NATIONAL OPEN UNIVERSITY OF NIGERIA

FACULTY OF SCIENCES

COURSE CODE: BIO102

COURSE TITLE: GENERAL BIOLOGY II

Course Team

Course Developer/Writer: Abiodun E. Adams
National Open University of Nigeria

Course Reviewer: Professor Dr. Mohammed Bello Abdullahi

Head of Department: Dr. Maureen N. Chukwu
Department of Biological Sciences
National Open University of Nigeria

Reviewed: 2023

NATIONAL OPEN UNIVERSITY OF NIGERIA

National Open University of Nigeria
Headquarters University Village
Plot 91, Cadastral Zone Nnamdi Azikiwe
Expressway Jabi, Abuja

Lagos Office
14/16 Ahmadu Bello Way
Victoria Island, Lagos

e-mail: centralinfo@nou.edu.ng
URL: www.nou.edu.ng

First Printed 2009

Reviwed 2023

Course Guide

GENERAL BIOLOGY II is a one semester, 18 Units course. It will be suitable to all students to take towards the core module of B.Sc. (Hons) Biological Sciences. It will also be suitable as an elective course for any student in Faculty of Sciences who does not want to complete an NOU qualification but want to learn about Biology. The course involves the study of the basic characteristics, identification and classification of viruses, bacteria and fungi. A generalized survey of the plant and animal kingdoms based mainly on the study of similarities and differences in the external features. Ecological adaptations. Briefs on physiology to include nutrition, respiration, circulatory systems, excretion, reproduction, growth and development.

Course Competencies

This course aims to enable you to know/understand the basic characteristics, identification and classification of viruses, bacteria and fungi. It also includes generalized survey of the plant and animal kingdoms. It will guide your understanding of the classification, adaptation and physiology of organisms on the planet earth.

Course Objectives

The Comprehensive Objectives of the Course as a whole are to;

1. List the characteristics, methods of identification and classification of viruses, bacteria and fungi;
2. State the unique characteristics of plant and animal kingdoms;
3. Explain the diversity in plant and animal kingdoms; and
4. Explain the physiology in plant and animal kingdoms; and
5. Describe ecological adaptations in plant and animal kingdoms;

Working Through this Course

To successfully complete this course, you are required to read each study unit, read the textbooks and other materials provided.

Reading the reference materials can also be of great assistance. Each unit has self –assessment exercise which you are advised to do.

There will be a final examination at the end of the course. The course should take you about 8 weeks to complete.

This course guide provides you with all the components of the course, how to go about studying and how you should allocate your time to each unit so as to finish on time and successfully.

Study Units

The study units in this course are given below:

BIO 102 GENERAL BIOLOGY II (2 UNITS)

MODULE 1: THE STUDY OF LIVING THINGS

Unit 1: Classification of Living Organisms

Unit 2: Basic Characteristics, Identification and Classification of Viruses.

Unit 3 Basic Characteristics, Identification and Classification of Prokaryotes
Unit 4 Eukaryotic Organisms
Unit 5 The Protists
Unit 6 Basic Characteristics, Identification and Classification of Fungi

MODULE 2: OVERVIEW OF THE PLANT KINGDOM
Unit 1 Kingdom Plantae
Unit 2 The Seedless Plants
Unit 3 Bryophytes
Unit 4 Seedless Vascular Plants
Unit 5 Seed Plant I: Gymnosperms
:

MODULE 3: OVERVIEW OF THE ANIMAL KINGDOM

Unit 1 Diversity of Animal Life
Unit 2 The Simplest Animals
Unit 3 Flatworms, Nematodes, and Arthropods
Unit 4 Mollusk and Annelids
Unit 5 Echinoderms and Chordates
Unit 6 Vertebrates I: Fishes and Amphibians
Unit 7 Vertebrates II: Reptiles, Birds and Mammals

References and Further Readings

You would be required to read the recommended references and textbooks as provided in each unit of the course.

Presentation Schedule

There is a time-table prepared for the early and timely completion and submissions of your TMAs as well as attending the tutorial classes. You are required to submit all your assignments by the stipulated date and time. Avoid falling behind the schedule time.

Assessment

There are three aspects to the assessment of this course. The first one is the in-text questions and the second is self-assessment exercises, while the third is the written examination or the examination to be taken at the end of the course. Review the exercises or activities in the unit by applying the information and knowledge you acquired during the course. The work submitted to your tutor for assessment will account for 30% of your total work. At the end of this course you will have to sit for a final or end of course examination of about a two hour duration and this will account for 70% of your total course mark.

How to get the Most from the Course

In this course, you have the course units and a course guide. The course guide will tell you briefly what the course is all about. It is a general overview of the course materials you will be using and how to use those materials. It also helps you to allocate the appropriate time to each unit so that you can successfully complete the course within the stipulated time limit.

The course guide also helps you to know how to go about your in-text questions and Self-assessment questions which will form part of your overall assessment at the end of the course. Also, there will be tutorial classes that are related to this course, where you can interact with your facilitators and other students. Please I encourage you to attend these tutorial classes.

This course exposes you to General Biology II, a sub-discipline and very interesting field of Biological Sciences.

Online Facilitation

Eight weeks are provided for tutorials for this course. You will be notified of the dates, times and location for these tutorial classes. As soon as you are allocated a tutorial group, the name and phone number of your facilitator will be given to you. The duties of your facilitator is to monitor your progress and provide any necessary assistance you need.

Do not delay to contact your facilitator by telephone or e-mail for necessary assistance if

- You do not understand any part of the study in the course material.
- You have difficulty with the self-assessment activities.
- You have a problem or question with an assignment or with the grading of the assignment.

It is important and necessary you attend the tutorial classes because this is the only chance to have face to face contact with your facilitator and to ask questions which will be answered instantly. It is also a period where you can point out any problem encountered in the course of your study.

Course Information

Course Code: BIO 102
Course Title: GENERAL BIOLOGY II
Credit Unit: 2
Course Status: Compulsory
Semester: 2 SEMESTERS
Course Duration: EIGHT WEEKS
Required Hours for Study: One hour

Ice Breaker

Dr. Mohammed Bello Abdullahi is a Professor of Biology (Biodiversity and Environmental Management) in the Department of Biological Sciences, Federal University, Kashere-Gombe. He has been briefly in the Department of Biological Sciences, National Open University of Nigeria from 2017-2021 participating in examining, moderating and facilitating courses such as; BIO 101; 102; 202; 204; 304 and 412, and research, seminars and practicals.

Dr. Abdullahi's research interest covers phytosociology, climate change, ecological economics, ethnobotany, plant physiology, biodiversity and environmental management and toxicology.

Module 1: The Diversity of Life

Module Structure

In this module we will discuss about the diversity of life, basic characteristics, identification and classification of viruses. bacteria and fungi:

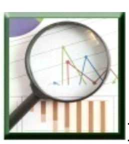
Unit 1: Classification of Living Organisms
Unit 2: Basic Characteristics, Identification and Classification of Viruses.
Unit 3: Basic Characteristics, Identification and Classification of Prokaryotes
Unit 4: Eukaryotic Organisms
Unit 5: The Protists
Unit 6: Basic Characteristics, Identification and Classification of Fungi
Glossary
End of the module Questions

Module 1: Classification and Characteristics of Living Organisms

Unit 1 Classification of Living Organisms

Unit Structure

1.1 Introduction
1.2 Intended Learning Outcomes (ILOs)
1.3 Main Contents
    1.3.1 Classifications of Living Organisms
    1.3.2 Modern Biological Classification
    1.3.3 Binomial Nomenclature
1.4 Summary
1.5 References/Further Readings/Web Sources
1.6 Possible Answers to Self-Assessment Exercises



1.1 Introduction

The quantity of living organisms in the planet is enormous, they have a long history, and their diversity is intricate. Numerous fields within the science of biology work to provide us a complete understanding of the nature of living things. Anywhere you go, a casual examination of the living things around you will reveal a broad diversity of plants and animals that differ in terms of their sizes, forms, colors, rates of locomotion, etc. Additionally, they share a few traits or behaviors. As a result, we will examine the numerous classification schemes for living things as well as the traits that distinguish each category in this unit.

1.2 Intended Learning Outcomes (ILOs)

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

- List the different groups of living organisms

- Explain the modern biological classification of organisms
- List the five–kingdom classification of organisms with examples
- Mention the characteristics of the major groups of plants and animals.

1.3 Main Contents

1.3.1 Classifications of Living Organisms

Over 1.8 million different species of living things have been studied and described. We need a useful system for classifying, naming, and identifying the many more that are still to be found and documented. We all learnt the distinction between plants and animals at a young age, but it was probably not until a few years later that we realized there are several kinds of animals and plants; despite some similarities, they are completely different. Animals and plants were the two main categories of living things centuries ago. We can now better grasp the world we live in, our relationship to other living things, and biology as a whole thanks to the taxonomy of living things. You probably already have some knowledge of taxonomy, another name for the classification of biological things. The fundamentals of taxonomy are taught to many children in primary school, but unless you spend a lot of time concentrating on Biology, the specifics may have faded over time. Carl Linnaeus, a Swedish botanist, is credited with establishing classification for all living things. His first classification manual, Systema Naturae, which was released in 1735, was inspired by his interest in both plants and animals. The classification scheme developed by Linnaeus, frequently referred to as the "Father of Taxonomy," is still in use today. Linnaeus will always play a crucial role in how we name, rank, and categorize plants and animals even as the classification system develops. In this concept, a genus is a collection of the species that are most similar to one another. Additionally, within a family, comparable genera (the plural of genus) are grouped together. The level at which all creatures are gathered together into groups is reached at the end of this grouping. From lowest to highest, the eight levels of the present taxonomic hierarchy are: species, genus, family, order, class, phylum, kingdom, and domain. As a result, species are organized into genera, which are then divided into families, which are then divided into orders, and so on.

Self-Assessment Exercises 1

1. Describe the hierarchical system of classification currently being followed.

1.3.2 Modern biological classification1.

Most scientists think that all living things can be classified in three domains: Archaea, Bacteria, and Eukarya. These domains are compared in Table 1 below. The Archaea Domain includes only the Archaea Kingdom, and the Bacteria Domain includes only the Bacteria Kingdom. The Eukarya Domain includes the Animal, Plant, Fungus, and Protist Kingdoms.

Table 1. **Comparison of the three domains of life**

Trait	Archaea	Bacteria	Eukarya
Multicellularity	No	No	Yes except for many protists
Cell Wall	Yes Without peptidoglycan	Yes With peptidoglycan	Yes for plants, fungi, and some protists No for animals and other protists
Cell Nucleus (DNA inside a membrane)	No	No	Yes
Cell Organelles (other structures inside membranes)	No	No	Yes

There are only single-celled creatures in the Bacteria and Archaea domains. Both Archaea and Bacteria have cell walls, however the composition of the walls varies. Bacteria and Archaea have nuclei-free cells. DNA is stored in a nucleus, a membrane-enclosed structure, in a cell. Although many Eukarya are multicellular, some are single-celled as well. Others lack a cell wall, while some do. All Eukarya have nuclei and other organelles in their cells, though. Bacteria and Archaea may appear to be more alike than either is to Eukarya. Scientists believe that Bacteria are more distantly connected to Eukarya than Archaea, nevertheless. Their shared DNA serves as the foundation for this opinion. What are the three domains of life?

Self-Assessment Exercises 2

1. Who developed the three-domain system?
2. Which organisms are contained within the Eukaryota domain?

1.3.3 Binomial Nomenclature

Though we are familiar with common names for living things like Mango, Goat, Pawpaw, Lion, etc., this is the usage of a systematic system to name living things. The way that Linnaeus named species is very well-known and is still in use today. It is known as binomial nomenclature. Each species has its own distinctive two-word moniker. It usually begins with the genus name and ends with the species name and is written in Latin. The genus name is usually capitalized, and both names are always written in italics. Homo sapiens, for instance, is the name of the human species. The family dog belongs to the *Canis familiaris* genus. It may not seem difficult to develop a scientific naming method, but it is. There wasn't a standard way to name species before Linnaeus. Scientists named species with lengthy, complicated names. The same species has frequently been given numerous names by various biologists. Common names varied as well, usually from one location to another. Each species should have a single, concise scientific name to reduce errors and misunderstandings. What was the major challenge to naming of organisms before the work of Linnaeus?

Self-Assessment Exercises 3

1. Which two levels of classification are included in the binomial system?
2. What does the Binomial nomenclature stands for?

1.4 Summary

All life is categorized according to a scale that you have learned: Domain, Kingdom, Phylum, Class, Order, Family, Genus, and Species. In order to organize similar organisms into taxonomic categories, Carolus Linnaeus created the taxonomic system. Binomial nomenclature gives organisms Latinized scientific names that include genus and species designations.You also discovered that there were five kingdoms in Robert Whittaker's tree: Animalia, Plantae, Protista, Fungi, and Monera.

1.5 References/Further Readings/Web Sources

Henderson's dictionary of biology (2011). / edited by Eleanor Lawrence. **ISBN:**9781408234303 (pbk.), 1408234300 (pbk.). **Edition:**15th ed. **Published/Created:**Harlow, Essex ; New York : Benjamin Cummings/Pearson, 2011.

Roth, Wolff-Michael, (2009)-. Science education from people for people : taking a stand(point) / edited by Wolff-Michael Roth. **Publisher:**New York : Routledge, 2009. **ISBN:**9780415995542 (hbk)

Kuhn, Thomas S. (2012).The structure of scientific revolutions / **Publisher:**Chicago ; London : The University of Chicago Press, **ISBN:**9780226458113 (cloth : alkaline paper)

Susan Randel (2017). **Principles of Biology** Salem Press Publisher s,ISBN-10: 1682173240 pp400

https://bio.libretexts.org/Courses/Prince_Georges_Community_College/PGCC_Microbiology/04%3A_Microscopy_Staining_and_Classification/4.03%3A_Classification_and_Identification/4.3.01%3A_Kingdom_Classification_According_to_Whittaker

https://biologyjunction.com/classification-of-living-things/

https://bio.libretexts.org/Courses/Lumen_Learning/Biology_for_Non_Majors_I_(Lumen)/01%3A_Introduction_to_Biology/1.15%3A_Taxonomy

https://www.tutorialspoint.com/biology_part2/biology_classification_of_organisms.htm

https://www.youtube.com/watch?v=sFMv7Gdryc0

https://www.youtube.com/watch?v=lnvlMlopu2A

1.6 Possible Answers to Self-Assessment Exercises

Answers to SAE 1

1. Domain- Broadest level covering similar Kingdoms together.
   Kingdom- Placing similar Phylum together with similar characters.
   Phylum/ Division- Placing similar Class together with similar characters (In animal it is Phylum and in plant it is Division).
   Class-Placing similar order together with similar characters.
   Order-Placing similar family together with similar characters.
   Family-Placing similar Genus together with similar characters.
   Genus-Placing similar Species together with similar characters.
   Species-Placing similar individuals together with similar characters which can interbreed.

Answers to SAE 2

1. Carl Linnaeus
2. Protists, fungi, plants and animals

Answers to SAE 3

1. Genus and species

2. Binomial nomenclature is the biological system of naming the organisms in which the name is composed of two terms, where, the first term indicates the genus and the second term indicates the species of the organism

Unit 2 Basic Characteristics, Identification and Classification of Viruses

2.1 Introduction
2.2 Intended Learning Outcomes (ILOs)
2.3 Main Contents
  2.3.1 The study of Viruses
    2.3.1.1 Basic Characteristics of Viruses
    2.3.1.2 Structure of a Virus
  2.3.2 Classification of Viruses
  2.3.3 Identification of viruses
  2.3.4 Cultivation of Viruses
2.4 Summary
2.5 References/Further Readings/Web Sources
2.6 Possible Answers to Self-Assessment Exercises

2.1 Introduction

Viruses are diverse entities: They vary in structure, methods of replication, and the hosts they infect. Nearly all forms of life—from prokaryotic bacteria and archaeans, to eukaryotes such as plants, animals, and fungi—have viruses that infect them. While most biological diversity can be understood through evolutionary history (such as how species have adapted to changing environmental conditions and how different species are related to one another through common descent), much about virus origins and evolution remains unknown.

2.2 Intended Learning Outcomes (ILOs)

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

- Define Viruses
- Explain the basic characteristics of viruses
- Describe the structure of a Virus
- Identification of viruses
- Describe the method of hemagglutination assay
- Explain the process of nucleic acid amplification test
- Descibe enzyme immunoassay
- Explain the various classification of viruses

2.3 Main Centents

2.3.1 The Study of Viruses

Do any of the three realms of life include viruses? Do viruses have life? We must first define and understand these questions in order to consider them. Microscopically small infectious organisms known as viruses can only replicate inside the cells of their hosts. Biologically speaking, viruses cannot be categorized as either living things or non-living things. A virus is a type of infectious agent that can only reproduce inside of its host organism. This is because they have specific distinguishing characteristics of both living and non-living things. A virus, in its simplest form, is an infectious, non-cellular organism consisting of genetic material and protein that can only enter and reproduce inside the living cells of bacteria, plants, and animals. For example, a virus is unable to replicate outside of the host cell. This is due to the absence of the necessary cellular machinery in viruses. As a result, it enters and binds to a particular host cell, injects its genetic material, reproduces using the genetic material of the host, and then the host cell ruptures, releasing the new viruses. Additionally, viruses can crystallize, something that no other living thing can achieve. These elements are what cause viruses to be categorized as existing in a gray area between living things and non-living things.

2.3.1.1 Basic Characteristics of Viruses

- A **virus** is nothing more than some DNA or RNA surrounded by a coat of proteins.
- A virus is not a cell.
- A virus cannot use energy, respond to stimuli, grow, or maintain homeostasis.
- A virus cannot reproduce on its own. However, a virus can reproduce by infecting the cell of a living host. Inside the host cell, the virus uses the cell's structures, materials, and energy to make copies of itself.
- Because they have genetic material and can reproduce, viruses can evolve. Their DNA or RNA can change through time. The ability to evolve is a very lifelike attribute.

Based on their characteristics, many scientists think that viruses should not be classified as living things because they lack most of the defining traits of living things. Other scientists aren't so sure. They think that the ability of viruses to evolve and interact with living cells earns them special consideration. Perhaps a new category of life should be created for viruses. What do you think?

2.3.1.2 Structure of a Virus

Viruses are extremely small, with sizes between 30 and 50 nm. In contrast to having no cells and frequently having no cell wall, viruses are encased in a layer of protective protein called a capsid. It has a genetic component and is distinguished by the coevolution of the host and the virus. The genetic material in them is either DNA or RNA. In order to spread, viruses primarily rely on hosts to provide the sophisticated metabolic machinery of prokaryotic or eukaryotic cells. The virus's primary function is to deliver its DNA or RNA genome to the host cell, where the host cell can then transpose it. A symmetric protein that has been capsuled contains the viral genome structure. The protein associated with nucleic acid (also known as nucleoprotein) produces the nucleocapsid with the genome.

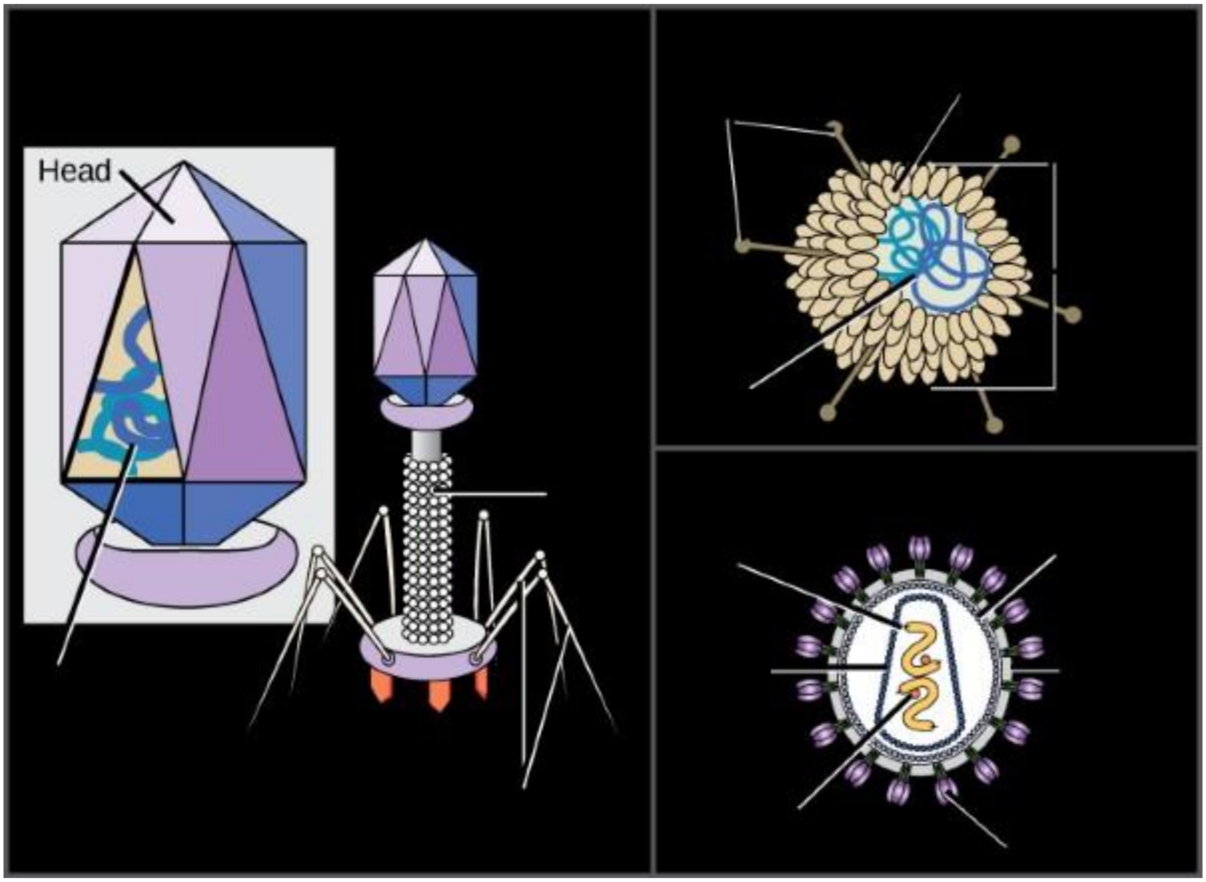


Figure1.1 Viruses can be either complex in shape or relatively simple. This figure shows three relatively complex virions: the bacteriophage T4, with its DNA-containing head group and tail fibers that attach to host cells; adenovirus, which uses spikes from its capsid to bind to host cells; and HIV, which uses glycoproteins embedded in its envelope to bind to host cells. Notice that HIV has proteins called matrix proteins, internal to the envelope, which help stabilize virion shape. Source: http://library.open.oregonstate.edu/microbiology/

These microorganisms belong to the virus genus and the viridae family. Because they essentially exist in a state beyond living entities and inanimate objects, viruses cannot be sorted into any of the established kingdoms. The term "virus" was coined by Dutch microbiologist Martinus Willem Beijerinck in 1897. Its etymology traces back to Latin, where it signifies a toxic or harmful substance. Following infection of a susceptible cell, a virus can activate the cell's mechanisms to generate additional virus particles. Viruses consist of a DNA or RNA core enveloped by a protein coat. Their dimensions range from 20 nanometers to 250 nanometers, an extraordinarily minute scale. Detection typically requires an electron microscope due to their size. Numerous viruses possess either DNA or RNA as their genetic material, often in single or double strands. A complete infectious virus, known as a virion, comprises genetic material and an outer protein shell. The complexity of viruses varies, with the simplest encoding around four proteins in their DNA or RNA, while the most intricate viruses encode 100 to 200 proteins. The study of virus is known as virology. Why is it that viruses could not be placed in any of the kingdoms?

Self-Assessment Exercises 1

1. What is a Virus?
2. Why are viruses neither considered living, nor non-living?

2.3.2 Classification of Viruses

The primary elements utilized for the classification of viruses encompass their observable characteristics, core composition, chemical constitution, capsid structure, size, shape, replication mechanisms, and other structures within their genetic makeup. The Baltimore classification system is the predominant method employed for studying virus classification. This system was formulated by American biologist David Baltimore during the 1970s, leading to his receipt of the Nobel Prize. The subsequent content delves into the categorization of viruses according to diverse criteria.

The conventional methods devised by scientists for categorizing prokaryotic and eukaryotic cells prove to be of limited utility since viruses are likely to have originated from varied sources. Genomic or protein analysis also holds minimal value if viruses are remnants of other life forms. This is due to the absence of a shared genomic sequence across all viruses. For instance, the commonly employed 16S rRNA sequence in constructing prokaryotic phylogenies becomes irrelevant for entities lacking ribosomes, like viruses. Biologists have employed multiple classification systems in the past. Initially, viruses were grouped based on shared morphology. Subsequently, different subsets of viruses were categorized based on the presence of DNA or RNA, as well as the single-stranded or double-stranded nature of their nucleic acids. Yet, these older classification schemes divided viruses into separate groups due to reliance on diverse virus characteristics. The Baltimore classification system, currently the predominant approach, hinges on how messenger RNA (mRNA) is generated in distinct types of viruses.

a) Classification based on the presence of nucleic acid

- **DNA**: The virus, having DNA as its genetic material. There are two different types of DNA virus. Single-stranded (ss) DNA virus: e.g. Picornaviruses, Parvovirus etc. Double-stranded (ds) DNA virus: e.g. Adenovirus, Herpes virus, etc.
- **RNA virus:** The virus, having RNA as its genetic material. There are two different types of RNA virus. Double-stranded (ds) RNA virus: e.g. Reovirus, etc. Single-stranded (ss) RNA virus. It is further classified into two Positive sense RNA (+RNA) and negative sense RNA (-RNA). Poliovirus, Hepatitis A, Rabies virus, Influenza virus are examples of single-stranded RNA virus.

b) Classification based on the structure or symmetry

Viruses come in different shapes, from basic helical and icosahedral shapes to more intricate ones. The classification based on different shapes and symmetry of viruses are as follows:

1. Complex virus. E.g Poxvirus
2. Radial symmetry virus. E.g.Bacteriophage
3. Cubical or icosahedral symmetry shaped virus. E.g. Reovirus, Picornavirus
4. Rod or Spiral shaped or helical symmetry virus. E.g. Paramyxovirus, orthomyxovirus

c) Classification based on the replication properties and site of replication

Here, viruses invade into the host cell, where it replicates and assembly within the cell organelles.

1. Replication within the cytoplasm of the host cell.
   E.g. All RNA viruses except the Influenza virus.

2. Replication within the nucleus and the cytoplasm of the host cell. E.g. Influenza virus, Poxvirus, etc.
3. Replication within the nucleus of the host cell. All DNA viruses except Pox virus.
4. Replication of the virus through the double-stranded DNA intermediate. E.g. All DNA viruses, Retrovirus and some tumour causing RNA virus.
5. Replication of the virus through a single-stranded RNA intermediate. E.g. All RNA viruses except Reovirus and tumour-causing RNA viruses.

d) Classification based on the host range

Based on the type of host, there are four different types of viruses:

- **Animal viruses**

These viruses infect by invading the cells of animals, including humans. Prominent examples of animal viruses include the influenza virus, mumps virus, rabies virus, poliovirus, Herpes virus, etc.

- **Plant viruses**

These viruses infect plants by invading the **plant cells.** Replication of plant viruses is obligate and does not happen without a host. Well-known examples of plant virus include the potato virus, tobacco mosaic virus (TMV), beet yellow virus, and turnip yellow virus, cauliflower mosaic virus, etc.

- **Bacteriophage**

The virus which infects bacterial cells is known as bacteriophage. There are many varieties of bacteriophages, such as DNA virus, MV-11, RNA virus, λ page, etc.

- **Insect virus**

The virus which infects insects is known as Insect virus, also called the viral pathogen of insects. These viruses are considered as a powerful biocontrol agent in the landscape of modern agriculture. Ascovirus virions and Entomopox virus, are best examples for insect virus.

e) Classification based on the mode of transmission

1. Airborne infections – Transmission of the virus through the air into the respiratory tract. E.g. Swine flu, and Rhinovirus.
2. Fecal oral route – Transmission of the virus through the contaminated water or food. E.g. Hepatitis A virus, Poliovirus, Rotavirus.
3. Sexually transmitted diseases – Transmission of the virus through sexual contacts with the infected person. E.g. Retrovirus, human papillomavirus, etc.

4. Transfusion-transmitted infections- Transmission of the virus through the blood transfusion.
   E.g. Hepatitis B virus, Human Immunodeficiency Virus, etc.
5. Zoonoses -Transmission of the virus through the biting of infected animals, birds, and insects to human. E.g. Rabies virus, Alpha virus, Flavivirus, Ebola virus, etc.

   What is the name of the virus that infects bacterial cell?

Self-Assessment Exercises 2

1. 1. List the different types of viruses based on their host.
2. List the classification of viruses based on their shapes and

2.3.3 Identification of Viruses

Regardless of the method of cultivation, once a virus has been introduced into a whole host organism, embryo, or tissue-culture cell, a sample can be prepared from the infected host, embryo, or cell line for further analysis under a brightfield, electron, or fluorescent microscope. Methods in identification of plant viruses

1. Viruses are inoculated into indicator plants which develop typical symptoms when infected by specific viruses and in virus assay.

2. Serological tests are carried out using antisera of known viruses.

3. Transmission aspects of the virus are considered: whether by sap inoculation, and the vectors, if any, involved; whether the virus is persistent or non-persistent in the vector; whether stylet borne, circulative or propagative, and other aspects of its transmission.

4. Such properties as the thermal inactivation point, the dilution end point, and survival outside the plant can be used to characterize viruses.

5. Interaction with other viruses is considered, notably cross-protection.

6. Host range and symptoms are studied.

7. Study of morphology and chemical constitution of the virus particle.

2.3.4 Cultivation of Viruses

Viruses cannot be grown in standard microbiological culture: e.g. broth and agar - They need to be cultured in the presence of a suitable host such as: prokaryotes (easiest to grow in the lab), plants and animals because they are unable to reproduce independently of living cells. Methods used include the following: - Use of embryonated eggs - Tissue culture - Culturing viruses in plants and animals - Culturing viruses in bacteria.

1. Culturing Viruses in Bacteria

- Viruses can be grown in cultures maintained in either liquid or agar plates - Bacteria and phages are mixed with warm nutrient agar and poured on a thin layer on the surface of an agar plate
- During incubation: - Bacterial cells infected by phages are lysed and release new phages that infect the nearby bacterial cells - The uninfected bacterial cells grow and reproduce normally
- Appearance of plate after incubation: - The plate has a uniform bacterial lawn interrupted by clear zones - The clear zones are known as plaques
- Estimation of phage numbers - This is done by using the plaque assay - Each plaque corresponds to a single phage in the original bacterium or virus mixture

2. Cell Culture

Cell culture is aseptically removing tissue fragments in order to cultivate multicellular eukaryotic cells, particularly animal cells. It is a helpful technique for growing clinical samples that may include viruses. It aids in the laboratory detection, characterisation, and identification of viruses. Because cell material is always available, cell lines make it easy to study viruses. Treatment of the tissues with an enzyme that dissolves the intracellular cement causes the tissues to become dissociated. A flat surface, such as the bottom of a culture flask or a Petri dish, is used to disperse the resulting suspension. A monolayer is the term used to describe the thin layer of cells that eventually appears on the plate's surface. This is incubated at the appropriate temperature and covered with an appropriate culture medium. Some cell cultures can be maintained as permanent cell lines and cultivated indefinitely. However, a culture won't always continue to grow indefinitely; instead, it may exist for a few days. These cultures are referred to as primary cell lines. Despite the necessity to occasionally prepare new viruses from different sources, these cells may still be useful for developing viruses.

Procedure

- A layer of animal cells is covered with a virus inoculums and viruses are allowed time to settle and attach to the cells
- Plates are usually incubated at 37°C in the presence of 5%CO_2
- Localised areas of destruction and lysis called plaques are often formed and may be detected if stained with dyes such as tryptan blue or neutral red that are used to distinguish live cells from dead ones
- In some cases virus growth may cause microscopic or macroscopic degenerative changes or abnormalities in host cells and tissues known as cytopathic effects
- Cytopathic effects may be lethal

Disadvantages

- Expensive and time consuming method used to cultivate viruses
- Cells are grown under controlled conditions outside their natural environment

Components of medium used in tissue culture

- Amino acids, vitamins, salts, glucose, bicarbonate buffer system
- Blood serum is usually added to obtain best growth
- Antibiotics are added to prevent bacterial and fungal contamination

3. Use of whole organs or part of organs of animals

In some cases, whole organs or pieces of animal organs may be used for successful replication of viruses - Involves use of less-controlled laboratory environment because part of animal is used - Animals used include: monkeys, rabbits, guinea pigs, rats, hamsters, and mice - Live inoculation of human volunteers was first used for the of yellow fever.

4. Culturing viruses in embryonated chicken eggs

- Inexpensive method to culture viruses
- The yolk is nourishing and this is a suitable environment for viruses to grow in
- Fertilized chicken eggs incubated for 6-8 days after laying are used

Procedure

- The egg shell surface is disinfected with iodine and a small sterile drill is used to create a hole.
- Viruses are then inoculated into the embryo either on the chloriallantoic membrane or on the allantoic cavity (these are the sites often used to grow animal viruses)
- The hole is then sealed with gelatine and the eggs are incubated.
- Viruses may be able to reproduce only in certain parts of the embryo and thus should be injected onto the proper region.
- Examples of viruses grown in this manner include: mumps virus (prefers the allantoic cavity), myxoma virus (prefers chloriallantoic membrane).
- Infection may be characterised by local tissue lesion known as a pock whose appearance often is characteristic of the virus

5. Cultivation of plant viruses

- Cultivated in a variety of ways o Use of plant tissue culture o or Cultures of separated cells o or cultures of protoplasts o or use of Whole plants
- Leaves are mechanically inoculated when rubbed with a mixture of viruses and an abrasive such as carborandum
- When the cell walls are broken by an abrasive, viruses directly contact the plasma membrane and infect the exposed host cells
- Insects may also fill the role of an abrasive by sucking or crushing the plant leaves and thus transmitting viruses
- A localized necrotic lesion often develops due to rapid death of cells in the infected area
- Infected plants may show symptoms such as changes in pigmentation or leaf shape
- Some plant viruses can be transmitted only if a diseased part is grafted onto a healthy plant

Self-Assessment Exercises 3

1. What is the full meaning of EIAs?
2. Why are Nucleic acid amplification tests (NAAT) carried out?

2.4 Summary

Scientists classify living things to make sense of biodiversity and who how living things are related. There are three widely recognized domains: Archaea, Bacteria, and Eukarya. Viruses lack many traits of living things so the majority of scientists do not classify them as living organisms.

2.5 References/Further Readings/Web Sources

Roossinck, M. J. (2016). *Virus.* Princeton: Princeton University Press.

Widmaier, E. P., Raff, H., & Strang, K. T. (2008). *Vander's Human Physiology: The Mechanisms of Body Function* (11th ed.). Boston: McGraw-Hill Higher Education.
http://library.open.oregonstate.edu/microbiology/
http://cnx.org/contents/185cbf87-c72e-48f5-b51e-f14f21b5eabd@11.6.
https://youtu.be/0h5Jd7sgQWY?t=3
https://youtu.be/papt5kGxStc?t=1
https://youtu.be/jX3MhWWi6n4

2.6 Possible Answers to Self-Assessment Exercises

Answers to SAE 1

1. A virus is a biological entity that can only reproduce within a host. Anatomically, viruses possess nucleic acids (DNA or RNA) which are encased within a protective protein coat. These entities are able to infect all forms of life, ranging from bacteria to humans, and consequently, they bring about a multitude of diseases in their host.
2. Viruses possess trademark characteristics of both living and non-living entities. For instance, they can only reproduce within a host, just like a parasite. But unlike parasites or any other living organisms, viruses can be crystallized. During this stage, they remain dormant, until they enter another host, restarting the cycle all over.

Answers to SAE 2

1. There are four different types of viruses based on their host, namely, animal viruses, plant viruses, and bacteriophages and insect viruses
2. Classification of viruses based on their shapes and symmetry is as follows:
   i. Complex virus, eg. Poxvirus
   ii. Radial symmetry virus, eg. Bacteriophage
   iii. Cubical or icosahedral symmetry shaped virus, eg. Reovirus, Picornavirus
   iv. Rod or Spiral shaped or helical symmetry virus, eg. Paramyxovirus, orthomyxovirus

Answers to SAE 3

1. Enzyme immunoassays

2. Nucleic acid amplification tests (NAAT) are used in molecular biology to detect unique nucleic acid sequences of viruses in patient samples.

Unit 3 Basic Characteristics, Identification and Classification of Prokaryotes

Unit Structure

3.1 Introduction to the study of Bacteria

Bacteria, a type of microorganisms, possess less complex cell structures compared to various other life forms. Their command center consists of a single DNA loop containing all genetic information. Bacteria can be categorized into five groups based on their basic shapes: spherical (cocci), rod-shaped (bacilli), spiral-shaped (spirilla), comma-shaped (vibrios), or corkscrew-shaped (spirochaetes). They exist as solitary cells, pairs, chains, clusters, or interconnected chains. Bacteria are ubiquitous, thriving in every Earth ecosystem such as soil, oceans, rocks, and even arctic snow. Some organisms inhabit or reside on other living entities like plants, animals, and humans. Within the human body, bacterial cells outnumber human cells by about tenfold, with a significant concentration within the digestive system's lining. Certain bacteria are present in soil or on decomposing plant material, contributing significantly to the nutrient cycle. They play a vital role in the production of fermented foods like yogurt and soy sauce, while certain strains can spoil food and damage crops. A relatively small fraction of bacteria act as pathogens or parasites, causing diseases in plants and animals.

3.2 Intended Learning Outcomes (ILOs)

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

- Describe the evolution of a bacteria cell
- Describe the ultrastructure of a bacteria cell
- Describe the general characteristics of bacteria Classification in Bacteria

3.3 Main Contents

3.3.1 The Evolution and Ultrastructure of a Bacteria Cell

Prokaryotes are found everywhere, occupying virtually every surface with enough moisture, including living within other organisms. In the human body alone, prokaryotic cells outnumber human cells by approximately ten to one. They constitute the majority of life forms across all ecosystems. Certain prokaryotes flourish in environments that most other organisms would find inhospitable. Prokaryotes play a vital role in recycling essential nutrients like carbon and nitrogen, contributing to the development of new ecosystems, both natural and man-made. They have existed on Earth long before the emergence of multicellular life. Bacteria, characterized by their simple prokaryotic cells lacking organelles and a true nucleus, are single-celled microorganisms. They are one of the three domains of life, along with Archaea and Eukaryota, the latter two of which also consist of single-celled organisms possessing prokaryotic cells. The sheer number of bacteria contributes to their total biomass on Earth exceeding that of all plants and animals combined. The earliest life forms on our planet were bacteria, originating around 4 billion years ago. Bacteria and archaea dominated Earth's living landscape for about 3 billion years. It wasn't until 1.6 to 2 billion years ago that multicellular eukaryotes emerged. Eukaryotic cells, forming the foundation of protists, fungi, animals, and plants, also harbor remnants of bacteria. The relatively simple body design of bacteria is well-known. These single-celled microorganisms possess prokaryotic characteristics, including the absence of a nucleus and other cell organelles. They demonstrate remarkable adaptability, thriving in extreme and challenging conditions—organisms with such capabilities are known as extremophiles. Extremophiles are further categorized based on the types of extreme environments they inhabit:

1. Thermophiles
2. Acidophiles
3. Alkaliphiles
4. Osmophiles
5. Barophiles
6. Cryophiles

Bacteria possess a captivating feature in their protective cell wall, comprised of a distinctive protein called peptidoglycan. This cell wall plays a pivotal role in facilitating bacterial division and serves as a foundational structure. The exceptional nature of this protein is that it's exclusively present in bacterial cell walls, making them distinct. Nonetheless, only a minority of bacteria lack this cell wall, and certain types bolster their defenses with an additional layer referred to as a capsule. Embedded within the outer layer, one or more flagella or pili function as locomotory structures. Some bacteria employ pili to facilitate adhesion to host cells. While lacking the organelles typically seen in animal or plant cells, bacteria do have ribosomes responsible for protein synthesis. Additionally, bacteria possess an extra circular DNA known as plasmid, in addition to their main DNA. These plasmids make some strains of bacteria resistant to antibiotics. What are the different types of bacteria?

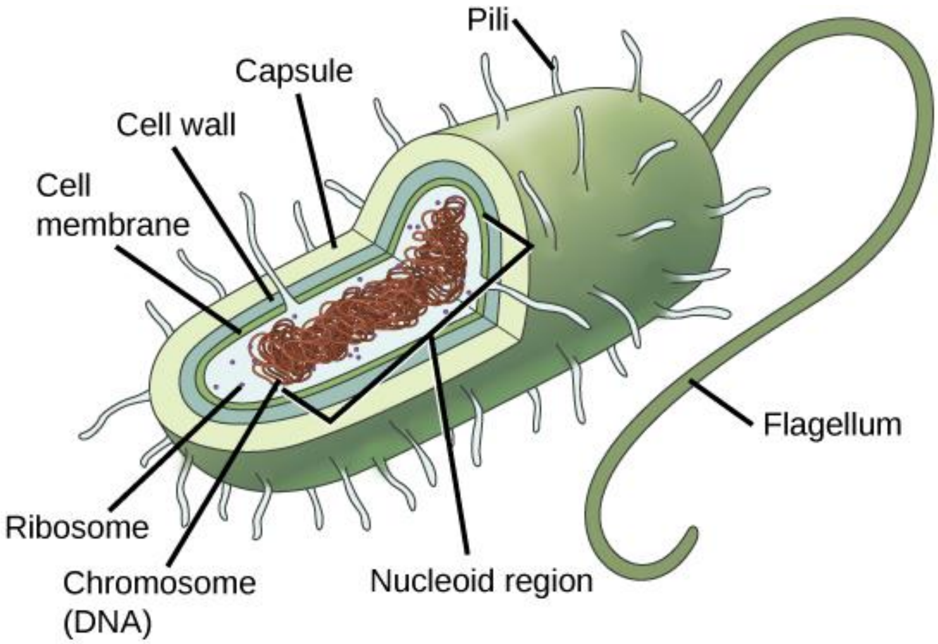


Figure 3.1 The features of a typical prokaryotic cell. Flagella, capsules, and pili are not found in all prokaryotes. Source: http://library.open.oregonstate.edu/microbiology/

Self-Assessment Exercises 1

1. The study of bacteria is called?
2. How do you define bacteria?

3.3.2 General Characteristics of Bacteria

Bacteria represent prokaryotic microorganisms composed of a single cell. The majority of bacterial species exhibit a highly pathogenic nature, contributing to diseases in both humans and animals. They possess fundamental components including a cell membrane, a nuclear region, a rigid cell wall, and ribosomes classified as the 70S subtype. Bacteria constitute a diverse group often considered among the simplest life forms. Their diversity has led to their categorization into the domains of life known as Eubacteria and Archaea. Despite this wide-ranging diversity, certain common characteristics unite bacteria, primarily their possession of prokaryotic cells. Additionally, shared attributes such as cell wall composition can be found between eubacteria and archaeans. Nonetheless, the extensive variety within the bacterial realm is further evidenced by the presence of exceptions that lack these nearly universal traits.

i. Single-Celled

Perhaps the most straightforward characteristic of bacteria is their existence as single-celled organisms. While most bacteria, archaeans and eubacteria alike, spend their entire microscopic life cycle as independent single cells, some such as the soil-dwelling myxobacteria will form multicellular fruiting bodies as part of their life cycle.

ii. Absent Organelles

Eukaryotic cells, found in organisms like plants, animals, and fungi, contain a nucleus enclosed by a membrane, which separates the cell's DNA from the surrounding cytoplasm. These cells also have distinct organelles enclosed by membranes that facilitate various cellular functions, such as mitochondria for cellular respiration and chloroplasts for photosynthesis. In contrast, bacterial cells lack a nucleus and complex membrane-bound organelles. Nonetheless, it's important to acknowledge that bacteria do exhibit internal organization, with their DNA often localized to a specific area within the bacterial cell called the nucleoid. However, it's worth noting that the nucleoid is not physically segregated from the rest of the cell by a membrane.

iii. Plasma Membrane

While plasma membranes are prevalent in various other living cells, they are not characteristic of bacteria. The lack of internal organelles in bacteria means that numerous functions typically found in eukaryotic cells take place on the plasma membrane of bacteria. As an illustration, specific invaginations of the plasma membrane enable photosynthetic bacteria to carry out the light-dependent stages of photosynthesis, a process akin to what photosynthetic eukaryotes accomplish on the thylakoid membranes within their chloroplasts.

iv. Cell Walls

The Gram stain, a fundamental technique in bacterial identification, categorizes eubacteria into two groups: Gram-positive or Gram-negative, determined by their cell wall's ability to retain crystal violet dye. The cell wall is a focal point for antibiotics like penicillin and its variants. Eubacteria known as penicilli share a common trait of having a peptidoglycan cell wall, which surrounds and reinforces the bacterial cell, offering stability and safeguarding against rupture in varying conditions. Archaeans also possess a cell wall, although their composition differs from that of peptidoglycan.

v. DNA

The distinctive multiple linear chromosomes frequently depicted in biology textbooks are a characteristic specific to eukaryotic cells. On the contrary, both archaeans and eubacteria possess a single, circular chromosome and a DNA sequence that is notably shorter than that present in eukaryotes. This reduced DNA length can be attributed partly to the comparatively simpler nature of bacterial cells, as well as to the lower occurrence of introns – segments of a gene that are excised during DNA translation into protein. Bacterial genomes are augmented by smaller DNA fragments referred to as plasmids, although these are not exclusive to bacteria and are also found in eukaryotes. Plasmids replicate within bacterial cells independently from the bacterial chromosome and can be transferred between different bacterial entities. Plasmids can confer characteristics to the host cell, such as antibiotic resistance. What are the three most notable characteristics of bacteria?

Self-Assessment Exercises 2

1. What are the examples of acidophilic bacteria?
2. What are the main characteristic features of bacteria?

3.5 Classification of Bacteria

Recall that prokaryotes are divided into two different domains, Bacteria and Archaea, which together with Eukarya, comprise the three domains of life (Figure 3.2). Major bacterial phyla include the Proteobacteria, the Chlamydias, the Spirochaetes, the photosynthetic Cyanobacteria, and the Gram-positive bacteria. The Proteobacteria are in turn subdivided into several classes, from the Alpha- to the Epsilon proteobacteria. Eukaryotic mitochondria are thought to be the descendants of alphaproteobacteria, while eukaryotic chloroplasts are derived from cyanobacteria. Archaeal phyla are described in figure 3.3 below:

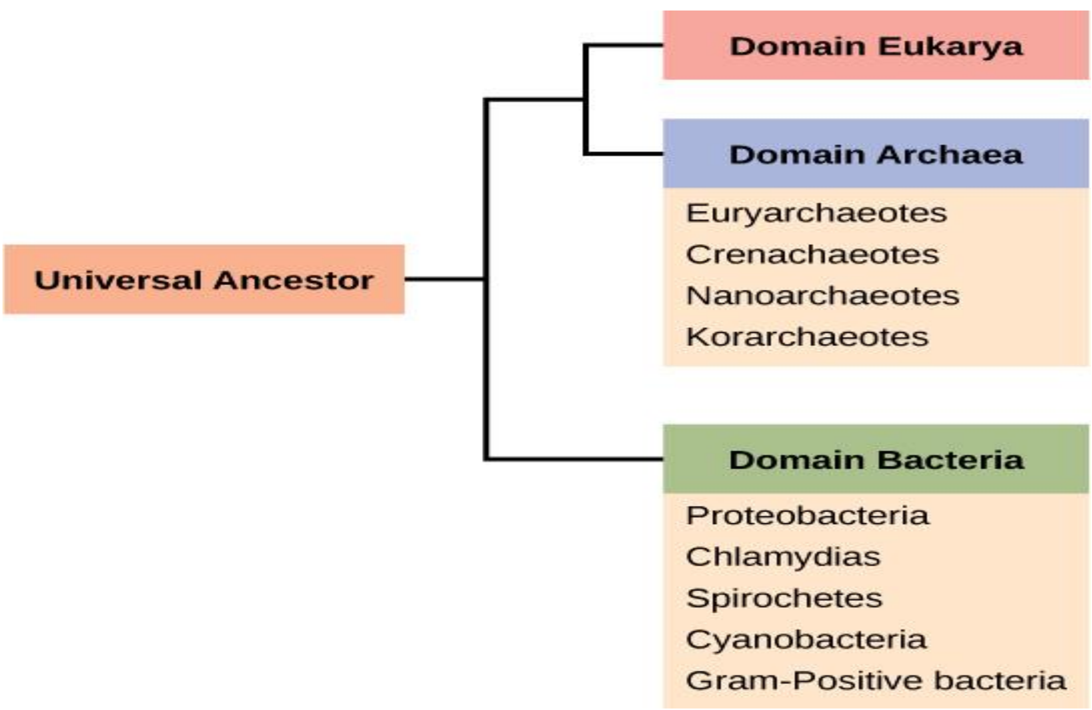


Figure 3.2: The three domains of living organisms. Source: http://library.open.oregonstate.edu/microbiology/

Most bacterial classification systems rely on key characteristics like cell shape, reaction to Gram staining, and the ability to produce spores for primary grouping. The technique of Gram staining involves using crystal violet dye, iodine, and safranin as a counterstain to differentiate bacteria. This method divides many bacteria into two groups: gram-positive bacteria, which retain the stain and appear violet under a microscope, and gram-negative bacteria, which only retain the counterstain and appear red. Gram-positive bacteria possess thick cell walls that capture the violet-iodine complex, leading to their violet coloration, whereas the delicate cell walls of gram-negative bacteria retain safranin but not the violet-iodine complex, causing them to appear red when Gram stained.

Gram staining serves for general bacterial identification or detection of specific bacteria, but not for precise species-level identification. Illustrations of gram-positive bacteria comprise genera such as Listeria, Streptococcus, and Bacillus, while gram-negative bacteria include Proteobacteria, green sulfur bacteria, and cyanobacteria.

In essence, bacteria exhibit an array of shapes. The three principal bacterial shapes are coccus (spherical or ovoid), spiral, and bacillus (rod-shaped).

- Cocci are round or oval bacteria. Some cocci stay attached after binary fission, forming pairs known as diplococci, chains referred to as streptococci, and clusters called staphylococci. Tetrads consist of four cocci in a square arrangement, and sarcinae are eight cocci forming a cube.
- Spiral bacteria possess a spiral form. Spirillums are robust spirals, whereas spirochetes are thin and flexible spirals. Vibrios are comma-shaped rods with a slight twist.
- Bacilli are rod-shaped bacteria. Like cocci, bacilli can exist individually or in arrangements. Diplobacilli represent two adjacent bacilli, and streptobacilli form chains of bacilli.

Bacteria can also take on other shapes such as filamentous (long and thin), square, star-shaped, and stalked. This diagram depicts the diverse array of bacterial shapes.

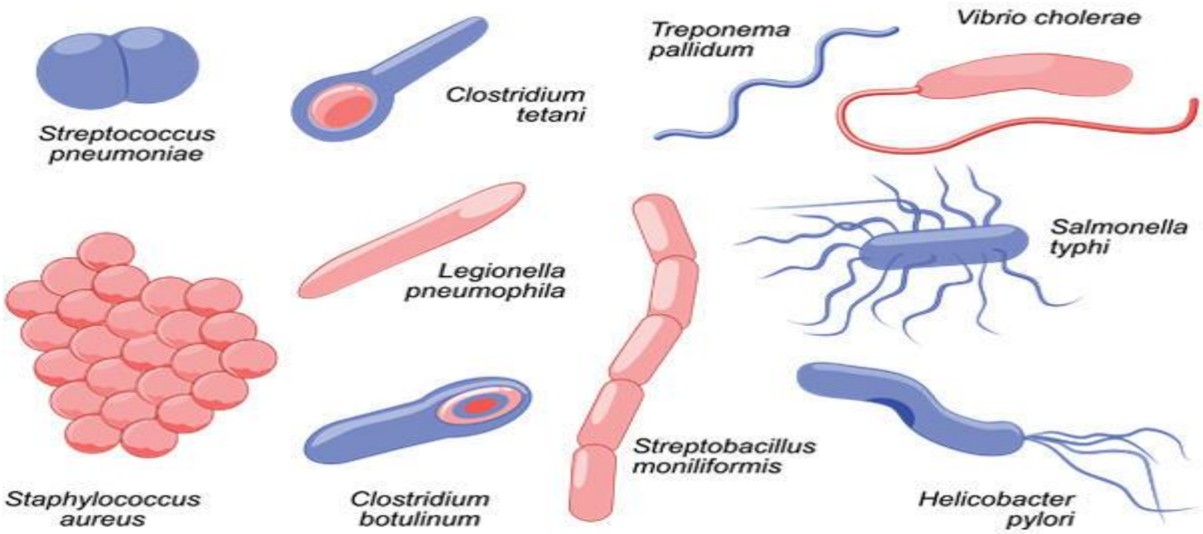


Figure 3.2 Different bacterial shapes.
Souce: https://gpatindia.com/classification-and-characteristics-of-bacteria/3.8

1. **Classification of bacteria based on Shape**

Type of Classification	**Examples**
Bacillus (Rod-shaped)	Escherichia coli (E. coli)

Spirilla or spirochete (Spiral)	Spirillum volutans
Coccus (Sphere)	Streptococcus pneumoniae
Vibrio (Comma-shaped)	Vibrio cholera

2. **Classification of bacteria based on the Composition of the Cell Wall**

Type of Classification	**Examples**
Peptidoglycan cell wall	Gram-positive bacteria
Lipopolysaccharide cell wall	Gram-negative bacteria

3. **Classification of bacteria based on the Mode of Nutrition**

Type of Classification	**Examples**
Autotrophic Bacteria	Cyanobacteria
Heterotrophic Bacteria	All disease-causing bacteria

4. **Classification of bacteria based on the Mode of Respiration**

Type of Classification	**Examples**
Anaerobic Bacteria	Actinomyces
Aerobic Bacteria	Mycobacterium

3.3.3.1 Relationship between Bacteria and Archaea

Differences and Similarities between Bacteria and Archaea		
Structural Characteristic	Bacteria	Archaea
Cell type	Prokaryotic	Prokaryotic
Cell morphology	Variable	Variable
Cell wall	Contains peptidoglycan	Does not contain peptidoglycan
Cell membrane type	Lipid bilayer	Lipid bilayer or lipid monolayer
Plasma membrane lipids	Fatty acids-glycerol ester	Phytanyl-glycerol ethers
Chromosome	Typically circular	Typically circular
Replication origins	Single	Multiple
RNA polymerase	Single	Multiple
Initiator tRNA	Formyl-methionine	Methionine
Streptomycin inhibition	Sensitive	Resistant

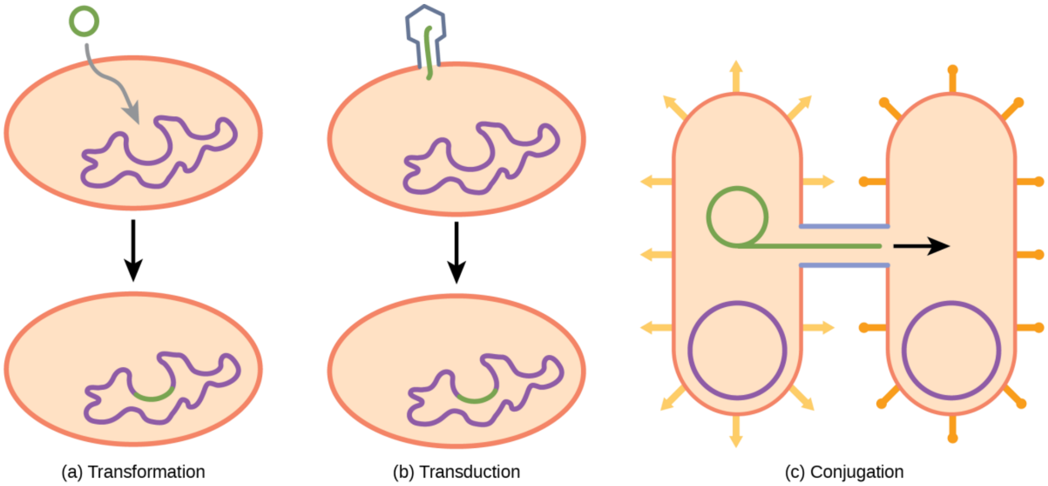
Differences and Similarities between Bacteria and Archaea		
Structural Characteristic	Bacteria	Archaea
Calvin cycle	Yes	No

3.3.4 Reproduction in Bacteria

Prokaryotic reproduction occurs asexually and is mainly achieved through a process called binary fission. In this process, which occurs because prokaryotes have a single circular chromosome for DNA, the chromosome is duplicated, and the resulting copies move apart as the cell grows. Once the cell has expanded, it undergoes constriction at its midpoint, leading to the separation of the two identical offspring cells. Although binary fission doesn't introduce genetic diversity, prokaryotes can exchange genes through alternative mechanisms.

Transformation involves a prokaryote absorbing DNA that other prokaryotes release into the environment. For instance, if a harmless bacterium acquires DNA carrying a toxin gene from a pathogen and integrates it into its own chromosome, it might also become pathogenic. In transduction, bacteriophages, viruses that infect bacteria, may transfer small sections of chromosomal DNA from one bacterium to another. This process leads to the creation of a recombinant organism. Archaea also possess viruses that can transfer genetic material between individuals. In conjugation, DNA is passed from one prokaryote to another using a pilus, a structure that brings the cells into contact and provides a conduit for DNA transfer. The DNA shared could be in the form of a plasmid or a combined molecule comprising both plasmid and chromosomal DNA. These three DNA exchange processes are depicted in Figure 3.3.

Prokaryotic reproduction can be incredibly rapid, with some species having a generation time of just a few minutes. This swift rate of reproduction, in combination with genetic recombination mechanisms and a high mutation rate, results in the swift evolution of prokaryotes. This adaptability enables them to respond promptly to changes in their environment, such as the introduction of antibiotics.



Gene transfer mechanisms in prokaryotes. There are three mechanisms by which prokaryotes can exchange DNA. In (a) transformation, the cell takes up prokaryotic DNA directly from the environment. The DNA may remain separate as plasmid DNA or be incorporated into the host genome. In (b) transduction, a bacteriophage injects DNA into the cell that contains a small fragment of DNA from a different prokaryote. In (c) conjugation, DNA is transferred from one cell to another via a mating bridge, or pilus, that connects the two cells after the sex pilus draws the two bacteria close enough to form the bridge. Source; http://library.open.oregonstate.edu/microbiology/

Self-Assessment Exercises 3

1. List the three main shapes of bacteria.
2. What are Monococcus bacteria?

3.4 Summary

Prokaryotes (domains Archaea and Bacteria) are single-celled organisms that lack a nucleus. They have a single piece of circular DNA in the nucleoid area of the cell. Most prokaryotes have a cell wall that lies outside the boundary of the plasma membrane. Some prokaryotes may have additional structures such as a capsule, flagella, and pili. Bacteria and Archaea differ in the lipid composition of their cell membranes and the characteristics of the cell wall. In archaeal membranes, phytanyl units, rather than fatty acids, are linked to glycerol. Some archaeal membranes are lipid monolayers instead of bilayers.

3.5 References/Further Readings/Web Sources

Trivedi, P.C., Pandey, S. and Bhadauria, S. (2010). Textbook of Microbiology. Pointer Publishers; First edition

Tortora, Gerard J., Funke, Berdell, R. Case, Christine, L. (2013) Microbiology:an introduction Boston : Pearson,

Madigan, M., Martinko, J. and Parker, J. 2003. Brock Biology of Microorganism, 10th ed., Pearson Education, Upper Saddle River, NJ

http://library.open.oregonstate.edu/microbiology/

https://www.slideshare.net/mylittlestobsession/the-bases-for-classifying-bacteria

https://sciencing.com/characteristics-common-bacteria-11367849.html

https://microbiologysociety.org/why-microbiology-matters/what-is-microbiology/bacteria.html

https://study.com/academy/lesson/what-is-eubacteria-definition-characteristics-examples.html

https://gpatindia.com/classification-and-characteristics-of-bacteria/3.8

https://www.youtube.com/watch?v=8IJRzcPC9wg

https://youtu.be/SI-rU5UbXaw

https://youtu.be/xPGZMUZWEmg

https://youtu.be/KXWurAmtf78

3.6 Possible Answers to Self-Assessment Exercises

Answers to SAE 1

1. The study of bacteria is called bacteriology.
2. Bacteria are prokaryotic unicellular organisms. They have a relatively simple cell structure compared to eukaryotic cells. They also do not possess any membrane-bound organelles

such as a nucleus. However, do they possess genetic material (DNA or RNA) in the intracellular space called the nucleoid

Answers to SAE 2

1. *Acetobacter aceti* and *Alicyclobacillus acidiphilus* are two examples of acidophilic bacteria.
2. The characteristic features of Bacteria are as follows:

- Bacteria are unicellular and prokaryotic organisms.
- They may be spherical, comma-shaped, rod-like, elliptical, or even occur as a cluster.
- They reproduce quickly by means of Binary fission.
- Some Bacteria are very useful for humans for example in curd making and some cause diseases like Typhoid, Cholera.

Answers to SAE 3

1. The three main shapes of bacteria are coccus, spiral, and bacillus.

2. These are also called micrococcus and represented by single, discrete round Example: *Micrococcus flavus*.

Unit 4 Eukaryotic Organisms

Unit Structure

4.1 Introduction

Living things fall into three large groups: Archaea, Bacteria, and Eukarya. The first two have prokaryotic cells, and the third contains all eukaryotes. A relatively sparse fossil record is available to help discern what the first members of each of these lineages looked like, so it is possible that all the events that led to the last common ancestor of extant eukaryotes will remain unknown. However, comparative biology of extant organisms and the limited fossil record provide some insight into the history of Eukarya. Data from these fossils have led comparative biologists to the conclusion that living eukaryotes are all descendants of a single common ancestor

4.2 Intended Learning Objectives (ILOs)

By the end of this section, you will be able to:

- Define and describe the key characteristics of eukaryotes
- Describe the endosymbiotic theory
- Explain the origin of mitochondria and chloroplasts

4.3 Main Contents

4.3.1 The Eukaryotes

Eukaryotic organisms that didn't conform to the characteristics of the Animalia, Fungi, or Plantae kingdoms were historically referred to as protists and were grouped under the Protista kingdom. Protists encompass single-celled eukaryotes found in pond water, although they inhabit various aquatic and terrestrial environments, occupying diverse niches. It's important to note that protists aren't exclusively microscopic and single-celled; some larger multicellular species like kelps also fall under this category. Over the last couple of decades, advancements in molecular genetics have revealed that certain protists share closer evolutionary relationships with animals, plants, or fungi than with other protists. As a result, some protist lineages initially categorized within the Protista kingdom have been reassigned to new kingdoms or existing ones. The exploration of protist evolutionary lineages remains an ongoing subject of investigation and discussion. Nonetheless, the term "protist" is still informally used to encompass this immensely diverse array of eukaryotic life forms. As a collective, protists showcase a remarkable assortment of shapes, physiological traits, and ecological roles. What are Protist organisms? Eukaryotic organisms that did not fit the criteria for the kingdoms Animalia, Fungi, or Plantae historically were called protists and were classified into the kingdom Protista. Most protists are microscopic, unicellular organisms that are abundant in soil, freshwater, brackish, and marine environments. They are also common in the digestive tracts of animals and in the vascular tissues of plants. Others invade the cells of other protists, animals, and plants. Not all protists are microscopic. Some have huge, macroscopic cells, such as the plasmodia (giant amoebae) of myxomycete slime molds or the marine green alga Caulerpa, which can have single cells that can be several meters in size. Some protists are multicellular, such as the red, green, and brown seaweeds. It is among the protists that one finds the wealth of ways that organisms can grow.

The volume of a typical eukaryotic cell is some 1000 times that of a typical bacterial cell. Imagine a bacterium as a 100 square foot room (the size of a small bedroom, or a large walk-in closet!) with one door. Now imagine a room 1000 times as big.That is, imagine a 100,000 square foot 'room'. You might expect many smaller rooms inside this room for such a large space to be functional. The eukaryotic cell is a lot like that large space, with lots of interior *rooms* (i.e., organelles) with their own entryways and exits. In fact, eukaryotic life would not even be possible without a division of labor of eukaryotic cells among different *organelles* (the equivalence to the small rooms in our metaphor).The smaller prokaryotic "room" has a much larger plasma membrane *surface area-to-volume ratio* than a typical eukaryotic cell. This enables required environmental chemicals to enter and quickly diffuse throughout the cytoplasm of e.g., an *E. coli* cell. The communication between chemicals and structures in a small cell is therefore rapid. In contrast, the communication over a larger expanse of cytoplasm inside a eukaryotic cell requires the coordinated (not to mention regulated!) activities of subcellular components and compartments. Such communication can be relatively slow in a large space. In fact, eukaryotic cells have lower rates of metabolism, growth, and reproduction than prokaryotic cells. Thus, the existence of large cells required the evolution of divided labors supported by *compartmentalization*.

Fungi, more closely related to animal than plant cells, are a curious beast for several reasons! For one thing, the organization of fungi and fungal cells is somewhat less defined than animal cells. Structures between cells called *septa* separate fungal *hyphae*, allow passage of cytoplasm and even organelles between cells. Some primitive fungi have few or no septa, in effect creating *coenocytes*, which are single giant cell with multiple nuclei. Fungal cells are surrounded by a wall,whose principal component is ***chitin***. Chitin is the same material that makes up the exoskeleton of *arthropods* (which includes insects and lobsters!). Typical animal and plant cells with organelles and other structures are illustrated below, in Figure 1.9 and in Figure 1.10)

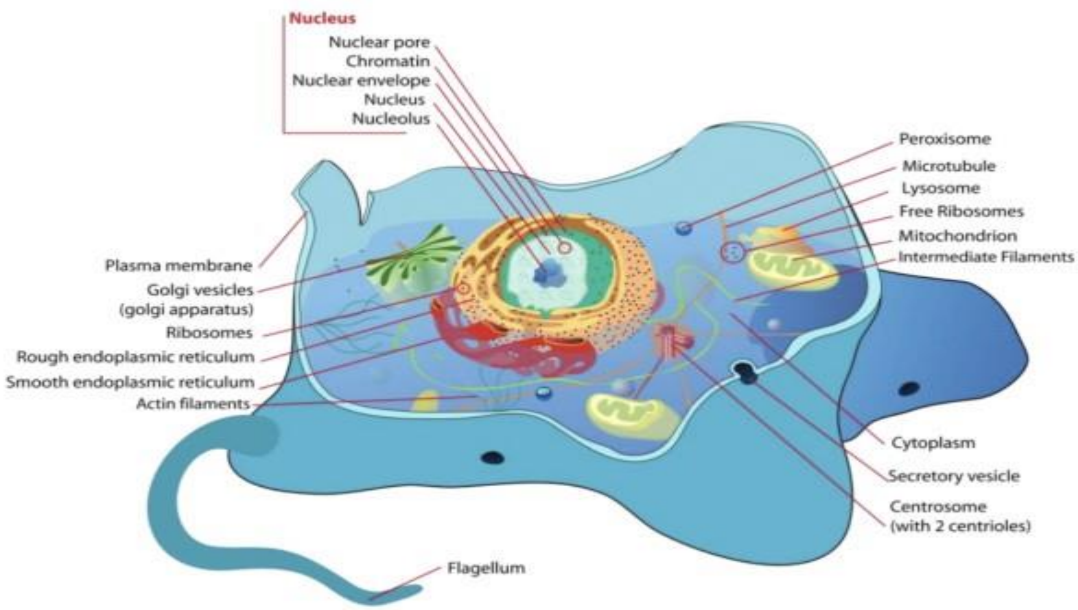


Figure4.1 Labeled drawing of the structural components of a typical animal cell.

Source: **https://evolution.berkeley.edu/evolibrary/article/history_24**

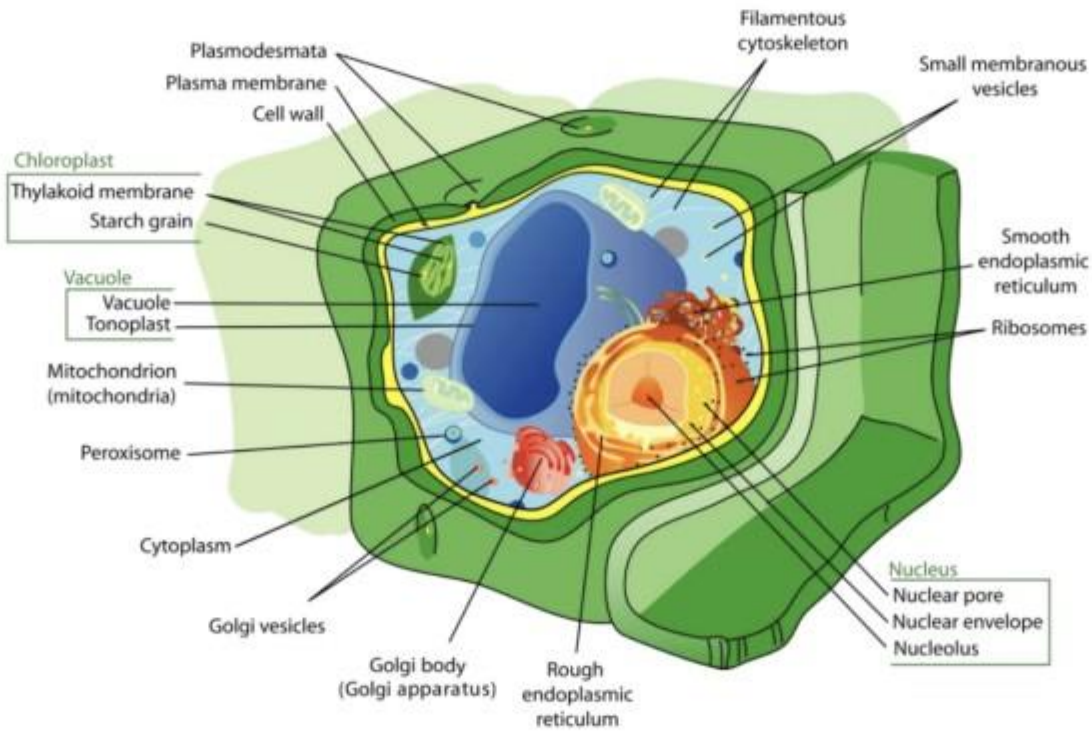


Figure 4.2 Labeled drawing of the structural components of a typical plant cell.

Source: **https://evolution.berkeley.edu/evolibrary/article/history_24**

The eukaryotes constitute the domain of **Eukaryota** , **organisms whose cells have a nucleus.** All animals, plants, fungi, and many unicellular organisms are eukaryotes. They constitute a major group of life forms, alongside the two groups of prokaryotes, the Bacteria and the Archaea.

Self-Assessment Exercises 1

1. What is the diversity of eukaryotes?
2. What are eukaryotic cells?

4.3.1.1 Characteritics of Eukaryotes

Mapping the characteristics found in all major groups of eukaryotes reveals that the following characteristics must have been present in the last common ancestor because these characteristics are present in at least some of the members of each major lineage. Some characteristics have been lost in some lineages over time.

1. Cells with nuclei surrounded by a nuclear envelope with nuclear pores.

2. Mitochondria. Some extant eukaryotes have very reduced remnants of mitochondria in their cells, whereas other members of their lineages have "typical" mitochondria.

3. A cytoskeleton containing the structural and motility components called actin microfilaments and microtubules.

4. Flagella and cilia, organelles associated with cell motility. Some extant eukaryotes lack flagella and/or cilia, but they are descended from ancestors that possessed them.

5. Chromosomes, each consisting of a linear DNA molecule coiled around basic (alkaline) proteins called histones. The few eukaryotes with chromosomes lacking histones clearly evolved from ancestors that had them.

6. Mitosis, a process of nuclear division wherein replicated chromosomes are divided and separated using elements of the cytoskeleton. Mitosis is universally present in eukaryotes. 7. Sex, a process of genetic recombination unique to eukaryotes in which diploid nuclei at one stage of the life cycle undergo meiosis to yield haploid nuclei and a subsequent stage where two haploid nuclei fuse together to create a diploid zygote nucleus.

4.3.1.2 The Endosymbiotic Theory

Eukaryotic cells are distinguished from prokaryotic cells through various characteristics, including the presence of internal membrane-bound structures like the nucleus, mitochondria, and chloroplasts. The evolutionary origins of these internal structures are a topic of interest. However, before delving into that, a discussion on energy is essential. Energy plays a fundamental role in life processes, and understanding energy metabolism differences between prokaryotes and eukaryotes is crucial.

Numerous significant metabolic processes originated in prokaryotic cells. Some of these, like nitrogen fixation, are exclusive to prokaryotes and not found in eukaryotes. In contrast, aerobic respiration, a process present across major eukaryotic lineages, takes place within mitochondria. While many prokaryotic lineages also engage in aerobic respiration, not all of them do. Several lines of evidence suggest that certain anaerobic prokaryotes and their ancestors never engaged in aerobic respiration. This relates to the fact that the Earth's early atmosphere lacked oxygen (O2), making aerobic respiration unlikely. Instead, organisms likely relied on fermentation in the absence of oxygen.

Around 3.5 billion years ago, some prokaryotes began utilizing sunlight to facilitate anabolic processes, converting carbon dioxide into organic compounds through photosynthesis. This marked the evolution of photosynthesis. Hydrogen, sourced from various origins, was harnessed using light-driven reactions in the Calvin cycle to reduce fixed carbon dioxide. A group of Gram-negative bacteria, which eventually gave rise to cyanobacteria, used water as a hydrogen source, releasing oxygen as a byproduct. However, the accumulating oxygen levels posed risks as it could damage organic compounds. This prompted the development of various protective metabolic processes, including aerobic respiration, which also generated substantial ATP.

Aerobic respiration became widespread among prokaryotes, including the group known as alpha-proteobacteria. Organisms without this metabolic capability had to inhabit oxygen-depleted environments. Initially, oxygen-rich environments were likely confined to regions with active cyanobacteria. Over time, geological evidence indicates that atmospheric oxygen levels increased around 2 billion years ago. Oxygen levels comparable to today's atmosphere only emerged within the last 700 million years. Notably, the earliest eukaryotic fossils date back around 2 billion years, coinciding with rising oxygen levels. Additionally, all existing eukaryotes trace their origins back to an ancestor with mitochondria.

The discovery of mitochondria, initially observed by light microscopists in the late 1800s, revealed worm-like structures with apparent motion within cells. Some early hypotheses suggested these structures might be bacteria living within host cells, although these ideas were largely unknown or rejected by the scientific community. Some people refute the theory that similar DNA is due to common descent, a cornerstone of endosymbiotic theory. They say that similar sequences of DNA can arise through convergent evolution, or pressure from similar sources. Why is this improbable?

4.3.1.3 Lynn Margulis and the Endosymbiotic Theory

In the late 1960s, Lynn Margulis studied the structure of cells. Mitochondria, for example, are bodies within the cell that generate the energy required for metabolism. To Margulis, they looked remarkably like bacteria. She knew that scientists had been struck by the similarity ever since the discovery of mitochondria at the end of the 1800s. Some even suggested that mitochondria began from bacteria that lived in a permanent symbiosis within the cells of animals and plants. There were parallel examples in all plant cells. Algae and plant cells have a second set of bodies (chloroplasts) that they use to carry out photosynthesis. These structures capture incoming sunlight energy and use the energy to drive biochemical reactions including the combination of water and carbon dioxide to make organic matter. Chloroplasts, like mitochondria, bear a striking resemblance to bacteria. Scientists, and Margulis in particular, became convinced that chloroplasts, like mitochondria, evolved from symbiotic bacteria — specifically, that they descended from cyanobacteria, the light-harnessing small organisms that abound in oceans and freshwater (Figure 4.1).

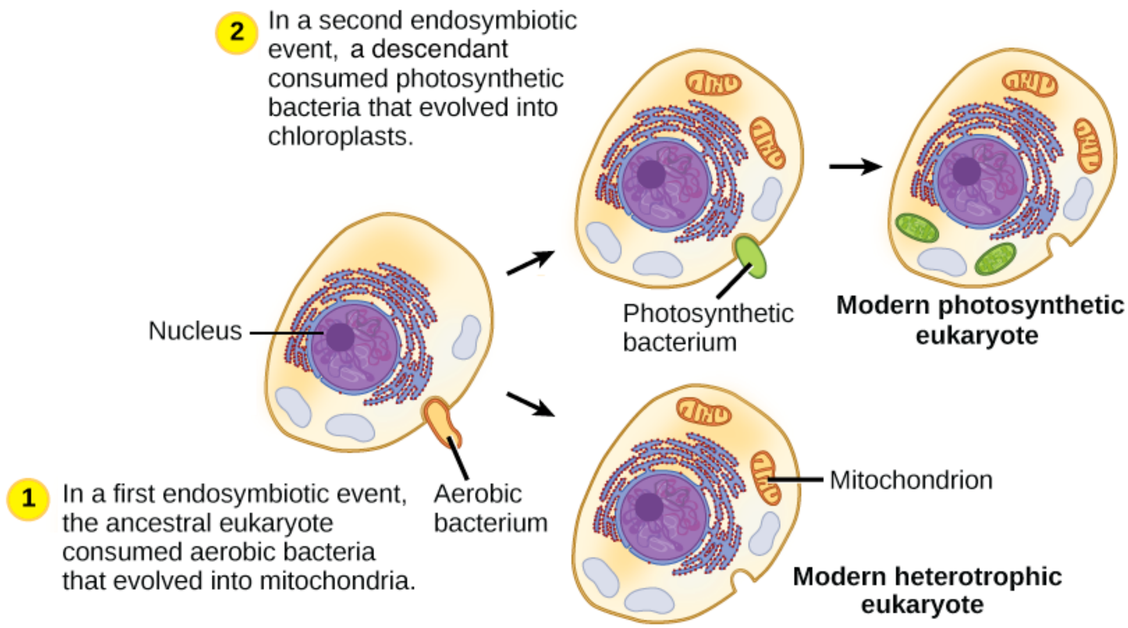


Figure 4.3 The first eukaryote may have originated from an ancestral prokaryote that had undergone membrane proliferation, compartmentalization of cellular function (into a nucleus, lysosomes, and an endoplasmic reticulum), and the establishment of endosymbiotic relationships with an aerobic prokaryote and, in some cases, a photosynthetic prokaryote to form mitochondria and chloroplasts, respectively. Source:
https://evolution.berkeley.edu/evolibrary/article/history_24

This once-revolutionary hypothesis is now widely (but not completely) accepted, with work progressing on uncovering the steps involved in this evolutionary process and the key players involved. Much still remains to be discovered about the origins of the cells that now make up the cells in all living eukaryotes. Broadly, it has become clear that many of our nuclear genes and the molecular machinery responsible for replication and expression appear closely related to those in Archaea. On the other hand, the metabolic organelles and genes responsible for many energyharvesting processes had their origins in bacteria. Much remains to be clarified about how this relationship occurred; this continues to be an exciting field of discovery in biology. For instance, it is not known whether the endosymbiotic event that led to mitochondria occurred before or after the host cell had a nucleus. Such organisms would be among the extinct precursors of the last common ancestor of eukaryotes. What is Endosymbiotic Theory?

Self-Assessment Exercises 2

1. What is an endosymbiont?
2. What is Primary endosymbiosis?

4.3.2 Secondary Endosymbiosis

Endosymbiosis involves one cell engulfing another to produce, over time, a co-evolved relationship in which neither cell could survive alone. The chloroplasts of red and green algae, for instance, are derived from the engulfment of a photosynthetic cyanobacterium by an early prokaryote. This leads to the question of the possibility of a cell containing an endosymbiont itself becoming engulfed, resulting in a secondary endosymbiosis. Molecular and morphological evidence suggest that the chlorarachniophyte protists are derived from a secondary endosymbiotic event. Chlorarachniophytes are rare algae indigenous to tropical seas and sand that can be classified into the rhizarian supergroup. Chlorarachniophytes extend thin cytoplasmic strands, interconnecting themselves with other chlorarachniophytes, in a cytoplasmic network. These protists are thought to have originated when a eukaryote engulfed a green alga, the latter of which had already established an endosymbiotic relationship with a photosynthetic cyanobacterium.

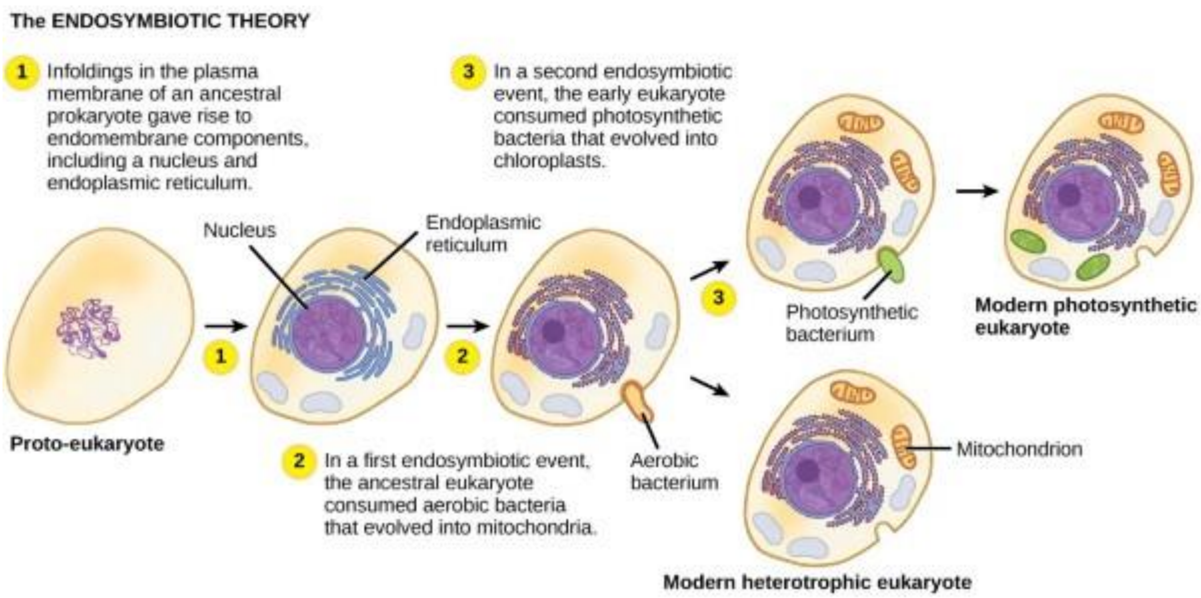


Figure 4.4 Secondary endosymbiosis in which a cell with an endosymbiont is engulfed by another cell. Source: https://evolution.berkeley.edu/evolibrary/article/history_24

Multiple pieces of evidence bolster the idea that chlorarachniophytes emerged from a secondary endosymbiotic process. The chloroplasts found within the internalized green algal symbionts retain their photosynthetic capabilities, rendering chlorarachniophytes capable of photosynthesis. The green algal symbiont also exhibits a reduced and non-functional nucleus. In fact, it seems that chlorarachniophytes have arisen relatively recently through a secondary endosymbiotic occurrence in their evolutionary history. The plastids in chlorarachniophytes are encompassed by four membranes. The initial two membranes correspond to the inner and outer membranes of the photosynthetic cyanobacterium, the third originates from the green alga, and the fourth arises from the vacuole that enclosed the green alga during its engulfment by the ancestor of the chlorarachniophyte. In other lineages that have undergone secondary endosymbiosis, only three membranes encase the plastids. This is interpreted as a progressive loss of one membrane over the course of evolution. The phenomenon of secondary endosymbiosis isn't exclusive to chlorarachniophytes. In fact, secondary endosymbiosis involving green algae also led to the emergence of euglenid protists. Similarly, secondary endosymbiosis with red algae gave rise to the evolution of dinoflagellates, apicomplexans, and stramenopiles.

Self-Assessment Exercises 3

1. What is secondary endosymbiosis?
2. What is the main difference between primary and secondary endosymbiosis?

4.4 Summary

The earliest fossil evidence of eukaryotes dates back approximately 2 billion years. Fossils older than this primarily exhibit characteristics of prokaryotes. It is likely that modern eukaryotes are descended from an ancestor with a prokaryotic structure. The most recent shared ancestor of present-day Eukarya possessed several distinctive features. These included cells containing nuclei that underwent mitotic division and featured linear chromosomes bound to histones. Additionally, this ancestor possessed a cytoskeleton, an endomembrane system, and the capability to produce cilia/flagella during specific stages of its life cycle. Its aerobic nature stemmed from the presence of mitochondria, which originated from an aerobic alphaproteobacterium residing within a host cell. The presence of a nucleus in the host cell during the initial symbiotic event remains uncertain. While the last common ancestor might have had a cell wall during some phases of its life cycle, further evidence is required to validate this hypothesis. Present-day eukaryotes exhibit a wide array of variations in terms of their shapes, structures, life cycles, and the number of cells per individual.

4.5 References/Further Readings/Web Sources

Fenchel, T., Finlay, B. J., and Esteban, G. F. (2019). Cosmopolitan Metapopulations?. Protist, 170(3), 314–318. https://doi.org/10.1016/j.protis.

Finlay B. J. (2004). Protist taxonomy: an ecological perspective. Philosophical transactions of the Royal Society of London. Series B, Biological sciences, 359(1444), 599–610. https://doi.org/10.1098/rstb.2003.1450

http://cnx.org/ contents/185cbf87-c72e-48f5-b51e-f14f21b5eabd@11.6. 23.1 Eukaryotic Origins

https://evolution.berkeley.edu/evolibrary/article/history_24
https://youtu.be/FGnS-Xk0ZqU
https://youtu.be/eCWwKrJyKxA
https://youtu.be/xTnNv7YplSo
https://youtu.be/7FN1NBoV2u0
https://youtu.be/8deF3Rw4ti4

4.6 Possible Answers to Self-Assessment Exercises

Answers to SAE 1

1. Eukaryotes are organisms that range from microscopic single cells, such as picozoans under 3 micrometres across, to animals like the blue whale, weighing up to 190 tonnes and measuring up to 33.6 metres (110 ft) long,
2. The eukaryotes constitute the domain of **Eukaryota**, **organisms whose** Eukaryotic cells **have a nucleus enclosed within the nuclear membrane and form large and complex organisms**. All animals, plants, fungi, and many unicellular organisms are eukaryotes. They constitute a major group of life forms, alongside the two groups of prokaryotes, the Bacteria and the Archaea.

Answers to SAE 2

1. An organism that lives with another organism, cause both organisms to receive benefits.
2. Primary endosymbiosis is when a prokaryotic cell is engulfed by a eukaryotic cell and becomes a symbiotic organelle. Secondary endosymbiosis results in the loss of independence of the engulfed cell and the formation of complex plastids. Secondary endosymbiosis occurred more frequently than primary endosymbiosis in evolutionary history.

Answers to SAE 3

1. Secondary endosymbiosis is a process of eukaryotic evolution in which a eukaryotic cell engulfs another eukaryotic cell that has already undergone primary endosymbiosis**.**

2. The main difference between primary and secondary endosymbiosis is that primary endosymbiosis is the engulfing and absorbing a prokaryotic cell by a eukaryotic cell, whereas secondary endosymbiosis is the engulfing and absorbing of a eukaryotic cell by another eukaryotic cell that has already undergone primary endosymbiosis.

Unit 5 The Protists

5.1 Introduction

Eukaryotic organisms that did not meet the criteria for classification into the Animalia, Fungi, or Plantae kingdoms were historically referred to as protists and grouped within the Protista kingdom. This category encompasses single-celled eukaryotes commonly found in pond water, although protist species inhabit various aquatic and terrestrial environments, occupying diverse niches. It's worth noting that not all protists are microscopic or single-celled; some large multicellular species, like kelps, also fall under this category. Advancements in molecular genetics over the past two decades have revealed that certain protists share closer genetic relationships with animals, plants, or fungi than with other protists. As a result, some protist lineages originally placed within the Protista kingdom have been reclassified into new kingdoms or existing ones. The evolutionary origins of protist lineages continue to be subject to examination and debate. Nonetheless, the term "protist" is still informally used to describe this highly diverse group of eukaryotes. Collectively, protists exhibit an astonishing array of variations in terms of their shapes, physiological traits, and ecological roles.

5.2 Intended Learning Objectives (ILOs)

By the end of this unit, you will be able to do the following:

- Define and describe the cell structure characteristics of protists
- Describe the metabolic diversity of protists
- Describe the life cycle diversity of protists
- Describe the adaptation of protists

5.3 Main Contents

5.3.1 Kingdom Protists

Protists are a group of loosely connected, mostly unicellular eukaryotic organisms that are not plants, animals or fungi. There is no single feature such as evolutionary history or morphology common to all these organisms and they are unofficially placed under a separate kingdom called Protista. Therefore, protists are no longer a formal classification, and different members show varying degrees of homology with species belonging to all five eukaryotic kingdoms. However, it is still used as a term of convenience to describe eukaryotic microscopic organisms. Initially this group included bacteria and fungi, but now it is comprised exclusively of organisms having a fully defined nucleus, with complex cellular structure but lacking tissue-level organization.
There are over 100,000 described living species of protists, and it is unclear how many undescribed species may exist. Since many protists live as commensals or parasites in other organisms and these relationships are often species-specific, there is a huge potential for protist diversity that matches the diversity of their hosts. Because the name "protist" serves as a catchall term for eukaryotic organisms that are not animal, plant, or fungi, it is not surprising that very few characteristics are common to all protists. On the other hand, familiar characteristics of plants and animals are foreshadowed in various protists.

i. Cell Structure

The cells of protists are among the most elaborate of all cells. Multicellular plants, animals, and fungi are embedded among the protists in eukaryotic phylogeny. In most plants and animals and some fungi, complexity arises out of multicellularity, tissue specialization, and subsequent interaction because of these features. Although a rudimentary form of multicellularity exists among some of the organisms labelled as “protists,” those that have remained unicellular show how complexity can evolve in the absence of true multicellularity, with the differentiation of cellular morphology and function. A few protists live as colonies that behave in some ways as a group of free-living cells and in other ways as a multicellular organism. Some protists are composed of enormous, multinucleate, single cells that look like amorphous blobs of slime, or in other cases, like ferns. In some species of protists, the nuclei are different sizes and have distinct roles in protist cell function. Single protist cells range in size from less than a micrometer to three meters in length to hectares! Protist cells may be enveloped by animal-like cell membranes or plant-like cell walls. Others are encased in glassy silica-based shells or wound with pellicles of interlocking protein strips. The pellicle functions like a flexible coat of armor, preventing the protist from being torn or pierced without compromising its range of motion.

ii. Metabolism

Protists exhibit many forms of nutrition and may be aerobic or anaerobic. Those that store energy by photosynthesis belong to a group of photoautotrophs and are characterized by the presence of chloroplasts. Other protists are heterotrophic and consume organic materials (such as other organisms) to obtain nutrition. Amoebas and some other heterotrophic protist species ingest particles by a process called phagocytosis, in which the cell membrane engulfs a food particle and brings it inward, pinching off an intracellular membranous sac, or vesicle, called a food vacuole. In some protists, food vacuoles can be formed anywhere on the body surface, whereas in others, they may be restricted to the base of a specialized feeding structure. The vesicle containing the ingested particle, the phagosome, then fuses with a lysosome containing hydrolytic enzymes to produce a phagolysosome, and the food particle is broken down into small molecules that can diffuse into the cytoplasm and be used in cellular metabolism. Undigested remains ultimately are expelled from the cell via exocytosis.

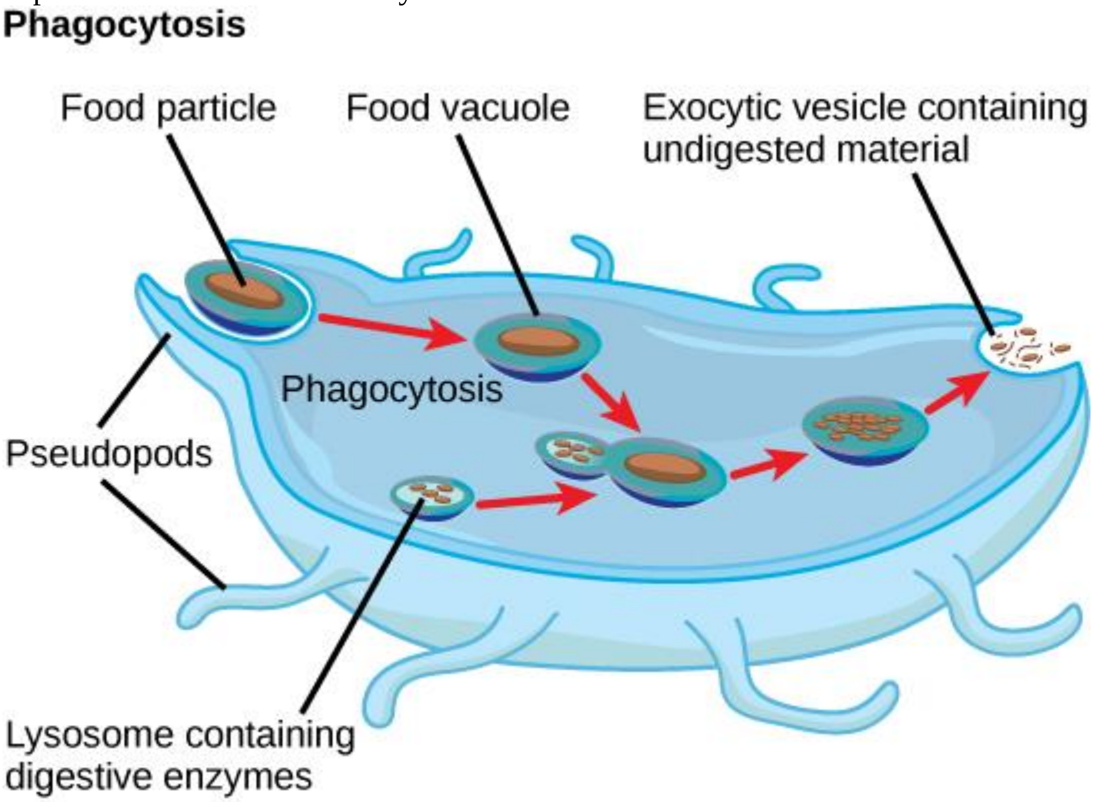


Figure 5.1 Phagocytosis. The stages of phagocytosis include the engulfment of a food particle, the digestion of the particle using hydrolytic enzymes contained within a lysosome, and the expulsion of undigested materials from the cell. Source: http://cnx.org/contents/185cbf87-c72e-48f5-b51e-f14f21b5eabd@11.6.

Subtypes of heterotrophs, called saprobes, absorb nutrients from dead organisms or their organic wastes. Some protists can function as mixotrophs, obtaining nutrition by photoautotrophic or heterotrophic routes, depending on whether sunlight or organic nutrients are available.

iii. Motility

The majority of protists are motile, but different types of protists have evolved varied modes of movement. Some protists have one or more flagella, which they rotate or whip. Others are covered in rows or tufts of tiny cilia that they beat in a coordinated manner to swim. Still others form cytoplasmic extensions called pseudopodia anywhere on the cell, anchor the pseudopodia to a substrate, and pull themselves forward. Some protists can move toward or away from a stimulus, a movement referred to as taxis. For example, movement toward light, termed phototaxis, is accomplished by coupling their locomotion strategy with a light-sensing organ.

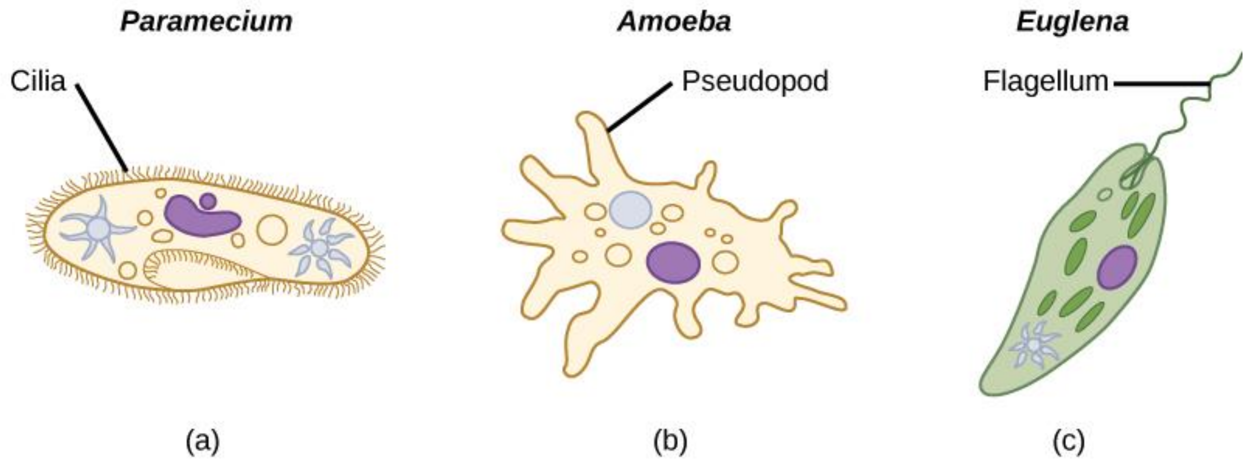


Figure 5.2 Locomotor organelles in protists. Protists use various methods for transportation. (a) Paramecium waves hair-like appendages called cilia to propel itself. (b) Amoeba uses lobe-like pseudopodia to anchor itself to a solid surface and pull itself forward. (c) Euglena uses a whip-like tail called a flagellum to propel itself. Source: http://cnx.org/contents/185cbf87-c72e-48f5-b51e-f14f21b5eabd@11.6.

iv. Life Cycles

Protists engage in a variety of reproduction methods. Most of them undergo a form of asexual reproduction, such as binary fission, which yields two daughter cells. In the case of protists, binary fission can be categorized as transverse or longitudinal based on the orientation axis. An example of this method is seen in Paramecium. Certain protists like true slime molds utilize multiple fission, dividing into multiple daughter cells simultaneously. Alternatively, some protists produce small buds that eventually divide and grow to match the size of the parent protist. Sexual reproduction, involving meiosis and fertilization, is widespread among protists. Many protist species can transition from asexual to sexual reproduction as required. Sexual reproduction often becomes prominent when nutrients become scarce or environmental shifts occur. This process allows protists to mix genes and generate new variations of offspring, some of which might be better suited to surviving alterations in their environment. However, sexual reproduction is often associated with the development of resistant cysts, which serve as protective resting stages. Depending on the species' habitat, these cysts can be remarkably resilient against factors like extreme temperatures, desiccation, or low pH levels. This strategy permits certain protists to endure stressors until their surroundings become more conducive to survival or until they are transported (by means like wind, water, or other organisms) to different environments, as cysts show minimal cellular metabolism. Protist life cycles exhibit a wide spectrum, ranging from uncomplicated to extremely intricate. Certain parasitic protists possess complex life cycles, necessitating infection of different host species during distinct developmental stages to complete their life cycle. Some protists exist as unicellular entities in their haploid form and transform into multicellular forms in the diploid state, a strategy reminiscent of animals. Other protists display multicellular phases in both haploid and diploid forms, a phenomenon known as alternation of generations, analogous to the strategy employed by plants.

v. Habitats

Nearly all protists exist in some type of aquatic environment, including freshwater and marine environments, damp soil, and even snow. Several protist species are parasites that infect animals or plants. A few protist species live on dead organisms or their wastes, and contribute to their decay. What is the majoe feature of group of photoautotrophs eukaryotes?

Self-Assessment Exercises 1

1. What are Protists organisms?
2. What are the locomotor organelles in the three major protists?

5.3.2 Protists Diversity

Protists are small, single-celled eukaryotic organisms that serve as a bridge between prokaryotes and eukaryotes. These microorganisms are typically found in aquatic habitats and play a significant role in the food chain of aquatic and marine ecosystems. They encompass a wide spectrum, ranging from autotrophic diatoms to heterotrophic amoebas. They are broadly categorized into three distinct groups: animal-like protists, plant-like protists, and fungi-like protists. In Whittaker's five-kingdom classification system, the second group consists of unicellular primitive forms as well as some that are multicellular. Their sources of nourishment and reproductive methods display notable diversity due to their wide-ranging characteristics. Protists predominantly inhabit moist environments, such as aquatic settings like lakes, oceans, rivers, marshes, as well as damp soil and puddles. They can exist as independent entities or engage in symbiotic relationships. To facilitate movement, they utilize specialized extensions like flagella, cilia, or pseudopods. While some are capable of active movement, others can be stationary and drift passively with the flow of water currents.

5.3.2.1 Animal-like protists:

They are also known as protozoa. What makes them reminiscent of animals is their capacity for movement and their method of obtaining nourishment. These are single-celled organisms with the ability to move, relying on specialized extensions like whip-like flagella or hair-like cilia. In certain organisms, there might be one or two flagella that act like oars, propelling the protist forward. Conversely, cilia are present in larger numbers on the surface of protists, and their beating motion propels the protists between locations. Similar to animals relying on plants and other autotrophs for sustenance, animal-like protists are heterotrophic, depending on other microorganisms as their source of nutrients. It's largely due to these characteristics that these protists are considered ancestral to the animal kingdom.

However, there are differences between protists and animals. Protists have simpler body organization compared to the more complex multicellular higher animals. These protists obtain sustenance through various methods, such as preying on other microorganisms like bacteria (acting as predators, as seen in paramecium), consuming photosynthetic algae (acting as herbivores), extracting nutrients from decaying matter in their environment (acting as saprophytes), or feeding on live hosts (acting as parasites, as seen in malarial plasmodium). The protozoa are further classified into four groups depending on the mode of locomotion that they possess:

- Amoeboid

It moves via the formation of the false foot that encircles the prey and engulfs the prey by the formation of vesicles. For example, *Amoeba.*

- Ciliate

They move with the help of the numerous hair-like structures on their outer surface called the cilia. The beating of the cilia in a pattered form helps the protozoa to move ahead. For example, *Paramecium*.

- Flagellate

They move with the whip-like long structure whose oar like movement helps in the propelling of the organism ahead. Mostly, there are two flagella present, one long and one short. For example, *Giardia.*

- Sporozoan

They are non-motile protozoans that do not move and reside in one given place only. For example, *Plasmodium.*

5.3.2.2 Plant-like protists

Algae comprise a group of protists that serve as a link connecting plants and prokaryotes. These organisms are autotrophic, capable of generating their own sustenance through the synthesis of nutrients from sunlight and diverse chemicals. Algae play a crucial role as primary producers within aquatic and marine ecosystems. They play a role in converting atmospheric oxygen into water and are responsible for utilizing approximately half of the Earth's carbon dioxide. Algae exhibit a spectrum of forms, ranging from single-celled varieties like diatoms to multicellular types like seaweed. What unites these protists with plants is their ability to produce their own nourishment, eliminating the need for external nutrient sources. They possess chloroplasts akin to plants. However, a notable distinction between the two lies in the less advanced nature of algae; they lack specialized structures such as roots, stems, and leaves that are characteristic of plants. Some algal cells, such as those in Chlamydomonas, exhibit mobility, while others, like kelps, are non-motile. The division of the plant-like protists is done into four main groups:

- Red algae

Procured their chloroplast from the cyanobacteria (prokaryotes). They have a red pigment called the xanthophyll that helps them to absorb a specific range of light that helps them to prepare their food. They are also called the *Rhodophyceae*. For example, *Porphyra* and *Gelidium*.

- Green algae

They also procured their chloroplast from the cyanobacteria and contain a pigment called chlorophyll. Examples are *Volvox* and *Ulva.*

- Euglenoids

Their chloroplast originated from the green algae and they also have chlorophyll. For example, *Euglena.*

- Dinoflagellates

They are characterized by the presence of two flagella, passing through their body perpendicular to each other. Their chloroplast was derived from the red algae. Examples are *Noctiluca* and *Gonyaulax*.

5.3.2.3 Fungi like protists:

Molds that feed on the dead and decaying matter are grouped into this category. They have the same mode of nutrition as the fungi and also, they form spores like the fungi. However, they are different concerning the fungi as they are motile and have a complex mode of reproduction. These protists are divided into two groups”

- Slime molds

Commonly found in rotting logs and compost. Examples are *Myxogastria* and *Physarum*.

- Water molds

Commonly found in, moist swamp and water. Examples are *Leptolegnia* and *Saprolegnia*.
What are the four major divisions of the plant-like protists?

Self-Assessment Exercises 2

1. What do you referthe animal like protists and into howmany groups were they classified?
2. What are the diferent groups of protozoans based on their mode of locomotion?

5.3.3 Habitat and Adaptation

The majority of the protists thrive in the aquatic environment, e.g. freshwater, marine milieu, damp soil, and some are even found in the snow. The common and classic example of aquatic protists is Paramecia. Paramecium is one of the most commonly used research organisms, especially in classrooms and laboratories. This is due to the ease and abundance of their availability. Some of the protists are parasitic and therefore they reside in host cells or organisms. Amoeba is a human parasite that can result in dysentery in the host human. Some of the protists thrive on the dead organisms or their wastes and are important scavengers of the ecology. Slime molds are the protists that live on bacteria and fungi found in rotting trees and forests.

While, in general, protists are typical eukaryotic cells and follow the same principles of physiology and biochemistry described for those cells within the "higher" eukaryotes (animals, fungi or plants), they have evolved a variety of unique physiological adaptations that do not appear in those eukaryotes.

- *Osmoregulation*. Freshwater protists without cell walls are able to regulate their osmosis through contractile vacuoles, specialized organelles that periodically excrete fluid high in potassium and sodium through a cycle of diastole and systole. The cycle stops when the cells are placed in a medium with different salinity, until the cell adapts.

- *Energetic adaptations*. The last eukaryotic common ancestor was aerobic, bearing mitochondria for oxidative metabolism. Many lineages of free-living and parasitic protists have independently evolved and adapted to inhabit anaerobic or microaerophilic habitats, by modifying the early mitochondria into hydrogenosomes, organelles that generate ATP anaerobically through fermentation of pyruvate. In a parallel manner, in the microaerophilic trypanosomatid protists, the fermentative glycosome evolved from the peroxisome.[74]

- *Sensory adaptations*. Many flagellates and probably all motile algae exhibit a positive phototaxis (i.e. they swim or glide toward a source of light). For this purpose, they exhibit three kinds of photoreceptors or "eyespots": (1) receptors with light antennae, found in many green algae, dinoflagellates and cryptophytes; (2) receptors with opaque screens; and (3) complex ocelloids with intracellular lenses, found in one group of predatory dinoflagellates, the Warnowiaceae. Additionally, some ciliates orient themselves in relation to the Earth's gravitational field while moving (geotaxis), and others swim in relation to the concentration of dissolved oxygen in the water.[74]

- *Endosymbiosis*. Protists have an accentuated tendency to include endosymbionts in their cells, and these have produced new physiological opportunities. Some associations are more permanent, such as *Paramecium bursaria* and its endosymbiont *Chlorella*; others more transient. Many protists contain captured chloroplasts, chloroplast-mitochondrial complexes, and even eyespots from algae. The xenosomes are bacterial endosymbionts found in ciliates, sometimes with a methanogenic role inside anaerobic ciliates.

Other adaptations of protists include**:**

- Parasitic protozoans live in a fairly constant environment, while free-living protists face short- or long-term changes in temperature, aquatic acidity, food supply, moisture, and light.
- Capture of living prey by the use of encircling pseudopodial extensions (in certain amoeboids).
- Trapping of particles of food in water currents by filters formed of specialized compound buccal organelles (in ciliates).
- Simple diffusion of dissolved organic material through the cell membrane.
- Sucking out of the cytoplasm of certain host cells (as in many parasitic protists).
- Adaptations to particular habitats over prolonged periods of time have resulted in both intracellular and extracellular elaborations seldom, if ever, found at the cellular level in higher eukaryotic species

Self-Assessment Exercises 3

1. How does the protists without cell walls regulate their osmosis?
2. What is the adaptation for protists that exhibit a positive phototaxis?

5.4 Summary

The fact that protists are an artificial collection of phylogenetically unrelated organisms contributes significantly to their extraordinary biological and ecological diversity. Protists exhibit a wide range of cell types, reproduction methods, almost every conceivable form of nourishment, and habitats. The majority of single-celled protists are movable, although they do so by use of a variety of different structures.Although the task of dividing protists into meaningful groups is still underway, genomic data have revealed many linkages that were previously ambiguous or incorrect. Currently, placing all eukaryotes into six supergroups is the prevailing theory. This system of classification aims to group species into groups that share a common ancestor.

5.5 References/Further Readings/Web Sources

Caron, David A. "Towards a molecular taxonomy for protists: benefits, risks, and applications in plankton ecology." *Journal of Eukaryotic Microbiology* 60.4 (2013): 407-413.

Foissner, W. (2007). "Protist diversity and distribution: some basic considerations." Protist diversity and geographical distribution. Springer, Dordrecht, pp1-8.

Gooday, A. J., Schoenle, A., Dolan, J. R., & Arndt, H. (2020). Protist diversity and function in the dark ocean – Challenging the paradigms of deep-sea ecology with special emphasis on foraminiferans and naked protists. European journal of protistology, 75, 125721. https://doi.org/10.1016/j.ejop.2020.125721

https://biologydictionary.net/protist/.
http://cnx.org/contents/185cbf87-c72e-48f5-b51e-f14f21b5eabd@11.6. 23.1
https://youtu.be/UOfY26qdbU0
https://youtu.be/8deF3Rw4ti4
https://youtu.be/0-6dzU4gOJo
https://youtu.be/-zsdYOgTbOk

5.6 Possible Answers to Self-Assessment Exercises

Answers to SAE 1

1. Protists are a group of loosely connected, mostly unicellular eukaryotic organisms that are not plants, animals or fungi.
2. Protists use various methods for transportation:

(a) Paramecium waves hair-like appendages called cilia to propel itself.

(b) Amoeba uses lobe-like pseudopodia to anchor itself to a solid surface and pull itself forward.

(c) Euglena uses a whip-like tail called a flagellum to propel itself.

Answers to SAE 2

3. The Protozoa, they are classified into four groups depending on the mode of locomotion that they possess.
4. The protozoa are classified into four groups depending on the mode of locomotion that they possess as follows: Amoeboid; Ciliate; Flagellate and Sporozoan

Answers to SAE 3

1. Freshwater protists without cell walls are able to regulate their osmosis through contractile vacuoles, specialized organelles that periodically excrete fluid high in potassium and sodium through a cycle of diastole and systole.
2. Many flagellates in response, exhibit three kinds of photoreceptors or "eyespots": (i) receptors with light antennae, found in many green algae, dinoflagellates and cryptophytes; (ii) receptors with opaque screens; and (iii) complex ocelloids with intracellular lenses, found in one group of predatory dinoflagellates, the Warnowiaceae.

Unit 6 Basic Characteristics, Identification and Classification of Fungi

Unit Structure

6.1 Introduction

The word fungus comes from the Latin word for mushrooms. Indeed, the familiar mushroom is a reproductive structure used by many types of fungi. However, there are also many fungus species that don't produce mushrooms at all. Being eukaryotes, a typical fungal cell contains a true nucleus and many membrane-bound organelles. The kingdom Fungi includes an enormous variety of living organisms collectively referred to as Eumycota, or true Fungi. While scientists have identified about 100,000 species of fungi, this is only a fraction of the 1.5 million species of fungus likely present on Earth. Edible mushrooms, yeasts, black mold, and the producer of the antibiotic penicillin, Penicillium notatum, are all members of the kingdom Fungi, which belongs to the domain Eukarya.

6.2 Intended Learning Objectives (ILO)

By the end of this section, you will be able to:

- Explain what a fungi is.
- List the characteristics of fungi
- Describe fungal parasites and pathogens of plants and infections in humans
- Describe the importance of fungi to the environment
- Summarize the beneficial role of fungi in food and beverage preparation and in the chemical and pharmaceutical industry

6.3 Main Contents

6.3.1 The Study of Fungi

The term "fungus" originates from the Latin word for mushroom. While the familiar mushrooms indeed fall under the category of fungi, there exists a diverse range of other fungal types as well (as depicted in Figure 6.1). The kingdom Fungi encompasses an immense variety of living organisms. Although scientists have identified around 135,000 fungal species, this accounts for just a fraction of the likely over 1.5 million fungal species present on Earth. Members of the kingdom Fungi, situated within the domain Eukarya, encompass edible mushrooms, yeasts, black mold, and Penicillium notatum (the producer of the antibiotic penicillin). As eukaryotes, typical fungal cells possess a genuine nucleus and numerous membrane-bound organelles.

In the past, fungi were perceived as plant-like entities; however, DNA comparisons have revealed that fungi share a closer genetic connection with animals than with plants. Fungi are incapable of photosynthesis, relying instead on complex organic compounds as their energy and carbon sources. The reproduction strategies of fungal organisms vary, with some exclusively reproducing asexually and others engaging in both asexual and sexual reproduction. The majority of fungi generate a multitude of spores that are dispersed by the wind. Analogous to bacteria, fungi play a vital role in ecosystems by acting as decomposers and participating in nutrient cycling through the breakdown of organic materials into simpler molecules.

Fungi often interact with other organisms, forming mutualistic relationships that are beneficial to both parties. However, fungi can also cause severe infections in plants and animals. For instance, Dutch elm disease, an extremely destructive fungal infection, targets many native elm species (Ulmus spp.). This fungus invades the tree's vascular system and was unintentionally introduced to North America in the 1900s, resulting in the widespread devastation of elm trees. The cause of Dutch elm disease is the fungus Ophiostoma ulmi, which is transmitted by the elm bark beetle from one tree to another. While European and Asiatic elms are generally less vulnerable, American elms are more susceptible.

In the context of humans, fungal infections pose a significant challenge to treat because, unlike bacteria, they do not respond to conventional antibiotic therapy due to their shared eukaryotic nature. Such infections can be especially dangerous for individuals with compromised immune systems. Fungi have diverse commercial applications: the food industry employs yeasts in baking, brewing, and winemaking, and various industrial compounds result from fungal fermentation. Moreover, many commercial enzymes and antibiotics originate from fungi.

6.3.1.1 Cell Structure and Function

Because they are eukaryotes, fungi have a sophisticated cellular structure. Fungal cells are eukaryotes and have a membrane-bound nucleus. Some varieties of fungi have structures resembling the plasmids (DNA loops) found in bacteria. Additionally, mitochondria and a sophisticated network of internal membranes, including the endoplasmic reticulum and Golgi apparatus, are found in fungus cells.Chloroplasts do not exist in fungus cells. Despite lacking the pigment necessary for photosynthetic life, chlorophyll, many fungi exhibit vibrant hues, from red to green to black. Fly agaric, a deadly Amanita muscaria, can be identified by its brilliant red crown with white patches (Figure 6.1). Fungi have pigments that are connected to their cell walls and act as a UV radiation shield. Some colors are poisonous.

Figure 6.1 *Amanita muscaria*, a poisonous species of mushroom
Source: http://openstaxcollege.org/l/fungi_kingdom

The stiff layers of the fungal cell wall are thick, like those of plant cells, but instead of cellulose, which is what plant cells employ, they are made of the complex polysaccharides chitin and glucan. The cell walls of fungi are strengthened structurally by chitin, which is also present in the exoskeleton of insects. The wall supports the cell's structural integrity and shields it from some predators and desiccation. Fungi have plasma membranes that are comparable to those of other eukaryotes, with the exception that ergosterol, a steroid molecule that performs similarly to the cholesterol present in animal cell membranes, stabilizes the structure. most people living in the kingdom Fungi do not move. Only the gametes in the archaic division Chytridiomycota may form flagella.

6.3.1.2 Growth and Reproduction

The fungal body, referred to as a thallus, can exist as either a single cell or as a collection of multiple cells. Some fungi exhibit a dual nature known as dimorphism, where they can transition from a single-celled to a multicellular state based on environmental conditions. Yeasts are the common designation for unicellular fungi. Examples of unicellular fungi include Saccharomyces cerevisiae (baker's yeast) and Candida species (responsible for thrush, a common fungal infection). The majority of fungi are multicellular entities that manifest two distinct morphological phases: vegetative and reproductive. The vegetative phase is characterized by an interweaving network of slender thread-like structures called hyphae (singular: hypha). In contrast, the reproductive phase tends to be more visibly prominent. A collection of hyphae is known as a mycelium (depicted in Figure 6.2). Mycelium can develop on surfaces, within soil or decaying matter, in liquids, or even within or on living tissues. While individual hyphae necessitate observation under a microscope, the mycelium of a fungus can grow to significant sizes, with certain species achieving monumental proportions. The Armillaria ostoyae, a massive honey mushroom, holds the distinction of being considered the largest organism on the planet. It spans more than 2,000 acres of subterranean soil in eastern Oregon and is estimated to be at least 2,400 years old.

Figure 6.2 The mycelium of the fungus *Neotestudina rosati*
Source: http://openstaxcollege.org/l/fungi_kingdom

The majority of fungal hyphae are segmented into distinct cells through end walls known as septa (singular: septum). In most fungal divisions (referred to as divisions, analogous to plant phyla by convention), these septa feature small openings that enable rapid nutrient and small molecule movement between cells along the hyphae. These are termed perforated septa. However, the hyphae in bread molds (classified under the Zygomycota division) lack septa and are composed of large cells containing multiple nuclei. This arrangement is termed coenocytic hyphae. Fungi thrive in environments characterized by moisture and slightly acidic conditions. They can flourish in both dark and well-lit settings. Their oxygen requirements vary: the majority are obligate aerobes, relying on oxygen for survival. On the other hand, certain species like Chytridiomycota found in cattle rumens are obligate anaerobes, unable to thrive and reproduce in oxygen-rich environments. Yeasts fall in between, thriving in oxygen-rich conditions but also capable of fermentation when oxygen is scarce. Yeast fermentation produces alcohol used in the production of wine and beer, and the carbon dioxide they generate adds carbonation to beer and sparkling wine while making bread dough rise. The reproductive stage of fungi can take either sexual or asexual forms. In both cases, fungi generate spores that disperse from the parent organism either by floating in the wind or hitching rides on animals. Although fungal spores are smaller and lighter than plant seeds, they typically don't disperse as high in the air. The giant puffball mushroom, for example, bursts open to release trillions of spores, maximizing the chances of these spores landing in environments conducive to growth (Figure 6.3).

(a) (b)

Figure 6.3 The (a) giant puffball mushroom releases (b) a cloud of spores when it reaches maturity. Source: http://openstaxcollege.org/l/fungi_kingdom

6.3.1.3 How Fungi Obtain Nutrition

Lke animals, fungi are heterotrophic organisms. Instead of fixing carbon dioxide from the atmosphere like certain bacteria and most plants, fungi rely on intricate organic compounds as their source of carbon. Furthermore, fungi do not engage in nitrogen fixation from the atmosphere and, akin to animals, they must acquire nitrogen from their diet. However, unlike the majority of animals that ingest food and then internally digest it within specialized organs, fungi reverse this process. Digestion precedes ingestion. Initially, exoenzymes – enzymes that catalyze reactions on substances external to the cell – are secreted from the hyphae to break down nutrients in the surrounding environment. Subsequently, the smaller molecules resulting from this external digestion are absorbed through the expansive surface areas of the mycelium. Analogous to animal cells, fungi store their polysaccharides as glycogen rather than starch, as is found in plants.

Predominantly, fungi are saprobes, organisms that extract nutrients from decaying organic matter. They primarily derive their nourishment from deceased or decomposing organic material, largely plant-based. Fungal exoenzymes possess the capability to break down insoluble polysaccharides, such as cellulose and lignin found in decaying wood, into glucose molecules that can be easily absorbed. Decomposers, a vital component of ecosystems, play a critical role in releasing nutrients from deceased organisms, rendering them usable for other life forms. This ecological function is explored in more detail later. With their diverse metabolic pathways, fungi fulfill crucial ecological functions and are being explored as potential tools for bioremediation. For instance, certain fungal species can be harnessed to degrade diesel oil and polycyclic aromatic hydrocarbons, while others are capable of absorbing heavy metals like cadmium and lead. What does the Latin word for mushroom called?

Self-Assessment Exercises 1

1. Why are Fungi no more considered plant-like organisms
2. What is the prepared habitat for Fungi?

6.3.2 Fungal Diversity

The kingdom Fungi is comprised of four primary divisions established based on their method of sexual reproduction. Additionally, for convenience, fungi that reproduce asexually and are unrelated are placed into a fifth division, and a sixth major fungal category that doesn't neatly fit into any of the preceding five has been recently described. It's worth noting that not all experts in the field of mycology universally agree with this classification system. Ongoing advancements in molecular biology and the sequencing of 18S rRNA, a component of ribosomes, consistently unveil novel and divergent connections between various fungal categories. The classical divisions within the Fungi realm encompass the Chytridiomycota (chytrids), Zygomycota (conjugated fungi), Ascomycota (sac fungi), and Basidiomycota (club fungi). A previous classification scheme had placed fungi that solely engaged in asexual reproduction under the Deuteromycota label, although this group is no longer widely utilized. The **Glomeromycota** belong to a newly described group (Figure 6.4).

Figure 6.4 Divisions of fungi include (a) chytrids, (b) conjugated fungi, (c) sac fungi, and (d) club fungi. Source: http://openstaxcollege.org/l/fungi_kingdom

6.3.2.1 Pathogenic Fungi

Numerous fungi exert adverse effects on various species, encompassing humans and the organisms vital for their sustenance. Fungi can function as parasites, pathogens, and, although quite rarely, predators. Ensuring the production of ample and high-quality crops is pivotal for our survival. The devastation of crops due to plant diseases has led to severe famine incidents. A significant portion of plant pathogens are fungi, which incite the decay of tissues and ultimately bring about the death of the host organism (illustrated in Figure 6.5). Beyond direct destruction of plant tissue, certain plant pathogens taint crops by producing potent toxins. Fungi are additionally accountable for the spoilage of food and the decomposition of stored crops. As an instance, the fungus Claviceps purpurea triggers ergot, a disease affecting cereal crops, particularly rye. While the fungus indeed diminishes cereal yields, the ramifications of ergot's alkaloid toxins on humans and animals are of even greater importance: among animals, the ailment is known as ergotism. Manifestations commonly involve convulsions, hallucinations, gangrene, and a decline in milk production in cattle. The central component of ergot is lysergic acid, which serves as a precursor to the drug LSD. Further instances of frequent fungal pathogens influencing crops comprise smuts, rusts, and powdery or downy mildews.

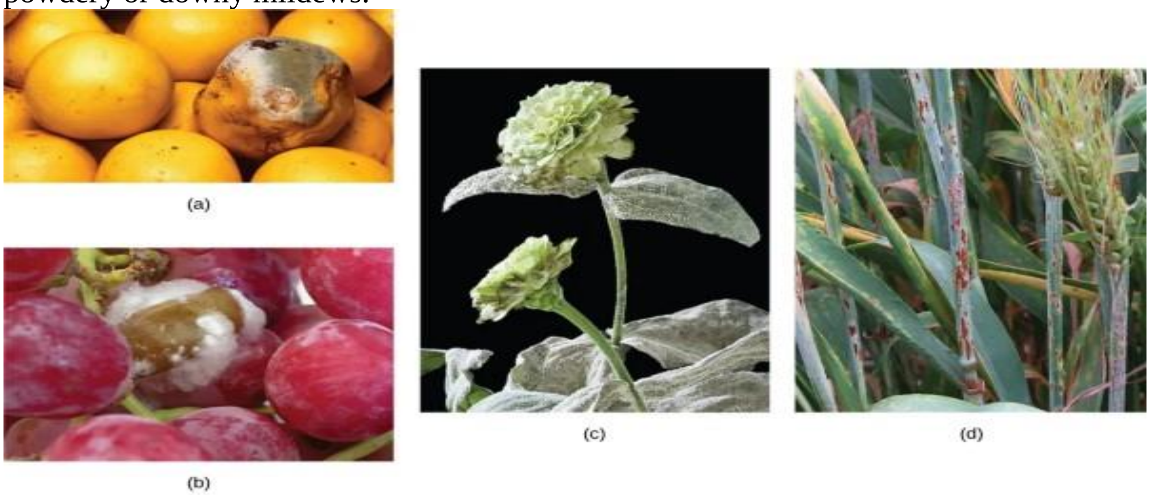


Figure 6.5 Some fungal pathogens include (a) green mold on grapefruit, (b) fungus on grapes, (c) powdery mildew on a zinnia, and (d) stem rust on a sheaf of barley. Notice the brownish color of the fungus in (b) *Botrytis cinerea*, also referred to as the "noble rot," which grows on grapes and other fruit. Controlled infection of grapes by *Botrytis* is used to produce strong and much-prized dessert wines. Source: http://openstaxcollege.org/l/fungi_kingdom

Aflatoxins are toxic and carcinogenic compounds released by fungi of the genus *Aspergillus*. Periodically, harvests of nuts and grains are tainted by aflatoxins, leading to massive recall of produce, sometimes ruining producers, and causing food shortages in developing countries.

6.3.3.2 Animal and Human Parasites and Pathogens

Fungi can impact animals, humans included, through various avenues. They directly assault animals by invading and damaging tissues. Toxic mushrooms or food contaminated with fungi can poison humans and other animals. Moreover, individuals who exhibit heightened sensitivity to molds and spores experience intense and perilous allergic responses. Treating fungal infections is generally challenging due to the fact that fungi are eukaryotic, in contrast to bacteria. Antibiotics exclusively target prokaryotic cells, whereas compounds that eliminate fungi also harm the eukaryotic host.

Numerous fungal infections (referred to as mycoses) are superficial and classified as cutaneous mycoses, which primarily affect the skin's surface. They are typically visible on the animal's skin. Fungi causing these superficial mycoses of the epidermis, hair, and nails seldom infiltrate the underlying tissue (as depicted in Figure 6.6). These fungi are sometimes mistakenly termed "dermatophytes" (from the Greek words dermis for skin and phyte for plant), even though they aren't plants. Also known as "ringworms," they trigger the characteristic red ring on the skin (although it's fungi causing the ring, not a worm). These fungi release external enzymes that degrade keratin, a protein present in hair, skin, and nails. This leads to conditions such as athlete's foot, jock itch, and other skin-related fungal infections. Typically, these ailments can be easily treated with over-the-counter topical creams and powders. Yet, persistent superficial mycoses might necessitate oral medications prescribed by a healthcare professional.

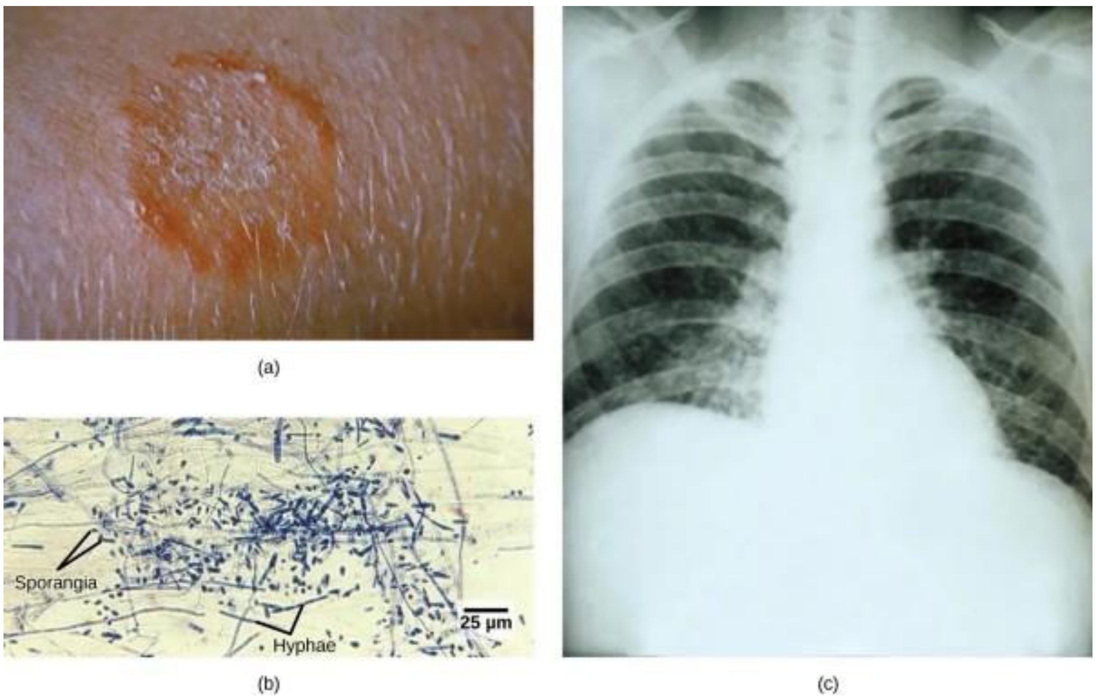


Figure 6.6 (a) Ringworm presents as a red ring on the skin. (b) *Trichophyton violaceum* is a fungus that causes superficial mycoses on the scalp. (c) *Histoplasma capsulatum*, seen in this X-ray as speckling of light areas in the lung, is a species of Ascomycota that infects airways and causes symptoms similar to the flu. Source: http://openstaxcollege.org/l/fungi_kingdom

Systemic mycoses disseminate to internal organs, often infiltrating the body through the respiratory system. A prime example is coccidioidomycosis, commonly known as valley fever, where the fungus is present in dust. Upon inhalation, the spores develop within the lungs and induce symptoms akin to tuberculosis. Histoplasmosis, caused by the dimorphic fungus Histoplasma capsulatum (depicted in Figure 6.6c), leads to pulmonary infections and, in rare instances, inflammation of the brain and spinal cord membranes. Treating numerous fungal illnesses necessitates antifungal medications, which can entail severe side effects.

Opportunistic mycoses involve fungal infections prevalent in all environments or a typical part of the natural biota. They predominantly impact individuals with compromised immune systems. Patients in the advanced stages of AIDS often encounter opportunistic mycoses, like Pneumocystis, which can pose life-threatening risks. The yeast Candida spp., a regular component

of the natural biota, can proliferate uncontrollably if pH levels, immune defenses, or the usual bacterial population are disrupted, resulting in yeast infections such as vaginal or oral thrush.
Fungi can even adopt a predatory lifestyle. Within nitrogen-poor soil environments, certain fungi resort to preying on nematodes, tiny roundworms. Species of Arthrobotrys fungi employ diverse mechanisms to ensnare nematodes. For instance, they possess constricting rings within their network of hyphae. When a nematode comes into contact with these rings, they expand and close around the nematode's body, entrapping it. The fungus extends specialized hyphae that infiltrate the worm's body and gradually digest the unsuspecting prey. What are Deuteromycota fungi?

Self-Assessment Exercises 2

1. What are the four traditional divisions of Fungi?
2. What are opportunistic mycoses?

6.3.4 Beneficial Fungi

Fungi play a crucial role in the balance of ecosystems. They colonize most habitats on Earth, preferring dark, moist conditions. They can thrive in seemingly hostile environments, such as the tundra, thanks to a most successful symbiosis with photosynthetic organisms, like lichens. Fungi are not obvious in the way that large animals or tall trees are. Yet, like bacteria, they are major decomposers of nature. With their versatile metabolism, fungi break down organic matter that is insoluble and would not be recycled otherwise.

1. Importance to Ecosystems

Fungi play essential roles in food webs by participating in the decomposition of organic matter. This process is crucial for the recycling of nutrients like carbon, nitrogen, and phosphorus, allowing them to re-enter the environment and become available to living organisms rather than remaining trapped in deceased organisms. Fungi are especially significant due to their evolution of enzymes capable of breaking down cellulose and lignin, components of plant cell walls that are challenging for many other organisms to digest, thus releasing their carbon content.
Fungi are also integral to ecologically vital symbiotic relationships, ranging from mutualistic to pathogenic interactions with organisms from different kingdoms. Mycorrhiza, a term derived from the Greek words "myco" meaning fungus and "rhizo" meaning root, describes the connection between vascular plant roots and their symbiotic fungi. The majority of plant species, around 80-90 percent, engage in mycorrhizal partnerships. Within these associations, fungal mycelia use their extensive hyphal network and substantial surface area to transport water and minerals from the soil to the plant. In return, the plant supplies the products of photosynthesis to fuel the fungus's metabolism. Ectomycorrhizae encompass fungi encasing roots in a mantle sheath and hyphal net, while Glomeromycota fungi create arbuscular mycorrhiza where specialized hyphae penetrate root cells, facilitating metabolic exchanges. Orchids rely on yet another type, forming a partnership with Basidiomycota for essential nutrients to sustain their growth.
Lichens, found on rocks and tree bark, encompass a diverse range of colors and textures. They serve as pioneer organisms, colonizing barren rock surfaces in environments created by glacial recession. Lichens extract nutrients from rocks, initiating soil formation. They also inhabit mature habitats on rocks and tree trunks, serving as a vital food source for caribou. Lichens comprise both

a fungal component (usually Ascomycota or Basidiomycota) and a photosynthetic organism (an alga or cyanobacterium). The thallus, the body of a lichen, is composed of hyphae enveloping the photosynthetic partner. The photosynthetic organism provides energy and carbon, while the fungal partner offers protection and essential minerals.

Fungi have also established mutualistic partnerships with various arthropods. An example is the association between Basidiomycota species and scale insects. The fungal mycelium shields and supports insect colonies, with the insects channeling nutrients from plants to the fungus. Another instance involves leaf-cutting ants in Central and South America, which cultivate fungi by farming leaves. The ants use the fungi to break down cellulose in the leaves they collect, creating smaller sugar molecules for consumption. The ants, in turn, feed on the fungi and protect their gardens by eliminating competing fungi. This association benefits both the ants and the cultivated fungi by providing a continuous supply of resources and eliminating competition.

2. Importance to Humans

While fungi are commonly associated with causing diseases and food spoilage, they hold significant importance for human life across various aspects. Their influence extends to the well-being of human populations on a larger scale as they play a crucial role in nutrient cycling within ecosystems. Fungi also fulfill other roles within ecosystems, such as acting as pathogens for animals, which aids in controlling populations of harmful pests. These fungal pathogens are highly specialized for the insects they target and do not infect other organisms like animals or plants. Researchers are exploring the potential of using fungi as microbial insecticides, and some species are already available in the market for this purpose. For instance, Beauveria bassiana, a fungus, is being tested as a potential solution to manage the emerald ash borer's recent proliferation. The mycorrhizal association between fungi and plant roots is vital for maintaining the productivity of farmland. The presence of these fungi in root systems is crucial for the survival of 80-90% of trees and grasses. Mycorrhizal fungal inoculants are sold as soil amendments in gardening supply stores and are advocated by proponents of organic farming, although evidence regarding their effectiveness remains limited. Fungi also contribute to our diets, with mushrooms being a notable example. Mushrooms like morels, shiitake mushrooms, chanterelles, and truffles are considered delicacies and find their place in various culinary creations. The common meadow mushroom, Agaricus campestris, is a staple ingredient in numerous dishes. Certain cheeses owe their distinct characteristics to molds from the Penicillium genus. These molds originate from natural environments, such as the caves of Roquefort, France, where they infuse sheep milk cheese with the blue veins and strong flavor that define the cheese's profile.


.

Figure 6.7 The morel mushroom is an ascomycete that is much appreciated for its delicate taste. Source: http://openstaxcollege.org/l/fungi_kingdom

Humans have been practicing the ancient skill of fermentation for thousands of years, using grains to make beer and fruits to make wine. Under anaerobic conditions, wild yeasts are obtained from the environment and used to ferment carbohydrates into CO2 and ethyl alcohol. Wild yeast isolated strains from several wine-making regions can now be bought. Saccharomyces cerevisiae, a dependable strain of brewer's yeast created for the French brewing business in the late 1850s, was made possible in large part by Pasteur. One of the earliest instances of biotechnology patenting was this one. Breads that rise are also made with yeast. The bubbles that form in the dough and turn into the air pockets of the cooked bread are caused by the carbon dioxide they release.Many secondary metabolites of fungi are of great commercial importance. Antibiotics are naturally produced by fungi to kill or inhibit the growth of bacteria, and limit competition in the natural environment. Valuable drugs isolated from fungi include the immunosuppressant drug cyclosporine (which reduces the risk of rejection after organ transplant), the precursors of steroid hormones, and ergot alkaloids used to stop bleeding. In addition, as easily cultured eukaryotic organisms, some fungi are important model research organisms including the red bread mold *Neurospora crassa* and the yeast, *S. cerevisiae.* **IN-TEXT QUESTION (ITQ):** Example of some fungi that are important model research organisms include? The red bread mold *Neurospora crassa* and the yeast, *S. cerevisiae.*

Self-Assessment Exercises 3

1. What is mycorrhizal association?
2. List any four Mushrooms that figure prominently in the human diet.

6.4 Summary

Eukaryotic creatures known as fungi first arrived on land more than 450 million years ago. They are heterotrophs and lack organelles like chloroplasts as well as photosynthetic pigments like chlorophyll. They are saprobes because they consume decaying and dead stuff. Fungi are significant decomposers that discharge vital substances into the environment. External enzymes break down nutrients that are taken in by the thallus, the fungus's body. The cell is enclosed by a substantial chitin cell wall. Fungi can grow a network of filaments termed a mycelium, which is sometimes compared to mold, or they can be unicellular like yeasts. Most animals reproduce sexually and asexually in cycles that alternate between generations.

6.5 References/Further Readings

Laakso, M.M., Paliulis, L.V., Croonquist, P., Derr, B., Gracheva, E., Hauser, C., Howell, C., Jones, C.J., Kagey, J.D., Kennell, J., Silver Key, S.C., Mistry, H., Robic, S., Sanford, J., Santisteban, M., Small, C., Spokony, R., Stamm, J., Van Stry, M., Leung, W., Elgin, S.C.R. 2017. An undergraduate bioinformatics curriculum that teaches eukaryotic gene structure. CourseSource. https://doi.org/10.24918/cs.2017.13

Prokaryotic Diversity – VCU BIOL 152: Introduction to Biological Sciences II (pressbooks.pub)
https://biologydictionary.net/protist/.

http://cnx.org/contents/185cbf87-c72e-48f5-b51e-f14f21b5eabd@11.6. 23.1
http://openstaxcollege.org/l/fungi_kingdom
http://openstaxcollege.org/l/lichenland
www.umn.edu

6.6 Possible Answers to Self-Assessment Exercises

Answers to SAE 1

1. It was DNA comparisons that shows that fungi are more closely related to animals than plants.
2. **Fungi thrive in environments that are moist and slightly acidic, and can grow in dark places or places exposed to light.**

Answers to SAE 2

1. The traditional divisions of Fungi are the Chytridiomycota (chytrids), the Zygomycota (conjugated fungi), the Ascomycota (sac fungi), and the Basidiomycota (club fungi).
2. Opportunistic mycoses are fungal infections that are either common in all environments or part of the normal biota. They affect mainly individuals who have a compromised immune system. Patients in the late stages of AIDS suffer from opportunistic mycoses, such as *Pneumocystis*, which can be life threatening.

Answers to SAE 3

1. **Mycorrhiza**, a term combining the Greek roots *myco* meaning fungus and *rhizo* meaning root, refers to the association between vascular plant roots and their symbiotic fungi.
2. Mushrooms that figure prominently in the human diet include; Morels, shiitake mushrooms, chanterelles, and truffles

Glossary

Antarctica: an extremely cold continent at the south pole almost entirely below the
Antarctic Circle: covered by an ice cap up to 13,000 feet deep
archaebacteria: considered ancient life forms that evolved separately from bacteria and blue-green algae
asexual reproduction: reproduction without the fusion of gametes
bacterial: relating to single-celled microorganisms
bacterium: a single-celled or noncellular organism lacking chlorophyll
building block: a block of material used in construction work
cell nucleus: a part of the cell containing DNA and RNA and responsible for growth and reproduction
cell death: the normal degeneration and death of living cells
chemotaxis: movement by a cell or organism in reaction to a chemical stimulus
chloroplast: organelle in which photosynthesis takes place
conjugation: the state of being joined together
contemporaneously: during the same period of time
Cytosol: the aqueous part of the cytoplasm within which various particles and organelles are suspended
Cytoskeleton: a microscopic network of actin filaments and microtubules in the cytoplasm of many living cells that gives the cell shape and coherence
discrete: constituting a separate entity or part
Eubacteria: a large group of bacteria having rigid cell walls
Eukaryotic: having cells with `good' or membrane-bound nuclei
eukaryote: an organism of one or more cells with membrane-bound nuclei
flagellum: a lash-like appendage used for locomotion
fossilized: set in a rigidly conventional pattern of behavior, habits, or beliefs
genetics: the study of heredity and variation in organisms
Genus Mycoplasma: type and sole genus of the family Mycoplasmataceae
hydrogen sulfide: a sulfide having the unpleasant smell of rotten eggs
intracellular: located or occurring within a cell or cells
mitochondrion: part of a cell involved in energy production
membranous: characterized by formation of a membrane
metabolic: of or relating to metabolism
multicellular: consisting of many basic structural and functional units
morphology: the study of the structure of animals and plants
mycoplasma: any of a group of small parasitic bacteria that lack cell walls and can survive without oxygen; can cause pneumonia and urinary tract infection
Myxobacteria: bacteria that form colonies in self-produced slime
organelle: a specialized part of a cell; analogous to an organ
oxidative: taking place in the presence of oxygen
prokaryote: a unicellular organism lacking a membrane-bound nucleus
phenotypic: of or relating to or constituting a phenotype

plankton:	aggregate of small organisms that float or drift in water
Plasma membrane:	a thin membrane enclosing the cytoplasm of a cell
plasmid:	a small cellular inclusion consisting of a ring of DNA that is not in a chromosome but is capable of autonomous replication
polymer:	a naturally occurring or synthetic compound
recombination:	the rearrangement of genes (by crossing over) in offspring
relatedness:	a particular manner of connectedness
ribosome:	a particle in a cell that helps synthesize proteins
signaling:	any nonverbal action or gesture that encodes a message
symbiotic:	of organisms living together, especially to mutual advantage
vacuole:	a tiny cavity filled with fluid in the cytoplasm of a cell

End of module questions

Historically, artisanal breads were produced by capturing wild yeasts from the air. Prior to the development of modern yeast strains, the production of artisanal breads was long and laborious because many batches of dough ended up being discarded. Can you explain this fact?

Compare the body structure and features, and provide an example of each of the four groups of perfect fungi

Describe each phylum in terms of major representative species and patterns of reproduction

Describe the similarities and differences in bacterial and archaeal structures

Explain differences between the plasma membranes of archaea and bacteria

Differentiate between gram-positive and gram-negative bacteria

Describe the types of cell walls and cell wall components that exist in *Archaea*

Module 2: Survey of the Plant Kingdom

Module Structure

In this module we will discuss about the cellular organization, structure and functions
Unit 1: Kingdom Plantae
Unit 2: The Seedless Plants
Unit 3: Bryophytes
Unit 4: Seedless Vascular Plants
Unit 5: Seed Plant I: Gymnosperms

Module 2: Overview of the Plant Kingdom

Unit 1 Kingdom Plantae
1.1 Introduction
1.2 Intended Learning Outcomes (ILOs)
1.3 Main Contents
  1.3.1 The Plant Kingdom
    1.3.1.1 Clasification of the Plant Kingdom
    1.3.1.2 The Diversity of Land Plants
  1.3.2 Seedless Vascular plants
    1.3.2.1 Algae and Evolutionary Paths to Photosynthesis
    1.3.2.2 Plant Adaptations to Life on Land
  1.3.3 Alternation of Generations
    1.3.3.1 Sporangia in Seedless Plants
    1.3.3.2 Gametangia in Seedless Plants
    1.3.3.3 sApical Meristems
1.4 Summary
1.5 References/Further Readings/Web Sources
1.6 Possible Answers to Self-Assessment Exercises

1.1 Introduction

A diverse array of non-seed-bearing plants graces the terrestrial landscape. Mosses might find their place on a tree trunk, and horsetails may stretch their segmented stems and delicate leaves across the forest floor. Although seedless plants constitute a small portion of our present-day plant life, about 300 million years ago, they dominated the scenery, thriving within the vast, marshy forests of the Carboniferous epoch. Their decomposition contributed to the formation of substantial coal deposits that we now extract. Contemporary evolutionary theory asserts that all plants, including certain types of green algae along with terrestrial plants, share a common ancestor—a monophyletic origin. The transition from aquatic to terrestrial environments presented significant challenges for plants. They needed to develop mechanisms to prevent desiccation, disperse reproductive cells in the air, provide structural support, and efficiently harness sunlight. While seed plants have evolved adaptations enabling them to inhabit even the most parched habitats on Earth, complete emancipation from water was not universally achieved among all plants. The majority of seedless plants still rely on a moist environment for their reproductive processes.

1.2 Intended Learning Outcomes (ILOs)

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

- Describe the characteristics features **of** the plant kingdom
- Describe the criteria and the **classification of the plant kingdom**
- Explain the diversity of the plant kingdom

- Discuss the challenges to plant life on land
- Describe the adaptations that allowed plants to colonize the land
- Describe the timeline of plant evolution and the impact of land plants on other living things
-

1.3 Main Contents

1.3.1 The Plant Kingdom

All the plant life present on our planet falls under the classification of Kingdom Plantae. This kingdom encompasses autotrophic, multicellular, photosynthetic eukaryotic organisms. These entities are primarily non-mobile, capable of forming embryos, and serve as the primary producers in ecosystems due to their capacity to convert solar energy into chemical energy through photosynthesis. They possess a firm cell wall composed largely of cellulose. The Kingdom Plantae encompasses a diverse array of organisms, with over 300,000 documented species. Among these, more than 260,000 are categorized as seed plants. Mosses, ferns, conifers, and flowering plants all belong to the plant kingdom. The emergence of land plants occurred within the larger Archaeplastida group, which also includes red algae (Rhodophyta) and two categories of green algae: Chlorophyta and Charophyta. While some biologists consider certain green algae as part of the plant kingdom, there is debate over this classification. This divergence in opinion arises from the fact that only specific green algae, the Chlorophytes and Charophytes, share key traits with land plants, such as utilizing chlorophyll a and b alongside carotene in the same proportions as plants. These attributes are absent in other types of algae.

1.3.1.1 Clasification of the Plant Kingdom

Kingdom Plantae is also referred to as the Kingdom of Plants. The five kingdoms—Monera, Protista, Fungi, Animalia, and Plantae—that Whittaker proposed as a general classification of living things in his system from 1969. The kingdom of Plantae includes all living things. All living things are multicellular, autotrophic eukaryotic creatures. Cell walls are one of the primary properties of plants. The cell wall gives the cell rigidity and structural stability. A stiff cell wall is present in each plant cell. Chloroplasts and the pigment chlorophyll are present in plants, which are necessary for photosynthesis. Subgroups are used to further categorize the plant kingdom. Classification is based on the following criteria:

1. **Plant body**: Presence or absence of a well-differentiated plant body. E.g. Root, Stem and Leaves.
2. **Vascular system**: Presence or absence of a vascular system for the transportation of water and other substances. E.g. Phloem and Xylem.
3. **Seed formation**: Presence or absence of flowers and seeds and if the seeds are naked or enclosed in a fruit.

Each subgroup of plants has a unique collection of identifying traits that are unique to that subgroup. The angiosperms are plants with a complicated assembly, a circulatory system, and a reproductive system that are well-established in their own families, whereas thallophytes are the greenest of the plants. The plant world has been classified into five groups by taking into account all of these traits. They go by the following names: The first of these is the Thallophyta, followed by the groups of organisms Bryophyta, Pteridophyta, and Gymnosperms and Angiosperms, which are all types of flowering plants. **IN-TEXT QUESTION (ITQ)**: Which members of the plant kingdom are the greenest? The thallophytes are the greenest of the plants.

1.3.1.2 The Diversity of Land Plants

Land plants are categorized into two primary divisions based on the presence or absence of vascular tissue, as outlined in Figure 1.4. Plants that lack specialized cells for transporting water and nutrients, collectively known as vascular tissue, are classified as nonvascular plants. Examples of these are bryophytes, including liverworts, mosses, and hornworts, which are seedless and devoid of vascular tissue. These plants are believed to have emerged early in the evolutionary timeline of land plants. Vascular plants, on the other hand, possess a system of cells designed to transport water and solutes throughout their structures. The initial vascular plants likely appeared during the late Ordovician period (461–444 million years ago) and were possibly similar to lycophytes, which encompass club mosses (distinct from actual mosses) and pterophytes such as ferns, horsetails, and whisk ferns. Lycophytes and pterophytes are collectively referred to as seedless vascular plants, signifying their lack of seed production. Seeds are embryonic structures protected by a tough covering and containing stored nutrients. Among all plant groups, seed plants constitute the largest, dominating the landscape. This category includes gymnosperms, notably conifers that produce "naked seeds," and the highly successful flowering plants, or angiosperms, which safeguard their seeds within chambers located within flowers. Over time, the walls of these chambers evolve into fruits.

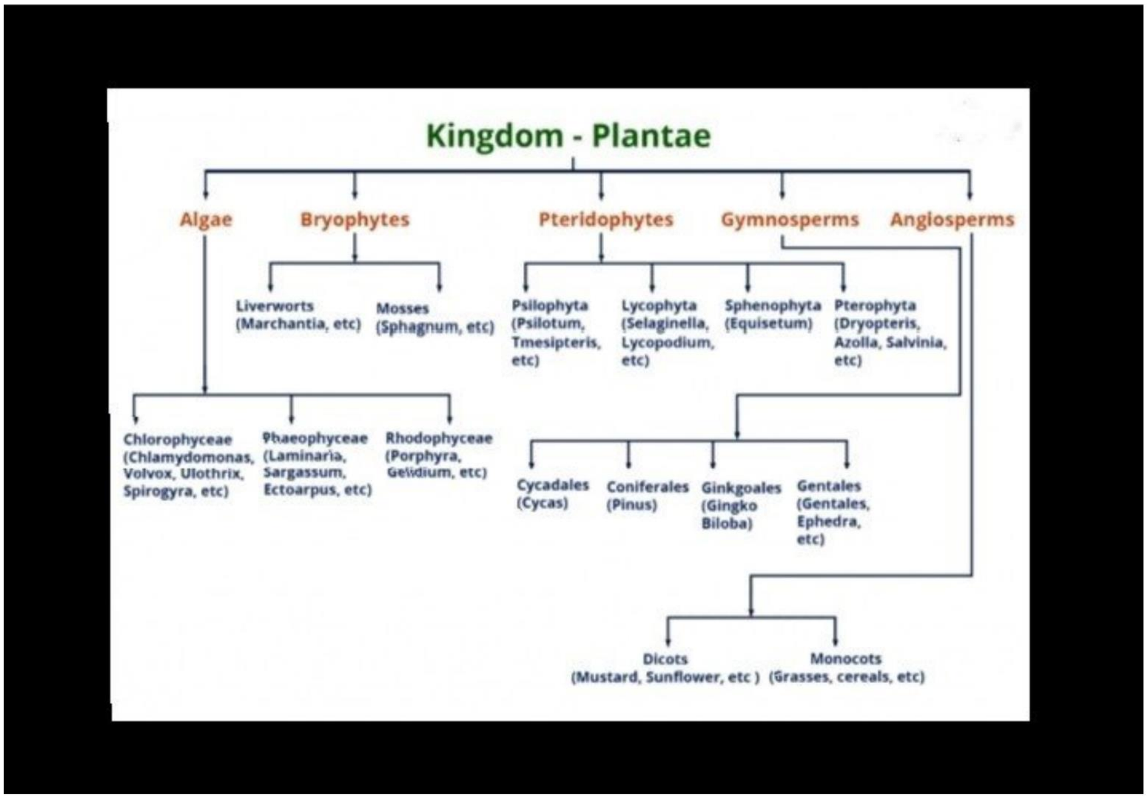


Figure 1.1 Diversity of Kingdom Plantae: Source: https://www.studocu.com/

Self-Assessment Exercises 1

1. What is the diversity of plants?
2. What is the most diverse group of the land plants?

1.3.2 Seedless Vascular plants

There are numerous and diverse groups of organisms in the kingdom Plantae. The number of cataloged plant species exceeds 300,000. More than 260,000 of these are seedlings. The plant kingdom includes ferns, conifers, flowering plants, and mosses. The Archaeplastida, which also includes the red algae Rhodophyta and the two classes of green algae Chlorophyta and Charaphyta, is where land plants first appeared. Most biologists agree that at least some green algae are plants, however some do not consider any algae to be part of the plant family. The only green algae, the Chlorophytes and Charophytes, share traits with land plants, such as utilising chlorophyll a and b plus carotene in the same proportion as plants, which is the basis for this argument. These characteristics are absent from other types of algae.

1.3.2.1 Algae and Evolutionary Paths to Photosynthesis

There are differing opinions among scientists regarding the classification of algae within the kingdom Plantae. Some argue that all algae should be considered plants, while others contend that the Plantae kingdom should encompass only green algae. Another perspective is to include only Charophytes as plants. These contrasting viewpoints stem from the diverse evolutionary pathways that different forms of algae have taken to achieve photosynthesis. Despite all algae being photosynthetic, possessing some form of chloroplast, the development of this capability varied. Approximately 1.65 billion years ago, the ancestors of the Archaeplastida engaged in an endosymbiotic relationship with a green, photosynthetic bacterium. The subsequent descendants from this lineage, such as red and green algae, ultimately gave rise to present-day mosses, ferns, gymnosperms, and angiosperms. This evolutionary trajectory followed a mostly linear and monophyletic path. On the other hand, brown and golden algae within the stramenopiles group, along with other algae beyond the Archaeplastida, acquired photosynthetic abilities through secondary or even tertiary endosymbiotic events. This involved the incorporation of cells that already contained endosymbiotic cyanobacteria. While these latecomers to photosynthesis are similar to the Archaeplastida in terms of autotrophy, they did not colonize or spread across the Earth to the same extent.

In summary, the classification of algae as plants is a subject of debate due to the various ways in which different types of algae have evolved photosynthetic processes. This diversity is linked to the manner in which their ancestral lineages acquired photosynthesis-related traits.

1.3.2.2 Plant Adaptations to Life on Land

The transition to terrestrial life posed numerous challenges for organisms, necessitating adaptations to cope with the new environment. Water, vital for life, becomes scarce on land, leading to the risk of desiccation. Even in proximity to water, aerial plant parts are vulnerable to dehydration. Buoyancy is absent, prompting the need for structural support. Additionally, the lack of water as a filter exposes organisms to harmful radiation, including ultraviolet rays. Reproduction faced hurdles, requiring novel strategies for male gametes to reach females without water assistance. This shift demanded protection against desiccation for both gametes and zygotes. Land plants devised strategies to tackle these challenges, although not all adaptations emerged simultaneously.

Despite these difficulties, terrestrial life offers advantages. Sunlight is abundant, offering energy for photosynthesis. Carbon dioxide diffuses faster in air, providing a ready source. The absence of land animals initially spared plants from predation, but defensive mechanisms like thorns and toxins evolved as animals adapted. Early land plants and animals, staying close to water, developed strategies like tolerance to drying. Others colonized humid environments or used desiccation resistance.

Successful land adaptation involved developing advantageous structures. Four key adaptations facilitated plant success on land. Alternation of generations, involving sporophyte and gametophyte stages, was present in all land plants. Apical meristems in roots and shoots enabled continual growth. A waxy cuticle resisted desiccation, while cell walls with lignin provided support. These adaptations contributed to land plant success, prompting debates on the placement of closely related green algae within the plant kingdom. Mosses, lacking some adaptations, represent an intermediate stage in land colonization. What are the 4 land plants?

Self-Assessment Exercises 2

1. What is the meaning of land plants?
2. What are the two main groups of land plants?

1.3.3 Alternation of Generations

All sexually reproducing organisms have both haploid and diploid cells in their life cycles. In organisms with haplontic life cycles, the haploid stage is dominant, while in organisms with a diplontic life cycle, the diploid stage is the dominant life stage. Dominant in this context means both the stage in which the organism spends most of its time, and the stage in which most mitotic cell reproduction occurs—the multicellular stage. In haplontic life cycles, the only diploid cell is the zygote, which undergoes immediate meiosis to restore the haploid state. In diplontic life cycles, the only haploid cells are the gametes, which combine to restore the diploid state at their earliest convenience. Humans, for example, are diplontic. Alternation of generations describes a life cycle in which an organism has both haploid and diploid multicellular stages. This type of life cycle, which is found in all plants, is described as haplodiplontic.

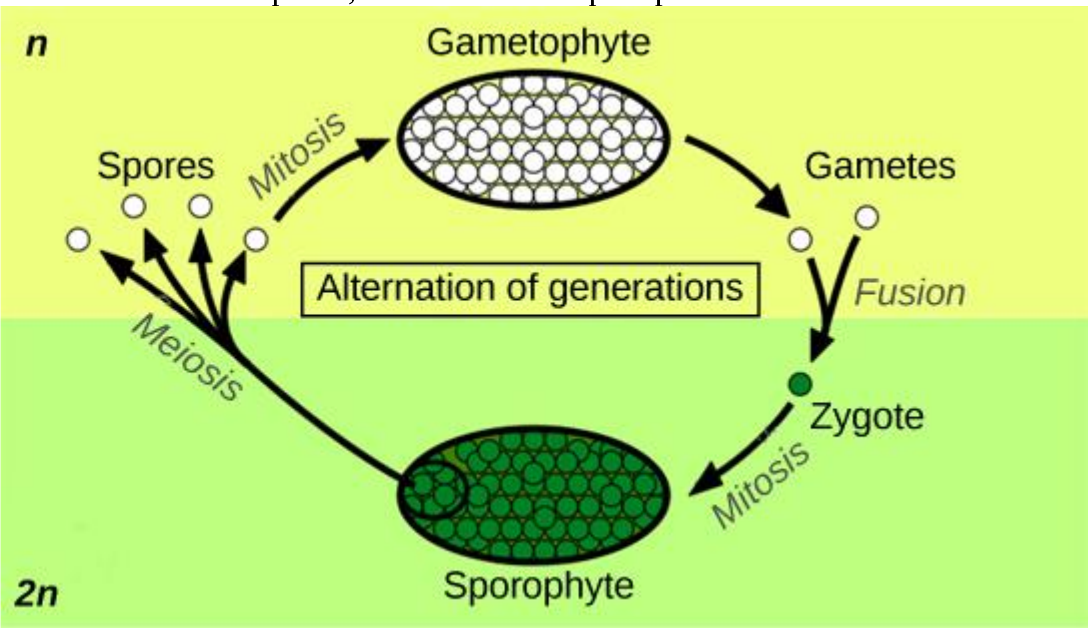


Figure 1.2 Alternation of generations between the 1*n* gametophyte and 2*n* sporophyte. Mitosis occurs in both gametophyte and sporophyte generations. Diploid sporophytes produce haploid spores by meiosis, while haploid gametophytes produce gametes by mitosis. Source: https://openstax.org/books/concepts-biology/pages/14-1-the-plant-kingdom

The developmental sequence is followed by a multicellular diploid form called a sporophyte after the multicellular haploid form known as a gametophyte. The gametophyte undergoes mitosis to produce the gametes (reproductive cells). This stage of the plant's life cycle can be the most visible, as it is in the case of mosses, or it can take place in a tiny structure, like a pollen grain, as is the case with seed plants. The sporophyte generation has become more prominent as terrestrial plants have evolved. When it comes to non-vascular plants, which include mosses and liverworts, the sporophyte stage is seldom evident. The sporophyte phase in seed plants can develop into a massive tree, as in the case of sequoias and pines. Protection of the embryo is a major requirement for land plants. The vulnerable embryo must be sheltered from desiccation and other environmental hazards. In both seedless and seed plants, the female gametophyte provides protection and nutrients to the embryo as it develops into the new sporophyte. This distinguishing feature of land plants gave the group its alternate name of embryophytes.

1.3.3.1 Sporangia in Seedless Plants

The seedless plant's sporophyte, which is diploid and created by the syngamy (fusing) of two gametes, lacks seeds. The sporangia (plural: sporangium) are carried by the sporophyte. The word "sporangia" literally translates to "a vessel for spores," since it refers to the reproductive sac in which spores are produced. It is important to note that in many plants, polyploidy causes chromosome number to be complicated; for instance, durum wheat is tetraploid, bread wheat is hexaploid, and some ferns are 1000-ploid. In the multicellular sporangia, the diploid sporocytes, or mother cells, produce haploid spores by meiosis, during which the 2n chromosome number is reduced to 1n. Later, the sporangia release the spores, which disperse throughout the environment. The haploid spore undergoes mitosis to produce a multicellular gametophyte when it germinates in a favorable environment. The gametophyte supports the zygote formed from the fusion of gametes and the resulting young sporophyte (vegetative form). The cycle then begins anew.

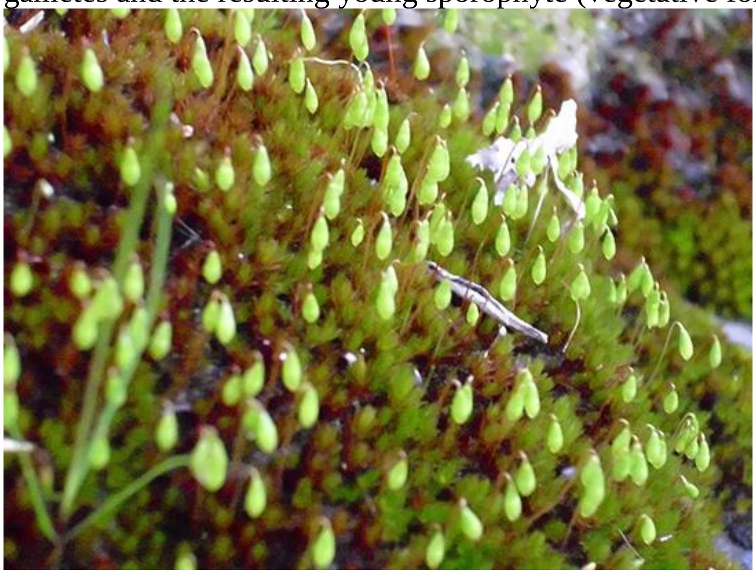


Figure 1.3 Sporangia. Spore-producing sacs called sporangia grow at the ends of long, thin stalks in this photo of the moss *Esporangios bryum*. Source: https://openstax.org/books/concepts-biology/pages/14-1-the-plant-kingdom

Plants that generate only one type of spore are termed homosporous, resulting in a gametophyte that produces both male and female gametes, typically on the same organism. This is observed in non-vascular plants where the gametophyte stage dominates the life cycle. Conversely, plants that yield two types of spores are referred to as heterosporous. The smaller male spores, known as microspores, develop into the male gametophyte, while the larger megaspores transform into the female gametophyte. Heterospory is observed in a few seedless vascular plants and all seed plants, with the sporophyte phase being dominant. The spores of seedless plants are encased in robust cell walls containing the resilient polymer sporopollenin, which is also present in pollen grain walls. This intricate substance is recognized by its elongated chains of organic molecules resembling fatty acids and carotenoids, giving pollen its yellow hue. Notably resistant to chemical and biological breakdown, sporopollenin's durability accounts for well-preserved pollen fossils in seed plants, where pollen functions as the male gametophyte. Previously attributed to land plants, sporopollenin is also found in the charophyte Coleochaetes.

1.3.3.2 Gametangia in Seedless Plants

Multicellular haploid gametophytes have structures called gametangia (plural: gametangium). Precursor cells undergo mitosis to produce gametes in the gametangia. Sperm are released from the male gametangium (antheridium). Seedless plants create sperm with flagella that can swim to the female gametangium, the archegonium, in a moist environment. As the sporophyte, the embryo grows inside the archegonium. In contrast to seed plants, which lack or have rudimentary gametangia, seed plants are dominated by them.

1.3.3.3 Apical Meristems

In a region known as the apical meristem, a small mitotically active zone of cells present at the tip of the shoot or root, plants' shoots and roots grow longer by fast cell division (Figure 1.4). Undifferentiated cells that continue to divide throughout the plant's lifetime make up the apical meristem. All of the organelle's specialized tissues are derived from meristematic cells. A plant can access more area and resources by growing its shoots and roots longer, including light in the case of the shoot and water and minerals in the case of the roots. Tree trunk diameter-increasing cells are produced by a distinct meristem known as the lateral meristem.

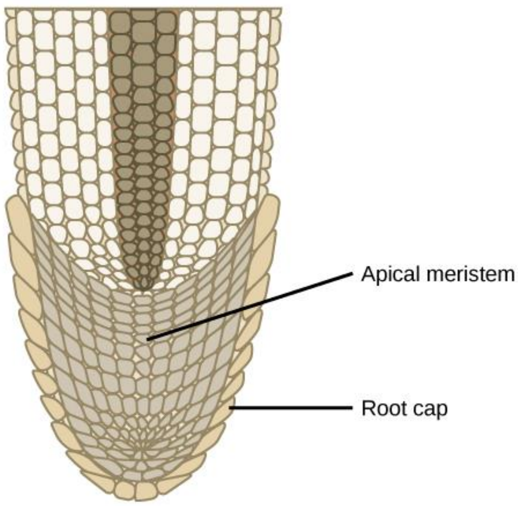


Figure 1.4 Apical meristem at a root tip. Source: https://openstax.org/books/concepts-biology/pages/14-1-the-plant-kingdom

Addition of new cells in a root occurs at the apical meristem. Subsequent enlargement of these cells causes the organ to grow and elongate. The root cap protects the fragile apical meristem as the root tip is pushed through the soil by cell elongation. What is haplodiplontic in the life cycle of a plant?

Self-Assessment Exercises 3

1. **What is Alternation of generations?**
2. **What is apical meristem?**

1.4 Summary

The terrestrial realm showcases a remarkable diversity of non-reproductive plants. Mosses can be found on tree trunks, and horsetails may spread across the forest floor with their segmented stems and thin leaves. However, around 300 million years ago, the landscape was dominated by seedless plants, flourishing in the expansive swampy forests of the Carboniferous era. Today, seedless plants constitute a smaller portion of the plant population in our surroundings. These plants significantly contributed to the formation of substantial coal deposits that we extract today. Contemporary evolutionary theory asserts that all plants, encompassing specific green algae and land plants, share a common ancestry, forming a monophyletic group. The transition from aquatic to terrestrial life posed significant challenges for plants. To combat desiccation, disperse reproductive cells through the air, provide structural support, and effectively capture sunlight, plants had to develop innovative strategies. While adaptations have enabled seed plants to thrive in even the driest conditions on Earth, not all plants have attained complete independence from water. Although many seedless plants still require moisture for reproduction, their adaptations have allowed them to survive and flourish in diverse environments.

1.6 References/Further Readings/Web Sources

A.D. Chapman (2009) *Numbers of Living Species in Australia and the World*. 2nd edition. A Report for the Australian Biological Resources Study. Australian Biodiversity Information Services, Toowoomba, Australia. Available online at **http://www.environment.gov.au/biodiversity/abrs/publications/other/species-numbers/2009/04-03-groups-plants.html.**

Steidinger, K.A. and Tangen, K. (1997), Dinoflagellates. *In* Tomas, C.R. (ed.), *Identifying Marine Diatoms and Dinoflagellates*. (Academic Press, San Diego). pp. 387–589.

Throndsen, J. (1997), The planktonic marine flagellates. *In* Tomas, C.R. (ed.), *Identifying Marine Diatoms and Dinoflagellates*. (Academic Press, San Diego). pp. 591–730.

https://openstax.org/books/concepts-biology/pages/14-1-the-plant-kingdom
https://opened.cuny.edu/courseware/6
https://byjus.com/biology/plant-kingdom-plantae/
https://youtu.be/hqH-n-OrUaA
https://youtu.be/os5mZQLpe98
https://youtu.be/sYdq1LOHKxs
https://www.youtube.com/watch?v=hqH-n-OrUaA

1.6 Possible Answers to Self-Assessment Exercises

Answers to SAE 1

1. Plant diversity refers to the existence of wide variety of plant species in their natural environments. There are around 300,000-500,000 species of vascular plants that exist on earth

2. Angiosperms: Flowering plants (angiosperms) are by far the largest, most diverse, and most important group of land plants, with over 250,000 species and a dominating presence in most terrestrial ecosystems.

Answers to SAE 2

1. The embryophytes are informally called land plants because they live primarily in terrestrial habitats (with exceptional members who evolved to live once again in aquatic habitats), while the related green algae are primarily aquatic.
2. Vascular plants are subdivided into two classes: seedless plants, which probably evolved first (including lycophytes and pterophytes), and seed plants. Seed-producing plants include gymnosperms, which produce "naked" seeds, and angiosperms, which reproduce by flowering.8 Jun 2022

Answers to SAE 3

1. Alternation of generations describes a life cycle in which an organism has both haploid and diploid multicellular stages. This type of life cycle, which is found in all plants, is described as haplodiplontic.
2. Apical meristem, is a small mitotically active zone of cells found at the shoot tip or root tip, it is made of undifferentiated cells that continue to proliferate throughout the life of the plant

Unit 2 The Seedless Plants

2.1 Introduction
2.2 Intended Learning Outcomes (ILOs)
2.3 Main Contents
 2.3.1 The Major Divisions of Land Plants
 2.3.2 The Diversity of the Green Algae
 2.3.3 Ecological Adaptation of Algae
2.4 Summary
2.5 References/Further Readings/Web Sources
2.6 Possible Answers to Self-Assessment Exercises

2.1 Introduction

Vascular plants are small and seedless, and the gametophyte stage of their life cycle dominates them. They don't have roots or a circulatory system, so they absorb nutrients and water from all of their exposed surfaces. The three main groups, collectively referred to as bryophytes, are liverworts, hornworts, and mosses. The oldest plants are liverworts, which were among the first plants to appear on land. Hornworts have developed stomata and one chloroplast per cell. Mosses have simple conductive cells and are connected to the substrate by rhizoids. After drying out, they may rehydrate and colonize hostile settings. Spore discharge from the parent plant is made possible by the complex structure of the moss sporangium.

2.2 Intended Learning Objectives (ILOs)

By the end of this section, you will be able to do the following:

- Describe the traits shared by green algae and land plants
- Explain why charophytes are considered the closest algal relative to land plants
- Explain how current phylogenetic relationships are reshaped by comparative analysis of DNA sequences

- Discuss the ecological adaptations of the algae

2.3 Main Contents

2.3.1 The Major Divisions of Land Plants

Streptophytes collectively refer to the green algae and land plants encompassing the Streptophyta subphylum. Within the realm of land plants, a fundamental division is based on the presence or absence of vascular tissue, as depicted in the diagram. Non-vascular plants, lacking specialized cells for water and nutrient transport, include liverworts, mosses, and hornworts. These seedless plants are likely among the earliest terrestrial plants. Vascular plants have evolved a network of cells to facilitate solute and water movement. The initial vascular plants likely resembled lycophytes such as club mosses, emerging in the late Ordovician period (500 to 435 MYA), along with pterophytes like ferns, horsetails, and whisk ferns. As they lack seed formation, lycophytes and pterophytes are termed "seedless vascular plants." However, seed plants, known as spermatophytes, dominate the plant kingdom and the landscape. Among them, gymnosperms, particularly conifers with their exposed seeds, and angiosperms, the flowering plants with the highest reproductive success, are prominent examples. Angiosperms encase their seeds within protective chambers at the flower's core, with these chambers eventually developing into fruits.The diversity of Embryopyhtes can be shown in the figure below:

<table>
<tr><th colspan="7">Embryophytes: The Land Plants</th></tr>
<tr><th colspan="3">Nonvascular Plants “Bryophytes”</th><th colspan="4">Vascular Plants</th></tr>
<tr><td rowspan="5">Liverworts</td><td rowspan="5">Hornworts</td><td rowspan="5">Mosses</td><th colspan="2">Seedless Plants</th><th colspan="2">Seed Plants</th></tr>
<tr><th>Lycophytes</th><th>Pterophytes</th><th>Gymno-sperms</th><th>Angio-sperms</th></tr>
<tr><td>Club Mosses</td><td>Whisk Ferns</td><td rowspan="3"></td><td rowspan="3"></td></tr>
<tr><td>Quillworts</td><td>Horsetails</td></tr>
<tr><td>Spike Mosses</td><td>Ferns</td></tr>
</table>

Figure 2.1 Major divisions of green plants (Streptophytes). Source: Biology 2e, Biological Diversity, Seedless Plants, Early Plant Life | OpenEd CUNY

1. **Characteristic Forms of Algae**

Plants and animals share specific general properties of algae. Eukaryotic cells make up algae. Algae, for example, may photosynthesize like plants and have specialized cell organelles like centrioles and flagella that are exclusively found in animals. Mannans, cellulose, and Galatians make up the algal cell walls. Listed below are some of the general characteristics of algae.

- Algae are photosynthetic organisms
- Algae can be either unicellular or multicellular organisms
- Algae lack a well-defined body, so, structures like roots, stems or leaves are absent
- Algae are found where there is adequate moisture, with a few on damp soils and shady places examples are spirogyra, anabaena and Sargassum
- Reproduction in algae occurs in both asexual and sexual forms.
- Asexual reproduction occurs by spore formation.

- Algae are free-living, although some can form a symbiotic relationship with other organisms.
- The cell wall of algae is composed of a true celloulose.
- Reserve carbohydrates are usually starch and not glycogen as in fungi.

2. **Classification of Algae**

Grouping creatures based on the traits they simulate is known as classification. From an evolutionary perspective, it is not improbable but true that animals with comparable morphology, life cycles, physiologies, and biochemistry are genetically related. Therefore, nine large taxonomic groups known as Divisions are recognized in the categorization of algae. These are:

- Chlorophycophyta (green algae) eg. Chlamydomonas, Spirogyra, Chlorella
- Xanthophycophyta (yellow-green algae) eg. Vaucheria, Botrydium
- Bacillariophycophyta (diatoms) eg. Diatoma, fragilaria.
- Phaeophycophyta (brown algae) eg. Fucus, Sargassum, laminaria.
- Rhodophycophyta (red algae) eg. Plumaria elegans.
- Chrysophycophyta (golden algae) eg. Synura, Mallomonas, Chromalina.
- Euglenophycophyta (euglenoids) eg. Euglena, Trachelommas.
- Cryptophycophyta (cryptomonads) eg. Crytomones, Chroomonas.
- Pyrrophycophyta (dinoflagellates) eg. Ceratium, Peridinum.

What is the striking difference between algae and protists?

Self-Assessment Exercises 1

1. What is the meaning of land plant?
2. What is another name for land plants?

2.3.2 The Diversity of the Green Algae

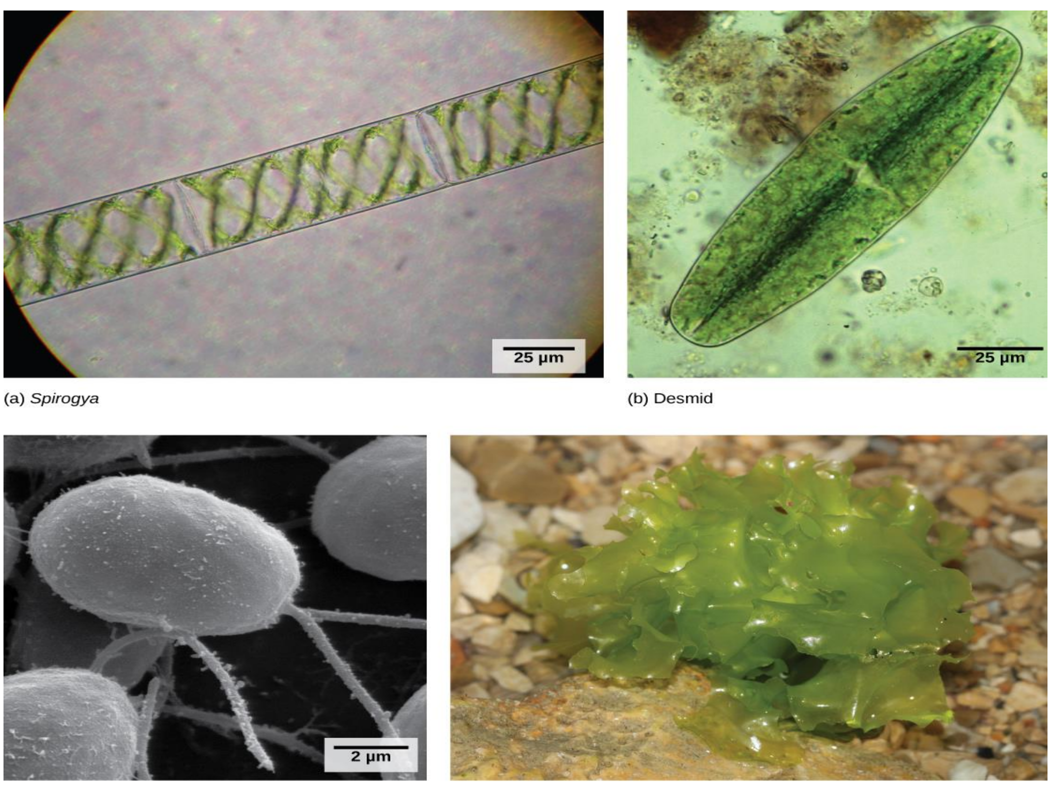
Algae, referred to as alga in singular form, constitute a diverse group of primarily aquatic photosynthetic organisms within the Protista kingdom. Algae exhibit a wide range of life cycles and vary in size from tiny Micromonas species to enormous kelps that can extend up to 60 meters (200 feet). These organisms possess a greater variety of photosynthetic pigments compared to plants and display unique cellular characteristics distinct from both plants and animals. Besides their essential roles in generating oxygen and serving as a fundamental food source for aquatic life, algae hold economic significance as sources of crude oil, food, pharmaceuticals, and various industrial products for humans.

The classification of algae is subject to ongoing debates and swift changes as new molecular insights emerge. The field dedicated to studying algae is termed phycology, and individuals who specialize in this area are known as phycologists. Evolutionarily, algae do not share close relationships, and the exact evolutionary lineage of the group remains to be fully elucidated. Certain algae share attributes with protozoa and fungi, which makes differentiation from these organisms challenging when chloroplasts and photosynthesis are not distinct defining features. In some cases, certain algae seem to share a closer evolutionary connection with protozoa or fungi than with other algae. In this context, we will explore the two primary categories of green algae.

1. Streptophytes

Until recently, all eukaryotic organisms capable of photosynthesis were categorized within the Plantae kingdom. Nevertheless, the brown and golden algae have been recently reclassified into the Chromalveolata supergroup of protists. This reclassification is due to their divergence from plants in terms of structural and biochemical characteristics, despite sharing the capacity to harness light energy and fix CO2. The current classification designates plants, along with red and green algae, under the Archaeplastida supergroup of protists. Green algae exhibit similar carotenoids, chlorophyll a and b, and starch storage as land plants. Their cells possess chloroplasts with diverse shapes, and their cell walls contain cellulose, mirroring features found in land plants. The exact inclusion of specific green algae within the plant category remains unresolved from a phylogenetic perspective.

Green algae can be broadly divided into two main groups: chlorophytes and charophytes. Chlorophytes encompass genera like Chlorella, Chlamydomonas, the seaweed "sea lettuce" Ulva, and the colonial alga Volvox. Charophytes encompass desmids, along with genera like Spirogyra, Coleochaete, and Chara. Notably, recognizable green algae exist within both groups. Some green algae, such as Chlamydomonas and desmids, consist of single cells, adding complexity to their classification due to the multicellular nature of plants. Conversely, other green algae, like Volvox, form colonies, while organisms like Ulva are multicellular entities. Spirogyra, characterized by long filaments of colonial cells, primarily inhabit freshwater, brackish water, seawater, or even snowy patches. A few green algae can even survive on soil, provided a thin layer of moisture covers it, allowing them to endure dry periods.



(a) *Spirogya*
(b) Desmid
(c) *Chlamydomonas*
(d) *Ulva*

Figure 2.2 Green algae. Charophyta include (a) *Spirogyra* and (b) desmids. Chlorophyta include (c) *Chlamydomonas*, and (d) *Ulva*. Desmids and *Chlamydomonas* are single-celled organisms, *Spirogyra* forms chains of cells, and *Ulva* forms multicellular structures resembling leaves, although the cells are not differentiated as they are in higher plants. Source: https://openstax.org/books/concepts-biology/pages/14-1-the-plant-kingdom

Differences between chlorophytes and charophytes provide insight, along with molecular analysis, into the relationship between land plants and charophytes. Charophytes and land plants share specific characteristics that place them as sister groups. Firstly, cell division in charophytes and land plants occurs through phragmoplasts, where microtubules parallel to the spindle guide forming cell plates. On the other hand, chlorophytes use phycoplasts with perpendicular microtubules for cell plate organization. Secondly, only charophytes and land plants possess plasmodesmata, facilitating material transfer between cells. Such intercellular connections do not persist in mature multicellular chlorophyte forms. Lastly, both charophytes and land plants exhibit apical growth—growth from plant tips instead of throughout the plant body. Consequently, land plants and charophytes constitute a newly identified monophyletic group called Streptophyta.

Green algae undergo both asexual and sexual reproduction. Asexual methods involve spore dispersal or fragmentation, while sexual reproduction entails the fusion of gametes. In single-celled organisms like Chlamydomonas, fertilization lacks subsequent mitosis. In the multicellular Ulva, a sporophyte develops through mitosis after fertilization, showcasing alternation of generations. Both Chlamydomonas and Ulva produce flagellated gametes.

2. Charophytes

Among the charophytes, several distinct algal orders have been proposed as the closest relatives of land plants: the Charales, Zygnematales, and Coleochaetales. The Charales, with a history dating back 420 million years, inhabit diverse freshwater environments and range from a few millimeters to a meter in length. The prominent genus Chara, also known as muskgrass or skunkweed due to its unpleasant odor, represents this group. The thallus, or main stem, consists of large cells, while branches emerging from nodes consist of smaller cells. Reproductive structures of both sexes are located on nodes, with flagellated sperm. Despite superficial resemblances to some land plants, a notable distinction is the absence of supportive tissue in the stem of Chara. However, Charales possess key traits relevant to adapting to terrestrial life, including the production of lignin and sporopollenin compounds, along with plasmodesmata connecting adjacent cells. Despite their haplontic life cycle (with the main form being haploid and short-lived diploid zygotes formed), eggs and later zygotes develop within a sheltered chamber on the haploid parent plant.

Figure 2.3 Chara. The representative alga, *Chara*, is a noxious weed in Florida, where it clogs waterways. Source: https://openstax.org/books/concepts-biology/pages/14-1-the-plant-kingdom

The multicellular forms known as coleochaetes are branching or disc-shaped. Although they are capable of both sexual and asexual reproduction, their life cycle is essentially haplontic. The Zygnematales are more closely connected to the embryophytes than the Charales or the Coleochaetales, according to a recent in-depth DNA sequence analysis of charophytes. The desmids and the well-known genus Spirogyra both belong to the Zygnematales. The study of the evolutionary relationships between charophytes and land plants will continue as DNA analysis methods advance and new knowledge on comparative genomics emerges in order to provide an acceptable answer to the question of where land plants came from. How do algae produces sexually?

Self-Assessment Exercises 2

1. What are the Streptophytes?
2. What are the two majorgroups of the green algae?

2.3.3 Ecological Adaptation of Algae

Aquatic algae are one of the simplest plant organisms on our planet. If life evolved from bacteria to plants, from sea creatures to land creatures, algae is likely one of the primal stepping stones in the evolutionary process. Aquatic algae demonstrate properties which are found in animal life and plant life, including the ability to adapt to its surroundings.

i. Interaction with Competition

Like chameleon lizards that change colour to blend in with their surroundings, individual algae strains have demonstrated the ability to uniquely adapt to individual environments in order to blend in with, or overcome the challenges of, their environment. In a coral reef setting, algae become highly regenerative.

ii. Reproductive Adaptation

Asexual reproduction allows a plant or animal species to procreate independently and endure in a hostile environment. A male and a female of the species are required for sexual reproduction in order to supply all of the components for a full regeneration phase. Mammals, for instance, need a male sperm to fertilize a female egg in order to produce a new life. Algae that live in water have evolved the capacity for both asexual and sexual reproduction. Fragmentation is the method used for asexual reproduction. The plant releases spores that have the ability to germinate and thrive. When gametes from two species come together to form a spore known as a syngamy, sexual reproduction takes place. This spore then develops and releases algal seeds, mature cells that can grow or reproduce. Asexual reproduction enables a plant or animal species to reproduce on its own and survive in a highly competitive surrounding.

iii. Environmental Adaptation

Aquatic algae demonstrate photosensitive and cosmetic adaptation throughout the ocean. If algae originated from a single strain, environmental evolutions have forced the adaptation into red, brown, yellow and green colour algae which each blend in with their environmental surroundings. This adaptation helps algae avoid being completely consumed by the local fish species.

iv. Internal Chemical Adaptation

In a research experiment conducted in the San Francisco Bay area, multiple samples of several algae species were taken from polluted and non-polluted waters. Tests demonstrated that the algae residing in polluted waters had internally adapted, and produced chemical variances as part of the adaptation process. These plants physically and chemically changed their composition in order to adapt to the pollutants in the water.

Self-Assessment Exercises 3

1. Are algae plants or bacteria?
2. What is the purpose of algae?

2.4 Summary

Charophytes share more traits with land plants than do other algae, according to structural features and DNA analysis. Within the charophytes, the Charales, the Coleochaetales, and the Zygnematales have been each considered as sharing the closest common ancestry with the land plants. Charophytes form sporopollenin and precursors of lignin, phragmoplasts, and have flagellated sperm. They do not exhibit alternation of generations.

2.5 References/Further Readings/Web Sources

A.D. Chapman (2009) Numbers of Living Species in Australia and the World. 2nd edition. A Report for the Australian Biological Resources Study. Australian Biodiversity Information Services, Toowoomba, Australia. Available online at http://www.environment.gov.au/biodiversity/abrs/publications/other/species-numbers/2009/04-03-groups-plants.html.

Steidinger, K.A. and Tangen, K. (1997), Dinoflagellates. *In* Tomas, C.R. (ed.), *Identifying Marine Diatoms and Dinoflagellates*. (Academic Press, San Diego). pp. 387–589.

Throndsen, J. (1997), The planktonic marine flagellates. *In* Tomas, C.R. (ed.), *Identifying Marine Diatoms and Dinoflagellates*. (Academic Press, San Diego). pp. 591–730.
https://openstax.org/books/concepts-biology/pages/14-1-the-plant-kingdom
https://www.science.org/doi/10.1126/science.308.5723.769c
https://www.clickview.com.au/curriculum-libraries/video-details/?id=52533480&cat=3705579&library=primary
https://www.youtube.com/watch?v=0-6dzU4gOJo
https://www.youtube.com/watch?v=kQdRVq0b9Bk

2.6 Possible Answers to Self-Assessment Exercises

Answers to SAE 1

The embryophytes are informally called land plants because they live primarily in terrestrial habitats (with exceptional members who evolved to live once again in aquatic habitats), while the related green algae are primarily aquatic.
EMBRYOPHYTA – LAND PLANTS. The Embryophyta, or embryophytes (commonly known as land plants), are a monophyletic assemblage within the green plants

Answers to SAE 2

Streptophytes are the collective name for the green algae and land plants that make up the Streptophyta subphylum.
Green algae fall into two major groups, the chlorophytes and the charophytes.

Answers to SAE 3

1. Algae are sometimes considered plants and sometimes considered "protists" (a grab-bag category of generally distantly related organisms that are grouped on the basis of not being animals, plants, fungi, bacteria, or archaeans).
2,All algae contain chlorophyll but most lack leaves, roots, vascular tissue, and stems. They play a vital role in aquatic ecosystems by forming the energy base of the food web for all aquatic organisms. As autotrophic organisms, algae convert water and carbon dioxide to sugar through the process of photosynthesis.

Unit 3 Bryophytes

3.5 References/Further Readings/Web Sources
3.6 Possible Answers to Self-Assessment Exercises

3.1 Introduction

During the course of evolution, a change from aquatic habitat to terrestrial habitat occurred and the only primitive land plants evolved. These are known as bryophytes. Although bryophytes colonize terrestrial habitats but they are still dependent on water for completion of their life cycle. They produce motile male gametes which require a thin film of water for their motility to reach the non-motile female gamete to accomplish fertilization.

3.2 Intended Learning Objectives

By the end of this section, you will be able to:

- Identify the main characteristics of bryophytes
- Describe the distinguishing traits of liverworts, hornworts, and mosses
- Chart the development of land adaptations in the bryophytes
- Describe the events in the bryophyte lifecycle
- Describe the major classes of seedless vascular plants

3.3 Main Contents

3.3.1 The Bryophytes

The earliest terrestrial plants, which are most closely related to bryophytes, likely emerged around 450 million years ago during the Ordovician epoch. Bryophytes are believed to have originated during this time, but their lack of durable components like lignin makes them unlikely to leave fossils. Some spores protected by early bryophytes have managed to survive. By the Silurian epoch (around 435 million years ago), vascular plants had already spread across all continents. This supports the idea that non-vascular plants existed before the Silurian epoch. Although over 25,000 types of bryophytes flourish mainly in moist environments, some also survive in deserts. In challenging environments like the tundra, where their small size and resistance to drying out provide significant benefits, they dominate the flora. Bryophytes are often called non-vascular plants, even though the term non-tracheophyte is more precise. Key vegetative structures of bryophytes, such as photosynthetic leaf-like parts, stems, rhizoids, and thalli (the "plant body"), belong to the haploid organism, or gametophyte. Bryophyte male gametes possess a flagellum for swimming, necessitating water for fertilization. Moreover, the bryophyte embryo remains attached to the parent plant, which nurtures and nourishes it. The sporophyte that emerges from the embryo is not very visible. The multicellular sexual reproductive structure called the sporangium, responsible for producing haploid spores through meiosis, exists in bryophytes and is absent in most algae. This feature is also shared among land plants. Why are plants called bryophytes?
The general characteristics of Bryophytes can be outlined as follows:

- Bryophytes are amphibians of plant kingdom as they complete their life cycle in both water and on land.
- Plants occur in damp and shaded areas.
- The plant body is thallus-like, ie. prostrate or erect.
- It is attached to the substratum by rhizoids, which are unicellular or multicellular.

- They have a root-like, stem-like, and leaf-like structure and lack true vegetative structure.
- Plants lack the vascular system (xylem, phloem).
- The dominant part of the plant body is the gametophyte which is a haploid.
- The thalloid gametophyte is divided into rhizoids, axis, and leaves.
- The gametophyte bears multicellular sex organs and is photosynthetic.
- The antheridium produces antherozoids, which are flagellated.
- The shape of an archegonium is a sort of a flask and produces one egg.
- The antherozoids fuse with an egg to make a zygote.
- The zygote develops into a multicellular sporophyte.
- The sporophyte is semi-parasitic and dependent on the gametophyte for its nutrition.
- Cells of sporophyte undergo meiosis to form haploid gametes which form a gametophyte.
- The juvenile gametophyte is known as protonema.
- The sporophyte is differentiated into foot seta and capsule.

Self-Assessment Exercises 1

1. Which plants are bryophytes?
2. What is the main plant of bryophyte?

3.3.2 Diversity of Bryopytes

The bryophytes are divided into three divisions (in plants, the taxonomic level "division" is used instead of phylum):

i. **Hepaticopsida (Liverworts):** Flat, ribbon-like – Liverworts (Marchantia).
ii. **Anthocerotopsida (Hornworts):** Flat, thalloid plant body bearing a horn-like sporophyte – Hornworts or Anthoceros
iii. **Bryopsida (Mosses):** Small, leafy plant body – Mosses (Funaria)

3.3.2.1 Hepaticopsida (Liverworts)

Liverworts (Marchantiophyta) are considered the plants most closely resembling the ancestor that transitioned to land. They have successfully established themselves in diverse habitats worldwide, with over 6,000 extant species. Certain gametophytes take on a lobate green structure resembling the lobes of the liver, which is the origin of their common name. Liverworts belong to the class Hepaticopsida, and they are a subset of bryophytes, with around 900 species. Liverworts are among

the most primitive bryophytes and are often found in damp environments like moist rocks and wet soil, reducing their risk of desiccation due to their proximity to water.
Gametophytes, a plant type, can exhibit a flat thalloid or ribbon-like morphology, often showing dichotomous branching. For instance, Marchantia is anchored to the soil by rhizoids. On the other hand, species like Porella grow upright and appear leafy, with differentiated fake stems and leaves. The gametophyte provides nourishment and shelter for the sporophyte. The reproductive organs are typically located at the tips of branches on the upper surface of the thallus. In cases like Marchantia, separate branches called antheridiophores and archegoniophores may develop on gametophytes to host sex organs.

Figure 3.1 (a) A 1904 drawing of liverworts shows the variety of their forms. (b) A liverwort, *Lunularia cruciata*, displays its lobate, flat thallus. The organism in the photograph is in the gametophyte stage. Source: https://openstax.org/books/concepts-biology/pages/14-1-the-plant-kingdom

3.3.2.2 Anthocerotopsida (Hornworts)

Hornworts (Anthocerotophyta) have successfully inhabited a range of terrestrial environments, although they always remain in close proximity to a moisture source. Approximately 100 hornwort species have been identified. They fall under a single order, Anthocerotales, and include genera like Anthoceros, Megaceros, and Notothylas. In comparison to Bryopsida and Hepaticopsida, this category of bryophytes displays a slightly more advanced nature in various aspects.
On a broader scale, the gametophyte of hornworts is characterized by pronounced lobes and irregularities. Unlike the early developmental stages, the sporophyte does not rely on the gametophyte for sustenance or protection. Antheridia and archegonia are partially submerged within the gametophytic tissue. The most prominent phase of the hornwort life cycle is the brief blue-green gametophyte stage. The distinctive feature of the group is the sporophyte, a slender, pipe-like structure that emerges from the parental gametophyte and continues to grow throughout the plant's life (Figure 3.2).

Figure 3.2 Hornworts grow a tall and slender sporophyte. (credit: modification of work by Jason Hollinger) Source: https://openstax.org/books/concepts-biology/pages/14-1-the-plant-kingdom

3.3.2.3 Bryopsida (Mosses)

With about 1400 species, it is a significant class of the Bryophyta. They are often referred to as mosses. Like liverworts, most mosses like moist surroundings. Unlike other bryophytes, they thrive in moderately dry settings. While mosses require water to proliferate, which is why they typically develop into cushions or mats. Examples include Sphagnum, Funaria, and Polytrichum. Their habitats range from the understory of tropical forests to the tundra, where they serve as the primary vegetation. Their short rhizoids enable them to attach to a substrate in the tundra without digging into the frozen ground. They prevent erosion, hold onto moisture and soil minerals, offer food for larger herbivores like the musk ox and shelter for lesser animals. Mosses are very sensitive to air pollution and are used to monitor the quality of air. The sensitivity of mosses to copper salts makes these salts a common ingredient of compounds marketed to eliminate mosses in lawns (Figure 3.3). Are bryophytes unicellular or multicellular?

Figure 3.3 This green feathery moss has reddish-brown sporophytes growing upward.
Source: https://openstax.org/books/concepts-biology/pages/14-1-the-plant-kingdom

Self-Assessment Exercises 2

1. What is the classification of bryophytes?
2. What are the main groups of bryophytes?

3.3.3 Adaptation of Bryophytes

Bryophytes possess remarkable resilience and unique abilities to survive in harsh environmental conditions. They demonstrate high phenotypic plasticity and the capacity to undergo photosynthesis when conditions are favorable, particularly enabling their survival in cold regions. Bryophytes can endure drought by entering a metabolic shutdown and later recovering under suitable conditions. Anchored to soil by rhizoids, small thread-like structures, they absorb water and nutrients. In mosses, rhizoids are multicellular and branched, while liverworts and hornworts have unicellular or multicellular rhizoids. Water distribution is facilitated by hydroids and leptoids in various bryophytes, and mosses possess an external capillary system for this purpose.

The dominant gametophyte phase of bryophytes is photosynthetically active and bears the sex organs, with antheridia as male and archegonia as female. After fusion, gametes develop into a zygote and then a sporophyte, which remains attached to the gametophyte and relies on it for nutrients. The sporophyte's sporogenous tissue undergoes meiosis to produce haploid spores. Upon dispersal, these spores germinate into new gametophytes, completing the alternation of generations life cycle seen in all three bryophyte types (mosses, liverworts, and hornworts).

3.3.3.1 Habitat of Bryophyte

Bryophytes—the group of seedless plants containing mosses, hornworts, and liverworts—often live in wetter habitats. They do not have to search far for water and nutrients, so they do not need very complex roots. Water loss does not present a large problem, so they do not need a waxy surface to retain water.

3.3.3.2 Comparison of gametophytic and sporophytic phases of bryophytes

Gametophytic phase	Sporophytic phase
1. Haploid phase, generally autotrophic	Diploid phase, heterotrophic or partially autotrophic
2. Has multicellular sex organs called antheridia and archegonia bearing sterile jacket surrounding the gametes	Has spore-producing structure
3. Produces gametes	Produces spores
4. Gametes are produced by mitosis	Spores are produced by meiosis
5. Dominant phase occupies most of the life period	Short-lived phase which remains attached to the gametophyte

Self-Assessment Exercises 3

1. What are the adaptations of bryophytes?
2. What is the habitat of bryophytes?

3.4 Summary

A category of plant species known as bryophytes reproduce by spores rather than flowers or seeds. The three non-vascular land plant kinds that make up the majority of bryophytes are mosses, hornworts, and liverworts. They are typically found in moist conditions. While any of the several plants with specialized vascular tissue is considered a vascular plant. The movement of water, nutrients, and the byproducts of photosynthesis throughout the plant is accomplished by the two forms of vascular tissue, xylem and phloem.

3.5 References/Further Readings/Web Sources

A.D. Chapman (2009) Numbers of Living Species in Australia and the World. 2nd edition. A Report for the Australian Biological Resources Study. Australian Biodiversity Information Services, Toowoomba, Australia. Available online at http://www.environment.gov.au/biodiversity/abrs/publications/other/species-numbers/2009/04-03-groups-plants.html.

https://openstax.org/books/concepts-biology/pages/14-1-the-plant-kingdom

https://www.science.org/doi/10.1126/science.308.5723.769c

Biology 2e, Biological Diversity, Seedless Plants, Bryophytes | OpenEd CUNY

3.6 Possible Answers to Self-Assessment Exercises

Answers to SAE 1

1. Bryophytes is the informal group name for mosses, liverworts and hornworts. They are non-vascular plants, which means they have no roots or vascular tissue, but instead absorb water and nutrients from the air through their surface (e.g., their leaves).
2. The main plant body in Bryophyte is a haploid gametophyte.

Answers to SAE 2

1. The Greek words 'Bryon' for mosses and 'phyton' for plants are combined to form the term 'Bryophyta. ' The Bryophyta family includes mosses, hornworts, and liverworts, among others. These are small plants that flourish in damp, shady areas.
2. Bryophytes are a group of land plants, sometimes treated as a taxonomic division, that contains three groups of non-vascular land plants (embryophytes): the liverworts, hornworts and mosses. In the strict sense, Bryophyta consists of the mosses only.

Answers to SAE 3

1. Although bryophytes have simple structures morphologically, they already possess the key innovations of land plants for the early adaptations to terrestrial habitats, namely a multicellular embryo, cuticle, stomata, water-conducting cells (WCCs), and a rooting system
2. Bryophytes grow densely in moist and shady places and form thick carpets or mats on damp soils, rocks, bark of trees especially during rainy season. Majority of the species are terrestrial but a few species grow in fresh water (aquatic) e.g., Riccia fluitans, Ricciocarpos natans, Riella etc.

Unit 4 Seedless Vascular Plants

4.1 Introduction
4.2 Intended Learning Outcomes (ILOs)
4.3 Main Contents
    4.3.1 Seedless Vascular Plants
        4.3.1.1 Diversity of Seedless Vascular Plant Groups
        4.3.1.2 General Characteristics
    4.3.2 The Life Cycle of Seedless Vascular Plants
        4.3.2.1 Fern life cycle
        4.3.2.2 Homospory versus heterospory

4.1 Introduction

The vascular plants are the dominant and most conspicuous group of land plants. There are about 275,000 species of vascular plants, which represent more than 90 percent of Earth's vegetation. Several evolutionary innovations explain their success and their spread to so many habitats.

4.2 Intended Learning Objectives (ILOs)

By the end of this section, you will be able to do the following:

- Identify the new traits that first appear in seedless tracheophytes
- Discuss how each trait is important for adaptation to life on land
- Identify the classes of seedless tracheophytes
- Describe the life cycle of a fern
- Explain the role of seedless plants in the ecosystem

4.3 Main Contents

4.3.1 Seedless Vascular Plants

Vascular plants, also known as tracheophytes, constitute the prominent group of land plants, accounting for over 260,000 species, which form more than 90 percent of terrestrial vegetation. Their success in occupying diverse habitats can be attributed to evolutionary innovations. While bryophytes were capable of transitioning from water to land, their reliance on water for reproduction and limited ability to absorb nutrients through the gametophyte surface restricted their size and habitat range. Vascular plants, in contrast, have developed roots for water and mineral absorption from the soil, along with specialized conducting tissues that facilitate the transport of water, minerals, and nutrients throughout the plant's structure. This adaptation enables vascular plants to attain significant heights, effectively competing for sunlight.

Across the course of plant evolution, the sporophyte generation's dominance has progressively increased. In seedless vascular plants, such as ferns, the diploid sporophyte phase takes precedence in the life cycle, while the gametophyte, although less conspicuous, remains independent of the sporophyte. However, water dependence persists during fertilization in seedless vascular plants, as flagellated sperm require moisture to reach the egg. Consequently, ferns and related species thrive primarily in moist environments due to this reproductive limitation.

i. Vascular Tissue: Xylem and Phloem

The Silurian period, which began roughly 430 million years ago, is when the earliest fossils with evidence of vascular tissue were discovered. The simplest configuration of conductive cells displays a pattern with xylem at the center and phloem on either side. The tissue known as xylem is in charge of carrying water and minerals over long distances, moving water-soluble growth factors from organs of synthesis to target organs, and storing water and nutrients.

Phloem, a different kind of vascular tissue, moves carbohydrates, proteins, and other solutes throughout the plant. Sieve components, also known as conducting cells, and supporting tissue are two categories of phloem cells. The vascular system of plants is composed of both xylem and phloem components.

ii. Roots: Support for the Plant

Roots, although not well-preserved in the fossil record, seem to have emerged later in evolution compared to vascular tissue. The development of an intricate root system marked a significant advancement in vascular plants. Unlike the delicate filaments called rhizoids in bryophytes, which only loosely anchored the plant and didn't absorb water and nutrients effectively, roots with their robust vascular tissue system serve as a conduit for transporting water and minerals from the soil throughout the plant. This extensive network of roots not only ensures access to water sources deep in the ground but also provides stability to trees, acting as both ballast and an anchor.

Most roots establish a mutually beneficial relationship with fungi, forming mycorrhizae. In this symbiotic interaction, fungal hyphae grow around the root, penetrating the root cells or even residing within them. This relationship significantly enhances the plant's absorption capabilities by greatly increasing the surface area available for nutrient uptake.

iii. Leaves, Sporophylls, and Strobili

A third adaptation marks seedless vascular plants. Accompanying the prominence of the sporophyte and the development of vascular tissue, the appearance of true leaves improved photosynthetic efficiency. Leaves capture more sunlight with their increased surface area. In addition to photosynthesis, leaves play another role in the life of the plants. Pinecones, mature fronds of ferns, and flowers are all sporophylls—leaves that were modified structurally to bear sporangia. Strobili are structures that contain the sporangia. They are prominent in conifers and are known commonly as cones: for example, the pine cones of pine trees. In the evolution andadaptation of seedless vascular plants what does the appearance of true leaves signifies?

4.3.1.1 Diversity of Seedless Vascular Plant Groups

Seedless vascular plants are mainly **split** into two groups, the **lycophytes** and the **monilophytes**. These aren’t common names, however, and might be a little confusing to remember. Below we go over what each of these names means and some examples of seedless vascular plants.

1. The Lycophytes

This group includes quillworts, spike mosses, and club mosses. Despite the term "moss" in their names, they are not true nonvascular mosses, as they possess vascular systems. Lycophytes differ from monilophytes in their leaf-like structures known as "microphylls," which have a single vein of vascular tissue and lack branching. Lycophytes exhibit alternation of generations similar to bryophytes, but with the sporophyte as the predominant life stage. Gametophytes in lycophytes are independent of the sporophyte for nutrients and may form mycorrhizal associations. In club mosses, the sporophyte develops sporophylls arranged in strobili, cone-like structures. Lycophytes can be either homosporous or heterosporous.

An example within this group is the club moss. These plants, dominant during the Carboniferous period, were sizable trees forming extensive swamp forests. Present-day club mosses are small evergreen plants with stems and microphylls. The Lycophyta division comprises nearly 1,000 species, encompassing quillworts, club mosses, and spike mosses. These plants produce spores within cone-like strobili for the development of haploid gametophytes, except for quillworts and silver mosses which bear spores on their microphylls.


.

Figure 4.1 *Lycopodium clavatum* is a club moss. Source: https://openstax.org/books/concepts-biology/pages/14-1-the-plant-kingdom

2. The Monilophytes

The "euphylls" or real leaves, the plant parts we today specifically think of as leaves, distinguish the monilophytes from the lycophytes. These "euphylls" are wide and lacerated with numerous veins. The ferns and horsetails are two of the plants in this class that you may be familiar with by their popular names. Ferns contain large leaves and sori, which are spore-bearing structures, under their leaves.

i. Horsetails

Horsetails possess "euphylls," which are actual leaves that have been minimized, resulting in their slender and non-wide structure, unlike the broader leaves of ferns. These horsetail leaves are positioned in a circular arrangement, known as a "whorl," along the stem. Nevertheless, the shared characteristic connecting club mosses, spike mosses, quillworts, ferns, and horsetails is their existence prior to the development of seeds. Instead of seeds, these lineages propagate their gametophyte phase using spores. Ferns and whisk ferns are categorized within the Pterophyta division. Among the plant groups in the Pterophyta, horsetails, forming a distinct category from ferns at times, belong here. Horsetails are represented by a sole genus, Equisetum. They endure as the remnants of a once-extensive plant category referred to as Arthrophyta, which once gave rise to towering trees and entire swamp forests during the Carboniferous period. Typically favoring damp habitats and marshy environments, these plants can be found (Figure 4.2).

Figure 4.2 Horsetails thrive in a marsh. Source: https://openstax.org/books/concepts-biology/pages/14-1-the-plant-kingdom

The stem of a horsetail is characterized by the presence of joints, or nodes: hence the name Arthrophyta, which means "jointed plant". Leaves and branches come out as whorls from the evenly spaced rings. The needle-shaped leaves do not contribute greatly to photosynthesis, the majority of which takes place in the green stem (Figure 4.3).

Figure 4.3 Thin leaves originating at the joints are noticeable on the horsetail plant. Source: https://openstax.org/books/concepts-biology/pages/14-1-the-plant-kingdom

ii. Ferns and Whisk Ferns

Ferns are advanced seedless vascular plants that exhibit characteristics commonly found in seed plants. They possess large leaves and branching roots. In contrast, whisk ferns (psilophytes) lack roots and leaves due to evolutionary reduction, a process driven by natural selection in response to changing environments. Whisk ferns perform photosynthesis in their green stems, with sporangia-containing yellow knobs at the branch tip. While traditionally classified apart from true ferns, recent DNA analysis suggests that whisk ferns might have lost vascular tissue and roots through evolution, actually being closely related to ferns. Ferns are easily recognizable due to their sizable fronds and represent the most prominent seedless vascular plants. Approximately 12,000 fern species inhabit diverse environments from tropics to temperate forests. While some tolerate arid conditions, most ferns prefer moist and shaded habitats. Their fossil record dates back to the Devonian period (416–359 million years ago), and they flourished during the Carboniferous period (359–299 million years ago) (Figure 4.5).

Figure 4.4 Some specimens of this short tree-fern species can grow very tall. Source: https://openstax.org/books/concepts-biology/pages/14-1-the-plant-kingdom

4.3.1.2 General Characteristics

1. Pteridophytes are considered as the first plants to be evolved on land: It is speculated that life began in the oceans, and through millions of years of evolution, life slowly adapted on to dry land. And among the first of the plants to truly live on land were the Pteridophytes.

2. They are cryptogams, seedless and vascular: Pteridophytes are seedless, and they reproduce through spores. They contain vascular tissues but lack xylem vessels and phloem companion cells.

3. The plant body has true roots, stem and leaves: They have well-differentiated plant body into root, stem and leaves.

4. Spores develop in sporangia: The sporangium is the structures in which spores are formed. They are usually homosporous (meaning: one type of spore is produced) and are also heterosporous, (meaning: two kinds of spores are produced.)

5. Sporangia are produced in groups on sporophylls: Leaves that bear the sporangia are termed as sporophylls. The tip of the leaves tends to curl inwards to protect the vulnerable growing parts.

6. Sex organs are multicellular: The male sex organs are called antheridia, while the female sex organs are called archegonia.

7. They show true alternation of generations: The sporophyte generation and the gametophyte generation are observed in Pteridophytes. The diploid sporophyte is the main plant body.

Why are the monilophytes separated from the lycophytes?

Self-Assessment Exercises 1

1. What are the characteristics feature of the plant body of a seedless vascular plant?
2. What is the most common seedless vascular plants?

4.3.2 The Life Cycle of Seedless Vascular Plants

The seedless vascular plants go through an alternation of generations just as the nonvascular plants and other vascular plants do. **The diploid sporophyte, however, is the more prevalent, noticeable generation.** Both the diploid sporophyte and haploid gametophyte are independent of each other in the seedless vascular plant.

4.3.2.1 Fern life cycle

The life cycle of a fern, for example, follows these steps.

- The **mature haploid gametophyte** stage has both male and female sex organs- or antheridium and archegonium, respectively.
- The **antheridium and archegonium both produce sperm and eggs via mitosis,** as they are already haploid.
- **The sperm must swim from the antheridium to the archegonium to fertilize the egg, meaning the fern depends on water for fertilization.**
- Once fertilization happens, **the zygote will grow into the independent diploid sporophyte.**
- The **diploid sporophyte has sporangia,** which is where **the spores are produced via meiosis.**
- On the fern, the underside of the leaves have clusters known as **sori, which are groups of sporangia**. The sori will release spores when they mature, and the cycle will restart.

Notice that in the fern life cycle, although the gametophyte is reduced and the sporophyte is more prevalent, the sperm still relies on water to reach the egg in the archegonium. This means that ferns and other seedless vascular plants must live in damp environments to reproduce.

4.3.2.2 Homospory versus heterospory

The majority of vascular seedless plants are homosporous, meaning they only generate one type of spore, which develops into a gametophyte with both male and female sex organs. Some, however, are heterosporous, which means they produce both megaspores and microspores. Megaspores develop into a gametophyte with exclusively female sex organs. A male gametophyte with only male sex organs develops from microspores. Although heterospory is not widespread in all vascular plants that produce seeds, it is common in those that do. Given that many plants that produce seeds have this adaptation, evolutionary biologists think that the development of heterospory in seedless vascular plants was a significant step in the evolution and diversification of plants. The sexuality of pteridophytic gametophytes can be classified as follows:

- **Dioicous:** the individual gametophyte is either a male producing antheridia and sperm or a female producing archegonia and egg cells.
- **Monoicous**: every individual gametophyte may produce both antheridia and archegonia and it can function both as a male as well as a female.

- **Protandrous**: the antheridia matures before the archegonia.
- **Protogynous**: the archegonia matures before the antheridia.

Pteridophyta is one of the older groups of plants present in the Plant kingdom. They have evolved much earlier than the angiosperms. They are one of the very first "true" plants to adapt to life on land.

Self-Assessment Exercises 2

1. What is Homospory?
2. Name the male and female reproductive organs in pteridophytes?

4.3.3 Ecological Adaptation

Seedless vascular plants are early vascular plants that contain a number of adaptations that helped them survive life on land. You will notice that a lot of the characteristics that developed in the seedless vascular plants are not shared with nonvascular plants.

- Vascular tissue

This is a novel adaptation**. The development of the tracheid, a type of elongated cell that makes up the xylem, in early land plants led to the adaptation of vascular tissue.** Xylem tissue contains tracheid cells fortified by lignin, a strong protein, that provides support and structure to vascular plants. The vascular tissue includes the xylem, which transports water, and the phloem, which transports sugars from the source (where they are made) to sink (where they are used).

- True roots, stems, and leaves

The introduction of the vascular system in lineages of seedless vascular plants marked a significant advancement, leading to the emergence of genuine roots, stems, and leaves. This transformation revolutionized how plants engaged with their environment, enabling them to achieve larger sizes and inhabit new terrains. Following the establishment of vascular tissue, true roots emerged, capable of delving deeper into the soil for stability and nutrient absorption. These roots often form mycorrhizal associations, connecting with fungi to trade sugars for soil-extracted nutrients. Through mycorrhizae and expansive root systems, vascular plants enhance their soil interface, facilitating rapid water and nutrient uptake.

The vascular tissue enabled water transport from roots to stems and leaves, essential for photosynthesis. Moreover, it facilitated the distribution of sugars generated in photosynthesis to non-photosynthetic parts. The development of vascular stems centralizes the plant body, enabling substantial growth. Microphylls, found in lycophytes like club mosses, represent the earliest leaf-like structures in vascular plants, characterized by a single vein of vascular tissue. On the other hand, euphylls, found in ferns, horsetails, and other vascular plants, are genuine leaves with multiple veins and interveinal photosynthetic tissue.

- A dominant sporophyte generation

Unlike the nonvascular plants, **the early vascular plants developed a dominant diploid sporophyte generation, independent of the haploid gametophyte.** Seedless vascular plants also have a haploid gametophyte generation, but it is independent and reduced in size compared to nonvascular plants.

4.3.3.1 Relationship of Seedless with Bryophytes

a). Similarities

- Both are land plants.
- Both possess distinct Gametophytic and Sporophytic generations.
- Both groups show heteromorphic alternation of generation.
- Rhizoids are present in both Bryophytes and Pteridophytes.
- Sexual reproduction is oogamous.
- Both consist of multicellular sporangia.
- The cuticle is present in both plants.
- Both groups have members with terrestrial mode of life.
- Formation of spores is the same in both groups.
- Like Bryophytes, many seedless plants are homosporous.

b). Differences

Following are the major differences between bryophytes and seedless plants:

Bryophytes	Seedless plants
Bryophytes are non-vascular plants.	Are vascular plants.
The plant body is leafy or thalloid.	The plant body is differentiated into roots, stem and leaves.
No vascular tissues.	Vascular tissues are present.
Rhizoids are present for anchorage.	Roots are present for anchoring.
The gametophyte is dominating.	The sporophyte is dominating.
Anthredium is stalked.	Anthredium is sessile.
Cells are haploid.	Cells are diploid.
E: Mosses, liverworts, hornworts, etc.	Eg: Spikemosses, ferns, quillworts, etc.

4.3.3.2 The Importance of Seedless Plants

Mosses and liverworts are pioneering organisms that often colonize areas during primary or secondary successions. Their spores are dispersed by various means. Once established, they provide nourishment and shelter for other plants. In harsh environments like frozen tundras, bryophytes thrive due to their adaptability. Mosses, foundational in tundra food chains, sustain a variety of species. Bryophytes can enhance soil for other plants by forming symbiotic relationships with nitrogen-fixing cyanobacteria, replenishing soil nitrogen. Urbanization led to moss and lichen decline, indicating pollution susceptibility. Mosses are sensitive to pollutants due to their direct absorption of rainwater-borne substances. Their disappearance serves as a pollution indicator. Ferns play roles in weathering, soil formation, and erosion control. Water ferns like Azolla restore nitrogen in aquatic habitats via cyanobacteria.

Historically, seedless plants were used as tools, fuel, and medicine. Sphagnum moss, used for fuel and soil conditioning, is renewable. Ferns are popular ornamentals and houseplants. Bracken fern fiddleheads are a Native American spring delicacy. Licorice fern serves as food and medicine for Pacific Northwest tribes due to its sweetness. These seedless plants have intertwined with human life for various purposes. What are the first leaf-like structures that evolved in vascular plants? Microphylls. These are small leaf-like structures, with only a single vein of vascular tissue running through them. Lycophytes (e.g., club mosses) have these microphylls.

Self-Assessment Exercises 3

1. What are the seedless vascular plants?
2. What is the striking difference between the non-vascular and vascular plant groups?

4.4 Summary

Seedless nonvascular plants are small. The dominant stage of the life cycle is the gametophyte. Without a vascular system and roots, they absorb water and nutrients through all of their exposed surfaces. There are three main groups: the liverworts, the hornworts, and the mosses. They are collectively known as bryophytes.

Vascular systems consist of xylem tissue, which transports water and minerals, and phloem tissue, which transports sugars and proteins. With the vascular system, there appeared leaves—large photosynthetic organs—and roots to absorb water from the ground. The seedless vascular plants include club mosses, which are the most primitive; whisk ferns, which lost leaves and roots by reductive evolution; horsetails, and ferns.

4.5 References/Further Readings/Web Sources

https://openstax.org/books/concepts-biology/pages/14-1-the-plant-kingdom
https://bio.libretexts.org/Bookshelves/Introductory_and_General_Biology/Seedless_Vascular_Plants
https://viva.pressbooks.pub/introbio2/chapter/8-4-seedless-vascular-plants-2/
Biology 2e, Biological Diversity, Seedless Plants, Seedless Vascular Plants | OpenEd CUNY
https://www.youtube.com/watch?v=4IcbmEnxe8g
https://www.youtube.com/watch?v=37hEIJXRyFM
https://www.youtube.com/watch?v=7uEtXyjsItM
https://www.youtube.com/watch?v=p7xu7jt8k8w

4.6 Possible Answers to Self-Assessment Exercises

Answers to SAE 1

1. The vascular plants, or tracheophytes, are the dominant and most conspicuous group of land plants.
2. The seedless plants do not have seed, but seed-bearing plants do. The seedless plants produces spores, and seed-bearing plants produce seeds. The seedless plants don't have the ability to produce flowers, but seed-bearing plants do. The seedless plants can be vascular or nonvascular, but all seed plants are vascular.

Answers to SAE 2

1. Most **seedless vascular plants are homosporous,** which means **they produce only one type of spore,** and that spore will grow into a gametophyte that has both male and female sex organs.
2. Male sex organs are called antheridia, and female sex organs are called archegonia. The male gametes discharged by the antheridia are known as antherozoids. 5. Write the name of gametophyte of fern. The prothallus is the fern gametophyte.

Answers to SAE 3

1. **Seedless vascular plants** are a **group of early land plants that have vascular systems but lack seeds,** and instead, disperse spores for their haploid gametophyte stage. They include ferns, horsetails, club mosses, spike mosses, and quillworts.
2. Unlike the nonvascular plants, **the early vascular plants developed a dominant diploid sporophyte generation, independent of the haploid gametophyte.**

Unit 5 Seed Plant I: Gymnosperms

5.1 Introduction

The first plants to colonize land were most likely closely related to modern-day mosses (bryophytes) and are thought to have appeared about 500 million years ago. They were followed by liverworts (also bryophytes) and primitive vascular plants, the pterophytes, from which modern ferns are derived. The life cycle of bryophytes and pterophytes is characterized by the alternation of generations. The completion of the life cycle requires water, as the male gametes must swim to the female gametes. The male gametophyte releases sperm, which must swim—propelled by their flagella—to reach and fertilize the female gamete or egg. After fertilization, the zygote matures and grows into a sporophyte, which in turn will form sporangia, or "spore vessels," in which mother cells undergo meiosis and produce haploid spores. The release of spores in a suitable environment will lead to germination and a new generation of gametophytes.

5.2 Intended Learning Objectives (ILOs)

By the end of this section, you will be able to:

- Discuss the type of seeds produced by gymnosperms, as well as other characteristics of gymnosperms
- List the four groups of modern-day gymnosperms and provide examples of each
- list out general characteristics of seed plants outline the specific characteristics features of gymnosperms
- highlight morphological characteristic of a named gymnosperm
- classify gymnosperms and highlight the terrestrial (ecological) of seed plants.

5.3 Main Contents

5.3.1 The Evolution of Seed Plants

The evolutionary progression in seed plants led to a dominant sporophyte generation, where the diploid plant is ecologically more significant. Simultaneously, gametophytes became smaller, transitioning from prominent structures to microscopic cell clusters within sporophyte tissues. Lower vascular plants are mostly homosporous, while seed plants are heterosporous, forming male microspores and female megaspores. Gametophytes in seed plants rely on sporophyte tissue for nutrients and water, differing from the free-living gametophytes in seedless vascular plants, indicating an evolutionary connection.

Two key adaptations—seeds and pollen—set seed plants apart from seedless vascular plants and enabled their land colonization. Fossils date distinct seed plants back around 350 million years, with gymnosperms emerging during the Carboniferous period. Gymnosperms transitioned from progymnosperms and dominated during the Mesozoic era, with angiosperms taking over in the Cretaceous period, becoming the most abundant plant group in terrestrial ecosystems.

The introduction of pollen and seeds freed seed plants from water-dependent reproduction and allowed them to thrive on land. Pollen, containing male gametes, is protected from desiccation and damage, aiding in long-distance gene dispersal. Seeds safeguard embryos, offer nourishment, and maintain dormancy, promoting survival in harsh conditions and ensuring optimal germination. This advancement facilitates both spatial and temporal dispersal, leading to the remarkable success of seed plants as the most prosperous and recognizable plant group. How seeds are evolved?

Self-Assessment Exercises 1

1. What is a seed plant?
2. What are 2 types of seed plants?

5.3.2 The Gymnosperms

Gymnosperms ("naked seed") are a diverse group of seed plants and are paraphyletic. Paraphyletic groups do not include descendants of a single common ancestor. Gymnosperm characteristics include naked seeds, separate female and male gametes, pollination by wind, and tracheids, which transport water and solutes in the vascular system.

5.3.2.1 General Characteristics

The general characteristics of gymnosperms include:
1. The adult plant (sporophyte) is a tall, woody, perennial tree or shrub mostly evergreen. The stem is usually branched, but rarely unbranched as in, Cycas.
2. Leaves may be simple (as in Pinus) or compound.
3. Leaves may be dimorphic or of one kind only. Foliage leaves are large green simple or pinnately compound, needle-like and grow on dwarf shoot as in, Pinus, or directly borne on the main trunk as in Cycas. Scale leaves are brown and simple.
4. Vascular bundles in stem are arranged in a ring and show secondary growth.
5 Gymnosperms bear cones which are usually unisexual (either male or female, rarely bisexual as in Gnetum.
6. Pollen grains are haploid produced in microsporangia of the male cones. In Pinus, each pollen grain has two large sacs, called wings to help in the dispersal by wind. Pollen grains produce two male gametes.
7. Ovules are not enclosed in ovary as in Angiosperms, but are borne naked on leafy megasporophylls of female cone, so the term gynmosperms or ‘naked seeds’ for this group. Ovules are produced side by side, inside which female gamete or egg is produced. The male gamete fuses with female gamete in the ovule. The fertilised ovule then develops into a seed (winged in case of Pinus). Examples

5.3.2.2 Diversity of Gymnosperms

About 1,000 known species make up the four main divisions of modern gymnosperms. Coniferophyta, Cycadophyta, and Ginkgophyta are not closely connected phylogenetically, but they do produce secondary cambium (cells that create the vascular system of the trunk or stem) and have comparable seed formation patterns. Because they produce true xylem tissue that includes both tracheids and vessel components, gnetophyta are regarded as being the most closely related group to angiosperms.

i. Conifers (Coniferophyta)

With the greatest variety of species, conifers constitute the dominant phylum of gymnosperms. Most are tall trees with leaves that resemble scales or needles. The needles' thin structure and waxy coating prevent excessive water loss through transpiration. Snow keeps the burden light and lessens branch breaking by easily sliding off needle-shaped leaves. The dominance of conifers at high altitudes and in cold climates can be attributed to these adaptations to cold and dry conditions. Conifers include well-known evergreen trees including yews, pines, spruces, firs, cedars, and sequoias. (Figure 5.2). A few species are deciduous and lose their leaves all at once in fall. The European larch and the tamarack are examples of deciduous conifers. Many coniferous trees are harvested for paper pulp and timber. The wood of conifers is more primitive than the wood of angiosperms; it contains tracheids, but no vessel elements, and is referred to as “soft wood.”

Figure 5.2 Conifers are the dominant form of vegetation in cold or arid environments and at high altitudes. Shown here are the (a) evergreen spruce, (b) sequoia, (c) juniper, and (d) a deciduous gymnosperm: the tamarack *Larix laricina*. Notice the yellow leaves of the tamarack. Source: **https://viva.pressbooks.pub/introbio2/chapter/8-5-seed-plants-gymnosperms/**

ii. Cycads

Cycads thrive in mild climates and are often mistaken for palms because of the shape of their large, compound leaves. They bear large cones, and unusually for gymnosperms, may be pollinated by beetles, rather than wind. They dominated the landscape during the age of dinosaurs in the Mesozoic era (251–65.5 million years ago). Only a hundred or so cycad species persisted to modern times. They face possible extinction, and several species are protected through international conventions. Because of their attractive shape, they are often used as ornamental plants in gardens (Figure 5.3).

Figure 5.3 This *Encephalartos ferox* cycad exhibits large cones. Source: **https://viva.pressbooks.pub/introbio2/chapter/8-5-seed-plants-gymnosperms/**

iii. Gingkophytes

The single surviving species of **ginkgophyte** is the *Ginkgo biloba* (Figure 14.22). Its fan-shaped leaves, unique among seed plants because they feature a dichotomous venation pattern, turn yellow in autumn and fall from the plant. For centuries, Buddhist monks cultivated *Ginkgo biloba*, ensuring its preservation. It is planted in public spaces because it is unusually resistant to pollution. Male and female organs are found on separate plants. Usually, only male trees are planted by gardeners because the seeds produced by the female plant have an off-putting smell of rancid butter.

Figure 5.4 This plate from the 1870 book *Flora Japonica, Sectio Prima (Tafelband)* depicts the leaves and fruit of *Gingko biloba*, Source: **https://viva.pressbooks.pub/introbio2/chapter/8-5-seed-plants-gymnosperms/**

iv. Gnetophytes

The three distinct plant genera in the genus Gnetophytes are the angiosperms' nearest relatives. They have broad leaves, just like angiosperms. In tropical and subtropical regions, Gnetum species are primarily vines. The deserts of Namibia and Angola are home to the unique, low-growing Welwitschia species. It could survive for as long as 2000 years. In dry regions of Mexico and the southwestern United States, the genus Ephedra is present in North America (Figure 5.5). The chemical ephedrine, a strong decongestant used in medicine, is derived from the tiny, scale-like leaves of ephedra. Ephedrine is only used in prescription medications because of its similarity to amphetamines in both chemical structure and neurological effects. What are the major groups modern gymnosperms are classified into? Modern gymnosperms are classified into four major divisions namely; Coniferophyta, Cycadophyta, Ginkgophyta and gnetophytes.

Figure 5.5 *Ephedra viridis*, known by the common name Mormon tea.Source: **https://viva.pressbooks.pub/introbio2/chapter/8-5-seed-plants-gymnosperms/**

5.3.2.3 Life Cycle of a Conifer

Pine trees, classified as conifers, bear both male and female sporophylls on the same plant. Like all gymnosperms, pines are heterosporous, producing male microspores and female megaspores. Within the male cones or staminate cones, microsporocytes undergo meiosis to generate microspores, which later mature into pollen grains. Each pollen grain contains two cells: a generative cell that will divide into two sperm cells, and another cell that will develop into a pollen tube cell. During spring, pine trees release abundant yellow pollen carried by the wind. Some pollen grains land on female cones. Gradually, the pollen tube grows from the pollen grain, and the generative cell within the pollen divides mitotically into two sperm cells. Eventually, one sperm cell fertilizes an egg cell, merging their haploid nuclei.

Female cones, also known as ovulate cones, possess two ovules per scale. In each ovule, a single megasporocyte undergoes meiosis. Only one surviving haploid cell proceeds to develop into a female multicellular gametophyte, encapsulating an egg. Upon fertilization, the zygote matures into the embryo, enclosed by a seed coat originating from parent plant tissue. Fertilization and seed development in pine trees are prolonged, sometimes taking up to two years after pollination. The resultant seed comprises three tissue generations: the seed coat derived from parent plant tissue, the female gametophyte supplying nutrients, and the embryo itself. The life cycle of a conifer is depicted in Figure 5.1.

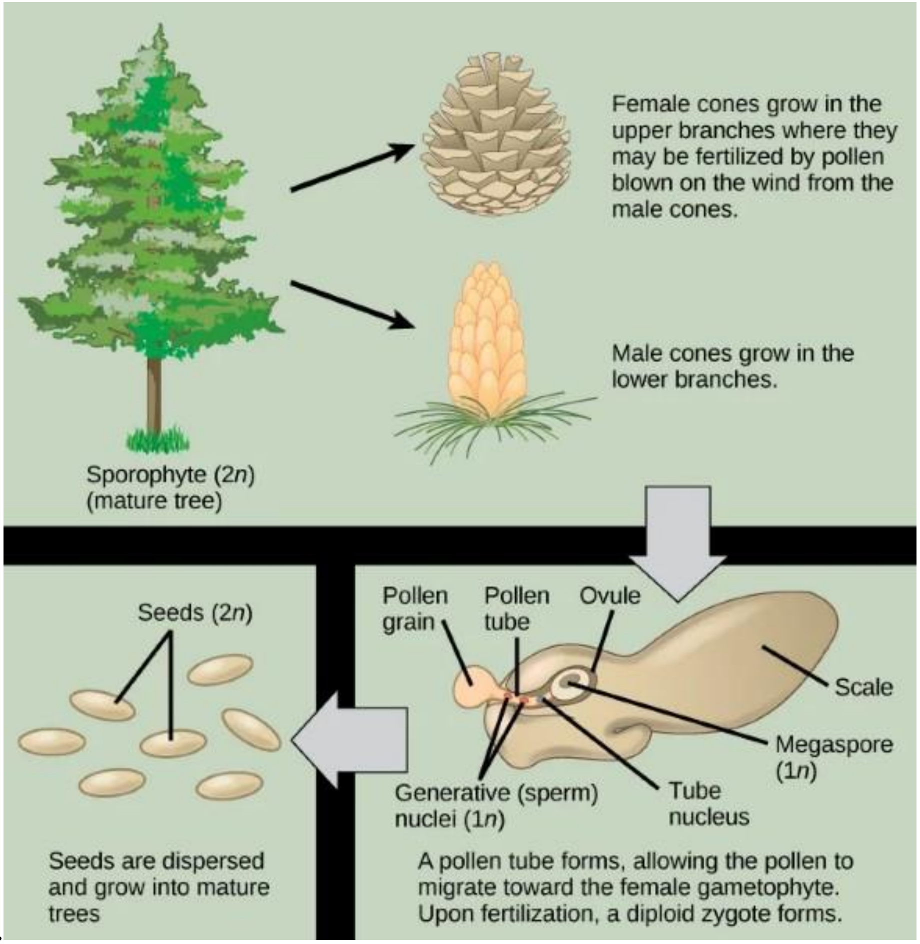


Figure 5.1 This image shows the lifecycle of a conifer.
Source: **https://viva.pressbooks.pub/introbio2/chapter/8-5-seed-plants-gymnosperms/**

Self-Assessment Exercises 2

1. Into how many major groups are modern gymnosperms classified?
2. Which group of plants is referred to as Paraphyletic?

5.3.2.4 Ecological Adaptation of Gymnosperms

Gymnosperms are seed plants adapted to life on land. They have several adaptations that make survival in diverse land habitats possible. These adaptations include:

- Retention of the megagametophyte within a protective coating to form a seed on the parent sporophyte
- Dissemination of the microgametophyte in durable pollen
- Production of complex root systems
- Extensive development of secondary xylem in the stem

Gymnosperms are adapted to live where fresh water is scarce during part of the year, or in the nitrogen-poor soil of a bog. They are found in colder regions where snowfall occurs. They are not differentiated into ovary, style and stigma, and are pollinated directly by the wind

- They produce seeds that are not enclosed by a fruit, which allows them to disperse their seeds in dry and cold environments.
- They have a vascular system that transports water and nutrients throughout the plant and provides structural support.
- They maintain high rates of photosynthesis at relatively low temperature.
- Their needles (leaves) have thick warty coatings and sunken stomatas which prevent excessive loss.

The seedless vascular plants have many adaptations helping them to survive in the conditions such as dry land and to grow in a much greater amount than non-vascular plants that are ferns, bryophytes, club mosses, and horsetails. How do gymnosperms adapt to their environment?

Self-Assessment Exercises 3

1. What are the characteristics of gymnosperms that help them survive?
2. What are adaptations that gymnosperms have to survive in dry environments?

5.4 Summary

Seed plants are vascular plants that produce seeds. They go by the name Spermatophyte as well. Their leaves, stems, and roots are all fully grown. The fertilized egg of a very little gametophyte, which is entirely dependent on the sporophytes, the plant forms we see around us, grows into the seeds that contain the embryo. The persistence and broad occurrence of seed plants are due to their effective seed dissemination. The male gamete, which is carried to the egg via pollination, fertilizes it. Next, the pollen tube that takes the male gamete to the egg grows. Since water is not required throughout this process, seed plants are actually terrestrial plants. Gymnosperms and Angiosperms, the seed plants, will be the focus of this subject.

5.5 References/Further Readings/Web Sources

https://viva.pressbooks.pub/introbio2/chapter/8-5-seed-plants-gymnosperms/
https://bio.libretexts.org/Seedless_Vascular_Plants
https://pressbooks-dev.oer.hawaii.edu/biology/chapter/seedless-vascular-plants/
https://bio.libretexts.org/Bookshelves/Introductory_and_General_Biology/Seed_Vascular_Plants
https://youtu.be/PVLACJsoGjk
https://youtu.be/FjisWvYO9pQ

5.6 Possible Answers to Self-Assessment Exercises

Answers to SAE 1

1. Seeds are an important feature of the spermatophytes, or seed plants, which are subdivided into gymnosperms, or "naked-seeded" plants such as conifers and cycads, and angiosperms, flowering plants with seeds enclosed in ovaries. Examples of plants that lack seeds are ferns and mosses

2. The seed plants are often divided arbitrarily into two groups: the gymnosperms and the angiosperms. The basis for this distinction is that angiosperms produce flowers, while the gymnosperms do not.

Answers to SAE 2

1. Modern gymnosperms are classified into four major divisions
2. Paraphyletic groups are groups that do not include descendants of a single common ancestor. eg gymnosperms.

Answers to SAE 3

1. Gymnosperms have features that help them survive in dry and cold conditions. These include needle-like leaves which help in preventing the loss of moisture. They also have naked seeds which allow them to reproduce better. Beside above, what are the main characteristics of gymnosperms?
2. Compared to ferns, gymnosperms have three additional adaptations that make survival in diverse land habitats possible. These adaptations include an even smaller gametophyte, pollen, and the seed. Gymnosperms are plants that bear seeds that are "naked," meaning not enclosed in an ovary.

Unit 6 Seed Plants II; Angiosperms

6.1 Introduction

From their humble and still obscure beginning during the early Jurassic period (202–145.5 MYA), the angiosperms, or flowering plants, have successfully evolved to dominate most terrestrial ecosystems. Angiosperms include a staggering number of genera and species; with more than 260,000 species, the division is second only to insects in terms of diversification.

6.2 Intended Learning Objectives (ILOs)

By the end of this section, you will be able to:

- Explain why angiosperms are the dominant form of plant life in most terrestrial ecosystems
- Describe the main parts of a flower and their purposes
- Detail the life cycle of an angiosperm
- Discuss the two main groups of flowering plants

6.3 Main Contents

6.3.1 The Angiosperms

Angiosperms, a significant plant division, constitute the majority of Earth's plant life. They are vascular seed plants where fertilization of the ovule results in seed development within a enclosed, hollow ovary. Typically found within flowers, the ovary is enveloped by male or female reproductive organs, or both. These plants, also referred to as flowering plants, inhabit all habitats except extreme conditions. They exist as epiphytes (living on other plants), as rooted and floating aquatics in both freshwater and marine environments, and as terrestrial plants with varying sizes, lifespans, and forms. Their diversity includes small herbs, parasitic plants, shrubs, vines, and towering trees. Additionally, they provide essential resources like medicine and timber. Familiar plants such as peas, mangos, coconuts, wheat, and rice are categorized as angiosperms. Their seeds are consistently enclosed within mature, fertilized ovaries known as fruits.

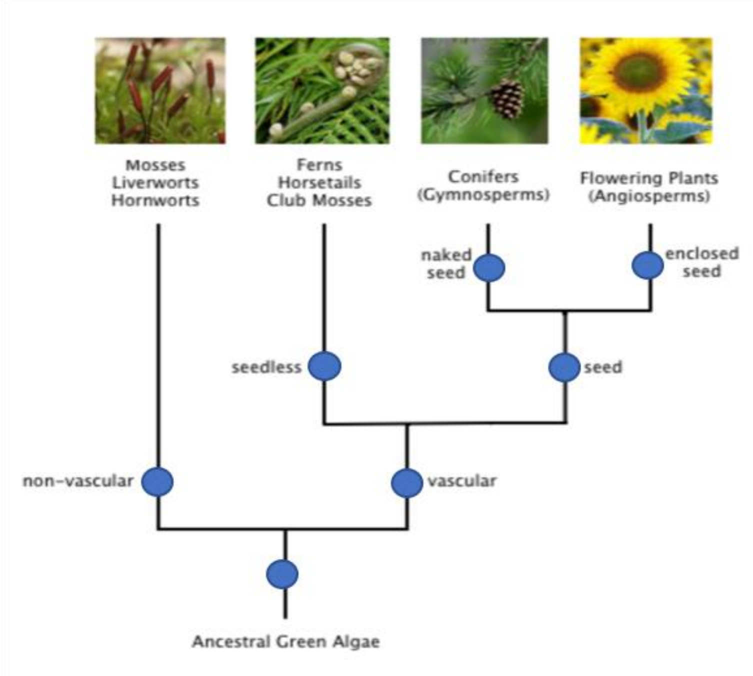


Figure 6.1. Phylogenetic tree of land plants indicating key evolutionary adaptations to life on land. Source: **https://viva.pressbooks.pub/introbio2/chapter/8-5-seed-plants- angiosperms /**

While various explanations have been proposed to account for the sudden proliferation and diversity of flowering plants, none have achieved the consensus of paleobotanists—scientists studying ancient plants. Nevertheless, new comparative genomic data has illuminated the evolution of angiosperms. Contrary to deriving from gymnosperms, angiosperms are a parallel sister clade to gymnosperms, evolving independently. From their modest and still not fully understood origins in the early Jurassic era, flowering plants, or angiosperms, have evolved to become dominant in terrestrial ecosystems. With over 250,000 species, the angiosperm group (Anthophyta) ranks second only to insects in terms of diversity. Their success is attributed to two innovative reproductive structures: flowers and fruits. Flowers serve to ensure pollination and protect the ovule and developing embryo within a receptacle. Fruits, on the other hand, aid in seed dispersal and safeguard the growing seed. Variations in fruit structures, like sweet flesh, wings, parachutes, or spines, reflect different seed dispersal strategies. Modern angiosperms are commonly classified as either monocots or eudicots, based on leaf and embryo structure. Basal angiosperms like water lilies are considered more primitive as they exhibit morphological traits shared by both monocots and eudicots.

Self-Assessment Exercises 1

1. What is the definition of an angiosperm?
2. What is difference between gymnosperm and angiosperm?

6.3.2 The Life Cycle of an Angiosperm

The main stage of an angiosperm's life cycle is the adult, or sporophyte, phase (Fig. 6.3). Angiosperms are heterosporous, just as gymnosperms. As a result, they produce megaspores, which create an ovule containing female gametophytes, and microspores, which produce pollen grains as the male gametophytes. Male gametophytes divide within the microsporangia of the anthers through meiosis to produce haploid microspores, which then go through mitosis to produce pollen grains. One generative cell that will divide into two sperm and one other cell that will become the pollen tube cell are both present in each pollen grain.

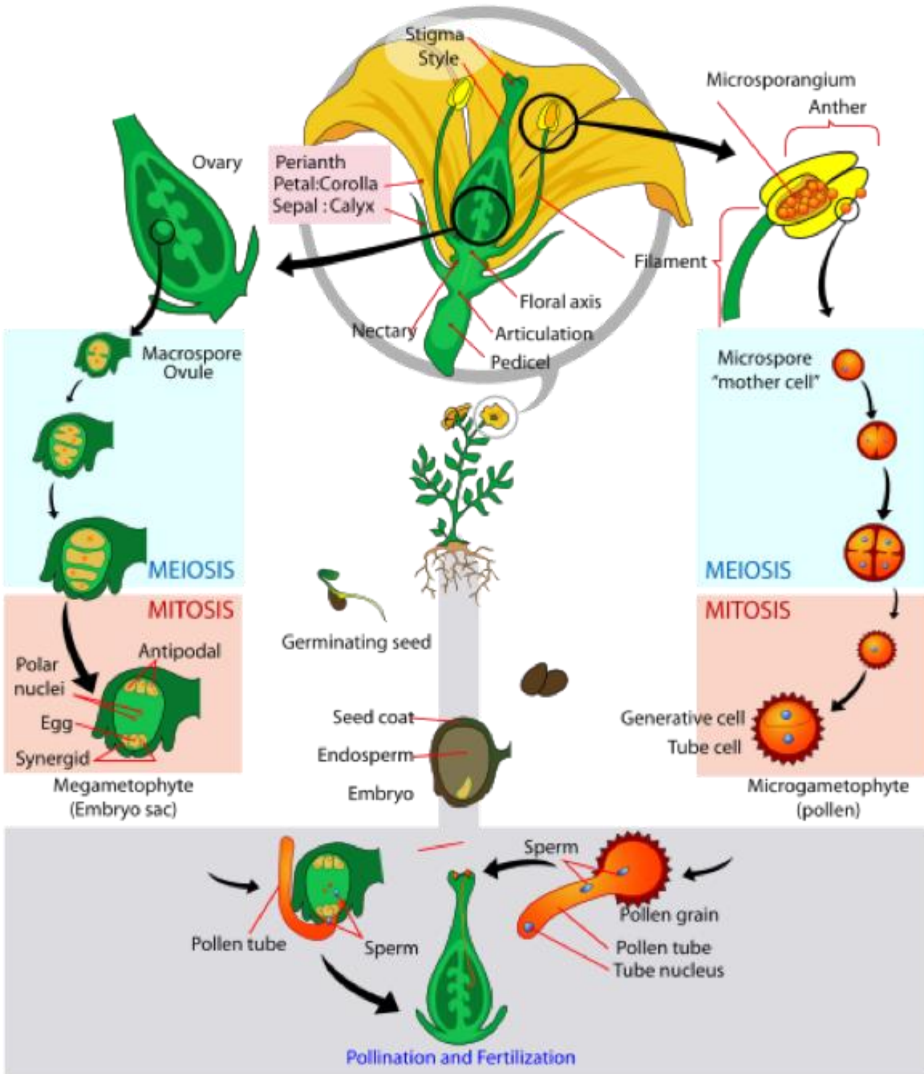


Figure 6.3. The life cycle of a typical Angiosperm: Source: **https://viva.pressbooks.pub/introbio2/chapter/8-5-seed-plants- angiosperms /**

In a flower lacking a megasporangium, the formation of female gametes (egg cells) would not occur. If the flower lacked a microsporangium, the formation of male gametes (sperm cells) would not take place. Within the ovule enclosed by the carpel's ovary, the megasporangium resides, protected by integument layers and the ovary wall. Meiosis in the megasporocyte within the megasporangium yields four megaspores, of which the larger one survives to develop into the female gametophyte called the embryo sac. This megaspore undergoes divisions to form an eight-cell stage, with specific cells becoming egg, synergids, antipodals, and polar nuclei.

Upon pollen grain arrival at the stigma, a pollen tube grows from it, traversing the style and entering the ovule via the micropyle. The pollen tube delivers two sperm cells to the embryo sac. A double fertilization occurs: one sperm unites with the egg to form a diploid zygote (future embryo), while the other fuses with 2n polar nuclei, creating a triploid cell that becomes endosperm, a nutrient store. The zygote develops into an embryo with a radicle (small root) and one or two cotyledons (leaf-like structures). Monocots have one cotyledon, while dicots have two,

differentiating the major angiosperm groups. Seed food reserves are outside the embryo, and cotyledons transport these reserves to the developing embryo. A seed consists of integument layers forming the coat, endosperm with nutrients, and a well-guarded embryo at the center.
Most flowers are monoecious (bisexual), containing both stamens and carpels, while a few self-pollinate. Monoecious flowers are referred to as "perfect" since they possess both sex organs, or as hermaphroditic in botanical terms. Dioecious plants have male and female flowers on separate individuals, facilitating cross-pollination. Double fertilization is a fertilization mechanism of flowering plants (angiosperms) that involves the joining of two male gametes (sperm) with two female gametes (egg and central cell). One sperm fuses with the egg to form a zygote, which develops into the embryo. The other sperm fuses with the central cell to form a triploid primary endosperm nucleus, which develops into the endosperm. This process is unique to angiosperms.

Both anatomical and environmental barriers promote cross-pollination mediated by a physical agent (wind or water), or an animal, such as an insect or bird. Cross-pollination increases genetic diversity in a species.

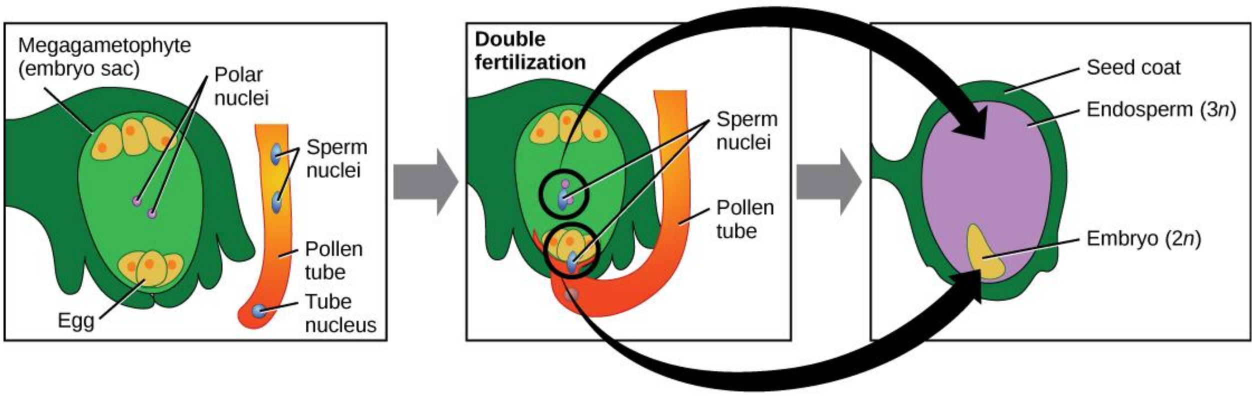


Figure 6.4 Double fertilization occurs only in angiosperms. Source: **https://viva.pressbooks.pub/introbio2/chapter/8-5-seed-plants- angiosperms /**
This process is unique to angiosperms

Figure 6.5 Monoecious plants have both male and female reproductive structures on the same flower or plant. In dioecious plants, males and females reproductive structures are on separate plants. Source: **https://viva.pressbooks.pub/introbio2/chapter/8-5-seed-plants- angiosperms /**

6.3.2.1 Flowers and Fruits as an Evolutionary Adaptation

Angiosperms, or flowering plants, produce their gametes within separate structures often found within a flower. This flower serves as a stable environment for fertilization and embryo development, sheltered from environmental fluctuations. As the second most diverse phylum after insects, flowering plants exhibit an astonishing range of sizes, shapes, colors, scents, and arrangements in their flowers. Most flowers engage in mutualistic relationships with pollinators, and the diverse flower traits often mirror the nature of these pollination agents, showcasing coevolution.

Flowers are modified sporophylls, resembling organized leaves clustered around a central stalk. Despite their varying appearances, all flowers share common structures: sepals, petals, carpels, and stamens. The peduncle attaches the flower to the plant, and sepals (collectively known as the calyx) form a base layer around the unopened bud. Sepals, usually photosynthetic, sometimes differ, as seen in lilies and tulips where petals and sepals seem identical. Petals, forming the corolla, are situated within the sepal whorl and often display vibrant hues to attract pollinators. Wind-pollinated flowers tend to be smaller, feathery, and less visually conspicuous. Sepals and petals collectively constitute the perianth. The central sexual organs—carpels and stamens—are located at the core of the flower.

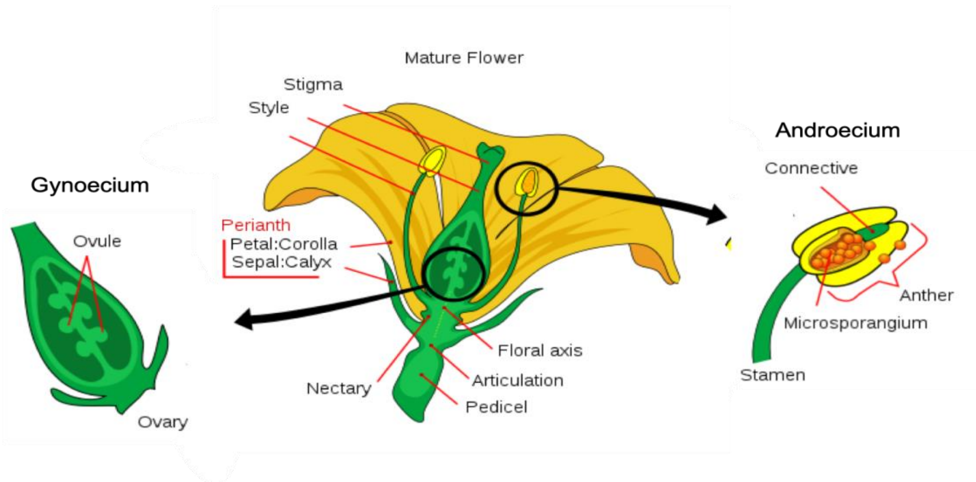


Figure 6.6. Diagram of a typical flower containing both male and female reproductive tissues. Source: **https://viva.pressbooks.pub/introbio2/chapter/8-5-seed-plants- angiosperms /**

The female reproductive organ in a flower is the gynoecium or carpel, consisting of styles, stigmas, and ovules. Flowers vary greatly in structure, with carpels existing as singular, multiple, or fused units. When multiple carpels are fused, they create a pistil. Carpel tissues offer protection to the megaspores and female gametophytes. A style, a lengthy and slender structure, extends from the sticky stigma (where pollen is received) to the ovary enclosed within the carpel. The ovary contains one or more ovules, which develop into seeds after fertilization.

Surrounding the central carpel are the male reproductive organs, collectively known as the androecium or stamens. Stamens comprise a thin stalk called a filament and a sac-like structure known as the anther. The filament supports the anther, within which microspores are produced through meiosis, eventually developing into pollen grains.

After fertilization of the egg, the ovule transforms into a seed. The tissues surrounding the ovary thicken, developing into a fruit that safeguards the seed and facilitates its dispersal over wider areas. Not all fruits originate from ovaries; some structures termed "false fruits." Fruit appearance, size, smell, and taste can vary greatly, with examples including tomatoes, walnut shells, and avocados. Fruits, similar to pollen and seeds, play roles in dispersal. Wind can carry certain fruits away, while others attract animals that eat the fruit, subsequently transporting the seeds through their digestive systems and depositing them elsewhere. Cockleburs, equipped with hooked spines, cling to fur or clothing and can travel long distances. These inspired the invention of Velcro by George de Mestral, who encountered them on his hike. As the seed develops, the ovary's walls thicken, forming the fruit. In botanical terms, a ripened ovary containing seeds becomes a fruit. Some foods called vegetables are technically fruit, like eggplants, zucchinis, and bell peppers, as they contain seeds and arise from thick ovary tissue. Acorns are nuts, and winged maple whirligigs (samara) also qualify as fruit. Botanists classify fruit into numerous categories, with only a few being fleshy and sweet.

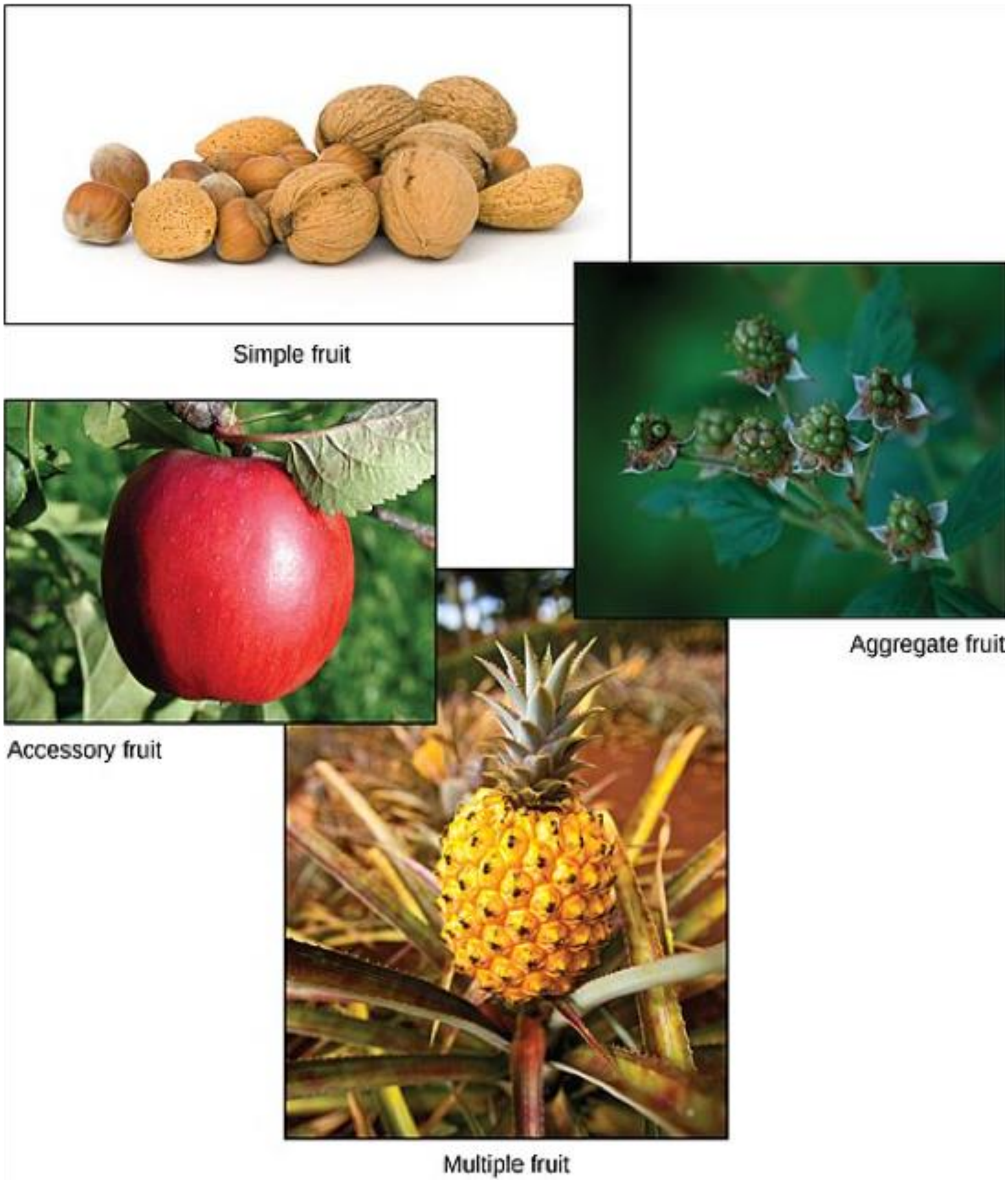


Figure 6.7. Fruits develop from the ovary which surrounds the seed. Some fruits also encase the pericarp and receptacle of the floral structure.Source: **https://viva.pressbooks.pub/introbio2/chapter/8-5-seed-plants- angiosperms /**

Mature fruits can be categorized as fleshy or dry. Fleshy fruits encompass well-known examples like berries, peaches, apples, grapes, and tomatoes. On the other hand, dry fruits include rice, wheat, and nuts. Another distinction lies in the fact that not all fruits originate from ovaries; for instance, strawberries develop from the receptacle, and apples from the pericarp or hypanthium. Some fruits arise from multiple ovaries within a single flower, such as raspberries, while others,

like pineapples, emerge from clusters of flowers. Certain fruits, like watermelons and oranges, possess rinds.
Despite their origins, fruits play a crucial role in seed dispersal. Their diverse shapes and characteristics are adapted for various modes of dispersal. Wind carries lightweight, dry fruits like those of trees and dandelions, while water transports floating coconuts. Some fruits attract herbivores through color, fragrance, or as food. Once ingested, undigested seeds pass through the herbivore's feces, contributing to dispersal. Other fruits have mechanisms like burs and hooks that cling to fur, allowing them to hitch rides on animals.

6.3.3 Diversity of Angiosperms

The Anthophyta is the only phylum in which angiosperms are categorized. It appears that modern angiosperms are a monophyletic group, which denotes that they have a single common ancestor. According to the structure of the cotyledons, pollen grains, and other components, flowering plants can be categorized into two main groupings. Grass and lilies are examples of monocots, whereas eudicots or dicots make up a polyphyletic group (Fig. 6.2). Because they have characteristics from both groups, basal angiosperms are a class of plants that are thought to have split off before the division into monocots and eudicots. They fall under different categories in various classification systems.

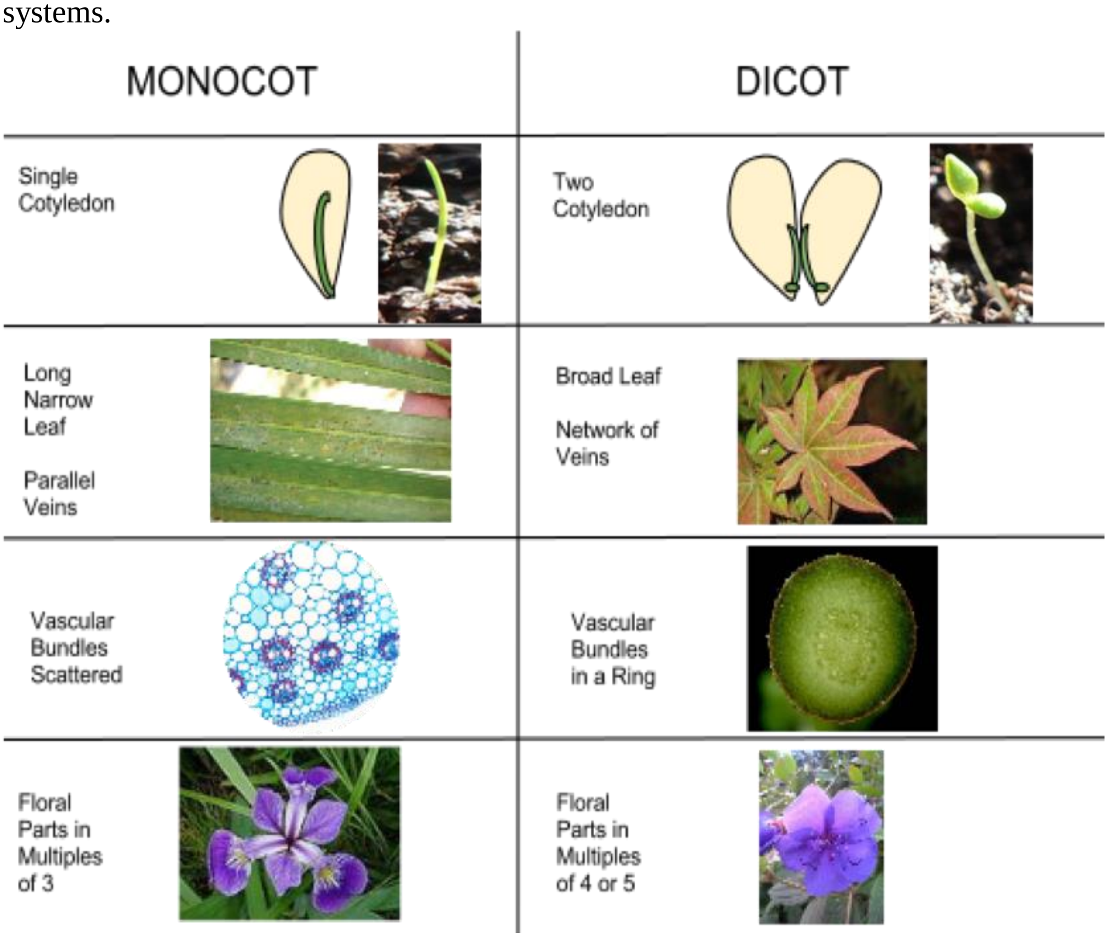


Figure 6.2. Key characteristics that separate monocots and dicots. Source: **https://viva.pressbooks.pub/introbio2/chapter/8-5-seed-plants- angiosperms /**

6.3.3.1 Basal Angiosperms

The Magnoliidae category encompasses distinctive plant groups. Magnolias, tall trees with fragrant, multipart flowers, are considered ancient. Laurel trees yield aromatic leaves and inconspicuous flowers. Laurales, typically small trees and shrubs, thrive in warmer climates. Notable examples include bay laurel, cinnamon, spicebush, and avocado trees. Nymphaeales comprise water lilies, lotus, and similar aquatic plants. Flourishing in freshwater habitats, these species have floating or submerged leaves. Water lilies, prized for their beauty, have adorned ponds for millennia. Piperales encompass herbs, shrubs, and small trees in tropical regions. They feature small, petal-less flowers arranged in long spikes. Many species offer valued fragrances or spices, like the black peppercorns from Piper nigrum, enhancing various dishes.

6.3.3.2 Monocots

Monocot plants are primarily characterized by having a single cotyledon in their seedlings. They also share anatomical traits like leaves with veins running parallel to their length and flowers exhibiting three- or six-fold symmetrical arrangements. Monocots typically lack true woody tissue, though exceptions like palm trees form trunks from vascular and parenchyma tissues. The pollen of the earliest angiosperms had a single furrow, a feature still present in contemporary monocots. The stem's vascular tissue lacks a specific arrangement, and the root system is often adventitious with no prominent taproot. Well-known monocot plants include true lilies, orchids, grasses, and palms. Many vital crops belong to this group, including rice, corn, sugar cane, bananas, and pineapples.

6.3.3.3 Eudicots

True dicots, or eudicots, are distinguished by having two cotyledons in the growing shoot. In leaves, veins create a network, and flower parts have four, five, or more whorls. In dicots, the vascular tissue is dispersed throughout the stem, forming a ring in the stem. Eudicots can generate woody tissues or be herbaceous (like grasses). The majority of eudicots generate trisulcate or triporate pollen, which has three furrows or pores. One major root that originated from the embryonic radicle often serves as the anchor for the root system. Two-thirds of all blooming plants are eudicots. Because many species have traits common to both groups, it is not always easy to determine if a plant is a monocot or a eudicot.

Comparison of Structural Characteristics of Monocots and Eudicots		
Characteristic	**Monocot**	**Eudicot**
Cotyledon	One	Two
Veins in Leaves	Parallel	Network (branched)
Stem Vascular Tissue	Scattered	Arranged in ring pattern
Roots	Network of fibrous roots	Tap root with many lateral roots
Pollen	Monosulcate	Trisulcate
Flower Parts	Three or multiple of three	Four, five, multiple of four or five and whorls

What are Eudicots? Eudicots or true dicots, are characterized by the presence of two cotyledons.

Self-Assessment Exercises 2

1. What is the diversity of angiosperms?
2. What are the divisions in angiosperms?

6.3.4 The Role of Seed Plants

Mosses and liverworts are often the first organisms to colonize new areas, whether in primary successions or after catastrophic events. Their spores are dispersed by wind, birds, or insects. Once established, they offer food and shelter for other plants. In harsh environments like the tundra, bryophytes thrive due to their rootless nature and ability to quickly rehydrate. They form the base of the tundra's food chain, providing sustenance for various species. Bryophytes also enhance soil conditions for other plants, thanks to their relationships with nitrogen-fixing cyanobacteria that enrich the soil.

Urban pollution impacts mosses due to their lack of protective features, like a cuticle. Their decline serves as an indicator of environmental pollution. Ferns contribute by aiding rock weathering, soil creation, and erosion prevention. Water ferns restore vital nitrogen to aquatic habitats through symbiosis. Seedless plants, like peat moss, have had historical uses as tools, fuel, and medicine. Plants overall maintain ecosystems by stabilizing soils, carbon cycling, and climate moderation. They provide habitat, food, and resources for various life forms, including humans. Plants are essential to the balance of terrestrial ecosystems and human life.

Some of the roles of seeds and plants include:

- Providing shelter to many lives forms
- Providing food for herbivores, thereby indirectly feeding carnivores

- Providing plant secondary metabolites for medicinal purposes and industrial production
- Providing wood, paper, textiles, and dyes for human use
- Providing ornamental species for decorations and inspiration in the arts

Self-Assessment Exercises 3

1. Why are angiosperms called flowering plants?
2. What are the major groups in the classification of angiosperms?

6.4 Summary

In this Unit, you have learnt that gymnosperms and angiosperms are seed producing vascular plants. The efficient seed dispersal of seed plants accounts for their continued existence and widespread occurrence. The distinguish features of Angiosperm in the possession of flower and fruits. Gymnosperms are mostly woody plants. Conifers are of immense economic value primary for timber and paper production. Seed plants do not need immediate aquatic habitat. Seed Plants

6.5 References/Further Readings/Web Sources

Baskin, C. and Baskin, J.M. 2014. Seed Ecology, Biogeography, and Evolution of Dormancy and Germination. 2nd Edition. Academic Press, Cambridge.

Angulo, J.C. Book Review: Vascular Plant Taxonomy, 7th edition. By Zack E. Murrell and Emily L. Gillepsie. Brittonia 74, 320 (2022). https://doi.org/10.1007/s12228-022-09713-z
https://en.wikipedia.org/wiki/Vascular_tissue
https://viva.pressbooks.pub/introbio2/chapter/8-5-seed-plants-angiosperms/
Biology 2e, Biological Diversity, Seed Plants, Angiosperms | OpenEd CUNY
https://youtu.be/PVLACJsoGjk
https://youtu.be/KPKM2uc2VNo
https://youtu.be/2SBVz4MgeIE
https://youtu.be/JSe_VUMymjo
https://youtu.be/V4IK6B_y0yk
https://youtu.be/WqgVks9NViQ

6.6 Possible Answers to Self-Assessment Exercises

Answers to SAE 1

1. Angiosperms are plants that produce flowers and bear their seeds in fruits. They are the largest and most diverse group within the kingdom Plantae, with about 300,000 species. Angiosperms represent approximately 80 percent of all known living green plants.
2. 1. Gymnosperms do not form fruit, angiosperm form fruit. 2. Gymnosperms have naked seeds, angiosperms have enclosed seeds.

Answers to SAE 2

1. The diversity that the angiosperms display is **very wide**. There are many plants that are tall woody trees, shrubs, and even herbaceous plants. These plants also have many adaptations in the roots, stems and leaves depending on the habitat that they grow in. In Angiosperms the flower is the reproductive organ.
2. Angiosperms are classified in a single division, the Anthophyta. Modern angiosperms appear to be a monophyletic group, which means that they originate from a single ancestor.

Answers to SAE 3

1. Angiosperms are also known as "flowering plants" because **flowers are a characteristic part of their reproductive structure** – though again, you may not always recognize their flowers as the pretty, colorful petaled things you think of when you hear the word. Angiosperms evolved between 250-200 million years ago.
2. Angiosperms are generally classified into two (2). These are: Monocotyledons (Monocots) Dicotyledons (Dicots).

Glossory

adventitious roots: root that grows from somewhere other than the primary root, for example, roots that arise from stems or leaves.

alternation of generations: life cycle in which haploid and diploid generations alternate with each other.

Amphiesma: the outer covering of a dinoflagellate, consisting of several membrane layers

amoeboid Having no definite shape to the cell, able to change shapecell: the basic structural and functional unit of all organisms

anemophily: Seed plants which are pollinated by wind are said to be anemophilous.

angiosperm: a group of plants that produce seeds enclosed within an ovary, which may mature into a fruit; flowering plants.

anther: the pollen producing tip of a stamen; part of a flower. More info?

antheridium: the organ on a gametophyte plant which produces the sperm cells.

anthophyte: a flowering plant, or any of its closest relatives, such as the Bennettitales, Gnetales, or Pentoxylales.

apical meristem: group of cells at the growing tip of a branch or root. It divides cells to create new tissues.

archegonium: the organ on a gametophyte plant which produces the egg cell, and nurtures the young sporophyte.

axil: the angle formed between a leaf stalk and the stem to which it is attached. In flowering plants, buds develop in the axils of leaves.

bipinnate describing a pinnate leaf in which the leaflets themselves are further subdivided in a pinnate fashion.

bisporangiate when a flower or cone produces both megaspores and microspores, it is said to be bisporangiate. Most flowers are bisporangiate.

blade: any broad and flattened region of a plant or alga, which allows for I ncreased photosynthetic surface area.

bract: any reduced leaf-like structure associated with a cone or flower.

bryophyte: plants in which the gametophyte generation is the larger, persistent phase; they generally lack conducting tissues. Bryophytes include the Hepaticophyta (liverworts), Anthocerotophyta (hornworts), and Bryophyta (mosses).

Capsid: the protein "shell" of a free virus particle

Carpel: a unit of the pistil; it is evolutionarily a modified leaf.

Cataphyll: in cycads, a scale-like modified leaf which protects the developing true leaves.

cell: fundamental structural unit of all life. The cell consists primarily of an outer plasma membrane, which separates it from the environment; the genetic material (DNA), which encodes heritable information for the maintainance of life; and the cytoplasm, a heterogeneous assemblage of ions, molecules, and fluid

cell cycle: complete sequence of steps which must be performed by a cell in order to replicate itself, as seen from mitotic event to mitotic event.

chloroplast: organelle in which photosynthesis takes place

cell membrane: The outer membrane of a cell, which separates it from the environment.

cell wall: Rigid structure deposited outside the cell membrane. Plants are known for their cell walls of cellulose, as are the green algae and certain protists, while fungi have cell walls of chitin chloroplast: A chlorophyll-containing plastid found in algal and green plant cells

chromosome: a threadlike strand of DNA that carries genes

coenocytic: Condition in which an organism consists of filamentous cells with large central vacuoles, and whose nuclei are not partitioned into separate compartments

cytoplasm: the substance inside a cell, not including the nucleus

colonial: condition in which many unicellular organisms live together in a somewhat coordinated group

contractile vacuole: in many protists, a specialized vacuole with associated channels designed to collect excess water in the cell.

Cytoskeleton: integrated system of molecules within eukaryotic cells which provides them with shape, internal spatial organization, motility, and may assist in communication with other cells and the environment.

Columella: a small column of tissue which runs up through the center of a spore capsule. It is present in hornworts, mosses, and some rhyniophytes.

compound leaves -- n. Leaves with two or more leaflets attached to a single leaf stem.

cotyledon -- n. The "seed leaves" produced by the embryo of a seed plant that serve to absorb nutrients packaged in the seed, until the seedling is able to produce its first true leaves and begin photosynthesis; the number of cotyledons is a key feature for the identification of the two major groups of flowering plants.

dikaryotic -- Having two different and distinct nuclei per cell; found in the fungi.

double membrane -- In mitochondria and plastids, there is a two-layered membrane which surrounds the organelle.

endoplasmic reticulum -- (ER) network of membranes in eukaryotic cells which helps in control of protein synthesis and cellular organization

diffusion: movement of a substance from an area of high concentration

eukaryote: an organism of one or more cells with membrane-bound nuclei

Elater: a cell or part of a cell which assists in dispersing spores.

Embryophyte: synonym for the Plantae, as here defined. It includes all green photosynthetic organisms which begin the development of the sporophyte generation within the archegonium.

enations: flaps of tissue such as those found on psilophytes.

endodermis: literally "inner skin", this is a layer of cells which surrounds the central core of vascular tissue, and which helps to regulate the flow of water and dissolved substances.

entomophily: seed plants which are pollinated by insects are said to be entomophilous.

epiphyte: a plant which grows upon another plant.

eustele: when a plant's vascular tissue develops in discrete bundles, it is said to have a eustele. See also protostele and siphonostele.

fiber: elongated and thickened cell found in xylem tissue. It strengthens and supports the surrounding cells.

flower: collection of reproductive structures found in flowering plants.

fruit: in flowering plants, the structure which encloses the seeds.

grain: the texture of wood, produced by the kinds of xylem cells present.

gymnosperm: a plant that produces seeds, which are not enclosed; includes any seed plant that does not produce flowers.

gynostemium: the central reproductive stalk of an orchid, which consists of a stamen and pistil fused together.

habit: the general growth pattern of a plant. A plant's habit may be described as creeping, trees, shrubs, vines, etc.

Herb: generally any plant which does not produce wood, and is therefore not as large as a tree or shrub, is considered to be an herb.

Heterosporangiate: producing two different kinds of sporangia, specifically microsporangia and megasporangia. Compare with heterosporous.

Heterosporous: producing two different sizes or kinds of spores. These may come from the same or different sporangia, and may produce similar or different gametophytes.

Holdfast: anchoring base of an alga.

Homosporous: producing only one size or kind of spore. Contrast with heterosporous.

Inflorescence: a cluster of flowers.

Internode: the region of a stem between two nodes, when there is no branching of the vascular tissue.

Lamina: any broad and flattened region of a plant or alga, which allows for increased photosynthetic surface area.

Leaf: an organ found in most vascular plants; it consists of a flat lamina (blade) and a petiole (stalk). Many flowering plants have additionally a pair of small stipules near the base of the petiole.

leaf trace: the strand of vascular tissue which connects the leaf veins to the central vascular system of the stem.

Leaflet: in a compound leaf, the individual blades are called leaflets.

lysosome: a membrane-bound organelle containing digestive enzymes

Magnoliid: any member of the basal assemblage of flowering plants.

Mannoxylic: wood in which there is a great deal of parenchyma tissue among the xylem is called mannoxylic. Cycads and pteridosperms have mannoxylic wood.

Megaspore: in plants which are heterosporous, the larger kind of spore is called a megaspore: it usually germinates into a female (egg-producing) gametophyte.

meiosis: cell division that produces reproductive cells

membrane: a sheet of tissue that lines or connects organs or cells

meristem: group of undifferentiated cells from which new tissues are produced.

merophytes: group of cells which have all been produced from the same initial cell.

Microphyll: a kind of leaf, specifically one which has a single, unbranched vein in it.

Microspore: in plants which are heterosporous, the smaller kind of spore is called a microspore; it usually germinates into a male (sperm-producing) gametophyte. Contrast with megaspore.

mitochondrion: part of a cell involved in energy production

mitosis: the process by which a cell divides into two smaller cells

mycorrhizae: symbiotic association between a fungus and the roots or rhizoids of a plant.

node: the region of a stem between two internodes, where there is branching of the vascular tissue into leaves or other appendages.

nucleolus: a round body in a cell that is involved in protein synthesis

nucleus: a part of the cell responsible for growth and reproduction

organelle: a specialized part of a cell; analogous to an organ

osmosis: diffusion of molecules through a semipermeable membrane permeable allowing fluids or gases to pass or diffuse through ovary: in flowering plants, the part of the flower which encloses the ovules.

ovule: in seed plants, the structure which gives rise to the seed.

paleoherb: any member of a group of basal flowering herbs which may be the closest relatives of the monocots.

parenchyma: a generalized cell or tissue in a plant.

perennial: a plant which continues to grow after it has reproduced, usually meaning that it lives for several years.

perianth: the sepals and petals of a flower are together called the perianth; literally "around the anthers". More info?

peristome: a set of cells or cell parts which surround the opening of a moss sporangium.

petal: one of the outer appendages of a flower, located between the outer sepals and the stamens.

phloem: utrient-conducting tissue of vascular plants.

phragmoplast: the cell plate formed during cell division.

phytomelanin: a papery "sooty" black layer over the seed of plants in the Asparagales, which includes agaves, aloes, onions and hyacinths.

pinnately compound: leaves which are divided up like a feather are said to be pinnately compound.

pistil: the central set of organs in a flower; it is composed of one or more carpels. More info?

pith: to severely damage the brain of a frog, also any central region of parenchyma tissue within a plant stem.

pits: thin regions of the cell wall in xylem conducting cells. Their structure is an important characteristic for recognizing different kinds of wood.

plasmodesmata: cytoplasmic connections between neighboring cells in plant tissues.

platyspermic: having seeds which are flattened and disc-like.

Plicate: folded like a paper fan, as in the leaves of palms, cyclanthoids, and some orchids.

Pollen: the microspore of seed plants.

pollen tube: in seed plants, the extension of the male gametophyte as it emerges from the pollen grain in search of the female gametophyte.

photosynthesis: formation of compounds in plants aided by radiant energy

prokaryote: a unicellular organism lacking a membrane-bound nucleus

pollination: process of transferring the pollen from its place of production to the place where the egg cell is produced.

pollinia: a mass of fused pollen produced by many orchids.

protostele: when a plant's vascular tissue develops in a solid central bundle, it is said to have a protostele. See also siphonostele and eustele.

pseudoelaters: moisture-sensitive cells produced in the sporangium of hornworts.

pteridophyte: plant in which the sporophyte generation is the larger phase and in which the gametophyte lives an existence independent of its parent sporophyte.

pteridosperm: an extinct group of seed plants which bore fern-like leaves.

pycnoxylic: wood in which there is little or no parenchyma tissue among the xylem is called pycnoxylic.

respiration: process converting nutrients into energy in a cell

radicle: the end of a plant embryo which gives rise to the first root.

radiospermic: having seeds which are round or ovoid. Contrast with platyspermic.

reticulate: interconnecting, like a network.

rhizoid: a cellular outgrowth of a plant that usually aids in anchoring to the surface and increasing surface area to acquire water or nutrients; found in mosses, liverworts, and hornworts.

rhizome: a horizontal underground stem, such as found in many ferns, where only the leaves may stick up into the air; sphenophytes (horsetails and their relatives) spread via rhizomes, but also produce erect stems.

ribosome: a particle in a cell that helps synthesize proteins

root: usually the below ground portion of a plant. Contrast with shoot.

rosette: a series of whorls of leaves or leaf-like structure produced at the base of the stem, just above the ground.

secondary growth: growth in a plant which does not occur at the tips of the stems or roots.

Sepal: the outermost structures of a flower. More info?

Shoot: usually, the above ground portion of a plant, bearing the leaves.

Siphonostele: when a plant's vascular tissue develops as a central cylinder, it is said to have a siphonostele. See also protostele and eustele.

Spermatophyte: a seed plant.

Sporangiophore: a stalk to which sporangia are attached.

Sporangium: a chamber inside of which spores are produced through meiosis.

Sporophyll: any leaf which bears sporangia is called a sporophyll.

Stamen: part of a flower, the tip of which produces pollen and is called the anther.

stigma: the sticky tip of a pistil.

stipe: a scientific term for "stalk".

stipules: paired appendages found at the base of the leaves of many flowering plants.

Stomata: openings in the epidermis of a stem or leaf of a plant which permit gas exchange with the air.

Streptophytes: the clade consisting of the plants plus their closest relatives, the charophytes.

Strobilus: tightly clustered group of sporophylls arranged on a central stalk; commonly termed a "cone" or "flower".

Style: the narrow stalk of the pistil, located above the ovary but below the stigma.

Synangium: a cluster of sporangia which have become fused in development.

Tepal: when the sepals and petals of a flower are indistinguishable, they are referred to as tepals. Tepals are common in many groups of monocots. More info?

Thalloid: plants which have no roots, stems, or leaves are called thalloid, such as liverworts and hornworts.

Tracheophyte: any member of the clade of plants possessing vascular tissue; a vascular plant.

Tree any tall plant, including many conifers and flowering plants, as well as extinct lycophytes and sphenophytes.

Tuber: in underground stem which has been modified for storage of nutrients, such as a potato.

turgor pressure: force exerted outward on a cell wall by the water contained in the cell. This force gives the plant rigidity, and may help to keep it erect. More info?

vegetative growth: growth of a plant by division of cells, without sexual reproduction.

venation: the arrangement and pattern of veins in a leaf.

whorl an arrangement of appendages, such as branches or leaves, such that all are equally spaced around the stem at the same point, much like the spokes of a wheel or the ribs of an umbrella

wood: a secondary tissue found in seed plants which consists largely of xylem tissue.

End of module questions

1). Describe the characteristics features **of** the plant kingdom
2). Describe the criteria and the **classification of the plant kingdom**

3). Describe the adaptations that allowed plants to colonize the land
4). Describe the timeline of plant evolution and the impact of land plants on other living things
5). Discuss the ecological adaptations of the algae
6). Chart the development of land adaptations in the bryophytes
7). Identify the new traits that first appear in seedless tracheophytes
8). Explain the role of seedless plants in the ecosystem

Module 3: Survey of the Animal Kingdom

1.1 Introduction

Animal evolution began more than 600 million years ago in the ocean, originating from small organisms unlike present-day creatures. The animal kingdom has evolved into a highly diverse group, with over one million identified species and ongoing discoveries. Estimates place the number of extant species between 3 and 30 million. Defining what constitutes an animal can be challenging, as organisms like corals and sponges are less straightforward to classify compared to familiar animals like dogs or birds. Animals encompass a wide range of complexity, and scientists classify them based on shared traits, anatomy, morphology, evolutionary history, embryological development, and genetics. This classification system evolves with new species knowledge. Accurately categorizing diverse species enhances our comprehension of life's variety and aids in conserving Earth's biodiversity.

1.2 Intended Learning Objectives (ILOs)

By the end of this section, you will be able to do the following:

- List the features that distinguish the kingdom Animalia from other kingdom
- Explain the processes of animal reproduction and embryonic development
- Explain the differences in animal body plans that support basic animal classification
- Compare and contrast the embryonic development of protostomes and deuterostomes

1.3 Main Contents

1.3.1 Complex Tissue Structure

Specialized animal tissues have evolved to fulfill specific functions related to finding and processing food, responding to the environment, movement, and communication. Sensory structures aid navigation and detecting food, while complex digestive systems are supported by accessory organs. Muscle tissues, along with nerve tissues, allow animals to rapidly sense and respond to changes, enabling survival and competition. Unlike plant and fungi cells, animal cells lack cell walls but may be surrounded by an extracellular matrix. Vertebrates have unique supportive tissues like bone. Epithelial tissues cover and protect surfaces, including skin and linings of organs. Animal tissues' differentiation and specialization drive their incredible diversity.

The animal kingdom is divided into five monophyletic clades: Porifera (sponges), Placozoa, Cnidaria (jellyfish and relatives), Ctenophora (comb jellies), and Bilateria (all other animals). Placozoa and Porifera lack specialized tissues from germ layers but have cells resembling tissues. Ctenophores are distantly related to Cnidarians and Bilateria in the Eumetazoa ("true animals"). Most animals belong to Eumetazoa, showcasing the diversity of multicellular animals and their distinct tissues derived from germ layers. Evolution of which two tissues resulted in nimals' unique ability to rapidly sense and respond to changes?

Self-Assessment Exercises 1

1. How does the tissue of animals differ from those of the other major multicellular eukaryotes, plants and fungi?
2. How movement is driven in the body of animals?

1.3.2 Animal Reproduction and Development

The majority of animals are diploid creatures, which means that their somatic (body) cells are diploid and their gametes are created by meiosis. There are certain outliers, such as the male bees, wasps, and ants, which originate from unfertilized eggs and are haploid. The majority of animals reproduce sexually. However, several species, including cnidarians, flatworms, and roundworms, are capable of asexual reproduction, in which the progeny derive from a portion of the parent species.

1. Processes of Animal Reproduction and Embryonic Development

Animal reproduction involves sexual and asexual methods. Sexual reproduction involves the fusion of male and female gametes through fertilization, forming a diploid zygote. Some aquatic animals reproduce asexually through budding or fragmentation. Parthenogenesis, occurring in insects and some vertebrates, results in offspring from unfertilized eggs. In parthenogenesis, offspring are genetically identical to the parent. Development begins with cleavage, a series of mitotic divisions, resulting in blastomeres. This leads to the formation of a morula, followed by a blastula in some animals. Gastrulation follows, forming the primitive gut and germ layers (endoderm, ectoderm, and in triploblastic animals, mesoderm), which specialize into various tissues, organs, and systems through organogenesis. Diploblastic animals have two germ layers, while triploblastic animals have three. These processes dictate the development of animal morphology and physiology.

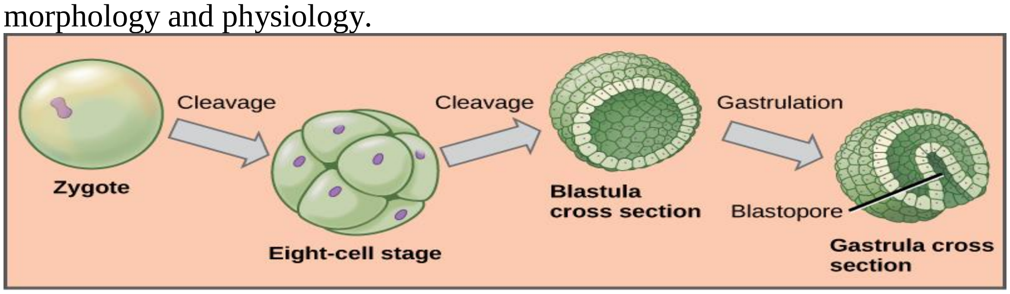


Figure 1.1 Embryonic development. Source: https://openstax.org/books/biology/pages/1-introduction.

2. Development of a simple embryo.

Embryonic development involves cleavages, where the zygote divides into smaller blastomeres. The blastula, a hollow structure, forms, with cells often arranged as a single layer. Gastrulation follows, involving cells moving inward to create an inner cavity, the primitive gut. The opening, the blastopore, may become the mouth in some invertebrates. Some animals have larval forms distinct from adults. Insects with incomplete metamorphosis, like grasshoppers, resemble adults but grow wings gradually. Others undergo complete metamorphosis, with embryos developing into diverse larval stages before forming adult structures. The series of embryonic developmental stages is relatively consistent across the animal kingdom.

Self-Assessment Exercises 2

1. What does it meant to say animals are diploid organisms?
2. Briefly describe the processes of animal reproduction and embryonic Development

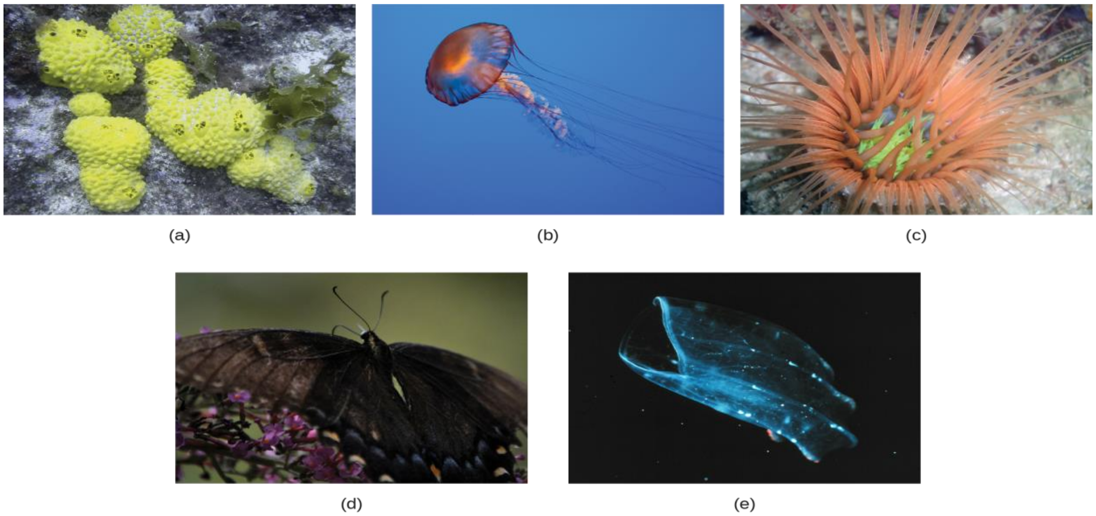
1.3.3 Diversity of Animal Life

All animals in the animal kingdom are categorized by scientists, while there are several deviations to the majority of the "rules" regulating animal classification. Animals have historically been categorized based on two traits: body layout and developmental pathway. The body plan's symmetry, or how the body parts are placed along the main body axis, is its most notable characteristic. Animals that are symmetrical can be split into about equal halves along at least one axis. The number of germ tissue layers formed during development, the origin of the mouth and anus, the presence or absence of an internal body cavity, and other aspects of embryological development, such as the type of larva or whether or not growth periods are broken up by molting, are examples of developmental characteristics.

1.3.3.1 Animal Characterization Based on Body Symmetry

True animals can be broadly categorized into three groups based on the symmetry of their body plans: radially symmetrical, bilaterally symmetrical, and asymmetrical, at the most fundamental level of classification. Two contemporary clades, the Parazoa and Placozoa, exhibit asymmetry. (However, it should be noted that the Parazoa's ancestors may have shown bilateral symmetry.) Radial or biradial symmetry is present in one clade, the Cnidaria; ctenophores have rotational symmetry. The biggest group, the Bilateria, exhibits bilateral symmetry; however, the Echinodermata are bilateral as larvae and undergo secondary metamorphosis to become radial adults. Each sort of symmetry is ideally suited to fit the special requirements of an animal's lifestyle.

Radial symmetry involves body parts arranged around a central axis, like a bicycle wheel or pie. Animals with radial symmetry have top and bottom surfaces but lack left and right sides or front and back. If divided along the oral/aboral axis, the halves of a radially symmetrical animal are mirror images. This symmetry is common in Cnidaria, such as jellyfish and adult sea anemones, aiding creatures that experience their environment from all directions. Bilateral symmetry, found in animals like butterflies, has one division plane creating equivalent halves. Ctenophora, resembling jellyfish, have rotational symmetry, with one body half rotated 180 degrees.



[Figure](#) 1.2 Symmetry in animals. The (a) sponge is asymmetrical. The (b) jellyfish and (c) anemone are radially symmetrical, the (d) butterfly is bilaterally symmetrical. Rotational symmetry (e) is seen in the ctenophore Beroe, shown swimming open-mouthed. Source: https://openstax.org/books/biology/pages/1-introduction.

Bilateral symmetry involves dividing an animal along a midsagittal plane, resulting in two mirror image halves (right and left). This symmetry is present in creatures like butterflies, crabs, and humans. Animals with bilateral symmetry have distinct anterior and posterior, dorsal and ventral, and right and left sides. Most animals in the Eumetazoa group have bilateral symmetry, promoting directional motion and cephalization (organized nervous system in the anterior end). This symmetry allowed for active mobility, resource-seeking, and predator-prey interactions. Some animals like echinoderms display modified radial symmetry as adults but have a bilateral symmetry during their larval stages.

1.3.3.2 Animal Characterization Based on Features of Embryological Development

Most animal species undergo embryonic development with germ layers that give rise to specific tissues and organs. Animals can be classified into two categories based on the number of germ layers they have: diploblasts and triploblasts. Diploblasts, which include animals with radial, biradial, or rotational symmetry, have two germ layers - an inner endoderm or mesendoderm, and an outer ectoderm. These animals lack a coherent third layer of tissue. Triploblasts, found in more complex animals with bilateral symmetry, have three germ layers - endoderm, ectoderm, and mesoderm. These layers differentiate into various tissues and organs during development.

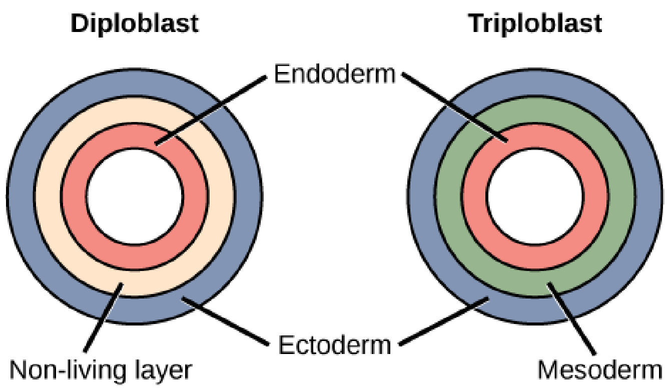


Figure 1.3 Diploblastic and triploblastic embryos. Source: https://openstax.org/books/biology/pages/1-introduction.

Diploblastic and triploblastic embryos.
During embryonic development, diploblasts develop two germ layers: an ectoderm and an endoderm or mesendoderm. Triploblasts, on the other hand, have a third layer known as the mesoderm, which arises from mesendoderm and is situated between the endoderm and ectoderm. These germ layers have specific roles in forming various body tissues and organs. The endoderm gives rise to the lining of the digestive and respiratory tracts, as well as other structures. The ectoderm contributes to the outer covering of the body, the central nervous system, and more. The mesoderm, unique to triploblasts, gives rise to muscle tissues, connective tissues, and visceral organs like the skeleton, blood cells, and internal organs. Diploblastic animals may have cells that serve multiple functions, such as covering and contraction.

Presence or Absence of a Coelom
In triploblasts, there is a subdivision between animals that develop an internal body cavity derived from the mesoderm, known as a coelom, and those that do not. The coelom is a fluid-filled cavity lined with epithelial cells that houses various organs like the digestive, urinary, and reproductive systems, as well as the circulatory system. This coelomic cavity has functional advantages such as shock absorption, organ flexibility, and optimal placement. Animals without a coelom are called acoelomates, while those with a true coelom developed entirely from the mesoderm are eucoelomates. Pseudocoelomates have a partially mesoderm- and partially endoderm-lined coelom. The presence and characteristics of the coelom play a role in the classification and functional attributes of different animal groups.

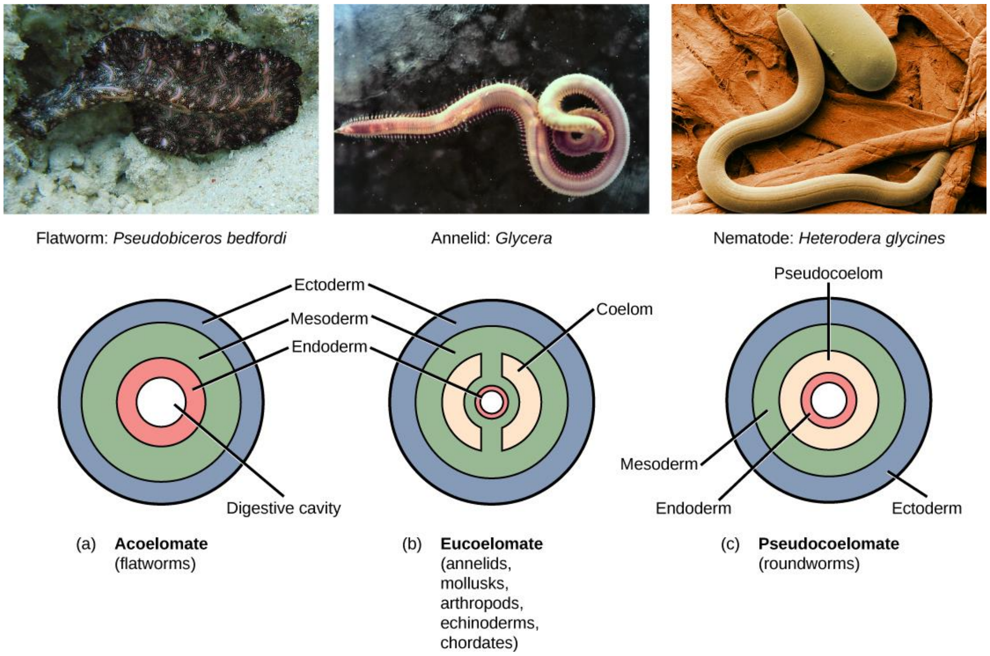


Figure 1.4 Body cavities. Triploblasts may be (a) acoelomates, (b) eucoelomates, or (c) pseudocoelomates. Acoelomates have no body cavity. Eucoelomates have a body cavity within the mesoderm, called a coelom, in which both the gut and the body wall are lined with mesoderm. Pseudocoelomates also have a body cavity, but only the body wall is lined with mesoderm. Source: https://openstax.org/books/biology/pages/1-introduction.

Embryonic Development of the Mouth

Bilaterally symmetrical eucoelomates can be categorized into Protostomes and Deuterostomes based on differences in the origin of the mouth during embryonic development. In Protostomes, the mouth forms at the blastopore, while in Deuterostomes, the mouth forms at the opposite end of the gut and the anus develops at the blastopore. These classifications also influence the method of coelom formation. In protostomes, the coelom forms through schizocoely, where specific blastomeres migrate and create mesodermal tissue clumps that eventually develop into cavities forming the coelom. In deuterostomes, coelom formation occurs through enterocoely, as mesoderm pouches pinch off from the endoderm tissue and expand to create the coelom. Another distinction lies in cleavage patterns. Protostomes undergo spiral cleavage, with cells at one pole misaligned with those at the opposite pole due to oblique cleavage angles. Deuterostomes experience radial cleavage, where cleavage axes are parallel or perpendicular to the polar axis, resulting in aligned cells between the poles. These developmental differences reflect broader distinctions in the organization and embryonic development of protostomes and deuterostomes.

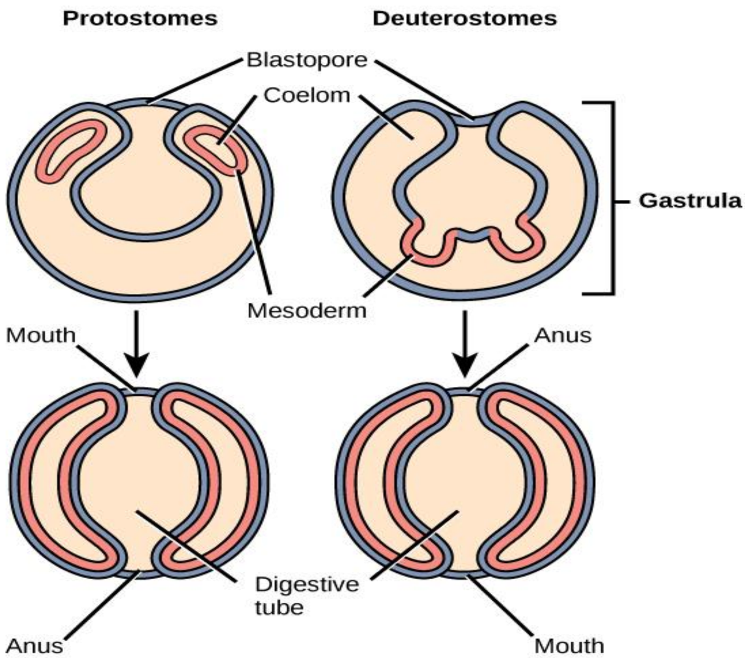


Figure 1.5 Protostomes and deuterostomes. Source: https://openstax.org/books/biology/pages/1-introduction.

Eucoelomates can be categorized based on their early embryonic development. In protostomes, the mouth forms near the blastopore, and the body cavity originates through the process of schizocoely, where mesodermal mass splits. Deuterostomes, on the other hand, have the mouth forming opposite the blastopore, and their coelom develops through enterocoely, with mesoderm pouches pinching off. Another distinction lies in the cleavage process. Protostomes undergo determinate cleavage alongside spiral cleavage, where each embryonic cell's fate is predetermined. If a blastomere is removed, structures might be missing, and the embryo might fail to develop. Deuterostomes experience indeterminate cleavage, where cells are not yet committed to specific cell types. Removing blastomeres doesn't lead to loss of structures, and even twins can develop from separated blastomeres. Deuterostomes can compensate for damaged cells through adjacent undetermined cells. This characteristic is reflected in embryonic stem cells, which can develop into various cell types until their fate is determined later in development. What do we refer to Triploblasts that do not develop a coelom?

Self-Assessment Exercises 3

1. What is the difference in organization of protostome and deuterostome embryos from cleavage point of view?
2. What are the three types of Triploblasts coelomates?

1.4 Summary

Animals encompass a vast array of organisms, varying from simple sea sponges to humans, yet they share fundamental traits. They are eukaryotic, multicellular, and heterotrophic, obtaining nutrients by consuming other organisms. Most animals develop mobility and adhere to a specific body plan. Notably, animals possess specialized tissues like nerve, muscle, and connective tissues, optimized for specific functions. Sexual reproduction is common among animals, resulting in similar embryonic stages across the kingdom. A set of regulatory genes known as Hox genes plays a pivotal role in shaping major animal body plans, displaying strong homology throughout the animal kingdom.

1.5 References/Further Readings

Barnes, R.S.K., P. Calow, P. J. W. Olive, D. W. Golding & J. I. Spicer (2001). *The invertebrates—a synthesis.* Oxford: Blackwell. 3rd edition [chapter 3.4.2, p. 54]. ISBN 0-632-04761-5.

Brusca, R.C., G.J. Brusca (2003). *Invertebrates.* Sunderland, Mass.: Sinauer Associates. 2nd edition [chapter 8, p. 219]. ISBN 0-87893-097-3.
https://openstax.org/books/biology/pages/1-introduction.
http://www.fleabites.net/beneficial-nematodes-for-fleas-how-they-work/."
https://youtu.be/e-txR1WSPBs
https://youtu.be/ZTYjLFIhQDM
http://openstaxcollege.org/l/symmetry

Answers to SAE 1

1. The tissues of animals differ from those of the other major multicellular eukaryotes, plants and fungi, because their cells don't have cell walls.
2. Movement is driven by muscle tissue attached to supportive structures like bone or chitin, and is coordinated by neural communication.

Answers to SAE 2

1. Most animals are diploid organisms, meaning that their body (somatic) cells are diploid and haploid reproductive (gamete) cells are produced through meiosis.
2. During sexual reproduction, the haploid gametes of the male and female individuals of a species combine in a process called fertilization. Typically, both male and female gametes are required: the small, motile male sperm fertilizes the typically much larger, sessile female egg.

Answers to SAE 3

1. Protostomes undergo spiral cleavage, whereas deuterostome do not, meaning that the cells of one pole of the embryo are rotated, and thus misaligned, with respect to the cells of the opposite pole.
2. Triploblasts may be (a) acoelomates, (b) eucoelomates, or (c) pseudocoelomates

Unit 2 **The Simplest Animals**

2.1 Introduction

The majority of animal species on earth are classified as invertebrates. They come in a very wide variety, including scorpions, octopuses, and centipedes. Some of their smallest members are the most fascinating despite their extreme diversity. The most basic animals are the sponges and cnidarians. Sponges appear to be the first multicellular organisms in the animal group. They lack real tissues, in which specialized cells are grouped according to their functional roles, even if they have cells that are specialized for specific functions. Sponges resemble the colonial, flagellated protists that are thought to have existed before mammals. Despite having only two tissue layers, the cnidarians, or jellyfish and their relatives, are the most basic animal group to exhibit real tissues.

2.2 Intended Learning Outcomes

- Describe the organizational features of the simplest multicellular organisms
- Explain the various body forms and bodily functions of sponges
- Identify the common characteristics of phylum Cnidaria
- Identify common structural and organizational characteristics of the phylum Cnidaria
- Identify the common characteristics of superphylum Lophotrochozoa
- Identify the common characteristics of superphylum Ecdysozoa
- Identify the common characteristics of superphylum Deuterostomia

2.3 Main Contents

2.3.1 Sponges

Invertebrates are animals without bony structures like cranium and vertebrae. The simplest invertebrates, Parazoans, encompass only the phylum Porifera, which includes sponges. Parazoans lack tissue-level organization but possess specialized cells for specific functions. While not having true tissues like more advanced animals, sponges still exhibit specialized cell groups that function like tissues. Sponges have body structures designed to facilitate water movement, crucial for functions such as feeding, excretion, and gas exchange. Despite not forming true tissues during embryogenesis, sponges have adapted to their aquatic environments with structures like canals and chambers that allow water to flow and enable essential exchanges within their bodies.

2.3.1.1 Characteristics of Sponges

Sponges, a diverse group of invertebrates, encompass around 5000 species globally, primarily in marine environments with some freshwater species. They lack true tissues but have specialized cells for various functions. Water movement in sponges is facilitated by flagella-bearing choanocytes that create currents through pores and canals. They can be radially symmetrical or asymmetrical, supported by a protein collagen and spicule skeleton embedded in a gelatinous matrix. Sponges capture food via water currents created by choanocytes and digest it within individual cells. Reproduction occurs sexually and asexually; gemmules, internal buds, aid survival in unfavorable conditions. In sexual reproduction, gametes are captured by choanocytes and transferred to eggs. Sponges exhibit different body plans: asconoid (simple tube), syconoid (larger tube with canals), and leuconoid (complex mass with numerous chambers). They are present in various aquatic habitats, often containing toxic substances for protection and competition. Sponges have potential pharmaceutical uses due to beneficial compounds they produce. They form symbiotic relationships with plants, bacteria, and algae, and some bore into corals and mollusks. Overall, sponges play important ecological roles in marine ecosystems.

2.3.1.1 Physiological Processes in Sponges

Sponges, despite being simple organisms, regulate their different physiological processes through a variety of mechanisms. These processes regulate their metabolism, reproduction, and locomotion.

Digestion

Sponges lack complex digestive, respiratory, circulatory, and nervous systems. They feed by trapping food particles as water flows through their ostia and out the osculum. Choanocytes capture bacteria for ingestion, while larger particles are taken in by pinacocytes on the surface. Amoebocytes transport food to cells that haven't ingested any. Digestion is intracellular, limiting the size of ingested food particles. Oxygen and carbon dioxide exchange, circulation, and waste excretion occur through diffusion between sponge cells and surrounding water. Some sponges host photosynthetic endosymbionts like algae or cyanobacteria. Around 150 species of carnivorous sponges feed on tiny crustaceans using sticky threads or spicules. While sponges lack a dedicated nervous system, intercellular communication regulates actions like body contraction and choanocyte activity.

Reproduction
Sponges reproduce through both sexual and asexual methods. Asexual reproduction involves fragmentation (breaking off a piece of the sponge that develops into a new individual) or budding (an outgrowth growing from the parent and detaching or forming a colony). Freshwater sponges exhibit an atypical asexual method using gemmules, resistant structures containing archeocytes surrounded by cells and spicules. Gemmules survive harsh environments and later colonize habitats. Sexual reproduction involves gamete formation. Oocytes develop from amoebocytes and are retained, while spermatozoa result from choanocyte differentiation and are expelled. Sponges are monoecious (hermaphroditic), producing both eggs and sperm. Gamete production varies with environmental conditions, and some sponges become sequentially hermaphroditic. Cross-fertilization is encouraged by the temporal separation of gametes. Spermatozoa from one sponge fertilize oocytes in others. Early larval development occurs within sponges, with free-swimming larvae released via the osculum.

Locomotion
As adults, sponges are often sessile and reside linked to a permanent substrate. They do not exhibit long-distance locomotion like other free-swimming sea invertebrates do. Sponge cells may, however, saunter around surfaces because to their organizational flexibility, or ability to rearrange their cells. Researchers have demonstrated that sponge cells spread out on a physical substrate have a leading edge for directed movement under experimental circumstances. It has been hypothesized that this restricted creeping motion aids sponges in adjusting to the microenvironments close to the attachment point. However, it should be highlighted that while this pattern of movement has been observed in lab settings, it has not yet been confirmed in environments where sponges naturally live. Are porifera only sponges?

Self-Assessment Exercises 1

1. What is the mode of nutrition in sponges?
2. Why are Poriferans confused to be plants instead of animals?

2.3.2 Diversity Sponges

Sponges are diverse invertebrates classified into four classes: calcareous sponges (Calcarea), glass sponges (Hexactinellida), demosponges (Demospongiae), and encrusting sponges (Homoscleromorpha). Different classes are distinguished by the presence and composition of spicules and spongin. Demosponges are the most common, comprising 90% of all sponge species, with variable spicules and spongin. Calcareous sponges have calcium carbonate spicules or exoskeletons, and are found in shallow marine waters. Homoscleromorpha sponges are simple and encrusting, with small, uniform spicules. Hexactinellid sponges have strong, lattice-like silica skeletons, often with a cup-shaped form.

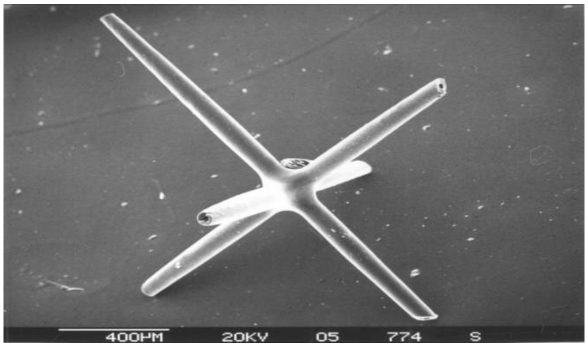


Figure 2.1 Sponge Spicule: Sponges are classified based on the presence and types of spicules they contain. Source: http://www.fleabites.net/beneficial-nematodes-for-fleas-how-they-work/."

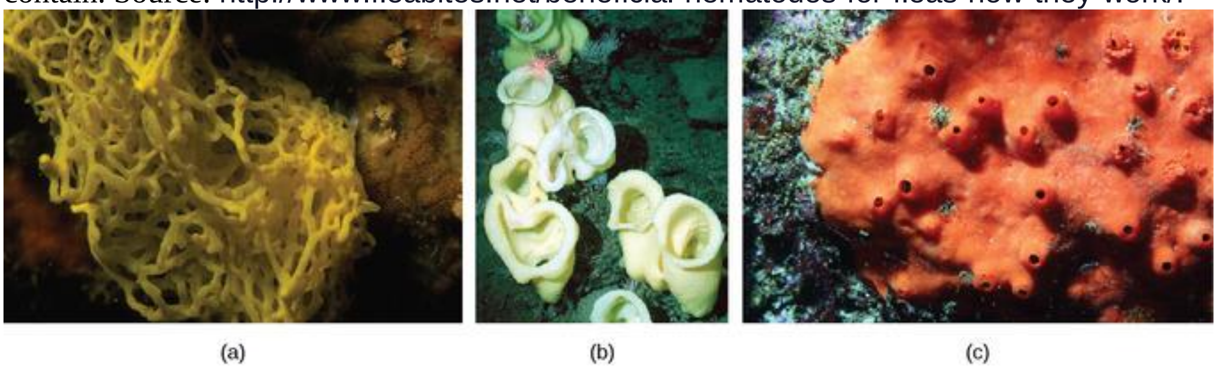


Figure 2.2 Types of sponges: (a) *Clathrina clathrus* belongs to class Calcarea, (b) *Staurocalyptu*s spp. (common name: yellow Picasso sponge) belongs to class *Hexactinellida*, and (c) *Acarnus erithacus* belongs to class Demospongia.Source: http://www.fleabites.net/beneficial-nematodes-for-fleas-how-they-work/."

Poriferans, or sponges, are multicellular organisms that lack true tissues and organs, and they do not exhibit body symmetry. They possess specialized cells that perform specific functions. Their bodies are adapted for efficient water flow, which is crucial for feeding, gas exchange, and excretion. They have pores called ostia through which water enters and canals, chambers, and cavities that enable water to reach most cells.

Sponges typically reproduce sexually, releasing sperm into the water to fertilize eggs. Fertilized eggs develop into larvae that search for suitable settling places. Asexual reproduction occurs through fragment regeneration, budding, and the formation of gemmules, dormant structures that allow survival in harsh conditions. Many of the thousands of sponge species are filter-feeders, consuming bacteria and particles from the water. Some species are carnivorous, preying on small crustaceans, while others host photosynthetic microorganisms as endosymbionts, benefiting from the produced food and oxygen.

2.3.2.1 Habitat and Adaptation of Sponges

Sponges have a global distribution, from polar to tropical latitudes, and can thrive in diverse habitats ranging from deep ocean depths to shallow rock pools. They are found in marine thermal vents, freezing Arctic waters, and freshwater environments. While most are in marine habitats, some occupy brackish water and freshwater. Sponges inhabit a wide array of ecosystems including reefs, seagrass beds, and ocean trenches, avoiding areas with strong currents or crashing waves. Their distribution spans the entire globe, with species inhabiting cold Arctic waters to warm tropical oceans, as well as various freshwater regions. Sponges have several adaptations that allow them to survive in different environments. These adaptations include:

- Body shapes that are adapted for maximal efficiency of water flow through the central cavity.
- Internal skeletons of spongin and/or spicules (skeletal-like fragments) of calcium carbonate or silicon dioxide.
- Lack of organs and specialized tissue.
- Flagellated cells that move water into the central cavity through the perforations.
- Individual cells that digest food, excrete waste, and absorb oxygen.
- Ability to reproduce asexually or sexually.
- Larval forms that are free-swimming but all adults are sessile.
- Skeleton types that allow them to live in either hard or soft sediments.
- Pores that allow them to filter the water around them for food.

Sponges are strong animals with dense skeletons that are well adapted to their environments. They may live almost everywhere and adapt to the regions and surfaces they grow in. Their skeletal type allows them to live on hard, rocky surfaces or soft sediments such as sand and mud. Certain sponge species are adapted to freshwater environments. Their pores allow them to filter the water around them for food. Where are Porifera sponges found?

2.3.2.2 Comparison to Other Phyla

Sponges themselves are really distinctive creatures and share few similarities with organisms in other phyla. They are the only invertebrates to be asymmetrical and along with cnidarians they are only classified on the tissue level of organization. In fact, although cnidarians are dissimilar in appearance, they share many characteristics with porifera. Both are sessile at one point in their life cycles, which also is diplontic. Porifera are one of the oldest animal ancestors, which also leads us to believe that they evolved much earlier than other invertebrates. These animals truly are remarkable and have evidently managed to distinguish themselves immensely form other invertebrates regarding characteristics, adaptations, as well as behaviour. What are the four types of sponges?

Self-Assessment Exercises 2

1. Describe the different cell types and their functions in sponges.
2. Describe the feeding mechanism of sponges and identify how it is different from other animals.

2.3.3 Cnidarias

Porifera are at a simpler level of organization than cnidarians. They have a noncellular mesoglea sandwiched between two layers of tissue on the outside and inside. Cnidarians do extracellular digestion and have a well-developed digestive system. The cnidocyte is a unique cell that can both warn off predators and give toxins to prey. A cnidarian's life cycle includes physically diverse forms, and they have separate sexes. At different times throughout their lives, these animals also exhibit the two distinct morphological forms known as polypoid and medusoid.

2.3.3.1 Characteristics of Phylum Cnidaria

Phylum Cnidaria consists of diploblastic animals that exhibit radial or biradial symmetry. Nearly all cnidarians are marine species. These organisms possess specialized cells called cnidocytes, which contain stinging organelles called nematocysts. These cells are primarily located around the mouth and tentacles and are used to immobilize prey or deter predators. Nematocysts contain coiled threads with barbs and are activated by touch through hairlike projections called cnidocils. Upon activation, these cells release toxins into the target, aiding in capturing prey or deterring predators.

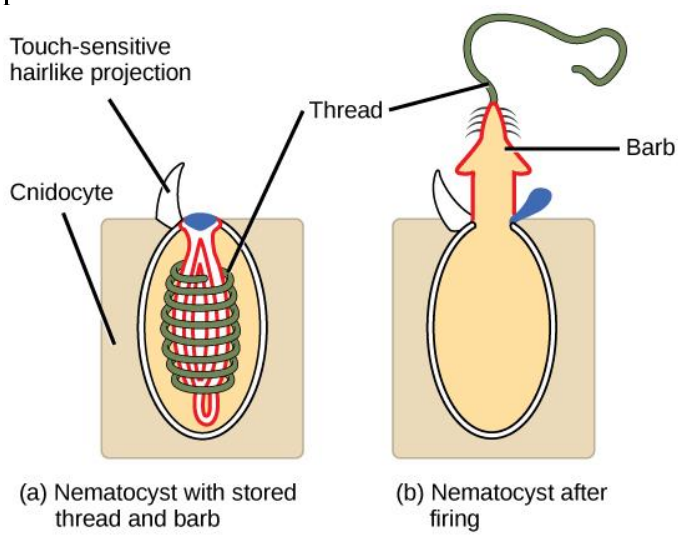


Figure 2.3. Animals from the phylum Cnidaria have stinging cells called cnidocytes. Cnidocytes contain large organelles called (a) nematocysts that store a coiled thread and barb. When hairlike projections on the cell surface are touched, (b) the thread, barb, and a toxin are fired from the organelle. Source: http://www.fleabites.net/beneficial-nematodes-for-fleas-how-they-work/."

The polyp or "stalk" and the medusa or "bell" body plans are two unique cnidarian body types (Figure 2.4). Freshwater Hydra species are examples of the polyp form; jellies (jellyfish) are probably the best-known medusoid creatures. As adults, polyps are sessile, with only one digestive system entrance (the mouth), which is surrounded by tentacles. The mouth and tentacles of a medusa hang from its bell-shaped body, and it is a moving creature. Other cnidarians have both a polyp and a medusa form, and these forms alternate throughout the life cycle.

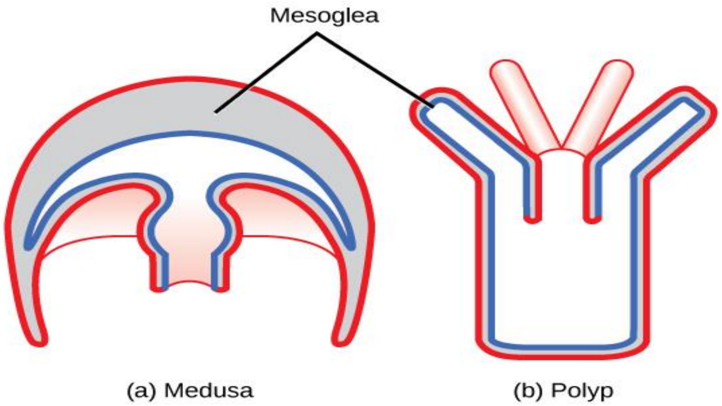


Figure 2.4 Polymorphic cnidarians. Source: http://www.fleabites.net/beneficial-nematodes-for-fleas-how-they-work/."

Some cnidarians exhibit polymorphism, displaying two different body plans during their life cycle. An example is the colonial hydroid called Obelia. This hydroid has two types of polyps in its sessile polyp form: gastrozooids for feeding and gonozooids for asexual reproduction of medusae. The medusae, which are free-swimming and either male or female, are produced from reproductive buds on the gonozooids. After maturing, these medusae release sperm or eggs. Fertilization leads to the development of a zygote into a blastula, and then into a planula larva. The larva swims freely for a period before attaching, eventually forming a new colonial reproductive polyp.

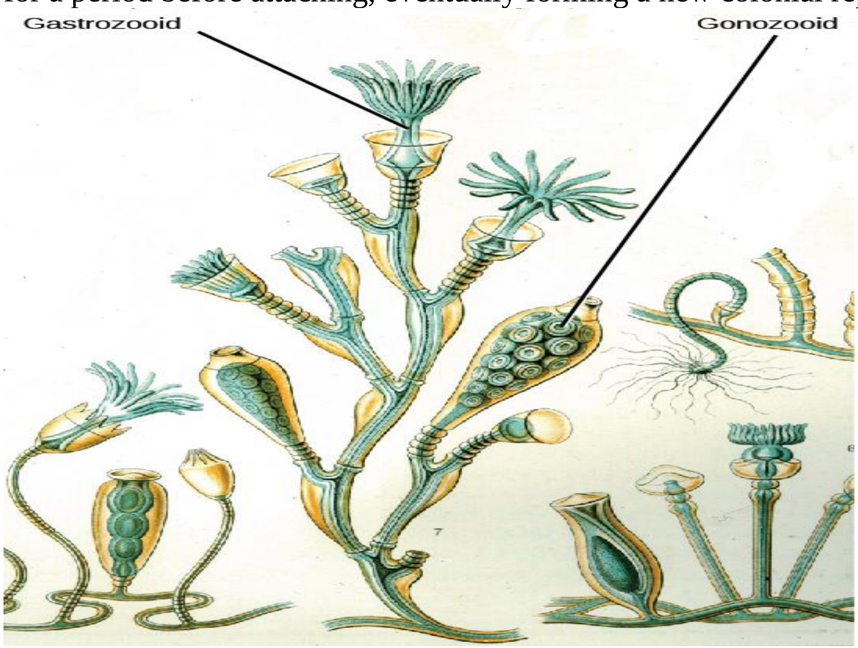


Figure 2.5. The sessile form of Obelia geniculate has two types of polyps: gastrozooids, which are adapted for capturing prey, and gonozooids, which bud to produce medusae asexually.Click here to follow the life cycle of the *Obelia.* Source: http://www.fleabites.net/beneficial-nematodes-for-fleas-how-they-work/."

Cnidarians exhibit a simple body structure with two main tissue layers: the outer epidermis derived from ectoderm and the inner gastrodermis derived from endoderm. These layers enclose a jelly-like mesoglea. While the cellular complexity is present, the development of organs is limited. Their nervous system is basic, with nerve cells scattered throughout the body, forming nerve nets, plexi, or cords. Despite its simplicity, the nervous system coordinates various functions like tentacle movement and prey capture. Cnidarians perform extracellular digestion, secreting enzymes into their gastrovascular cavity for nutrient absorption. They have an incomplete digestive system with a single opening for both ingestion and egestion. Oxygen and carbon dioxide exchange occurs through diffusion between cells and the environment. Cnidarians lack circulatory and excretory systems, and waste elimination happens through diffusion. Nutrient distribution also relies on diffusion through the mesoglea between cells.

2.3.3.2 Physiological Processes of Cnidarians

Cnidarians possess two tissue layers: the outer epidermis and the inner gastrodermis, separated by a jelly-like mesoglea. These layers contain different cell types and intercellular connections. Despite cellular differentiation, cnidarians lack organs and organ systems. Their basic nervous system consists of scattered nerve cells forming a network that transmits signals from sensory to contractile cells. They engage in extracellular digestion followed by intracellular digestion. Enzymes are secreted into the gastrovascular cavity, and absorbed nutrients aid intracellular digestion. The gastrovascular cavity functions as both a mouth and an anus (incomplete digestive system). Oxygen, carbon dioxide, and nitrogenous waste exchange occur through diffusion between cells and the environment.

2.3.3.3 Diversity of Cnidaria

About 10,000 identified species make up the phylum Cnidaria, which is classified into the Anthozoa, Scyphozoa, Cubozoa, and Hydrozoa classes. The scyphozoans (jellyfish) and cubozoans (box jellies) are swimming forms, in contrast to the anthozoans, sea anemones, and corals, which are all sessile species. The hydrozoans include swimming colonial forms like the Portuguese Man O' War and sessile forms.

1. Class Anthozoa

The class Anthozoa encompasses cnidarians with a solitary polyp body plan, excluding the medusa stage. This group includes sea anemones, corals, and sea pens, totaling about 6,100 species. Sea anemones are cylindrical and attached to substrates, with colorful appearance and tentacles containing cnidocytes for prey capture. Their mouth is surrounded by tentacles and a siphonophore-lined pharynx. The gastrovascular cavity is divided by mesenteries, increasing nutrient absorption and gas exchange. Sea anemones feed on small fish and shrimp, using their cnidocytes to immobilize prey. Some establish symbiotic relationships with hermit crabs and clownfish. Anthozoans reproduce asexually via budding or fragmentation, or sexually by producing gametes. Polyps produce both gametes, which can fuse to generate a planula larva, eventually settling into a sessile polyp form.

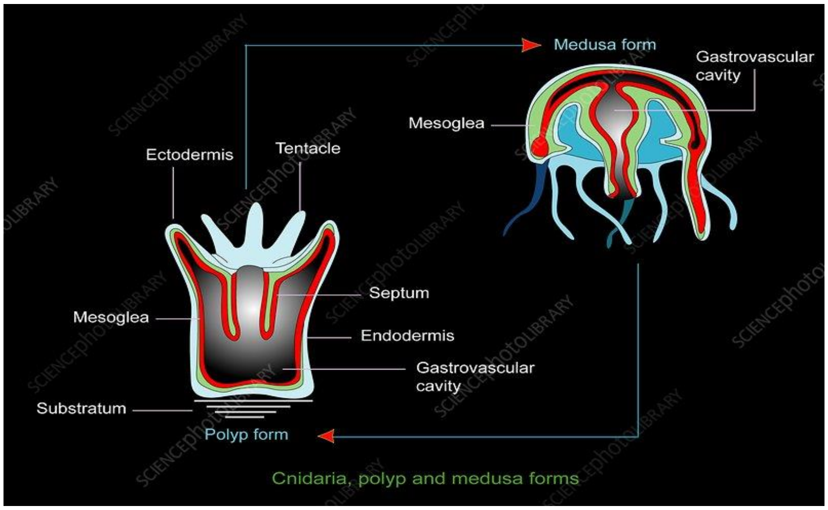


Figure 2.6 Cnidaria polyp and medusa forms. Source: http://www.fleabites.net/beneficial-nematodes-for-fleas-how-they-work/."

Class Scyphozoa includes all the jellies and is exclusively a marine class of animals with about 200 known species. The defining characteristic of this class is that the medusa is the prominent stage in the life cycle, although there is a polyp stage present. Members of this species range from 2 to 40 cm in length but the largest scyphozoan species, *Cyanea capillata*, can reach a size of 2 m across. Scyphozoans display a characteristic bell-like morphology (Figure 2.7).

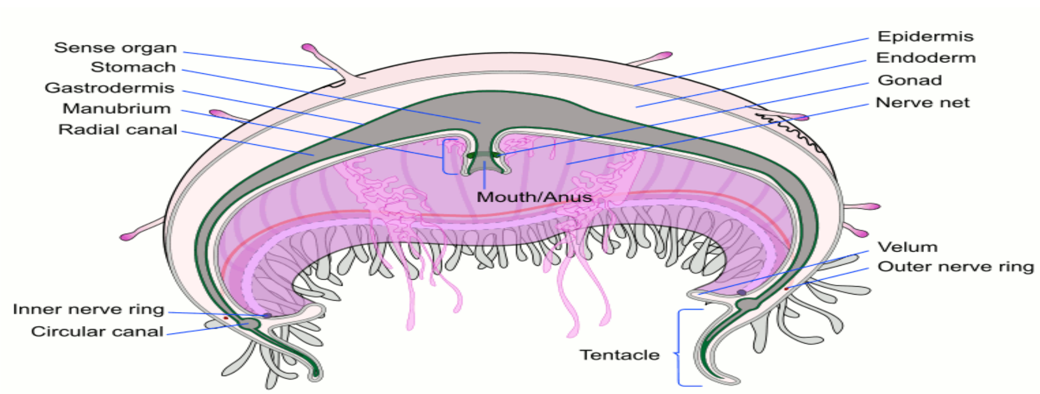


Figure 2.7 A jelly illustrating its morphology. Source: http://www.fleabites.net/beneficial-nematodes-for-fleas-how-they-work/."

Jellyfish belonging to the class Scyphozoa have a mouth opening surrounded by tentacles bearing nematocysts on their underside. These solitary carnivores spend most of their life cycle as free-swimming organisms. The mouth leads to a gastrovascular cavity divided into interconnected sacs called diverticuli, potentially further branched into radial canals. This structure enhances nutrient absorption and diffusion due to increased contact with the gastrovascular cavity. Nerve cells are scattered throughout the body, and a ring of muscles around the dome enables swimming.

Scyphozoans are dioecious, with separate sexes and gonads formed from the gastrodermis. Gametes are expelled through the mouth. They have a polymorphic life cycle, exhibiting both medusal and polypoid body plans. The life cycle involves planula larvae produced through external fertilization, which settle as polypoid forms called scyphistoma. These can give rise to additional polyps through budding or transform into the medusoid form.

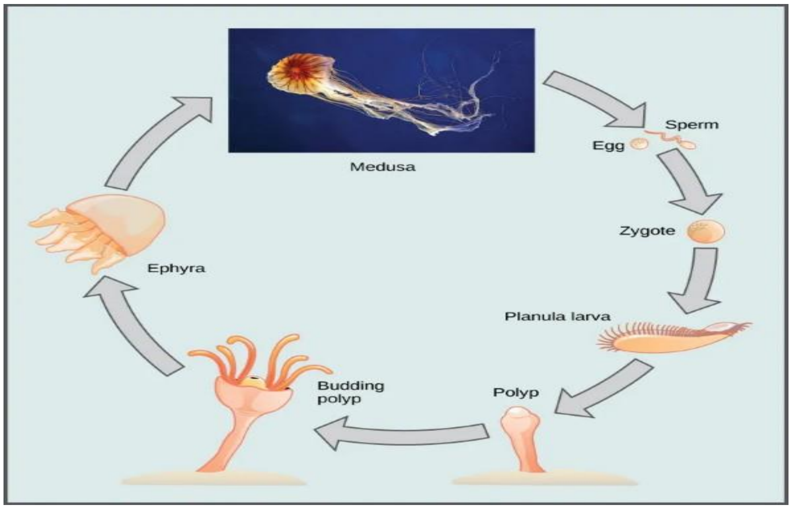


Figure 2.8. The life cycle of a jellyfish includes two stages: the medusa stage and the polyp stage. The polyp reproduces asexually by budding, and the medusa reproduces sexually. Source: http://www.fleabites.net/beneficial-nematodes-for-fleas-how-they-work/."

Class Cubozoa

The class Cubozoa includes box jellyfish, characterized by their box-shaped medusa or square bell. These species can reach sizes of 15-25 cm. They share similar morphological and anatomical features with scyphozoans. A key distinction is in tentacle arrangement. Cubozoans are highly venomous among cnidarians. They possess muscular pads called pedalia at the corners of the bell, with tentacles attached to each pedalium. Tentacles might have nematocysts arranged spirally for effective prey capture. These creatures are categorized into orders based on the number of tentacles per pedalium. The digestive system can extend into the pedalia. Cubozoans have a polypoid form that arises from a planula larva. These polyps have limited mobility, may bud to create more polyps for habitat colonization, and eventually transform into medusoid forms.

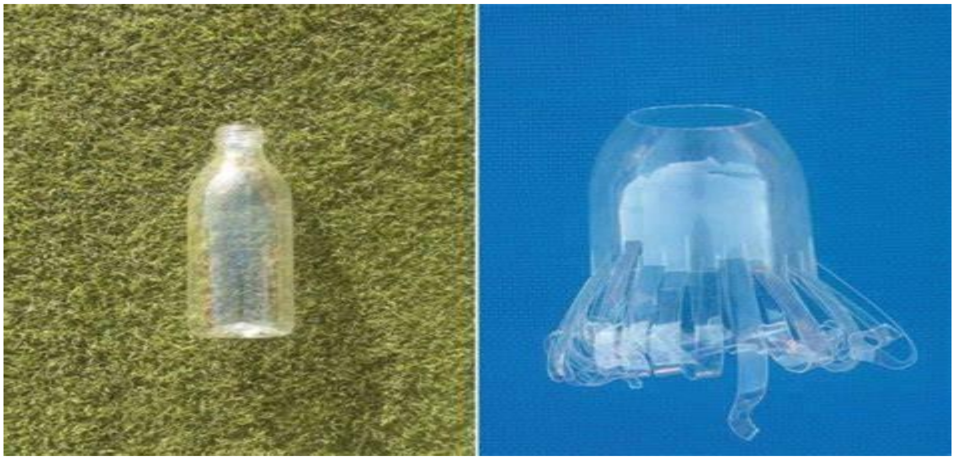


Figure 2.9. A tiny cubazoan jelly *Malo kingi* is thimble shaped and, like all cubozoan jellies. Source: http://www.fleabites.net/beneficial-nematodes-for-fleas-how-they-work/."

Class Hydrozoa

The class Hydrozoa comprises around 3,200 species, most of which are marine, with some freshwater species. Hydrozoans are polymorphic, often showing both polypoid and medusoid forms in their life cycle. The polyp form is typically cylindrical, with a central gastrovascular cavity lined by gastrodermis. Tentacles surround a mouth opening at the oral end. Many hydrozoans form colonies composed of specialized polyps sharing a gastrovascular cavity, like in the colonial hydroid Obelia. Some colonies are free-floating and include both medusoid and polypoid individuals, as seen in Physalia and Velella. Other species exist as solitary polyps (Hydra) or solitary medusae (Gonionemus). Notably, their gonads for sexual reproduction are derived from epidermal tissue, unlike other cnidarians where they originate from gastrodermal tissue. Explain the function of nematocysts in cnidarians. The nematocysts are “stinging cells” designed to paralyze prey. The nematocysts contain a neurotoxin that renders prey immobile.

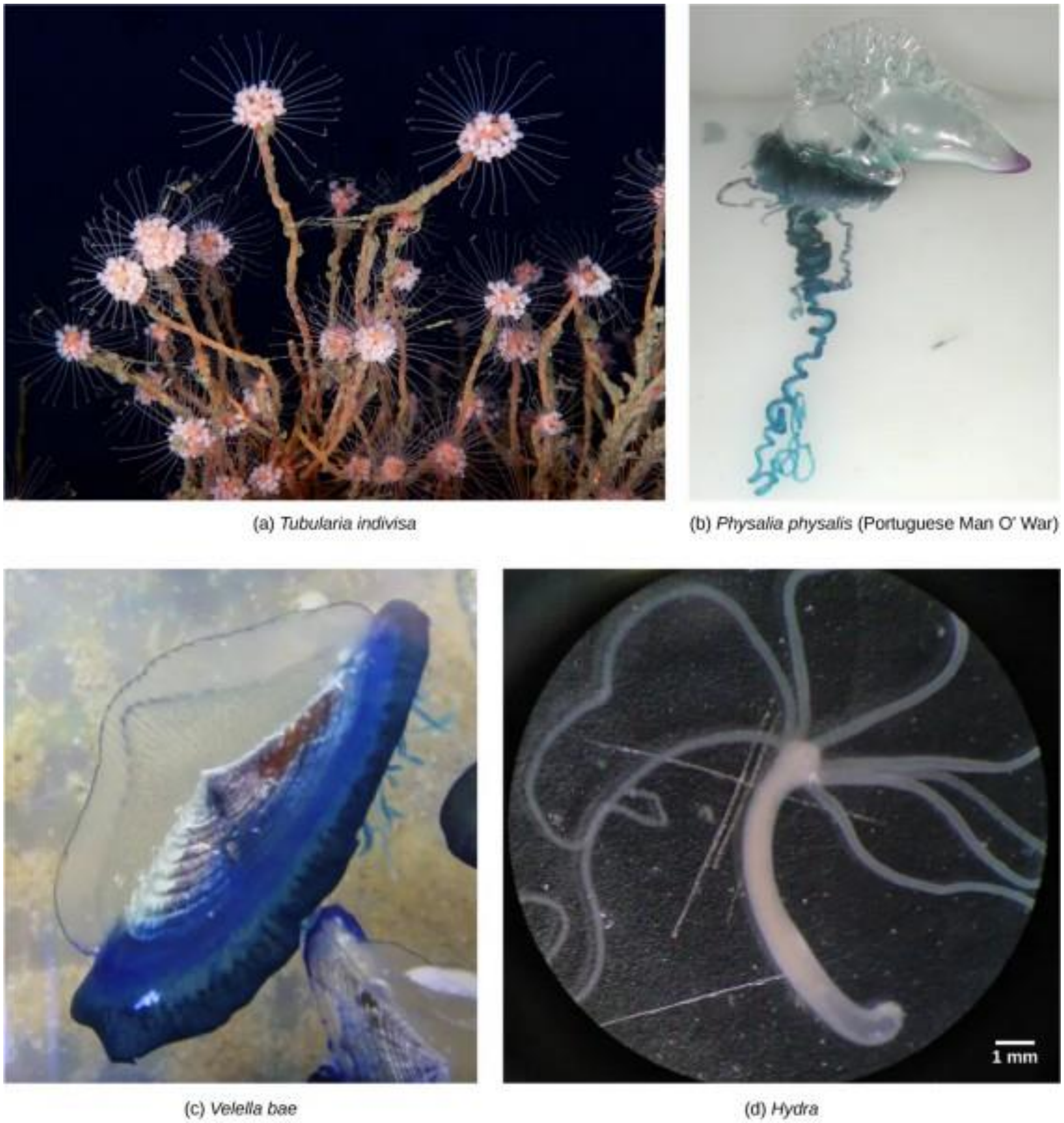


Figure 2.10 Hydrozoans. The *Tubularia indivisa* (a), siphonophore colonies *Physalia* (b) *physalis*, known as the Portuguese man o' war and *Velella bae* (c), and the solitary polyp *Hydra* (d) have different body shapes but all belong to the family Hydrozoa. Source: http://www.fleabites.net/beneficial-nematodes-for-fleas-how-they-work/."

2.3.3.4 Habitat and Adaptation

Cnidarians exhibit a range of adaptations that suit their diverse habitats. They often attach to solid substrates or burrow into sediments, with polyps being common in shallow waters and even deep ocean environments. Medusae are carried by currents and have preferred depths. Cnidarians are radially symmetrical, lack cephalization, and have two cell layers instead of three like higher animals. Their activities are coordinated by a decentralized nerve net and simple receptors. Some free-swimming Cubozoa and Scyphozoa species have balance-sensing statocysts and simple eyes.

Cnidarians were the first animals to possess muscles and nerves for behavior, and they feature specialized structures for pumping and circulating water. Other adaptations of cnidarians include:

- Gastrovascular cavity (incomplete gut) divided with septa
- Extracellular digestion
- Epitheliomuscular cells which help in muscular contractions
- Well-developed statocysts for balance
- Ocelli (photosynthetic)

Self-Assessment Exercises 3

1. Compare the structural differences between Porifera and Cnidaria.
2. Compare the differences in sexual reproduction between Porifera and Cubozoans. How does the difference in fertilization provide an evolutionary advantage to the Cubozoans?

2.4 Summary

The sponges and the cnidarians represent the simplest of animals. Sponges appear to represent an early stage of multicellularity in the animal clade. Although they have specialized cells for particular functions, they lack true tissues in which specialized cells are organized into functional groups.

2.5 References/Further Readings/Web Sources

Antcliffe, J.B., Callow, R.H.T., and Brasier, M.D. (2014). Giving the earliest fossil record of sponges a squeeze. *Biological Reviews*, **89**, 972-1004.

Barnes, R.S.K., P. Calow, P. J. W. Olive, D. W. Golding and J. I. Spicer (2001). *The invertebrates—a synthesis.* Oxford: Blackwell. 3rd edition [chapter 3.4.2, p. 54]. ISBN 0-632-04761-5.

Brusca, R.C. and G.J. Brusca (2003). *Invertebrates.* Sunderland, Mass.: Sinauer Associates. 2nd edition [chapter 8, p. 219]. ISBN 0-87893-097-3.

Dalby, A. (2003). *Food in the Ancient World: from A to Z.* London: Routledge.

Jordan EL and Verma PS. 2018. Invertebrate Zoology. 14th Edition. S Chand Publishing.

https://manoa.hawaii.edu/exploringourfluidearth/biological/invertebrates/phylum-porifera

https://en.wikipedia.org/wiki/Sponge

https://openstax.org/books/biology/pages/1-introduction.

http://www.fleabites.net/beneficial-nematodes-for-fleas-how-they-work/."

https://www.youtube.com/watch?v=CxHgoPx-Go0

https://www.youtube.com/watch?v=74v498Oqlm8

https://www.shapeoflife.org/video/cnidarian-animation-anemone-body-plan

https://www.shapeoflife.org/video/cnidarians-deep-sea-research

https://www.shapeoflife.org/video/nematocyst-animation-fighting-tentacles

https://www.shapeoflife.org/video/cnidarians-anemone-catches-goby

2.6 Possible Answers to Self-Assessment Exercises

Answers to SAE 1

1. Poriferans exhibit holozoic nutrition. They filter the tiny, floating organic particles and planktons that they feed on, hence called filter-feeders. They collect the food in specialized cells called choanocytes which are transported throughout the body by amoebocytes.
2. Poriferans are attached to the seafloor and cannot move from one place to the other. Since they share this characteristic with plants, they are often confused to be plants instead of animals.

Answers to SAE 2

1. Pinacocytes are epithelial-like cells, form the outermost layer of sponges, and enclose a jelly-like substance called mesohyl. In some sponges, porocytes form ostia, single tube-shaped cells that act as valves to regulate the flow of water into the spongocoel. Choanocytes ("collar cells") are present at various locations, depending on the type of sponge, but they always line some space through which water flows and are used in feeding.
2. The sponges draw water carrying food particles into the spongocoel using the beating of flagella on the choanocytes. The food particles are caught by the collar of the choanocyte and are brought into the cell by phagocytosis. Digestion of the food particle takes place inside the cell. The difference between this and the mechanisms of other animals is that digestion takes place within cells rather than outside of cells. It means that the organism can feed only on particles smaller than the cells themselves.

Answers to SAE 3

1. Poriferans do not possess true tissues, while cnidarians do have tissues. Because of this difference, poriferans do not have a nervous system or muscles for locomotion, which cnidarians have.
2. There are two key differences between Porifera (sponges) and Cubozoans (box jellyfish) – gamete production and fertilization strategy. Box jellyfish have separate sexes, while a single sponge can produce both types of gametes. Box jellyfish also undergo internal fertilization, while sponges reproduce by external fertilization. Internal fertilization allows box jellyfish to control which sperm is used for fertilization and increases the likelihood of ova and spermatozoa meeting.

3.2 Main Contents

3.3.1 Flatworms

3.1 Introduction

The triploblastic animal phyla in this and the following modules have an embryonic mesoderm in the middle of the ectoderm and endoderm. Additionally, a longitudinal section of these phyla will separate them into right and left sides that are mirror reflections of one another because to their bilateral symmetry. The onset of cephalization, the evolution of a concentration of neurological systems and sensory organs in the organism's head, where the creature first interacts with its environment, is connected to bilateralism.

3.2 Intended Learning Objectives (ILOs)

By the end of this section, you will be able to:

- Describe the structure and systems of flatworms
- Describe the characteristics and physiological processes of flatworms
- Describe the structural organization of nematodes
- Compare the internal systems and the appendage specialization of arthropods

3.3 Main Contents

3.3.1 Flatworms

Flatworms, or phylum Platyhelminthes, encompass a diverse range of acoelomate organisms with varying lifestyles, including both free-living and parasitic forms. Nematodes, or roundworms, are pseudocoelomate organisms and comprise both free-living and parasitic species. Arthropods, a highly successful group, are coelomate organisms characterized by a rigid exoskeleton and jointed appendages. Nematodes and arthropods are part of the Ecdysozoa clade, sharing the feature of periodic molting of their exoskeleton. This clade includes various phyla with hard cuticles that need to be shed for growth. Flatworms, or Platyhelminthes, possess three embryonic germ layers that give rise to different tissue types, including epidermal, mesodermal, and digestive lining tissues. Their bodies lack a true coelom and are covered by a layer of circular muscle, longitudinal muscle, and an epidermal layer. Flatworms have various lifestyles, with many being parasitic, and they are of medical importance to humans.

3.3.1.1 Characteristic Features of Flatworms

They are bilaterally symmetrical Their body are dorsiventrally flattened; known as flatworms Triploblastic animals – made up of three body layers They lack body cavity hence called Acoelomate They have complete reproductive organs Digestive system is absent in some; and when present has only the mouth but no anus Nervous system are ladder-like, with simple sense organs They have no respiratory, circulatory or skeletal system They have a proto-nephridial type of excretory system.

The phylum platyhelminthes is classified into three main classes. These are. i. Turbellaria: mostly free-living and aquatic, with soft bodies and leaf like in form. They have body covered with cilias, some are terrestrial and confined to humid areas and with only one opening to the gut. Examples include planaria, etc. ii. Trematoda: They are parasitic; lacking cilia; cuticle covering leaf like body with one or more suckers. Examples include faciola hepatica (also known as liver fluke) schistosoma, also known as blood fluke, etc. iii. Cestoda: They are endoparasites (internal parasites), having no gut (digestive) system. There are parasites in the digestive tracts of various vertebrates. They are Ribbon – like in form made up of many segments (proglottids) with an anterior scolex carrying suckers and hooks to hest tissues. When mature, each prolothic has a complete set of reproductive organs of both sexes. Examples are the Tapeworms like Taenia solium, Taenia saginata etc.What are the three main classes of members of phylum platyhelinthes?

3.3.1.2 Physiological Processes of Flatworms

Flatworms exhibit diverse feeding strategies depending on their lifestyle. Free-living species can be predators or scavengers, while parasitic forms feed on host tissues. Their digestive systems can be incomplete with a mouth used for both intake and waste expulsion, sometimes accompanied by an anal opening. Some flatworms have a simple sac-like gut, while others possess a more branched structure. Digestion occurs outside cells, with enzymes secreted into the digestive tract and absorbed by phagocytosis. Cestodes, a specific group of flatworms, lack a digestive system due to their parasitic nature within their host's digestive cavity, where they directly absorb nutrients across their body wall. Flatworms possess an excretory system consisting of tubules and flame cells distributed throughout the body. These cells beat cilia to expel waste fluids, helping regulate salt levels and eliminate nitrogenous waste. Their nervous system includes paired nerve cords along the body connected to a ganglion at the anterior end, often with sensory cells concentrated in this region (Figure 3.1).

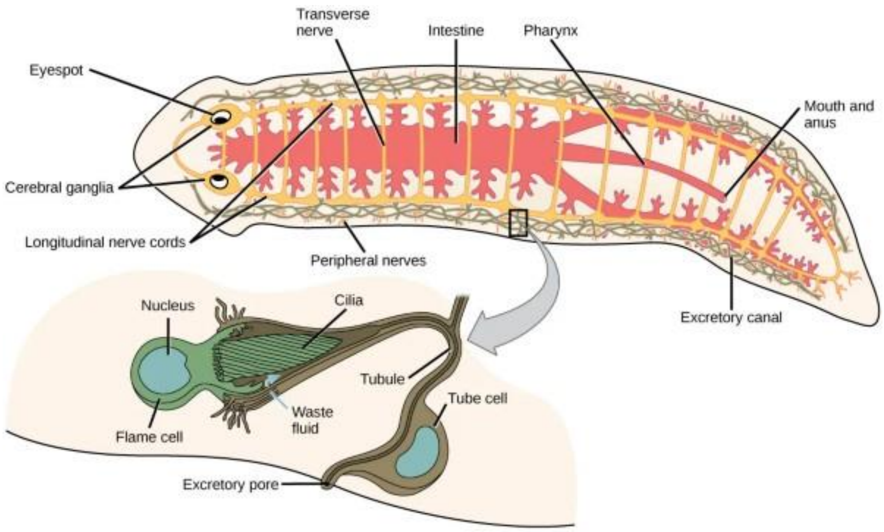


Figure 3.1 This planarian is a free-living flatworm that has an incomplete digestive system, an excretory system with a network of tubules throughout the body, and a nervous system made up of nerve cords running the length of the body with a concentration of nerves and photosensory and chemosensory cells at the anterior end. Source: http://cnx.org/contents/185cbf87-c72e-48f5-b51e-f14f21b5eabd@10.8

Since there is no circulatory or respiratory system, gas and nutrient exchange is dependent on diffusion and intercellular junctions. This necessarily limits the thickness of the body in these organisms, constraining them to be “flat” worms. Most flatworm species are monoecious (hermaphroditic, possessing both sets of sex organs), and fertilization is typically internal. Asexual reproduction is common in some groups in which an entire organism can be regenerated from just a part of itself.

3.3.1.3 Diversity of Flatworms

Flatworms are traditionally divided into four classes: Turbellaria, Monogenea, Trematoda, and Cestoda (Figure 15.16). The turbellarians include mainly free-living marine species, although some species live in freshwater or moist terrestrial environments. The simple planarians found in freshwater ponds and aquaria are examples. The epidermal layer of the underside of turbellarians is ciliated, and this helps them move. Some turbellarians are capable of remarkable feats of regeneration in which they may regrow the body, even from a small fragment.

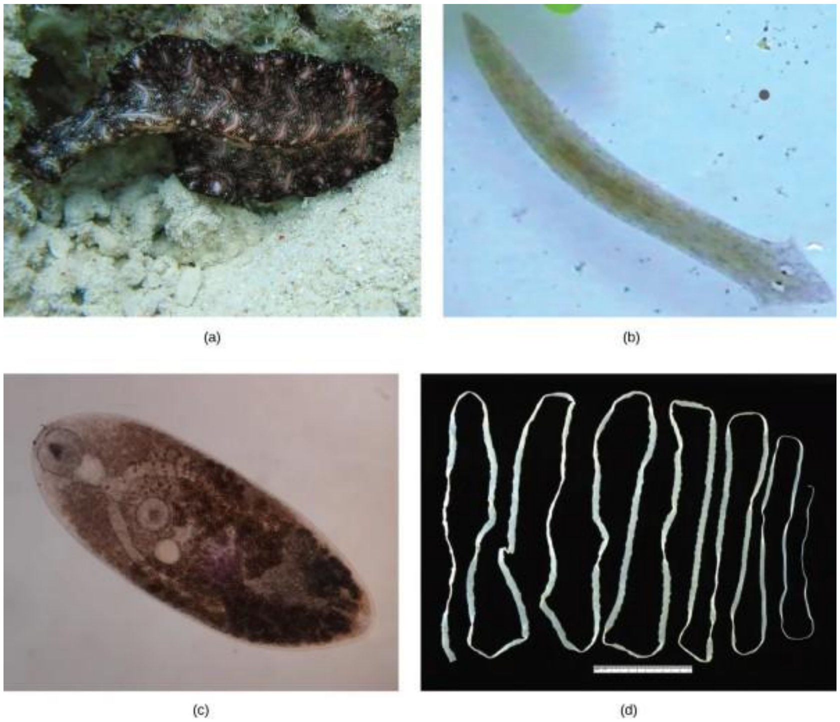


Figure 3.2 Phylum Platyhelminthes is divided into four classes: (a) Bedford's Flatworm (*Pseudobiceros bedfordi*) and the (b) planarian belong to class Turbellaria; (c) the Trematoda class includes about 20,000 species, most of which are parasitic; (d) class Cestoda includes tapeworms such as this *Taenia saginata*; and the parasitic class Monogenea (not shown). Source: http://cnx.org/contents/185cbf87-c72e-48f5-b51e-f14f21b5eabd@10.8

Monogeneans are external parasites primarily found on fish, with a simple life cycle involving attachment to a single fish host. They may digest host tissues or feed on surface mucus and skin particles. Most are hermaphroditic, mating between individuals rather than self-fertilizing. Trematodes, or flukes, are internal parasites with complex life cycles involving mollusk primary hosts and other secondary hosts. Some cause serious human diseases like schistosomiasis, infecting millions and causing organ damage. Cestodes, or tapeworms, are internal parasites of vertebrates. They live in the host's intestinal tract, anchored by a scolex and comprising proglottids for reproduction. Tapeworms lack a digestive system, absorbing nutrients from the host's food. Reproduction occurs in mature proglottids, which detach and are released in host feces. Tapeworms have a cycle involving intermediate hosts and often infect humans through undercooked meat consumption.

3.3.1.4 Habitat and Adaptation

The liver fluke Fasciola hepatica primarily infects sheep and other vertebrates, residing in their liver and bile passages. It can also infect other animals like goats, dogs, cows, deer, rabbits, elephants, and even humans. It has a complex life cycle involving an intermediate mollusk host and a primary vertebrate host. The adult fluke causes liver damage in its host and can lead to liver disease. The fluke's body is protected by a tough cuticle. It possesses a suctorial pharynx for feeding, and its alimentary canal distributes nutrients using interlinary caeca. The excretory system is prolonephridial, composed of flame cells that remove waste via cilia-driven excretory capillaries. Respiration occurs through the general body surface. The liver fluke is hermaphroditic, containing both male and female reproductive organs in the same individual.

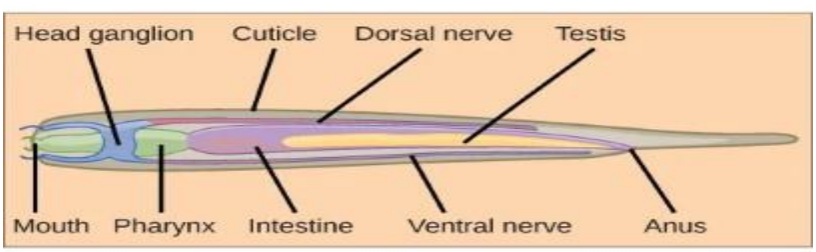
Self-Assessment Exercises 1

1. **What are the four t**raditional classes of flatworms?
2. What are the structural adaptations of the flatworms?

3.3.2 Nematodes

The phylum **Nematoda**, or roundworms, includes more than 28,000 species with an estimated 16,000 parasitic species. The name Nematoda is derived from the Greek word “nemos,” which means “thread.” Nematodes are present in all habitats and are extremely common, although they are usually not visible (Figure 3.3).

(a)



(b)

Figure 3.3 (a) An scanning electron micrograph of the nematode *Heterodera glycines* and (b) a schematic representation of the anatomy of a nematode are shown. Source: http://cnx.org/contents/185cbf87-c72e-48f5-b51e-f14f21b5eabd@10.8

Most nematodes share a similar appearance: elongated tubes with tapered ends (Figure 3.3). Nematodes belong to the pseudocoelomate group and possess a complete digestive system with distinct mouth and anus openings. These organisms are covered by a flexible but sturdy external skeleton called a cuticle, which provides protection and structural support. This cuticle contains chitin, a carbohydrate-protein compound, and it lines both the pharynx and rectum. Although the cuticle safeguards the nematode, it hinders growth, necessitating regular shedding and replacement as the organism grows larger. At the front end, a nematode's mouth is equipped with three or six lips, sometimes including cuticular extensions that resemble teeth. Additionally, some species feature a pointed stylet that can extend from the mouth to pierce prey or plant and animal cells. The mouth leads to a muscular pharynx and intestine, eventually leading to the rectum and an anal opening at the rear end.

3.3.2.1 Characteristics of Nematods

The Phylum Nematoda, commonly known as roundworms, encompasses a diverse group of organisms with approximately 12,000 described species, though the actual number could be much higher. Nematodes are abundant in various habitats, including terrestrial, freshwater, and saltwater environments, as well as within other organisms as parasites. They display a range of feeding habits and ecological roles, contributing significantly to decomposition and nutrient cycling.

Nematodes have a slender, unsegmented body that tapers at both ends and a round cross-section. Their external cuticle provides protection and support, which is shed periodically during growth. The hypodermis underneath the cuticle is a syncytium with muscle cells beneath it. Nematodes lack a true coelom, and their internal cavity isn't lined by cells derived from the mesoderm.

The nervous system of nematodes consists of a nerve ring around the pharynx and longitudinal nerve cords along the body. Sensory receptors are present at both ends, including tactile and chemosensory cells. They lack complex eyes but may possess light-sensitive organs. Nematodes have a complete digestive system with a muscular pharynx, and nutrient absorption occurs in the intestine. Waste elimination and gas exchange happen through the body surface, which is feasible due to their small size.

Most nematodes are dioecious, with separate male and female reproductive organs, while some are hermaphroditic. Mating involves specialized structures in males, and sperm lacks flagella, moving through amoeboid motion. Nematodes can be either live-bearing or egg-laying, with eggs often escaping through a gonopore in females. They lack a distinct larval stage, with eggs directly developing into juveniles that closely resemble adults. Nematodes exhibit a unique feature called "eutely," where individuals of a species have the same number of cells, achieved during development, leading to growth through cell size increase rather than cell number increase.

3.3.2.2 Physiological Processes of Nematodes

In nematodes, the excretory system is not specialized, and nitrogenous waste elimination occurs through diffusion. In marine nematodes, water and salt regulation is achieved by specialized glands that maintain internal body fluid concentrations by removing unwanted ions.

Nematodes typically have four nerve cords running along their body's length, which fuse around the pharynx to form a head ganglion (a rudimentary brain) and at the tail to form the tail ganglion. Beneath the outer layer, there are longitudinal muscles enabling side-to-side body movement.

Nematodes exhibit various sexual reproductive strategies depending on the species. They can be monoecious (both sexes in one individual), dioecious (separate sexes), or reproduce asexually through parthenogenesis. The species Caenorhabditis elegans is unique with both self-fertilizing hermaphrodites and a male sex that can mate with the hermaphrodite.

3.3.2.3 Diversity of Nemadotes

The phylum Aschelminthes is divided into five classes: Rotifera, Gastrotricha, Echinodera, Priapulide, and Nematode. Rotifers are marine parasites with a ciliary organ called corona on their anterior end. Gastrotricha are free-living, unsegmented organisms found in water with algae and debris, often hermaphroditic. Echinodera are small marine worm-like animals, generally dioecious. Priapulides are marine animals with a proboscis and trunk, also dioecious. Nematodes are unsegmented roundworms with a cylindrical body, having separate sexes, and the males are smaller than females.

These organisms are bilaterally symmetrical with a radial tendency along the longitudinal axis. They have circular cross-sections, lack segmentation and appendages, and possess a complex cuticle. Tissues and organs are present, and the body has more than two cell layers. Circular muscles are absent from the body wall, and the body cavity is a pseudocoel under high pressure. The digestive system extends from the anterior mouth to the anus. Muscles in the body wall have distinctive features. There's no circulatory system, flame cells, or nephridia. Cilia and flagella are absent. Development is direct, involving an increase in cell size rather than cell number.

3.3.2.4 Habitat and Adaptation

Nematodes can inhabit a wide range of environments, including cultivated fields, forests, grasslands, deserts, tundras, and ocean beaches. They can thrive at varying elevations, from high to low. A single square yard of soil might contain more than a million nematodes, making them the dominant organisms in many terrestrial ecosystems. These creatures constitute around 90% of all life forms found on the ocean floor. They provide benefits to diverse ecosystems for various reasons. Nematodes possess a remarkable ability to withstand extreme dryness, known as desiccation, due to their abundance of late embryogenesis proteins. In soil environments, many nematodes prefer areas rich in nutrients and bacteria, where they feed on decomposing organic matter. Their wide range of sizes and uncomplicated body structures enables them to function effectively in virtually every ecosystem. Nematodes are also widely distributed on the ocean floor, participating in the decomposition of various substances in aquatic environments. Their small size, sometimes microscopic, allows them to carry out decomposition processes throughout the earth's lithosphere, which is the outermost crust. Nematodes are pivotal in the breakdown of soil nutrients, contributing significantly to soil fertility.

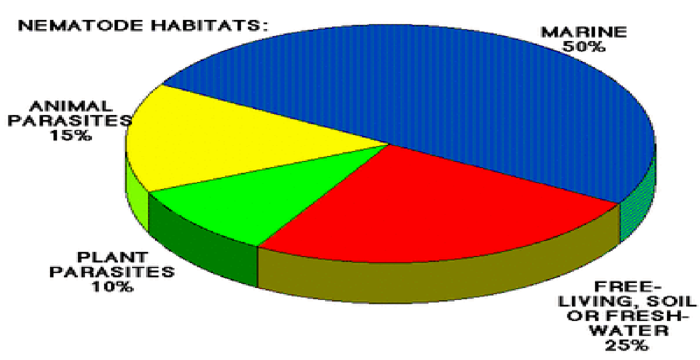


Figure 3.4 Nematode habittats: Source: http://cnx.org/contents/185cbf87-c72e-48f5-b51e-f14f21b5eabd@10.8

Nematodes are bilaterally symmetrical, elongate, and usually tapered at both ends. Some species possess a pseudocoel, a fluid-filled body cavity between the digestive tract and the body Nematodes are a highly diverse group of organisms that show a variety of adaptations to extremes in soil and plant environments. Some of the unique adaptations of nematodes include:

- Epidermis (skin) is not made of cells, but a mass of cellular material and nuclei without separate membranes.
- Muscle cells only run in longitude direction.
- Nematodas can only bend their body's from side to side, so when free-swimming, it thrashes its body from side to side, trying to move.
- You can find 90,000 individual nematodes in a rotting apple.

Self-Assessment Exercises 2

1. How is nitrogenous wastes removed in nematodes?
2. What are the divisions of phylum Aschelminthes?

3.3.3 Arthropods

The word "arthropoda" literally translates as "jointed legs," which perfectly sums up each of the countless species that make up this phylum. With an estimated 85% of known species in the animal kingdom, including many that are still undiscovered or unrecorded, arthropods dominate the animal kingdom. The functional segmentation of the body and the existence of jointed appendages are the defining traits of all the creatures in this class (Figure 3.5). Arthropods, which are Ecdysozoa, also have an exoskeleton that is primarily formed of chitin. In terms of species count, Arthropoda is the animal kingdom's greatest phylum, and insects make up its single largest group. True coelomate creatures, arthropods display prostostomic development.

3.3.3.1 Characteristic features of Arthropods

Arthropods, members of the phylum Arthropoda, are a diverse group of animals including insects, crustaceans, spiders, scorpions and centipedes. However, the members of this phylum, despite their incredible diversity and sheer numbers, share a number of important distinguishing characteristics.

Exoskeleton

Arthropods are invertebrates, which means their bodies do not have internal bones for support. To compensate for this, they produce a hard exoskeleton made of chitin, a mixture of lipids, carbohydrates and protein, which covers and protects their bodies like a suit of armor. As arthropods grow, they must shed or molt their exoskeletons. They first produce new, softer exoskeletons underneath the old ones. Once their hardened, old coverings crack and shed, they sport roomier, albeit soft, exoskeletons. Arthropods are incredibly vulnerable during the molting process, and will often hide until their new exoskeletons harden.

Segmented Bodies

Arthropods have bodies that are internally and externally segmented. The number of segments depends on the individual species; millipedes, for example, have more segments than lobsters.

Jointed Appendages

The name arthropod actually comes from the Greek “arthro,” meaning joint, and “pod,” meaning foot. All arthropods have jointed limbs attached to their hard exoskeletons that allow for flexibility and movement. The joints generally bend in only one direction but allow for sufficient predatory and defensive actions.

Bilateral Symmetry

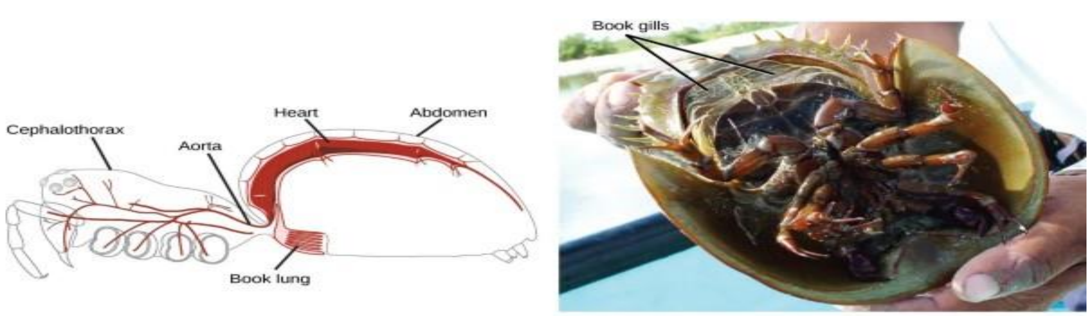
An arthropod's body can be divided vertically into two mirror images. This is called bilateral symmetry. An arthropod shares this symmetry with many other animals such as fish, mice and even humans. Other animals such as the jellyfish and sea star exhibit radial symmetry, while coral and sea sponge are asymmetrical -- exhibiting no pattern at all.

Open Circulatory System

An arthropod has an open circulatory system. This means instead of a closed circulatory system of interconnected veins and capillaries, an arthropod’s blood is pumped through open spaces called sinuses in order to reach tissues. An arthropod does, however, have a heart which pumps blood into the hemocoel, the cavity where the organs are located, where it surrounds the organs and tissues.

3.3.3.2 Physiological Processes of Arthropods

Arthropods are characterized by their segmented body structure, where certain segments fuse to form functional units like the head, thorax, and abdomen or other combinations. They possess a hemocoel (blood cavity) as their coelom and have an open circulatory system. This system involves a two-chambered heart that pumps blood, which directly bathes internal organs instead of flowing through vessels. The respiratory systems in arthropods vary: insects and myriapods use tracheae tubes branching throughout their bodies and opening through spiracles for direct gas exchange with cells. Aquatic crustaceans have gills, arachnids utilize internal "book lungs" resembling stacked pages, and aquatic chelicerates employ external "book gills" made of leaf-like structures for gas exchange with surrounding water (Figure 3.4).



(a) (b)

Figure 3.5 The book lungs of (a) arachnids are made up of alternating air pockets and hemocoel tissue shaped like a stack of books. The book gills of (b) crustaceans are similar to book lungs but are external so that gas exchange can occur with the surrounding water. Source: http://cnx.org/contents/185cbf87-c72e-48f5-b51e-f14f21b5eabd@10.8

3.3.3.3 Arthropod Diversity

The phylum Arthropoda consists of organisms that have successfully adapted to various environments including land, water, and air. This phylum is subdivided into five subphyla: Trilobitomorpha (trilobites), Hexapoda (insects and their relatives), Myriapoda (millipedes, centipedes, and similar creatures), Crustacea (crabs, lobsters, etc.), and Chelicerata (horseshoe crabs, arachnids, etc.). Trilobites, now extinct, existed from the Cambrian to Permian periods, and are possibly most closely related to Chelicerata. There are around 17,000 identified species of trilobites through fossils.

Hexapoda, as indicated by their name, possess six legs or three pairs. Their segments are fused into distinct regions like the head, thorax, and abdomen. The thorax holds both wings and three pairs of legs. Examples of Hexapoda include everyday insects such as ants, butterflies, bees, and cockroaches. What are the classes into which the phylum Arthropoda is divided? What are the three main classes and some of their representative species?

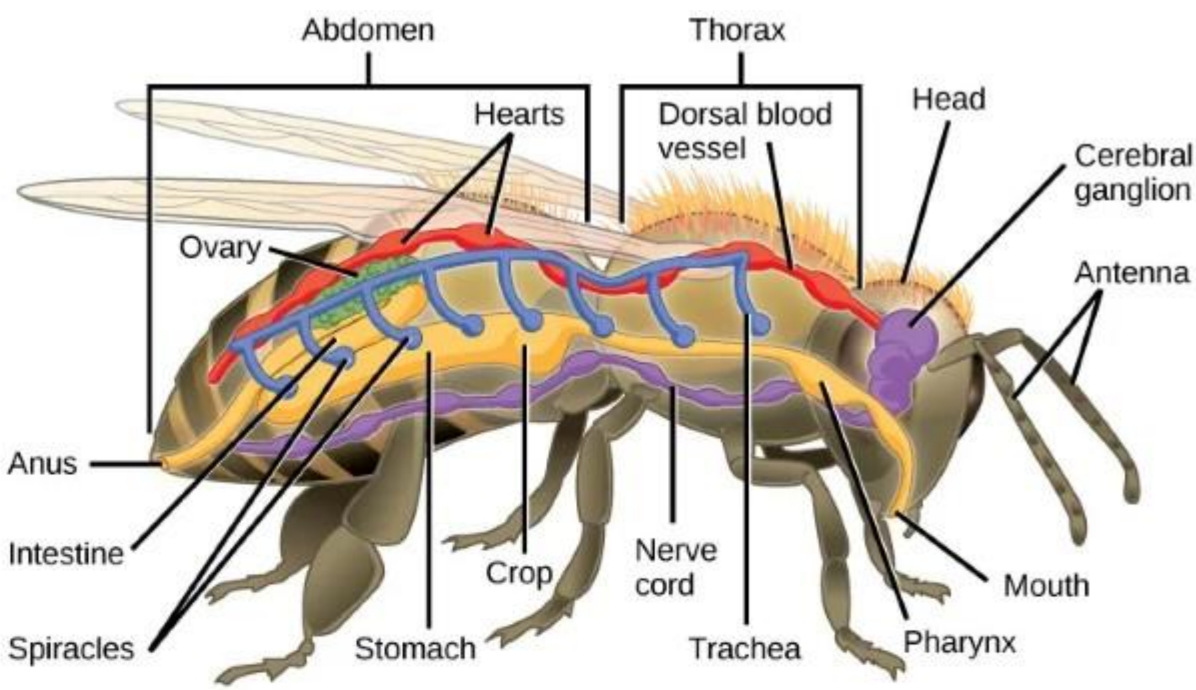


Figure 3.6 In this basic anatomy of a hexapod, note that insects have a developed digestive system (yellow), a respiratory system (blue), a circulatory system (red), and a nervous system (purple). Source: http://cnx.org/contents/185cbf87-c72e-48f5-b51e-f14f21b5eabd@10.8

Subphylum Myriapoda includes arthropods with legs that may vary in number from 10 to 750. This subphylum includes 13,000 species; the most commonly found examples are millipedes and centipedes. All myriapods are terrestrial animals and prefer a humid environment (Figure 3.5).

Figure **3.7** (a) The centipede *Scutigera coleoptrata* has up to 15 pairs of legs. (b) This North American millipede (*Narceus americanus)* bears many legs, although not one thousand, as its name might suggest. Source: http://cnx.org/contents/185cbf87-c72e-48f5-b51e-f14f21b5eabd@10.8

Aquatic arthropods known as crustaceans, including species like shrimp, crabs, lobsters, and crayfish, dominate their habitat. A handful of crustaceans are adapted to live on land, such as pill bugs and sow bugs. The currently recognized number of crustacean species is around 47,000. While the fundamental body structure of crustaceans resembles that of Hexapoda, involving a head, thorax, and abdomen, in certain species, the head and thorax can merge to create a cephalothorax, which is shielded by a plate called the carapace. Furthermore, the exoskeleton of many crustaceans is strengthened with calcium carbonate, making it more robust than that of other arthropods. Crustaceans operate with an open circulatory system, where blood is pumped into the hemocoel by the dorsal heart. Although most crustaceans have distinct genders, a few, like barnacles, may be hermaphroditic. Some crustacean species exhibit serial hermaphroditism, where their gonads can switch from producing sperm to producing eggs. Many crustaceans experience larval stages during their early development. While the majority of crustaceans are carnivorous, detritivores and filter feeders are also prevalent. What are the main morphological features of arthropods?

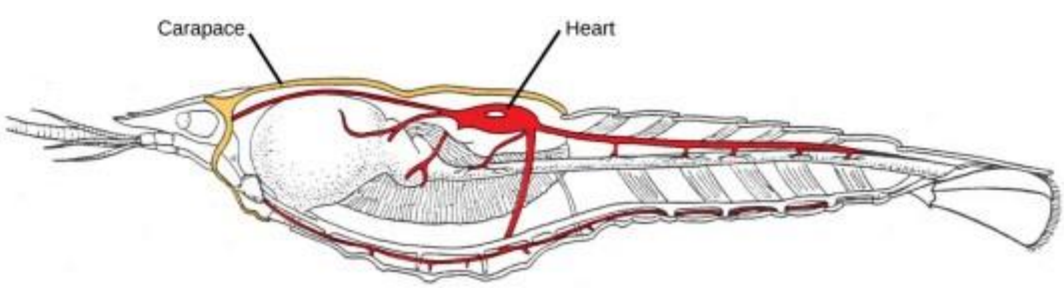


Figure 3.8 The crayfish is an example of a crustacean. It has a carapace around the cephalothorax and the heart in the dorsal thorax area. Source: http://cnx.org/contents/185cbf87-c72e-48f5-b51e-f14f21b5eabd@10.8

Subphylum Chelicerata includes animals such as spiders, scorpions, horseshoe crabs, and sea spiders. This subphylum is predominantly terrestrial, although some marine species also exist. An estimated 103,000[4] described species are included in subphylum Chelicerata.

The body of chelicerates may be divided into two parts and a distinct "head" is not always discernible. The phylum derives its name from the first pair of appendages: the **chelicerae** (Figure 3.9**a**), which are specialized mouthparts. The chelicerae are mostly used for feeding, but in spiders, they are typically modified to inject venom into their prey (Figure 3.9**b**). As in other members of Arthropoda, chelicerates also utilize an open circulatory system, with a tube-like heart that pumps blood into the large hemocoel that bathes the internal organs. Aquatic chelicerates utilize gill respiration, whereas terrestrial species use either tracheae or book lungs for gaseous exchange. What are the five subphyla of phylum arthropods?

Figure 3.9 (a) The chelicerae (first set of appendages, circled) are well developed in the Chelicerata, which includes scorpions (a) and spiders (b). Source: http://cnx.org/contents/185cbf87-c72e-48f5-b51e-f14f21b5eabd@10.8

3.3.3.4 Habitat and Adaptation

The arthropods are seen from 30,000 feet below to 20,000 feet above the sea level. These bilaterally symmetrical, jointed-leg invertebrates may be marine, fresh-water, terrestrial, subterranean and aerial. Some arthropods like barnacles are sedentary. Innumerable crustaceans which live as planktons move passively in the current of water. But well-developed structures are present in many arthropods for moving effectively by swimming, crawling and flying. Some arthropods live within burrows, some are efficient diggers and many others build well-designed nests. Certain arthropods like honey-bees, ants and termites are polymorphic and lead a complicated social life. All the food habits—herbivorous, carnivorous and omnivorous are seen among arthropods and various food-getting devices are met within this group.

Large numbers of arthropods live as parasites, and structural changes occur in them to adjust with the peculiar mode of life. Many arthropods are well- known for their habit of migration. Some of them can produce sound and nearly all are equipped with efficient sense organs. Some forms exhibit a phenomenon—suspended animation, to overcome unfavourable conditions. Sexual reproduction is often accompanied by courtship dances. The members may either be oviparous or viviparous or ovoviviparous and some forms exhibit parental care. Parthenogenesis is quite common in arthropods.

Arthropods are the largest animal phylum on earth. One million species of arthropods have been recognized worldwide. They show various types of adaptation to their environment. They are listed below.

1. Most arthropods are small in size.
2. Arthropods develop a prominent head, which is composed of pairs of antennae and compound eyes. Arthropoda was the first group of animals to develop a head.
3. The jointed appendages of arthropods occur in pairs. One or two pairs of wings occur in aerial arthropods. This facilitates their propagation.
4. The body of arthropods is covered with a chitinous exoskeleton. Exoskeleton provides support to the body and sites for the attachment of muscles. It also prevents water loss from the body. The process of shedding the exoskeleton is called molting or ecdysis; this facilitates the growth.
5. Arthropods have a complete digestive system with an anus and mouth. Mouthparts of them are varied based on the type of diet they get. Some of them have lapping and chewing, sucking or siphoning
6. Breathing occurs through gills, trachea or book lungs.
7. The excretion of terrestrial arthropods occurs through Malpighian tubules. Nitrogenous wastes are excreted as uric acid, reducing the water loss from the body.
8. Arthropods are unisexual animals.

Self-Assessment Exercises 3

1. What is the most important unique feature of arthropods?
2. What is the meaning of bilateral symmetry as displayed by arthropods?

3.4 Summary

Flatworms are acoelomate organisms with three tissue layers. They lack circulatory and respiratory systems, and their excretory system is rudimentary. Their digestive system is often incomplete. There are four main classes: free-living turbellarians, ectoparasitic monogeneans, and endoparasitic trematodes and cestodes. Trematodes have complex life cycles with mollusk and vertebrate hosts, while cestodes infect vertebrate digestive systems.

Nematodes, within the Ecdysozoa clade, are pseudocoelomates with a complete digestive system. They include free-living and parasitic species, with diverse reproductive strategies. Their excretory system is underdeveloped, and their embryonic development involves external stages separated by molts.

Arthropods, the most successful animal phylum, exhibit segmented bodies and jointed appendages. Each body segment usually has a pair of appendages. Arthropods have a chitinous exoskeleton and use gills, tracheae, or book lungs for respiration. They're classified based on mouthparts and appendage modifications. Their embryonic development often involves multiple larval stages.

3.6 References/Further Readings/Web Sources

Brusca, R.C., G.J. Brusca (2003). *Invertebrates.* Sunderland, Mass.: Sinauer Associates. 2nd edition [chapter 8, p. 219]. ISBN 0-87893-097-3.

Hickman, C.P. and L. S. Roberts. 1994. Animal Diversity. Wm. C. Brown, Dubuque, IA.
at http://cnx.org/contents/185cbf87-c72...f21b5eabd@10.8
https://openstax.org/books/biology/pages/1-introduction.
http://cnx.org/contents/185cbf87-c72e-48f5-b51e-f14f21b5eabd@10.8
https://youtu.be/_bk2nnDI68g
https://youtu.be/US58f-SwO0k
https://youtu.be/2OJeZ8q75KA

3.6 Possible Answers to Self-Assessment Exercises

Answers to SAE 1

1. Flatworms are traditionally divided into four classes: Turbellaria, Monogenea, Trematoda, and Cestoda
2. The body-wall of the liver fluke is composed of only cuticle (and musculature) which covers the body as a thick and tough layer, proving protection to the fluke against chemicals of the hurt.

Answers to SAE 2

1. Nitrogenous wastes are removed by diffusion.

2, The phylum Aschelminthes is divided into 5 (five) classes These are: 1. Rotifera; Gastrotricha; Echinodera; Priapulide and. Nematode.

Answers to SAE 3

1. The unique feature of arthropods is the presence of a segmented body with fusion of certain sets of segments to give rise to functional segments
1. An arthropod's body can be divided vertically into two mirror images. This is called bilateral symmetry.

Unit 4 Mollusk and Annelids

4.1 Introduction

The mollusks are a diverse group (85,000 described species) of mostly marine species. They have a variety of forms, ranging from large predatory squid and octopus, some of which show a high degree of intelligence, to small grazing forms with elaborately sculpted and colored shells. The annelids traditionally include the oligochaetes, which include the earthworms and leeches, the polychaetes, which are a marine group, and two other smaller classes. The phyla Mollusca and Annelida belong to a clade called the **Lophotrochozoa**, which also includes the phylum Nemertea, or ribbon worms. They are distinct from the Ecdysozoa (nematodes and arthropods) based on evidence from analysis of their DNA, which has changed our views of the relationships among invertebrates.

4.2 Intended Learning Objectives (ILOs)

By the end of this section, you will be able to:

- Describe the unique anatomical features of mollusks
- Describe the characteristic features of Mollusk
- Describe the diversity in the mollusks
- Describe the features of an animal classified in phylum Annelida

4.3 Main Contents

4.3.1 Phylum Mollusk

Mollusca is the predominant phylum in marine environments, where it is estimated that 23 percent of all known marine species belong to this phylum. It is the second most diverse phylum of animals with over 75,000 described species. The name "mollusca" signifies a soft body, as the earliest descriptions of mollusks came from observations of unshelled, soft-bodied cuttlefish (squid relatives). Although mollusk body forms vary, they share key characteristics, such as a ventral, muscular foot that is typically used for locomotion; the visceral mass, which contains most of the internal organs of the animal; and a dorsal mantle, which is a flap of tissue over the visceral mass that creates a space called the mantle cavity. The mantle may or may not secrete a shell of calcium carbonate. In addition, many mollusks have a scraping structure at the mouth, called a **radula** (Figure 4.1).The muscular foot varies in shape and function, depending on the type of mollusk (described below in the section on mollusk diversity). It is a retractable as well as extendable organ, used for locomotion and anchorage. Mollusks are eucoelomates, but the coelomic cavity is restricted to a cavity around the heart in adult animals. The mantle cavity, formed inside the **mantle**, develops independently of the coelomic cavity. It is a multi-purpose space, housing the gills, the anus, organs for sensing food particles in the water, and an outlet for gametes. Most mollusks have an open circulatory system with a heart that circulates the hemolymph in open spaces around the organs. The octopuses and squid are an exception to this and have a closed circulatory system with two hearts that move blood through the gills and a third, systemic heart that pumps blood through the rest of the body. What morphological feature gives the phylum Mollusca its name?

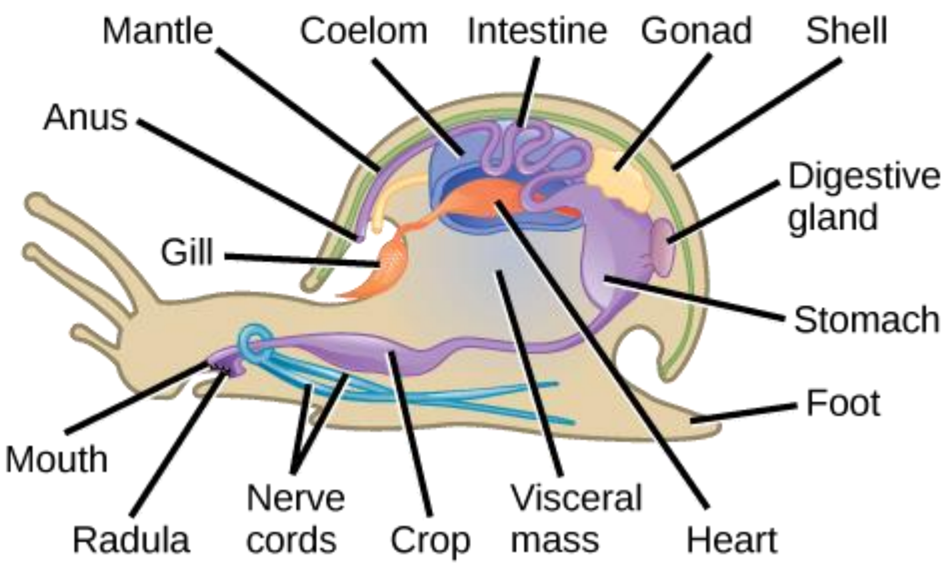


Figure 4.1 There are many species and variations of mollusks; the gastropod mollusk anatomy is shown here, which shares many characteristics common with other groups. Source: http://cnx.org/contents/185cbf87-c72e-48f5-b51e-f14f21b5eabd@10.8

4.3.1.1 **Characteristic Features of Mollusk**

- They are mostly marine in water, few freshwater and some terrestrial form.

- They can be found inside other animals, as secret parasites.
- They range in size from giant squids and clams to small snails, one mm long.
- They have at least two radula and mantle characters, which are not found elsewhere.
- The body is soft, unsegmented, bilateral symmetrical, coelomates, triploblastic (except in Monoplacophora).
- Body organization is tissue-systems grade.
- The body has head, foot, mantle and visceral mass.
- The body is covered with often ciliated one-layered epidermis.
- The body is commonly protected by one or more pieces of exoskeletal calcareous shell secreted by the mantle.
- Except in pelecypoda and scaphopoda, the head is distinct, containing the mouth , eyes, tentacles and other sense organs.
- The ventral body is converted into a muscular plough-like surface, the foot which is modified in different ways for creeping, burrowing and swimming.
- Mantle or pallium is a fold of a wall of the body that leaves the main body, mantle cavity, within itself.
- Cavity of the body is hemocoel. The coelom is reduced and characterized by pericardial cavity, gonadial cavity.
- Organ rasping, usually occurring radula or in pelecypoda.
- Except in cephalopods, the circulatory system is open type.
- There are numerous gills or ctenidia in the respiratory organs usually provided with osphradium at the base. In terrestrial forms the lung develops.
- Respiration in Mollusca is provided by gills or lungs, or both.
- Their respiratory pigments are haemocyanin;
- Excretion is achieved by paired metanephridia (kidney).
- The mollusca nervous system consists of paired prefrontal, pleural, pedal and visceral ganglia, along with longitudinal and transverse nervous connections. Usually ganglia form a circumentary ring.
- Sense organs are composed of skin, statocysts and touch, smell , and taste receptors.Sexes are usually separate (dioecious) but some are monoecious (hermaphroditic).
- Development through the trochophore stage called veliger larva is direct or with metamorphosis.

- The visceral mass, in its compact form, contains the vital organs of the body, taking the form of dorsal humps or dome.

4.3.1.2 Mollusk Diversity

This phylum is comprised of seven classes: Aplacophora, Monoplacophora, Polyplacophora, Bivalvia, Gastropoda, Cephalopoda, and Scaphopoda. Class Aplacophora ("bearing no plates") includes worm-like animals living mostly on deep ocean bottoms. These animals lack a shell but have aragonite spicules on their skin. Members of class Monoplacophora ("bearing one plate") have a single, cap-like shell enclosing the body. The monoplacophorans were believed extinct and only known as fossils until the discovery of *Neopilina galatheae* in 1952. Today, scientists have identified nearly two dozen living species.

Animals in the class Polyplacophora ("bearing many plates") are commonly known as "chitons" and bear an armor-like, eight-plated shell (Figure 4.2). These animals have a broad, ventral foot that is adapted for attachment to rocks and a mantle that extends beyond the shell in the form of a girdle. They breathe with **ctenidia** (gills) present ventrally. These animals have a radula modified for scraping. A single pair of nephridia for excretion is present.

Figure 4.2 This chiton from the class Polyplacophora has the eight-plated shell indicative of its class. Source: http://cnx.org/contents/185cbf87-c72e-48f5-b51e-f14f21b5eabd@10.8

Class Bivalvia ("two shells") includes clams, oysters, mussels, scallops, and geoducks. They are found in marine and freshwater habitats. As the name suggests, bivalves are enclosed in a pair of shells (or valves) that are hinged at the dorsal side. The body is flattened on the sides. They feed by filtering particles from water and a radula is absent. They exchange gases using a pair of ctenidia, and excretion and osmoregulation are carried out by a pair of nephridia. In some species, the posterior edges of the mantle may fuse to form two siphons that inhale and exhale water. Some bivalves like oysters and mussels have the unique ability to secrete and deposit a calcareous **nacre** or “mother of pearl” around foreign particles that enter the mantle cavity. This property is commercially exploited to produce pearls.

Gastropods (“stomach foot”) include well-known mollusks like snails, slugs, conchs, sea hares, and sea butterflies. Gastropods include shell-bearing species as well as species with a reduced shell. These animals are asymmetrical and usually present a coiled shell (Figure 4,3).

Figure 4.3 (a) Like many gastropods, this snail has a stomach foot and a coiled shell. (b) This slug, which is also a gastropod, lacks a shell. Source: http://cnx.org/contents/185cbf87-c72e-48f5-b51e-f14f21b5eabd@10.8

The visceral mass in the shelled species is characteristically twisted and the foot is modified for crawling. Most gastropods bear a head with tentacles that support eyes. A complex radula is used to scrape food particles from the substrate. The mantle cavity encloses the ctenidia as well as a pair of nephridia. Are mollusks Metameric? Are molluscs metameric organisms?

The class Cephalopoda (“head foot” animals) includes octopuses, squids, cuttlefish, and nautilus. Cephalopods include shelled and reduced-shell groups. They display vivid coloration, typically seen in squids and octopuses, which is used for camouflage. The ability of some octopuses to rapidly adjust their colors to mimic a background pattern or to startle a predator is one of the more awe-inspiring feats of these animals. All animals in this class are predators and have beak-like jaws. All cephalopods have a well-developed nervous system, complex eyes, and a closed circulatory system. The foot is lobed and developed into tentacles and a funnel, which is used for locomotion. Suckers are present on the tentacles in octopuses and squid. Ctenidia are enclosed in a large mantle cavity and are serviced by large blood vessels, each with its own heart.

Cephalopods (Figure 4.3) are able to move quickly via jet propulsion by contracting the mantle cavity to forcefully eject a stream of water. Cephalopods have separate sexes, and the females of some species care for the eggs for an extended period of time. Although the shell is much reduced and internal in squid and cuttlefish, and absent altogether in octopus, nautilus live inside a spiral, multi-chambered shell that is filled with gas or water to regulate buoyancy.

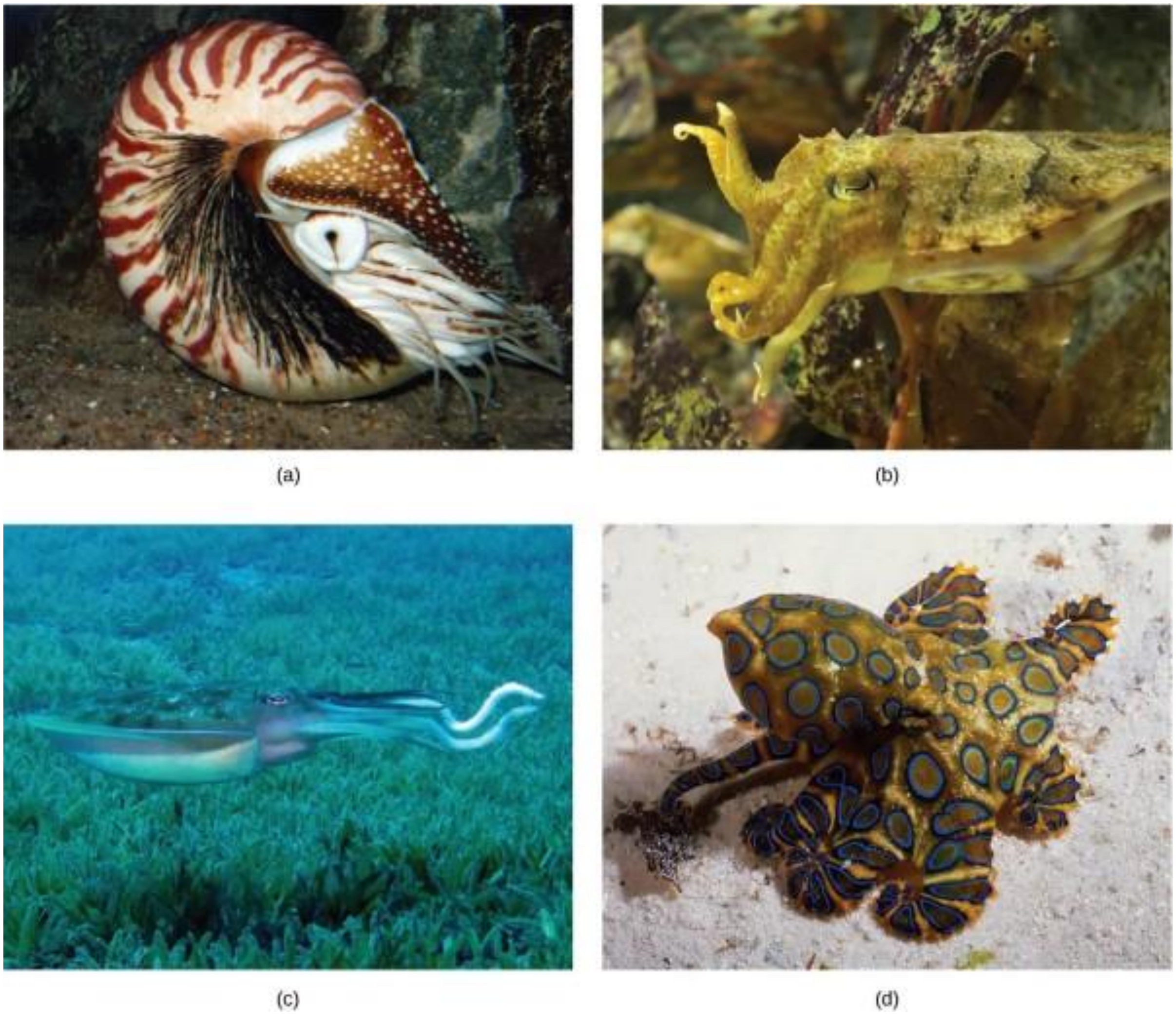


Figure 4.4 The (a) nautilus, (b) giant cuttlefish, (c) reef squid, and (d) blue-ring octopus are all members of the class Cephalopoda. Source: http://cnx.org/contents/185cbf87-c72e-48f5-b51e-f14f21b5eabd@10.8

Members of the class Scaphopoda ("boat feet") are known colloquially as "tusk shells" or "tooth shells." Tooth shells are open at both ends and usually lie buried in sand with the front opening exposed to water and the reduced head end projecting from the back of the shell. Tooth shells have a radula and a foot modified into tentacles, each with a bulbous end that catches and manipulates prey (Figure 4.5).

Figure 4.5 *Antalis vulgaris* shows the classic Dentaliidae shape that gives these animals their common name of "tusk shell." Source: http://cnx.org/contents/185cbf87-c72e-48f5-b51e-f14f21b5eabd@10.8

4.3.1.3 Habitat and Adaptation

Phylum Mollusk is the second largest animal phylum on the planet. They are mostly marine, but many occur in fresh water and some even in damp soil. Molluscs have conquered most habitats in the ocean, with their distributions ranging from the intertidal zone, the open ocean to the deep sea and extreme environments like hydrothermal vents. They usually live in the sea shores or in shallow water, and some are pelagic and can sink down to the depth of about 35,000 feet. Most of the Molluscs are free-living forms.

Adaptation of a mollusk is the process of adjusting to different habitats and environmental conditions**.** Mollusks have adapted to all habitats except air, and have diverse modes of locomotion and feeding. Some of the unique adaptations of mollusks include a specialized feeding organ called a radula, a dorsal layer of tissue called a mantle, and a complex nervous system. Some mollusks also have highly developed eyes, ink glands, and skin cells that can change color. **A**mong the adaptations Mollusks have gained over time, the most obvious, and most important, is the muscular foot all mollusks possess. This foot adaptation is also something that differentiates all different species of Mollusks. There is a lot of variation in this adaptation, so species to species, Mollusk feet will look different. Are mussels Gastropoda? The freshwater mollusks include two classes, the Gastropoda (snails and limpets) and the Bivalvia (clams and mussels). The gastropods constitute the most diverse class of the phylum Mollusca, with about 75,000 species of marine and freshwater snails worldwide.

Self-Assessment Exercises 1

1. What is the purpose of a radula?
2. How do Gastropods move?

4.3.2 Annelids

Phylum **Annelida** are segmented worms found in marine, terrestrial, and freshwater habitats, but the presence of water or humidity is a critical factor for their survival in terrestrial habitats. The name of the phylum is derived from the Latin word *annellus*, which means a small ring. Approximately 16,500 species have been described. The phylum includes earthworms, polychaete worms, and leeches. Like mollusks, annelids exhibit protostomic development. Annelids are bilaterally symmetrical and have a worm-like appearance. Their particular segmented body plan results in repetition of internal and external features in each body segment. This type of body plan is called **metamerism**. The evolutionary benefit of such a body plan is thought to be the capacity it allows for the evolution of independent modifications in different segments that perform different functions. The overall body can then be divided into head, body, and tail.

4.3.2.1 Characteristic of Phylum Annelids

- They are mostly aquatic, some are terrestrial.
- They are generally burning animals, some are sedentary or free living, and some are ectoparasites.
- The body is vermiform, bilaterally symmetrical, and metamerically segmented.
- They have straight tube alimentary canal, and undergo extra-cellular digestion.
- Has segmentally arranged Locomotory organs, repeated groups of chitinous setae or chaetae.
- Leaches have no setae.
- Respiration is generally through body surface or through a special projection of parapods.
- Has well developed closed type blood vascular system.
- Possesses Nephridia which is the excretory organs.
- Nervous system consists of paired cerebral ganglia or brain, a double ventral nerve cord bearing segmental ganglia.
- Gonads develop from the coelomic epithelium.
- Sex may be separate or united, and development may be direct or indirect.

4.3.2.2 Physiological Processes of Annelids

The skin of annelids is protected by a cuticle that is thinner than the cuticle of the ecdysozoans and does not need to be molted for growth. Chitinous hairlike extensions, anchored in the skin and projecting from the cuticle, called **chaetae**, are present in every segment in most groups. The chaetae are a defining character of annelids. Polychaete worms have paired, unjointed limbs called parapodia on each segment used for locomotion and breathing. Beneath the cuticle there are two layers of muscle, one running around its circumference (circular) and one running the length of the worm (longitudinal). Annelids have a true coelom in which organs are distributed and bathed in coelomic fluid. Annelids possess a well-developed complete digestive system with specialized organs: mouth, muscular pharynx, esophagus, and crop. A cross-sectional view of a body segment of an earthworm is shown in Figure 4.6; each segment is limited by a membrane that divides the body cavity into compartments.

Annelids have a closed circulatory system with muscular pumping "hearts" in the anterior segments, dorsal and ventral blood vessels that run the length of the body with connections in each segment, and capillaries that service individual tissues. Gas exchange occurs across the moist body surface. Excretion is carried out by pairs of primitive "kidneys" called metanephridia that consist of a convoluted tubule and an open, ciliated funnel present in every segment. Annelids have a well-developed nervous system with two ventral nerve cords and a nerve ring of fused ganglia present around the pharynx. How does digestion in organisms of the phylum Annelida take place? What type of digestive system do they have?

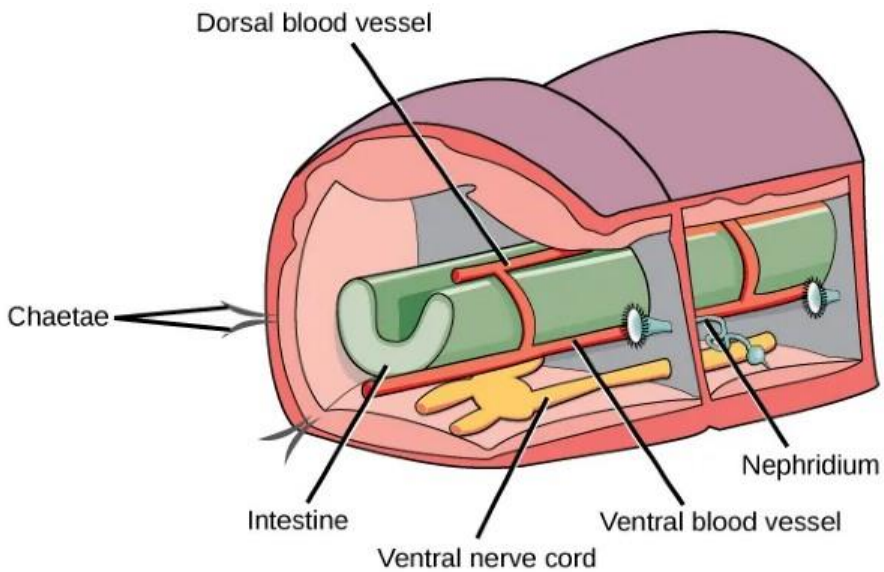


Figure 4.6 Extracellular digestion in annelids. In this schematic showing the basic anatomy of annelids, the digestive system is indicated in green, the nervous system is indicated in yellow, and the circulatory system is indicated in red. Source: http://cnx.org/contents/185cbf87-c72e-48f5-b51e-f14f21b5eabd@10.8

Annelids may be either monoecious with permanent gonads (as in earthworms and leeches) or dioecious with temporary or seasonal gonads (as in polychaetes). How does a change in the circulatory system organization support the body designs in cephalopods compared to other mollusks?

Self-Assessment Exercises 2

1. Describe the morphology and anatomy of mollusks.
2. What are the anatomical differences between nemertines and mollusks?

4.3.2.3 Annelid Diversity

The phylum Annelida is divided into three classes: oligochaetes (for example, earthworms), hirudineans (such as leeches) and polychaetes (these are mostly marine aquatic organisms with parapodia, such as nereis). The phylum includes the classes Polychaeta and Clitellata (Figure 4.67); the latter contains subclasses Oligochaeta, Hirudinoidea, and Branchiobdellida.

Earthworms are the most abundant members of the subclass Oligochaeta, distinguished by the presence of the **clitellum**, a ring structure in the skin that secretes mucus to bind mating individuals and forms a protective cocoon for the eggs. They also have a few, reduced chaetae (oligo- = "few"; -chaetae = "hairs"). The number and size of chaetae is greatly diminished in oligochaetes as compared to the polychaetes (poly- = "many"; -chaetae = "hairs"). The chaetae of polychaetes are also arranged within fleshy, flat, paired appendages on each segment called parapodia.

The subclass Hirudinoidea includes leeches. Significant differences between leeches and other annelids include the development of suckers at the anterior and posterior ends, and the absence of chaetae. Additionally, the segmentation of the body wall may not correspond to internal segmentation of the coelomic cavity. This adaptation may allow leeches to swell when ingesting blood from host vertebrates. The subclass Branchiobdellida includes about 150 species that show similarity to leeches as well as oligochaetes. All species are obligate symbionts, meaning that they can only survive associated with their host, mainly with freshwater crayfish. They feed on the algae that grows on the carapace of the crayfish. Into which classes is the phylum Annelida divided?

Figure 4.7 The (a) earthworm and (b) leech are both annelids. Source: http://cnx.org/contents/185cbf87-c72e-48f5-b51e-f14f21b5eabd@10.8

4.3.2.4 Habitat and Adaptation

Annelids are found worldwide in nearly every habitat on the planet, but they prefer to live in wet environments due to their inability to protect themselves from desiccation. They are especially common in oceanic waters, fresh waters, and damp soils. Most polychaetes live in the ocean, where they either float, burrow, wander on the bottom, or live in tubes they construct.

Annelids have adapted to different environments through convergent evolution. Some annelids adapted to the space between sand grains by progenesis, while others evolved by miniaturization of ancestral adult stages. Miniaturization is as important as progenesis in the adaptation to the interstitium. When the environmental conditions in an earthworm's habitat change, many earthworms become inactive in a process called aestivation. They move deeper into the soil, coil into a tight ball, excrete a protective mucus and lower their metabolic rate in order to reduce water loss. Species lacking a pelagic trochophore stage show special adaptive features.

4.3.3 Similarities between Mollusk and Annelids

Mollusks and annelids are very similar creatures. Both groups are invertebrates, meaning they lack a backbone. They also both have a soft, unsegmented body. Mollusks and annelids also both have a coelom, or a fluid-filled body cavity. Another similarity between these two groups is that they both have a muscular foot used for locomotion**.**

Self-Assessment Exercises 3

1. What is the purpose of chromatophores?
2. What is the difference between annelids and molluscs?

4.4 Summary

The phylum Mollusca is a large, mainly marine group of invertebrates. Mollusks show a variety of morphologies. Many mollusks secrete a calcareous shell for protection, but in other species, the shell is reduced or absent. Mollusks are protostomes. The dorsal epidermis in mollusks is modified to form the mantle, which encloses the mantle cavity and visceral organs. This cavity is distinct from the coelomic cavity, which the adult animal retains, surrounding the heart. Respiration is facilitated by gills known as ctenidia. A chitinous scraper called the radula is present in most mollusks. Mollusks are mostly dioecious and are divided into seven classes.

The phylum Annelida includes worm-like, segmented animals. Segmentation is both external and internal, which is called metamerism. Annelids are protostomes. The presence of chitinous hairs called chaetae is characteristic of most members. These animals have well-developed nervous and digestive systems. Polychaete annelids have parapodia that participate in locomotion and respiration. Suckers are seen in the order Hirudinea. Breeding systems include separate sexes and hermaphroditism.

4.5 References/Further Readings

Hickman, C.P. and L. S. Roberts. 1994. Animal Diversity. Wm. C. Brown, Dubuque, IA.
at http://cnx.org/contents/185cbf87-c72...f21b5eabd@10.8

Karl M. Wilbur, C. M. Yonge (2013). Physiology of Mollusca: Volume I. Edition. Elsevier Science, ISBN 1483275841, 9781483275840

https://openstax.org/books/concepts-biology/pages/1-introduction
https://en.wikipedia.org/wiki/File:Caribbean_reef_squid.jpg.
https://openstax.org/books/biology/pages/1-introduction.

http://cnx.org/contents/185cbf87-c72e-48f5-b51e-f14f21b5eabd@10.8

https://youtu.be/mW4PbW893ik
https://youtu.be/7hORx7hp-3Y
https://youtu.be/HEOjIRv9XQQ

4.6 Possible Answers to Self-Assessment Exercises

Answers to SAE 1

1. *The radula is generally used for cutting or scraping food in the phylum Mollusca. This is sometimes compared to the tongue. The main function of this radula is feeding. But the forces which are used for cutting the food with teeth are unknown. This can be recognized as a rasping organ in molluscs. Scraping of food from rocks and other substances is done by radula.*
2. *The visceral mass in the shelled species displays torsion around the perpendicular axis on the centre of the foot which is modified for crawling.*

Answers to SAE 2

1. Mollusks have a large muscular foot that may be modified in various ways, such as into tentacles, but it functions in locomotion. They have a mantle, a structure of tissue that covers and encloses the dorsal portion of the animal, and secrete the shell when it is present. The mantle encloses the mantle cavity, which houses the gills (when present), excretory pores, anus, and gonadopores. The coelom of mollusks is restricted to the region around the systemic heart. The main body cavity is a hemocoel. Many mollusks have a radula near the mouth that is used for scraping food.
2. Mollusks have a shell, even if it is a reduced shell. Nemertines do not have a shell. Nemertines have a proboscis; mollusks do not. Nemertines have a closed circulatory system, whereas Mollusks have an open circulatory system.

Answers to SAE 3

1. *These are organs that are present in the skin of many cephalopods, such as squids, cuttlefish, octopuses, etc., whose primary function is camouflage. These are the pigment-containing cells whose function is to adjust the body's colouration to its environment.*
2. Mollusks are invertebrates such as the common snail. Most mollusks have shells. Annelids are worms such as the familiar earthworm. They have segmented bodies.

Unit 5 Echinoderms and Chordates

5.1 Introduction

5.1 Introduction

Echinoderms and chordates are two closely-related groups of animals. They belong to the clade Deuterostomia, which means their blastopore develops into the anus**.** Deuterostomes include the phyla Echinodermata and Chordata (which includes the vertebrates) and two smaller phyla. Deuterostomes share similar patterns of early development. They also show bilateral symmetry at some stage of their life cycle and exhibit radial cleavage. Echinoderms are marine organisms that include starfish, while chordates include humans and other vertebrates. Their shared common ancestor was likely a bilaterally symmetrical organism with a cephalized nervous system.

5.2 Intended **Learning Objectives (ILOs)**

By the end of this section, you will be able to:

- Describe the distinguishing characteristics of echinoderms
- Explain the haracteristic features of echinoderms
- Physiological Processes of Echinoderms
- Describe the distinguishing characteristics of chordates

5.3 Main Contents

5.3.1 Echinoderms

Echinodermata are named for their spiny skin (from the Greek “echinos” meaning “spiny” and “dermos” meaning “skin”). The phylum includes about 7,000 described living species, such as sea stars, sea cucumbers, sea urchins, sand dollars, and brittle stars. **Echinodermata** are exclusively marine. Adult echinoderms exhibit pentaradial symmetry and have a calcareous endoskeleton made of ossicles (Figure 5.1), although the early larval stages of all echinoderms have bilateral symmetry. The endoskeleton is developed by epidermal cells, which may also possess pigment cells, giving vivid colors to these animals, as well as cells laden with toxins. These animals have a true coelom, a portion of which is modified into a unique circulatory system called a **water vascular system**. An interesting feature of these animals is their power to regenerate, even when over 75 percent of their body mass is lost.

5.3.1.1 Characteristic Features of Phylum Echinodermata

i. All Echinoderms are marine animals, and the adults are mostly with Pentamerous radial symmetry (ie can be divided into 5 equal parts). Body is not metamerically segmented;
ii. Could be rounded, cylindrical or star shaped without head.
iii. They have no brain, only few specialized sense organs.
iv. They have a complete digestive system.
v. Locomotive is mainly by tube feet, in some by means of spines or by movement of arms.
vi. They have no olfactory organs.
vii. Sexes are separate, fertilization is external.
viii. They have indeterminate type of development.
ix. Respiration is by dermal branchiae, tube feet or respiratory trees.
x. They have an internal skeleton (endoskeleton) made up of plates of calcium carbonate, imbedded in the body wall.

5.3.1.2 Physiological Processes of Echinoderms

Echinoderms have a unique system for gas exchange, nutrient circulation, and locomotion called the water vascular system. The system consists of a central ring canal and radial canals extending along each arm. Water circulates through these structures allowing for gas, nutrient, and waste exchange. A structure on top of the body, called the **madreporite**, regulates the amount of water in the water vascular system. "Tube feet," which protrude through openings in the endoskeleton, may be expanded or contracted using the hydrostatic pressure in the system. The system allows for slow movement, but a great deal of power, as witnessed when the tube feet latch on to opposite halves of a bivalve mollusk, like a clam, and slowly, but surely pull the shells apart, exposing the flesh within.

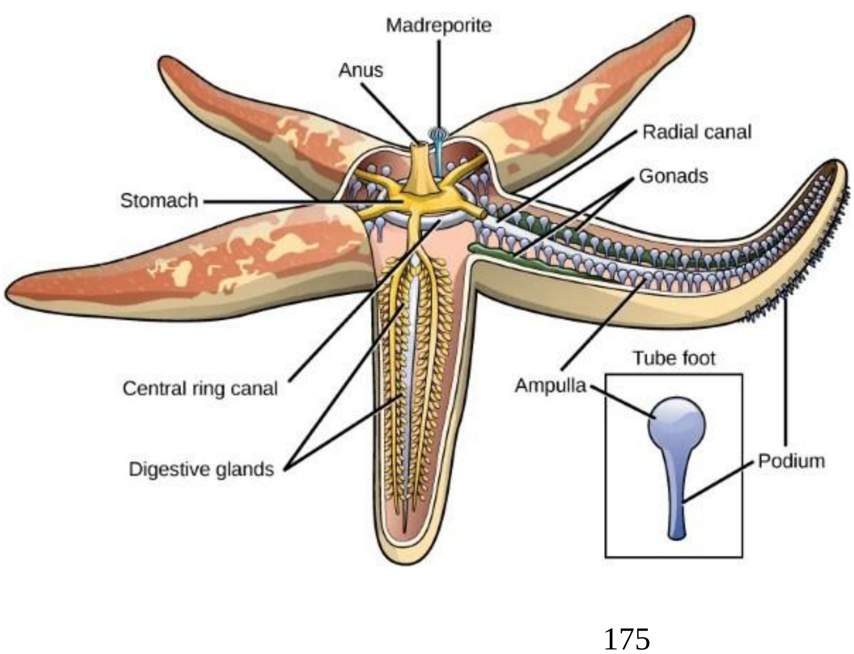


Figure 5.1 The echinoderm nervous system has a nerve ring at the center and five radial nerves extending outward along the arms. There is no centralized nervous control. Echinoderms have separate sexes and release their gametes into the water where fertilization takes place. Source: http://www.ucmp.berkeley.edu/echinodermata/blastoidea.html

Echinoderms may also reproduce asexually through regeneration from body parts. What is the unique system for gas exchange, nutrient circulation, and locomotion in Echinoderms?

Self-Assessment Exercises 1

1. Why are the adult Echinoderms said to have a mostly Pentamerous radial symmetry?
2. What is the structure on top of the body,that regulates the amount of water in the water vascular system?

5.3.2 Echinoderm Diversity

This phylum is divided into five classes: Asteroidea (sea stars), Ophiuroidea (brittle stars), Echinoidea (sea urchins and sand dollars), Crinoidea (sea lilies or feather stars), and Holothuroidea (sea cucumbers) (Figure 5.2). Perhaps the best-known echinoderms are members of the class Asteroidea, or sea stars. They come in a large variety of shapes, colors, and sizes, with more than 1,800 species known. The characteristics of sea stars that set them apart from other echinoderm classes include thick arms that extend from a central disk where organs penetrate into the arms. Sea stars use their tube feet not only for gripping surfaces but also for grasping prey. Sea stars have two stomachs, one of which they can evert through their mouths to secrete digestive juices into or onto prey before ingestion. This process can essentially liquefy the prey and make digestion easier.

Brittle stars have long, thin arms that do not contain any organs. Sea urchins and sand dollars do not have arms but are hemispherical or flattened with five rows of tube feet, which help them in slow movement. Sea lilies and feather stars are stalked suspension feeders. Sea cucumbers are soft-bodied and elongate with five rows of tube feet and a series of tube feet around the mouth that are modified into tentacles used in feeding. Which is the best-known class of echinoderms?

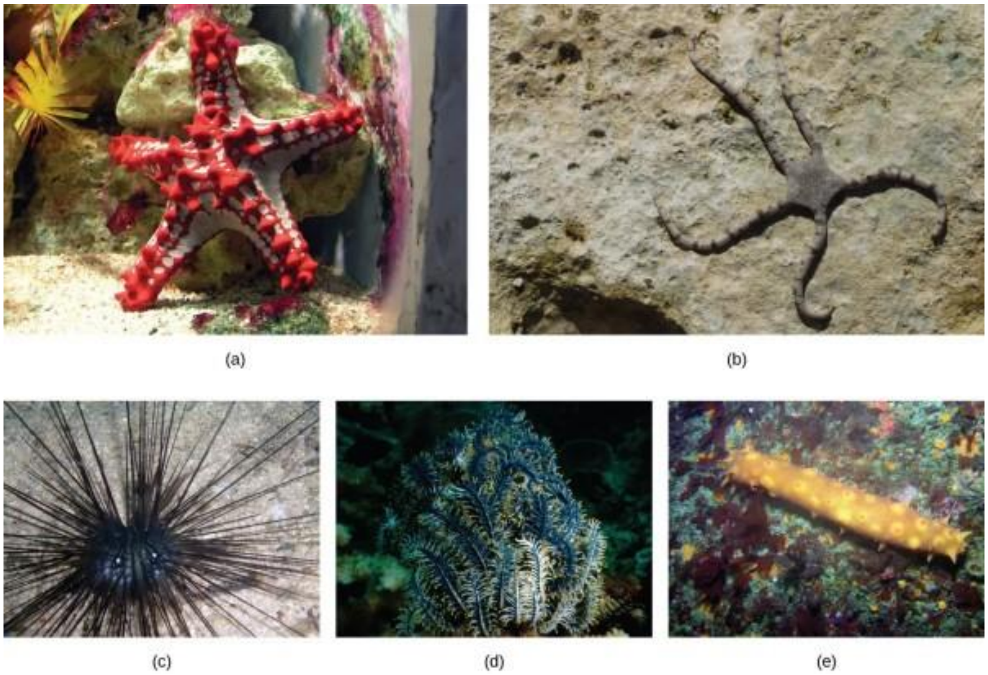


Figure 5.2 Different members of Echinodermata include the (a) sea star in class Asteroidea, (b) the brittle star in class Ophiuroidea, (c) the sea urchins of class Echinoidea, (d) the sea lilies belonging to class Crinoidea, and (e) sea cucumbers representing class Holothuroidea. Source: http://www.ucmp.berkeley.edu/echinodermata/blastoidea.html

5.3.2.1 Habitat

Echinoderms are globally distributed in almost all depths, latitudes and environments in the ocean. Adults are mainly benthic, living on the seabed, whereas larvae are often pelagic, living as plankton in the open ocean. Some holothuroid adults such as *Pelagothuria* are however pelagic. Some crinoids are pseudo-planktonic, attaching themselves to floating logs and debris, although this behaviour was exercised most extensively in the Paleozoic, before competition from organisms such as barnacles restricted the extent of the behaviour.

5.3.2.2 Ecological Adaptation

Echinoderms have several adaptations to their environment.Some of these adaptations include**:**

- Radial symmetry and five lines of symmetry
- Amazing vision or about 20/20 vision
- A nerve ring at the center and five radial nerves extending outward along the arms
- No centralized nervous control
- Separate sexes and release of gametes into the water where fertilization takes place
- Asexual reproduction through regeneration from body parts
- Defense mechanisms such as spines, toxins, and camouflage
- Water vascular system
- Body regeneration
- Cutaneous and cloacal respiration

- Open circulatory systems

Self-Assessment Exercises 2

1. What are the five classes of Echinoderms?
2. Which members of Echinoderms have two stomachs, which confers on it the ability to liquefy its prey and make digestion easier?

5.3.3 Chordates

The majority of species in the phylum Chordata are found in the subphylum Vertebrata, which include many species with which we are familiar. The vertebrates contain more than 60,000 described species, divided into major groupings of the lampreys, fishes, amphibians, reptiles, birds, and mammals. Animals in the phylum **Chordata** share four key features that appear at some stage of their development: a notochord, a dorsal hollow nerve cord, pharyngeal slits, and a post-anal tail (Figure 5.3). In certain groups, some of these traits are present only during embryonic development. The chordates are named for the notochord, which is a flexible, rod-shaped structure that is found in the embryonic stage of all chordates and in the adult stage of some chordate species. It is located between the digestive tube and the nerve cord, and provides skeletal support through the length of the body. In some chordates, the notochord acts as the primary axial support of the body throughout the animal's lifetime. In vertebrates, the notochord is present during embryonic development, at which time it induces the development of the neural tube and serves as a support for the developing embryonic body. The notochord, however, is not found in the postnatal stage of vertebrates; at this point, it has been replaced by the vertebral column (the spine). What happens to the notochord in vertebrates and protochordates? In vertebrates, the notochord disappears and to produce the spine (vertebral column). In protochordates, the notochord remains during their whole life.

The **dorsal hollow nerve cord** is derived from ectoderm that sinks below the surface of the skin and rolls into a hollow tube during development. In chordates, it is located dorsally to the notochord. In contrast, other animal phyla possess solid nerve cords that are located either ventrally or laterally. The nerve cord found in most chordate embryos develops into the brain and spinal cord, which compose the central nervous system.

Pharyngeal slits are openings in the pharynx, the region just posterior to the mouth, that extend to the outside environment. In organisms that live in aquatic environments, pharyngeal slits allow for the exit of water that enters the mouth during feeding. Some invertebrate chordates use the pharyngeal slits to filter food from the water that enters the mouth. In fishes, the pharyngeal slits are modified into gill supports, and in jawed fishes, jaw supports. In tetrapods, the slits are further modified into components of the ear and tonsils, since there is no longer any need for gill supports in these air-breathing animals. ***Tetrapod*** means "four-footed," and this group includes amphibians, reptiles, birds, and mammals. (Birds are considered tetrapods because they evolved from tetrapod ancestors.)

The post-anal tail is a posterior elongation of the body extending beyond the anus. The tail contains skeletal elements and muscles, which provide a source of locomotion in aquatic species, such as fishes. In some terrestrial vertebrates, the tail may also function in balance, locomotion, courting, and signaling when danger is near. In many species, the tail is absent or reduced; for example, in apes, including humans, it is present in the embryo, but reduced in size and nonfunctional in adults. What are the characteristic features of the chordates? What are the two main subdivisions of the phylum Chordata?

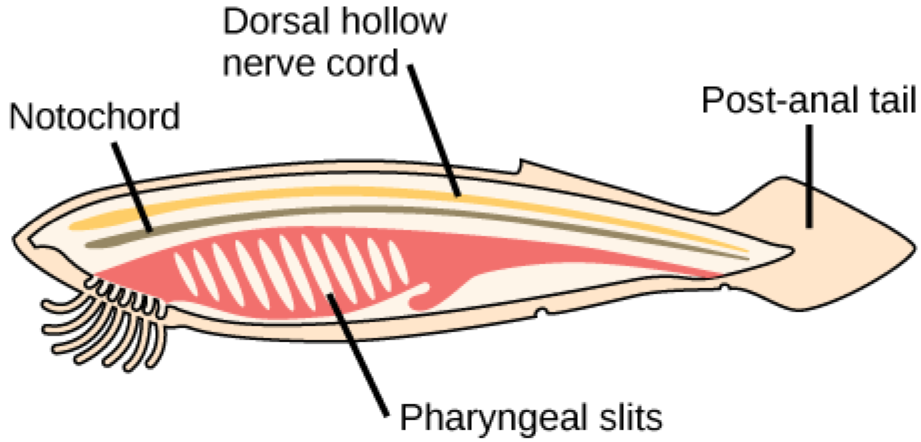


Figure 5.3 Chordate features. In chordates, four common features appear at some point during development: a notochord, a dorsal hollow nerve cord, pharyngeal slits, and a post-anal tail. The endostyle is embedded in the floor of the pharynx. Source: http://www.environment.gov.au/biodiversity/abrs/publications/other/species-numbers/2009/03-exec-summary.html.

5.3.3.1 Invertebrate Chordates

In addition to the vertebrates, the phylum Chordata contains two clades of invertebrates: **Urochordata** (tunicates) and **Cephalochordata** (lancelets). Members of these groups possess the four distinctive features of chordates at some point during their development.The **tunicates** (Figure 5.4) are also called sea squirts. The name tunicate derives from the cellulose-like carbohydrate material, called the tunic, which covers the outer body. Although tunicates are classified as chordates, the adult forms are much modified in body plan and do not have a notochord, a dorsal hollow nerve cord, or a post-anal tail, although they do have pharyngeal slits. The larval form possesses all four structures. Most tunicates are hermaphrodites. Tunicate larvae hatch from eggs inside the adult tunicate's body. After hatching, a tunicate larva swims for a few days until it finds a suitable surface on which it can attach, usually in a dark or shaded location. It then attaches by the head to the substrate and undergoes metamorphosis into the adult form, at which point the notochord, nerve cord, and tail disappear.

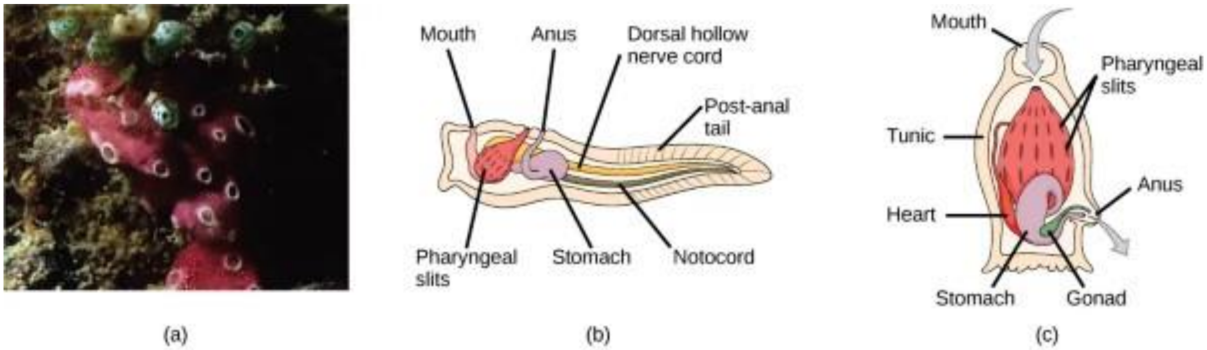


Figure 5.4 (a) This photograph shows a colony of the tunicate *Botrylloides violaceus*. In the (b) larval stage, the tunicate can swim freely until it attaches to a substrate to become (c) an adult. Source: http://www.environment.gov.au/biodiversity/abrs/publications/other/species-numbers/2009/03-exec-summary.html.

Most tunicates live a sessile existence in shallow ocean waters and are suspension feeders. The primary foods of tunicates are plankton and detritus. Seawater enters the tunicate's body through its incurrent siphon. Suspended material is filtered out of this water by a mucus net (pharyngeal slits) and is passed into the intestine through the action of cilia. The anus empties into the excurrent siphon, which expels wastes and water.

Lancelets possess a notochord, dorsal hollow nerve cord, pharyngeal slits, and a post-anal tail in the adult stage (Figure 5.5). The notochord extends into the head, which gives the subphylum its name (Cephalochordata). Extinct fossils of this subphylum date to the middle of the Cambrian period (540–488 mya).The living forms, the lancelets, are named for their blade-like shape. Lancelets are only a few centimeters long and are usually found buried in sand at the bottom of warm temperate and tropical seas. Like tunicates, they are suspension feeders. What are two clades of invertebrates contained in the phylum Chordata?

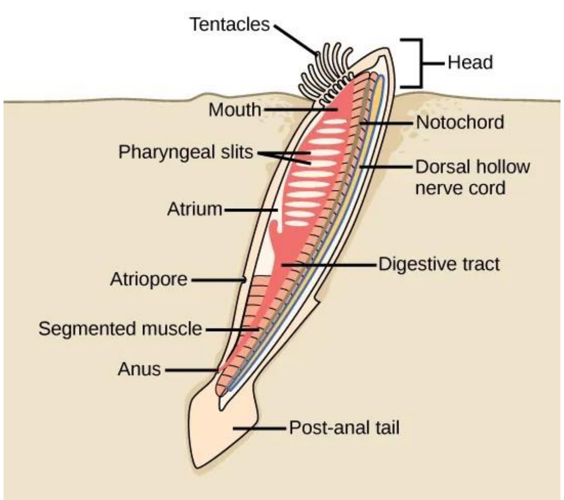


Figure 5.5 Adult lancelets retain the four key features of chordates: a notochord, a dorsal hollow nerve cord, pharyngeal slits, and a post-anal tail. Source:

http://www.environment.gov.au/biodiversity/abrs/publications/other/species-numbers/2009/03-exec-summary.html.

5.3.3.2 Habitat and Ecological Adaptation

These organisms reside in **marine environments** living individually or in colonies. Invertebrate chordates feed on tiny organic matter, such as plankton, suspended in the water. Invertebrate chordates are coelomates or animals with a true body cavity.

An animal may adapt to its habitat in different ways. It may be a physical or structural adaptation, just as the limbs of birds have modified into wings or the way the cheetah is shaped for running at a fast speed. It may be in the way the body works in circulating and respiration, for instance the gills that fish have enable them to breathe in water. Or it may be the way the animal behaves whether it is hunting for food, or running fast to avoid predators or migrating to other places for food or survival. An animal's environment consists of many different things. The climate, the kinds of food plants that grow in it, other animals that may be predators or competitors- the animal must learn to adapt to each of these factors in order to survive. With increasing population growth and human activity that disturbs the natural habitat, animals must learn to adapt to these kind of threats as well.

Animals in the wild can only live in places they are adapted to. They must have the right kind of habitat where they can find the food and space they need. Did you know that animals camouflage themselves so they can adapt to their environment? Adaptation can protect animals from predators or from harsh weather. Many birds can hide in the tall grass and weeds and insects can change their colour to blend into the surroundings. This makes it difficult for predators to seek them out for food.

Some animals, like the apple snail, can survive in different ecosystems- from swamps, ditches and ponds to lakes and rivers. It has a lung/gills combination that reflects its adaptation to habitats with oxygen poor water. This is often the case in swamps and shallow waters.
In the harsh cold climate of Alaska, the animals have learnt to adapt to the weather by storing food in their body and protecting themselves from the cold with thick furs. Human inhabitants in Alaska have also learnt to cope with the environment by building shelters that insulate and hold the heat, and yet do not allow the structure to melt.

5.3.3.3 Vertebrates and Invertebrates Animals

Vertebrates are typically more complex as compared to invertebrates, with a more developed nervous system and a greater level of cognitive function. They have an integral skeleton made up of bones and cartilage that provide support and protection for their internal organs. They also have a wide range of reproductive strategies, including internal and external fertilization. Coming to invertebrates, on the other hand, there is a lack of a true skeleton and instead, have an exoskeleton or a hydrostatic skeleton. They are generally less complex than vertebrates, having a simpler nervous system. They are also found in a variety of habitats, but many are restricted to specific environments. Which of vertebrates or invertebrates, are typically more complex organisms?

Self-Assessment Exercises 3

1. Sessile adult tunicates lose the notochord; what does this suggest about the function of this structure?
2. During embryonic development, what features do we share with tunicates or lancelets?

5.4 Summary

Echinoderms are deuterostome marine organisms. This phylum of animals bear a calcareous endoskeleton composed of ossicles covered by a spiny skin. Echinoderms possess a water-based circulatory system. The madreporite is the point of entry and exit for water for the water vascular system. The characteristic features of Chordata are a notochord, a dorsal hollow nerve cord, pharyngeal slits, and a post-anal tail. Chordata contains two clades of invertebrates: Urochordata (tunicates) and Cephalochordata (lancelets), together with the vertebrates. Most tunicates live on the ocean floor and are suspension feeders. Lancelets are suspension feeders that feed on phytoplankton and other microorganisms.

5.5 References/Further Readings/Web Sources

Chen, J. Y., Huang, D. Y., and Li, C. W., "An early Cambrian craniate-like chordate," *Nature* 402 (1999): 518–522, doi:10.1038/990080.

Zamora, S., Rahman, I. and Smith, A. (2012). Plated Cambrian Bilaterians Reveal the Earliest Stages of Echinoderm Evolution. *PLoS ONE, 7*(6).

http://www.ncbi.nlm.nih.gov/pubmed/24850925
http://www.starfish.ch/reef/echinoderms.html
http://animals.nationalgeographic.com/animals/invertebrates/starfish/
http://www.ucmp.berkeley.edu/echinodermata/blastoidea.html
http://www.environment.gov.au/biodiversity/abrs/publications/other/species-numbers/2009/03-exec-summary.html.
https://youtu.be/ypYesuV3PoI
https://youtu.be/SiaIouBgzPc
https://youtu.be/s0gc8lkrUlQ
https://youtu.be/kgZRZmEc9j4

5.6 Possible Answers to Self-Assessment Exercises

Answers to SAE 1

1. The adult Echinoderms are mostly with Pentamerous radial symmetry, this means they can be divided into 5 equal parts.
2. A structure on top of the body, called the madreporite, regulates the amount of water in the water vascular system.

Answers to SAE 2

1. The five classes of Echinoderms are: Asteroidea (sea stars), Ophiuroidea (brittle stars), Echinoidea (sea urchins and sand dollars), Crinoidea (sea lilies or feather stars), and Holothuroidea (sea cucumbers)
2. Its class Asteroidea (Sea stars) which have two stomachs, one of which they can evert through their mouths to secrete digestive juices into or onto prey before ingestion, a process that can essentially liquefy the prey and make digestion easier.

Answers to SAE 3

1. It suggests that the notochord is important for support during locomotion of an organism.
2. During embryonic development, we also have a notochord, a dorsal hollow nerve tube, pharyngeal slits, and a post-anal tail.

Unit 6 Vertebrates I: Fishes and Amphibians

6.1 Introduction

Vertebrates are among the most recognizable organisms of the animal kingdom. More than 62,000 vertebrate species have been identified. The vertebrate species now living represent only a small portion of the vertebrates that have existed. The best-known extinct vertebrates are the dinosaurs, a unique group of reptiles, reaching sizes not seen before or since in terrestrial animals. They were the dominant terrestrial animals for 150 million years, until they died out near the end of the Cretaceous period in a mass extinction. A great deal is known about the anatomy of the dinosaurs, given the preservation of their skeletal elements in the fossil record.

6.2 Intended Learning Objectives (ILOs)

By the end of this section, you will be able to:

- Describe the general characteristics and classification of vertebrates
- Describe the difference between jawless and jawed fishes

6.3 Main Contents

6.3.1 Vertebrate Organisms

Vertebrates have several basic features. First, vertebrates have a complex central nervous system. This includes a well-developed brain and a spinal cord that is held in the vertebral column. Vertebrates also have a closed circulatory system. This means the blood of a vertebrate circulates through its body in blood vessels. Vertebrates also have skin that is protected by hair, feathers, or scales. Finally, as embryos, vertebrates have neural crest cells. These cells develop into nerve cells and cells that form facial features.

In addition to these basic features, there are five key characteristics that are common to all vertebrates. These include:

1. **Vertebra/backbone**: Vertebra are a series of small bones that make up the backbone. The spinal cord passes through the vertebral column.
2. **Skull:** Vertebrates have a skull. This protects the delicate, well-developed brain.
3. **Endoskeleton**: Vertebrates have a well-developed endoskeleton. This is an internal skeleton that provides structure to the vertebrate's body.
4. **Bilateral Symmetry**: These organisms are bilaterally symmetrical. This means that vertebrates have mirror-image right and left halves of their bodies.
5. **Two Pairs of Appendages:** Vertebrates have appendages such as wings, fins, or limbs. These appendages are seen in pairs on the vertebrate's body.

Vertebrates are divided into five classes: - Pisces - Amphibia - Reptilia - Aves, and - Mammalia. What does the complex central nervous system of vertebrates consisted? Vertebrates have a complex central nervous system that includes a well-developed brain and a spinal cord that is held in the vertebral column.

Self-Assessment Exercises 1

1. What are the five classes of Vertebrates?
2. What are the two pairs of appendages possessed by vertebrates?

3.3.1.1 Fishes

Modern fishes include an estimated 31,000 species. Fishes were the earliest vertebrates, and jawless fishes were the earliest of these. Jawless fishes—the present day hagfishes and lampreys—

have a distinct cranium and complex sense organs including eyes, distinguishing them from the invertebrate chordates. The jawed fishes evolved later and are extraordinarily diverse today. Fishes are active feeders, rather than sessile, suspension feeders.

3.3.1.2 Jawless Fishes

Jawless fishes are **craniates** (which includes all the chordate groups except the tunicates and lancelets) that represent an ancient vertebrate lineage that arose over one half-billion years ago. Some of the earliest jawless fishes were the **ostracoderms** (which translates as "shell-skin"). Ostracoderms, now extinct, were vertebrate fishes encased in bony armor, unlike present-day jawless fishes, which lack bone in their scales.

The clade **Myxini** includes 67 species of hagfishes. **Hagfishes** are eel-like scavengers that live on the ocean floor and feed on dead invertebrates, other fishes, and marine mammals (Figure 6.1**a**). Hagfishes are entirely marine and are found in oceans around the world except for the polar regions. A unique feature of these animals is the slime glands beneath the skin that are able to release an extraordinary amount of mucus through surface pores. This mucus may allow the hagfish to escape from the grip of predators. Hagfish are known to enter the bodies of dead or dying organisms to devour them from the inside.

(a) (b)

Figure 6.1 (a) Pacific hagfishes are scavengers that live on the ocean floor. (b) These parasitic sea lampreys attach to their lake trout host by suction and use their rough tongues to rasp away flesh in order to feed on the trout's blood. Source: https://openstax.org/books/concepts-biology/pages/15-6-vertebrates

The skeleton of a hagfish is composed of cartilage, which includes a cartilaginous notochord, which runs the length of the body, and a skull. This notochord provides support to the fish's body. Although they are craniates, hagfishes are not vertebrates, since they do not replace the notochord with a vertebral column during development, as do the vertebrates.

The clade **Petromyzontidae** includes approximately 40 species of lampreys. **Lampreys** are similar to hagfishes in size and shape; however, lampreys have a brain case and incomplete vertebrae. Lampreys lack paired appendages and bone, as do the hagfishes. As adults, lampreys are characterized by a toothed, funnel-like sucking mouth. Some species are parasitic as adults, attaching to and feeding on the body fluids of fish (Figure 15.37**b**). Most species are free-living.

Lampreys live primarily in coastal and fresh waters and have a worldwide temperate region distribution. All species spawn in fresh waters. Eggs are fertilized externally, and the larvae are distinctly different from the adult form, spending 3 to 15 years as suspension feeders. Once they attain sexual maturity, the adults reproduce and die within days. Lampreys have a notochord as adults.

6.3.1.3 Jawed Fishes

Gnathostomes or “jaw-mouths” are vertebrates that have jaws and include both cartilaginous and bony fishes. One of the most significant developments in early vertebrate evolution was the origin of the jaw, which is a hinged structure attached to the cranium that allows an animal to grasp and tear its food. The evolution of jaws allowed early gnathostomes to exploit food resources that were unavailable to jawless fishes.

The clade **Chondrichthyes**, the cartilaginous fishes, is diverse, consisting of sharks (Figure 6.3**a**), rays, and skates, together with sawfishes and a few dozen species of fishes called *chimaeras*, or ghost sharks. Chondrichthyes have paired fins and a skeleton made of cartilage. This clade arose approximately 370 million years ago in the middle Devonian. They are thought to have descended from an extinct group that had a skeleton made of bone; thus, the cartilaginous skeleton of Chondrichthyes is a later development. Parts of the shark skeleton are strengthened by granules of calcium carbonate, but this is not the same as bone.

Most cartilaginous fishes live in marine habitats, with a few species living in fresh water for some or all of their lives. Most sharks are carnivores that feed on live prey, either swallowing it whole or using their jaws and teeth to tear it into smaller pieces. Shark teeth likely evolved from the jagged scales that cover their skin. Some species of sharks and rays are suspension feeders that feed on plankton.

Figure 6.3(a) This hammerhead shark is an example of a predatory cartilaginous fish. (b) This stingray blends into the sandy bottom of the ocean floor when it is feeding or awaiting prey.
Source: https://openstax.org/books/concepts-biology/pages/15-6-vertebrates

Sharks have well-developed sense organs that aid them in locating prey, including a keen sense of smell and electroreception, the latter being perhaps the most sensitive of any animal. Organs called **ampullae of Lorenzini** allow sharks to detect the electromagnetic fields that are produced by all living things, including their prey. Electroreception has only been observed in aquatic or amphibious animals. Sharks, together with most fishes, also have a sense organ called the **lateral line**, which is used to detect movement and vibration in the surrounding water, and a sense that is often considered homologous to "hearing" in terrestrial vertebrates. The lateral line is visible as a darker stripe that runs along the length of the fish's body.

Sharks reproduce sexually and eggs are fertilized internally. Most species are ovoviviparous, that is, the fertilized egg is retained in the oviduct of the mother's body, and the embryo is nourished by the egg yolk. The eggs hatch in the uterus and young are born alive and fully functional. Some species of sharks are oviparous: They lay eggs that hatch outside of the mother's body. Embryos are protected by a shark egg case or "mermaid's purse" that has the consistency of leather. The shark egg case has tentacles that snag in seaweed and give the newborn shark cover. A few species of sharks are viviparous, that is, the young develop within the mother's body, and she gives live birth.

Rays and skates include more than 500 species and are closely related to sharks. They can be distinguished from sharks by their flattened bodies, pectoral fins that are enlarged and fused to the head, and gill slits on their ventral surface (Figure 6.3**b**). Like sharks, rays and skates have a cartilaginous skeleton. Most species are marine and live on the sea floor, with nearly a worldwide distribution.

6.3.1.4 Bony Fishes

Members of the clade **Osteichthyes**, or bony fishes, are characterized by a bony skeleton. The vast majority of present-day fishes belong to this group, which consists of approximately 30,000 species, making it the largest class of vertebrates in existence today. Nearly all bony fishes have an ossified skeleton with specialized bone cells (osteocytes) that produce and maintain a calcium phosphate matrix. This characteristic has only reverted in a few groups of Osteichthyes, such as sturgeons and paddlefish, which have primarily cartilaginous skeletons. The skin of bony fishes is often covered in overlapping scales, and glands in the skin secrete mucus that reduces drag when swimming and aids the fish in osmoregulation. Like sharks, bony fishes have a lateral line system that detects vibrations in water. Unlike sharks, some bony fish depend on their eyesight to locate prey. Bony fish are also unusual in possessing taste cells in the head and trunk region of the body that allow them to detect extremely small concentrations of molecules in the water. All bony fishes, like the cartilaginous fishes, use gills to breathe. Water is drawn over gills that are located in chambers covered and ventilated by a protective, muscular flap called the operculum. Unlike sharks, bony fishes have a **swim bladder**, a gas-filled organ that helps to control the buoyancy of the fish. Bony fishes are further divided into two clades with living members: **Actinopterygii** (ray-finned fishes) and **Sarcopterygii** (lobe-finned fishes). The ray-finned fishes include many familiar fishes—tuna, bass, trout, and salmon (Figure 6.4**a**), among others. Ray-finned fishes are named for the form of their fins—webs of skin supported by bony spines called rays. In contrast, the fins of lobe-finned fishes are fleshy and supported by bone (Figure 6.4**b**). Living members of lobe-finned fishes include the less familiar lungfishes and coelacanth. **IN-TEXT QUESTION (ITQ)**: Which of the fishes were the earliest vertebrates that evolved? Fishes were the earliest vertebrates, and jawless fishes were the earliest of these.

Figure 6.4 The (a) sockeye salmon and (b) coelacanth are both bony fishes of the Osteichthyes clade. The coelacanth, sometimes called a lobe-finned fish, was thought to have gone extinct in the Late Cretaceous period 100 million years ago until one was discovered in 1938 between Africa and Madagascar. Source: https://openstax.org/books/concepts-biology/pages/15-6-vertebrates

Self-Assessment Exercises 2

1. What are jawless fishes?
2. What is the mot important characteristic of members of the clade Osteichthyes?

6.3.2 A

Amphibians are vertebrate tetrapods. Amphibia includes frogs, salamanders, and caecilians. The term amphibian means "dual life," which is a reference to the metamorphosis that many frogs undergo from a tadpole to an adult and the mixture of aquatic and terrestrial environments in their life cycle. Amphibians evolved in the Devonian period and were the earliest terrestrial tetrapods. As tetrapods, most amphibians are characterized by four well-developed limbs, although some species of salamanders and all caecilians possess only vestigial limbs. An important characteristic of extant amphibians is a moist, permeable skin, achieved by mucus glands. The moist skin allows oxygen and carbon dioxide exchange with the environment, a process called cutaneous respiration. All living adult amphibian species are carnivorous, and some terrestrial amphibians have a sticky tongue that is used to capture prey. 90% of all amphibian species are frogs. **IN-TEXT QUESTION (ITQ):** Which chordate class is considered evidence of the transition of vertebrates from an aquatic environment to dry land?

Amphibians are totally aquatic during their larval stage and partially terrestrial animals as adults. Because of this, they are considered intermediate organisms in the evolutionary passage of vertebrates from an aquatic to dry land. Amphibians are also the first tetrapod animals; that is, the first with two pairs of limbs, a typical feature of terrestrial vertebrates. The name "amphibian" comes from the double life (aquatic as larvae and partially terrestrial as adults) of these animals.

6.3.2.1 Characteristics Features of Amphibians

Below are some of the characteristics shared by the amphibians.

1. Egg Are Fertilized Outside Of The Body

Most amphibians reproduce in fresh water while a few lay their eggs on land and have developed mechanisms to keep the eggs moist. Reproduction in amphibians has more similarities with the fish than with reptiles or mammals. Although they reproduce sexually, fertilization and development of the young ones take place outside the body.

2. Cold-Blooded

Although amphibians exhibit both terrestrial and aquatic characteristic, they are strictly cold-blooded or ectothermic. They do not have the internal mechanisms to regulate their own body temperatures like mammals do. They rely on the external environment to regulate their body temperature. Amphibians tend to bask in the sun to raise their body temperature and retreat to a cold place to lower their temperature. Their cold-blooded nature has limited the ecosystem in which they can thrive in since they cannot survive in areas of high or low temperatures. Amphibians do not have hair or fur to insulate them from heat loss. To survive the cold winter, most amphibians remain active throughout the period. Some also sink deep into the water to stay warm. Other species hibernate at the bottom of the ponds. Salamanders have the ability to antifreeze ice forming around them by converting glycogen into glucose.

3. Breathe Through Skin

Amphibians have primitive lungs compared to other amniotes. They possess large alveoli and few internal septa, responsible for a slow oxygen diffusion rate into the blood. The lungs have low internal volumes and cannot process as much air as mammals or reptiles. Some species of salamanders are lungless and have to employ other means to breathe. Most amphibians exchange gases or breathe through their moist, permeable skin. To facilitate sufficient gaseous exchange, the vascular skin of the amphibians must be moist. The moist skin allows the oxygen to diffuse at a sufficiently high rate. The process by which gaseous exchange takes place through the skin is called cutaneous respiration. Aquatic amphibians like the Titicaca water frog can rely entirely on cutaneous respiration since the concentration of oxygen in water increases at both low temperature and high rate of flow. A network of cutaneous capillaries enables for the exchange of gases and the diffusion of water and iron between the environment and the animal.

4. Carnivores

Amphibians are mainly carnivores and feed on almost anything that moves and they can swallow. The adult amphibian is a predator with its diet consisting of a wide variety of food. Some of these foods include spiders, earthworms, beetles, and caterpillars. Burrowing caecilians mainly feed on earthworms whereas salamanders and anurans feed mainly on insects and arthropods. Large amphibians can also feed on small vertebrates such as birds and mammals. Food is often selected by sight, even in areas with dim light.

5. Time Spent In Water And On Land

Amphibians spend their life both on land and in water. The term “amphibian” is a Greek word for “amphibious” which means “living a double life.” Most have a biphasic life cycle which involves the fertilization and development of eggs and larvae in water. The larvae metamorphose into a semi-terrestrial or terrestrial juvenile and adults. On the evolutionary tree, amphibians are found midway between fish which fully live in water and reptiles and mammals which lead a fully terrestrial lifestyle. Adult amphibians have to live near water since they need steady moisture supply in order to survive. They can be found in a wide range of habitat near water including swamps, streams, forests, and dump areas.

6.3.2.2 Amphibian Diversity

Amphibians are animals that are characterized by their ability to survive both in water and on land. The name “amphibian” is derived from the Greek word “amphibious” which means “to live a double life.” There are over 6,500 living species of amphibians with the majority of the species living within fresh aquatic water ecosystem. Most of them are born in water and start off as a larva and develop a land-based lifestyle as they develop. The class Amphibia is divided into three modern orders:

- **Anura** (“tail-less ones”), which includes the toads and frogs.
- **Apoda** (“legless ones”), which comprises the caecilians.
- **Urodela** (“tailed-ones”), which are mainly salamanders.

Living **salamanders** (Figure 6.5**a**) include approximately 500 species, some of which are aquatic, others terrestrial, and some that live on land only as adults. Adult salamanders usually have a generalized tetrapod body plan with four limbs and a tail. Some salamanders are lungless, and respiration occurs through the skin or external gills. Some terrestrial salamanders have primitive lungs; a few species have both gills and lungs.

Figure 6.5 (a) Most salamanders have legs and a tail, but respiration varies among species. (b) The Australian green tree frog is a nocturnal predator that lives in the canopies of trees near a water source. Source: https://openstax.org/books/concepts-biology/pages/15-6-vertebrates

Frogs (Figure 6.5**b**) are the most diverse group of amphibians, with approximately 5,000 species that live on all continents except Antarctica. Frogs have a body plan that is more specialized than the salamander body plan for movement on land. Adult frogs use their hind limbs to jump many times their body length on land. Frogs have a number of modifications that allow them to avoid predators, including skin that acts as camouflage and defensive chemicals that are poisonous to predators secreted from glands in the skin.

Frog eggs are fertilized externally, as they are laid in moist environments. Frogs demonstrate a range of parental behaviors, with some species exhibiting little care, to species that carry eggs and tadpoles on their hind legs or backs. The life cycle consists of two stages: the larval stage followed by metamorphosis to an adult stage. The larval stage of a frog, the **tadpole**, is often a filter-feeding herbivore. Tadpoles usually have gills, a lateral line system, long-finned tails, but no limbs. At the end of the tadpole stage, frogs undergo a gradual metamorphosis into the adult form. During this stage, the gills and lateral line system disappear, and four limbs develop. The jaws become larger and are suited for carnivorous feeding, and the digestive system transforms into the typical short gut of a predator. An eardrum and air-breathing lungs also develop. These changes during metamorphosis allow the larvae to move onto land in the adult stage (Figure 6.6).

Figure 6.6 A frog begins as a (a) tadpole and undergoes metamorphosis to become (b) a juvenile and finally (c) an adult. Source: https://openstax.org/books/concepts-biology/pages/15-6-vertebrates

Caecilians comprise an estimated 185 species. They lack external limbs and resemble giant earthworms. They inhabit soil and are found primarily in the tropics of South America, Africa, and southern Asia where they are adapted for a soil-burrowing lifestyle and are nearly blind. Unlike most of the other amphibians that breed in or near water, reproduction in a drier soil habitat means that caecilians must utilize internal fertilization, and most species give birth to live young (Figure 6.7).

Figure 6.7 Caecilians lack external limbs and are well adapted for a soil-burrowing lifestyle. Source: https://openstax.org/books/concepts-biology/pages/15-6-vertebrates

6.3.2.3 Ecological Adaptation of Amphibians

The amphibians are as class, typically furnished with five fingered limbs which are adapted for locomotion both on land as well as in water. They are cold –blooded or poikilothermic animals of jumping and swimming habits. Their skin is smooth, clammy and naked, that is without scales. There is remarkable difference between the young and the adults; the limbless but tailed young forms or tadpoles, as they are called, live in water and breathe by gills while almost in every case the adults breathe by lungs and can live both on land as well as in water and hence the name amphibian. The skin is usually soft and moist in order to carry on the important functions of skin or cutaneous respiration and this is the reason why the presence of moisture is essential for the wellbeing of all amphibians. The tailless amphibians, such as frogs and toads, numbering some thousand species, have a worldwide distribution. They are most abundantly found in tropical countries. Bu it is remarkable that notwithstanding their natural inclination to live in and around water no amphibian has been discovered to live in salt and marine waters. Is a crocodile an amphibian?

Self-Assessment Exercises 3

1. Which animals are called amphibians?
2. What is considered an amphibian?

6.4 Summary

You have studied in this unit that fishes are adapted to life in water, with specialized structures like gills for breathing and fins for swimming, while amphibians have adaptations that allow them to live both in water and on land, including their unique skin and specialized limbs**.**

The earliest vertebrates that diverged from the invertebrate chordates were the jawless fishes. Hagfishes are eel-like scavengers that feed on dead invertebrates and other fishes. Lampreys are characterized by a toothed, funnel-like sucking mouth, and some species are parasitic on other fishes. Gnathostomes include the jawed fishes (cartilaginous and bony fishes) as well as all other tetrapods. Cartilaginous fishes include sharks, rays, skates, and ghost sharks. Bony fishes can be further divided into ray-finned and lobe-finned fishes.

As tetrapods, most amphibians are characterized by four well-developed limbs, although some species of salamanders and all caecilians are limbless. Amphibians have a moist, permeable skin used for cutaneous respiration. Amphibia can be divided into three clades: salamanders (Urodela), frogs (Anura), and caecilians (Apoda). The life cycle of amphibians consists of two distinct stages: the larval stage and metamorphosis to an adult stage.

6.5 References/Further Readings/Web Sources

Kikuyama, Sakae; Kawamura, Kousuke; Tanaka, Shigeyasu; Yamamoto, Kakutoshi (1993). "Aspects of amphibian metamorphosis: Hormonal control". *International Review of Cytology: A Survey of Cell Biology*. Academic Press. pp. 105–126. ISBN 978-0-12-364548-7. Archived from the original on April 14, 2021. Retrieved October 15, 2020.

Schoch, Rainer R. (2014). Amphibian Evolution: The Life of Early Land Vertebrates. John Wiley & Sons. ISBN 9781118759134. Archived from the original on July 25, 2020.

Uno, Yoshinobu (2021). "Inference of evolution of vertebrate genomes and chromosomes from genomic and cytogenetic analyses using amphibians". *Chromosome Science*. **24** (1–2): 3–12. doi:10.11352/scr.24.3.

https://openstax.org/books/concepts-biology/pages/1-introduction

https://openstax.org/books/concepts-biology/pages/15-6-vertebrates

https://youtu.be/GT2iSFj19DE
https://youtu.be/XvvpaGsoY_U
https://youtu.be/xSUCSB6uQVk

6.6 Possible Answers to Self-Assessment Exercises

Answers to SAE 1

1. Vertebrates are divided into five classes: - Pisces - Amphibia - Reptilia - Aves, and - Mammalia.
2. The two pairs of appendages include appendages such as wings, fins, or limbs. These appendages are seen in pairs on the vertebrate's body.

Answers to SAE 2

1. Jawless fishes are craniates (which include all the chordate groups except the tunicates and lancelets) that represent an ancient vertebrate lineage that arose over one half-billion years ago.
2. Members of the clade Osteichthyes, or bony fishes, are characterized by a bony skeleton.

Answers to SAE 3

1. Amphibians are specialized organisms within the class Amphibia. This order contains salamanders (urodeles or caudates), frogs and toads (anurans), and caecilians (apodans or gymnophionans).
2. An amphibian is usually an organism that exhibits a metamorphic life strategy, though this isn't always true. Amphibians are ectothermic animals that usually have thin, slimy skin. They include salamanders, frogs, and caecilians.

Unit 7 Vertebrates II: Reptiles, Birds and Mammals

7.1 Introduction

In this unit, we shall study about the amniotes which are a clade of tetrapod vertebrates comprising the reptiles, birds, and mammals. Amniotes are characterized by having an egg equipped with an amnion, an adaptation to lay eggs on land or retain the fertilized egg within the mother. Amniote embryos, whether laid as eggs or carried by the female, are protected and aided by several extensive membranes. In eutherian mammals (such as humans), these membranes include the amniotic sac that surrounds the fetus. These embryonic membranes and the lack of a larval stage distinguish amniotes from tetrapod amphibians.

7.2 Intended Learning Objectives (ILOs)

- Identify the classes of animals that are amniotes
- Explain the main characteristics of amphibians, reptiles, and birds
- Discuss the evolution of amniotes
- Describe the derived characteristics in birds that facilitate flight
- Name and describe the distinguishing features of the three main groups of mammals
- Describe the derived features that distinguish primates from other animals

7.3 Main Contents

7.3.1 Vertebrates II: The Amniotes

The **amniotes**—reptiles, birds, and mammals—are distinguished from amphibians by their terrestrially adapted (shelled) egg and an embryo protected by amniotic membranes. The evolution of amniotic membranes meant that the embryos of amniotes could develop within an aquatic environment inside the egg. This led to less dependence on a water environment for development and allowed the amniotes to invade drier areas. This was a significant evolutionary change that distinguished them from amphibians, which were restricted to moist environments due to their shell-less eggs. Although the shells of various amniotic species vary significantly, they all allow retention of water. The membranes of the amniotic egg also allowed gas exchange and sequestering of wastes within the enclosure of an eggshell. The shells of bird eggs are composed of calcium carbonate and are hard and brittle, but possess pores for gas and water exchange. The shells of reptile eggs are more leathery and pliable. Most mammals do not lay eggs; however, even with internal gestation, amniotic membranes are still present.

In the past, the most common division of amniotes has been into classes Mammalia, Reptilia, and Aves. Birds are descended, however, from dinosaurs, so this classical scheme results in groups that are not true clades. We will discuss birds as a group distinct from reptiles with the understanding that this does not reflect evolutionary history.

7.3.1.1 Reptiles

They are basically Tetrapods. Snakes and other squamates have **vestigial organs** such as limbs and are categorised as tetrapods, like caecilians, since they are descended from four-limbed ancestors. Reptiles deposit eggs encased in shells on land. Even reptiles that live in the water come ashore to lay their eggs. I**nternal fertilisation** is the most common method of **reproduction** for them. Some species are ovoviviparous, meaning the eggs stay in the mother's body until the time comes for them to hatch. Other species are viviparous, meaning they give birth to live offspring. Which vertebrate class is considered to be the first that was entirely terrestrial?

- **Reptiles have Oviparous Characteristics:** The majority of reptiles reproduce sexually, however others can reproduce asexually. The cloaca, which is located at the base of the tail, is used for reproduction. Most reptiles have copulatory organs, which are generally hidden inside their bodies. A penis is seen in male turtles and crocodiles, whereas a pair of hemipenes is found in lizards and snakes. Because some species, such as the tuatara, lack copulatory organs, mating is accomplished by forcing the cloaca together.

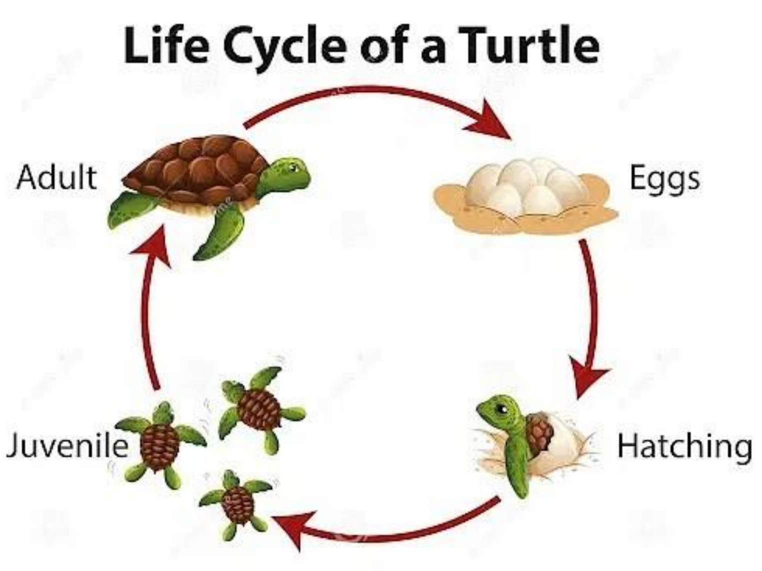


Figure 7.1 Life cycle of a Turtle. Source: https://openstax.org/books/concepts-biology/pages/15-6-vertebrates

Life Cycle of Reptiles

- **Reptiles have scales:** The creation of reptiles' scaly skin, which includes the protein keratin and waxy lipids to reduce water loss from the skin, was one of the important adaptations that allowed them to survive on land. Because reptiles and amphibians have occlusive skin, they can't breathe through their skin and must rely on their lungs.
- **Reptiles are Ectotherms:** Ectotherms are animals whose primary source of body heat is derived from their surroundings. Endotherms, on the other hand, control body temperature using heat produced by metabolism. Reptiles are classified as poikilotherms, or creatures whose body temperatures fluctuate rather than remain constant, in addition to being ectothermic. Reptiles have behavioural adaptations to assist control body temperature, such as warming up by basking in the sun and cooling down by choosing shaded regions or burrowing underground.
- **Lungs are used by reptiles to breathe:** Lungs are used by reptiles to breathe. The breathing process can only be completed through the lungs, despite the fact that turtles have porous skin through which gaseous exchange occurs, and certain species improve the pace of gaseous exchange through the cloaca. Distinct reptile species have different ways of breathing through their lungs. The lungs of lizards and snakes are ventilated by axial musculature, which is also utilised to move. As a result of these factors, the majority of animals are obliged to hold their breath during strenuous activity. Some lizards, on the other hand, use buccal pumping to help them breathe. Crocodiles have muscular diaphragms, which pull the pubis backwards to provide room for the lungs to expand. Because certain reptiles lack secondary palates, they must hold their breath while swallowing.

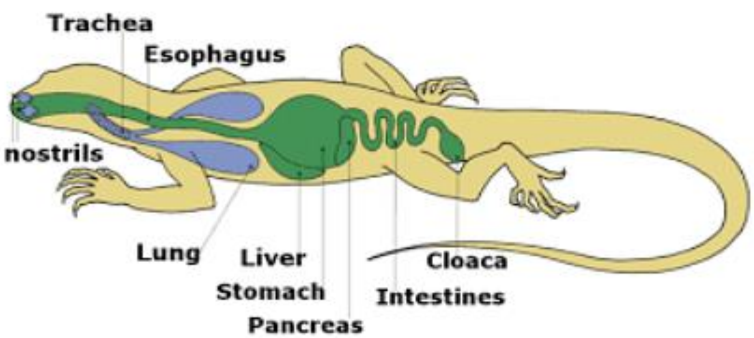


Figure 7.2 Breathing lungs in reptiles. Source: https://openstax.org/books/concepts-biology/pages/15-6-vertebrates

Respiratory System of Reptiles

- **Reptiles have characteristics of a Vertebrate:** Reptiles have traits that are comparable to those of mammals, birds, and certain amphibians. The spinal cords that span the length of their bodies are housed in their backbones. From the tail to the skull, reptiles contain a chain of bone parts. The cranium or skull, appendages, and limb girdles make up the bone endoskeleton. The inner tissue is protected by the endoskeleton, which also assists in bodily mobility. What constitutes the bone exoskeleton in rptiles?

Self-Assessment Exercises 1

1. How does reproduction atake place in animals of the class Reptilia?
2. Do organisms of the class Reptilia have direct or indirect development?

7.3.1.2 Diversity of Reptiles

Class Reptilia includes diverse species classified into four living clades. These are the Crocodilia, Sphenodontia, Squamata, and Testudines. The **Crocodilia** ("small lizard") arose approximately 84 million years ago, and living species include alligators, crocodiles, and caimans. Crocodilians (Figure 7.3**a**) live throughout the tropics of Africa, South America, the southeastern United States, Asia, and Australia. They are found in freshwater habitats, such as rivers and lakes, and spend most of their time in water. Some species are able to move on land due to their semi-erect posture.

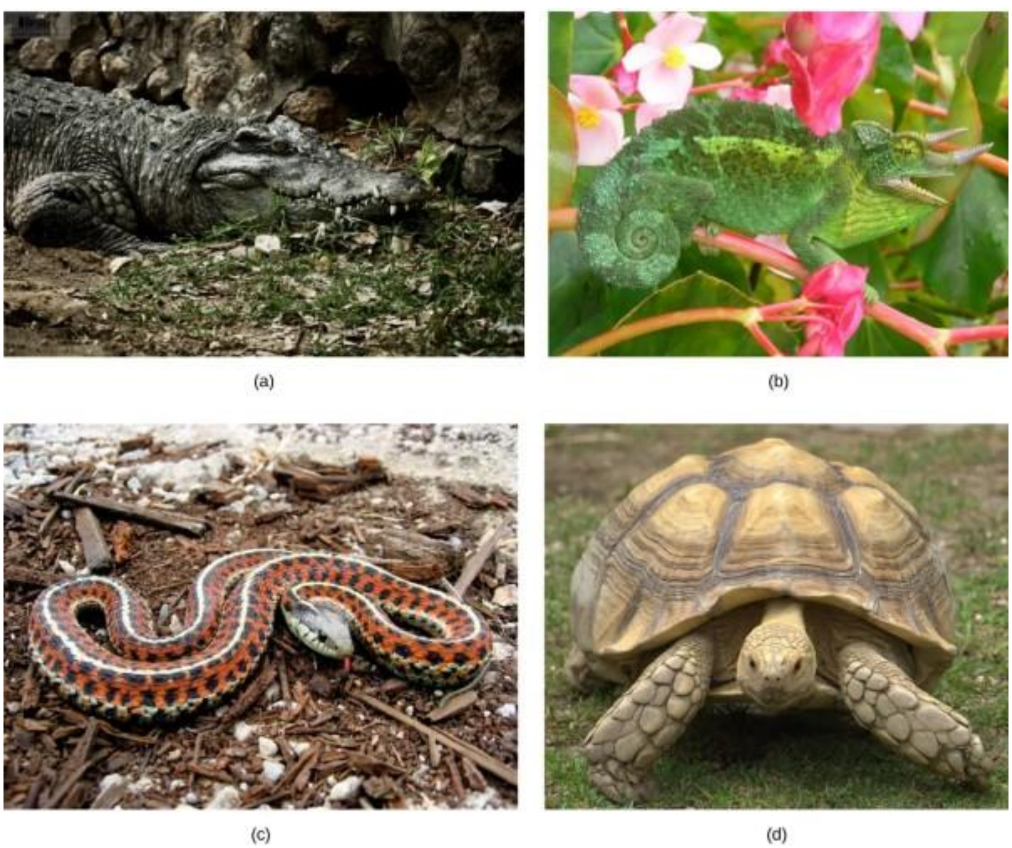


Figure 7.3 (a) Crocodilians, such as this Siamese crocodile, provide parental care for their offspring. (b) This Jackson's chameleon blends in with its surroundings. (c) The garter snake

belongs to the genus *Thamnophis*, the most widely distributed reptile genus in North America. (d) The African spurred tortoise lives at the southern edge of the Sahara Desert. It is the third largest tortoise in the world. Source: https://openstax.org/books/concepts-biology/pages/15-6-vertebrates

The **Sphenodontia** ("wedge tooth") arose in the Mesozoic Era and includes only one living genus, *Tuatara*, with two species that are found in New Zealand. There are many fossil species extending back to the Triassic period (250–200 million years ago). Although the tuataras resemble lizards, they are anatomically distinct and share characteristics that are found in birds and turtles.

Squamata ("scaly") arose in the late Permian; living species include lizards and snakes, which are the largest extant clade of reptiles (Figure 7.**3b**). Lizards differ from snakes by having four limbs, eyelids, and external ears, which are lacking in snakes. Lizard species range in size from chameleons and geckos that are a few centimeters in length to the Komodo dragon, which is about 3 meters in length.

Snakes are thought to have descended from either burrowing lizards or aquatic lizards over 100 million years ago (Figure 7.3**c**). Snakes comprise about 3,000 species and are found on every continent except Antarctica. They range in size from 10 centimeter-long thread snakes to 7.5 meter-long pythons and anacondas. All snakes are carnivorous and eat small animals, birds, eggs, fish, and insects.

Turtles are members of the clade Testudines ("having a shell") (Figure 7.3**d**). Turtles are characterized by a bony or cartilaginous shell, made up of the carapace on the back and the plastron on the ventral surface, which develops from the ribs. Turtles arose approximately 200 million years ago, predating crocodiles, lizards, and snakes. Turtles lay eggs on land, although many species live in or near water. Turtles range in size from the speckled padloper tortoise at 8 centimeters (3.1 inches) to the leatherback sea turtle at 200 centimeters (over 6 feet). The term "turtle" is sometimes used to describe only those species of Testudines that live in the sea, with the terms "tortoise" and "terrapin" used to refer to species that live on land and in fresh water, respectively. Compared to amphibians, what is an example of an evolutionary innovation present in organisms of the class Reptilia to combat the loss of water through the skin? Reptile skin is keratinized and impermeable to water whereas amphibian skin is permeable. The impermeability of their skin made the cutaneous gas exchange performed by amphibians impossible, making respiration dependent on internal organs such as airways and lungs. Reptiles have developed several adaptations to lead a complete terrestrial life. These adaptations include:

- Thick, scaly skin that helps them to conserve moisture inside their bodies, which helps them survive on land (especially in hot and dry areas).
- Efficient excretory systems which help them to excrete a highly concentrated urine.
- Kidneys that have adapted to living on land with limited access to drinking water.
- A reproductive strategy that involves laying soft-shelled eggs.
- Lungs that are adapted to breathing air.
- Basking in the sun to regulate their body temperature
- Legs that are adapted for walking on land

7.3.2 Birds

The most obvious characteristic that sets birds apart from other modern vertebrates is the presence of feathers, which are modified scales. While vertebrates like bats fly without feathers, birds rely on feathers and wings, along with other modifications of body structure and physiology, for flight.

7.3.2.1 Characteristics of Birds

Birds are endothermic, and because they fly, they require large amounts of energy, necessitating a high metabolic rate. Like mammals, which are also endothermic, birds have an insulating covering that keeps heat in the body: feathers. Specialized feathers called **down feathers** are especially insulating, trapping air in spaces between each feather to decrease the rate of heat loss. Certain parts of a bird's body are covered in down feathers, and the base of other feathers have a downy portion, whereas newly hatched birds are covered in down.

Feathers not only act as insulation but also allow for flight, enabling the lift and thrust necessary to become airborne. The feathers on a wing are flexible, so the collective feathers move and separate as air moves through them, reducing the drag on the wing. **Flight feathers** are asymmetrical, which affects airflow over them and provides some of the lifting and thrusting force required for flight (see the figure below).

Two types of flight feathers are found on the wings, primary feathers and secondary feathers. **Primary feathers** are located at the tip of the wing and provide thrust. **Secondary feathers** are located closer to the body, attach to the forearm portion of the wing and provide lift. **Contour feathers** are the feathers found on the body, and they help reduce drag produced by wind resistance during flight. They create a smooth, aerodynamic surface so that air moves smoothly over the bird's body, allowing for efficient flight.

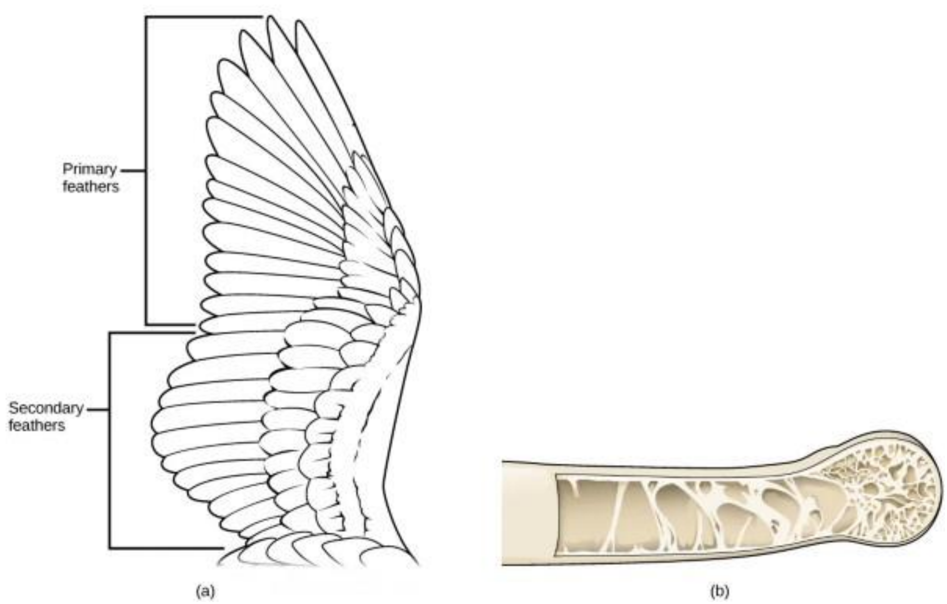


Figure 7.4 (a) Primary feathers are located at the wing tip and provide thrust; secondary feathers are located close to the body and provide lift. (b) Many birds have hollow pneumatic bones, which make flight easier. Source: https://openstax.org/books/concepts-biology/pages/15-6-vertebrates

Flapping of the entire wing occurs primarily through the actions of the chest muscles, the pectoralis and the supracoracoideus. These muscles are highly developed in birds and account for a higher percentage of body mass than in most mammals. These attach to a blade-shaped keel, like that of a boat, located on the sternum. The sternum of birds is larger than that of other vertebrates, which accommodates the large muscles required to generate enough upward force to generate lift with the flapping of the wings. Another skeletal modification found in most birds is the fusion of the two clavicles (collarbones), forming the **furcula** or wishbone. The furcula is flexible enough to bend and provide support to the shoulder girdle during flapping.

An important requirement of flight is a low body weight. As body weight increases, the muscle output required for flying increases. The largest living bird is the ostrich, and while it is much smaller than the largest mammals, it is flightless. For birds that do fly, reduction in body weight makes flight easier. Several modifications are found in birds to reduce body weight, including pneumatization of bones. **Pneumatic bones** are bones that are hollow, rather than filled with tissue (see the figure below). They contain air spaces that are sometimes connected to air sacs, and they have struts of bone to provide structural reinforcement. Pneumatic bones are not found in all birds, and they are more extensive in large birds than in small birds. Not all bones of the skeleton are pneumatic, although the skulls of almost all birds are.

Figure 7.5 Birds have hollow, pneumatic bones, which make flight easier. Source: https://openstax.org/books/concepts-biology/pages/15-6-vertebrates

Other modifications that reduce weight include the lack of a urinary bladder. Birds possess a cloaca, a structure that allows water to be reabsorbed from waste back into the bloodstream. Uric acid is not expelled as a liquid but is concentrated into urate salts, which are expelled along with fecal matter. In this way, water is not held in the urinary bladder, which would increase body weight. Most bird species only possess one ovary rather than two, further reducing body mass. The air sacs that extend into bones to form pneumatic bones also join with the lungs and function in respiration. Unlike mammalian lungs in which air flows in two directions, as it is breathed in and out, airflow through bird lungs travels in one direction (see the figure below). Air sacs allow for this unidirectional airflow, which also creates a cross-current exchange system with the blood. In a cross-current or counter-current system, the air flows in one direction and the blood flows in the opposite direction, creating a very efficient means of gas exchange. What is the role of the cloaca in the success of birds for live in the terrestrial environment?

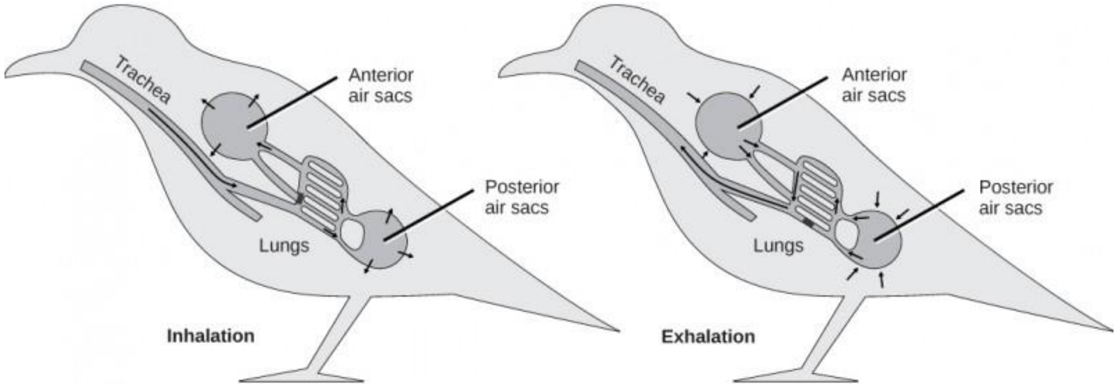


Figure 7.6 Avian respiration is an efficient system of gas exchange with air flowing unidirectionally. During inhalation, air passes from the trachea into posterior air sacs, then through the lungs to anterior air sacs. The air sacs are connected to the hollow interior of bones. During exhalation, air from air sacs passes into the lungs and out the trachea. Source: https://openstax.org/books/concepts-biology/pages/15-6-vertebrates

7.3.2.2 External Features of Birds

The body of the birds is steamlined or spindle-shaped well adapted for aerial life. The neck is usually long and flexible. The head is rounded and the facial portion is produced into beak. Close to the base of the beak are two slit-like nostrils. The eyes of the bird are of considerable size for the sense of smell seems to be feebly developed but the powervision is correspondingly advanced, especially in some birds of prey. Each eye is provided with three eyelids: the upper and lower eyelids are like fold of skin while the third eyelid, the nictitating membrane, is a delicate transparent membrane which can be drawn across the eye. Usually the lower lid is movable. On each side of the head there is a small aperture with a short passage leading to the ear-drum. It lies behind and below the eyes and is usually hidden by the features. Unlike mammals, the external ears are absent. What are the main morphological features of birds?

7.3.2.3 Adaptive Features of Birds to Their Environment

The fore limbs form the wings which are organs of flight while the hind limbs are adapted for bearing the entire weight of the body when walking. For this purpose the hind limbs are usually attached somewhat for forward and the skeleton is also modified to this end. The legs are covered with scales. The cloaca lies on the ventral surface at the root of the tail and on the dorsal surface of the same region is an oilgland. Its oily secretion is used for preening feathers. The feet, break and the tongue present very large number of variations of form which are closely associated with the habits of the birds. The typical number of the toes is four, of which, three are directed forwards and one backwards. In perching birds the toes are adapted for grasping and automatically clutching the support. Three toes are directed forwards and one backwards. The same arrangement of the toes is also found in birds of prey which use their feet for seizing. The claws form great talons as in the eagles, hawks, kites, falcons, etc. The legs of the wading birds are usually very long and partly or completely unfeathered up to the tibial region. They have very long toes. Swimming birds like ducks have webbed feet which serve as paddles. What adaptations for flight are present in birds?

Self-Assessment Exercises 2

1. What adaptations for flight are present in birds?
2. What similarities are present in birds and reptiles regarding external coverage, reproduction and excretion?

7.3.3 Mammals

Mammals are vertebrates that have hair and mammary glands used to provide nutrition for their young. Certain features of the jaw, skeleton, skin, and internal anatomy are also unique to mammals. The presence of hair is one of the key characteristics of a mammal. Although it is not very extensive in some groups, such as whales, hair has many important functions for mammals. Mammals are endothermic, and hair provides insulation by trapping a layer of air close to the body to retain metabolic heat. Hair also serves as a sensory mechanism through specialized hairs called vibrissae, better known as whiskers. These attach to nerves that transmit touch information, which is particularly useful to nocturnal or burrowing mammals. Hair can also provide protective coloration.

Mammalian skin includes secretory glands with various functions. **Sebaceous glands** produce a lipid mixture called sebum that is secreted onto the hair and skin for water resistance and lubrication. Sebaceous glands are located over most of the body. **Sudoriferous glands** produce sweat and scent, which function in thermoregulation and communication, respectively. **Mammary glands** produce milk that is used to feed newborns. While male and female monotremes and eutherians possess mammary glands, some male marsupials do not.

The skeletal system of mammals possesses unique features that differentiate them from other vertebrates. Most mammals have **heterodont teeth**, meaning they have different types and shapes of teeth that allow them to feed on different kinds of foods. These different types of teeth include the incisors, the canines, premolars, and molars. The first two types are for cutting and tearing, whereas the latter two types are for crushing and grinding. Different groups have different proportions of each type, depending on their diet. Most mammals are also **diphyodonts**, meaning they have two sets of teeth in their lifetime: deciduous or “baby” teeth, and permanent teeth. In other vertebrates, the teeth can be replaced throughout life.

Modern mammals are divided into three broad groups: monotremes, marsupials, and eutherians (or placental mammals). The eutherians, or placental mammals, and the marsupials collectively are called therian mammals, whereas monotremes are called prototherians.

7.3.3.1 Diversity and Characteristics of Mammals

There are three living species of **monotremes**: the platypus and two species of echidnas, or spiny anteaters (Figure 7.7). The platypus and one species of echidna are found in Australia, whereas the other species of echidna is found in New Guinea. Monotremes are unique among mammals, as they lay leathery eggs, similar to those of reptiles, rather than giving birth to live young. However, the eggs are retained within the mother's reproductive tract until they are almost ready to hatch. Once the young hatch, the female begins to secrete milk from pores in a ridge of mammary tissue along the ventral side of her body. Like other mammals, monotremes are endothermic but regulate body temperatures somewhat lower (90 °F, 32 °C) than placental mammals do (98 °F, 37 °C). Like reptiles, monotremes have one posterior opening for urinary, fecal, and reproductive products, rather than three separate openings like placental mammals do. Adult monotremes lack teeth.

Figure 7.7 The platypus (left), a monotreme, possesses a leathery beak and lays eggs rather than giving birth to live young. An echidna, another monotreme, is shown in the right photo. Source: https://openstax.org/books/concepts-biology/pages/15-6-vertebrates

Marsupials are found primarily in Australia and nearby islands, although about 100 species of opossums and a few species of two other families are found in the Americas. Australian marsupials number over 230 species and include the kangaroo, koala, bandicoot, and Tasmanian devil (Figure 7.8). Most species of marsupials possess a pouch in which the young reside after birth, receiving milk and continuing to develop. Before birth, marsupials have a less complex placental connection, and the young are born much less developed than in placental mammals. What are the three main groups into which mammals are divided?

Figure 7.8 The Tasmanian devil is one of several marsupials native to Australia. Source: https://openstax.org/books/concepts-biology/pages/15-6-vertebrates

Eutherians are the most widespread of the mammals, occurring throughout the world. There are several groups of eutherians, including Insectivora, the insect eaters; Edentata, the toothless anteaters; Rodentia, the rodents; Chiroptera, the bats; Cetacea, the aquatic mammals including whales; Carnivora, carnivorous mammals including dogs, cats, and bears; and Primates, which includes humans. **Eutherian mammals** are sometimes called placental mammals, because all species have a complex placenta that connects a fetus to the mother, allowing for gas, fluid, waste, and nutrient exchange. While other mammals may possess a less complex placenta or briefly have a placenta, all eutherians have a complex placenta during gestation.

The main Characteristics of a mammal are as follows: It is warm-blooded. Its skin has sweat and sebaceous glands and a covering of hairs. It has different types of teeth, with each type carrying out a specific function. It has external ears called pinnae. Its body cavity is separated into two by a muscular sheet called a diaphragm. The upper thoracic cavity contains the lungs and the heart while the lower abdominal cavity contains the alimentary canal, the Kidneys and the reproductive organs. It has a well-developed heart. It has a well-developed brain. Fertilization is internal. In most mammals, the tiny fertilized egg develops inside the body of the female parent for a period. During this time, the young is attached to the mother by a placenta, an organ through which it obtains nourishment from the mother. The young is born alive (Vivipary) and feeds on the milk secreted by the mother's mammary glands. It is looked after by the parents until it learns to be independent.

7.3.3.2 Primates

Order **Primates** of class Mammalia includes lemurs, tarsiers, monkeys, and the apes, which include humans. Non-human primates live primarily in tropical or subtropical regions of South America, Africa, and Asia. They range in size from the mouse lemur at 30 grams (1 ounce) to the mountain gorilla at 200 kilograms (441 pounds). The characteristics and evolution of primates are of particular interest to us as they allow us to understand the evolution of our own species.

All primate species have adaptations for climbing trees, as they all descended from tree-dwellers, although not all species are arboreal. This arboreal heritage of primates resulted in hands and feet that are adapted for **brachiation**, or climbing and swinging through trees. These adaptations include, but are not limited to 1) a rotating shoulder joint, 2) a big toe that is widely separated from the other toes and thumbs that are widely separated from fingers (except humans), which allow for gripping branches, and 3) **stereoscopic vision**, two overlapping visual fields, which allows for the depth perception necessary to gauge distance. Other characteristics of primates are brains that are larger than those of many other mammals, claws that have been modified into flattened nails, typically only one offspring per pregnancy, and a trend toward holding the body upright.

Order Primates is divided into two groups: prosimians and anthropoids. **Prosimians** include the bush babies of Africa, the lemurs of Madagascar, and the lorises, pottos, and tarsiers of Southeast Asia. **Anthropoids** include monkeys, lesser apes, and great apes (Figure 7.9). In general, prosimians tend to be nocturnal, smaller in size than anthropoids, and have relatively smaller brains compared to anthropoids.

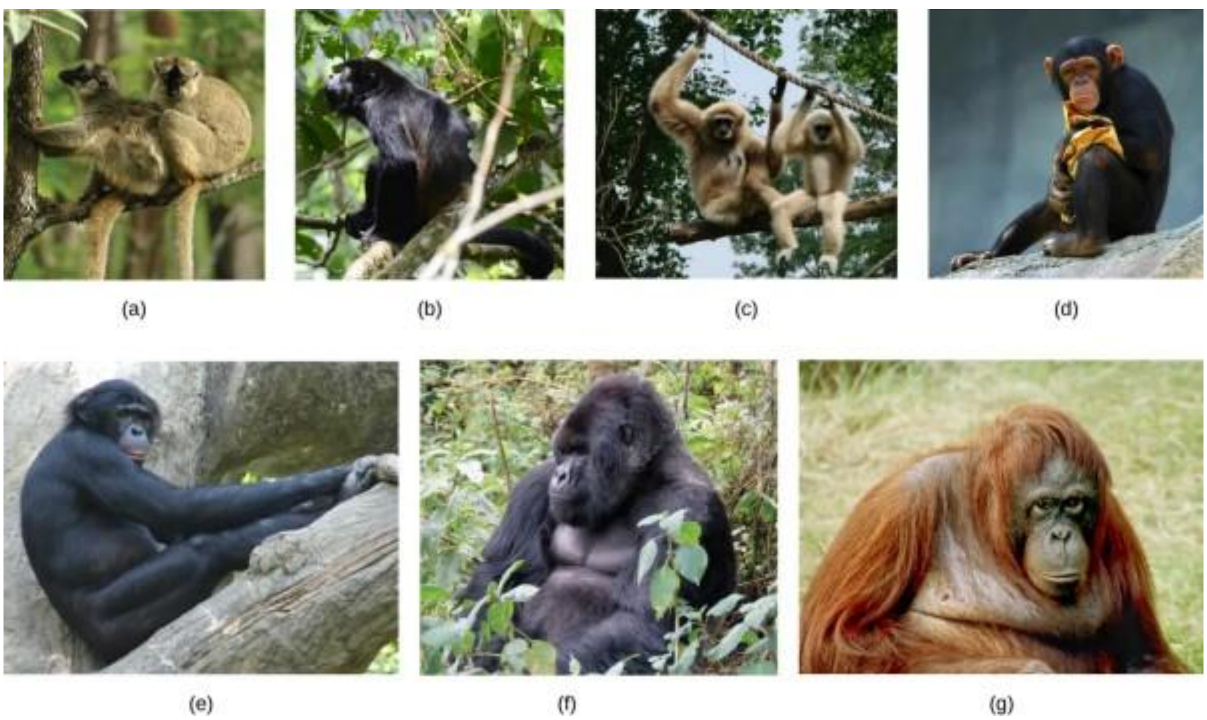


Figure 7.9 Primates can be divided into prosimians, such as the (a) lemur, and anthropoids. Anthropoids include monkeys, such as the (b) howler monkey; lesser apes, such as the (c) gibbon; and great apes, such as the (d) chimpanzee, (e) bonobo, (f) gorilla, and (g) orangutan. Source: https://openstax.org/books/concepts-biology/pages/15-6-vertebrates

7.3.3.3 Adaptations of Vertebrates to the Terrestrial Environment

The animals, when they left the aquatic environment to colonize the terrestrial environment , had to face the problem of desiccation. Only those that had the necessary adaptations to avoid desiccation were able to conquer the terrestrial environment. Some of these adaptations are:

- The skin: A skin is needed to isolate the organism from the environment and prevent water loss. Reptiles have their skin covered with scales, which prevents it from growing. This is the reason they have to shed their skin. Mammals have fur covered skin and Birds have feathers cover their skin.

- Efficient kidneys allow more water to be used by reducing its loss in excretion.
- Movement: terrestrial vertebrates have four legs with which they can move or manipulate.
- Lungs: necessary to capture oxygen from the air and be able to carry it, through the circulatory system, to the cells. Amphibians have their lungs are rudimentary, they need cutaneous respiration as a complement, and Birds and mammals have their lungs are more evolved.

Reproduction: Amphibians is the group worst adapted to life on land. Their fertilization is external, they lay eggs in the water and the young cannot leave the water until they become adults. The rest of tetrapods have sexual reproduction with internal fertilization. While Reptiles and birds are oviparous. The bone has a hard shell and a protective bag, the *amnion*, filled with a liquid that protects and isolates the embryo. Normally, the mother deposits the eggs and the embryo does not come out until it is already developed. In some cases, they are ovoviviparous, and the eggs remain inside the mother until the young hatch. Mammals, except for the platypus, are viviparous**.** The embryo is not protected by an egg, but instead develops in the mother's womb and is nourished through the umbilical cord (except in marsupials). When they are born, they feed on mother's milk. How do placental mammals reproduce?

Vertebrates are adapted to life underground, on the surface, and in the air. They range in size from minute fishes to elephants and whales. Vertebrates feed upon plants, invertebrate animals, and one another. Vertebrate faunas are important to humans for food and recreation. Important adaptations of vertebrates include:

- Structural adaptations, such as the color of skin, body shape, and body covering.
- Behavioral adaptations, such as special behavioral changes that allow an organism to survive in its natural habitat.

Self-Assessment Exercises 3

1. What are the typical features of mammals?
2. How is circulation characterized in mammals?

7.4 Summary

The amniotes are distinguished from amphibians by the presence of a terrestrially adapted egg protected by amniotic membranes. The amniotes include reptiles, birds, and mammals. A key adaptation that permitted reptiles to live on land was the development of scaly skin. Reptilia includes four living clades: Crocodilia (crocodiles and alligators), Sphenodontia (tuataras), Squamata (lizards and snakes), and Testudines (turtles).

Birds are endothermic amniotes. Feathers act as insulation and allow for flight. Birds have pneumatic bones that are hollow rather than tissue-filled. Airflow through bird lungs travels in one direction. Birds evolved from dinosaurs.

Mammals have hair and mammary glands. Mammalian skin includes various secretory glands. Mammals are endothermic, like birds. There are three groups of mammals living today: monotremes, marsupials, and eutherians. Monotremes are unique among mammals as they lay eggs, rather than giving birth to live young. Eutherian mammals have a complex placenta.

7.5 References/Further Readings/Web Sources

Uno, Yoshinobu (2021). "Inference of evolution of vertebrate genomes and chromosomes from genomic and cytogenetic analyses using amphibians". *Chromosome Science*. **24** (1–2): 3–12. doi:10.11352/scr.24.3.

https://evolution.berkeley.edu/evolibrary/article/arthropodstory

https://openstax.org/books/concepts-biology/pages/15-6-vertebrates

https://opentextbc.ca/biology/chapter/1-1-themes-and-concepts-of-biology/
https://bio.libretexts.org/Bookshelves/Introductory_and_General_Biology/Book%3A_
https://tse1.mm.bing.net/th?&id=OVP.K6420fn65IB07ZD09OcwGwHgFo&w=608&h=342&c=7&pid=1.7&rs=1
https://youtu.be/oxDNa6Ao4jI
https://youtu.be/529mXVmvQ_E
https://youtu.be/Nss9MYvuIAo
https://youtu.be/Nss9MYvuIAo
https://youtu.be/9wAC01Vdu0o
https://www.openstaxcollege.org/l/chordate_evol
https://youtu.be/DZN7L0X5fuM

7.6 Possible Answers to Self-Assessment Exercises

Answers to SAE 1

1. These animals reproduce sexually through internal fertilization by means of the copulation between males and females. They lay eggs with a shell and extraembryonic membranes. The embryo then develops within the egg and outside the mother's body (there also exists ovoviviparous reptiles, which keep the egg within their body until it hatches).

2. In organisms of the class Reptilia, embryonic development is direct. Therefore, there is no larval stage.

Answers to SAE 2

1. The features of birds that allow them to fly are: wings attached to a well-developed pectoral musculature, pneumatic bones, less accumulation of feces in the bowels due to the absence of the colon, the absence of a bladder (no urine storage), an aerodynamic body and lungs with specialized air sacs.

2. Regarding external coverage, birds are similar to reptiles in that they present impermeable keratinized outside. Concerning reproduction, fertilization is internal in both and the embryo develops within a shelled egg. Regarding excretion, both excrete uric acid.

Answers to SAE 2

1. The typical features of mammals are: a body (more or less) covered with hair; the presence of the diaphragm muscle (that separates the thorax from the abdomen); mammary glands that produce milk (in females); non-nucleated blood red cells; and a middle ear with three ossicles.

2. Mammals have a closed and complete circulatory system. Their heart has four chambers and arterial blood does not mix with venous blood.

Glossary

Abdomen: Region of the body furthest from the mouth. In insects, the third body region behind the head and thorax.

Altricial: Refers to animals with young that are unable to move on their own after hatching or birth, and require extensive parental care.

Ambulacra: Row of tube feet of an echinoderm.

amniotic egg: An egg that can be laid on land due to the presence of a fluid-filled amniotic sac (**amnion**) that cushions and protects the developing embryo.
Amniote: Any of a group of land-dwelling vertebrates that have an amnion during embryonic development, including reptiles, birds, and mammals.

Anapsid: A vertebrate distinguished by a skull with no openings in the side behind the eyes, e.g. turtles.

Anus: End of the digestive tract, or gut, through which waste products of digestion are excreted, as distinct from the mouth.

Bipedal: Describes an animal that walks on two legs.

Biramous: Arthropod appendages that are biramous have two branches, an outer branch and an inner branch.

Blood: Fluid which circulates throughout the body of an animal, distributing nutrients, and often oxygen as well.

book lung: A set of soft overlapping flaps, covered up by a plate on the abdomen, through which oxygen is taken up and carbon dioxide given off.

Brain: Collection of nerve cells usually located at the anterior end of an animal, when present at all.

Cephalon: In trilobites, the head shield bearing the eyes, antennae, and mouth.

Chaetae: Stiff bristles characteristic of annelids.

Chela: The claw of an arthropod.

Chelicera: The first pair of appendages of a **chelicerate** arthropod. Originally a short clawed appendage, the chelicerae of many arachnids are highly modified for feeding.

Chordate: an animal with a notochord (a cartilaginous rod that extends the length of the body), dorsal hollow nerve cord (a fluid-filled tube that runs the length of the body), gill slits or pouches, and a tail at some stage in its life cycle.

Clitellum: In annelids, a swelling of the body towards the head of the animal, where the gonads are located.

Cnidocyst: The "stinging cell" of a cnidarian.

Coelom: Fluid-filled cavity within the body of an animal; usually refers to a cavity lined with specialized tissue **peritoneum** in which the gut is suspended.

compound eye: found in many but not all arthropods, a compound eye is composed of a large number of small, closely packed simple eyes (**ommatidia**), each with its own lens and nerve receptors.

Cuticle: In animals, a multilayered, extracellular, external body covering, usually composed of fibrous molecules such as chitin or collagen, and sometimes strengthened by the deposition of minerals such as calcium carbonate.

Diapsid: A vertebrate distinguished by a skull with two pairs of openings in the side behind the eyes, e.g., lizards, snakes, crocodiles, dinosaurs, and pterosaurs.

Ectoderm: The outer basic layer of tissue in those animals with true tissues.

Endoderm: The innermost basic layer of tissue in those animals with true tissues.

Epidermis: The outermost layer of cells or skin. This tissue often contains specialized cells for defense, gas exchange, or secretion.

Epithelium: Layer of cells which lines a body cavity; cells may be ciliated or unciliated, and may be **squamous** (flat, scale shaped), **cuboidal** (cube-shaped), or **columnar** (column-shaped).

Esophagus: That portion of the gut which connects the pharynx to the stomach.

Exoskeleton: An external, often hard, covering or integument that provides support and protection to the body.

Gastrodermis: In cnidarians, the endodermis which lines the gut cavity.

Genus: A category in the classification of plants and animals between species and family; **genera**- pl.

Gill: In aquatic animals, highly vascularized tissues with large surface area; these are extended out of the body and into the surrounding water for gas exchange.

gill arches: Stiffenings which support the flesh between the gill slits of chordates.

gill slit: A slitlike or porelike opening connecting the pharynx of a chordate with the outside of the body.

Gnathobase: The expanded and hardened base of the appendage of many arthropods, notably trilobites, crustaceans, and marine cheliceramorphs.

gut (enteron): Body cavity formed between the mouth and anus in which food is digested and nutrients absorbed; it consists of the mouth, pharynx, esophagus, **stomach**, intestine, and anus, though some animals do not have all these regions.

Head: That part of the body at the "front" end, where the brain, mouth, and most sensory organs are located.

Heart: Muscular pump which circulates the blood.

Histostructure: The organization and arrangement of tissue

Incubation:	In birds and reptiles, the maintaining of a constant temperature during the development of the embryo.
Intestine:	The portion of the digestive tract between the stomach and anus; it is the region where most of the nutrients and absorbed.
Jaw:	Often loosely applied to any movable, toothed structures at or near the mouth of an animal, such as the scolecodonts of annelids.
Jointed:	When stiff body parts are connected by a soft flexible region, the body is said to be jointed.
Librigenae:	The "free cheeks"; separate, detachable portions of the trilobite cephalon.
Lophophore:	Complex ring of hollow tentacles used as a feeding organ.
Mammilla:	In eggshell, the cone-like structure at the base of the shell unit where the shell unit attaches to the inner organic membrane.
Marsupial:	A mammal that gives live birth to young that have gestated for only a short period of time.
Mesoderm:	In animals with three tissue layers (i.e. all except sponges and cnidarians), the middle layer of tissue, between the **ectoderm** and the **endoderm**.
Mesogloea:	Jellylike material between the outer ectoderm and the inner endoderm of cnidarians.
Metabolism:	The chemical processes within an organic body that supply the energy necessary for life.
Microstructure:	In eggshell, the shape, size, orientation, and distribution of components of the shell.
Monotreme:	A mammal that lays eggs rather than giving live birth.
Mouth:	Front opening of the digestive tract, into which food is taken for digestion.
Mucus:	Sticky secretion used variously for locomotion, lubication, or protection from foreign particles.
Muscle	Bundle of contractile cells which allow animals to move.
Myotome:	Segment of the body formed by a region of muscle.

Nematocyst: Older name for a cnidocyst.

Nerve: A bundle of **neurons**, or nerve cells.

Nerve cord: Primary bundle of nerves in chordates, which connects the brain to the major muscles and organs of the body.

Neuron: A specialized cell that can react to stimuli and transmit impulses.

Notochord: Characteristic of chordates, the notochord is a stiff rod of tissue along the back of the body.

Organ: Collection of tissues which performs a particular function or set of functions in an animal or plant's body.

organ system: Collection of organs which have related roles in an organism's functioning.

Osculum: The main opening through which filtered water is discharged.

Ovulation: The process by which an egg (the female gamete) is released from the ovary.

papilla(e): Cellular outgrowths.

Parapodia: A sort of "false foot" formed by extension of the body cavity.

Pathology: The study of disease and abnormalities.

Pedipalps: The second pair of appendages of cheliceromorphs.

Pharyngeal slits: Characteristic of chordates, pharyngeal slits are openings through which water is taken into the pharynx, or throat.

Pharynx: Cavity in the digestive tract just past the mouth itself.

Phylum: A category in the hierarchy of animal classification between class and kingdom; **phyla**- pl.

Placenta: In mammals, a tissue formed within the uterus through which nutrients are passed from the mother to the embryo (and later the fetus) and its wastes are removed.

Pleurae: In trilobites and other arthropods, pleurae are elongated flat outgrowths from each body segment, that overlie and protect the appendages.

Pore: Any opening into or through a tissue or body structure.

Precocial:	Describes young that are mobile and fairly self-sufficient at birth.
Proboscis:	Elongated organ, usually associated with the mouth.
Pygidium:	In trilobites, the posterior division of the body, formed by fusion of the **telson** with one or more posterior **pleurae**.
Segmentation:	In many animals, the body is divided into repeated subunits called **segments**, such as those in centipedes, insects, and annelids.
Septum:	Partition which divides up a larger region into smaller ones, such as in the central body cavity of some anthozoa.
Siphon:	Opening in molluscs or in urochordates which draws water into the body cavity.
Skeleton:	Support structure in animals, against which the force of muscles acts.
Spicule:	Crystalline or mineral deposits found in sponges, sea cucumbers, or urochordates.
Spiracle:	In insects and some other terrestrial arthropods, a small opening through which air is taken into the **tracheae**.
Spongocoel:	Central body cavity of sponges.
Synapsid:	A vertebrate distinguished by a skull with one pair of openings in the sidebehind the eyes, e.g., mammals and their close relatives.
Telson:	The last segment of the abdomen in many arthropods.
Tentacles:	Appendages which are flexible, because they have no rigid skeleton.
Tetrapod:	An animal with four limbs that evolved from a common fish ancestor during the Devonian Period (~365 million years ago).
Thorax:	In insects, the second body region, between the head and thorax. It is the region where the legs and wings are attached.
Tissue:	A group of cells with a specific function in the body of an organism.
Tracheae:	Internal tubes through which air is taken for respiration.

Tube feet: Extensions of the water-vascular system of echinoderms, protruding from the body and often ending in suckers.

Tubercle: Any small rounded protrusion.

Uniramious: Among arthropods, uniramous refers to appendages that have only one branch.

Vascular: Refers to a network of tubes which distribute nutrients and remove wastes from the tissues of the body.

Vertebra: A component of the **vertebral column**, or backbone, found in vertebrates.

Zooxanthellae: Symbiotic dinoflagellates in the genus *Symbiodinium* that live in the tissues of a number of marine invertebrates and protists, notably in many foraminiferans, cnidarians, and some mollusks.

End of module questions

1). List the features that distinguish the kingdom Animalia from other kingdom

2). Explain the processes of animal reproduction and embryonic development

3). Describe the organizational features of the simplest multicellular organisms

4). Describe the characteristics and physiological processes of flatworms

5). Compare the internal systems and the appendage specialization of arthropods

6). Describe the features of an animal classified in phylum Annelida

7). Describe the difference between jawless and jawed fishes

8). Explain the main characteristics of amphibians, reptiles, and birds

9). Describe the derived features that distinguish primates from other animals