MO001/4/2018

Plant Structure: Cytology, Morphology and Anatomy

BOT1501

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 BOT1501/17/S1 OR BOT1501/17/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 Plant Structure: Cytology, Morphology and Anatomy (BOT1501).

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 Plant Structure: Cytology, Morphology and Anatomy 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

AR Mudau

Learning Units	Module site	Things to remember
Learning unit 0	**Learning unit 0: Welcome and introduction** Content 0.1 Getting started 0.2 Lecturer and contact details 0.2.1 Lecturer and department 0.2.2 University 0.2.3 Student support services 0.3 Purpose and outcomes of this module 0.4 How the content of this module is structured 0.5 Learning resources 0.6 Study plan 0.7 How should you go about studying this module? 0.7.1 Learning strategies you can apply: the SSS method 0.7.1.1 Skimming 0.7.1.2 Scanning and outlining 0.7.1.3 Study-reading and active learning 0.7.2 Managing your self-paced study time 0.7.3 Finding research/scientific articles 0.7.4 Avoiding plagiarism 0.8 Using myUnisa 0.8.1 The myUnisa menu options 0.8.2 myUnisa etiquette 0.8.3 Activity 0.1: Introduce yourself 0.9 Assessment in this module	
0.1	**Getting started** Welcome to Plant Structure: Cytology, Morphology and Anatomy (BOT1501). This module is offered by Unisa's Department of Life and Consumer Sciences. This is an online module, which means that you will find everything you need to complete the module on this site. Check this site regularly for updates, posted announcements and additional resources that will be uploaded throughout the semester. The university's online platform, myUnisa, allows you to • submit assignments (**I recommend that you submit your assignment online, as this will ensure that you receive rapid feedback and comments**) • 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 tools and resources are. I shall 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 also can 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 also will receive further tutorial letters shortly after the due dates for the submission of the assignments; these will contain suggested solutions to the assignment questions. In this learning unit, I shall give you an overview of and some general information about this module. I also shall tell you more about possible study strategies, how to use myUnisa and about the assessment in the module. Click on "Next" below 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 shall 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 also shall 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 replies to your enquiries being delayed. Please write a separate letter to each department and mark each letter clearly for the attention of that department. **You may not send letters to lecturers in the same envelope as your assignments.**	
0.2.1	**Lecturer and department** Lecturer: Mr Ambani R Mudau Telephone number: +27 11 471 3921 (during office hours 8:00–16:00) E-mail address: mudauar@unisa.ac.za Postal address: The Lecturer (BOT1501)	

Department of Life and Consumer Sciences

Private Bag X6

Florida

1710

Telephone number (Departmental secretary): +27 11 471 2230

Fax number: +27 11 471 2796

0.2.2 University

If you need to contact the university about matters not related to the content of this module, consult *my Studies @ Unisa*. This brochure contains information on how to contact the university (e.g. to whom you can write with 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 www.unisa.ac.za/contents/study2012/docs/myStudies-Unisa-2014.pdf

You also can use the following contact routes:

- Unisa website: http://www.unisa.ac.za & http://mobi.unisa.ac.za
- E-mail (general enquiries): info@unisa.ac.za.

  International students can use the e-mail address info@unisa.ac.za
- study-info@unisa.ac.za for enquiries related to application and registration
- assign@unisa.ac.za for assignment enquiries
- exams@unisa.ac.za for examination enquiries
- despatch@unisa.ac.za for study material enquiries
- finan@unisa.ac.za for student account enquiries
- myUnisaHelp@unisa.ac.za for assistance with myUnisa
- myLifeHelp@unisa.ac.za for assistance with myLife e-mail accounts
- SMS 32695 – South Africa only

  You will receive an auto response SMS with the various SMS options. The cost per SMS is R1,00.
- Fax 012 429 4150

0.2.3 Student support services

For information about the various student support systems and services available at Unisa (e.g. student counselling, tutorial classes, language support), consult *my Studies @ Unisa* at www.unisa.ac.za/contents/study2012/docs/myStudies-Unisa-2014.pdf

- **Fellow students**

It's always a good idea to have contact with fellow students. You can do this using the **Discussion** menu option on myUnisa. You also can 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

To log onto the Library website, you need to provide your login details, i.e. your student number and

	your myUnisa password, 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 also can contact Ms Vukati Ndlovu on 012 441 5470.	
0.3	**Purpose and outcomes of this module** The purpose of this module is to acquaint you with some of the most important concepts in Plant Science. This includes the structure and functions of the primary and secondary plant body, normal and modified plant organs, and flowers, seeds and fruit. You also will learn more about the importance of plants for life on Earth, basic evolutionary theory and the development of classification systems. The outcomes of the module are that, after completing the module, you should be able to • compare the structures and functions of prokaryotic and eukaryotic cells • discuss the structures and functions of primary and secondary cells and tissues • explain the structures and functions of the normal and modified plant organs of which the plant body consists • relate flower morphology to the types of seeds and fruit that are produced • substantiate the importance of plants for sustaining life on Earth • discuss the evidence of evolution and the main evolutionary mechanisms that lead to new species • explain the development of classification systems 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. It may be useful to consider the module as starting	

with an introduction to plant structure from deep within a cell where you will look at organelles such as the cell membrane, ribosomes, endoplasmic reticulum, Golgi apparatus to mention a few. Then you will expand your view to look at the tissues and organs of the plant, particularly those involved in storing, transporting as well as protecting the body from damage and disease. Finally, you will focus on an even larger picture by examining the evolution and classification of plants.

We shall start out in **learning unit 1** by looking at some general aspects of plants, such as plants' contribution on Earth and the way humans use plants. In learning unit 2, we shall study the plant cell, and in learning units 3 to 6 we shall study the structure of plants, which includes the primary and secondary plant body, and plants' reproductive organs. In learning unit 7 we shall look at evolution and in learning unit 8 at plant classification.

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 these 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:

Graham, Linda, Graham, J and Wilcox, L. 2014. *Plant Biology: Pearson New International Edition*. 2nd edition. Essex: Pearson. ISBN: 9781292042497.

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 Botany such as plant anatomy and physiology, taxonomy, environmental botany and plant systematics. Thus, you don't have to learn everything in the textbook, so please follow the guidelines I shall 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 additional reading about it.

For the sake of convenience, I shall refer to the textbook in the learning units as "Graham et al (2014)"

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.

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 this module at least eight hours per week.

Here is a 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 1–8 and textbook (two hours per learning unit)	16
In-depth study of learning units 1–8: 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 approximately eight hours of study time)
1 (January/July)	• Read and reread Tutorial Letter 101 and learning unit (LU) 0 • Skim the learning units and textbook, forming a thorough general impression of the whole module • Skim through the learning units and textbook to form an impression of the whole module
2	Read through the learning units and textbook, and identify all key areas
3	
4	Study LU 1–2 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	• Study LU 3–5 in depth(make mind maps and summaries and do learning activities) • If possible, participate in the online discussion activities
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	• Study LU 6–8 in depth (make mind maps and summaries and do learning activities) • If possible, participate in the online discussion activities
12	
13	
14	Revise and prepare for the 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 yourself, you will understand the full value of this exercise.

The assignments for this module are written 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 shall 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) • your reflections on each learning unit • extra reading material taken from the internet, additional books, and medical and/or scientific journals • a list or glossary of concepts and of new terms explained in your own words • 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 also shall say more about managing your study time, finding articles for further reading and avoiding plagiarism.	
0.7.1	**Learning strategies you can apply: the SSS method** 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 • **s**kimming • **s**canning and outlining • **s**tudy-reading and active learning To help you understand what these steps involve, I shall give you more detail in the sections that follow.	
0.7.1.1	**Skimming** Skimming involves moving your eyes over a piece of text quickly to get a general overview of what it is about. **1. Page through and explore.** 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.) **2. Make a cursory survey.** As you read, ask yourself: What key terms occur in this learning unit or chapter? Stop when you have identified 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: **Where** is it?	
0.7.1.2	**Scanning and outlining** Scanning also involves moving your eyes over a text quickly, but in this case you are doing it to find specific key words or specific items of information. **1.** Keeping in mind the key concepts you identified during skimming, **scan** the chapter, learning unit or	

	section. If you have internet access, you can find more information on skimming and scanning here: https://www.aacc.edu/tutoring/file/skimming.pdf **2. Outline** the section by **starting a mind map** (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: **What** is the main topic of this section/unit? What are the key concepts, and how do they relate to the topic? 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 • http://www.wikihow.com/Make-a-Mind-Map • http://www.mind-mapping.co.uk/make-mind-map.htm **3. Extend your outline.** 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.	
0.7.1.3	**Study-reading and active learning** **1. Study-reading and completing activities.** 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 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 words and concepts. Consult a dictionary to understand the meaning of new words, or use Google to find definitions. You could compile a list of new concepts 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 tool** 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 tool**. 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 • What are the main 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 use knowledge of biology might have in my life or career? (Either write down your thoughts on this, or share them with fellow students by means of the **Discussions tool.**) 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 your learning process has 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 may need slightly more time and some slightly less). Considering you will have about 15 weeks to complete a semester module, you should plan to devote at least eight study hours per week to a module.

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

Certain journals, such as *Science Direct*, however, can be accessed only 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.
3. In the menu on the left-hand side of the screen, click on "Search library resources".
4. Follow the guidelines if you are a first-time user.
5. Click on the option "Find e-resources".
6. Now click on "A–Z list of electronic resources".
7. Various links for databases will appear 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.)
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 usually will result in too much information that does not relate to the specific topic you are looking for.
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 that needs to be supplemented with information from internet sources.

Contact the Unisa Library if you have any difficulties or need assistance: +27 12 429 3206 or visit the Library website for the local branch library's telephone number.

0.7.4 **Avoiding plagiarism**

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 **always** acknowledge your source. Use the Harvard referencing method. You can search for more information on this method online; a good source is http://www.staffs.ac.uk/assets/harvard_quick_guide_tcm44-47797.pdf. If you are not sure about the correct way to acknowledge sources, contact Unisa's Library Information Desk.

Students who do not acknowledge quotes from other sources, 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.	
0.8	**Using myUnisa** I explained the advantages of online learning in section 0.1 of this learning unit. In the sections that follow, I shall give you guidelines to using myUnisa. You will see how the Unisa menu options work, and I shall 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 Discussions tool.	
0.8.1	**The myUnisa menu options** 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. Click on the links below to see where the various options are located. • Learning Units: 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. • Official Study Material: A copy of Tutorial Letter 101 as well as past examination papers will be stored as printable PDF versions under this option. • Announcements: From time to time I shall use this facility to give you important information about this module. You should receive e-mail notification of new announcements posted on myUnisa. • Schedule: This tool 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. • Course Contact: If you want to send me e-mails in connection with this module, use this tool to communicate with me. • Additional Resources: A copy of the learning units will be stored as printable PDF versions under this option. This tool allows you to access any additional learning support material that might help you study this module. I shall send an e-mail alert or announcement to inform you when I add anything to this folder. • Discussions: This tool allows us to hold discussions as if we were in a contact setting. I hope this will give you clarity on many of the issues that students tend to struggle with. I shall set up a number of discussion forums that you can visit to discuss specific topics. There will be a forum for students as well where you can discuss issues among yourselves, or just support one another. • Assignments: This tool allows you to submit your assignments electronically, and to monitor your results. If possible, please submit your assignments via myUnisa. If you don't know how to do this, consult Tutorial Letter 101.	
0.8.2	**myUnisa etiquette** myUnisa is the University's online platform, where lecturers and students meet, interact and participate in an on-going process of learning and teaching. When 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 **netiquette** – a term that means "online manners". You can access these websites to learn more about netiquette: • http://networketiquette.net/ • http://www.studygs.net/netiquette.htm	

	• http://www.carnegiecyberacademy.com/facultyPages/communication/netiquette.html Please observe the rules of netiquette during your normal, everyday online communications with colleagues, lecturers and friends. In particular, remember to be courteous to your fellow students when using the Discussions tool.	
0.8.3	**Activity 0.1: Introduce yourself** At this point, I would like you to do an activity called an ice breaker. **What is an ice breaker?** An ice breaker helps you to • get to know the myUnisa online environment • get to know and connect with your fellow students To do the activity, click on the **Discussions** option in the menu on the left-hand side of the screen. From here, click on the forum **Module-related discussions**, and then on the topic "Introducing yourself". Once inside the topic, post a short entry in which you • tell us who you are and where you live • share what the subject area you are studying means to you, and why you chose to study it Also respond to at least one posting by one of your fellow students.	
0.9	**Assessment in this module** Your work in this module will be assessed by the following: • Two written assignments, which will be used to calculate a year mark that will count 30% towards your final mark • One written examination of two (2) hours that will count 70% towards your final mark **Please consult Tutorial Letter 101** for details about assessment for 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 access an electronic version by using the link on this page, or else by going to **Official Study Material.** I wish you well with your studies. Enjoy the course!	

Learning unit 1

Introduction: The world of plants

Contents

1.1 Introduction

To complete the learning unit, you will need to refer to pages 19–51 of chapter 1 and 2 in Graham et al (2014).

Have you ever wondered what the world would be like without plants; why plants are very useful and essential for our day to day existence? This unit focuses on the aspects of plants, such as plants and their closely related organisms, plants and their scientific names, plants' contribution on Earth and how humans use plants. We shall learn more about plants providing us with food, and the role they play toward medicine, as cures for various diseases are produced through their secondary compounds.

In the text I have included links to some internet sources that you may find interesting and helpful.

1.2 Learning outcomes

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

- explain the importance of photosynthesis and its products for all life on Earth
- list sources of food for life on Earth and relate this to diversity
- analyse the importance of plant products for the ecosystem and the economy
- explain the concepts "enthobotany" and "economic botany", as well as their importance in

the field of genetically modified products

- describe the contribution plants make toward human health

1.3

What are plants?

Recommended reading: pages 21–22 of chapter 1 in Graham et al (2014)

It is not as easy to define plants as many people may think.

Most people assume that an easy definition of plants would be that a plant is any rooted organisms that usually lives on land and has green leaves. Some people may link plants with photosynthesis. Photosynthesis is the process that makes it possible for higher life forms to survive on Earth. During the process of photosynthesis organic food is produced from inorganic molecules (carbon and water) by using light energy.

Although there is no universally accepted definition of what plants are, defining plants by these criteria does not always work owing to the fact that not all plants are photosynthetic. An example is a dodder (figure 1.1), which is a parasitic plant. Unlike most plants, dodders have thin, leafless stems and almost no chlorophyll. In addition, mature dodders are not rooted to the ground.

Figure 1.1: Great dodder, *Cuscuta europaea* L. attached itself to a plant.

(Source: http://commons.wikimedia.org/wiki/File%3ACuscuta_europaea_(plant).jpg)

Plants are neither fungi nor bacteria, though fungi and bacteria have some plant-like features. However, plants are defined as organisms composed of **many cells**, have **cellulose-rich cell walls**, have **chlorophyll** and are **photosynthetic** (or, if non-photosynthetic, originated from photosynthetic ancestors), and are adapted in many ways to life on land.

One example of a plant adapted to conditions on land is a multicellular embryo, which refers to a young stage that develops from a fertilised egg within a mother plant's tissues. Plants are known as embryophytes, solely because all groups of land-adapted plants have such embryos. Modern groups of embryophytes include mosses and other simple plants known as bryophytes, club mosses – lycophytes, ferns and fern relatives – pteridophytes, seed-bearing gymnosperms such as trees, and flowering plants – angiosperms.

Plants have a relationship to fungi and bacteria that is either positive or negative. In nature, about 80% to 90% of plants live in close association with fungi that help them to obtain essential nutrients

	from soil. Notably, the first plants to become stabilised on land did so with great help from fungi. Other fungi, like bacteria, are known as pathogens because they infect plants and cause disease.	
1.3.1	**Activity 1.1** **Do this activity and add it to your portfolio.** **Remember, you could use it as a summary to prepare for the exam!** Refer to your textbook, and answer the following questions: a) Briefly explain why it is so difficult to define plant(s). b) List three elements that disqualify dodders from being regarded as plants. c) Based on you answers to the questions above, what are the four criteria used to define plants?	
1.3.2	**Feedback on activity 1.1** When answering question a) it is very important to mention that plants share some of the most basic features, for example with fungi, which are immobile and their cells are enclosed by organic walls. Also, many bacteria are photosynthetic, but those microscopic organisms have a much simpler structure than plants do. b) Dodders have almost no chlorophyll; mature dodders are not rooted in the ground; dodders consist of leafless stems and lastly, dodders have no roots. c) As defined in our textbook, an organism should pass four criteria to qualify as a plant: i) Plants have cellulose-rich walls, ii) plants are multicellular, iii) plants usually have chlorophyll and are photosynthetic, and iv) plants are adapted to life on land, or if aquatic, they descended from plants that were adapted to life on land.	
1.4	**Plants and their scientific names** **Recommended reading:** pages 24–27 of chapter 1 in Graham et al (2014) Imagine if individual plants had no specific names. Since the beginning of time humans have given plants common names of local relevance, which often reflect appearance or usefulness. It becomes a challenge to use common names when conversing with people from other regions owing to the fact that common names for the same plants often differ according to region and language. Adding to the confusion, the same common names sometimes are used for several different species. This kind of confusion could be detrimental to commerce, agriculture and health. Instead scientists introduced scientific names. Scientific names were established by the biologists who formally described organisms to ensure accuracy and specificity needed for communication in the fields of commerce, agriculture, medicine and other practical applications. The scientific name is two names in Latin, therefore it is called the binomial system. The first part of the name identifies the genus (plural, genera) of which the first letter always is a capital letter, and a specific epithet or species name. Both parts of a scientific name either are underlined or italicised. A combination of the generic name and specific epithet provides a unique name for every species. The list below has some examples: 1) *Amorphophallus titanum* – the titan arum's scientific name 2) *Erythroxylum coca* – scientific name for coca plant 3) *Cocos nucifera* – coconut 4) *Theobroma cacao* – cacao plant *5)* *Acacia karroo* – sweet thorn	

	To find more scientific names of Southern African plants, visit http://posa.sanbi.org/searchspp.php.	
1.4.1	**Activity 1.2** **Do this activity and add it to your portfolio.** Refer to your textbook and answer the following questions: a) What are the advantages of using scientific names over common names? b) Name the simple rules that need to be followed when writing a scientific name. c) List at least 10 scientific names of South African plants.	
1.4.2	**Feedback on activity 1.2** a) Advantages are to ➢ ensure accuracy and specificity ➢ enable people from different parts of the world to engage about plant species with ease ➢ prevent any ambiguity or confusion b) Genus (plural, genera) of which the first letter always is a capital letter. Both parts of a scientific name either are underlined or italicised. When answering question c), I believe you did well with accessing scientific names for South African plants. Surely your answers will vary. Nevertheless, below are some scientific names I thought about: *Lantana camara; Cotyledon orbiculata; Gnidia burchellii; Strelitzia reginae; Acacia karroo*; *Acacia sieberiana* DC. var. woodii (Burtt Davy); *Adansonia digitata* L.*; Aloe africana; Dichrostachys cinerea (L.); Peltophorum africanum Sond.; Ziziphus mucronata*	
1.5	**Plants and associated organisms** **Recommended reading:** pages 27–33 of chapter 1 in Graham et al (2014) It has been noted world-wide that plants, fungi, protists, archaea and bacteria maintain the chemistry of the Earth's atmosphere and our planet's climate at levels required for human and other life. Also, these organisms are well known for their pivotal contribution toward the food web (figure 1.2). Plants produce about half of the oxygen in the Earth's atmosphere. I am sure you know that without oxygen humans and most other organisms would not be able to live. Less familiar, perhaps, is the fact that some of the oxygen produced by plants, algae and bacteria is converted into ozone by solar radiation in the upper atmosphere. Once again, without the ozone layer life on Earth could not exist as it shields the Earth's surface against harmful ultraviolet (UV) radiation.	

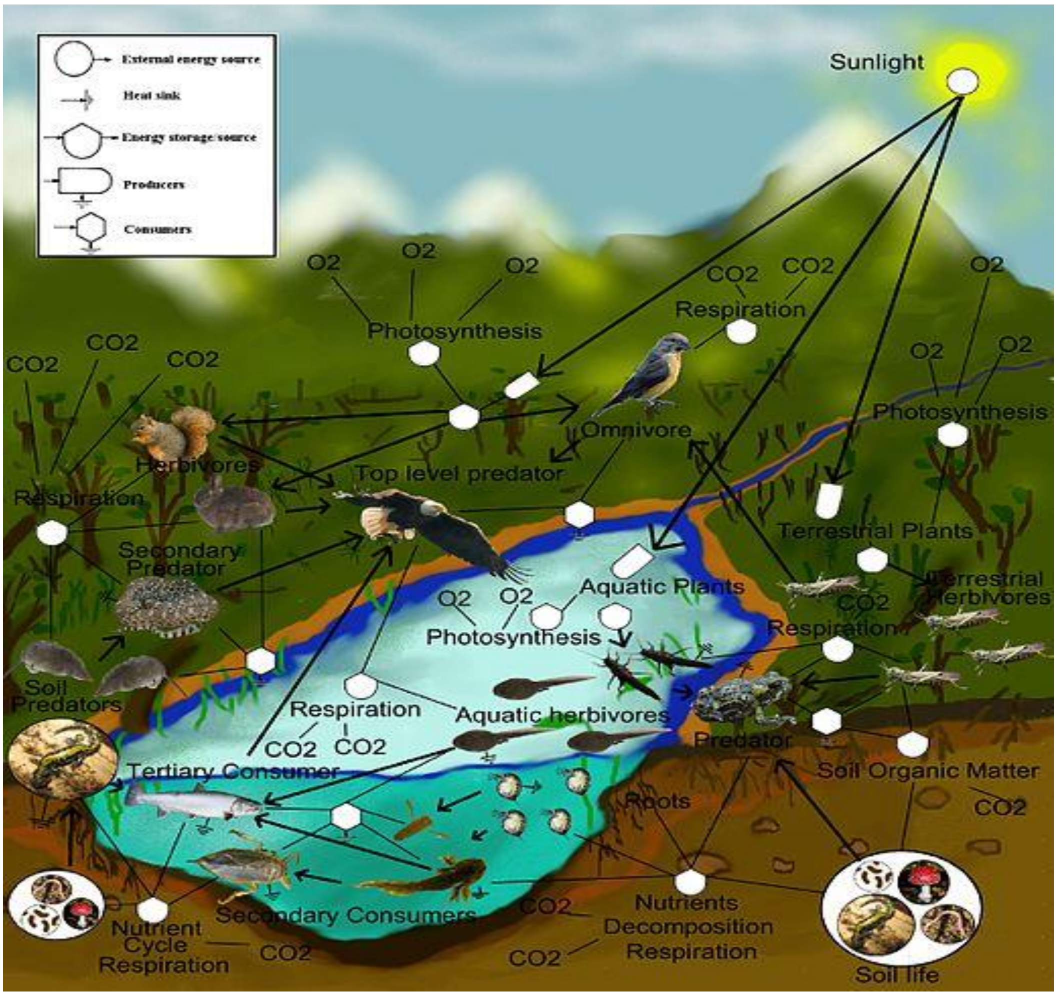

Figure 1.2: The food web showing plants contributing to the surrounding environments

(http://upload.wikimedia.org/wikipedia/commons/thumb/b/b3/FoodWeb.jpg/518px-FoodWeb.jpg)

Plants do not provide oxygen only. They also perform another rarely recognised ecological service as they help by lowering the level of carbon dioxide (CO_2) gas in the atmosphere. Ancient plants that never decayed were compressed into coal deposits. Likewise, over hundreds of millions of years, ocean-dwelling algae have generated huge deposits of oil and natural gas, which are called fossil fuels. Many bacteria and fungi are decomposers. Without such decomposers, Earth's plants, algae and cyanobacteria would not be able to produce the organic food on which humans and other organisms depend.

Like any other living organisms, plants do not live in isolation in nature. They are linked to bacteria, fungi and animals in a variety of ecological associations such as the food web, symbioses and in evolutionary relationships. In most instances, plants gain real benefits from these alliances.

1.5.1 **Activity 1.3**

Do this activity and add it to your portfolio.

Refer to your textbook and the internet, and answer the following questions:

a) Describe the manner in which plants contribute toward animals as well as humans.

b) How can we reduce the threat of global warming?

c) Do you think plants can survive without animals? If you say so, why?

1.5.2	**Feedback on activity 1.3** a) As you were describing the contribution plants make toward animals, did you think about their essential roles in maintaining Earth's climate and atmosphere? Did you describe their contribution to animal diversity as they form the basis of the food web? When answering question b), note that one of the best ways to stabilise global warming is to reduce fossil fuel combustion and also conserve forests. Take into consideration that forests play an integral part in keeping atmospheric carbon-dioxide levels low. In addition to using common sense when answering question c), the answer obviously should be NO as plants cannot live alone. Plants source the majority of their CO_2 from the atmosphere after it has been exhaled by animals. Note that without CO_2, the process of photosynthesis will not take place.	
1.6	**Plants and people** **Recommended reading:** pages 37–51 of chapter 2 in Graham et al (2014) Through the ages plants have played an essential role in human medicine; they also provide us with food, beverages, spices, cosmetics, fibres, building materials and many other products. If all the plants on Earth suddenly were to die, all the animals, including humans would follow soon. Why are humans so dependent on plants and not the other way round? In the next sections, I shall address that question, while also providing an overview of ancient and modern ways in which humans use plants, as well as the importance of botany.	
1.6.1	**Ethnobotany and economic botany** **Recommended reading:** pages 39 of chapter 2 in Graham et al (2014) The word "ethno" comes from the Greek word for people, and botany is the study of plants, otherwise known as plant science. Ethnobotany can be described as the scientific study of the ways in which traditional societies used plants, while economic botany is concerned with the ways in which modern industrialised societies use plants. These two areas are related very closely in that ethnobotanical work reveals indispensable information to developed societies, including about the previously unknown medicinal properties of plants. On the other hand, economic botany often involves investigating the history of cultivating modern crop plants to identify their wild relatives. To identify the wild relatives is crucial since wild plants harbour genetic material that is useful when developing crops that are more resistant to disease, insect attack or drought. For example, one form of teosinte, known as *Zea mays ssp parviglumis*, shares a particular close genetic relationship with maize and available evidence indicates that it is the direct ancestor of maize (Figure 1.3). Through ethnobotanical studies, it has been noted that indigenous people often use trial-and-error methods closely resembling the processes of modern science. These methods have led to the discovery of the most useful properties of thousands of plants. Using such methods, humans have discovered how to use more than 3 000 kinds of plants and how to cultivate hundreds of them. Folk traditions also may function to protect plants and their environments from over-harvest, improving food security. Notably, ethnobotany combines folk wisdom and modern science, bringing to industrialised societies traditional knowledge that otherwise may have been lost.	

Figure 1.3: Over time, selective breeding modifies teosinte's few fruit cases (left) into modern maize's rows of exposed kernels (right).
(https://commons.wikimedia.org/wiki/File:Cornselection.jpg)

1.6.2 **Food plant genetic resources**

Recommended reading: pages 45-48 of chapter 2 in Graham et al (2014)

Probably the most dramatic alteration that humans have achieved in food plants has occurred with maize. Genetic (DNA) evidence has shown that the closest wild relative of modern maize is a grass known as teosinte, as indicated in the previous section (figure 1.3). Conserving the wild relatives of modern crop plants and their habitats, as well as traditional varieties of crop plants from around the world, is being recognised as essential for the development of new crops and new varieties of older crops by plant-breeding methods. Hence it is essential to modern strategies for improving crops to preserve the genetic material from crop plants and their wild relatives. It is likewise important to obtain and preserve information about indigenous agricultural methods.

1.6.3 **Natural plant products are useful as medicine and in other ways**

Recommended reading: pages 48-50 of chapter 2 in Graham et al (2014)

Crop plants are valued primarily because they provide us with primary compounds, which are carbohydrates, lipids and proteins, as well as minerals and vitamins. These plant materials are very important as major components of plant structure or in plant metabolism. They are essential components of all living organisms including humans. You would have realised that people use plants as sources of medicines, herbal dietary supplements, psychoactive drugs, as well as poisons, spices, oil dye, to mention a few. It is important to note that these uses are based on the presence of organic compounds known as natural products or secondary compounds in the plants. About 100 000 different kinds of secondary compounds are produced by plants. The roles of secondary compounds in plants include defence and reproduction. Since plants cannot move or run like we can, they solely depend on chemicals for defence. Also, plants cannot move to achieve mating or migration as animals can, hence they often produce flower and fruit colours and fragrances that entice animals to serve as dispersal agents. Thus, natural selection explains the presence of secondary compounds in plants.

Among the common medications used in developed countries, more than one quarter include plant-derived ingredients. For example, ipecac is used to induce vomiting in cases of poisoning. Ipecac is derived from the plant *Cephaelis ipecacuanha*, which is native to South America. In addition, cancer drugs derived from plants include podophyllin produced by the North American mayapple (*Podophyllum peltatum*), leukaemia drugs from the Madagascar periwinkle (*Catharanthus roseus*), and taxol from the Pacific yew (*Taxus brevifolia*). Even today, many people rely primarily on medicines derived from plants collected directly from nature.

The fact that plants typically contain mixtures of compounds that can influence human health is a source of concern to the pharmaceutical industry in industrialised countries, and the extent to which such products should be regulated is a contentious issue. It is difficult to use established scientific testing methods to determine the safety and efficacy of these products because each contains many types of secondary compounds that could vary in relative proportions. Therefore, herbal products could affect people or their various health conditions differently or interact with prescription medicines in unexpected ways.

Some plants have psychoactive compounds that help protect them against herbivores by altering the function of the attacker's nervous system. When herbivores consume these compounds, they may experience behaviour changes that decrease feeding or increase vulnerability to their own predators. This could affect humans in the same way, since the human nervous system does not differ largely from those of other animals. Depending on their effects on humans, psychoactive plant compounds are classified as stimulants, depressants, hallucinogens or narcotics. Plants that have been used for their hallucinogenic properties include *Cannabis sativa* (marijuana/dagga, figure 1.4 a), native to Asia. Stimulants include cocaine, derived from the *Coca* plant; and caffeine, derived from *Coffea* plant (figure 1.4 b).

Figure 1.4: Plants that contain psychoactive compounds a) *Cannabis sativa* and b) *Coffea arabica.* (https://commons.wikimedia.org/wiki/Cannabis_sativa#/media/File:Cannabis_01_bgiu.jpg) (https://upload.wikimedia.org/wikipedia/commons/0/04/Coffea_arabica01.jpg)

1.6.3.1 **Activity 1.4**

Do this activity and add it to your portfolio.

Refer to your textbook and answer the following questions:

a) What is the main reason for preserving genetic material?

b) What are the roles of secondary compounds in the plant? Why are these compounds regarded as very essential?

c) What are the three effects that psychoactive plant compounds have on humans?

d) Think about what you have learnt in this learning unit and write down any two new things you have learnt. Did your views about the value of plants change in any way? If so, explain how.

1.6.3.2 **Feedback on activity 1.4**

To answer the first question, to identify the wild relatives is crucial since wild plants harbour genetic material that is useful for developing crops that are more resistant to disease, insect attacks or drought.

To answer the second question, did you note that the principal reason why plants have secondary compounds is to defend themselves against herbivores and disease-causing microbes? Secondly, secondary compounds are involved in producing flower and fruit colours and fragrances that entice certain animals to serve as dispersal agents. This cements the fact that reproduction has been made easier by secondary compounds.

To answer c), were you able to identify the stimulants, depressants, hallucinogens, or narcotics easily as the effects psychoactive plant compounds have on humans?

1.7

Summary

Plants, as defined here, are multicellular photosynthetic organisms with cellulose-rich cell walls; they adapted in many ways to life on land or, if aquatic, had ancestors with these features. Bacteria, fungi, and protists are central to the lives or history of plants and therefore are studied along with them. Unique, two-part scientific names (binomial nomenclature) are given to all living things. These names reduce confusion and foster accurate communication in science, commerce, agriculture and medicine.

People use plants and microbes as food and food supplements; in the food-processing, baking and brewing industries; as medicines and building materials; as subjects in art; and in many other ways. Plants and microbes play essential roles in maintaining Earth's climate, atmosphere and organisms. Plants and other organisms often are involved in beneficial relationships. Flowering plants and many animals have influenced each other's evolution.

Ethnobotany is the study of traditional uses of plants, while economic botany is the science of how modern industrial societies use plants. The wild ancestors of today's crop plants are valuable sources of genetic material to breed plants with increased resistance to pests and diseases, but are increasingly endangered by habitat destruction. Plants are useful as sources of medicines, fibre, building and industrial materials, beverages and spices. Plants contain secondary compounds that give them defensive capabilities or play essential roles in plant reproduction.

Learning unit 2	## The structure of cells Content 	
2.1	## Introduction **To complete the learning unit, you will need to refer to pages 81–104, chapter 4 in Graham et al (2014).** Before the 1600s, no one knew that large organisms are made up of many small, living units that today we call cells. The cell is the basic functional and biological unit of all known living organisms. It is the smallest unit of life that can replicate independently. Cells often are called the building blocks of life. The word “cell” comes from the Latin word *cella*, which means “a small room”. Since most cells are microscopic, we cannot see them with the naked eye. The typical size of cells range between 1 and 300 micrometres (µm). The cell theory states that cells form the basic structure of all life and that all cells arise from parental cells. You should keep in mind that this theory ranks among the major scientific achievements of all time. The cell theory is the basis of many advances in biology that affect our daily lives, including controversial issues such as cloning and cultivation of human stem cells, which are reported on often in the news media. For this reason, new discoveries relating to cells have captured the interest of scientists and non-scientists alike. Understanding the world of plants, or any other organisms, involves first exploring the structure and function of cells. In this learning unit, we shall examine the world of cells, *plant cells specifically*, to see how they form the basis of the life of an organism, how they are organised, and how they divide to allow	

	for growth and reproduction.	
2.2	**Learning outcomes** By the end of this learning unit you should be able to • compare the different types of microscopes and explain the basic differences between them • explain the cell theory and its importance • tabulate the differences between prokaryotic and eukaryotic cells • describe the different organelles of eukaryotic cells, discuss their structures and state their functions • state the parts of the cytoskeleton of plant cells, discuss the structure and functions of each part, and discuss the importance of plant cell walls • explain the basic structure and composition of cell walls, explain how plant cells communicate with each other and explain how each part works • discuss the importance of plant cell walls • explain how plant cells communicate with each other	
2.3	**Organisms are composed of one or more microscopic cells** **Recommended reading:** page 83 of chapter 4 in Graham et al (2014) All living organisms are composed of one or more cells. Most cells are microscopic and are either barely visible or not visible with the naked eye. Why are cells so small? A simple answer would be that a cell should remain relatively small so that its surface area, which controls the entry of oxygen, water and nutrients, can supply the needs of its internal regions. Moreover, if a cell grows too large, its genetic material cannot supply information fast enough to meet the needs of the cell. Although they are tiny, cells are far from simple, owing to the fact that they carry out a wide variety of functions that sustain the lives of organisms. Many organisms are composed of just one tiny cell; they have unicellular bodies. These include most bacteria and archaea, many protists and some fungi. Due to their unicellular construction, most microbes are so small they can be seen only through a microscope. Organisms that are large enough to be seen easily are composed of many minute cells and hence have multicellular bodies. Multicellular bodies are known to consist of one or more types of tissues. Examples of multicellular organisms include seaweeds, fungi, plants and animals. As an example, if you have access to the internet, see what plant cells (onion cells) look like when viewed under a microscope. You can follow this link: https://www.youtube.com/watch?v=XXTz-5rbHDI	
2.3.1	**Activity 2.1** **Do this activity and add it to your portfolio.** Refer to your textbook and answer the following questions : a) Why are cells so tiny? b) Describe unicellular and multicellular organisms in respect of their cells. Give two examples of each.	

2.3.2

Feedback on activity 2.1

To answer a) Cells are microscopic, enabling adequate absorption of oxygen, water and nutrients through the cell's surface to meet the needs of the internal regions.

b) Unicellular organisms are organisms with only one tiny cell, whilst multicellular organisms have one or two types of tissues. Examples of unicellular organisms are bacteria, archaea and protists. Examples of multicellular organisms are seaweeds, plants and animals.

2.4

Using microscopes to reveal cells

Recommended reading: pages 83- 86 of chapter 4 in Graham et al (2014)

It remains impossible, of course, to speak about cells without mentioning the significance of microscopes. Microscopes allow us to observe objects that are less than a millionth the size of a person. Without them scientists, or cell biologists in particular, would not be able to view amazing organisms and structures that most people never have seen. There are two major types of microscopes – light and electron microscopes.

Light microscopes have glass lenses to bend the path of visible light, thereby producing a magnified image (figure 2.1). Light microscopes either are compound or stereo dissecting. Figure 2b on page 84 and figure 3a on page 85 in Graham et al (2014) show diagrams of compound light microscopes and stereo dissecting microscopes, respectively. The difference between the two types is that compound microscopes allow you to magnify an object to a much greater extent (up to 1000x) compared to a stereo microscope (maximum about 300x). Moreover, stereo microscopes allow you to see the object stereoscopically (three-dimensionally).

Figure 2.1: A light microscope (LM)

(https://commons.wikimedia.org/wiki/File:Leica_DMRX.jpg)

On the other hand, electron microscopes have about 100 times the magnifying power of light microscopes because they use electrons and magnetic lenses to form images. There are two types of electron microscopes – the transmission electron microscope (TEM) and the scanning electron microscope (SEM). The TEM is used to examine extremely thin slices of specimens made by an ultramicrotome. This is possible only after specimens have been infiltrated with liquid plastic that hardens it and provides stability. It should be noted that TEM reveals structures within cells by passing electrons completely through thin sections of tissue. A TEM can magnify objects up to about 100 000 times. A scanning electron microscope (SEM) bounces electrons off a specimen to reveal the surface structure, often a detailed 3-D view. A SEM can magnify up to about 20 000 times, giving detailed views of cells, groups of cells and tiny organisms.

Electron microscopes are better than light microscopes in that they distinguish very tiny objects lying close together because electrons have much shorter wavelengths than visible light.

You may have noticed that these various types of microscopes provide different and complementary ways of viewing cells. For examples, the transmission electron microscope has revealed that cell interiors of plants, animals, fungi and protists are remarkably complex and similar in many ways, containing structures that do not occur within the cells of bacteria and archaea. The transmission electron microscope also reveals that plant cells share some distinctive features that are more difficult or impossible to observe under light microscopes or scanning electron microscopes.

2.4.1

Activity 2.2

Complete the following table.

Major type of microscope	Subtype	Brief description of function
Light microscope		
Electron microscope		

2.4.2

Feedback on the activity 2.2

Make sure that you complete the table in your own words. Do not copy and paste.

2.5

Eukaryotic cells and prokaryotic cells

Recommended reading: pages 87–95 of chapter 4 in Graham et al (2014)

All living organisms are classified as either **prokaryotes** or **eukaryotes**, based on their cell type. For example, plants, animals, fungi and protists have eukaryotic cells. In contrast, bacteria and archaea have prokaryotic cells. It is important to highlight that prokaryotes were the first forms of life on Earth. For about 1, 4 billion years, no other organisms existed until eukaryotes evolved from prokaryotes.

Prokaryotic cells lack the true nucleus, whilst eukaryotic cells contain a **nucleus** and other membrane-enclosed structures, collectively known as **organelles**. Eukaryotic cells are more complex than prokaryotic cells. In general, eukaryotic cells are larger than prokaryotic cells, ranging in size between 5 and 300 µm, while a typical prokaryotic cell ranges from 1 to 10 µm. Most prokaryotic cells are unicellular, while many eukaryotic cells are multicellular.

Eukaryotic cells, such as plant cells, have nuclei, mitochondria, plastids and other structures (figure 2.2). In contrast, nuclei and other organelles are absent in prokaryotes (figure 2.3). Despite their differences in size and structure, prokaryotic and eukaryotic cells are similar in their basic metabolism, or chemical reactions. They are all capable of producing four general kinds of macromolecules that organisms need in order to survive. These are nucleic acids, proteins, carbohydrates and lipids.

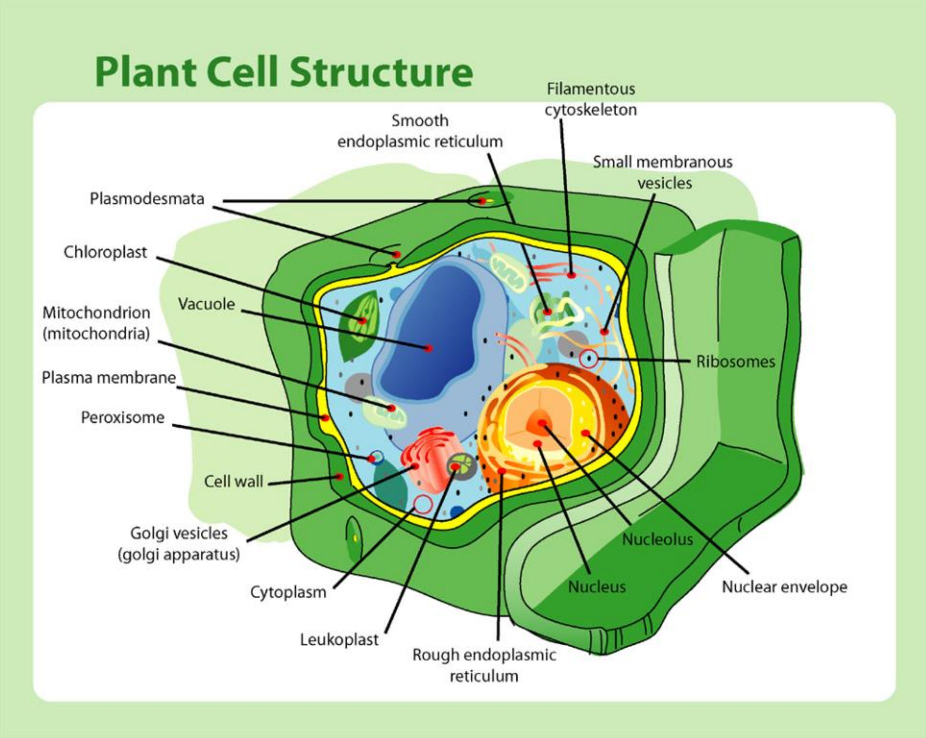

Figure 2.2: A eukaryotic cell, plant cell, (as opposed to animal cell) has chloroplast and a cell wall.

(https://commons.wikimedia.org/wiki/File:Plant_cell_structure.png#file)

All eukaryotic cells and prokaryotic cells have at least three components in common: an outer membrane, also known as a plasmalemma or plasma membrane; internal cytoplasm; and numerous ribosomes. The cell membrane, which defines the cytoplasm's outer limit, is composed of phospholipids, protein and other materials. The cytoplasm is a watery solution that includes ribosomes and other cell structures. Lastly, ribosomes, composed of protein and RNA, are the cell's protein synthesis machinery.

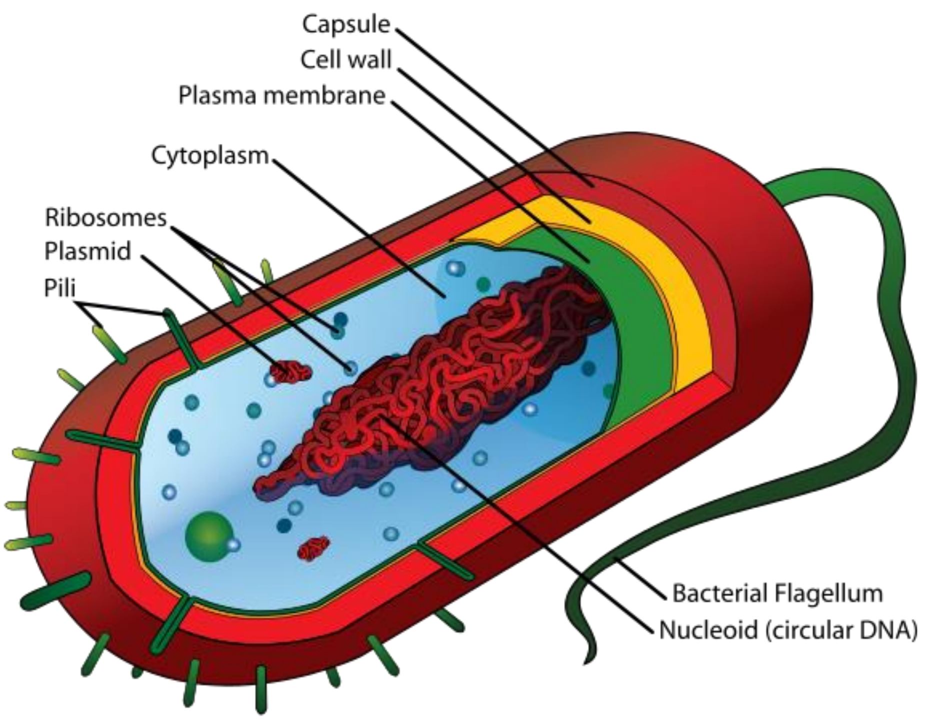

Figure 2.3: A prokaryotic cell

(https://commons.wikimedia.org/wiki/File:Average_prokaryote_cell-_en.svg)

2.6 Major plant cell organelles

Almost all the organelles in a typical plant cell are also found in the cells of other eukaryotes. The exceptions are chloroplasts and a large central vacuole, which are not typically found in other photosynthetic organisms, fungi or animals.

2.6.1 Cell membrane

Recommended reading: pages 87–95 of chapter 4 in Graham et al (2014)

It is very normal at this juncture, to find yourself bombarded with questions such as how do cells perceive stimuli from the environment and influence other cells? How can cells allow entry of needed materials while preventing entry of harmful ones? How can cells get rid of wastes?

All cells are surrounded by a flexible, protective layer called a **cell membrane** or **plasma membrane.** The cell membrane is described as selectively permeable because it allows free passage of some materials. Such materials should be very small, unchanged molecules – water; gases such as oxygen, carbon dioxide and nitrogen. In contrast, cell membranes do not allow passage of larger molecules and ions unless specific membrane transporter proteins are present. Some cell membrane proteins transport nutrient molecules into cells or wastes from cells, while others receive communication signals from the environment.

Within the cell membrane are **receptor proteins** and **transport proteins.** Receptors proteins perceive environmental information in the cell membrane as they bind to chemical messengers in their environment. Receptor proteins with messengers bound to them transmit signals to the cytoplasm, within which the response occurs. Also, receptors allow cells to sense their chemical environments and respond appropriately. On the other hand, transport proteins shuttle molecules into or out of cells through passageways. Like electronic systems that regulate human entry to buildings (for example, codes, fingerprint or retinal scans), cell membrane proteins allow materials or information to move inside cells, but restrict entry of harmful or unneeded substances. This is demonstrated clearly in figure 9 in chapter 4 of Graham et al (2014). Transport proteins are largely dominant as they comprise 50 – 75% membranes. They also are known as carrier, channel or pump proteins.

2.6.2	**Cytoplasm** The jelly-like substance composed of mainly water and found between the cell membrane and nucleus. The cytoplasm makes up most of the "body" of a cell and is constantly streaming. The main function of cytoplasm is that organelles are found here and substances like salts may be dissolved in the cytoplasm.	
2.6.3	**Nucleus** The largest organelle in the cell. It is dark and round, and is surrounded by a double membrane called the nuclear envelope/membrane. In spots the nuclear envelope fuses to form pores which are selectively permeable. The nucleus contains genetic information (DNA) on special strands called chromosomes. The nucleus is the "control center" of the cell, for cell metabolism and reproduction.	
2.6.4	**Endoplasmic Reticulum (ER)** The Endoplasmic Reticulum is a network of membranous canals filled with fluid. They carry materials throughout the cell. The ER is the "transport system" of the cell. There are two types of ER: rough ER and smooth ER. Rough Endoplasmic Reticulum is lined with ribosomes and is rough in appearance and smooth endoplasmic reticulum contains no ribosomes and is smooth in appearance.	
2.6.5	**Ribosomes** Ribosomes are small particles which are found individually in the cytoplasm and also line the membranes of the rough endoplasmic reticulum. Ribosomes produce protein. They could be thought of as "factories" in the cell.	
2.6.6	**Mitochondria** The mitochondria are round "tube-like" organelles that are surrounded by a double membrane, with the inner membrane being highly folded. The mitochondria are often referred to as the "powerhouse" of the cell. The mitochondria release food energy from food molecules to be used by the cell. This process is called respiration. Some cells require more energy than other cells and so would have many more mitochondria.	
2.6.7	**Golgi body/apparatus** Golgi bodies are stacks of flattened membranous stacks (they look like pancakes). The Golgi Body temporarily stores protein which can then leave the cell via vesicles pinching off from the Golgi.	
2.6.8	**Plastids** Plastids are double membrane bound organelles. It is in plastids that plants make and store food. Plastids are found in the cytoplasm and there are two main types: **Leucoplasts** - colourless organelles which store starch or other plant nutrients. (example - starch stored in a potato) **Chromoplasts** - contain different coloured pigments. The most important type of chromoplast is the chloroplast, which contains the green pigment chlorophyll. This is important in the process of photosynthesis.	
2.7	**Activity 2.2** **Do this activity and add it to your portfolio.** Refer to your textbook and answer the following questions: a) Describe the differences between eukaryotic cells and prokaryotic cells. b) List organisms that are classified as eukaryotes. c) Describe the functions of cell membrane proteins. d) Think what you have learnt about the component parts of cells. What insights does this give you about the functioning of plant and animal bodies? Write a few notes to express your thoughts on	

this.

e) In tabular form name all the cell organelles and their functions that you have learned about.

Name of the cell organelle	Function
1.	
2.	
3.	

f) Make sure that you can be able to describe structures of each and every cell organelles.

2.8 **Feedback on activity 2.2**

When answering question a), did you note that the major difference is that prokaryotic cells do not have a true DNA nucleus? Notably, eukaryotic cells generally are larger and more complex than prokaryotic cells. Also, it is worth noting that most known prokaryotes are single-cell organisms, while many eukaryotes are multicellular.

b) Prokaryote organisms are bacteria, archaea and some protists.

To answer question c): Cell membrane proteins form channels through which molecules can enter or leave the cell or organelle. They control the movement of water and other substances through the membrane. They act as receptor sites for transported molecules and even other cells. They are able to recognise other cells or organisms. They serve as attachment sites for molecules that control the cell's structure and function. To make your learning more exciting, visit http://www.sheppardsoftware.com/health/anatomy/cell/plant_cell_tutorial.htm where you can play games from an educational point of view.

2.9 **Summary**

In this learning unit we explored the structure and functions of plant cells. We saw how cells are organised, and how they divide to allow for growth and reproduction. Indeed, all life are composed of cells having a cell membrane and enclosed cytoplasm that includes ribosomes- the protein-producing structures in cells. Microscopes of various types are very essential tools of cell biology because cells are typically too small to be seen with the unaided eye. Eukaryotic cells are distinguished by a nucleus, an endomembrane system composed of endoplasmic reticulum (ER) and Golgi bodies. Most eukaryotic cells also possess one or more mitochondria. Plant cells are distinguished by cellulose-rich cell walls, large watery vacuoles and plastids.

Learning unit 3	**Plant structure, growth and development** Contents **3.1 Introduction** **3.2 Learning outcomes** **3.3 Plant structure variation** **3.4 Plants bodies are composed of organs, tissues and many types of cells** 3.4.1 Secondary meristems produce wood and bark 3.4.2 Primary apical meristems produce primary tissues 3.4.3 Plant tissues are composed of one to several cell types 3.4.4 Activity 3.1 3.4.5 Feedback on activity 3.1 **3.5 Plants develop from single cells or small pieces** **3.6 Summary**	
3.1	**Introduction** **To complete the learning unit, you will need to refer to pages 166–181 of chapter 8 in Graham et al (2014).** When studying this study unit, do not simply study the properties of the various cell types and the anatomical structure of plant organs in isolation. If you understand the connection between the structure of the plant tissue or organ and its function, and know in which habitats plants with specific anatomical characteristics are able to grow, you will experience the rewards that knowledge of external and internal plant morphology offers. You may wonder how big and tall trees transport water and minerals from the soil to the highest branches, hundreds of feet in the air. Also, how are trees able to live for so long? The answer to such questions can be found by exploring some basic characteristics of plant structure and growth. In this unit we shall look at how cells, tissues and organs form the plant and how cells can be specialised for such purposes as transport, support and protection. Then we shall look at basic patterns of plant growth. Knowledge of plant structure and development also helps us understand the great variation in plant form that we see in nature.	
3.2	**Learning outcomes** By the end of this learning unit you should be able to • list the different types of cells occurring in seed plants • list the structures and functions of the cells and tissues of seed plants, and in each case discuss the relationship between the structure and function • distinguish between the tissue systems (dermal, vascular and ground tissues) and explain their composition, position, structure and functions • discuss the origin, structure and functions of roots, stems and leaves (typical as well as modified) • describe the developmental phases from zygote to mature plant • discuss the process by which plants grow, and the tissues responsible for growth • state the plant groups in which secondary growth occurs • differentiate between primary and secondary tissues, and between primary and secondary growth • discuss the growth and structure of annual, biennial and perennial plants	

3.3 Plant structure variation

The more than 250 000 different types of plants that occur worldwide vary greatly in size and shape. Obviously, the structural variation of plants is important to plants' ecological roles and also relevant to how humans use plants. For example, in figure 1 on page 167 of your textbook, you will see that the duckweed has its role toward pond surfaces, providing essential food for ducks and other animals. On the other hand, redwood has its own role toward humans as sources of wood products. What explains the dramatic difference in size and structure of duckweed and redwood? Part of the answer is that the growth process in duckweed and redwood is somewhat different. In plants, **growth** is a process by which the number and size of cells increase. Redwood trees feature a particular type of growth that greatly increases stem girth and generates wood. This type is absent in duckweed of which the stems remain slender and non-woody. Surely different plants will vary in the number and arrangements of their organs, such as leaves, stems and roots. These differences arise from variations in body development. **Development** is the process by which a reproductive structure with a few cells or a single cell is transformed into a multicellular adult body by means of growth and cell specialisation. Different types of plants also feature different amounts and types of tissues and cells with specialised structures and functions.

3.4 Plants bodies are composed of organs, tissues and many types of cells

Plant bodies, like those of animals, are well organised in functional units. **Organ systems** comprise one or more types of organs, **organs** comprise one or more types of tissues, and **tissues** comprise one or more type of cells.

3.4.1 Primary apical meristems produce primary tissues

All plants have shoot and root tip growth points known as primary **apical meristems** that generate new primary tissues at root and shoot tips. Root apical meristems increase the length of roots, and shoot apical meristems increase the height or length of shoots. This type of growth is known as primary growth. Three primary meristems, as well as embryo leaves and buds, develop from apical meristems. These primary meristems are called **protoderm, ground meristem** and **procambium.** The tissues they produce are known as primary tissues, which are the outermost **dermal ("skin") tissues, the vascular (conducting system) tissues** and **ground tissues.** The activity of the shoot apical meristem produces new stem tissue and young leaves, as well as **axillary buds** located in the angle between stem and leaf stalks. The region of a stem from which one or more leaves or branches emerge is a **node.** The stem regions between nodes are the **internodes.**

3.4.2 Secondary meristems produce wood and bark

Maturing and adult trees, shrubs, woody vines and other plants that produce some wood have two meristems in addition to the primary root and shoot meristems, namely the **vascular cambium** and **the cork cambium.** The vascular cambium and the cork cambium are lateral meristems, which produce tissue that increase the girth of roots and stems. The **vascular cambium,** often referred to simply as the **cambium**, produces secondary tissues that function primarily in support and conduction. The cambium, which extends throughout the length of roots and stems in perennial and many annual plants, is in the form of a thin cylinder of mostly brick-shaped cells. The individual remaining cells of the cambium are referred to as *initials*, while their sister cells are called *derivatives*. The cork cambium, like the vascular cambium, is in the form of a thin cylinder that runs the length of the roots and stems of woody plants. It lies outside the vascular cambium, just inside the outer bark, which it produces.

3.4.3	**Plant tissues are composed of one to several cell types** Some tissues consist of only one kind of cell, whereas others may have two to several kinds of cells. Tissues that contain just one or two cell types are known as simple tissues. Simpler, basic types of such tissues are discussed in this section. Let us look at the **parenchyma tissue** first. **Parenchyma tissue** comprises *parenchyma cells*, which are the most abundant of the cell types and are more or less spherical in shape when they are produced. Parenchyma cells have thin primary cell walls and usually do not have secondary walls. Their thin walls enable them to grow into various shapes to fill the space available, but usually they are spherical, cubical or elongated. There are two very popular types of parenchyma cells – ***aerenchyma*** (with extensive connected air space) and ***chlorenchyma*** (containing numerous chloroplasts). One function of these cells is to store starch, but parenchyma cells may have a variety of other roles. Parenchyma cells serve in the photosynthetic process as they store food and water in roots, stems, leaves and fruits. When you eat a fruit, most of what you take in is probably parenchyma. Secondly, let us look at **collenchyma. Collenchyma** (from the Greek word *kolla*, meaning "glue") is another type of tissue composed of only one cell type. This cell commonly is found under the epidermis of herbaceous stems or leaf stalks, the petioles. The main function of collenchyma cells is to provide flexible support, functioning somewhat like an athlete's elastic knee brace. Their walls are thickened unevenly with carbohydrate pectin and they lack secondary walls. The thickened areas lend strength, while the intervening thinner wall areas allow cells to stretch during rapid growth. One can draw the conclusion from this collenchyma cell functioning that it occurs on the primary growth part. Lastly, we look at **sclerenchyma** (from the Greek word *skleros*, meaning "hard"). Unlike collenchyma cells and most parenchyma cells, sclerenchyma cells have secondary walls, often hardened with lignin. In this case the term "hard" referring to sclerenchyma is reflecting the fact that the thick secondary cell wall provides rigid support. Indeed, sclerenchyma cell walls are much harder than those of either collenchyma or parenchyma cells. Accordingly, sclerenchyma cells are considerably less common in smaller plants than parenchyma or collenchyma. Unlike parenchyma and collenchyma cells, sclerenchyma cells are typically dead at maturity. The main function of sclerenchyma cells is that they provide structural strength/support in regions that have stopped growing in length and no longer need to be flexible. There are two types of sclerenchyma cells that provide protection and support. These are **sclereids** and **fibres**.	
3.4.4	**Activity 3.1** **Do this activity and add it to your portfolio.** Refer to your textbook and answer the following questions: a) How do apical meristems affect the growth of a plant? b) How do meristematic cells differ from parenchyma, collenchyma and sclerenchyma cells? c) Compare the three basic types of differentiated cells.	
3.4.5	**Feedback on activity 3.1** Answering a), primary growth (growth in length) comes from apical meristems at tips of roots and shoots. Leaves originate on shoot apical meristems. Hence, without apical meristems in plants surely there will be no growth in length. b) Bear in mind that meristematic cells enable plants to grow throughout their lives, whilst parenchyma, collenchyma and sclerenchyma cells are functioning to support, protect, store and perform some of photosynthetic activities. When answering question c) make sure that you compare the three basic cells that are found in plants – parenchyma, collenchyma and sclerenchyma cells – with regard to their structure, function and location within the plant body.	

3.5

Plants develop from single cells or small pieces

Plants development is an amazing thing. Many differences in size, structure and complexity, as well as the various ways in which plant bodies differ from those of animals, can be explained by the way plants develop.

Adult plant bodies, like those of animals, can develop from a single-cell **zygote**, which is the product of sexual fusion of **egg** and **sperm**. Indeed, zygotes of animals and of plants develop into multicellular **embryos** and adults by repeated mitotic cell divisions.

However, plants differ from animals in that they have not one, but two multicelled bodies that develop from single cells. One of these bodies is produced from a zygote and the other body is produced from a **spore.** A spore is a cell that can develop into a multicellular adult body without having to fuse first with another reproductive cell. The two plant bodies are called the **sporophyte** and the **gametophyte.**

Although these two life stages are different in their development pathways, they both begin from a single cell. A sporophyte develops from a zygote and is a spore-producing plant body. In contrast, the gametophyte develops from a spore and is a gamete-producing plant body. Bryophytes and ferns provide particularly good examples of how plant gametophyte and sporophyte bodies differ.

Another difference between plants and animals is that plants more commonly reproduce asexually, that is, without the formation of eggs, sperm and zygotes. Most plants undergo asexual reproduction, regenerating new adult bodies from small pieces of tissue or a specialised bud, whereas most types of plants can reproduce in this way. Unlike animals, most plants grow throughout their life. This is called indeterminate growth. Annuals are plants characterised by a life cycle of one year. Perennials are plants that live for many years and they do not die of old age, only of disease.

3.6

Summary

Plants have multicellular bodies that vary structurally in ways that adapt them to different environmental conditions. Plants grow by addition and enlargement of new cells. Leaves, stems and roots are basic plant organs. Plant growth and body form are functions of (1) the cell division activity of primary apical meristems and often also secondary meristems, (2) cell enlargement after division, and (3) the types of specialised cells that develop by differentiation. Meristems are localised regions of cell division activity. Shoot and root primary meristems increase plant height or length by producing primary plant tissues and also generate leaves and branches. The three basic types of differentiated cells are parenchyma, collenchyma and sclerenchyma cells. Parenchyma cells are the most common type of living differentiated cell. Parenchyma cells are usually spherical, cubical or elongated. They are alive at maturity. The functions of parenchyma cells are photosynthesis and storage. Collenchyma cells are alive at maturity. They lack secondary walls, and have thicker primary walls. Collenchyma cells provide flexible support. Sclerenchyma cells usually are dead at maturity and have secondary walls. They provide rigid support. Plant bodies develop from zygotes, spores or asexual structures. Plants that reproduce sexually have two distinct types of reproductive bodies. Sporophytes develop from zygotes and produce spores, whereas gametophytes develop from spores and produce gametes, which mate to form zygotes.

Learning unit 4

Roots, stems and leaves: the primary plant body

Contents

4.1	**Introduction** **To complete the learning unit, you will need to refer to pages 183–227 of chapter 9, 10 and 11 in Graham et al (2014).** Having completed learning unit 3, you should have realised that growth produced by the apical meristems at the tips of shoots and roots results in what is called the primary plant body. Thus, roots, stems, and leaves of plants are all derived from apical meristems. The root is typically the organ that lies below the surface of the soil. However, this is not always true as some roots are adapted to exist above the soil. Furthermore, some stems occur below the ground, hence one can refer to the root as the part of a plant body that has no leaves, and therefore also has no nodes and internodes. On the other hand, the stem is the plant axis that possesses buds and shoots with leaves and roots at its basal end. The stem should be the stalk of a plant or the main trunk of a tree. Indeed leaves are the most noticeable organs on a plant and they are probably the most important in a plant as they ensure that photosynthesis is carried out successfully. Note that the photosynthesis process produces the main source of the plant's food. A leaf is an above-ground organ of the plant that is typically flat and thin, and specialised for the process of photosynthesis. Here we will focus on the aspects that concern roots, stems, and leaves. We will also look at how these organs in vascular plants develop and function together. It is logical to say that roots, stems and leaves do not function in isolation hence they need each other. As we explore what makes each of these organs unique, we will also take a closer look at how they relate to and depend on each other.	

4.2	Learning outcomes	
	By the end of this learning unit you should be able to • compare the structures of taproot systems and fibrous root systems • draw a labelled line diagram of the structure of the apical meristem of the root • explain the process of differentiation in the root tip in detail • discuss the relationship between the structure and function of each part of the root tip, with special reference to the general functions of roots • draw a labelled line diagram of the anatomical structure of the root • explain in detail the position, structure and functions of each type of tissue in the root • discuss the relationship between the structure and functions of modified roots, with specific reference to the special and general functions of each of these root types • discuss the importance of mycorrhizae for plants • explain in detail the process of differentiation in the tip of the stem • discuss the relationship between the structure and functions of each part of the tip of the stem, with special reference to the general functions of stems • draw a labelled line diagram of the anatomical structure of the stem • discuss in detail the position, structure and functions of each type of tissue in the stem • explain the transition between the vascular tissue of the root and the stem in the hypocotyl • state where leaf primordia appear and explain how they are formed • discuss the relationship between the structure and functions of modified stems, with specific reference to the special and general functions of each of these types of stems • summarise the structures of the leaf epidermis, mesophyll and the vascular tissue of the leaf and relate them to the functions of each of these tissues and the leaf as a whole • draw a labelled line diagram of the anatomical structure of the leaf • discuss in detail the position, structure and functions of each type of tissue in the leaf • relate the structure and shape of its leaves to the environment in which a plant occurs • explain the process by which leaf abscission takes place, and the importance of this process • discuss the relationship between the structure and functions of modified leaves, with specific reference to the special and general functions of each type of leaf	

4.3

Roots play a variety of roles in plants

It does not matter whether you are working with houseplants, garden vegetables, or flowers, or whether you are interested in the use of roots for food or medicinal purposes, it is important to understand the many ways in which roots function in plants.

Did you know that when seeds germinate, the first part/organ of plant to emerge is the embryonic root (the radicle) and thereafter a primary root soon presents on seedling? The radicle may develop into a thick, tapered taproot from which thinner branch roots arise, or many adventitious roots may arise from the stem which is attached to the radicle and continuous with it. You should understand that the rapidity of root development signifies the importance of roots in anchorage as well as in the absorption of water and minerals needed by the plant. Roots anchor plants firmly in the soil so that they can begin the process of absorbing water and minerals from the soil as soon as possible. This rapid root development occurs because both the shoot development and photosynthesis process require an early supply of water and minerals. Many plants can produce enormous amounts of root materials depending on the need for a very large amount of root absorptive surface area. In most plants, roots are needed and are essential for anchorage, water and mineral absorption and other functions. Amazingly, roots also play a significant role in preventing soil erosion by water and wind. For example, grass roots have the ability to bind large clumps of soil. Note that not all plants require roots for their existence, for example bryophytes. These plants absorb water and minerals through their leaves from their wet environment.

Some roots have so-called specialised functions. As mentioned above, the main purpose of roots is to anchor and support the plant and to absorb water and minerals. Some plants, however, have roots with modifications that adapt them for performing specific functions as well as absorbing water and minerals in solution. These modifications, among many, serve for reproduction, storage, respiration, and acquiring adequate nutrition. Firstly, we will take a look at **storage roots**. These can be divided into **water** and **food storage roots**. Most roots store food, but in certain plants the roots are enlarged and able to store large quantities of starch and other carbohydrates, which may later be utilised for extensive growth. Popular examples for food storage roots are sweet potatoes, carrots (figure 4.1 A), sugar beets, parsnips and yams. The physiological process that occurs is that extra cambial cells develop in parts of the xylem of branch roots and produce large numbers of parenchyma cells. As result, the organs swell and provide storage areas for large amounts of starch and other carbohydrates. Water storage roots can be related to some members of the pumpkin family (Cucurbitaceae). They produce huge water-storage roots. This roots are dominant in plants that grow in arid regions where there may be no or limited precipitation for longer periods. The water stored in the roots is then used by plants when the supply in the soil is inadequate. The second type of modified roots are **prop or stilt roots**. Prop roots develop from adventitious roots on horizontal branches and provide additional anchorage and support to the plant, for example at the base of corn plants (figure 4.1B). Among modified roots that provide additional support or anchorage for a plant, there are **aerial roots** which are adventitious roots that arise from stems. In corn, aerial roots known as prop roots grow out of the stem and into the soil, helping to anchor and support the plant. **Pneumatophores** are specialised roots of some types of mangrove trees (figure 4.1C). Pneumatophores, also known as **air roots**, provide oxygen for plants in areas such as swamps where the high rate of aerobic decay reduces the oxygen supply in the water. Thus, plants growing with their roots in water may not have enough oxygen available for normal respiration in their root cells. B**uttress roots** are dominantly found in some tropical trees that grow in shallow soils. The buttress roots develop toward the base of the trunk giving the tree great stability (figure 4.1D). Some herbaceous dicots and monocots have **contractile roots** that pull the plant deeper into the soil. This process pulls the shoot deeper into the ground where the soil is relatively warm, helping these plants survive changeable early spring weather. Some plants, including dodders, broomrapes, and pine drops, have no chlorophyll and have become dependent on chlorophyll-bearing plants for their nutrition. They thus obtain water, minerals and organic food from host plants using peg-like projections called **haustoria** (singular: haustorium). These are also known as **parasitic roots**.

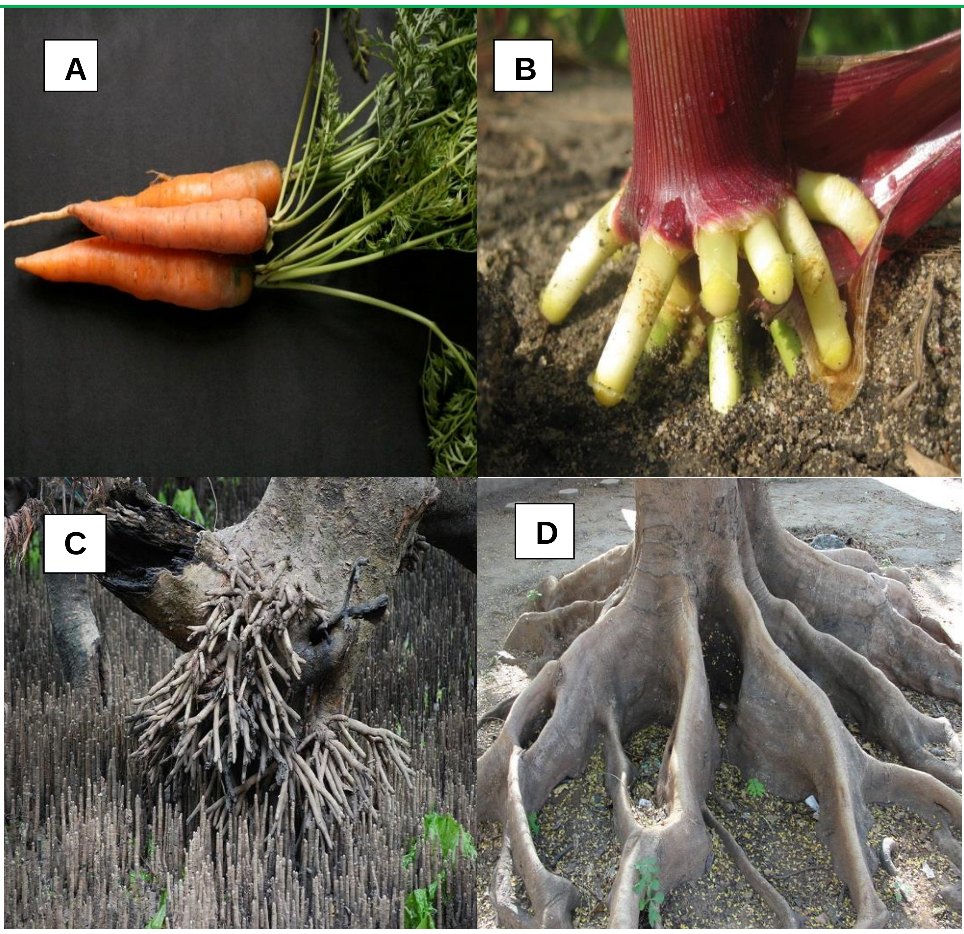

Figure 4.1: (A) An example of a food storage root - the carrot. **(B)** Prop roots of corn. **(C)** Pneumatophore of grey mangrove (*Avicennia marina*)**. (D)** Buttress roots in *Ficus sycomorus*.

(https://commons.wikimedia.org/wiki/Category:Carrots#/media/File:Karotoj.jpg; https://upload.wikimedia.org/wikipedia/commons/0/09/Prop_roots_of_maize_%285480649879%29.jpg; https://commons.wikimedia.org/wiki/File:Pneumatophore_overkill_-_grey_mangrove.JPG; https://commons.wikimedia.org/wiki/File:A_Above_ground_root.JPG)

4.4

Taproot and fibrous roots are major types of underground root growth

There are two main forms of root growth: the **taproot system** and the **fibrous system**. Most dicots and gymnosperms have a taproot system which has a large main root known as a taproot. The function of a taproot is to “tap” deep sources of water and also to provide a plant with the necessary support. This taproot develops directly from the radicle (embryonic root) and produces branch roots called lateral roots. Taproots generally penetrate deeply and are therefore well suited for plants that become larger each year, such as trees. Most monocots and seedless vascular plants have a fibrous root system. Instead of one main root developing from the radicle, the radicle, or embryonic root soon dies and numerous roots arise from the lower part of the stem. These are also called **adventitious roots** simply because they do not come from the usual location; that is, they do not come from other roots but directly from the stem. Noticeably, in a fibrous root system, no single root stands out as the main or largest. In a fibrous root system the roots are more or less the same in size.

4.5

Root structure and function are intimately related

Did you know that roots can grow through extremely dense soils, and that they can sense gravity? The fact that roots can branch repeatedly to generate huge surface areas for absorption of water and minerals shouldn't no longer be a secret to you. Have you ever wondered how roots are capable of selecting minerals needed for plant metabolism and at the same time prevent harmful materials from entering the rest of the plant? Isn't this interesting? We will therefore now examine root structure at three increasingly finer levels: the external structure, root tissues and then we will look more closely at some important root-cell types. By doing this, we will be able to understand much better how roots grow and function.

Whether a root is long or short, its growth – like the growth of a stem – begins with the **cell division** in the **apical meristem** near its tip. It can be divided into several regions. At the very tip is the **root cap** and the apical meristem where new root cells are produced by cell division. These cells grow larger in the **region of elongation** and start to specialise in their function in the **region of maturation**. It is in the region of maturation that the root hairs are found that are so important to the uptake of nutrients and water for the plant by the root.

The root cap and meristematic cell division: It is in the root cap that the cells which will form the new root are produced by the division of the meristematic cells (dividing cells) of the apical meristem. Cells towards the top of the apical meristem divide, forming new cells that enter the region of elongation where they increase in size. These cells are destined to become the cells which make up the young parts of the root. The cells on the lower part of the apical meristem divide to form a structure which is a specific characteristic of roots (it is not present in stem) - the root cap. The cells which are formed by the lower portion of the apical meristem differentiate or change into cells which are arranged in columns and are therefore known as columella cells. The columella cells contain amyloplasts which tend to sink to the bottom of each cell. Roots may be able to sense gravity and therefore also ways to grow downwards due to this characteristic of the columella cells. After 2-3 days the columella cells are pushed towards the outside of the root cap by the new cells which are being formed. Here they differentiate into peripheral cells which are eventually sloughed off the root cap by the action to the root growing between the rough soil particles. The peripheral cells secrete a slimy mucous-like substance known as mucilage.

Together, the root cap and the mucilage it secretes have a number of important functions:

- They protect the root, i.e. the mucilage protects the root from becoming dried out.
- The mucilage lubricates the root for movement between the soil particles.
- The water-absorbing properties of the mucilage help to increase the root's ability to absorb water.
- The chemical composition of the mucilage helps the uptake of nutrient ions in the surrounding soil by the root.

The region of elongation - Behind the apical meristem of the root is an area known as the region of elongation, which is about 4 -10 mm in length. It is in this zone where the root cells begin to elongate primarily by filling their cell vacuoles with water. These cells are thus easily distinguished from the cells of the apical meristem by the fact that they are elongated with large water-filled vacuoles, whereas the apical meristem cells are small and densely filled with cytoplasm. It is this action of cellular elongation which pushes the root tip with the root cap forward, through and between the soil particles. Note that the growth in the root and any plant structure is due to a combination of the increase in the number of cells which takes place in the apical meristem in roots, and also in the size of the individual cells which takes place in the region of elongation in the root.

The region of maturation - Behind the region of elongation is a region of differentiation. It is in this region of the root that cells mature and begin to change their structure and their function. This process is known as differentiation. The epidermal cells of this zone produce long extension cells - root hairs which are a characteristic of the zone of maturation. Near the top of this zone, the cells have differentiated into the various tissues types which make up a typical root. Beyond the region of elongation in the roots of long-lived plants, the root will start to thicken by a process called secondary thickening.

The **cortex** is formed from the ground meristem cells formed in the apical meristem of the root tip. It consists of three concentric layers of tissues.
(i) Firstly, there is the **hypodermis.** In many plant species, especially those from arid areas, the hypodermis is the outermost layer of cells of the cortex which have suberin-enriched cell walls. These cells are only fully differentiated above the region of the root which is covered with root hairs. This layer is important in preventing the loss of water and nutrients which have been absorbed by the region of root hairs lower down the root.

(ii)Secondly, there is the **endodermis.** The endodermis is the layer of cells which surrounds the stele. Unlike the cortex cells to its outside, the endodermis cells are very tightly packed with no intercellular air spaces. The radial and transverse cell walls of the endodermis cells are impregnated with lignin and suberin which forms a structure known as the **Casparian strip**. If one thinks of the cells of the endodermis as the bricks which make up the wall of a tower, the Casparian strips are arranged in the same way as the cement between the bricks. The Casparian strip is developed in the endodermis cell shortly behind the root tip before the region of maturation and the root hairs. It prevents water from moving into the stele through the cell walls of the endodermal cells. Water and dissolved nutrients must thus move through the cytoplasm of the endodermal cells which can therefore control the amount of water entering the vascular tissues of the central stele. The endodermis thus plays a crucial role in the uptake of water by the roots.

(iii) Thirdly, the layer of cells on the inside of the endodermis known as the **pericycle**. This layer of cells is important as these cells are able to divide (they are meristematic). It is these cells which divide to give rise to the branch roots (also known as secondary or lateral roots). The pericycle also forms part of the vascular cambium which forms new cells when the root starts to thicken (secondary thickening). In some plants (mainly dicots), the primary xylem (xylem which differentiated from the cells formed by the apical meristem of the root tip) forms a solid core with lobes, in which case the root is termed protostelic. In other species (mainly monocots) the vascular tissue surrounds a central parenchymatous pith and the root is siphonostelic. In siphonostelic plants the xylem forms isolated rows orientated towards the outside of the root. When the xylem differentiates out of the procambium - cells formed in the apical meristem of the root tip- it is the cells nearest the pericycle which differentiate first, called the protoxylem, and the cells that develop later towards the middle of the root are called the metaxylem. Thus, the older xylem cells are towards the outside of the root and the root is termed exarch. The opposite situation is true in a stem which is **endarch**.

In the root, bundles of phloem are found between the lobes of the xylem, i.e. the xylem and phloem alternate with each other. This is different to the situation in the stem where the xylem is found towards the inside and the phloem towards the outside of the vascular bundles.

In order for the mature root to get thicker it must produce more cells. These cells are produced by a layer of cells which are still able to divide (meristematic) - the vascular cambium. This process, called secondary thickening, takes place in the roots of dicotyledonous plants.

Root hairs - Cells of the young epidermis in the region of maturation give rise to the root hairs. These are formed by extensions of the cell wall of the epidermal cells and protrude into the surrounding soil. When plants are grown in moist air, the hairs form long slender tubes but in the soil they are greatly contorted as they must grow between the soil particles. The root hairs are not separate from the epidermal cells, but form a single cell. As the cell wall extension moves out from the epidermal cell into surrounding soil, the nucleus of the cell moves to the tip of the new root hair along with much of the cytoplasm. An epidermal cell with a mature root hair thus has a large central vacuole. The cell walls of the epidermal cell and its root hair are thin, thus not inhibiting the uptake of water and dissolved salts by the epidermal cell.

Root hairs greatly increase the area of the root which is exposed to the soil and through which water and dissolved nutrients can move into the root. They are ephemeral however, and only last a few days or weeks before they wither and die. New root hairs are constantly being formed at the anterior end of the region of maturation as it is pushed forward by the growing root and those further back die. In this way the new root hairs are constantly coming into contact with fresh soil. Most plants produce roots hairs, however, they are absent in certain firs and redwood species and some aquatic plants. Root hair development is suppressed when some land plants are grown with their root suspended in water (hydroponically) and their growth is negatively influenced by high soil nutrient concentrations and high and low soil temperatures.

4.6

Plant roots are associated with beneficial microbes

Plant roots can be remarkably efficient in finding and absorbing mineral nutrients, but the challenges of growth in soils of low mineral nutrient content often require the aid of beneficial microorganisms that form symbiotic relationships with plant roots. These include mycorrhizal fungi and the nitrogen-fixing bacteria. The mycorrhizal fungi are called mycorrhizae (from the Greek "mukés", meaning fungus, and "rhiza," meaning roots).

When mycorrhizal fungi colonise the plant's root system, they create a network that increases the plant's capacity to absorb more water and nutrients such as phosphorus, copper and zinc. This process in turn enhances growth and favours rapid development of roots and plants.

Importance of mycorrhizae

- Roots with mycorrhizae spread over the available space more rapidly.
- Roots with mycorrhizae have more surface area to absorb water.
- Roots with mycorrhizae have a greater capacity to absorb nutrients from the soil. You thus get plants that are healthier, more vigorous, and more resistant to stress.
- Up to 80% of phosphorus absorbed by plants takes place through mycorrhizae.
- The root extension (filaments) provided by mycorrhizae holds soil particles together which reduces erosion.

There are two main types of mycorrhizae, namely **endomycorrizae** and **ectomycorrhizae**.

Endomycorrhizae are associated with 80% of plants, thus with most deciduous trees and herbaceous plants. Ectomycorrhizae are associated with 5 to 7% of plants, i.e. with most evergreen trees.

4.7

Activity 4.1

Do this activity and add it to your portfolio.

Refer to your textbook and answer the following questions:

a) How do taproot and fibrous root systems differ?

b) Describe cell development and maturation through the zones near a root tip.

c) What are the functions of the root tap, mucigel, and root hairs?

d) Describe the roles of the pericycle and endodermis.

e) What are mycorrhizae, and how are they beneficial?

f) Complete the table about types of roots.

Type of Root	Description	Mainly in Dicots or Monocots?	Examples
	Long and thick primary roots that grow deep into the soil		
	Roots that are usually shallow and consist of many thin roots		

4.8	**Feedback on activity 4.1** This activity included answers that are very easy to find either in these notes or in the prescribed textbook. a) A taproot is a large main root that comes off from the stem and has many smaller lateral roots; a fibrous root system has many roots of the same size that break off into small lateral roots. b) In answering this question you should have touched on a few of the following points - within the root tip; cells differentiate, actively divide, and increase in length, depending on in which zone the cells are located. Dividing cells make up the zone of cell division in a germinating plant. The newly-forming root increases in size in the zone of elongation. Differentiating cells make up the zone of cell maturation. Find the answers to questions c), d), e) and f) by yourself.	
4.9	**Stems are fundamental plant organs having multiple functions** Vascular plants are those plants that have a conducting system composed of vascular tissue (xylem and phloem). Vascular plants include all land plants except bryophytes. During the evolution of plants, stems appeared well before leaves and roots. Evidence for this is the fact that the earliest known fossils of vascular plants have stems, but not roots or leaves. Among modern vascular plants' organs, stems are the oldest and most fundamental. It is interesting to note that all other organs or organ systems - roots, buds, leaves, flowers and fruits, or cones - are attached to stems. It is also obvious that stems enable plants to increase their height or length, mass, and surface by the activity of apical meristems. There are two forms of stems: **herbaceous (non-woody)** and **woody stems**. Herbaceous stems do not produce a cork cambium. The stems are usually green and photosynthetic, with at least the outer cells of the cortex containing chloroplasts. Herbaceous stems commonly have stomata, and may have various types of trichomes (hairs). Woody stems can persist over a number of years and develop distinctive markings in addition to the original organs that form. Terminal buds usually extend the length of the shoot during the growing season.	
4.10	**The structure of conducting tissues helps explain their functions** As in roots, there is an apical meristem at the tip of each stem which produces primary tissues that contribute to the stem's increases in length. The protoderm gives rise to the epidermis. The ground meristem produces parenchyma cells. Parenchyma cells in the centre of the stem constitute the pith; parenchyma cells away from the centre constitute the cortex. The procambium produces cylinders of primary xylem and primary phloem which are surrounded by ground tissue. A strand of xylem and phloem, called a trace, branches off from the main cylinder of xylem and phloem and enters the developing leaf, flower, or shoot. These spaces in the main cylinder of conducting tissues are called gaps. In dicots, a vascular cambium develops between the primary xylem and primary phloem. In many ways this is a connect-the-dots game where the vascular cambium connects the ring of primary vascular bundles. In monocots, these bundles are scattered throughout the ground tissue and there is no logical way to connect them that would allow a uniform increase in girth.	

4.11	Modified stems	
	As in roots and leaves, in most stems there are some modifications that serve a special purpose, including that of natural vegetative propagation. As you become acquainted with the following modified stems, keep in mind that stems have leaves at nodes, with internodes between the nodes, and buds in the axils of the leaves, while roots have no leaves, nodes, or axillary buds. **Bulbs:** Onions, lilies, and tulips have swollen underground stems that are really large buds with adventitious roots at the base. Most of a bulb consists of fleshy leaves attached to a small, knoblike stem. **Corms:** Crocuses, gladioluses, and other popular garden plants produce corms that superficially resemble bulbs. Cutting a corm in half, however, reveals no fleshy leaves. Instead, almost all of a corm consists of a stem, with a few papery, brown non-functional leaves on the outside and adventitious roots below. **Rhizomes:** Perennial grasses, ferns, irises, and many other plants produce rhizomes, which typically are horizontal stems that grow underground, often close to the surface. Each node has an inconspicuous scale-like leaf with an axillary bud; much larger photosynthetic leaves may be produced at the rhizome tip. Adventitious roots are produced throughout the length of the rhizome, mainly on the lower surface. **Runners and stolons:** Strawberry plants produce horizontal stems with long internodes, which, unlike rhizomes, usually grow along the surface of the ground. **Tubers:** In Irish potato plants, carbohydrates may accumulate at the tips of stolons, which swell, becoming tubers. **Tendrils:** Many climbing plants, such as grapes and Boston ivy, produce modified stems knows as tendrils, which twine around supports and aid in climbing.	

4.12

Humans use stems in many ways

Since ancient times, stems of both woody and non-woody plants have been useful to people in many ways. These include the production of paper, cork, bamboo building materials (figure 4.2), lumber, fuel (wood), medicines, furniture and other products.

Paper

Paper has been used to transmit information in written form for thousands of years since its invention in China. Egyptians used papyrus to make rafts, sails, cloth, mats and cord. To make paper, they peeled the outer layers of papyrus stems off, exposing the inner tissue (pith). Today, most paper is made from wood pulp generated from trees grown in plantations.

Cork

Cork or corkwood consists of the outer bark of the tree, which can be harvested without injury to the tree. It is renewed annually. Harvesting consists of making vertical and horizontal cuts with hatchets or saws, and then prying off large pieces of the bark. The rich dark-red colour of the exposed areas is one of the typical sights in a cork forest that is being used for commercial purposes. The stripping is usually done in mid-summer when weather conditions are favourable. A great variety of products are manufactured from cork. Sometimes the natural cork is utilised; in other cases a composition cork is utilised which is made up of coarse or finely ground pieces treated with adhesives and then moulded.

Lumber

Lumber from wood has been in use for building and construction purposes since early times. The word “lumber” refers to wood that has been prepared to some extent for future use. The larger pieces of lumber that are used in heavy construction are often called “timber”.

Bamboo

The tall tropical grass known as bamboo has strong, resilient stems that have many uses. The use of bamboo in building costs half as much as other basic construction materials, allows assembly in as little as three weeks, and yields buildings predicted to survive at least 50 years.

Figure 4.2. Forest in Taiwan dominated by bamboo (https://commons.wikimedia.org/wiki/File:Bamboo_forest,_Taiwan.jpg)

Wood (Fuel)

Wood is used in so many ways that it is impossible to discuss all of it in detail. In many countries there is a great deal more wood cut each year than is replaced by normal growth, which does not bode well for a continuous supply in the future. Fuel is an indispensable necessity of life both in the home and in industry. Any material that burns readily in air can be utilised, but this includes a great variety of plant products.

4.13	**Activity 4.2** **Do this activity and add it to your portfolio.** Refer to your textbook and answer the following questions: a) What are the roles of the stem in a plant? b) What is the role of the cork cambium? c) Name and describe five modified stems. d) Having studied this section, do you think people should carry on using stems for various reasons? If so, why? e) What thoughts come to you when you come across people harvesting trees, and why?	
4.14	**Feedback on activity 4.2** a) By now you should know that the stem supports the leaves, flowers and fruits and connects them with the roots. Secondly, it conducts water, nutrients and the products of photosynthesis to and from roots and leaves. Also, it helps store water. Young green stem also perform a minor role in the production of food through the process of photosynthesis, but in some species (e.g. cactus) the stem is the chief photosynthesising organ. b) Cork cambium is mainly responsible for secondary growth that replaces the epidermis. You could have provided more than five modified stems. c) This is based on your opinion that should be strongly supported by the literature. In other words, your opinion must make sense in terms of the knowledge we have in botany. d) The same applies to this question. Make sure your opinion is based on what we know from the experts in botany.	

4.15

As photosynthetic organs, leaves occur in a vast range of forms

A typical leaf of a dicotyledonous plant consists of two main parts: the **blade** and the **petiole**. The blade is thin and expanded, and is supported by a network of veins, while the petiole is slender and connects the leaf to the stem. The leaf blade varies greatly in shape and there are numerous terms to describe its general shape. These terms include apex, base, margin and veins. The leaf blade has two types of configuration. It may be in one unit, in which case the leaf is called a **simple leaf** (figure 4.3. A), or it may be divided into numerous small parts that look like individual leaves and which form a **compound leaf** (figure 4.3. B). It may be difficult to tell whether one is looking at a simple leaf or the **leaflet** (**pinna**) of a compound leaf. The distinction can be made by the fact that a leaf (simple or compound) has an axial bud between the petiole and the stem.

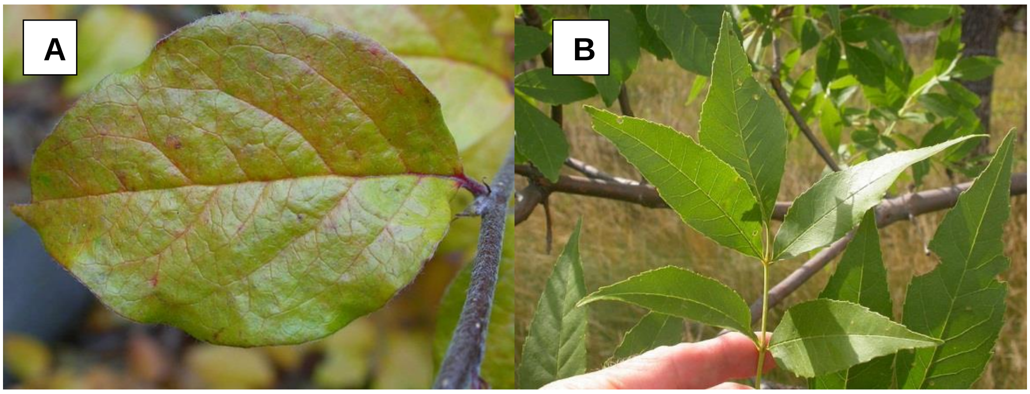

Figure 4.3. (A) Simple alternative leaf bears stipules and **(B)** the compound leaves has leaflets with uniformly serrate margins.

(https://commons.wikimedia.org/wiki/File:Cotoneaster_lucidus_(5071620787).jpg; https://commons.wikimedia.org/wiki/File:Fraxinus_pennsylvanica_(5107489733).jpg)

The petiole of a leaf may vary considerably and can be long, short, rounded or flat. Some leaves have no petioles in which case they are said to be sessile. At the base of the petiole in many leaves are small leaf-like structures called stipules, e.g. in peas, beans and roses. Between the petiole and the stem is a bud of a potential branch (an axial bud). Leaves may be arranged on the stem in a variety of ways. The place on the stem from where the leaves grow is called a **node** and the part between the nodes is the internode. If only one leaf arises at a node, the leaves are said to be **alternate**, if there are two leaves they are **opposite** and if there are more than two they are **whorled**. If you have access to the internet, you can follow this link https://www.youtube.com/watch?v=nnjh0H6ThFc and improve your understanding of leaf arrangements.

Some plants and trees are monocotyledonous, e.g. bamboo, bananas and palms. The leaves of these plants do not have petioles like typical dicotyledonous leaves. Instead, their leaves consist of a sheath and a blade. The **sheath** is often nearly as large as the blade and completely surrounds the stem, sometimes extending over the length of the internode. The leaf blade is characterised by **parallel venation**. It is often necessary to examine the blade carefully to see that the veins are indeed parallel. Pines, cedars, spruces and yellowwoods, which belong to the group Coniferophyta or the conifers, are the largest group of gymnosperms (naked-seeded plants) and have various leaf types. Pine trees (family Pinaceae) have needle-like leaves which are grouped together in fascicles and grow from a short branch which grow no longer than one node.

4.16

The major tissues of leaves: epidermis, mesophyll, xylem and phloem

Cut out a little section of a leaf. Cut it all the way through. There are many different types of cells, specialised to do different things - all for the good of the tree, of course. On the top and bottom are the cuticle layer and the epidermal cells. In the middle, between the epidermis cells on the top and bottom, are the mesophyll cells where the chloroplasts live.

Let us first look at **epidermis** and **cuticle.** These words sound suspiciously like we are talking about the skin. As must be obvious to you, they do indeed act a lot like skin. The epidermis cells on our leaf have stiff cell walls (which our skin does not). They protect the leaf, help support it and give it shape, and they keep the moisture inside. Plants cannot perform photosynthesis if all their water evaporates away. The cuticle is a hard, waxy, water-tight material. It is the reason water beads up so nicely on most leaves. Cuticle thickness is different in different plant species. It is usually thickest in plants that live in deserts and semi-arid climates. Why do you suppose that is? The cuticle is made from a material secreted by epidermis cells.

Mesophyll cells: Photosynthesis happens in chloroplasts, and chloroplasts are in mesophyll cells. There can be 1 to 50 or more chloroplasts in a single mesophyll cell. The number varies with the plant species, age, and health of the cell. The closely packed cells right under the top epidermis are in the palisade parenchyma region. The cells in this area generally have the most chloroplasts. The palisade region is photosynthesis-central, where most carbohydrate-making takes place. There are small tight air spaces around these cells. In the other region, called the spongy parenchyma region the cells seem more loosely placed and irregularly shaped. The air spaces here are large and spacious.

The little round flat pillow or pancake-shaped things are called **thylakoids**. A stack of them is called a **granum**. Two or more stacks are called **grana**. There can be from 2 to around 100 thylakoids in one granum. The little tube-like strands connecting thylakoids from granum to granum are called **stroma lamellae** (figure 4.4).

The vascular bundles (**xylem** and **phloem**) form the midrib and veins of the leaf. A dicotyledon leaf has a branching network of veins that get smaller as they branch away from the midrib. Within each vein, the xylem can be seen on top of the phloem. Xylem is used to transport water and minerals from roots to leaves. It consists of tubes for water, fibres for support, and living parenchyma cells. Phloem, on the other hand, functions to conducts dissolved sugars and other photosynthate from the leaf tissues. Phloem is made of sieve tube elements and companion cells.

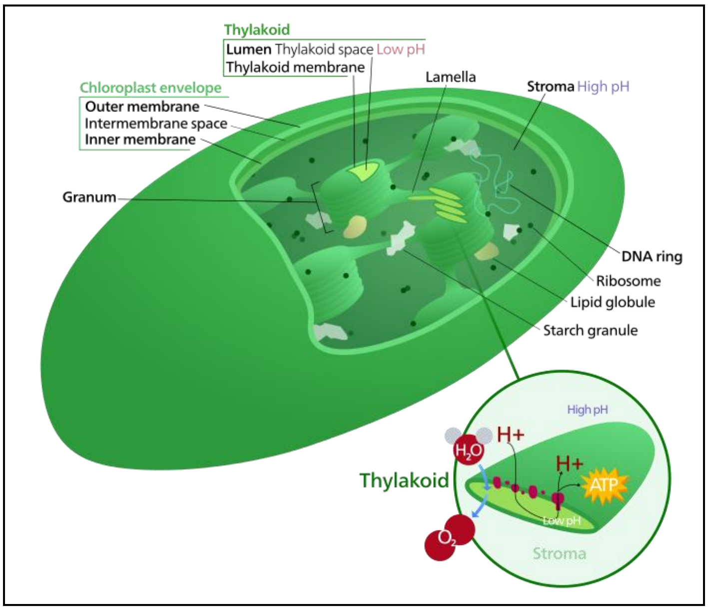

Figure 4.4. Chloroplast showing almost all the organelles found in it.

(https://upload.wikimedia.org/wikipedia/commons/thumb/c/c5/Chloroplast_%28borderless_version%29-en.svg/701px-Chloroplast_%28borderless_version%29-en.svg.png)

4.17	**Plants lose large quantities of water through transpiration** In most plants, leaves are the main place where food is made. In order to do this, there has to be a way to move the water and minerals to the leaf cells doing photosynthesis, and a way to carry the food to other parts of the plant. A lot of water has to be delivered because most of it is lost by evaporation through the stomas. Other plants, like the thorny cacti that tend to live in extremely dry climates, have adapted by always closing the openings during the hot day time to reduce transpiration and water loss. At night when it is cooler, the stomas are opened and gaseous exchange takes place with less water loss.	
4.18	**Leaves perform many functions in addition to photosynthesis** Not all leaves function as photosynthetic organs. Depending on various factors, leaves undergo extensive modifications in structure to perform other functions that are not usually executed by leaves. A brief description of a few modified leaves follows. **Floral leaves (bracts):** Poinsettias and dogwoods have relatively inconspicuous, small, greenish-yellow flowers. However, both plants produce large modified leaves, called bracts (mostly coloured red in poinsettias and white or pink in dogwoods). These bracts surround the true flowers and perform the same function as showy petals. It should be noted, however, that bracts can also be quite small and not as conspicuous as those of the examples mentioned. **Spines:** The leaves of many cacti, barberries, and other plants are modified as spines. In the case of cacti, the reduction of leaf surface reduces water loss and also may deter predators. Spines should not be confused with thorns, which are modified stems, or with the prickles on raspberries and rose bushes, which are simply outgrowths from the epidermis or the cortex just beneath it. **Reproductive leaves:** Several plants produce tiny but complete plantlets along their margins. Each plantlet, when separated from the leaf, is capable of growing independently into a full-sized plant. **Shade leaves:** Leaves produced where they receive significant amounts of shade tend to be larger in surface area, but thinner and with less mesophyll than leaves on the same tree receiving more direct light. This plasticity in development is remarkable, as both types of leaves on the plant have exactly the same genes. **Insectivorous leaves:** Almost 200 species of flowering plants are known to have leaves that trap insects, with some digesting their soft parts. Plants with insectivorous leaves often grow in acid swamps deficient in needed elements, or containing elements in forms not readily available to the plants; this inhibits the plants' capacity to maintain metabolic processes sufficient to meet their growth requirements. Their needs are, however, met by the supplementary absorption of nutrients from the animal kingdom.	
4.19	**Humans use leaves in many ways** There are many befits leaves have for humans. We use leaves for food, for example lettuce and herbs, tobacco, or for medical purposes (such as fever, malaria and menstrual pain). Tea, for example, is made from leaves of many plant species. And the leaves of some plants are used in the manufacture of perfumes. Natural dyes and fibres can also be obtained from the leaves.	

4.20	**Activity 4.3** **Do this activity and add it to your portfolio.** Refer to your textbook and answer the following questions: a) Try to find at least three different leaves and draw a picture of each one. (You can look at leaves that are on the ground or ones that are still attached to their trees.) As you are drawing, you might want to think about these questions: • Where did you find these leaves? • How would you describe this leaf? • Are parts of your leaf pointy? • Are parts of your leaf smooth? • Can you find the tree that this leaf came from? What kind of tree do you think it is? • How are the leaves on the ground different from the leaves that are still in the tree? When you are finished, look at all of your pictures. What are the similarities and differences? b) Why do you think leaves are so important to the plant? c) Do you think plants can exist without leaves at all? If so, why? d) Describe three types of modified leaves. e) Mention the role played by the epidermis and the cuticle on the leave surface.	
4.21	**Feedback on activity 4.3** a) I encourage you to go beyond three types of leaves – you will have more fun learning about the different leaves and get a better understanding of the different types of leaves. b) Leaves are the powerhouse of plants. In most plants, leaves are the major site of food production for the plant. Structures within a leaf convert the energy in sunlight into chemical energy that the plant can use as food. Chlorophyll is the molecule in leaves that uses the energy in sunlight to turn water (H_2O) and carbon dioxide gas (CO_2) into sugar and oxygen gas (O_2). This process is called photosynthesis. Moreover, photosynthesis is vital to the plant as it generates sugar that forms part of plant nutrients. c) Remember, there is no wrong answer to this question, simply because there are plants with leaves and there are plants that rely on their stems for photosynthesis. It is thus important that you substantiate your answer with good reasons. d) Describe any three of these modified leaves: floral leaves (bracts), spines, reproductive leaves, shade leaves and insectivorous leaves e) Just like our skin helps protect us, leaves have an outer layer that protects them. This outermost layer is called the cuticle. It is generally waxy to protect the leaf and prevent water loss. When you touch a leaf, you may feel this waxy coating, and on some plants, you may actually be able to see the waxy coat shine a bit. Below the cuticle is the epidermis. On the top of the leaf, this is known as the upper epidermis. This is a single layer of cells found directly below the cuticle. It helps protect the leaf by aiding in preventing water loss and providing an extra layer between the outside and inside of the leaf.	

4.22 Summary

Taproots: The primary root grows long and thick, while the secondary roots stay small. Fibrous roots: These are secondary roots that grow and branch out. Roots have two main functions: anchor a plant in the ground and to absorb water and dissolved nutrients from the soil. Some plants have modified roots, adapted for photosynthesis, food or water storage, structural support, or parasitism. At the tip of any root there are four distinct regions or zones: Root cap, zone of cell division, zone of cell elongation, and zone of maturation. Vascular tissue in a non-woody root is organised into a stele; the pattern of xylem and phloem in the stele varies in monocot and dicot roots. The stele is surrounded by a cortex and an outer layer of epidermis. Extending from the epidermal cells are root hairs through which most of the water and minerals that enter a root are absorbed.

Stems support leaves to maximise light absorption and are part of the conduit for the transport of water, minerals, and organic solutes. Leaves are the main photosynthetic structures in most plants. Unlike roots, the vascular tissue in both stems and leaves is organised into vascular bundles. In stems of herbaceous dicots, the vascular bundles are arranged in a ring around a pith; in monocots, the vascular bundles are scattered. In woody dicots, the discrete vascular bundles are replaced by continuous rings of xylem that correspond to the xylem produced during a single growing season. Humans use stems for many purposes, such as for wood products, food, textiles, dyes, medicines, chemicals, and fuel.

A leaf may have three parts: the blade, the petiole, and a pair of stipules. If the blade is undivided, the leaf is said to be simple; if the blade is divided into separate leaflets, the leaf is compound. According to the pattern of the leaflets, compound leaves may be pinnately or palmately compound. Leaf venation patterns are either parallel (most monocots) or net (most dicots). The entire leaf surface is covered by the epidermis; the epidermis secretes a waxy layer, the cuticle. Guard cells are found in the leaf epidermis. They regulate the entry and exit of gases through the stomata. The mesophyll of the leaf is composed of photosynthetic parenchyma cells, palisade and spongy cells.

Learning unit 5 Secondary growth in plants

Contents

5.1 Introduction

To complete the learning unit, you will need to refer to pages 165–181 of chapter 8 in Graham et al (2014).

Today, plant cloning is a widespread, standard technique for producing ornamentals and other plant crops. Plant cloning requires an in-depth understanding of how adult bodies grow and develop from single cells, including the processes that generate specialised cells, tissues, and organs. This learning unit will introduce growth phenomena and provide a discussion of the distinctions among growth, differentiation, and development. Knowledge of the plant structure and its development also helps us understand the great variation in plant forms that we see in nature.

5.2 Learning outcomes

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

- discuss the manner in which lateral meristems give rise to secondary tissue
- tabulate the origins, structures, cell division and functions of the different lateral meristems
- explain the functions of secondary tissues
- discuss the relationship between the structure, appearance and functions of secondary tissues
- explain the various terms relating to lateral meristems and secondary tissue
- state the types of secondary tissue formed during various seasons and explain why the tissues differ in different seasons

5.3 Plant structural variation is ecologically and economically important

You might have realised that different kinds of plants that now occur on earth vary greatly in size and shape. Of course, both size and shape of plants are determined by the growth of the plant. In biology, growth is always associated with cells. Hence, growth may be defined as an irreversible increase in mass due to cell division and enlargement of cells, and may also be applied to an organism as a whole or to any of its parts. Many plants, such as radishes and pumpkins, go through a sequence of growth stages. They grow very rapidly at first, then for a while they show little, if any, increase in volume, and eventually, they stop growing completely. Finally, tissues break down, and the plant dies. Such growth is regarded as determinate. Parts of other plants may exhibit indeterminate growth and continue to be active for many years. All living organisms begin as a single cell and increase in mass through cell division and enlargement until a body consisting of possibly billions of cells is formed. Once cells have fully enlarged, differentiation occurs; that is, the cells develop different forms adapted to specific functions, such as to the conduction, support, or secretion of special substances.

Redwoods, duckweeds, and other plants also vary in the number of arrangements of their organs, such as leaves, roots, and stems. These differences arise from variations in body development. Development is the process by which a few or single-celled reproductive structures are transformed into a multicellular adult body by means of growth and cell specialisation.

5.4 Plant bodies are composed of organs, tissues, and many types of cells

Plant bodies, like those of animals, are organised from smaller components: organ systems composed of one or more types of organs, organs composed of one or more types of tissues, and tissues composed of one or more types of cells. Here we will describe the major plant organ systems and organs, as well as examples of plant tissues and specialised cells.

A plant has two organ systems: the **shoot system** and the **root system**. The shoot system is found above ground and includes the organs such as leaves, buds, stems, flowers (if the plant has any), and fruits (if the plant has any). The root system includes those parts of the plant below ground, such as the roots, tubers, and rhizomes. Plant cells are formed at meristems, and then develop into cell types which are grouped into tissues. Plants have only three tissue types: **dermal, ground** and **vascular tissue**. Dermal tissue covers the outer surface of herbaceous plants. Dermal tissue is composed of epidermal cells, which are closely packed cells that secrete a waxy cuticle that aids in the prevention of water loss. The ground tissue comprises the bulk of the primary plant body. **Parenchyma, collenchyma,** and **sclerenchyma cells** are common in the ground tissue. Vascular tissue transports food, water, hormones and minerals within the plant. Vascular tissue includes xylem, phloem, parenchyma, and cambium cells. Plant cell types arise by means of mitosis from a meristem. A meristem may be defined as a region of localised mitosis. Meristems may be at the tip of the shoot or root (a type known as the apical meristem) or lateral, occurring in cylinders extending nearly the length of the plant. A cambium is a lateral meristem that produces (usually) secondary growth. Secondary growth produces both wood and cork (although from separate secondary meristems).

As a generalised plant cell type, parenchyma cells are alive at maturity. They function in storage, photosynthesis, and as the bulk of ground and vascular tissues. Palisade parenchyma cells are elongated cells located in many leaves just below the epidermal tissue. Spongy mesophyll cells occur below the one or two layers of palisade cells. Ray parenchyma cells occur in wood rays, the structures that transport materials laterally within a woody stem. Parenchyma cells also occur within the xylem and phloem of vascular bundles. The largest parenchyma cells occur in the pith region, often, as in corn (*Zea*) stems, being larger than the vascular bundles. In many prepared slides they stain green. Collenchyma cells support the plant. These cells are characterised by thickenings of the wall; they are alive at maturity. They tend to occur as part of vascular bundles or on the corners of angular stems. In many prepared slides they stain red. Sclerenchyma cells support the plant. They often occur as bundle cap fibers. Sclerenchyma cells are characterised by thickenings in their secondary walls. They are dead at maturity. They, like collenchyma, stain red in many commonly used prepared slides. A common type of sclerenchyma cell is the fiber. **Xylem** is a term applied to woody (lignin-impregnated) walls of certain cells of plants (figure 5.1A). Xylem cells tend to conduct water and minerals from roots to leaves. While parenchyma cells do occur within what is commonly termed the "xylem" the more identifiable cells, **tracheids** and **vessel elements**, tend to stain red with Safranin-O. Tracheids are the more primitive of the two cell types, occurring in the earliest vascular plants. Tracheids are long and tapered, with angled end-plates that connect cell to cell. Vessel elements are shorter, much wider, and lack end plates. They occur only in angiosperms, the most recently evolved large group of plants.

Tracheids, longer and narrower than most vessels, appear first in the fossil record. Vessels occur later. Tracheids have obliquely-angled end walls cut across by bars. The evolutionary trend in vessels is for shorter cells, with no bars on the end walls**. Phloem cells** conduct food from the leaves to the rest of the plant (figure 5.1B). They are alive at maturity and tend to stain green (with the stain fast green). Phloem cells are usually located outside the xylem.

The two most common cells in the phloem are the companion cells and sieve cells. Companion cells retain their nucleus and control the adjacent sieve cells. Dissolved food, as sucrose, flows through the sieve cells. The epidermal tissue functions in the prevention of water loss and acts as a barrier to fungi and other invaders. Thus, epidermal cells are closely packed, with little intercellular space. To further cut down on water loss, many plants have a **waxy cuticle** layer deposited on top of the epidermal cells. To facilitate gaseous exchange between the inner parts of leaves, stems, and fruits, plants have a series of openings known as stomata (singular stoma). Obviously these openings would allow gas exchange, but at a cost of water loss. Guard cells are bean-shaped cells covering the stomata opening. They regulate the exchange of water vapour, oxygen and carbon dioxide through the stoma. If you wish to deepen your understanding of these plant organs, you can visit the following website: https://www.youtube.com/watch?v=L1uOwaaguL8.

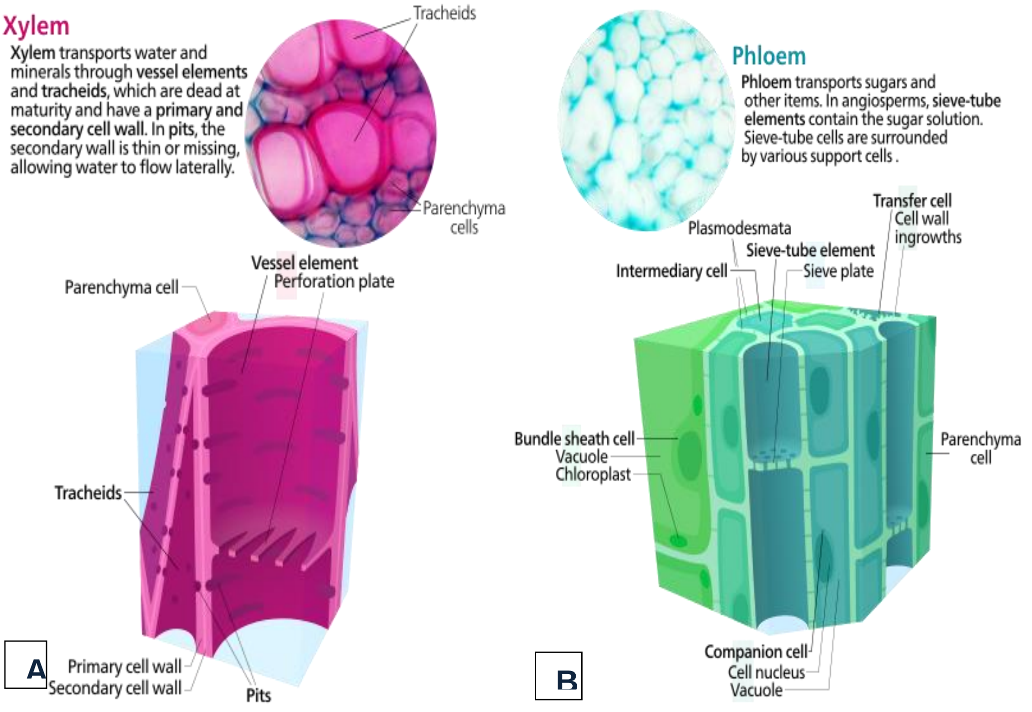

Figure 5.1. (A) Diagram of xylem tissues in plants and **(B)** diagram of xylem tissues in plants. (https://commons.wikimedia.org/wiki/File:Xylem_cells.svg#/media/File:Xylem_cells.svg https://commons.wikimedia.org/wiki/File:Xylem_cells.svg#/media/File:Phloem_cells.svg)

5.5

Plants develop from single cells or small pieces

Plant development is an amazing phenomenon. Cell division in meristems, by increasing the cell number, increases the potential for growth. However, it is cell expansion that accounts for the actual increase in plant mass. Together, these processes contribute to plant form. The plane (direction) of cell division is an important determinant of plant form. If the planes of division by a single cell and its descendants are parallel to the plane of the first cell division, a single file of cells will be produced. If the planes of cell division of the descendent cells are random, an unorganised clump of cells will result. While mitosis results in a symmetrical redistribution of chromosomes between daughter cells, cytokinesis does not have to be symmetrical. Asymmetrical cell division, in which one cell receives more cytoplasm than the other, is common in plants cells and usually signals a key developmental event. For example, this is how guard cells form from an unspecialised epidermal cell.

5.6

Activity 5.1

Do this activity and add it to your portfolio.

Refer to your textbook and answer the following questions:

(a) List the three basic plant organs.

(b) How are the above organs arranged into the above-ground and below-ground plant systems?

(c) Plants may produce variety of meristems over the course of its life. What is a meristem?

(d) If you remove a terminal bud from a stem, will growth in length stop altogether? Explain.

(e) Describe a different means of cell growth available to plant cells but not to animal cells.

5.7

Feedback on activity 5.1

To answer all the above questions, you will need to study all the sections in this learning unit with reference to the prescribed book.

5.8 Summary

Plants have multicellular bodies that vary structurally in many ways that adapt them to different environmental conditions. Plants grow by addition and enlargement of new cells. Plant development is very important to plant as it helps in transforming single reproductive cells or small pieces of plants into multicellular bodies containing many types of specialised cells, tissues, and organs. Leaves, stems and roots are basic plant organs. Plant growth and body form is a function of the cell division activity of primary apical meristems and often also secondary meristems, cell enlargement after division, and the types of specialised cells that develop by differentiation. Meristems are localised regions of cell division activity.

Learning unit 6	**Reproduction, meiosis, and life cycles** Contents 	
6.1	**Introduction** Like all other organisms, plants reproduce. You already might have assumed that plant production is more varied and complex than human reproduction, which is the case. Unlike humans, who reproduce only sexually and by one method of sexual reproduction, plants have a variety of ways of reproducing both asexually and sexually. As you know, asexual reproduction involves only one parent and produces offspring that are genetically identical to the parent, whilst in sexual reproduction, the genetic material of two parents combines to produce offspring that are a genetic combination of both parents. In this unit we shall take a closer look at sexual and asexual reproduction in plants.	

6.2	**Learning outcomes** By the end of this learning unit you should be able to • relate the process of mitosis to the reproduction of plants • compare the phases of meiosis with those of mitosis • discuss the importance of meiosis in the formation of spores • distinguish the sporophyte generation from the gametophyte generation with regard to the structures and functions of each • define terms and concepts pertaining to the alternation of generations • relate the structures of cones and flowers to the formation of spores and gametes • distinguish between the different types of flowers • identify the parts of seeds and discuss the origin and functions of each part • relate seed germination to the structure of the sporophyte in gymnosperms and angiosperms • explain the origin and structures of different types of fruit • relate the structure of seeds and fruit to the dispersal mechanisms of different types of seeds	
6.3	**Sexual and asexual reproduction** Reproduction can be described in terms of life cycles. A life cycle of a species is a sequence of stages leading from the adults of one generation to the adults of the next generation. A life cycle can be either sexual or asexual. Keep in mind that nearly all plants undergo sexual reproduction, which in flowering and cone-bearing plants ultimately results in the formation of seeds. Yet other organisms, including many plants, reproduce by both sexual and asexual means.	
6.3.1	**Sexual reproduction accelerates adaptation** When male and female gametes fuse together they form a zygote through the process known as sexual reproduction. Sperm and eggs are male and female gametes respectively. In seedless plants, sperm have flagella, which enable the sperm to swim and reach the egg. Sexual reproduction involves some risk because egg cells or sperm cells can be damaged or destroyed, preventing fertilisation from taking place. The major disadvantage of sexual reproduction is that it is expensive, since sex requires organisms to invest scarce resources and expend considerable energy to produce gametes, accomplish mating, and undergo meiosis. Given these considerations, why does sexual reproduction occur? Apparently the genetic diversity generated by sexual reproduction provides a tremendous selective advantage to many organisms. If offspring have genetic variability, the species has an increased potential of colonising a new type of environment or surviving in a particular environment, especially if some parameter of that environment is changing. Compared to asexual reproduction, sexual reproduction also speeds up the loss of deleterious genes and allows potentially beneficial genes to escape the influences of inhibitory genes that had held them in check before.	
6.3.2	**Asexual reproduction can occur rapidly** Asexual reproduction, also known as vegetative reproduction, involves one parent, and the offspring are genetically identical to the single parent. Such offspring are often called clones of the parent. Through asexual reproduction, a plant that is well adapted to a stable environment can quickly produce offspring that will be equally successful in that environment. Asexual reproduction often requires fewer resources and less energy than sexual reproduction, and therefore can be accomplished more quickly and efficiently. Moreover, asexual organisms do not expose themselves to the risk of gametes not finding mates. Another advantage of asexual reproduction is that it requires only one parent. In addition, asexual reproduction may be more effective than sexual reproduction in harsh environments. In such habitats there may be too few pollinators (animal) to transfer the pollen among flowering plants or too little water to allow the sperm of seedless plants to swim to the eggs.	

6.3.3

Many organisms that reproduce only asexually evolved from sexually reproducing ancestors

There are many examples of protists, fungi and plants of which the closest relatives reproduce by both sexual and asexual means but are thought to have lost the ability to reproduce sexually through the evolutionary process. Such organisms now depend on asexual reproduction. For example, fungi reproduce by asexual spores. Also *Elodea* relies on asexual reproduction.

6.3.4

Many organisms reproduce by both asexual and sexual means

The relative advantages of both sexual and asexual reproduction are illustrated by a wide variety of organisms that are able to reproduce both sexually and asexually. This ability is often important in agriculture. Among plants there are examples of species that reproduce by asexual and sexual means. Aspen trees often form large groves of hundreds of individuals that are genetically alike because they have been generated by asexual reproduction by developing young sapling shoots from the horizontally growing roots of parent trees. Yet aspens also produce seeds by sexual means. Also, many grasses produce huge spreading populations from underground, horizontal stems as well as by seeds.

6.3.5

Activity 6.1

Do this activity and add it to your portfolio.

Refer to your textbook and answer the following questions:

a) How does asexual reproduction differ from sexual reproduction?

b) Name some methods of asexual reproduction in plants. Briefly explain each method.

c) What might be some reasons why plants reproduce both sexually and asexually?

6.3.6

Feedback on activity 6.1

a) Examine the following when answering this question: number of organisms involved, cell division, types, advantages and disadvantages, unit of reproduction, time taken, energy invested and number of offspring. In the final analysis, in terms of number of organisms, one may say that asexual reproduction requires only one parent whilst sexual reproduction requires two parents.

b) Make sure that you list and describe the following: budding, vegetative reproduction, fragmentation and spore formation.

c) It enables plants to have offspring with genetic variation, and this will allow them to survive in a variety of changing and unchanging environments; asexual reproduction allows a rapid production of offspring.

6.4

Meiosis is essential to sexual reproduction

Meiosis is a cell division process that is associated with sexual reproduction, but not with asexual reproduction. Let us consider what happens when two gametes fuse during sexual mating, a process known as **syngamy** or fertilisation. Cytoplasm of the two cells combines, and the nuclei of the two cells also fuse together. The zygote that formed from syngamy is a single cell having cytoplasmic components and nuclear chromosomes contributed by both parents. It is no surprise that mating usually takes place between individual organisms of the same species that have the same number of chromosomes in their nuclei. Thus, fusing gametes usually have an equal number of chromosomes. The basic number of chromosomes present in mates is known as n – the **haploid** chromosome number. The value of n varies greatly among organisms. For example, in one plant n may be equal to 2, yet in some plants n can be greater than 500, whereas for humans it is always at 23. Because zygote nuclei contain all the chromosomes contributed by each gamete, a zygote's chromosome number is 2n – the **diploid** chromosome number (46 for humans). Therefore, if the zygote grows into an adult organism by means of mitosis, as is the case for animal and plants, each adult cell nucleus will contain 2n chromosomes. For most people, body cell nuclei contain chromosomes, with the exception of gametes, which contain only 23 chromosomes. Imagine what would happen if adult organisms with a 2n chromosome number produced gametes also having 2n chromosomes. Imagine then that such 2n gametes fuse. The zygote formed from this mating would have 4n chromosomes! Obviously this will be disastrous as many generations later, cell nuclei would include immense numbers of chromosomes – too many for cells to separate evenly during mitosis. Therefore meiosis plays a pivotal role as it prevents chromosome build-up resulting from sexual reproduction by reducing the chromosome number in a cell by one half at some point prior to gamete production. Meiosis has another critical function in sexual reproduction as it shuffles and recombines the genetic information contained in the chromosomes contributed by each parent.

6.5

Meiosis resembles mitosis in some respects, but differs in important ways

If one should be able to compare meiosis and mitosis, one will be able to understand how different organisms reproduce. Mitosis occurs in shoot and root tips, and other meristematic plant tissues and therefore is associated with growth. On the other hand, meiosis occurs in flower parts or other tissues that are involved in sexual reproduction. One may ask how meiosis and mitosis differ as you now know, meiosis and mitosis occur in different plant tissues, and they are associated with sexual and asexual reproduction, respectively. At the cell level there are additional important differences. Most importantly, meiosis is a double division process involving two sequences of: prophase →metaphase →anaphase →telophase →cytokinesis. If you have access to the internet, you can follow this link https://www.youtube.com/watch?v=OGX8Bn7Kjjc so that you may be able to observe how meiosis and mitosis differ. I also summarised the different phases of the meiosis and mitosis in the table below:

Table 6.1 Difference between meiosis and mitosis

	Meiosis	**Mitosis**
Type of reproduction	Sexual	Asexual
Occurs in	Humans, animals, plants, fungi	All organisms
Genetically	Different	Identical
Crossing over	Yes, mixing of chromosomes can occur	No, crossing over cannot occur
Definition	A type of cellular reproduction in which the number of chromosomes are reduced by half through the separation of homologous chromosomes, producing two haploid cells	A process of asexual reproduction in which the cell divides in two, producing a replica with an equal number of chromosomes in each resulting diploid cell
Pairing of homologues	Yes	No
Function	Genetic diversity through sexual reproduction	Cellular reproduction and general growth and repair of the body
Number of divisions	2	1
Number of daughter cells produced	4 haploid cells	2 diploid cells
Chromosome number	Reduced by half	Remains the same
Steps	(Meiosis 1) prophase I, metaphase I, anaphase I, telophase I; (meiosis 2) prophase II, metaphase II, anaphase II and telophase II	Prophase, metaphase, anaphase, telophase
Karyokinesis	Occurs in interphase I	Occurs in interphase
Cytokinesis	Occurs in telophase I and in telophase II	Occurs in telophase
Centromeres split	The centromeres do not separate during anaphase I, but during anaphase II	The centromeres split during anaphase
Creates	Sex cells only: female egg cells or male sperm cells	Makes everything other than sex cells

6.6 Life cycles link one generation to the next

Asexual organisms typically have very simple life cycles. They produce genetically identical reproductive structures, such as the zoospores produced by aquatic algae and fungi. Mitosis is the only division process involved in asexual reproduction (figure 6.1). Contrary to asexual reproduction, sexually reproducing organism have more complex life cycles involving haploid and diploid stages and specialised reproductive cells, being gametes, zygotes and sexual spores. There are three basic types of sexual life cycles: gametic, zygotic and sporic. Life cycles differ among organisms in the point at which meiosis occurs, the relative importance of haploid versus diploid stages, and the types of reproductive cells generated by meiosis.

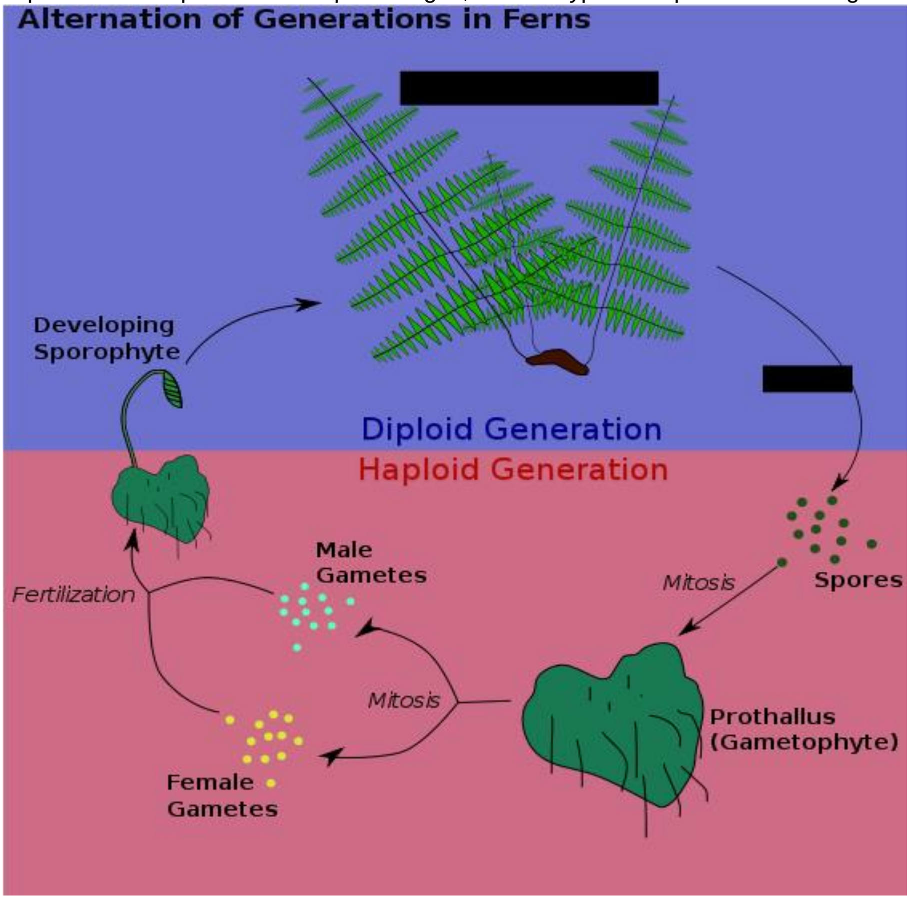

Figure 6.1. The biological concept of alternation of generations, specifically in ferns.

(https://commons.wikimedia.org/wiki/File:Alternation_of_generations_in_ferns.svg)

6.7 Activity 6.2

Do this activity and add it to your portfolio.

Refer to your textbook and answer the following questions:

a) What is the principal difference between mitosis and meiosis?

b) Describe pairing of homologous chromosomes.

c) Differentiate the three basic types of sexual life cycles.

d) What have you learnt in this learning unit that you did not know? Was it difficult to grasp some of the concepts?

6.8 Feedback on activity 6.2

a) To answer this question, you should be able to point out all the principal differences from table 6.1.

b) Homologous chromosomes: chromosomes with the same genes and in the same sequence but do not necessarily have the same allele of those genes.

6.9		

Summary

Reproduction may take place through natural vegetative propagation or by spores (asexual reproduction) or by sexual processes (sexual reproduction). In sexual reproduction, two gametes unite, forming a zygote, which is the first cell of a new individual. Sexual reproduction provides genetic variation and accelerates adaptation, whereas asexual reproduction allows organisms to reproduce very rapidly and in harsh environments that do not favour sexual reproduction. The process of meiosis ensures that gametes will have half the number of chromosomes of the zygote by reducing the number of chromosomes in cells by one half. Meiosis also usually ensures that offspring will not be identical to the parents in every aspect. Meiosis also provides the opportunity for chromosomes to exchange segments. Meiosis takes place by means of two successive divisions, each of which, like mitosis, is divided into arbitrary phases even though the process is continuous. Any cell having one set of chromosomes is said to be haploid, or to have n chromosomes; any cell having two sets of chromosomes is said to be diploid, or to have 2n chromosomes. In the life cycle of an organism that undergoes sexual reproduction, there is an alternation between a haploid phase and diploid phase. The haploid body is called a gametophyte, and the diploid part is called a sporophyte.

Learning unit 7

Biological Evolution

Contents

7.1

Introduction

To complete the learning unit, you will need to refer to pages 309–329 of chapter 15 in Graham et al (2014).

Biological evolution, simply put, is descent with modification. The term "evolution" is so closely linked to Charles Darwin that the two are almost inseparable in the public view. Perhaps this is because Darwin made a major contribution in the early development of evolutionary concepts through his theory of evolution through natural selection. As you learnt in learning unit 1, change in living things over time is referred to as evolution. Evolution is a constant feature of the universe that also applies to non-living things; however, in this learning unit it will be based on living things, plants in particular. In this learning unit, we will look at the background of evolution and also discuss evolution with a focus on plants and other photosynthetic organisms. Then we will consider the mechanisms of evolution, including natural selection. Finally, we will investigate the concept of "species" and how evolution can produce new species.

7.2	**Learning outcomes** By the end of this learning unit you should be able to • write notes on the following sources of evidence for evolution: - fossils (including index fossils) and their radiometric dating - molecular dating - biogeography, anatomy, embryology and physiology • discuss the relationship between evolution and the change in the frequency of alleles in a population over time • list the main sources of genetic variation • discuss the concept of natural selection • discuss the rate of evolution • define coevolution in a population • discuss a biological species • discuss the role of natural selection and geographical isolation in the formation of new species	

7.3

Pre-Darwinian science held that species were unchanging

Long ago, before Darwin developed the theory of evolution, natural science was greatly influenced by theology and the concept of specifically creation. According to this concept, all species were created simultaneously in their present forms and have remained unchanged to the present. Hence, variation in a species was less important. By the 18th century, however, new discoveries were beginning to challenge the idea of a static natural world. During this age the science of geology in particular made meaningful advances. Geologist found that rocks occur in distinct layers and those layers often contained **fossils**. A fossil is the Latin word for “dug up”. It became apparent that fossils were the remnant of plants that had died a long time ago (see examples of fossils in figure 7.1). At that time, a new branch of science called **palaeontology** arose and was dedicated to the study of fossils. Studies of rock layers and their fossils led to several findings. In was thus discovered that some old rock layers contained fossils of plants and animals that were extinct. This meant that no members of those species were still living on earth. In fact, there were more extinct species than living ones. In the midst of these findings, several questions were posed, for example, why were so many species created if most of them were to become extinct? French palaeontologists attempted to address the question by proposing that all species were created initially, but a series of catastrophes destroyed most of them.

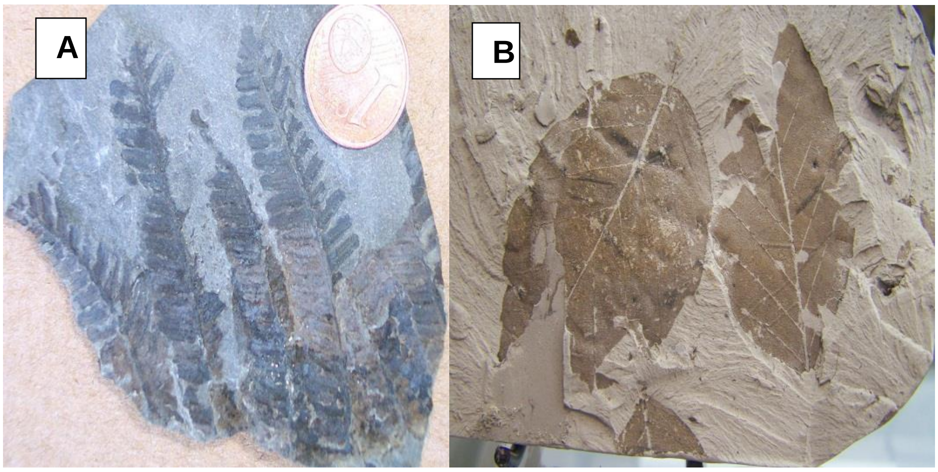

Figure 7.1. (A) Part of *Pecopteris* (form genus of fossil fronds of tree ferns) in grey siltstone of the earliest Permian and **(B)** Fossil leaves of the tree species *Fagus gussonii* from the Pliocene age.

(https://commons.wikimedia.org/wiki/File:Lower_Permian_fern_leaves.jpg; https://commons.wikimedia.org/wiki/File:Fagus_gussonii.jpg)

7.4 Some early biologists proposed species could evolve

Before Darwin, a few naturalists had proposed that species might be capable of changing with time. Very interestingly, French naturalist Georges Louis LeClerc had suggested that the original creation might have produced only a few founder species, and that modern species evolved by some natural process. Moreover, Erasmus Darwin (grandfather of Charles Darwin) proposed that species might transmute into new species. Nevertheless, the first biologist to introduce a mechanism of evolution was Jean Baptiste Lamarck. He suggested that organisms can evolve through the inheritance of acquired characteristics. In his well-known illustration, Lamarck hypothesised that ancestral giraffes had short necks, which they stretched to feed on leaves at higher levels in trees (figure 7.2). He went on to say, the giraffes that stretched the most acquired longer necks and passed them on to their offspring. Over time, this process produced the giraffe that we see today. Today, such a hypothesis seems naïve, but in the 18th century no one understood how inheritance worked. Although Lamarck's proposal was wrong, he introduced the idea that species could change by some natural process over a period of time.

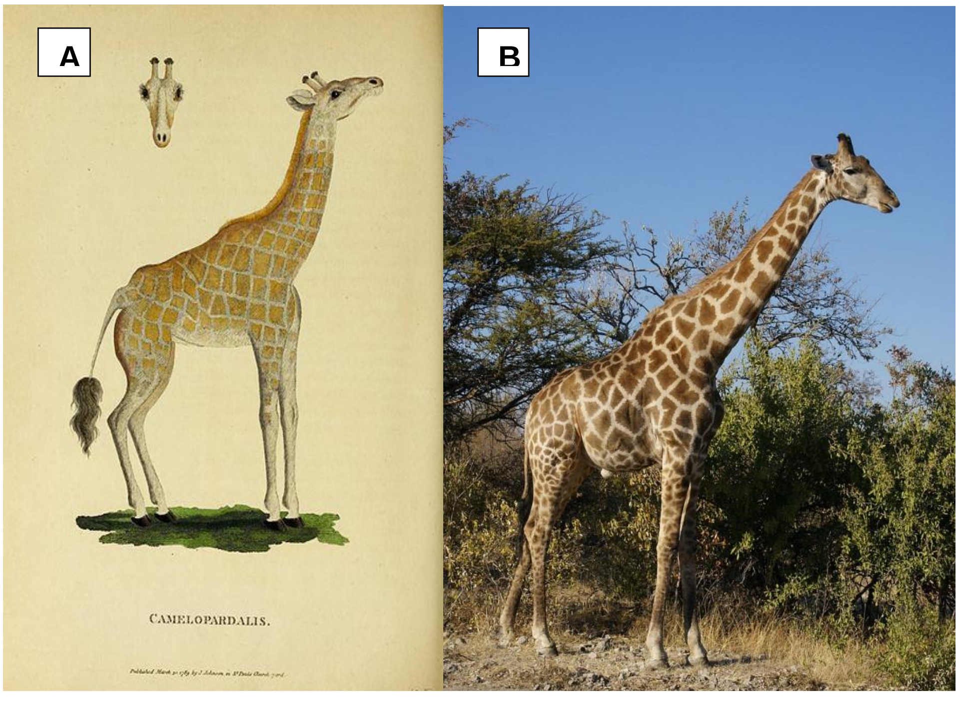

Figure 7.2. (A) Early giraffe with a short neck and **(B)** modern giraffe with long neck.

(https://commons.wikimedia.org/wiki/File:A_narrative_of_four_journeys_into_the_country_of_the_Hottentots,_and_Caffraria_(17202370493).jpg; https://commons.wikimedia.org/wiki/Giraffa_camelopardalis#/media/File:Giraffa_camelopardalis_angolensis.jpg)

7.5 During the voyage of the Beagle, Darwin made observations that revolutionised biology

What Darwin saw in his historic voyage suggested an alternative. First, the Beagle sailed along the coasts of South America, making frequent stops along the route. Darwin studied the plants, animals, fossils, and geological formations of the coastal and inland areas. In Argentina, he discovered fossil bones of large, extinct animals. When he observed a snake with rudimentary hind limbs, he noted that it marked "the passage by which nature joins the lizards to the snakes." Darwin made his most significant observations on the Galapagos islands. He observed that large groups of Galapagos plants and animals closely resembled those in nearby South America, but the entire groups of the continental organisms were absent. If the island forms were the result of special creation, why should they resemble those in South America? Why should they not be something unique? Furthermore, the plants and animals varied among different islands. The Galapagos islands were also inhabited by giant tortoises. The organisms that most astonished and confounded Darwin were the finches. The many finches on the islands differed mainly in the size and shape of their beaks, apparently to depend on different food resources. There were parrot beaks, large and small beaks, and straight beaks.

7.6	**How Darwin developed his theory of evolution by natural selection** After a remarkable voyage, the problem of the origin of species always remained in his mind. He deduced from his observations in the Galapagos islands that evolution had occurred, but he did not know how species changed over time. What was the mechanism of evolution? He was aware that plants and animals breeders practise selective breeding of domestic species to produce new varieties for agriculture. This artificial selection can produce significant changes in domesticated species in a few generations. From this knowledge Darwin concluded that because all species vary in the characteristics of their individuals, selection of some individuals and elimination of others could be the key to evolutionary changes. He also questioned the mechanism of selection in nature. Based on an essay on human population by Thomas Malthus (1798), Darwin proposed that the population of all species in nature is governed by famines, diseases, and availability of resources such as living space. Moreover, natural populations tend to remain constant over long periods. As a result, many individuals in every generation perish without reproducing. Survival of an individual depends solely on the characteristics of that individual. Thus, individuals with favourable characteristics are more likely to survive and thus to reproduce, while others that have fewer favourable characteristics are more likely to die. Whether a characteristic is favourable or not is determined by the environment. Favourable characteristics, if inheritable, then become more common in populations. These conclusions formed the basis of the theory of evolution by natural selection. Note, **natural selection** refers to the differential survival and reproduction of individuals with different inheritable characteristics; nature is thus the selective mechanism. In artificial selection, on the other hand, humans decide on the favourable characteristics they wish an organism to have.	
7.7	**Theory of evolution by natural selection** In common usage, the word “theory” refers to a guess, hunch, or idea. In scientific usage, however, a theory is a principle or a conclusion that derives from and explains a considerable group of observations and/or experiments. Darwin’s theory of evolution is not a guess but, rather, a tested principle that explains observations about species in nature. This theory or explanation can be summarised as a simple chain of logic. **Organisms produce more offspring than the environment can support**. All living things produce more individuals than can survive to maturity. Think of the thousands of acorns that one mature oak tree produces every year. A female salmon produces about 28,000,000 eggs when spawning. Darwin calculated that in elephants, which are among the slowest breeding land mammals, if all of the potential young of a single female survived and reproduced at the same rate, after 750 years the descendants of this single mother could number 19,000,000! Clearly, if all of these seeds, eggs, and young survived to become adults who also reproduced, the world would soon be overrun with oak trees, salmon, and elephants to mention just a few. **The sizes of natural populations tend to remain fairly constant over time**. A population of plants includes all the members of a single species of plant in a particular area. Over time, populations tend to vary in numbers about some fairly consistent level. The resources available in a particular area, such as food, water and living space, as well as factors including, but not limited to, disease and other populations of plant-eating herbivores, determine this consistent population level. **Competition exists among individuals**. Regardless of the rate of reproduction in a species, all of the young do not survive to become reproducing adults. This fact indicates that large numbers of offspring somehow are eliminated from the population. Some die by accident. But most of them succumb to competition with other individuals. The most intense competition may be among individuals of the same species who compete for nearly identical environmental requirements. **Variation exists among individuals within species**. Anyone who looks at their friends and relatives, or their pets, can see variation. Breeders of animals and plants use these diverse characteristics to establish new varieties of dogs, cats, pigeons, wheat, cotton, corn, and other domesticated organisms. Scientists who name and classify plants and animals are acutely aware of variation in natural populations. For example, the level of resistance to insecticides varies among individuals within species of insects. This variation enables some individuals to survive application of insecticides and produce offspring that inherit this resistance to these insecticides. **The organisms whose variations best fit them to the environment are the ones who are most likely to survive, reproduce, and pass those desirable variations on to the next generation.** Many of the natural variations we observe in species do not seem to be either particularly helpful or particularly harmful to an individual in its struggle for survival. Hair and eye colour may be such neutral variations in human beings. Some variations certainly lower the chances of survival, such as haemophilia in mammals, albinism in wild animals, or an unusually thin shell in clams living where there are numerous hungry snails.	

7.8 Evidence of evolution

A large pool of data supports the modern synthetic theory of evolution. Let us examine some of the major lines of evidence.

Artificial selection

Long before Darwin and Wallace, farmers and breeders were using the idea of selection to cause major changes in the features of their plants and animals over the course of decades. Farmers and breeders allowed only the plants and animals with desirable characteristics to reproduce, thereby causing the evolution of farm stock. This process is called artificial selection because people (instead of nature) select which organisms get to reproduce.

Change in protein and DNA trace evolutionary changes

All living things are fundamentally alike. At the cellular and molecular level living things are remarkably similar to each other. These fundamental similarities are most easily explained by evolutionary theory: life shares a common ancestor. All organisms are made of cells, which consist of membranes filled with water containing genetic material, proteins, lipids, carbohydrates, salts and other substances. The cells of most living things use sugar for fuel while producing proteins as building blocks and messengers. Different species share genetic homologies as well as anatomical ones. Roundworms, for example, share 25% of their genes with humans. These genes are slightly different in each species, but their striking similarities nevertheless reveal their common ancestry. In fact, the DNA code itself is a homology that links all life on Earth to a common ancestor. DNA and RNA possess a simple four-base code that provides the recipe for all living things. In some cases, if we were to transfer genetic material from the cell of one living thing to the cell of another, the recipient would follow the new instructions as if they were its own. These characteristics of life demonstrate the fundamental sameness of all living things on Earth and serve as the basis of today's efforts at genetic engineering.

Comparative anatomy reveals many evolutionary relationships

Evolutionary theory predicts that related organisms will share similarities that are derived from common ancestors. Similar characteristics due to relatedness are known as **homologies**. Homologies can be revealed by comparing the anatomies of different living things, looking at cellular similarities and differences, studying embryological development, and studying vestigial structures within individual organisms.

Fossils provide a record of large-scale evolutionary changes

The fossil record provides snapshots of the past that, when assembled, illustrate a panorama of evolutionary change over the past four billion years. The picture may be smudged in places and may have bits missing, but fossil evidence clearly shows that life is old and has changed over time. Today we may take fossils for granted, but we continue to learn from them. Each new fossil contains additional clues that increase our understanding of life’s history and help us to answer questions about their evolutionary story. For example, fossils can tell us about growth patterns in ancient animals.

7.9	**Evolution occurs when forces change allele frequencies in the gene pool of a population**	

Because a genetic population is described as the sum of gene (or allelic) frequencies for all the genes represented by that population, it follows that for evolution of a species to occur the gene frequencies of that population must undergo change. The Hardy-Weinberg law describes a population that exists in genetic equilibrium. Several factors can act to change fitness. Viability and fertility are traits that are associated with fitness and are directly related to the ability of an individual to survive long enough to reproduce. By altering the fitness of an individual, the mating distribution will change. The distribution will change because genotypes in the subsequent generation will not appear in direct relationship to the gene frequencies of that population prior to the change. Consequently the gene frequencies will change and the population will evolve.

The synthetic theory of evolution as described by Sewell Wright attempts to explain evolution in terms of changes in gene frequencies. This theory states that a species evolves when gene frequencies change and the species moves it to a higher level of adaptation for a specific ecological niche. Several factors such as mutation of alleles and migration of individuals with those new alleles will create variation in the population. Selection will then chose the better adapted individuals, and the population will have evolved.

The classic example which supports this theory is that of the peppered moth in England. The moth can be either dark or light coloured. Prior to the industrialisation of central England, the light-coloured allele was most prevalent. The light-coloured moths would hide on the white-barked trees and avoid bird predation. But the pollution generated by the new industries stained the light-coloured trees dark. Gradually the light-coloured moth was attacked and that allele became much less prevalent. In its place, the dark-coloured allele became the most predominant allele because moths that carried that allele could camouflage themselves on the stained trees and avoid being eaten by their bird predators. Clearly the population had evolved to a higher adaptive condition.

Because population changes require changes in gene frequencies, it is important to understand how these frequencies can change. The three primary methods of change are **mutation, migration** and **selection**. Each will be considered individually.

Mutation

Mutations are classified as beneficial, harmful or neutral. Harmful mutations will be lost if they reduce the fitness of the individual. If fitness is improved by a mutation, then frequencies of that allele will increase from generation to generation. The mutation could be a change in one allele to resemble one currently in the population, for example from a dominant to a recessive allele. Alternatively, the mutation could generate an entirely new allele. Most of these mutations though will be detrimental and lost. But if the environment changes, then the new mutant allele may be favoured and eventually become the dominant allele in that population. If the mutation is beneficial to the species as a whole, migration from the population in which it initially arose must occur for it to spread to other populations of the species.

The most basic type of mutation is the change in a single nucleotide in the gene. Mutations are generally deleterious and are selected against. But the genome of a species can undergo another type of change, gene duplication, which actually favours mutational events. If a single gene that is important undergoes duplication, mutation in the duplicated copy would not necessarily reduce the fitness of the individual because it still would have a functioning copy of the original gene. With this adaptive constraint removed, further changes can occur that generate a new gene that has a similar function in the organism, but may function at a specific time in development, or in a unique location in the individual. This type of evolution generates multigene families. Many important genes such as haemoglobin and muscle genes in humans and seed storage and photosynthetic genes in plants are organised as multigene families.

Migration

One of the assumptions of the **Hardy-Weinberg law is that the population is closed**. But for many populations this is not the case. Human populations clearly are not closed. Migration will change gene frequencies by bringing in more copies of an allele already in the population or by bringing in a new allele that has arisen by mutation. Because mutations do not occur in every population, migration will be required for that allele to spread throughout that species. Migration, in a sociological context, implies the movement of individuals into new populations. In a genetic context, though, migration requires that this movement be coupled with the introduction of new alleles into the population. This will only occur after the migrant has successfully mated with an individual in the population. The term that is used to describe this introduction of new alleles is **gene flow**.

The two effects of migration are to increase variability within a population and at the same time prevent a population of that species from diverging to the extent that it becomes a new species. The first effect is important because it provides the variability that a population will require to survive if the environment changes drastically. As migration continues over a period of time, the new mutation will be shared between populations. This blending effect helps stabilise the similarities between the population and prevent more isolated populations from evolving reproductive barriers that may lead to speciation.

Selection

A natural result of mutation is that new forms develop, and these new forms may or may not add to the fitness of the individual. If the fitness of the individual leads to a reproductive advantage then the alleles present in that individual will be more prevalent in the population. In this manner the alleles of this individual are selected. This process is called selection. In a Darwinian context this is also called natural selection. The three forces that have been described lead to changes in gene frequencies within a population that are stabilising, directional, and diversifying. But evolution, as defined by Darwin, is driven by natural selection. Under **stabilising selection**, extreme varieties from both ends of the frequency distribution are eliminated. The frequency distribution looks exactly as it did in the generation before. Probably this is the most common form of natural selection, and we often mistake it for no selection. Under **directional selection**, individuals at one end of the distribution of beak sizes, for instance, do especially well, and so the frequency distribution of the trait in the subsequent generation is shifted from where it was in the parental generation. This is what we usually think of as natural selection. Under **disruptive selection**, both extremes are favoured at the expense of intermediate varieties. This is uncommon but of theoretical interest because it suggests a mechanism for species formation without geographic isolation.

7.10 New species originate through the development of reproductive isolation

The last subsection of this unit focuses on the mechanisms by which natural selection brings about speciation. To understand speciation it is important to have a definition of a species. Let us begin with defining **morphological species**, where organisms are classified in the same **species** if they appear identical by **morphological** (anatomical) criteria. Morphology is the most common method of identifying species. Certain scientists have underlined the challenges of the morphological concept. Thus, it is not rare to note morphological differences between juvenile and adult forms, or female and male forms (sexual dimorphism).

In terms of **the biological concept**, the species are isolated from/to each other by barriers of reproduction preventing the production of too large a number of disharmonised, incompatible gene combinations. These barriers are intrinsic, since they are related to the population under consideration; geographical insulation as well as the intervention of man cannot thus be qualified barriers of reproduction in the biological design of the species. In a nutshell, **the concept of biological species** refers to members of populations that actually or potentially interbreed in nature, but do not interbreed as a result of similarity of appearance.

Speciation involves the genetic change in a subgroup of a population that renders the new population incapable of reproducing offspring with the original population. If a reproductive barrier occurs because of isolation by a physical barrier, the isolated population can evolve and develop into a new species. This process is termed **allopatric speciation**. This has been considered for a long time to be the primary mode of speciation.

Speciation can also occur when a sub-population migrates into a new niche. This is termed **parapatric speciation**, and this process seems to have been used by some annual plants.

The final form of speciation is called sympatric speciation. This type of speciation occurs when a subpopulation that occupies the same niche as the remainder of the species develops a unique mutation that prevents it from mating with the original population. That new species may also have an ecological advantage which permits its establishment as a species in the same niche. A good example of this method of speciation is the development of the new saltmarsh species *Spartina townsendii*, that was derived from *S. alterniflora* (American saltmarsh grass) and *S. maritima* (European saltmarsh grass), but is reproductively incompatible with either parent. This new species is better adapted to the coastal regions of Holland than either of the parental species and was able to better establish itself in that niche.

7.11	**Activity 7.2** **Do this activity and add it to your portfolio.** Refer to your textbook and answer the following questions: a) How can fossils help a biological scientist? b) How did Darwin's theory of evolution differ from that of Lamarck? c) Define evolution in general terms as well as in terms of population genetics. d) What is meant by a mechanism of evolution? e) One of the Darwin's principles was that there is a struggle for existence among living organisms. Do plants struggle with one another to survive? If so, how do they do it? f) Define natural selection. g) List four sources of genetic variation. h) List some examples of limiting factors that can cause competition between plants. i) Have you ever witnessed an example of evolution? If so, please share with us.	

7.12 Feedback on activity 7.2

a) I have provided a brief answer for you and which you can compare to your own answer: Once people began to recognise that some fossils looked like living animals and plants, they gradually began to understand what they were. They realised they were actually the ancestors of today's plants and animals. While we can easily recognise and identify some fossils, many fossils represent animals that no longer exist on Earth. We only know about extinct groups like dinosaurs, ammonites and trilobites through fossils. By studying the fossil record we can tell how long life has existed on Earth, and how different plants and animals are related to each other. Often we can work out how and where they lived, and use this information to find out about ancient environments.

b) Their perceptions towards a theory of evolution differ in that Darwin proposed that the nature dictates or rather selects traits in a population that are best suited for survival; therefore, there is variation to begin with. Lamarck, on the other hand, believed that organisms had the capability of evolving within their lifetime. Subsequently, these acquired traits would get passed on to their offspring.

c) Make sure that you define evolution based on general and population genetics.

d) The mechanism of evolution is the process that leads to evolution. There are a few preconditions/mechanisms that are needed in order for evolution to take place. Such mechanisms include the struggle faced by living organisms, variation, reproduction and natural selection.

e) Indeed plants do struggle with each other; for example, plants compete for resources such as light and water, and in the process they develop a strategy that may allow them to survive better than the competitors. Another example are plants which have developed a dense canopy in order to ensure that no other plants can establish themselves in that territory. During pollination some plants are attract pollinators at the cost of their energy as they have to provide the pollinators with nectar, and this on its own is a struggle for the plant. You can list any examples as long as you ensure that they are relevant.

f) Natural selection - refer to the prescribed textbook.

g) The four sources of genetic variation are mutation, genetic recombination, migration and genetic drift. Make sure that you can also describe them.

h) There are many factors that may lead to competition among plants. For example, availability of resources (light, water, soil nutrients), growth rate (for instance after fires plants tend to compete for a space solely relying on their growth rate), etc.

7.13 Summary

Charles Darwin's theory of evolution by natural selection produced a paradigm shift in the life sciences. In *On the Origin of Species*, Darwin presented two revolutionary ideas: (a) the wide diversity of life we see around us has descended from previously existing species, which share common ancestry, and (b) the present forms of these species are a result primarily of natural selection, a process in which forms that are better suited to their environment increase in frequency over time. The core of Darwin's theory is natural selection, a process that occurs over successive generations and is defined as the differential reproduction of genotypes. Natural selection requires heritable variation in a given trait, and differential survival and reproduction associated with possession of that trait.

Evolutionary biologists infer the causes of ancient events. They develop and test hypotheses through a combination of observation and experimental manipulations. Artificial selection by humans is the counterpart to natural selection. Humans select which individuals get to reproduce by choosing those that possess traits that are beneficial to us, and this selection in turn changes the phenotype of domesticated varieties over time. Practical applications of understanding evolution via natural selection include, but are not limited to, controlling resistance to insecticides and antibiotics, as well as using evolutionary principles to address problems in conservation biology and the medical sciences.

Learning unit 8

Classification: Naming and organising plants and microbes

Contents

8.1 Introduction

Biologists sometimes are thought by the general public to be slightly mad or weird when they refer to marula tree as *Sclerocarya birrea*. It may appear to be unnecessary to the lay person to use the Latin names or “scientific names” when referring to living organisms such as animals and plants. However, it simplifies matters, as there is only one correct scientific name that applies to all individuals of a specific kind of organism, no matter where they are found. In this way scientists know exactly what is meant when they use the scientific name, no matter where in the world they are. With so many different languages, common names can become very numerous indeed. It is therefore very important, that despite all the languages in the world, scientists use the same word to refer to a specific organism. In this learning unit we will look at how newly discovered organisms are given scientific names. We will also take a look at how plants are organised and classified.

8.2 Learning outcomes

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

- provide a historical perspective on the development of classification up to and including Darwin
- explain the contribution made by Linnaeus to the binomial nomenclature
- discuss the multidisciplinary approach to modern systematics
- explain what a hierarchy involves
- examine the question of whether relationships should be seen as hypotheses
- draw a mindmap to show the classification of organisms into domains and kingdoms

8.3

Scientific names originated with Linnaeus

Taxonomy is the part of science that focuses on naming and classifying or grouping organisms. A Swedish naturalist called **Carolus Linnaeus** is considered the father of taxonomy because in the 1700s he developed a way to name and organise species that we still use today. His two most important contributions to taxonomy were: (i) a hierarchical classification system, and (ii) the system of **binomial nomenclature** (a two-part naming method). During his lifetime, Linnaeus collected around 40,000 specimens of plants, animals, and shells. He believed it was important to have a standard way of grouping and naming species. So in 1735, he published his first edition of *Systema Naturae* (The System of Nature), which was a small pamphlet explaining his new system of the classification of nature.

He continued to publish more editions of *Systema Naturae* that included more named species. In total, Linnaeus named 4,400 animal species and 7,700 plant species using his binomial nomenclature system. In *Systema Naturae*, Linnaeus classified nature into a hierarchy. He proposed that there were three broad groups, called kingdoms, into which the whole of nature could fit. These kingdoms were animals, plants, and minerals. He divided each of these kingdoms into classes. Classes were divided into orders. These were further divided into genera (genus is singular) and then species.

Today, we only use this system to classify living things. Originally Linnaeus included non-living things in his mineral **kingdom**. The broadest level of life is now a domain. All living things fit into only three domains: **Archaea, Bacteria,** and **Eukarya**. Within each of these domains there are kingdoms. For example, Eukarya includes the kingdoms **Animalia, Fungi, Plantae**, and more. Each kingdom contains phyla (singular is phylum), followed by **class, order, family, genus,** and **species**. Each level of classification is also called a **taxon** (plural is **taxa**). Before Linnaeus came up with a standardised system of naming, there were often many names for a single species, and these names tended to be long and confusing - up to 12 words. Linnaeus decided that all species names should be in Latin and should have two parts. This system is still used today and gives every species one unique two-part scientific name. In print, scientific names should always be either italicised or underlined. Scientific names consist of two parts: the **genus** name (the name's first part) and the **specific epithet** (the second part). You can have some fun with scientific names on the Web. For instance, if you have access to the Internet you can look up scientific names of Southern African plants at http://posa.sanbi.org/searchspp.php.

There is a correct way to write scientific names. After the first use, the genus name can be abbreviated just after it is fully written, e.g. *Coffea arabica*. When you introduce the name of another species in the same genus, you can use the abbreviated genus name for the new species, for example: "Among the 60 or so species of *Coffea, C. arabica, C. canephora*, and *C. liberica* are major cultivated species." Below the level of species there are subspecies and varieties. The subspecies are indicated by "subsp." or "ssp." For example, *Coffea mufindiensis* subsp. *lundaziensis*. The "subsp." label is not italicised.

The immediate impact of Darwinian evolution on classification was negligible for many groups of organisms, and unfortunate for others. As taxonomists began to accept evolution, they recognised that what had been described as natural affinity, i.e. the more or less close similarity of forms with many of the same characters, could be explained as relationship by evolutionary descent. In groups with little or no fossil record, a change in interpretation rather than alteration of classifications was the result. Unfortunately, some authorities, believing that they could derive the group from some evolutionary principle, would proceed to reclassify it. The long-term impact of Darwinian evolution is very important. It indicates that the basic arrangement of living things, if enough information were available, would be a phylogenetic tree rather than a set of discrete classes. Many groups are so poorly known, however, that the arrangement of organisms into a dendrite is impossible. Extensive and detailed fossil sequences—the laying out of actual specimens—must be broken up arbitrarily. Many groups, especially at the species level, show great geographical variation, so that a simple definition of species is impossible. Difficulties of classification at the species level are considerable.

8.4 Identifying and archiving plant specimens

The identification of plant specimens requires a considerable amount of time and effort. It is important to find out what research is being or has been done on the flora of the region where you are working. A thorough literature review and consultation with herbarium personnel will give you a good basis for starting the identification process.

The identification of unknown plant material is accomplished with the use of dichotomous keys, published plant descriptions, illustrations and photographs, and comparison with properly identified herbarium specimens. A microscope is essential for the observation of many diagnostic features.

Regulations pertaining to collecting plants vary from country to country and state to state, so it is important for you to make official contacts well in advance. It is customary and may be required to deposit one full set of specimens in a herbarium (see example of pressed specimen in figure 8.1) in the host state or country. A local herbarium is the ideal place to begin your quest for identifications, as its collection may be the most comprehensive for the region. It may be possible to arrange to identify your plants and receive assistance from staff members at this institution. But, one must realise that the identification of even relatively common plants may be time-consuming.

When submitting a plant specimen for identification, it is critical that the sample includes flowers and/or fruits and a portion of the stem with at least several leaves attached. Information of the plant's growth habit, size, and the habitat where it is found (as well as any other features of the plant that may not be apparent from the sample, such as plant colour or fragrance) often assist in the identification process. Watch the following video which shows how herbarium specimens are prepared:
https://www.youtube.com/watch?v=HaaX5WzlAiI.

Figure 8.1. Dried specimen of *Berula angustifolia* with stem, leaves, and flowers.

(https://commons.wikimedia.org/wiki/Category:Berula_erecta_(herbarium_specimens)#/media/File:Neuch%C3%A2tel_Herbarium_-_Berula_angustifolia_-_NEU000005742.jpg)

By looking at characteristics of a plant or animal and using a **dichotomous key**, you can identify most living things in terms of the species. In this situation the term "dichotomous" means to divide into two groups that are not alike, and most dichotomous keys work by using the individuals' characteristics to place the organism into smaller and smaller groups until it can be identified to the species. Dichotomous keys usually include only certain groups of organisms, for instance trees. The usefulness of a key is only as good as the author's purpose. Some keys are intended to cover only the most common species, while others are very comprehensive and require extensive knowledge of biology or botany.

8.5

Classification of plants and other organisms

Today there are more than 250 000 known species of plants, including flowering plants, gymnosperms, ferns, lycophytes, and bryophytes. The species of algae, fungi, and bacteria are thought to be in the millions. How can biologists bring order to this tremendous diversity? Deciding what living things should be classified in the same groups requires an understanding of what is related to what, and how close those relationships are. Long ago, it was often done by lumping together **analogous traits**: features that are used to do the same function. This is why, in Biblical times, if they were streamlined and swam ("beasts of the water"), or had wings and flew ("creatures of the air"), they were classified into the same groups. Certain simple forms were also used for grouping: by this approach, snakes would be grouped with earthworms and eels.

As more and more people studied nature in detail, it became obvious that a butterfly's wings were very different structures than a bird's wings. And sometimes, it could be seen that two structures used for very different functions - such as a human hand, a bat's wing and a whale's flipper - all contained the same basic internal architecture, with changes in parts producing the outward changes. Traits with similar internal structure are called homologous traits, and it was eventually decided that these traits were a better measure of relatedness than analogous traits. Keep in mind, however, that traits can be both **analogous** and **homologous** (like a monkey hand and a human hand).

There are, in modern taxonomy, two somewhat different approaches to putting together "family trees" of organisms. In **systematics**, branches occur when one species splits into two - at the point of a common ancestor to the new branches. **Cladistics** is similar, but the focus is on when certain "new," special traits arise - humans might split from chimps, for instance, at the point where our ancestors started to walk upright. Both apply a fairly rigid "branching" to points that in real time probably were more spread out, and only sometimes do they seem to be at odds with each other. Their representations also tend to differ - systematics, the older approach, usually uses fluid, naturalistic branching diagrams, while **cladograms** tends to branch at geometrical angles and use a lot of straight lines. There is a third approach that might be added - **molecular evolutionary taxonomy** which is concerned with when certain key genetic differences arise. This tends to be an offshoot of **cladistics**, but the connection may get less clear over time. Much basic taxonomy is still done anatomically, although the level of detail has gotten smaller through the use of microscopes and broader through the discoveries of genetics and biochemistry.

8.6

Activity 8.1

Do this activity and add it to your portfolio.

Refer to your textbook and answer the following questions:

a) What are the advantages of using scientific names rather than common names?

b) Why are scientific names preferred in sciences, medicine, agriculture and commerce?

c) After Linnaeus organised all the genera known to him into classes, a number of other categories of classification between the level of kingdom and genus were added. Are these other categories really useful? Make sure you explain your answer in depth.

8.7

Feedback on activity 8.1

Find the answers to questions a), b), and c) by yourself.

8.8

Summary

Classification provides scientists with a way to sort and group organisms for easier study. Linnaeus, a Swedish botanist in the 18th century, is credited with the creation of the binomial, or scientific name. Although common names are often informative and readily accessible, scientific names have the advantage of being recognised the world over and being unique to a single species. The taxonomic hierarchy includes the major ranks: kingdom, division, class, order, family, genus, and species/ specific epithet. Specimens may need to be collected so that correct identifications can be made and a checkable voucher preserved for posterity. Specimens are also often valuable in especially difficult groups so that they can be used for taxonomic study. As a general rule, collect only when you can take a good representative specimen without doing significant harm to the population; preserve it well so as to show the diagnostic features; label it properly, and if possible deposit it in a secure and well-curated herbarium. Organisms are classified according to physical structure (how they look), evolutionary relationships, embryonic similarities (embryos), genetic similarities (DNA), and biochemical similarities.