is associated with the ecological roles of fungi as decomposers (saprobies), parasites and mutualistic symbionts. <b>Saprobic fungi</b> absorb nutrients from non-living organisms. <b>Parasitic fungi</b> absorb nutrients from the cells of living hosts. Some parasitic fungi, including some that infect humans and plants, are pathogenic. It has been reported that fungi cause about 80% of plant diseases. <b>Mutualistic fungi</b> also absorb nutrients from a host organism, but they reciprocate with functions that benefit their partner in some way.</p> <p><b>Body structure adapts fungi for absorptive nutrition</b></p> <p>Yeasts are single-celled fungi. Most species of fungi are multicellular. The vegetative bodies of most fungi are constructed of tiny filaments called <b>hyphae</b> that form an interwoven mat called a mycelium. Fungal hyphae have cell walls. These are built mainly of <b>chitin</b>, a strong but flexible nitrogen-containing polysaccharide identical to that found in arthropods. Most fungi are multicellular with hyphae divided into cells by cross walls, or <b>septa</b>. These generally have pores large enough for ribosomes, mitochondria and even nuclei to flow from cell to cell. Fungi that lack septa, coenocytic fungi, consist of a continuous cytoplasmic mass with hundreds or thousands of nuclei. This results from repeated nuclear division without cytoplasmic division. Parasitic fungi usually have some hyphae modified as <b>haustoria</b>, nutrient-absorbing hyphal tips that penetrate the tissues of their host. Some fungi even have hyphae adapted for preying on animals. The filamentous structure of the mycelium provides an extensive surface area that suits the absorptive nutrition of fungi. 1 cm<sup>3</sup> of rich organic soil may contain 1 km of fungal hyphae with a surface area of more than 300 cm<sup>2</sup>. A fungal mycelium grows rapidly. Proteins and other materials synthesised by the entire mycelium are channelled by cytoplasmic streaming to the tips of the extending hyphae. The fungus concentrates its energy and resources on adding hyphal length and absorptive</p>	

	<p>surface area. While fungal mycelia are non-motile, by swiftly extending the tips of their hyphae they can extend into new territory.</p>	
5.3.1	<p><b>Activity 5.1</b></p> <p><b>Do this activity and add it to your portfolio.</b></p> <p>Refer to your textbook and answer the following questions:</p> <ol style="list-style-type: none"> <li>Describe the distinguishing characteristics of fungi in feeding mode.</li> <li>Describe the body plan of a fungus.</li> <li>Compare and contrast the nutritional mode of a fungus with your own nutritional mode.</li> </ol>	
5.3.2	<p><b>Feedback on activity 5.1</b></p> <ol style="list-style-type: none"> <li>Fungi are eukaryotic heterotrophs that secrete digestive enzymes onto their food source and then absorb the predigested food.</li> <li>Make sure that in your answer you have included hyphae, mycelium and septa or cross walls.</li> <li>Both a fungus and a human are heterotrophs. Many fungi digest their food externally by secreting enzymes into the food and then absorb the small molecules that result from digestion. Other fungi absorb such small molecules directly from their environment. In contrast, humans (and most other animals) ingest relatively large pieces of food and digest the food within their bodies.</li> </ol>	
5.4	<p><b>Fungi produce spores through sexual or asexual life cycles</b></p> <p><b>Recommended reading:</b> pages 713–715 of chapter 31 in Campbell et al (2015)</p> <p>Fungi reproduce by producing vast numbers of spores, either sexually or asexually. The output of spores from one reproductive structure can be enormous, since puffballs may release trillions of spores. Dispersal is widely driven by wind or water. Spores germinate to produce mycelia if they land in a moist place where there is food.</p> <p><b>Many fungi have a heterokaryotic stage</b></p> <p>The nuclei of fungal hyphae and spores of most species are haploid, except for transient diploid stages that form during sexual life cycles. Sexual reproduction in fungi begins when hyphae from two genetically distinct mycelia release sexual-signalling molecules called pheromones. Pheromones from each partner bind to receptors on the surface of the other. The union of the cytoplasm of the two parent mycelia is known as <b>plasmogamy</b> (see figure 31.5 in your prescribed textbook). In some species, <b>heterokaryotic</b> mycelia become mosaics, with different nuclei remaining in separate parts of the same mycelium or mingling and even exchanging chromosomes and genes. In some fungi, the haploid nuclei pair off two to a cell, one from each parent. Such a mycelium is known as <b>dikaryotic</b>, meaning "two nuclei". In many fungi with sexual life cycles, <b>karyogamy</b>, the fusion of haploid nuclei contributed by two parents, occurs well after plasmogamy, cytoplasmic fusion of cells from the two parents. The delay may be hours, days, months or even centuries. During karyogamy, the haploid nuclei contributed by the two parents fuse, producing diploid cells. In most fungi the zygotes of transient structures formed by karyogamy are the only diploid stages in the life cycle. These undergo meiosis to produce haploid cells that develop as spores in specialised reproductive structures. These spores disperse to form new haploid mycelia. The sexual processes of karyogamy and meiosis generate genetic variation. The heterokaryotic condition also offers some of the advantages of diploid, in that one haploid genome may be able to compensate for harmful mutations in the other.</p> <p><b>Many fungi reproduce asexually</b></p> <p>The processes of asexual reproduction in fungi vary widely. Some species reproduce only asexually. Some fungi that can reproduce asexually grow as mould. Moulds grow rapidly as mycelia and produce spores. Yeasts live in liquid or moist habitats. Instead of producing spores, yeasts reproduce asexually by simple cell division or by budding of small cells. Most moulds and yeasts have no known sexual stage. These fungi are called <b>deuteromycetes</b>, or imperfect fungi. Whenever a sexual stage of a deuteromycete is discovered, the species is</p>	

	classified in a particular phylum depending on its sexual structures. Fungi can be identified from their sexual stages and by new genetic techniques.	
5.5	<p><b>The ancestor of fungi was an aquatic, flagellated protist</b></p> <p><b>Recommended reading:</b> pages 715–716 of chapter 31 in Campbell et al (2015)</p> <p>Data from palaeontology and molecular systematics offer insights into the early evolution of fungi. Systematists recognise Fungi and Animalia as sister kingdoms. Interesting to know, fungi and animals are more closely related to one another than they are to plants or other eukaryotes.</p> <p>Phylogenetic systematics suggests that fungi evolved from a unicellular, flagellated protist. The lineages of fungi that diverged earliest (the <b>chytrids</b>) have flagella. Members of the clade Opisthokonta, including animals, fungi, and closely related protists, possess flagella. This name refers to the posterior (opistho) location of the flagellum. Scientists estimate that the ancestors of animals and fungi diverged into separate lineages 1.5 billion years ago. However, the oldest undisputed fungal structures are only 460 million years old. It is likely that the first fungi were unicellular and did not fossilise. Fungi underwent an adaptive radiation when life began to colonise land. Fossils of the first vascular plants from the Silurian period contain evidence of mycorrhizae, symbiotic relationships between plants and subterranean fungi.</p>	
5.6	<p><b>Fungi have radiated into a diverse set of lineages</b></p> <p><b>Recommended reading:</b> pages 716–723 of chapter 31 in Campbell et al (2015)</p> <p>Fungi classified in the phylum Chytridiomycota, called the chytrids, are widespread in lakes, ponds and soil. As mentioned before, some are saprobes, while others parasitise protists, plants and animals. However, recent molecular evidence supports the hypothesis that chytrids diverged earliest in fungal evolution. Like other fungi, chytrids use an absorptive mode of nutrition, have chitinous cell walls and have similar key enzymes and metabolic pathways. While there are a few unicellular chytrids, most form coenocytic hyphae. Chytrids are unique among fungi in having flagellated spores, called <b>zoospores</b>. Until recently, systematists thought that fungi lost flagella only once in their history, after chytrids had diverged from other lineages. However, molecular data now indicates that some flagellated fungi are more closely related to another fungal group, the zygomycetes. If this is true, flagella were lost on more than one occasion during fungal evolution.</p> <p><b>Phylum Zygomycota: Zygote fungi form resistant structures during sexual reproduction</b></p> <p>The 1 000 zygomycetes exhibit a considerable diversity of life history. The phylum includes fast-growing moulds, parasites and commensal symbionts. The life cycle and biology of <i>Rhizopus stolonifer</i>, black bread mould, is typical of zygomycetes. The hyphae are coenocytic, with septa found only where reproductive cells are formed. Horizontal hyphae spread out over food, penetrate it and digest nutrients. In the asexual phase, hundreds of haploid spores develop in sporangia at the tips of upright hyphae. Some zygomycetes, such as <i>Pilobolus</i>, can actually aim their sporangia toward conditions that would be favourable for their spores. If environmental conditions deteriorate, <i>Rhizopus</i> may reproduce sexually. Plasmogamy of opposite mating types produces a zygosporangium. Inside this multinucleate structure, the heterokaryotic nuclei fuse to form diploid nuclei that undergo meiosis. The zygosporangia are resistant to freezing and drying. When conditions improve, the zygosporangia undergo meiosis and release haploid spores that colonise new substrates.</p> <p><b>Microsporidia are unicellular parasites</b></p> <p>Microsporidia are unicellular parasites of animals and protists. They are often used in biological control of insect pests. Microsporidia lack conventional mitochondria, and represent something of a taxonomic mystery. Some researchers suggest that they are an ancient, deep-branching eukaryotic lineage. Recent evidence suggests that they are highly derived parasites that may be related to zygomycete fungi.</p> <p><b>Glomeromycetes form mycorrhizae</b></p> <p>Only 160 species of glomeromycetes have been identified. Nonetheless, they are an economically significant group. All glomeromycetes form symbiotic mycorrhizae with plant roots. Mycorrhizal fungi can deliver phosphate ions and other minerals to plants. In exchange, the plants supply the fungi with organic nutrients. There are several different types of mycorrhizal fungi. Ectomycorrhizal fungi form sheaths of hyphae over the surface of the</p>	

plant root and grow into the extracellular spaces of the root cortex. Endomycorrhizal fungi extend their hyphae through the root cell wall and into tubes formed by invagination of the root cell membrane. Glomeromycetes all form a distinct type of endomycorrhizae called arbuscular mycorrhizae. The tips of the hyphae that push into plant root cells branch into tiny tree-like structures known as **arbuscles**. These symbiotic partnerships with glomeromycetes are present in 90% of all plants.

**Phylum Ascomycota: Sac fungi produce sexual spores in sac-like asci**

Mycologists have described more than 32 000 species of ascomycetes, or sac fungi, from a variety of marine, freshwater and terrestrial habitats. Ascomycetes produce sexual spores in sac-like asci and are called sac fungi. Most ascomycetes bear their sexual stages in fruiting bodies called ascocarps. They range in size and complexity from unicellular yeasts to elaborate cup fungi and morels. Some are devastating plant pathogens. Many are important saprobes, particularly of plant material. About 40% of ascomycete species live with green algae or cyanobacteria in mutualistic associations called **lichens**. Some ascomycetes form mycorrhizae with plants or live between mesophyll cells in leaves where they may help protect the plant tissue from insects by releasing toxins. Ascomycetes reproduce asexually by producing enormous numbers of asexual spores, which are usually dispersed by the wind. These naked spores, or conidia, develop in long chains or clusters at the tips of specialised hyphae called conidiophores. Ascomycetes are characterised by an extensive heterokaryotic stage during the formation of ascocarps. Plasmogamy between two parental hyphae produces a heterokaryotic bulge called an ascogonium. The coenocytic ascogonium extends hyphae that are partitioned by septa into dikaryotic cells, each with two haploid nuclei representing two parents. The cells at the tip of these dikaryotic hyphae develop into asci. Within an ascus, karyogamy combines the two parental genomes, and meiosis forms four genetically different nuclei forming eight ascospores. In many asci, the eight ascospores are lined up in a row in the order in which they formed from a single zygote nucleus. One of the best-studied ascomycetes is *Neurospora crassa*, a bread mould. This ascomycete serves as a model organism.

**Phylum Basidiomycota: Club fungi have long-lived dikaryotic mycelia**

Approximately 30 000 fungi, including mushrooms and shelf fungi, are called basidiomycetes and are classified in the phylum Basidiomycota. The name of the phylum is derived from the basidium, a transient diploid stage. The club-like shape of the basidium is responsible for the common name club fungus. Basidiomycetes are important decomposers of wood and other plant materials. Of all fungi, the saprobic basidiomycetes are best at decomposing the complex polymer lignin, abundant in wood. The life cycle of a club fungus usually includes a long-lived dikaryotic mycelium. Environmental cues, such as rain or temperature change, induce the dikaryotic mycelium to reproduce sexually by producing elaborate fruiting bodies called basidiocarps. A mushroom is a familiar basidiocarp that can pop overnight as it absorbs water and cytoplasm steams in from the dikaryotic mycelium. The dikaryotic mycelia are long-lived, generally producing a new crop of basidiocarps each year. The cap of a mushroom supports and protects a large surface area of basidia on the gills. The basidia form sexual spores called basidiospores. A common white mushroom has a gill surface of about 200 cm<sup>2</sup> and may release a billion basidiospores, which drop from the cap and blow away. Asexual reproduction is much less common in basidiomycetes than in ascomycetes. Watch the following video which shows the sexual and asexual reproduction of fungi: <https://www.youtube.com/watch?v=uMucnzlH4gk>

5.7

**Fungi play key roles in the environment as well as human welfare**

**Recommended reading:** pages 723–727 of chapter 31 in Campbell et al (2015)

**Ecosystems depend on fungi as decomposers and symbionts.**

Fungi are important decomposers of organic material, including cellulose and lignin of plant cell walls. Fungi and bacteria are essential for providing ecosystems with the inorganic nutrients responsible for plant growth. Without decomposers, carbon, nitrogen and other elements would become tied up in organic matter. Fungi form symbiotic relationships with plants, algae and animals. Mycorrhizae are extremely important in natural ecosystems and agriculture. Almost all vascular plants have mycorrhizae and rely on their fungal partners for essential nutrients. Some fungi break down plant material in the guts of cows and other grazers. Many species of ants and termites raise fungi in "farms". The fungi break the leaves down into a substance that the insects can digest. Some mutualistic associations between "farmer" insects and "farmed" fungi have been established for more than 50 million years. In many cases, the fungi can no longer survive without the insects. Lichens are a symbiotic

association of millions of photosynthetic microorganisms held in a mesh of fungal hyphae. The fungal component is commonly an ascomycete, but several basidiomycete lichens are known. The photosynthetic partners are usually unicellular or filamentous green algae or cyanobacteria. The fungal hyphae provide most of the lichen's mass and give it an overall shape and structure. The algae or cyanobacteria usually occupy an inner layer below the lichen surface. The merger of fungus and alga is so complete that they are actually given genus and species names, as though they were single organisms. More than 13 500 species of lichen have been described—a fifth of all known fungi. In most lichens, each partner provides things that the other could not obtain on its own. For example, the alga provides the fungus with food by "leaking" carbohydrate from its cells. The cyanobacteria provide organic nitrogen through nitrogen fixation. The fungus provides a suitable physical environment for growth, retaining water and minerals, allowing for gas exchange, shading the algae or cyanobacteria from intense sunlight with pigments and deterring consumers with toxic compounds. The fungus also secretes acids, which aids in the uptake of minerals. The fungi of many lichens reproduce sexually by forming ascocarps or basidiocarps. Lichen algae reproduce independently by asexual cell division. Asexual reproduction of symbiotic units occurs either by fragmentation of the parental lichen or by the formation of structures called **soredia**, small clusters of hyphae with embedded algae. Phylogenetic studies of lichen DNA have helped illuminate the evolution of this symbiosis. The same studies also suggest that many free-living fungi, including *Penicillium*, descended from lichen-forming ancestors. Lichens are important pioneers on newly cleared rock and soil surfaces, such as burned forests and volcanic flows. The lichen acids penetrate the outer crystals of rocks and help break down the rock. This allows soil-trapping lichens to establish and starts the process of succession. Nitrogen-fixing lichens also add organic nitrogen to some ecosystems. Some lichens can survive severe cold or desiccation. In the arctic tundra, herds of caribou and reindeer graze on carpets of reindeer lichens under the snow in winter. In dry habitats, lichens may absorb water quickly from fog or rain, gaining more than ten times their mass in water. Lichens are particularly sensitive to air pollution, and their deaths can serve as an early warning of deteriorating air quality.

### **Some fungi are pathogens**

About 30% of the 100 000 known species of fungi are parasites, mostly on or in plants. Invasive ascomycetes have had drastic effects on forest trees such as American elms and American chestnuts in the northeastern United States. Other fungi, such as rusts and ergots, infect grain crops, causing tremendous economic losses each year. Fungi are also serious agricultural pests. Between 10% and 50% of the world's fruit harvest is lost each year to fungal attack. Some fungi that attack food crops produce compounds that are harmful to humans. For example, the mould *Aspergillus* can contaminate improperly stored grains and peanuts with aflatoxins, which are carcinogenic. Poisons produced by ergots of the ascomycete *Claviceps purpurea* can cause gangrene, nervous spasms, burning sensations, hallucinations and temporary insanity when infected rye is milled into flour and consumed. One of the compounds to have been isolated from ergots is lysergic acid, the raw material from which the hallucinogen LSD is made. Animals are much less susceptible to parasitic fungi than are plants. Only about 50 fungal species are known to parasitise humans and other animals, but their damage can be disproportionate to their taxonomic diversity. The general term for a fungal infection is mycosis. Infections of ascomycetes produce the disease ringworm, known as athlete's foot when they grow on the feet. Systemic mycoses spread through the body and cause very serious illnesses. They are typically caused by inhaled spores. Coccidioidomycosis is a systemic mycosis that produces tuberculosis-like symptoms in the lungs. It is so deadly that it is now considered a potential biological weapon. Some mycoses are opportunistic, occurring only when a change in the body's microbiology, chemistry, or immunology allows the fungi to grow unchecked. *Candida albicans* is a normal inhabitant of moist epithelia such as human vaginal lining, but it can become an opportunistic pathogen. Other opportunistic mycoses have become more common due to AIDS, which weakens the immune system.

### **Fungi are commercially important**

In addition to the benefits that we receive from fungi in their roles as decomposers and recyclers of organic matter, we use fungi in a number of ways. Most people have eaten mushrooms, the fruiting bodies (basidiocarps) of subterranean fungi. The fruiting bodies of certain mycorrhizal ascomycetes, truffles, are prized by gourmets for their complex flavours. The distinctive flavours of certain cheeses come from the fungi used to ripen them. The ascomycete mould *Aspergillus* is used to produce citric acid for colas. Yeasts are even more important in food production and are used in baking, brewing and winemaking. The yeast *Saccharomyces cerevisiae* is the most important of all cultured fungi, and is available in many strains as baker's and brewer's yeast. Contributing to medicine, some fungi produce antibiotics used to treat bacterial diseases. In fact, the first antibiotic discovered

	<p>was penicillin, made by the common mould <i>Penicillium</i>. A compound extracted from ergots is used to reduce high blood pressure and stop maternal bleeding after childbirth. Fungi play an important role in molecular biology and biotechnology. Researchers use <i>Saccharomyces</i> to study the molecular genetics of eukaryotes. Scientists have learnt about the genes involved in Parkinson's and Huntington's diseases by examining the homologous genes in <i>Saccharomyces</i>. Genetically modified fungi are used to produce human glycoproteins.</p>
5.8	<p><b>Activity 5.2</b></p> <p><b>Do this activity and add it to your portfolio.</b></p> <p>Refer to your textbook and answer the following questions:</p> <ol style="list-style-type: none"> <li>What types of reproduction occur in fungi?</li> <li>What are mycorrhizas? How do both fungi and plants benefit from this ecological interaction?</li> <li>What are lichens? How do fungi participate in this ecological interaction?</li> <li>Discuss the economic importance of yeast which belongs to the kingdom Fungi.</li> </ol>
5.9	<p><b>Feedback on activity 5.2</b></p> <ol style="list-style-type: none"> <li>In fungi, both asexual and sexual reproduction occurs. Fungi reproduce asexually by fragmentation, gemmation and sporulation. Some species can reproduce sexually through the fusion of hyphae from different specimens, and even with metagenesis (alternation of generations).</li> <li>Mycorrhizas are mutualistic ecological interactions between fungi and some plant roots. Fungi provide more water and mineral salts to the plant and obtain organic material from the plant in return.</li> <li>Lichens are formed through the mutualist ecological interaction between fungi and algae or between fungi and cyanobacteria. In this ecological interaction, the fungi absorb water that is then used by algae (or cyanobacteria), and the algae (or cyanobacteria), as autotrophs, produce organic material in excess to serve as food for the fungi.</li> <li>Remember that your approach to this question may differ slightly from mine; however, this is how you can attempt the question. Yeast plays an important role in the brewing and baking industries. It forms alcoholic beverages under anaerobic conditions. <i>Saccharomyces cerevisiae</i> plays an important role in the brewing industry. This species also plays an important role in the baking industry by forming carbon dioxide and alcohol. It is also used as vitamin-rich food. It can spoil foodstuff. It plays a vital role in the formation of silk. Some of the species like <i>Candida albicans</i> attack human beings and lead to thrush and inflammation of the genital organs. Some of the species of <i>Cryptococcus</i> and <i>Torula</i> also attack human beings.</li> </ol>
5.10	<p><b>Summary</b></p> <p>All fungi (include decomposers and symbionts) are heterotrophs that acquire nutrients by absorption. Many fungi secrete enzymes that break down complex molecules. Most fungi grow as thin, multicellular filaments called hyphae, whereas relatively few species grow only as single-celled yeasts.</p> <p>In fungi, the sexual life cycle involves cytoplasmic fusion (plasmogamy) and nuclear fusion (karyogamy), with an intervening heterokaryotic stage in which cells have haploid nuclei from two parents. The diploid cells resulting from karyogamy are short-lived and undergo meiosis, producing genetically diverse haploid spores. Many fungi can reproduce asexually as filamentous fungi or yeasts.</p> <p>Chytrids is a group of fungi with flagellated spores, including some basal lineages. Fungi were recorded among the earliest colonisers of land. Moreover, fossil evidence indicates that these included species that were symbionts with early land plants. There are five existing fungal phyla, namely Chytridiomycota, Zygomycota, Glomeromycota, Ascomycota and Basidiomycota.</p> <p>Fungi perform essential recycling of chemical elements between the living and non-living world. Lichens are highly integrated symbiotic associations of fungi and algae or cyanobacteria. Many fungi are parasites, mostly of plants. Humans use fungi for food and to make antibiotics.</p>



<b>Learning unit 6</b>	<p><b>Plant structure, growth and development</b></p> <p>Contents</p> <p><b>6.1 Introduction</b></p> <p><b>6.2 Learning outcomes</b></p> <p><b>6.3 Plant bodies have a hierarchical organisation consisting of organs, tissues and cells</b></p> <p><b>6.4 The three basic organs of a plant</b></p> <p><b>6.5 Plant tissue systems</b></p> <p><b>6.6 Cell types</b></p> <p><b>6.7 Meristems generate cells for new organs</b></p> <p><b>6.8 Primary growth lengthens roots and shoots</b></p> <p><b>6.9 Secondary growth adds girth to stems and roots in woody plants</b></p> <p><b>6.10 Activity 6.1</b></p> <p><b>6.11 Feedback on activity 6.1</b></p> <p><b>6.12 Summary</b></p>
<b>6.1</b>	<p><b>Introduction</b></p> <p><b>To complete the learning unit, you will need to refer to pages 816–841 of chapter 35 in Campbell et al (2015)</b></p> <p>There are more than 300 000 species of flowering plants that live in and adapt to the many environments on earth and they represent a remarkable variety. Most plants show much greater diversity in their individual forms because the growth of most plants, much more than in animals, is affected by local environmental conditions. Take the example of adult lions. They have four legs and are of roughly the same size, but oak trees vary in the number and arrangement of their branches. This is because plants respond to challenges and opportunities in their respective local environment by altering their growth. The highly adaptive development of plants is critical in facilitating their acquisition of resources from their respective growing environments.</p> <p>In this learning unit, we focus on the structure, growth and development of flowering plants, which are vascular plants characterised by flowers, double fertilisation, endosperm and seeds enclosed within fruits. We then explore the key differences between the two main groups of flowering plants, eudicots and monocots.</p>
<b>6.2</b>	<p><b>Learning outcomes</b></p> <p>By the end of this learning unit, you should be able to</p> <ul style="list-style-type: none"> <li>• identify and discuss the structures of the three basic organs of a plant body, namely the roots, stems and leaves</li> <li>• describe the characteristics of the three tissue systems that these organs are composed of, namely dermal, vascular and ground tissues</li> <li>• describe the characteristics of the three cell types that these tissue systems are composed of, namely parenchyma, collenchyma and sclerenchyma cells</li> <li>• describe the structure and function of apical meristems</li> <li>• name the meristems responsible for primary growth</li> <li>• name the meristems responsible for secondary growth</li> </ul>

	<ul style="list-style-type: none"> <li>• discuss secondary growth of stems and roots</li> <li>• describe the production of the periderm</li> </ul>	
6.3	<p><b>Plant bodies have a hierarchical organisation consisting of organs, tissues and cells</b></p> <p><b>Recommended reading:</b> pages 817–823 of chapter 35 in Campbell et al (2015)</p> <p>Plants, like multicellular animals, have organs that are composed of different tissues, and tissues are composed of different cell types. A tissue is a group of cells with a common structure and function. An organ consists of several types of tissues that work together to carry out particular functions. We will first study the organs, since they are the most visible parts of a plant and easy to locate.</p>	
6.4	<p><b>The three basic organs of a plant</b></p> <p>The basic morphology of vascular plants reflects their evolutionary history as terrestrial organisms that inhabit and draw resources from two very different environments that are below the ground and above the ground. In addition, plants obtain water and minerals from the soil and they obtain CO<sub>2</sub> and light above ground.</p> <p>For vascular plants to obtain the resources they need, they have evolved two systems: a subterranean root system and an aerial shoot system of stems and leaves. Each part of this system depends on the other for carrying out its purpose. You may now be aware that if a plant is lacking chloroplasts and is living in the dark, roots will starve without the sugar and other organic nutrients imported from the photosynthetic tissues of the shoot system. Reciprocally, the shoot system (and its reproductive tissues, flowers) depends on water and minerals absorbed from the soil by the roots. A root is an organ that anchors a vascular plant in the soil, absorbs minerals and water and stores food. Most eudicots and gymnosperms have a taproot system, consisting of one large vertical root (the taproot) that produces many small lateral, or branch, roots. In angiosperms, taproots often store food that supports flowering and fruit production later.</p> <p>Seedless vascular plants and most monocots, including grasses, have fibrous root systems consisting of a mat of thin roots that spread out below the soil surface. A fibrous root system is usually shallower than a taproot system. Grass roots are concentrated in the upper few centimetres of soil. As a result, grasses make excellent ground cover for preventing erosion. Sturdy, horizontal, underground stems called rhizomes anchor large monocots such as palms and bamboo. The root system helps anchor a plant. In both taproot and fibrous root systems, absorption of water and minerals occurs near the root tips, where vast numbers of tiny root hairs increase the surface area enormously. Root hairs are extensions of individual epidermal cells on the root surface.</p> <p>Absorption of water and minerals is also increased by mutualistic relationships between plant roots and bacteria and fungi. Some plants have modified roots. Some arise from roots while adventitious roots arise above ground from stems or even from leaves. Some modified roots provide additional support and anchorage. Others store water and nutrients or absorb oxygen or water from the air. A stem is an organ consisting of alternating nodes, the points at which leaves are attached, and internodes, the stem segments between nodes.</p> <p>At the angle formed by each leaf and the stem is an axillary bud with the potential to form a lateral shoot or branch. Growth of a young shoot is usually concentrated at its apex, where there is a terminal bud with developing leaves and a compact series of nodes and internodes. The presence of a terminal bud is partly responsible for inhibiting the growth of axillary buds, a phenomenon called apical dominance. By concentrating resources on growing taller, apical dominance is an evolutionary adaptation that increases the plant's exposure to light. In the absence of a terminal bud, the axillary buds break dominance and give rise to a vegetative branch complete with its own terminal bud, leaves and axillary buds. Modified shoots with diverse functions have evolved in many plants. These shoots, which include stolons, rhizomes, tubers and bulbs, are often mistaken for roots. Stolons, such as the “runners” of strawberry plants, are horizontal stems that grow on the surface and enable a plant to colonise large areas asexually as plantlets form at nodes along each runner. Rhizomes, like those of ginger, are horizontal stems that grow underground. Tubers, including potatoes, are the swollen ends of rhizomes specialised for food storage. Bulbs, such as onions, are vertical, underground shoots consisting mostly of the swollen bases of leaves that store food.</p> <p>Leaves are the main photosynthetic organs of most plants, although green stems are also photosynthetic. While leaves vary extensively in form, they generally consist of a flattened blade and a stalk, the petiole, which joins the</p>	

	<p>leaf to a stem node. Grasses and other monocots lack petioles. In these plants, the base of the leaf forms a sheath that envelops the stem. Most monocots have parallel major veins that run the length of the blade, while eudicot leaves have a multi-branched network of major veins.</p> <p>Plant taxonomists use floral morphology, leaf shape, spatial arrangement of leaves and the pattern of veins to help identify and classify plants. For example, simple leaves have a single, undivided blade, while compound leaves have several leaflets attached to the petiole. The leaflet of a compound leaf has no axillary bud at its base. In a doubly compound leaf, each leaflet is divided into smaller leaflets. Most leaves are specialised for photosynthesis. Some plants have leaves that have become adapted for other functions. These include tendrils that cling to supports, spines of cacti for defence, leaves modified for water storage and brightly coloured leaves that attract pollinators.</p>	
6.5	<p><b>Plant tissue systems</b></p> <p>Every organ of a plant has three tissue systems: dermal, vascular and ground. Each system is continuous throughout the plant body.</p> <p>The <b>dermal tissue</b> is the outer covering. In non-woody plants, it is a single layer of tightly packed cells, or epidermis, which covers and protects all young parts of the plant. The epidermis has other specialised characteristics consistent with the function of the organ it covers. For example, the root hairs are extensions of epidermal cells near the tips of the roots. The epidermis of leaves and most stems secretes a waxy coating, the cuticle, which helps the aerial parts of the plant retain water. In woody plants, protective tissues called periderm replace the epidermis in older regions of stems and roots.</p> <p><b>Vascular tissue</b>, continuous throughout the plant, is involved in the transport of materials between roots and shoots. Xylem conveys water and dissolved minerals upward from roots into the shoots. Phloem transports food made in mature leaves to the roots, to non-photosynthetic parts of the shoot system and to sites of growth, such as developing leaves and fruits. The vascular tissue of a root or stem is called the stele. In angiosperms, the vascular tissue of the root forms a solid central vascular cylinder, while stems and leaves have vascular bundles, strands consisting of xylem and phloem.</p> <p><b>Ground tissue</b> is tissue that is neither dermal tissue nor vascular tissue. In eudicot stems, ground tissue is divided into pith, internal to the vascular tissue, and cortex, external to the vascular tissue. The functions of ground tissue include photosynthesis, storage and support. For example, the cortex of a eudicot stem typically consists of both fleshy storage cells and thick-walled support cells.</p>	
6.6	<p><b>Cell types</b></p> <p>Plant cells are differentiated, with each type of plant cell possessing structural adaptations that make specific functions possible. Cell differentiation may be evident within the protoplast, the cell contents exclusive of the cell wall. Modifications of cell walls also play a role in plant cell differentiation. We will consider the major types of differentiated plant cells: parenchyma, collenchyma, sclerenchyma, water-conducting cells of the xylem and sugar-conducting cells of the phloem.</p> <p>Mature <b>parenchyma cells</b> have primary walls that are relatively thin and flexible, and most lack secondary walls. The protoplast of a parenchyma cell usually has a large central vacuole. Parenchyma cells are often depicted as “typical” plant cells because they generally are the least specialised, but there are exceptions. For example, the highly specialised sieve-tube members of the phloem are parenchyma cells. Parenchyma cells perform most of the metabolic functions of the plant, synthesising and storing various organic products. For example, photosynthesis occurs within the chloroplasts of parenchyma cells in the leaf. Some parenchyma cells in the stems and roots have colourless plastids that store starch. The fleshy tissue of most fruit is composed of parenchyma cells. Most parenchyma cells retain the ability to divide and differentiate into other cell types under special conditions, such as the repair and replacement of organs after injury to the plant. In the laboratory, it is possible to regenerate an entire plant from a single parenchyma cell.</p> <p><b>Collenchyma cells</b> have thicker primary walls than parenchyma cells, though the walls are unevenly thickened. Grouped into strands or cylinders, collenchyma cells help support young parts of the plant shoot. Young stems</p>	

and petioles often have strands of collenchyma just below the epidermis, providing support without restraining growth. Mature collenchyma cells are living and flexible and elongate with the stems and leaves they support.

**Sclerenchyma cells** have thick secondary walls usually strengthened by lignin and function as supporting elements of the plant. They are much more rigid than collenchyma cells. Unlike parenchyma cells, they cannot elongate. Sclerenchyma cells occur in plant regions that have stopped lengthening. Many sclerenchyma cells are dead at functional maturity, but they produce rigid secondary cell walls before the protoplast dies. In parts of the plant that are still elongating, secondary walls are deposited in a spiral or ring pattern, enabling the cell wall to stretch like a spring as the cell grows. Two types of sclerenchyma cells, fibres and sclereids, are specialised entirely for support. Fibres are long, slender and tapered, and usually occur in groups. Hemp fibres are used for making rope, and flax fibres are woven into linen. Sclereids are irregular in shape and are shorter than fibres. They have very thick, lignified secondary walls. Sclereids impart hardness to nutshells and seed coats and the gritty texture to pear fruits. The water-conducting elements of xylem, the tracheids and vessel elements, are elongated cells that are dead at functional maturity. The thickened cell walls remain as a non-living conduit through which water can flow. Both tracheids and vessels have secondary walls interrupted by pits, thinner regions where only primary walls are present. Tracheids are long, thin cells with tapered ends. Water moves from cell to cell mainly through pits. Because their secondary walls are hardened with lignin, tracheids function in support as well as transport.

Vessel elements are generally wider, shorter, thinner walled and less tapered than tracheids. Vessel elements are aligned end to end, forming long micropipes or xylem vessels. The ends are perforated, enabling water to flow freely. In the phloem, sucrose, other organic compounds and some mineral ions move through tubes formed by chains of cells called sieve-tube members. These are alive at functional maturity, although a sieve-tube member lacks a nucleus, ribosomes and a distinct vacuole. The end walls, the sieve plates, have pores that facilitate the flow of fluid between cells. Each sieve-tube member has a non-conducting nucleated companion cell, which is connected to the sieve-tube member by numerous plasmodesmata. The nucleus and ribosomes of the companion cell serve both that cell and the adjacent sieve-tube member. In some plants, companion cells in leaves help load sugar into the sieve-tube members, which transport the sugars to other parts of the plant.

6.7

### Meristems generate cells for new organs

**Recommended reading:** pages 824–825 of chapter 35 in Campbell et al (2015)

A major difference between plants and most animals is that plant growth is not limited to an embryonic period. Most plants demonstrate indeterminate growth, growing as long as the plant lives. In contrast, most animals and certain plant organs, such as flowers and leaves, undergo determinate growth, ceasing to grow after they reach a certain size. Indeterminate growth does not mean immortality. Annual plants complete their life cycle — from germination to flowering and seed production to death — in a single year or less. Many wildflowers and important food crops, such as cereals and legumes, are annuals. The life of a biennial plant spans two years. Often, there is an intervening cold period between the vegetative growth season and the flowering season.

Plants such as trees, shrubs and some grasses that live many years are perennials. Perennials do not usually die from old age, but from an infection or some environmental trauma. A plant is capable of indeterminate growth because it has perpetually embryonic tissues called meristems in its regions of growth. These cells divide to generate additional cells, some of which remain in the meristematic region, while others become specialised and are incorporated into the tissues and organs of the growing plant. Cells that remain as wellsprings of new cells in the meristem are called initials. Those that are displaced from the meristem, derivatives, continue to divide for some time until the cells they produce differentiate within developing tissues. The pattern of plant growth depends on the location of meristems. Apical meristems, located at the tips of roots and in the buds of shoots, supply cells for the plant to grow in length. This elongation, primary growth, enables roots to extend through the soil and shoots to increase their exposure to light and carbon dioxide. In herbaceous plants, primary growth produces almost all of the plant body.

Woody plants also show secondary growth, progressive thickening of roots and shoots where primary growth has ceased. Secondary growth is produced by lateral meristems, cylinders of dividing cells that extend along the

	<p>length of roots and shoots. The vascular cambium adds layers of vascular tissue called secondary xylem and phloem. The cork cambium replaces the epidermis with thicker, tougher periderm.</p> <p>In woody plants, primary growth produces young extensions of roots and shoots each growing season, while secondary growth thickens and strengthens the older parts of the plant. At the tip of a winter twig of a deciduous tree is the dormant terminal bud, enclosed by bud scales that protect its apical meristem. In the spring, the bud will shed its scales and begin a new spurt of primary growth. Along each growth segment, nodes are marked by scars left when leaves fell in autumn. Above each leaf scar is either an axillary bud or a branch twig. Further down the twig are whorls of scars left by the scales that enclosed the terminal bud during the previous winter.</p> <p>Each spring and summer, as the primary growth extends the shoot, secondary growth thickens the parts of the shoot that formed in previous years.</p>
6.8	<p><b>Primary growth lengthens roots and shoots</b></p> <p><b>Recommended reading:</b> pages 825–829 of chapter 35 in Campbell et al (2015)</p> <p>Primary growth produces the primary plant body, the parts of the root and shoot systems produced by apical meristems. The herbaceous plant and the youngest parts of a woody plant represent the primary plant body.</p> <p>Apical meristems lengthen both roots and shoots. However, there are important differences in the primary growth of these two systems. The root tip is covered by a thimble-like root cap, which protects the meristem as the root pushes through the abrasive soil during primary growth. The cap also secretes a polysaccharide slime that lubricates the soil around the growing root tip.</p> <p>Growth in length is concentrated just behind the root tip, where three zones of cells at successive stages of primary growth are located. These zones — the zone of cell division, the zone of elongation and the zone of maturation — grade together. The zone of cell division includes the root apical meristem and its derivatives. New root cells are produced in this region, including the cells of the root cap. The zone of cell division blends into the zone of elongation where cells elongate, sometimes to more than ten times their original length. It is this elongation of cells that is mainly responsible for pushing the root tip, including the meristem, ahead. The meristem sustains growth by continuously adding cells to the youngest end of the zone of elongation. In the zone of maturation, cells become differentiated and become functionally mature.</p> <p>The primary growth of roots consists of the epidermis, ground tissue and vascular tissue. Water and minerals absorbed from the soil must enter through the epidermis, a single layer of cells covering the root. Root hairs greatly increase the surface area of epidermal cells. Most roots have a solid core of xylem and phloem. The xylem radiates from the centre in two or more spokes, with phloem developing in the wedges between the spokes.</p> <p>In monocot roots, the vascular tissue consists of a central core of parenchyma surrounded by alternating patterns of xylem and phloem. The ground tissue of roots consists of parenchyma cells that fill the cortex, the region between the vascular cylinder and the epidermis. Cells within the ground tissue store food and are active in the uptake of minerals that enter the root with the soil solution. The innermost layer of the cortex, the endodermis, is a cylinder one-cell thick that forms a selective barrier between the cortex and the vascular cylinder.</p> <p>An established root may sprout lateral roots from the outermost layer of the vascular cylinder, the pericycle. The vascular tissue of the lateral root maintains its connection to the vascular tissue of the primary root. The apical meristem of a shoot is a dome-shaped mass of dividing cells at the terminal bud. Leaves arise as leaf primordia on the flanks of the apical meristem. Axillary buds develop from islands of meristematic cells left by apical meristems at the bases of the leaf primordia. Within a bud, leaf primordia are crowded close together because internodes are very short.</p> <p>Most of the elongation of the shoot occurs by growth in length of slightly older internodes below the shoot apex. This growth is due to cell division and cell elongation within the internode. In some plants, including grasses, internodes continue to elongate all along the length of the shoot over a prolonged period. These plants have meristematic regions called intercalary meristems at the base of each leaf. This explains why grass continues to grow after being mowed. Unlike their central position in a root, vascular tissue runs the length of a stem in</p>

strands called vascular bundles. Because the vascular system of the stem is near the surface, branches can develop with connections to the vascular tissue without having to originate from deep within the main shoot.

In gymnosperms and most eudicots, the vascular bundles are arranged in a ring, with pith inside and cortex outside the ring. The vascular bundles have xylem facing the pith and phloem facing the cortex. In the stems of most monocots, the vascular bundles are scattered throughout the ground tissue rather than arranged in a ring. In both monocots and eudicots, the stem's ground tissue is mostly parenchyma.

Many stems are strengthened by collenchyma just beneath the epidermis. Sclerenchyma fibre cells within vascular bundles also help support stems. The leaf epidermis is composed of cells tightly locked together like pieces of a puzzle. The leaf epidermis is the first line of defence against physical damage and pathogenic organisms, and its waxy cuticle is a barrier to water loss from the plant. The epidermal barrier is interrupted only by the stomata, tiny pores flanked by specialised epidermal cells called guard cells.

Each stoma is an opening between a pair of guard cells that regulate the opening and closing of the pore. The stomata regulate CO<sub>2</sub> exchange between the surrounding air and the photosynthetic cells inside the leaf. They are also the major avenues of evaporative water loss from the plant — a process called transpiration. The ground tissue of the leaf, the mesophyll, is sandwiched between the upper and lower epidermis. It consists mainly of parenchyma cells with many chloroplasts and specialised for photosynthesis.

In many eudicots, a layer or more of columnar palisade mesophyll lies over spongy mesophyll. Carbon dioxide and oxygen circulate through the labyrinth of air spaces around the irregularly spaced cells of the spongy mesophyll. The air spaces are particularly large near stomata, where gas exchange with the outside air occurs. The vascular tissue of a leaf is continuous with the xylem and phloem of the stem. Leaf traces, branches of vascular bundles in the stem, pass through petioles and into leaves.

Vascular bundles in the leaves are called veins. Each vein is enclosed in a protective bundle sheath consisting of one or more layers of parenchyma. Within a leaf, veins subdivide repeatedly and branch throughout the mesophyll. The xylem brings water and minerals to the photosynthetic tissues and the phloem carries sugars and other organic products to other parts of the plant. The vascular infrastructure also functions to support and reinforce the shape of the leaf.

6.9

### Secondary growth adds girth to stems and roots in woody plants

**Recommended reading:** pages 829–833 of chapter 35 in Campbell et al (2015)

The stems and roots of most eudicots increase in girth by secondary growth. The secondary plant body consists of the tissues produced during this secondary growth in diameter. Primary and secondary growth occurs simultaneously but in different regions. While elongation of the stem (primary growth) occurs at the apical meristem, increases in diameter (secondary growth) occur further down the stem. The vascular cambium is a cylinder of meristematic cells that form secondary vascular tissue. It forms successive layers of secondary xylem to its interior and secondary phloem to its exterior.

The accumulation of this tissue over the years accounts for most of the increase in diameter of a woody plant. The vascular cambium develops from parenchyma cells that retain the capacity to divide. This meristem forms in a layer between the primary xylem and primary phloem of each vascular bundle and in the ground tissue between the bundles.

The meristematic bands unite to form a continuous cylinder of dividing cells. This ring of vascular cambium consists of regions of ray initials and fusiform initials. The tapered, elongated cells of the fusiform initials form secondary xylem to the inside of the vascular cambium and secondary phloem to the outside.

Ray initials produce vascular rays that transfer water and nutrients laterally within the woody stem and also store starch and other reserves. As secondary growth continues over the years, layer upon layer of secondary xylem accumulates, producing the tissue we call wood. Wood consists mainly of tracheids, vessel elements (in angiosperms) and fibres. These cells, dead at functional maturity, have thick, lignified walls that give wood its hardness and strength.

	<p>In temperate regions, secondary growth in perennial plants stops during the winter. The first tracheid and vessel cells formed in the spring (early wood) have larger diameters and thinner walls than cells produced later in the summer (late wood). The structure of the early wood maximises delivery of water to new, expanding leaves.</p> <p>The thick-walled cells of later wood provide more physical support. This pattern of growth — cambium dormancy, early wood production and late wood production — produces annual growth rings. As a tree or woody shrub ages, the older layers of secondary xylem, known as heartwood, no longer transport water and minerals. The outer layers, known as sapwood, continue to transport xylem sap. Only the youngest secondary phloem, closest to the vascular cambium, functions in sugar transport. The older secondary phloem dies and is sloughed off as part of the bark.</p> <p>The cork cambium acts as a meristem for a tough, thick covering for stems and roots that replaces the epidermis. Early in secondary growth, the epidermis produced by primary growth splits, dries and falls off the stem or root. It is replaced by two tissues produced by the first cork cambium, which arises in the outer cortex of stems and in the outer layer of the pericycle of roots.</p> <p>The first tissue, phelloderm, is a thin layer of parenchyma cells that forms to the interior of the cork cambium. Cork cambium also produces cork cells, which accumulate at the cambium's exterior.</p> <p>Waxy material called suberin, deposited in the cell walls of cork cells before they die, acts as a barrier against water loss, physical damage and pathogens. The cork plus the cork cambium form the periderm, a protective layer that replaces the epidermis.</p> <p>In areas called lenticels, spaces develop between the cork cells of the periderm. These areas within the trunk facilitate gas exchange with the outside air. Unlike the vascular cambium, cells of the cork cambium do not divide. The thickening of a stem or root splits the first cork cambium, which loses its meristematic activity and differentiates into cork cells.</p> <p>A new cork cambium forms to the inside, resulting in a new layer of periderm. As this process continues, older layers of periderm are sloughed off. This produces the cracked, peeling bark of many tree trunks. Bark refers to all tissues external to the vascular cambium, including secondary phloem, cork cambium and cork.</p>								
<p><b>6.10</b></p>	<p><b>Activity 6.1</b></p> <p><b>Do this activity and add it to your portfolio.</b></p> <p>Refer to your textbook and answer the following questions:</p> <ol style="list-style-type: none"> <li>What is the general function of stems? What are some specialised evolutionary adaptations of stems?</li> <li>What is the advantage of apical dominance to a plant?</li> <li>What are five additional functions that modified leaves can perform?</li> <li>Plants have three types of tissues. Place the name of each tissue type and its function in this table.</li> </ol> <table border="1" data-bbox="280 1469 1369 1615"> <thead> <tr> <th>Tissue type</th> <th>Tissue type function</th> </tr> </thead> <tbody> <tr> <td> </td> <td> </td> </tr> <tr> <td> </td> <td> </td> </tr> <tr> <td> </td> <td> </td> </tr> </tbody> </table> <ol style="list-style-type: none"> <li>Explain the following relationships: <ul style="list-style-type: none"> <li>▪ apical meristems and primary growth</li> <li>▪ lateral meristems and secondary growth</li> <li>▪ primary growth and secondary growth</li> </ul> </li> <li>Explain what events occur in the zone of cell division, zone of elongation and zone of differentiation.</li> <li>Why must new roots formed by the pericycle originate in the centre of the root?</li> <li>How is the arrangement of vascular bundles different in monocot and dicot stems?</li> </ol>	Tissue type	Tissue type function						
Tissue type	Tissue type function								
<p><b>6.11</b></p>	<p><b>Feedback on activity 6.1</b></p>								

- a) Keep in mind that the stem raises or separates leaves, exposing them to sunlight. Stems also raise reproductive structures, facilitating the dispersal of pollen and fruit.
- b) Apical dominance is the tendency for growth to be concentrated at the tip of a plant shoot, because the apical bud partially inhibits axillary bud growth. Removing the apical bud stimulates growth of auxiliary buds, regulating the growth of a plant in case a shoot is eaten, or the plant loses sunlight.
- c) The five additional functions that modified leaves can perform are support, protection, storage, reproduction and attract pollination.
- d)

Tissue type	Tissue type function
Dermal tissue system	Plant's outer protective covering
Vascular tissue system	Carries out long-distance transport of materials between root and shoot systems
Ground tissue system	Includes various cells specialised for functions such as storage, photosynthesis and support

- e) This is how you should explain the relationship between the two processes:

**Apical meristems** and **primary growth**: Apical meristems, located at the tips of roots and shoots and in axillary buds or shoots, provide additional cells that enable growth in length, also called primary growth.

**Lateral meristems** and **secondary growth**: Growth in thickness, known as secondary growth, is caused by lateral meristems called the vascular cambium and cork cambium.

**Primary growth** and **secondary growth**: Primary growth allows roots to extend throughout the soil and shoots to increase their exposure to light. Woody plants also grow in circumference in the parts of stems and roots that no longer grow in length; this growth in thickness is called secondary growth.

- f) **Zone of cell division**: New roots are produced.  
**Zone of elongation**: Growth occurs and new root cells elongate.  
**Zone of differentiation**: Cells complete differentiation and become distinct cell types.
- g) Bear in mind that for the vascular tissue of the new root and the original root to be continuous, the new root must originate from the centre of the original root (remember that the vascular tissue in the root is in the centre, or stele, of the root).
- h) In most eudicot species, the vascular tissue consists of vascular bundles arranged in a ring. In most monocot stems, the vascular bundles are scattered throughout the ground tissue rather than forming a ring.

6.12

**Summary**

Vascular plants have shoots of stems, leaves and, in angiosperms, flowers. Roots anchor the plant, absorb and conduct water and minerals, and store food. Plants have three tissue systems: dermal, vascular and ground. Parenchyma cells are relatively unspecialised and thin-walled cells that retain the ability to divide; they perform most of the metabolic functions of synthesis and storage. Collenchyma cells have unevenly thickened walls. Their function is to support young, growing parts of plants. Sclerenchyma cells, which consist of sclereids and fibres, have thick, lignified walls that help support mature, non-growing parts of the plant.

The root apical meristem is located near the tip of the root, where it generates cells for the growing root axis and the root cap. The apical meristem of a shoot is located in the bud, where it gives rise to alternating internodes and leaf-bearing nodes. Eudicot stems have vascular bundles in a ring, whereas monocot stems have scattered vascular bundles.

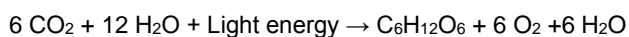


	<p>Cell division and cell expansion are the primary determinants of growth. A preprophase band of microtubules determines where a cell plate will form in a dividing cell. Microtubules orientation also affects the direction of cell elongation by controlling the orientation of cellulose microfibrils in the cell wall. Morphogenesis, the development of body shape and organisation, depends on cells responding to positional information from neighbours. Cell differentiation, arising from differential gene activation, enables cells within the plant to assume different functions despite having identical genomes. The manner in which a plant cell differentiates is determined largely by the cell's position in the developing plant.</p>	
<p><b>Learning unit 7</b></p>	<p><b>Photosynthesis</b></p> <p>Contents</p> <p><b>7.1 Introduction</b></p> <p><b>7.2 Learning outcomes</b></p> <p><b>7.3 Photosynthesis: converting light energy to chemical energy</b></p> <p><b>7.4 Light reactions convert solar energy to the chemical energy of ATP and NADPH</b></p> <p><b>7.5 The Calvin cycle uses the chemical energy of ATP and NADPH to reduce CO<sub>2</sub> to sugar</b></p> <p><b>7.6 Alternative mechanisms of carbon fixation have evolved in hot, arid climates</b></p> <p><b>7.7 Activity 7.1</b></p> <p><b>7.8 Feedback on activity 7.1</b></p> <p><b>7.9 Summary</b></p>	
<p><b>7.1</b></p>	<p><b>Introduction</b></p>	

	<p><b>To complete the learning unit, you will need to refer to pages 261–285 of chapter 11 in Campbell et al (2015)</b></p> <p>Consider all the living organisms that surround you. You will definitely see trees, wild animals, pets and your own body. Most of the biomass is made up of carbon-based biological molecules. Have you ever wondered what the ultimate source is of all that carbon? It may be very surprising to some, but the source is carbon dioxide (CO<sub>2</sub>) from the air. It is obvious that your body cannot take in carbon dioxide from the air and incorporate it into organic molecules, but some plant cells can. They do so through a process called photosynthesis. Photosynthesis is the process whereby the chloroplasts in plants and other photosynthetic organisms capture the light energy from the sun and convert it to chemical energy that is stored in sugar and other organic molecules. Photosynthesis nourishes almost the entire living world directly or indirectly.</p> <p>In this learning unit we will look at how solar energy is used in the synthesis of ATP and other molecules. We will also focus on how the energy powers the anabolic pathway by which a photosynthetic cell synthesises stable organic molecules from the simple inorganic compounds CO<sub>2</sub> and water. Finally, we will consider some aspects of photosynthesis from an evolutionary point of view.</p>	
7.2	<p><b>Learning outcomes</b></p> <p>By the end of this learning unit, you should be able to</p> <ul style="list-style-type: none"> <li>• describe where each phase of photosynthesis takes place in the plant cell</li> <li>• explain the nature of sunlight and how it is absorbed by plants</li> <li>• explain the light reactions that convert solar energy to chemical energy</li> <li>• explain the biochemical reactions that use chemical energy to convert CO<sub>2</sub> to sugar</li> <li>• name and define the alternative mechanisms of carbon fixation in plants</li> </ul>	
7.3	<p><b>Photosynthesis: converting light energy to chemical energy</b></p> <p><b>Recommended reading:</b> pages 263–266 of chapter 11 in Campbell et al (2015)</p> <p>The capturing of light energy by an organism to execute the synthesis of organic compounds emerges from structural organisation in the cell. Photosynthetic enzymes and other molecules are grouped together in a biological membrane, enabling the necessary series of chemicals to be carried out efficiently. The process of photosynthesis most likely originated in a group of bacteria that had infolded regions of plasma membrane containing clusters of these molecules. Some of you might be aware of endosymbiont theory; the original chloroplast was a photosynthetic prokaryote that lived inside an ancestor of eukaryotic cells. It is a fact that chloroplasts are present in a variety of photosynthesising organisms.</p> <p><b>Chloroplast: the sites of photosynthesis in plants</b></p> <p>All green parts of a plant, including green stems and unripened fruit, have chloroplasts, but the leaves are the major sites of photosynthesis in most plants. If you examine a section of leaf tissue under a microscope, you will see that the green pigment, <b>chlorophyll</b>, is not uniformly distributed in the cell, but is confined to organelles called chloroplasts. In plants, chlorophyll lies mainly inside the leaf in the cells of the <b>mesophyll</b>, the tissue interior of the leaf that includes many air spaces and a very high concentration of water vapour. The gaseous exchange between the interior of the leaf and the outside is carried out through microscopic pores, called <b>stomata</b> (singular, <i>stoma</i>; from the Greek, meaning “mouth”). Each mesophyll cell has about 20 to 40 chloroplasts. The chloroplast, like the mitochondrion, is enclosed by outer and inner membranes. The inner membrane encloses a fluid-filled region called the <b>stroma</b>, which contains most of the enzymes required to produce carbohydrate molecules. Suspended within the stroma is a third membrane, made up of sacs known as <b>thylakoids</b>. Chlorophyll, the main pigment of photosynthesis that gives leaves their colour, resides in the thylakoid membranes of the chloroplast. Although there are several kinds of chlorophyll, the most important are <b>chlorophyll a</b> and <b>chlorophyll b</b>. Chlorophyll a is the pigment that initiates the light-dependent reactions of photosynthesis. Chlorophyll b is an accessory pigment that also participates in photosynthesis. It differs from</p>	

chlorophyll a only in that the functional group on the porphyrin ring: the methyl group ( $-\text{CH}_3$ ) in chlorophyll a, is replaced in chlorophyll b by a terminal carbonyl group ( $-\text{CHO}$ ).

During photosynthesis a cell uses light energy captured by chlorophyll to power the synthesis of carbohydrates. Although we still don't completely understand some of the steps, the overall photosynthetic equation has been known since the 1800s. In the presence of light, the green parts of plants produce organic compounds and oxygen from carbon dioxide and water. Using molecular formulae, the overall reaction of photosynthesis can be summarised as



One of the first findings regarding the mechanism of photosynthesis came from the discovery that the  $\text{O}_2$  given off by plants is derived from  $\text{H}_2\text{O}$  and not from  $\text{CO}_2$ . The chloroplast splits water into hydrogen and oxygen. Furthermore, all the oxygen produced comes from water, so 12 water molecules are required to produce 12 oxygen atoms. However, since there is no net yield of  $\text{H}_2\text{O}$ , we can simply summarise the equation of photosynthesis for this argument:  $6 \text{CO}_2 + 6 \text{H}_2\text{O} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6 \text{O}_2$

### The two stages of photosynthesis

You might have already picked up that the photosynthesis process is a very complex one. Photosynthesis is not a single-step process, but consists of two processes, each with multiple steps. These two processes of photosynthesis are known as the light reaction (the photo art of photosynthesis) and the Calvin cycle (synthesis part).

It is given that the light reactions are the stages of photosynthesis that convert solar energy into chemical energy. In this stage, water splits providing a source of electrons and protons (hydrogen ions,  $\text{H}^+$ ) and giving  $\text{O}_2$ , of course, as a by-product. As light is absorbed by chlorophyll, there is a transfer of electrons and hydrogen ions from water to an acceptor called  $\text{NADP}^+$  (nicotinamide-adenine dinucleotide phosphate), where they are stored temporarily. The electron acceptor  $\text{NADP}^+$  is first cousin to  $\text{NAD}^+$ , which functions as an electron carrier in cellular respiration. It is also important to note that the light reaction generates ATP, in a process called photophosphorylation. Thus, light energy is initially converted in the form of two compounds: NADPH and ATP.

Have you noticed that light reactions produce no energy? That happens in the second stage of photosynthesis, the Calvin cycle. This stage begins by incorporating  $\text{CO}_2$  from the air into organic molecules already present in the chloroplast. The Calvin cycle then reduces the fixed carbon to carbohydrate by the addition of electrons. The metabolic steps of the Calvin cycle are sometimes referred to as the dark reaction, solely because none of the steps requires light directly. In a nutshell, the chloroplast uses light energy to make sugar by coordinating the two stages of photosynthesis.

7.4

## Light reactions convert solar energy to the chemical energy of ATP and NADPH

**Recommended reading:** pages 266–275 of chapter 11 in Campbell et al (2015)

The thylakoids convert light energy into the chemical energy of ATP and NADPH. Light is a form of electromagnetic radiation. Like other forms of electromagnetic energy, light travels in rhythmic waves. The distance between crests of electromagnetic waves is called the **wavelength**. Wavelengths of electromagnetic radiation range from less than a nanometre (gamma rays) to more than a kilometre (radio waves). The entire range of electromagnetic radiation is the **electromagnetic spectrum**. The most important segment for life is a narrow band between 380 to 750 nm, the band of **visible light**.

While light travels as a wave, many of its properties are those of a discrete particle, the **photon**. Photons are not tangible objects, but they do have fixed quantities of energy. The amount of energy packaged in a photon is inversely related to its wavelength. Photons with shorter wavelengths pack more energy. While the sun radiates a full electromagnetic spectrum, the atmosphere selectively screens out most wavelengths, permitting only visible light to pass in significant quantities. Visible light is the radiation that drives photosynthesis. When light meets matter, it may be reflected, transmitted, or absorbed.

Different pigments absorb photons of different wavelengths, and the wavelengths that are absorbed disappear. A leaf looks green because chlorophyll, the dominant pigment, absorbs red and blue light, while transmitting and

reflecting green light. A **spectrophotometer** measures the ability of a pigment to absorb various wavelengths of light. It beams narrow wavelengths of light through a solution containing the pigment and measures the fraction of light transmitted at each wavelength. An **absorption spectrum** plots a pigment's light absorption versus wavelength. The light reaction can perform work with those wavelengths of light that are absorbed. There are several pigments in the thylakoid that differ in their absorption spectra.

**Chlorophyll a**, the dominant pigment, absorbs best in the red and violet-blue wavelengths and least in the green. Other pigments with different structures have different absorption spectra. Collectively, these photosynthetic pigments determine an overall **action spectrum** for photosynthesis. An action spectrum measures changes in some measure of photosynthetic activity (for example, O<sub>2</sub> release) as the wavelength is varied. The action spectrum of photosynthesis does not match exactly the absorption spectrum of any one photosynthetic pigment, including chlorophyll *a*.

**Chlorophyll b**, with a slightly different structure than chlorophyll *a*, has a slightly different absorption spectrum and funnels the energy from these wavelengths to chlorophyll *a*. **Carotenoids** can funnel the energy from other wavelengths to chlorophyll *a* and also participate in *photoprotection* against excessive light. These compounds absorb and dissipate excessive light energy that would otherwise damage chlorophyll. They also interact with oxygen to form reactive oxidative molecules that could damage the cell. When a molecule absorbs a photon, one of the electrons of that molecule is elevated to an orbital with more potential energy.

The electron moves from its ground state to an excited state. The only photons that a molecule can absorb are those whose energy matches exactly the energy difference between the ground state and excited state of this electron. Because this energy difference varies among atoms and molecules, a particular compound absorbs only photons corresponding to specific wavelengths. Thus, each pigment has a unique absorption spectrum.

Excited electrons are unstable. Generally, they drop to their ground state in a billionth of a second, releasing heat energy. Some pigments, including chlorophyll, can also release a photon of light in a process called fluorescence. If a solution of chlorophyll isolated from chloroplasts is illuminated, it will fluoresce and give off heat.

Chlorophyll excited by absorption of light energy produces very different results in an intact chloroplast than it does in isolation. In the thylakoid membrane, chlorophyll is organised along with proteins and smaller organic molecules into **photosystems**. A photosystem is composed of a reaction centre surrounded by a light-harvesting complex.

Each **light-harvesting complex** consists of pigment molecules (which may include chlorophyll *a*, chlorophyll *b* and carotenoid molecules) bound to particular proteins. Together, these light-harvesting complexes act like light-gathering "antenna complexes" for the reaction centre.

When any antenna molecule absorbs a photon, it is transmitted from molecule to molecule until it reaches a particular chlorophyll *a* molecule, the **reaction centre**. At the reaction centre is a **primary electron acceptor**, which accepts an excited electron from the reaction centre chlorophyll *a*.

The solar-powered transfer of an electron from a special chlorophyll *a* molecule to the primary electron acceptor is the first step of the light reactions. Each photosystem — reaction-centre chlorophyll and primary electron acceptor surrounded by an antenna complex — functions in the chloroplast as a light-harvesting unit.

**There are two types of photosystems in the thylakoid membrane:**

- **photosystem I (PS I)**, which has a reaction centre chlorophyll *a* that has an absorption peak at 700 nm; and
- **photosystem II (PS II)**, which has a reaction centre chlorophyll *a* that has an absorption peak at 680 nm.

The differences between these reaction centres (and their absorption spectra) lie not in the chlorophyll molecules, but in the proteins associated with each reaction centre. These two photosystems work together to use light energy to generate ATP and NADPH. During the light reactions, there are two possible routes for electron flow: cyclic and non-cyclic. **Non-cyclic electron flow**, the predominant route, produces both ATP and NADPH. Photosystem II absorbs a photon of light. One of the electrons of P680 is excited to a higher energy state. This electron is captured by the primary electron acceptor, leaving the reaction centre oxidised. An enzyme

extracts electrons from water and supplies them to the oxidised reaction centre. This reaction splits water into two hydrogen ions and an oxygen atom that combines with another oxygen atom to form O<sub>2</sub>.

Photoexcited electrons pass along an electron transport chain before ending up at an oxidised photosystem I reaction centre. As these electrons "fall" to a lower energy level, their energy is harnessed to produce ATP.

Meanwhile, light energy has excited an electron of PS I's P700 reaction centre. The photoexcited electron was captured by PS I's primary electron acceptor, creating an electron "hole" in P700. This hole is filled by an electron that reaches the bottom of the electron transport chain from PS II.

Photoexcited electrons are passed from PS I's primary electron acceptor down a second electron transport chain through the protein ferredoxin (Fd). The enzyme NADP<sup>+</sup> reductase transfers electrons from Fd to NADP<sup>+</sup>. Two electrons are required for NADP<sup>+</sup>'s reduction to NADPH. NADPH will carry the reducing power of these high-energy electrons to the Calvin cycle. The light reactions use the solar power of photons absorbed by both photosystem I and photosystem II to provide chemical energy in the form of ATP and reducing power in the form of the electrons carried by NADPH.

Under certain conditions, photoexcited electrons from photosystem I, but not photosystem II, can take an alternative pathway, **cyclic electron flow**. Excited electrons cycle from their reaction centre to a primary acceptor, along an electron transport chain, and return to the oxidised P700 chlorophyll.

As electrons flow along the electron transport chain, they generate ATP by **cyclic photophosphorylation**. There is no production of NADPH and no release of oxygen. What is the function of cyclic electron flow? Non-cyclic electron flow produces ATP and NADPH in roughly equal quantities. However, the Calvin cycle consumes more ATP than NADPH. Cyclic electron flow allows the chloroplast to generate enough surplus ATP to satisfy the higher demand for ATP in the Calvin cycle.

Chloroplasts and mitochondria generate ATP by the same mechanism: **chemiosmosis**. In both organelles, an electron transport chain pumps protons across a membrane as electrons are passed along a series of increasingly electronegative carriers.

This transforms redox energy to a proton-motive force in the form of an H<sup>+</sup> gradient across the membrane. ATP synthase molecules harness the proton-motive force to generate ATP as H<sup>+</sup> diffuses back across the membrane. Some of the electron carriers, including the cytochromes, are very similar in chloroplasts and mitochondria.

The ATP synthase complexes of the two organelles are also very similar. There are differences between oxidative phosphorylation in mitochondria and photophosphorylation in chloroplasts. Mitochondria transfer chemical energy from food molecules to ATP; chloroplasts transform light energy into the chemical energy of ATP. The spatial organisation of chemiosmosis also differs in the two organelles.

The inner membrane of the mitochondrion pumps protons from the mitochondrial matrix out to the intermembrane space. The thylakoid membrane of the chloroplast pumps protons from the stroma into the thylakoid space inside the thylakoid. The thylakoid membrane makes ATP as the hydrogen ions diffuse down their concentration gradient from the thylakoid space back to the stroma through ATP synthase complexes, whose catalytic knobs are on the stroma side of the membrane. The proton gradient, or pH gradient, across the thylakoid membrane is substantial.

When chloroplasts are illuminated, the pH in the thylakoid space drops to about 5 and the pH in the stroma increases to about 8, a thousandfold difference in H<sup>+</sup> concentration. The light-reaction "machinery" produces ATP and NADPH on the stroma side of the thylakoid. Non-cyclic electron flow pushes electrons from water, where they have low potential energy, to NADPH, where they have high potential energy. This process also produces ATP and oxygen as a by-product.

7.5

### The Calvin cycle uses the chemical energy of ATP and NADPH to reduce CO<sub>2</sub> to sugar

**Recommended reading:** pages 275–276 of chapter 11 in Campbell et al (2015)

The Calvin cycle regenerates its starting material after molecules enter and leave the cycle. The Calvin cycle is anabolic, using energy to build sugar from smaller molecules. Carbon enters the cycle as CO<sub>2</sub> and leaves as sugar. The cycle spends the energy of ATP and the reducing power of electrons carried by NADPH to make

sugar. The actual sugar product of the Calvin cycle is not glucose, but a three-carbon sugar, **glyceraldehyde-3-phosphate (G3P)**.

Each turn of the Calvin cycle fixes one carbon. For the net synthesis of one G3P molecule, the cycle must take place three times, fixing three molecules of CO<sub>2</sub>. Making one glucose molecule requires six cycles and the fixation of six CO<sub>2</sub> molecules.

### The Calvin cycle has three phases

#### *Phase 1: Carbon fixation*

In the **carbon fixation** phase, each CO<sub>2</sub> molecule is attached to a five-carbon sugar, ribulose biphosphate (RuBP). This is catalysed by RuBP carboxylase or **rubisco**. Rubisco is the most abundant protein in chloroplasts and probably the most abundant protein on earth. The six-carbon intermediate is unstable and splits in half to form two molecules of 3-phosphoglycerate for each CO<sub>2</sub>.

#### *Phase 2: Reduction*

During **reduction**, each 3-phosphoglycerate receives another phosphate group from ATP to form 1,3-bisphosphoglycerate. A pair of electrons from NADPH reduces each 1,3-bisphosphoglycerate to G3P. The electrons reduce a carboxyl group to the aldehyde group of G3P, which stores more potential energy. If our goal was the net production of one G3P, we would start with three CO<sub>2</sub> (3C) and three RuBP (15C). After fixation and reduction, we would have six molecules of G3P (18C). One of these six G3P (3C) is a net gain of carbohydrate. This molecule can exit the cycle and be used by the plant cell.

#### *Phase 3: Regeneration*

The other five G3P (15C) remain in the cycle to **regenerate** three RuBP. In a complex series of reactions, the carbon skeletons of five molecules of G3P are rearranged by the last steps of the Calvin cycle to regenerate three molecules of RuBP. For the net synthesis of one G3P molecule, the Calvin cycle consumes nine ATP and six NADPH. The light reactions regenerate ATP and NADPH. The G3P from the Calvin cycle is the starting material for metabolic pathways that synthesise other organic compounds, including glucose and other carbohydrates.

7.6

## Alternative mechanisms of carbon fixation have evolved in hot, arid climates

**Recommended reading:** pages 277–283 of chapter 11 in Campbell et al (2015)

One of the major problems facing terrestrial plants is dehydration. At times, solutions to this problem require trade-offs with other metabolic processes, especially photosynthesis. The stomata are not only the major route for gas exchange (CO<sub>2</sub> in and O<sub>2</sub> out), but also for the evaporative loss of water.

On hot, dry days, plants close their stomata to conserve water. This causes problems for photosynthesis. In most plants (**C<sub>3</sub> plants**), initial fixation of CO<sub>2</sub> occurs via rubisco, forming a three-carbon compound, 3-phosphoglycerate. C<sub>3</sub> plants include rice, wheat and soybeans. When their stomata partially close on a hot, dry day, CO<sub>2</sub> levels drop as CO<sub>2</sub> is consumed in the Calvin cycle. At the same time, O<sub>2</sub> levels rise as the light reaction converts light to chemical energy. While rubisco normally accepts CO<sub>2</sub>, when the O<sub>2</sub>:CO<sub>2</sub> ratio increases (on a hot, dry day with closed stomata), rubisco can add O<sub>2</sub> to RuBP. When rubisco adds O<sub>2</sub> to RuBP, RuBP splits into a three-carbon piece and a two-carbon piece in a process called **photorespiration**. The two-carbon fragment is exported from the chloroplast and degraded to CO<sub>2</sub> by mitochondria and peroxisomes. Unlike normal respiration, this process produces no ATP. In fact, photorespiration *consumes* ATP. Unlike photosynthesis, photorespiration does not produce organic molecules.

In fact, photorespiration *decreases* photosynthetic output by siphoning organic material from the Calvin cycle. A hypothesis for the existence of photorespiration is that it is evolutionary baggage. When rubisco first evolved, the atmosphere had far less O<sub>2</sub> and more CO<sub>2</sub> than it does today. The inability of the active site of rubisco to exclude O<sub>2</sub> would have made little difference. Today it does make a difference. Photorespiration can drain away as much as 50% of the carbon fixed by the Calvin cycle on a hot, dry day.

	<p>Certain plant species have evolved alternate modes of carbon fixation to minimise photorespiration. <b>C<sub>4</sub> plants</b> first fix CO<sub>2</sub> in a four-carbon compound. Several thousands of plants, including sugarcane and corn, use this pathway. A unique leaf anatomy is correlated with the mechanism of C<sub>4</sub> photosynthesis. In C<sub>4</sub> plants, there are two distinct types of photosynthetic cells: bundle-sheath cells and mesophyll cells. <b>Bundle-sheath cells</b> are arranged into tightly packed sheaths around the veins of the leaf. <b>Mesophyll cells</b> are more loosely arranged cells located between the bundle sheath and the leaf surface.</p> <p>The Calvin cycle is confined to the chloroplasts of the bundle-sheath cells. However, the cycle is preceded by the incorporation of CO<sub>2</sub> into organic molecules in the mesophyll. The key enzyme, phosphoenolpyruvate carboxylase, adds CO<sub>2</sub> to phosphoenolpyruvate (PEP) to form oxaloacetate. <b>PEP carboxylase</b> has a very high affinity for CO<sub>2</sub> and can fix CO<sub>2</sub> efficiently when rubisco cannot (i.e. on hot, dry days when the stomata are closed). The mesophyll cells pump these four-carbon compounds into bundle-sheath cells. The bundle-sheath cells strip a carbon from the four-carbon compound as CO<sub>2</sub>, and return the three-carbon remainder to the mesophyll cells. The bundle-sheath cells then use rubisco to start the Calvin cycle with an abundant supply of CO<sub>2</sub>.</p> <p>In effect, the mesophyll cells pump CO<sub>2</sub> into the bundle-sheath cells, keeping CO<sub>2</sub> levels high enough for rubisco to accept CO<sub>2</sub> and not O<sub>2</sub>. C<sub>4</sub> photosynthesis minimises photorespiration and enhances sugar production. C<sub>4</sub> plants thrive in hot regions with intense sunlight.</p> <p>A second strategy to minimise photorespiration is found in succulent plants, cacti, pineapples and several other plant families. These plants are known as CAM plants – crassulacean acid metabolism. They open their stomata during the night and close them during the day. Temperatures are typically lower at night and humidity is higher. During the night, these plants fix CO<sub>2</sub> into a variety of organic acids in mesophyll cells. During the day, the light reactions supply ATP and NADPH to the Calvin cycle and CO<sub>2</sub> is released from the organic acids.</p> <p>Both C<sub>4</sub> and CAM plants add CO<sub>2</sub> into organic intermediates before it enters the Calvin cycle. In C<sub>4</sub> plants, carbon fixation and the Calvin cycle are spatially separated. In CAM plants, carbon fixation and the Calvin cycle are temporally separated. Both eventually use the Calvin cycle to make sugar from carbon dioxide.</p>	
7.7	<p><b>Activity 7.1</b></p> <p><b>Do this activity and add it to your portfolio.</b></p> <p>Refer to your textbook and answer the following questions:</p> <ol style="list-style-type: none"> <li>What is photosynthesis?</li> <li>Exactly why is photosynthesis so important?</li> <li>Photosynthesis is often described in two steps: the light reactions and the dark reactions. Given what you have learnt about photosynthesis and the ways that plants have adapted to optimise it, why is dividing photosynthesis into these categories misleading?</li> <li>Are plants more important to people, or are people more important to plants? Explain.</li> <li>Why can't we humans perform photosynthesis?</li> <li>Describe the major differences and similarities between C<sub>3</sub>, C<sub>4</sub> and CAM plants.</li> </ol>	
7.8	<p><b>Feedback on activity 7.1</b></p> <ol style="list-style-type: none"> <li>Photosynthesis is a chemical reaction in which light energy is converted to chemical energy in glucose. It is the means by which the energy in sunlight becomes usable to living things. Living things can eat glucose, we can't eat sunlight.</li> <li>Two main reasons. One product of photosynthesis is glucose (sugar), which provides the basis for most food chains. The second product of photosynthesis is oxygen, which comes in handy if you happen to be an aerobic organism that requires oxygen for survival.</li> <li>It is misleading because, although the activation of the photosystems is light-dependent, the Calvin cycle can run in the light; it is light-independent, meaning that it does not require light to occur.</li> </ol>	

	<p>d) We could argue that plants are more important to people because we subsist on plants. That is, we consume them and are higher up in the food chain. However, many plants have been domesticated by people and require people to be able to actually disseminate their seeds; for example, corn. Therefore, in the case of domesticated plants, people are just as important to their survival as we are to theirs.</p> <p>e) Humans lack chloroplasts, which are the places where all the major proteins and pathways required for photosynthesis occur. Instead of being autotrophs ourselves, we eat the carbon of others and are therefore heterotrophs.</p> <p>f) <math>C_3</math>, <math>C_4</math> and CAM plants all perform photosynthesis and generate their own carbohydrates from <math>CO_2</math>. <math>C_3</math> plants do this through a 3-carbon intermediate (PGA, or phosphoglycerate) while <math>C_4</math> plants do this through a 4-carbon intermediate (malate). <math>C_3</math> plants have adapted to reduce the amount of photorespiration that occurs, which is basically RuBisCO's malfunction, by isolating RuBisCO from oxygen and shuttling <math>CO_2</math> to RuBisCO via the <math>C_4</math> intermediate. CAM plants have adapted to dry climates by only opening their stomata at night to minimise water loss, as well as storing their <math>CO_2</math> as malate, just like in <math>C_4</math> plants.</p>
7.9	<p><b>Summary</b></p> <p>Light consists of particles called photons that move as waves. In autotrophic eukaryotes, photosynthesis occurs in chloroplasts, organelles containing thylakoids. The overall reaction of photosynthesis can be summarised as <math>6 CO_2 + 12 H_2O \rightarrow C_6H_{12}O_6 + 6 O_2 + 6 H_2O</math>. Chloroplasts split water into hydrogen and oxygen, incorporating the electrons of hydrogen into sugar molecules. Photosynthesis is a redox process: <math>H_2O</math> is oxidised and <math>CO_2</math> is reduced. The light reactions in the thylakoid membranes split water, releasing <math>O_2</math>, producing ATP and forming NADPH, whereas the <b>Calvin cycle</b> in the stroma forms sugar from <math>CO_2</math>, using ATP for energy and NADPH for reducing power.</p> <p>A pigment absorbs light of specific wavelengths; <b>chlorophyll a</b> is the main photosynthetic pigments in plants. A pigment moves from a ground state to an excited state when a photon of light boosts one of the pigment's electrons to a higher-energy orbital. A <b>photosystem</b> is composed of a reaction-centre complex surrounded by light-harvesting complexes that funnel the energy of photons to the reaction-centre complex.</p> <p>The <b>Calvin cycle</b> occurs in the stroma, using electrons from NADPH and energy from ATP. One molecule of <b>G3P</b> exits the cycle per three <math>CO_2</math> molecules fixed and is converted to glucose and other organic molecules.</p> <p>During dry, hot days, <b><math>C_3</math> plants</b> close their stomata, conserving water. Oxygen from the light reactions builds up. The <b><math>C_4</math> plants</b> minimise the cost of photorespiration by incorporating <math>CO_2</math> into four-carbon compounds in mesophyll cells. <b>CAM plants</b> open their stomata at night, incorporating <math>CO_2</math> into organic acids, which are stored in mesophyll cells.</p>
Learning unit 8	<p><b>Animal reproduction</b></p> <p>Contents</p> <p><b>8.1 Introduction</b></p> <p><b>8.2 Learning outcomes</b></p> <p><b>8.3 Both asexual and sexual reproduction occur in the animal kingdom</b></p> <p>8.3.1 Mechanisms of asexual reproduction</p> <p>8.3.2 Reproductive cycles</p> <p>8.3.3 Variation in patterns of sexual reproduction</p> <p>8.3.4 Activity 8.1</p>



	<p>8.3.5 Feedback on activity 8.1</p> <p><b>8.4 Fertilisation</b></p> <p><b>8.5 Reproductive organs</b></p> <p><b>8.6 The interplay of tropic and sex hormones</b></p> <p><b>8.7 Placental mammals</b></p> <p><b>8.8 Activity 8.2</b></p> <p><b>8.9 Feedback on activity 8.2</b></p> <p><b>8.10 Summary</b></p>	
8.1	<p><b>Introduction</b></p> <p><b>To complete the learning unit, you will need to refer to pages 1055–1078 of chapter 45 in Campbell et al (2015)</b></p> <p>The survival of each species relies basically on its members to produce new individuals to replace those that die. The ability to reproduce and perpetuate its species is a basic characteristic of living things.</p> <p>As humans, we tend to think of reproduction in terms of the mating of males and females and the fusion of sperm and eggs. Animal reproduction, however, takes many different forms. For example, in some species, individuals change their sex during their lifetime; in other species, such as sea slugs, an individual is both male and female. There are animals that can fertilise their own eggs, as well as others that can reproduce without any form of sex. For certain species, such as the honeybee, only a few individuals within a large population reproduce.</p> <p>In this learning unit, we will compare some major features of animal reproduction that have evolved among animals. Then we will focus on mammalian reproduction, with an emphasis on the well-studied example of humans. We will conclude the learning unit focusing on reproduction mostly from the parents' perspective.</p>	
8.2	<p><b>Learning outcomes</b></p> <p>By the end of this learning unit, you should be able to</p> <ul style="list-style-type: none"> <li>• demonstrate your knowledge of animal structure and function</li> <li>• describe the relationship between animal structure and function</li> <li>• describe the different types and characteristics of cells and explain how they are organised to form tissues</li> </ul>	
8.3	<p><b>Both asexual and sexual reproduction occur in the animal kingdom</b></p> <p><b>Recommended reading:</b> pages 1056–1058 of chapter 45 in Campbell et al (2015)</p> <p>There are two modes of animal reproduction: <b>asexual</b> and <b>sexual</b>. <b>Asexual reproduction</b> involves the formation of individuals whose genes come from a single parent. There is no fusion of sperm and egg. <b>Sexual reproduction</b> is the formation of offspring by the fusion of haploid gametes to form a diploid zygote. The female gamete, the unfertilised egg, or ovum, is usually large and non-motile. The male gamete is the sperm, which is usually small and motile. Sexual reproduction increases genetic variation among offspring by generating unique combinations of genes inherited from two parents.</p>	
8.3.1	<p><b>Mechanisms of asexual reproduction</b></p> <p>Many invertebrates can reproduce asexually by fission, in which a parent separates into two or more approximately equal-sized individuals. <b>Budding</b> is also common among invertebrates. This is a form of asexual reproduction in which new individuals split off from existing ones. Also common among invertebrates is <b>fission</b>. In <i>fragmentation</i>, the body breaks into several pieces, some or all of which develop into complete adults.</p>	

	<p>Reproducing in this way requires <i>regeneration</i> of lost body parts. Many animals can also replace new appendages by regeneration.</p> <p><b>Asexual reproduction has a number of advantages</b></p> <ul style="list-style-type: none"> <li>▪ It allows isolated animals to reproduce without needing to find a mate.</li> <li>▪ It can create numerous offspring in a short period.</li> <li>▪ In stable environments, it allows for the perpetuation of successful genotypes.</li> </ul> <p><b>Parthenogenesis</b> is the process by which an unfertilised egg develops without being fertilised. Parthenogenesis plays a role in the social organisation of some bees, wasps and ants. Male honeybees (drones) are haploid, and female honeybees (queens and workers) are diploid. Several genera of fishes, amphibians and lizards reproduce by a form of parthenogenesis that produces diploid "zygotes". Fifteen species of whiptail lizards reproduce exclusively by parthenogenesis. There are no males in this species, but the lizards imitate courtship and mating behaviour typical of sexual species of the same genus.</p>	
8.3.2	<p><b>Reproductive cycles</b></p> <p>Most animals exhibit cycles in reproductive activity, usually related to changing seasons. This allows animals to conserve resources and reproduce when more energy is available and when environmental conditions favour the survival of offspring. Reproductive cycles are controlled by a combination of environmental and hormonal cues. Environmental cues may include seasonal temperature, rainfall, day length and lunar cycles. Animals may reproduce exclusively asexually or sexually or they may alternate between the two modes, depending on environmental conditions. <i>Daphnia</i> reproduce by parthenogenesis under favourable conditions and sexually during times of environmental stress.</p>	
8.3.3	<p><b>Variation in patterns of sexual reproduction</b></p> <p>For many animals, sexual reproduction presents a problem for sessile or burrowing animals or parasites that may have difficulty encountering a member of the opposite sex. One solution to this challenge is <b>hermaphroditism</b>, in which one individual functions as both a male and a female. Some hermaphrodites can self-fertilise, but most mate with another member of the same species. In such mating, each individual receives and donates sperm. This results in twice as many offspring as would be produced if only one set of eggs were fertilised. In <b>sequential hermaphroditism</b>, an individual reverses its sex during its lifetime. In some species, the sequential hermaphrodite is female first. In other species, the sequential hermaphrodite is male first.</p>	
8.3.4	<p><b>Activity 8.1</b></p> <p><b>Do this activity and add it to your portfolio.</b></p> <p>Refer to your textbook and answer the following question:</p> <p style="padding-left: 40px;">What are the differences between sexual and asexual reproduction?</p>	
8.3.5	<p><b>Feedback on activity 8.1</b></p> <p><b>Sexual reproduction</b> requires a union of gametes and provides a unique diploid individual. It produces diversity and allows for more than one offspring at a time.</p> <p><b>Asexual reproduction</b> requires one parent. There is not a union of gametes. It usually creates only one offspring at a time.</p>	
8.4	<p><b>Fertilisation</b></p> <p><b>Recommended reading:</b> pages 1058–1061 of chapter 45 in Campbell et al (2015)</p> <p>The mechanisms of <b>fertilisation</b>, the union of sperm and egg, play an important part in sexual reproduction. In <b>external fertilisation</b>, eggs are released by the female into a wet environment, where they are fertilised by the male. In species with <b>internal fertilisation</b>, sperm are deposited in or near the female reproductive tract, and fertilisation occurs within the tract. A moist habitat is almost always required for external fertilisation, both to</p>	

prevent gametes from drying out and to allow the sperm to swim to the eggs. In species with external fertilisation, timing is crucial to ensure that mature sperm encounter ripe eggs. Environmental cues such as temperature or day length may cause gamete release by the whole population. Individuals may engage in courtship behaviour that leads to fertilisation of the eggs of one female by one male. Internal fertilisation is an adaptation to terrestrial life that enables sperm to reach an egg in a dry environment. Internal fertilisation requires sophisticated reproductive systems, including copulatory organs that deliver sperm and receptacles for their storage and transport to ripe eggs. Mating animals may use **pheromones**, chemical signals released by one organism that influences the behaviour or physiology of other individuals of the same species. Pheromones are small, volatile, or water-soluble molecules that disperse into the environment. Like hormones, pheromones are active in minute amounts. Many pheromones act as male attractants. All species produce more offspring than can survive to reproduce. Internal fertilisation usually involves the production of fewer zygotes than does external fertilisation. However, the survival rate is higher for internal fertilisation. Major types of protection include tough eggshells, development of the embryo within the reproductive tract of the mother and parental care of the eggs and offspring. Marsupial mammals retain their embryos for only a short period in the uterus. The embryos crawl out and complete fetal development attached to a mammary gland in the mother's pouch. The embryos of eutherian mammals develop entirely within the uterus, nourished through the placenta. Parental care of offspring can occur regardless of whether fertilisation is external or internal.

#### ***Gamete production and delivery***

The least complex reproductive systems lack **gonads**, the organs that produce gametes in most animals. Polychaete worms lack gonads. Eggs and sperm develop from undifferentiated cells lining the coelom. As the gametes mature, they are released from the body wall and fill the coelom. In some species, the body splits open to release the gametes, killing the parent. Some reproductive systems, such as those of parasitic flatworms, are very complex. Most insects have separate sexes with complex reproductive systems. In many species, the female reproductive system includes a **spermatheca**, a sac in which sperm may be stored for a year or more. The basic plan of all vertebrate reproductive systems is very similar. However, there are variations. In many non-mammalian vertebrates, the digestive, excretory and reproductive systems share a common opening to the outside, the **cloaca**. Mammals have separate openings for the digestive and reproductive systems. Female mammals also have separate openings for the excretory and reproductive systems. The uterus of most vertebrates is partly or completely divided into two chambers. Male reproductive systems differ mainly in copulatory organs. Many mammalian vertebrates do not have a well-developed penis and simply turn the cloaca inside out to ejaculate.

8.5

### **Reproductive organs**

**Recommended reading:** pages 1061–1066 of chapter 45 in Campbell et al (2015)

#### **Human reproduction involves intricate anatomy and complex behaviour**

The reproductive anatomy of the human female includes external and internal reproductive structures. External reproductive structures consist of two sets of labia surrounding the clitoris and vaginal opening. Internal reproductive organs consist of a pair of gonads and a system of ducts and chambers. The role of the ducts and chambers is to conduct the gametes and house the embryo and fetus. The **ovaries**, the female gonads, lie in the abdominal cavity, attached to the uterus by a mesentery. Each ovary is enclosed in a tough protective capsule and contains many follicles. Each **follicle** consists of one egg cell surrounded by one or more layers of follicle cells. A woman is born with about 400 000 follicles. Only several hundred of these will release eggs during a female's reproductive years. Follicles produce the primary female sex hormones, oestrogen. Usually one follicle matures and releases its egg during each menstrual cycle in the process of **ovulation**. After ovulation, the remaining follicular tissue develops into the corpus luteum. The corpus luteum secretes additional oestrogen and progesterone; hormones that help maintain the uterine lining during pregnancy. If pregnancy does not occur, the corpus luteum disintegrates and a new follicle matures during the next cycle. At ovulation, the egg is released into the abdominal cavity near the opening of the oviduct. The cilia-lined funnel-like opening of the oviduct draws in the egg. Cilia convey the egg through the oviduct to the **uterus**. The highly vascularised inner lining of the uterus is called the **endometrium**.

The neck of the uterus, the **cervix**, opens into the **vagina**. The vagina is a thin-walled chamber that forms the birth canal and is the repository for sperm during copulation. It opens to the outside at the **vulva**, the collective

term for the external female genitalia. The vaginal opening is partially covered by a thin sheet of tissue called the **hymen**. The vaginal and urethral openings are located within a recess called the **vestibule**. The vestibule is surrounded by a pair of slender folds called the **labia minora**. The labia majora enclose and protect the labia minora and vestibule. The **clitoris** is found at the front edge of the vestibule. During sexual arousal, the clitoris, vagina and labia engorge with blood and enlarge. During sexual arousal, **Bartholin's glands** secrete mucus into the vestibule, providing lubrication and facilitating intercourse. **Mammary glands** are present in both males and females but normally function only in females. They are not a component of the human reproductive system, but are important to mammalian reproduction. Within the glands, small sacs of epithelial tissue secrete milk, which drains into a series of ducts opening at the nipple.

The male's external reproductive organs consist of the **scrotum** and **penis**. The internal reproductive organs consist of gonads that produce sperm and hormones, accessory glands that secrete products essential to sperm movement, and ducts to carry the sperm and glandular secretions. The male gonads, or **testes**, consist of highly coiled tubes surrounded by layers of connective tissue. The tubes are **seminiferous tubules**, where sperm are produced. **Leydig cells** scattered between the seminiferous tubules produce testosterone and other androgens. The **scrotum**, a fold in the body wall, holds the testes outside the body cavity at a temperature about 2 °C below that of the abdomen. This keeps testicular temperature cooler than that in the body cavity. The testes develop in the body cavity and descend into the scrotum just before birth. From the seminiferous tubules of the testes, the sperm pass through the coiled tubules of the **epididymis**. As they pass through this duct, sperm become motile and gain the ability to fertilise an egg. **Ejaculation** propels sperm from the epididymis to the **vas deferens**. The vas deferens runs from the scrotum and behind the urinary bladder. Each vas deferens joins with a duct from the seminal vesicle to form an **ejaculatory duct**. The ejaculatory ducts open into the urethra. The urethra drains both the excretory and reproductive systems.

Accessory sex glands add secretions to **semen**. A pair of seminal vesicles contributes about 60% of total semen volume. Seminal fluid is thick, yellowish and alkaline. It contains mucus, fructose, a coagulating enzyme, ascorbic acid and prostaglandins. The **prostate gland** secretes directly into the urethra. Prostatic fluid is thin and milky. This fluid contains anticoagulant enzymes and citrate. Prostate problems are common in males older than 40 years. Benign prostate enlargement occurs in virtually all males older than 70 years. Prostate cancer is one of the most common cancers in men.

The **bulbourethral glands** are a pair of small glands along the urethra below the prostate. Prior to ejaculation, they secrete clear mucus that neutralises any acidic urine remaining in the urethra. Bulbourethral fluid also carries some sperm released before ejaculation. This is one of the reasons the withdrawal method of birth control has a high failure rate. A male usually ejaculates about 2–5 ml of semen, with each millilitre containing about 50–130 million sperm. Once in the female reproductive tract, prostaglandins in semen thin the mucus at the opening of the uterus and stimulate uterine contractions that help move the semen. When ejaculated, semen coagulates, making it easier for uterine contractions to move it along. Anticoagulants then liquify the semen, and the sperm begin swimming. The alkalinity of semen helps neutralise the acidic environment of the vagina, protecting the sperm and increasing their motility.

The human penis is composed of three layers of spongy erectile tissue. During sexual arousal, the erectile tissue fills with blood from arteries. The resultant increased pressure seals off the veins that drain the penis, causing it to engorge with blood. The engorgement of the penis with blood causes an erection, which is essential for the insertion of the penis into the vagina. The penis of some mammals possesses a **baculum**, a bone that helps stiffen the penis. Temporary impotence can result from the consumption of alcohol or other drugs, and from emotional problems. Irreversible impotence owing to nervous system or circulatory problems can be treated with drugs and penile implant devices. The oral drug Viagra acts by promoting the action of nitric oxide, enhancing relaxation of smooth muscles in the blood vessels of the penis. This allows blood to enter the erectile tissue and sustain an erection. The main shaft of the penis is covered by relatively thick skin. The sensitive head, or glans penis, is covered by thinner skin. The glans is covered by the foreskin, or prepuce, which may be removed by circumcision.

In females, plateau includes vasocongestion of the outer third of the vagina, expansion of the inner two-thirds of the vagina and elevation of the uterus to form a depression that receives sperm at the back of the vagina. Orgasm is the shortest phase of the sexual response cycle. It is characterised by rhythmic, involuntary contractions of the reproductive structures in both sexes. In male orgasm, emission is the contraction of the glands and ducts of the reproductive tract, which forces semen into the urethra. Ejaculation occurs with the

	<p>contraction of the urethra and expulsion of semen. In female orgasm, the uterus and outer vagina contract. Resolution completes the cycle and reverses the responses of earlier stages. Vasocongested organs return to their normal sizes and colours; muscles relax.</p>	
8.6	<p><b>The interplay of tropic and sex hormones</b></p> <p><b>Recommended reading:</b> pages 1066–1070 of chapter 45 in Campbell et al (2015)</p> <p><b>Spermatogenesis and oogenesis both involve meiosis but differ in three significant ways</b></p> <p><b>Gametogenesis</b> is based on meiosis. <b>Spermatogenesis</b> is the production of mature sperm cells from spermatogonia. Spermatogenesis is a continuous and prolific process in the adult male. Each ejaculation contains 100–650 million sperm. Spermatogenesis occurs in seminiferous tubules.</p> <p>Primordial germ cells of the embryonic testes differentiate into spermatogonia, the stem cells that give rise to sperm. As spermatogonia differentiate into spermatocytes and then into spermatids, meiosis reduces the chromosome number from diploid to haploid. As spermatogenesis progresses, the developing sperm cells move from the wall to the lumen of a seminiferous tubule and then to the epididymis, where they become motile. A head containing the haploid nucleus is tipped with an acrosome, which contains enzymes that help the sperm penetrate to the egg. Behind the head are a large number of mitochondria (or a single large one) providing ATP to power the flagellum.</p> <p><b>Oogenesis</b> is the production of ova from <b>oogonia</b>. Oogenesis differs from spermatogenesis in three major ways. At birth an ovary may contain all of the primary oocytes it will ever have. Sperm are produced from spermatogonia throughout a man's life.</p> <p>Unequal cytokinesis during meiosis results in the formation of a single large secondary oocyte and three small polar bodies. The secondary oocyte becomes the ovum, while the polar bodies degenerate. In spermatogenesis, all four products of meiosis become mature sperm.</p> <p>Oogenesis has long "resting" periods. Spermatogenesis produces mature sperm from spermatogonia in an uninterrupted sequence. Oogenesis begins in the female embryo with differentiation of primordial germ cells into oogonia, ovary-specific stem cells. An oogonium multiplies by mitosis and begins meiosis, but the process stops at prophase I. The primary oocytes remain quiescent within small follicles until puberty. Beginning at puberty, follicle-stimulating hormone (FSH) stimulates a follicle to grow and induces its primary oocyte to complete meiosis I and start meiosis II. It is arrested at metaphase II as a secondary oocyte. The secondary oocyte is released when the follicle breaks open at ovulation. Meiosis is completed when a sperm penetrates the oocyte. Oogenesis is completed, producing an ovum.</p> <p>In females, the secretion of hormones and the reproductive events they regulate are cyclic. Hormonal control of the female cycle is complex. Humans and many other primates have menstrual cycles. If pregnancy does not occur, the endometrium is shed through the cervix and vagina in menstruation. Other mammals have oestrous cycles. If pregnancy does not occur, the uterus reabsorbs the endometrium. Oestrous cycles are associated with more pronounced behavioural cycles than menstrual cycles. The period of sexual activity, oestrus, is the only time the condition of the vagina permits mating.</p> <p>Human females may be sexually receptive throughout their menstrual cycle. The term "menstrual cycle" refers specifically to the changes that occur in the uterus, and is also called the uterine cycle. It is caused by cyclic events that occur in the ovaries, the ovarian cycle. The cycle begins with the release from the hypothalamus of <b>GnRH</b> or <b>gonadotropin-releasing hormone</b>, which stimulates the pituitary to secrete small amounts of <b>FSH</b> and <b>LH (luteinising hormone)</b>. Follicles stimulate the hormone, aided by LH, and the cells of the growing follicles start to make oestrogen.</p> <p>The high concentration of oestrogen stimulates the secretion of gonadotropins by acting on the hypothalamus to increase its output of GnRH. This stimulates the secretion of FSH and LH. LH secretion is especially high because the high concentration of oestrogen increases the sensitivity of LH-releasing cells in the pituitary to GnRH. LH induces the final maturation of the follicle and ovulation.</p>	

	<p><b>Menopause</b>, the cessation of ovarian and menstrual cycles, usually occurs between the ages of 46 and 54. During these years, the ovaries lose their responsiveness to FSH and LH, and menopause results from a decline in oestrogen production by the ovary. Menopause is an unusual phenomenon. In most species, females and males retain their reproductive capacity throughout life. There might be an evolutionary explanation for menopause. One hypothesis is that cessation of reproduction allowed a woman to provide better care for her children and grandchildren, increasing the survival of individuals bearing her genes and increasing her fitness.</p> <p>The principal sex hormones in the male are the <b>androgens</b>. The androgens are steroid hormones produced mainly by the Leydig cells of the testes, interstitial cells near the seminiferous tubules. Testosterone, the most important male androgen, and other androgens are responsible for the primary and secondary male sex characteristics. Primary sex characteristics are associated with the development of the vas deferens and other ducts, development of the external reproductive structures and sperm production. Secondary sex characteristics are features not directly related to the reproductive system, including deepening of the voice, distribution of facial and pubic hair and muscle growth. Androgens also affect behaviour. In addition to specific sexual behaviours and sex drive, androgens increase general aggressiveness. They are responsible for vocal behaviour, like singing in birds and calling by frogs. Hormones from the anterior pituitary and hypothalamus control androgen secretion and sperm production by the testes.</p>
8.7	<p><b>Placental mammals</b></p> <p><b>Recommended reading:</b> pages 1070–1076 of chapter 45 in Campbell et al (2015)</p> <p>In placental mammals, pregnancy or gestation is the condition of carrying one or more embryos. A human pregnancy averages 266 days. Many rodents have gestation periods of 21 days. Cows have a gestation of 279 to 289 days, and elephant gestation lasts 600 days.</p> <p>Fertilisation or conception occurs in the oviduct. Twenty-four hours later, cleavage begins. Three to four days after fertilisation, the embryo reaches the uterus as a ball of cells. By one week past fertilisation, the blastocyst forms as a sphere of cells containing a cavity.</p> <p>After a few more days, the blastocyst implants in the endometrium. The embryo secretes hormones to signal its presence and control the mother's reproductive system. Human chorionic gonadotropin (HCG) acts like pituitary LH to maintain secretion of progesterone and oestrogen by the corpus luteum for the first few weeks of pregnancy. Some HCG is excreted in the urine, where it is detected by pregnancy tests. Human gestation is divided into three trimesters of three months each. For the first 2–4 weeks of development, the embryo obtains nutrients from the endometrium. The outer layer of the blastocyst, called the trophoblast, invades the endometrium, eventually helping to form the placenta.</p> <p>The placenta allows diffusion of material between maternal and embryonic circulations, providing nutrients, exchanging respiratory gases and disposing of metabolic wastes for the embryo. Blood from the embryo travels to the placenta and returns via the umbilical vein. Organogenesis occurs during the first trimester. By the end of week 4, the heart is beating. By the end of week 8, all the major structures of the adult are present in rudimentary form. The rapidity of development makes this a time when the embryo is especially sensitive to environmental insults such as radiation or drugs.</p> <p>High levels of progesterone initiate changes in the maternal reproductive system. These include increased mucus in the cervix to form a protective plug, growth of the maternal part of the placenta, enlargement of the uterus and cessation of ovarian and menstrual cycling.</p> <p><b>Contraception can be achieved in several ways</b></p> <p>Some methods prevent the release of mature secondary oocytes and sperm from gonads, others prevent fertilisation by keeping sperm and egg apart and still others prevent implantation of an embryo.</p> <p>Fertilisation can be prevented <b>by abstinence from sexual intercourse</b> or by any of several barriers that keep sperm and egg apart.</p> <p>Temporary abstinence is called the <b>rhythm method</b> of birth control. This means of natural family planning depends on refraining from intercourse when conception is most likely. Ovulation can be detected by noting changes in cervical mucus and body temperature during the menstrual cycle.</p>

	<p><b>Natural family planning brings a pregnancy rate of 10–20%</b></p> <p>As a method of preventing fertilisation, coitus interruptus, or withdrawal (removal of the penis from the vagina before ejaculation), is unreliable. Sperm may be present in secretions that precede ejaculation. The several barrier methods of contraception that block sperm from meeting the egg have pregnancy rates of less than 10%.</p> <p>The <b>condom</b> used by the male is a thin latex or natural membrane sheath that fits over the penis to collect the semen. The diaphragm is a dome-shaped rubber cap that fits into the upper portion of the vagina before intercourse. Both methods are more effective when used in conjunction with a spermicide.</p> <p>Birth control pills are chemical contraceptives with a pregnancy rate of less than 1%. The most commonly used birth control pills are a combination of a synthetic oestrogen and progestin (progesterone-like hormone). This combination acts by negative feedback to stop the release of GnRH by the hypothalamus and, thus, of FSH and LH by the pituitary. The prevention of LH release prevents ovulation. As a backup mechanism, the inhibition of FSH secretion by the low dose of oestrogen in the pills prevents follicles from developing.</p> <p>A second type of birth control pill, the <b>minipill</b>, contains only progestin.</p> <p>Sterilisation is the permanent prevention of gamete release. Tubal ligation in women involves cauterisation or ligation of a section of the oviducts to prevent the eggs from travelling into the uterus. Vasectomy in men is the cutting of each vas deferens to prevent sperm from entering the urethra.</p> <p><b>Abortion is the termination of a pregnancy</b></p> <p>Spontaneous abortion or miscarriage occurs in as many as one-third of all pregnancies. In addition, many women choose abortions performed by physicians each year. A drug called mifepristone, or RU-486, enables a woman to terminate pregnancy non-surgically within the first seven weeks. An analogue of progesterone, RU-486 blocks progesterone reception in the uterus, preventing progesterone from maintaining pregnancy. It is taken with a small amount of prostaglandin to induce uterine contractions.</p> <p><b>Modern technology offers solutions for some reproductive problems</b></p> <p>It is now possible to diagnose many genetic and congenital abnormalities while the fetus is in the uterus. Amniocentesis and chorionic villus sampling are invasive techniques in which amniotic fluid or fetal cells are obtained for genetic analysis. Commonly used non-invasive techniques use ultrasound imaging to detect fetal conditions. A newer non-invasive method uses the fact that maternal blood contains fetal blood cells that can be tested. A maternal blood sample yields fetal cells that can be identified by specific antibodies and tested for genetic disorders. Reproductive technology can help with infertility treatments. Hormone therapy can increase sperm and egg production.</p>
8.8	<p><b>Activity 8.2</b></p> <p><b>Do this activity and add it to your portfolio.</b></p> <p>Refer to your textbook and answer the following questions:</p> <ol style="list-style-type: none"> <li>What organs are parts of the male genital system?</li> <li>Concerning reproduction, what is the function of the testicles?</li> <li>What is the function of the secretions of the prostate, seminal vesicle and bulbourethral glands in reproduction?</li> <li>What organs are parts of the female reproductive system?</li> <li>During which period of life does the formation of gametes begin in women?</li> <li>What endocrine glands are involved in the menstrual cycle? What hormones are involved?</li> <li>In what part of the female reproductive system does fertilisation occur?</li> <li>How do contraceptive pills generally work?</li> </ol>
8.9	<p><b>Feedback on activity 8.2</b></p>

	<ul style="list-style-type: none"> <li>a) The organs that comprise the male genital system are the testicles, the epididymis, the vas deferens, the seminal vesicles, the ejaculatory duct, the prostate, the bulbourethral glands, the urethra and the penis.</li> <li>b) The testicles are the male gonads; that is, the organs where the production of gametes takes place. In human beings, gametes are produced by meiosis that occurs in the testicles.</li> <li>c) These secretions, along with sperm cells from the testicles, form semen. These secretions have the function of nourishing the sperm cells and serving as a fluid means of propagation for them. The alkaline pH of seminal fluid also neutralises the acidic secretions of the vagina, allowing the survival of sperm cells in the vaginal environment after copulation.</li> <li>d) The organs that make up the female reproductive system are the ovaries, the Fallopian tubes (or uterine tubes), the uterus, the vagina and the vulva.</li> <li>e) The meiosis that forms female gametes begins in the cells of ovarian follicles before birth. After the beginning of puberty, under hormonal stimuli, during each menstrual cycle, one of the cells is released on the surface of the ovary and meiosis resumes. However, the meiotic process is only concluded if fertilisation occurs.</li> <li>f) The endocrine glands that secrete hormones involved in the menstrual cycle are the hypophysis (the pituitary gland) and the ovaries. The hormones from the adenohypophysis are FSH (follicle-stimulating hormone) and LH (lutinising hormone) and the hormones from the ovaries are oestrogen and progesterone.</li> <li>g) Fertilisation generally occurs in the Fallopian tubes, but it can also take place in the uterus. There are cases when fertilisation may occur even before the ovum enters the uterine tube, which may lead to a severe medical condition known as abdominal pregnancy.</li> <li>h) Contraceptive pills generally contain the hormones oestrogen and progesterone. If taken daily from the fourth day after menses, the abnormal elevation of these hormones acts upon the hypophysis-hypothalamus endocrine axis, inhibiting FSH and LH secretions. Since these hormones do not reach their normal high levels during the menstrual cycle, ovulation does not occur.</li> </ul>
<p><b>8.10</b></p>	<p><b>Summary</b></p> <p>Asexual reproduction is the production of offspring without gamete fusion. Mechanisms of asexual reproduction include budding, fission and fragmentation with regeneration. Sexual reproduction requires the fusion of gametes to form a zygote. Variation modes of reproduction are achieved through parthenogenesis, hermaphroditism and sex reversal.</p> <p>Fertilisation occurs externally when sperm and eggs are both released outside the body, or internally when sperm is deposited by the male to fertilise an egg in the female reproduction system. In some cases, fertilisation requires coordinated timing, which may be mediated by environmental cues, pheromones, or courtship behaviour.</p> <p>In human males, sperm are always produced in testes, which are suspended outside the body in the scrotum. Ducts connect the testes to internal accessory glands and the penis. The reproductive system of the human female consists principally of the labia and the glans of the clitoris externally. Eggs are produced in the ovaries and, upon fertilisation, develop in the uterus.</p> <p>In mammals, GnRH from the hypothalamus regulates the release of two hormones, FSH and LH, from the anterior pituitary. In males, FSH and LH control the secretion of androgens (chiefly testosterone) and sperm production. In females, cyclic secretion of FSH and LH orchestrates the ovarian and uterine cycles via oestrogen (primarily oestradiol) and progesterone. The developing follicle and the corpus luteum also secrete hormones, which help coordinate the uterine and ovarian cycles through positive and negative feedback.</p> <p>After fertilisation and the completion of meiosis in the oviduct, the zygote undergoes a series of cell divisions and develops into a blastocyst before implantation in the endometrium. All major organs start developing by eight weeks. Contraception may prevent release of mature gametes from the gonads, fertilisation, or embryo implantation.</p>
<p><b>Learning unit 9</b></p>	<p><b>Animal nutrition</b></p> <p>Contents</p>



	<p><b>9.1 Introduction</b></p> <p><b>9.2 Learning outcomes</b></p> <p><b>9.3 An animal's diet should be the source of energy and essential nutrients</b></p> <p>9.3.1 Essential nutrients</p> <p>9.3.2 Dietary deficiencies</p> <p>9.3.3 Assessing nutritional needs</p> <p><b>9.4 The main stages of food processing</b></p> <p>9.4.1 Digestive compartments</p> <p><b>9.5 Important organs that form the mammalian digestive system</b></p> <p>9.5.1 The oral cavity, pharynx and oesophagus</p> <p>9.5.2 Digestion in the stomach</p> <p>9.5.3 Digestion in the small intestine</p> <p>9.5.4 Absorption in the small intestine</p> <p>9.5.5 Absorption in the large intestine</p> <p><b>9.6 Evolutionary adaptations of vertebrate digestive systems</b></p> <p>9.6.1 Stomach and intestinal adaptations</p> <p>9.6.2 Mutualistic adaptations</p> <p><b>9.7 Feedback circuits regulate digestion, energy storage and appetite</b></p> <p>9.7.1 Regulation of digestion</p> <p><b>9.8 Activity 9.1</b></p> <p><b>9.9 Feedback on activity 9.1</b></p> <p><b>9.10 Summary</b></p>	
9.1	<p><b>Introduction</b></p> <p><b>To complete the learning unit, you will need to refer to pages 978–1000 of chapter 42 in Campbell et al (2015)</b></p> <p>Nutrition in animals involves taking in food material that will be chewed into smaller pieces, broken down by chemical processes and then absorbed by the body to provide energy and organic molecules.</p> <p>Although there is a common need for nutrition in animals, there are diverse diets, for example herbivores (which mainly consume plants), carnivores (which consume other animals) and omnivores (which consume animals and plants).</p>	
9.2	<p><b>Learning outcomes</b></p> <p>By the end of this learning unit, you should be able to</p>	

	<ul style="list-style-type: none"> <li>• give a basic description of animal nutrition, specifically in terms of nutritional requirements, food types, feeding mechanisms and food processing</li> <li>• explain animal nutrition specifically with regard to <ul style="list-style-type: none"> <li>- the essential nutrients for biosynthesis</li> <li>- the mechanisms by which food is ingested</li> <li>- the way in which food is processed</li> <li>- the digestive system of a mammal</li> </ul> </li> </ul>	
9.3	<p><b>An animal's diet should be the source of energy and essential nutrients</b></p> <p><b>Recommended reading:</b> pages 979–982 of chapter 42 in Campbell et al (2015)</p> <p>Nutrition does not just involve taking in any kind of food material. An adequate diet has to satisfy three nutritional needs: chemical energy which plays a role in cellular processes (i.e. production of ATP), organic building blocks for macromolecules and also essential nutrients.</p>	
9.3.1	<p><b>Essential nutrients</b></p> <p>Essential nutrients include essential amino acids, essential fatty acids, vitamins and minerals.</p> <p>Animals require amino acids to make up proteins. The amino acids have to be obtained from the animal's food source, so they are called essential amino acids.</p> <p>Essential fatty acids (e.g. linoleic acid) are fatty acids that cannot be synthesised in the body, and therefore a diet of unsaturated fatty acids is required.</p> <p>Vitamins are fat-soluble or water-soluble organic molecules that have diverse functions in the body.</p> <p>Minerals are inorganic nutrients that are required in small amounts in the body. These minerals can be magnesium which is present in enzymes and helps in their functioning, to iodine which is required in producing thyroid hormones.</p>	
9.3.2	<p><b>Dietary deficiencies</b></p> <p>Malnutrition is the lack of essential nutrients or the supply of less chemical energy than what the body requires in the diet.</p> <p>Insufficient intake of essential nutrients can cause deformities, disease and even death. This can affect herbivores and carnivores alike.</p> <p>Undernutrition is a diet that fails to provide adequate sources of chemical energy. This means that the body is not getting enough nutrients to sustain itself. The body will start to use up stored carbohydrates and fats, and ultimately muscle proteins will start to be broken down, causing a decrease in size and stature.</p>	
9.3.3	<p><b>Assessing nutritional needs</b></p> <p>Determining the ideal diet for animals requires consideration of genetic morphology and the surrounding environment that the animal is exposed to.</p>	
9.4	<p><b>The main stages of food processing</b></p> <p><b>Recommended reading:</b> pages 983–983 of chapter 42 in Campbell et al (2015)</p> <p>For the body to take up nutrients from food, it first has to process the food. Food processing stages are divided into ingestion, digestion, absorption and elimination. Ingestion is the act of eating or feeding. Digestion is the stage when food is broken down into small molecules that can be taken up by the body; this involves chewing and chemical processes. In the third stage we have absorption when the body takes up the digested food as forms of amino acids and simple sugars. Undigested material passes out of the digestive system through the process of elimination.</p>	

9.4.1	<p><b>Digestive compartments</b></p> <p>Digestive compartments entail sections within an animal's body that are specialised to perform a specific function in food processing.</p> <p>Intracellular digestion comprises food vacuoles that contain hydrolytic enzymes that break down food. The food enters the cell by phagocytosis, forming a food vacuole. The food vacuole then fuses with lysosomes containing hydrolytic enzymes, allowing digestion to occur.</p> <p>Extracellular digestion occurs in most animal species, and these animals mostly have more than one digestive compartment. Animals with a simple body plan have only one opening (e.g. hydra). Gastrovascular cavity is a pouch that functions in digestion as well as in the distribution of nutrients throughout the body. Most animals have a digestive tube extending between two openings (a mouth and an anus). This type of complete digestive tract is commonly known as an alimentary canal.</p>	
9.5	<p><b>Important organs that form the mammalian digestive system</b></p> <p><b>Recommended reading:</b> pages 986–991 of chapter 42 in Campbell et al (2015)</p> <p>Most animals have a digestive system that consists of the alimentary canal as well as various accessory glands that secrete digestive juices through ducts and into the canal. Accessory glands found in mammalian digestive systems include three pairs of salivary glands, the pancreas, liver and the gallbladder.</p>	
9.5.1	<p><b>The oral cavity, pharynx and oesophagus</b></p> <p>Ingestion occurs in the oral cavity, where teeth mechanically digest food for ease of swallowing. Presence of food stimulates a nervous reflex that causes the salivary glands to deliver saliva through ducts into the oral cavity. Swallowed food passes the pharynx, then passes down to the oesophagus, which connects to the stomach.</p>	
9.5.2	<p><b>Digestion in the stomach</b></p> <p>The stomach is composed of elastic walls and it is capable of storing food and initiates digestion of proteins. The stomach secretes gastric juices that chemically digest foods.</p> <p>Gastric juices consist of two components that help carry out chemical digestion: hydrochloric acid and pepsin.</p>	
9.5.3	<p><b>Digestion in the small intestine</b></p> <p>Most of the enzymatic hydrolysis of the macromolecules from food occurs in the small intestine. The first 25 cm of the small intestine form the duodenum. At this point, chyme from the stomach mixes with digestive juices from the pancreas, liver and gallbladder.</p> <p>Pancreatic secretions include production of an alkaline solution rich in bicarbonate as well as several enzymes that neutralise the acidity of chyme.</p> <p>Bile production by the liver assists in the digestion of fats and other lipids. This bile is produced by the liver and stored in the gallbladder.</p> <p>Secretions of the small intestine occur in the duodenum with the presence of hydrolytic enzymes. The remaining sections of the small intestine (jejunum and ileum) are mainly involved in absorption of nutrients and water.</p>	
9.5.4	<p><b>Absorption in the small intestine</b></p> <p>Most of the absorption in the small intestine occurs across the highly folded surface. The intestine is studded with finger-like projections called villi (singular, villus). In turn, each epithelial cell of a villus has microscopic projections on its surface called microvilli. There are capillaries and veins that carry nutrient-rich blood away from the villi converging into the hepatic portal vein.</p>	
9.5.5	<p><b>Absorption in the large intestine</b></p> <p>Absorption in the large intestine forms the last section of the alimentary canal. The sections of the large intestine are the colon, caecum and rectum through which faeces (waste product of digestion) are eliminated from the alimentary canal.</p>	

9.6	<p><b>Evolutionary adaptations of vertebrate digestive systems</b></p> <p><b>Recommended reading:</b> pages 992–993 of chapter 42 in Campbell et al (2015)</p> <p>Animals have different digestive systems to suit their diet, for example the dental formula.</p>	
9.6.1	<p><b>Stomach and intestinal adaptations</b></p> <p>A carnivore has a larger stomach than herbivores, but has a shorter alimentary canal compared to herbivores and omnivores. This is because vegetation is hard to break down owing to the presence of cell walls around plant cells.</p>	
9.6.2	<p><b>Mutualistic adaptations</b></p> <p>Some digestive adaptations involve mutualistic symbiosis, for example microorganisms help herbivores digest plants. The location of mutualistic microbes in the alimentary canal varies, depending on the type of herbivore.</p>	
9.7	<p><b>Feedback circuits regulate digestion, energy storage and appetite</b></p> <p><b>Recommended reading:</b> pages 994–997 of chapter 42 in Campbell et al (2015)</p>	
9.7.1	<p><b>Regulation of digestion</b></p> <p>As food enters the stomach, it stretches the stomach walls, triggering the release of the hormone gastrin which stimulates the production of gastric juices. This is an example of a positive feedback mechanism.</p>	
9.8	<p><b>Activity 9.1</b></p> <p><b>Do this activity and add it to your portfolio.</b></p> <p>Refer to your textbook and answer the following questions:</p> <ol style="list-style-type: none"> <li>Try and find examples of herbivores, carnivores and omnivores and consider the types of nutritional benefits they get from their diet.</li> <li>How do animals provide nutrients for their bodies in times of food shortage or great demand?</li> <li>Why do you think that determining an ideal diet for humans is more difficult than in laboratory animals?</li> <li>What kinds of organisms would use intracellular digestion and what kinds would use extracellular digestion?</li> </ol>	
9.9	<p><b>Feedback on activity 9.1</b></p> <ol style="list-style-type: none"> <li>This question requires you to be able to distinguish between herbivores, carnivores and omnivores and, by doing so, identify what kinds of nutrients are obtained from the different food sources.</li> <li>At this point you need to know what kinds of mechanisms come into play when the body requires energy to sustain itself. This includes learning the sequence of breaking down the body's own glycogen, fat and protein.</li> <li>You have to understand that an animal's nutrition is dependent on its environment and constant monitoring of its activities. Laboratory animals can be manipulated and kept in an environment that will be easy to monitor and thus determine on the basis of trial which diet is best for the animal. Humans are most likely not influenced by same environment and cannot be monitored daily without external influences.</li> <li>At this point you need to know that there are organisms that engulf food into their cells and use cellular enzymes to break them down to molecules that can be used as part of their daily nutrition. Some animals have organs that help with digestion, and these animals usually have a more complex digestive system with different compartments.</li> </ol>	
9.10	<p><b>Summary</b></p>	

	<p>Food provides animals with energy for ATP production, carbon skeletons for biosynthesis and essential nutrients, vitamins and minerals.</p> <p>Food processing in animals involves ingestion, digestion, absorption and elimination. Evolution adaptations are associated with the type of food that an animal consumes, i.e. the type of dentition and type of alimentary canal of the organism.</p> <p>Vertebrates store excess calories in glycogen, and fat which can be tapped into when the animal needs it.</p>	
<p><b>Learning unit 10</b></p>	<p><b>Circulation and gas exchange</b></p> <p>Contents</p> <p><b>10.1 Introduction</b></p> <p><b>10.2 Learning outcomes</b></p> <p><b>10.3 Circulatory systems link exchange surfaces with cells throughout the body</b></p> <p>10.3.1 Gastrovascular cavities</p> <p>10.3.2 Evolutionary variation in circulatory systems</p> <p>10.3.3 Organisation of vertebrate circulatory systems</p> <p><b>10.4 Coordinated cycles of heart contraction drive double circulation in mammals</b></p> <p>10.4.1 Mammalian circulation</p> <p>10.4.2 A closer look at the mammalian heart</p> <p>10.4.3 Maintaining the heart's rhythmic beat</p> <p><b>10.5 Patterns of blood pressure and flow reflect the structure and arrangement of blood vessels</b></p> <p>10.5.1 Blood vessel structure and function</p> <p>10.5.2 Blood flow velocity</p> <p>10.5.3 Blood pressure</p> <p>10.5.4 Capillary function</p> <p>10.5.5 Fluid return by the lymphatic system</p> <p><b>10.6 Blood components function in exchange, transport and defence</b></p> <p>10.6.1 Blood composition and function</p> <p>10.6.2 Cardiovascular disease</p> <p><b>10.7 Gas exchange occurs across specialised respiratory surfaces</b></p> <p>10.7.1 Partial pressure gradients in gas exchange</p> <p>10.7.2 Respiratory media</p> <p>10.7.3 Respiratory surfaces</p> <p>10.7.4 Gills and aquatic animals</p> <p>10.7.5 Lungs</p> <p><b>10.8 Breathing ventilates the lungs</b></p> <p>10.8.1 How a mammal breathes</p>	

	<p>10.8.2 Control of breathing in humans</p> <p><b>10.9 Adaptations for gas exchange include pigments that bind and transport gases</b></p> <p>10.9.1 Respiratory pigments</p> <p><b>10.10 Activity 10.1</b></p> <p><b>10.11 Feedback on activity on 10.1</b></p> <p><b>10.12 Summary</b></p>	
10.1	<p><b>Introduction</b></p> <p><b>To complete the learning unit, you will need to refer to pages 1003–1032 of chapter 43 in Campbell et al (2015)</b></p> <p>Living organisms require nutrients and oxygen to survive; circulatory and respiratory systems help assure that nutrients and oxygen are distributed throughout the body. The presence of a circulatory system reduces the distance a substance must diffuse to enter or leave the cell. The circulatory system does more than move gases; it is a critical component to maintain homeostasis of the body.</p>	
10.2	<p><b>Learning outcomes</b></p> <p>By the end of this learning unit, you should be able to</p> <ul style="list-style-type: none"> <li>• explain why animals need circulatory systems</li> <li>• distinguish between the different types of circulatory systems and describe their structural components</li> <li>• explain gas exchange in animals in terms of <ul style="list-style-type: none"> <li>- general requirements</li> <li>- adaptations</li> <li>- differences between animals with different lifestyles</li> </ul> </li> </ul>	
10.3	<p><b>Circulatory systems link exchange surfaces with cells throughout the body</b></p> <p><b>Recommended reading:</b> pages 1002–1004 of chapter 43 in Campbell et al (2015)</p> <p>Certain invertebrates have cells that exchange oxygen and nutrients directly with the surrounding medium. Other animals have a circulatory system that moves fluid between each cell's immediate surroundings and the tissues where exchange with the environment occurs.</p>	
10.3.1	<p><b>Gastrovascular cavities</b></p> <p>Animals with gastrovascular cavities lack a distinct circulatory system (e.g. hydras and jellies). In these organisms an opening at one end connects the cavity to the surrounding water. These animals have fluid that bathes both the inner and outer tissue layers.</p>	
10.3.2	<p><b>Evolutionary variation in circulatory systems</b></p> <p>Circulatory systems have three basic components: circulatory fluid, a set of interconnecting vessels and a muscular pump (the heart).</p> <p>Arthropods and most molluscs have open and circulatory systems, meaning that they have circulatory fluid that bathes the organs directly. This fluid is referred to as haemolymph. In a closed circulatory system, a circular fluid called blood is confined to vessels. One or more hearts pump blood into large vessels that branch into smaller ones that infiltrate the organs.</p>	
10.3.3	<p><b>Organisation of vertebrate circulatory systems</b></p>	

	<p>The closed circulatory system of humans and other vertebrates is often called the cardiovascular system. Arteries, veins and capillaries are the three main types of blood vessels. The arteries carry blood away from the heart to organs; capillaries are microscopic vessels called capillary beds, and they infiltrate every tissue in the body. Capillaries converge into venules which in turn converge into veins; then the veins carry blood back to the heart.</p> <p>Bony fishes and sharks have two heart chambers: an atrium and a ventricle, and the blood passes through the heart once in each complete cycle. This phenomenon is called single circulation.</p> <p>Double circulation occurs in amphibians, reptiles and mammals. In this arrangement the pumps for the two circuits are combined into a single organ (the heart).</p>	
<b>10.4</b>	<p><b>Coordinated cycles of heart contraction drive double circulation in mammals</b></p> <p><b>Recommended reading:</b> pages 1006–1008 of chapter 43 in Campbell et al (2015)</p>	
<b>10.4.1</b>	<p><b>Mammalian circulation</b></p> <p>We will first examine the pulmonary circuits. Contraction of the right ventricle pumps blood to the lungs via the pulmonary arteries. As it passes through the capillary beds in the lungs, oxygen is loaded and carbon dioxide is unloaded. Oxygen-rich blood returns to the left atrium of the heart via the pulmonary veins. Then the oxygen-rich blood is pumped into the heart's left ventricle, which pumps the blood to the body tissues via the aorta.</p>	
<b>10.4.2</b>	<p><b>A closer look at the mammalian heart</b></p> <p>The heart contracts and relaxes in a rhythmic cycle. When it contracts, it pumps blood; when it relaxes, its chambers are filled with blood. A complete sequence of pumping and filling is called a cardiac cycle. The contraction phase of the cardiac cycle is referred to as systole, and the relaxation phase is known as diastole. The volume of blood that each ventricle pumps per minute is known as cardiac output. The cardiac output is affected by the rate of contraction (heart rate) and the stroke volume (amount of blood pumped by the ventricle in a single contraction).</p> <p>The heart has valves that control the direction of flow of blood during cardiac cycles. An atrioventricular (AV) valve lies between each atrium and ventricle. These valves keep blood from flowing back into the atria. Semilunar valves are located at the two exits of the hearts: where aorta leaves the left ventricle and where the pulmonary artery leaves the right ventricle.</p>	
<b>10.4.3</b>	<p><b>Maintaining the heart's rhythmic beat</b></p> <p>In vertebrates, the heartbeat originates in the heart itself. Some cardiac muscles contract and relax repeatedly without any signal from the nervous system. This phenomenon is known as autorhythmic, and it is possible because of the presence of autorhythmic cells located at the wall of the atrium near where the superior vena cava enters the heart. This cluster of cells is called sinoatrial (SA) node, or pacemaker. The SA node causes contraction of both atria to occur.</p> <p>After contraction of the atria, the signal that originated from the SA node now reaches another set of autorhythmic cells that are located at the wall between the left and right atria. These cells form a relay point called the atrioventricular (AV) node that causes the ventricles to contract.</p>	
<b>10.5</b>	<p><b>Patterns of blood pressure and flow reflect the structure and arrangement of blood vessels</b></p> <p><b>Recommended reading:</b> pages 1009–1013 of chapter 43 in Campbell et al (2015)</p>	
<b>10.5.1</b>	<p><b>Blood vessel structure and function</b></p> <p>Blood vessels contain a central lumen (cavity) lined with an endothelium; the capillaries have a thinner layer of the smooth endothelium to minimise resistance.</p>	
<b>10.5.2</b>	<p><b>Blood flow velocity</b></p> <p>The blood flow is affected by the diameter of the vessels; arteries have a smaller diameter than veins, so blood flow is much higher in the arteries.</p>	

10.5.3	<p><b>Blood pressure</b></p> <p>Blood pressure is generated by the contractions of the heart. Arterial blood pressure is the highest when the heart contracts during ventricular systole. The pressure at this point is called systolic pressure. Diastolic pressure is low, and occurs when the ventricles are relaxed.</p> <p>Blood pressure changes, depending on the physical or emotional state of the body. This is triggered by hormonal responses that cause smooth muscles in arteriole walls to contract (this is known as vasoconstriction). Narrowing of the arterioles increases pressure upstream in the arteries. When the smooth muscles relax, the arterioles undergo vasodilation; increase in the diameter of the arterioles causes a fall in the blood pressure of the arteries.</p>	
10.5.4	<p><b>Capillary function</b></p> <p>Capillaries play a role in directing blood flow where needed or when required. For example, blood flow to the skin is promoted when it's hot to control the body temperature, and blood flow to the digestive tract increases after a meal. During strenuous exercise blood flow will be redirected to the skeletal muscles and diverted from the digestive tract. The redirecting of blood flow in capillaries is due to the precapillary sphincters that prevent blood flow to the capillary beds when they contract.</p>	
10.5.5	<p><b>Fluid return by the lymphatic system</b></p> <p>There is fluid that normally leaks out of the capillaries, and the lymphatic system is responsible for returning that fluid back to the blood. The fluid lost from the blood is called lymph. The lymphatic system drains into large veins of the circulatory system at the base of the neck.</p> <p>The lymphatic system also branches out in a system of tubes called lymph vessels. Along the lymph vessels are organs called lymph nodes. These organs house cells that attack viruses and bacteria.</p>	
10.6	<p><b>Blood components function in exchange, transport and defence</b></p> <p><b>Recommended reading:</b> pages 1014–1017 of chapter 43 in Campbell et al (2015)</p>	
10.6.1	<p><b>Blood composition and function</b></p> <p>Vertebrates' blood is a connective tissue consisting of cells suspended in a liquid matrix called plasma.</p> <p>The blood contains two classes of cells: red blood cells which transport oxygen, and white blood cells which function in defence. Also suspended in blood plasma are platelets; these are fragments of cells that are involved in the clotting process.</p>	
10.6.2	<p><b>Cardiovascular disease</b></p> <p>Disturbances in the heart valve function disrupt the blood flow and could be fatal if they occurs in the brain or heart.</p> <p>Cholesterol metabolism plays a central role in cardiovascular disease. Examples of these cholesterol molecules are low-density lipoproteins (LDLs) and high-density lipoproteins (HDLs).</p> <p>Atherosclerosis occurs because of high LDL levels and low HDL levels in the blood accompanied by inflammation.</p>	
10.7	<p><b>Gas exchange occurs across specialised respiratory surfaces</b></p> <p><b>Recommended reading:</b> pages 1019–1022 of chapter 43 in Campbell et al (2015)</p> <p>Gas exchange is the uptake of molecular oxygen from the environment and the discharge of carbon dioxide to the environment.</p>	
10.7.1	<p><b>Partial pressure gradients in gas exchange</b></p> <p>To understand the driving forces of gas exchange, we must calculate the partial pressure, which is the pressure exerted by a particular gas in a mixture of gases.</p>	



	<p>At sea level, the atmosphere exerts a downward force equal to that of column mercury (Hg) 760 mm high. This means that atmospheric pressure at sea level is 760 mm high.</p> <p>To calculate partial pressure of oxygen in the atmosphere, you have to consider the percentage of oxygen that is present in the total atmospheric volume (which is 21%). Then calculate the partial pressure:</p> $P_{O_2} = 21\% \times 760 \text{ mm Hg (value of atmospheric pressure at sea level)}$ $= 21/100 \times 760 \text{ mm Hg}$ $= 0.21 \times 760 \text{ mm Hg}$ $= 159.6 \text{ mm Hg}$	
10.7.2	<p><b>Respiratory media</b></p> <p>Conditions for gas exchange are different, depending on whether the respiratory medium (source of oxygen) is air or water.</p>	
10.7.3	<p><b>Respiratory surfaces</b></p> <p>The movement of oxygen and carbon dioxide across moist respiratory surfaces takes place entirely by diffusion.</p>	
10.7.4	<p><b>Gills and aquatic animals</b></p> <p>Gills are an outfolding of the body surface that is suspended in the water. The movement of the respiratory medium over the respiratory surface is called ventilation.</p>	
10.7.5	<p><b>Lungs</b></p> <p>The lungs are localised respiratory organs that have respiratory surfaces that are not in direct contact with all other parts of the body; so the circulatory system bridges the gap and transports gases between the lungs and the rest of the body.</p> <p>The mammalian respiratory system consists of branching ducts that convey air to the lungs. Air enters through the nostrils and passes down to the pharynx, which leads to the trachea or windpipe. The trachea branches into two bronchi (singular, bronchus) which enter the lung. In the lung each bronchus further divides into finer and finer tubes called bronchioles. The tips of terminal bronchioles form alveoli (singular, alveolus). Gas exchange in mammals occurs in alveoli sacs.</p>	
10.8	<p><b>Breathing ventilates the lungs</b></p> <p><b>Recommended reading:</b> pages 1024–1026 of chapter 43 in Campbell et al (2015)</p> <p>On the first inhalation in birds, air fills the posterior air sacs. Then the bird exhales, and the posterior air sacs contract and push the air into the lungs. On the second inhalation air passes through the lungs and fills the anterior air sacs. On the second exhalation the anterior air sacs contract and push air from the first inhalation out of the body.</p>	
10.8.1	<p><b>How a mammal breathes</b></p> <p>Mammals employ negative pressure breathing. Air is pulled into the lungs, rather than being pushed into the lungs. Expanding the thoracic cavity during inhalation involves the animal's rib muscles and the diaphragm.</p>	
10.8.2	<p><b>Control of breathing in humans</b></p> <p>Most of the time breathing is regulated by involuntary mechanisms. This means that there are neurons (found in the medulla oblongata). The medulla oblongata regulates breathing with the use of the pH of the surrounding tissue fluids as an indicator of blood CO<sub>2</sub> concentration. As the pH in the blood decreases, the medulla's control circuits increase the depth and rate of breathing.</p>	
10.9	<p><b>Adaptations for gas exchange include pigments that bind and transport gases</b></p>	

	<b>Recommended reading:</b> pages 1027–1029 of chapter 43 in Campbell et al (2015)	
<b>10.9.1</b>	<p><b>Respiratory pigments</b></p> <p>Animals transport most of their O<sub>2</sub> bound to the protein called respiratory pigments. These respiratory pigments are often contained within specialised cells and they greatly increase the amount of oxygen that can be carried in the circulatory fluid.</p> <p>The respiratory pigments have a distinct colour and consist of protein bound to metal (e.g. haemocyanin and haemoglobin). Haemoglobin occurs in all vertebrates and some invertebrates. This molecule transports oxygen and carbon dioxide.</p>	
<b>10.10</b>	<p><b>Activity 10.1</b></p> <p><b>Do this activity and add it to your portfolio.</b></p> <p>Refer to your textbook and answer the following questions:</p> <ol style="list-style-type: none"> <li>Why do you think arteries have a thicker connective tissue and smooth muscle layer than the veins?</li> <li>Why do you think veins have valves but arteries don't have any?</li> <li>Show your calculation of partial pressure of carbon dioxide and nitrogen.</li> </ol>	
<b>10.11</b>	<p><b>Feedback on activity 10.1</b></p> <ol style="list-style-type: none"> <li>When the blood leaves the heart to the rest of the body, it enters the arteries that are narrow and are filled with pressure. The arteries need to be able to withstand the pressure, so the muscles and tissue around it need to be capable of withstanding pressure.</li> <li>Since there is less pressure in the veins owing to the wider diameter of the veins compared to the arteries, blood is most capable of flowing back, especially in the legs (gravity also plays a role). The valves simply prevent blood from flowing backwards.</li> <li>For this type of question you need to find out the percentage of volume that carbon dioxide and nitrogen contribute to the total atmospheric air. Then multiply each percentage by the atmospheric pressure at sea level (which is 760 mm Hg).</li> </ol>	
<b>10.12</b>	<p><b>Summary</b></p> <p>Arthropods and most molluscs have an open circulatory system, and vertebrates have a closed circulatory system. The closed circulatory system consists of blood vessels, a heart and blood. The heart has chambers: ventricles and atriums. These chambers are able to contract (pump) and relax (fill) because of the presence of the sinoatrial (SA) node and atrioventricular (AV) node, respectively.</p>	
<b>Learning unit 11</b>	<p><b>The body's defences</b></p> <p>Contents</p> <p><b>11.1 Introduction</b></p> <p><b>11.2 Learning outcomes</b></p> <p><b>11.3 In innate immunity, recognition and response rely on shared pathogen traits</b></p> <p>11.3.1 Innate immunity of invertebrates</p>	

	<p>11.3.2 Innate immunity of vertebrates</p> <p>11.3.3 Evasion of innate immunity by pathogens</p> <p><b>11.4 In adaptive immunity, receptors provide pathogen-specific recognition</b></p> <p><b>11.5 Adaptive immunity defends against infection of body cells and fluids</b></p> <p>11.5.1 Helper T cells</p> <p>11.5.2 Cytotoxic T cells</p> <p>11.5.3 Five major classes of antibodies</p> <p><b>11.6 Disruptions in immune system function can elicit or exacerbate disease</b></p> <p>11.6.1 Exaggerated, self-directed and diminished immune responses</p> <p>11.6.2 Exertion, stress and the immune system</p> <p>11.6.3 Immunodeficiency disease</p> <p>11.6.4 Attack on the immune system by HIV</p> <p>11.6.5 Cancer and immunity</p> <p><b>11.7 Activity 11.1</b></p> <p><b>11.8 Feedback on activity 11.1</b></p> <p><b>11.9 Summary</b></p>	
11.1	<p><b>Introduction</b></p> <p><b>To complete the learning unit, you will need to refer to pages 1104–1128 of chapter 47 in Campbell et al (2015)</b></p> <p>The immune system, our defence system, is made up of the molecules and cells that shield the body against foreign macromolecules, including disease-causing organisms, or pathogens. The latter include certain viruses, bacteria, fungi, protozoa and worms. In this learning unit, we will examine how each type of immunity protects animals from disease. We will also investigate how pathogens can avoid or overwhelm the immune system and how defects in the immune system can endanger health.</p>	
11.2	<p><b>Learning outcomes</b></p>	

	<p>By the end of this learning unit, you should be able to</p> <ul style="list-style-type: none"> <li>• demonstrate your knowledge of the defence mechanisms of vertebrates</li> <li>• explain and identify the non-specific (innate) and specific defences (acquired) in vertebrates</li> <li>• discuss the different lines of defence in vertebrates</li> <li>• discuss the role immunity plays in health and disease</li> </ul>	
11.3	<p><b>In innate immunity, recognition and response rely on shared pathogen traits</b></p> <p><b>Recommended reading:</b> pages 1104–1126 of chapter 47 in Campbell et al (2015)</p> <p>It is well known that innate immunity is found all animals as well as plants. We will study both invertebrates and vertebrates.</p>	
11.3.1	<p><b>Innate immunity of invertebrates</b></p> <p>An insect's exoskeleton is the first line of defence against infection. Composed largely of the polysaccharide chitin, the exoskeleton provides an effective barrier defence against most pathogens. A chitin-based barrier is also present in the insect intestine, where it blocks infection by many microbes ingested with food. Lysozyme, an enzyme that digests microbial cell walls, and low pH also protect the digestive system.</p> <p>In insects, circulating cells called <i>haemocytes</i> flow throughout the haemolymph, the insect equivalent of blood. Some haemocytes can phagocytose microbes. Other haemocytes trigger the production of chemicals that kill microbes and entrap parasites. Haemocytes and other cells secrete antimicrobial peptides that bind to and destroy bacteria and fungi by disrupting their plasma membranes. Haemocytes recognise unique structures in the outer layers of bacteria and fungi. Fungal cell walls have unique polysaccharides, while bacterial cell walls contain combinations of sugars and amino acids not found in animal cells. Insect immune cells secrete specialised recognition proteins, each of which binds to the macromolecule specific to a particular type of microbe.</p> <p>Immune responses are distinct for different classes of pathogens. For example, when the fungus <i>Neurospora crassa</i> infects a fruit fly, pieces of the fungal cell wall bind a recognition protein that activates the protein Toll, a receptor on the surface of immune response cells. Signal transduction from the Toll receptor to the cell nucleus leads to synthesis of a particular set of antimicrobial peptides. When the bacterium <i>Micrococcus luteus</i> infects a fly, a distinct recognition protein is activated, and the fly produces a different set of <i>antimicrobial peptides</i>.</p>	
11.3.2	<p><b>Innate immunity of vertebrates</b></p> <p>In mammals, epithelial tissues block the entry of harmful viruses and bacteria. An invading microbe must penetrate the external barrier formed by the skin and mucous membranes, which line the digestive, respiratory and genitourinary tracts. Mucous membranes produce mucus, a viscous fluid that traps microbes and other particles. In the trachea, ciliated epithelial cells sweep out mucus with its trapped microbes, preventing them from entering the lungs.</p> <p>Microbial colonisation is also inhibited by the washing action of saliva, tears and mucous secretions that continually bathe the exposed epithelium. Beyond their role as a physical barrier, the skin and mucous membranes counter pathogens with chemical defences. Lysozymes in saliva, mucous secretions and tears kill bacteria that enter the upper respiratory tract or the openings around the eyes. Microbes present in food or water, or those in swallowed mucus, must contend with the highly acidic environment of the stomach.</p> <p>The acid destroys many microbes before they can enter the intestinal tract. Secretions from sebaceous and sweat glands give the skin a pH ranging from 3 to 5, which is acidic enough to prevent colonisation by many microbes.</p> <p>Pathogens that penetrate the first line of defence face phagocytic white blood cells (leukocytes). Leukocytes recognise microbes through receptors that are very similar to the Toll receptor of insects.</p> <p>Each mammalian Toll-like receptor (TLR) functions to recognise molecules common to a set of pathogens. TLR4 of immune cell plasma membranes recognises lipopolysaccharide, a molecule found on the surface of many bacteria. TLR3 on the inner surface of endocytic vesicles is the sensor for double-stranded RNA, a form of</p>	

	<p>nucleic acid characteristic of certain viruses. In each case, the recognised macromolecule is normally absent from the vertebrate body and is an essential component of a class of microbes.</p> <p>Phagocytosis is often the first step in internal defences. White blood cells recognise and engulf microorganisms, forming a vacuole that fuses with a lysosome. Microbes are destroyed within lysosomes in two ways. Lysosomes contain nitric oxide and other gases that poison the engulfed microbes. Lysozymes and other enzymes degrade microbial components. The most abundant phagocytic cells in the mammalian body are neutrophils. Signals from infected tissues attract neutrophils, which engulf and destroy microbes. Macrophages are even more effective phagocytic cells. Some macrophages migrate throughout the body, whereas others reside permanently in certain tissues, especially in lymph nodes and the spleen. Microbes that enter the blood become trapped in the spleen, whereas microbes in interstitial fluid flow into lymph and are trapped in lymph nodes. In either location, microbes soon encounter resident macrophages. Eosinophils contribute to defence against large invaders, such as parasitic worms. Eosinophils position themselves against the external wall of a parasite and discharge destructive enzymes. Dendritic cells populate tissues that are in contact with the environment, acting to stimulate the development of acquired immunity.</p>	
11.3.3	<p><b>Evasion of innate immunity by pathogens</b></p> <p>Some pathogens can avoid destruction by phagocytic cells. For example, the outer capsule that surrounds certain bacteria hides polysaccharides on their surface, preventing recognition. Some bacteria do not avoid recognition but are resistant to breakdown within lysosomes following phagocytosis. One example is the bacterium that causes the disease tuberculosis. Rather than being destroyed within the host's cells, such microbes grow and reproduce, effectively hidden from the acquired defences of the body. Tuberculosis, also known as TB, kills more than a million people a year worldwide.</p>	
11.4	<p><b>In adaptive immunity, receptors provide pathogen-specific recognition</b></p> <p><b>Recommended reading:</b> pages 1110–1112 of chapter 47 in Campbell et al (2015)</p> <p>Vertebrates are unique in having both adaptive and innate immunity. The vertebrate body is populated by two main types of lymphocytes: B lymphocytes (B cells) and T lymphocytes (T cells). Both types of lymphocytes are critical for acquired immune defence. Lymphocytes that originate from stem cells in the bone marrow and migrate to the thymus mature into T cells. Lymphocytes that mature in the bone marrow develop as B cells. B and T cells recognise and inactivate foreign cells and molecules. Both types of cells also contribute to immunological memory, an enhanced response to a foreign molecule encountered previously.</p> <p>Although B and T cells function only in the acquired immune system, innate and acquired immunity are not independent. At the start of an infection, signals from phagocytic cells activate lymphocytes, stimulating an acquired response. For example, phagocytic cells secrete chemokines that help recruit and activate lymphocytes. Macrophages and dendritic cells also have a direct role in pathogen recognition by B and T cells.</p> <p>Each B and T cell has on its surface many receptor proteins that can bind a foreign molecule. The receptor proteins on a single lymphocyte are all the same, but there are millions of lymphocytes in the body that differ in the foreign molecules that their receptors recognise. When a host animal is infected, B and T cells with receptors that can recognise the microbe are activated. Activation involves the B and T cells interacting with fragments of microbes displayed on the surface of cells.</p> <p>Some T cells assist in activating other lymphocytes, while other T cells detect and kill infected host cells. Foreign molecules and cells that circulate in body fluids are subject to attack by soluble receptor proteins secreted by specialised B cells. Activated lymphocytes also undergo cell division, with some of the daughter B and T cells being set aside to fight any future infections of the host by the same microbe.</p> <p>Any foreign molecule that is specifically recognised by lymphocytes and elicits a response from them is called an antigen. Most antigens are large molecules such as proteins or polysaccharides. Most antigens are cell-associated molecules that protrude from the surface of pathogens or transplanted cells. Others, such as toxins secreted by bacteria, are released into extracellular fluid. Each B and T cell has many antigen-specific receptors embedded in its plasma membranes. A single B or T lymphocyte bears about 100 000 identical antigen receptors. B cells sometimes give rise to plasma cells that secrete a soluble form of the antigen receptor.</p> <p>This secreted protein is called an antibody, or immunoglobulin. A lymphocyte actually recognises and binds to a small portion of an antigen called an epitope or antigenic determinant. A single antigen usually has several different epitopes, each capable of inducing a response from a lymphocyte. Because lymphocytes recognise and respond to particular microbes and foreign molecules, they are said to display specificity for a particular epitope on an antigen. Each B cell receptor for an antigen is a Y-shaped molecule consisting of four polypeptide chains:</p>	

two identical heavy chains and two identical light chains linked by disulphide bridges. A transmembrane region near one end of each heavy chain anchors the receptor in the cell's plasma membrane.

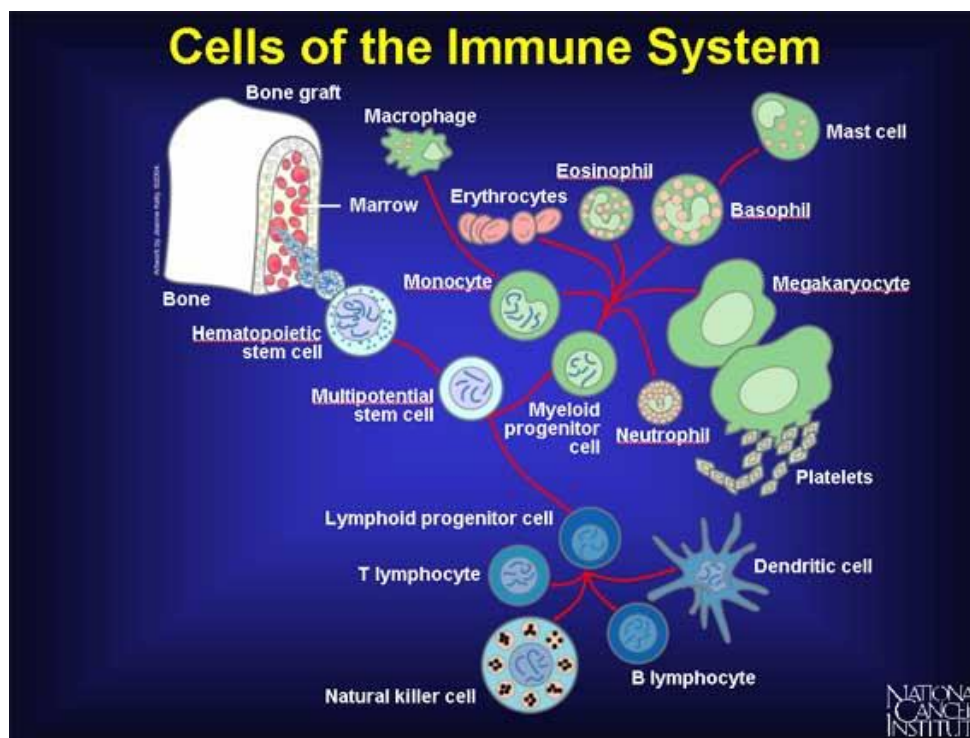
Differences in the amino acid sequence of the variable (V) region account for the specificity of antigen receptors on lymphocytes. A single B or T cell displays about 100 000 identical antigen receptors. It is highly unlikely that any two B or T cells have the same antigen receptor. The variable regions at the tip of a particular antigen receptor differ in amino acid sequence from one cell to the other. Because the variable regions form the antigen-binding site, a particular amino acid sequence generates specificity for a certain epitope. Each person has more than 1 million different B cells and 10 million different T cells, each with a particular antigen-binding specificity.

11.5

**Adaptive immunity defends against infection of body cells and fluids**

**Recommended reading:** pages 1116–1121 of chapter 47 in Campbell et al (2015)

The immune system can mount two types of immune responses to antigens: humoral and cell-mediated. The humoral immune response involves the activation and clonal selection of effector B cells, which secrete antibodies that circulate in the blood plasma and lymph. The cell-mediated immune response involves the activation and clonal selection of cytotoxic T lymphocytes, which identify and destroy target cells (figure 11.1). A third population of lymphocytes, the helper T cells, aids both responses.



**Figure 11.1:** Cells of the immune system

[http://upload.wikimedia.org/wikipedia/commons/f/f2/Cells\\_of\\_the\\_immune\\_system.jpg](http://upload.wikimedia.org/wikipedia/commons/f/f2/Cells_of_the_immune_system.jpg)

Note that the cells of the immune system are generated in bone marrow to give rise to stem cells. These stem cells mature into lymphoid and myeloid progenitor cells and these cells then mature further into the various cell lines as shown in figure 11.1.

11.5.1

**Helper T cells**

Activated by encounters with antigen-presenting cells, helper T cells play a central role in enhancing humoral and cell-mediated responses. The helper T cell proliferates after interacting with peptide antigens displayed by antigen-presenting cells. The resulting clone of cells differentiates into activated helper T cells and memory helper T cells. The activated helper T cells then secrete cytokines that stimulate the activation of nearby B cells and cytotoxic T cells.

The T cell receptors on the surface of the helper T cell bind the peptide antigen that is held by a class II MHC molecule on the antigen-presenting cell. At the same time, a protein called CD4, found on the surface of most

	<p>helper T cells, binds the class II MHC molecule. CD4 helps keep the helper T cell and the antigen-presenting cell joined. As the two cells interact, signals in the form of cytokines are exchanged in both directions. For example, cytokines stimulate the helper T cell, which produces its own set of cytokines. The net result is activation of the helper T cell. The three principal types of antigen-presenting cells — dendritic cells, macrophages and B cells — interact with helper T cells in different contexts. Dendritic cells serve as sentinels in the epidermis and other tissues frequently exposed to foreign antigens, acting to trigger a primary immune response. After dendritic cells capture antigens, they migrate from the infection site to lymphoid tissues, where they present antigens, via class II MHC molecules, to helper T cells. Macrophages play the key role in initiating a secondary immune response by presenting antigens to memory helper T cells.</p>	
11.5.2	<p><b>Cytotoxic T cells</b></p> <p>Cytotoxic T cells are the effector cells in cell-mediated immune response. To become active, they require signals from helper T cells as well as interaction with an antigen-presenting cell. Once activated, they eliminate body cells infected by viruses or other intracellular pathogens. Fragments of non-self proteins synthesised in target cells associate with class I MHC molecules and are displayed on the cell surface, where they can be recognised by cytotoxic T cells. A surface protein called CD8, found on most cytotoxic T cells, enhances the interaction between a target cell and a cytotoxic T cell. Binding of CD8 to the side of a class I MHC molecule helps keep the two cells in contact while the cytotoxic T cell is activated. Thus, the roles of class I MHC molecules and CD8 are similar to those of class II MHC molecules and CD4, except that different cell types are involved.</p> <p>The targeted destruction of an infected cell by a cytotoxic T cell involves the secretion of proteins that cause cell rupture and cell death, depriving the pathogen of a place to reproduce and exposing it to circulating antibodies, which mark it for disposal. After destroying an infected cell, the cytotoxic T cell moves on to kill other cells infected with the same pathogen.</p>	
11.5.3	<p><b>Five major classes of antibodies</b></p> <p>The antibodies produced by a given B cell differ from the B cell receptor only in the constant (C) region of the heavy chain, which contains sequences that determine where the D is distributed and how it mediates antigen disposal.</p> <p>The five major types of heavy-chain constant regions determine the five major classes of antibodies. Two classes exist primarily as polymers of the basic antibody molecule: IgM as a pentamer and IgA as a dimer. The other three classes — IgG, IgE and IgD — exist exclusively as monomers.</p> <p>The power of antibody specificity and antigen-antibody binding has been applied in laboratory research and clinical diagnosis. Some antibody tools are polyclonal—the products of many different clones of B cells, each specific for a different epitope. Others are monoclonal, prepared from a single clone of B cells grown in culture. These cells produce monoclonal antibodies, identical and specific for the same epitope on an antigen.</p>	
11.6	<p><b>Disruptions in immune system function can elicit or exacerbate disease</b></p> <p><b>Recommended reading:</b> pages 1122–1126 of chapter 47 in Campbell et al (2015)</p> <p>Malfunctions of the immune system can produce effects ranging from the minor inconvenience of some allergies to the serious and often fatal consequences of certain autoimmune and immunodeficiency diseases.</p>	
11.6.1	<p><b>Exaggerated, self-directed and diminished immune responses</b></p> <p>Allergies are hypersensitive (exaggerated) responses to certain environmental antigens, called <i>allergens</i>. The most common allergies involve antibodies of the IgE class. Hay fever, for example, occurs when plasma cells secrete IgE specific for pollen allergens. Some IgE antibodies attach by their base to mast cells present in connective tissue. Later, pollen grains that enter the body attach to the antigen-binding sites of mast-cell-associated IgE, cross-linking adjacent antibody molecules. This event triggers the mast cell to <i>degranulate</i> — that is, to release histamines and other inflammatory agents from vesicles called granules. High levels of histamines cause dilation and increased permeability of small blood vessels.</p> <p>These inflammatory events lead to typical allergy symptoms: sneezing, runny nose, tearing eyes and smooth muscle contractions that can result in difficulty breathing. Antihistamines diminish allergy symptoms by blocking receptors for histamine.</p> <p>Sometimes, an acute allergic response can result in <i>anaphylactic shock</i>, a whole-body, life-threatening reaction to injected or ingested allergens. Anaphylactic shock results when widespread mast cell degranulation triggers abrupt dilation of peripheral blood vessels, causing a precipitous drop in blood pressure. Death may occur within</p>	

	minutes. Triggers of anaphylactic shock in susceptible individuals include bee venom, penicillin, or foods such as peanuts or fish. Some hypersensitive individuals carry syringes with epinephrine, which counteracts this allergic response.	
11.6.2	<p><b>Exertion, stress and the immune system</b></p> <p>Moderate exercise improves immune system function and reduces the risk of infection. Exercise to the point of exhaustion leads to more frequent infections with more severe symptoms. Physiological stress disrupts immune system regulation by altering the interplay of the hormonal, nervous and immune systems.</p>	
11.6.3	<p><b>Immunodeficiency disease</b></p> <p>In immunodeficiency diseases, the ability of the immune system to protect against pathogens is compromised, leading to frequent and recurrent infections and increased susceptibility to certain cancers. An immunodeficiency disease caused by a genetic or developmental defect in the immune system is called an inborn immunodeficiency. An immunodeficiency defect in the immune system that develops later in life, following exposure to a chemical or biological agent, is called an acquired immunodeficiency.</p> <p>Inborn immunodeficiencies result from defects in the development of various immune system cells or the production of specific proteins, such as antibodies or the proteins of the complement system. In severe combined immunodeficiency (SCID), functional lymphocytes are rare or absent. Individuals with this disease require a bone marrow or stem cell transplant in order to supply functional lymphocytes. Several gene therapy approaches are in clinical trials to attempt to reverse SCID.</p> <p>Immune deficiencies may also develop later in life. Drugs used to fight autoimmune diseases or prevent transplant rejection suppress the immune system, leading to an immunodeficient state. Certain cancers suppress the immune system. An example is Hodgkin's disease, which damages the lymphatic system. Acquired immunodeficiency syndrome, or AIDS, is an acquired immune deficiency.</p>	
11.6.4	<p><b>Attack on the immune system by HIV</b></p> <p>The human immunodeficiency virus (HIV), the pathogen that causes AIDS, escapes and attacks the acquired immune response. HIV gains entry into cells by using proteins that participate in normal immune responses. The main receptor for HIV on helper T cells is the cell's CD4 molecule. HIV also infects some cell types that have low levels of CD4, including macrophages and brain cells. Once inside the cell, the HIV RNA is reverse-transcribed, and the product DNA is integrated into the host cell's genome. In this form, the viral genome can direct the production of new viral particles. Although the body responds to HIV with an aggressive immune response sufficient to clear most viral infections, some HIV invariably escapes. One reason HIV persists is antigenic variation.</p> <p>It mutates at a very fast rate during viral replication, preventing recognition and elimination by the immune system. Some viruses survive, proliferate and mutate further, evolving within the body. The continued presence of HIV is also helped by latency. When the virus integrates into the chromosome of an infected cell but does not produce new virus proteins or particles, it is shielded from surveillance by the immune system. The antiviral agents currently used against HIV attack only an actively replicating virus. Over time, an untreated HIV infection not only avoids the acquired immune response but also abolishes it. Virus reproduction and cell death triggered by the virus lead to loss of T cells, impairing both humoral and cell-mediated immune responses.</p> <p>The result is a susceptibility to infections and cancers that can be successfully rebuffed by people with a healthy immune system. HIV infection cannot yet be cured, although certain drugs slow HIV reproduction and the progression to AIDS. The mutational changes that occur with each round of virus reproduction can generate drug-resistant strains of HIV.</p> <p>The impact of viral drug resistance is reduced by the use of a combination of drugs; viruses newly resistant to one drug can be defeated by another. Strains resistant to multiple drugs reduce the effectiveness of multidrug "cocktails" in some patients. Frequent mutational changes in HIV surface antigens have also hampered efforts to develop an effective vaccine. In 2006, more than 2.5 million people died of AIDS, which is the leading cause of death in Africa. Transmission of HIV requires the transfer of body fluids containing infected cells, such as semen or blood, from person to person. Most HIV transmission is due to unprotected sex or the use of HIV-contaminated needles. People infected with HIV transmit the disease most readily in the first few weeks of infection, before they express HIV-specific antibodies that can be detected in a blood test.</p>	
11.6.5	<p><b>Cancer and immunity</b></p>	



	<p>The increase in cancer rates with an impaired immune response may occur because the immune system normally attacks body cells that become cancerous. There is an alternative explanation: Impairment of the immune response leaves the body open to infection, which causes inflammatory responses, now known to be a contributing event to the development of many cancers. Determining the link between cancer and immunity and finding out whether passive or active immunisation can be used to fight cancer are active areas of investigation.</p>	
11.7	<p><b>Activity 11.1</b></p> <p><b>Do this activity and add it to your portfolio.</b></p> <p>Refer to your textbook and answer the following questions:</p> <ol style="list-style-type: none"> <li>What is the function of the immune system?</li> <li>What are the two groups of the defence mechanisms of the body against foreign or harmful agents? What is the difference between them?</li> <li>What is an antigen?</li> <li>Why is maternal milk important for the immune protection of a baby?</li> <li>Why are vaccines used in the prevention but not in the treatment of infections? Why can antivenin serums be used in prevention and treatment?</li> <li>How do 25 000 protein-coding genes in the human genome generate such remarkable diversity in antigen receptors?</li> </ol>	
11.8	<p><b>Feedback on activity 11.1</b></p> <ol style="list-style-type: none"> <li>The immune system is responsible for the specific defence against agents, called antigens, which are foreign or harmful to the body. Exogenous antigens often come into contact with the skin or enter through the airway, the digestive tract and genital orifices and mucosae. They can also penetrate into circulation directly through wounds.</li> <li>The body has many defence mechanisms against foreign pathogenic agents. These mechanisms are divided into two groups: specific mechanisms and non-specific mechanisms. Specific mechanisms are part of the immune system and consist of the humoral immune response and the cellular immune response that produce antibodies and defence cells against specific antigens, respectively. Non-specific mechanisms fight in a general manner against any type of antigen (they are not specific) and, in them, a series of defence mechanisms are included, such as the skin barrier against foreign agents, the mucus and ciliated epithelium of the airway, inflammation (the inflammatory response) and the action of non-specific proteins and defence cells (such as interferons and macrophages).</li> <li>An antigen is any substance, particle or infectious agent recognised as foreign to the body. The contact of the antigen with the body triggers a defence reaction against the antigen (non-specific, specific or both).</li> <li>Besides being nutritionally important, maternal milk is involved in the defence of the baby against infectious agents. Shortly after delivery, the mother produces more fluid milk called colostrum, which is rich in immunoglobulins (antibodies). These antibodies are not absorbed by the baby's circulation, but rather cover the internal surface of the baby's bowels, attacking possible antigens and making it more difficult for pathogenic bacteria to proliferate within the organ.</li> <li>Vaccines are not used in the treatment of infections because they depend on the primary immune response, which takes about a week to occur and is not so intense and effective. On the other hand, antivenin serums are inoculated into circulation and are used as an immediate treatment because they are made of a large amount of immunoglobulin (antibodies) which are potent against their specific venom.</li> <li>The answer is the variety of combinations: By combining variable elements, the immune system assembles many different receptors from a smaller collection of parts. Consider the immunoglobulin (Ig) gene, which encodes one chain of the B cell receptor. This gene is used to make secreted antibodies (immunoglobulins) and membrane-bound receptors.</li> </ol>	
11.9	<p><b>Summary</b></p> <p>An animal must defend itself against pathogens, infectious agents that cause disease. Infectious agents include viruses, bacteria, protists and fungi. Immune cells patrol the body fluids of animals, seeking out and destroying foreign cells. Responses to infection include proteins that punch holes in bacterial membranes or block viruses from entering body cells. Immune systems help animals to avoid or limit many infections. External barriers,</p>	

	<p>formed by the skin or shell, provide an obstacle to microbes. Chemical secretions that trap or kill microbes guard the body's entrances and exits. The internal defences include macrophages and other phagocytic cells that ingest and destroy pathogens. An animal's immune system must detect foreign particles and tissues that invade the body. To identify pathogens, animal immune systems use receptors that specifically bind molecules from foreign cells or viruses. Two general strategies for molecular recognition form the basis for innate and acquired immunity. Innate immunity is common to all animals.</p> <p>Innate immune responses are active immediately upon infection and are the same whether or not the pathogen has been encountered previously. Innate immunity includes the barrier defences (for example, skin) as well as defences that combat pathogens after they enter the body. The activation of many of these internal defences relies on the recognition of pathogens. Innate immune cells produce a small, preset group of receptor proteins that accomplish this recognition. Each innate immune receptor binds a molecule or structure that is absent from animal bodies but is shared among a large class of microbes. In this way, innate immune systems detect a very broad range of pathogens. Acquired immunity, also known as adaptive immunity, is found only in vertebrates. Acquired immune responses are activated after innate immune defences and develop more slowly. These acquired defences are enhanced by previous exposure to the infecting pathogen. Animals with acquired immunity have a large number of receptors, each recognising a feature typically found only on a particular molecule in a particular microbe.</p>	
<b>Learning unit 12</b>	<p><b>Regulating the internal environment</b></p> <p>Contents</p> <p><b>12.1 Introduction</b></p> <p><b>12.2 Learning outcomes</b></p> <p><b>12.3 Animal form and function are correlated at all levels of organisation</b></p> <p>12.3.1 Evolution of animal size and shape</p> <p>12.3.2 Exchange with the environment</p> <p><b>12.4 Feedback control maintains the internal environment in many animals</b></p> <p>12.4.1 Regulating and conforming</p> <p>12.4.2 Homeostasis</p> <p><b>12.5 Homeostatic processes for thermoregulation involve form, function and behaviour</b></p> <p>12.5.1 Endothermy and ectothermy</p> <p>12.5.2 Variation in body temperature</p> <p>12.5.3 Balancing heat loss and gain</p> <p>12.5.4 Acclimatisation in thermoregulation</p> <p>12.5.5 Physiological thermostats and fever</p> <p><b>12.6 Energy requirements are related to animal size, activity and environment</b></p> <p>12.6.1 Energy allocation and use</p> <p>12.6.2 Quantifying energy use</p> <p>12.6.3 Minimum metabolic rate and thermoregulation</p> <p>12.6.4 Influence on metabolic rate</p> <p>12.6.5 Torpor and energy conservation</p>	

	<p><b>12.7 Activity 12.1</b></p> <p><b>12.8 Feedback on activity 2.1</b></p> <p><b>12.9 Summary</b></p>	
12.1	<p><b>Introduction</b></p> <p><b>To complete the learning unit, you will need to refer to pages 933–957 of chapter 40 in Campbell et al (2015)</b></p> <p>Animal groups are dramatically diverse, with radically different body structures. For example, consider how different elephants and mice are, not only in size but also in body form and lifespan. Despite their differences, animal groups share many characteristics.</p> <p>Over the course of its life, an elephant faces the same fundamental challenges as any other animal, whether hydra, snake or human. All animals must obtain nutrients and oxygen, and produce offspring. Because form and function are correlated, examining anatomy often provides clues to physiology. In this learning unit, we will use the example of body temperature regulation to demonstrate how animals control their internal environment. We also look at how anatomy and physiology relate to an animal's interactions with the environment and its management of energy use.</p>	
12.2	<p><b>Learning outcomes</b></p> <p>By the end of this learning unit, you should be able to</p> <ul style="list-style-type: none"> <li>• explain how different animals regulate their internal environments and body temperature</li> <li>• discuss the process of homeostasis</li> <li>• explain osmoregulation</li> <li>• discuss the elimination of waste products in animals</li> </ul>	
12.3	<p><b>Animal form and function are correlated at all levels of organisation</b></p> <p><b>Recommended reading:</b> pages 934–940 of chapter 40 in Campbell et al (2015)</p> <p>Size and shape affect the way an animal interacts with its environment. The body plan of an animal is programmed by the genome, itself the product of millions of years of evolution.</p>	
12.3.1	<p><b>Evolution of animal size and shape</b></p> <p>Physical laws govern strength, diffusion, movement and heat exchange. Properties of water limit possible shapes for fast-swimming animals. As animals increase in size, thicker skeletons are required for support. Convergent evolution often results in similar adaptations of diverse organisms facing the same challenge.</p>	
12.3.2	<p><b>Exchange with the environment</b></p> <p>Materials such as nutrients, waste products and gases must be exchanged across the cell membranes of animal cells. Rate of exchange is proportional to a cell's surface area while amount of exchange material is proportional to a cell's volume. A single-celled organism living in water has sufficient surface area to carry out all necessary exchange. Multicellular organisms with a saclike body plan have body walls that are only two cells thick, facilitating diffusion of materials. In flat animals such as tapeworms, most cells are in direct contact with the environment. More complex organisms are composed of compact masses of cells with complex internal organisation. Evolutionary adaptations, such as specialised, extensively branched or folded structures, enable sufficient exchange with the environment. In vertebrates, the space between cells is filled with interstitial fluid, which allows for the movement of material into and out of cells. A complex body plan helps an animal living in a variable environment to maintain a relatively stable internal environment.</p>	

12.4	<p><b>Feedback control maintains the internal environment in many animals</b></p> <p><b>Recommended reading:</b> pages 941–941 of chapter 40 in Campbell et al (2015)</p> <p>Faced with environmental fluctuations, animals manage their internal environment by either regulating or conforming.</p>	
12.4.1	<p><b>Regulating and conforming</b></p> <p>A regulator uses internal control mechanisms to control internal change in the face of external fluctuation. A conformer allows its internal condition to vary with certain external changes. Animals may regulate some environmental variables while conforming to others.</p>	
12.4.2	<p><b>Homeostasis</b></p> <p>Organisms use homeostasis to maintain a "steady state" or internal balance regardless of external environment. In humans, body temperature, blood pH and glucose concentration are each maintained at a constant level. Mechanisms of homeostasis moderate changes in the internal environment. For a given variable, fluctuations above or below a set point serve as a stimulus; these are detected by a sensor and trigger a response. The response returns the variable to the set point. Homeostasis in animals relies largely on negative feedback, which helps to return a variable to a normal range. Positive feedback amplifies a stimulus and does not usually contribute to homeostasis in animals. Set points and normal ranges can change with age or show cyclic variation. In animals and plants, a circadian rhythm governs physiological changes that occur roughly every 24 hours. Homeostasis can adjust to changes in the external environment, a process called acclimatisation.</p>	
12.5	<p><b>Homeostatic processes for thermoregulation involve form, function and behaviour</b></p> <p><b>Recommended reading:</b> pages 944–948 of chapter 40 in Campbell et al (2015)</p> <p>Thermoregulation is the process by which animals maintain an internal temperature within a tolerable range.</p>	
12.5.1	<p><b>Endothermy and ectothermy</b></p> <p>Endothermic animals generate heat by metabolism; birds and mammals are endotherms. Ectothermic animals gain heat from external sources; ectotherms include most invertebrates, fishes, amphibians and non-avian reptiles. Endotherms can maintain a stable body temperature even in the face of large fluctuations in environmental temperature. Endothermy is more energetically expensive than ectothermy. In general, ectotherms tolerate greater variation in internal temperature.</p>	
12.5.2	<p><b>Variation in body temperature</b></p> <p>The body temperature of a poikilotherm varies with its environment. The body temperature of a homeotherm is relatively constant. The relationship between heat source and body temperature is not fixed (that is, not all poikilotherms are ectotherms).</p>	
12.5.3	<p><b>Balancing heat loss and gain</b></p> <p>Organisms exchange heat by four physical processes: radiation, evaporation, convection and conduction. Heat regulation in mammals often involves the integumentary system: skin, hair and nails. Five adaptations that help animals thermoregulate are insulation, circulatory adaptations, cooling by evaporative heat loss, behavioural responses and adjusting metabolic heat production.</p> <p><b>Insulation</b> is a major thermoregulatory adaptation in mammals and birds. Skin, feathers, fur and blubber reduce heat flow between an animal and its environment. Insulation is especially important in marine mammals such as whales and walrus.</p> <p><b>Circulatory adaptations</b></p>	

	<p>Regulation of blood flow near the body surface significantly affects thermoregulation. Many endotherms and some ectotherms can alter the amount of blood flowing between the body core and the skin. In vasodilation, blood flow in the skin increases, facilitating heat loss. In vasoconstriction, blood flow in the skin decreases, lowering heat loss. The arrangement of blood vessels in many marine mammals and birds allows for countercurrent exchange. Countercurrent heat exchangers transfer heat between fluids flowing in opposite directions and thereby reduce heat loss. Some bony fishes and sharks also use countercurrent heat exchanges. Many endothermic insects have countercurrent heat exchangers that help maintain a high temperature in the thorax.</p> <p><b>Cooling by evaporative heat loss</b></p> <p>Many types of animals lose heat through evaporation of water from their skin. Sweating or bathing moistens the skin, helping to cool an animal down. Panting increases the cooling effect in birds and many mammals.</p> <p><b>Behavioural responses</b></p> <p>Both endotherms and ectotherms use behavioural responses to control body temperature. Some terrestrial invertebrates have postures that minimise or maximise absorption of solar heat. Honeybees huddle together during cold weather to retain heat.</p> <p><b>Adjusting metabolic heat production</b></p> <p>Thermogenesis is the adjustment of metabolic heat production to maintain body temperature. Thermogenesis is increased by muscle activity such as moving or shivering. Non-shivering thermogenesis takes place when hormones cause mitochondria to increase their metabolic activity. Some ectotherms can also shiver to increase body temperature.</p>	
12.5.4	<p><b>Acclimatisation in thermoregulation</b></p> <p>Birds and mammals can vary their insulation to acclimatise to seasonal temperature changes. When temperatures are subzero, some ectotherms produce "antifreeze" compounds to prevent ice formation in their cells.</p>	
12.5.5	<p><b>Physiological thermostats and fever</b></p> <p>Thermoregulation in mammals is controlled by a region of the brain called the hypothalamus. The hypothalamus triggers heat loss or heat-generating mechanisms. Fever, a response to some infections, reflects an increase in the normal range for the biological thermostat. Some ectothermic organisms seek warmer environments to increase their body temperature in response to certain infections.</p>	
12.6	<p><b>Energy requirements are related to animal size, activity and environment</b></p> <p><b>Recommended reading:</b> pages 949–952 of chapter 40 in Campbell et al (2015)</p> <p><b>Bioenergetics</b> is the overall flow and transformation of energy in an animal. It determines how much food an animal needs and it relates to an animal's size, activity and environment.</p>	
12.6.1	<p><b>Energy allocation and use</b></p> <p>Organisms can be classified by how they obtain chemical energy. Autotrophs, such as plants, harness light energy to build energy-rich molecules. Heterotrophs, such as animals, harvest chemical energy from food. Energy-containing molecules from food are usually used to make ATP, which powers cellular work. After the needs of staying alive are met, remaining food molecules can be used in biosynthesis. Biosynthesis includes body growth and repair, synthesis of storage material such as fat, and production of gametes.</p>	
12.6.2	<p><b>Quantifying energy use</b></p>	

	<p>Metabolic rate is the amount of energy an animal uses in a unit of time. Metabolic rate can be determined by</p> <ul style="list-style-type: none"> <li>• an animal's heat loss</li> <li>• the amount of oxygen consumed or carbon dioxide produced</li> <li>• measuring energy content of food consumed and energy lost in waste products</li> </ul>	
12.6.3	<p><b>Minimum metabolic rate and thermoregulation</b></p> <p>Basal metabolic rate (BMR) is the metabolic rate of an endotherm at rest at a "comfortable" temperature. Standard metabolic rate (SMR) is the metabolic rate of an ectotherm at rest at a specific temperature. Both rates assume a non-growing, fasting and non-stressed animal. Ectotherms have much lower metabolic rates than endotherms of a comparable size.</p>	
12.6.4	<p><b>Influence on metabolic rate</b></p> <p>Metabolic rates are affected by many factors besides whether an animal is an endotherm or ectotherm. Some key factors are age, sex, size, activity, temperature and nutrition.</p>	
12.6.5	<p><b>Torpor and energy conservation</b></p> <p>Torpor is a physiological state in which activity is low and metabolism decreases. Torpor enables animals to save energy while avoiding difficult and dangerous conditions. Hibernation is long-term torpor that is an adaptation to winter cold and food scarcity. Summer torpor, called estivation, enables animals to survive long periods of high temperatures and scarce water. Daily torpor is exhibited by many small mammals and birds and seems adapted to feeding patterns. There are many aspects to the relationship between structure and function in animals. There are also some fundamental similarities in the evolutionary adaptations of plants and animals.</p>	
12.7	<p><b>Activity 12.1</b></p> <p><b>Do this activity and add it to your portfolio.</b></p> <p>Refer to your textbook and answer the following questions:</p> <ol style="list-style-type: none"> <li>Differentiate between ectotherms and endotherms.</li> <li>How do humans and iguanas differ in body temperature regulation?</li> <li>What are some physiological and behavioural adaptations to extreme cold and extreme heat?</li> <li>How do land animals gain and lose water?</li> </ol>	
12.8	<p><b>Feedback on activity 2.1</b></p> <ol style="list-style-type: none"> <li>Ectotherms use the environment, not their own internal mechanisms, to regulate their body temperature. Endotherms regulate their body temperature through internal mechanisms.</li> <li>Iguanas are ectotherms; they lack an internal temperature-regulating mechanism so they must move to areas where they can gain or lose heat. Humans are endotherms; we regulate body temperature internally to maintain a relatively constant body temperature.</li> <li>Some physiological adaptations to extreme cold include countercurrent exchange systems, shunting of blood from extremities and shivering. Behavioural adaptations to extreme cold include fluffing fur or feathers, huddling and hibernating. Some physiological adaptations to extreme heat include evaporative cooling, dilating surface blood vessels near the skin and rerouting skin-cooled blood towards the brain. Behavioural adaptations to extreme heat include hiding in shade, digging burrows, swimming, shedding clothes and consuming cold drinks.</li> <li>Land animals take in water through food, drink and metabolism. They lose it through their lungs, skin, faeces and urine.</li> </ol>	
12.9	<p><b>Summary</b></p>	

The forms of signalling between animal cells differ in the type of secreting cell and the route taken by the signal to its target. Endocrine signals, or hormones, are secreted into the extracellular fluid by endocrine cells or ductless glands and reach target cells via circulatory fluids. Pheromones are released into the surrounding environment for communication between animals of the same species.

Hormone pathways may be regulated by negative feedback, which dampens the stimulus, or positive feedback, which amplifies the stimulus and drives the response to completion. In invertebrates, neurosecretory cells in the hypothalamus produce two hormones that are secreted by posterior pituitary and that act directly on non-endocrine tissues: oxytocin, which induces uterine contractions and release of milk from mammary glands, and antidiuretic hormone, which promotes water retention by the kidneys.